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Research Article

Probability of Earthquake Events and Building Damage Ratios: A Framework for Estimating Earthquake Insurance Premiums in Lampung, Indonesia

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Abstract
Sumatra Island is located in the Pacific Ring of Fire, which has resulted in high seismic activity. Several large earthquakes have been recorded in this region. Earthquake hazards lead to loss of life, damage to building infrastructure, losses in production sectors, and cross-sectoral losses. Hazard mitigation is necessary by calculating earthquake insurance premiums to anticipate disaster risks in earthquake-prone areas. This study aims to estimate the value of earthquake insurance premiums in Lampung Province based on the probability of an earthquake occurring at an intensity (SH_I), defined as seismic hazard intensity, derived from the peak ground acceleration (PGA) and damage ratio calculations. We compiled multivariate data that can reveal periodic earthquake activity patterns, such as detailed information on earthquake activity over the past three decades and building damage data. The analysis results show that the larger the PGA value, the smaller the SH_I value. The average damage ratio for all buildings indicates that the more significant the proportion of severe damage, the higher the average building damage ratio. Residential buildings have the highest estimated pure premium due to the use of simple materials that are highly vulnerable to earthquakes. Understanding these statistical patterns is crucial for comprehensively assessing earthquake disaster threats in the long term. The goal is to enable more effective disaster risk mitigation for frequent earthquake activity in the Lampung Province in the future.

Keywords: building damage, earthquake, estimated insurance premium, probability

1. INTRODUCTION

The determination of building insurance premiums related to earthquake risk is based on various factors that reflect a building's vulnerability to such disasters. The geographic location is a primary consideration; buildings situated in earthquake-prone areas, such as along tectonic plate boundaries or from volcanic activity in regions with a history of frequent quakes [1]-[5], typically face higher premiums [6][7]. Additionally, the structural strength of the building plays a crucial role; those constructed to earthquake-resistant standards generally qualify for lower premiums. The history of earthquakes in the area also influences the premium; the frequency and magnitude of past quakes can increase the perceived risk. The type and usage of the building (such as commercial or industrial versus residential) often require broader coverage, leading to higher premiums for these properties [8][9]. Government Regulation No. 36 of 2005, which governs building permits, includes provisions regarding earthquake-resistant structures. Additionally, Constitution No. 40 of 2014 in Indonesia on insurance covers earthquake-related insurance. These regulations serve as a basis for recognizing that building characteristics are significant in determining insurance premium rates, particularly when the insurance policy includes earthquake coverage for buildings in certain areas. Finally, an insurance history involving previous earthquake damage claims is taken into account; if a building has filed claims in the past, its premium is likely to increase due to the demonstrated risk [6][10][11].

All these factors are carefully assessed by insurance companies to determine a premium that accurately reflects the earthquake risk associated with a particular building. Earthquakes and peak ground acceleration (PGA) are closely related in measuring the strength of ground vibrations produced by seismic activity [12][13]. PGA is defined as the maximum acceleration experienced at the Earth's surface during an earthquake, typically expressed in units of "g" (where 1 g equals 9.8 m/s²). PGA does not measure the duration of an earthquake; instead, it quantifies the maximum

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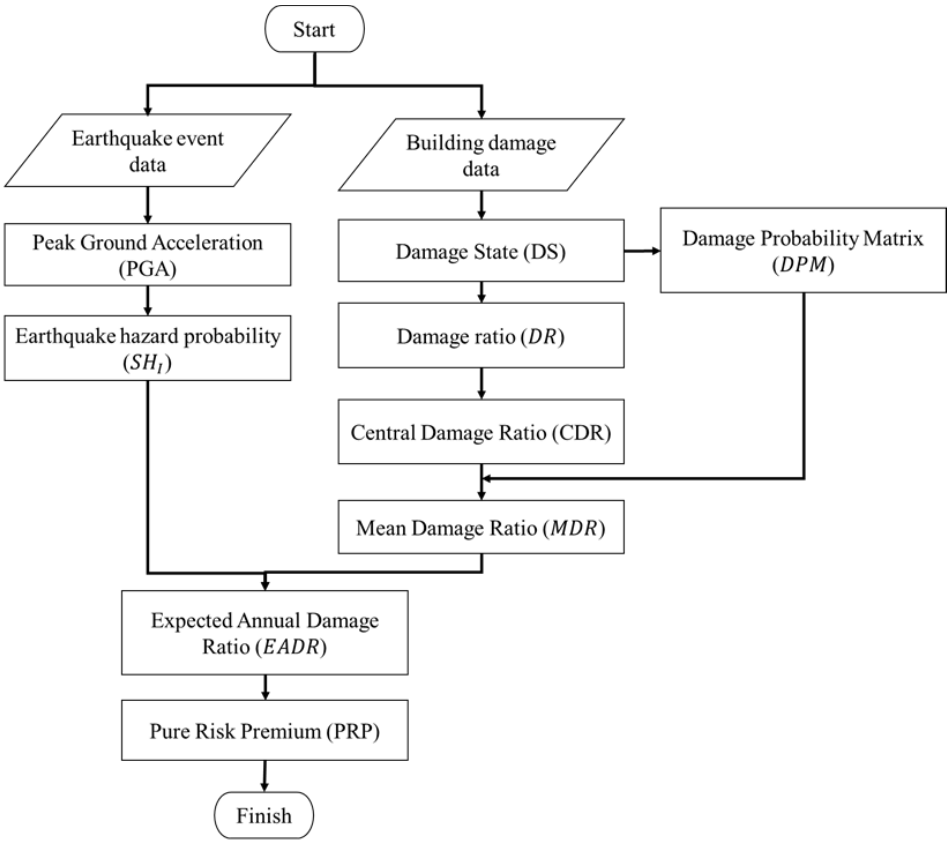

