Mapping of Two Models Peak Ground Acceleration (PGA) of Indonesia

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Abstract. This research was conducted to determine and mapping the value of the PGA in Indonesian territory using two empirical models of attenuation equations from the transition of the second generation to the third generation. The research was conducted by applying the Frisenda’s and Luzi’s. The calculation is based on a catalog of earthquakes that occurred from 1 January 1970 - 31 December 2020 with a variable earthquake magnitude ≥ 5 SR and hypocentre depth ≤ 60 km (destructive earthquake). The calculation results in the maximum value of PGA respectively 0.6613 g for Frisenda, and 12.257 g in the Luzi. The maximum PGA value in the Luzi model is the effects of the Andaman Islands earthquake on December 26th, 2004, with a magnitude of 9.1 SR, and the maximum PGA value in the Frisenda model is the effects of the Flying Fish Cove, Christmas Island earthquake on June 13th, 2013, with the magnitude 6.7 SR. In general, these two maps show different or even opposite patterns.

1. Introduction
Indonesia’s territory is located on three main plates, namely the Eurasian plate in the north, the Indo-Australian plate in the south, and the Pacific in the northeast causing high seismic intensity and becoming the main tectonic character of the Indonesian archipelago. Several large earthquakes that have occurred in the last 50 years in Indonesia have caused significant losses and casualties. These include the Banda earthquake (8.5 SR) in 1983, the Sumatra-Andaman Islands earthquake (9.1 SR) in 2004, the North Sumatra/Nias earthquake (8.6 SR) in 2005 the West Coast earthquake of Sumatra (8.6 SR) in 2012 the Lombok (7 SR) in 2018, the Donggala-Palu (7.5 SR) in 2018 and others. Earthquakes as a natural disaster, apart from being unpredictable when they will occur, also have other effects in the form of ground movement. This ground movement causes losses because it can damage buildings and other facilities.

As a preventive effort to overcome the impact of the earthquake, it is necessary to make an earthquake risk map base on the effect it causes. One of the effects of an earthquake that can be used as a reference is a map of the acceleration of ground motion which is known as Peak Ground Acceleration (PGA). These values can then be mapped and an overview of areas that are vulnerable or safe to the risk of ground movement can be seen. As a result of the accumulation of earthquakes, the peak ground acceleration will change every time an earthquake occurs, so this map needs to be updated every certain period [1].
The Researches on earthquakes and Peak Ground Acceleration (PGA) has been carried out by many researchers. Atkinson and Boore have made an empirical relation of ground motion for subduction areas [2], and the Hybrid empirical method in the ground movement was also carried out by Campbell [3]. Research on PGA in several regions of Indonesia, which was conducted separately, Megawati researches ground motion attenuation for major earthquakes in Sumatra [4]. Irsyam it. All proposed a seismic risk map for the islands of Sumatra and Java for the micro-zoning study of the city of Jakarta [5]. Tati Zera et.al a study compared the PGA map based on three different models for Bengkulu [6]. Tati and Nafian also conducted similar research to compare the three PGA models for the West Java region [7]. Research for zoning earthquake hazard areas using the global attenuation function developed by Young et.al has also been carried out by Edy Irwansyah [8] This research mapping the PGA value for all regions of Indonesia as an area with high seismic activity based on two models that are rarely used but are proposed in the BRGM Intermediary Report [9].

2. Peak Ground Acceleration (PGA)

As the effect of an earthquake, the Peak Ground Acceleration (PGA) can be measured using an accelerometer. However, it is difficult to use for large areas. Another alternative to obtain the PGA value is to determine it from the accumulation of earthquakes. Acceleration is a quantity that states the change in velocity from rest to a certain speed. Peak Ground motion acceleration (PGA) is the greatest value of acceleration at a place due to earthquake vibrations during a certain period. One of the effects of an earthquake in a place is the acceleration of the ground on the surface. The magnitude of the acceleration of the ground surface movement indicates the risk of an earthquake that needs to be estimated.

In calculation, the value of ground motion, especially Peak Ground Acceleration (PGA) requires several earthquake parameters, including (1) earthquake magnitude on the surface (Ms). If the Earthquake incident data obtained is not in the form of a Magnitude Surface, it needs to be converted first. (2) Distance to the Site (R), namely the distance from the hypocentre to the recording station. (3) Epicenter (Δ) is the distance from the projection of the hypocenter on the earth's surface of the site or the recording station. Expressed in geographical coordinates, usually accompanied by distance and direction information. Mathematically the value of Δ can be determined from the formulation between two points. (4) Depth of Earthquake (h), is the place/center of the earthquake which is below the earth's surface. Besides these four parameters, local conditions of the soil also affect the PGA value.

