Earthquake-prone Zonation of North Bengkulu Based on Peak Ground Acceleration of Katayama's and Kanai's Formula

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Abstract*— We have done mapped earthquake-prone zonation of North Bengkulu, Indonesia, based on peak ground acceleration by kanai's and Katayama's formula. Twenty nine microtremor data have recorded by Digital portable Seismometer that installed in North Bengkulu regency. The result of HVSR analysis, we got resonance frequency and A0 which explained the condition of surface rocks. Peak ground acceleration on rock surface which applied local geology condition (dominant period of natural soil vibration). Based on A_0 value, the risk of earthquakes in north Bengkulu was on moderate to high level because this area has relatively soft rock structure. Kanai's formula has correlation near 70.6% with Katayama's formula to showed PGA value on rock surface. Peak Ground acceleration of Kanai formula in North Bengkulu about 152,441 - 674,391 gal and based on Katayama formula between 35.2 gal until 51.3 gal. Based on PGA value, we estimated that North Bengkulu has on IV and IX of MMI scales. It meant that in North Bengkulu potential have heavy damage when an earthquake occurred. Distribution of PGA values based on the observation has correspond to effects earthquake of North Bengkulu at September 2007.

***Keywords*— Earthquake-prone, HVSR, PGA, sediment rock.**

I. INTRODUCTION

Sumatra Island has a great historical record of earthquakes since 1833 until 2010, and even some earthquakes cause tsunamis such as Aceh Tsunami in 2004 [1]. Epicenter of earthquake has located in the Subduction zone of Sumatra Hindi-Australia and Eurasian Plates as shown in Fig 1.

North Bengkulu was a regency in Bengkulu province, Sumatra, which have high levels of damage due to earthquakes, such earthquakes in 2000 and 2007 (Table 1). The high number of death and damage infrastructure has showed that preparedness of North Bengkulu societies of the earthquake disaster was still low even though they have realized that a large earthquake in North Bengkulu might repetition in the future [2; 4].

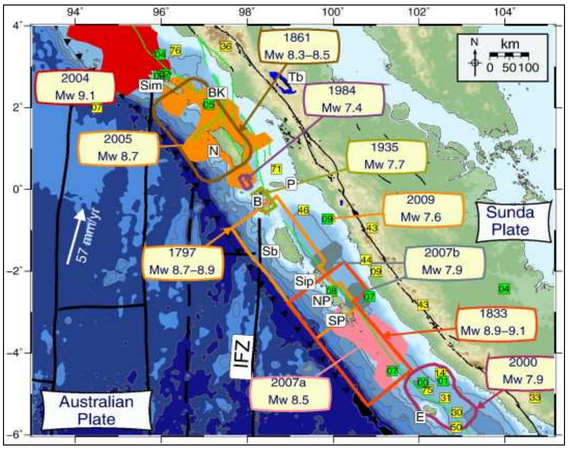

Fig.1: Distribution of Epicenter in Sumatera Island [13]

Table 1. Effects of North Bengkulu earthquake at 2000 and 2007 [2; 4]

Data	Earthquake at 2000	Earthquake at 2007
Magnitude	7.9 Mw	8.5 Mw
Death	90 peoples	3 Peoples
Minor damage	18.928	1.400
Heavy damage	10.460	2.000

The Effects of an earthquake was very dependent on the distance of epicenter, earthquake magnitude and characteristics of geology. Local geological conditions which were relatively soft and thin sediment potentially experiencing maximum reinforcement vibrations on the surface layer [5;6;8;9;10;11;13]. Peak Ground Acceleration (PGA) was one of the physical parameters to describe the nature of rocks in the surface layers. Kanai [6] and Katayama [5] has outlined a mathematical formula to calculate the PGA in surface rocks, which implement parameter dominant period which was a responses to ambient noise vibration natural of ground surface. The condition of the surface rocks, distribution of the value of PGA and Modified Mercalli Intensity scales were used to make maps the risk of earthquakes in North Bengkulu. Furthermore, these results verified with map damage level and visual evidence of damage that have occurred in the earthquake of 2007. In addition, we found the correlation PGA value of both kanai's and

Katayama's formulas to estimating the vulnerability level of earthquakes danger area. These three parameters would be the basis of earthquake risk reduction planning in North Bengkulu in the future.

