Comparative Analysis of Peak Ground Acceleration Before and After Padang Earthquake 2009 Using Mc. Guirre Method

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Abstract. We have analyzed the earthquakes data in West Sumatra province to determine peak ground acceleration value. The peak ground acceleration is a parameter that describes the strength of the tremor that ever happened. This paper aims to compare the value of the peak ground acceleration by considering the b-value before and after the Padang earthquake 2009. This research was carried out in stages, starting by taking the earthquake data in West Sumatra province with boundary coordinates 0.923° LU - 2.811° LS and 97.075° - 102.261° BT, before and after the 2009 Padang earthquake with a magnitude ≥ 3 and depth of ≤ 300 km, calculation of the b-value, and ended by creating peak ground acceleration map based on Mc. Guirre empirical formula with Excel and Surfer software.

Based on earthquake data from 2002 until before Padang earthquake 2009, the b-value is 0.874 while the b-value after the Padang earthquake in 2009 to 2016 is 0.891. Considering b value, it can be known that peak ground acceleration before and after the 2009 Padang earthquake might be different. Based on the seismic data before 2009, the peak ground acceleration value of West Sumatra province is ranged from 7,002 to 308.875 gal. This value will be compared by the value of the peak ground acceleration after the Padang earthquake in 2009 which ranged from 7,946 to 372,736 gal.

Keywords: Padang Earthquake, b-value, Peak ground acceleration, Mc. Guirre method

1. Introduction

Indonesia is the area of triple junction plate convergence such as Indo-Australian Plate, Eurasian Plate, and Pacific Plate. It moves and interacts each other like Indo-Australian plate plunging to Eurasian plate which known as subduction [1]. Several islands in Indonesia are on the border of subduction zones such as Sumatra Island. West Sumatra especially Padang as the capital of West Sumatra province have a high risk of an earthquake because the location is close to the subduction zones. An Earthquake is an event of ground movement due to wave propagation generated by tectonic activity [2]. Based on [3] data an earthquake have moment magnitude 7.6 had hit West Sumatra on 30th September 2009 at 17:16:09 GMT with its epicenter located at coordinates LS 0.84 - 99.65 BT about 60 km WNW of the city of Padang with depth 71 km. The highest number of deaths and damage is in the Padang and surrounding.
Earthquakes are caused by the stress that accumulates continuously and release suddenly [4]. The accumulation of stress before the earthquake in 2009 known from the b value by Gutenberg-Richter equation [5]. Padang earthquake in 2009 has about 809 deaths and 2498 injuries. Most of the victims died due to crushed by building [3]. Which one cause the destruction by the earthquake is the peak ground acceleration. The peak ground acceleration is the acceleration value due to land in a place of earthquakes in a given period where the value is calculated at the point of research at the Earth's surface based on the data of earthquakes with the greatest value calculation [6]. Using earthquake data from USGS, the peak ground acceleration is calculated by Mc. Guirre method. The purpose of this paper is comparing and to map the value of peak ground acceleration before and after Padang earthquake 2009 to reduce seismic risk, from 7 years before and after Padang earthquake 2009.

![Figure 1. The map of study area, including the Padang City and its surrounding with coordinates 0.923° LU - 2.811° LS and 97.075° - 102.261° BT.](image-url)

Figure 1 Shows that the earthquake data was taken from USGS with coordinates 0.923° - 2.811° LU and 97.075° - 102.261° BT as the area of West Sumatra, Padang city, and its surrounding, from 2002 until to the day before the mainshock in 2009 and at that day until 2016. West Sumatera, Padang city and surrounding had chosen an observed area because it has high seismicity and high population.

