Earthquake hazard zonation using peak ground acceleration (PGA) approach

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Abstract. The objective of this research is to develop seismic hazard area zones in the building infrastructure of the Banda Aceh City Indonesia using peak ground acceleration (PGA) measured using global and local attenuation function. PGA is calculated using attenuation function that describes the correlation between the local ground movement intensity the earthquake magnitude and the distance from the earthquake’s epicentre. The data used comes from the earthquake damage catalogue available from the Indonesia meteorology, climatology and geophysics agency (BMKG) with range from year 1973 – 2011. The research methodology consists of six steps, which is developing the grid, calculation of the distance from the epicentre to the centroid of the grid, calculation of PGA values, developing the computer application, plotting the PGA values to the centroid grid, and developing the earthquake hazard zones using kriging algorithm. The conclusion of this research is that the global attenuation function that was developed by [20] can be applied to calculate the PGA values in the city of Banda Aceh. Banda Aceh city in micro scale can be divided into three hazard zones which is low hazard zone with PGA value of 0.8767 gals up to 0.8780 gals, medium hazard zone with PGA values of 0.8781 up to 0.8793 gals and high hazard zone with PGA values of 0.8794 up to 0.8806 gals.

1. Introduction
Indonesia is one of the countries in the world with a high intensity of earthquakes. The United States Geological Survey catalog (USGS) recorded four large earthquake incidence in Indonesia which is Banda earthquake (8.5 Mw) in 1983, Sumatera-Andaman Islands earthquake (9.1 Mw) in 2004, North Sumatera earthquake (8.6 Mw) in 2005 [17] and Sumatera West Coast earthquake (8.6 Mw) in 2012 [18]. The high intensity of earthquake is the main characteristics of tectonic of the Islands of Indonesia which is located between three main plates, which is the Eurasia plate at the North, Indo-Australia plate at the South and Pacific plate at the Northeast. Earthquake with a specific intensity and magnitude as a response of plate movements can cause physical infrastructure damage and casualties.

The most dominant physical Infrastructure damage due to earthquake is the damage of the buildings, whether is due to the poor quality of constructions (internal) or due to the building conditions (external) where the building is located. The number of building damages that is significant is recorded in Banda Aceh city Indonesia as the effect of the Sumatera-Andaman Islands earthquake in 2004 with a total building damage up to 35% out of all buildings [8]. The condition
also occurred in other towns as an effect of a different earthquake with a total damage on 140,000 building units caused by the Bantul, Indonesia earthquake in 2006 [11]. The most casualties as a result of earthquake followed by tsunami are recorded at the Province of Aceh and North Sumatera occurred in December 2004 with total casualties of 110,229 people died, 12,123 people missing and 703,518 people evacuated [5]. The study to assess building damages caused by earthquakes conducted by [8] in Banda Aceh city concluded that the building damages shows a certain directed spatial pattern on the northwest-northeast relatively parallel to the coast line.

On an earthquake case, the damage pattern on buildings is determined by the earthquake factor itself and the environment conditions where the building is built. The relationship between earthquake factor and the effect it causes can be studied by the attenuation function (attenuation relationship) where this function serves as a key component to assess earthquake hazard [13]. The earthquake hazard assessment and its relationship with the damage of building infrastructure can be performed using the acceleration value in the ground or peak ground acceleration (PGA).

In order to assess the earthquake hazard especially for Banda Aceh city, this research is aimed to develop an earthquake hazard zonation for the building infrastructure using the PGA value approach which is adopted from the global attenuation function by [20], and the local attenuation function that is adopted from [12]. The information resulted from the earthquake hazard assessment in the city is necessary nowadays for development in order to develop a city with earthquake resistance physical infrastructure and to minimize the casualties in an earthquake event.

2. Attenuation Function
The information regarding the PGA characteristic caused by earthquake can be obtained from the records of earthquake events in the past. The records of ground acceleration allow to extract the main characteristics from the ground motion recordings such as the peak ground velocity, can be calculated as the acceleration of the ground (ground acceleration) as well as the acceleration of earthquake on the ground surface. The PGA values can be calculated using the attenuation function. The attenuation function is a function that represents the correlation between the intensity of local ground movement (a), the earthquake’s magnitude (M), and the distance between one point in the source of the earthquake (r).