II. FUNDAMENTAL OF THEORY

Peak Ground Acceleration was a maximum rock acceleration that have been occurred in area caused by Earthquake. Peak ground acceleration value on surface rock was calculated by Kanai [6] and Katayama [5] equation, as given on the equations below:

$$\alpha_{Kn} = \frac{5}{\sqrt{T_g}} 10^{0,61M_w - 1,66 + \frac{3,6}{R}[\log R + 0,167 - \frac{1,83}{R}} \quad (1)$$

$$\log \alpha_{Kt} = 0,509 M_w - 2,32 \log(R+10) + 0,039 T_g + 2,33 \quad (2)$$

where, α_{Kn} = Peak Ground Acceleration by Kanai, α_{Kt}= Peak Ground Acceleration by Katayama, T_g = dominant period value, M_w = moment magnitude and R = epicenter distance of observation point (Km).

Dominant period (T_g) has relationship with the thickness of the sediment layer [8]. A high dominant period demonstrated the thick sediment layer and vice versa. An area that has a high dominant periods generally have the high potential of damage if hit by an earthquake. Dominant period could value estimated by one per magnitude of the resonant frequency which obtained from the analysis HVSR on a recording of ambient noise or mikrotremor data [8;9;10;]. *Horizontal to Vertical Spectrum Ratio* (HVSR) was effective method for site effect analysis. It was obtained by ratio between horizontal spectrums with vertical spectrum of micro-tremor data, it was given by equation 3.

$$\frac{S_{HS}}{S_{VS}} = \frac{\sqrt{[(S_{Utara-Selatan})^2 + (S_{Barat-Timur})^2]}}{S_{Vertikal}} \quad (3)$$

S_{HS}= spectrum of horizontal component on sediment dan S_{VS} = spectrum of vertical component on sediment. The result of HVSR analysis showed on Fig 2.

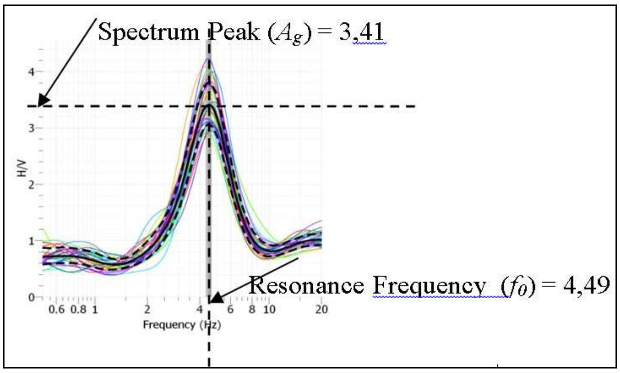

Fig.2: Illustration of microtremor spectrum from HVSR analysis. The Peak of Spectrum was knew as Amplification factor (A_g) and X-axes as resonance frequency (f_0).

III. METHODOLOGY

Twenty nine microtremor data have recorded by Digital portable Seismometer that installed in North Bengkulu regency. Every site, recording process have done for 30 minutes with sampling frequency 100 Hz. The result of HVSR analysis, we got resonance frequency from HVSR curve. PGA value have calculated by using formulas of Kanai and Katayama, added to other data such as Sumatra seismic data that downloaded from the USGS for 124 years (1890-2016) with magnitude of between 5-9 Ms and the depth of the hypocenter between 10-150 km. The results of them was interpreted into maps to illustrate earthquake-prone zonation areas in North Bengkulu. The results were then verified with the 2000-2007 historical earthquake damage (North Bengkulu) and compared the both of these interpretations in describing the level of earthquakes vulnerability in North Bengkulu.

