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The Investigation of Subsurface Beds using Microtremor and Geo-electric Methods in A Liquefied Area in Bengkulu City After The Bengkulu-Mentawai Earthquake

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Abstract - Bengkulu Province, Indonesia, is one of regions prone to earthquake hazards. Daily seismic activity, albeit minor, and imperceptible to humans is common place. Data from the Meteorology, Climatology, and Geophysics Agency reveals an average of eight earthquakes per week. Earthquakes often trigger subsequent disasters such as tsunamis, landslides, and liquefaction. However, liquefaction-related phenomena are often overlooked in researchs, particularly concerning subsurface layers. A notable event occurred on September 12th, 2007, when a powerful 8.6 magnitude earthquake struck Indonesia, causing significant damage, particularly in Bengkulu City. This was followed by a liquefaction disaster in Tanah Patah Village, Bengkulu City. Consequently, the aim of this study is to assess the subsurface conditions in the liquefaction-affected area using geophysical techniques, including microtremor and geo-electric surveys. The data was analyzed to evaluate soil conditions in the affected zone. The resistivity values indicate a predominance of water and sand mixtures at depths of 0 - 20 m (ranging from 1.46 to 15.5 Ω·m in Geo_TP-1 and from 4.64 to 15.1 Ω·m in Geo_TP-2). These conditions can facilitate processes like condensation and water flow, leading to sand compaction and increase susceptibility to liquefaction. The findings reveal that loose sand dominates the subsurface layers, rendering them highly vulnerable to liquefaction during intense seismic events. Furthermore, the environmental characteristics of the studied area exacerbate its susceptibility to liquefaction. This study provides a comprehensive analysis of soil conditions in the liquefied zone of Bengkulu City.

Keywords: earthquake, liquefaction, microtremor, geo-electric, loose sand

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Introduction

On September 12th, 2007, an 8.6 Mw earthquake, known as the Bengkulu-Mentawai Earthquake, struck the west coast of Sumatra Island (Mase, 2020) (see Figure 1), resulting in significant damage across various areas, particularly in Bengkulu City (Mase, 2018). Subsequently, a liquefaction disaster occurred in Tanah Patah Village, Ratu Agung Sub-Regency, Bengkulu City. Several preliminary studies have investigated this phenomenon in Bengkulu City. Mase (2017) examined liquefaction potentials on the west coast following the Bengkulu-Mentawai Earthquake.

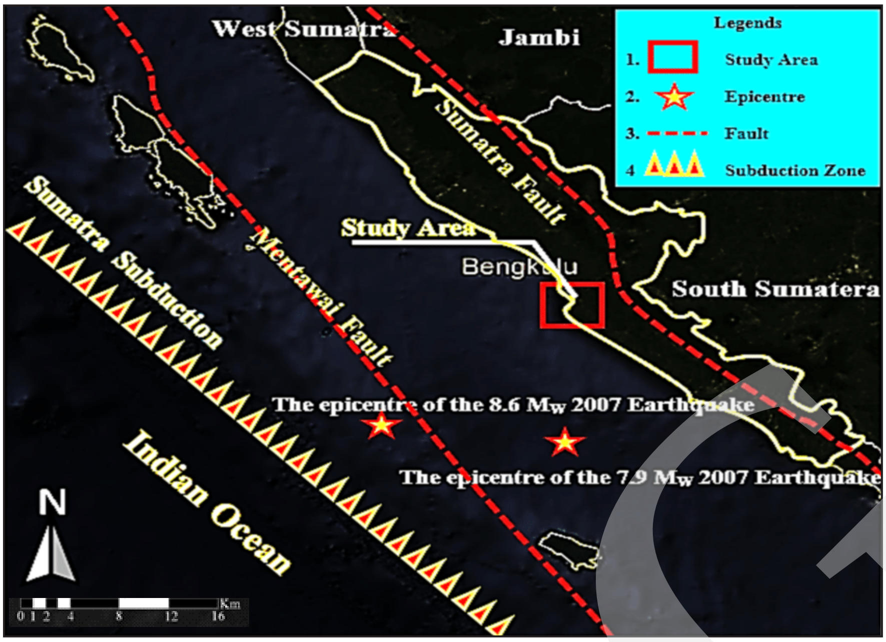

Figure 1. Map of seismotectonic setting in Bengkulu Province (after Mase *et al.*, 2021); modifed (Google Earth, 2021).

Farid and Mase (2020) conducted geophysical measurements to explore the characteristics of Bengkulu City, and analyzed seismic disaster vulnerability based on the concept of ground shear strain. Furthermore, Mase *et al*. (2021) studied local sites and liquefaction potentials along the Muara Bangkahulu River Basin. These previous studies generally concluded that the sandy soil beds prevalent in this coastal area are susceptible to liquefaction. However, there has not been a specific investigation utilizing geophysical methods in the liquefaction-affected areas during the Bengkulu-Mentawai Earthquake of 2007.

Some studies suggest that geophysical measurements are utilized for practical purposes in seismic research. Notably, microtremor measurement emerged as a commonly used method to investigate liquefied soil beds during the 2014 Mae Lao Earthquake in northern Thailand (Mase *et al*., 2018). This paper aims to summarize the findings of geophysical studies conducted using microtremor and geo-electric equipment at locations affected by liquefaction following the Bengkulu-Mentawai Earthquake in 2007. The study presents a basic analysis, including the horizontal to vertical spectral ratio (H/V) curve and observation of geo-electrical data. Overall, this study provides a comprehensive overview of the liquefied subsurface layers in 2007. Additionally, it is recommended that the local administration in Bengkulu City considers these findings when making decisions regarding construction designs.

