Development of Earthquake Risk-Targeted Ground Motions for Indonesian Earthquake Resistance Building Code SNI 1726-2012

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ABSTRACT: This paper presents recent efforts in the development of risk-targeted ground motions for the Indonesian Earthquake Resistance Building Code SNI 1726-2012. Recently, in 2010, the Indonesian seismic hazard map was revised by our Indonesian Team from the 2002 map to a new hazard map. The revised map has adopted the most recent data and current state of knowledge in probabilistic and deterministic seismic hazard assessment methodologies, and through the use of the most recent ground motion predictive equations. So-called risk-targeted ground motions (RTGM) have also been developed. The risk-targeted ground motions for Indonesia are calculated as spectral response accelerations that result in 1% probability of building collapse in 50 years through a similar methodology as conducted by Luco et al. (2007). The authors do so by adopting generic fragility curves with alogarithmic standard deviation, β, value considered to be representative of Indonesian buildings. The risk-targeted ground motions mapped for the whole of Indonesia have been developed for short and 1.0 second spectral periods. These maps have become the risk-targeted maximum considered earthquake (MCE_R) maps in the new SNI 1726-2012.

Since Indonesia is located within the convergence of Eurasian, Indian-Australian, Pacific and the Philippine plates, many areas in Indonesia are highly potential to seismic hazards. In fact, almost everyday relatively small earthquake occurs in Indonesia. Several relatively large to very large earthquakes have occurred in the last 10 years that have caused many fatalities and collapse and damages of many buildings and infrastructures. Some of these are the 2004 Aceh Earthquake (Mw=9.2) which was followed by tsunami, the 2005 Nias Earthquake (Mw=8.7), 2006 Yogyakarta earthquake (Mw=6.3), September 2007 Bengkulu earthquake (Mw=8.4), 2009 West Java Earthquake (Mw=7.3), and 2009 West Sumatra Earthquake (Mw=7.6).

Prior to 2012, the seismic design criteria for buildigs in Indonesia (SNI-1726-2002) is based on map with ground motion spectral accelerations of 10% probability of being exceeded (PE) in 50 years. The seismic design criteria and map was hazard-based without considering uncertainty from collapse capacity of building structures.

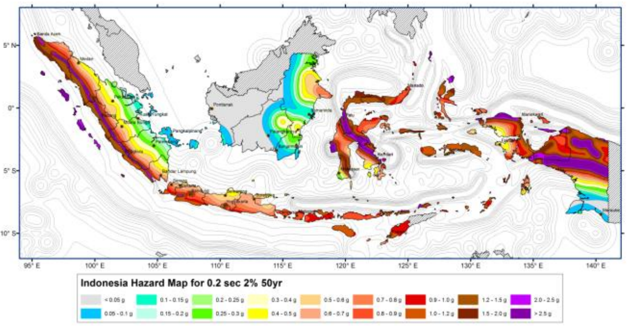
In 2010, new development has been made to update the 2002 Indonesian seismic hazard map based on 2% PE in 50 years, defined as Maximum Cosidered Earthquake (MCE). In this new map, uncertainty in structural capacity or building fragility was still not involved. Later on, in 2011 the MCE map was combined with building fragility, to produce risk-targeted maximum considered earthquake (MCE_R) as new seismic design criteria. A method, which determine the risk, has been used by implementing direct integral to calculating risk-targeted ground motions (RTGM) of 1% probability of building collapse in 50 years that is derived by integrating 2% PE in 50 years hazard curves of the new 2010 Indonesian seismic hazard with fragility curve of Indonesian buildings defined to have 10% probability of collapse. This follows new development in seismic design criteria developed for United States of America by Luco et al. (2007), that has been adopted in ASCE-SEI-7-10.

