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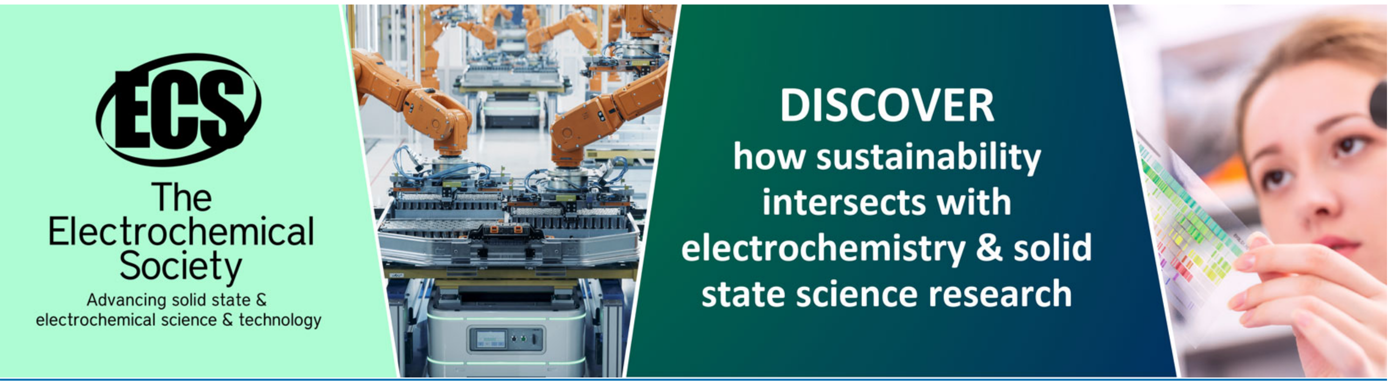

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ASSESSING EARTHQUAKE-INDUCED HOUSING DAMAGE: A FUZZY AHP APPROACH INCORPORATING LOCAL PARAMETERS AND PGA ZONING IN THE BANTUL DISTRICT, INDONESIA

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Abstract. Earthquakes used to cause significant harm, including loss of life and damage to buildings and infrastructure. For example, the 2006 Yogyakarta earthquake in Indonesia resulted in widespread devastation, injuries, and extensive damage. In the past, people relied on Seismic Risk Assessment (SRA) to estimate the chances of earthquake-related damage to buildings and infrastructure and the economic losses involved. SRA used vulnerability functions to understand how susceptible buildings were to earthquake damage. Many places and situations used the Hazard United States (HAZUS) system, which had categories like slight, moderate, extensive, and complete damage, to classify building damage. However, there used to be differences in expert opinions about earthquake vulnerability due to variations in their knowledge and experience. Experts often used words like "very high" or "low irregularity" to express their understanding, and they evaluated these factors using qualitative logic. Different approaches were explored in the past to tackle the complexity and uncertainty in the assessment process, including fuzzy logic. The methodology presented in this paper introduced a framework called Fuzzy Analytic Hierarchy Process (FAHP). This framework aimed to assist decision-makers, engineers, and policymakers in choosing the most appropriate category for assessing earthquake-induced housing damage. Four experts with over twenty years of experience in disaster management, earthquake-affected residential housing, and related fields were involved in the research. The goal was to present a method for estimating the Best Nonfuzzy Performance value (BNP) weight based on differences in Peak Ground Acceleration (PGA) zoning (green, yellow, and red zones) in the Bantul district. The results showed that slight damage had the highest score in the green zone, while complete damage had the lowest score. Similarly, in the yellow zone, slight damage maintained the highest score, while complete damage received the lowest score. Lastly, moderate damage was identified as the most critical in the red zone, and complete damage had the lowest score. These findings had implications for decision-makers, engineers, and policymakers: 1). Decision-makers could use this information to allocate budgets efficiently for safety measures. 2). Engineers were able to focus on strengthening structures in the green zone for slight damage and allocate more resources to address moderate damage in the red zone. 3). Policymakers had the opportunity to tailor disaster response plans based on the predominant damage state in each zone, allowing them to prioritize evacuations and resource deployment accordingly. This paper provides an overview that needs to be developed by researchers in order to improve the results and offer more effective education.

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1. Introduction

Seismic Risk Management (SRM) refers to the strategies and measures put in place to mitigate the impact of earthquakes and their potential consequences. SRM includes earthquake preparedness, response planning, building design and construction standards, and emergency management systems. SRM strategies are developed based on Seismic Risk Assessment (SRA) results to reduce the risk of destruction of facilities, effect on the economy and mortality rate. In SRA, vulnerability played the primary role. Vulnerability is the likelihood that specific assets are at risk, especially buildings and people. Vulnerability functions express the likelihood that assets like buildings and people are at risk in SRA [1].

