

## SEISMIC HAZARD ANALYSIS FOR INDONESIA

Rusnardi Rahmat PUTRA<sup>\*,\*\*</sup>

Junji KIYONO<sup>\*\*\*</sup>

Yusuke ONO<sup>\*\*\*\*</sup>

Hari Ram PARAJULI<sup>\*\*\*\*\*</sup>

\*PhD Student, Graduate School of Engineering, Dept. of Urban Management, Kyoto University, Japan

\*\*Lecturer, Civil Engineering Dept, Padang State University, Indonesia

\*\*\*Professor, Dept. of Urban Management, Kyoto University, Japan

\*\*\*\*Assistant Professor, Department of Urban Management, Kyoto University, Japan

\*\*\*\*\*Post Doctoral Fellow, RGIRO, Ritsumeikan University, Japan

(Received January 6, 2011 Accepted January 10, 2012)

### ABSTRACT

Based on compiled data during the period 1779-2010, 48,000 earthquake events exceeding M4 had occurred in Indonesia. Since the earthquake data are available in various magnitude scales, we converted all scales into moment magnitude. By using the catalogs compiled, we constructed area earthquake source model and estimated the frequency-magnitude relationship. From recorded data by accelerometers installed at four stations in Padang, we plotted observed data on the several existing attenuation equations and selected a suitable attenuation relationship for Indonesia. Peak ground acceleration on 10% probability of exceedance in 50 years for rock and soft soil condition were calculated. We compared the expected acceleration with existing ones and discussed. Based on the expected acceleration calculated, we proposed design spectra in several major cities in Indonesia.

**Keyword:** seismic hazard, earthquake, faults, source zone, areal model, design spectrum

### 1. INTRODUCTION

The Indonesian archipelago is located at the boundary of three major tectonic plates, the Indo-Australian, Pacific, and Eurasian plates, stretching from Sumatra in the west to Papua in the east (Fig.1). Indonesia is at the collision point of these three crustal plates. The high subduction-related seismicity in this region means that tsunami and other earthquake hazards are also high. Indonesia has approximately 17,504 islands, with a total land area of  $1.92 \times 10^6$  km<sup>2</sup> and a sea area of  $3.26 \times 10^6$  km<sup>2</sup>. It has experienced a

large number of earthquakes in the past. According to catalogued events, the number of earthquakes that have occurred in this region exceeds 48,000 with a magnitude greater than 4.0 from AD 1779 to 2010.

Most of the major historical earthquakes in Indonesia have caused significant damage to facilities (e.g., Utsu et al., 1992; Fauzi et al., 1999; EERI, 2010). Many large earthquakes have occurred in the shallow seas of the area that can produce massive tsunami like the 2004 Banda Aceh event. This earthquake off the coast of Sumatra resulted in hundreds of thousands of deaths and a million people homeless (Ghobarah.

A et al., 2006). The most recent one is the Mentawai tsunami that occurred on October 25, 2010.

When Indonesian region clustered into two regions, the west cover Sumatera, Kalimantan and Java, on the other hand the east covers Bali, Flores, Timor, Ambon, Sulawesi and Papua.

In western Indonesia (i.e. Java and Sumatera), Sumatra subduction zone is formed by the subduction of the Indian-Australian plate beneath the Eurasian plate at a rate of about 50 to 70 mm per year and this is the main source of subduction-related seismicity (Prawirodirjo et al., 2000). Based on our catalog, several giant earthquakes occurred in this region: 1779 (Mw8.4), 1833 (Mw9.2), 1861 (Mw8.3), 2004 (Mw9.2), 2007 (Mw7.9 and 8.4) and 2009 (Mw7.6). Although the source of the 2009 Padang earthquake on September 30 located in the ocean slab of the Indian-Australian plate at (-0.81S, 99.65E) and its depth of 80km. It produced a large shaking and severe damage to houses and building in Padang and Padang Pariaman, because its epicenter was about 60km offshore from Padang. As the Padang earthquake was an intra-slab earthquake at intermediate depth with comparable magnitude, the event did not generate a tsunami of significance (EERI. 2010). Due to this earthquake, about 1,117 people were killed, 1,214 severely injured, 1,688 slightly injured, and 3 missing. Damage to houses is about 114,797 heavily, 67,198 moderate and 67,837 slightly. About 4,000 buildings and 93 schools in Padang city were sustained damaged (Report, BNPB. 2009). This event occurred just a few minutes after office and school hour, but if it struck earlier time, the higher number of casualties would definitely occur resulted by buildings collapse.

The oblique convergence also results in lateral displacement along the Sumatera fault (Peterson et al., 2004). This fault also generates large destructive earthquakes such as in 1892 (Mw7.1), 1943 (Mw7.6) and 2007 (Mw6.4). These faults are capable of generating future strong ground motion that would affect to vulnerable structures. According to our catalogs, the Sumatera fault produces a very high annual rate of earthquakes and many of the major earthquakes occurred in shallow region under the Sumatra Island (**Fig. 2**).

In eastern Indonesia that covers Bali, Flores, Timor, Ambon, Sulawesi and Papua, three major tectonic plates (Indian-Australian, Pacific, and Eurasian

plates) interact each other. The Pacific plate subducts beneath the Eurasian plate with a rate of about 100-110mm per year at eastern Papua island (Hall et al., 2000). Subduction of Indian lithosphere beneath the Banda sea and the northern Australia plate boundary is a complex- and active-deforming region which has one of the fastest relative plate motions on the Earth (Hall et al., 2000). Based primarily on the tsunami records from 1608 to 2010 (Major et al. 2008), the eastern Indonesia experienced over 30 significant earthquake events such as 1938 (Mw8.5), 1976 (Mw7.1), 1992 (Mw7.8), 1996 (Mw8.1), 2006 (Mw7.1), 2008 (Mw7.5), 2009 (Mw7.6) and 35 tsunamis.

Probabilistic Seismic Hazard Analysis (PSHA) aims to quantify the uncertainties and produces an explicit description of the distribution of future shaking that may occur at a site (Baker, 2008). We consider all possible earthquake events and estimate ground motion along with their associated probabilities of occurrence in order to assess design ground motion for structure. The annual probability of exceedance is determined for some level of earthquake shaking at site. In this study,

We consider the earthquakes of which magnitudes are larger than 4.0 in moment magnitude scale, and adopt an areal model to determine source because earthquake events may occur anywhere in the region (see **Fig.2**). For accelerometer records observed, we compared several existing attenuation equations and selected a suitable one for Indonesia. In addition, we calculated the seismic hazard for peak ground acceleration (PGA) with 10% probabilities of exceedance in 50 years and proposed design spectra at several sites.

