MODIFICATION OF THE ATTENUATION EQUATION FOR PEAK GROUND ACCELERATION (PGA) IN THE NORTH SUMATERA REGION

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Received: 15th August 2024; Revised: 23rd October 2024; Accepted: 25th October 2024

ABSTRACT

Prediction of the empirical formula for ground acceleration is an important thing to analyze for seismic estimation in an area. This needs to be done to reduce the negative impact of earthquakes as a more appropriate mitigation effort in planning and designing earthquake-resistant buildings. Therefore, the empirical formulation from Zhaou, et al is used, which is well adapted to the seismotectonic conditions of the North Sumatra region, which has high seismic vulnerability, considering that this region is located in an active subduction zone. This advantage allows the model to more accurately predict the maximum ground acceleration (PGA) produced by earthquakes in the region. The purpose of this research is to obtain an empirical formulation of the maximum ground acceleration value based on seismic parameters such as distance, depth, and magnitude. It will also show the relationship between these parameters and the value of maximum ground acceleration or peak ground acceleration (PGA) in the North Sumatra region. This study modifies the empirical formulation of Zhao, et al data sourced from the Meteorology Climatology and Geophysics Agency (BMKG) of North Sumatra in 2017-2023 with a magnitude of 3 - 6 Mw. This research uses non-linear regression with the least squares method. The results of the analysis of the empirical formula produce the constant value sought a = 1.4703 b = -0.0025, c = 20.7441, d = 0.0196, e = 0.0015, S_{SS} = -2.0843, and S_{SL} = -0.0529. An empirical formula was obtained for the North Sumatra region based on the research results. This equation can be used on a scale of 3.0 - 6.0 Mw and a distance to the earthquake source between 0 - 300 km. The relationship between each parameter of this empirical formula is that the PGA value will increase with the magnitude, and the PGA value will decrease as the epicentre distance increases.

Keywords: Peak Ground acceleration; earthquake; empirical formulation of Zhao; North Sumatera.

Introduction

The National Center for Earthquake Studies (2017) states that one of the most active subduction zones in Indonesia is located in the western part of Sumatra Island.[1] Because Sumatra Island is part of the Eurasian Plate that interacts convergently with the Indo-Australian Plate.[2] The meeting zone between the Eurasian plate and the Indo-Australian plate forms a trough-shaped subduction zone. This zone is where the Indo-Australian plate subducts beneath the Eurasian plate. The process of subduction of the Indo-Australian plate into the Eurasian plate in the western part of Sumatra Island has resulted in many earthquakes of considerable magnitude, between magnitudes 6 - 9 Mw.[3]

Earthquakes are large shocks that travel to the earth's surface due to disturbances within the lithosphere. It occurs due to the accumulation of energy in the 100 km thick layer of the Earth's crust due to crustal displacement. Earthquakes can cause significant damage to buildings. One of the key factors that determine the extent of damage is the maximum ground acceleration (PGA). PGA measures the intensity of ground motion at a given location during an earthquake, and the higher the PGA value, the greater the potential damage that can occur to building structures.[4]

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The ground motion attenuation equation is a mathematical equation used to estimate how much ground motion will decrease with increasing distance from the earthquake source during an earthquake. This equation is based on the earthquake magnitude and various other factors, such as earthquake depth and ground conditions, to provide an estimate of the intensity of shaking that will be felt at various ground conditions in the area.[5] This equation is a model developed based on the analysis of seismic data from various earthquakes and is used to predict ground motion at a certain distance from the earthquake source. Using historical data and earthquake characteristics, the model helps estimate the intensity of vibration at different locations, thus becoming an important tool in disaster mitigation planning and earthquake-resistant building design.

The GMPE (Ground Motion Prediction Equation) developed by Zhao et al,[8] is designed to be applied to earthquake sources located in subduction areas. In this study, the empirical formulation of the GMPE will be further analyzed by taking into account various seismic parameters specific to the North Sumatra region. The aim is to adjust and validate the model to more accurately predict ground motion in the region, which has unique seismic characteristics due to its proximity to an active subduction zone. Research related to earthquakes in the North Sumatra region has been conducted by Amiroh, et al on Peak Ground Acceleration Analysis of the North Sumatra Region Using the MC Method. GUIRE R.K Method and Campbell Method.[6] But it still uses formulations derived from areas that are not in accordance with the character or condition of seismicity in the North Sumatra region so that in this case it is necessary to determine the empirical formulation in the North Sumatra region based on earthquake data in the North Sumatra region using regression analysis.