The vulnerability function can help identify areas that may need more assistance in the aftermath of an earthquake, the allocation of government aid distribution funds is typically based on more specific criteria, such as the level of destruction caused, the amount of people who have been impacted, and the total amount of available resources. As a result, the funds are distributed to those most in need, regardless of their level of vulnerability before the earthquake [2, 3].

Assessing empirical vulnerability functions based on analytic studies can be expensive. It typically involves collecting a large amount of data on past earthquakes and the resulting damage and conducting statistical analysis to develop the vulnerability function. This can require significant resources and expertise and may be challenging in areas with limited resources or infrastructure [2, 3].

On the other hand, using expert judgment to assess empirical vulnerability functions may be less expensive, but it can also result in biased results. This is because expert judgment relies on the knowledge and experience of individuals familiar with structures and local conditions in a given area. However, this can be influenced by personal biases, limited information, or a lack of understanding of the underlying statistical relationships between the intensity measure and damage [4].

The expert judgment technique was one of the first steps in assessing the seismic susceptibility of infrastructure and had some disadvantages. Each house's vulnerability assessment due to earthquake impact has a varied probability degree of damage states, namely slight, moderate, extensive, and complete, the value of which changes depending on various aspects, including geography. Every home's safety is affected by Peak Ground Acceleration (PGA) [5].

The procedure is entirely subjective and based on the expertise and experience of the individuals with little correlation to observed earthquake damage. However, the results may be misleading [6]. The subjective judgment of the expert constantly influences the evaluation and decision-making process. As a result, all of the judgments must be processed statistically.

Because of variances in expert knowledge and experience, the expert's assessment of the possible earthquake vulnerability may differ from that of another expert. The expert's knowledge is reflected in linguistic terms such as very high or low irregularity. Qualitative logic is used to evaluate these specialists. As a result, finding a solution in qualitative reasoning is crucial; complexity and a lack of evaluation cause ambiguity in the assessment process, which can be mitigated by applying diverse strategies, such as fuzzy logic. Fuzzy logic is a mathematical tool that can represent both fuzziness and imprecision. It translates qualitative features into quantitative reasoning, making it useful for linguistic analysis [7, 8].

Using fuzzy logic alone is insufficient to measure expert judgments' consistency. Instead, researchers often turn to the Analytic Hierarchy Process (AHP) for decision-making. AHP breaks down complex problems into smaller, more manageable parts, and decisions are made by considering a hierarchy of criteria. However, a more effective approach is to combine fuzzy logic with AHP, creating what has known as the Fuzzy Analytic Hierarchy Process (FAHP). FAHP method combines the advantages of both approaches and helps address the issues mentioned earlier.One challenge in decision-making is dealing with uncertainty due to tolerance constraints. FAHP means there can be ambiguity in selecting the value scale because it is challenging to identify values or vagueness in certain situations precisely. Fuzzy AHP is a helpful strategy for dealing with this uncertainty, as it helps determine alternative weights and rankings. When look at the comparison matrix used in AHP and Fuzzy AHP, the most noticeable difference is that AHP uses crisp, fixed values [24].

In contrast, Fuzzy AHP uses fuzzy values because the numerical comparisons in the matrix have a range or a degree of difference, reflecting the uncertainty and imprecision present in the decision-making process.The FAHP method effectively identified a suitable supplier and evaluated their performance, as seen in the case study [9]. Several works of literature regarding the latest developments related to FAHP in Indonesia as in research conducted by previous researchers [24,25]

This paper aims to demonstrate the process of analyzing qualitative data on house damage determined by experts into quantitative data using the FAHP method, so that a rating value for the state of damage to houses can be obtained involving several categories in different zoning/locations.

2. Literature Review

2.1. The earthquake had an impact on house damaged

Earthquakes have a devastating impact on human lives, killing thousands of people. It has the potential to destroy buildings, factories, roads, and bridges, displacing a large number of people. In addition, it will result in job and income losses for the country, making the economy unstable. Natural disasters kill approximately 60,000 people worldwide each year. Building collapse is the leading cause of death during earthquakes, especially in poorer nations. Most of these fatalities still occur even though engineering solutions exist to eliminate the danger virtually [1]. S. Abeling et al.[2] found that between 1840 and 2017, the majority (431) of earthquake-related fatalities in New Zealand were caused by damage to buildings, while the remaining (7%) were caused by damage to the ground.

