Estimating the casualties of the earthquake caused by the Lembang Fault in Coblong, Bandung, Indonesia

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Abstracts. Bandung is a metropolis in Indonesia located 10 km from the Lembang Fault. Being near a fault and having a dense population places Bandung at a high risk of suffering an earthquake. The lack of an earthquake risk assessment for the Lembang Fault is the main motivation of this study, which aims to provide information on the risk of building damage and estimated casualties in the Coblong District. This study uses earthquake scenarios with magnitudes of 6 and 7 caused by the Lembang Fault. Earthquake acceleration data on bedrock along with building vulnerability curves are used to obtain the probability of building damage. The number of victims is calculated based on the level of building damage using the event tree model from the HAZUS method. The results of the calculation show that the Lembang Fault earthquake with a magnitude of 6 could cause casualties in Coblong amounting to around 0.6% of the population, rising to as much as 1.5% for a magnitude of 7. The level of building damage is 36.6% and 55.6%, respectively.

1. Introduction
The City of Bandung is the capital of West Java Province and third largest city in Indonesia with more than 2.5 million inhabitants. Being located 140 km southeast of Jakarta makes Bandung a leading city that supports the provision of natural resources to the capital. However, located at an altitude of 750 m above sea level, Bandung is also less than 10 km from the active Lembang Fault. Its large population and dense buildings place Bandung at a high risk of earthquakes [1]. Previous research shows that the Lembang Fault has a slip rate of 6 mm/year based on GPS observations [2]. Given the dearth of research on earthquake disaster risk in Bandung, this study focuses on determining the risk of building damage and calculating the number of victims in Coblong District. Risk assessment is necessary as a basis for carrying out disaster mitigation efforts and minimizing the number of victims.

2. Method
There are several stages in our analysis: classifying and distributing the population, calculating building damage, and estimating the number of victims. The calculation of casualties is via the HAZUS method, which defines the estimated number of victims using previous earthquake data based on the level of building damage [3].

Building data are classified into two categories based on their role in estimating the number of victims. The first building classification is used to determine the density of each building according to its size; this is also the first step to distribute the population to each building. To obtain the estimated number
of victims, the population distribution needs to be placed in a single building because the number of victims comes directly from the level of damage to each building.

The number of residential buildings in Coblong is 21,705 units divided into three types based on their size, namely luxurious, moderate and simple (see Figure 1a). To distribute the population, weighting is applied to determine the population in each type of residence in each subdistrict (person/m²). Afterwards, the population in each house can be calculated using the population density multiplied by the size of the building (see Figure 1b).

Building data need to be classified according to structure because not all buildings have the same response to ground shaking. Building structures are classified based on residential regularity patterns (irregular and regular patterns). Residential buildings with a regular pattern usually have uniform shapes and distances, making the structure well planned by real estate developers. Meanwhile, irregular residential buildings are built separately and adapted specifically to their environment. Hence, this study generalizes this type of building structure into two types. A well-planned building structure built by an expert is one of the criteria in building Reinforced Masonry (RM2 class), whereas buildings not built by an expert are included in Unreinforced Masonry (URM class) [4]. Figure 1c shows the classification distribution of buildings based on their structure.

The level of building damage caused by an earthquake needs to be calculated to estimate the number of victims. This research uses earthquake hazard data represented as peak ground acceleration (PGA). The source of the earthquake hazard used is the Lembang Fault located north of Coblong, Bandung. The fault extends from east to west for 22 km and at a depth of 3–15 km. The eastern part of the Lembang Fault was first formed 100,000 years ago, followed by the western part around 27,000 years ago [5]. PGA values are calculated using deterministic scenarios based on earthquake hazard assessment methods. Two scenarios of earthquake magnitude are used: 7 Mw and 6 Mw.