One of the liquefied areas under investigation is located in Tanah Patah Village, Bengkulu City, which falls within the administrative jurisdiction of Ratu Agung Subdistrict. Figure 2 depicts the prominent geological features of this region, characterized by sand, silt, and gravel-filled alluvium terraces.

Materials and Methods

Materials

According to Farid and Mase (2020) and Mase *et al*. (2021), areas where alluvium terraces intersect with sand beds in Bengkulu City are particularly susceptible to liquefaction. Additionally, measurement points for geo-electric and microtremor analyses were selected within the researched area (see Figure 3). Microtremor measurements were conducted at three designated points labeled as Micro_TP-1 to TP-3, while geo-

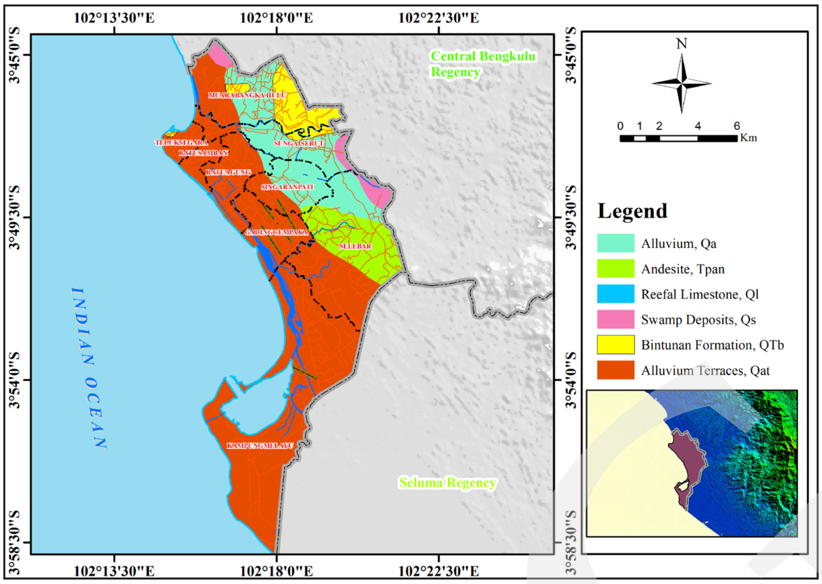

Figure 2. Geological map of Bengkulu Province (after (Mase *et al.*, 2021); modified from Google Earth (2021).

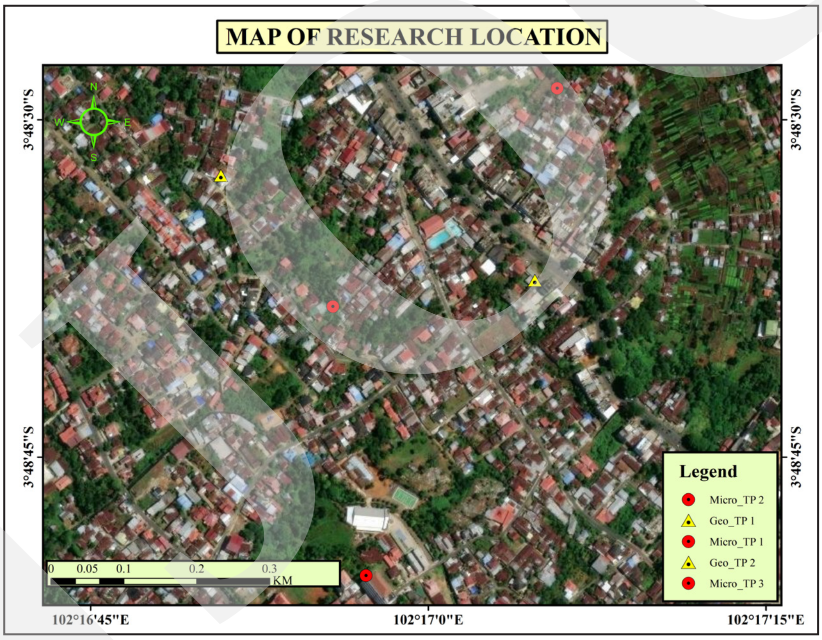

Figure 3. A map displaying the locations of microtremor and geo-electric measurement observations within the liquefied area of Bengkulu City (modified from Google Earth, 2021).

electrical measurements were undertaken at two specified points identified as Geo_TP-1 and TP-2.

In this area, multiple points were found to have experienced liquefaction during the 2007 earthquake. Hausler and Anderson (2007) conducted an investigation in Tanah Patah Village following the 2007 Bengkulu-Mentawai Earthquake and reported extreme land subsidence in one of the two-storey buildings (refer to Figure 4). Furthermore, this incident represents the most severe case of liquefaction in the region, attributed to heightened pore water stress resulting from seismic activity. According to Mase (2019), Ratu Agung Sub-Regency is particularly susceptible to land damage from seismic disasters. However, the condition of the soil beds in the liquefied area has yet to be specifically examined.

Figure 4. Evidence of liquefaction events in Tanah Patah (after Hausler and Anderson, 2007).

Methodology

This study analyzed the impact of the 2007 Bengkulu-Mentawai Earthquake, with its primary focus on interpreting liquefied subsurface beds. Additionally, several previous studies were conducted to assess the geological and seismic conditions in Bengkulu City by employing geophysical measurement concepts, including microtremor and geo-electric tools, to identify soil beds. Building on a solid theoretical foundation, these instruments were utilized in Tanah Patah Village. In 2007, liquefaction was observed at a specific location with coordinates 3.80362°S; 102.27617°E, which was investigated in this study (Table 1).