The catalogue of significant and destructive earthquakes includes four significant and destructive earthquakes in Yogyakarta, Indonesia, and more than 100 earthquake data felt from the Station Yogyakarta Geophysics between 1821 and 2009 [3] . Yogyakarta's VII MMI earthquakes cracked the Ambarukmo Hotel's wall in 1943 and 1981. Minor damage was caused on May 25, 2001, by a magnitude 6.3 SR earthquake with a depth of 143 km and an intensity of V MMI in Yogyakarta. The devastating earthquake in Yogyakarta resulted in the largest number of casualties between 1821 to 2009, on May 27, 2006. The earthquake, which measured 5.9 on the Richter scale and had a depth of 33 km, hit Bantul, Klaten, Sleman, and the City of Yogyakarta. Daerah Istimewa Yogyakarta (DIY) and Jawa Tengah provinces were greatly affected by the earthquake in Yogyakarta in 2006. The following were among the casualties caused by the 2006 Yogyakarta earthquake: In addition to the over 5,700 lives lost and the 37,927 injured, over 240,396 homes were destroyed, and regional and national economies were thrown into disarray [4]. Some findings, such as those depicted in Figs. 1 and 2, were discovered based on the research conducted by Wibowo et al.[5]. Damage caused by the earthquake in Jawa Tengah and DIY is depicted on the map in Figure 1. Bantul Regency has three different zones based on Peak Ground Acceleration (PGA), as shown in Fig. 2: 57.7-91 gal (Green Zone), 92-179 gal (Yellow Zone), and >180 gal (Red Zone).

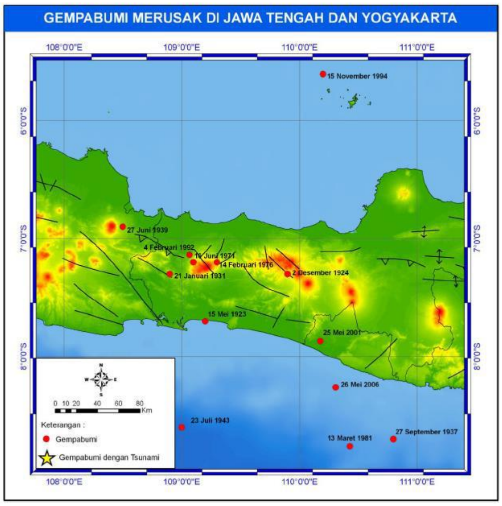

Figure 1. Map of Destructive Earthquakes in Jawa Tengah and DIY Province.

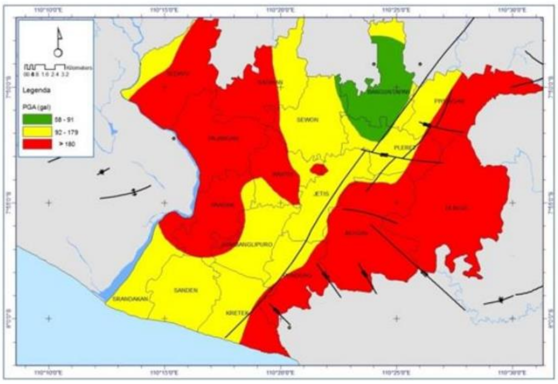

Figure 2. PGA Zone in Bantul.

2.2. Seismic Risk Assessment

Based on potential seismic hazards or scenario earthquakes, Seismic Risk Assessment (SRA) estimates the likelihood of building and infrastructure damage and economic losses. There are typically two (2) distinct steps: analyzing seismic hazards and assessing the vulnerability of structural/assets at risk. As a result, the primary aspect of SRA is structural vulnerability assessment.

Vulnerability functions generally represent the vulnerability of buildings. For example, the seismic vulnerability function is an essential tool for SRA. The vulnerability function can aid in formulating earthquake vulnerability of buildings in terms of various damage levels, ranging from no damage to destruction/complete. Performing a quantitative analysis of the damage and loss data, which may be collected, simulated, or assumed at various levels of ground motion intensities, is essential in developing vulnerability functions for seismic risk assessment. These values may be obtained from previous earthquake observations, expert opinions, analytical or numerical studies, or probability calculations. The expected damage or loss for a specific type of building or infrastructure can be determined based on the magnitude of ground motion using statistical analysis of damage and loss values. This approach provides essential insights for decision-making in earthquake risk management.

2.3. House Damage State

Numerous countries and situations have made use of the HAZUS method. Due to the numerous benefits and advantages of employing local parameters in an algorithm, this is the case [6-12]. However, some improvements need to be made, as suggested by the researchers. For example, according to HAZUS, house damage has four (4) categories: slight, moderate, extensive, and complete. Indonesian local agencies also divide building damage into slight, moderate, extensive, and complete, but what is often used is the category according to the Ministry of Public Works [4, 13-15].

