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Landslide Potential Analysis Using Micro-tremor and Slope Data on Bengkulu-Kepahiang Main Road at Km 31-60

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Abstract: *Bengkulu province is the convergence zone of active plate tectonic of Eurasia and Indo-Australia in an ocean and passed by Sumatran fault on its continent. Those conditions make Bengkulu has natural disaster potential such as flood, bad weather, hurricane, and landslide. The aim of this study is to map the potential landslide spot based on micro-tremor data correlated to the value of ground shear strain and slope and to analyze landslide potential on Bengkulu-Kepahiang main road at KM 31-60. This study was conducted using the method of horizontal to vertical spectrum ratio (HVSR). The micro-tremor data was obtained using portable short period PASI Gemini-2 seismometer. The record of micro-tremor data was analyzed its wave spectrum so that it was obtained the ground shear strain. After that, the location station slope was determined based on the percentage of the slope according to Zuidam. The result shows that the spot of landslide potential based on micro-tremor data correlated to ground shear strain and slope consist of high, medium and low potential and not the potential of a landslide. The high potency of the landslide is at the point of d (of Bengkulu-Kepahiang main road at KM 54.3 Tebatmonok village, Kepahiang sub-district, Kepahiang district) with the value of ground shear strain of 1.15×10^{-2} and slope of 15%-30%.*

Keywords: *Ground shear strain, HVSR, Seismometer, PASI Gemini-2.*

I. Introduction

Bengkulu province is one of the area of the convergence zone of the wind direction from Asia and Australia which is known as inter-tropical convergence zone (ITCZ) and the region which has high rainfall throughout the year [1] Bengkulu is also the area of active plate-tectonic of Eurasia and indo-Australia in ocean and passed by Sumatran fault on the continent. Those conditions make Bengkulu has natural disaster potential such as flood, bad weather, hurricane, and landslide caused by weather or the movement of plate-tectonic and fault which may cause an earthquake.

The weather which is high correlated rainfall is one of the factors that can lead the landslide. Based on the prediction map of the land movement potential area of Geological Agency, Ministry of Energy and Mineral Resources Republic Indonesia, the area of study (Bengkulu-Kepahiang main road) has the potential of a landslide which refers to the rainfall data. Besides rainfall, the earthquake is also one of the triggers of the landslide. Geologically, a landslide can be affected by the texture and structure of the rock, lithology of the subsurface, elevation, and slope [2].

Bengkulu-Kepahiang main road is the way of main transportation to connect Bengkulu to other provinces. This road is also potential to have landslide due to its steep slope angle at the side of the road. The area of study is also located on the Sumatran fault of Musi segment of which is highly potential to trigger the occurrence of a landslide caused by the earthquake. Based on the history of the earthquake in this area was caused by Sumatran fault of Musi segment movement with M_w = 7.2 and slip rate of 11mm/year [3]. Based on that condition, so that it is necessary to do some study on the landslide on Bengkulu-Kepahiang main road at KM 31-60 using microtremor dan slope. This study aim to map the distribution spot of landslide potential based on microtremor data which is correlated to the value of ground shear strain and the slope also analyzing the potential of landslide in this area.

II. Research Method

This study was conducted in Bengkulu-Kepahiang main road at KM 31-60, Bengkulu province (Fig. 1). To determine landslide potential micro-tremor and slope data were used. This study was conducted using horizontal to vertical spectrum ratio (HVSR) method. HVSR is one of the measurement methods to find out the structure character of the subsurface layer without causing a disturbance on its structure. The output from HVSR method is amplification and predominant frequency value in the location. Amplification and predominant frequency value were used as the input of parameters to generate seismic vulnerability index and ground shear strain value. Seismic vulnerability index is formulated as [4, 5]:

$$K_g = \frac{A_g^{\,2}}{f_g}, \tag{1}$$

where A_g is the amplification factor (it's the comparison between shear wave velocity in the basement and surface) and f_g is predominant frequency. Based on the table of [6], the value of ground shear strain was used to predict the phenomena and characteristics of dynamic soil correlated to rock deformation. The value of ground shear strain indicates the presence of rock movement ranged at 10^{-2} to 10^{-1}. Ground shear strain is formulated as [4]:

$$\gamma_g = K_g \times \frac{\alpha}{\pi^2 v_b}, \tag{2}$$

where α as peak ground acceleration (PGA) on the basement (gal = cms^{-2}) and v_b as shear wave velocity on the basement which is the value is 600 ms^{-1}.

