GEOLOGICAL CONDITION AT LANDSLIDES POTENTIAL AREA BASED ON MICROTREMOR SURVEY

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ABSTRACT

Vulnerability to landslide hazard significant affected by geological condition such as decrease of material strength. The weakness in the composition or structure of rock can be estimated by seismic vulnerability index and shear wave velocity. A hundred seismic stations have installed at along Central Bengkulu to Kepahyang cross lane (mountain region: Bukit Barisan) to record ambient noise as rock response. All of microtremor data analysed by using HVSR and Dinver to get amplification factor, resonance frequency of ground motion and 1D models of shear wave velocity, respectively. Based on distribution of seismic vulnerability index, it has been divided into four zones, including brown zone, red zone, yellow zone, and green zone. Brown zone was a highest seismic vulnerability index (K_g= 25.82) in along of line, then red zone yellow zone and green zone, respectively. Based on shear wave velocity model, red and yellow zones were not significant different with brown zone. Rock structure of them was soft, escpecially on the surface with the thickness about 4 meters. Both of these zone still high risk to landslide like brown zone. Different results have been found on green zone. Green zone was stable and safe zone because it has the lowest seismic vulnerability index. In addition, based on shear wave velocity models, it has hard rock structure on the surface. All of them were compatible with visual observation results and landslide profile in the past. These combination showed that microtremor survey be able to describe geological condition of landslide potential area.

Keywords: landslides, microtremor survey, seismic vulnerability indexes, shear wave velocity, geological condition.

INTRODUCTION

The main road of Central Bengkulu to Kepahyang (mountain Region) are one of the important road which connects to others province from the east. It located at boundary of Central Bengkulu and Kepahyang regency, Bengkulu province, Sumatera Island, Indonesia. It has high topography up to 888 meters above sea level (Figure-1) which is one of Bukit Barisan mountains series in the Western Sumatera island. The highway was quite crowded because many various types of vehicles used this road like motorcycles, cars and ton trucks.

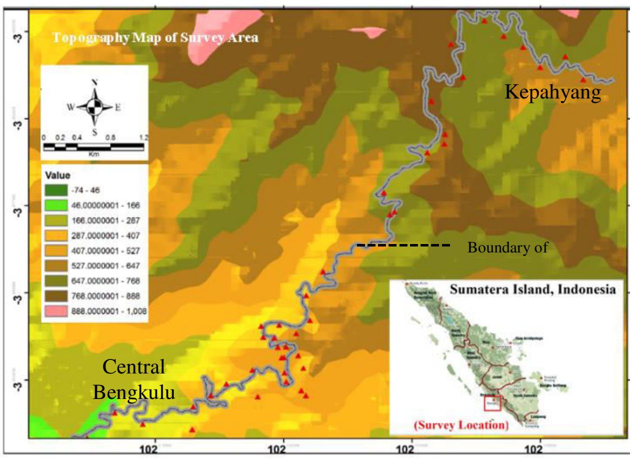

Figure-1. Topography map of survey area (a part of Central Bengkulu to Kepahyang area).

The sites of this cross line often experienced moving ground or landslides. It has very serious impact, especially disruption the society economics activities that depended on this road. Some of the causes of landslides in along these line included topography conditions (which have steep slopes) as showed by Figure-1, high level of rainfall (235-280 mm/year based on BMKG data) and human activity like logging, conversion of land into settlements, improper use of slopes, slope cutting and strong ground vibrations from vehicles. Some of these causes were thought to significantly alter the physical properties and rocks structure along the slopes [1; 2; 3; 4]. The weakness for the nature and rock structures caused the resisting force in the rock to be smaller than the driving force, so soil or rock material can be very easily moved or shifted from its original position [1; 2; 4; 5; 6]. Potential landslide area have a weaker rock structure compared to a stable area [6].

Microtremor survey was popular method of geological condition analysis [7; 8; 9; 10; 11; 12; 13; 14]. It was used to know characteristics of local site effects by recording ambient noise as responses of ground to natural shaking [8; 16]. Seismic vulnerability index and surface wave velocity to be two parameters to explain it [9; 7]. They were two physics parameters that used to describe the structure condition of ground surface, rock solidity level, lithology of rock and the thickness of each material composition of rock.

