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CORRECTION OF THE EMPIRICALOF PEAK GROUND ACCELERATION AND EARTHQUAKE INTENSITY OF PADANG CITY USING ACCELEROGRAPH DATA

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ABSTRACT

Padang City is an area that was severely affected by the earthquake that occurred in the Subduction Zone. Earthquakes with large magnitudes greatly affect the damage to buildings, one of the factors that can determine the size and extent of the damage was the peak ground acceleration. The value of peak ground acceleration and earthquake intensity in Padang City can be calculated using an empirical formula. Calculates the error correction for each peak ground acceleration value from each empirical formula with the ground acceleration value from the accelerograph. The empirical formula used was Mc. Guire, Si and Midorikawa, Fukushima-Tanaka, and Donovan. The error correction calculation was carried out to determine the empirical formula that has the smallest average error correction. So that the appropriate empirical formula was used to calculate the maximum ground acceleration value in the city of Padang. The error correction calculation shows that the Si and Midorikawa formula has the smallest average error correction, which is 0.003 so that the formula can be used to calculate the peak ground acceleration value in Padang City. The results of the calculation show that the highest peak ground acceleration value is in Bungus Teluk Kabung District, which is 50.3-51.1 gal, while the lowest peak ground acceleration value is in Koto Tangah District, which is 48.5-49.5 gal. The intensity of the earthquake in the city of Padang based on the peak ground acceleration value has a scale of IV MMI.

Keywords : Earthquake; PGA; Empirical Formulation; Si and Midorikawa; Accelerograph.

I. INTRODUCTION

Padang is one of the areas most affected by the earthquake. This is because the city of Padang is located at the confluence of the Indo-Australian plate which subducts under the Eurasian plate, as a result of the subduction three zone are formed which are the source of the earthquake, namely the Subduction Zone, Mentawai Fault, and Sumatran Fault [1]. Regionally, Padang City is an inseparable part of the Sumatran great fault system. The Semangko Fault which is located in the middle of Sumatra Island and the sea trench in the west of Sumatra Island which flank the Padang City area is also the center of tectonic activity in this region [2]. The city of Padang is composed of rocks which are lithologically divided into three periods of formation, namely quarternary, tertiary, and pre-tertiary (Mesozoic). The geological information of the Padang City area can be seen in Figure 1 [3]. This condition causes the Padang City area to become a disaster-prone area with a destructive earthquake source.

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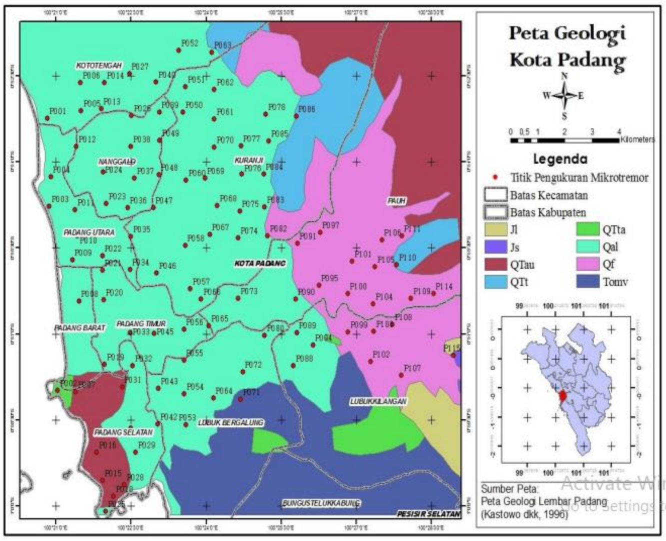

Fig.1. Padang City Geological Map [3]

An earthquake is an event that vibrates the earth caused by the sudden release of energy that occurs in the earth and is characterized by the fracture of the rock layers in the earth's crust. The accumulation of energy that causes earthquakes and the release of that energy is the result of the movement of the tectonic plates. The release of this energy results in the deformation of the tectonic plates in the earth's crust [4]. An earthquake of a large magnitude has an impact on building damage. One of the factors that can determine the size of the damage is the peak ground acceleration [5].