## 2. PROBABILISTIC SEISMIC HAZARD ANALYSIS

### 2.1 Earthquake catalog

Estimation of future seismicity is based on the rate of past earthquake determined from earthquake catalog. In this study, we compiled a new catalog of instrumentally recorded by combining several sources such as USGS catalog, ISC catalog (various bulletin of the International Seismological), Indonesian meteorology agency (BMG) and Tsunami catalog and zone in Indonesia (Hamzah et al. 2000). The new catalog is constructed by omitting overlap data of each source catalog. Since the earthquake data have been reported

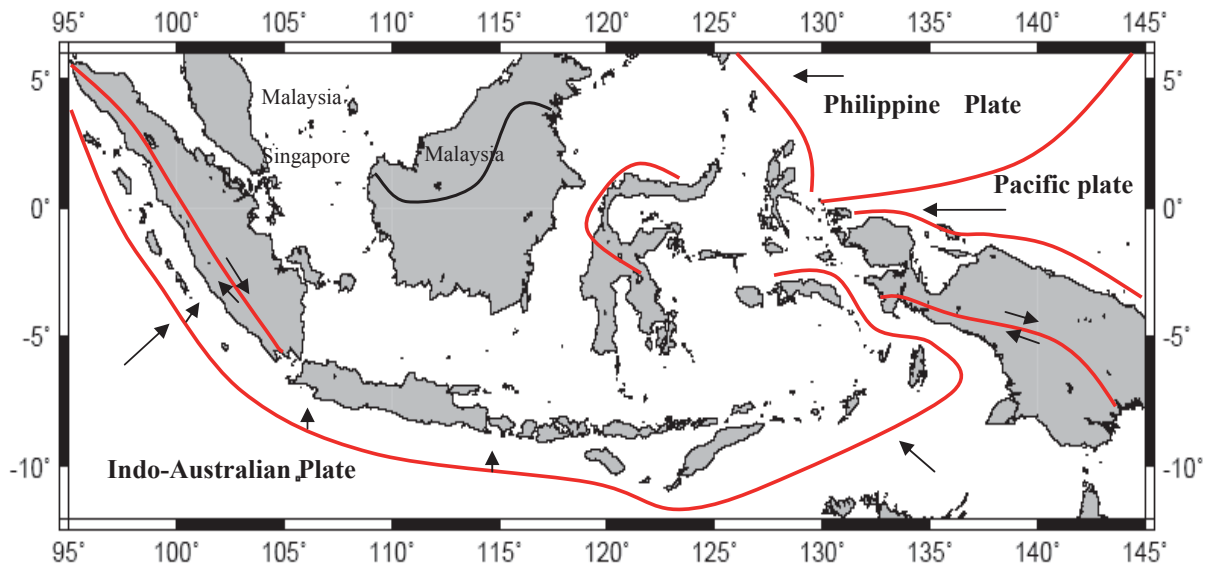


Fig. 1 Tectonic and plate boundaries, large arrows indicate the direction of plate motion

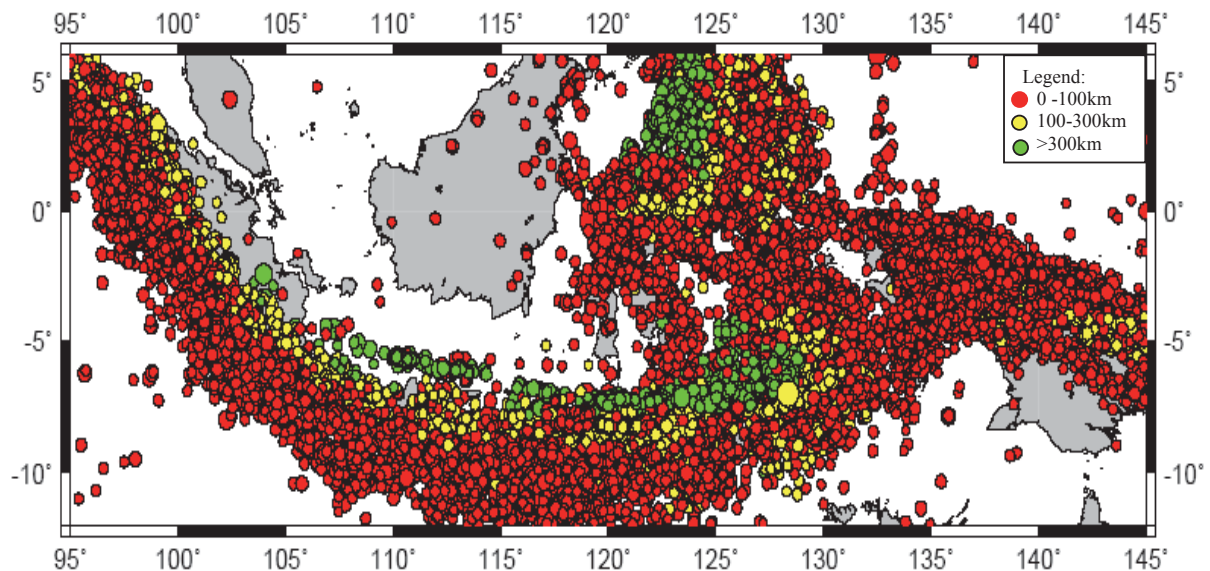


Fig. 2 Seismicity map of Indonesia region,  $M_w > 4$ . Data from USGS, ISC, Hamzah & Puspito, BMKG, the period 1779 - 2010

in different magnitude and intensity scale by the source catalogs, all data converted to moment magnitude (Hank et al. 1979). Here we are interested in all earthquake sources that have a potential to produce damaging ground motions at the site. These sources could be active faults and subductions, which are typically planar surface indentified through various means such as observation of past earthquake location and geological evidence. If individual faults are not identifiable then earthquake sources may be described by an areal region in which earthquakes may occur anywhere (Baker, 2008). In Indonesia, there are still

remains much uncertainty in active fault parameters, therefore, we adopt an area source model that can be determined only from historical earthquake data.

## 2.2 Source Zones and Recent Damage

In this study, we determine the earthquake sources described by the areal region in which earthquake occurred within radius 75 km from a target site. Main part of Indonesian island locates 95.0E to 145.0E in longitude and -9.0S to 6.0N in latitude as shown in Fig.3. The area divided into 1,400 meshes and frequency-magnitude relationship was calculated.