1. DEVELOPMENT OF NEW 2010 INDONESIAN SEISMIC HAZARD MAP

Formal efforts to improve seismic hazard map of Indonesia have been conducted since 2006. The efforts were initiated by the Department of Public Works and supported by ITB, Geology Research Center, and the United States Geological Survey (USGS). The studies have been reported by Irsyam et al. (2007). Seismic hazard study for Sumatra has also been performed by Sengara et al. (2008). All the studies considered 3-Dimensional source zones model, with more detailed seismic source zoning and more recent recurrence models, as well as ground motion prediction equation (GMPE) using the most recent methodology of probabilistic seismic hazard analysis (PSHA). An integrated PSHA by team members from geological, seismological, crustal deformation, and earthquake engineering specializations from related agencies and ITB coordinated by Ministry of Research and Technology has also been conducted and presented in Sengara et al. (2009). Most recently, the finalization of the revision of Indonesian seismic hazard maps has been conducted by Indonesian team members (Team-9) supported by Indonesian Ministry of Public Work and National Disaster Management Agency (BNPB) through Australia-Indonesia Facility for Disaster Reduction (AIFDR).

The new revision of Indonesian seismic hazard map has been developed from PSHA considering the most recent seismicity data, seismo-tectonic source zones considering tomographical cross section of subduction zones, most recent GMPEs (for subduction: Youngs*et al*. (1997), Atkinson and Boore (2003), and Zhao *et al*.(2006)) including Next Generation Attenuation (NGA) models for shallow crustals faults (Boore-and Atkinson(2008), Campbell and Bozorgnia(2008), and Chiou and Youngs(2008)) documented in Steward et al. (2008). In addition, the PSHA for background seismicity data that not associated with particular faults and interface seismic source zones is modeled by gridded seismicity in which the seismicity rates is calculated through spatially smoothed evaluation, Frankel (1995). Results of PSHA is presented for various levels of probability and at three spectral response acceleration values, that is for T=0 (PGA), T=0.2 (short period) and for T=1.0 seconds (5% of critical damping and site class B). More detail analysis of the PSHA is presented in Irsyam et al. (2010). Figure 1 (a) shows MCE ground motion parameter for Indonesia at 0.2 s spektral acceleration (5% of critical damping), site class B, while Figure 1 (b) shows at 1.0 s spektral acceleration (5% of critical damping), site class B.

Further, seismic design criteria is defined by introducing risk-targeted MCE (MCE_R) derived from risk-targeted ground motion, to be summarized below for input to the new 2012 Indonesian seismic building codes. FEMA (2009) adopts directivity factor to be used for scalling spektral values. Factor of 1.1 is used for short periode, while 1.3 for T = 1.0 sec. For this study, MCE in DSHA and PSHA spectral values are multiplied by directivity factors of 1.05 for Ss and 1.15 for S_1.



(a)

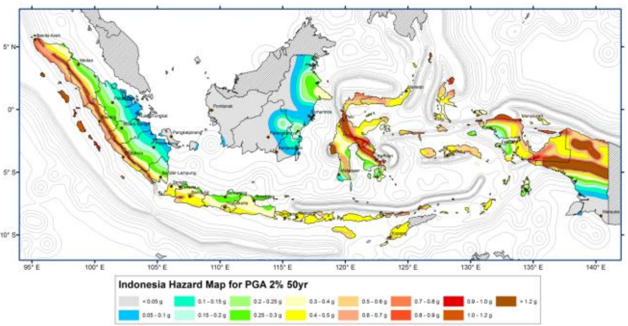


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Figure 1: (a) MCE ground motion parameter for Indonesia for 0.2 s spektral acceleration (5% of critical damping), site class B; (b) MCE ground motion parameter for Indonesia for 1.0 s spectral acceleration (5% of critical damping), site class B

Detailed PSHA also resulted in hazard curves for all grids of Indonesia. These hazard curves have been captured and stored as tabulation data. The data was further used as input in development of MCE_R.

2. DISTRIBUTION OF STRUCTURE COLLAPSE CAPACITY

Luco et al. (2007) stated several reasons why collapse capacity of structure is uncertain. First is that the structure which can withstand without collapsing will typically depend on characteristics of ground motion. The second one is that a collapse structure subjected by ground motion will depend on the construction details of the structure.

