

The site effect analysis based on microtremor data using the Horizontal to Vertical Spectral Ratio (HVSr) method in the Bandar Lampung City

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Abstract. Bandar Lampung is the capital of Lampung Province which is crossed by faults, one of the faults that crosses Bandar Lampung namely the Panjang Fault or commonly called the Tarahan Fault, it is making the Bandar Lampung to be a potential earthquake area. Over the past 20 years many large earthquakes have rocked Indonesia, especially in the western part of Indonesia, such as Aceh, Nias, Padang, Bengkulu, Tasikmalaya, and Ciamis. Lampung Province is located near the subduction boundary of the Indo-Australian Plate against the Eurasian Plate, and also there is another fault, the Semangko Fault. Therefore, Lampung Province and especially Bandar Lampung have greater potential to the earthquake effect. The potential of this earthquake needs to be carried out by disaster mitigation activities to minimize the consequences that occur due to earthquakes, namely by classifying soil vulnerability by characterizing site effects. This study aims to determine the site effect based on dominant frequency parameters. The study used 135 microtremor measurement points by using the Ref-Tek 130-SMHR strong motion accelerograph type (3 components). Microtremor data was analyzed using the Horizontal to Vertical Spectral Ratio (HVSr) method in Geopsy software. Based on the HVSr method, the Bandar Lampung is dominated by soft soil types with a dominant frequency of $f_0 < 1.33$ Hz. This shows that Bandar Lampung City has a high vulnerability to earthquakes. Moreover, based on map analysis of the dominant frequency, the areas that have the highest risk are Panjang, Bumi Waras, Teluk Betung Utara, Teluk Betung Selatan, Teluk Betung Timur, Tanjung Karang Pusat, Tanjung Karang Barat, Rajabasa, Enggal, Langkapura, Kedamaian, Wayhalim, and Kedaton .

1. Introduction

Sumatra is one of the biggest islands and the second most populated in Indonesia. However, it is very vulnerable to an earthquake. It is recorded that many big earthquakes have happened in Sumatra, such as 1994 Liwa earthquake, 2000 Enggano earthquake, 2004 Aceh earthquake, 2005 Nias earthquake, and 2009 Padang earthquake. Sumatra lies at a subduction zone, where Indian plate (oceanic) slide beneath the Eurasian plate (continental) (figure 1). The boundary of the contact can be seen as oceanic trench at the west of Sumatra to the Andaman Islands. Indian plate subducts the Sumatra with a velocity of 5.0-6.0 cm/year and angle of 12° [1], [2]. This subduction zone can be observed by using seismicity data down to 300 km beneath the Sumatra.

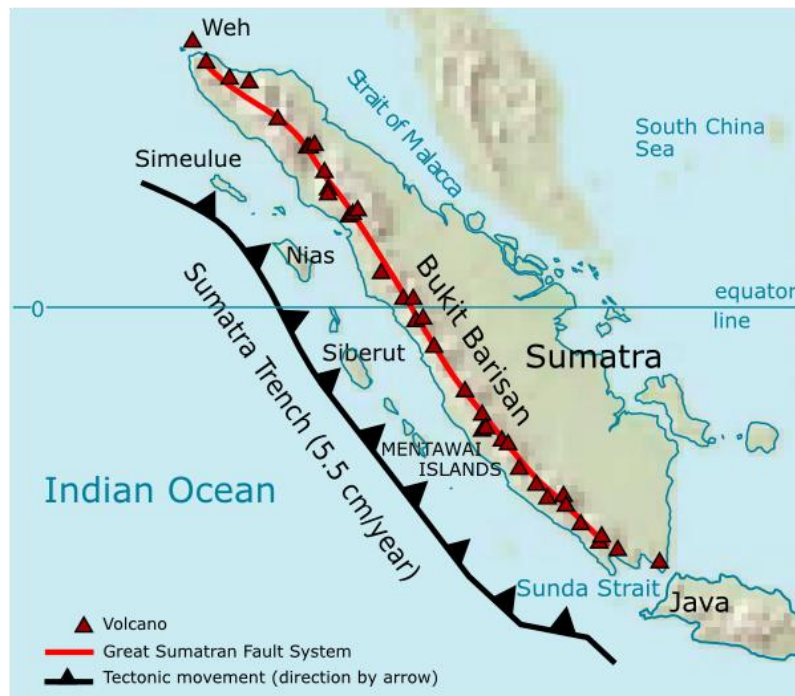


Figure 1. Active tectonic illustration of Sumatra Island.

