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Advantages of Realistic Model Based on computational method: NDSHA versus Standard PSHA

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Abstract. Procedure of standard Seismic Hazard Assessment (PSHA) has a problem with over simplifying recurrence since being represented by a linear relationship. However, the relationship will be satisfied only if the size of the study area is large enough with respect to linear dimensions of sources.. PSHA lies in attenuation relations are usually not translation invariant in the phase space. Regarding the problem of completeness data, instead of using recurrence relationship DSHA select the most credible earthquakes. However, the DSHA remain lies in attenuation relations, assume the same propagation model for all the events, but such a hypothesis is not very realistic. On the contrary, NDSHA procedure has advantages in calculation strong ground motion from the realistic model of synthetic seismograms from source specific properties and cooperates with the available structural model. Additionally, The NDSHA produced more information such as PGD, PGV, PGA for horizontal and vertical components each. Using realistic computation for Banda Aceh, NDSHA provides an accurate value for each of those components, achieving probability of exceedance in the range between 10% to 2% probability of exceedance PGA from PSHA computation. Regarding some limitation from PSHA, Indonesia needs to establish research on NDSHA for the area has critical infrastructures to face the seismic hazard.

1. Introduction

Recent destructive earthquakes in Sumatra, such as Sumatra Andaman (2004), Nias (2005), Mentawai (2007), Padang (2009), Indian Ocean Strike Slip (2012), and Takengon (2013), provided new challenges for urgent action to improve a procedure for seismic hazard assessment (SHA). Realistic and accurate SHA will benefit the community and scientific studies. Moreover, this research may improve the SHA results in previous studies (Panza, Irikura, et al., 2011; Stein, Geller, & Liu, 2011, Panza, et al. 2012).



The mapping of the expected earthquake ground motion that accounts for event's recurrence – e.g., the standard Probabilistic Seismic Hazard Assessment (PSHA) – may be suitable for insurances in dealing with economical profit. When dealing with critical structures, where it is necessary to consider extremely long time intervals, the standard PSHA estimates are by far unsuitable, due to their basic heuristic limitations (Panza, et al. 2012).

A thorough discussion of different approaches available for SHA is behind the purposes of the present review. In fact, the PSHA method (Bommer & Abrahamson, 2006 and Cornell, 1968) and its applications are widely described in the literature, and have been the subject of intensive debate in recent years (e.g., Bilham, 2009; Klugel, 2007a). Criticisms have been expressed on the probabilistic method by many authors (e.g., Castanos & Lomnitz, 2002; Klugel, 2007b; Krinitzsky, 1998; Wang, 2011, Peresan & Nekrasova 2014), who evidenced some essential limits in the physical and mathematical models, as well as in other basic assumptions. Several issues related to the PSHA approach and possible alternatives are discussed in the recent Topical Volume of Pure and Applied Geophysics (Panza, Irikura, et al., 2011). A posteriori quantitative evaluation of the performances of the PSHA is given by Kossobokov and Nekrasova (2010, 2011). They showed that the worldwide maps resulting from the Global Seismic Hazard Assessment Program, GSHAP (Giardini, Grunthal, Shedlock, & Zhang, 1999), are grossly misleading, as proved by fatal evidence of the deadliest earthquakes occurred since the year 2000, selected event for Sumatra are shown in Table 1.

Why are the standard probabilistic methods of estimating seismic hazard and risks too often wrong? A simple answer exists to the question in the title of this chapter: most, if not all, the standard probabilistic methods to assess seismic hazard, namely PSHA, and associated risks are based on subjective, commonly unrealistic, and even erroneous assumptions about seismic recurrence (Panza et al., 2014).

Table 1. List of the deadliest earthquakes occurred during the period 2000-2011, and the corresponding intensity differences, $\Delta I_0 = I_0(M) - I_0(\text{mPGA})$, among the observed values and predicted by GSHAP. $I_0(M)$ and $I_0(\text{mPGA})$ are computed from the observed magnitude M and the maximum GSHAP PGA around the observed epicenter, see (Panza et al., 2013, Kossobokov and Nekrasova, 2010).

