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## Investigation of Earthquake-Induced Landslide Along Way Ratai Road, Teluk Pandan, Lampung, Indonesia Using on-Ground Shear Strain and Soft Layer Thickness Analysis

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### Abstract

Seismic shaking is a primary trigger of landslides in tectonically active regions. In the Teluk Pandan area, Lampung, Indonesia, earthquake hazards are associated with the nearby megathrust southwest of Lampung Province, the Great Sumatran Fault – particularly the Semangko segment – and other active regional faults. This study aims to investigate the extent to which earthquakes contribute the occurrence of landslides using ground shear strain (GSS) value and the thickness of soft soil layers along Way Ratai Road, the main route to a tourist destination. GSS values range from  $1.57 \times 10^{-8}$  to  $5.23 \times 10^{-6}$ , all below the  $10^{-4}$  threshold, indicating predominantly elastic soil behaviour with no permanent deformation under current seismic loading conditions. Despite this, potential vulnerability remains, particularly under scenario earthquakes originating from the nearby Lampung-Panjang Fault (~12 km). Soft soil thickness varies from 0.2 m to 178 m, with critical locations (T25, T28, and T43) exhibiting very thick deposits (149–178 m), which can significantly amplify seismic waves. This amplification effect, combined with high annual rainfall (~3000 mm/year), increases the likelihood of slope instability and landslide occurrence. The results demonstrate that low GSS values alone may not fully represent landslide hazard. Therefore, integrating GSS with subsurface soil conditions is essential for more reliable and conservative landslide susceptibility assessment in earthquake-prone areas.



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### Introduction

Landslides are defined as the downslope movement of soil and rock masses under the influence of gravity [1]. They are commonly triggered by slope saturation, which increases soil weight while reducing effective stress [2-3]. In addition to hydrological factors, landslides may also be induced by seismic forces associated with earthquakes [4-6]. Seismic shaking can alter

the internal structure and mechanical properties of soils, reducing shear strength and, consequently, slope stability. These effects may be further intensified by prolonged or intense rainfall, particularly in slopes composed of weathered or weak materials that are inherently susceptible to failure [7].

Earthquake-induced landslides have been documented since ancient times, including events in China (1789 BCE) and Greece (373–372 BCE) [8-9]. Systematic scientific investigations began to emerge following the 1783 Calabria earthquake in Italy (Mw 7.0) [10]. Subsequent studies have demonstrated that such landslides are primarily governed by soil deformation in response to seismic loading, which degrades soil mechanical properties and reduces slope stability [11-12].

These processes are particularly relevant in regions characterized by complex geomorphology and active tectonics, such as the Teluk Pandan District in Pesawaran Regency, Lampung Province, Indonesia, the study area in this research. This region exhibits relatively high seismic vulnerability due to the presence of several active seismic sources, including the Great Sumatran Fault, the southwest Lampung megathrust zone, the Lampung-Panjang Fault, and submarine faults in the Tanggamus region and the Sunda Strait [13]. The Lampung-Panjang Fault extends along the eastern coast of Lampung Bay, continues inland through the Tarahan and Panjang areas, and follows the eastern flank of Mount Rajabasa toward the Sunda Strait. It is interpreted as a right-lateral strike-slip fault influenced by vertical tectonic movements [14], indicating ongoing tectonic activity that contributes to local seismic hazards.

Among these sources, the Lampung-Panjang Fault deserves particular attention due to its proximity to the study area, located approximately  $\pm 12$  km from Teluk Pandan District. This distance is considerably shorter than that of the Liwa earthquake source (1994) [15], which has frequently been used as a reference in previous studies. Such proximity suggests the potential for higher Peak Ground Acceleration (PGA) during future seismic events. PGA represents the maximum ground acceleration and serves as an indicator of shaking intensity at the surface [16]. An increase in PGA is generally associated with higher Ground Shear Strain (GSS), which reflects the level of shear deformation experienced by soil under seismic loading. Elevated GSS values indicate greater deformation potential and reduced slope stability, thereby increasing the likelihood of landslides [7].

The study area is characterized by steep hilly terrain extending along Way Ratai Road. Way Ratai Road serves as the primary access route to major tourism destinations and as a key connector between villages in the region. Between 2022 and 2025, several landslide events were recorded, including occurrences in Sukajaya Lempasing Village in 2025 [17] Hurun Village in 2022, along Way Ratai Road, where landslide debris covered the road shoulder to a height of approximately 15 cm [18].

Previous studies have evaluated landslide susceptibility in this area using the Factor of Safety (FoS) approach. An FoS value of 0.602 at coordinates  $5^{\circ}33'56''\text{S}$  and  $105^{\circ}11'21''\text{E}$  indicates unstable slope conditions ( $\text{FoS} < 1$ ) [19]. In addition, earthquake-induced landslides associated with the Liwa source (1994) have been assessed, with Ground Shear Strain (GSS) values ranging from  $3.5 \times 10^{-6}$  to  $3.2 \times 10^{-5}$ . While the FoS approach provides useful insights, it

represents slope stability under static conditions and does not fully capture soil behavior under dynamic seismic loading. Moreover, reliance on a single seismic source does not adequately reflect the influence of nearer active faults, particularly the Lampung-Panjang Fault [14], [20].

