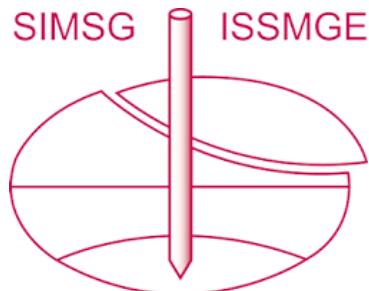


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Development of new seismic hazard maps of Indonesia 2017

Développement de nouvelles cartes de risques sismiques en Indonésie 2017

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ABSTRACT: This paper presents the progress in developing Indonesia seismic hazard maps. The revision of seismic hazard maps has been developed based upon updated: seismotectonic data, fault models, and GMPEs. Important information is considered for updating seismic hazard maps such as significant results of recent active-fault studies utilizing trenching, carbon dating, epicenter relocation, strain analysis (GPS) as well as availability of basic data including the SRTM-30, IFSAR, LiDAr and other data that is just recently available. The new information was gathered in order to obtain more accurate tectonic model and their seismic parameters, such as maximum magnitudes and slip-rates. Based on the latest researches and investigations, revised seismotectonic models for Indonesia were developed and used in developing new seismic hazard maps. Finally, probabilistic and deterministic analyses were then performed in order to develop new seismic hazard maps 2017.

RÉSUMÉ: Cet article présente les progrès réalisés dans le développement des cartes de risque sismique en Indonésie. La révision des cartes des risques sismiques a été élaborée sur la base de mises à jour: données sismotectoniques, modèles de pannes et GMPE. Des informations importantes sont à l'étude pour la mise à jour des cartes des risques sismiques, telles que les résultats significatifs des récentes études de failles actives utilisant le creusage des tranchées, la datation au carbone, la réinstallation des épicentre, l'analyse des souches (GPS) ainsi que la disponibilité des données de base incluant SRTM-30, IFSAR, D'autres données récemment disponibles. Les nouvelles informations ont été recueillies afin d'obtenir un modèle tectonique plus précis et leurs paramètres sismiques, tels que les grandeurs maximales et les taux de glissement. Sur la base des dernières recherches et recherches, des modèles sismotectoniques révisés pour l'Indonésie ont été développés et utilisés pour l'élaboration de nouvelles cartes de risques sismiques. Enfin, des analyses probabilistes et déterministes ont ensuite été effectuées afin de développer de nouvelles cartes de risques sismiques 2017.

KEYWORDS: New seismotectonic model, probabilistic and deterministic seismic hazards, peak ground acceleration

1 INTRODUCTION

The need to revise and to update the Indonesian Seismic Hazard Map 2010, was driven based on recommendation proposed by Team for Revision of Seismic Hazard Maps of Indonesia 2010 (TRSHMI 2010) (Irsyam et al, 2010). The team consists of several institutions in Indonesia such universities, private and government institutions, research centres and professional associations. The recommendations include: conduct periodic updating of seismic hazard maps and related national design codes every three to five years; conduct micro seismicity investigation of active faults that have not been well identified and well quantified, especially near big cities such as Jakarta, Surabaya, Semarang; accelerate the installation of strong-

motion accelerometer networks in Indonesia in order to develop database of time histories and attenuation functions; and perform seismic microzonation studies for big cities in Indonesia.

In order to follow up the recommendation from TRSHMI 2010, in 2015 the Ministry of Public Works started to established a team for updating the current maps. The team consists of experts from Institute of Technology Bandung, Meteorological Climatological and Geophysical Agency (BMKG), Center of Volcanology and Geological Hazard Mitigation (PVMBG), Ministry of Public Works, Indonesian Institute of Sciences (LIPI), Geospatial Information Agency (BIG), Agency for the Assessment and Application of Technology (BPPT), and professional associations such as Indonesian Disaster Expert Association (IABI). The team were

then divided into several working groups, such as geology, geodesy, seismology, ground motion prediction equations, and seismic hazard analysis (Hendriyawan et al., 2016).

This paper presents the progress of the team in developing Indonesia seismic hazard maps 2017.

2 SEISMOTECTONIC INDONESIA 2010

The identification and characterization of seismic sources are often the major part of a seismic hazard analysis and require knowledge of the regional and local geology, seismicity and tectonics (Reiter, 1990). Therefore, in the seismic hazard assessment process, seismic source modeling is very important. The models were developed based on combination of information and data such as earthquake catalogs and all available seismotectonic information. A complete and thorough evaluation of all available earthquake data and information of seismic sources need to evaluated and identified in order to develop more accurate seismic source model.

