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Comparison Among the Three Peak Ground Acceleration Models in Bengkulu Province, Indonesia

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Abstract: *Bengkulu Province is a region located on the a subduction zone in the West coast of Sumatra. It's a highly prone and risk of earthquakes. One of the important effects of earthquakes is Peak Ground Acceleration (PGA). This value is needed to determine the strength of the foundation of the building to be constructed. This article presents comparisons among the three PGA models in Bengkulu province, Indonesia. Research on the three models of PGA in the first generation, namely; Esteva, Pathwardan and Crouse have been tested and compared on the Bengkulu area based on historical data of earthquakes with magnitude, $M \geq 4$ SR and hypocenter, $H \leq 100$ km that occurred in 1974 - 2014. The model produces 4.16 to 68.66 gal Esteva, Pathwardan 72, 6 to 533.95 and 115.15 to 275.89 gal Crouse is on the PGA. In general, these three models produce the same map, in which the maximum value PGA is at Mukomuko in North Bengkulu and in Kaur in South Bengkulu.*
Keywords: *Crouse Model, Esteva Model, Hypocentre, Pathwardan Model, Peak Ground Acceleration.*

I. Introduction

Bengkulu Province is located on the western part of Sumatra Island. This area is located at the confluence of two tectonic plates, i.e. the Indo-Australian plate and the Eurasian plate. Regional meeting of the two plates is known as subduction zones, which become the main generator large earthquake. The movement generated by the collision of two plates creates the formation of active faults in the western part of Sumatra. Thus, in the frame of geotectonic, Bengkulu was lying in a subduction zone, located between two active faults - Semangko fault and Mentawai fault. The above conditions led to Bengkulu as earthquake-prone area that has a very frequent occurrence of earthquakes and has an index of seismicity. Due to the frequent earthquakes in Bengkulu, then led to the emergence of ground movement.

One of the parameters of ground movement caused by earthquakes is the PGA used in geotectonic and mechanical engineering. PGA is one of the key factors to analyze the potential damage caused by the earthquake.

Physically, PGA is one of the parameters of ground motion caused by earthquakes that are important in geotectonic and engineering mechanics. By knowing the value of this PGA we can determine how deep and strong the foundation of a building must be made so as to have resistance to earthquakes. As the other parameters of ground movement caused by earthquakes, can be described mathematically that the ground motion attenuation is the relationship between the parameters of the distance to the location of earthquake seismic recording [1].

This research is the study of the three models of the first generation method of attenuation applied to the Bengkulu subduction area with the aim to looking for model are most appropriate for the region to be analyzed further alignment with regional conditions.

II. Literature Review

The studies on the ground movement parameter had taken in a long time and continuously since the first generation until today. A number of studies on the maximum ground motion parameter estimation have been carried out and published. Likewise, the various studies on the relationship between the value of the PGA and the value of Peak Ground Velocity (PGV) with MMI scale have been made to various areas. David J Wald [2] had done so in California areas, Liu Sing [3] for the Taiwan region, and Danciu & Tselentis [4] did well in the area of Greece. In 2012, Pailoplee [5] also published a similar study in the area of Myanmar.

In Indonesia, Hadi *e.t al* [6] has conducted an analysis of Bengkulu Earthquake parameter data based on Single and Multi Station. A number of other studies with different methods about the value of PGA had been done and in general get the conclusion that the geological soil conditions in the area were observed very decisive of the PGA values that obtained. The geological condition that it means is the density of the soil, where the more solid ground in an area, the smaller value of the PGA is obtained. This is consistent with the fact that the building is built on a solid ground structure at the time of the earthquake damage is lighter than buildings built on land that is less dense structure [1].

2.1. Gegraphical Condition of Bengkulu

Bengkulu province is located on the west coast of Sumatra at -2°16 '- 3°31' latitude and 101°1'- 103°41' East Longitude. Administratively, Bengkulu is bordering on the north by West Sumatra, to the south by Lampung, on the west by the Indian Ocean and on the east by Jambi and South Sumatera. Geographical conditions of Bengkulu are shown in Fig. 1.