Methods

The research site chosen to determine earthquake-induced maximum ground acceleration is in the North Sumatra region, with coordinates of 1°-4°N and 98°-100°N. This area covers a significant part of North Sumatra, which is known as one of the regions with high seismic activity, making it important to analyze and understand the maximum ground motion patterns in the region.[7]

The tools and materials used in this research include key hardware and software for data analysis and presentation. The primary hardware is a laptop, which was used for efficient data processing and report writing, allowing researchers to manage and analyze data effectively.

To process Peak Ground Acceleration (PGA) values from earthquake data obtained from BMKG, Microsoft Excel was extensively used for calculations and creating necessary tables and graphs. The study applied the Least Squares method in non-linear regression to identify the most accurate model parameters, minimizing the error between predicted and observed values, which leads to a more precise estimate of PGA.

To present the calculation results and data visualization, this research uses Visual Studio Code version 3.8.5. This software helps in writing and editing the code and in graphing and visualizing the calculation results, which is important for clear and effective interpretation and presentation of the data. This combination of tools and methods ensures that the research can be conducted accurately and with reliable results.

In this study, the empirical formulation of PGA was developed by Zhao et al.[8] In this research, the empirical formulation of Peak Ground Acceleration (PGA) was developed from existing models. The PGA value is determined using parameters such as distance, depth, and earthquake magnitude derived from observations of 1,508 subduction interface earthquakes in Japan. This formulation establishes a maximum interface depth of 50 km, with the parameters and functions detailed in the equations below.

$$log\,(y) = aM + bx - log\,log\,(r_{ij}) + e(h - h_c)\delta_h + F_R + S_1 + S_S + S_{SL} log_s(x) + C_K + \xi_{i,j} + \eta_i \qquad (1)$$

where y is the PGA (gal), M is the moment magnitude, x is the sour distance, h as the depth, F_R as the reverse-fault parameter, S_1 as the parameter for the interface source, S_S as the parameter for intraslab events, S_{SL} as the magnitude-independent path parameter for intraslab events, C_K as the site class coefficient, h_c as the constant depth, and a,b,c,d, dan e are constants.

The primary data utilized in this research consists of earthquake arrival times collected from the Meteorology, Climatology, and Geophysics Agency (BMKG) over the past seven years. This dataset includes information on the arrival times of various earthquakes that occurred in the North Sumatra region. After filtering the catalogue, a total of 5,232 earthquake events were selected for this study. These events were recorded by several earthquake recording stations throughout North Sumatra, which are crucial for gathering accurate seismic data. This data facilitates in-depth analysis of seismic activity patterns and is essential for understanding earthquake behaviour and its impact on maximum ground acceleration in the region studied.[9]

In this study, a comparison was made between the formula developed by Zhao et al.[8] with magnitude and distance parameters to evaluate the accuracy of ground motion prediction in the North Sumatra region.[10] This approach was chosen because the North Sumatra region has significant geological similarities and is located in an active subduction zone, which is similar to the geological conditions used as the basis for the Zhao et al. formula.

This comparison is important to assess if the formula, designed for subduction areas, can be effectively applied in North Sumatra or if special adjustments are needed to reflect local conditions. By comparing the predicted results of the formulation of Zhao et al. with the acquired earthquake data, this study aims to identify whether the formulation can accurately predict the maximum ground acceleration in the region, and provide recommendations for model improvement or modification if necessary. This study only looks for the coefficient of a,b,c,d,e dan S_S dan S_{SL}.

This study also analyzes earthquake distribution using estimates from the empirical formulation of Zhao et al..[8] It employs collected earthquake data to assess how earthquakes are distributed in North Sumatra. By applying this empirical formula, the study aims to predict distribution patterns and evaluate the model's accuracy in reflecting actual seismic conditions in the area.

In this analysis, existing earthquake data will be used to consider the results of earthquake distribution estimates based on the Zhao et al.[8] formula with observed earthquake distribution. This was done to assess the accuracy of the empirical formula in describing earthquake distribution patterns in the North Sumatra region and to find out whether the formula requires adjustments to improve more precise predictions. This approach is expected to provide better insight into the seismic characteristics of the North Sumatra region with modifications to the empirical formula of Zhou et al.[8] The results obtained will increase understanding of how empirical models can be applied in the North Sumatra region if an earthquake occurs.

Result and Discussion

To get accurate results, there are several steps that must be taken to see how close the relationship is for each parameter used in this study.