Peak ground acceleration is the greatest ground acceleration that can be felt on the earth's surface due to the propagation of seismic waves [6]. This peak ground acceleration cannot be calculated directly using velocity equations, because the peak ground acceleration value is determined by earthquake parameters such as magnitude, the position of earthquake epicenter and hypocenter, and depth of hypocenter [1]. The peak ground acceleration value is directly proportional to the level of earthquake intensity. Whereas the greater the value of peak ground acceleration caused by an earthquake, the greater the intensity of the earthquake felt by the community [7]. Earthquake intensity is a measure of the level of damage to an area due to vibrations originating from an earthquake [8]. The intensity level of the earthquake can be calculated based on direct observations of the damage caused by the earthquake and can be used as an illustration of the earthquake strength value at the epicenter.

The peak ground acceleration value can be obtained from the measurement results either directly using an accelerograph or through calculations using an empirical formula using earthquake data commonly known as the Ground Motion Prediction Equation (GMPE) [9]. Accelerograph is an instrument used to record ground shaking which is very accurate in measuring the acceleration of ground vibration [1]. Recordings from accelerographs are very useful, one of which is to design earthquake-resistant buildings.

Several empirical formulas that can be used as an approach to estimate the peak ground acceleration value in an area, include :

A. Mc. Guire

This formula is set in the Southern California region in the form of equations.

$$a = \frac{472 * 10^{0,278 Ms}}{(R + 25)^{1,801}} \tag{1}$$

With:

a = Peak ground acceleration value (gal)

Ms = Surface magnitude

R = Hypocenter distance (km) [10].

B. Si and Midorikawa

Si and Midorikawa empirical formula in determining the value of ground acceleration using a moment of magnitude in the form of an equation.

$$\log A = 0.5Mw + 0.0036D + \sum d_i s_i - \log X_{eq} - 0.003X_{eq} + e + \varepsilon \quad (2)$$

With :
A = Peak ground acceleration value (gal)
Mw = Moment of earthquake magnitude (SR)
D = Earthquake depth (km)
X_{eq} = Hypocenter distance (km)
d = Distance from earthquake center to location (km)
S = Dummy's variable for the type of fault (S=1)
e = Coefficient regression (0.6)
ε = Standard deviation (0.24) [11].

C. Fukushima-Tanaka

This formula uses 1372 components of horizontal peak ground acceleration of 28 earthquakes in Japan originating from the Subductions Zone. This formula is applied in Japan in the form of an equation.

$$\log a = 0.41Ms - \log(R + 0.032 * 10^{0.41Ms}) - 0.0034R + 1.30 \quad (3)$$

With :
a = Peak ground acceleration value (gal)
Ms = Surface magnitude
R = Hypocenter distance (km) [12].

D. Donovan

The empirical formulation has been carried out using recorded data of an earthquake that occurred on February 9, 1971, in San Fernando. The following is the form of the equation of this formula.

$$a = \frac{1080 \exp^{0.5Mw}}{(R + 25)^{1.32}} \quad (4)$$

With :
a = Peak ground acceleration value (gal)
Mw = Moment of earthquake magnitude (SR)
R = Hypocenter distance (km) [10].

Calculating the peak ground acceleration value using an empirical formula is one alternative to determine the level of earthquake hazard in an area. Considering the frequent occurrence of earthquakes in the city of Padang, a calculation of the peak ground acceleration value is needed to minimize the impact caused by earthquakes. The mapping of the peak ground acceleration value will be very important information in supporting the development and spatial planning in the Padang City area.