FUNDAMENTAL OF THEORY

Moving ground or landslide was a process of moving the mass of soil or rock to a lower place due to disturbing the slope equilibrium [3; 4]. Landslides occurred when surface ground moved to slope. Landslide occurred when driving force of ground more than resisting force [1; 2; 3; 4; 5; 6; 7]. Resisting force was affected by

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strengthening of rock and solidity level of ground [1], whereas driving force affected by topography site effects, water, the height and angle of slope, the present of breaks and convexity on its surface [3; 4; 5] and the effects of geology sites [8; 9; 13]. Geology site included geometry of the layer and impedance of strong contrast between the layers and bedrock [7; 8; 13; 5]. It was one of characteristic of seismic parameter. Ground can be potentially to moving even though at this time it was in stable condition. Landslide mitigation made two choices to do, increased resisting force or decreased driving force of ground.

Ground vibration could be trigger of ground motion by weakening the physical structure of the rock. The weakness of soil particles of the slope lead to increase driving forces dan reduce the resisting force of them [3; 5; 6]. This condition indicated by strain soil changes what included forming [15] and healing of crack accompanied by release of microseismic survey. Characteristics of surface ground and seismic response of structure can be approximated by spectral ratio of horizontal to vertical component of microtremor data which measured simultaneously on structures and their foundation ground surface [10; 11; 12; 14; 16; 17; 18; 19]. Seismic vulnerability index (Kg) can be considered as an index to indicate weak point of the ground [9; 14].

Local geologi condition can be described by resonance frequency and amplification factor on each observation site. They obtained by HVSR Analysis of microtremor data. Empirically calculated using equation 1 below [10; 19]:

$$HVSR = \frac{\sqrt{(H_E{}^2)(H_N{}^2)}}{V_Z} \qquad (1)$$

where H_E dan H_N was amplitude spectrum of East-west dan North-South seismogram components dan V_z was amplitude spectrum of vertical component. The interpretation of them shown on by Figure-2.

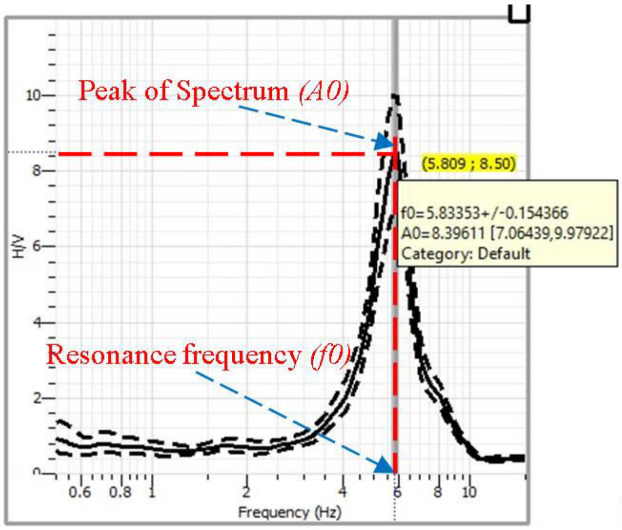

Figure-2. HVSR curve, it was a result of spectrum amplitude analysis for microtremor data. It showed resonance frequency and amplification factor value which described ground response to shake.

Then, seismic vulnerability index (K_g) obtained by Equation 2, as given by [9]:

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

Seismic vulnerability index used to estimate geological structure condition [9; 14]. It also can be used to estimate susceptible area to crack and potential level of ground deformation [9]. As great as the Kg velue at a site, as great as the potential for ground motion and vice versa.

In addition, shear wave velocity profiling also can be used to describe geotechnical condition of soil layers [20]. It obtained by HVSR inversion. Dinver was a complete framework for solving inversion problems. It was one of geopsy software packed which implements forward computations for surface wave and handles phase and/or group dispersion curve for Rayleigh and love waves. The input of this programe was HVSR curve which has saved to *.hv extension file. Shear wave velocity profile to be a model of ground structure of each soil layer. The relationship of shear wave velocity with geotechnical condition of soil layers shown on Table-1.