Beside the subduction zone at the west of Sumatra, there is one big fault in Sumatra, which is Sumatra Mega Fault. This fault stretches along Bukit Barisan Mountains from Semangko Bay in the Sunda Strait to the northern Aceh Region. In the last 100 years, 20 big earthquakes happened in Sumatra Mega Fault. The fault potentially releases big earthquake, Magnitude (M_w) >8, in the range of 2-3 times in 100 years. While an earthquake that has a magnitude less than M_w 7.7 has more probability of being occurred in a dense population area of Sumatra.

Lampung is one of Province in Sumatra has a long history of earthquake. Destructive earthquake in 1933 and 1994 happened in Lampung, which was caused by Sumatra Fault with epicenter at Liwa. The 1933 earthquake has M_w 7.5, and the 1994 earthquake has M_w 7.2. This 1994 earthquake caused serve damage in West Lampung, Lampung Province. Around 75 thousand people were left homeless, 2000 people were injured, and around 196 people died both from villages and sub-districts in West Lampung. The last earthquake happened on June 16th, 2006, with M_w 3.4 in the western area of Lampung, which did not cause much damage [3].

Bandar Lampung is the capital city of Lampung Province which is crossed by faults. One of the faults that cross Bandar Lampung is the Panjang Fault or commonly called the Tarahan Fault. Therefore, as the biggest city in Lampung, Bandar Lampung has two big earthquake potential, externally from the subduction zone and Semangko Fault and internally from the Panjang Fault or Tarahan Fault.

This earthquake vulnerability must be followed by hazard mitigation. The hazard mitigation is applied to minimize the consequences that occur due to earthquakes. Many aspects influence shaking intensity that can be caused by an earthquake. These aspects are the earthquake magnitude and distance between an area with the source. Besides that, one aspect that also influences the shaking intensity is the geological condition of an area. An area with a surface of sediment soil can amplify seismic wave so that will produce higher shaking than the harder rock beneath it.

One aspect of earthquake mitigation is micro zonation of earthquake ground motion potential of an area, in this case is Bandar Lampung. This micro zonation can determine the ground motion potential based on classifying soil vulnerability by characterizing site effects. This study aims to determine the site effect based on dominant frequency parameters. Furthermore, the result can be used as a reference for building construction that is earthquake resistant.

2. Geology and Morphology

Based on the geological map of the study area (figure 2), we can see that Bandar Lampung is constructed geologically by Tarahan Formation, Lampung Formation, and Young Volcanic Deposits. The Tarahan Formation is a welded tuff and breccia with intercalations of chert. The Lampung Formation is Pleistocene terrestrial sediment of epiclastic pumice, tuff, sandy tuff, and tuffaceous sandstone. The young volcanic deposit consists of andesite-basalt lava, breccia, and tuff from eruptions of surrounding volcanoes.