Bengkulu is a province located in the western of *Bukit Barisan* with an area of ± 19.919,33 km^2. Bengkulu consists of 10 districts/cities i.e. South Bengkulu, *Rejang Lebong*, North Bengkulu, *Kaur*, *Seluma*, *Mukomuko*, *Lebong*, *Kepahiang*, Central Bengkulu, and Bengkulu City. The administrative area of Bengkulu extends from the border of West Sumatra to the border of *Lampung* by a distance of approximately 567 kilometers. Bengkulu has several small islands are uninhabited well as *Enggano*, as well as the islands are uninhabited, *Mega* island and other small islands.

Figure 1. Geographical conditions Bengkulu Province

Based on the state of nature and its location, the region of Bengkulu has different height from sea level. The state of the province's altitude varies greatly, ranging from 0-100 m covering 35.8% of the area of Bengkulu, 100-500 m is the slope of the *Bukit Barisan* mountain reaches 31.60%, 500-1000 m covers 20.50% of the total area of Bengkulu and the region with an altitude of over 1000 meters above sea level to the peak of *Bukit Barisan* mountain range which generally is an area of volcanic activity and tectonic area of about 12.10%. In geomorphology, Bengkulu can be divided into four parts form regions, namely:

1. Coastal Plain
   These plains are along the coast, which stretches from *Mukomuko* until the *Padang Guci*, generally this area is narrow and there are basins and wetlands.
2. Alluvial Plain
   This plateau is elongated at the back of the coastal plain which has wide-ranging between 5-10 Km, this area generally have fairly high soil fertility.
3. Plain Folds
   This area extends almost parallel to the alluvial plains with an altitude between 100-400 meters above sea level. These areas include the following *Lumbuk Pinang*, *Beringin*, *Tambun* and *Hulu Sungai Ipuh*.
4. Volcanic Region
   This region occupies most of the *Bukit Barisan* range, which is a mountain path faulting and complex volcanic eruption outside the center of Bengkulu.

Physically Bengkulu composed of andesite lava rock covered by volcanic breccia sediment, clay stone, pumice, and swamp alluvium rock sediment. These natural conditions were vulnerable to natural hazards, such as earthquakes, ground cracks and subsidence, erosion, landslides, floods, and sea storms, while the tsunami danger has never been recorded in actual conditions.

Bengkulu area is located between the masonry pre-tertiary, tertiary volcanic rocks and alluvial. In Bengkulu few tertiary formations encountered, especially skis crystalline which include the type of genes and glimmer skis, in addition, there is plutonic rocks-granite until heartland granite. Limited spreading in a mountainous area *Bukit Barisan*, among others in the southeast of *Gunung Patah* (North Bengkulu) Triassic formations is in the southeast and west of the *Curup* (*Rejang Lebong*) consisting of Janis slate *flitis kwarsitis* besides sandstone, calcareous *filit*, limestone, and the kind of stuff which is rather wide spread up to the border area of South Sumatra. In the west and northeast of *Muara Aman* there is a formation of tertiary found in mountainous areas *Bukit Barisan*.

The young tertiary formation has a very broad distribution area on the hills of western of the *Bukit Barisan*. The rock type is mainly composed of sandstone and clay which arranged in a pleated structure. On the other hand, there is a kind of old andesite in the form of a bulge in the *Bukit Barisan* backs of volcanic regions [7].

2.2. Tectonic Frame of Sumatera Island.

Sumatra island form the western end of the Indonesian archipelago. Regionally, the tectonic frames of Sumatra can be seen in the Fig. 2. Sumatra is composed of two main parts, the west is dominated by the presence of the oceanic plate, being east is dominated by the presence of continental plates. Based on gravity, magnetism and seismic the thickness of oceanic plate is about 20 kilometers, and the thickness of the continental shelf about 40 kilometers [8].