2.4. Fuzzy Analytical Hierarchy Process (FAHP)

Incorporating fuzzy set theory and utilizing findings from practical applications in the literature [3, 17-26] is a widely used approach for developing decision-making frameworks that can account for uncertainty and imprecision. The use of fuzzy set theory has been demonstrated to have significant advantages in dealing with unquantifiable or qualitative criteria, leading to highly reliable results. Therefore, four (4) experts are involved in this research with the background of academics, researchers, contractors, consultants, and government stakeholders, with the criteria of having more than twenty years of experience, being frequently involved in disaster management and being frequently involved in efforts to deal with residential houses affected by the earthquake.

Using the FAHP, the value of the probability of damage to each zoning will be calculated. With this assessment, it is hoped that when an earthquake occurs in the Bantul area, the level of damage to buildings can be predicted.

3. Methodology

Based on Figure 2, it is found that the zoning of Bantul is divided into three (3), namely red, green, and yellow. Therefore, the experts (academics, researchers, contractors, consultants, and government stakeholders) were asked to assess how different the four (4) values of the level of house damage were (slight, moderate, extensive, and complete) in three (3) different zones (red, yellow, and green). After collecting qualitative damage data, the data is converted into quantitative data using the Fuzzy AHP method. The following steps comprise the procedure [16]:

3.1. Establish Hierarchy Structure of Research

Flowchart Analytical Hierarchy Process as shown in Figure 3.

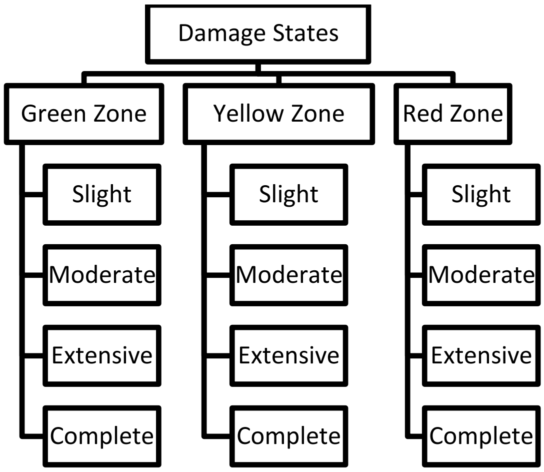

Figure 3. Flowchart Analytic Hierarchy Process.

3.2. Fuzzy Number

Uncertainty expressed through fuzzy numbers can stand in for approximate data. Confidence intervals can be calculated with these numbers, which are a special class of reals. A triangular fuzzy number (TFN) is a type of fuzzy number with the characteristics described in [17–19].
A fuzzy number Ã in three (3) is TFN when its membership function μÃ (x): 3 → [0,1] is Equation 1.

$$\mu_{\tilde{A}}(x) = \begin{cases} (x-L)/(M-L), & L \leq x \leq M, \\ (U-x)/(U-M), & M \leq x \leq U, \\ 0 & otherwise, \end{cases} \tag{1}$$

Where: L and U are the Lower and Upper bounds of the fuzzy number Ã, whereas M is the Middle value as seen in Figure 4, TFN can be denoted by Ã = (L, M, U), and the following is the operation law of two (2) TFN Ã1 = (L1, M1, U1) and Ã2 = (L2, M2, U2).

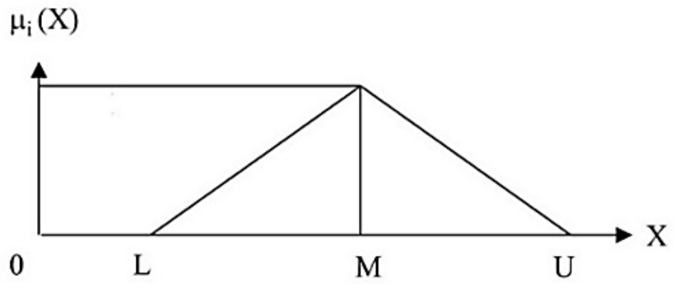

Figure 4. Triangular Fuzzy Number (TFN)

Equations 2 to 6 represent the basic fuzzy operations.