2. B-Value
Kirbani [7] represents the relation between magnitude and number of magnitude as follows:

\[
\log N = a - bM
\]

Where N is the number of magnitude M or larger which a cumulative curve, a is productivity, and b is called b value as a gradient of the graph LogN vs. M, and it has served of the tectonic parameter. B value depends on the stress level of a region where the stress value inversly toaws b value [8][9][10].
3. Peak Ground Acceleration  
Peak Ground Acceleration (PGA) is the value of the maximum ground acceleration due to earthquake shaking at a location. The definition PGA, in general is the accelerations of maximum ground vibrations that occurs at a point of a particular position in an area that is calculated by the result of all the earthquakes that happened at a definite time which concern to the magnitude and distance of its hypocenter.

PGA calculation can be done by several methods, one of the calculation methods is the empirical formula of Mc Guirre [11], as follows:

\[ E[v] = a10^{bM}(R + 25)^c \]

where \( a = 472.3 ; b = 0.278 ; c = 1.301 \) and \( E[v] \) is the magnitude of the acceleration estimation in units of gal, \( M \) is the magnitude of the surface wave in the Richter scale; \( R \) is the distance between the hypocenter to the receiver (receiver station waves) in units of kilometers. Surface seismic acceleration can be expressed with "g", due to the similarity to Earth's gravity, either in decimal or percentage which can be expressed in m / s\(^2\), where 1 g = 9.81 m / s\(^2\) or when converted into "gal", then 1 Gal = 0.01 m / s\(^2\) with 1 g = 981 Gal.

The calculation of magnitude in Indonesia, (especially BMKG) use the calculation of body wave magnitude (Mb) and local magnitude (ML), it is necessary to convert the magnitude become surface magnitude (Ms). Gutenberg has redefined the relationship from the third magnitude as follows:

\[ Mb = 0.56 Ms + 2.9 \text{ and } Mb = 1.7 + 0.8 ML - 0.01 ML^2 \]  

(3)

So, Ms can be derived from the relationship above as follows :

\[ Ms = 1.8 Mb - 5.2 \]  

(4)

4. The Influence of Ground Motion toward Vulnerability  
The Tectonic earthquake caused by the alignment process due to large deformation are derived by movements in the earth [12]. The Earthquake which has high magnitude and shallow hypocenter can damage the area near of epicenter and its surrounding.

Earthquake cause a wave of energy is release and propagation [2]. The wave will be constructive if the frequency of seismic wave is equal to the natural frequency of an area [13]. The natural frequency of an area depends on the lithology [14]. Based on geoengineering, soft, and unconsolidated rocks have a higher risk when shaken by a wave of earthquakes, because of a greater amplification compared with the most compact rock (Central Geological Survey, 2007). The high risk of damage can be caused by strong ground motion in soft lithology [15]. Therefore, in the earthquake-resistant infrastructure planning, analysis and the selection of ground motion parameters are absolutely necessary to obtain seismic load plan.(Irsyam et.al 2010) [15].
Table 4.1. Risk Level of Earthquake (BMKG, 2016)

| Skala SIG BMKG | Warna | Deskripsi Sederhana | Deskripsi Rinci | Skala MMI | PGA (gal) |
|---------------|-------|---------------------|----------------|-----------|-----------|
| I             | Putih | TIDAK DIRASAKAN (Not Felt) | Tidak dirasakan atau dirasakan hanya oleh beberapa orang tetapi mereka tidak alat. | I-II | <2,9 |
| II            | Hijau | DIRASAKAN (Felt) | Dirasakan oleh orang banyak tetapi tidak menimbulkan kerusakan. Benda-benda ringan yang digantung bergoyang dan jendela kaca bergetar. | III-V | 2,9-88 |
| III           | Kuning | KERUSAKAN RINGAN (Slight Damage) | Bagian non struktur bangunan mengalami kerusakan ringan, seperti retak rambut pada dinding, genteng bergeser ke bawah dan sebagian berjatuh. | VI | 89-167 |
| IV            | Jingga | KERUSAKAN SEDANG (Moderate Damage) | Banyak retak terjadi pada dinding bangunan sederhana, sebagian roboh, kaca pecah. Sebagian plester dinding lepas. Hampir sebagian besar genteng bergeser ke bawah atau jatuh. Struktur bangunan mengalami kerusakan ringan sampai sedang. | VI-VIII | 168-564 |
| V             | Merah | KERUSAKAN BERAT (Heavy Damage) | Sebagian besar dinding bangunan permanen roboh. Struktur bangunan mengalami kerusakan berat. Rel kereta api melengkung. | IX-XII | >564 |