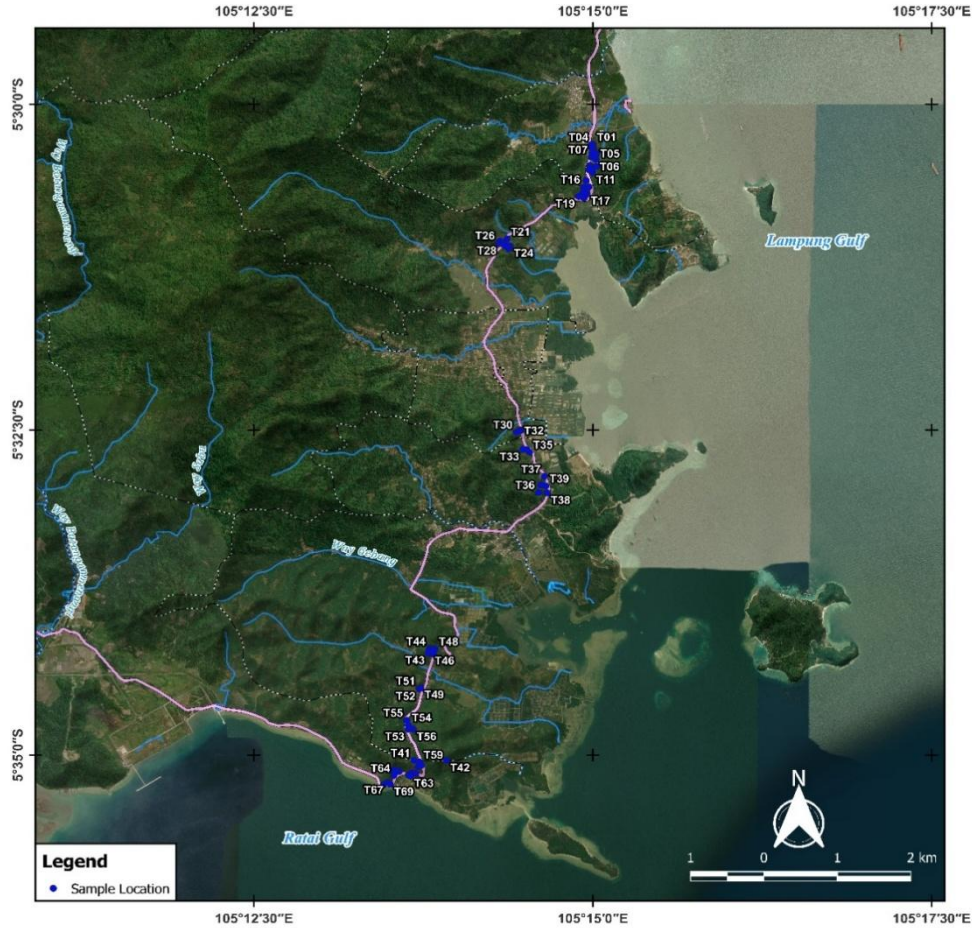
To address these limitations, this study adopts a response-based approach by mapping the spatial distribution of Ground Shear Strain (GSS) and the thickness of soft soil layers. This approach complements the FoS method and provides a more comprehensive representation of subsurface conditions, including the potential amplification of seismic waves within soft layers. GSS is influenced by the seismic vulnerability index ( $K_g$ ) and Peak Ground Acceleration (PGA) [21]. Microtremor analysis using the Horizontal-to-Vertical Spectral Ratio (HVSR) method is employed to obtain the dominant frequency ( $f_0$ ), amplification factor ( $A_0$ ), and seismic vulnerability index ( $K_g$ ). These parameters are subsequently used to estimate sediment thickness and GSS values across the study area [12].

High GSS values during seismic events may lead to substantial soil deformation and ultimately slope failure. Therefore, assessing earthquake-induced landslide hazards is essential in strategic areas such as Way Ratai Road, which supports the Teluk Pandan Tourism Special Economic Zone (SEZ). The combination of steep slopes, high rainfall, and multiple active seismic sources—including the Lampung-Panjang Fault—indicates a considerable potential for landslide occurrence. Such events may disrupt transportation access and regional connectivity. Accordingly, a comprehensive and integrated assessment of earthquake-induced landslide risk is necessary to support effective mitigation strategies and enhance infrastructure resilience in this strategically important area.

## **Experimental Method**

### *2.1. Research Location.*

Data collection in this study was conducted on landslide-prone slopes along the shoulders of Way Ratai Main Road, Teluk Pandan Subdistrict, Pesawaran Regency, Lampung Province. A total of 69 measurement points were established along an approximately 15 km transect from north to south, with coordinates ranging from -5.491039 to -5.585018 latitude and 105.250447 to 105.220917 longitude (Figure 1).



**Figure 1.** Distribution of microtremor measurement points along Way Ratai road, bordering the slopes and hills.

2.1.1. Geological Settings.

Way Ratai Road is located in the eastern part of Teluk Pandan Subdistrict, Pesawaran Regency, Lampung Province. Geologically, the study area comprises several formations, including alluvial deposits (*Qa*), the Tarahan Formation (*Tpot*), the G. Kasih Complex (*Pzg*), the Menanga Formation (*Km*), the Sabu Formation (*Tpos*), and the Hulusimpang Formation (*Tomh*), as shown in Figure 2.

The study area is predominantly composed of volcanic-derived rocks formed during the early Tertiary period (*Tpos*, *Tpot*, *Tomh*), as well as older formations such as those from the Early Cretaceous (*Km*). The youngest unit consists of Holocene alluvial deposits, while the oldest unit comprises metamorphic rocks of the G. Kasih Complex, dating back to the Paleozoic era. A northwest-southeast (NW-SE) trending normal fault is identified near the study area, marking the boundary between the *Pzg* and *Km* formations. In addition, a north-south (N-S) trending fault is interpreted to exist west of the study area (Figure 2).

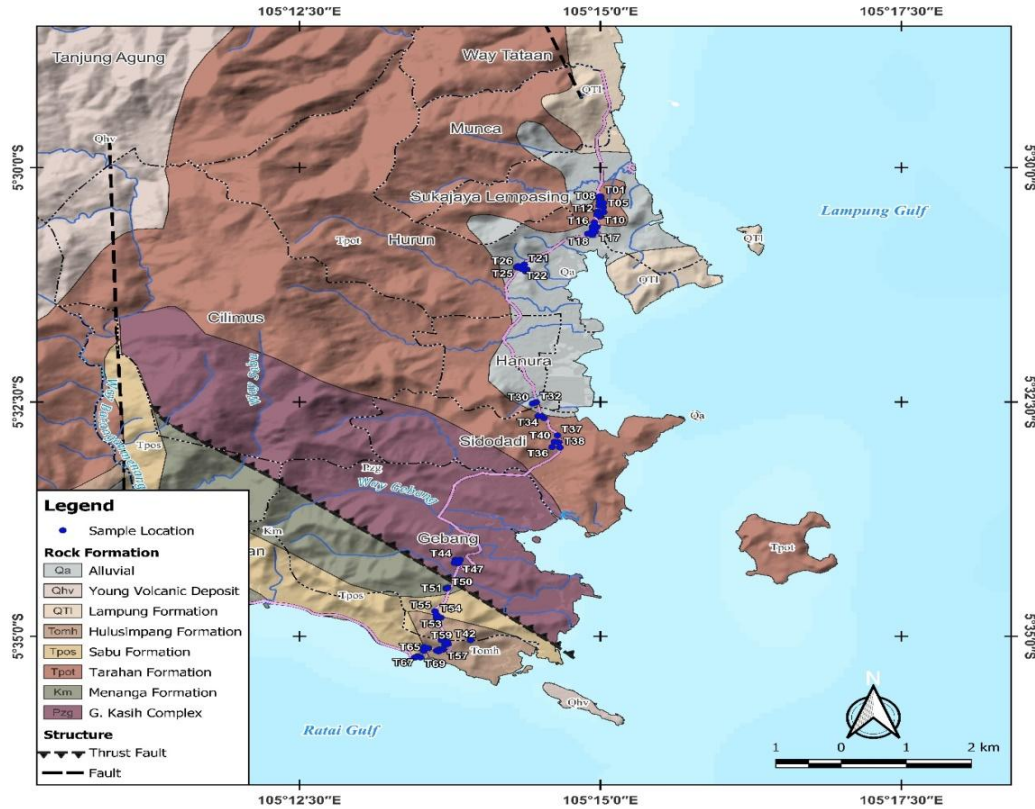


Figure 2. Geological map of the study area.

Rock type plays an important role in landslide susceptibility analysis, as its physical and mechanical properties, such as shear strength, porosity, and permeability, significantly influence slope stability [22]. The dominant lithologies along Way Ratai Road include sandstone, tuff, claystone, siltstone, and limestone.