1. Fuzzy-number addition ⊕

$$\tilde{A}_1 \oplus \tilde{A}_2 = (L_1, M_1, U_1) \oplus (L_2, M_2, U_2) \quad (2)$$

2. Fuzzy-number multiplication ⊗

$$\tilde{A}_1 \otimes \tilde{A}_2 = (L_1, M_1, U_1) \otimes (L_2, M_2, U_2) = (L_1 L_2, M_1 M_2, U_1 U_2) \quad (3)$$

For Li > 0, Mi > 0, Ui > 0

3. Fuzzy-number subtraction Θ

$$\tilde{A}_1 \Theta \tilde{A}_2 = (L_1, M_1, U_1) \Theta (L_2, M_2, U_2) = (L_1 - L_2, M_1 - M_2, U_1 - U_2) \quad (4)$$

4. Fuzzy-number division ∅

$\tilde{A}_1 \varnothing \tilde{A}_2$= (L1, M1, U1) ∅ (L2, M2, U2) = (L1 / U2, M1 / M2. U1 / L2) (5)

For Li > 0, Mi > 0, Ui > 0

5. Fuzzy-number inversion/reciprocity (-1)

$$\tilde{A}_1^{-1} = (L_1, M_1, U_1)^{-1} = (1/L_1, 1/M_1, 1/U_1) \quad (6)$$

For Li > 0, Mi > 0, Ui > 0

Where ⊕⊗ Θ∅ are basic fuzzy operators that have been addressed in most fuzzy mathematics books, i.e. [16-18, 20].

3.3. Linguistic Variables

A linguistic variable has a value of words or sentences in natural or artificial language [21]. In this case, compare two (2) criteria using five (5) basic linguistic definitions: Equally Important (Eq), Weakly Important (Wk), Essential Important (Es), Very Strongly Important (Vs), and Absolutely Important (Ab), which refer to five levels of fuzzy scale. Table 1 shows that the computing technology is based on the fuzzy numbers defined by Don-Lin Mon (1994). In order to define the membership function for each fuzzy number scale, it is necessary to use three (3) symmetrical parameters: L and U represent the Lower and Upper bounds, respectively, and M is the Middle-value within the interval where the linguistic variable is applied. This approach allows for examining evaluators' and experts' linguistic priorities, as demonstrated in Figure 5.

Table 1. Membership Function of Linguistic Scale.

Fuzzy Number	Linguistic Scale	Fuzzy Numbers Scale
$\tilde{1}$	Equally Important (Eq)	(1, 1, 3)
$\tilde{3}$	Weakly Important (Wk)	(1, 3, 5)
$\tilde{5}$	Essential Important (Es)	(3, 5, 7)
$\tilde{7}$	Very Strongly Important (Vs)	(5, 7, 9)
$\tilde{9}$	Absolutely Important (Ab)	(7, 9, 9)

Source: [16, 22]

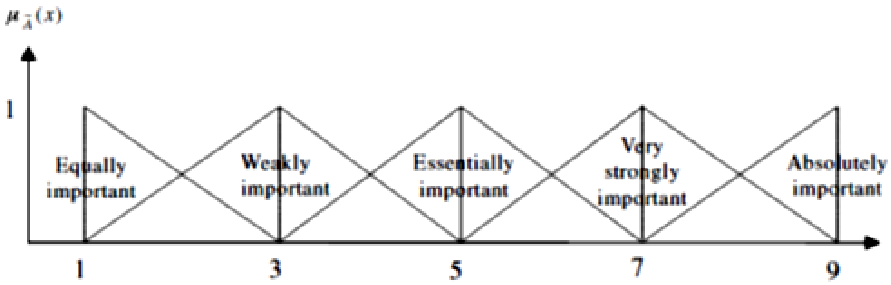

Figure 5. Triangular Fuzzy Number (TFN)

Source: [16, 22]

The following procedure can be used to explain the weight of the evaluation criteria using Fuzzy:

3.4. Calculating the AHP Consistency Value for each Expert

Construct a pairwise comparison matrix among all the elements/criteria in the dimensions of the hierarchy system. Assign linguistic definitions to the pairwise comparisons by asking which is the more important of every two (2) elements/criteria, as in as Equation 7 to Equation 12

$$\tilde{A} = \begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/\tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & 1 \end{bmatrix}$$

$$\tilde{A} = \begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ 1/\tilde{a}_{21} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/\tilde{a}_{1n} & 1/\tilde{a}_{n2} & \cdots & 1 \end{bmatrix} \tag{7}$$

There are:

$$\tilde{a}_{ij} = \begin{cases} \tilde{1}, \tilde{3}, \tilde{5}, \tilde{7}, \tilde{9} & criterion\ i\ is\ relatif\ importance\ to\ criterion\ j, \\ 1 & i = j \\ \tilde{1}^{-1}, \tilde{3}^{-1}, \tilde{5}^{-1}, \tilde{7}^{-1}, \tilde{9}^{-1} & criterion\ i\ is\ relatif\ less\ importance\ to\ criterion\ j \end{cases}$$