Region	Date	M	Fatalities	Intensity difference ΔI_0
Sumatra-Andaman “Indian Ocean Disaster”	26.12.2004	9.0	227898	4.0
Nias (Sumatra, Indonesia)	28.03.2005	8.6	1313	3.3
Padang (Southern Sumatra, Indonesia)	30.09.2009	7.5	1117	1.8

2. Method

Seismic hazard assessment procedures generally can be divide into four steps as shown in Figure 1. Each method (PSHA, DSHA, and Neo-DSHA) is starting from scenario of seismic source, earthquake locations in space lead to a distribution of location. Figure 1a schematically shows the procedure for conduction a PSHA. The figure illustrates the specific hazard of ground motion, but it could be redrawn in like fashion for any other earthquake hazard. The step divides the earthquake threat into sources (these may be identified faults or geographical areas) that produce earthquakes and earthquake characteristics. It is assumed that earthquakes act independently – that is, the occurrence of an event at one source does not affect the occurrence of events at other source (McGuire, 2004).

The second step of the PSHA method is recurrence, which can be represented by a linear relation, and this will produce useful information for risk analysis. However, the relation will be satisfied only if the size of the study area is large with respect to linear dimensions of the sources. The third step of the PSHA method lies in attenuation relations, which are usually not translation invariant in the phase space (M , R , S), M – magnitude; R – source distance; S - local soil conditions, i.e. the relative decay is independent from (M , R , S). Even when the attenuation relations are translation invariant, they are not a conditional probability density function, but they are those that represent the functional dependency of the random spectral acceleration on the random variates, magnitude, distance and measurement error (Klügel, ENGEO 90, 186-192, 2007).

Regarding the issue with the data completeness, instead of using recurrence relations as mentioned in the second step of the DSHA method, this study selects the most credible earthquakes fixed source distance R and magnitude M as shown in Figure 1b. However, the DSHA method remains in attenuation relations, which often emphatically called laws, by assuming the same propagation model for all of the events, but such a hypothesis is not very realistic (Panza, 2010). Therefore, this study produces DSHA for Sumatra after Natawidjaja & Triyoso (2007).

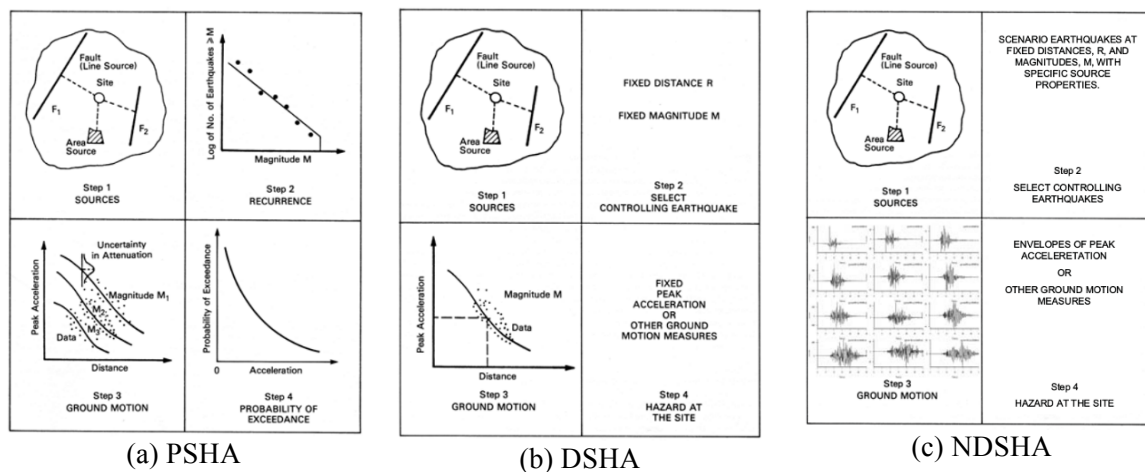


Figure 1. The comparison steps in performing PSHA, DSHA, and NDSHA Panza (2010)

Regarding the issue with the estimation ground shaking lies in generic attenuation relations for all types of sources, NDSHA (Neo-Deterministic Seismic Hazard Assessment) procedure has advantages in calculation strong ground motion from realistic model of synthetic seismograms from source specific properties, see Figure 1c. The NDSHA procedure, which represents a drastic enhancement of DSHA, permits incorporating, as they become available, new geophysical and geological data, as well as the information from the different Morphostructural Zonation (MZ) developed for the space-time identification of strong earthquakes. All this leads to the natural definition of a set of scenarios of expected ground shaking at the bedrock (Panza et al., 2013).