Figure 1. Flowchart of the process to calculate the PRP based on earthquake event data and building damage data.

intensity of vibrations at a specific location, providing an indication of the potential damage to structures in that area [14][15]. The higher the PGA value, the stronger the ground shaking, which increases the risk of structural damage, especially to buildings not designed to earthquake-resistant standards [6]. Civil engineers and urban planners often use PGA to design earthquake-resistant structures, and insurance companies rely on it to assess earthquake risk when setting insurance premiums [6][11]. In the context of earthquakes, alongside magnitude, PGA serves as a critical parameter for understanding the direct impact of ground vibrations. In areas with high PGA values, buildings must be designed to be more robust and incorporate technologies that can mitigate vibrations, reducing the potential for damage.

2. DATA AND METHODS

2.1. The Data Collection

Earthquake data for Lampung Province was obtained from the United States Geological Survey (USGS), comprising a total of 4,048 records from 1960 to 2024. The parameters collected include latitude, longitude, depth, and magnitude. Data on infrastructure damage in South Sumatra, Bengkulu, and Lampung Provinces was sourced from the National Disaster Management Agency (BNPB). This infrastructure includes residential buildings, healthcare facilities, places of worship, and office buildings, categorized by the extent of damage as light, moderate, or severe [6]. Insured value (INSV) is the maximum amount payable by an insurance company in the event of damage or loss to the insured property, as stated in the insurance policy. The INSV is obtained from the Building Component Cost List (DBKB), which provides detailed coverage values for residential, commercial, and industrial properties with varying numbers of floors—specifically, properties with nine floors or fewer, and those with more than nine floors.

2.2. The Methodological Steps

The methodological steps undertaken in this study are illustrated in the flowchart below (see Figure 1). This diagram outlines the structured process, beginning with the collection of earthquake event data and building damage data, and proceeding through a series of calculations—including PGA, earthquake hazard probability (SH_I), and damage ratio estimations—towards the final estimation of the pure risk premium (PRP). Each step is crucial role in quantifying seismic risk and evaluating earthquake insurance premiums.

2.2.1. PGA

The impact of earthquakes, as indicated by PGA, is crucial in determining the extent of damage experienced by buildings and infrastructure. PGA measures the maximum acceleration of ground vibrations during an earthquake, providing insight into the intensity of shaking felt at the surface [16] [17]. Below are the effects of earthquakes categorized by PGA values, i.e., low, medium, high, and very high PGA. At low PGA values, ground vibrations typically do not cause serious damage. People may feel light shaking, but the impact on buildings is minimal. Structures not built to earthquake-resistant standards are unlikely to sustain significant damage. As PGA values increase to medium PGA level, vibrations become more noticeable and can result in light damage to buildings not designed to withstand earthquakes. Minor cracks in walls, damage to plaster, and some interior items may be affected. Older buildings or those that do not meet modern construction standards are at greater risk of more serious damage. At high PGA value, earthquakes can cause significant structural damage, particularly to buildings that are not reinforced for seismic activity. Damage may include cracked or collapsed walls, broken windows, and other structural failures. Infrastructure such as roads, bridges, and underground pipes is also at risk of being compromised. At very high PGA level, the impact of an earthquake can be devastating. Buildings that lack earthquake-resistant design are at risk of collapse, and severe damage can occur to major infrastructure such as bridges and tunnels. Even structures built to earthquake standards may sustain considerable damage. The consequences for people are also more severe, with increased risks of injury or death due to collapsing buildings or infrastructure.

2.2.2. The probability of an Earthquake Occurring at an Intensity (SH_I)

SH_I represents the probability of earthquake occurrence at a given intensity, calculated by determining the annual earthquake occurrence rate (λ) Eq. 1.

$$\lambda = \frac{1}{\text{average incidence per year}} \quad (1)$$

Before calculating the value of SH_I, the initial step is to convert the PGA into earthquake intensity, which is commonly expressed using the modified Mercalli intensity (MMI) scale [14]. Subsequently, the SH_I value is obtained by calculating the average of λ across each MMI level, as shown in the following Equation 2.

$$SH_I = \frac{\sum_{i=1}^{n} \lambda_i}{n} \quad (2)$$

where n is the number of PGAs.

Table 1. Commercial and industrial building construction classes.

Construction Class	Information
Com: *Steel*, *Wood*, RC ≤ 9	Building construction using steel, wood, and reinforced concrete frames with up to 9 floors.
Com: *Steel*, *Wood*, RC > 9	Building construction using steel, wood, and reinforced concrete frames with more than 9 floors.
Com: *Others*	Building construction without using steel, wood, or reinforced concrete frames.

