Seismic risk for Sumbawa Island based on seismicity and peak ground acceleration

C B Santoso\(^1\) and D S Agustawijaya\(^2\)
\(^1\)Postgraduate Study Program in Civil Engineering, Universitas Mataram, Indonesia
\(^2\)Department of Civil Engineering, Universitas Mataram, Indonesia

E-mail: caturbsantoso@gmail.com

Abstract. Sumbawa Island, West Nusa Tenggara Province, is one of the regions in Indonesia that has a relatively moderate to high seismic activity. This research aims to determine the seismic risk in Sumbawa Island based on seismicity and Peak Ground Acceleration (PGA) value. The results of Gutenberg-Richter parameters are a-value 7.43 and b-value 0.80 that indicated medium to high categories of seismicity. The PGA value of earthquake events is between 0.001g and 0.203g. The result of this analysis is shown within the probabilistic seismic hazard curve that indicates seismic risk level at Sumbawa Island.

1. Introduction

Sumbawa Island in West Nusa Tenggara province is one of the regions in Indonesia that has a relatively moderate to high seismic activity. The high seismic activity of the Sumbawa Island area is due to the fact that the region is flanked by two earthquake sources; from the southern part there is a subduction zone (Indo-Australian Plate) and from the northern part, there is back-arc thrust zone (Flores back arc thrust fault) [1]. These two sources make different types of seismic events. The subduction leads to generate deep seismic events; on the contrary the back-arc thrust leads to generate shallow seismic events [2]. These two sources cause an area prone to earthquake hazards.

Sumbawa Island had experienced many damaging earthquakes greater than 6 Mw in 1821-2017 based on catalogs of significant earthquakes issued by the Indonesian Geophysics and Climatology Agency (BMKG), i.e. on 19 August 1977 (7.0 Mw), 10 April 1978 (6.7 Mw), 1 December 2006 (6.2 Mw), 25 November 2007 (6.7 Mw), 25 November 2007 (6.8 Mw), and 8 November 2009 (6.7 Mw) [3]. There were major earthquakes in Lombok island and felt in Sumbawa Island in 2018, i.e. on 29 July 2018 (6.4 Mw), 5 August 2018 (7.0 Mw), and 19 August 2018 (6.5 Mw) [4]. These earthquakes have caused many casualties and damages to infrastructure, where about 483 people were killed, 1,413 injured, 431,416 people were evacuated from their homes, 31,925 houses were heavily damaged, 3,135 houses were moderately damaged, and 36,680 houses were slightly damaged [5, 6]. Considering the high seismic hazard level, seismic hazard analysis of Sumbawa Island is very necessary to reduce damages.

Every case of earthquake generates ground shaking that can be identified through the value of acceleration in the site. If the value of the ground motion acceleration is occurring it means the seismic hazard is getting higher. Enormous and small acceleration values of the ground motion are one of the
factors that can show the risk level of an earthquake [7]. Acceleration value will be considered as one of the parts in earthquake-resistant infrastructure planning.

Earthquakes are symptoms of nature at random that cannot be determined with any certainty, scale, location nor time of the occurrence. With probability concept, there have been earthquakes with certain repeated intensity and period predictability. The objective of Probabilistic Seismic Hazard Analysis (PSHA) is to quantify the uncertainties and produce an explicit description of the distribution of future ground motion that may occur at a site [8]. We consider all possible earthquake events and estimate ground motion along with their associated probabilities of occurrence in order to access ground motion design for a structure. The annual probability of exceedance is determined for some level of earthquakes occurred at the site [9]. The results of this analysis is shown within the probabilistic seismic hazard curve of Sumbawa Island.

2. Method

2.1 Earthquake catalog
This research was done using secondary data sourced from the United States Geological Survey (USGS) and Indonesian Geophysics Climatology Agency (BMKG) from 1970 to 2018 with grid coordinates 116.5°-119.5° (longitude) and 8°-9° (latitude). The criteria of the earthquakes are those with magnitude bigger than 4 Mw and depth ≤ 500 km, and a distance of less than 200 km. Earthquake data is divided into 5 intervals, i.e. shallow background (0-50 km), deep background 1 (50-100 km), deep background 2 (100-200 km), deep background 3 (200-300 km) and the last one is deep background 4 (300-450 km).