The result of the PGA data is bedrock acceleration. To estimate building damage, the PGA value must be converted into PGA at the ground surface where the building is built using a formula [6]. The average shear velocity for the West Java region is classified as a class C site, which is solid and soft rock [7]. The results of the calculations of PGA at the ground surface can be seen in Table 1 and Figure 2. The PGA surface values are larger than the PGA bedrock value.
Table 1. PGA Value of Each Earthquake Magnitude Scenario

| Magnitude | PGA value range | Median PGA Value | Surface PGA Value |
|-----------|-----------------|------------------|-------------------|
| 7         | 0.32-0.38       | 0.35             | 0.42              |
| 6         | 0.25-0.29       | 0.27             | 0.32              |

The level of building damage is determined using the fragility curve based on the type of building [3]. The fragility curve illustrates the possibility of reaching or exceeding a certain level of damage based on the peak response of a building caused by ground shaking in an earthquake scenario. The level of building damage on the fragility curve is defined as four levels, namely Slight (S), Moderate (M), Extensive (E) and Complete (C).

Figure 2. PGA Distribution in Coblong Area (a) Magnitude 6 and (b) Magnitude 7.

Figure 2 illustrates the building fragility curve used in this research. The fragility curves for low-rise Unreinforced Masonry and Reinforced Masonry building types use the results of the research conducted by Park (2009) and Özün (2007) [8, 9]. The fragility curve of Unreinforced Masonry is shown in Figure 2a and that for Reinforced Masonry is shown in Figure 2b. The level of damage can be quantified and calculated using Equation (1). The sum of the percentages from the results of the fragility curve interpretation is shown in Table 2.

Table 2. Damage Stages Probability

| Building Type | Damage Stages Probability (%) | URM | RM2 |
|---------------|-------------------------------|-----|-----|
| PGA           | Complete                      |     |     |
|               | Extensive                     | 20  | 12  |
|               | Moderate                      | 22.5| 13  |
|               | Slight                        | 18  | 18  |
|               | No Damage                     | 27  | 52  |

The fragility curve only determines the number of buildings that have a certain damage level. As a consequence, the spatial distribution of the building damage cannot be known only from interpreting.
The fragility curve. The spatial distribution of the building damage must be estimated to obtain the number of victims.

Therefore, this research uses slope data derived from the West Java Digital Elevation Model to determine the spatial distribution of damaged buildings. These slope data are overlaid with building data to distribute the slope values to each building. Then, the steepest slope of the building is assumed to have the greatest damage, and this gradually decreases as the slope changes.

![Figure 3](image-url)  
**Figure 3.** Fragility curve of (a) Rise Unreinforced Masonry/URM (PARK, 2009) and (b) Reinforced Masonry/RM2 (Özün, 2007).

The method for estimating the number of victims used in this study is based on the assumption of how building damage affects the number and severity of victims. The probability of the number of victims comes from the casualty severity table developed by FEMA under the HAZUS methodology [3]. After the spatial location is determined, the total population can be obtained in each building affected by the earthquake. Each building type and damage level has a certain probability for the severity of the estimated victims, defined as minor injury, hospitalization, life-threatening and death [10].

To obtain the estimated number of victims, this research uses an event tree model that is initiated by an earthquake scenario and followed by a possible event that causes injuries. The population distribution is defined first, followed by each type of building and the level of damage. The probability of the number of victims is known from the severity based on the type of building and level of damage [3]. Then, the estimated number of victims can be found.

3. Results

The probability of building damage according to the fragility curves of buildings are changed to discrete values in Table 2. Reinforced Masonry buildings have a zero probability of damage. Therefore, our assessment of building damage only uses Reinforced Masonry buildings. The PGA surfaces used to determine building damage are 0.42 g and 0.32 g for the 7 Mw and 6 Mw earthquake scenarios, respectively. Further details can be seen in Table 3.

Earthquakes with a magnitude of 7 damage about 55.7% of the residential buildings in Coblong. Most affected buildings have a moderate damage status (see Table 3). Although the numbers of buildings at each damage level are similar in this scenario, the magnitude 6 scenario shows that 63.4% of the residential buildings in Coblong district have no damage. There is a possibility of slight damage to nearly 13.7% of buildings. In this earthquake scenario, the amount of each damage level varies more than in the magnitude 7 earthquake scenario.