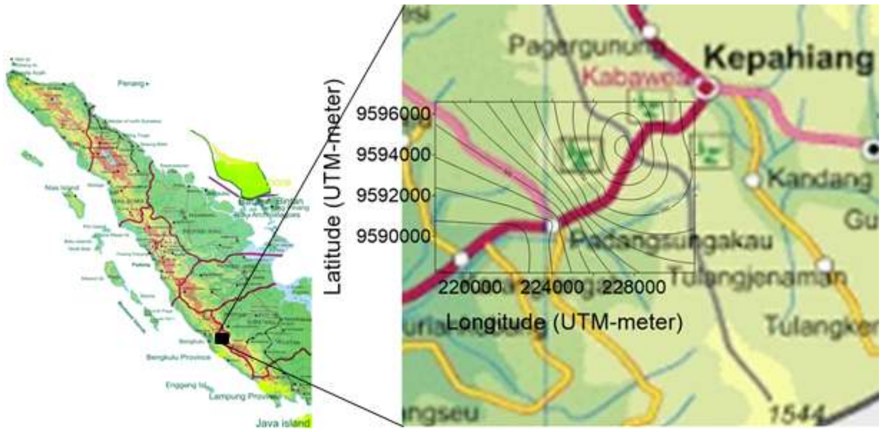

Figure 1. Location of study area

The data collecting and study spots determining were carried out by the zoning system which refers to the distribution of potential landslides spots based micro-tremor and the slope data as long as Bengkulu-Kepahiang main road at KM 31-60 with Google Earth software. From this road, it was taken the data such as the position and elevation using the global positioning system (GPS) as well as micro-tremor data at that location using a portable short period seismometer consisting of a seismometer PASI Gemini-2, laptops, digitizer, and battery (Fig. 2).


Figure 2. Portable short period seismometer PASI Gemini-2

Micro-tremor data record wave spectrum was then analyzed using Geopsy software, to obtain the soil data amplification and predominant frequency as the input parameters to obtain the value of the seismic vulnerability index. Also, other parameters input in the form of PGA in the basement obtained by approximation using McGuire formula. The affecting parameter to the value of PGA at the McGuire formula is earthquakes magnitude that has occurred and the distance to the observation station to the hypocenter (earthquake focus). PGA values according to McGuire in [7] are:

$$\alpha = 472 e^{0,278 M_w} (R + 25)^{-1,301}, \quad (3)$$

where M_w is the earthquake magnitude and R is the distance of earthquake focus to the observation station (km). To get the value of the PGA, in this study the earthquake magnitude is taken based on the historical data of earthquakes occurred in the region of Bengkulu province for 100 years (1913 to 2013) from of the United States Geological Service (USGS) and International Seismological Centre (ISC) catalog. From these input parameters the values of ground shear strain at the surface will be obtained which is used as a parameter to determine the potential of landslides.

The locations that have the potential of landslides based on the ground shear strain value were then mapped is ready to be interpreted. After that the location slope was determined based on the percentage of slope [8]. The slope percentage classification is shown in Table 1. The area having the slope ≥ 15% and high value of ground shear strain is a highly potential landslides occurrence area.

Table 1. Classification of slope percentage according to Zuidam [8]

Slope (degree)	Slope (%)	Slope classification
0 - 2	0 - 2	Flat or almost flat
2 - 4	2 - 7	Gently sloping
4 - 8	7 - 15	sloping
8 - 16	15 - 30	Moderately steep
16 - 35	30 - 70	Steep
35 - 55	70 - 140	Very steep
> 55	> 140	Extremely steep

III. Results and Discussion

Kepahiang-Bengkulu main road at KM 31-60 Bengkulu province is included in the district of Central Bengkulu (Tanjung Heran village and surrounding areas) and Kepahiang district (Tebatmonok village and surrounding areas). The area of study is an area crossed by Sumatran fault of Musi segments which is an area that is prone to the vulnerable of the earthquake. Micro-tremor data acquisition was conducted on 21st to December 26th 2014. The data obtained as many as 33 station spot. After microtremor data was obtained, it was then processed using Geopsy software to get the value of ground amplification and predominant frequency. The value of ground predominant and predominant frequency are then inserted into the Eq. (1) to get the seismic vulnerability index and Eq. (2) to obtain the value of the ground shear strain that has been substituted with PGA values over a period of 100 years (1913 to 2013) from Eq. (3).