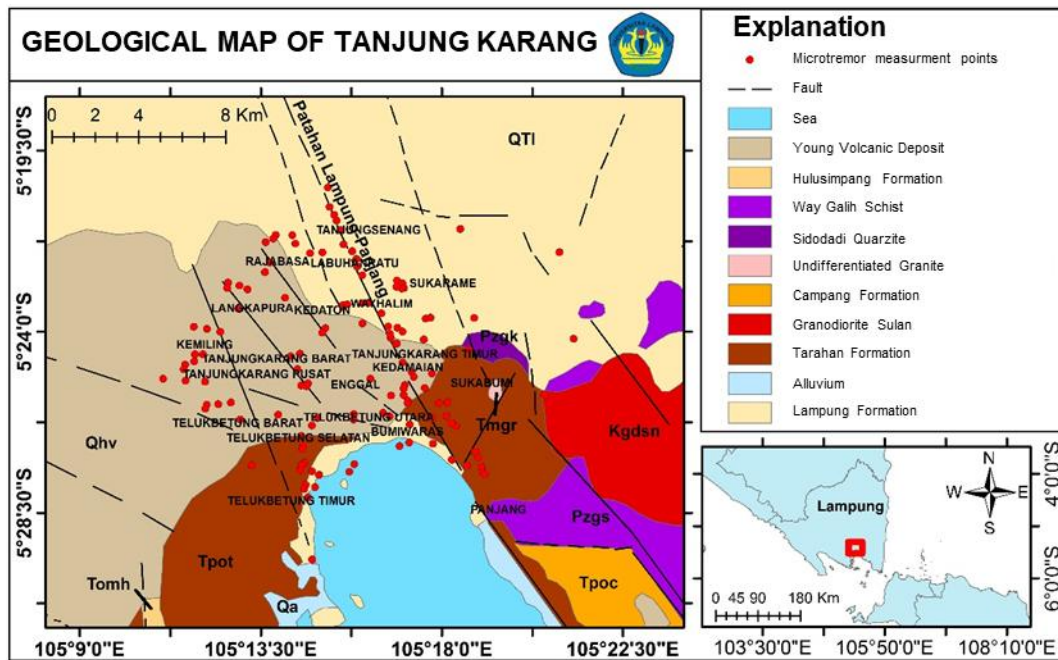


Figure 2. Geological map of Tanjung Karang [4].

The landscape of the west and south area of the study area is a coastline and hills, which is a part of Bukit Barisan in Sumatra. The central area is low flat plain, where the eastern part is the Java Sea. In the southeastern area, we can find a Quaternary volcanic rock, sediment rock, limestone, sandstone, basalt, Surung Batang Formation (tuff, claystone, breccia, and sandy tuff) which is from Early Miocene [4]. According to [5] in northern side of Lampung, there is Kasai Formation (Conglomerate, quartz sandstone, and claystone), Kikim Formation (volcanic breccia, tuff, lava, sandstone, and claystone), Ranau Formation (tuff and limestone), andesite-basalt volcanic rock, volcanic breccia, tuff, and granite.