Table-1. Ground identification and deskripsi umum based on shear wave velocity value on 30 m (Vs30) [21].

Class	Average of vs (m/s) above 30 m	Description umum
A B	>1500 760-1500	Hard rock Intermediate rock
C D	360-760 180-360	Hard soil and soft rock Intermediate soil
E F	<180	Soft soil Specific soil investigated geotechnical

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METHODOLOGY

In this research focused on landslide potential zonation, so one hundred seismic stations were installed on right and left sides of the main road. At the site that has never been landslides, only installed one seismic station, while at the site that was considered vulnerable (based on visual observation) and old landlslide site installed up to three seismic stations. It has done to get detail interpretation of its conditions. HVSR analysis had done to each data to get amplification factor *(A_0)*, resonance frequency *(f_0)* values and HVSR curve (saved on *.hv extension files). A_0 and f_0 used to determine Seismic vulnerability index and HVSR curve was an input to Dinver for microtremor data inversion. Inversion process had done ten-time iteration to find the model which has the lowest minimum misfit values of them. Landslide potential area described by seismic vulnerability index and lithology of rock estimation by shear wave velocity value on the depth. These parameters were used to analyze the characteristics of geological conditions on each site observed. They interpreted to a map and 1D shear wave velocity models. Map and velocity model were matched with visual observation result. Their relationship widened foundation to describe the actual of local geological conditions on each site.

RESULT AND DISCUSSIONS

In the past research, seismic vulnerability index has been a parameter to describe the local geology condition in Bengkulu City [14]. It used to estimate characteristics of ground structure and rock solidity level. High seismic vulnerability index was detected on soft soil and this area was considered to have the weak structure. It was estimated more susceptible to movef when an earthquake. In this research, this parameter also used to know characteristics of ground and rock solidity level on landslide potential area. The site which have high seismic vulnerability index was thought to have the soft or weak structure and when the ground was weak, the resistance force would be low and landslide might be occurred.

One hundred seismic stations have installed in along of Bengkulu Tengah-Kepahyang main road. Characteristic of seismic respond on each site analyzed by spectral ratio of microtremor data and found seismic vulnerability index by Equation 2. Seismic vulnerability index interpreted into lateral model and for vertical models described by shear wave velocity model to depth (next session). The lateral geological condition in along of main road shown on Figure-3.