## 2.2. Methods

### 2.2.1. Ground Shear Strain.

Ground Shear Strain (GSS) represents the shear deformation of soil caused by seismic wave loading. It reflects the level of relative displacement within the soil and can be calculated using the following equation [4]

$$GSS = K_g \times 10^{-6} \times \alpha \tag{1}$$

where  $K_g$  is the seismic vulnerability index (dimensionless),  $10^{-6}$  is a scaling factor representing microstrain level (dimensionless), and  $\alpha$  is the peak ground acceleration (PGA) at the bedrock, expressed in  $m/s^2$  or  $g$ .

The seismic vulnerability index  $K_g$  is derived from the amplification factor ( $A_0$ ) and dominant frequency ( $f_0$ ) obtained from the peak of the Horizontal-to-Vertical Spectral Ratio (HVSR) curve. The units of these parameters are as follows:  $K_g$  is dimensionless,  $A_0$  (amplification factor) is also dimensionless, and  $f_0$  (dominant frequency) is expressed in Hertz (Hz), representing the natural frequency of the soil layer.

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

The HVSR method, introduced by Nakamura (1997), is a geophysical technique used to investigate subsurface conditions by analyzing ambient vibrations or microtremors [4]. This method is widely applied due to its simplicity, cost-effectiveness, and non-invasive nature. The HVSR value is calculated using the following equation:

$$HVSR = \frac{\sqrt{H_{E-W} + H_{N-S}}}{V} \quad (3)$$

Where  $H_{E-W}$ ,  $H_{N-S}$  and  $V$  represent the average spectral amplitudes of all analyzed windows for the east-west, north-south, and vertical components, respectively. These parameters have the same units (e.g., velocity spectrum in m/s or displacement spectrum in m), depending on the type of processed seismic data. Consequently, the HVSR value is dimensionless, as it is a ratio of horizontal to vertical spectral amplitudes. HVSR analysis in this study was performed using *Geopsy* software. Another key parameter in GSS calculation is Peak Ground Acceleration (PGA), which represents the maximum ground acceleration during an earthquake. PGA is estimated using the empirical equation proposed by [23] :

$$\log \alpha = 1.3 + 0.41M - \log(0.32R \times 10^{0.42M}) - 0.0034R \quad (4)$$

where  $\alpha$  is the peak ground acceleration (PGA) at the bedrock expressed in gal ( $\text{cm/s}^2$ ),  $M$  is the moment magnitude (Mw), which is dimensionless, and  $R$  is the hypocentral distance expressed in kilometers (km).

In this study, PGA estimation is based on a seismic scenario associated with the Lampung-Panjang Fault, located approximately  $\pm 12$  km from the study area. This fault is considered a more representative seismic source due to its proximity and its potential to generate stronger ground motion compared to more distant sources [11]. The selection of the Lampung-Panjang Fault aims to better reflect site-specific seismic hazard conditions and to provide a more realistic estimation of GSS values.

Given that GSS is highly sensitive to PGA, the use of a nearby active fault is essential to avoid underestimation of seismic-induced soil deformation. Therefore, adopting the Lampung-Panjang Fault scenario enables a more conservative, hazard-relevant assessment of landslide susceptibility in the study area.

### 2.2.2. Soft Layer Thickness.

The relationship between soft layer thickness and dominant frequency can be explained by the principle of soil resonance in seismic wave propagation. In general, thicker soft layers correspond to lower dominant frequencies. This relationship follows the closed organ pipe principle [4] and can be expressed as:

$$H = \frac{V_s}{4f_0} \quad (5)$$

where  $H$  is the thickness of the surface sediment layer expressed in meters (m),  $V_s$  is the shear wave velocity expressed in (m/s), and  $f_0$  is the dominant frequency expressed in Hertz (Hz).

In this study, the shear wave velocity ( $V_s$ ) is approximated using ( $V_{s30}$ ), which represents the average shear wave velocity to a depth of 30 meters. The ( $V_{s30}$ ) value is obtained through inversion of the HVSr curve using Dinver, an open-source software for surface wave inversion.

**Results and Discussion**

*3.1.1. Ground Shear Strain.*

Based on the microtremor measurements conducted at 69 observation points (Table 1), the ground shear strain (GSS) values in the study area range from  $1,57 \times 10^{-8}$  to  $5,23 \times 10^{-6}$ , as generally illustrated in Figure 3. Physically, GSS represents the degree of soil deformation induced by seismic loading, where higher GSS values indicate greater shear deformation and, consequently, a higher susceptibility to earthquake-induced landslides. In contrast, lower GSS values reflect relatively stable soil behavior under the analyzed seismic scenario [24].

The distribution of GSS values across the study area's segments is shown in Figure 2. This figure provides a segment-based representation of GSS values along the measurement transect, allowing for a more detailed characterization of local variations along the Way Ratai Road corridor. It should be noted that this representation is constrained to the measurement corridor and does not imply a fully continuous areal distribution. Based on the mapping results, elevated GSS values are identified at points T28–T29, T31, T33–T34, T41–T44, T48–T49, and T51, as indicated by red zones on the map, with values ranging from  $>7 \times 10^{-8}$  to  $5,23 \times 10^{-6}$ .

