Peak ground acceleration at surface for Mataram city with a return period of 2500 years using probabilistic method

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Abstract. The Lombok region especially Mataram city, is situated in a very active seismic zone because of the existence of subduction zones and the Flores back arc thrust. Hence, the peak ground acceleration (PGA) at the surface is necessary for seismic design regulation referring to SNI 1726:2012. In this research we conduct a probabilistic seismic hazard analysis to estimate the PGA at the bedrock with a 2% probability of exceedance in 50 years corresponding to the return period of 2500 years. These results are then multiplied by the amplification factor referred from shear wave velocity at 30 m depth (V_{s30}) and the microtremor method. The result of the analysis may describe the seismic hazard in Mataram city which is important for building codes.

1 Introduction

West Nusa Tenggara is an area that is prone to earthquakes because it is flanked by two earthquake sources. In the southern part of West Nusa Tenggara there is a subduction zone and in the northern part there is Back Arc Thrust zone. According to the Mataram Geophysics Station data, the 6.2 SR earthquake on 6 June, 2016 has caused damage in Mataram and Central Lombok. Even in 2017 there have been 9 earthquakes felt with scale II-III MMI in Mataram City. Considering the high earthquake hazard level, a seismic hazard analysis of the Mataram region is very necessary. Peak Ground Acceleration value is related to earthquake damage index or intensity [1]. Peta Sumber dan Bahaya Gempa Indonesia 2017 released by PUSGEN [2] only provides spectrum acceleration values with small resolution, so we cannot know the specific value at a location because all of the Lombok region has a uniform value. In addition, the study of spectral acceleration on the surface is still rarely conducted even though this value has considered the type of soil in a location.

Therefore, we conduct research on the value of spectrum acceleration in Mataram city with a higher resolution and input soil amplification factor, so as to give a reliable

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description of the local earthquake hazard level. The seismic hazard analysis is conducted by probabilistic approach with a 2500-year quake period or corresponding to a 2% probability of exceedance 2% in 50 years. The study of the surface spectrum acceleration is expected to provide input for engineering in designing earthquake resistant buildings in the city of Mataram. In addition, this earthquake hazard update is a major step for earthquake disaster mitigation in Indonesia [3].

2 Data and method

Data used in this research is earthquake data in 1960-2017 obtained from catalogues of Engdahl [4] and the BMKG [5]. The earthquake database is limited to 6° LS- 14° LS and 113° BT- 122° BT with magnitudes ≥ 4.5 as shown in figure 1. In addition, secondary data of fault and subduction earthquake source parameters from Peta Sumber dan Bahaya Gempa Indonesia 2017 [2] and Vs30 from USGS [6] and Marjiyono [7] are also used.

This research consists of several steps, which are declustering earthquake data, uniforming magnitude to Mw, compiling and calculating earthquake source parameters, determining the logic tree, calculating the Probabilistic Seismic Hazard Analysis using USGS software developed by Harmsen [8], determining the amplification factor coefficient based on site class, and the calculating spectral acceleration on surface. This is summarised in figure 2.

Declustering the earthquake is done using the Gardner and Knopoff scheme [9] included in Zmap [10]. The main shock is separated in order to not overestimate the hazard analysis resul. Different magnitude types of earthquake data are converted into Moment Magnitude (Mw) using the PUSGEN equation [2]. Mw is vastly used because it is not saturated for large earthquakes [11].

Fig. 1. Seismicity map around Mataram city from 1960-2017 ([4, 5])