IV. RESULT AND DISCUSSION

North Bengkulu regency was part of the Bukit Barisan and Bengkulu Basin zone. Based on the topography map, North Bengkulu was mostly undulated terrain marked by hills with varying heights. Altitude less than 150 meters above sea level located in the western part longitudinally parallel to the coast from south to north, in the eastern part topography height about over 541 meters above sea level [4]. Subarnas [12] said that geological conditions in the area of North Bengkulu is composed by several rock formations which have a range of age between Tertiary to Quaternary.

Zonation of earthquake prone areas in north Bengkulu regency has been described by the distribution of peak ground acceleration value. Peak ground acceleration analysis that have done in this research was the peak ground acceleration on rock surface which applied local geology condition (dominant period of natural soil vibration). It was one of the parameters in Kanai and Katayama equations.

Before we discussed about the PGA, the first we would discuss about the condition of the surface rocks in North Bengkulu based on HVSR analysis of mikrotremor data. It was showed by amplification factor (A_0) and resonance frequency (f_0) value. Amplification factor (A_0) used to explain the solidity level of the surface rock and resonance frequency (f_0) to explain the thickness of sediments layer. The solidity level and thickness of sediments layer have correlation with the probability of damage level of the caused by earthquake [13]. The solidity of sediments as high as when amplification factor (A_0) has a high value. It was mean the risk of damage the caused by the earthquake would be high. It would be complete if supported by the thickness of sediments layer, because the wave would have strengthened many times over in a thick layer of sediments (if f_0 small). The spatial distribution of the value A_0 and f_0 in North Bengkulu have shown in Fig 3 and Fig 4 below.

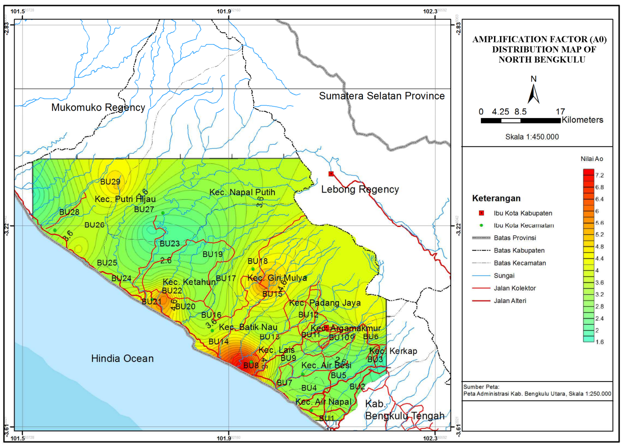

Fig.3: Spatial distribution of ampilfication factor (A_0) in North Bengkulu

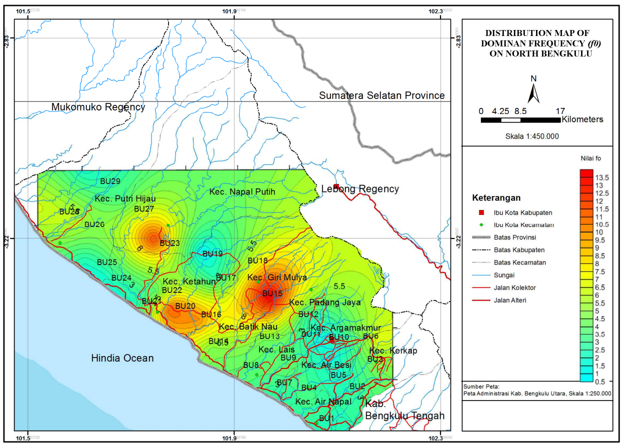

Fig.4: Spatial distribution of dominant frequency (f_0) in North Bengkulu.