Table 2. Damage ratio and central damage ratio values at different damage states [21].

Damage State (DS)	Damage Ratio (DR) (%)	Central Damage Ratio (CDR) (%)
Light	1–10	5
Moderate	10–50	30
Strong	50–90	70

Table 3. Damage Probability Matrix (DPM).

Damage State (DS)	Center Damage Ratio (%)	Intensity	
		Residental Building Type	Comersial and Industrial Building Type with ≤ 9 and >9 floor
Light	5	$P_{Residental}\,(Light,I)$	$P_{(Comersial\ and\ Industrial\ )}\,(Light,I)$
Moderate	30	$P_{Residental}\,(Moderate,I)$	$P_{(Comersial\ and\ Industrial)}\,(Moderate,I)$
Strong	85	$P_{Residental}\,(Strong,I)$	$P_{(Comersial\ and\ Industrial)}\,(Strong,I)$

2.2.3. Building Type

According to OJK Circular Letter No. 6/ SEOJK.05/2017, buildings are categorized into two types: commercial and industrial buildings, and residential homes. These two types are further classified into various construction classes. For commercial and industrial buildings, the construction classes are divided into three categories (Table 1).

2.2.4. Building Damage

In the Indonesian Government Regulation No. 16 of 2021, Article 66, Paragraph 3, concerning building structures, it is explained that building damage refers to the condition where a building or its components fail to function, caused by factors such as wear and tear, the end of the building's lifespan, human negligence, or natural disasters. Based on the earthquake catalog published by BMKG [18], the level of building damage is divided into three categories: minor damage (RR), moderate damage (RS), and severe damage (RB). Minor damage refers to damage affecting non-structural components of a building, such as roofing, ceilings, floor coverings, and partition walls. This type of damage is typically easy and straightforward to repair. Moderate damage involves partial damage to both non-structural and/ or structural components, such as roof and floor structures. Criteria for moderate damage classification include a building tilt of no more than 1%, structural damage not exceeding 30%, particularly in column and beam joints, and the deformation limits must not surpass allowable thresholds. Severe damage occurs when the majority of the building's components, both structural and non-structural, are compromised. A building is considered severely damaged if structural damage exceeds 30%, requiring replacement and demolition of the affected elements [19].

2.2.5. Damage Ratio

The damage ratio (DR) is defined as the ratio of repair costs for earthquake damage to the replacement cost of the building [20]. A single damage ratio value is assigned to each damage state (DS), referred to as the central damage ratio (CDR). The CDR represents the best estimate of the damage ratio for each damage state. Deniz, A. estimated the damage ratio and central damage ratio values for various damage states [21] (Table 2).

2.2.6. Damage Probability Matrix

The damage probability matrix (DPM) is a popular tool for estimating future losses caused by earthquakes and is widely used to estimate the potential liability of insurance companies [22]. DPM displays the probability distribution of damage to the same type of building with different DS at a specified earthquake intensity (I) [21]. Based on available post-earthquake damage data, DPM can be formulated as follows Eq. 3.

$$P_k(DS, I) = \frac{N(DS, I)}{N(I)} \quad (3)$$

where P_k (DS,I) is the probability of DS observed in the k-th type building when exposed to earthquake intensity I, $N(DS,I)$ is the number of k-th type buildings in DS damaged condition and when exposed to earthquake intensity I, and $N(I)$ is the total number of type k buildings when exposed to earthquake intensity I. The general form of the damage probability matrix (DPM) is presented in Table 3.

The damage distribution corresponding to each intensity level can be expressed by one parameter called the mean damage ratio (MDR). MDR quantifies the expected proportion of damage to a building relative to its total value, given a specific level of ground motion intensity. It is widely used in seismic risk assessment and loss estimation models to relate structural vulnerability with earthquake intensity levels such as MMI, PGA, or spectral acceleration [23][24]. A higher MDR value indicates greater expected damage, and this metric is critical for estimating economic losses and setting insurance premiums for different building types, and is shown in the following Equation 4.

$$MDR_k(I) = \sum_{DS} P_k(DS, I) \times CDR_{DS} \quad (4)$$

where P_k (DS,I) represents the damage status probability, and CDR_{DS} represents the central damage ratio. The combination of seismic hazard and average damage ratio is the sum of the simple multiplication of SH and MDR at different earthquake intensities, as shown in Equation (5), where $EADR_k$ represents the expected annual