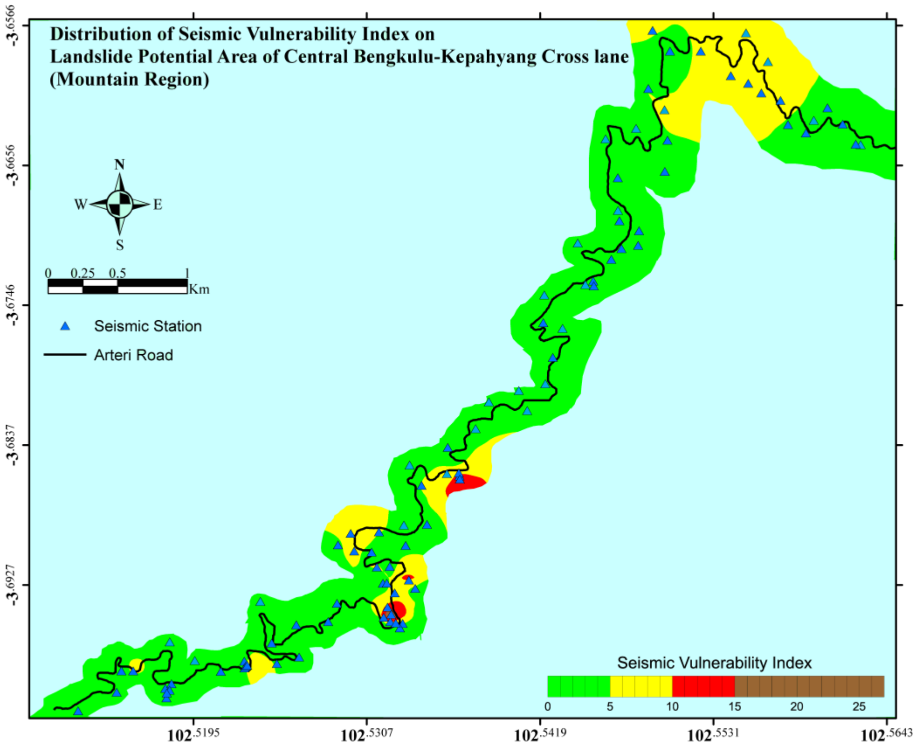

Figure-3. Map of Seismic Vulnerability Index distribution on landslide potential area. There were four zone of its value. The highest value showed by brown contour and the lowest value showed by green. The brown contour estimated the highest risk to landslide, and green zone estimated more safe than other.

Figure-3 was a general overview of geological conditions at survey area. It showed the property and characteristic of the ground laterally. Structure and rock solidity level can be influenced the magnitude of resistance force on ground. The sites which high seismic vulnerability index, the ground resisting force of them is low. Based on seismic vulnerability index distribution, it has four zones, that was brown zone, red zone, yellow zone and green zone.

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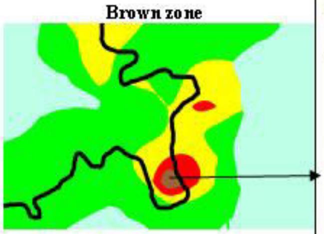
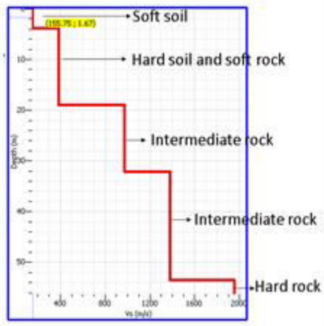
Based on value and distribution of seismic vulnerability index (Figure-3), brown zone has the highest seismic vulnerability index in along of main road. Seismic vulnerability indexes on this site about 25.82. In this zone have been installed three seismic stations because based on visual observation documents, it was often landslide happened from a few years ago. The results showed that seismic vulnerability index of three stations were relatively similar and fall into the brown zone category. This zone was thought to have the softest or weakest rock structure among other zones. The next were red zone. Red zone was the zone which has high seismic vulnerability index after brown zone. Red zone has value about 10 to 15. This zone also has soft rock structure like as brown zone. Based on its interpretation, red zone found on three locations. The first location was found in around of brown zone, second location was found in a site which had been landslide, and the last location was found in a new landslide location (about one month ago). The third zone were yellow zone. Yellow zones have seismic vulnerability index about 5 to 10 and found on five areas (Figure 3). Sites belonging to the yellow zone were generally the sites that have a landslide in the past. Other than that, yellow zone also found in never landslide locations. However, based on visual observation, they potential for landslide. The last zones were green zone. According to seismic vulnerability index, this zone was relatively more stable or safe. It estimated have hard structure of ground and low potential of deformation.

All of them were estimation of lateral geological condition in survey area. For more detail analysis, the interpretation of them can be described to vertical model. Vertical model showed by 1D profiling of seismic vulnerability indexes which obtained by HVSR inversion. Shear wave velocity inversion on each site have done by Dinver application. This model sued to estimate the rock structure and lithology on each layer of rock. Their models shown on Table-2.

Table-2. Vertical geology conditions on main road of Bengkulu Tengah-Kepahyang. The first column was classification of zones. They analyzed to get shear wave velocity model on its site (second column). This model used to know lithology of site on each layer. The last coulomb was visual field condition on each site selected.

