Mapping of Peak Ground Acceleration (PGA) using The Kawashumi Model for Sumatera

Tati Zera[1,†]

[1]Department of Physics, Faculty of Science and Technology, Syarif Hidayatullah Islamic State University, Ir. H. Djuanda St, No.95, Cempaka Putih, Ciputat, South Tangerang, Banten 15412, Indonesia
[†]tati_zera@uinjkt.ac.id

Abstrak. Posisi pantai barat pulau Sumatera yang merupakan wilayah pertemuan lempeng Eurasia dan IndoAustralia memiliki seismisitas yang tinggi karena aktivitas tektoniknya. Tingkat seismisitas yang tinggi ini mengindikasikan sangat banyaknya kejadian gempabumi yang memberikan efek gerakan tanah. Penelitian ini melakukan perhitungan dan analisis terhadap percepatan gerakan tanah maksimum *(Peak Ground Acceleration - PGA)* sebagai efek kejadian gempabumi merusak di Sumatera selama 100 tahun sejak 1 Januari 1920 - 31 Desember 2020 berdasarkan model Kawashumi. Hasil perhitungan memberikan nilai PGA dalam rentang 388.190 – 4008.210 gal dengan nilai maksimum 4199,45 gal pada 3.295°LU, 95.982°BT yang disebabkan gempa 9,1 M di Pulau Andaman pada 24 Desember 2004. Sementara nilai PGA minimum sebesar 314,9 gal yang terletak di 4.438°LS - 101.367°BT yang disebabkan gempa Bengkulu 8,4 M. Pemetaan hasil perhitungan ini menghasilkan pola PGA yang tinggi di utara Sumatera dan dan semakin berkurang ke arah selatan. Hal ini memperlihatkan bahwa gempabumi - gempabumi merusak yang terjadi di utara pulau Sumatera lebih memberikan resiko yang besar terhadap pergerakan tanah dibandingkan gempabumi-gempabumi merusak yang terjadi di selatan pulau Sumatera. Pola PGA ini berbeda dengan beberapa penelitian sebelumnya.
Kata Kunci : Peak Ground Acceleration, Kawashumi, seismisitas.

Abstract. The position of the west coast of the island of Sumatra, which is the meeting point of the Eurasian and Indo-Australian plates, has high seismicity due to its tectonic activity. This high level of seismicity indicates that many earthquakes have an effect on ground motion. This study calculates and analyses the maximum ground motion acceleration (Peak Ground Acceleration - PGA) as the effect of destructive earthquakes in Sumatra for 100 years from January 1, 1920 - December 31, 2020, using the Kawashumi model. The calculation results give PGA values in the range of 388,190 – 4008,210 gal with a maximum value of 4199.45 gals at 3,295°N, 95,982°E caused by the 9.1 M earthquake on Andaman Island on December 24, 2004. While the minimum PGA value is 314.9 gals located at 4.438°LS - 101.367°BT caused by the Bengkulu 8.4 M earthquake. This calculation results in a map showing a high PGA pattern in the northern part of Sumatra and decreasing towards the south. This indicates that destructive earthquakes that occur in the northern part of Sumatra Island pose a greater risk of ground movement that destructive earthquakes that occur in the southern part of Sumatra Island. This PGA pattern is different from several previous studies.
Keywords : *Peak Ground Acceleration, Kawashumi, seismicity.*

INTRODUCTION

A abrupt displacement of the earth's plates produced by tectonic or volcanic activity, as well as landslides, is known as an earthquake. Because of the meeting route of tectonic plates, the Indo-Australian Plate, the Eurasian Plate, and the Pacific Plate, earthquakes are highly prevalent in Indonesia. Sumatra is one of the islands that is regularly struck by earthquakes. This island is situated near the subduction zone formed by the junction of the Indian-Australian plate and the Eurasian plate. A Semangko fault system runs the length of the island, while a Mentawai fault system runs the length of the offshore. Ground movement caused by earthquakes causes damage to houses and other structures. A Peak Ground Acceleration (PGA) map is required as a precautionary step to mitigate the effects of the earthquake. PGA may be measured using an accelerometer as a result of an earthquake. It is, however, difficult to apply it over vast regions. Another method for determining the PGA value is to use the earthquake accumulation. These values may then be plotted, giving an overview of which locations are sensitive to ground movement and which are not. The peak ground acceleration will vary every time an earthquake happens due to the accumulation of shocks, thus this map will need to be updated at regular intervals. [1].