Furthermore, microtremor measurements were conducted to assess the geophysical characteristics and overall condition of the sediment beds in the studied area. Meanwhile, geo-electric measurements were employed to acquire specific descriptions related to the condition of the soil beds in the studied area. The results obtained and their interpretations are then presented in the form of graphs and soil profiles. In addition to investigating the liquefied soil beds, this study also conducted an inversion analysis of the microtremor data to generate a shear wave velocity profile. This profile is used to gather information about the distribution of soil resistance and the soil site class conditions under examination. The liquefaction potential of the soil beds under investigation was calculated using an empirical technique suggested by Andrus *et al*. (2004). Overall, this study provides a comprehensive analysis of the subsurface beds in the area that experienced liquefaction as a result of the 2007 earthquake.

Measurement of Ambient Noise Microtremor

Several studies have suggested the use of microtremors to measure noise levels around a site. The commonly employed method is the Horizontal-to-Vertical (H/V) spectral ratio, which reflects the site dominant period (T_0) and amplification (A_0) (Kanai and Tanaka, 1954). The H/V ratio can be calculated by dividing the spectral ratio obtained in the horizontal direction by that obtained in the vertical direction, as shown in the following equation:

$$H/V = \sqrt{\frac{H^2_{(EW)} + H^2_{(NS)}}{2V^2}} \quad \text{.............................(1)}$$

where:

H(EW) and H(NS) represent the horizontal Fourier spectra in the E-W and N-S directions, respectively,

V denotes the Fourier spectra in the vertical direction.

Lachet *et al.* (1996), Koçkar and Akgün (2012), and Mase *et al*. (2019, 2020) had reported that the H/V method is valuable for predicting local site

Table 1. Coordinates of Investigated Points

Investigated Points	Measurement Types	Coordinates		Location
		Longitude (°E)	Latitude (°S)	
Micro_TP-1	Microtremor	102.282	3.810	Tanah Patah
Micro_TP-2	Microtremor	102.283	3.813	Tanah Patah
Micro_TP-3	Microtremor	102.285	3.807	Tanah Patah
Geo_TP-1	Geo-electricity	102.285	-3.810	Tanah Patah
Geo_TP-2	Geo-electricity	102.276	-3.803	Tanah Patah

conditions. Compared to other raw noise spectra, the spectral ratio produced by this method is considerably more s. Koçkar and Akgün (2012) noted that f_0 correlated with the peak H/V amplitude (A_0). However, the accuracy of measurements can be affected by background noise from human activity, environmental factors, and other active vibration sources on the earth surface. Therefore, careful execution is necessary to ensure accurate results. Bonnefoy-Claudet *et al.* (2006) stated that the H/V method had been effectively used to predict the dominant frequency (f_0) which is sufficiently predicted by $1/T_0$. Additionally, Raptakis *et al.* (2005) observed that despite its limitations, this method is commonly employed. SESAME (2004) established specific criteria for determining the peak H/V amplitude, aiding engineers in selecting sui locations for engineering practices.

The microtremor at each location in this study is measured using a triaxial geophone wideband seismometer known as PASI Gemini. It comprises three components: east−west (EW), north−south (NS), and up-down (UD), which enables the detection of both strong and weak movements. Prior to measurement, the digitizer of the microtremor is heated up for 5 minutes to mitigate low-frequency range issues and ensure data reliability. Each measurement session lasts for 30 minutes. The recorded data is then processed and cleaned in accordance with SESAME (2004) requirements, including the creation of an H/V curve through additional analysis of the results. For inversion analysis, the model developed by García-Jerez *et al*. (2016) was utilized, generating a shear wave velocity profile. This profile consists of five important parameters for each bed: soil thickness, pressure wave velocity (Vp), shear wave velocity (Vs), soil density (ρ), and Poisson's ratio (ν). The base of the bed assumes semi-elastic space conditions. The minimum and maximum values for each parameter are determined based on Monte Carlo simulation, incorporating known minimum and maximum values of soil characteristics (Bonnefoy-Claudet *et al.* 2008).

<u>Geo-electric Measurement</u>

Geo-electricity is a geophysical method that utilizes electrical properties to discern specific conditions beneath the earth surface (Parwatiningtyas, 2021). Electric current emanating from a single source beneath the earth surface tends to disperse in all directions within a half-spherical space (Zarif, 2021). The electrodes, typically iron pegs, used for these measurements have a diameter of 1 cm and a length of approximately 40 cm. They are affixed to a cable connected to a geo-electrical measurement device, which is inserted into the ground. Current electrodes (A and B) are electrodes linked to an electric current transmitter, while potential electrodes (M and N) are electrodes connected to a potential reader. The configuration of electrodes refers to the arrangement of the current and potential electrodes. Geo-electric profiles, whether 1-D or 2-D, constructed with these electrodes, are typically arranged linearly to form a straight line. The resulting data is presented in the form of a vertical cross-section, providing insights into the geological conditions below the surface. The subsurface of the earth is conceptualized as composed of blocks, each with its own specific resistivity value (Loke and Barker, 1996).

The utilization of geo-electric methods has been identified as a sui approach for subsurface analysis, as demonstrated in several earlier studies. Abudeif *et al.* (2019) examined the geotechnical characteristics of a construction site in New Akhmim City, Sohag, Egypt, and highlighted the integration of two-dimensional profiles obtained from geo-electrical measurements with geotechnical investigation data. Similarly, Abdulrazzaq *et al*. (2020) utilized geo-electric measurements to explore important aquifer properties and determined svitable well placements in the Bahr Al-Najaf depression, Iraq. Aizebeokhai *et al.* (2021) also emphasized the effective identification of crystalline basement aquifers in Basiri, Ado-Ekiti, Southwest Nigeria, using geo-electric resistivity. Moreover, for practical purposes, these measurements are employed to investigate beds prone to liquefaction, as observed in the Kabonena area anticipated to experience such phenomena after the 2018 Palu Earthquake, and Lobu Tua 4, located on the west coast of Sumatra in north Bengkulu (Syandi and Tampubolon, 2020; Badaruddin *et al*., 2021). Generally, geo-electrical measurements find applications in hydrological and geotechnical investigations. However, these measurements have not yet been conducted in liquefied areas resulting from the Bengkulu-Mentawai Earthquake in 2007. Therefore, the focus of this study is to identify the condition of liquefied subsurface beds in 2007.

