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Original Article

Developing the Fragility Curves of Confined Masonry Structure in Bener Meriah Regency, Aceh Province, Indonesia

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Abstract: The earthquake in Bener Meriah Regency on July 2, 2013 with 6.1 Mw tectonic caused physical damage and construction losses to 1,778 typical confined masonry residential buildings. One of the assessments of damage caused by the earthquake was the development of a fragility curve that can be formed by empirical methods based on the Generalized Linear Model (GLM) procedure with log it, pro bit and complementary log-log link functions. This study used data from 9 sub-regencies to identify light, medium and heavy damage levels. Data processing uses ArcGIS and MATLAB software based on data obtained from secondary data survey results and USGS Earthquakes. One of the resulting seismic fragility curves, the pro bit link model, gives a high probability at low and medium PGA intensities for light, medium and heavy damage. The logit link model provides a high probability of high PGA intensities for light, medium, and heavy damage. On the basis of the goodness of fit measurement results, the link pro bit model has the smallest standardized residual error value, which shows the best model of the method because probit has values of 20.16%, 21.12%, and 21.83% in DS1, DS2, and DS3 compared to the link logit and complementary clog-log models.

Keywords: Fragility Curve; Generalized Linear Model; Confined Masonry Structure; Bener Meriah Regency; Earthquake.

1. Introduction

Bener Meriah Regency is one of the regency's located in a high earthquake-prone area in Aceh Province. On July 2, 2013, an earthquake with a magnitude of 6.1 Mw was recorded, centred 35 kilometres southwest of Bener Meriah Regency (Mun awar et al., 2016). More than 4,000 buildings were damaged and collapsed, 12 people died, and more than 349 people were injured (Bencana, 2013). One of the impacts of the earthquake, among others, caused physical damage and losses to the construction of residential buildings (D'Ayala et al., 2014). Feasibility studies of typical buildings using earthquake-friendly structural planning are very important to create a sense of security and comfort for the owner. Ground motion caused by earthquakes can damage building structures and even displacement from their original positions (Anzala et al., 2015). The effects of ground shaking are not only felt by buildings located directly above the fault line, but surrounding buildings also get the effects of the shaking (Mujahid et al., 2016).

Typical building damage levels can be developed by predicting the treatment of buildings during an earthquake using a fragility curve. Fragility curve development uses generalized linear model (GLM) procedures with three models: probit, logit, and complementary log-log (McCullagh & Nelder, 2019). The earthquake's intensity will be assessed by peak ground acceleration (PGA), which is the peak ground acceleration at the time of the earthquake. The best fragility curve model is selected by evaluating the model's goodness of fit (Palazzi, 2019). The fragility curve will illustrate the building damage probability for various ground motion intensities. Based on the description above, it is necessary to determine the development of fragility curve patterns in typical residential buildings caused by the earthquake in Bener Meriah Regency. The object of this research is residential buildings with confined masonry structures damaged by the Bener Meriah earthquake on July 2, 2013, located in 9 sub-regencies in Bener Meriah Regency. This research can be used as an evaluation material and input for the local government to determine the building damage caused by the earthquake in July 2013.

2. Materials and Methods

This study uses a quantitative approach, namely data in numbers and then analysis, to produce a hypothesis. This research uses a database from BPBD Bener Meriah Regency in the form of data on damage to residential buildings. This study uses secondary data, including residential buildings that suffered damage from the house. The total data obtained was 1,778 dwellings that suffered damage during the July 2, 2013 earthquake.

2.1. Data Processing

Data processing begins with identifying the damage level based on the building type that refers to Permen PU No. 22/PRT/M/2018 (Kementerian Pekerjaan Umum, 2018) and HAZUS MH 2.1 (Erickson, 2019). The level of damage studied is light damage (RR), medium damage (RS), and heavy damage (RB). It is known that, based on the level of damage, there are 1,778 buildings with confined masonry structures. Digitizing the coordinate points of residential buildings serves to see the spatial distribution of building points in Bener Meriah Regency. After knowing the location of residential building points, PGA modelling processing is carried out using ArcGIS with overlay and intersect techniques to determine the PGA value of each residential building affected by the earthquake and determine the PGA value in each village.