The previous Indonesia seismic hazard maps 2010 use three types of seismic-sources for Indonesian region, which are: intra crustal fault sources, subduction-zone (intercrustal fault) sources, and background seismicity. The seismotectonic model was used for developing Indonesia Seismic Hazard Maps 2010 and implemented in SNI 1726-2012. The design seismic sources are shown in Figure 1 and Figure 2 (Irsyam et al, 2010).

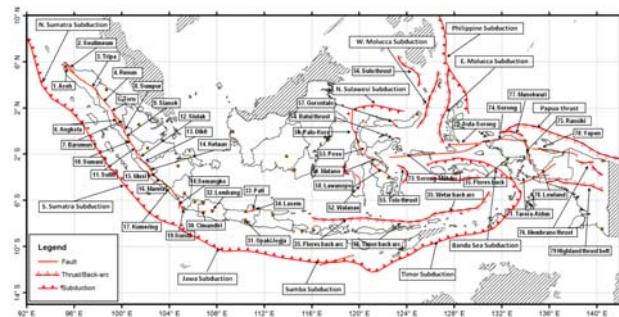


Figure 1. Shallow intra-crustal faults used in SNI 1726-2012 (Irsyam et al, 2010)

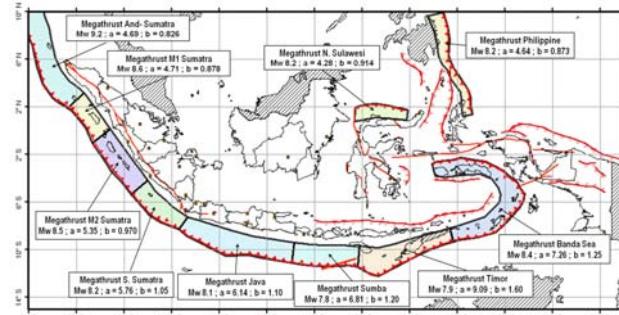


Figure 2. Model of interplate megathrust used in SNI 1726-2012 (Irsyam et al, 2010)

3 DEVELOPING THE NEW SEISMIC SOURCES MODEL

3.1 Updating the historical earthquake data

Seismic hazard assessment requires as complete as possible of a historical earthquake data in or near the region of interest. It is necessary to have a comprehensive knowledge of historical recording coverage in order to assess the completeness level of an earthquake catalogue.

In order to update the seismicity data, the earthquake databases around Indonesia were compiled from several sources as follows: The Preliminary Determination of Epicenters (PDE) from 1901 to 2014, the EHB catalog that calculated based on Engdahl et al. (1998), the Meteorological, Climatological, and

Geophysical Agency (BMKG) of Indonesia earthquake data catalog from April 2009 to June 2014, and focal mechanism from International Seismological Comission (ISC) database which compile most reliable focal mechanism solution.

The catalogs were relocated in order to obtain more accurate hypocenter locations, using teleseismic double-difference relocation (teletomoDD) as proposed by Pesicek et al. (2010). The teletomoDD code is an improvement from double-difference relocation (DD) (Waldhauser and Ellsworth, 2000) which relocated hypocenter based on events pairs. Figure 3 shows the relocated earthquakes distribution by applying 3D seismic velocity from tomographic inversion study (Widyantoro and Van Der Hilst, 1996, 1997).

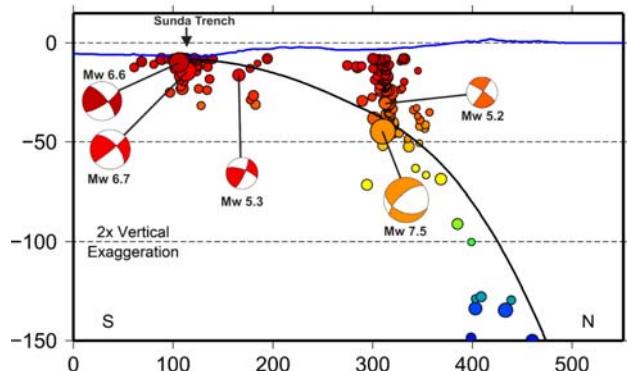


Figure 3. Relocation epicenter for cross-section below East Java using 3D Velocity Model (Nugraha et al., 2015; Nugraha et al., 2016)

3.2 Earthquake-fault assessments

The assessments of the active faults were conducted based on SRTM-30, WORLD-30m digital map IFSAR, LiDAr and other data that is just recently available (Figure 4a). In a selected site, more detailed investigations were conducted such as ground penetration radar (GPR) (Figure 4b), hand drilling and sample corings to analyze soil and rock strata related to faultings and trenching (Figure 5), and carbon dating.