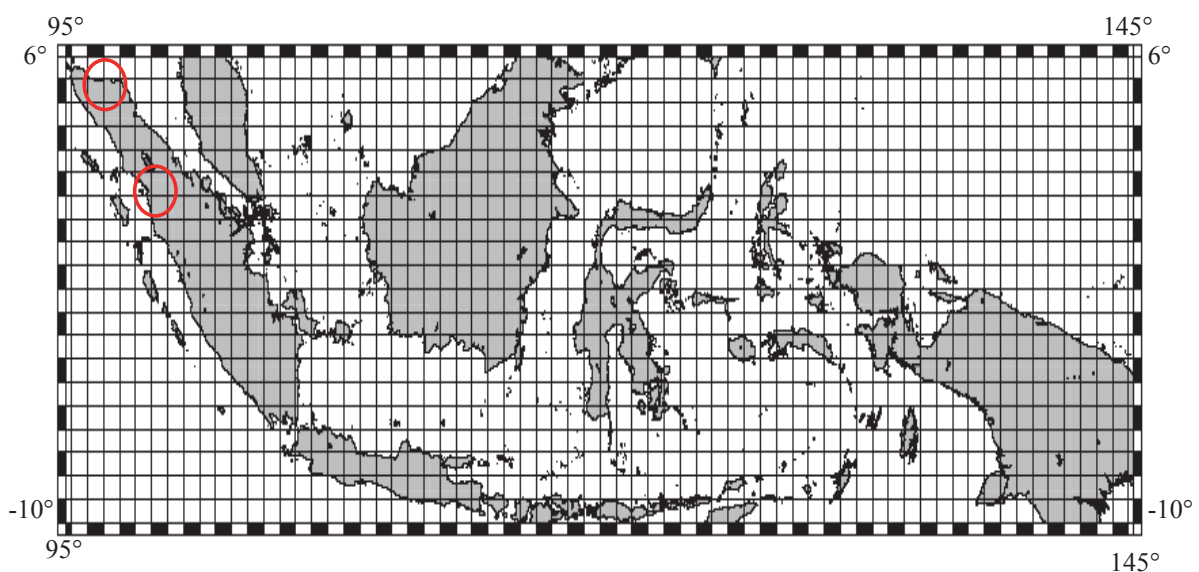
Probabilistic seismic hazard analysis carried out to estimate seismicity at the site. Firstly, hazard curves for Padang city and Banda Aceh city were calculated and compared because these cities have many experiences of giant earthquakes that produced high number of casualties and destroyed many infrastructures in the previous years.

The city of Padang, located on the west coast of Sumatra in western Indonesia, lies close to the Sumatran subduction zone that is formed by the subduction of the Indo-Australian Plate beneath the Eurasian Plate. Relative motion of the plates occurs at a rate of about 50 to 70 mm/year and this is the main source of subduction-related seismicity in the area (Prawirodirjo et al., 2000), and the Sunda trench fault. Each fault is still active until now with the slip rate ranges from 10 to 27 mm/year (Natawidjaja et al., 2007). The city of Padang, with a population of 856,814 people as of 2008, is the capital of West Sumatra province. The location of the city center is at 100.38°E, 0.95°S. The population density is very high, about 8500 people/km<sup>2</sup>. About 80% of population lives in seaside (Padang city government, 2009).

According to our catalog, about 2,995 events occurred in this region during the period from 1779 to 2010 (Fig. 4). Many giant earthquakes such as in 1779 (Mw8.4), 1833 (Mw9.2), 1861 (Mw 8.3), two times in 2007 (Mw7.9 and 8.4), the recent Padang earthquake on September 30, 2009 (Mw7.6) and the latest Mentawai earthquake on October 25, 2010

(Mw7.2) are included. The recent 2010 Mentawai earthquake, that produced tsunami damage, caused about 490 people dead and about 520 houses severely damage (Padang City Government. 2010).

On the other hand, Banda Aceh city is the capital of Aceh province. The population is approximately 260,000 as of 2006 and locates at (95.3E, 5.5N). Same as Padang, Banda Aceh situates on the coast of the Indian Ocean. According to historical earthquake catalog, about 1,839 events occurred in this region during the period from 1779 to 2010 (Fig. 5). Large earthquakes occurred in 1936 (Mw7.1), 1967 (Mw6.1), 1983 (Mw6.6), 1990 (Mw6.8) and December 26, 2004 (Mw9.3). When the 2004 Indian Ocean earthquake struck off the western coast of Sumatra, Aceh province including the cities of Banda Aceh, Calang and Maulaboh, were among hardest-hit areas by the tsunami. Banda Aceh city was the major closest city to the earthquake epicenter, and suffered destructive damage when the tsunami struck shortly afterwards. About 167,000 people died and more were injured. Tsunami resulted from an earthquake with moment magnitude 9.3 and struck at about 6:58 am. The epicenter was about 155 mile off the coast of Banda Aceh. Massive tsunami wave wiped out entire coastal areas across southeastern Asia, Sri Lanka, India, Thailand, Myanmar, island in the Andaman Sea and the Maldives in the Indian Ocean. The death toll thus has been reported as 260,000 and more than 1.5 million people became homeless around this region (Ghobarah et al. 2006).



**Fig. 3** Indonesia area analyzed and two red circles are two samples of source zone with 75 km radius for Padang city and Band Aceh

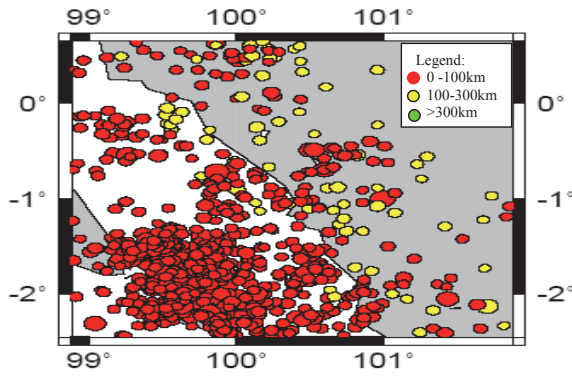


Fig. 4 Seismicity map of Padang city,  $M_w > 4$ , the period from 1779 to 2010

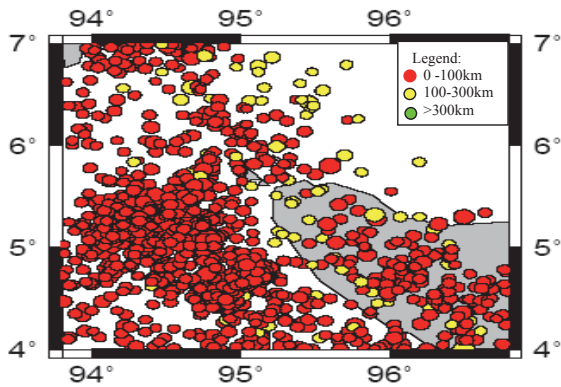


Fig. 5 Seismicity map of Banda Aceh,  $M_w > 4$ , the period from 1779 to 2010

### 2.3 Identify Earthquake Magnitudes

Subduction and faults are capable of producing earthquakes with various sizes of magnitudes. The distribution of these earthquake sizes in region generally follows a particular distribution (Gutenberg et al. 1944) given as