2.2 Gutenberg-Richter relationship
Seismicity is the relationship between the strength of the earthquake (magnitude) and the frequency of earthquake events in one area, where the earthquake event will affect infrastructure. The formula of the Gutenberg-Richter relationship will describe the seismicity of Sumbawa Island. It can is provided in the formula below [10]:

\[
\log N(M) = a - bM
\]

(1)

where \(N(M)\): the number of earthquakes with magnitude greater than or equal to M, \(a\)-value, and \(b\)-value: constant. The \(a\)-value describes a seismic intensity parameter which depends on the number of earthquake events. The \(b\)-value describes a seismicity parameter determined as the linear slope on the graph of the \(N(M)\) number and magnitude M. The \(b\)-value can also be determined by utilizing the maximum likelihood method [4,6]:

\[
b = \frac{\log e}{M_{av} - M_{min}}
\]

(2)

\[
a = \log N + \log (b \ln 10) + M_{av}b
\]

(3)

where \(e\): exponential number (2.7183), \(M_{av}\): the average magnitude and \(M_{min}\): the minimum magnitude

2.3 Moment magnitude (Mw) conversion
In our compiled data set, we found several types of earthquake magnitude. They include moment magnitude (Mw), surface-wave magnitude (Ms) and body-wave magnitude (Mb). However, we converted them to moment magnitude (Mw) using relations developed by Pusgen. (Table 1) [11].

| Conversion Correlation | Range of Magnitude | Consistency (R²) |
|------------------------|-------------------|-----------------|
| Mw = 1.0107 Mb + 0.0801 | 3.7≤Ms≤8.2        | 69.75%          |
| Mw = 0.6016 Ms +2.476   | 2.8≤Ms≤6.1        | 80.13%          |
| Mw = 0.9239Ms + 0.5671  | 6.2≤Ms≤8.7        | 81.83%          |
2.4 Probabilistic seismic hazard analysis
The method of PSHA was developed by McGuire [12] based on the probability concept developed by Cornell [13]. This method has four stages, that are: identification of the source of the earthquake, characterizing the source of the earthquake, selective function attenuation, and hazard analysis. The PSHA theory assumed magnitude earthquakes M and range R are constantly independent random variables [14]. In the general form, the theorem of total probability could be represented in the 4 equation bellow:

$$P_X(x) = \int_M \int_R P(X > x | m, r) f_M(m) f_R(r) dr dm$$  \hspace{1cm} (4)

where $f_M(m)$ is density function of magnitude, $f_R(r)$ is density function of hypocenter distance, and $P(X > x | m, r)$ is conditional probability of (random) intensity I exceeding value I at the site for a given earthquake magnitude M and hypocenter distance.

$$f_M(m) = \frac{\beta}{1-e^{-(M_{av} - M_{min})}} e^{-(M_{max} - m) - \alpha (m_2 - m_1)}$$  \hspace{1cm} (5)

where $\beta = b \ln (10)$, $M_{av}$: average magnitude, $M_{min}$: minimum magnitude, $M_{max}$: maximum magnitude, $m_1$: magnitude range a, and $m_2$: magnitude range b.

2.5 Attenuation
The attenuation function is a function that illustrates the correlation between the intensity (I), magnitude (M) and distance (R) from one point to the source area. The attenuation function used is Joyner-Boore [2], can be expressed in the 6 (six) equation bellow. The formula of Joyner-Boore represents the ground motion of seismic event characteristics in the island since the deep Benioff mixed with shallow back-arc thrust earthquakes dominantly occur around the island [2].

$$PGA = 10^{0.87 + 0.23(M - 6) - \log(R) - 0.0027(R)}$$  \hspace{1cm} (6)

where PGA in g, M is moment magnitude and R is hypocenter distance($R = \sqrt{R_0^2 + B^2}$).

2.6 Seismic risk
Seismic risk is a probability of exceeded an earthquake with certain intensity and periodicity during a period of building [15], which is:

$$RN = 1 - (1 - RA)^N$$  \hspace{1cm} (7)

where $R_n$ is a seismic risk (%), RA is annual rate = 1/T, N is a period of building and T is return period (years)

| Annual rate | T (Periodicity) | RN (Seismic Risk) | N (period of a building) |
|-------------|-----------------|-------------------|--------------------------|
| 0.0021050   | 475             | 10                | 50                       |
| 0.0004040   | 2475            | 2                 | 50                       |
| 0.0002020   | 4950            | 2                 | 100                      |

In this research, the risk of Sumbawa Island seismic used 2 (two) parameters that were 2% probability of exceeded in 50 years and a 10% probability of exceeded in 50 years.