**Table 1** The ground shear strain value.

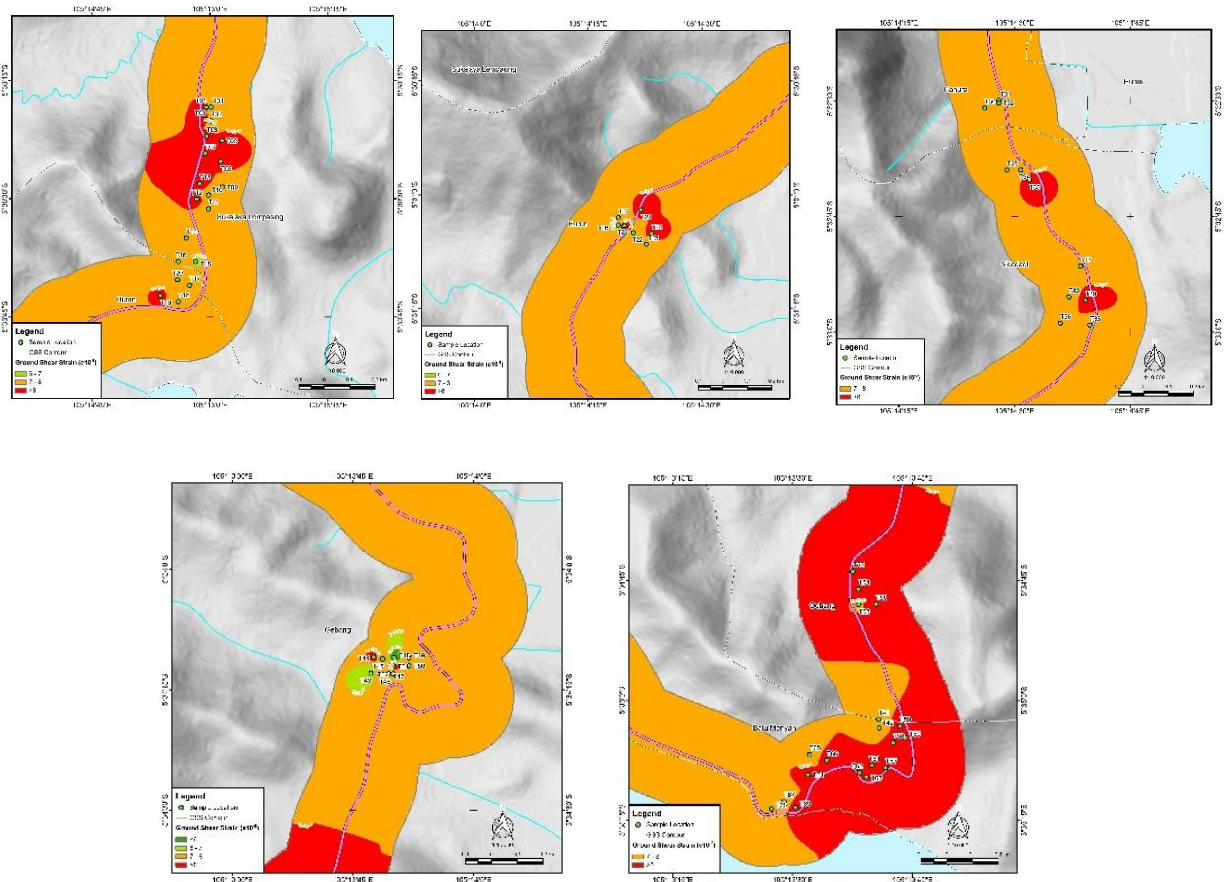
Class	GSS Value	Number of Points	Approximate Point IDs
Class 1 (Low)	$1.57 \times 10^{-8} - 6 \times 10^{-8}$	47	T04 - T14, T18 - T25, T27 - T30, T32 - T40, T45 - T47, T50 - T58, T60 - T65, T67, T69
Class 2 (High)	$> 6 \times 10^{-8} - 5.23 \times 10^{-6}$	22	T02 - T03, T10 - T17, T19 - T24, T26, T28 - T29, T31, T33 - T34, T41 - T44, T48 - T49, T51

Conversely, low GSS values dominate other segments along the transect, indicating relatively stable ground conditions under seismic loading. This spatial variability reflects differences in the dynamic response of soils, which are strongly controlled by local geological and geotechnical characteristics [11].

Geologically, zones with high GSS values are generally associated with materials with high porosity and significant clay content. These conditions favor the development of potential slip surfaces and reduce shear strength, thereby increasing slope instability. Furthermore, soft, clay-rich materials tend to amplify seismic waves more efficiently than competent or consolidated materials, resulting in greater deformation under seismic excitation [16].

Exceptionally high GSS values observed at several locations suggest the combined influence of high amplification factors and low dominant frequencies, which are indicative of thick soft sediment layers. Such conditions enhance seismic wave amplification and significantly

increase shear deformation during earthquake events. This finding highlights that GSS is governed not only by soft layer thickness but also by the interaction between subsurface dynamic properties and site amplification effects [21].



**Figure 3.** The distribution of GSS values across each segment.

From a hazard perspective, zones characterized by elevated GSS values in conjunction with thick soft sediment layers can be classified as areas with high susceptibility to earthquake-induced landslides and should therefore be prioritized in mitigation planning [25]. Conversely, areas with low GSS values indicate relatively stable ground conditions under the considered seismic scenario. However, it is important to note that these conditions may change with different seismic sources or higher ground-motion intensities, particularly given the proximity of active faults such as the Lampung-Panjang Fault.

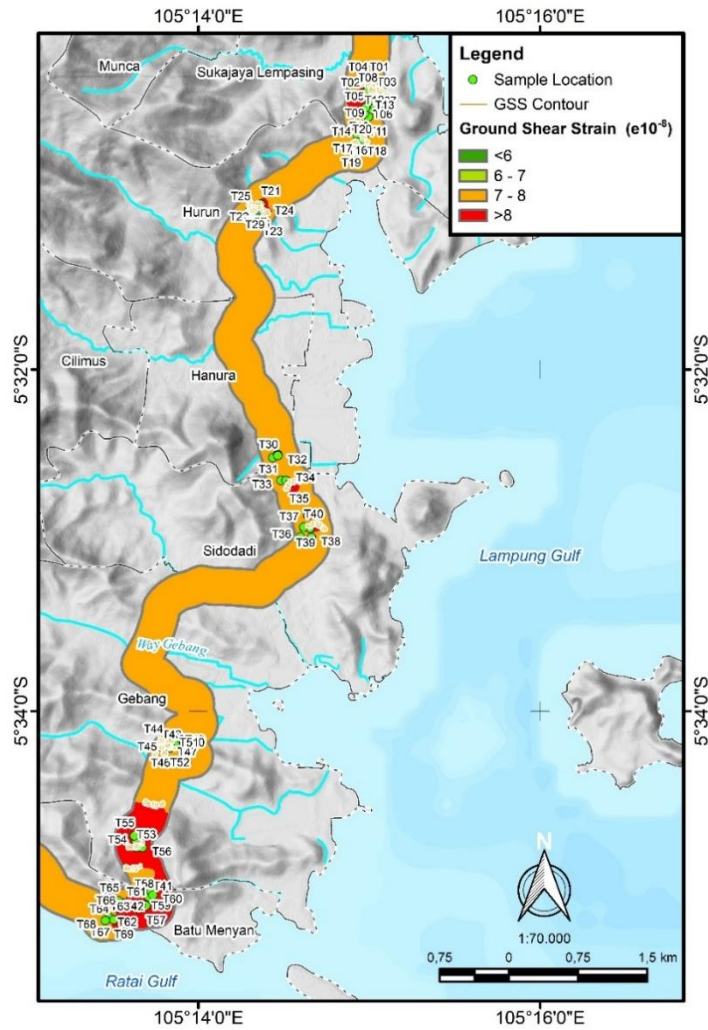


Figure 4. Spatial distribution of GSS values in the study area.