Recent advances in the physical knowledge of seismic waves generation and propagation processes, along with the improving computational tools, make it feasible the realistic modeling of the ground shaking caused by an earthquake, taking into account due consideration the complexities of the source and of the propagation path. A neo-deterministic scenario that bases its approach on the seismic hazard assessment (NDSHA) has been developed to naturally supply realistic time series of ground shaking,

including reliable estimation of ground displacement readily applicable to seismic isolation techniques (Panza et al., 2013).

The NDSHA approach has already been applied in several regions worldwide, including a number of local scale studies accounting for two-dimensional and three-dimensional lateral heterogeneities in inelastic media. NDSHA is an innovative, but already well consolidated, procedure that supplies realistic time histories, with very solid physics roots, from which it is natural to retrieve peak values for ground displacement, velocity and design acceleration in correspondence of earthquake scenarios (e.g., Parvez et al., 2010; Paskaleva et al., 2010). Synthetic seismograms can be efficiently constructed with the modal summation technique (e.g., Panza et al., 2001; La Mura et al. 2011) to model ground motion at sites of interest, using the available knowledge of the physical process of earthquake generation and wave propagation in realistic media and this makes it possible to easily perform detailed parametric analysis that permit to account for the uncertainty in input information.

Estimates of seismic hazard obtained using NDSHA and PSHA are compared for the Italian territory (Fig. 2). NDSHA provides values larger than those given by PSHA in areas where large earthquakes are observed and in areas identified as being prone to large earthquakes but provides lower values in low-seismicity areas. These differences suggest the adoption of the flexible, robust, and physically sound NDSHA approach for reliable seismic hazard estimation. NDSHA allows us to overcome the shortcomings of PSHA, including its proven tendency to underestimate ground shaking for the largest earthquakes, especially for those areas characterized by a prolonged quiescence, i.e. in tectonically active sites where events of only moderate size have occurred in historical times (Panza et al. 2011, Panza and Romanelli 2014).