Based on the Mercalli Modification Scale, PGA surfaces values of 0.32 g and 0.42 g are considered to be weak earthquakes [11]. However, this research surprisingly finds that most residential buildings in Coblong experience varying levels of damage. A total of 12,096 houses have slight-to-complete damage in the magnitude 7 scenario, indicating that residential buildings in Indonesia, especially in
Coblong, have vulnerable structures. Based on the building fragility curves, Reinforced Masonry and Unreinforced Masonry structures can be easily damaged by ground shaking. In addition, the HAZUS earthquake loss assessment methodology tends to obtain results that overestimate lower intensity earthquakes based on several preliminary studies in other urban areas [3]. Moreover, 36.6% and 55.7% of residential buildings in Coblong are slightly damaged by an earthquake in the 6 and 7 Mw scenarios, respectively.

Table 3. Building Infected in Each Earthquake Scenario

| Magnitude | Structure Type | URML | RM2L | Total |
|-----------|----------------|------|------|-------|
| 7         | Complete       | 2071 | 0    | 2071  |
|           | Extensive      | 3314 | 0    | 3314  |
|           | Moderate       | 3728 | 0    | 3728  |
|           | Slight         | 2983 | 0    | 2983  |
|           | No Damage      | 4474 | 5135 | 9609  |

| Magnitude | Structure Type | URML | RM2L | Total |
|-----------|----------------|------|------|-------|
| 6         | Complete       | 829  | 0    | 829   |
|           | Extensive      | 1988 | 0    | 1988  |
|           | Moderate       | 2154 | 0    | 2154  |
|           | Slight         | 2983 | 0    | 2983  |
|           | No Damage      | 8616 | 5135 | 13751 |

Once the number of damaged buildings is estimated, the spatial location of each damaged building must be found to obtain the total number of victims. Coblong slope data are overlaid with residential building data. Based on the level of damage, the building is placed on a slope location from an even to steep area. The results are shown in Figure 4, which illustrates the distribution of the level of building damage.

Figure 4 shows certain spatial patterns in damage level. For example, the northern part of the Dago subdistrict has a number of damaged buildings because the slopes are steepest, and thus the most damaged buildings are scattered there. On the contrary, buildings without damage are distributed in the gentlest slope areas. The spatial locations of each partially or completely damaged building are used to extract the number of victims. The severity of the victims at each damage level is different. Since low-rise Reinforced Masonry buildings are not affected by ground shaking in this scenario, the probability of the severity of the victims is only derived from the structure of Unreinforced Masonry buildings (see Table 4). Each probability is multiplied by the total population. Then, the total number of each severity at the whole building damage level is summed to find the number of earthquake victims (see Table 5).
Table 4 Casuality Severity Level of URML Building

| URML Building Damage State | Casualty Severity Level (%) |
|----------------------------|----------------------------|
|                            | 1  | 2  | 3  | 4  |
| Complete                   | 10 | 2  | 0.02 | 0.02 |
| Extensive                  | 2  | 0.2 | 0.002 | 0.002 |
| Moderate                   | 0.35 | 0.4 | 0.001 | 0.001 |
| Slight                     | 0.05 | 0  | 0  | 0  |
| No Damage                  | 0  | 0  | 0  | 0  |

Figure 4. Spatial Models of Building Damage States in (a) Magnitude 6 and (b) Magnitude 7

Table 5 shows that most victims had a severity of level 1, namely minor injury. Of the 1,935 victims due to a magnitude 7 earthquake, around 81.6% suffered minor injuries, followed by injuries treated in hospital (severity level 2; 18%). The number of estimated victims shown in Table 5 is considered to be high. The HAZUS model tends to find results that overestimate earthquakes with low intensity. Figure 5 shows the map of the distribution of the estimated victims based on the slope of the previous building damage distribution. This map shows the possibility of a certain area having a certain severity of victims.
Figure 5. Spatial Models of Casualty Severities in (a) Magnitude 6 and (b) Magnitude 7.