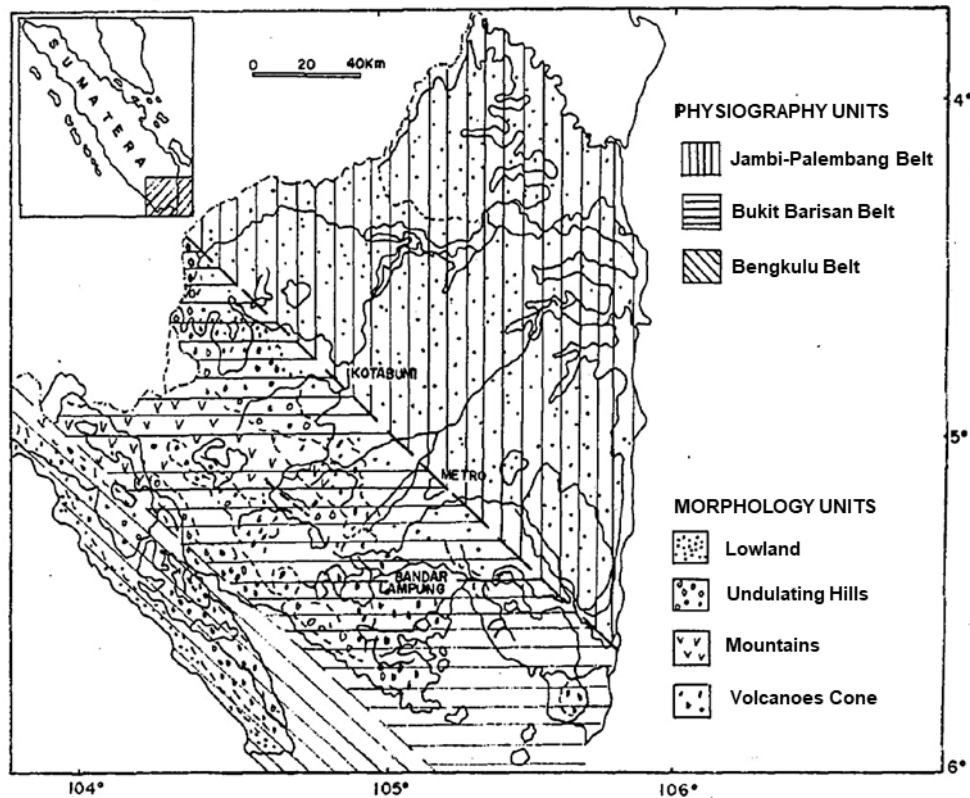


Figure 3. Physiography and Geomorphology map of Lampung Province [4].

In general, this area can be classified into three morphology units: undulating terrain in the East and Northeast, rough mountains in the middle and southwest, and hilly coastal areas to flat terrain (figure 3). Undulating terrain covers 60% of the area and consists of volcanoclastic sediment from Tertiary-Quaternary and alluvium with a thickness of several meters above sea level. Bukit Barisan mountains covers 25-30% of the area, which consists of igneous and metamorphic basement rock and young volcanic rock. The slopes generally are steep with an elevation of 500-1.680 m above sea level. The coastline has various topography types and usually consists of a rough hill, which has 500 m above sea level and made of Tertiary and Quaternary volcanic rock and intrusion.

3. Horizontal to Vertical Spectral Ratio (HVSR)

Microtremor is ambient vibration with low amplitude from the ground which made from natural phenomenon or man-made, such as wind, sea wave, or vehicle vibration. Microtremor data, which has a higher frequency than the earthquake (figure 4), can represent near-surface geology condition. Seismometer with high sensitivity or accelerometer can be used to measure the microtremor. Microtremor observation can be used for determining earth layer characteristic based on a dominant period and amplification factor parameters. In addition, this data can be applied for monitoring volcanic activity, support geothermal exploration, micro zonation, geophysical environment study, and geotechnics.

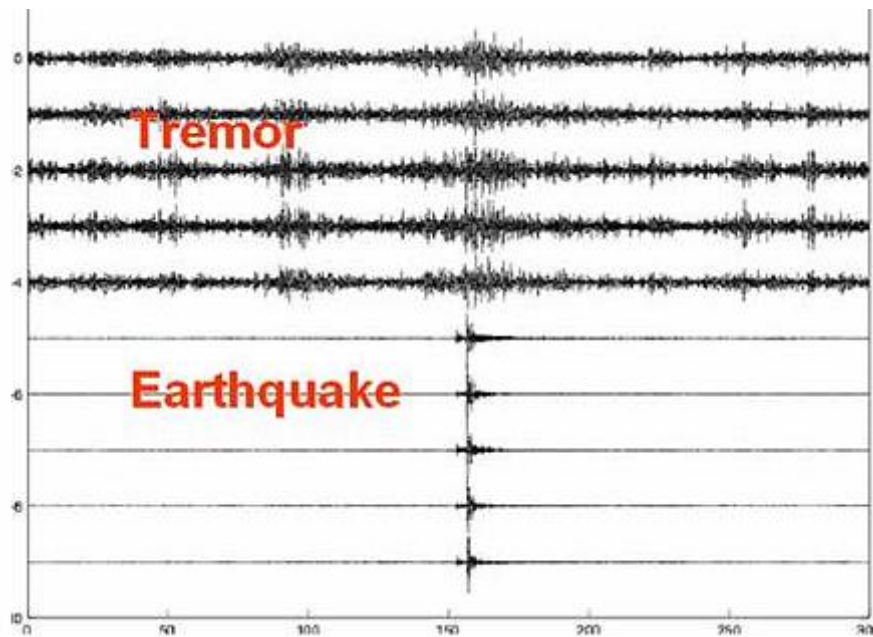


Figure 4. Difference between tremor and earthquake [6].