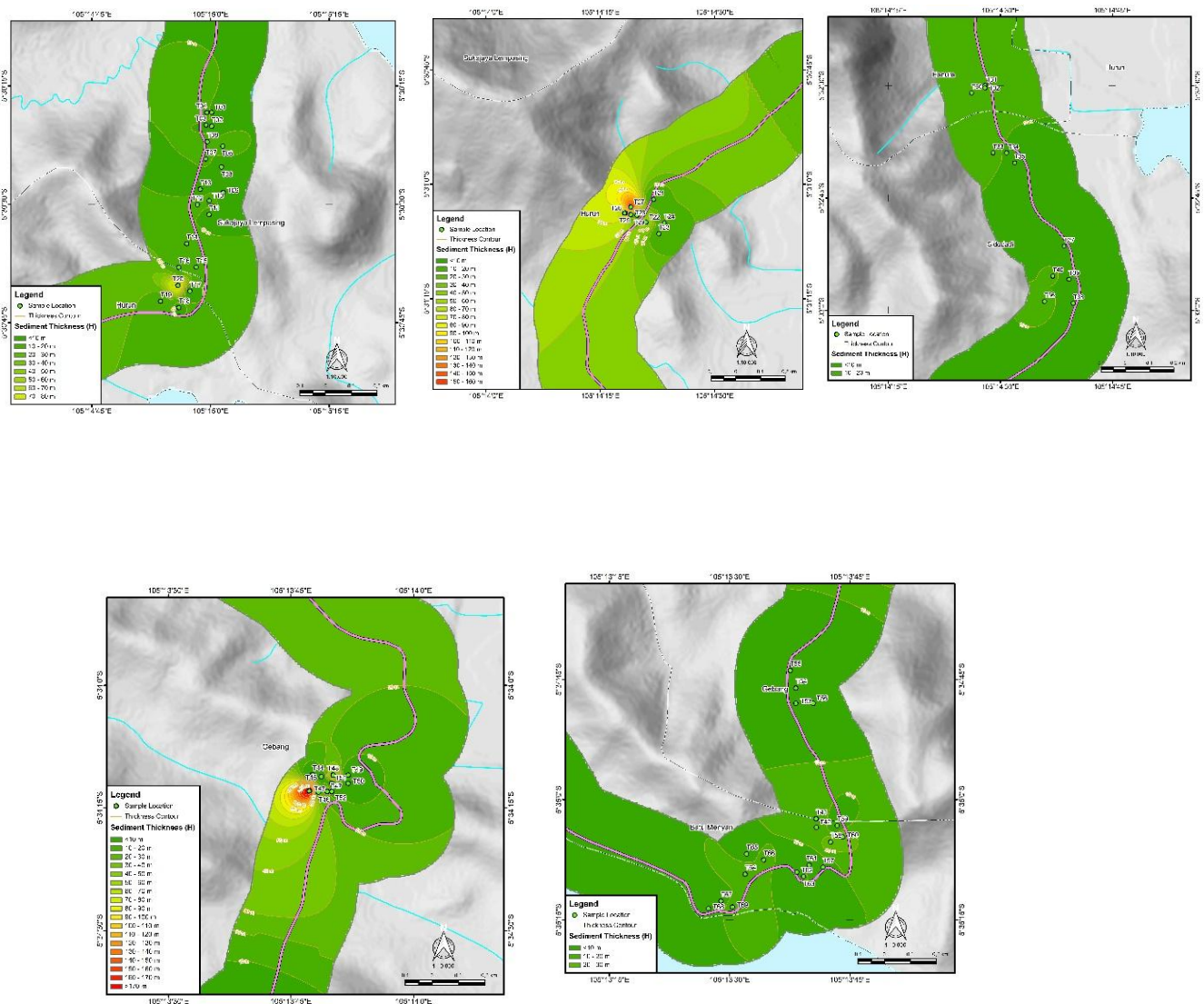
3.1.2. Soft Layer Thickness.

The thickness of the soft soil layers obtained from 69 measurement points is summarized in Table 2, ranging from 0.2 to 178 m. In general, the distribution of soft-layer thickness is shown in Figure 5. The figure shows a segment-based representation along the measurement transect, reflecting local variations along the Way Ratai Road corridor rather than a continuous areal distribution. Areas with relatively thick soft layers are indicated by orange to red colors, while thinner deposits are represented by green to yellow colors. Based on the mapping results, measurement points T25 to T28 and T43 to T48 exhibit the greatest sediment thickness in the study area, indicating a significant accumulation of soft sediments within this segment.

**Table 2** The soft layer thickness value

Class	Thickness Range (m)	Number of Points	Approximate Point IDs
Class 1 (Thin)	0.27 – 10.62	36	T02 – T14, T36 – T40, T45 – T53, T60 – T63
Class 2 (Thick)	> 10.62 – 178	33	T05 – T35, T41 – T44, T48 – T59, T61, T64 – T69

Field observations at points T43 to T48 indicate intensely weathered soil, characterized by reddish-brown color and very loose structure. These characteristics suggest the dominance of weakly consolidated, low-density soft sediments. From a geophysical perspective, thick soft sediment layers are generally associated with low shear wave velocity ( $V_s$ ) and low shear modulus, resulting in a medium that is highly susceptible to deformation under dynamic loading such as seismic excitation [6].



**Figure 5.** The distribution of GSS values across each segment.

Moreover, increasing sediment thickness significantly reduces the natural frequency of the soil-bedrock system. Lower dominant frequencies correspond to longer fundamental periods, which increase the likelihood of resonance when incoming seismic waves have similar frequency components. This resonance mechanism can lead to significant amplification of ground motion at the surface [16].

The influence of sediment thickness is consistently reflected in the Ground Shear Strain (GSS) results. Relatively high GSS values are observed at points T43-T48, with the maximum at T48 exceeding those at other locations by up to three orders of magnitude. This indicates significant shear deformation within the soil mass due to the combined effects of thick soft sediments, high amplification factors, and low dominant frequencies. From a soil mechanics perspective, high shear strain indicates that soil deformation approaches or exceeds the elastic limit and enters a nonlinear regime, potentially reducing effective shear strength due to degradation of interparticle bonds. Therefore, the strong correlation between thick sediment layers and high GSS values highlights the critical role of soft sediments in controlling slope instability.

In addition to subsurface conditions, regional climatic factors such as rainfall may also influence slope stability [26]. The study area is characterized by an average annual rainfall of approximately 3000 mm, which is considered high for tropical regions. The spatial distribution of rainfall is presented in Figure 7, constructed from BMKG (2025) rainfall data and supplemented with CHIRPS 2.0 data (UCSB) to improve spatial coverage. In this figure, rainfall data are integrated with the location of the Lampung-Panjang Fault, which is situated approximately  $\pm 12$  km from the study area, providing a more comprehensive representation of the interaction between climatic and tectonic factors. High rainfall conditions may increase soil moisture content and reduce effective shear strength, particularly in areas dominated by thick, weakly consolidated soft sediments, such as those identified at points T43 to T48. This condition may enhance soil deformation under external loading. However, it should be emphasized that the influence of rainfall on landslide occurrence, particularly in relation to liquefaction processes, cannot be conclusively determined in this study due to the lack of detailed hydrogeological data, such as groundwater level variations and soil saturation conditions. Therefore, rainfall is interpreted cautiously as a contributing factor rather than a primary controlling parameter [27].