$$\log \gamma_m = a - bm \quad (1)$$

where  $\gamma_m$  is the mean annual rate of exceeding of magnitude  $m$ ,  $a$  and  $b$  parameter are generally obtained by regression on database of seismicity from the source zone of interest. The  $a$  value indicates the overall rate of earthquake in a region, and the  $b$  value describe the relative likelihood of large and small earthquake. It is obvious that smaller earthquake events occur more frequently than the larger ones, and hence the recurrence rates of smaller earthquake can be evaluated even from the most recent data of the last 15-20 years. On the other hand, for larger events have to consider a

much longer time frame, such as about 100 years. It is essential to identify the interval of complete recording for different magnitude ranges. To minimize the effects of incompleteness, an empirical and statistically simple method by Stepp (1972) was adopted.

The compute a cumulative distribution function (CDF) for the magnitudes of earthquake that larger than some minimum magnitude  $m_{min}$ , Eq. (1) can be also utilized. There generally is a limit on the upper bound of earthquake magnitude in a region, due to the finite size of the source faults (Baker. 2008). If a maximum magnitude can be determined as

$$F_M(m) = \frac{1 - (10)^{-b(m - m_{min})}}{1 - 10^{-b(m_{max} - m_{min})}} \quad (2)$$

$$(m_{min} < m < m_{max})$$

where  $F_M(m)$  is the cumulative distribution function for  $M$ . The probability density function (PDF) for  $M$  can be computed by taking the derivative of the CDF.

$$f_M(m) = \frac{b \ln(10)^{-b(m - m_{min})}}{1 - 10^{-b(m_{max} - m_{min})}} \quad (3)$$

$$(m_{min} < m < m_{max})$$

where  $f_m(m)$  is the probability density function for  $M$ ,  $m_{max}$  is a maximum magnitude earthquake from source. From the continuous distribution of magnitude, it will be converted into a discrete set of magnitude as follows.

$$P(M = m_j) = f_m(m_{j+1}) - f_m(m_j) \quad (4)$$

where  $m_j < m_{j+1}$ , and  $m_j$  are the discrete set of magnitude. Here we calculated the probability associated with all magnitude between  $m_j$  and  $m_{j+1}$ ,  $m_j$  started from magnitude 4 to maximum magnitude in our historical data and  $m_{j+1}$  is at interval of 0.25.

### 3. GROUND MOTION INTENSITY

Ground intensities are referred to attenuation equation or ground motion prediction. The ground motion prediction models are obtained by developing statistical regression on observation data from large libraries of observed ground motion intensities (Baker. 2008).

In Padang, there are four accelerometers, three

accelerometers were donated by the Engineer without Border, Japan (EWBJ) and the other was installed by Indonesian Government (Fig. 6).



Fig. 6 Accelerometer in Padang city

We also carried out microtremor array investigation at each station PDG001, PDG002 and PDG003 to determine the soil condition of subsurface structures (Ono et al. 2010). From the dispersion curve of array observation, we obtained the following results of  $V_{s30}$  (average shear wave velocity of upper 30m soil profile): The value at PDG001 is 1323m/sec (1<sup>st</sup> layer of 3m thickness is 163m/sec, 2<sup>nd</sup> layer of 8m thickness is 409m/sec and 3<sup>rd</sup> layer of 19m thickness is 1891m/sec) and at PDG002 is 470m/sec (1<sup>st</sup> layer of 2m thickness is 135m/sec, 2<sup>nd</sup> layer of 10m thickness is 468m/sec and 3<sup>rd</sup> layer of 18m thickness is 508m/sec). By considering the these results, the soil condition at PD001 and PDG002 are corresponding to the hard soil of which 30m-averaged shear velocity ( $V_{s30}$ ) are greater than 400m/s (Tselentis et al. 2008). Therefore, we assume that the soil type at stations of PDG001 and PDG002 is engineering bedrock with the shear wave velocity of  $400 < V_{s30} < 700$ m/s. We surveyed several attenuation relationships based on physical characteristics such as an earthquake source, seismotectonic environment and the saturation of acceleration amplitude in a near-source region of which extent depends on the size of the earthquake.

Taking into account above characteristic, three attenuation equations by Fukushima et al. (1999), Young et al. (1997) and Megawati et al. (2005) were selected. The conditions of data used for attenuation equations for 1) Fukushima et al., 2) Young et al., and 3) Megawati et al., are: 1) The earthquake sources is subduction interface,  $M_w > 5.0$  with a shortest distance

of 10-300km, the soil condition are rock and soil site, 2) The earthquake sources is subduction interface,  $M_w > 5.0$  with a hypocenter distance of 10-500km, the soil conditions are rock and soil site. 3) The earthquake sources is subduction interface, all sources data is from Sumatran earthquakes, Indonesia,  $M_w > 5.0$  with an epicentral of 150-1500 km, the soil condition is rock site.

They are compared with peak ground acceleration observed at 2 stations in Padang (Figs. 7 and 8). As no attenuation equation is currently exist in Indonesia, a suitable attenuation equation for Indonesia is determined.

Peak ground accelerations plotted are the data for earthquakes occurred in 2009 ( $M_w 4.3$  and  $M_w 6.1$ ).

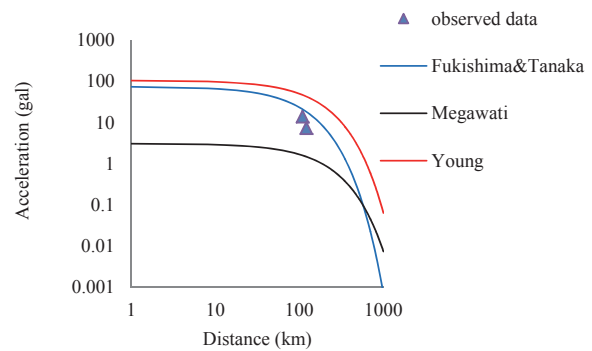


Fig. 7 Comparison of attenuation relation for subduction zone and rock condition,  $M_w=4.3$