Soil Site Classification

The National Earthquake Hazard Reduction Programme (NEHRP, 1998) established specific criteria for determining local site conditions (Table 2).

Table 2. Site Classification Based on the Range of V_{s30} (NEHRP, 1998)

A	Hard Rock	$V_s30>1500$
B	Rock	$760< V_s30\leq1500$
C	Very Dense Soil and Soft Rock	$360< V_s30\leq760$
D	Stiff Soil Profile	$180< V_s30\leq360$
E	Soft Soil Profile	$V_s30\leq180$

These are based on the following equation, which represents the average shear wave velocity in terms of the time needed to travel the first 30 m below the surface (Vs30):

$$V_{s30} = \frac{30(m)}{\sum_{i=1}^{n} \frac{d_i}{V_{si}}} \qquad \text{...(2)}$$

where:

d_i is each soil bed thickness,

Vsi is its shear wave velocity, and

n is the total number of soil beds taken into consideration up to the first 30 m of depth.

Liquefaction Potential Analysis

An empirical method developed based on Vs data was employed (Andrus *et al*., 2004). The first step involves calculating the cyclic stress ratio (CSR), which is a metric that quantifies the ratio of the stress generated during an earthquake, as shown in the following equations:

$$CSR = 0.65\left(\frac{a_{\max}}{g}\right)\left(\frac{\sigma_v}{\sigma_v'}\right) r_d \qquad \text{.................................(3a)}$$

$$r_d = 1.0 - 0.00765z \quad \text{for } z \leq 9.15 \text{ m} \qquad \text{..........................(3b)}$$

$$r_d = 1.0 - 0.00765z \quad \text{for } 9.15 \text{ m} < z \leq 23 \text{ m} \qquad \text{.................(3c)}$$

where:

α_{max} is the maximum soil surface acceleration,

g is the gravitational acceleration,

σv is the total stress from the analyzed depth,

σv′is the initial effective stress of the analyzed depth,

rd is the stress reduction factor, and
z is the analyzed depth.

Soil resistance to liquefaction is defined as the Cyclic Resistance Ratio which is highly dependent on the soil strength. Thus, it is just a prediction made using information from the site inquiry. In this work, Vs from geophysical surveys is utilized as a parameter to calculate CRR using the Equations below:

$$CRR = MSF\left\{0.022\left(K_{a1}V_{s1}\right)^2 + 2.8\left(\frac{1}{V_{S1}^* - \left(K_{a1}V_{s1}\right)} - \frac{1}{V_{s1}^*}\right)\right\}K_{a2} \quad \text{..(4a)}$$

$$V_{s1} = V_s\left(\frac{P_a}{\sigma_v'}\right)^{0.25}\left(\frac{0.5}{K_0'}\right)^{0.125} \qquad \text{...................................(4b)}$$

$$MSF = \left(\frac{M_w}{7.5}\right)^{-2.56} \qquad \text{...(4c)}$$

$$V_{s1}^* = 215 \text{ m/s} \quad \text{for } FC \leq 5\% \text{..................................(4d)}$$

$$V_{s1}^* = 215 - 0.5\left(FC - 5\right) \quad \text{for } 5\% < FC < 35\% \quad \text{..(4e)}$$

$$V_{s1}^* = 200 \text{ m/s} \quad \text{for } FC \geq 35\% \text{.................................(4f)}$$

where:

MSF is a scale factor,

Vs1 is corrected by Vs,

Pa is atmospheric pressure,

$K^{0'}$ is effective lateral soil pressure at rest,

FC is fine content,

Vs* is a reference of Vs based on fine content, while

Ka1 and Ka2 are age correction factors (Andrus *et al.*, 2000; Andrus *et al.*, 2004).

After obtaining the two liquefaction control factors (CSR and CRR), the safety factor (FS) was realized. It reflects the stability of the soil under the dynamic forces generated by the earthquake. Meanwhile, when FS is < 1, it means liquefaction is possible, while FS 1 depicts it as impossible. The following equation is the formula used to calculate FS as below:

$$FS = \frac{CRR}{CSR} \quad \text{...(5)}$$

Results and Discussion

Microtremor Measurement

The relationship between the H/V ratio and frequency of measurement data acquired with the microtremor at the observed points in Tanah Patah Village is depicted in Figure 5. At Micro_TP-1, TP-2, and TP-3, the peak values of H/V amplitudes are 3,601, 2,794, and 8,129, respectively. Correspondingly, the predominant frequency values (f_0) are 6.306 Hz, 10.424 Hz, and 0.411 Hz, respectively. The magnitude of the impedance between the sediment and rock beds is often indicated by the peak value of the H/V amplitude. As noted by Mase *et al.* (2021), the higher the value of the H/V amplitude, the greater the effect of impedance contrast on soil and rock beds. Additionally, the predominant frequency value generally reflects the potential conditions of the sediment beds in the studied area. According to Mase *et al.* (2020), a smaller dominant frequency value suggests thicker sediment beds in the observed area.