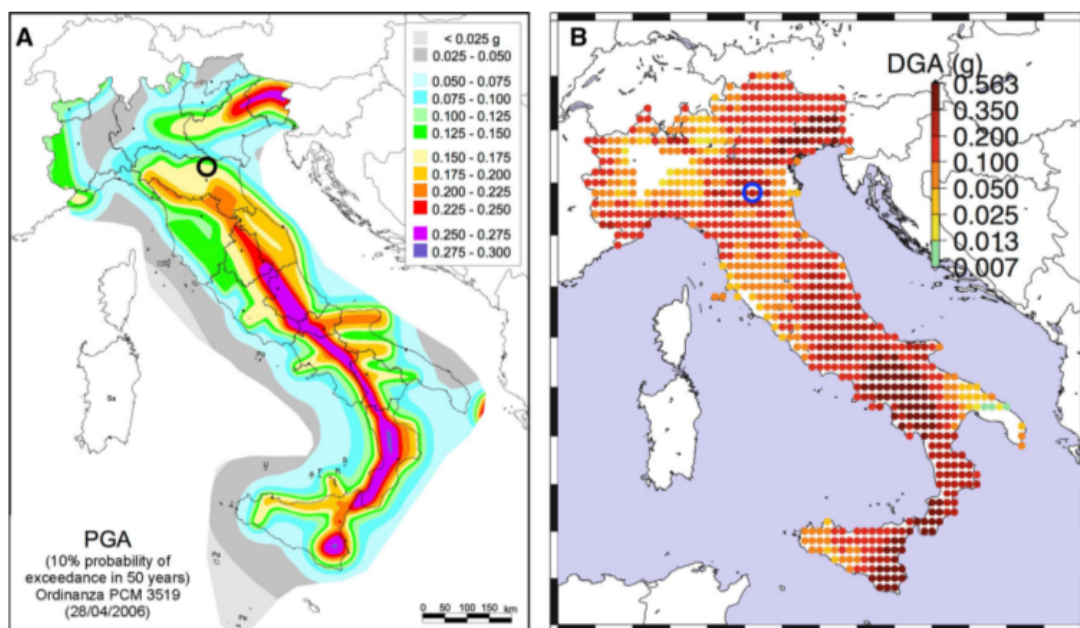


Figure 2. Seismic hazard maps developed using a PSHA and b NDSHA. The PSHA map is currently the official reference seismic hazard map for Italy. The epicenter of the Emilia earthquake is marked (black dot in (a); blue circle in (b)). a Puts the Emilia epicenter in an area expected to have low ground shaking. Contrary to this, b assesses the seismic hazard in the area near the epicenter to be higher (from Peresan and Panza 2012).

3. Official Seismic Hazard Map for Indonesia

Probabilistic seismic hazard map of Indonesia expressed in terms of expected PGA (g) with a probability of exceedance of 10% in 50 years (in a return period of 475 years), see Figure 3. In 2009 the Ministry of Public Work decided to establish a team to revise and update the SNI 03-1726-2002 seismic hazard map of Indonesia. There are three seismic source models used in their assessment: fault zone, subduction zone, and gridded seismicity. The earthquake source models are derived using all available information from earthquake catalogs, tectonic setting, regional and geological data and focal mechanisms. Fault source is treated as a plane in 3-D space for calculation of distance from a site to a certain point at the plane. The main input fault parameters to develop the seismotectonic sources are fault traces, focal mechanism, slip-rate, dip, length and width of the fault (Irsyam et al., 2010 and 2013).

Due to insufficient ground motion records needed to develop an attenuation relationship (GMPE) in Indonesia region, the relations developed from similar regions are used. The selection is based upon the similarity on source characteristic, geologic and tectonic conditions where the attenuation functions are developed. Most of the attenuation relations used in this study are Next Generation Attenuation (NGA), which are derived using worldwide observed earthquake data.

The new Indonesian code for building, SNI 1726-2012, follows the concept of MCEG used by ASCE 7-10 for the purpose of geotechnical calculation. It combines both the results from PSHA for 2% probability of exceedance in 50 years (2,500 years earthquake) and DSHA for area located near active fault. Both approaches are utilized according to the procedure proposed by Leyendecker et al. (2000), (Irsyam et al., 2010 and 2013).