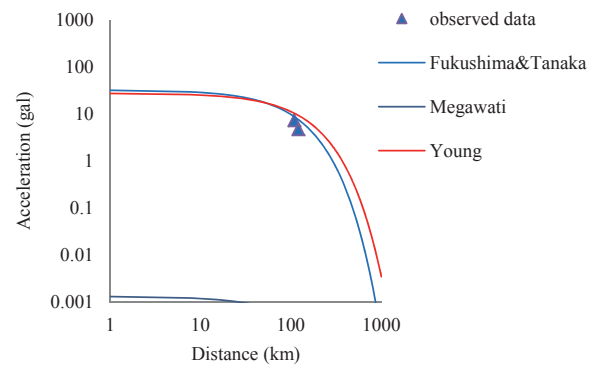


Fig. 8 Comparison of attenuation relation for subduction zone and rock condition,  $M_w=6.1$

From the comparison, we adopted Fukushima's attenuation as an appropriate equation and applied to seismic hazard analysis.

$$\begin{aligned} \log A &= 0.41 * M_w \\ &- \log(R + 0.032 * 10^{0.41 * M_w}) \quad (5) \\ &- 0.0034R + 1.3 \end{aligned}$$

in which  $A$  is peak ground acceleration;  $M_w$  is moment magnitude;  $R$  is close distance to epicenter; and  $\sigma$  is standard deviation and its value is 0.21. According to Fukushima's formulation, when the peak horizontal accelerations at the site for rock and soft soil condition are estimated, the value derived from Eq. (5) have to be multiplied by 0.60 and 1.4, respectively.

The logarithm of  $PGA$  assumed to obey normally distributed to compute the probability of exceeding any  $PGA$  level by using the mean and standard deviation.

$$P(PGA > x|m, r) = 1 - \Phi\left(\frac{\log x - \overline{\log PGA}}{\sigma_{\log PGA}}\right) \quad (6)$$

in which  $\Phi(*)$  is the cumulative distribution function. Eq. (6) is used to compute the cumulative distribution function  $P(PGA > x|m, r)$ ,  $m$ ,  $r$ , and  $x$  are magnitude, distance and acceleration respectively.

Eq. (6) can be also expressed by using the probability density function as follows

$$(PGA > x|(m, r)) = \int_x^\infty f_{PGA}(u) du \quad (7)$$

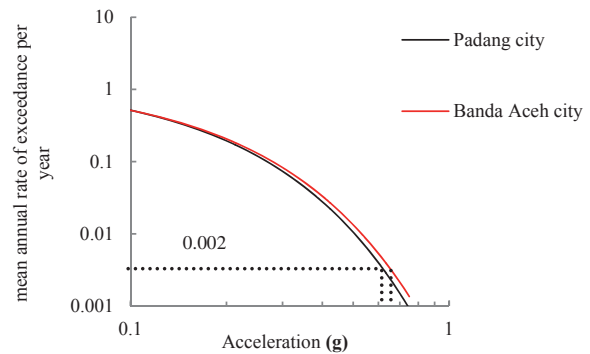
where  $f_{PGA}(u)$  is the probability density function of  $PGA$ , given  $m$  and  $r$ .

#### 4. SEISMIC HAZARD CURVE

Seismic hazard curve describes the aggregate hazard at a particular site. The seismic hazard  $H(A)$  is defined as the annual occurrence rate of earthquake that produce a ground motion exceeding a given level at a specific site, base on Cornel et al. (1968) and McGuire et al. (1976). The overall hazard is composed of the respective contribution  $H_i(A)$  from each source zones,  $i$ , out of the set of zone I as shown in Eq. (8). The range of possible  $M_i$  and  $R_i$  have been discretized into  $n_M$  and  $n_R$  interval, respectively, by using the discretization technique.

$$\begin{aligned} \lambda(IM > x) &= \sum_{i=1}^{sources} \lambda_m(M_i > m_{min}) \sum_{j=1}^{n_M} \sum_{k=1}^{n_R} P(IM > x|m_j, r_k) \\ &* P(M_i = m_j) P(R_j = r_k) \end{aligned} \quad (8)$$

where  $\lambda(IM > x)$  is the annual earthquake occurrence rate of which peak value exceeds a given level,  $x$ ;  $\lambda(M_i > m_{min})$  is the rate of earthquake with magnitude greater than  $m$ ,  $P(IM > x|m_j, r_k)$  is the probability of occurrence of the associated magnitude and distance;  $P(M_i = m_j)$  is the probability associated with all magnitude between  $m_j$  and  $m_{j+1}$  to the discrete value  $m_j$ ;  $P(R_j = r_k)$  is the probability of occurrence of the associated distance. Following above procedures, the seismic hazards for Padang city and Banda Aceh city are estimated (Fig. 9). The tendency of the curve is almost same because both cities locate under the same environment of seismic activities along the Sumatra subduction zone and the Sumatra fault (zone 7). The expected acceleration for annual rates of exceedance, 0.002 (475 years) is 0.73g and 0.70g, respectively.



**Fig. 9 Comparison of total hazard for Padang city and Banda Aceh city at 10% probability of exceedance in 50 years**

One of the advantages of probabilistic seismic hazard analysis is that we can account for all possible earthquake source in area. A disadvantage of PSHA is that concept of design earthquake is lost. Which earthquake scenario is most likely to cause  $PGA > x$ ?. Various researchers (Mcguire 1995, Chapman 1995, Harmsen et al., 1999 and Harmsen et al., 2001) have developed a model for deaggregation of hazard, calculated means and modal magnitude and distance. The mean rate of exceedance is corresponding to particular value of response acceleration at specified probability of exceedences specified period at year (e.g. 10% in 50 years) is a sum of all contribution of mean rate of exceedences from various magnitudes and distances.

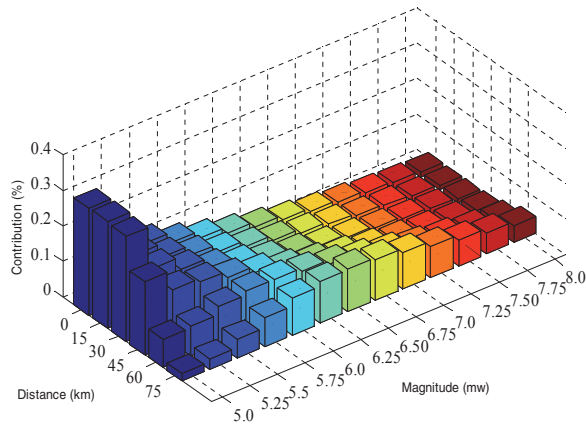
In Figs.10 and 11 shown the deaggregation results of peak ground accelerations for  $PGA > 0.2g$  with

10% probability of exceedance in 50 years for Padang city and Banda Aceh. Seismic hazard at Padang city (**Fig.10**) has the most marked magnitudes Mw5.0 with 0-45km distance, and larger magnitude (Mw7.25-8.0) are relatively higher contribution compared with seismic hazard for Banda Aceh (**Fig.11**). Seismic hazard at Banda Aceh (**Fig.11**), the most frequent magnitudes are Mw.5.0-5.25 with 0-45km distance, and larger magnitudes (Mw7.25-8.0) are relatively lower contribution compare with seismic hazard for Padang city.

