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# The application of Seismic Coefficients in simple earthquake-resistant houses

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## Abstracts

After an earthquake, reconstruction and rehabilitation are often carried out. One of them is by building a simple house. A simple house is the one built without involving construction experts, and hence it rarely follows earthquake-resistant building regulations. This study aims to determine and apply seismic coefficient in the planning of earthquake-resistant, simple houses. The seismic coefficient calculation is applied by comparing the maximum ground acceleration with gravity in cities in three provinces, namely Banten, DKI Jakarta, and West Java. From the calculation results in 21 cities in 3 provinces, the obtained seismic coefficient ranges from 0.175 to 0.411. The smallest seismic coefficient occurs in Indramayu, while the largest seismic coefficient occurs in Sukabumi. Based on the seismic coefficient, the level of earthquake risk for simple house buildings can be known. The lowest risk level occurs in Indramayu with the value of 17.5% and the highest risk level is in Sukabumi with the value of 41.1% of the standard price of a simple house building in each city. The risk level difference from one city to another can be used to strengthen and save the cost of building simple, earthquake-resistant houses.


***Keywords:*** earthquake; maximum ground acceleration; seismic coefficient; earthquake-resistant houses; earthquake risk level

## 1. Introduction

In 2017, there was a large earthquake in West Java, precisely on December 16, 2017 at 23:47:58 with a magnitude of 6.9 Richter scale and a depth of 107 km. The epicenter of the earthquake was 42 km southwest of Kawalu, West Java. Two years later, on August 2, 2019, another large and destructive earthquake occurred with a magnitude of 7.4 Richter scale in Banten Province. The two earthquakes caused casualties, mostly as a result of the collapse of residential buildings [1].

Functionally, buildings must be able to protect its occupants from all possible disasters that affect the buildings [2]. However, in reality many people were injured or died from the rubble of the buildings where they lived in. This happens a lot in regions prone to tectonic earthquakes. Ironically, this building was not built according to earthquake-resistant building regulations. This condition can be seen from the results of observations of collapsed buildings in every major earthquake events [3].

From the history of earthquake resistant building regulation in Indonesia from 1970 to 2019, there are several regulations on the planning of earthquake-resistant buildings [4]. Among them are Indonesian Loading Regulation 1970 [5], Indonesian Loading Regulation for Building 1983 [6], Earthquake-Resistant Building Planning Regulation SNI-03-1726-2002 [7], Procedure of Earthquake-Resistant Building and non Building Planning Regulation SNI-1726-2012 [8], most recently SNI 2847: 2019 [9].

The existing earthquake-resistant building planning regulations have not been fully applied to various types of residential buildings, especially simple residential buildings, which are mostly occupied by middle to lower economic groups [10]. This community group has a large population and is very vulnerable to earthquakes. Therefore, it needs serious attention.

After every earthquake, the government and its staff carry out reconstruction and rehabilitation. The program is carried out to rebuild urban, rural infrastructure, public services, and community welfare. One of them is by building houses for people who do not have a place to live after the disaster because their houses are damaged [10].

In this study, the researchers raise the topic of planning the construction of simple, earthquake-resistant houses based on the seismic coefficient value. Apart from being habitable, such houses are also resistant to earthquake vibrations because periodically earthquakes will occur again at a later date so it is expected that the community will not experience a second loss if an earthquake occurs again in the future [11].

## 2. Experiments Procedure

The research location is indicated by the coordinates of the South Latitude (S) and East Longitude (E) for cities in the Provinces of Banten, DKI Jakarta, and West Java. The cities in Banten Province are Serang (6,11S-106,16E), Pandeglang (6,30S-106,11E), Lebak (6,49S-106,18E), and Tangerang (6,18S-106.64E) [12]. The city of DKI Jakarta Province is Jakarta (6,13S-106,80E), while for West Java Province, it covers Bekasi (6,25S-106,03E), Bogor (6,59S-106,81E), Sukabumi (6,92S-106.93E), Cianjur (6,83S-107,14E), Karawang (6,29S-107,03E), Purwakarta (6,57S-107,45E), Subang (6,57S-107,76E), Bandung (6,91S-107,60E), Sumedang (6,87S-107,82E), Garut (7,22S-107,90E), Indramayu (6,33S-108,32E), Cirebon (6,72S-108.57E), Majalengka (6,83S-108,23E), Kuningan (6,99S-108,48E), Tasikmalaya (7,33S-108,22E), and Ciamis (7,33S-108, 36E) [13]. It shown in Figure 1.