II. METHOD

This research is a descriptive type of research using secondary data in the form of earthquake data that occurred in the Mentawai Segment in the 2015-2020 period. Data is earthquake downloaded from the catalog National Earthquake Information Center US Geological Survey (USGS). This study examines the peak ground acceleration value in the city of Padang to identify areas that are prone to damage from earthquakes. The earthquake parameters used in this study were the position of the epicenter, the magnitude, the depth of the hypocenter of the earthquake, and the peak ground acceleration value obtained from the measurement data using an accelerograph. The data used is the peak ground acceleration value recorded at the BMKG Teluk Bayur. The magnitude earthquake used in this study is 5 SR and has a maximum depth of 300 km.

The method in this study was carried out in several stages, namely calculating the distance between the epicenter coordinates of each earthquake that occurred using the coordinates of the earthquake and the coordinates of the accelerograph using equation 5.

$$D^2 = (x_2 - x_1)^2 + (y_2 - y_1)^2 \quad (5)$$

Where D is the distance from the earthquake epicenter to the coordinates of the calculation area, x_1 is the latitude of the epicenter, x_2 is the latitude of the reference point of the calculation area, y_1 is the longitude of the epicenter and y_2 is the longitude of the reference point of the calculation area. The units for D, x_1, x_2, y_1, and y_2 are in the form (°). The obtained epicenter distance is converted into km, where 1° = 111km.
Calculate the hypocenter distance of each earthquake that occurs using the coordinates of the earthquake and the coordinates of the accelerograph using the theorem Pythagorean as equation 6.

$$R = \sqrt{D^2 + H^2} \quad (6)$$

Where R is the distance to the hypocenter (km), D is the distance to the epicenter (km), and H is the depth of the earthquake (km).

After obtaining the value of the epicenter distance and the value of the hypocentre distance from each earthquake that occurs, then these values are substituted into the empirical formula used, namely the empirical formula Mc. Guire, Si and Midorikawa, Fukushima-Tanaka, and Donovan. The peak ground acceleration value obtained from the calculation results using the four empirical formulas is compared with the ground acceleration value measured on the accelerograph. The comparison process is carried out by calculating the average error correction of each empirical formula used. This error correction is calculated using the following formula 7.

$$\Delta\bar{x} = \frac{\Sigma\Delta x}{N} \quad (7)$$

Where x is the error correction between the empirical formula and the accelerograph data, (Δx) is the average error correction, and N is the amount of accelerograph data used. This error correction is carried out to obtain the appropriate formula used for the Padang City area based on the smallest average error correction.

Before calculating the peak ground acceleration value, first, the research area is on a grid with a distance of 0.02° shown as in Figure 2, this is to ensure that the peak ground acceleration value obtained is accurate. From the process of dividing the research area, it was found that 196 calculation points were used to calculate the peak ground acceleration value in Padang City.

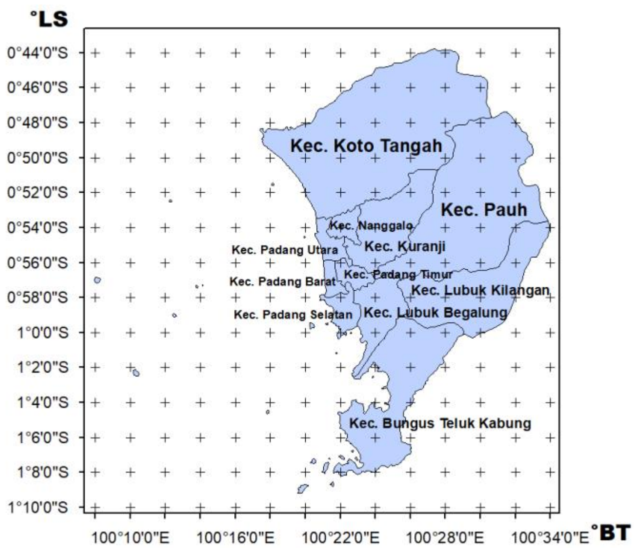

Fig.2. Padang City area grid map

The distance of the earthquake epicenter coordinates to the coordinates at each grid point, calculated using equation 5 while the hypocentre distance from the earthquake source to the coordinates at each grid point is calculated using equation 6. Peak ground acceleration value for the Padang City area was calculated at each grid point using an empirical formula that is following the tectonic conditions of the City of Padang from the smallest average error correction. The peak ground acceleration value obtained is converted to the MMI scale (Modified Mercalli Intensity) to determine the intensity of the earthquake that occurred.

