INTERNATIONAL SOCIETY FOR SOIL MECHANICS AND GEOTECHNICAL ENGINEERING

Development of Map of Maximum Considered Earthquake Geometric Mean (MCE_G) PGA for Earthquake Resistance Building Design in Indonesia

Élaboration de la carte de moyenne géométrique du tremblement de terre maximum considéré (MCEG) PGA pour la conception antisismique des bâtiments en Indonésie

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ABSTRACT: This paper presents the development of Maximum Considered Earthquake Geometric Mean (MCE_G) PGA map of Indonesia. The map was developed by combining probabilistic approach for 2% probability of exceedance in 50 years and deterministic approach. The study was performed to develop hazard map of Indonesia for revision of the hazard map in the Indonesian Earthquake Resistant Building Code SNI-03-1726-2002. The seismic parameters used in this study were derived from published journals, proceedings, previous researchers and by considering latest geological and seismological data. Earthquake source parameters were determined based on earthquake catalog, geological and seismological information of active faults. Seismic sources were divided into subduction, fault, and background zones by considering recurrence relationship that included truncated exponential model and pure characteristic model. Geometry of fault and subduction were represented by three-dimensional (3D) models based on the result of tomography, while slip-rates of faults were determined by considering the results of GPS measurement. Background source zones were modeled using gridded models based on spatially smoothed earthquake rates. Finally map of Maximum Considered Earthquake Geometric Mean (MCE_G) PGA was then developed by combining probabilistic and deterministic results.

RÉSUMÉ: Cet article présente l'élaboration de la carte de moyenne géométrique du tremblement de terre maximum considéré (MCE_G) PGA de l'Indonésie. La carte a été élaborée en combinant une approche probabiliste pour une probabilité de 2% de dépassement en 50 ans, et l'approche déterministe. L'étude a été réalisée en vue de développer la carte des aléas de l'Indonésie dans le cadre de la révision de la carte des risques du Code indonésien du bâtiment résistant aux tremblements de terre SNI-03-1726-2002. Les paramètres sismiques utilisés dans cette étude ont été tirés de revues scientifiques, de comptes rendus de congrès, de contributions de chercheurs précédents et de la prise en considération des données géologiques et sismologiques les plus récentes. Les paramètres des sources des tremblements de terre ont été déterminés sur la base du catalogue des séismes, ainsi que d'informations géologiques et sismologiques concernant les failles actives. Les sources sismiques ont été classées en zones de subduction, zones de faille et zones de bruit de fond en considérant une loi de retour établie sur la base du modèle exponentiel tronqué et du modèle caractéristique pur. La géométrie de la faille ou de la zone de subduction ont été représentées par des modèles tridimensionnels (3D) basés sur le résultat de la tomographie, tandis que les vitesses de glissement des failles ont été déterminées à partir de mesures par GPS. Les sources des zones de bruit de fond ont été modélisées à l'aide de modèles de grilles basés sur un lissage spatial de la fréquence des tremblements de terre. Finalement, la carte de moyenne géométrique du tremblement de terre maximum considéré (MCE_G) PGA a été construite en combinant les résultats probabilistes et déterministes..

KEYWORDS: Maximum Considered Earthquake Geometric Mean, seismic hazard analysis, deterministic, probabilistic approach

1. INTRODUCTION

Since the seismic hazard map of Indonesia was published in SNI 03-1726-2002 that partially adopting the concept of UBC 1997, several great earthquakes have occurred in Indonesia including the 2004 Aceh Earthquake (Mw 9.0-9.3) which was followed by giant tsunami, the 2005 Nias Earthquake (Mw 8.7), the 2009 Tasik Earthquake (Mw 7.3), the 2009 Padang Earthquake (Mw 7.6), and the latest 2012 Simeuleu Earthquake (Mw 8.5). These earthquakes urgently underline the need to better reflect potential larger earthquake disasters faced by the nation predictably in the future and to consider the new conceptual approach and technological shift shown in the transition of UBC 1997 to IBC 2000 which evolved further to current IBC 2009.

This paper presents the latest study in developing map of Maximum Considered Earthquake Geometric Mean (MCE_G) PGA of Indonesia using probabilistic and deterministic approaches. The map was developed from the basis of updated available seismotectonic data, implementing new fault models, and incorporating new ground-motion prediction equations. The seismotectonic setting of the Indonesian region was evaluated in order to develop a seismic source model for input to seismic hazard analysis (SHA). The source models were defined based upon earthquake catalogs, tectonic boundaries, and fault information. The characteristics of the major tectonic feature used in this study were based on historical earthquakes data in the catalog and the seismotectonic setting of Indonesia, where the seismic source models were composed of background seismicity, fault sources, and subduction sources (Irsyam, et al, 2010).