Soil beds were determined using the inversion analysis method proposed by García-Jerez *et al.*

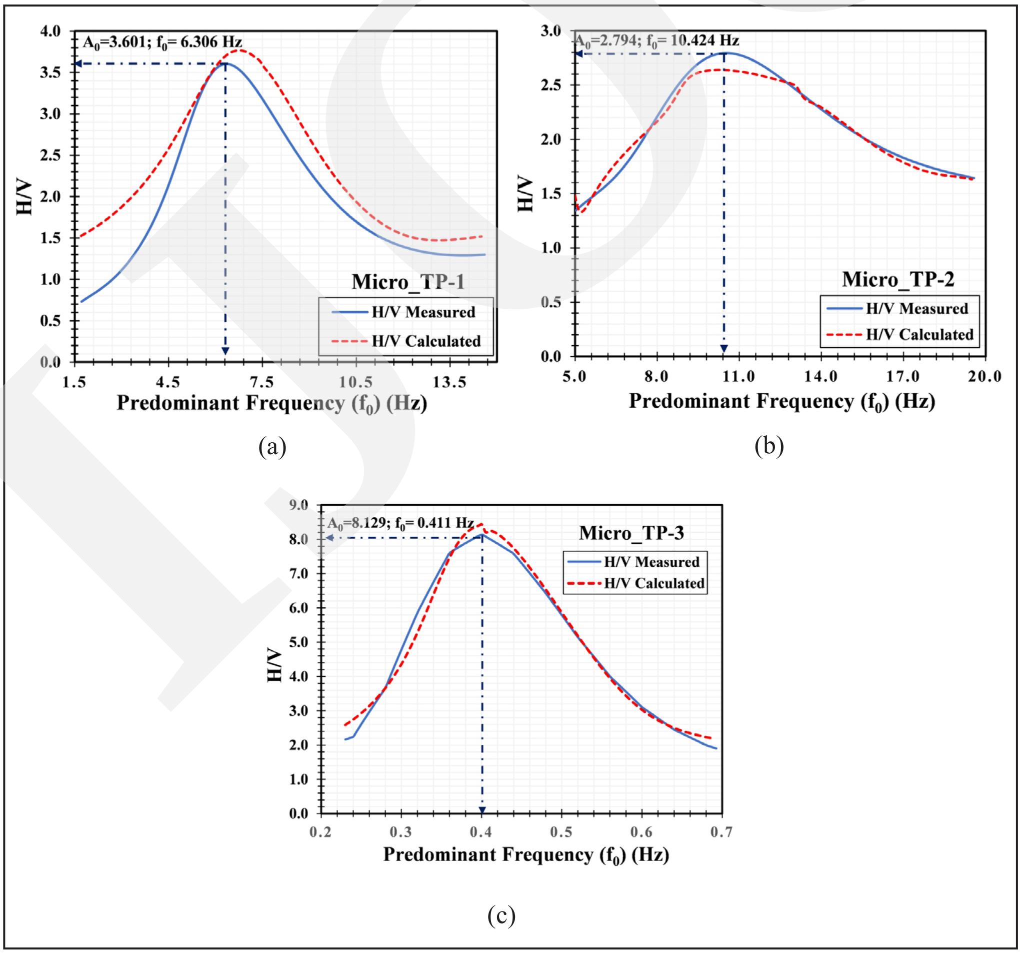

Figure 5. Comparison of measurement and inversion H/V curves using the inversion model of Garcia-Jerez *et al.* (2016) for points (a) Micro_TP-1, (b) Micro_TP-2, and (c) Micro_TP-3.

(2016). This process relies on the compatibility of the soil bed model with the measured H/V curve. Additionally, both the measured and inverted H/V curves are depicted in Figure 5, and they generally exhibit consistency with each other. Furthermore, the relationship between the unit weight of the soil volume (γ), shear wave velocity (Vs), and soil bed type was established. This study utilized Mayne's correlation (Mayne, 2001) as a modeling justification. The interpretation of the soil beds at each microtremor point is illustrated in Figure 6.

The soil beds in the studied area are generally classified as Site Classes D and C. At Micro_TP-1 and TP-2, the average shear wave velocity with respect to the first 30 m depth (Vs30) is 646 and 445 m/s, respectively. Both values fall within the Site Class C (soft rock) category, with Vs30 ranging between 360 and 760 m/s (NEHRP, 1998). On Micro TP-3, Vs30 has a value of 189 m/s, placing it within the Class D site category, where Vs30 ranges from 180 m/s to 360 m/s. These findings align with studies conducted by Mase *et al.* (2021), which indicated that Site Classes C and D are prevalent in Bengkulu City.

Based on the interpretation of soil beds in Tanah Patah Village, Micro_TP-1 and TP-2 are primarily composed of sand beds. Loose sands are found near the soil surface with shear wave velocities (Vs) measuring less than 180 m/s, indicating a susceptibility to liquefaction during earthquakes. Engineering bedrock (Vs values ranging from 400 m/s to 760 m/s on Micro_TP-1 and TP-2) is typically encountered at depths of less than 30 m, while none has been identified in Micro_TP-3. Micro_TP-3 is dominated by clay beds, which are relatively resistant to liquefac-