In addition to the ground shear strain and slope, rainfall of the study area was also greatly affects the occurrence of landslides. The area of study is the area of Tanjung Heran village, Taba Penanjung sub-district, Central Bengkulu and Tebatmonok village, Kepahiang sub-district, Kepahiang district. Rainfall data for the two districts are obtained from the Indonesian Agency for Meteorology, Climatology and Geophysics (BMKG) of Bengkulu province. Based on rainfall data during five years (2010-2014), the rainfall in the village of Tanjung Heran was 3790.4 mm/year and Tebatmonok village was 3098 mm/year. According to [9], Bengkulu and the surrounding area are the area that has a very wet rainfall. Rainfall is fairly high at ≥ 2500 mm/year and very wet rainfall is one of indicators of potential landslide areas.

The value of ground shear strain is affected by seismic vulnerability index (*Kg*) and value PGA bedrock in location. Generally if the *Kg* is high, the value of ground shear strain is also high. However, at some spots of the observed location, for example, the survey *b* spot (station) with Kg = 15.82, the value of its ground shear strain higher as 5.34×10^{-3} compare to *u* stations that have Kg = 16.25 and the value of its ground shear strain of 3.43×10^{-3}. This is because the value of the PGA at the station *b* is higher as 200.61 gal than *u* stations with PGA value of 124.68 gal. The PGA value in the bedrock is influenced by earthquake magnitude and distance of the survey point to the earthquake focus. The greater the magnitude and the closer distance to the earthquake focus survey point, the greater the value of PGA will be, and thus will affect the value of ground shear strain. Ground shear strain rate map is shown in Fig. 3.

To determine the potential for landslides, slope class should be known and the value of ground shear strain in the survey location. To map the location of slope in this study ArcGIS software trial version was used. They can cause landslides in an area that has a slope of ≥ 15% with a moderately steep to extremely steep slope class [8, 10] and the value of ground shear strain $\gamma_g = 10^{-2}$-10^{-1} [6]. With considering class slopes and ground shear strain value can be known potential landslides as shown in Table 2, while the map of potential landslides in the study area is shown in Fig. 4.

Table 2. Survey data points along with the slope classes and landslides potency

Sta.	Loc. (KM)	A_g	f_g (Hz)	K_g	PGA (ms^{-2})	γ_g	Slope classes	Landslides potency
a	60	1.96	0.66	5.83	1.19	1.17×10^{-3}	Flat	Not potential
b	55.6	5.71	2.06	15.82	2.01	5.36×10^{-3}	Gently sloping	Not potential
c	54.9	5.03	4.63	5.45	1.21	1.11×10^{-3}	Moderately steep	Medium
d	54.3	6.24	0.69	56.27	1.21	1.15×10^{-2}	Moderately steep	High
e	53.7	2.99	0.70	12.84	1.21	2.63×10^{-3}	Steep	Medium
f	53	4.30	2.41	7.70	1.21	1.58×10^{-3}	Steep	Medium
g	52.1	3.13	3.70	2.65	1.25	5.44×10^{-4}	Steep	Low
h	49.8	3.12	3.55	2.75	1.22	5.68×10^{-4}	Steep	Low
i	51.1	2.31	3.53	1.51	1.22	3.11×10^{-4}	Steep	Low
j	50.3	2.48	5.33	1.15	1.22	2.38×10^{-4}	Steep	Low
k	47.7	2.41	7.27	0.80	1.23	1.66×10^{-4}	Steep	Low
l	47.3	3.41	7.35	1.58	1.23	3.28×10^{-4}	Steep	Low
m	45	3.86	6.19	2.41	1.23	5.00×10^{-4}	Steep	Low
n	42.5	7.64	5.13	11.38	1.25	2.41×10^{-3}	Steep	Medium
o	45.5	5.82	5.79	5.85	1.24	1.23×10^{-3}	Steep	Medium
p	45.7	7.19	4.34	11.91	1.24	2.50×10^{-3}	Steep	Medium
q	40.5	6.15	9.19	4.12	1.26	8.75×10^{-4}	Steep	Low
r	46.3	2.68	13.45	0.53	1.24	1.12×10^{-4}	Moderately steep	Low
s	45	3.63	9.31	1.42	1.25	2.98×10^{-4}	Steep	Low
t	44	2.79	1.29	6.04	1.25	1.27×10^{-3}	Moderately steep	Medium
u	43.5	8.86	4.83	16.25	1.25	3.43×10^{-3}	Steep	Medium
v	42	3.60	5.69	2.28	1.26	4.84×10^{-4}	Moderately steep	Low
w	41	2.68	5.58	1.29	1.26	2.74×10^{-4}	Moderately steep	Low
x	40	2.59	4.00	1.68	1.26	3.58×10^{-4}	Sloping	Not potential
y	39	3.47	2.99	4.02	1,26	8.59×10^{-4}	Moderately steep	Low
z	39.5	3.10	6.49	1.48	1.27	3.17×10^{-4}	Moderately steep	Low
aa	35	2.76	4.09	1.87	1.29	4.07×10^{-4}	Gently sloping	Not potential
bb	37	3.06	3.71	2.53	1.27	5.45×10^{-4}	Gently sloping	Not potential
cc	38	3.67	3.76	3.59	1.27	7.67×10^{-4}	Moderately steep	Low
dd	57	3.40	1.22	9.50	1.19	1.92×10^{-3}	Gently sloping	Not potential
ee	46.5	4.24	4.23	4.25	1.24	8.90×10^{-4}	Steep	Low
ff	36.5	1.56	9.27	0.26	1.28	5.72×10^{-5}	Gently sloping	Not potential
gg	31	2.46	4.53	1.33	1.32	2.99×10^{-4}	Gently sloping	Not potential