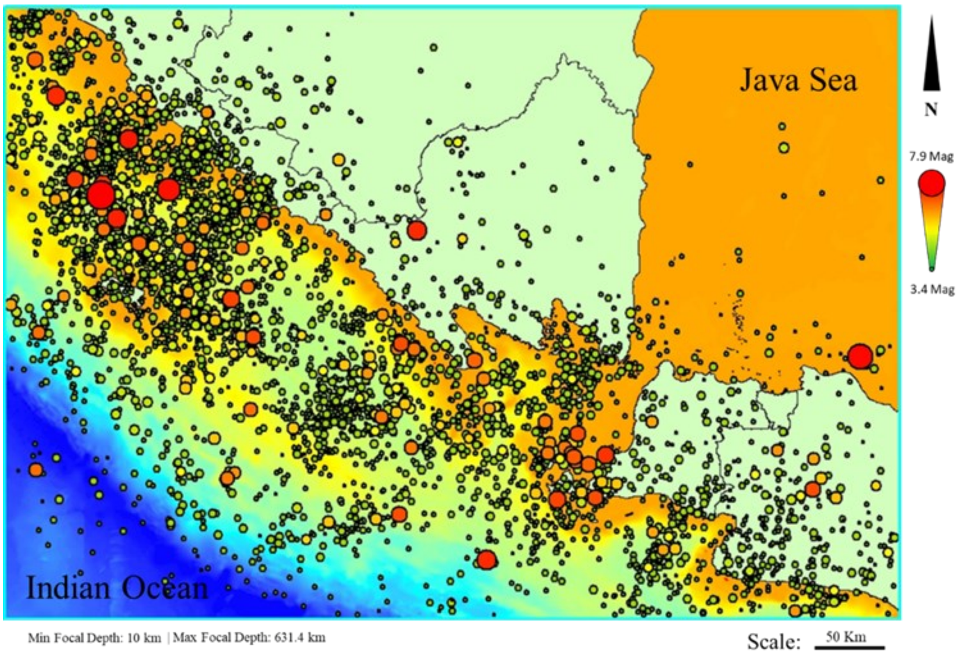

Figure 2. Earthquake epicentre distribution in Java and Lampung regions (1960–2024). The map shows spatial clustering of earthquakes along the southern Java coast, reflecting high seismic activity near the Sunda subduction zone. Circle size and color (green to red) represent earthquake magnitude. High-magnitude events are concentrated offshore in the Indian Ocean, indicating active tectonic interaction. The Java Sea shows relatively low seismicity.

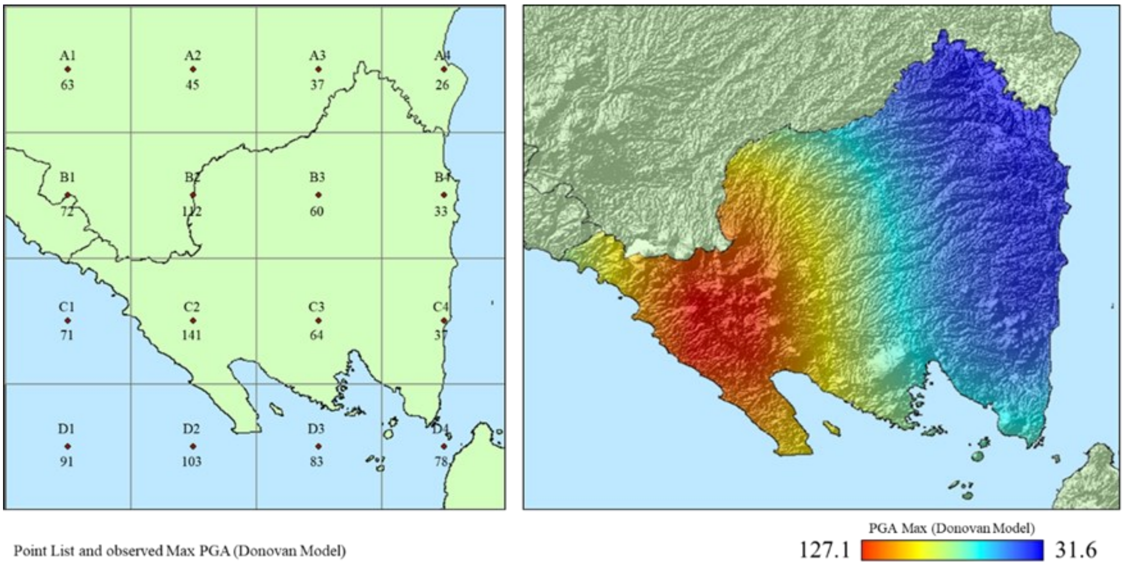

Figure 3. Grid-based division, event distribution, and PGA interpolation in Lampung Province (1960–2024). The left panel shows the spatial grid system with earthquake event counts per block (n = 4048), based on recorded events from 1960 to 2024. The right panel presents interpolated PGA gradients overlaid on topographic variation, where red indicates higher elevation and stronger PGA values, and blue indicates lower elevation and weaker PGA.

damage ratio of building type *k* (Equation 5).

$$EADR_k = \sum_I MDR_k(I) \times SH_I \quad (5)$$

$EADR_k$ describes the insurance rate percentage of the replacement cost of the property unit [21]. Meanwhile, SH_I is the probability of an earthquake occurring, which is obtained from the annual earthquake occurrence rate (λ).

2.2.7. Premium

The price charged by the insurance company to transfer the risk of loss from the insured to the insurer is called the insurance premium. Premiums are the primary source of funds used for the business operations of an insurance company. In each period, insurance companies must determine the appropriate premium amount to charge users of their services. The premium charged must be commensurate with the potential losses that may occur. Therefore, proper risk measurement is essential for determining insurance premiums.