For each earthquake, PGA is a disruption that is measured. The maximum ground acceleration, or PGA, is chosen to be mapped in order to have a better knowledge of a location's most severe effects. The greatest peak ground acceleration is the highest figure ever recorded in a location as a result of an earthquake. The bigger the PGA value that has occurred in a location, the higher the hazard and risk of an earthquake occurring. Because ground acceleration is the most important component that impacts building design and produces a uniform moment of force at all places of the structure, it is the starting point for earthquake-resistant building calculations.

A lot of researchers have studied PGA in different ways. Ground motion and subduction zones have been empirically linked by Atkinson and Boore [2]. Campbell [3] uses the Hybrid Empirical Method in Ground Motion as well. Megawati investigated the attenuation of ground motion for the big earthquake in Sumatra [4] in PGA studies performed individually in many locations of Indonesia. For a micro-zoning analysis of Jakarta, Irsham et al. produced seismic risk maps for the islands of Sumatra and Java [5]. Tati Zera et al., compare PGA maps for the Bengkulu area using three alternative models [6]. Based on Kawashumi models, this study calculates and maps the PGA value for Sumatera as locations with strong seismic activity. The 2011 Tohoku Earthquake [7] was investigated using these Kawashumi models. This model was also utilized to compare the estimated PGA value to the accelerograph data in Cilacap after the 6.1 M earthquake on January 25, 2014 [8]. This study will put Kawashumi's model to the test by looking at the ground motion patterns created by this PGA model over a 100-year period in Sumatra.

DATA AND METHOD

There are many PGA models proposed by experts, both to calculate PGA on the surface and in bedrock. No fewer than 20 PGA formulations were submitted by Douglas in 1991 and became a reference for various research on PGA [9]. However, this research will use Kawashumi's model as used in [8] in the form

$$\log \alpha = M_s - 5,4 - 0,00084\,(R - 100) + (\log \frac{100}{R}) \times \frac{1}{0,43429} \tag{1}$$

where α is the PGA value in gal, Ms is the earthquake's magnitude at the surface, and R is the distance to the hypocentre (km). Because the calculated PGA is the PGA value on the surface, it is necessary to first convert the earthquake into a surface magnitude. The R-value is obtained by determining the depth of the earthquake center (hypocentre) and the distance from the epicenter to the measuring station (in this case, the corner points of the grid marked on the map).

The data used in this research is the incidence of destructive earthquakes within a period of 100 years from January 1, 1920, to December 31, 2020, in Sumatra with M>5 and a depth of hypocentre (h) < 60 km. The data plot on the base map of the island of Sumatra can be seen in Figure 1, which shows the fairly high seismicity of the island of Sumatra along its west coast. The destructive earthquakes spread quite widely and evenly in the western part, but they were decreasing and did not occur in the eastern part of the island of Sumatra. The epicentre of the earthquake is mostly in the sea, and only a small part is in the region of the mainland. These earthquakes along the coast are generally subduction earthquakes. Only a small part of it is the earthquakes from the Mentawai fault. While the earthquakes on the mainland of Sumatra are earthquakes with an active fault source from the Semangko fault segment, almost all of these destructive earthquakes are caused by three tectonic frameworks on the island of Sumatra, the subduction zone, the Mentawai fault, and the Semangko fault [10].
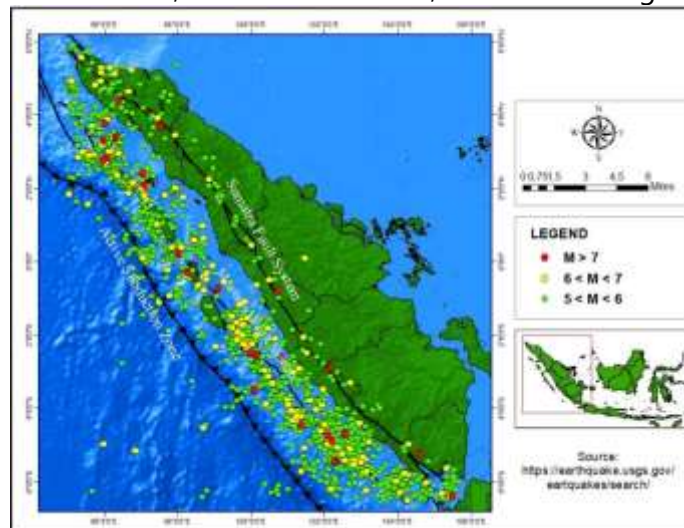