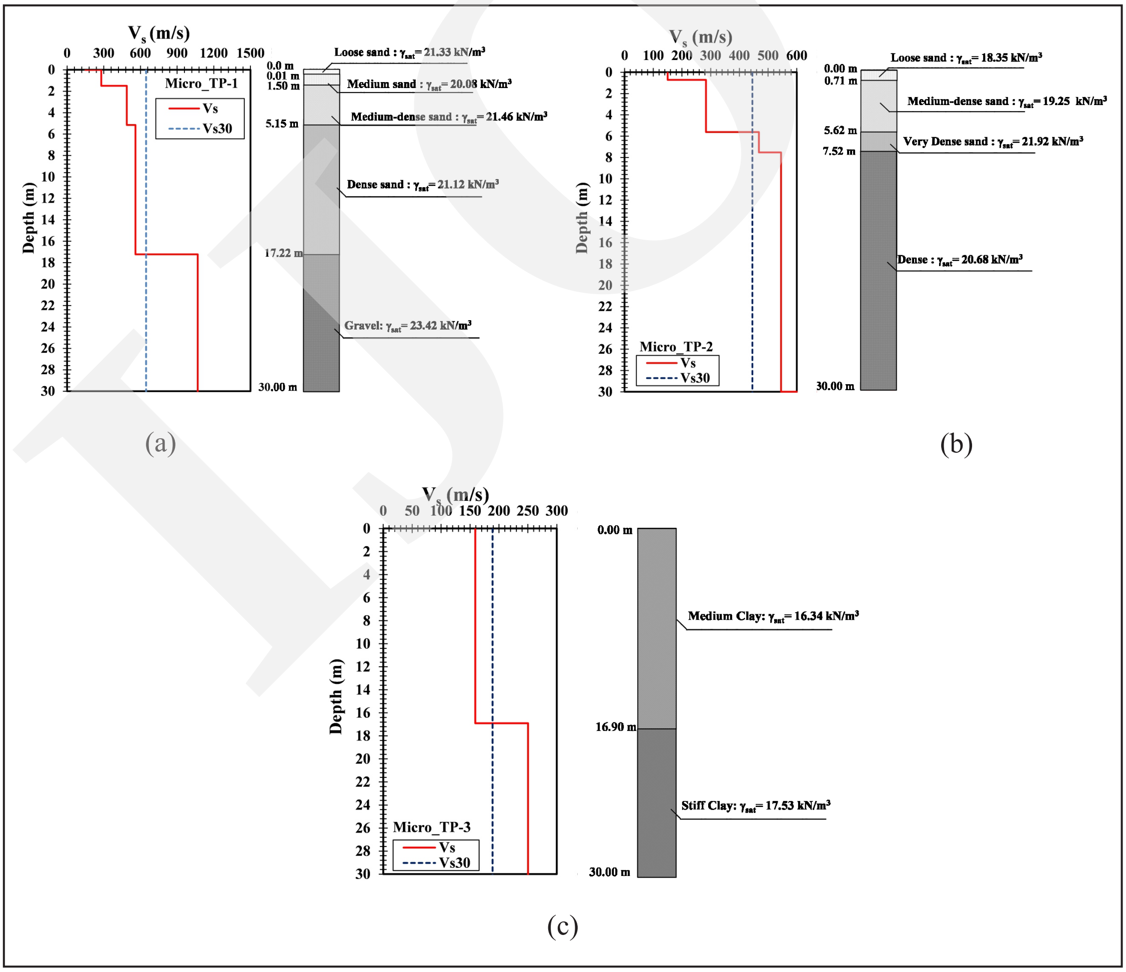

Figure 6. Vs profile of inversion analysis results at points (a) Micro_TP-1, (b) Micro_TP-2, and (c) Micro_TP-3.

tion. However, there is still a potential for ground amplification during earthquakes in areas with thick soft clay beds (Likitlersuang, 2019). The inversion results corroborate the findings from the microtremor measurements, where areas with higher dominant frequency values indicate relatively thin sediment beds, and vice versa. This is consistent with studies conducted by Gosar (2010) and Mase *et al.* (2021).

Geo-electrocity Measurement

The results of geo-electrical survey analysis conducted on Geo_TP-1 and TP-2 are displayed in Figures 7 and 8. Figure 7 specifically illustrates that the TP-1 point contains various rock lithologies in Tanah Patah Village, Bengkulu City. At depths of 0 to 20 m, the resistivity is predominantly influenced by water and sand, with values ranging from 1.46 to 15.5 Ω·m. At depths of 20 to 30 m, the resistivity values range relatively from 164 to 533 Ω·m, indicating the possible presence of loamy sand.

Moreover, at depths ranging from 30 to 86.2 m, the resistivity values very from 1,734 to 5,640 Ω·m, suggesting the presence of hard rock. According to the local residents, the foundation of one of the hotels in the studied area was excavated to a depth of 30 m, encountering hard rock. Figure 8 specifically illustrates that the Geo_TP-2 point contains various rock lithologies in Tanah Patah Village, Bengkulu City. The resistivity values ranging from 4.64 to 15.1 Ω·m are suspected to indicate a mixture of water and sand, beginning at a depth of 0 to 20 m. Between the 36th and 37th electrodes, the resistivity values range from 1,727 to 5,645 Ω·m, suggesting the presence of hard rock, possibly associated with a damaged gas station building. Similar values were also observed at depths of 20 to 86.2 m across the 5th to 40th electrodes. Additionally, sandy clay is believed to be distributed across the 5th to 48th electrodes at various depths ranging from 0 to 20 m, as indicated by resistivity values varying from 162 to 529 Ω·m.