In the insurance and reinsurance industry, specifically in the general insurance industry, the number of claims (claims frequency) and the size of claims (claims severity) from historical claims data in the past are used to determine pure premiums in the future. The pure premium is generally obtained from the aggregate expected loss value, denoted by *E(S)* (Equation 6) [25].

$$E(S) = Claims\ frequency \times Claims\ severity \quad (6)$$

Meanwhile, in earthquake insurance, the PRP of a property can be calculated based on the value of the probability of an earthquake occurring and the building damage ratio, as well as the building insurance value, which is shown through the following Equation 7.

$$PRP_k = EADR_k \times INSV \quad (7)$$

where $EADR_k$ represents the expected annual damage ratio of building type *k*, and INSV represents the insured value of the building.

3. RESULTS AND DISCUSSIONS

The conversion of earthquake magnitude to PGA is not direct, as PGA is influenced by several factors beyond earthquake magnitude. These factors include the distance from the earthquake's source (hypocenter or epicenter), the depth of the earthquake, the soil characteristics at a specific

Table 4. The relationship between the Richter scale, modified Mercalli intensity, and the form of damage represented.

Richter Scale	MMI	Category	Damage Observations
1–2	I	Instrumental	Only recorded on seismographs, almost not felt.
2–3	II	Very Weak	Slightly felt, especially on upper floors of buildings.
3–4	III	Weak	Felt by people indoors, especially on upper floors, like a passing truck.
4	IV	Light	Felt by many indoors, furniture shakes, hanging objects sway, creaking noises heard in buildings.
4–5	V	Moderate	Felt by most people, furniture and unstable objects may fall, like a small truck hitting a building.
5–6	VI	Strong	Felt by everyone, difficult to stand, light structural damage, plaster may crack, some chimneys may break.
6–7	VII	Very Strong	Minor damage to well-built structures, moderate damage to poorly built structures.
6–7	VIII	Severe	Moderate damage to well-built structures, major damage to poorly built structures, buildings may partially collapse.
7–8	IX	Violent	Significant damage to buildings, foundations may shift, some structures may collapse.
7–8	X	Extreme	Most buildings and foundations destroyed, ground is significantly displaced, landslides may occur.
8	XI	Very Extreme	Total destruction, very few buildings left standing, broad ground ruptures.
>8	XII	Extremely Extreme	Total destruction, ground waves visible, objects thrown into the air.

location, and the type of fault that triggered the earthquake. In general, the value of PGA tends to increase with the magnitude of the earthquake, but the distance from the earthquake source also plays a significant role. For example, a high-magnitude earthquake occurring deep below the surface or far from a specific area may result in a lower PGA in that area compared to a smaller earthquake occurring near the surface or closer to that location (Figure 2).

Based on the results of this study, the distance from the epicenter, earthquake depth, and surface geological conditions significantly affects the estimated PGA value. PGA decreases rapidly as the distance from the earthquake's epicenter increases. The farther the distance, the weaker the shaking felt, resulting in a lower PGA value. Shallow earthquakes typically produce higher PGA values at the surface compared to deeper ones. Additionally, soft soil or clay tends to amplify ground shaking, increasing the PGA value, whereas rocky or solid ground absorbs more energy, leading to a lower PGA value. The analysis of PGA values in the observation area refers to the calculations using Donovan's empirical method (Figure 3).

The Donovan empirical method was selected for estimating the PGA in this study because of its established applicability in tectonically active regions with limited strong motion instrumentation, such as Lampung. This method provides a practical balance between data availability and estimation accuracy, relying on readily available earthquake magnitude, depth, and epicentral distance parameters from historical catalogs. Additionally, previous studies in Southeast Asia have demonstrated that Donovan's model produces reasonable PGA estimates in regions with similar geological settings. Its simplicity and compatibility with regional data conditions make it a suitable choice for preliminary hazard assessments and spatial risk modeling in areas where more advanced ground motion prediction equations (GMPEs) may be constrained by data availability.

A more detailed consideration of local soil conditions across Lampung revealed significant implications for PGA distribution and insurance

Table 5. Details of PGA max calculation results (Donovan Method) for MMI ≥ V from recorded data 1960 to 2024.

Earthquakes in Lampung and Surrounding Areas 1960-2024			**Record Span of 64 Years**	
Observation Point	**PGA Max Donovan**	**Earthquake Intensity Frequency**	**Average Occurences per Year**	λ_i
A1	62.84	80	1.3	0.7692
A2	44.52	28	0.4	2.5000
A3	36.68	12	0.2	5.0000
A4	25.74	9	0.1	10.0000
B1	75.27	251	3.9	0.2564
B2	11.69	58	0.9	1.1111
B3	60.21	36	0.6	1.6667
B4	32.54	26	0.4	2.5000
C1	102.76	389	6.1	0.1639
C2	141.23	193	3.0	0.3333
C3	64.41	70	1.1	0.4348
C4	66.17	62	1.0	0.7143
D1	91.17	459	7.1	0.1389
D2	103.77	401	6.3	0.1587
D3	82.56	335	5.2	0.1923
D4	78.22	208	3.3	0.3030

Figure 4. Documentation search results for the 1994 Liwa Earthquake, which occurred in West Lampung (Documentation source: The Associated Press, New York: Friday, 18 February 1994).

risk estimation. Areas dominated by soft alluvial deposits, particularly along coastal and lowland zones such as in South Lampung and parts of Tulang Bawang, tend to experience ground motion amplification due to the low shear strength of unconsolidated sediments. Conversely, regions underlain by volcanic rocks or compacted sedimentary units, such as those in the highland areas of West Lampung and Tanggamus, tend to dampen seismic energy transmission, resulting in lower PGA. Variations in soil composition should be integrated into seismic risk models to enable more accurate premium assessments, particularly in urban areas with dense infrastructure and high exposure to seismic risk. Table 4 shows the relationship between Richter scale, modified Mercalli intensity, and the form of damage represented [26].