Some researchers already showed that earthquake resistance structures designed using equal hazard concept will not give value of equal risk (e.g. Liel et al. (2009); Luco et al. (2007); and Porter et al. (2007)) subjected to a particular earthquake. With reference to Luco et al. (2007), to link between equal hazard and equal risk concepts, a concept that introduces fragility function is adopted in this study. This is done by adopting a probability density function of structure resistance to the earthquake effects in terms of ground acceleration. As has been adopted previously by several researches: e.g. Luco et al. (2007); Ryu et al.(2008); Heintz (2010),the fragility function of high-rise structure follows log-normal distribution.

Refering to the same equation as used in Luco et al. (2007), a log-normal distribution of structure collapse capacity against earthquake load is adopted in this study. This equation can be written as follow:

$$f_F(a) = \frac{1}{a\beta\sqrt{2\pi}} \exp\left[-\frac{\left(\ln a - \overline{\ln y}\right)^2}{2\beta^2}\right] \quad (1)$$

where:

a : spectral acceleration
β : logarithmic standard deviation
$\overline{\ln y}$: median of logarithmic capacity

Median of logarithmic capacity can be replaced by:

$$\overline{\ln y} = \ln(MCE_R) + 1.28\,\beta \quad (2)$$

Analysis and recommendation on representative β values for Indonesian buildings has been conducted through hazard analysis and probability based factor of safety by Sidi(2011). The analysis identifies inherent variability of concrete compressive strength and steel reinforcement tension capacity, simplification on the field actual condition representing random phenomena in the design formulation, and random human error through reliablity analysis in derivation of fragility function that considered to be representative to Indonesian condition. The analysis suggests that β value for Indonesia varies between 0.65 – 0.7. For development of RTGM, a value of β=0.7 is adopted.

3. RISK TARGETED GROUND MOTION

New concept in the seismic design criteria is introduced in ASCE-SEI-7-10 that the seismic criteria not only based on seismic hazard as previously adopted by many building codes, but also based on probability of collapse of the buildings. This concept is illustrated in Figure 2, McGuire (2004), showing annual frequency of exceedance as a function of ground motion amplitudes. Two curves are shown in the figure, combining hazard curve from PSHA and structure capacity distribution curve. The ground motions derived from this concept is called risk-targeted ground motion (RTGM). New 2012 Indonesian building codes will be based on MCE_R defined as 1% probability of collapse of the buildings, in reference to ASCE-SEI-7-10. Since the new criteria is based on RTGM, then MCE_R needs to be derived from MCE seismic hazard and characteristics of buildings in the form of their fragility. As the MCE_R is available, then design spectral values are adopted to be (2/3) of the spectral values derived from MCE_R with reference to two ground motion amplitudes that is in terms of spectral values of S_S (spectral value for short period at T=0.2 second) and S_1 (spectral value at T=1.0 second). This concept is introduced for collapse prevention of the buildings.

Calculation of RTGM representing MCE_R is done by direct integration method of multiplication of annual frequency of ground motion value $F_R(a)$ (site-specific hazard curve) and probability of building resistance $f_F(a)$.

$$P(a) = \int_0^\infty F_R(a) f_F(a)\, da \quad (3)$$

In order to compute the RTGM representing this MCE_R, an optimization variable using Newton-Rhapson method was adopted in which 1% probability of collapse of the buildings must be satisfied.

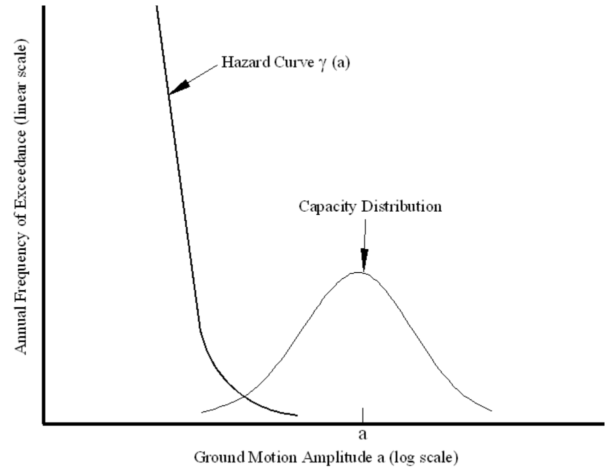
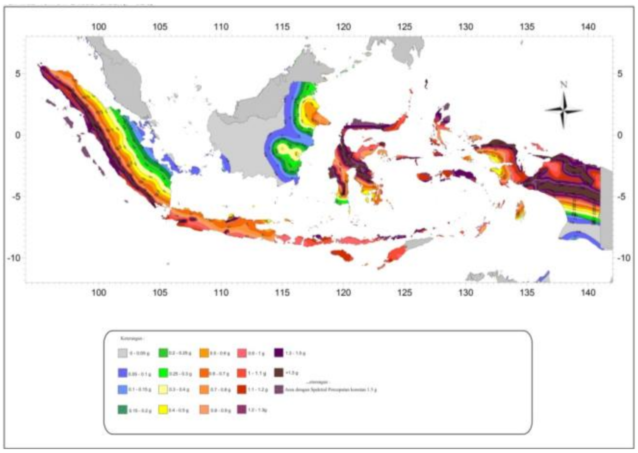


