Seismic hazard analysis with PSHA method in four cities in Java.

Y. Elistyawati, I. R. Palupi, and Suharsono
Physics Department of Program Pembangunan Nasional “Veteran” University,
Jl. SWK 104 (Lingkar Utara) Condongcatur Yogyakarta 55283, INDONESIA
E-mail: Yuppi_elistyawati@yahoo.co.id

Abstract. In this study the tectonic earthquakes was observed through the peak ground acceleration through the PSHA method by dividing the area of the earthquake source. This study applied the earthquake data from 1965 - 2015 that has been analyzed the completeness of the data, location research was the entire Java with stressed in four large cities prone to earthquakes. The results were found to be a hazard map with a return period of 500 years, 2500 years return period, and the hazard curve were four major cities (Jakarta, Bandung, Yogyakarta, and the city of Banyuwangi). Results Java PGA hazard map 500 years had a peak ground acceleration within 0 g ≥ 0.5 g, while the return period of 2500 years had a value of 0 to ≥ 0.8 g. While, the PGA hazard curves on the city's most influential source of the earthquake was from sources such as fault Cimandiri background, for the city of Bandung earthquake sources that influence the seismic source fault dent background form. In other side, the city of Yogyakarta earthquake hazard curve of the most influential was the source of the earthquake background of the Opak fault, and the most influential hazard curve of Banyuwangi earthquake was the source of Java and Sumba megatruts earthquake.

1. Introduction
The earthquake that happened on July 17, 2006 with a magnitude of 7.7 Mw had occurred around the island of Java and had resulted tsunami 2m tall with the type of slow earthquake. Causing substantial losses and the deaths of up to ± 659 inhabitants. Recognizing that an earthquake is one of the natural disasters that can not be predicted and caused the loss of influence on the material nor economy. Based on the research done by the source of the seismic tectonics, the method applied is a method PSHA (Probabilistic seismic hazard analysis) by dividing the seismic source into several sections. Several previous studies had done for the construction of buildings and bridges. One previous study were used as the reference was based on a map of acceleration bedrock of Team Revised 2010 for the whole of Indonesia. This paper is intended to determine the source of the most influential effect in major cities in Java. From the results of this analysis obtained map Java acceleration for a period of 500 years and 2,500 years, as well as the possible hazard curve exceeded 5%.

2. Probabilistic Seismic Hazard Analysis Method (PSHA)
On the results of the seismic hazard analysis obtained spectral response, maximum acceleration, and time-history. One method applied was the probability or often referred to PSHA developed by Cornell (1968). PSHA method is basically an analysis by performing various scenarios involving frequency
ground motion. The use of PSHA method has the advantage of taking into account factors of uncertainty so that it can estimate the greater the probability for the worst conditions that would occur in a particular area. This method has four stages, namely the identification and characterization of the earthquake, based on the characteristics of the seismicity, Election attenuation function, and a calculation to a combination of factors of uncertainty. The use of earthquake catalog of some site measurements needed to analyze the data completeness. This catalog consists of 4 different magnitude of which body wave magnitude (mb), Surface wave magnitude (ms), Richter local magnitude (ML), and the moment magnitude (MW). The scale is then converted to a magnitude that is MW.

| Correlation Conversion | Amount of Data (Event) | Range Data | Conformity |
|------------------------|------------------------|------------|------------|
| M_w = 0.143 M_s^2 – 105.1 M_s + 7.285 | 3.173 | 4.5 \leq M_s \leq 8.6 | 93.90% |
| M_w = 0.114 M_b^2 – 0.556 M_b + 5.560 | 978 | 4.9 \leq M_b \leq 8.2 | 72.00% |
| M_w = 0.787 M_E + 1.537 | 154 | 5.2 \leq M_E \leq 7.3 | 71.20% |
| M_b = 0.125 M_L^2 – 0.389 M_L + 3.513 | 722 | 3.0 \leq M_L \leq 6.2 | 56.10% |
| M_L = 0.717 M_D + 1.003 | 384 | 3.0 \leq M_D \leq 5.8 | 29.10% |

Table 1 Relationship between types magnitude earthquake (Asrurifak, 2010)

Converted data were then analyzed the completeness of the data with the first was the stage splitting time of the observation into multiple intervals of time counting backwards \[1\], then in each interval the seismic data was divided based on those ranges in magnitude \[2\], then calculated the range of the earthquake and calculate variances in each range of magnitude \[3\], and then at the last stage graphing the observation interval relationship with the variance magnitude \[4\].