Donovan's PGA model, estimates PGA based on earthquake magnitude and distance from the epicenter. This early method helps assess maximum ground acceleration experienced at the surface during an earthquake, which is crucial for earthquake-resistant building design. The model indicates that as magnitude increases, PGA values rise, reflecting stronger ground acceleration, while PGA decreases with increasing distance from the epicenter. The maximum PGA can then be converted to MMI values for assessing recorded building damage [15][27]. Table 5 shows details of PGA max calculation results (Donovan Method) for MMI ≥ V from recorded data 1960 to 2024.

The maximum PGA value that is important for reference includes the recorded event during the Liwa Earthquake in West Lampung on February 15, 1994. The Liwa Earthquake is one of the significant earthquakes that occurred in Indonesia [28][29]. The earthquake had a magnitude of 7.0 and caused significant damage in the city of Liwa and surrounding areas, resulting in substantial casualties and material losses (Figure 4). It occurred along the Semangko Fault, part of the active Sumatra fault system, which often triggers major earthquakes [30][31]. The Liwa earthquake, with a depth of approximately 15–20 km, damaged over 8,000 buildings, including homes, schools, and public facilities. Critical infrastructure such as roads, bridges, and communication systems also suffered severe damage. More than 200 people died, and thousands were injured.

Additionally, the quake triggered landslides in various locations around Liwa, exacerbating the destruction and increasing risks for residents in hilly areas. During the Liwa earthquake in 1994, aftershocks continuously shook the city, leaving thousands homeless and in fear. The city, still reeling from the major quake two days prior, faced smaller quakes on the morning of February 18, worsening the trauma. The previous major quake had killed at least 186 people and injured over 2,300, causing extensive damage to homes, schools, and city infrastructure. Survivors were forced to stay in emergency shelters, grappling with uncertainty and fear of further aftershocks, while rescue and evacuation efforts continued amid widespread debris.

3.1. Building Damage Analysis

From Table 6, it can be observed that the probability values of the damage state (DS) at intensity levels greater than V vary for each type of building due to the differing frequencies of damage associated with each damage status. For residential buildings, the probability of experiencing minor damage is the highest compared to moderate and severe damage statuses. In contrast, for commercial and industrial buildings with ≤ 9 and > 9 floors, the probability values are the same, influenced by the available damage data. The mean damage ratio (MDR) for residential buildings is greater than that for commercial and industrial buildings, both ≤ 9 and > 9 floors, because damage statuses for residential buildings are recorded more frequently than those for commercial and industrial structures. The differences in average damage ratio values in this study arise from varying damage frequencies according to damage status and building type. Data from Table 6 indicate that damage occurs more frequently in residential buildings, suggesting that these structures are more vulnerable to earthquakes compared to others. This vulnerability is attributed to the fact that commercial and industrial buildings are generally designed to higher standards, using stronger materials capable of withstanding heavy loads, along with more advanced structural designs. These buildings often utilize more complex construction systems, such as steel frames, reinforced concrete, or a combination of both, which provide better structural strength than residential buildings.

3.2. Expected Annual Damage Ratio (EADR) Value

In this study, the expected annual damage ratio (EADR) represents the percentage of the earthquake insurance premium rate relative to the replacement cost of the property unit [32], commonly referred to as the premium rate. The EADR can be calculated using the formula provided in Equation (4). Based on the calculation results, Table 6 presents the findings. From Table 7, it can be observed that the premium rate for residential buildings is significantly higher compared to that for commercial and industrial buildings with ≤ 9 and > 9 floors. Additionally, the premium rate for residential buildings is 7,247 times greater than the premium rate for commercial and industrial buildings with fewer than nine floors and more than nine floors. This is attributed to the higher MDR for residential buildings compared to commercial and industrial structures with ≤ 9 and > 9 floors.

3.3. Estimation of the Pure Premium for Earthquake Insurance

The estimation of the pure premium for

Table 6. Damage probability matrix (DPM) and mean damage ratio (MDR).

Damage State (DS)	Central Damage Ratio (CDR) (%)	Intensity Residental Building Type	Intensity Comersial and Industrial Building Type with ≤9 and >9 floor
Light	0.05	0.594470	1
Moderate	0.3	0.003078	0
Strong	0.7	0.402452	0
Mean Damage Ratio **(MDR), (%)**		0.312363	0.05

Table 7. Expected annual damage ratio (EADR).