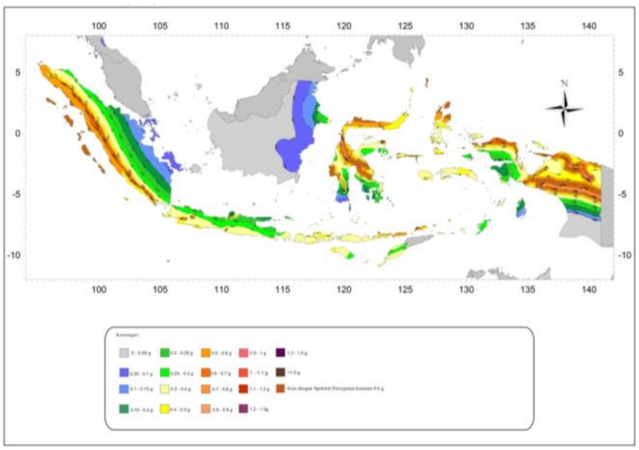
Figure 2: Hazard curve and collapse capacity distribution, McGuire (2004).

4. RESULTS OF ANALYSIS

Site-specific MCE_R spectral response acceleration is taken as the lesser of the spectral response accelerations from RTGM involving MCE from PSHA and deterministic MCE ground motions from DSHA. With reference to ASCE-SEI-7-10 and NEHRP-P-705/2009, the deterministic spectral response acceleration at particular period is calculated as an 84^{th}-percentile 5 percent damped spectral response acceleration in the direction of maximum horizontal response computed at that period. Deterministic MCE is the largest of spectral acceleration calculated for the characteristic earthquakes considering all known active faults within the region. In this case, the deterministic ground motion is taken not lower than the corresponding values from RTGM of PSHA, with the value of S_S taken as 1.5g and the value of S_1 taken as 0.6g. Figure 3(a) and (b) shows distribution map of MCE_R Ground Motion Parameter for Indonesia for 0.2 s and 1.0 s spectral response acceleration, respectively (5% of critical damping), Site Class B.



(a)



(b)

Figure 3: Risk-Targeted Maximum Considered Earthquake (MCE_R) ground motion parameter for Indonesia spectral response acceleration (5% of critical damping), Site Class B; a) Ss (b)S1

5. CONCLUSIONS

Recent efforts in the development of risk-targeted ground motions map for the 2012 Indonesian Earthquake Resistance Building Code has been made. The map has been developed based on 2010 revised Indonesian seismic hazard-based of 2% probability of exceedence map adopting most recent data, ground-motion predictive equations, and current state of knowledge in probabilistic and deterministic seismic hazard assessment methodologies.Risk-targeted ground motions (RTGM) in the form of risk-targeted maximum considered earthquake (MCE_R) maps for Indonesia have been developed as spectral response accelerations that result in 1% probability of building collapse in 50 years. Generic fragility curves with alogarithmic standard deviation, β, has been adopted. The risk-targeted ground motions mapped for the whole of Indonesia have been developed for short (0.2) and 1.0 second spectral periods. These MCE_R maps have been adopted in the new 2012 Indonesian seismic building codes (SNI 1726-2012). Future research on improving and enhancing seismic hazard map and fragility functions, with particular emphasis in β parameter need to be conducted.

6. ACKNOWLEDGMENT

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