2. SEISMIC SOURCE MODELS

Seismic source model was defined as the zones that have the same degree of the earthquake, whichever each point in the zone has the same probability of accident in the future. The model was developed using earthquake catalogs, tectonic boundaries, and fault information. The earthquake catalog covered earthquake period between 1900 to 2009, relocated catalog by the year 2005, and area between 90^oE to 145^oE longitudes and 15^oS to 15^oN latitudes.

The seismic hazard parameters for each source zones consisted of maximum magnitude and recurrence relationship that included truncated exponential model and pure characteristic model. Geometry of fault and subduction were represented by three-dimensional (3D) models based on the result of tomography, while slip-rates of faults were determined by considering the results of GPS measurement. Maximum magnitude and slip-rate of fault sources was summarized and shown in Figure 1.

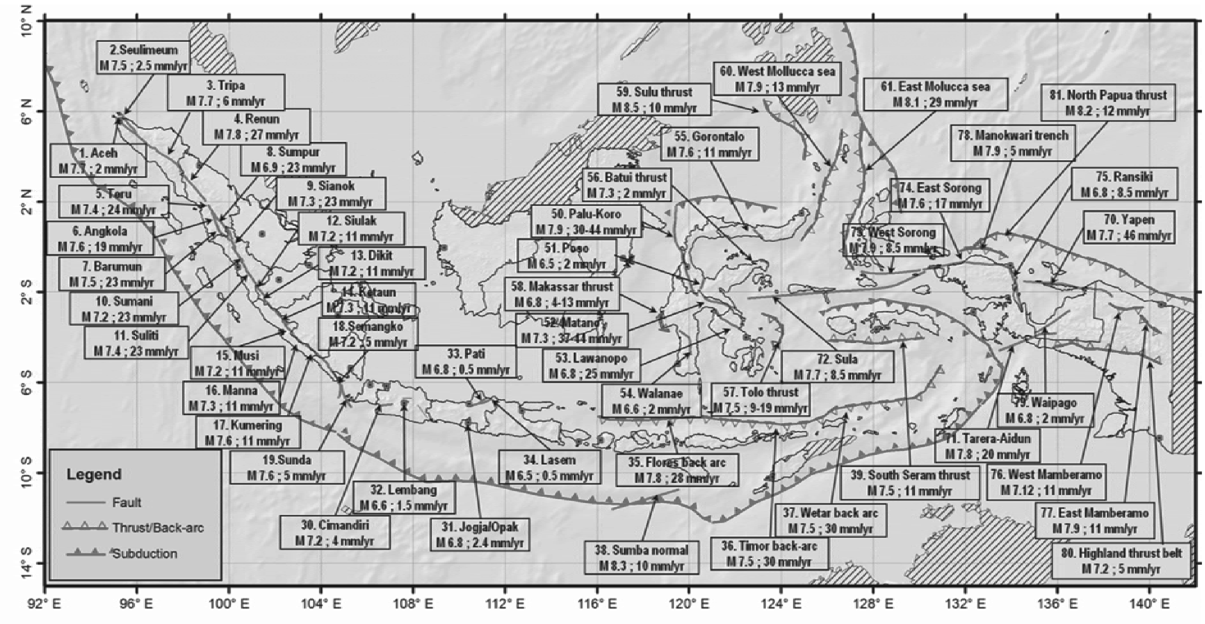


Figure 1. Maximum magnitudes and slip-rate of fault sources.

Background source zones were modeled using gridded seismicity model based on spatially smoothed earthquake rates. The gridded model was based on spatially smoothed earthquake rates (Frankel, 1995). This model accounts for the observation that larger earthquakes ($M \geq 5$) occur near smaller ($M \geq 4$ or 5) earthquakes. Gridded seismicity included in the model was based on earthquakes at five depth intervals: shallow (0-50 km), intermediate (50–100 km and 100–150 km), and deep source model (150–200 km and 200–300 km). A truncated-exponential or Gutenberg-Richter (Gutenberg and Richter, 1944) magnitude-frequency distribution between M5.0 and M6.5.0 was used to model rates for different sizes of earthquakes in each grid cell or zone.

Several well-known attenuation functions were selected in accordance with the mechanism of seismic source including the Next Generation Attenuation (NGA). Logic tree was also applied to account for epistemic uncertainty including recurrence model, maximum magnitude, and several attenuation functions.