Fig. 2. Diagram of the method used in this study

3 Source parameters

In this research, earthquake sources are referred from Peta Sumber dan Bahaya Gempa Indonesia 2017 from PUSGEN [2]. We divide the earthquake source into 3 parts, ie the source of earthquake subduction, fault, and background. Parameters needed for the analysis of subduction earthquake sources include the b-value, plate motion type, maximum magnitude, and geometry of earthquake sources. The subduction zone used in the study is the Sunda Megathrust region of Bali. An analysis of fault earthquake sources requires additional parameters of dip, width, and fault length. In this study there are 8 faults that are assumed to cause destructive earthquakes in Mataram, namely Sumbawa Strait South1, Sumbawa Strait South 2, Sumbawa Strait North, Sumbawa Strait Central, Lombok Strait North, Lombok Strait Central, Nusa Tenggara Oceanic Normal Fault and Back Arc Thrust. The source parameters used in this study can be seen in Table 1. The source of the background earthquake is used to account for possible earthquakes with magnitudes of 4.5-6.5 around the fault and 4.5-7.0 earthquakes outside the fault zone [12]. Referring to Peta Sumber dan Bahaya Gempa Indonesia 2017 [2] criteria, background earthquakes are divided into 5 intervals, which are shallow background (0-50 km), deep background 1 (50-100 km), deep background 2 (100-150 km), deep background 3 (150-200 km), and deep background 4 (200-300 km). Fault width is another important parameter needed. This can be obtained from the maximum magnitude and was formulated by Papazachos [13].

The a-b value source parameter is an important part of hazard analysis. The a-value is a seismic parameter whose magnitude depends on the number of earthquakes for a particular region depending on the determination of volume and time window. The b-value is a tectonic parameter, usually close to 1 and shows the relative amount of small and large shaking [14]. The a-b value can be calculated using the Gutenberg-Richter equation [15].

Table 1. Data and parameters of earthquake sources around Mataram ([2, 16])

No.	ID	Name-segment	Dip	Length	Slip rate (mm/yr)	Top	Bottom	Mmax	Width
1	19	Flores Backarc Thrust-Lombok	45	310	9.9	3	18	8.0	18.5
2	27	Nusa Tenggara oceanic normal fault	60	540	0.5	3	18	7.8	17.9
3	84	Sumbawa strait strikeslip-north	90	79	0.5	3	18	7.3	11.9
4	85	Sumbawa strait strikeslip- central	90	104	0.5	3	18	7.4	12.1
5	86	Sumbawa strait strikeslip-south 1	90	40	0.5	3	18	6.9	10.9
6	87	Sumbawa strait strikeslip-south 2	90	47	0.5	3	18	7.0	11.2
7	89	Lombok strait strikeslip-north	90	156	0.5	3	18	7.5	12.3
8	92	Lombok strait strikeslip-central	90	133	0.5	3	18	7.5	12.3
9	99	Java Megathrust-Bali		500	4.0			9.0	200

The calculation of the b-value using the Gutenberg-Richter equation is done by using Zmap [10]. The results of every background source depth interval are shown in Table 2. The earthquake source is obtained by digitizing the earthquake source map included in Peta Sumber dan Bahaya Gempa Indonesia 2017 [2], the locations and fault names of which can be seen in figure 1.

Table 2. Result of calculating a-b value for background source

Depth interval (km)	a value	b value
0-50	7.13	0.944
50-100	7.32	1.09
100-150	9.39	1.56
150-200	8.54	1.41
200-300	6.63	1.06

4 Probabilistic seismic hazard analysis

Probabilistic Seismic Hazard Analysis (PSHA) is a commonly used tool to evaluate the hazard of seismic ground motion at a site by considering all possible earthquakes in the area [17]. Probabilistic Seismic Hazard Analysis (PSHA) is calculated using probabilistic formula [18] as shown in equation (1) below:

$$Px(x) = \int_M \int_R P(X>x|m,r)f_M(m)f_R(r) drdm \tag{1}$$

Where $P(X>x|m,r)$ is random probability condition of Intensity (X) which exceed x value in a location due to earthquake with magnitude m and distance r . $f_M(m)$ and $f_R(r)$ are the probabilistic density functions for R magnitude and distance respectively. In this research, Probabilistic maximum considered earthquake is defined as a predicted maximum acceleration based on PSHA by defining ground motions as having a 2% probability of

being exceeded (PE) in 50 years (return period of 2500 years), as in SNI 1726:2012 [19]. The analysis is done using software obtained from USGS [8] with selected periods 0.2 sec and 1.0 sec, corresponding to IBC-2006 [20].