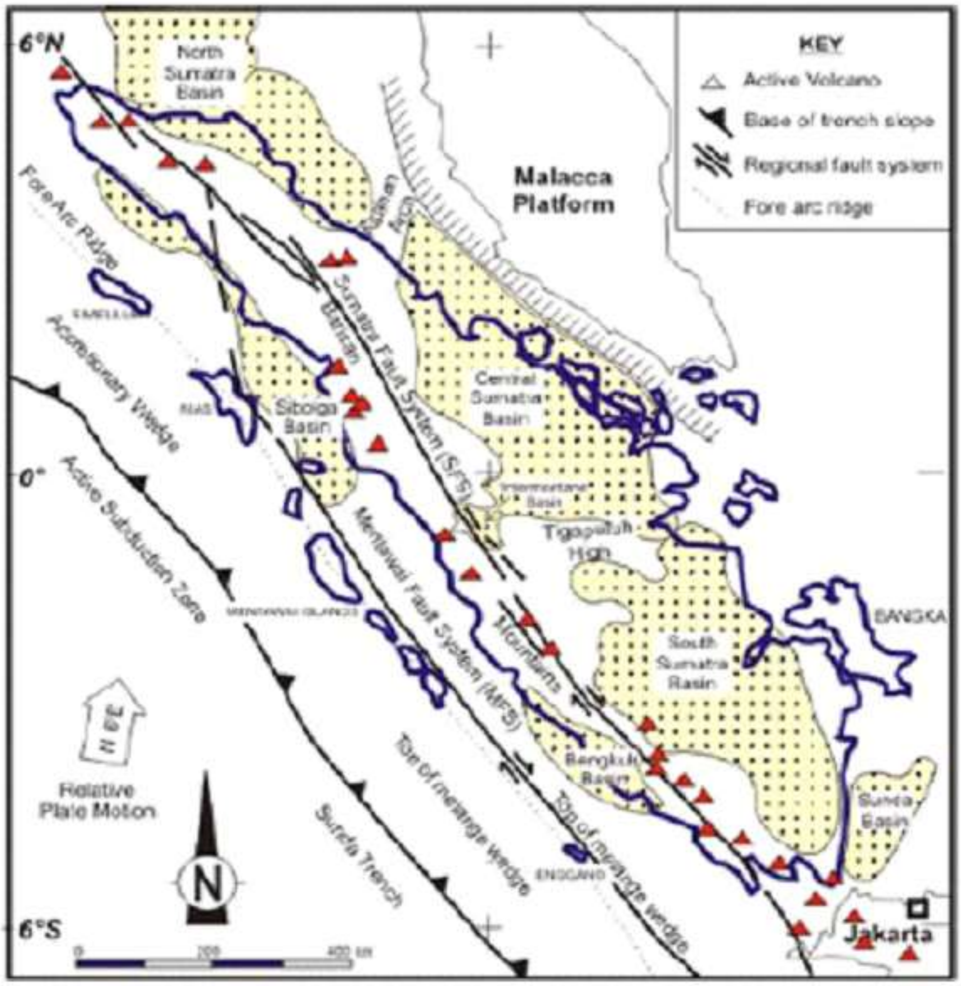

Figure 2. Tectonic frame of Sumatera Island

The tectonic history of Sumatra is closely linked with the start of the event of a collision between the Indian-Australian plate and Southeast Asia, about 45.6 million years ago, which resulted in a series of systematic changes of the relative movement of the plates is accompanied by changes in the relative velocity between the plates following extrusion activities happened to them. The India-Australia plate motion which initially has a speed 86 mm / year decreased to 40 millimeters / year due to the collision process (Char-shin Liu et all, 1983 in [9]). And then the speed has increased to about 76 millimeters/year (Sieh, 1993 in [10]). This collision process ultimately resulted in the formation of many fault systems Eastern India. The schematic of Sumatran subduction system is shown in Fig. 3.