In this study, the high potential landslide areas are in *d* point survey with the ground shear strain of 1.15×10^{-2} and class moderately steep slopes (≥15%). This location is on the Bengkulu-Kepahiang main roads at KM 54.3 Tebatmonok village, Kepahiang sub-district, Kepahiang district. According to [6] the value of ground shear strain, $\gamma_g = 10^{-2}$ may indicate high deformations so that it can cause landslides; $= 10^{-3}$ has the character of elastoplasticity which can cause cracks. The value of ground shear strain, $\gamma_g = 10^{-3}$ with a moderately steep up to steep slopes is considered medium potential (crack), such as at point survey of *c*, *e*, *f*, *n*, *o*, *p*, *t*, and *u*, for $\gamma_g = 10^{-4}$ with class of moderately steep to steep slope is categorized potentially low, whereas $\gamma_g = 10^{-5}$-10^{-3} with a flat to the sloping class is categorized not potential to landslide. But the value of $\gamma_g = 10^{-3}$ on the flat slope up to sloping area needs to be aware also crack particularly in residential areas even more if the $\gamma_g = 10^{-2}$ can cause liquefaction.

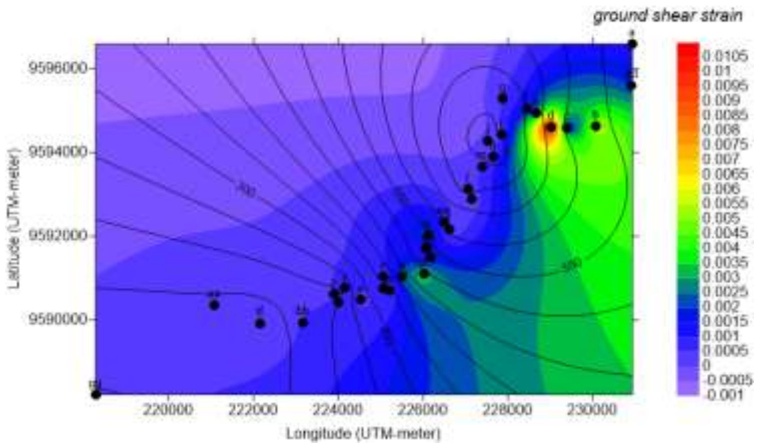

Figure 3. Map survey point and ground shear strain value in the area of study

Bengkulu region is an area that has the highest seismic activity compare to other areas in the island of Sumatra. The greatest cumulative tectonic energy and strain rate value is in the zone around Bengkulu. The high value is implicated to strain rate on slab movement which leads to fracture compared to lower strain rate zone. Therefore, it can be interpreted material is more easily to the fracture and cause the material to be relatively less elastic. This also implies the high seismic activity compared with other zones on the island of Sumatra [11]. High seismicity activity can affect slope stability in these areas. Because the survey area is also crossed by the Sumatran fault of Musi segment, it will increase the level of potential landslides in the case of ground motion caused by strong earthquakes, especially those in Kepahiang sub-district. According to [12], lineament located around the survey point of *h* and *j* are steep. The existence of lineament near this location can also trigger the occurrence of cracks due to a weak zone, so that in the locations around the lineament is an area that needs to be aware of the landslide, in addition to the highly potential (landslide) and medium (crack). The rock crack can result in reduced slope stability, so that the rock may fall or slide when the water to seep into the cracks or when vibration occurs on the slopes.