Experts have formulated the attenuation function where the attenuation function which is applied in one location does not necessarily mean that it can be applied elsewhere, because the attenuation function is highly dependent on the natural condition in one location. The selection of attenuation function is based on the equality geological condition and tectonic in the area where attenuation function is developed [7].

Currently variants of attenuation function exists, such as a function for shallow earthquake source, deep earthquake background and attenuation function for the source of the earthquake caused by subduction, as published by[1][4][6][15][10][13][15][20].

A regression attenuation function using the earthquake data catalogue between plates with variety of magnitude between 5–8.2 Mw recorded in subduction area in Alaska, Chile, Cascadia, Japan, Mexico, Peru and the Solomon Islands suggested by [20]. The attenuation function is modified by [15] by comparing the observed value and the predicted value using earthquake data catalogue year 1991 – 2001 in the area covering New Ireland, New Britain, Kamchatca, Santa Cruz Islands, Peru, Kurile Islands, Japan and Sumatra. The modification of the attenuation function is concentrated on the case with the distance of the epicenter greater than 200 Km with a magnitude 6.8 – 8.3 Mw.

An attenuation function for the subduction in Cascadia from the function recommended by [20] using stochastic finite-fault ground motion model with a variant on the high magnitude ranging from 8.0 – 9.0 Mw developed by [6]. The advantage using this model is that there are no empirical attenuation relation, which require a sample and geometrical based on a series of available strong motion, the effect of finite-fault such as rupture propagation, directio and source to the geometrical site, can be systematically calculated with the stochastic finite-fault model.
Maximum similarity regression method with moment magnitude 5.0 - 8.3 Mw coming from subduction area in the world such as Alaska, Japan, Mexico and Central America is used by [1] to develop the attenuation function. The result of the analysis of the regional variables from ground motion amplitude using an available global database to support facts that there exists a significant difference between regional as shown by the different amplitudes two or more facts between the area of Cascadia and Japan. This model is only using the closest distance from the epicenter on the range 10 – 500 Km as used by [20] and [6].

In the same year [4] used a combination of empirical model that uses the estimated ground motion value, whether it is stochastic or theoretical model to develop a typical regression model to be implemented in the east of North America zone (ENA) using a regression model which has been developed earlier using earthquake data in the west of North America (WNA). Attenuation function by [4] is developed mostly using earthquake with a variety of magnitude 5.0 – 7.5 with the closest straight line distance from the epicenter (1 – 1000 Km).

[10] Using an earlier reference of attenuation function that was developed by [20] a regression attenuation function model using the recordings of earthquake at the surface in a subduction between plates in Northeast Taiwan and other area with a low magnitude around 4.1 up to 8.7 on the Richter scale. The usage of low magnitude (< 5.0 Mw) is somewhat different from attenuation function that was developed by earlier researcher.

The development of the latest local attenuation function was developed by [13] from the attenuation function also developed by [12] in the form of synthetic movement regression of surface rocks in the earthquake zone cause by subduction between plates on the West coast of Sumatra using finite-fault kinematic model as adopted from [6]. The validation of this model is using megathrust Sumatra data covering earthquakes with a magnitude up to 9.0 Mw.

3. Methodology

Research data is obtained from the earthquake catalogue from the Indonesia meteorology, climatology and geophysics agency (BMKG) with damages (< 5.0 Mw) spanning from year 1973 – 2011 (39 years) in a radius of 500 Km from Banda Aceh city. Data attribute consist of the date and time of the earthquake, the coordinates of earthquake center, depths and the earthquake magnitude.

The data processing in this research consists of six steps which is (1) grid development, (2) the calculation of distance from the epicenter to the grid centroid, (3) computer application development, (4) PGA value calculation, (5) plotting the PGA values in each of the grid centroid, and (6) development of hazard zone using kriging algorithm. Grids with a size of 1 x 1 square Km with a total of 255 grids covering all of the area and surroundings, each grid is determined by the centroid. The distance from the epicenter to the grid centroid is calculated by comparing the epicenter coordinate grid centroid and following equation:

\[
D = \sqrt{(A_{long} - B_{long})^2 + (A_{lat} - B_{lat})^2}
\]  

(1)

Where D is the distance from the epicenter to the centroid (Km); A_{long} is longitudinal coordinate of the epicenter; B_{long} is the longitudinal coordinate of the grid centroid; A_{lat} serves as the latitude of the epicenter and B_{lat} serves as a latitude of the grid centroid.