5. Methodology
To get the peak ground acceleration values using Mc. Guirre method is done in several steps as follows.

- The first stage consists of:
  a. The data of earthquake parameters is collected from West Sumatra and its surrounding areas derived from the USGS. The data that used are seismic data which recorded from 2002 to 2009 and data from 2009 until 2016.
  b. The data is being selected at a magnitude $\geq$ 4 SR and depth of $\leq$ 300 km
  c. The body magnitude (Mb) or other magnitude quantities are converted into the surface magnitude (Ms) as in equation (4).
  d. The seismicity maps are created based on seismic data acquired using Python software, which consists of seismicity maps before and after the Sumatra earthquake in 2009.
- The second step. The seismicity map of Padang and surrounding with the coordinate 0.923° LU – 2.811° LS and 97.075° - 102.261° BT is gridded into 0.5 x 0.5 degree.
- The third step consists of:
  a. The distance of the epicenter is calculated by the equation as follows:

$$I = \sqrt{x^2 + y^2}$$

(5)

Where I as epicenter, $x$ as latitude and $y$ as longitude. The distance of epicenter which are obtained then made in units of kilometers.

b. The distance of hypocenter is calculated by this following equation.

$$R = \sqrt{I^2 + h^2}$$

(6)

Where $R$ as hypocenter, $I$ as epicenter and $h$ as the depth of an earthquake.
The fourth step consists of:

a. The value of peak ground acceleration in every point is calculated either before or after Padang earthquake 2009 using Mc. Guirre equation (2) and then, the highest PGA in every grid is chosen.
b. Based on the highest PGA that has been chosen in every grid, PGA that have same value will be drawn in contour map using Surfer Software.

6. Result and Discussion
Catalog earthquake data is obtained from the United States Geological Survey (USGS) either before or after Padang earthquake 2009 from 2002 to the day before Padang mainshock 2009 and after the mainshock until 2016. Based on the earthquakes catalog, obtained the relationship between seismicity and b-value for seven years before and after the earthquake.

![Seismicity Map of Padang and its Surrounding Area from 2002 to 2009](image)

**Figure 2.** Seismicity Map of Padang and its Surrounding Area from 2002 to 2009
Figure 2 and figure 3 show the number of the earthquakes with the magnitude range 4.0 to 7.7 Ms. The distribution color from blue towards red indicates the higher magnitude of an earthquake. Figure 2 explains the distribution of seismicity as many as 1518 events in Padang and surrounding from 2002 until the day before the earthquake of 2009. The allocation of earthquakes centered in Mentawai Strait and Hindia Ocean. The seismicity for post-seismic shown by figure 3 in this period, USGS recorded 442 events from 2009 to 2016. Seven years before Padang earthquake, there is no seismicity gap like after the Padang earthquake that have a space in every earthquake event. Based on the comparison of seismicity before and after the earthquake, the seismic intensity for before Padang earthquake is higher than after Padang earthquake.

Figure 3. Seismicity Map of Padang and its Surrounding Area from 2009 to 2016

Figure 4. Graph of log N vs Magnitude Before Padang Earthquake 2009

\[ y = -0.8742x + 3.9648 \]
B value is also obtained from earthquakes catalog, b-value itself is the ratio between the number of the event with magnitude [7]. B value for pre-seismic and post-seismic is 0.874 and 0.891, where b value graph is shown in figure 4 and figure 5 as the gradient of the line.