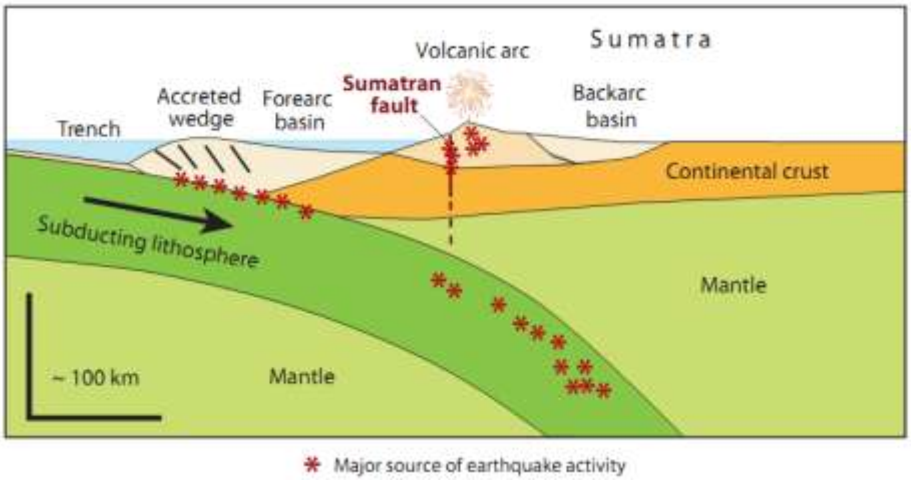

Figure 3. Schematic cross-section of the Sumatran plate boundary [11]

Bengkulu is located in the southern part of Sumatra Island that gives the appearance of tectonic patterns:
1. Sumatra Fault shows a slide right en echelon pattern and is located at 100 ~ 135 kilometers above the subduction.
2. The location of volcanoes generally east-sea or near the fault.
3. Arc basin formed modest advance, with a depth of 1 - 2 kilometers and destroyed by a major fault.
4. The ridge arc relatively close to the face, consisting of a single anti form and simple form.
5. Mentawai Fault and homoclinal ridge, which are separated by a ridge arc basin face to face and relatively intact.
6. Slope angle of subduction is relatively uniform.

III. Experiment Method

Attenuation of Ground Motion is the process or formulation of ground movement caused by the earthquake (acceleration, velocity, deviation) or the intensity of the earthquake that continues to shrink to its distance from the earthquake source. Mathematically, the attenuation of ground motion is a relationship between the earthquake parameters (acceleration, velocity, deviation, intensity, or earthquake magnitude) with the distance to the location of the earthquake recorder (the distance of the epicenter, hypocenter, the shortest distance). The influencing factors of the ground motion are the earthquake magnitude and the distance to the site, Earthquake Source Mechanisms (Shallow crustal and subduction Earthquake) and site conditions.
Specific ground motion attenuation equations proposed by (Mc. Guirre, 1974 in Prawirodikromo [1]) and presented by (Dowrick, 1982 in Prawirodikromo [1]) in a form:

$$Y = b_1 * 10^{b_2 M}(R+\Delta)^{-b_3} \qquad (1)$$

The development of further research on methods of categorizing attenuation phase - development phase into 3 groups (Douglas, 1991 in Prawirodikromo [1]),
1. First Generation on Base Rock, Peak Ground Analysis (PGA)
2. Second Generation, Peak Spectral Analysis (PSA)
3. Third Generation, Next Generation Attenuation (NGA)

This research was conducted to test the three models of acceleration of ground motion attenuation of the first generation (Pathwardan, Esteva and Crouse) for Bengkulu region located on the western coast of Sumatra. The model proposed by Pathwardan using 23 events and the 32 records subduction earthquake that occurred in Japan. The resulting empirical model is as follows:

$$\ln Y = \ln 363 + 0.587 M_s - 1.05(R + 0.864\exp(0.463 M_s) \qquad (2)$$

Under the California earthquake that has been corrected and evaluated statistically, Esteva obtains empirical models as follows:

$$Y = \frac{5600 * \exp(0.8 M_s)}{(R+40)^2} \qquad (3)$$

The next attenuation function developed by Crouse based on earthquake data with subduction mechanism taken from the Cascadia subduction zone in western North Pacific. Crouse formulates the empirical models as follows:

$$\ln Y = 11.5 + 0.657M_s - 2.09\ln(R + 63.7 * 0.128M_s - 0.00397 * h \quad (4)$$