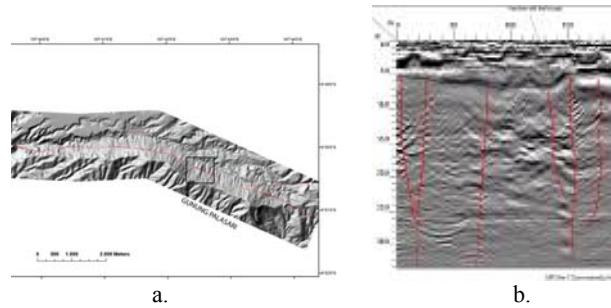


Figure 4 a) Plot of LiDAr Map, b) result from GPR



Figure 5. Results from trenching and carbon dating

3.3 New seismotectonic maps of Indonesia

Based on the latest researches and investigations, revised seismotectonic models for Indonesia were developed and to be used in developing new seismic hazard maps of Indonesia 2016. The significant results of recent active-fault studies utilizing trenching, carbon dating, epicenter relocation, strain analysis (GPS) were utilized to develop seismotectonic models of Indonesia. The process in developing seismotectonic model can be seen in Figure 6.

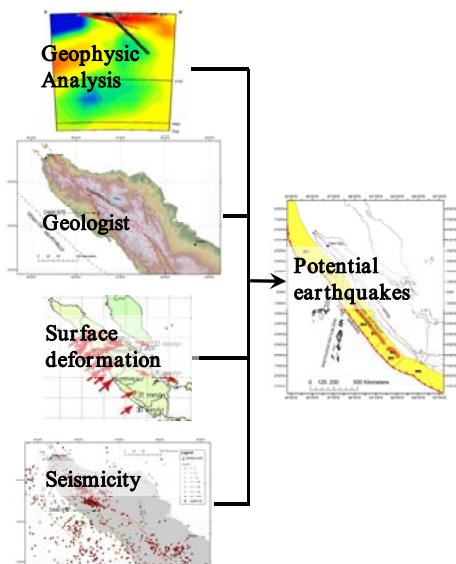


Figure 6. The process in developing seismotectonic model

The results from geodetic observation were used to identify the activity and to determine the slip rate of the active faults as shown in Figure 7 and Figure 8.

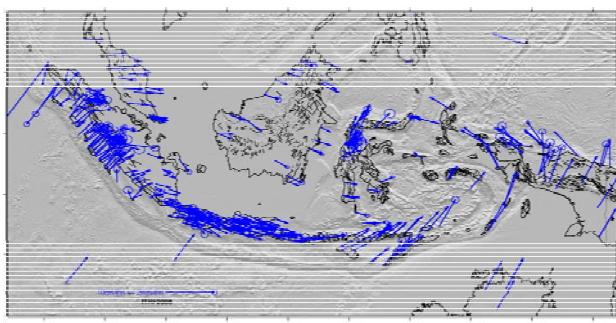


Figure 7. Geodetic displacement rate 2010-2015 (Susilo et al., 2016)

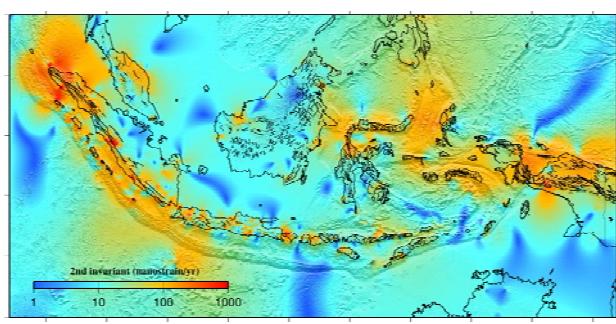


Figure 8. Geodetic strain rate 2010-2015 (Susilo et al., 2016)

There are some major differences between the previous model (used in SNI 1726-2012) and the updated seismotectonic model, such as (Figure 9 and Figure 10):