Building Type	MDR (%)	SH_I	MDR x SH_I	$EADR$(%)
Residential	0.312363		0.5123291	0.594338
Commercial and Industrial ≤ 9 floors	0.05	1.64017	0.0820085	0.082009
Commercial and Industrial > 9 floors	0.05		0.0820085	0.082009

Table 8. Estimated pure premium for residential housing area.

Building Areas (m^2)	Nummber of Floor	INSV (IDR)	EADR (%)	PRP (IDR/m^2)
1–69	1	563,000.00	0.512329	2,884.41
70–99		722,000.00		3,699.02
100–149		703,000.00		3,601.67
150–299		837,000.00		4,288.19
225–299		929,000.00		4,759.54
300–449		1,003,000.00		5,138.66
450–549		1,059,000.00		5,425.56
≥550		1,080,000.00		5,533.15
1–69	2–4	563,000.00	0.512329	2,884.41
70–99		703,000.00		3,601.67
100–149		865,000.00		4,431.65
150–299		1,026,000.00		5,256.50
225–299		1,165,000.00		5,968.63
300–449		1,309,000.00		6,706.39
450–549		1,447,000.00		7,413.40
≥550		1,539,000.00		7,884.74

earthquake insurance involves several key steps. First, the process begins with preparing the coverage value data for buildings. In this study, we utilized the Building Component Cost List (DBKB) from Lampung Province, which serves as a reference for the coverage value of buildings and is considered representative of the real prices of structures. Next, the estimated pure premium for earthquake insurance is calculated. Typically, the premium amount is determined based on the severity of claims and the frequency of claims derived from historical claims data. The estimated PRP can be calculated using the formula outlined in Equation (6), with the results presented in Table 8.

Table 8 presents the estimated pure premium for various types of residential buildings, categorized based on building area and number of floors. The information includes three key parameters: INSV, EADR, and PRP, which reflects the pure insurance premium per square meter. The data is grouped by building size (ranging from 1–69 to ≥ 550 m²) and number of floors (single-story and multi-story buildings with 2 to 4 floors). The results show that as the building area increases, both INSV and PRP tend to rise. For example, a single-story building with an area of ≥ 550 m² has an INSV of IDR. 1,080,000.00 and a PRP of IDR. 5,533.15/m². In comparison, a multi-story building (2–4 floors) of the same size has a higher INSV of IDR. 1,539,000.00 and a PRP of IDR. 7,884.74/m². This indicates that multi-story buildings are associated with higher pure premiums than single-story buildings of similar size, reflecting their greater potential risk and expected losses.

Table 9 shows that as building area and the number of floors increase, both INSV and PRP also tend to rise. For example, for a one-story commercial building with an area of ≥ 550 m², the INSV is IDR. 1,080,000.00 and the PRP is IDR. 885.69/m². In comparison, a commercial building with 2 to 4 floors and the same area has a higher INSV of IDR. 1,280,000.00 and a PRP of IDR. 1,049.71/m². This indicates that multi-story buildings are considered to have a higher potential risk of damage, leading to higher insurance premiums. A similar pattern is observed in the hospital category. INSV and PRP values for hospital buildings are consistently higher than those for other commercial structures. For instance, a hospital building with an area of ≥ 550 m² and 2 to 4 floors has a PRP of IDR. 1,259.65/m², which is significantly higher than that of a comparable commercial building. This suggests that in addition to size and number of floors, the function of a building also influences the premium value, as hospitals are perceived to carry greater risk and asset value. Therefore, this table is crucial in determining risk-based insurance premiums for various types of non-residential buildings.

From the Tables 8 – 10, it can be seen that the estimated pure premium for earthquake insurance varies for each type of building. For residential

Table 9. Pure premium estimates for commercial and industrial building types ≤ 9 floors.

Office, Pharmacy, Shop, Market, Shophouse, Restaurant, Hotel, Guesthouse, Government Buildings				
Building Areas (m^2)	**Nummber of Floor**	**INSV (IDR)**	**EADR (%)**	**PRP (IDR/m^2)**
1–69	1	563,000.00	0.0820085	461.71
70–99		722,000.00		592.10
100–149		703,000.00		576.52
150–299		837,000.00		686.41
225–299		929,000.00		761.86
300–449		1,003,000.00		822.55
450–549		1,059,000.00		868.47
≥550		1,080,000.00		885.69
1–69	2–4	563,000.00	0.0820085	461.71
70–99		703,000.00		576.52
100–149		865,000.00		709.37
150–299		956,000.00		784.00
225–299		1,011,000.00		829.11
300–449		1,107,000.00		907.83
450–549		1,192,000.00		977.54
≥550		1,280,000.00		1,049.71
Hospital				
1–69	1	676,000.00	0.0820085	554.38
70–99		866,000.00		710.19
100–149		844,000.00		692.15
150–299		1,004,000.00		823.37
225–299		1,115,000.00		914.39
300–449		1,204,000.00		987.38
450–549		1,271,000.00		1,042.33
≥550		1,296,000.00		1,062.83
1–69	2–4	676,000.00	0.0820085	554.38
70–99		844,000.00		692.15
100–149		1,038,000.00		851.25
150–299		1,147,000.00		940.64
225–299		1,213,000.00		994.76
300–449		1,328,000.00		1,089.07
450–549		1,430,000.00		1,172.72
≥550		1,536,000.00		1,259.65

Table 10. Estimated pure premium for commercial and industrial building types > 9 floors.