Figure 1. Sumatera Seismicity Map in 1920 - 2020

The data used in this study was obtained from the official website of the United States Geological Survey (USGS) with a total of 1757 destructive earthquakes, each consisting of 1580 earthquakes with 5<M<6, 152 earthquakes with 6<M<7, and only 25 earthquakes with M>7. The distribution of earthquakes based on 5 years of occurrence can be seen in Figure 2 below.
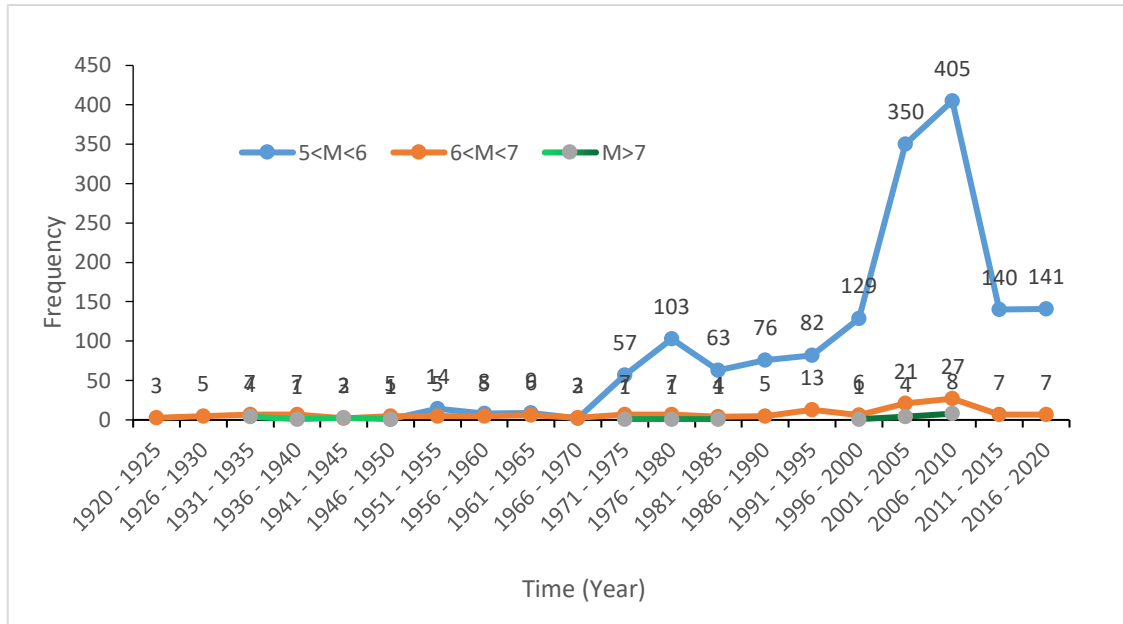
Figure 2. Sumatra Earthquakes Data 1920-2020

Earthquakes data as shown in Figure 2 shows that earthquakes with a magnitude range of 5–6 experienced an increase in the number of events during the period 1966–2010 and reached a peak of 405 at the end of this range. This condition is depicted by the blue line on the chart. Meanwhile, earthquakes with a magnitude of 6–7 showed an almost constant number of events in each period, although 2001–2010 also showed an increase. It is marked with an orange line. Large earthquakes with a magnitude > 7, on the graph marked with a green line, occurred discretely in 3 periods: 1931–1950, 1971–1985, and 1996–2010. Overall, the graph shows a significant increase in the incidence of earthquakes for all three classifications in the range of 1991–2015.