Nakamura [7] purposed Horizontal to Vertical Spectral Ratio (HVSr) method for estimating natural frequency and amplification of a geological site from microtremor data. This method can be used for a localized area that has building damage vulnerability from the site effect, building and ground interaction, and building structure strength[8].

HVSr is one from geophysical methods that can determine subsurface structure without causing any disturbance to the structure. This method shows the relation between the subsurface structure to the Fourier spectrum ratio of the microtremor horizontal to the vertical signal [7]. HVSr produce important parameters, namely dominant frequency value and amplification factor, which are related to the subsurface physical properties.

Moreover, this method can explain the resonance frequency phenomenon of the surface layer without using reference from bedrock. This can be applied by measuring microtremor in three components, which are vertical, horizontal north-south, horizontal east-west from an area. In addition, this method can be used for identifying resonance response at the sediment basin that consists of sediment material. Therefore, we can say that this method is an effective, inexpensive, and environment-friendly, which can be applied in the various area, including residence or populated area.

From [9], it is known that the amplitude and peak frequency of the HVSr method represent amplification and site frequency of an area. Site effect happens because of the existence of soft earth layer that fills half of the basin from a bedrock. In this condition, there are four components that that involved, which are horizontal and vertical movement of the bedrock and the horizontal and vertical movement of the surface. Amplification factor from that horizontal and vertical movement of the sediment layer on the surface based on the seismic movement of the surface layer that directly contacts the bedrock in basin area are labelled as T_H and T_V [9].

Site Effect (T_{SITE}) at the surface of the sediment layer, usually is stated with comparing the amplification factor from the horizontal and vertical movement at the sediment surface.

$$T_{SITE} = \frac{T_H}{T_V} \quad (1)$$

The horizontal amplification factor T_H is

$$T_H = \frac{S_{HS}}{S_{HB}} \quad (2)$$

with S_{HS} is frequency spectrum from horizontal movement component at the surface, and S_{HB} is frequency spectrum from horizontal movement component at the base of the earth layer. The vertical amplification T_V is

$$T_V = \frac{S_{VS}}{S_{VB}} \quad (3)$$

with S_{VS} is frequency spectrum from vertical movement component at the surface, and S_{VB} is frequency spectrum from vertical movement component at the base of the earth layer.

In microtremor data, Rayleigh wave greatly dominates the data compared to other types of wave. This implies that the horizontal component of the Rayleigh wave has the same value as the vertical component at the frequency range of 0.2 Hz – 20.0 Hz. Therefore, the spectrum ratio between horizontal and vertical component in the bedrock approaching one.

$$\frac{S_{HB}}{S_{VB}} \approx 1 \quad (4)$$

By substituting this equation to the horizontal and vertical amplification in the sediment rock (equation 1) we get the site effect as

$$T_{SITE} = \frac{T_{HS}}{T_{VS}} \quad (5)$$

Equation above become the base of the horizontal vertical spectrum ratio (HVSr) from microtremor data. The equation can be simplified as relation of north-south spectral ($S_{north-south}$), west-east spectral ($S_{west-east}$) and vertical spectral $S_{vertical}$, and it can be written as

$$HVSr = T_{SITE} = \frac{\sqrt{(S_{north-south})^2 + (S_{west-east})^2}}{S_{vertical}} \quad (6)$$

HVSr method is handy for identifying basin resonance response that filled with sediment material. Resonance phenomenon in the sediment layer happens because the seismic wave is trapped in the surface layer. The seismic wave is trapped because there is an impedance contrast between the sediment layer with the deeper hard rock. Interference between the trapped seismic wave in the sediment layer developed to be a resonance pattern that related to sediment layer characteristic [10]. Qaryouti and Tarazi [11] explained that amplification spectrum of HVSr would be amplified in thicker and finer sediment formation.