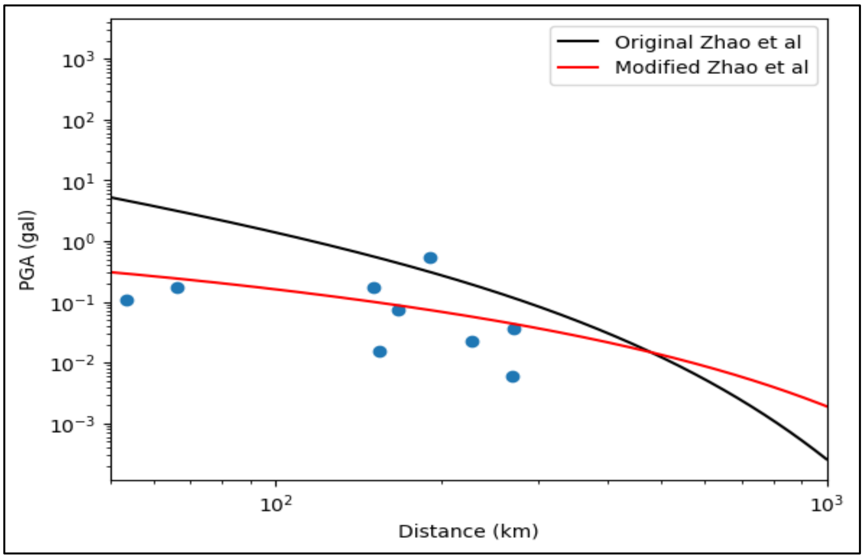

Figure 1. Graph of the Relationship Between Distance and PGA

Relationship between Peak Ground Acceleration (PGA) Values and Distance Parameters in the North Sumatra Region

One key aspect of analyzing the impact of earthquakes is understanding how the distance from the epicentre influences Peak Ground Acceleration (PGA). This distance is crucial in determining the level of ground acceleration experienced at a location following an earthquake. As the distance from the epicentre decreases, the seismic energy released by the earthquake is greater and more directly received by the surrounding ground, resulting in a significant increase in PGA values.

Conversely, as a location moves further from the epicentre, the seismic energy diminishes, leading to lower PGA values. Therefore, it is essential to model and analyze this relationship to predict the effects of earthquakes across various locations accurately. This understanding is useful for academic research and critically important in disaster mitigation planning and the construction of earthquake-resistant infrastructure, thereby reducing the risks and potential losses that may occur due to earthquakes.

Figure 1 shows that the close proximity of an earthquake results in large PGA values being obtained, while small PGA values are obtained at large distances. While the distance from the epicentre of an earthquake is the main factor in determining the PGA, ground surface conditions and local geological structures play an important role in modifying the intensity of vibrations felt at a particular location. Therefore, an in-depth analysis of soil characteristics and surface structures is essential to obtain an accurate picture of earthquake impacts at various locations. To reduce earthquake risk, understanding the relationship between PGA and distance is essential. This information can be used to design more earthquake-resistant buildings, establish evacuation zones, and make safer development policies in earthquake-prone areas.

The Peak Ground Acceleration (PGA) is strongly influenced by the distance from the epicentre.[11] At very close distances from the epicentre, PGA values tend to be very high due to the enormous intensity of seismic energy reaching the site. This is due to the fact that earthquakes release a large amount of seismic energy that is directly received near the source, resulting in strong and significant ground motion.

However, as the distance from the epicentre increases, the PGA value will gradually decrease. This decrease occurs because seismic energy propagates from the earthquake source outwards and undergoes a damping or reduction in intensity as it propagates through the soil medium. During this journey, seismic energy decreases due to absorption by the soil and rock layers it passes through and wider dispersion of the seismic waves. These factors cause ground shaking to be less intense and less pronounced at greater distances from the epicentre.

Overall, the relationship between PGA and distance from the epicentre is inverse, with PGA being high near the source and decreasing significantly with increasing distance, reflecting the important role of seismic energy attenuation in determining the intensity of ground shaking felt at more distant locations.

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Relationship between Depth and Magnitude Parameters of Earthquakes in the North Sumatra Region

In earthquake analysis, it is important to explore the interaction between depth and magnitude, as this relationship affects the behaviour and impact of earthquakes. Earthquakes at greater depths tend to have higher energy and magnitude, but their effects can vary depending on the materials through which seismic waves travel.

Understanding this interaction also helps predict the strength and distance of vibrations felt at the surface. Although deep earthquakes can have large magnitudes, the intensity of vibrations at the surface is often lower compared to shallow earthquakes of similar magnitude due to the reduction of energy as waves pass through more material. Therefore, a comprehensive analysis of this relationship is essential for developing earthquake prediction models and effective disaster mitigation planning.

