Landslide Potential Analysis Using Microtremor Data on The Main Route to Beach Tourism in Tanjung Pandan, Pesawaran, Lampung

Ikah Ning P. Permanasari¹, Vico Luthfi Ipmawan¹*, Rifki Prayoga¹, Alamta Singarimbun²

¹ Department of Physics, Institut Teknologi Sumatera, Lampung, Indonesia
² Department of Physics, Institut Teknologi Bandung, Bandung, Indonesia

*Corresponding email: vico.luthfi@fi.itera.ac.id

Abstract. Tanjung Pandan has much beach tourism which attracts many tourists. However, the only road access to these tourist destinations is bordered by hills and cliffs on either side. Its condition has a potential to landslides. This study aims to determine the landslides potential caused by earthquakes considered as external force by obtaining the ground shear strain (GSS) value and obtaining the depth of the slip surface at the measurement location. There are 10 measurement points in two different locations. The method used is the horizontal to vertical spectral ratio (HVSR) method to obtain the value of the dominant frequency and the amplification factor. These two parameters are then used to obtain the value of peak ground acceleration (PGA) and GSS. The depth of the slip surface is obtained by the ellipticity curve inversion method. The frequency natural values vary from 1.4 to 8.2 Hz and the amplification factor values vary from 2.4 to 5.2. The PGA values obtained from Fukushima-Tanaka equation have range from 3.02 to 3.04 gal using the 6.6 Mw Liwa earthquakes considered as the reference earthquake. The GSS values vary from 3.5x10⁻⁶ to 3.2x10⁻⁵. Based on the value, the caused-earthquake landslides potential is very small. This result does not rule out landslides caused by other factors, such as rainfall. Meanwhile, from the inversion method, it is found that the depth of the slip plane at the second location is about 11 to 16 meters with a slope ranging from 23° to 33°.

Keywords: slip plane depth, horizontal to vertical spectral ratio, peak ground acceleration, ground shear strain, Liwa earthquake

1. Introduction

Sumatera has a landscape heavily influenced by the subduction of the Australian plate against the Eurasian plate. Due to the subduction zone in the west, Sumatra has two main natural landscapes, the mountains in the west called the Bukit Barisan and the lowlands in the east. The existence of a subduction zone in Sumatra has also caused several threatening natural disasters, such as earthquakes, volcanic eruptions, and landslides.

However, Sumatra also has much natural tourism. Several tourist attractions are located in Lampung Province, especially in Pesawaran District. Pesawaran Regency is one of the districts in Lampung Province located in the southern part and directly adjacent to the sea. Because of its location, Pesawaran has many beaches and exotic island tourism destinations, for example, Teluk Kiluan, underwater tourism of Pahawang Island, Mutun Beach, Sariringgung Beach, and Klara Beach. However, the only road access to these tourist destinations is bordered by hills on either side. It was formed by the endogenous force lifting and folding the areas. The area
near the road access also has a high slope (30-60 degrees). It will make the threat of landslides along the access route for marine tourism in Pesawaran.

Several studies have been conducted to mitigate landslides in Pesawaran. Identification of slip surface in the landslide area in Padang Cermin, Pesawaran has been done using the 2D resistivity method. Slip surface is around 39 m [1]. The same method, 2D-resistivity, was applied to obtain the presence of the resistivity contrast in an area study near Mount Betung, Pesawaran. This method also for identifying the potential of a landslide in the research area. The result was the presence of layers with high resistivity at the top and low resistivity at the bottom layer. This high one is likely due to pyroclastic flow and the lower one is due to fracture-filled, mostly with water and clay. [2]

Landslide potential also can be analyzed by the Horizontal to Vertical Spectral Ratio (HVSR) method applied to a seismic signal called a microtremor. The method can be used to determine landslide events due to external forces, in this case, due to earthquakes. The HVSR is very flexible to obtain various soil characteristics in response to waves such as ground frequency, soil amplification factor [3-4], the thickness of the sediment layer [5], Peak Ground Acceleration (PGA), and Ground Shear Strain (GSS) [6]. The GSS parameters can be used to predict events if an earthquake occurs in an area. Analysis of sediment thickness using microtremor data can also be used to determine the location of the slip plane in the landslide area [7-9].

This study aims to obtain GSS value to predict whether landslides will occur in the research area in Tanjung Pandan, Pesawaran and to determine the location of the slip plane by ground profile of shear wave velocity (vs) obtained by microtremor analysis.