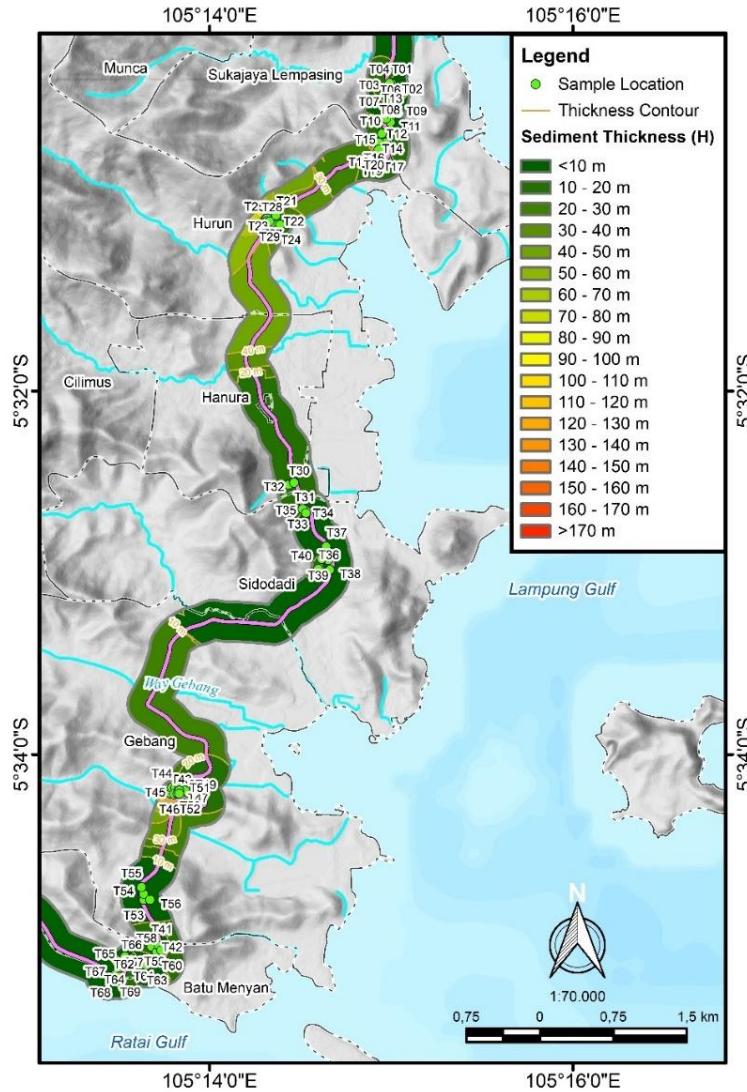
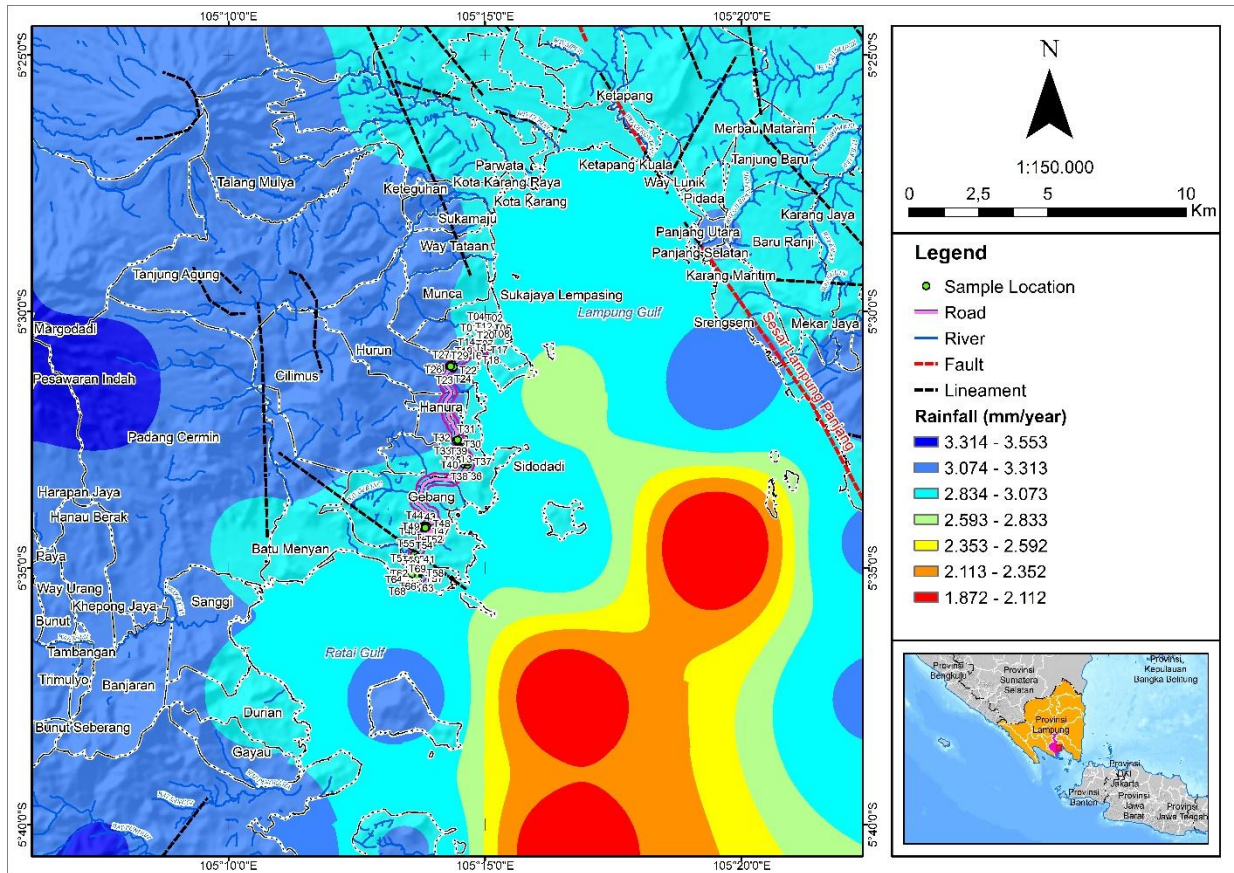


Figure 6. Spatial distribution of soft layer thickness in the study area.

Nevertheless, prolonged or intense rainfall, which may lead to increased soil saturation, could further enhance ground deformation and increase susceptibility to earthquake-induced landslides, particularly when combined with seismic loading from nearby active structures such as the Lampung-Panjang Fault.



**Figure 7.** Annual rainfall distribution map of the study area derived from BMKG (2025) and CHIRPS 2.0 (UCSB) data, including the location of the Lampung-Panjang Fault (~12 km from the study area).