2.2. Data Analysis

Analysis is the step in processing the data of this research. This subchapter consists of the analysis:

2.2.1. Peak Ground Acceleration Modeling Analysis

Peak Ground Acceleration (PGA) modelling uses data from the United States Geological Survey (USGS) Earthquakes on July 2, 2013 (Jaiswal et al., 2015). The data is obtained in the form of shape files that can be processed with the help of ArcGIS applications. Overlay and intersect techniques determine the PGA value of each residential building affected by the earthquake and the PGA value in each village. Furthermore, residential buildings with PGA values are classified against PGA intervals (bins).

2.2.2. Damage Probability Matrix Analysis

Damage probability matrices (DPMs) express the probability that a building will suffer a certain level of damage given earthquake intensity. The development of DPMs is referred to as Cumulative Damage Probabilities Matrices (C-DPMs). C-DPMs will give the highest possible probability of that level of damage (McCullagh & Nelder, 2019). Once plotted onto a fragility curve graph, GLM statistical procedures with probit, logit and complementary log-log models will be used.

2.2.3. Analysis of Fragility Curve Development Based on GLM Procedure

The analysis results using GLM procedures with probit, logit, and complementary log-log models with three levels of damage obtained seismic fragility curves based on building type (Wibowo, 2016). In determining the probability of the 3 (three) models, we first estimate the price of α and β using Maximum Likelihood Estimation (MLE) with the following likelihood function:

$$M = \prod_{j=1}^{m} \binom{n_j}{z_j} \pi^{z_j} (1-\pi)^{n_j - z_j} \tag{1}$$

Where:

n_j = Number of wooden structures, restrained brick walls, and reinforced concrete houses in PGA bins based on C-DPMs results
z_j = Number of damaged houses of wooden structure, restrained brick wall, and reinforced concrete in PGA bins based on the results of C-DPMs
π = Odds of the pro bit/lo git/ complementary log-log model

To find the first derivative and second derivative, the parameter estimates of α and β are the values of α and β that maximize the likelihood function on the sample data (n_j, z_j). The maximum value is achieved under the following conditions:

$$\frac{d \ln M}{d\,\alpha} = \frac{d \ln M}{d\,\beta} = 0 \tag{2}$$

After obtaining the values of α and β, a conversion of the brittleness curve parameters is performed where $\hat{\beta} = 1/\beta$ as the lognormal standard deviation value and $\hat{\mu} = e^{\alpha/\beta}$ as the median PGA value. In this research, the calculation process of α and β uses MATLAB software. Computation script MATLAB based on a publication by Baker (2015).

2.2.4. Goodness of Fit Analysis of Fragility Curve

The goodness of fit can analyze how well a set of data points fits the actual model in selecting the best model (Lallemant et al., 2015). The results are used to measure the regression line's prediction error by taking the residual error's smallest value as the best model selection.

3. Results and Discussion

The results of this study are fragility curves with log it, pro bit, and complementary log-log link models. Then, the three link models were re-analyzed to determine the fragility curve with the best model.

3.1. Digitization of Residential Building

The results of digitizing the coordinates of residential buildings that have been used in Google Earth Pro are then exported to ArcGIS. The results of house digitization aim to see the distribution of densely populated houses determine the average value of PGA in an area and estimate the number of residential buildings.

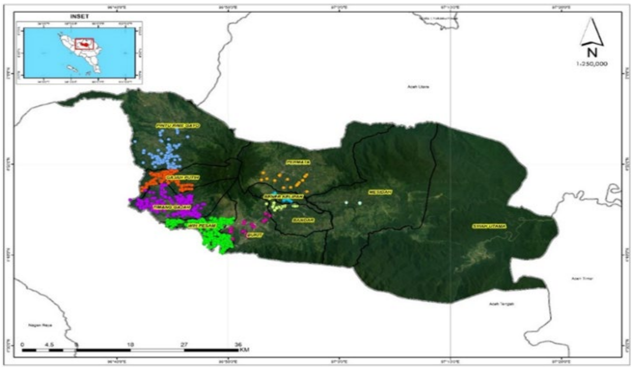


Figure 1. Map Digitizing the Coordinates of Residential Buildings in Bener Meriah Regency

3.2. PGA Estimation

Each region in Bener Meriah Regency has a different PGA value. The greater the PGA value, the greater the risk of earthquake damage and losses (Massinai et al., 2016). PGA modelling using data from the

United States Geological Survey (USGS) Earthquakes on July 2, 2013. The data was obtained in shape file format and then processed with the help of the ArcGIS application.