![Completeness Model of the data hit the area of Indonesia from 1907 to 2015](image)

**Figure 1** Completeness Model of the data hit the area of Indonesia from 1907 to 2015

In the early stage of the identification and characteristics of the earthquake source was done by dividing the area into sections based on the source of the earthquake. Indonesia, which is between the three major continental plates, the area Brada on active tectonic zone. The existence of tectonic
activity that work resulted in the formation of mountains and forming pathways plate meetings, these areas which later became the source of the quake. Java has Java-Sumba subduction zone that stretches from the Sunda Strait to Bali Basin, but (Newcomb & McCann, 1987) divides the segment into two parts, namely Java and Sumba segment.

![Figure 2](image)

Figure 2 Megathrust segment division of earthquake source in the region of Indonesia (Asrurifak, 2010).

In addition, the development fault in Java Island, including an active fault, so that it influenced the occurrence of the earthquake. In this study the fault that was applied for Java area including fault Cimandiri, Lembang fault, Pati, Lasem, and Opak. In this study seismic source zones were divided into several sections including interface with the depth of 0-50 km zone, intraslab zone at a depth of 50-300 km, the zone at shallow crustal depths of 0-50 km consist of fault and shallow background.

![Figure 3](image)

Figure 3 The maximum magnitude and slip-rate of the sources of earthquakes (Asrurifak, 2010).

In the second stage based on the characteristics of the seismicity could be seen through the parameter b-value and earthquake rate by applying the least square method and maximum likelihood. In the area of Java the separation into two parts, a megathrust area and Benioff. Least square method can be expressed by the was conducted formula \( \log N (m) = a - bm \) with information \( N (m) \) was the frequency of earthquakes per time unit, \( m \) is the magnitude of the earthquake, \( a \) is \( a / \ln10 \), and \( b \) is \( \beta / \ln10 \). Applying the Maximum likelihood method because a value can produce \( -b \) more stable. Meanwhile,
a parameter—b— relations and annual rate \( (v) \) expressed by the formula \( v = \exp (a - \beta m) \). This method can be expressed by \( b = \log e / (-\text{Mi}) \), is the middle value of the data magnitude greater than \( \text{Mi} \).

Figure 4 b-value analysis for Siberut segment Sumatra and South Sumatra megathrust implementing the least square method and the maximum likelihood

Figure 5 analyzes of the b-value segment of Sumatra and South Sumatra Siberut Benioff implementing the least square method and maximum likelihood

Figure 6 b-value analysis for Java and Sunda megathrust segments implementing the least squares method and maximum likelihood
Figure 7 b-value analysis to segment the Javanese and Sundanese Benioff implementing the least square method and maximum likelihood.

Then we get the parameter b-value and the annual rate (v) for megathrust, Benioff, Shallow crustal and deep background in Table 2.

Table 2 Parameter values of b-value and the annual rate

| No  | Keterangan         | b     | a   | Mc  | β    | v    |
|-----|--------------------|-------|-----|-----|------|------|
| 1   | Siberut Megathrust | 0.785 | 4   | 5.8 | 1.81 | 0.28 |
| 2   | Southern Sumatra Megathrust | 1.02 | 5.73 | 5.8 | 2.35 | 0.65 |
| 3   | Jawa Megathrust    | 1.17  | 6.7 | 5.8 | 2.69 | 0.82 |
| 4   | Sumba Megathrust   | 1.18  | 6.63 | 5.6 | 2.72 | 1.05 |
| 5   | Timor Megathrust   | 1.66  | 9.3 | 5.6 | 3.82 | 1.01 |
| 6   | Siberut Benioff    | 1.58  | 8.67 | 5.8 | 3.64 | 0.32 |
| 7   | Southern Sumatra Benioff | 1.01 | 5.59 | 5.8 | 2.33 | 0.54 |
| 8   | Jawa Benioff       | 1.36  | 7.93 | 5.7 | 3.13 | 1.51 |
| 9   | Sumba Benioff      | 1.48  | 8.37 | 5.6 | 3.41 | 1.21 |
| 10  | Timor Benioff      | 1.61  | 9.33 | 5.8 | 3.71 | 0.98 |
| 11  | Shallow Crustal    | 1.24  | 7.58 | 5.8 | 2.86 | 2.44 |
| 12  | Deep Bacground     | 1.61  | 9.37 | 5.8 | 3.71 | 1.08 |