2. Methods
A total of two locations have been determined as landslide-prone areas in Tanjung Pandan, Pesawaran. There are 10 points for taking microtremor recording data using a Geobit Instrument type C100 seismometer. The recording has a duration of 40-45 minutes per location and with a sampling frequency of 100 Hz. The recorded microtremors were analyzed using the HVSR method [10-11] with Geopsy software. There are assumptions used for HVSR method. First, Rayleigh waves are noise that affects the surface layer of the sediments only. Second, the sedimentary layer does not amplify the spectrum of the micro tremors in the vertical channel. Third, the Rayleigh wave has the same effect on all channels. Mathematically, HVSR can be written as equation (1)

\[
HVSR = T_{site} = \frac{S_{NS}}{S_{SV}} \sqrt{\left(\frac{S_{SN}}{S_{SV}}\right)^2 + \left(\frac{S_{SW}}{S_{SV}}\right)^2}
\]

with SHS is horizontal ambient noise spectral in surface, SVS is vertical ambient noise spectral in surface, SNS is recorded horizontal ambient noise spectral in North-South direction, SEW is recorded horizontal ambient noise spectral in East-West direction, and SV is recorded vertical ambient noise spectral.

The recorded data from the seismometer needs to be separated from noise. Separation of noise can be done by removing transient signals using the STA / LTA method. STA and LTA value were set at 1 second and 30 seconds respectively. Minimum and maximum values of STA/LTA were set at 0.2 and 2. If there were some long transient data chosen after applying STA/LTA method then those were removed manually. The objective is to keep the most stationary parts of microtremor data.

After the noise-free recording is obtained and the HVSR method is applied, the HV curve will be obtained. The HV curve is justified with parameters published by SESAME to get the reliability predicate. Furthermore, the natural frequency parameters and amplification factors can be determined.

The ground profile of vs can be determined by inversion with elliptical curve modeling. Ellipticity curve method is an inverse modeling that used for knowing ground profile based on velocity wave. The method use HVSR curve as input and was affected by some parameters i.e. Poisson’s ratio, vs, compression-wave velocity (vp) and density [12]. Ellipticity Curve Modeling was running in Dinver, open-source software. The input of the modeling is HVSR curve obtained from Geopsy. Compression-wave velocity, Poisson’s ratio, vs, and density values have to be filled as a parameter constraint in the modeling. The vp range from 200 to 5000 m/s whereas
those of $v_s$ range from 150 to 3500 m/s. The assumption that $v_p > v_s$ was selected in Diver program based on the elastic seismic wave theory. The range Poisson’s ratio and the density value vary from 0.05 to 0.4 and 1500 to 5000 kg/m$^3$, respectively based on the lithology of Tanjung Pandan, Pesawaran. The output of Elipcity Curve Modeling is the ground profile of the $v_s$.

Ground shear strain (GSS) is a parameter used to indicate the ability of the soil in an area to stretch or shift when an earthquake occurs. Earthquake damage usually occurs when the GSS value limit is exceeded. GSS value can be calculated by equation (2) [13].

$$\gamma = \left(\frac{A \ 2}{f_o \ \alpha}\right) \times 10^{-6} \tag{2}$$

Where $\gamma$ is GSS, $A_o$ is the amplification factor, $f_o$ is the natural frequency and $\alpha$ is the Peak Ground Acceleration which is obtained from equation (3)

$$\log(\alpha) = 1.3 + 0.41M - \log \left(0.32R \times 10^{6\text{GW}}\right) - 0.0034R \tag{3}$$

where $M$ is the moment magnitude in Mw and $R$ is the hypocenter distance with measurement in km. It can be seen that the PGA value in bedrock only depends on the magnitude of the earthquake moment $M$ and the hypocenter distance ($R$).

3. Results and Discussion

After applied HVSR method, HV curve has been obtained (Figure 1). The value of the frequency and amplification factor obtained from each HV curve can be seen in Table 1. The frequency value at point T01-T10 has a value range from 1.8 to 8.1 Hz. The frequency value can be associated with the thickness of the sediment. The thickness value can be assumed through the wave reflection approach in a two-layer system that has homogeneous properties in each layer. The smaller the frequency, the thicker the sediment layer will be.