3. Result and Discussion

3.1 Earthquake distribution
The data of earthquake distribution is shown in Figure 1. As many as 1012 earthquake events occurred around Sumbawa Island during the period 1970-2018. The shallow background (0-50 km) seems to occur around the north of Sumbawa Island (Flores back-arc thrust) (Figure 1). Deep background 1 (50-
100 km) seems to occur at southern (subduction zones), deep background 2 (100-200 km) seems to occur at northern-eastern direct to Tambora Mountain and is like divided into 2 parts as western (Dompu and Sumbawa District) to eastern (Bima and Kota Bima District). Deep background 3 and 4 (200-450 km) seem to occur at northern-western of the island (Figure 1).

![Figure 1. Distribution of earthquakes during the period 1970-2018](image)

Based on Figure 2, the Moment Magnitude (Mw) is greater than 4 (four) and the depth is ≤ 450 km, most of the earthquakes occurred at a depth of 0-200 km. The earthquakes occurred at shallow background to deep background 1. would certainly be felt to the surface. In the deep background 4 some earthquakes occurred and were not significant and not be felt on the surface. The biggest earthquake occurred at the shallow background in 6.6 Mw with a depth of <50 km. This was felt on the surface and probably causing damage to infrastructure buildings.

![Figure 2. Relationship between moment magnitude and depth](image)

### 3.2 Seismicity
Generally, using the maximum likelihood method for magnitude equal to or over 4.0 Mw that results in a-values = 7.43 and b-values = 0.80 (Figure 3). Those values described categories of seismic activity in the medium to high [16]. This research tried to use the same analysis with a-value and b-value in the depth of different intervals (Table 3). The variation of b-value based on certain depths was 1.49 to 2.37. This value means that the higher the b-value will show low-stress levels and large heterogeneity. In addition, for a-value based on certain depths was 7.47-12.96.
Figure 3. Earthquake data distribution of the Gutenberg-Ritcher relation

Table 3. Data and parameter results of the background earthquakes sourced in Sumbawa Island

| Background Zones  | Interval Depth (km) | a-value | b-value | The magnitude of Completeness (Mc) |
|-------------------|---------------------|---------|---------|----------------------------------|
| Shallow background| 0-50                | 8.85    | 1.57    | 4.8                              |
| Deep background 1 | 50-100              | 8.56    | 1.60    | 5                                |
| Deep background 2 | 100-200             | 12.96   | 2.37    | 5                                |
| Deep background 3 | 200-300             | 10.52   | 2.02    | 5                                |
| Deep background 4 | 300-450             | 7.47    | 1.49    | 5                                |

3.3 Peak ground acceleration and seismic hazard curve

Peak Ground Acceleration (PGA) value is related to earthquake damage index or intensity [17]. The formula of Joyner-Boore empirical equations was utilized. The PGA values are between 0.001 g and 0.203 g (Figure 4).

Figure 4. PGA value for Sumbawa Island

Analysis of the seismic hazard probabilistic for Sumbawa Island is available in hazard curves (Figure 5). This analysis is to know the contribution of each significant earthquake source which is
very vulnerable to the investigated site. The hazard curve is a relationship between annual rate exceedance to the hazard [15].

There are three points to analysis seismic hazard: the distribution function of magnitude, the distribution function of hypocenter distance and attenuation [14]. We divide into three sources based on the distribution of hypocenter distance: source 1 (0-50 km), source 2 (50-100 km), and source 3 (100-200 km) (Figure 5).

The Probabilistic Seismic Hazard Curve shows that the PGA at the bedrock in Sumbawa Island with a 2% probability of being exceeded in 50 years (return period of 2500 years) ranged between 0.05g and 0.20g. The PGA with a 10% probability of being exceeded in 50 years (return period 500 years) ranged between 0.08g-0.85g (Figure 5).

![Figure 5. Probabilistic seismic hazard curve of Sumbawa Island](image)

### 4. Conclusion

In this research, we can conclude that Sumbawa island is categorized into medium to high seismicity. The PGA value of earthquake events was between 0.001g and 0.203g. The Probabilistic Seismic Hazard Curve shows that the PGA in Sumbawa Island bedrock with a 2% probability of being exceeded in 50 years (return period of 2500 years) ranged between 0.05g and 0.22g. The PGA with a 10% probability of being exceeded in 50 years (return period 500 years) ranged between 0.08g-0.45g. PGA values are very important to calculate the spectrum response in infrastructure planning, to reduce the seismic risks that may occur in Sumbawa Island.

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