$$MMI = 2.86\log(PGA) + 1.24 \tag{8}$$

The next step is to make a contour map of the peak ground acceleration value and earthquake intensity for the city of Padang, using the peak ground acceleration value obtained from the calculation using an empirical formula that is close to the peak ground acceleration value measured on the accelerograph. The map was created using the help of ArcGIS software and Surfer.

The size of the peak ground acceleration value in an area indicates the risk of an earthquake. Every earthquake that occurs in an area will cause a peak ground acceleration value obtained from direct measurements using accelerographs or by calculations using empirical formulas. This is useful for disaster mitigation to reduce the impact of damage caused by earthquakes.

III. RESULTS AND DISCUSSION

The results obtained from this study are the peak ground acceleration value and earthquake intensity using an empirical formula based on the error correction between the peak ground acceleration value data using an empirical formula and the peak ground acceleration value data recorded on the accelerograph. This error correction process is carried out by comparing the peak ground acceleration value from the calculation results using an empirical formula with the data measured on the accelerograph. The error correction process is useful for finding the appropriate empirical formula used to calculate the peak ground acceleration value in Padang City based on the smallest average error correction of the four empirical formulas used. The graph of the comparison of the peak ground acceleration value from accelerograph data with the calculation results using the empirical formula can be seen in Figure 3.