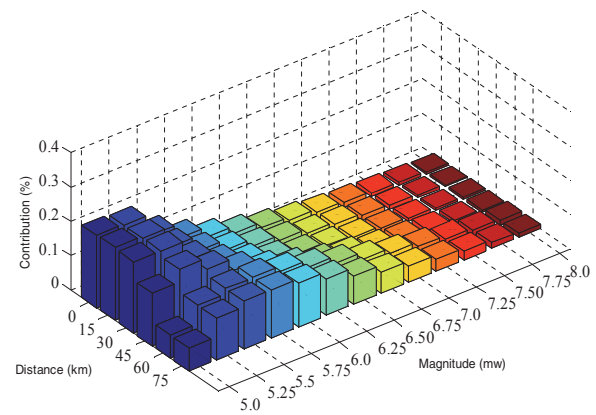
By doing the same procedure for seismic hazard

analysis as mentioned at above, we determined seismic hazard map for all Indonesian regions, which the peak ground accelerations at 10% probability of exceedance in 50 years shown in **Fig. 12** and the ranges of acceleration in the legend are the same as those in **Fig.13**, that shows hazard map of Indonesia.

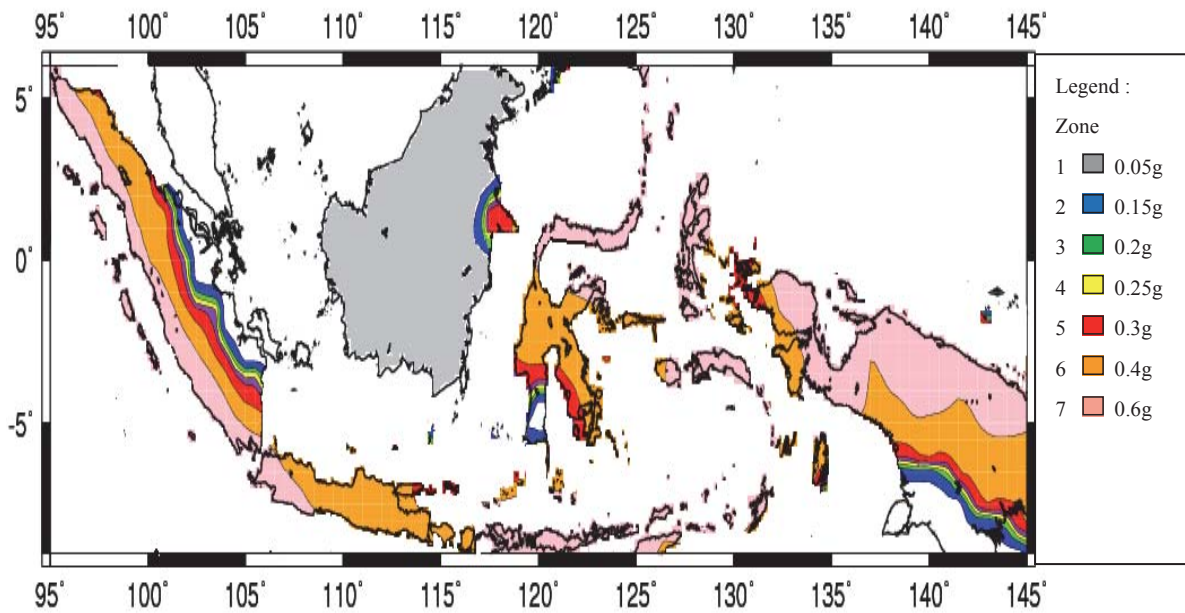
We compared our result with existing hazard map of Indonesia in 2002 (**Fig. 13**) for bedrock condition. In **Fig.13**, the area is classified into zones for hazard, each zone determined from ground peak acceleration.



**Fig. 10** Deaggregation of peak ground acceleration for  $PGA > 0.2g$ , 10% probability of exceedance in 50 years for Padang city.

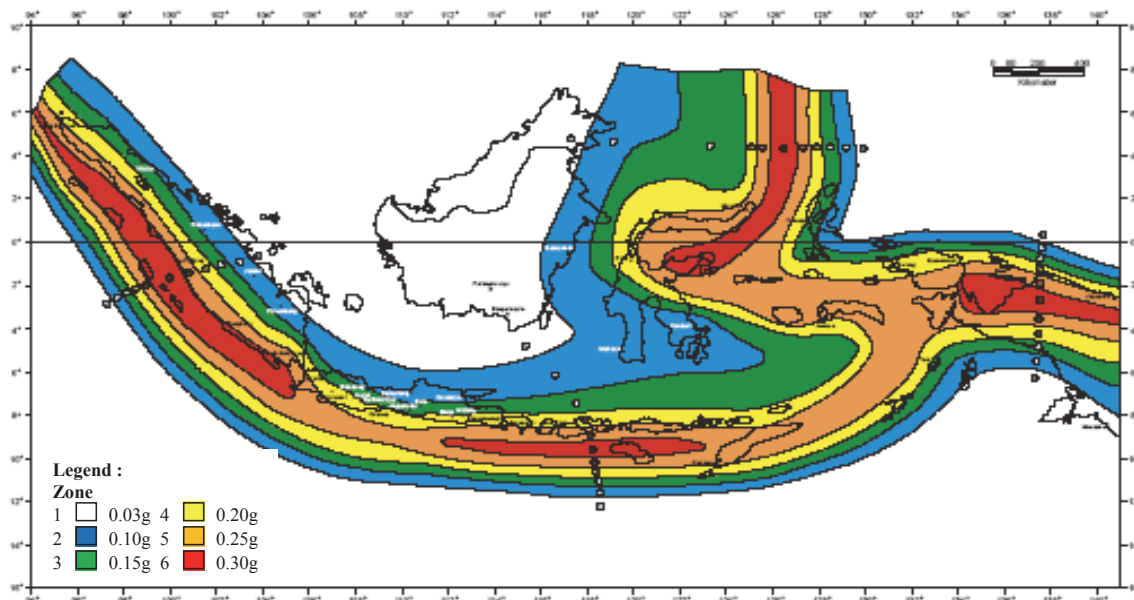


**Fig. 11** Deaggregation of peak ground acceleration for  $PGA > 0.2g$ , 10% probability of exceedance in 50 years for Banda Aceh city.