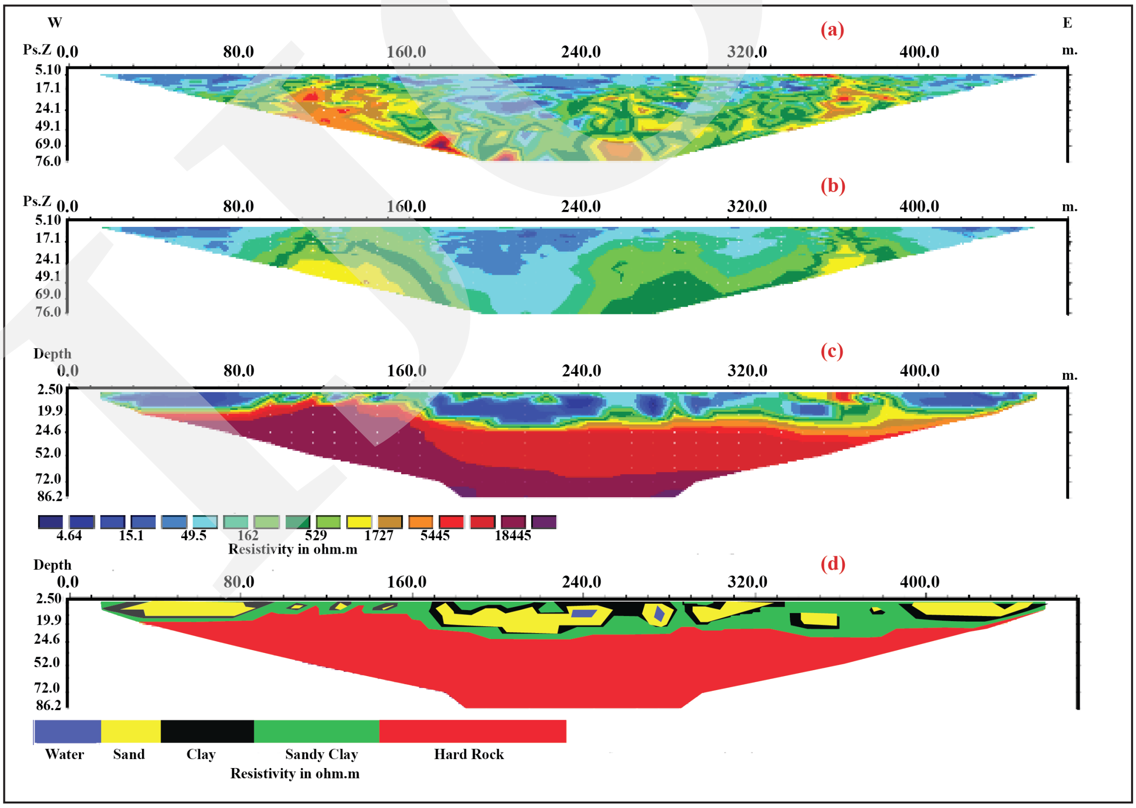

Figure 7. Geo_TP-1 measurement point's 2D resistivity depth inversion cross-section model is made up of four parts: (a) A measured apparent resistivity pseudo-section, (b) A calculated apparent resistivity pseudo-section, (c) A resistivity inversion model cross section, and (d) An interpreted geo-electric cross section.

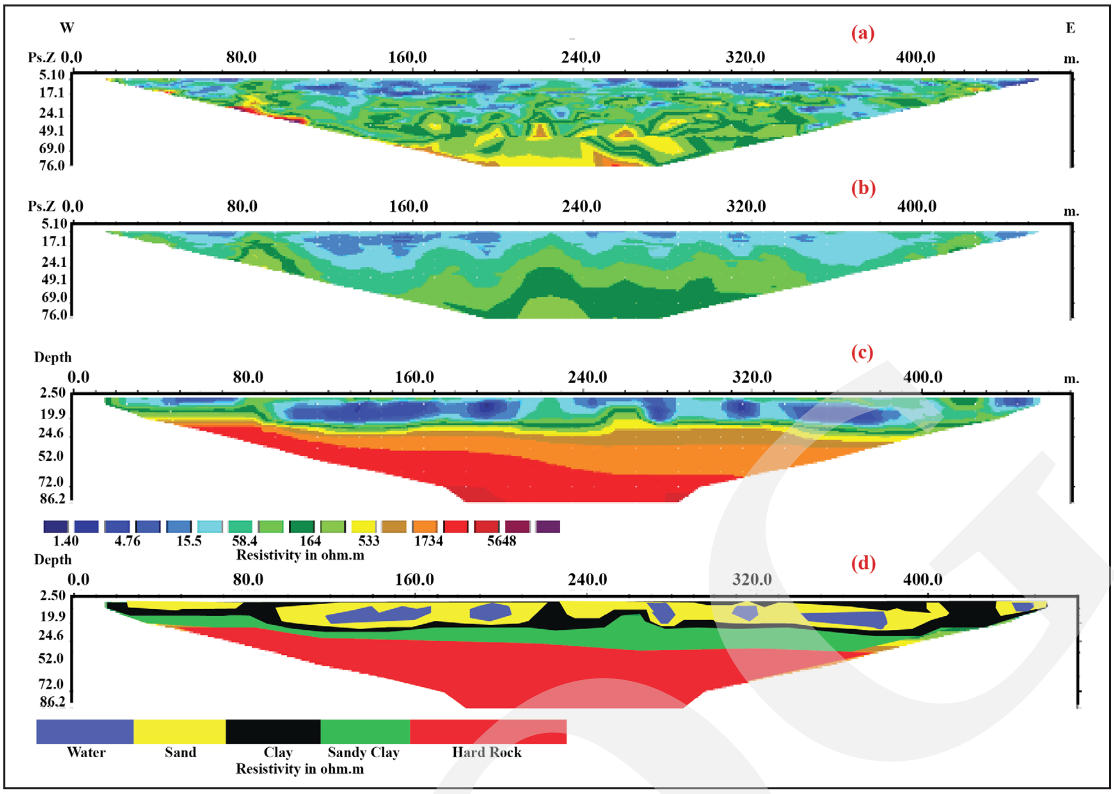

Figure 8. Geo_TP-2 measurement point's 2D resistivity depth inversion cross-section model.

Based on the results of geo-electrical measurements, it was concluded that sand beds were identified in areas susceptible to liquefaction. The susceptibility to liquefaction in this area is further evidenced by the presence of shallow groundwater, particularly during the 2007 Bengkulu-Mentawai Earthquake. A potential liquefaction analysis was conducted in the studied area, specifically focusing on points where shear velocity values were obtained, and a detailed description is provided in the subsequent section.