In the third stage of determining the attenuation function to parts of Indonesia are still using the attenuation of other regions that have almost the same characteristics. This can not be avoided because until now, the data ground-mention for the Indonesian region is still not enough to manufacture attenuation. For it is based on Indonesian Earthquake Map Revision Team 2010 attenuation function Indonesian territory based on those conditions of each seismic source composed as follows:

- Sources of shallow crustal earthquake, the model applied was the model of the earthquake source fault and shallow background with attenuation function (Boore-NGA Atkinson, 2008; Campbell-Bozorgnia NGA, 2008; Chiou-NGA Youngs, 2008).
• Source earthquake subduction interface (megathrust), the model applied was the model of the earthquake source subduction with attenuation function is used (Geomatrix subduction (Youngs et al., 1997); Atkinson-Boore BC rock and global source subduction, 2003; Zhao et al, 2006).

• Source earthquake Benioff, the model used is the model of the earthquake source deep background with attenuation function is used (Atkinson and Boore, Cascadia 2003; Youngs et al., 1997; Atkinson and Boore, Wordwide 2003).

In the fourth stage the calculations for uncertainty factors one with a tree logic models. The logic tree approach made it possible to use models by determining the weight factor that described the percentage chance relative of accuracy a model against other models.

![Figure 8 Logic Model tree for earthquake Background](image)

**Figure 8 Logic Model tree for earthquake Background**

![Figure 9 Logic Model Fault tree for earthquake](image)

**Figure 9 Logic Model Fault tree for earthquake**
3. Results and Discussion

![Figure 10 Logic Model tree for subduction earthquakes](image)

![Figure 11 Map of the island of Java with a possible hazard exceeded 5% in a period of 500 years anniversary](image)

Based on the analysis using a map obtained PSHA accelerated renewal of the basis for Java is composed of a map of the acceleration peaks, spectra of 0.2 seconds, and 1 second spectra with the possibility exceeded 5% return period of 500 years and return a period of 2500 years. For peak acceleration (PGA) of bedrock with the possibility of 5% exceeded the return period of 500 years can be seen in figure 10. For this area between dominated by the acceleration of 0 g - 0.2 g with a range of acceleration from 0 g ≥ 0.5 g. The value of the acceleration in the bedrock to Jakarta 0.15 g - 0.2 g, to the city of Bandung 0.25 g - 0.4 g, Yogyakarta 0.2 g - 0.4 g and 0.2 g Banyuwangi - 0.25 g.
Figure 12 Map of the island of Java hazard spectra of 0.2 seconds with the possibility of 5% exceeded the return period of 500 years

To map the basic spectral acceleration bedrock 0.2 seconds with the possibility of 5% exceeded the return period of 500 years can be seen in figure 11. This Wilayah dominated bedrock acceleration anatara 0.25 g - 0.7 g acceleration range from 0 g ≥ 1 g. Value of acceleration on the bedrock of the city of 0.4 g - 0.5 g to 0.6 g of Bandung - 0.9 g, Yogyakarta 0.35 g - 0.1 g and 0.45 g Banyuwangi - 0.6 g.

Figure 13 Map of the island of Java hazard spectra of 1 second with the possibility of 5% exceeded the return period of 500 years

To map the acceleration base rock with spectra 1 second possibility is exceeded 5% in the period of 500 years can be seen in figure 12. For this area dominated the bedrock acceleration between 0 g - 0.25 g with a range of acceleration from 0 g ≥ 0.6 g , Value of acceleration on the bedrock of the city of 0.2 g - 0.3 g to 0.2 g Bandung - 0.35 g, the city of Yogyakarta, Bandung almost equal to 0.2 g - 0.35 g, and the city of Banyuwangi 0.15 g - 0.25 g.
**Figure 14** Map of peak acceleration hazard Java with the possibility exceeded 5% in the period of 2500 years.

For peak acceleration (PGA) rock basis with the possibility exceeded 5% in the period 2500 years can be seen in figure 13. For this wilayah dominated bedrock acceleration anatara 0.25 g - 0.6 g with a range of acceleration from 0 g ≥ 0.8 g. Value of acceleration on the bedrock of the city of 0.3 g - 0.4 g, to the city of Bandung 0.45 g - 0.7 g, Yogyakarta 0.3g - 0.8 g and 0.35 g Banyuwangi city - 0.45 g.

**Figure 15** Map of the island of Java hazard spectra of 0.2 seconds with a chance exceeded 5% in the period of 2500 years.