Based on Figure 2, it can be explained that the seismic of north Sumatera tends to be at a depth of 50 - 150 km with a magnitude of 3 - 4 Mw, and this data includes earthquakes that do not have the potential to cause severe damage, but can be felt by humans, especially in areas near the epicentre. The depth of these medium earthquakes causes seismic wave energy to experience greater dissipation when it reaches the surface, so the effect is not as strong as a shallow earthquake of the same magnitude.

The relationship between the depth parameter and the magnitude parameter generally illustrates that earthquakes that occur at greater depths tend to have greater energy and can produce higher magnitudes.[12] This is because higher pressures and temperatures at greater depths allow for greater accumulation of energy before it is released as an earthquake. Earthquakes that occur at greater depths may propagate through more material before reaching the surface, so the earthquake energy may be dampened more.

Deep earthquakes can be felt more widely because seismic waves can propagate through the earth more efficiently at greater depths. Although deep earthquakes can have large magnitudes, the intensity of vibrations at the earth's surface may be lower compared to a shallow earthquake of the same magnitude due to the damping effect and the greater distance from the hypocenter to the surface.[13]

The value of determination or Adjusted R-squared in this study, which measures the effect of the Distance variable on the Resultant Horizontal PGA (gals) variable, shows a figure of 0.65 or 65%. This indicates that about 65% of the variation in the Resultant Horizontal PGA (gals) value can be significantly explained by the Distance variable. In other words, Distance plays an important role in determining the magnitude of the measured horizontal PGA. However, about 35% of the variation in horizontal PGA cannot be explained by the Distance variable and can be explained by other parameters such as magnitude, depth, longitude, and latitude.

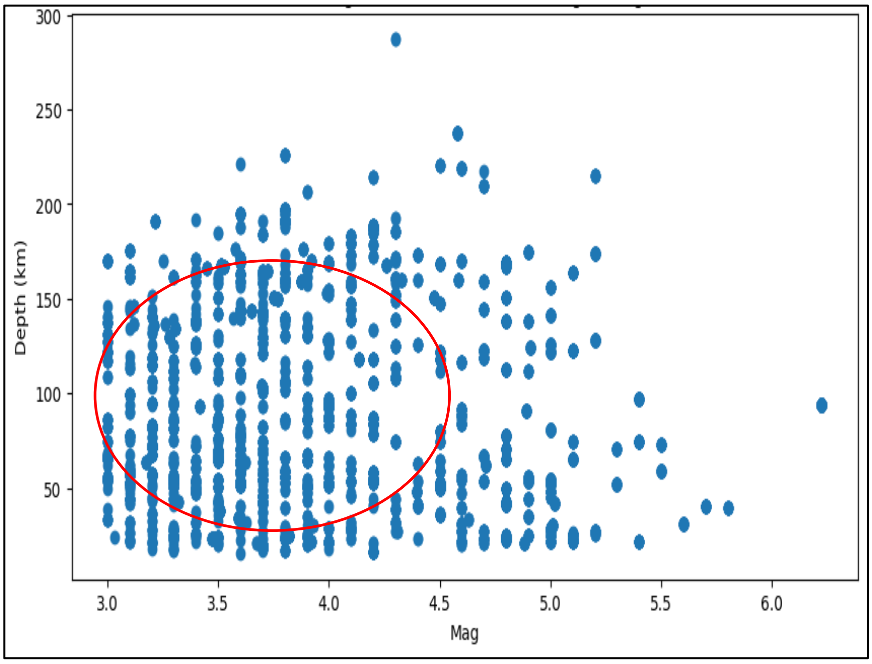

Figure 2. Graph of Relationship between Depth and Magnitude

After processing the data using non-linear regression with the least square method and inputting several parameters such as depth, distance, and magnitude, the coefficients obtained based on the equation of Zhao, et al.[8] obtained a new constant value for earthquake events in the North Sumatra region as follows:

$a = 1,4703$

$b = -0,0025$

$c = 20,7441$

$d = 0,0196$

$e = 0,0015,$

$S_S = -2,0843$

$S_{SL} = -0,0529.$

So the equation obtained for the North Sumatra region is:

$$log\ (y) = 1,4703Mw - 0,0025R_{hypo} - inr + 0,0015(h - 15) - 2,0843 - 0,0529\ In\ R_{hypo} + 20,7441 \quad (2)$$

The equation developed in this study can be used to predict or calculate Peak Ground Acceleration (PGA) values by considering various earthquake parameters.[14] The formula is particularly applicable for earthquake magnitudes between 3 and 6 Mw and covers distances from the epicentre ranging from 50 – 600 km and depths between 50 – 300 km. Using this formula, it is possible to estimate how much PGA is likely to occur based on variations in earthquake magnitude, distance from the epicentre, and depth. This provides a useful tool for seismic risk planning and evaluation and assists in infrastructure design and disaster mitigation.