Liquefaction Potential Analysis

Based on the results of the geophysical investigation, Micro_TP-1 and TP-2 are predominantly composed of sand beds that experienced liquefaction during the Bengkulu Mentawai Earthquake in 2007. Therefore, to validate this occurrence, an empirical analysis was conducted to estimate the potential liquefaction susceptibility in the studied area. The analytical method utilizing shear wave velocity, as designed by Andrus *et al.* (2004), was applied in this study. Based on the geo-electrical analysis results, the depth of the groundwater is relatively shallow. Therefore, to estimate the most critical conditions, this depth is assumed to be close to the ground surface (Mase, 2017). Previous studies indicated that the maximum earthquake acceleration value in the studied area is 0.217 g (Mase, 2018), which is consistent with the estimated peak ground acceleration (PGA) (Farid and Mase, 2020), where the region has a PGA within the range of 0.2 to 0.3 g. In this study, the potential liquefaction analysis was specifically conducted on Micro_TP-1 and TP-2, known to have sandy soil beds. Figure 9 illustrates the relationship between the Factor of Safety (FS) and liquefaction concerning the depth and soil bed profile.

In Micro_TP-1 (Figure 9a), the first sandy soil bed exhibits potential liquefaction, as indicated by the resulting Factor of Safety (FS) value of less than 1, which serves as the threshold for distinguishing between safe and unsafe states regarding liquefaction. Similarly, in Micro_TP-2 (Figure 9b), the first sandy soil bed also shows

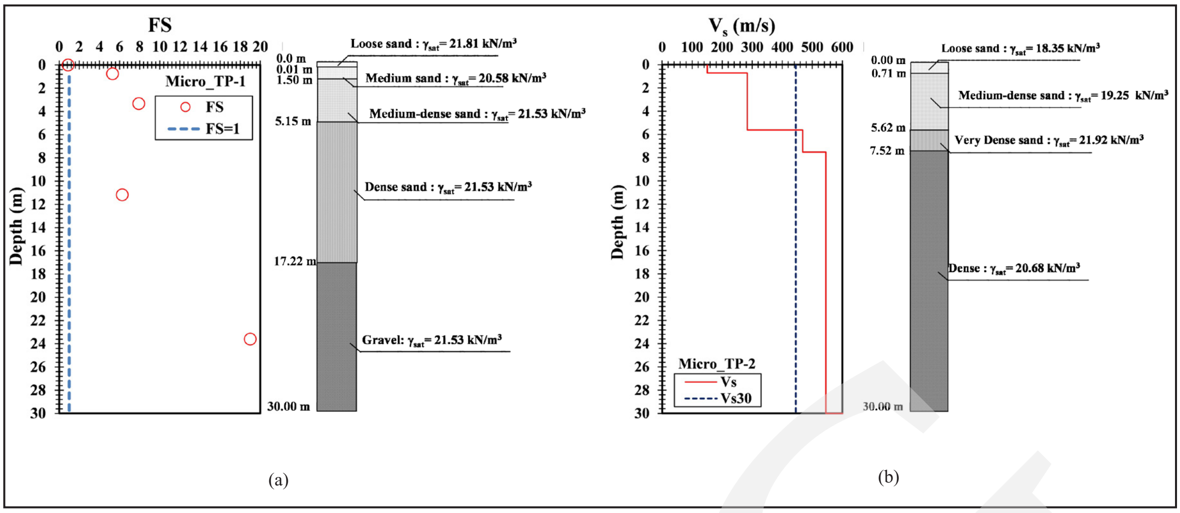

Figure 9. Results of empirical liquefaction potential analysis at points (a) Micro_TP-1 and (b) Micro_TP-2.

potential for liquefaction, with an FS value less than 1. Consistent with empirical analysis results, it is evident that deeper sand beds tend to exhibit greater resistance to liquefaction (Kramer, 1996). Several studies have suggested that peak ground acceleration (PGA) values greater than 0.1g are likely to trigger liquefaction in loose sand beds (Maurer *et al*., 2014; Mase, 2017; Mase, 2019; Mase *et al*., 2021; Sukkarak *et al*., 2021). It has been confirmed that liquefaction in Tanah Patah Village was caused by a loose sand bed saturated with water at a maximum depth of 1 m. Overall, these findings are consistent with field surveys conducted after the 2007 Bengkulu-Mentawai Earthquake. This study contributes to the advancement of liquefaction science in Indonesia, particularly in the province of Bengkulu.

Conclusions

This study explores the subsurface beds in Bengkulu City following the 2007 Bengkulu-Mentawai Earthquake, employing geophysical methods. Microtremor measurements, geophysical surveys, and inversion analysis were utilized to investigate the soil beds with liquefaction potential in the studied area. Therefore, the following conclusions were drawn as below.

In general, Tanah Patah Village is characterized by a sandy soil bed extending to a depth of 30 m. The shear wave velocity values tend to increase with depth, indicating denser and harder soil beds at relatively shallow depths. Additionally, a considerable thickness of clay bed was identified in the studied area. Regarding sediment thickness, there is variability ranging from relatively thin to thick beds, influencing the impedance contrasts between different sediments and rocks. This observation aligns with previous studies that reported a range of damages from building destruction to liquefaction in the studied area (Hausler and Anderson, 2007).

Based on the geo-electrical investigations, the analyzed soil bed exhibits relatively high saturation, suggesting a shallow groundwater in this area. These findings lead to the conclusion that the presence of saturated and loose sand beds, particularly those near the surface, underwent liquefaction during the Bengkulu-Mentawai Earthquake in 2007 (Mase, 2017a).

An empirical analysis of the potential for liquefaction confirmed that this event occurred at a relatively shallow depth during the Bengkulu-Mentawai Earthquake in 2007. This is evidenced by the Factor of Safety (FS) value, which is less than 1, particularly at the same depth. The research findings are generally consistent with field observations reported in previous studies by Hausler and Anderson (2007).

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