The dominant frequency is the frequency value that often appears so that it is recognized as the frequency value of the rock layers in the region. From that, the frequency value can indicate the type and characteristics of the rock. Lachet and Brad [12] conducted a simulation test using six simple geological structure models with a combination of variations in shear wave velocity contrast and sediment layer thickness. Simulation results show the peak value of frequency changes with variations in geological conditions [12]. Soil classification based on the dominant frequency value of microtremor according to [13] is divided into 3 types, which are type I has dominant frequency value of $f_0 > 5$ Hz which indicates the thickness of the surface sediment is very thin and dominated by hard rock, type II has dominant frequency of $1.33 < f_0 < 5$ Hz indicate the thickness of surface sediments in the middle category of 5-10 meters, type III has dominant frequency of $f_0 < 1.33$ Hz indicating the thickness of surface sediments included in the category of thickness 10 – 30 (table 1).

Table 1. Soil classification by Kanai based on microtremor dominant frequency (modified from [13]).

1981 (Revised)		1950		Soil Condition
Classification	Dominant Frequency (Hz)	Classification		
Type I	>5	Type I		Tertiary or older rocks, consists of hard sandy rock, gravel.
Type II	1,33 – 5	Type II		Mostly diluvium layer, consists of gravel, sandy hard clay and loam.
		Type III		Most are dominated by the alluvium layer, consists of sand, sandy clay and clay.
Type III	<1,33	Type IV		Very soft soil which formed in swamps and mud. Especially the alluvium layer.

4. Result and Discussion

Microtremor measurement was held in Bandar Lampung over 135 measurement points with Ref-Tek 130-SMHR strong motion accelerograph type (3 components). The microtremor data was processed by the Horizontal to Vertical Spectral Ratio (HVSr) method. In the field, every measurement station was measured in 15 to 20 minutes. Afterward, the raw data was converted to .sac data and processed using Geopsy with a window width of 20-25 seconds corresponding to the existing noise. The smoothing process followed the Konno & Omachi method with a smoothing constant of 40.