Figure 3 shows that the residual value in this study means the difference between the actual observed or measured Peak Ground Acceleration (PGA) value and the PGA value predicted by the model used. This residual indicates how accurate and efficient the model is in estimating PGA values based on important parameters such as distance from the epicentre, earthquake depth, and earthquake magnitude.

In the research, the residual value is close to 0. It has a small value, which is close to the model prediction with the actual observed results and shows that the modification of the formulation that the researchers did has a good relationship between the variables.[15]

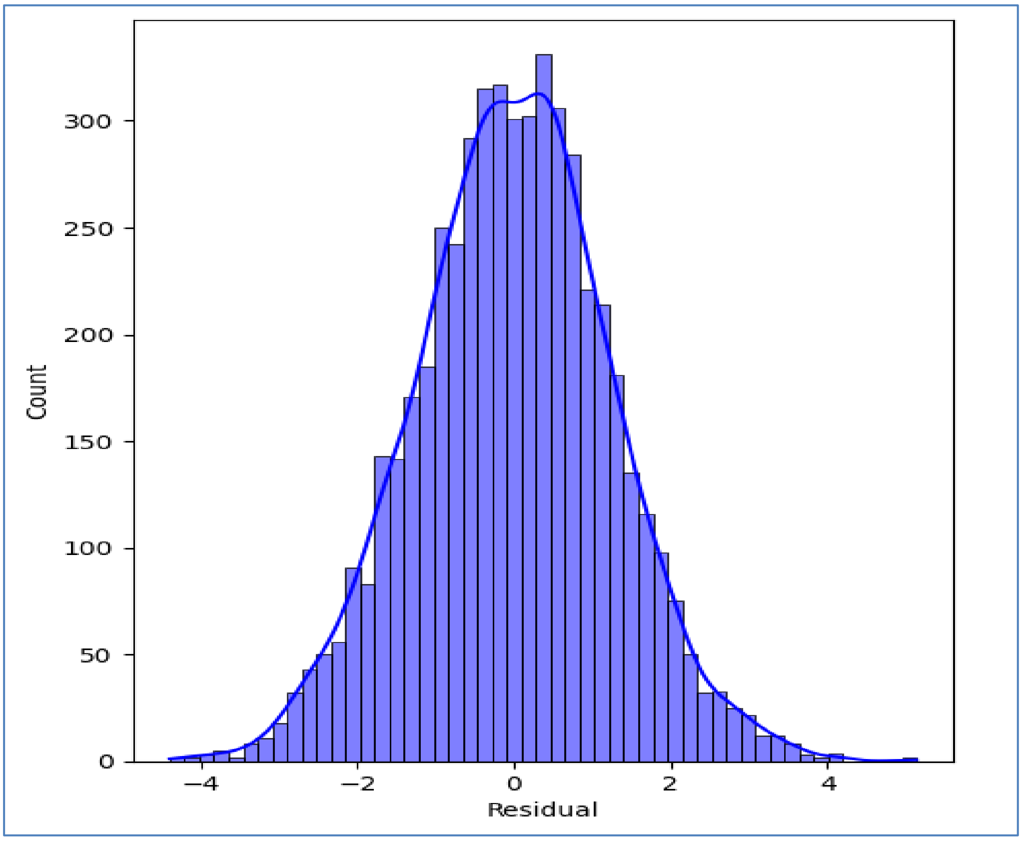

Figure 3. Residual graph of the equation modified with the empirical formula Zhao et al.[8]

Conclusions

Based on the analysis and discussion results, it can be concluded that the relationship for each parameter in the earthquake with a time span of 2017 - 2023 in the North Sumatra region is 65%. This PGA value will increase as the distance increases, and the PGA value will also be greater as the Magnitude value increases. These two parameters are very important in calculating the value of Maximum Ground Acceleration during an earthquake.

Based on the results of research and discussion of depth with Magnitude, it has a value spread between 50 - 150 km with a magnitude of 3 - 4 Mw, and this data includes medium earthquakes that do not have the potential to cause severe damage but can be felt by humans.

Acknowledgement

Thanks to the Seismological Center for Potential Geophysical Engineering and Time Signatures (BMKG), which has allowed researchers to research, explore and analyze relevant seismic data related to the modification of the maximum ground acceleration value attenuation equation in the North Sumatra region.

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