PSHA needs some logic tree to define the weighting of some alternative models available [21]. The result of every analysis gives suitable probabilistic for every weighting used. Fault segments tend to have occurrences of earthquakes with similar size or within a narrow range of magnitudes. These earthquakes are called characteristic earthquakes. Typically, smaller earthquakes on the fault follow the GR line and characteristic earthquakes occur at higher rates. So, for the fault and subduction sources both truncated exponential (GR) and characteristic models (char) are used with a weighting of 0.34 and 0.66 [22]. An important part of hazard analysis is the attenuation function used. So far, Indonesia, especially West Nusa Tenggara, does not have any specific attenuation function yet, thus we use currently available attenuations. Attenuation functions used refer to the Peta Sumber dan Bahaya Gempa Indonesia 2017 [2].

Figure 3 shows the PGA calculated spatially for earthquakes with a 2% probability of being exceeded in 50 years (return period of 2500 years) in Mataram. Generally, Mataram has a maximum PGA of around 0.171-0.187 g. The lowest is in the south part of Mataram and the value gradually increases further to the north. This value is lower than the information in Indonesian sources and the earthquake hazard map 2017 that show that the PGA in Lombok is around 0.4-0.5 g.

The spectral acceleration map for $t=0.2s$ (S_s) as shown in figure 4 shows that the acceleration value is around 0.37-0.45g which is much lower than the S_s from PUSGEN [2] of around 0.9-1.0 g. Spectral acceleration for $T=1s$ (S_1) is around 0.16-0.18 g, as can be seen in figure 5 which is lower than the PUSGEN value [2] has. The tendency of these aspects to have a lower value than that of PUSGEN [2] is due to differences in the amount of earthquake sources and earthquake catalogues used. In this research, earthquake sources used are based on historical earthquake data that caused significant impacts for Mataram while PUSGEN [2] also uses some earthquake sources with a low historical data, hence these cannot be used as a reference of earthquake sources in Mataram. Another difference is the catalogue used. PUSGEN [2] uses data from 1900-2016 while this research uses data from 1960-2017. The catalogue difference affects the source parameter analysis such as the b value and maximum magnitude but generally, the value difference is relatively small and still in same scale, which is IV SIG-BMKG [23]. The PUSGEN map [2] also shows similar characteristics that the peak ground acceleration increases from the south to the north. It shows that the most significant source is the back arc thrust which is located near Mataram.

Fig. 3. Peak ground acceleration (PGA) map at bedrock with 2% PE in 50 years.

Fig. 4. Spectral acceleration map at bedrock for T= 0.2 seconds with 2% PE in 50 years.

Fig. 5. Spectral acceleration map at bedrock for T= 1.0 seconds with 2% PE in 50 years.

5 Site classification

Peak ground acceleration produced by PSHA has not described soil effect in particular site. One parameter that can define soil classification is vs30 or shear velocity in a depth of 30 meters. Soil classification is regulated in SNI 1726:2012 [19].

Peak acceleration amplitudes and shapes of response spectra are strongly dependent on the local soil conditions. Peak accelerations at the surfaces of soil deposits are slightly greater than peak accelerations on rock when these values are small, and somewhat the reverse with higher acceleration levels. At higher acceleration levels, the low stiffness and nonlinearity of soft soils often prevent them from developing peak ground accelerations as large as those observed on rock [24].

In this research Vs30 of Mataram is obtained from USGS [6], USGS estimate Vs30 value from slope of topography with 30 arcs second resolution. As validation, microtremor array data from Marjiyono is also used [7]. Even though Vs30 can be obtained from the derivation slope data, it would be better if measured directly on field [25]. Hence, if there are any differences between USGS [6] and Marjiyono [7], we tend to prefer the Marjiyono [7] result. Validated Vs30 data are then converted into site classes as illustrated in figure 6. From figure 6 we can see that Mataram is classified into D class soil on the east side and E

class soil in the opposite direction, which is probably caused by the proximity of that area with the ocean.

Fig. 6. Site class map for Mataram city

6 Peak ground acceleration and spectral acceleration at surface

PGA, Ss and S₁ at the surface can be calculated by multiplying PGA, Ss and S₁ at bedrock with the amplification coefficient of each site class. The amplification coefficients of site classes in certain PGA, Ss and S₁ are referred from SNI 1726:2012 [19].