3.4.1. Adding each column to a pairwise comparison matrix/the number of matrix columns in pairs (Σj)

3.4.2. Calculate the Normalized Relative Weight (NRW) in each matrix value

Calculate NRW refers to Equation 8.

$$NRW = \sum \tilde{a}_{ij} / \sum j \quad (8)$$

3.4.3. Normalized Principal Eigenvector (NPE)
Calculate NPE refers to Equation 9.

$$NPEi = NRW\ average\ on\ each\ line \quad (9)$$

3.4.4. Consistency Index (CI)
Saaty [23] has proved that the consistency index of the matrix can be obtained by the formula, which has Equation 10.

$$\frac{\lambda\, max\, imum - n}{n-1} \quad (10)$$

Where is: λ maximum is the most eigenvalue from the matrix with ordo n.
The largest eigenvalue is by summing the results of the column multiplication with the primary eigenvector. Alternatively, it can be written in the following Equation 11.

$$\lambda\, max\, i\, mum = \sum(\Sigma_j \times NPE_i) \quad (11)$$

Where is: NPEi is Normalized Principal Eigenvector/Fuzzy comparison value i.

3.4.5. Consistency Ratio (CR)
CR compares the Consistency Index (CI) with the random generator value/Ratio Index (RI), as calculated by Equation 12.

$$CR = \frac{CI}{RI} \quad (12)$$

In Equation 12, the CR should be less than 0.1 (10%), indicating that the consistency of the pairwise comparison matrix is acceptable [23]. Table 2. shows how Saaty [23] calculated the RI value as a function of Matrix Order (n) from one (1) to fifteen (15).

Table 2. Saaty Random Index.

Order	**1, 2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
RI	**0.00**	**0.52**	**0.89**	**1.11**	**1.25**	**1.35**	**1.40**	**1.45**	**1.49**	**1.52**	**1.54**	**1.56**	**1.58**	**1.59**

3.5. Define the Fuzzy Geometric Mean and Fuzzy Weights of each Criterion using a Geometric Mean Technique
To obtain fuzzy weight (w ̃_i), using Equation 13 to Equation 15 [24].

$$\tilde{a}_{1j} = (\tilde{a}^1{}_{1j} \otimes \tilde{a}^2{}_{1j} \otimes \tilde{a}^3{}_{1j} \otimes \tilde{a}^4{}_{1j})^{1/4} \quad (13)$$

$$\tilde{r}_i = (\tilde{a}_{i1} \otimes \tilde{a}_{i2} \otimes \ldots \otimes \tilde{a}_{in})^{\frac{1}{n}} \quad (14)$$

$$\widetilde{w}_i = \tilde{r}_i \otimes (\tilde{r}_1 \oplus \ldots \oplus \tilde{r}_n)^{-1} \quad (15)$$

Where: a ̃_in Is fuzzy comparison value of criterion I to criterion n, thus, r ̃_1 is the geometric mean of the fuzzy comparison value of criterion i to each criterion, w ̃_i is the fuzzy weight of each criterion, which a TFN can indicate, w ̃_i=Lw ̃_i; Mw ̃_i ; Uw ̃_i. Here Lw ̃_i, Mw ̃_i and Uw ̃_i, stand for the lower, middle, and upper values of the fuzzy weight of each criterion.

3.6. BNP Value of the Weight of Building

Using the COA method, the BNP value of the fuzzy weights of each dimension can be calculated through the following process, which is described in Equation 16.

$$BNP\widetilde{w}_i = \frac{\left[\left(U_{\widetilde{w}_i} - L_{\widetilde{w}_i}\right) + \left(M_{\widetilde{w}_i} - L_{\widetilde{w}_i}\right)\right]}{3} + L_{\widetilde{w}_i} \tag{16}$$

4. Result and Discussion

4.1. Matrix Pairwise Comparison Sample

As a sample of the matrix assessment from academics in the green zone, as shown in Table 3.

Table 3. Matrix Pairwise Comparison for Green Zone.

Damage States	Slight	Moderate	Extensive	Complete
Slight	1.00	3.00	5.00	7.00
Moderate	0.33	1.00	3.00	5.00
Complete	0.20	0.33	1.00	3.00
Extensive	0.14	0.20	0.33	1.00
Total (Σj)	1.68	4.53	9.33	16.00

4.2. NRW and NPE Sample

Calculate the Normalized Principal Eigenvector (NPE) using Equation 8 and Equation 9 in each matrix value from Academic in the green zone, as shown in Table 4.

Table 4. NRW and NPE for Green Zone from Academic.