In this case the Pathwardan and Esteva model is expressed in units of cm/sec^2 while the Crouse expressed in *gal*, where 1 gal = 10^{-3} cm/sec^2. These three models are elected to find the suitability of the model for the subduction zone with the object selected research areas, Bengkulu which was in the area of subduction too.

Furthermore, the value of the ground motion acceleration (Y) is referred to as the PGA. In this study will be determined and then map the values PGA in three models, empirical method of attenuation of the first generation as described above by using historical data of earthquakes in 2273 from the year 1973-2013 with ≥ 4 Mb of magnitude and depth of ≤ 100 km (shallow earthquake) that occurred in the area of Bengkulu with limit - 60 - 00 LS and 950-1090 BT.

To get the value of the PGA of three models which will be determined performed steps - steps as follows:

1. Filter the data according to predetermined criteria based on parameters of earthquakes, time occurrence, magnitude, latitude, longitude, and hypocenter.
2. Convert value of body magnitude (Mb) to surface magnitude (Ms).
3. Make grid on map.
4. Determine the distance to the epicenter grid coordinates.
5. Determine the distance hypocenter.
6. Determining the value of the PGA.
7. Mapping the PGA values obtained.

IV. Results and Discussion

Calculation of the three models, Pathwardan, Esteva and Crouse shows that the first two models give maximum PGA values at the same location (-4^0.83 of latitude and 102^0.03 of longitude) is in *Mukomuko* districts located in North Bengkulu. While Crouse models give different results with the results of the maximum PGA 275.89 gal (-2^0.48 of latitude and 101^0.03 of longitude) in the *Kaur* district in the South Bengkulu. The results can be seen in Table 1.

Table 1. The Maximum PGA position on Bengkulu

Model	Range of PGA value (gal)	Maximum PGA position		
		Latitude	Longitude	Sub District
Pathwardan	72.6 – 533.95	- 4^0.83`	102^0.03`	*Kaur*
Esteva	4.16 – 68.66	- 4^0.83`	102^0.03`	*Kaur*
Crouse	115.1 – 275.9	- 2^0.48`	101^0.03`	*Muko Muko*

The plotting of the value of PGA result on the map of Bengkulu for all three models provide different contour, but generally showed similar results to each other. Each mapping of PGA for Pathwardan models with a range of values 72.6 - 533.95 gal can be seen in Fig. 4. The Esteva models have a range of values 4:16 - 68.66 gal can be seen in Fig. 5 and the Crouse model has a range of PGA value 115.1 - 275.9 gal can be seen in Fig. 6.