Multi-reflection wave would occurred in soft of sediment layer relatively. Amplification factor of sediments in North Bengkulu dominant between 3.5 - 5 (Fig 3). The highest A_0 value has identified at BU8 site, Sub district of Lais (A_0 = 7.2). If we saw the distribution of A_0 value (structure of sediment), the risk of earthquakes in north Bengkulu was on moderate to high level because this area has relatively soft rock structure. In addition, vulnerability of rock conditions also depend on the thickness of the sediment layer (**Fig 4**). Sediment layers in North Bengkulu has dominantly thick though at three sites have higher f_0 value (sediment layer of them was thin) than others. High risk areas of earthquakes when they have softer structures and thick of layers sediment [14], so based on physical properties (A_0 and f_0) of the sedimentary rock, we could estimate high risk areas toward of earthquake in North Bengkulu. Peak ground acceleration on the surface rock would completed discussion about them.

Peak Ground acceleration of Kanai equation (α_{Kn}) in North Bengkulu about 152,441 - 674,391 gal. According the map analysis, the highest α_{Kn} value 674 gal was identified at Giri Mulya sub district and the lowest PGA α_{Kn}<250 gal was identified Argamakmur sub district (Fig 5). In other that, Peak ground acceleration based on Katayama equation between 35.2 gal until 51.3 gal. The Highest PGA value (α_{Kt}) identified at Lais sub district and the lowest α_{Kt} available at Putri Hijau sub district (Fig 6). The higher α_{Kt} value was distributed to northern of North Bengkulu regency and lower PGA value became as small as to western of North Bengkulu.

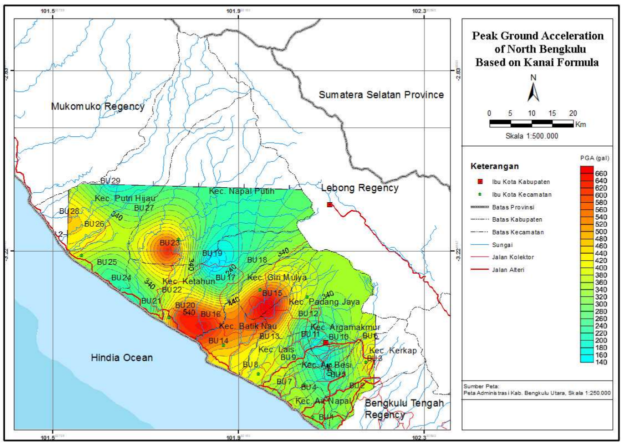

Fig.5: distribution of peak ground acceleration value which identified in Nort Bengkulu. this map obtained by Kanai formula calculating.

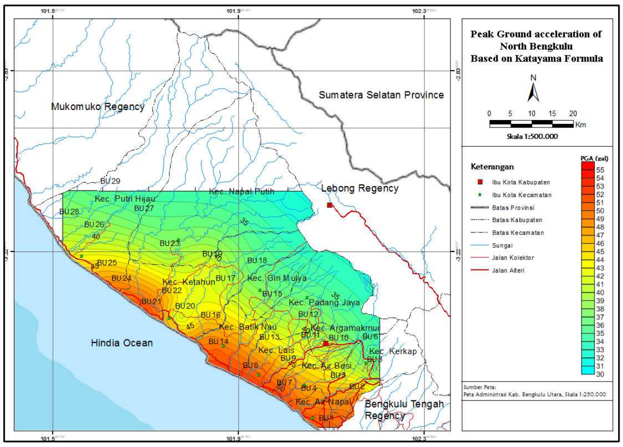

Fig.6: Distribution of peak ground acceleration value which identified in Nort Bengkulu based on Katayama's formula calculating.

In general, the distribution of PGA values based on the observation corresponds to a distribution rate of North Bengkulu earthquake damage in September 2007. When it connected with a map PGA SNI at 2010 (Fig 7) [2] PGA value based on Kanai's formula in North Bengkulu have in common was in the range 250 gal up to greater than 350 gal and by Katayama vice versa. However, the distribution of PGA on this interpretation show relatively similar in earthquake prone zones in North Bengkulu. Kanai's formula has correlation near 70.6% with Katayama's formula to Showed PGA value on rock surface. In spite of the PGA distribution levels are relatively the same, but the value range PGA in both very different. This difference is likely to occur, because the two formulas using different constants to explain the PGA in rock surface, although entering dominant period as local site effect parameter.