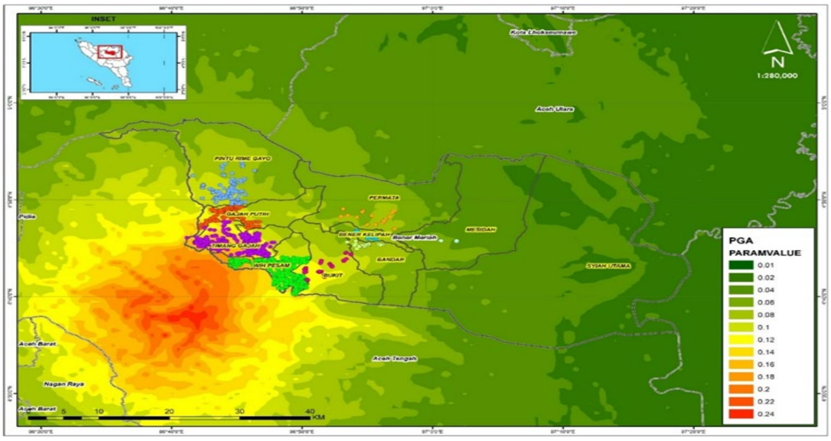


Figure 2. Map of PGA distribution in Bener Meriah Regency

The results were plotted against the digitized results of residential buildings. PGA values were obtained using data from USGS and then exported into ArcGIS. Furthermore, the distribution point of the PGA was mapped. Once the PGA values for each house have been obtained, they are grouped into specific PGA ranges according to the specified criteria.

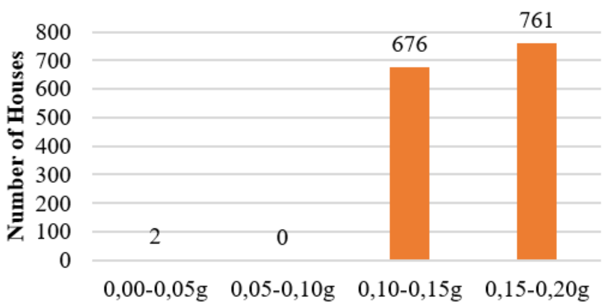


Figure 3. Number of damaged residential buildings based on PGA range

3.3. Grouping of Residential Buildings by Damage Type

The results of digitizing residential building points are then grouped based on the level of damage, namely lightly damaged (DS1), moderately damaged (DS2), and severely damaged (DS3). The results of grouping residential buildings based on the level of damage with the specified range of PGA values can be seen.

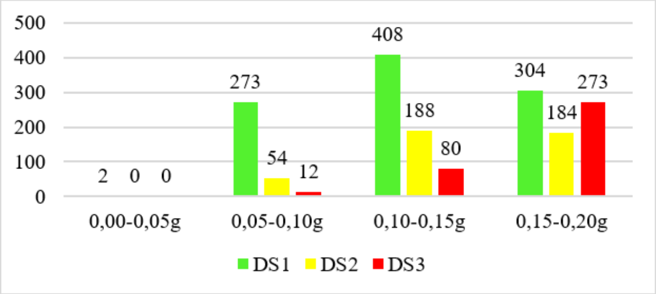


Figure 4. Number of residential buildings with damage levels based on PGA intervals

3.4. The Damage Probability Matrix

Damage Probability Matrices (DMPs) describe the chances of damage occurring at a certain level based on the PGA bins. The following are the results of the Damage Probability Matrices (DMPs) based on each PGA interval.