The PGA value is calculated using two global attenuation functions which is adopted from [20] and the local attenuation function from [12]. The equation of Youngs’ attenuation function can be elaborated as follows:

\[
\ln(\text{PGA}) = 0.2418 + 1.414M + C1 + C2(10-M)^3 + C3 \ln(r_{rup}) + 1.781M0.55M + 0.006M + 0.3846Zr
\]

(2)

where PGA is the peak ground acceleration (gals) value; M is the earthquake magnitude value (Richter Scale); r_{rup} is the horizontal distance from the epicenter to the grid centroid; H is the depth of
the earthquake center (Km); Zr is the type of epicenter (0 for interface and 1 for intraslab) and C1, C2, C3 represent the regression coefficient from the function (C1 and C2 value 0 and C3 = -2.552).

The equation for the local attenuation function from Megawati et al, 2005 can be elaborated as follows:

\[ \ln(\text{PGA}) = \alpha_0 + \alpha_1 Mw + \alpha_2 Mw^2 + \alpha_3 \ln(R) + \alpha_4 R + \alpha_5 H + \varepsilon H \]  

where PGA is the peak ground acceleration (gals); M is the earthquake magnitude (Richter Scale); R is the horizontal distance from the epicenter to the centroid; H represents the depth of the earthquake center (Km). The variation of PGA is highly dependent on the \( \varepsilon H \) value, which is a random number from the source’s parameter (\( \varepsilon H = 0.4413 \)); \( \alpha_3 \) represents the average value of geometrical regression (\( \alpha_3 = -1 \)); \( \alpha_4 \) represents the inelastic attenuation coefficient (\( \alpha_4 = -0.001548 \)) and other coefficient values which is \( \alpha_0 = -7.198, \alpha_1 = 2.3691, \alpha_2 = -0.013856 \) and coefficient \( \alpha_5 = 0.08909 \).

The calculation of the distance as well as the PGA values for the whole grid is performed by the computer application which is developed especially for this research. The application is developed using Visual C with a database is connected to an MS. Excell spreadsheet.

Next step is to plot the average PGA on each grid, using ArcMap Software, and the development of zonation using kriging algorithm. Kriging is a method of optimal prediction or estimation in geographical space, often known as a best linear unbiased predictor (BLUP). It is the geo-statistical method of interpolation for random spatial processes. Kriging provides a solution to a fundamental problem faced by environmental scientists of predicting values from sparse sample data based on a stochastic model of spatial variation. One methods of kriging is ordinary kriging. Consider that a random variable, \( Z \), has been measured at sampling points or locations, \( x_i \), \( i = 1, \ldots, n \), and we want to use this information to estimate its value at a point \( x_0 \) (punctual kriging) with the same support as the data.

\[ \hat{Z}(x_0) = \sum_{i=1}^{n} \lambda_i z(x_i) \]  

Kriging is calculate the best estimation of \( \hat{Z}(x_0) \) which based on spatial dependencies stochastic model which good perform by semi-variogram \( \gamma(h) \). The value of \( \lambda \) estimated by:

\[ \lambda = C^{-1}D \]

\[ \lambda = \begin{bmatrix} \lambda_1 \\ \lambda_2 \\ \vdots \\ \lambda_n \\ \mu \end{bmatrix}, \quad C = \begin{bmatrix} C_{11} & C_{12} & \cdots & C_{1n} \\ C_{21} & C_{22} & \cdots & C_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ C_{n1} & C_{n2} & \cdots & C_{nn} \\ \end{bmatrix}, \quad D = \begin{bmatrix} C_{10} \\ C_{20} \\ \vdots \\ C_{n0} \\ 1 \end{bmatrix} \]  

where \( C \) is the matrix of semi-variances between data points and \( D \) is the vector of semi variances between data points and the target. The empirical semi-variances can be estimated from data, \( z(x_i), z(x_j), \ldots \), by

\[ \hat{\gamma}(h) = \frac{1}{2n(h)} \sum_{i=1}^{n(h)} [z(x_i + h) - z(x_i)]^2 \]  

where \( n(h) \) is the number of data points within the distance \( h \).
where $z(x_i)$ and $z(x_i+h)$ are the actual values of $Z$ at places $(x_i)$ and $(x_i+h)$, and $m(h)$ is the number of paired comparisons at lag $h$

4. Result and Discussion

4.1. Ground Acceleration and Attenuation Function

PGA in the research area is calculated using attenuation function adopted from [20] to represent the global attenuation function and the attenuation functio by [12] representing local attenuation. Local attenuation function has been validated using the Sumatera earthquake incident in 2004, which also represents one of the data series used in this research. The usage of two different attenuation function in this research is to realize the difference and similarities of data and results in order to achieve the goal of this research.