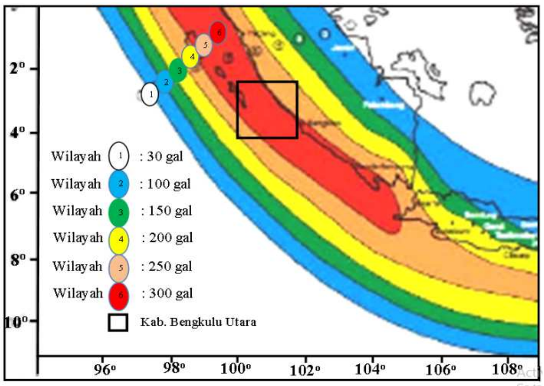

Fig.7: Peak ground acceleration map by SNI at 2010 [2].

Peak ground acceleration has relationship with the degree of damage that caused earthquake effect. As high as PGA value in a region, it estimated linearly with the degree of damage that may occurred. This relationship was knew as modified Mercalli Intensity (MMI) scale. Based on PGA value, we estimated that North Bengkulu has on IV and IX of MMI scales. It meant that in North Bengkulu potential have heavy damage of earthquake (Fig 8).

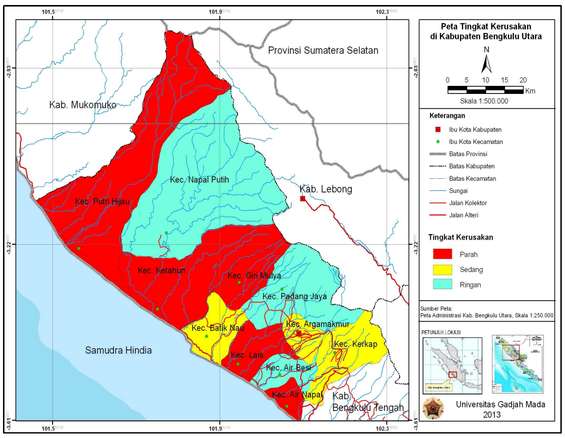

Fig.8:Damage level that effected by earthquake in North Bengkulu at 2000 and 2007.

In this research, we also found that distribution of PGA value based Kanai and Katayama formula have shown that they have similarities with the historical seismicity of North Bengkulu in the past. They linear with MMI scale and the destruction caused by the earthquake in 2007 at North Bengkulu [11] as shown on Table 2. As high as the value of the PGA in a region, the potential of perceived when the earthquake happened would be high also. This result could be a concern for the society and local government of North Bengkulu to realize the earthquake disaster preparedness.

Table.2: Building damage data in North Bengkulu regency on earthquake at 2007 [11].

Subdistrict	Heavy damage	Moderate damage	Minor damage
Kerkap	341	728	536
Air Napal	862	308	443
Lais	1053	506	1513
Batik Nau	413	616	547
Ketahun	1080	1151	2055
Putri Hijau	103	734	1879
Napal Putih	103	86	150
Argamakmur	387	110	645
Air Besi	248	292	279
Padang Jaya	181	315	379
Giri Mulya	766	382	648

V. CONCLUSION

The risk of earthquakes in North Bengkulu were at moderate to high. In addition to near of epicentre distance, rock surface structure of North Bengkulu was soft relatively with a thick of sediment layer (based on A0 and f0). This condition was also supported by the distribution with peak ground acceleration value based on Kanai's and Katayama's formulas and PGA map of SNI 2010 which relatively similar to show earthquake prone zones in North Bengkulu. High peak ground acceleration value was distributed to western of North Bengkulu and peak ground acceleration became value as small as to eastern and northern of North Bengkulu. Peak ground acceleration value distribution formula based Kanai and Katayama was also showed similarities with the historical seismicity of North Bengkulu in the past (2000 and 2007). The correlation both of them was approximately 70.6% to showing earthquake prone areas by PGA. If they were related to the MMI scale, North Bengkulu has on IV and IX of MMI scale. It was mean that North Bengkulu potentially experiencing the earthquake felt and suffered heavy damage.

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