**Fig. 12** Result, the seismic hazard map of Indonesia for return period 475 years, for engineering bedrock condition.





Gambar 2.1. Wilayah Gempa Indonesia dengan percepatan puncak batuan dasar dengan perioda ulang 500 tahun

Fig. 13 Copy of the seismic hazard map of Indonesia for return period 475 years, for bedrock condition

From the comparison of existing hazard map and proposed one, we obtained the value of acceleration at 10% in 50 years for propose one is increase 25% through 100% at every site. The differences of the values might be mainly caused by the number of data collected, in which many earthquakes with magnitude greater than 6 occurred after 2002 are included. The other reasons come from the difference of attenuation equation (Chapter 3) and the difference of definition for bedrock. In Indonesia code, it is defined as the layer of  $V_s > 750 \text{ m/sec}$ , however, this paper defined it as average shear wave velocity of upper 30m soil profile  $V_s > 400 \text{ m/sec}$ .

## 5. DESIGN RESPONSE SPECTRUM

From probabilistic seismic analysis, we apply the obtained results to propose design response spectra. It becomes a useful tool for earthquake-resistant design and geotechnical response analysis. The response spectrum can also be used to represent seismic loading for the static and dynamic analysis of structure.

In this study, we adopt Indonesian code (SNI 2002) to determine the design response spectrum. The conditions of data used for Standar Nasional Indonesi (SNI2002) are  $M_w > 5.0$  with a shortest distance of 0-300km, the soil condition are rock and 10% prob-

ability of exceedance in 50 years.

According to SNI in chapter 4.7.6, the maximum acceleration response is calculated as follows;

$$A_m = 2.5 A_0 \quad (9)$$

in which  $A_0$  is the maximum earthquake ground motion considered, which is defined with uniform likelihood of exceedance of 10% in 50 years (approximate return period of 475 years). The schematic diagram is shown in Fig. 14. The value, 2.5 is amplification factors for 5% damping (Newmark et al. 1978). Period-related parameters,  $T_0$  and  $T_c$ , are determined as follows;  $T_0 = 0.2 \text{ sec}$  and  $T_c = 0.5, 0.6, 1.0 \text{ sec}$  for rock, medium (stiff soil) and soft soil (SNI. 2002), respectively. Earthquake response factor, ( $C$ ) is calculated as follows

$$C = A_m \quad \text{for } T \leq T_c \quad (10)$$

$$C = \frac{A_r}{T} \quad \text{for } T > T_0 \quad (11)$$

$$A_r = A_m * T_c \quad (12)$$

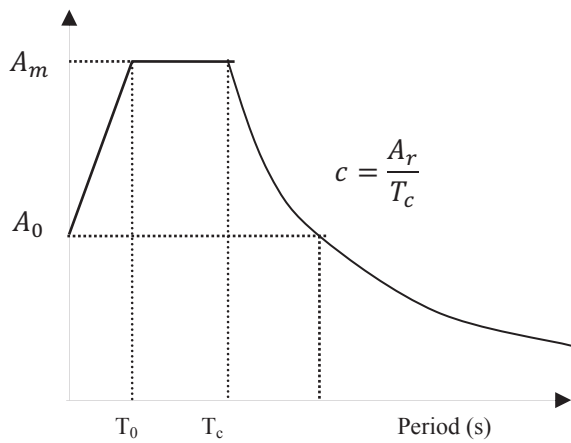


Fig. 14 Design acceleration response spectrum

Based on our analysis, we propose new response spectra for Jakarta (the capital of Indonesia), Banda Aceh city and Padang city. The results shown in Figs. 15 and 16.

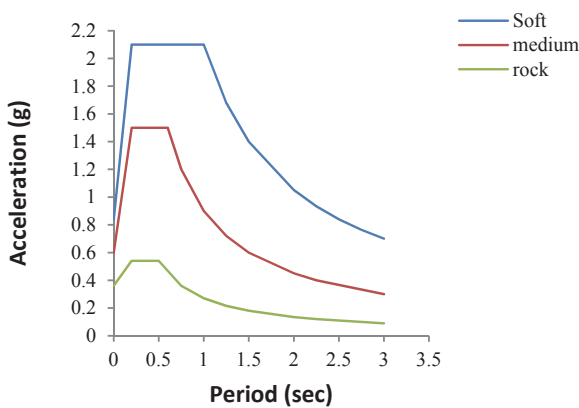


Fig. 15 Design Response spectrum 5% damping for Jakarta (zone 6)

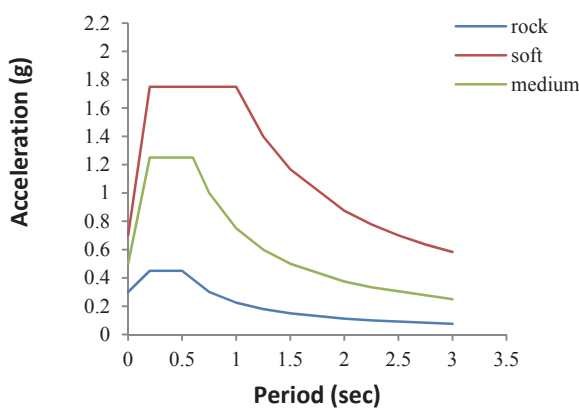


Fig. 16 Design response spectrum 5% damping for Banda Aceh city and Padang city (zone 7)

Because Banda Aceh city and Padang city locate at the same zone 7, in other to, the purpose of design response spectrum showed in the same figure (Fig. 16).

The proposed response spectrums show that the value of acceleration at each soil type for zone 6 and 7 increased about 50% through 121% by comparing with existing response spectrum in 2002. The differences of the values mainly caused by the difference value of peak ground accelerations at 10% probability of exceedance in 50 years from each hazard map.

## 6. CONCLUSIONS

From the comparison of existing hazard map and proposed one, the result of this study shows that the ground peak acceleration of 475 years at every site is higher about 30% through 90% compared with existing seismic hazard of Indonesia. The differences of the values might be mainly caused by the number of data collected, in which many earthquakes with magnitude greater than 6 occurred after 2002 are included. The other reasons are difference on attenuation equation and the definition for bedrock. The definition of engineering bedrock in our study is average shear wave velocity of upper 30m soil profile ( $V_{s30}$ ) > 400m/sec and  $V_s > 750$ m/sec for existing hazard map (SNI. 2002).

From the comparison of total hazard curve for Banda Aceh city and Padang city, Banda Aceh has higher value of the peak ground acceleration at 10% probability of exceedance in 50 years is 0.73g and 0.7g for Padang city. The proposed response spectra is larger than existing response spectra about 50% through 121%, it is due to deference of attenuation equation and bedrock level.