To realize the data consistency and the resulting PGA value, plotting is performed to recognize the regression relationship between the resulting PGA values against the distance of the epicenter and depth of earthquake for both attenuation functions. The use of the local attenuation function where the relation of the PGA values and the epicenter distance showed the data distribution with a considerable amount of maximum and minimum differences, although it still showed the reduction of linear PGA values against the increase of distance from the measured location against the epicenter (Fig. 1). The graphs measuring the PGA and the depth of the earthquake showed a data distribution that is inconsistent where the data distribution showed that the high value of the depth of the earthquake showed a high value of PGA (Fig. 2).

This fact still requires further reassessments especially for the calculation of the PGA with a series of large data in an area of destructive earthquake.

![Figure 1](image1.png) ![Figure 2](image2.png)

**Figure 1.** Relation between PGA Values and Distance from the epicenter using [12] attenuation function

**Figure 2.** Relation between PGA Values and depth of earthquake using [12] attenuation function

Plotting the calculated data that uses attenuation function [20] shows the relation between the PGA values and the epicenter’s distance with data distributed with a small difference between the maximum and minimum values and also shows that there is a strong relation between the decrease of linear PGA value against the increase of the distance to the measured location against the epicenter. (Fig. 3)

Plotting the PGA relation and the depth of the earthquake also shows that the data distributed is consistent, where the graphs shows the increase of the linear earthquake’s depth against the PGA values which is decreasing (Fig. 4). The consistency of these relations represents facts that the use of global attenuation function as explained by [20] can be applied accordingly to the local condition
(Banda Aceh City) where its tectonic conditions may differ from those where the model was developed.

![Figure 3](attachment:image1.png)  ![Figure 4](attachment:image2.png)

**Figure 3.** Relation between PGA Values and Distance from the earthquake’s epicenter using [20] attenuation function  
**Figure 4.** Relation between PGA Values and Distance from the earthquake’s depth using [20] attenuation Function.

The validity of the PGA values with the global attenuation function is also supported by the model developed by [15] which is using the Sumatra earthquake catalogue with various global as well as regional attenuation functions. The linear relation resulted from the model (Fig.5) is similar with the relation of PGA values and the distance from the earthquake’s epicenter which is the result of this research (Fig.3).

![Figure 5](attachment:image3.png)

**Figure 5.** Model of the relation of PGA and the distance to the earthquake’s epicenter from [15] attenuation function

### 4.2. Peak Ground Acceleration in Banda Aceh City Indonesia

The PGA value calculated by the global attenuation function varies with a minimum of 0.8767 gals and maximum of 0.8806 gals with the average of 0.8785 gals. The PGA which is calculated using the local attenuation function has a variation with minimum value 1.2375 gals and maximum value of 1.2729 gals with average value of 1.2557 gals. The PGA values resulted from the two different attenuation function shows a significant difference of average 0.3771 gals. The global PGA value has the tendency to be lower than the PGA value resulting from the local attenuation function (Table 1).

[3] In their research, experimented using two different methods, that is calculating PGA from the attenuation function adopted from [12] using the data from the Sumatera Earthquake Incident 2004 and performed a direct measurement. The PGA resulting from the calculation is 1.11 gals and from direct measurement is 0.3 gals. The PGA values from this measurement is slightly higher compared to

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the result that was published by [2] where Banda Aceh city has PGA value in the range of 0.2 gals up to 0.25 gals and lower than the result of direct measurement from the area by [16] in the district of Meuraxa, city of Banda Aceh, using cone penetration test with a result between 0.325 gals up to 0.4 gal.

[7] In their proposal to improve the Sumatra and Java earthquake hazard map using attenuation function [20] and 3-Dimensional (3D) fault source model resulting in PGA value from 0.6 to 0.7 gals for Banda Aceh city and its surroundings. The proposal for the improvement of this value is based on the Sumatera earthquake 2004, North Sumatra earthquake 2005 and Bantul earthquake 2006.