Since the acceleration of ground motion decreases with increasing distance, the distribution function of acceleration will be the logarithm of the distance. And the distance is one of the important (main) parameters in the acceleration function of ground motion. In addition, the energy that spreads from the epicenter will decrease due to the attenuation of soil material. Furthermore, Kramer [10] said that the amplitude of the ground motion will decrease exponentially both concerning the distance and magnitude of the earthquake, so the function of peak ground acceleration, in general, expressed as,

\[ \log (y) = f(M, R, c) \] (1)

Where y is Peak Ground Acceleration (PGA), M is Earthquake Magnitude at the surface, R is the distance from the hypocenter to the recording station (site) and c is the coefficient. Research on attenuation of ground acceleration due to earthquakes in various formulations has been carried out for a long time and is divided into two groups, namely Worldwide Attenuation which is the attenuation of ground acceleration using mixed data from various places, various variables, and general attenuation. Next is the specific attenuation where this attenuation takes into account the place, the mechanism of earthquake occurrence, the type of soil, and the activity of certain tectonic movements. This attenuation is then grouped into shallow crustal attenuation in both active and passive areas and then earthquake attenuation in subduction areas [11]. Research on the function of attenuation for the acceleration of ground motion has progressed very well and has produced many models that accommodate conditions in various regions with different geological structures. This research will use a global attenuation function with mixed data will be used.
3. Method

In this research, the value of peak ground acceleration was calculated based on a catalog of the earthquake that occurred for 50 years from 1 January 1970 - 31 December 2020 with parameters; magnitude 5 SR and hypocentre < 60 km (destructive earthquake) that occurred within the territory of Indonesia at the limits of 6° N - 11° S and 95° - 141° E. A total of 7488 earthquake data was obtained according to the established criteria [12]. The plot of the data obtained is shown on the Indonesia seismicity map as shown in Figure 1.

![Indonesian Seismicity Map Jan 1970 - December 2021](image)

**Figure 1.** Indonesian Seismicity Map Jan 1970 - December 2021

Calculations were carried out using two equation models proposed by Frisenda and Luzi. These two-equations are included in the 207 ground motion equation models for the prediction of peak ground acceleration listed in the BRGM intermediate report by Douglas [9]. The model developed by Frisenda is based on earthquake data that occurred in northern Italy and data from the Lunigiana – Garfagnana seismic network. Frisenda formulates the empirical method for the PGA as equation (2):

$$\log \left( \frac{\text{PGA}}{g} \right) = -3.19 + 0.87 \frac{M}{1839} + 0.042 \frac{M^2}{1870} - 1.92 \log \left( \frac{g}{1844} \right)$$  \hspace{1cm} (2)

In this model, there are four Frisenda constants with two of them positive and the other two negative. It is necessary to convert the Magnitude (M) value obtained from the catalog to the surface magnitude value to be used in this Frisenda model. The distance from the epicenter to the recording station or, in this case, is the distance from the hypocentre to all grid corner points specified on the map.

While the model proposed by Luzi is built based on research on 2895 earthquake records from 78 events with a hypocenter depth of < 60 km at 22 stations and several other studies, Luzi (2006) proposes an empirical form of PGA as follows equation (3):

$$\log \left( \text{PGA} \right) = -4.417 + 0.77 \frac{M}{1839} - 1.097 \log \left( \frac{g}{1844} \right)$$  \hspace{1cm} (3)

The provisions for a magnitude (M) and distance (R) applied to the Frisenda model are also applied to the Luzi model in this study. PGA results obtained are in units of g while 1 g = 1000 gals. The plot of the calculation results of each model on the base map provides an overview of the PGA values in the form of contours.
4. Results and Analysis

The results of the PGA calculation using the Frisenda model produce a maximum value of 0.6613 g which is at the position 4°S, 130°E and is thought to have been caused by an earthquake that occurred at 3.913°S – 131.368°E Christmas Island on June 13th with the 6.7 SR and the minimum value of PGA is obtained at 0.028 g which is at 14°S, 95°E and is thought to have been caused by an earthquake that occurred at 10.004°S – 107.236°E Seram Sea on January 8th 2008 with the 5.8 SR.

The plot of the calculation results using this model on the PGA contour base map with the maximum value being in the eastern part of Indonesia around the Seram Island and continuing to decline to the west. While the minimum value is around the Sambas area of Kalimantan. This picture asks for compatibility with seismicity data in the eastern region of Indonesia but does not match seismicity data in the western region. Further research is needed to determine the suitability of the Frisenda model with the subduction area which in this study is located on the west coast of Sumatra and continues to the south of Java. The suitability of the Frisenda model with Indonesia seismicity in eastern Indonesia looks quite good, especially the Banda Arc [13]. But overall, for the Indonesian region, this model is not satisfactory. PGA value contour map with Frisenda model can be seen in Figure 2 below.