### 3.2. Discussion.

Microtremor measurements, also known as ambient noise, were conducted at 69 points along Way Ratai Road, Teluk Pandan, Lampung, and analyzed to investigate landslide susceptibility using ground shear strain (GSS) and soft-layer thickness parameters via the HVSR method. Overall, the GSS values ranged from  $1.57 \times 10^{-8}$  to  $5.23 \times 10^{-6}$ . These values remain below the threshold of  $10^{-4}$ , indicating that, under the analyzed seismic scenario, the soil response remains within the elastic range, where deformation is reversible, and the ground primarily experiences vibration without permanent displacement. Therefore, the study area along Way Ratai Road is generally considered relatively safe from earthquake-induced landslides under current conditions

Geologically, zones with relatively high GSS values are associated with materials characterized by high porosity and significant clay content, which tend to reduce shear strength and facilitate the development of potential slip surfaces. This observation is consistent with the characteristics of clay-rich formations such as the Gunung Kasih Formation. In addition, an anomalously high GSS value was identified at point T48, exceeding those at surrounding locations by up to 3 orders of magnitude. This anomaly is supported by field observations indicating intensely weathered soil, characterized by a reddish-brown color and very loose structure. Such conditions reflect weakly consolidated, low-density soft sediments that are highly susceptible to seismic amplification. The

combination of high amplification factors and low dominant frequency at this location suggests the presence of a thick soft sediment layer, which enhances ground motion and results in significantly higher shear deformation during seismic loading [11].

The thickness of the soft layer in the study area ranges from 0.2 to 178 m. Locations at points T25-T28 and T43-T48 are characterized by thick, soft layers (149–176 m) and low dominant frequencies (<0.5 Hz). These conditions are critical because thick soft layers with low natural frequencies are highly prone to resonance effects when subjected to seismic waves with similar frequency content. This resonance can significantly amplify ground motion, increasing the potential for landslides and potentially exacerbating damage to infrastructure, particularly along the Way Ratai Road corridor. Prolonged or repeated seismic shaking under such conditions may accelerate the degradation of slope materials and reduce structural integrity over time [28].

In addition to geological and geophysical factors, regional climatic conditions also play an important role in slope stability [2]. The study area is characterized by a relatively high annual rainfall of approximately 3000 mm, which is considered high for tropical regions. Such conditions may enhance soil moisture content and reduce effective shear strength, particularly in areas composed of thick, weakly consolidated soft sediments. However, despite these conditions, the current risk of earthquake-induced landslides remains relatively low, as indicated by the GSS values, which are still within the elastic range. It should be noted that the influence of rainfall on liquefaction-induced landslides cannot be conclusively determined in this study due to the lack of detailed hydrogeological data, such as groundwater level variations and soil saturation conditions. Therefore, rainfall is considered a contributing factor that may increase susceptibility, particularly during prolonged or intense rainfall events, which could lead to higher groundwater saturation. [29].

Nevertheless, under prolonged or extreme rainfall, increased soil moisture and pore water pressure may reduce effective stress, particularly in areas composed of thick, weakly consolidated, soft sediments. This condition may enhance soil deformation and increase susceptibility to earthquake-induced landslides, especially when combined with strong seismic loading.

At T25 to T28, the location coincides with alluvial deposits, with the rocks in the area consisting of claystone and siltstone. The strength of siltstone and claystone generally ranges from low to moderate. These locations have thick, soft layers (149–176 m), which pose a risk, as increased layer thickness increases the likelihood of earthquake-induced landslides due to greater instability and seismic amplification. This risk is exacerbated during prolonged earthquake shaking, as extended exposure worsens slope conditions [12], [20]. Therefore, appropriate mitigation measures are required, including structural approaches such as slope reinforcement to enhance shear strength, ground improvement to increase soil stiffness, and shear wave velocity ( $V_s$ ) thereby reducing seismic amplification and optimizing drainage systems to decrease pore water pressure and maintain effective stress. Non-structural measures include continuous monitoring of seismic response, hazard zonation based on amplification characteristics and dominant frequency, and the implementation of early warning systems to reduce exposure to strong ground motion.

Importantly, despite the currently low GSS values, the study area remains inherently vulnerable due to its proximity to the Lampung-Panjang Fault. The relatively short distance (~12 km) to this active tectonic structure increases the likelihood of exposure to strong ground motion in future seismic events. When combined with thick, soft sediment layers and potential increases in soil saturation, this condition may significantly elevate the risk of earthquake-induced landslides.

Therefore, the study area should be considered as having latent susceptibility, requiring continuous monitoring and proactive mitigation planning.

### Conclusion

Microtremor measurements were conducted at 69 points along Way Ratai Road, Teluk Pandan, Lampung, using the HVSR method to evaluate landslide susceptibility based on ground shear strain (GSS) and soft layer thickness. The GSS values range from  $1.57 \times 10^{-8}$  to  $5.23 \times 10^{-6}$ , remaining below the threshold of  $10^{-4}$ , indicating that the soil response is still within the elastic range and that the study area is relatively safe from earthquake-induced landslides under the analyzed seismic conditions.

However, the proximity of the study area to the active Lampung-Panjang Fault may increase seismic loading and potentially trigger slope instability in future events. Soft layer thickness ranges from 0.2 to 178 m, with points T25, T28, and T43 showing thick soft sediments and low dominant frequencies, indicating higher susceptibility to seismic wave amplification and ground instability. Therefore, mitigation measures such as optimization of drainage systems to reduce pore water pressure, continuous seismic monitoring, hazard zonation, land-use regulation, and the development of early warning systems are recommended to reduce future landslide risk and support infrastructure stability along the Way Ratai Road corridor.

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### References

- [1] I. N. P. Permanasari, V. L. Ipmawan, and E. Khairuman, "Determination of Slip Surface Using 2D Geoelectric Resistivity Method and Laboratory Analysis for Landslide Prone Area Pesawaran, Lampung," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 537, no. 1, pp. 1–4, 2020.
- [2] A. Hojat, D. Arosio, V. I. Ivanov, L. Longoni, M. Papini, M. Scaioni, G. Tresoldi, L. Zanzi, "Geoelectrical characterization and monitoring of slopes on a rainfall-triggered landslide simulator," *J. Appl. Geophys.*, vol. 170, p. 103844, 2019.
- [3] V. L. Ipmawan, I. N. P. Permanasari, and R. N. Siregar, "Spatial Analysis of Seismic Hazard based on Dynamical Characteristics of Soil in Kota Baru, South Lampung," *J. Sci. Appl. Technol.*, vol. 2, no. 1, pp. 169–175, 2019.
- [4] Y. Nakamura, "Seismic Vulnerability Indices for Ground and Structures Using Microtremor," *World Congr. Railw. Res. Florence*, vol. 1, no. 1, pp. 1–7, 1997.
- [5] S. Nakamura, A. Wakai, J. Umemura, H. Sugimoto, and T. Takeshi, "Earthquake-induced landslides: Distribution, motion and mechanisms," *Soils Found.*, vol. 54, no. 4, pp. 544–559, 2014.
- [6] I. N. P. Permanasari, I. N. Ba'asyir, M. R. Setiawan, I. Pardede, and Y. Monica, "Landslide Vulnerability Analysis Based on the Seismic Vulnerability Index Using the HVSR Microtremor Method on Cliff Areas in Hanura Village, Teluk Pandan District, Pesawaran Regency," *Indones. Phys. Rev.*, vol. 07, no. 02, pp. 281–290, 2025.