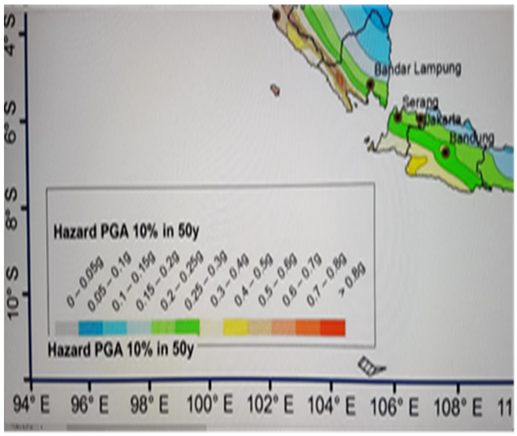


**Figure 1.** Earthquake Risk Map 2017 [4]

To determine the maximum ground acceleration, the coordinates of the locations in these cities are needed. The maximum ground acceleration data for the research location are obtained using the linear interpolation method from the 2017 Probabilistic Seismic Hazard Analysis (PSHA) Map. This linear interpolation method is used to determine the maximum ground acceleration value of cities in the study areas.

The maximum ground acceleration in city A is calculated using the linear interpolation formula [14]:

$$A = y + (b / c)(x - y) \qquad (1)$$

where y and x are the maximum ground accelerations at the lower and upper boundaries of the contour lines. Whereas b is the distance between A and the lower bound, and c is the distance between the lower and upper limit of the contour line.

Earth's gravity for the position of each city is determined by the following formula [15]:

$$Gln = 978.031846\,(1 + 0.5024 \times 10^{-3}\sin 2\theta - 5.8 \times 10^{-6}\sin^2 2\theta) \qquad (2)$$

where θ is the latitude of the place. With this formula, the latitude position of each city is used as a correction so that the gravity value is not the same even though the difference is very small. The gravity value in each city is used to determine the seismic coefficient.

The calculation of the seismic coefficient of cities in the study area was carried out using equation [16]:

$$Ks = \alpha / g \quad (3)$$

where Ks is the seismic coefficient, α of maximum ground acceleration, and g of gravity.

Data processing was carried out to obtain the maximum ground acceleration and seismic coefficient. The seismic coefficient is determined by comparing the maximum ground acceleration with the local gravitational force. The seismic coefficient number serves as a multiplier against the general standard of simple housing costs. The multiplication result is calculated as the difference between the general standard cost of building a simple house and the cost of building an earthquake-resistant, simple house.

The cost of a simple, earthquake-resistant house is higher than the general standard. The cost difference is used to meet the construction needs of simple, earthquake-resistant houses at the research location. With this higher cost, it can be used to build housing structures that meet the requirements of simple, earthquake-resistant houses compared to general cost standards [17].

## 3. Result and Discussion

The maximum ground acceleration of the research areas which include cities in DKI Jakarta and Banten, West Java is determined based on the PSHA Map for 2017. Because the coordinates of these cities are not exactly on the contour lines of the map, the calculation of the maximum ground acceleration values is done using the linear interpolation method. The results of determining the maximum ground acceleration value in the study areas are presented in the Table 1.

The value of gravity at the research location is a very important parameter because it can be used to determine the value of the earthquake coefficient at that location. Theoretically, the gravity value can be determined using equation (2) by entering the latitude correction for the location of each city. The results of the calculation of the gravity value in the cities in the study areas are presented in the Table 2.