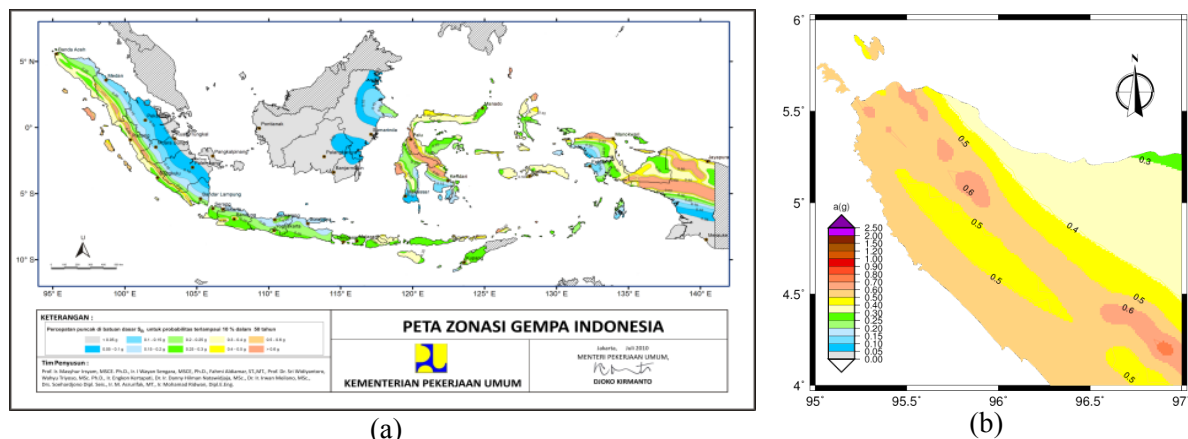


Figure 3. (a) Seismic Hazard of Indonesia, Ministry General Work (PU) 10% probability of exceedance in 50 years SNI 1726-2012. <http://loketpeta.pu.go.id/peta/zonasi-gempa-indonesia-4/>. (b) PGA scale to Banda Aceh and surrounding area (Fauzi et al. 2013).

4. Comparison PSHA and NDSHA for a site on Banda Aceh

Regional scale NDSHA will compute synthetic seismogram from several sources defined for most significant historical or expectation sources, (Figure 4a Seismicity around Banda Aceh) for each area in the cell area, namely source definition. At the regional scale, a set of sources is defined in the tectonically active areas of the considered region. From these sources, and once the physical properties of average structural models have been defined, wave propagation is efficiently modeled with the modal summation technique and broadband synthetic seismograms are generated at the free surface on

a predefined grid of points covering the study region (Florsch, Fah, Suhadolc, & Panza, 1991; Panza, 1985; Panza et al., 2012) .

In fact, recent destructive earthquakes demonstrate that a single hazard map cannot meet the requirements from different end-users. Therefore, the computation strong ground motion will calculate not only PGA but also PGD and PGV from seismograms generated by all sources. In order to investigate the most significant sources for hazard at the Banda Aceh city, we have calculated synthetic seismograms from all earthquake sources $M > 4$ (Figure 4a) and selecting the most significant earthquake sources for contribution to strong ground motion PGD, PGV, and PGA at horizontal and vertical dimensions as produced in Figure 4b.

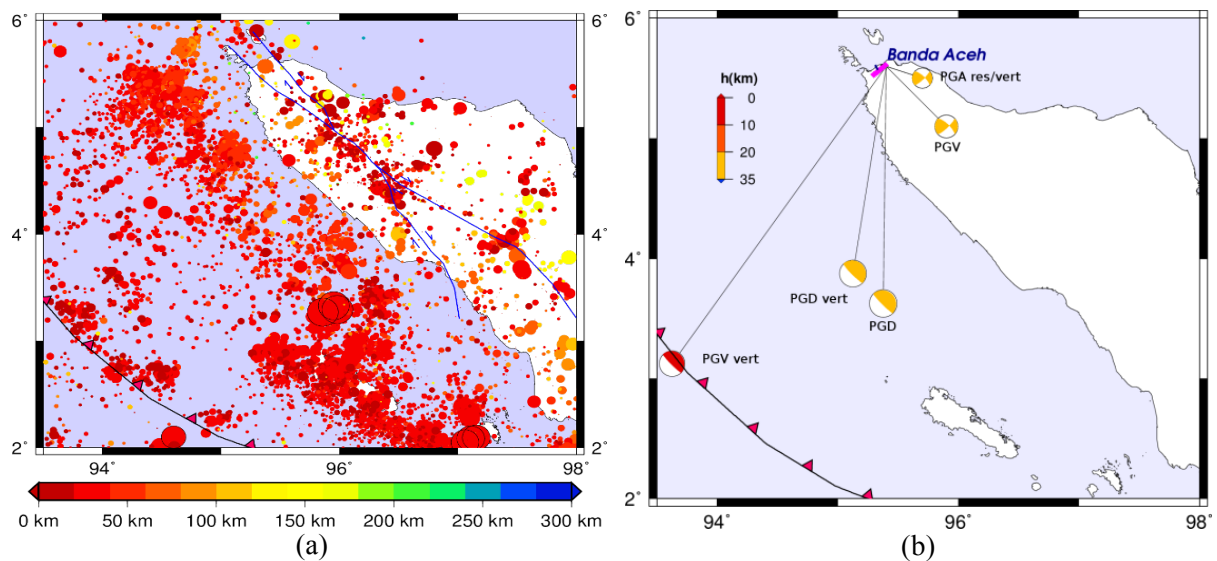


Figure 4. (a) Seismicity around Banda Aceh. (b) The source location which contributes to significant strong ground motion PGD, PGV, and PGA at maximum frequency 10Hz. The PGD and PGV for the vertical and horizontal component have different sources. Only PGA for the horizontal and vertical components have the same sources.