3. SEISMIC HAZARD ANALYSIS

There are two methods commonly used in Seismic Hazard Analysis (SHA), namely: deterministic (Deterministic Seismic Hazard Analysis/DSHA) and probabilistic (Probabilistic Seismic Hazard Analysis/PSHA) and both approaches have been used for over 30 years. The results of SHA can be obtained in the form of peak ground acceleration, response spectra, and time-histories.

In general, DSHA is usually conducted in four stages (Kramer, 1996); (1) identification and characterization of all earthquake sources capable of producing significant ground motion at the site including source locations and geometry, focal mechanisms, earthquake history, and earthquake recurrence relations, (2) determination of earthquake parameters for certain scenario such as maximum magnitude and closest distance to the site, (3) selection of the controlling earthquake that is generally expressed in term of ground motion parameters, (4) calculation of seismic design parameters such as peak acceleration, peak velocity, and response spectrum ordinates that is usually selected as the worst case scenario.

DSHA is usually applied to infrastructures for which failure could have catastrophic consequences, such as nuclear power plants and large dams. The advantages of this method are its simplicity to apply and often conservative where the tectonic features are well defined (line sources). The shortcomings of this method are not providing the information for the level of shaking that might be expected during a finite period of time (such as the useful lifetime of a particular structure or facility), producing a big (and perhaps unrealistic) result, and not accounting the effects of uncertainties in the various step required to compute the resulting ground motion characteristics (Kramer, 1996).

PSHA was developed by McGuire (1995) is based on the probability concept developed by Cornell (1968), which assumed the earthquake magnitude M and the hypocenter distance R as a continuous independent random variable. Although the basic steps of the method remain the same up to today, the models and the computational techniques of the analysis keep being improved as the earth scientists and engineers collect and process more information about earthquakes. The total probability theorem can be represented in the most basic form as follows,

$$P[I \geq i] = \int_r \int_m P[I \geq i|m \text{ and } r] . f_M(m) . f_R(r) dm dr$$

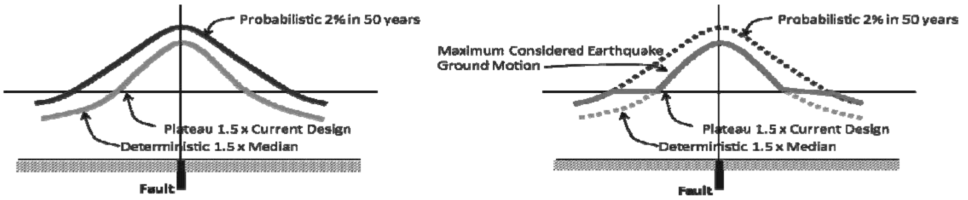
Where,

f_M = density function of magnitude
f_R = density function of hypocenter distance.
$P [I \geq i |m \text{ and } r]$ = conditional probability of (random) intensity I exceeding value i at the site for a given earthquake magnitude M and hypocenter distance R.

The software from the USGS (Harmsen, 2007) was used for the analysis. A site spacing of 0.1 degrees in latitude and longitude were used in the analysis, so that the calculations of seismic hazard for the Indonesia region are performed for more than 96,600 sites. The ground motion parameters obtained from this study can be used for development of mapping spectra response on the bedrock (site class B).

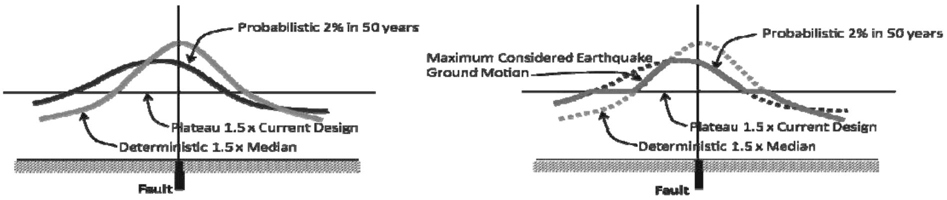
4. COMBINING DETERMINISTIC AND PROBABILISTIC CONTOURS.