**Table 1.** Maximum ground acceleration of the cities

| No | City | Maximum ground acceleration (gal) |
|---|---|---|
| 1 | Serang | 254.8 |
| 2 | Pandeglang | 274.4 |
| 3 | Lebak | 294.0 |
| 4 | Tangerang | 245.0 |
| 5 | Jakarta | 225.4 |
| 6 | Bekasi | 245.0 |
| 7 | Bogor | 274.4 |
| 8 | Sukabumi | 401.8 |
| 9 | Cianjur | 362.6 |
| 10 | Krawang | 245.0 |
| 11 | Purwakarta | 254.8 |
| 12 | Subang | 254.8 |
| 13 | Bandung | 269.5 |
| 14 | Sumedang | 254.8 |
| 15 | Garut | 274.4 |
| 16 | Indramayu | 171.5 |
| 17 | Cirebon | 205.8 |
| 18 | Majalengka | 225.4 |
| 19 | Kuningan | 225.4 |
| 20 | Tasikmalaya | 269.5 |
| 21 | Ciamis | 269.5 |

**Table 2.** Gravity of the cities

| No | City | Gravity (gal) |
|---|---|---|
| 1 | Serang | 978.0371580133 |
| 2 | Pandeglang | 978.0874920546 |
| 3 | Lebak | 978.0878394393 |
| 4 | Tangerang | 978.0872809817 |
| 5 | Jakarta | 978.0871917636 |
| 6 | Bekasi | 978.0872702253 |
| 7 | Bogor | 978.0380223357 |
| 8 | Sukabumi | 978.0386360084 |
| 9 | Cianjur | 978.0884775156 |
| 10 | Krawang | 978.0874732510 |
| 11 | Purwakarta | 978.0379847851 |
| 12 | Subang | 978.0879847851 |
| 13 | Bandung | 978.0386323478 |
| 14 | Sumedang | 978.0888454140 |
| 15 | Garut | 978.0892551155 |
| 16 | Indramayu | 978.0875484223 |
| 17 | Cirebon | 978.0882663292 |
| 18 | Majalengka | 978.0884775156 |
| 19 | Kuningan | 978.0887920369 |
| 20 | Tasikmalaya | 978.0394820638 |
| 21 | Ciamis | 978.0894820638 |

The seismic coefficient number at the research location is very important to indicate the level of earthquake risk in a place. With this seismic coefficient number, the level of earthquake risk can be distinguished from one place to another. Theoretically, the seismic coefficient number can be determined using equation (3), which is the ratio between the maximum ground acceleration and gravity at the research location. The results of calculating the seismic coefficient of cities in the study areas are presented in the Table 3.

**Table 3.** Seismic coefficient of the cities

| No | City | Seismic Coeficient |
|---|---|---|
| 1 | Serang | 0.261 |
| 2 | Pandeglang | 0.281 |
| 3 | Lebak | 0.301 |
| 4 | Tangerang | 0.251 |
| 5 | Jakarta | 0.230 |
| 6 | Bekasi | 0.251 |
| 7 | Bogor | 0.281 |
| 8 | Sukabumi | 0.411 |
| 9 | Cianjur | 0.371 |
| 10 | Krawang | 0.251 |
| 11 | Purwakarta | 0.261 |
| 12 | Subang | 0.261 |
| 13 | Bandung | 0.276 |
| 14 | Sumedang | 0.261 |
| 15 | Garut | 0.281 |
| 16 | Indramayu | 0.175 |
| 17 | Cirebon | 0.211 |
| 18 | Majalengka | 0.231 |
| 19 | Kuningan | 0.231 |
| 20 | Tasikmalaya | 0.276 |
| 21 | Ciamis | 0.276 |

To determine the maximum ground acceleration in the cities in the study areas, the correct position is required. The position is expressed in latitude longitude coordinates [13]. Latitude longitude coordinates are used to determine the maximum ground acceleration based on the 2017 Probabilistic Seismic Hazard Analysis (PSHA) map [4]. This PSHA map is global in nature with contour lines showing the same maximum ground acceleration values.

Surely one city and another have different positions of latitude longitude coordinates. This difference will give a different maximum ground acceleration value even though the cities are at the same contour line interval on the PSHA map. Based on the position of the latitude and longitude coordinates, the maximum ground acceleration value is more accurate according to the level of earthquake risk.

In previous studies, the earthquake coefficient to determine the maximum ground acceleration was calculated based on an empirical formula with less identified earthquake sources [13]. This will result in an inaccurate interpretation of earthquake risk and lead to an inaccurate determination of the seismic coefficient. The empirical formula that is often used to calculate the maximum ground acceleration is the formula from Mc. Guirre, Donova, Kanai, Kawashumi [18].