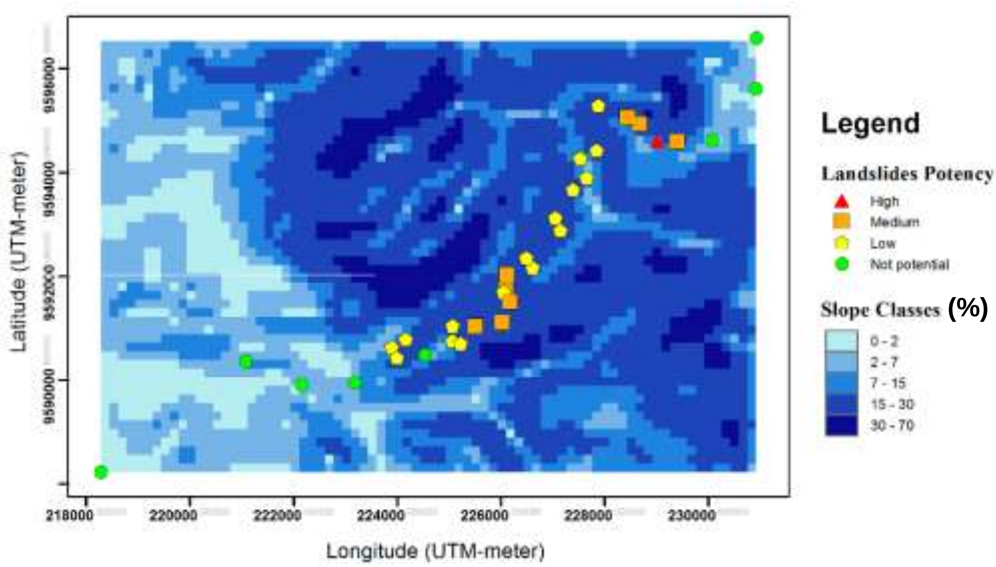

Figure 4. Map of slopes and landslides potency in the area of study

The value of ground shear strain is also influenced by the type of material of the rock and velocity of seismic waves that propagate in the rock. The difference of ground shear strain value at several locations showed that the presence of different constituent materials so that it has a different value of ground shear strain. Loose material is easily deformed than the compact material. Sand layer and graveled material near the earth's surface physically has higher ground shear strain values. Water saturated layer does not allow the compaction process; this is due to water-saturated layer is usually composed of loose sand and graveled materials, making it easy to deform such as cracks and liquefaction [13]. If the ground crack occurs in residential areas, it may cause damage to the foundation and walls of houses, whereas in the case of ground cracks along the highway can disturb the flow of traffic and transport pathways. In the quite steep to steep slopes with the high ground shear strains value, it can cause landslides.

The velocity of seismic waves that propagate in the rock depending on how hard or soft rock is. The harder rock, the greater the stored energy or seismic wave is transmitted by hard rock, which means energy loss [14, 15]. With such seismic wave velocity in hard rock is greater than the velocity of seismic waves in soft rocks. In this study, in general, the velocity of seismic waves in the rocks of subsurface potential landslide sites has a smaller velocity. This indicates that the rock beneath the surface in locations prone to landslide consists of soft rock so that in the case of high-intensity rainfall will cause a landslide.

IV. Conclusion

Based on these results it can be concluded that distribution of the potential landslides spot based micro-tremor data associated with the ground shear strain value, and the slope consists of high, medium, small, and no potential of the landslide. The area that has high potential causes of landslides are at the point survey of *d* (Bengkulu-Kepahiang main road at KM 54.3 Tebatmonok village, Kepahiang sub-district, Kepahiang district) with ground shear strain value of 1.15×10^{-2} and slope of 15%-30 %.

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