The difference of PGA value whether it is calculated using local or global attenuation function and the value resulted by the earlier researchers and the differences by using a variety of methods is shown in Table 1.

Table 1. Average PGA value calculated using global attenuation function by [20] and local by [12] and its corresponding differences from the calculated values and actually measured by [3]

| Adopted Attenuation Function | PGA Minimum | PGA Maximum | PGA Average |
|------------------------------|--------------|-------------|-------------|
| PGA value [12]              | 1.23758      | 1.27293     | 1.25568     |
| PGA value [20]              | 0.87670      | 0.88064     | 0.87858     |
| Difference [12] and [20]    | 0.36087      | 0.39229     | 0.37710     |
| Difference [12] and [3] - Calculated | 0.12758 | 0.16293     | 0.14568     |
| Difference [12] and [3] - Measured | 0.93758 | 0.97293     | 0.95568     |
| Difference [20] and [3] - Calculated | 0.23330 | 0.22936     | 0.23142     |
| Difference [20] and [3] - Measured | 0.57670 | 0.58064     | 0.57858     |

The difference in the calculated result of PGA value from two attenuation function local and global, also represented by [3] in the research of earthquake hazards conducted in [10] uses attenuation function from [10] as a reference in the global attenuation function. In that research, a difference of result is obtained, where the results from the researcher states that using attenuation function to calculate the PGA value, the predicted value is higher compared to the result obtained using the earlier attenuation function to calculate the PGA values and lower compared to using the attenuation equation used globally in particular for earthquake zones of subduction.

4.3. Earthquake Hazard Zonation in Banda Aceh City Indonesia

Banda Aceh and its surroundings, based on the result of PGA calculations from a series of earthquake data within the last 39 years, can be divided into three different hazard zones for each of the attenuation functions used. Zonation which resulted from the attenuation function [20] Banda Aceh can be divided into low hazard zone, with PGA value 0.8767 gals up to 0.8780 gals, medium hazard zone with PGA value 0.8781 gals up to 0.8793 and high hazard zone with PGA value 0.8794 gals up to 0.8806 gals. The spatial distribution of each hazard zone class can be seen on Fig.6.

As the zoning of attenuation function [20], the zoning obtained from the attenuation function Megawati et al, 2008, Banda Aceh can also be divided into three hazard zones which is low hazard zone with PGA value ranging from 1.2375 gals up to 1.2493 gals, medium hazard zone with PGA values ranging from 1.2494 gals up to 1.2611 and high hazard zones with PGA value ranging from 1.2612 gals till 1.2729 gals. The spatial distribution on each hazard zone class can be seen in Fig.7.

In more detail and using actual measurement dataset from the incident on the field, [16] performed micro-zonation of earthquake hazard, particularly in district of Meuraxa in Banda Aceh city and divided the region into three zones, whic is hard soil, medium soil and soft soil, each having PGA value 0.325 gals, 0.325 gals up to 0.375 gals and 0.375 gals up to 0.40 gals respectively. Spatially, the zonation proposed is within the medium earthquake hazard zone based on the zonation developed by using the calculated value using [20] attenuation function as well as the attenuation function from [12].
5. Conclusion

The global attenuation function that was developed by [2] can be applied accordingly to calculate the peak ground acceleration (PGA) in Banda Aceh City Indonesia using the earthquake data from Sumatera. The attenuation function from [12] requires further assessment to be able to apply it especially for the Sumatera earthquake for destructive earthquake.

The PGA value in Banda Aceh City which is calculated using global attenuation function varies from a value of minimum 0.8767 gals and maximum 0.8806 gals with average value 0.87858 gals. There is a discrepancy in the result obtained between the PGA value calculated by global and local attenuation function with a difference of 0.37710 gals. Banda Aceh can be divided into three earthquake hazard zones which is low hazard zone with PGA value 0.8767 gals up to 0.8780 gals, medium hazard zone with PGA value 0.8781 gals up to 0.8793 and high hazard zone with PGA value 0.8794 gals up to 0.8806 gals.