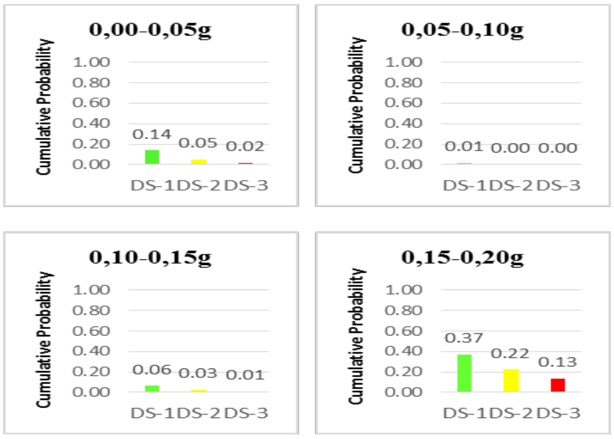


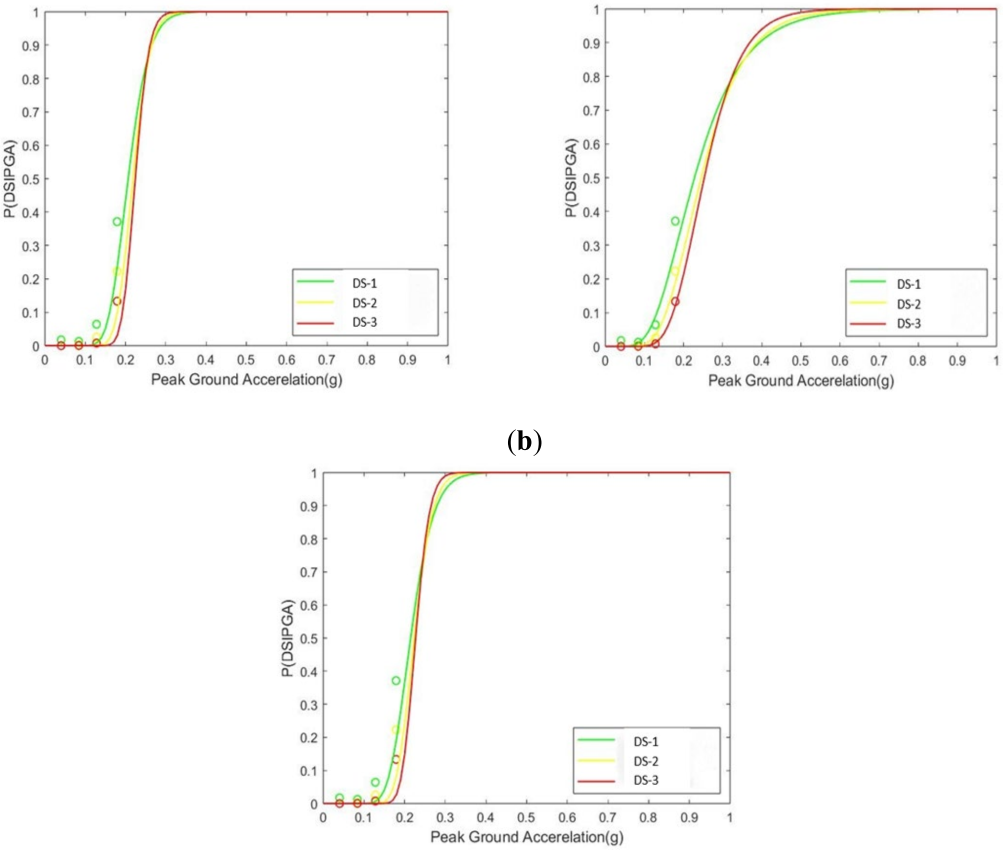
Figure 5. DPMs

Furthermore, the results of the DPMs are sought for their cumulative value. The results of Cumulative Damage Probability Matrices (CDPMs) can be seen in Figure 6 below.

Figure 6. CDPMs

3.5. Fragility Curve Results

The fragility curve development using Equation 1, Equation 2, and Equation 3 also sought MLE based on Equation 4. The fragility curve with the log it, pro bit, and complementary log-log link models are shown in Figure 7, respectively.



(a) (b)

(C)

Figure 7. Fragility curve with link model (A) logit, (B) probit, (C) clog-log

3.6. Fragility Curve Goodness of Fit

The results of the fragility curve and the residual standard error are based on equation X. The results of the fragility curve fit are shown in Table 1.

Table 1. Result of Fragility Curve Conformity

Model	**Damage Rate**		
	DS1	**DS2**	**DS3**
Logit	21.42	22.14	22.61
Probit	20.16	21.12	21.83
Clog-Log	21.6	22.26	22.67

4. Conclusion

This study concludes that the probit link model provides the greatest probability with low PGA intensity. While at high PGA intensity, the complementary log-log link model provides the greatest probability. Based on the results of the goodness of fit calculation analysis, it can be concluded that the fragility curve with the best model is the probit link because probit has the smallest standard error of 20.16%, 21.12%, and 21.83% in DS1, DS2, and DS3 compared to the log it and complementary log-log link models. This research is expected to reference research on a similar topic. In addition, it is hoped that further research will be conducted to review other public facilities that are also affected by the impact of earthquakes. Researchers also hope there will be research on the development of fragility curves using other earthquake scenarios so that a comparison of curve models can be made.

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