The next prospective is to estimate the effective peak velocity in Indonesia region for determining the exactly value of  $T_0$  and  $T_c$ . Because based on Indonesian code (chapter 4.7.6), it does not take into account the peak velocity for determining the value of  $T_0$  and  $T_c$ .

## ACKNOWLEDGMENTS

We would like to express our sincere gratitude to the Director General of Higher Education for the Indonesian Government (DIKTI) for financial support.

Special thanks are provided to the Engineer Without Border, Japan (EWBJ) who installed three accelerometers in Padang, and we used the data in our study. We gratefully acknowledge Dr. Abdul Hakam, School of Civil Engineering, Andalas University. Finally, a special thanks to Suhardjono M.eng, Director of BMKG, who provided time history data for the 2009 Padang earthquake and observation data by accelerometers around Indonesia region.

## REFERENCES

- Baker, Jack W, 2008. Introduction probabilistic hazard analysis, Handbook, Version 1.3 Oct 1<sup>st</sup> 2008.
- BNPB, 2009. Total damage report and verification for West Sumatra due to Padang earthquake, available at <http://www.bnpb.go.id>.
- Chapman, M.C, 1995. A probabilistic approach for ground motion selection for engineering design, Bull. Seimol. Soc. Am. 85, 937-942.
- Cornell, C.A. and Winterstein, S.R, 1968. Temporal and magnitude dependence in earthquake recurrence mode, Bull of the Seismological Society of America, 78(4), 1522-1537.
- EERI, 2010. The  $M_w < S > / S > 7.6$  Western Sumatra earthquake of September 30, 2009, Special Report.
- Fauzi, 1999. Private home page, Available at <http://www.gretchen.geo.rpi.edu/fauzi/xt>.
- Fukushima, Y. and Tanaka, T, 1999. A new attenuation relation for peak horizontal acceleration of strong earthquake ground motion in Japan, Bull of the Seismological Society of America. Soc. Am. 80, 757-783.
- Ghobarah, A. and Danciu, L, 2006. The impact of the 26 December 2004 earthquake and tsunami on structures and infrastructure, J. Engineering Structure 28, 312-326.
- Gutenberg, B. and Richter, C.F, 1944. Frequency of earthquake in California, Bull of Seismological Society of America, 34(4), 185-188.
- Hall, R. and Wilson, M.E.J, 2000. Neogene suture in eastern Indonesia, J. of Asian Earth Science, 34:185-188.
- Hamzah and Puspito, 2000. Tsunami catalog and zones in indonesia, J. of Natural Disaster Science, Volume 22, number 1, 2000, pp25-43.
- Hank, T. C. and Kanamori, H, 1979. A moment magnitude scale, J. of Geophysics Res., Vol. 84,2348-2350.
- Harmsen,S., Perkins, D. and Frankel, A, 1999. Deaggregation of probabilistic ground motion in central and eastern United States, Bull. Seismol. Soc. Am., 89(1), 1-13.
- Harmsen,S., Perkins, D. and Frankel, A, 2001. Mean and modal  $\epsilon$  in the deaggregation of probabilistic ground motion, Bull. Seismol. Soc. Am.,91(6),1537-1552.
- Kramer, S. L, 1996. Geotechnical earthquake engineering, 106-138, Prentice-Hall International Series in Civil Engineering and Engineering Mechanic.
- Major, J.R, Robinson, J.S and Harris, R.A, 2008. Earthquake and tsunami history and hazards of eastern Indonesia, American Geophysical Union, Fall Meeting 2008.
- McGuire, R.K, 1976. Seismic hazard and risk analysis, Earthquake Engineering Institute, MNO-10.
- Megawati, K., Pan, T.-C. and Koketsu, K, 2005. Response spectral attenuation relationships for Singapore and the Malay Peninsula due to distant Sumatran-fault earthquake, Earthquake Engineering and Structural Dynamics, Vol. 32, No. 14, pp 2241-2265.
- Natawidjaja and Wahyu Triyoso, 2007. The Sumatran fault zone-from source to hazard, J. of Earthquake and Tsunami Vol.1 No.1 (2007) 21-47.
- Newmark, N. M. and Hall, W.J, 1978. Development of criteria for earthquake resistant design, Report NUREG/CR-0098, Nuclear Regulatory Commission, Washington D.C., 49pp.
- Ono, Y., Kiyono, J., Rusnardi, P. R. and Noguchi, T, 2010. Microtremor observation in Padang city, Indonesia to estimate site amplification of seismic ground motion, Proc. of International Symposium on a Robust and Resilient Society against Natural Hazards and Environmental Disasters and the third AUN/SEED-Net Regional Conference on Geodisaster Mitigation, pp.386-391.
- Padang City Government, available at <http://www.Padang.go.id>
- Peterson Mark D., James Dewey., Stephan Hartzell., Charles Mueller., Stephan Harmsen., ArthurD. Frankel and Ken Rukstales, 2004. Probabilistic seismic hazard analysis for Sumatera, Indonesia and across the Southern Malaysian Peninsula, Tectonophysics 390 (2004) 141-158.
- Prawirodirjo, L. and Y. Bock, J.F, 2000, One century of tectonic deformation along the Sumatran fault from triangulation and global positioning system surveys, J. of Geophysical Research, 105, 28, 343-363.
- Robert Hall and Wim Spakman. 2002. Subducted slabs

- beneath the Eastern Indonesia-Tonga region: insights from tomography, *J. Earth and Planetary Letters* 201 (2002) 321-336.
- Standar Nasional Indonesia (SNI 2002) 03-1726-2002. Perencanaan struktur beton bertulang tahan gempa, ISBN: 979-8897-04-8.
- Stepp, J.C, 1972. Analysis of completeness of earthquake sample in the Pudet Sound area and its effect on statistical estimates of earthquake hazard, *Proceedings of the first microzonation conference*, Seattle, WA, 897-909
- Tselentis G-Akis and Laurentiu Danciu, 2008. Empirical relationship between modified Mercalli Intensity and Engineering ground-motion parameters in Greece, *Bull. Of the Seismological Society of America*, vol.98, No.4, pp.1863-1875.
- Utsu, T. 1992, *Catalog of destructive earthquake in the world 1500-1992*, In the *Disaster Reduction Handbook*, International Institute of Seismology and Earthquake Engineering, pp, 1-24.
- Young, R.R., Chiou, S. J. Silva, W. J. and Humphrey, J. R. 1997. Strong ground motion attenuation relationship for subduction zone. *Seimol. Res. Lett.* 68, 58-73.