In the following years, research on maximum ground acceleration began to use better methods. This method is known as the Probabilistic Seismic Hazard Analysis (PSHA) which considers the characteristics of the earthquake source from both seismicity, fault, and subduction zone. Research on maximum ground acceleration using the PSHA method has been conducted in Bali [19], East Java [20], Bengkulu [21], Java [22], Sumatra [23] and most recently in 2017 PSHA throughout Indonesia. The determination of the maximum ground acceleration in this study is based on the 2017 PSHA map.

The gravity of the research location is very important in calculating the earthquake coefficient. This is because the seismic coefficient is the ratio between the maximum ground acceleration and the earth's gravitational force. In practice, the gravity value between one city and another city that is nearby does not differ much because it is still in a horizontal distance [24].

Theoretically, the calculation of gravity using a formula that takes into account the correction of latitude will produce different numbers, although small from one city to another. This small difference in the magnitude of gravity is very important because it will produce an accurate earthquake coefficient according to the level of earthquake risk in each research location.

The results of determining the seismic coefficient of cities in the study area are in the range of 0.175 - 0.411. The smallest earthquake coefficient was in the City of Indramayu and the largest occurred in the City of Sukabumi. The seismic coefficient shows the level of seismic risk equal to the maximum seismic force that has occurred in these cities. When compared with the PSHA earthquake map, the earthquake coefficient is more accurate in its application to earthquake resistant building planning.

The maximum ground acceleration values on the PSHA map are at the lower and upper limits of the contour lines. This contour line is a line that has the same maximum ground acceleration. Meanwhile, the seismic coefficient is a parameter of earthquake risk which is calculated at certain coordinate locations. Earthquake-resistant building plans at certain locations designed in accordance with the lower limit of the maximum ground acceleration contour on the PSHA map will have a very high risk of collapse in the event of an earthquake. However, if it is designed according to the upper limit of the maximum ground acceleration contour on the PSHA map, the building structure will be very strong and very expensive.

Chronologically, from time to time, the number of seismic coefficients in a place has generally increased[25]. This is due to an increase in the occurrence of earthquakes both in terms of number and increase in energy (magnitude). In the previous studies, in 1986, cities in the Banten and West Java regions had seismic coefficients ranging from 0.021 to 0.143. Based on the research results, in Indramayu, the smallest seismic coefficient was 0.021 and the largest seismic coefficient occurred in Sukabumi at 0.143 [13].

The results showed that the seismic coefficient value in the study areas ranged from 0.175 to 0.411. The minimum seismic coefficient value increased eightfold and the maximum seismic coefficient value tripled from the results of the 1986 study [13]. This is due to an increase in the incidence of earthquakes in the study areas after 1986 by 22 times with a depth of 10 - 100 km and a magnitude of 4.0 - 7.5 on the Richter scale [1].

On the PSHA map, the contour lines of the lower and upper limits show the value of the maximum ground acceleration. Earthquake-resistant building plans at certain locations that are designed according to the lower limit of the maximum ground acceleration contour on the PSHA map will have a very high risk of collapse in the event of an earthquake. However, if it is designed according to the upper limit of the maximum ground acceleration contour on the PSHA map, the building structure will be very strong and very expensive.

## 4. Conclusion

From the linear interpolation of the 2017 PSHA map for 21 cities in the study areas, it is found that the maximum ground acceleration price ranges from 171.5 - 471.8 gal. The smallest maximum ground acceleration occurs in the city of Indramayu, while the largest maximum ground acceleration is in the city of Sukabumi.

Seismic coefficients in 21 cities in the study ranged from 0.175 to 0.411. The lowest earthquake coefficient value occurred in the city of Indramayu, while the largest earthquake coefficient was in the city of Sukabumi.

Based on the seismic coefficient above, the smallest earthquake risk level occurs in Indramayu with the value of 17.5% and the largest earthquake risk level is in Sukabumi with the value of 41.1% of the total damage. The difference in the level of earthquake risk between cities is used to strengthen earthquake resistant construction and can save construction costs.

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