RESULT AND DISCUSSION

The PGA calculation using Kawashumi's model with 1757 data on the occurrence of destructive earthquakes in Sumatra at the geographical boundaries of 6°N - 6.5°S and 95°E - 106.5°E was carried out by making a 2o grid, which resultedin a PGA in the range of 388.190 - 4008.210 gal. This calculation results in the maximum PGA being 4199.45 gal, located at 3.295°N and 95.982°E caused by the 9.1 M earthquake in Andaman on December 24, 2004. This earthquake has also caused a large tsunami that has hit and damaged Aceh. While the minimum PGA is 314.9 gal located at 4.438°S,101.367°E which is caused by the 8.4 M Bengkulu earthquake on 12 September 2007. The results of the PGA calculation are then mapped to see the ground motion pattern. This map is shown in Figure 3 below.
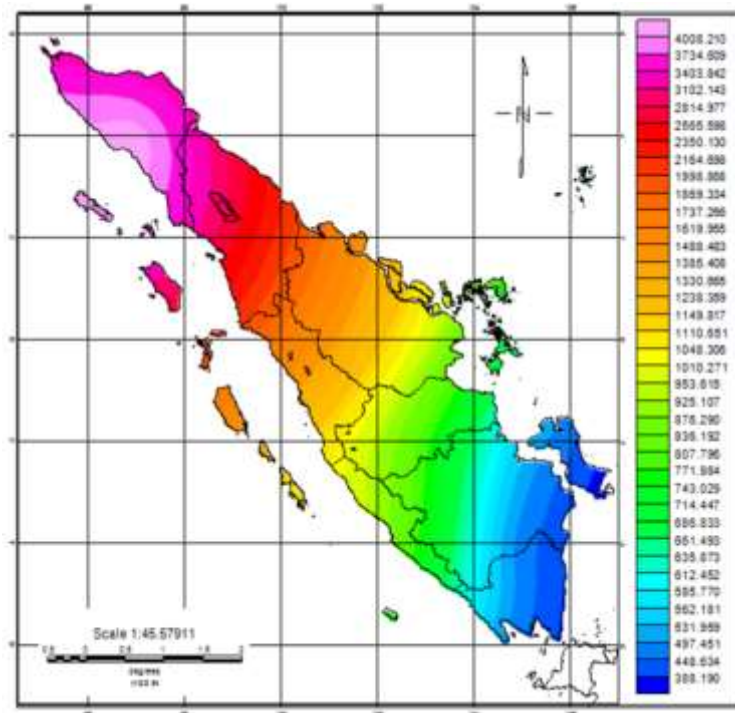
Figure 3. PGA map of Sumatera with Kawashumi's Model

The resulting map shows a high change in the PGA value in the north of Sumatra, which continues to decline towards the south. This is indicated by gradations of pink, red, and light blue and dark blue at the southern end. At first glance, this looks very different from the seismicity pattern of the island of Sumatra, as shown in Figure 1, where the seismicity density is concentrated evenly along the coast of Sumatra. However, if we look in more detail, the distribution of large earthquakes marked in red on the seismicity map tends to be more concentrated in the northern part than in other regions. This concentration of large earthquakes causes the PGA value on the northwest coast of Sumatra to be higher.

Although it does not follow the tectonic framework of the island of Sumatra, which has three active tectonic arrangements in the form of a subduction zone along the west coast, the Mentawai fault, and the Semangko fault along the mainland of Sumatra, all three are parallel to each other [10], but the PGA pattern generated using the Kawashumi model formed a different pattern due to the concentration of large earthquake events in the northern part of Sumatra. This is what causes the difference.

CONCLUSION

The determination of the peak ground acceleration (PGA) value that has been carried out using the Kawashumi model in this study, based on a catalogue of destructive earthquakes for 100 years in Sumatra, has resulted in a pattern that does not follow the tectonic setting of the island of Sumatra. The pattern formed shows a change in the high PGA value gradually decreasing from North Sumatra to the South, caused by the concentration of large earthquakes in North Sumatra. Calculation of the data with the limits used has resulted in PGA values in the range of 388.190–4008.210 gal with a maximum value of 4199.45 gal, which is located at 3.295ºN and 95.982ºE, caused by the 9.1 M earthquake on Andaman Island on December 24, 2004. Meanwhile, the minimum value is 314.9 gal, located at 4,438ºS and 101.367ºE, which was caused by the Bengkulu

8.4 M earthquake. The pattern of ground motion risk will be like this pattern if the PGA value is converted to the MMI scale. This conversion can be carried out in future research, even using other empirical models.

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