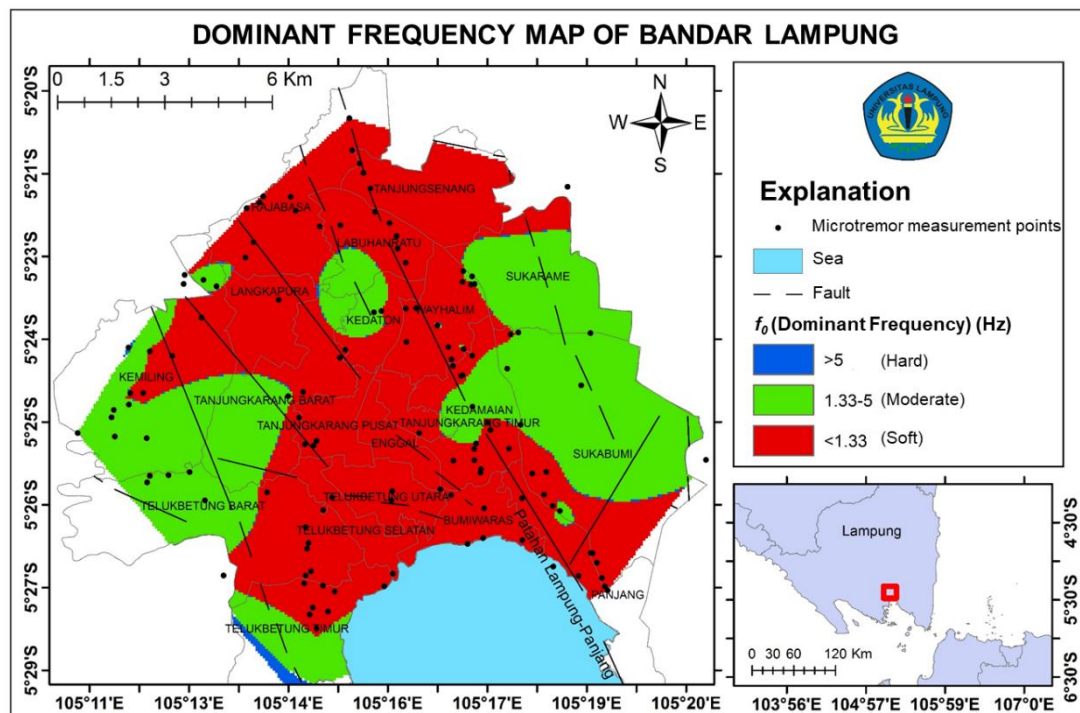


Figure 5. Dominant frequency distribution map of Bandar Lampung.

Natural frequency is a frequency value that usually appears, so it is considered as a frequency value of the rock layer in that area. Furthermore, the dominant frequency value can show rock type and characteristic in a specific area. This value related to the depth of reflection plane for the wave under the surface since that reflection plane is a boundary between the loose sediment rock and the hard bedrock. Hence, the smaller frequency from the wave reflection, the thicker sediment of that wave.

If the ground in an area undergoes shaking/earthquake that has similar frequency to the natural frequency of the area, the resonance will take place and amplify the earthquake shaking. Hence, the worse damage will happen to the building structure.

Referring to the dominant frequency distribution map in figure 5, we can interpret that Bandar Lampung has a dominant frequency of 0.59-8.01 Hz. The distribution of the dominant frequency value ($f_0 < 1.33$) is mostly spread in the middle of Bandar Lampung, and this dominant frequency value is spread along the Panjang Fault. If it is connected with the geological map, a low frequency is an alluvium deposit. The alluvium deposition was found with the characteristics of clay-sized, reddish-brown material, which was found at the time of microtremor data acquisition. This frequency is spread in almost all subdistricts in Bandar Lampung, including the subdistrict of Panjang, Bumi Waras, Teluk Betung Utara, Teluk Betung Selatan, Teluk Betung Timur, Tanjung Karang Pusat, Tanjung Karang Barat, Rajabasa, Enggal, Langkapura, Kedamaian, Way Halim, and Kedaton. The areas are type III, according to Kanai, with an indication of sediment thickness of 10-30 meters.

The distribution of the dominant frequency value of $1.33 < f_0 < 5$ Hz is spread in the west and east of Bandar Lampung. When viewed from the morphological unit of the Bandar Lampung, these areas are the lowland, undulating hills and mountains morphology unit. This dominant frequency is distributed in undulating hills and mountain slopes. Moreover, it includes several districts, which are Sukarame, Sukabumi, Teluk Betung Barat, Kemiling, and Kedaton Utara. The areas are type II, according to Kanai, with an indication of sediment thickness of 5-10 meters.

The distribution of the dominant frequency with a value of > 5 Hz is spread in the hill areas in the rocky hill slopes in the Kemiling and the rocky hill slopes in the Teluk Betung Timur which is a rock mining area, which produces a high dominant frequency value. Hence, according to Kanai, this area is type I, with an indication of sediment thickness that is less than 5 meters.

5. Conclusion

Based on the HVSR method, the Bandar Lampung has various dominant frequency distribution, which is low dominant frequency up to high dominant frequency. However, it is dominated by very soft soil types with a dominant frequency of $f_0 < 1.33$ Hz. This shows that Bandar Lampung has a high vulnerability to earthquakes. Based on map analysis of the dominant frequency, the areas that have the highest risk are Panjang, Bumi Waras, Teluk Betung Utara, Teluk Betung Selatan, Teluk Betung Timur, Tanjung Karang Pusat, Tanjung Karang Barat, Rajabasa, Enggal, Langkapura, Kedamaian, Way Halim, and Kedaton.

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