The PGA on the surface (PGA_M) in Mataram as shown in figure 7 has values ranged from 0.2 to 0.3 g or 1.5 times larger than at the bedrock and tend to be larger on the west side of the city. This result shows that the amplification effect is really dominant in Mataram. Bintaro and Ampenan Utara which are closer to the Back Arc Thrust have largest PGA_M ranged from 0.28 to 0.3 g and are thus categorized E in the site class while Turida village has the lowest PGA_M in the south with 0.22 g measured, and can be classified into the D site class.

Figure 8 (spectral acceleration map for $T=0.2$ s at the surface or S_{MS}) shows that Mataram has an S_{MS} value ranged from 0.45 to 0.65 g which 1.4 times higher than the S_s at the bedrock. The west side of the city has a larger S_{MS} than any area, with the largest values in Bintaro and Ampenan Utara. It can be interpreted that the spectral acceleration surface for $T=0.2$ s in Mataram is dominated by the amplification factor, site class, and distance to the back arc thrust.

Figure 9 shows that the S_{MI} value of Mataram is ranged between 0.3-0.6 g which is 3 times larger than the S_1 . The largest value lies around Ampenan Utara with a value of around 0.45-0.6 g, which is similar to PGA_M and S_{MS} .

Based on the analysis that been made, spectral acceleration amplification is larger in longer periods. The natural vibration period of the site (1D) would appear more in long periods. So, when earthquake wave propagated in sufficient thickness site, high frequency wave will be filtered and frequency of earthquake wave will be closer to the natural vibration period of site, this condition make soil amplification will be greater [17]. This research also reveals that Ampenan Utara village has highest PGA and spectral acceleration at surface values in Mataram.

Fig. 7. Peak ground acceleration (PGA) map at surface with 2% PE in 50 years.

Fig. 8. Spectral acceleration map at surface for T= 0.2 seconds with 2% PE in 50 years.

Fig. 9. Spectral acceleration map at the surface for T= 1.0 seconds with 2% PE in 50 years.

The design spectral response study is also conducted with reference to SNI 1726:2012 [19] for D and E site classes which Mataram mostly consists of. We then compare our result with the PUSGEN [2] design which we present in graph form as shown in figure 10 for the D site class and 14 for the E site class. Figure 10 shows that the peak response spectral of this research is valued 0.42 at the 0.114-0.171 s period and has a 0.29 difference compared to PUSGEN's [2] 0.71g at 0.117-0.586 s response spectra.

While this research's response spectral for the E site class is valued 0.51 g at the 0.15-0.75 s period, which is 0.1 g smaller than the PUSGEN [2]. Sa value of the D site class is smaller than the E class, which means the E class makes slightly larger amplifications at

0.4s. It is also noted that peak response spectral for the D class has shorter period (0.114-0.571s) than the E class (0.15-0.75 s).

Fig. 10. Response spectrum for Mataram city

7 Conclusion

The PSHA analysis shows that the PGA at the bedrock in Mataram with a 2% probability of being exceeded in 50 years (return period of 2500 years) ranged between 0.171 and 0.187g. The spectral acceleration for $T=0.2$ s (S_s) ranged from 0.37 to 0.45 g and 0.16-0.18 g for $T=1$ s. The north area of Mataram has larger PGA, S_s , and S_1 values than southern Mataram which is caused by the dominance of the Back Arc Thrust north of the city.

The PGA_M of Mataram corrected by the amplification factor shows a value between 0.2 and 0.3g. The spectral acceleration at the surface for $T=0.2$ s (S_{MS}) ranged between 0.45 and 0.65 g while for $T=1$ s, this was valued from 0.3 to 0.6g.

Ampenan Utara is the area with the largest PGA_M , S_{MS} , and S_{M1} , which is mostly caused by its close proximity with the back arc thrust and because it is dominated with E class soil. While the lowest PGA_M , S_{MS} , and S_{M1} area is located at Turida village which relatively far away from the Back arc thrust and has D class soil.

The peak design response spectrum of Mataram for D class sites is 0.42 g at 0.114-0.571 s, while for the E class it is 0.51 g at 0.15-0.75s. These values are very important in the planning of earthquake resistant buildings and risk category determination.

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