Building Areas (m^2)	Nummber of Floor	INSV (IDR)	EADR (%)	PR-P (IDR/m^2)
Workshop/Warehouse/Agricultural Building Type				
< 10		370,000.00		303.43
10–13		375,000.00		307.53
14–17		387,000.00		317.37
18–21		403,000.00		330.49
22–25	8–10	435,000.00	0.0820085	356.74
26–29		475,000.00		389.54
30–33		533,000.00		437.11
34–37		600,000.00		492.05
> 37		677,000.00		555.20
< 10		462,000.00		378.88
10–13		455,000.00		373.14
14–17		460,000.00		377.24
18–21		469,000.00		384.62
22–25	> 10	492,000.00	0.0820085	403.48
26–29		526,000.00		431.36
30–33		581,000.00		476.47
34–37		648,000.00		531.42
> 37		724,000.00		593.74
Factory				
< 10		481,000.00		394.46
10–13		488,000.00		400.20
14–17		503,000.00		412.50
18–21		524,000.00		429.72
22–25	8–10	566,000.00	0.0820085	464.17
26–29		618,000.00		506.81
30–33		693,000.00		568.32
34–37		780,000.00		639.67
> 37		880,000.00		721.67
< 10		601,000.00		492.87
10–13		592,000.00		485.49
14–17		598,000.00		490.41
18–21		610,000.00		500.25
22–25	> 10	640,000.00	0.0820085	524.85
26–29		684,000.00		560.94
30–33		755,000.00		619.16
34–37		842,000.00		690.51
> 37		941,000.00		771.70

buildings, the estimated pure premium starts from IDR. 2,884.41 to over IDR. 7,884.74 per square meter of building area. In contrast, for commercial and industrial buildings with fewer than nine floors, the estimated pure premium ranges from IDR. 461.70 to over IDR. 1,259.65, while for those with more than nine floors, it starts from IDR. 303.43 to over IDR. 771.70. The differences in the estimated pure premiums identified in this study may be attributed to several factors, such as the uneven distribution of building types in the study area, where residential buildings dominate compared to other types. Furthermore, this study's limitations include the incomplete damage data used in the analysis, which affects the mean damage ratio values and results in less accurate estimates of the pure premium for earthquake insurance, as well as the potential influence of other factors not discussed in this study that may also contribute to the observed differences. Although this study is focused on the Lampung region, the methodology can be adapted for use in other areas. However, several regional factors must be considered. Variations in soil type can significantly affect ground shaking intensity and, therefore, the damage potential of structures. Furthermore, differences in the enforcement and quality of building codes may lead to varying degrees of vulnerability, influencing the damage ratio and corresponding pure premium. Economic factors such as construction costs, local insurance market practices, and public awareness also shape premium estimates. These factors should be integrated into future applications of this model in other regions to ensure accuracy and relevance.

4. CONCLUSIONS

The PGA analysis shows an essential relationship with earthquake risk, as it measures the strength of ground vibrations. Generally, the greater the PGA value, the smaller the probability of an earthquake occurring at a specific SH_I, and vice versa. Consequently, a higher SH_I indicates a greater risk for earthquake insurance premiums, reflecting a higher and more frequent potential for loss that insurance providers must cover. This happens because SH_I considers not only the level of seismic hazard but also the ability of buildings to resist damage. In areas with high PGA, buildings are often designed to be stronger due to stricter building codes, which reduces their vulnerability and lowers the relative risk. As a result, even though the ground shaking is stronger, the SH_I value can be smaller. This demonstrates that SH_I does not solely reflect hazard intensity but also incorporates how well structures are expected to withstand seismic events, making it useful for assessing insurance risk. A similar inverse relationship is observed between PGA and the SH_I value. While PGA represents ground motion intensity, SH_I reflects relative risk by balancing seismic hazard and structural capacity. In regions with higher PGA values, improved building practices and materials often lead to better structural performance, lowering SH_I. Therefore, although the seismic hazard is higher, the SH_I value may be lower due to increased resilience. This highlights SH_I's utility as a composite index for insurance-based risk assessment, integrating hazard and structural vulnerability. Chances of building damage for MMI ≥ V are primarily recorded in the light damage category, with residential buildings showing an intensity value of 0.59447. In contrast, commercial and industrial buildings with fewer than nine floors and those with more than nine floors show intensity values around 1. The estimated pure premium for residential buildings is approximately 6.25 times greater than that for commercial and industrial buildings under nine floors and 7.31 times greater for those with more than nine floors. This is mainly due to the higher frequency of damage reported for residential structures, which typically use simpler materials and have lower resistance to seismic forces. Additionally, commercial and industrial buildings are relatively scarce in the studied area, resulting in fewer recorded damages.

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Conflicts of Interest

The authors declare no conflict of interest.

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DECLARATION OF GENERATIVE AI

The authors declare that no generative AI or AI-assisted technologies were used in the preparation, writing, or editing of this manuscript.

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