The map used in the design is obtained by combining deterministic and probabilistic maps prepared by Team for Revision of Seismic Hazard Maps of Indonesia 2010. The approach is based on Leyendecker et al. (1995) and The National Earthquake Hazards Reduction Program (NEHRP) 2003 in Commentary Appendix B. The procedure for obtaining maximum considered earthquake ground motion is illustrated in Figure 2.



a) Probabilistic and Deterministic Spectral Acceleration

b) Maximum Considered Earthquake Ground Motion obtained from Probabilistic and Deterministic Spectral Acceleration



c) Probabilistic and Deterministic Spectral Acceleration

d) Maximum Considered Earthquake Ground Motion obtained from Probabilistic and Deterministic Spectral Acceleration

Figure 2. The procedure for combining deterministic and probabilistic contours to obtaining maximum considered earthquake ground motion (NEHRP 2003, Commentary Appendix B)

5. RESULTS AND DISCUSSION

The model for estimation of Maximum Considered Earthquake Geometric Mean (MCE_G) PGA has been developed based on available data, studies, and literature. Seismotectonic setting was evaluated in order to develop a seismic source model for input to SHA. The model includes parameters for the background, fault, and subduction sources. Relative distribution of magnitude for each source was modeled using truncated exponential model and pure characteristic model. Several attenuation functions including NGA were selected in order to consider the type of rupture mechanism as well as the regional geology. In order to account for epistemic uncertainties, the logic-tree was implemented. Maps of probabilistic and deterministic from fault and Subduction sources PGA are shown in **Figure 3** to **Figure 5**. Maps of MCE_G obtain from combining probabilistic and deterministic contours are shown in **Figure 6**.

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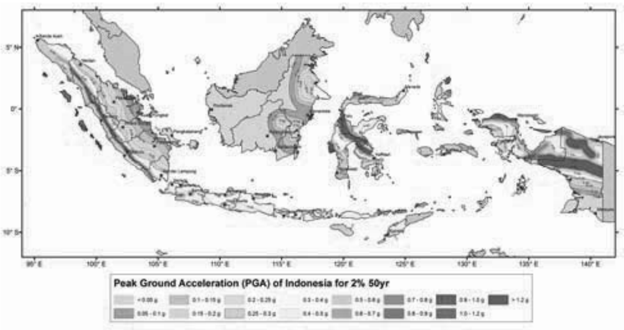

Figure 3. Peak ground acceleration (PGA) map of Indonesia for 2% 50 years

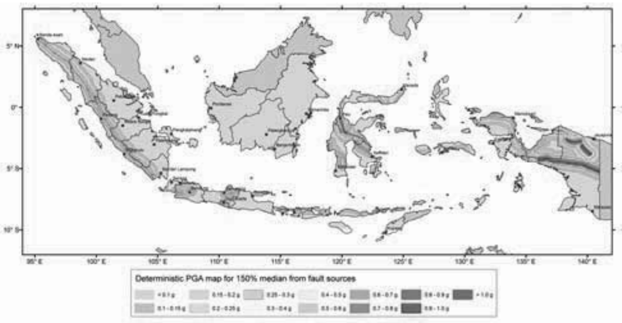

Figure 4. Deterministic PGA map for 150% median from fault sources.

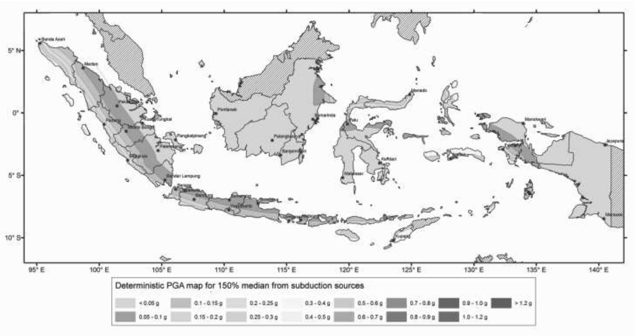

Figure 5. Deterministic PGA map for 150% median from subduction sources

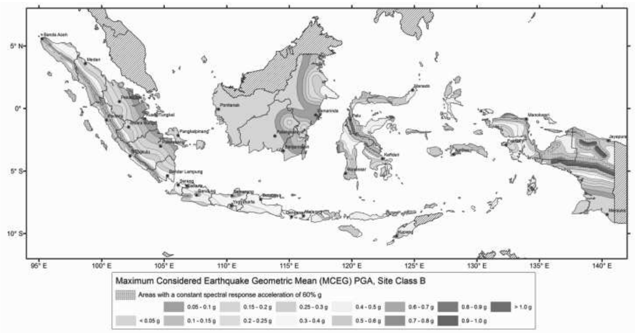

Figure 6. Map of Maximum Considered Earthquake Geometric Mean (MCE_G) peak ground acceleration (PGA)