- [7] T. Arrisaldi, W. Wilopo, and T. F. Fathani, "Landslide Susceptibility Mapping and Their Rainfall Thresholds Model in Tinalah Watershed, Kulon Progo District, Yogyakarta Special Region, Indonesia," *J. Appl. Geol.*, vol. 6, no. 2, pp. 112–118, 2021.
- [8] A. Hansen, "Characterization and mapping of earthquake-triggered landslides for seismic zonation," *Int. Conf. Seism. Zo.*, vol. 11, no. 2, pp. 149–195, 1991.
- [9] H. B. Seed, "The fourth Terzaghi lecture: landslides during earthquakes due to liquefaction," *J. Soil Mech. Found. Div.*, vol. 94, no. 5, pp. 1053–1122, 1968.
- [10] D. K. Keefer, "Investigating landslides caused by earthquakes – a historical review," *Surv. Geophys.*, vol. 23, no. 6, pp. 473–510, Nov. 2002.
- [11] Suhendra, Z. Bahrum, and N. Sugianto, "Geological condition at landslides potential area based on microtremor survey," *ARPN J. Eng. Appl. Sci.*, vol. 13, no. 8, pp. 3007–3013, 2018.
- [12] S. Supriyadi, W. H. Muttaqin, K. Khumaedi, and S. Sugiyanto, "Soil Vulnerability Levels based on Microtremor Data using the HVSR method in the Old City Area of Semarang," *J. Phys. Theor. Appl.*, vol. 6, no. 1, pp. 34–42, 2022.
- [13] R. Mulyasari, N. Haerudin, Karyanto, I. G. B. Darmawan, and Y. Arifianti, "Zonasi Area Potensi Gerakan Massa di Sepanjang Sesar Lampung-Panjang Kota Bandar Lampung," *Pros. Semnas SINTA FT UNILA*, vol. 1, no. 1, pp. 190–197, 2018.
- [14] R. C. Wibowo, I. Maulia, N. Haerudin, and M. Sarkowi, "Sliding Plane Identification for Landslide Hazard Mitigation with Electrical Resistivity Tomography Method," *Indones. Phys. Rev.*, vol. 07, no. 02, pp. 281–290, 2024.
- [15] C. Widiwijayanti, J. Deverchere, R. Louat, M. Sebrier, H. Harjono, M. Diament, D. Hidayat, "Aftershock sequence of the 1994, Mw 6.8, Liwa earthquake (Indonesia): seismic rupture process in a volcanic arc," *HAL Auth.*, vol. 23, no. 21, pp. 3051–3054, 2016.
- [16] M. Ridwan, Y. Yatini, and S. Pramono, "Mapping of Potential Damage Area in Lombok Island Based on Microtremor Data," *J. Pendidik. Fis. Indones.*, vol. 17, no. 1, pp. 49–59, 2021.
- [17] Lampung Pro, "Dampak Longsor dan Banjir di Desa Sukajaya Lempasing, Pemkab Pesawaran Turun Langsung Tanggulangi," *lampungpro.co*, 2025. Accessed: Apr. 05, 2026. [Online]. Available: <https://lampungpro.co/news/dampak-longsor-dan-banjir-di-desa-sukajaya-lempasing-pemkab-pesawaran-turun-langsung-tanggulangi>
- [18] Polres Pesawaran, "Polres Turun Cari Tau Penyebab Longsor Di Teluk Pandan," *tribatanews.lampung.polri.go.id*, 2022. Accessed: Apr. 05, 2026. [Online]. Available: <https://tribatanews.lampung.polri.go.id/index.php/detail-post/polres-turun-cari-tau-penyebab-longsor-di-teluk-pandan>
- [19] D. Elviani, "Analisis Kestabilan Lereng Menggunakan Software Geostudio Slope/W 2012 Studi Kasus Daerah Wisata Kabupaten Pesawaran Lampung Tugas Akhir," Institut Teknologi Sumatera, 2020.
- [20] A. I. Hadi, Refrizon, M. Farid, B. Harlianto, and J. I. Sari, "Landslide Potential Investigation for Disaster Risk Reduction in Central Bengkulu Regency, Bengkulu Province, Indonesia," *Indones. J. Geosci.*, vol. 8, no. 3, pp. 313–328, 2021, doi: 10.17014/ijog.8.3.313-328.

- [21] D. I. Fadli, A. I. Hadi, Z. Allifya, S. Anggraini, R. Ramdani, B. S. Idris, Refrizon, "Identifikasi Daerah Rawan Longsor secara Mikrozonasi di Jalan Alternatif Provinsi menggunakan Metode Simple Additive Weighting (SAW)," *Indones. J. Appl. Phys.*, vol. 13, no. 1, pp. 37-52, 2023.
- [22] A. Noviyanto, J. Sartohadi, and B. H. Purwanto, "The distribution of soil morphological characteristics for landslide-impacted Sumbing Volcano, Central Java - Indonesia," *Geoenvironmental Disasters*, vol. 7, no. 1, pp. 1-19, 2020.
- [23] Y. Fukushima and T. Tanaka, "A new attenuation relation for peak horizontal acceleration of strong earthquake ground motion in Japan," *Bull. - Seismol. Soc. Am.*, vol. 80, no. 4, pp. 757-783, 1990.
- [24] A. I. Hadi, K. S. Brotopuspito, S. Pramumijoyo, and H. C. Hardiyatmo, "Regional landslide potential mapping in earthquake-prone areas of Kepahiang Regency, Bengkulu Province, Indonesia," *Geosci.*, vol. 8, no. 6, pp. 1-10, 2018.
- [25] A. Zamroni, A. C. Kurniati, H. Nur, and E. Prasetya, "The assessment of landslides disaster mitigation in Java Island, Indonesia: a review," *J. Geosci. Eng. Environ. Technol.*, vol. 5, no. 3, pp. 124-128, 2020.
- [26] A. C. Mondini, F. Guzzetti, and M. Melillo, "Deep learning forecast of rainfall-induced shallow landslides," *Nat. Commun.*, vol. 14, no. 1, pp. 1-11, 2023.
- [27] M. S. Brook and C. Nicoll, "Brief report of fatal rainfall-triggered landslides from record-breaking 2023 storms in Auckland, New Zealand," *Landslides*, vol. 21, no. 7, pp. 1581-1589, 2024.
- [28] R. S. Yuliatmoko, D. Dairoh, A. F. Masykuri, W. Suryanto, and S. Rohadi, "Site Analysis Using Microtremor Array for Disaster Mitigation of Landslide in the Cianjur Aquatic Resort," *E3S Web Conf.*, vol. 468, no. 01005, pp. 1-8, 2023.
- [29] I. H. Aruan, Y. Yuniardi, N. Khoirullah, and R. I. Sophian, "Analysis of Landslide Causes in Nanggerang Village, Sukasari Sub District, Sumedang Regency Through Identification of Landslide Slope Material Characteristics," *J. Geol. Sci. Appl. Geol.*, vol. 8, no. 1, pp. 13-19, 2024.