Damage States	Slight	Moderate	Extensive	Complete	NPE
Slight	0.60	0.66	0.54	0.44	0.56
Moderate	0.20	0.22	0.32	0.31	0.26
Complete	0.12	0.07	0.11	0.19	0.12
Extensive	0.09	0.04	0.04	0.06	0.06

From the calculation of Equation 11, given $\lambda\_max = 4.1767$. From the calculation of Equation 10 given CI = 0.0589. From the calculation of Equation 12, given CR = 0.0662 < 0.1(10%), so it is still considered acceptable.

4.3. Triangular Fuzzy Numbers (TFN) Matrix

After obtaining a consistency value of 10% and determining that the results are acceptable, enter the TFN value in Table I into the matrix shown in Table 5.

Table 5. TFN Matrix for Green Zone from Academic.

Damage States	Slight			Moderate			Extensive			Complete		
Slight	1.00	1.00	3.00	1.00	3.00	5.00	3.00	5.00	7.00	5.00	7.00	9.00
Moderate	0.20	0.33	1.00	1.00	1.00	3.00	1.00	3.00	5.00	3.00	5.00	7.00
Complete	0.14	0.20	0.33	0.20	0.33	1.00	1.00	1.00	3.00	1.00	3.00	5.00
Extensive	0.11	0.14	0.20	0.14	0.20	0.33	0.20	0.33	1.00	1.00	1.00	3.00

After obtaining the value of the TFN Matrix, the following procedure for determining BNP weight is to use FAHP, which can be summarized as follows:

4.4. Synthetic Pair Wise Comparison Matrix ($\tilde{a}$1j)

Synthetic Pair Wise Comparison ($\tilde{a}$1j) Matrix, obtained from the joint assessment of all experts, using Equation 13, as all comparisons, shown in Table 6.

Table 6. Synthetic Pairwise Comparison ($\tilde{a}$1j) Matrix.

Damage States	Slight			Moderate			Extensive			Complete		
Slight	1.00	1.00	3.00	1.00	2.28	3.87	2.28	4.40	6.44	3.34	5.66	7.77
Moderate	0.45	0.44	1.73	1.00	1.00	3.00	1.00	3.00	5.00	1.73	4.40	5.92
Complete	0.16	0.23	0.44	0.20	0.33	1.00	1.00	1.00	3.00	1.00	2.28	4.40
Extensive	0.13	0.18	0.30	0.17	0.23	0.58	0.30	0.44	1.32	1.00	1.00	3.00

Table 6. represents a pairwise comparison matrix for different levels of damage states. The numbers in Table 6 show how much one damage state is compared to another in terms of its importance or impact.

4.5. Mean of Fuzzy Comparison ($\tilde{r}$i)

The geometric mean of the fuzzy comparison values of criterion i to each criterion can be calculated using Equation 14 and denoted as $\tilde{r}$i. The calculated result is presented in Table 7.

Table 7. Mean of Fuzzy Comparison ($\tilde{r}_i$) Matrix.

$\tilde{r}_1$	L_{ri}	M_{ri}	U_{ri}
Slight	1.6616	2.7454	4.9095
Moderate	0.9381	1.5513	3.5210
Extensive	0.4199	0.6446	1.5513
Complete	0.2840	0.3642	0.9087

Table 7 mean values help quantify each damage state's relative importance or preference for the reference levels, providing a clearer picture of how each state relates to the specified criteria or standards.

4.6. Fuzzy Weight ($\tilde{w}$i)

The calculation of the fuzzy weight of each criterion can be determined using the formula presented in Equation 15 and denoted as $\tilde{w}$i. The result is shown in Table 8.

Table 8. Fuzzy Weight ($\tilde{w}$i) Matrix.

$\tilde{w}_i$	L_{wi}	M_{wi}	U_{wi}
Slight	0.1526	0.5175	1.4861
Moderate	0.0861	0.2924	1.0658
Extensive	0.0386	0.1215	0.4696
Complete	0.0261	0.0687	0.2751

In decision-making, these fuzzy weights in Table 8 help determine the significance or influence of each damage state when considering the specified criteria or reference levels. Fuzzy weights reflect each state's degree of preference or importance and reference level combination.

4.7. Best Nonfuzzy Performance (BNP) of Weight

The BNP value of the weight of the Green Zone for Damage States can be determined by applying Equation 16, as demonstrated in Table 9.

Table 9. BNP of Green Zone for Damage States.

Damage States	BNP
Slight	0.7187
Moderate	0.4815
Extensive	0.2099
Complete	0.1233

BNP scores in Table 9 can be used to help prioritize or make decisions regarding different damage states, with higher scores indicating greater importance or benefit.