References

[1] Atkinson, G. M., & Boore, D. M. 2003 Empirical ground-motion relations for subduction-zone earthquakes and their application to Cascadia and other regions Society, 93(4), 1703-1729
[2] Badan Standarisasi Nasional 2002 (In Bahasa) Standar Nasional Indonesia-Tata Cara Perencanaan Ketahanan Gempa Untuk Bangunan Gedung (SNI 03-1726-2002).
[3] Balendra, T., & Li, Z. 2008 Seismic Hazard of Singapore and Malaysia Earthquake 57-63.
[4] Campbell, K. W. 2003 Prediction of Strong Ground Motion Using the Hybrid Empirical Method and Its Use in the Development of Ground-Motion (Attenuation) Relations in Eastern North America. Society, 93(3), 1012-1033.
[5] Indonesia. State Ministry for National Planning Development Agency/BAPPENAS 2005 Preliminary damage and loss assessment-the December 26, 2004 natural disaster. Jakarta: Government Printer.
[6] Gregor, N. J., Silva, W. J., Wong, I. G., & Youngs, R. R. 2002 Ground-Motion Attenuation Relationships for Cascadia Subduction Zone Megathrust Earthquakes Based on a Stochastic
Finite-Fault Model. *Society*, 92(5), 1923-1932.

[7] Irsyam, M., Dangkua, D. T., Hendriyawan, Hoedajanto, D., Hutapea.B.M., Kertapati, E.K., Boen, T., Petersen. M.D 2008 Proposed seismic hazard maps of Sumatra and Java islands and microzonation study of Jakarta city Indonesia. *Earth System Science*, (November), 865-878.

[8] Irwansyah. E 2010 Building Damage Assessment Using Remote Sensing, Aerial Photograph and GIS Data: Case Study in Banda Aceh After Sumatera Earthquake 2004. *Proc. Int. Conf on Intelligent Technology and Its Application-SITIA 2010* vol 11, pp.57.

[9] Kramer. S.L 1996 *Geotechnical Earthquake Engineering*. Prentice Hall, Upper Saddle River, New Jersey, USA.

[10] Lin, P.-S., & Lee, C.-T 2008 Ground-Motion Attenuation Relationships for Subduction-Zone Earthquakes in Northeastern Taiwan. *Bulletin of the Seismological Society of America*, 98(1), 220-240. doi:10.1785/0120060002

[11] Miura, H., Wijeyewickrema, A. & Inoue, S 2006 Evaluation of Tsunami Damage in the Eastern Part of Sri Lanka due to the 2004 Sumatra Earthquake using High-Resolution Satellite Images. *Proc.Int. Work. on Remote Sensing for Post-Disaster Response* [Online]. Available: http://ares.tu.chiba-u.jp/workshop/ChibaRS2005/Paper_Miura.pdf [Sep.13, 2005]

[12] Megawati K, Pan TC, Koketsu K 2005 Response spectral attenuation relationships for Sumatran-subduction earthquakes and the seismic hazard implications to Singapore and Kuala Lumpur. *Soil Dynamics and Earthquake Engineering*, vol.25, no.1, pp11-25.

[13] Megawati, K., & Pan, T.-chien 2010 Ground-motion attenuation relationship for the Sumatran megathrust earthquakes. *Earthquake*. 827-845. doi:10.1002/eqe

[14] MM. Fischer and A. Getis 2010 *Handbook of applied spatial analysis: software tools, method, and applications*. New York:Springer.

[15] Petersen, M. D., Dewey, J., Hartzell, S., Mueller, C., Harmen, S., Frankel, A. D., & Rukstales, K 2004 Probabilistic seismic hazard analysis for Sumatra , Indonesia and across the Southern Malaysian Peninsula. *Tectonophysics*, 390, 141-158. doi:10.1016/j.tecto.2004.03.026

[16] Sengara I.W 2008 Seismic Hazard And Microzonation For A District In Banda Aceh City Post 2004 Great Sumatra Earthquake. *Proc.Int.Conf on Earthquake Engineering* October 12-17, 2008, Beijing, China

[17] USGS 2009 Historic World Earthquakes [Online]. Available: http://earthquake.usgs.gov/earthquakes/world/historical_country.php#indonesia. [November 23th, 2009]

[18] USGS 2012 Magnitude 8.6 - Off The West Coast Of Northern Sumatra. [Online]. Available: http://earthquake.usgs.gov/earthquakes/recenteqww/Quakes/usc00905e.php. [May 13th, 2012]

[19] Villaverde. R 2009 *Fundamental Concepts of Earthquake Engineering*, CRC Press-Taylor and Francis Group, Boca Raton, FL, USA

[20] Youngs et al 1997 Strong Ground Motion Attenuation Relationship For Subduction Zone Earthquake.pdf. (n.d.).