| Location point | Longitude($) | Latitude($) | $f_o$(Hz) | $A_o$(-) | GSS(-) |
|----------------|--------------|-------------|-----------|----------|--------|
| T01            | 105.229      | -5.584      | 4.5       | 2.4      | 1.3E-05|
| T02            | 105.229      | -5.585      | 8.1       | 3.1      | 3.5E-06|
| T03            | 105.228      | -5.584      | 1.8       | 4.5      | 3.2E-05|
| T04            | 105.228      | -5.585      | 8.1       | 5.2      | 1.0E-05|
| T05            | 105.231      | -5.585      | 7.8       | 5.1      | 1.0E-05|
| T06            | 105.231      | -5.585      | 7.8       | 3.3      | 4.2E-06|
| T07            | 105.231      | -5.584      | 5.5       | 3.1      | 5.1E-06|
| T08            | 105.232      | -5.584      | 5.0       | 3.0      | 5.5E-06|
| T09            | 105.232      | -5.584      | 4.2       | 3.6      | 9.3E-06|
| T10            | 105.232      | -5.584      | 4.1       | 4.5      | 1.5E-05|
Figure 1. HV curve obtained from the location of T10. The solid black line is the average of the HV spectrum whereas the dashed black line is the standard deviation of the average of the HV spectrum. The amplification value of all measurement points ranges from 2.4 to 5.2. The amplification factor has no units. The amplification factor value represents how much the amplification of the earthquake waves propagating through the sediment layer when an earthquake occurs. The higher the amplification factor, the greater the vibration at that point.

The amplification and frequency values can be used to calculate the GSS value which can then be interpreted with potential geological phenomena that will occur. The GSS value is obtained from equation (2). The relationship between GSS value and potential geological phenomena is shown in Table 2. GSS is influenced by the PGA value. To find the PGA value, a reference to the previous earthquake magnitude is needed. The earthquake reference used is the value of the 1994 Liwa earthquake with a magnitude of 6.6 Mw.

The results of the GSS value range from $3.5 \times 10^{-6}$ to $3.2 \times 10^{-5}$. Based on Table 2, the results of the GSS conclude that the dynamic properties of the soil at all measurement point locations are elastic and if an earthquake occurs, the ground conditions will experience normal vibrations.

Table 2. Relation of ground shear strain to dynamic conditions and properties surface ground [15]

| Ground Shear Strain Value Range | 10^{-6} to 10^{-4} | 10^{-4} to 10^{-2} | 10^{-2} to 10^{-1} |
|--------------------------------|-------------------|-------------------|-------------------|
| Ground conditions              | Only propagation wave, vibration | Crack, ground subsidence | Lanslides, compaction, liquefaction |
| The nature of dynamics soil     | Elastic            | Elastic-plastic    | Elastic-plastic collapse |
|                                 |                   | It happens repeatedly, happens quickly (accumulation effect) | It happens repeatedly, happens quickly (accumulation effect) |

Inversion of the HV curve results in a ground profile vs. From this curve, the interpretation of the vs values is obtained based on Table 3. The inversion of the HV curve is only performed at points T05, T06, and T07. The purpose of this inversion is to get the depth of the landslides slip surface in the area. The output of the inversion of the HV curve is the ground profile of the vs (Figure 2). From this graph, the value of vs can be interpreted from each soil layer. Based on Table 3, the characteristics of the soil can be identified from the value of vs. The slip surface determination can be determined by assuming that the soil layer consists of two layers, namely the
soft sediment layer and the bedrock layer. Soil layers with classes C, D, E, and F can be interpreted as soft sedimentary layers. Meanwhile, soil layers with classes A and B can be interpreted as bedrock layers.

Table 4 contains the $v_s$ value data for each layer for the three inverted points. Table 4 also provides depth information which is presented based on the obtained ground profiles (Figure 2). From Table 4, we can model the bedrock layer as shown in Figure 3. The slip surface is the plane between the sediment layer and the bedrock layer. The depth of the slip surface varies from 11 s.d. 16 m with a slope of 23° to 33°.

Table 3. Ground identification and general description based on shear wave velocity value [16]

| Class | Average of $v_s$(m/s) | Latitude General description |
|-------|-----------------------|------------------------------|
| A     | >1500                 | Hard rock                    |
| B     | 760-1500              | Intermediate rock            |
| C     | 360-760               | Hard soil and soft rock      |
| D     | 180-360               | Intermediate soil            |
| E     | <180                  | Soft soil                    |
| F     |                       | Specific soil                |

Table 4. Shear wave velocity and layer thickness ($h$) obtained from elipticity curve inversion

| Location | Shear wave velocity(m/s) | Layer Thickness(m) |
|----------|--------------------------|--------------------|
|          | Layer 1                  | Layer 2            | Layer 3 | $h_1$ | $h_2$ |
| T05      | 945.2                    | 1787.0             | 2481.5  | 22.7  | 76.4  |
| T06      | 475.7                    | 964.2              | 1286.8  | 11.4  | 51.3  |
| T07      | 729.8                    | 1379.6             | 1878.1  | 16.5  | 78.8  |

Figure 2. Ground profile of the $v_s$ obtained from elipticity curve inversion in location of T05 (a), location of T06 (b), and location of T07 (c)
4. Conclusions
Microtremor investigations of 10 locations in Tanjung Pandan, Pesawaran led to the following conclusions:
1. The GSS values vary from 3.5x10^{-6} to 3.2x10^{-5}. Based on the value, the caused-earthquake landslides potential is very small.
2. The sampled locations (T05, T06, and T07) produced shear-waves velocities vary from 475.7 to 2481.5 m/s. Those results lead to information that the depth of the slip surface vary from 11–16 m with a slope ranging from 23^o to 33^o.