To map the basic spectral acceleration rock 0.2 seconds with a chance exceeded 5% in the period 2500 years can be seen in figure 14. This area between dominated bedrock acceleration of 0.45 g - 1.2 g with a range of acceleration from 0 g ≥ 3 g. Value of acceleration on the bedrock of the city of 0.6 g - 0.7 g to 0.9 g of Bandung - 1.2 g, Yogyakarta 0.6 g - 2 g, and the city of Banyuwangi 0.8 g - 1 g.
To map the basic spectral acceleration rock 1 second with a chance exceeded 5% in the period 2500 years can be seen in figure 15. This area rock acceleration between dominated basic 0.25 g - 0.7 g acceleration range from 0 g ≥ 1 g. Value of acceleration on the bedrock of the city of 0.4 g - 0.45 g to 0.45 g Bandung - 0.5 g, Yogyakarta 0.3 g - 0.5 g and 0.3 g Banyuwangi - 0.35 g.

In addition to a map obtained acceleration rock base, also obtained hazard curves for the four major cities of Jakarta, Bandung, Yogyakarta, and the city of Banyuwangi. In the city hazard curve bedrock peak acceleration with the possibility exceeded 5% can be seen in Figure 16 (a). Seen in the city's most influential source of an earthquake originating from the fault Cimandiri. In addition there are sources of the fault zone megathrust earthquake on Java, but not very big. Hazard curve acceleration of bedrock in the city of Bandung in Figure 16 (b) of the most visible source of seismic influence derived from fault, fault Lembang. For megathrust fault Cimandiri and Java still have an influence on this town, but not very big.

Figure 16 Map of the island of Java hazard spectra of 1 second with a chance exceeded 5% in the period of 2500 years

Figure 17 Curve hazard peak acceleration in Jakarta (a) and the city of Bandung (b) the possibility exceeded 5%

Hazard curve acceleration of bedrock in the city of Yogyakarta in Figure 17 (c) of the most visible source of seismic influence derived from fault, fault Opak. For Lasem fault, fault Pati, megathrust Sumba and Java megathrust still have an influence on this town, but not very big. While the hazard
curve acceleration bedrock Banyuwangi shown in figure 17 (d) of the most visible source of seismic influence comes from megathrust Java and Sumba megathrust.

Based on the results of the analysis of the PSHA could be concluded that influence as the source of the earthquake the most important in several big cities in Java derived from the fault that developed as in the city of the earthquake on the Cimandiri fault, Bandung sourced from Lembang fault, and the city of Yogyakarta sourced from Opak fault. Yet, do not rule out the influence of the larger zones to Banyuwangi that the most influential source of the earthquake derived from two segments, namely Java and Sumba Megathrust. Value of acceleration on the bedrock of the island of Java was becoming southwest towards higher value.

The value of the acceleration in the higher bedrock towards the southwest visible on the map bedrock acceleration spectra exceeded 0.2 seconds with the possibility of 5% on a 500-year return period and a return period of 2500 years. Value bedrock acceleration in 0.2 seconds maps spectra return period of 500 years for the city of 0.4 g - 0.5 g to 0.6 g of Bandung - 0.9 g, 0.35 g Yogyakarta - 0, 1 g, and the city of Banyuwangi 0.45 g - 0.6 g. Acceleration value bedrock on map 0.2 spectra return period of 2500 years for the city of 0.6 g - 0.7 g to 0.9 g of Bandung - 1.2 g, Yogyakarta 0.6 g - 2 g, and the town of Banyuwangi 0.8 g - 1 g.

4. References

[1] Asrurifak M 2010 Peta Respon Spektra Indonesia Untuk Perencanaan Bangunan Tahan Gempa Berdasarkan Sumber Gempa 3D Dalam Analisa Probabilitas, Disertasi Doktor Jurusan Teknisipil, ITB
[2] Aki K 1965 Maximum Likelihood Estimate of b value in The Formula log N = a-bM and Its confidence Limits Bull Earthq 43 237240
[3] Irsyam, M., Sengara, W., Aldiamar, F., Widiantoro, S., Triyoso, W., Hilman, D., Kertapati, E., Meilano, I., Asrurifak, M., Ridwan, M., Huhardjono., 2010. Ringkasan Hasil Studi Tim Revisi Peta Gempa Indonesia 2010, Kementrian Pekerjaan Umum
[4] Jimmi N, Guntur P, Bambang S, Sri Widiyanto (2014) Analisis Hazard Gempa Dan Isoseismal Untuk Wilayah Java-Bali-NTB, Paper Jurnal Meteorologi Dan Geofisika Vol 15 No 1 Tahun 2014
[5] Widodo P, 2012 Seismologi Teknik & Rekayasa Kegempaan, Pustaka Pelajar, Yogyakarta