<table>
<tr><th>Classification</th><th>Shear Wave Velocity Inversion</th><th>Visual Field Condition</th></tr>
<tr><td>Brown zone
</td><td></td><td>
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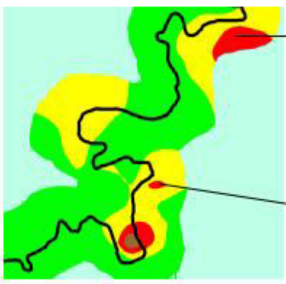
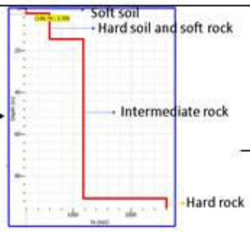
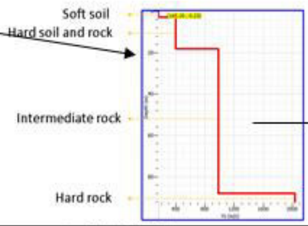
<tr><td>Red Zones
</td><td>
</td><td>
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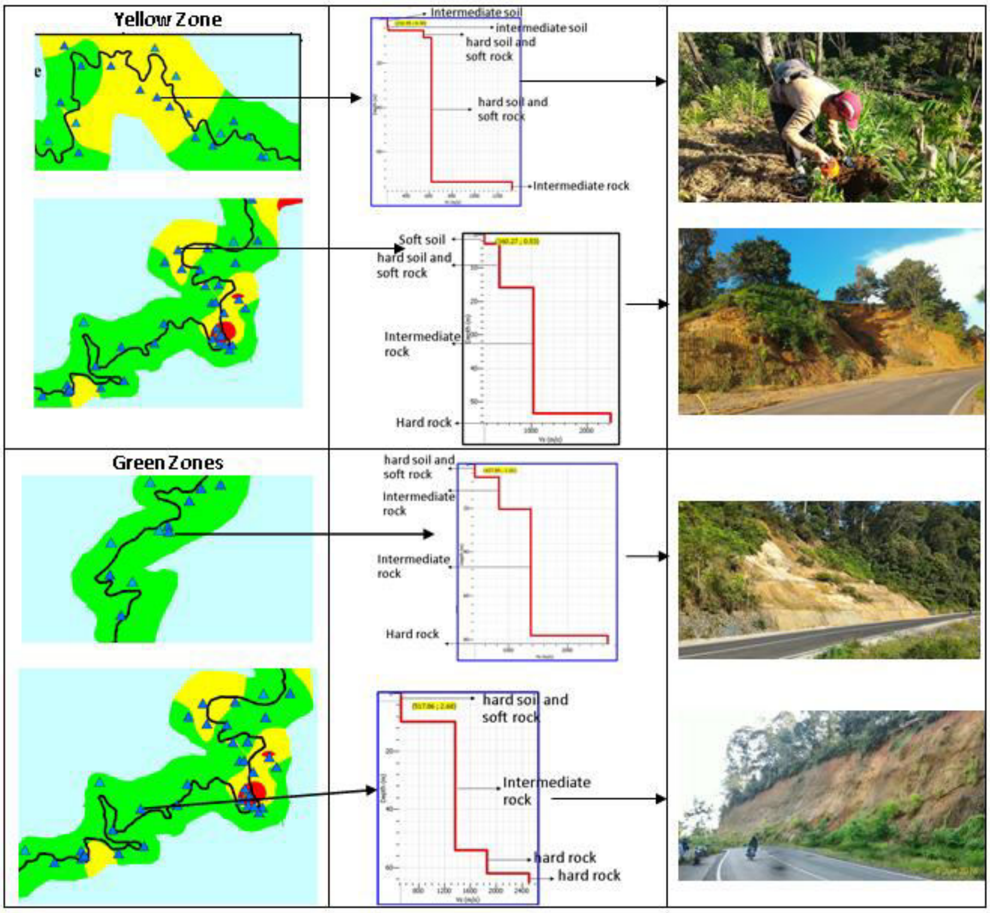

Table-2 included the results of shear wave velocity inversion. On this paper, not all shear wave velocity analysis results interpreted on its table. Two sites were randomly selected to represent the interpretation of all site in one zone. The first column contained zones classification which two sites have selected to continue analysis. Second column was results of shear wave velocity inversion of two sites selected and the last column showed view of field observation.