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References
[1] I. Permanasari, V. Ipmawan and E. Khairuman, “Determination of Slip Surface Using 2D Geoelectric Resistivity Method and Laboratory Analysis for Landslide Prone Area Pesawaran, Lampung”, IOP Conference Series: Earth and Environmental Science, vol. 537, p. 012011, 2020. Available: 10.1088/1755-1315/537/1/012011 [Accessed 1 December 2020].
[2] E. Ibrahim et al., “Preliminary Result: Identification of Landslides Using Electrical Resistivity Tomography Case Study Mt. Betung”, Journal of Science and Application Technology, vol. 2, no. 1, 2019. Available: 10.35472/281455 [Accessed 1 December 2020].
[3] V. Ipmawan, I. Permanasari and R. Siregar, “Spatial Analysis of Seismic Hazard Based on Dynamical Characteristics of Soil in Kota Baru, South Lampung”, Journal of Science and Application Technology, vol. 2, no. 1, 2019. Available: 10.35472/281437 [Accessed 1 December 2020].
[4] E. Fattah, G. Januarta, A. Tohari, T. Yadistira, H. Gultaf and V. Ipmawan, “Fundamental Frequency Anomaly Around Cimeta River, Padalarang, West Java”, IOP Conference Series: Earth and Environmental Science, vol. 537, p. 012001, 2020. Available: 10.1088/1755-1315/537/1/012001 [Accessed 1 December 2020].
[5] V. Ipmawan, I. Permanasari and R. Siregar, "Determining Soft Layer Thickness Using Ambient Seismic Noise Record Analysis in Kota Baru, South Lampung", Makara Journal of Science, vol. 23, no. 1, 2019. Available: 10.7454/mss.v23i1.10802 [Accessed 1 December 2020].
[6] R. Prastowo, V. Ipmawan, A. Zamroni, R. Umam, I. Permanasari and R. Siregar, "Identification of ground motion prone areas triggering earthquakes based on microtremor data in Jati Agung district, South Lampung Regency, Lampung, Indonesia", 2ND INTERNATIONAL CONFERENCE ON EARTH SCIENCE, MINERAL, AND ENERGY, 2020. Available: 10.1063/5.0012081 [Accessed 1 December 2020].
[7] M. Kazemnia Kakhki, F. Peters, W. Mansur, A. SadidKhoii and S. Rezaei, "Deciphering site response directivity in landslide-prone slopes from ambient noise spectral analysis", Engineering Geology, vol. 269, p. 105542, 2020. Available: 10.1016/j.enggeo.2020.105542 [Accessed 1 December 2020].

[8] Hadi, A., Sismanto and K. S. Brotopuspito. “Landslide Potential Analysis Using Micro-tremor and Slope Data on Bengkulu-Kepahiang Main Road at Km 31-60.” (2016)

[9] Suhendra, Zul Bahrum and Nanang Sugianto. “GEOLOGICAL CONDITION AT LANDSLIDES POTENTIAL AREA BASED ON MICROTREMOR SURVEY.” (2018).

[10] Y. Nakamura, J. Saita, and T. Sato, Development of Vulnerability Assessment Models using Microtremor/Strong Motion, Prepared for 6th EQTAP Workshop, Kashikojima, Japan, December, 2003.

[11] Y. Nakamura, On the H/V Spectrum, The 14th World Conference on Earthquake Engineering, Beijing, China, October 12-17, 2008.

[12] Burger, H.R. 1992. Exploration Geophysics of the Shallow Subsurface. Prentice Hall

[13] Nakamura, Y, 1997, Seismic Vulnerability Indices for Ground And Structures Using Microtremor, World Congress on Railway Research, Florence, Nov. 1997.

[14] Fukhusima, Y., dan Tanaka, T., 1990, A New Attenuation Relation for Peak Horizontal Acceleration of Strong Earthquake Ground Motion in Japan, Bull of the seismological society of America. Soc. Am., 80, 757-783.

[15] Ishihara, K., 1982, Evaluatian of Soil Properties for Use in Earthquake Response Analysis. Proc. Int. Symp. On Numerical Model in Geomech, 237-259.

[16] Motazedian D., Hunter J.A., Pugin A., Crow H. 2010. Development of a Vs30 (NEHRP) map for the city of Ottawa, Ontario, Canada. NRS Research Press, Canada Bulletin of Earthquake Engineering. 8: 519- 534.