Table 5 Casualty Severity Level of URML Building

| Mag | URML Building Damage State | Pop | Number of Casualty (people) |
|-----|---------------------------|-----|-----------------------------|
|     |                           |     | 1  | 2  | 3  | 4  |
| 7   | Complete                  | 11157 | 1116 | 223 | 2  | 2  |
|     | Extensive                 | 18780 | 376  | 38  | 0  | 0  |
|     | Moderate                  | 22444 | 79   | 90  | 0  | 0  |
|     | Slight                    | 18596 | 9    | 0   | 0  | 0  |
|     | No Damage                 | 25831 | 0    | 0   | 0  | 0  |
|     | Total:                    | 1580 | 351 | 2   | 2  |
| 6   | Complete                  | 4261 | 426 | 85  | 1  | 1  |
|     | Extensive                 | 11016 | 220  | 22  | 0  | 0  |
|     | Moderate                  | 12308 | 43   | 49  | 0  | 0  |
|     | Slight                    | 17890 | 9    | 0   | 0  | 0  |
|     | No Damage                 | 51333 | 0    | 0   | 0  | 0  |
|     | Total:                    | 698  | 156 | 1   | 1  |
Conclusion
A total of 21,705 buildings were assessed in this study. Estimated building damage was 55.7% for the earthquake scenario with PGA 0.32 g and 36.6% for PGA 0.42 g. For earthquakes with a magnitude of 7, 1.5% of the population are affected, while a magnitude 6 earthquake causes casualties of up to 0.6% of the population. The severity of the victims was distributed from minor to severe injuries and death. This estimated percentage is overestimated compared with the 2006 Jogjakarta Earthquake. Generally, the assessment of building damage and classification of building structures uses building height and building conditions as several of its parameters. However, as this research did not adopt this approach, its estimation results may be imprecise.

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References
1. Montoya, L. and I. Masser, Management of natural hazard risk in Cartago, Costa Rica. Habitat International, 2005. 29(3): p. 493-509.
2. Meilano, I., et al., Slip rate estimation of the Lembang Fault West Java from geodetic observation. Journal of Disaster Research, 2012. 7(1): p. 12-18.
3. (FEMA), F.E.M.A., Multi-hazard Loss Estimation Methodology, in Earthquake Model Hazus®–MH 2.1. 2003, United States. Federal Emergency Management Agency: Washington DC.
4. Winarno, S., Effectiveness to Additional Cost on The Implementation of Seismic Resistance Features For Residential Houses. 2012.
5. Dam, M., et al., A chronology forgeomorphological developments in the greater Bandung area, West-Java, Indonesia. Journal of Southeast Asian Earth Sciences, 1996. 14(1-2): p. 101-115.
6. Wald, D.J. and T.I. Allen, Topographic slope as a proxy for seismic site conditions and amplification. Bulletin of the Seismological Society of America, 2007. 97(5): p. 1379-1395.
7. Nasional, B.S., Standar Perencanaan Ketahanan Gempa Untuk Struktur Bangunan Gedung SNI-1726-2002. Jakarta: BSN, 2002.
8. Ay, B.O., FRAGILITY BASED ASSESSMENT OF LOW–RISE AND MID–RISE REINFORCED CONCRETE FRAME BUILDINGS IN TURKEY. Middle East Technical University, MSc. Thesis, 2006.
9. Park, J., et al., Seismic fragility analysis of low-rise unreinforced masonry structures. Engineering Structures, 2009. 31(1): p. 125-137.
10. Durkin, M. and C. Thiel. Estimating Casualties in Earthquakes: An Assessment. in Fourth International Conference on Seismic Zonation. Stanford University, Palo Alto, California. Oakland, CA: Earthquake Engineering Research Institute. 1991.
11. Wu, Y.-M., et al., Relationship between peak ground acceleration, peak ground velocity, and intensity in Taiwan. Bulletin of the Seismological Society of America, 2003. 93(1): p. 386-396.