Table 2. Analysis of the peak values of seismograms shows most significant sources for each component, located near the Banda Aceh basin (longitude=95.4°, latitude=5.6°).

Component	Source location (degree and km)				Focal mechanic (°)			magnitude	peak value	note
	longitude	latitude	distance	depth	strike	dip	rake			
PGD Horizontal	95.375	3.625	218	31	325	7	100	8.83	45.55 m	
PGV Horizontal	95.9	5.1	78	20	313	72	168	7.41	38.83 m/s	
PGA Horizontal	95.7	5.5	35	20	313	72	168	6.5	0.314 g	
PGD Vertical	95.125	3.875	193	28	325	7	100	8.73	38.33 m	
PGV Vertical	93.625	3.125	337	5	325	7	100	8.31	21.86 m/s	
PGA Vertical	95.7	5.5	35	20	313	72	168	6.5	0.123 g	

The result, calculated at 10hz maximum frequency, shows the source of PGD and PGV coming from a subduction zone and for PGA coming from strike-slip fault as PGD in the city is the dominant contributor in a big earthquake at a subduction zone, whereas PGA is related to a near source. However, for vertical components, almost all vertical PGD are contributed by a subduction zone because it has a vertical movement caused by the Sunda megathrust mechanic. The PGA for vertical components remains dominant by a near field source as the strikes slip is the nearest source in the land of Sumatra.

The NDSHA produced several sets of information as shown in Table 2, which contains six PGD, PGV, and PGA in horizontal and vertical components. The table shows vertical components that have lower values compared with those in the horizontal components. Therefore, to reduce a computing cost, the vertical component is ignored. The results provide more sets of information compared with the results that PSHA provides as shown in Figure 3. The available data from PSHA (Fauzi et al. 2013) are the PGA values at bedrock with 10% probability of exceedance in 50 years. The official PSHA map for PGA at bedrock with 10% and 2% probability of exceedance in 50 years are 0.298 g and 0.552 g. The PSHA analysis can give you various PGA values depending on your insurance analysis, and this is one of the reason why PSHA more popular. The NDSHA provides an exact value for each component, naturally, with realistic computation and the value in Banda Aceh in the range between 2% and 10% probability of PGA exceedance compared to the PSHA calculation.

5. Conclusions and Suggestion

The limitations that PSHA estimates are due not only to the data scarcity but also to the invalid physical model and mathematical formulation employed (Castanos H. e Lomnitz C., (2002), PSHA: is It Science?, Eng. Geo., 66, 315-317. Wang, 2011; Paskaleva et al., 2007). The limitations become unacceptable when considering the number of casualties and injured people (Wyss et al., 2012). The evolving situation makes it compulsory for any national or international regulation to be open to accommodate the most important new results, as they are produced and validated by the scientific community.

NDSHA has the capability to solve some issues, which have largely been neglected in traditional hazard analysis. For example, how crustal properties affect attenuation as ground motion parameters are not derived from simplified attenuation relations but rather from synthetic time histories. Starting from the available information on the Earth's structure (mechanical properties), seismic sources, and the level of seismicity of the investigated area, it is possible to estimate PGA, PGV, and PGD for horizontal and vertical components or any other parameters relevant to seismic engineering, which can be extracted from the synthetic seismograms (Panza 1985, Panza et al., 2013).

NDSHA is an innovative, and already well consolidated, procedure that supplies realistic time histories, with very solid physics roots, from which it is natural to retrieve peak values for ground displacement, velocity, and design acceleration in correspondence of earthquake scenarios (e.g., Parvez et al., 2010; Paskaleva et al., 2010). As PSHA is limited, Indonesia needs to establish further research on the uses of NDSHA for areas, whose critical infrastructures are at risk of seismic hazard.

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