![Figure 2. Peak Ground Acceleration (PGA) Map with Frisenda Model.](image)

The results of the PGA calculation using the Luzi model produce a maximum value of 12,257 g which is at the position 6°S, 95°E eastern Indonesia (Aceh) and is thought to have been caused by an earthquake that occurred at 3.295°N – 95.982°E Andaman Island on December 26th, 2004 with the magnitude 9.1 SR and the minimum value of PGA is obtained at 5,750 g which is located at 9°S, 140°E eastern Indonesia (Papua) and is thought to have been caused by an earthquake that occurred at 3.295°N – 95.982°E Andaman Island on December 26th, 2004 with the magnitude 9.1 SR.
Figure 3. Peak Ground Acceleration (PGA) Map with Luzi Model

Plotting the PGA using the Luzi model on the base map shows the PGA value increasing from Eastern Indonesia to the West. The minimum value is in eastern Indonesia (Papua) and the maximum value is in the north of Aceh which is the western part of Indonesia. This is different from the pattern produced by the Frisenda model where the maximum value of the PGA is around the Seram Islands, the Banda Sea which is the eastern part of Indonesia. This map shows the correspondence with seismicity data in western Indonesia, where the seismicity level is quite high along the subduction zone that stretches along the west coast of Sumatra and south of Java. However, it is not suitable for eastern Indonesia, especially in the Banda Basin area.

The extreme conditions in the form of maximum and minimum PGA values generated from these two models along with the earthquake that caused can be seen in Table 1 below. From the table, it is clear that these two models give different results.

| Model | PGA Max  | PGA Min  |
|-------|----------|----------|
| Frisenda | 0.6613 g  | 0.0285 g  |
| 4°S, 130°E | 4°S, 95°E   | 14°S, 95°E   |
| 2013-06-13 16:47:23 | 2008–01–08 19:23:31 | 6.7 SR, 3.913° S – 131.368° E | 5.8 SR, 10.004° S – 107.236° E |
| Christmas Island | Seram Sea | 12.257 g | 5.750 g |
| Luzi | 12.257 g | 5.750 g |
| 6°S, 95°E | 9°S, 140°E   | 12.257 g | 5.750 g |
| 2004-12-26 T 00:58:53 | 2004-12-26 T 00:58:53 | 9.1 SR, 3.295° N – 95.982° E | 9.1 SR, 3.295° N – 95.982° E |
| Andaman Island | Andaman Island | 9.1 SR, 3.295° N – 95.982° E | 9.1 SR, 3.295° N – 95.982° E |
5. Conclusion

The calculations and plots of the PGA that have been carried out for the two models tested in this research have given different results. Frisenda gives the maximum value of PGA in Eastern Indonesia (Seram Islands, Banda) and the minimum value is obtained in Eastern Indonesia (Sambas, Kalimantan). On the other hand, the Luzi model gives a maximum value in the west (Aceh) and the minimum in the east (Papua). These two models provide a good fit for different seismicity data groups or regions of Indonesia. The Frisenda model is more suitable for the eastern part of Indonesia and the Luzi model is more suitable for the western part of Indonesia. Further research is needed to obtain an appropriate model for Indonesia's overall seismic conditions.

References

[1] Masyhur I, Wayan S, Fahmi A, Sri W, Wahyu T, Danny H N, Engkon K, Irwan M, Suhardjono, Asrurifak M and Ridwan M 2010. Bandung
[2] Atkinson, G M and Boore D M 2003 Society of Amerika. 93(4) 1703 – 29
[3] Campbell, K W 2003 Society of Amerika. 93(3) 1012 – 33
[4] Megawati K and Pan T C 2010 Eng. And Struct. Dyn. 39 827 – 45
[5] Irsyam M, Dangkua D T, Hendriyawan, Hoedajanto D, Hutapea B M, Kertapati E K, Boen T and Petersen M D 2008 J. Earth. Sys. And Sci. 117 865 – 78
[6] Tati Z, Sutrisno and Agus B 2017 IOSR J. Apple. Geology and Geophy. 5 31 – 36
[7] Tati Z, and Muhammad N 2017 Int. L Conf. on Sci and Tech 149 140 – 42
[8] Eddy I and Edi W 2012 price. Sem. Nas. If 2012 E14-21
[9] Douglas J 2006 Errata of addition to Ground Motion Estimation Equation 1964 – 2003 Intermediary Report BRGM 54603- FR
[10] Kramer, S L 1996 Geotecnical Earthquake Engineering (New Jersey: Prentice Hall)
[11] Widodo P 2012 Seismologi Teknik & Rekayasa Kegempaan (Yogyakarta: Universitas Islam Indonesia) p. 330
[12] http://earthquake.usgs.gov/earthquakes/search/  
[13] Warren H 1979 Tectonic of Region, Indonesia (Banner Science: Library US Dept. Of Interior)