4.8. Ranking of Weight

Based on Table 9, as in the green zone, it can be seen that the highest weight is the category of slight damage, and the lowest weight is complete. The results of the ranking calculation of all zones (green, yellow, and red) can be seen in Table 10.

Table 10. BNP of Green Zone for Damage States.

Damage States	Green Zone	Yellow Zone	Red Zone
Slight	0.7187	0.7111	0.4308
Moderate	0.4815	0.5299	0.5109
Extensive	0.2099	0.2562	0.3652
Complete	0.1233	0.1504	0.1979

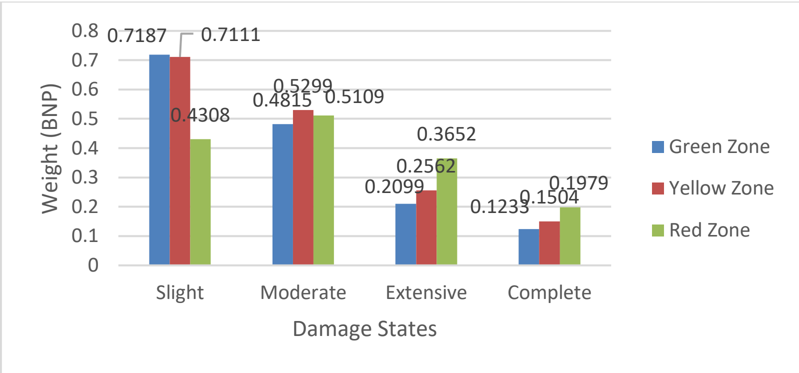

Figure 6. BNP of three (3) Differences Zone.

Table 10 and Figure 6 BNP scores represent each damage state's relative importance or priority within a specific zone. The BNP scores are typically calculated based on criteria and decision-making considerations relevant to each zone.

In the green zone, the highest BNP score is for slight damage, with a score of 0.7187, and complete damage has the lowest score of 0.1233 in the Green Zone. In the yellow zone, slight damage still holds the highest BNP score, although it slightly decreases to 0.7111, while complete damage has the lowest score of 0.1504. In the red zone, moderate damage has a score of 0.5109, making it the most critical damage state in the Red Zone, and complete damage has the lowest score of 0.1979 in the Red Zone.

4.9. Discussion

Table 10 and Figure 6 provide valuable insights into the level of risk and potential damage that can occur in the various zones. In addition, the data's graphical representation highlights trends visually appealingly, making it easier to interpret and understand the findings.

This paper provides valuable insight into the level of risk and potential damage that can occur in different zones. The data's graphical representation highlights trends visually appealingly, making interpreting and understanding the findings easier. The discussion from this paper could have significant implications for decision-makers, engineers, and policymakers responsible for ensuring the safety of structures and people in different zones. There are: 1). Decision-makers can allocate budgets efficiently by considering the prioritized damage states, ensuring that funds are directed toward the most impactful safety measures. 2). Engineers can focus on strengthening or retrofitting structures in the green zone primarily for slight damage resistance, while allocating more extensive resources in the red zone to address moderate damage, where it's most critical. 3) Policymakers Policymakers can tailor disaster response plans to prioritize evacuations, resource deployment, and emergency services based on the predominant damage state within each zone. This paper provides an overview that needs to be developed by researchers in order to improve the results and offer more effective education.

5. Conclusion

This paper introduces an estimation method for calculating the weight (BNP) based on differences in PGA zoning in the Bantul district. The estimated weight is then utilized to propose a new system and criteria for accepting or rejecting the matrix, based on inconsistencies identified in the Analytical Hierarchy Process (AHP). This process may be time-consuming due to potential inconsistencies among assessment experts. In cases where the consistency value exceeds 0.1, it is crucial to conduct a competency test again for the expert before proceeding to the next stage.

This paper applies the Fuzzy Analytic Hierarchy Process (FAHP) to establish the weights of decision criteria for each relative interest group to cope with qualitative features in subjective assessment. This paper demonstrates that a systematic Fuzzy AHP offers a meaningful approach to effectively and efficiently aggregate important information across multiple regions. This paper's ability to align, scale, and aggregate qualitative and quantitative risk information, even in uncertainty, is a significant advantage.
The prioritization of damage states within different zones based on BNP scores provides a clear roadmap for decision-makers, engineers, and policymakers:

1. Helps allocate resources effectively, focusing efforts where they matter most.

2. Guides safety measures, structural upgrades, and emergency response plans based on the specific risks in each zone.

3. Tailoring actions to the prioritized damage states can enhance safety, reduce costs, and improve overall disaster resilience.

In conclusion, these findings underscore prioritizing vulnerability and resilience when planning long-term seismic risk assessment programs.

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