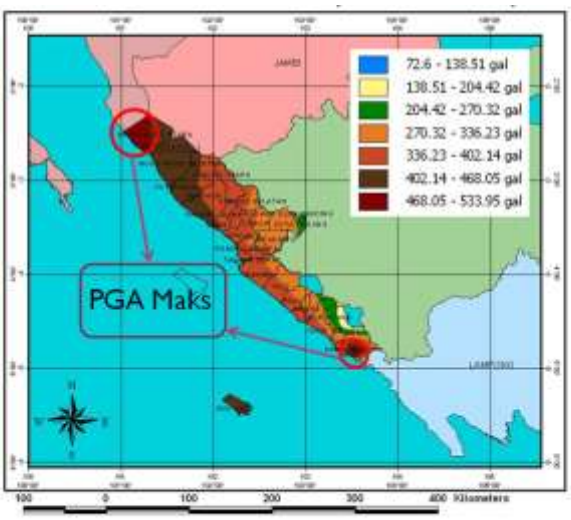

Figure 4. Contour map of PGA by *Pathwardan*'s model

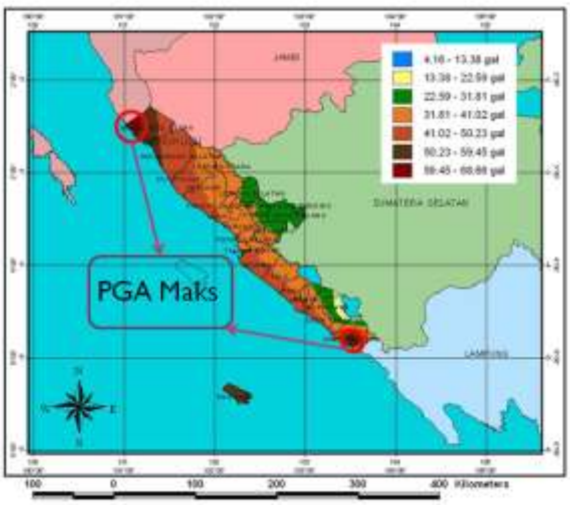

Figure 5. Contour map of PGA by *Esteva*'s model

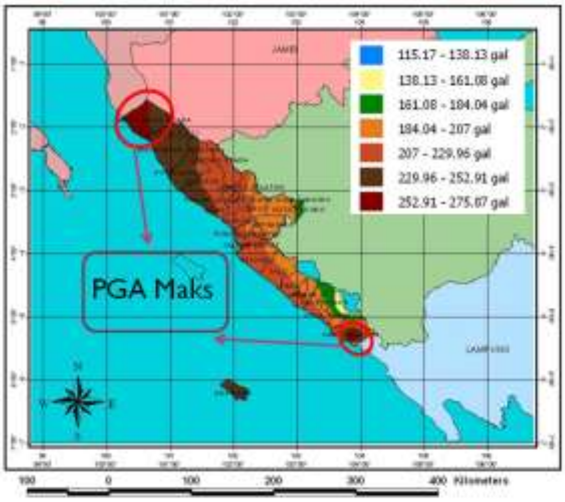

Figure 6. Contour map of PGA by *Crouse'*s model

Although the Crouse model gives the different result in details, the maximum value of the PGA is located in the Mukomuko, while the two other models - Pathwardan and Esteva - delivering maximum value in Kaur, but in general the three models showed a similar pattern to each other. This pattern is clearly visible on a contour map, which, overall of Bengkulu have the PGA in the range of blue (low) to maroon (high). The maximum PGA values are at two locations, namely Mukomuko on the northern tip of Bengkulu and *Kaur* on the southern tip of Bengkulu which in this case is maroon. This is the conformity with the historical data on Bengkulu earthquakes and surrounding areas which classified as high seismicity index. This is because of Bengkulu and surrounding areas located in earthquake-prone lines in the collision zone of Indonesia, Australia and Eurasia plate that forms the Sumatran Trench that always moves 7 cm/year with an angle N20^{0}E [12]. In addition Bengkulu was flanked by two active faults; Mentawai and Semangko.

By obtaining two of the three models of subduction zones that have given similar results, showing that both models are suitable for Bengkulu area. To get a more appropriate model among that two models, need to be done further research by testing against with several other models of the first generation and testing with measurement data to obtain the alternative model for Bengkulu.

V. Conclusion

The calculation of the value of PGA with three models has been obtained that the two models (Pathwardan and Esteva) produce maximum PGA values at the same location (*Kaur* district in South Bengkulu). Meanwhile, Crouse model produces maximum PGA values in *Mukomuko* district in North Bengkulu. Although three models give the different values, the contour maps of the PGA show the similarity to each other. By obtaining two corresponding results show two models that are appropriate for the area of Bengkulu. These results need to be tested by further research by other models of the first generation and examine it with a calculation based on the results of direct measurements.

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