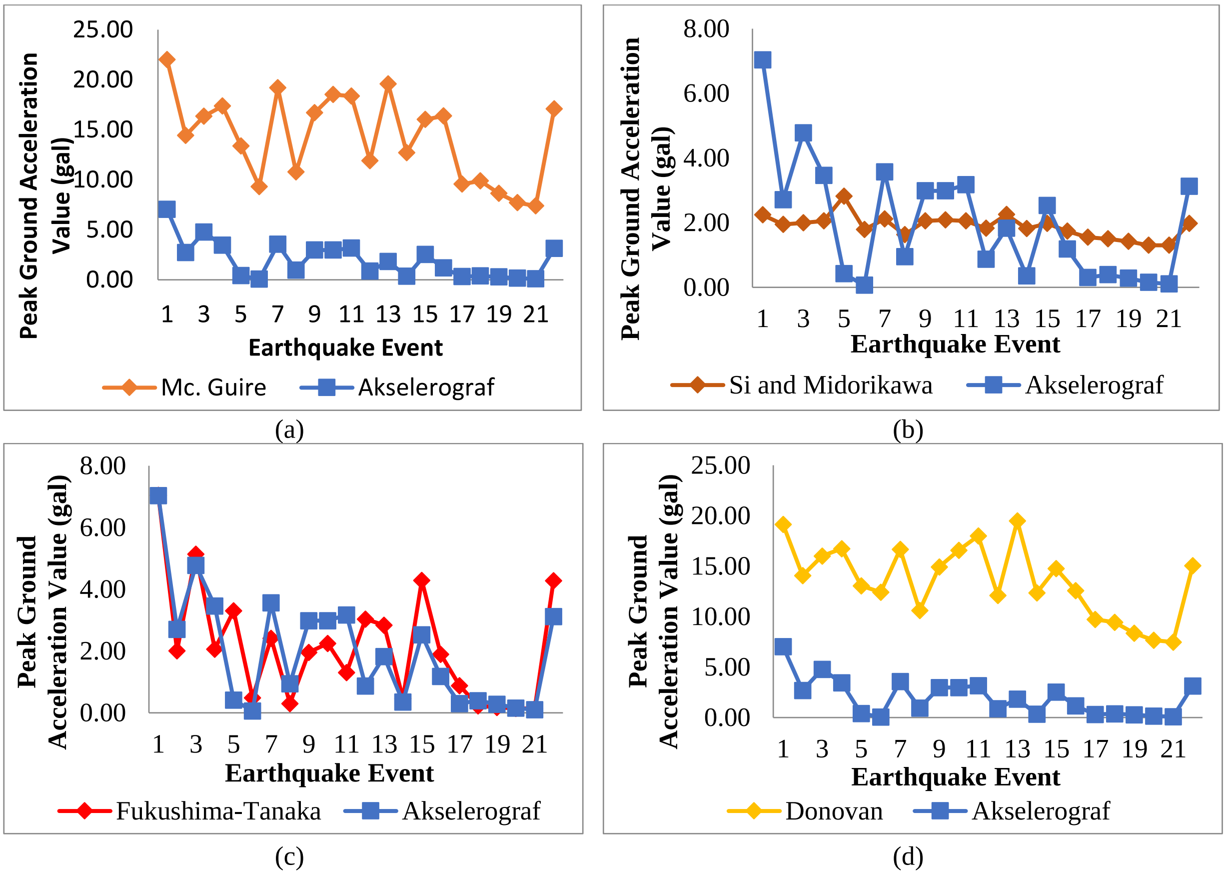

Fig.3. The graph of the comparison of the peak ground acceleration value from the accelerograph with (a) the Mc. Guire, (b) the Si and Midorikawa, (c) the Fukushima-Tanaka, and (d) the Donovan formula

Figure 3 shows a graph of the comparison of the peak ground acceleration value from the accelerograph with calculations using the empirical Mc. Guire, Si and Midorikawa, Fukushima-Tanaka, and Donovan. To find out the appropriate empirical formula used in calculating the peak ground acceleration value, an error correction calculation is carried out on the peak ground acceleration value data. The calculation results show that the Mc. Guire’s has an average error correction of 0.55, Si and Midorikawa’s formula has an error correction of 0.0033, the Fukushima-Tanaka formula has an error correction of 0.007, and Donovan’s formula has an error correction of 0.52.

The calculation of the error correction of the accelerograph data shows that the Si and Midorikawa formula has the smallest average error correction compared to other empirical formulas. Si and Midorikawa’s formulation when viewed in terms of graphic patterns has pattern that is much different from the pattern of accelerograph data, but when viwed from the average error correction, this formula has the smallest error correction. This indicates that the Si and Midorikawa formula can be used in calculating the peak ground acceleration value in Padang City.

In calculating the peak ground acceleration value for Padang City, this study used data on the earthquake that occurred on June 2, 2016. Based on the 2019 earthquake catalogue, the earthquake measuring 6.6 on the Richter scale with a depth of 50 km and this earthquake centered at sea 79 km southwest Pesisir Selatan. This earthquake is classified as a destructive earthquake where the earthquake has a significant impact such as the death toll, injuries, and damage to houses and schools [13]. Based on the results of the calculation of the peak ground acceleration value in Padang City using the Si and Midorikawa formula, the peak ground acceleration value of Padang City is 48.5-51.3 gal as shown in Figure 4.