The first row was vertical geology condition at brown zone. In before discussion, this zone was the highest of seismic vulnerability index. This zone was thought to have a soft rock structure because it often landslide happened in the past and at some point has occurred soil subsidence. The results of shear wave velocity inversion showed that up to depth of 4 meters of subsurface, shear wave velocity on this site about 155.75 m/s. According to Table 1 [21], ground structure of them was soft soil. From depth 4 meters to 10 meters, shear wave velocity on this site about 395 m/s and it has hard soil and soft rock. For the next depth, structure of rock relatively intermediate to hard. One of the ground deformation features in this zone was showed in third column and the first of Table 2. At 2016, the ground collapsed about 30 cm and at 2017 ground collapse up to 143 cm. It showed that for a year ground collapsed up to 117 cm. This phenomenon evidently corresponded with seismic vulnerability index and shear wave velocity which obtained in this research. An addition, they also corresponded with visual observation results and profile or phenomenons of ground deformation in the past.

Shear wave velocity models at red zone showed on the second row of Table 2. The rock structure of this zone was almost similar like rock structure of the brown zone. The pattern of their rock properties was similar also. Soft soil identified on the surface with velocity about 190.78 m/s and 165.20 m/s and thickness of them were 3 meters. Hard soil and soft rock identified from the depth 4 to 16 meters. Based on seismic vulnerability index and shear wave velocity, surface rock of red zones were soft dan they might easy to deformation. This result similar like as before discussion. Then, rock structure of yellow zones was also has similar pattern with brown and red zones. On the surface identified soft and intermediate soil. Ground characteristics of this zone still high probability to deformation if other factor which caused landslides added to them.

Green zones significant different to others zone. According the result of shear wave velocity inversion, soft soil and intermediate soil was not detected on the surface, but hard soil and soft rock. The first location has velocity 427.89 m/s and the second site about 517.86 m/s. Green zones have the lowest seismic vulnerabililty index. Not only laterally, but also vertically both of them showed similar characteristics of geology condition. The rock structure of this zone estimated more solid, strength, stable and safe to ground deformation like landslide.

Landslide occurred on weak zone (low resisting force) and physically, they showed by soft soil. Soft soil indicated by high seismic vulnerability index and small or weak shear wave velocity. Based on seismic vulnerability index, brown zone was the most vulnerable and high potential of ground deformation (first level). Red zone was second level, yellow zone in third level and green zone at the last level which is stable and safe zone. However, based on shear wave velocity models, the difference of brown zones, red zones and yellow zones were not significant. It means that red zones and yellow zones were potentially a landslide-prone like the brown zone. Their condition is different to green zone. Green zone has significant characteristic of rock structure. It has hard soil in the surface. It estimated more stable, but this condition can be changed when factor of resisting force was decreased, like Over-steepened slopes, adding water to slope from landscape irrigation, roof downspouts, broken sewer and water lines, heavy rainfall, etc.

Seismic vulnerability index showed the same results as shear wave velocity in describing the geological condition of rock surface. Rock structure of the surface more softer and as solid as to depth. In addition, analysis both of them corresponded and strengthened by the results of visual observation and phenomenon or profile of landslides in the past. The combination of two analyzes showed that microtremor survey was able to describe geological condition in landslide-prone area either laterally or vertically. Next research can be used other analysis or other method to prove it.

CONCLUSIONS

Landslide can be occurred when resisting force of ground is low. Resisting force affected by strength of ground and solidity level of soil. Seismic vulnerability index and shear wave velocity used to know them on each site. According on Seismic vulnerability index distribution, in survey area divided to four 4 zones. Brown zone has the highest seismic vulnerability index, then red zone, and yellow zone, respectively. Based on the result of shear wave velocity inversion, red and yellow zones were not significant different with brown zone. It means that the property of red and yellow zone was similar as brown zone. Their rock structure was soft and easy to move. Green zone was stable zone. It has the lowest Seismic vulnerability index and its structure was relatively hard soil and hard rock (based on shear wave velocity model). These results suggest that the combination of seismic vulnerability index and shear wave velocity analysis was appropriate. They also corresponded to the visual observation and profile of landslide in the past. The combination of them showed that the microtremor survey was able to describe geological conditions in the landslide-prone area.

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