B value of pre-seismic and post-seismic increase for 0.0168, the increasing value indicate releasing stress towards lower magnitude after the earthquake happens. It is characterized by the b value of pre-seismic lesser than post-seismic b-value [8]. It can also be seen from seismic intensity and distribution of higher magnitude after the earthquake 2009 is lower than before the earthquake 2009. Releasing stress over the ground characterized by minor earthquakes that occurred intensive few days after the mainshock which is the release of energy from the remnants of the previous large earthquake [17].

PGA value obtained by calculation using mc. Guirre method with seismicity data from USGS either pre-seismic and post-seismic 2009. The maximum PGA value between seven years before and after Padang earthquake 2009 is different. The maximum PGA value in Padang and its surrounding before the mainshock is about 150 gals, while the maximum PGA value after the mainshock is about 38 gals in Padang and its surrounding. Increasing PGA value is caused by the difference a number of event for before and after Padang earthquake. The number of the phenomenon after the mainshock is less than before the mainshock. Also, distribution of magnitude with its depth also affects to PGA value as well.

![Figure 5. Graph of log N vs Magnitude After Padang Earthquake 2009](image-url)

![Figure 6. Maximum PGA values Map Before Padang Earthquake (2002-2009)](image-url)

![Figure 7. Maximum PGA values Map After Padang Earthquake (2009-2016)](image-url)
According to National Disaster Management Agency (BNPB), an earthquake on September 30th 2009 caused many casualties and destroyed many facilities. Based on BNPB and Implementing Disaster Management Coordination Unit (Satkorlak PB) West Sumatra, the largest casualties and damage were in Padang city, Padang Pariaman city, and Agam regency. The earthquake killed more than 800 people, and more than 2000 facilities were destroyed.

Figure 8. Peak Ground Acceleration Map After Padang Earthquake (2009-2016)

Figure 9. Casualties Map of Padang Earthquake 2009

Based on the collateral damage map by BNPB and the maximum PGA value at the day the mainshock has similarity area for high impact of the mainshock that indicates by red color in figure 9 and highest PGA value in figure 9 is in Padang and surrounding include Padang, Padang Pariaman, and Agam. So, we can conclude that when the PGA value is below to 200 gal such as maximum PGA value before and after the earthquake in 150 gals and 38 gals, it doesn’t cause the significant damage or casualties, but when the PGA is about 200 gal or more like PGA value at the day the mainshock, it can cause significant effect like damaging many facilities even kill peoples. So, PGA value had relation with casualties and damaged by considering magnitude, the distance of epicenter and site effect [15]. According to Tabel 1 (BMKG, 2016) maximum PGA value at the day the mainshock in Padang and surrounding is 200 gals has risk level ‘Moderate Damage’ when the earthquake happens.

7. Conclusion
Based on seismicity data from USGS, had known the comparison of the b value for seven years before and after Padang earthquake by Gutenberg-Richter equation is 0.874 and 0.894. Increasing b-value indicates releasing stress towards lower magnitude.

Mc. Guirre method applied accordingly to calculate the peak ground acceleration (PGA) in Padang city and its surrounding. The maximum PGA value before the mainshock is about 150 gals, while after the mainshock is about 38 gals, and at the day the mainshock is about 200 gal, even more were located in Padang and its surrounding.

Most deaths people and damage were in Padang, Padang Pariaman, and Agam. The casualties data by BNPB and the maximum PGA value at the day 2009 have the similarity area for high impact of the mainshock and highest PGA value. The maximum PGA value of Padang is about 200 gals, even more were located about in Padang, Padang Pariaman, and Agam too. The PGA value had relation with casualties and damaged by considering magnitude, the distance of epicenter and site effect [15]. According to Tabel 1 (BMKG, 2016), the maximum PGA value at the day the mainshock in Padang and surrounding indicate ‘Moderate Damage’ when the earthquake happens.
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