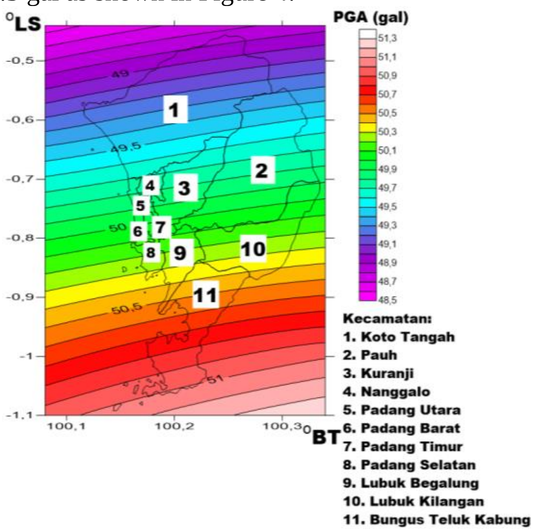

Fig.4. Map of the peak ground acceleration of the Padang City area

Figure 4 shows the distribution of the peak ground acceleration value for Padang City. Based on the map, it is known that the highest peak ground acceleration value is in Bungus Teluk Kabung District, which is 50.3-51.1 gal. While the lowest peak ground acceleration value is in Koto Tangah District, which is 48.5-49.5 gal. This is because Bungus Teluk Kabung has a geological formation dominated by alluvial deposits, where these deposits tend to crack and break more easily so that if vibrations occur due to an earthquake, this area will suffer severe damage [14]. Meanwhile, Koto Tangah has geological formations of quaternary surface sedimentary rocks of Holocene age and tertiary volcanic rocks of Pleistocene age [15]. Besides being influenced by geological formations, the peak ground acceleration value is also influenced by the epicenter and hypocenter of the earthquake. Where the closer the distance between the epicenter and hypocenter, the higher the peak ground acceleration value produced.

The peak ground acceleration value obtained from the calculation using the empirical formula is converted to the MMI scale to determine the level of intensity of the earthquake that occurred in the city of Padang. The distribution of earthquake intensity levels in Padang City is shown in Figure 5.

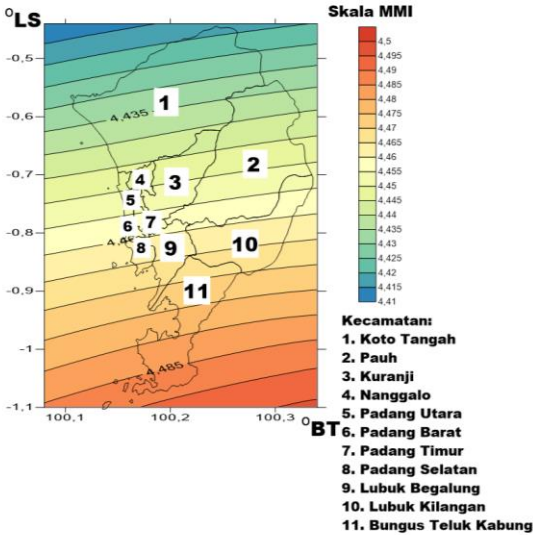

Fig.5. Map of earthquake intensity zones in Padang City

Figure 5 shows that Padang City has a fairly high level of earthquake intensity. The calculation results show that the intensity value in Padang City is on the IV MMI scale with symptoms caused by an earthquake that can be felt by everyone. The greater the value of the peak ground acceleration, the higher the intensity scale due to the earthquake that occurred.

Based on the calculation of the peak ground acceleration value, the city of Padang is grouped into two areas, namely vulnerable and alert areas. The area that has the largest peak ground acceleration value is included in the vulnerable area group, while the area with the smallest ground acceleration value is included in the alert area group [5]. The vulnerable areas include the Bungus Teluk Kabung District, while the alert area includes part of Koto Tangah and Pauh Districts.

The value of peak ground acceleration and earthquake intensity that occurred in the Padang City area based on earthquake data originating from the Mentawai segment can be important information in planning for better spatial and regional development planning in Padang City. Buildings built in the Padang City area should have met the requirements for earthquake-resistant buildings because almost all areas are the IV MMI intensity. Likewise with areas that are classified as vulnerable areas, because this area has a fairly high peak ground acceleration value. So disaster mitigation is needed in this area to minimize the damage caused by the earthquake.

IV. CONCLUSION

Based on the results and analysis obtained from this study, it can be concluded that the error correction between the peak ground acceleration value calculated using an empirical equation and that measured using an accelerograph obtained the appropriate formula, namely the Si and Midorikawa formula, so that the Si and Midorikawa formula was used to determine the peak ground acceleration in the city of Padang. Based on the results of the calculation of the peak ground acceleration value using an empirical formula, it was found that Bungus Teluk Kabung District had the highest peak ground acceleration value in Padang City. The intensity of the earthquake in the city of Padang based on the peak ground acceleration value has a scale of IV MMI.

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