- Revision of Sumatra Fault Zone (SFZ) segments. The revised SFZ seismotectonic model is similar to that used by the SNI-2012 PSHA. The differences are the revised fault-source model for Toru-Renun-Tripa segments and for the Aceh-Seulimeum segments. We have also revised the most-southern part of SFZ, i.e Kumering Fault and other fault segments (Figure 10).
- Revision of Sumatra Megathrust Zone (SMZ). The significance change for SMZ is the change in M_{max} of the Mentawai segment from Mw 8.5 to Mw 8.9, M_{max} of the Southern segment (i.e. Enggano) from Mw 8.2 to Mw 8.4, adding the Sunda Strait megathrust segment that has maximum magnitude, M_w 9.0, and the revised geometry of the Aceh-Andaman and Nias-Simelue megathrust.
- Revision of shallow faults on Java Island. The updated of shallow faults are the fault type on locations of the Cimandiri fault zone, as well as adding several auxiliary faults around the main fault (the Baribis Fault, Semarang Thrust, and Kendeng-Rembang fold-thrusts). The Lembang fault were updated by the results from latest detailed studies.
- Revision of shallow faults on Eastern part of Indonesia such as Sulawesi and Papua.

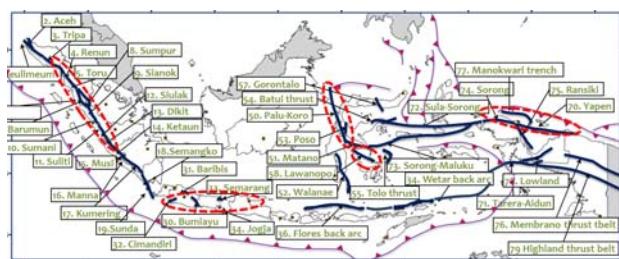


Figure 9. Revised shallow fault sources geometry

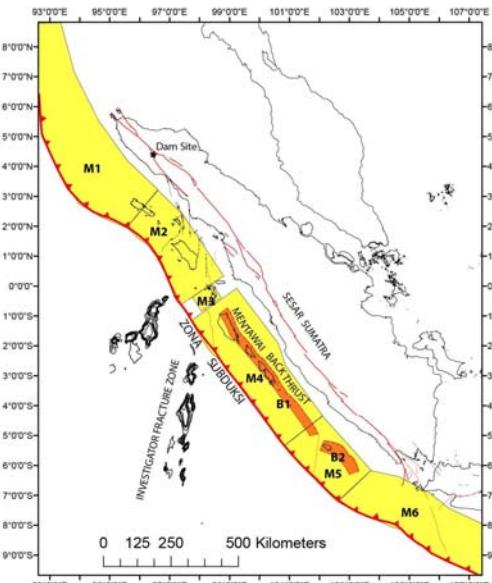


Figure 10. Revised seismic segmentation of the Sumatran megathrust

4 GROUND MOTION PREDICTION EQUATIONS

As referred to TRSHMI 2010, the ground motion predictive equations (GMPEs) or attenuation functions selection was based on seismotectonic conditions, which is generally categorized into shallow crustal (fault and shallow background sources), Subduction sources (Interface Megathrust) and intraslab Benioff zones. Most of the attenuation functions used in this study is Next Generation Attenuation (NGA), which was

derived using worldwide historical earthquake data. The attenuation functions with the weighting of logic tree used in this study are listed in Table 1 (Irsyam et al., 2010).

Table 1. Ground motion prediction equations used in seismic hazard analysis (Irsyam et al., 2010)

Seismic Sources	Attenuation Functions	Weight
Shallow crustal (fault and shallow background sources)	Boore-Atkinson NGA (Boore and Atkinson, 2008)	0.33
	Campbell-Bozorgnia NGA (Campbell and Bozorgnia, 2008)	0.33
	Chiou-Young NGA (Chiou and Youngs, 2008)	0.33
Interface Megathrust (Subduction sources)	Geomatrix subduction (Youngs et al., 1997)	0.25
	Atkinson-Boore BC rock & global source Subduction. (Atkinson & Boore, 2003)	0.25
	Zhao et al. (2006)	0.50
Intraslab Benioff (deep background sources)	AB Intraslab seismicity Cascadia region BC-rock condition. (Atkinson-Boore, 2003)	0.33
	Geomatrix slab seismicity rock, 1997 (Youngs et al., 1997)	0.33
	AB 2003 Intraslab seismicity worldwide data region BC-rock condition (Atkinson-Boore, 2003)	0.33

5 NEW INDONESIA SEISMIC HAZARD MAPS

The new Indonesia seismic hazard maps 2017 were developed by combining probabilistic and seismic hazard analyses as proposed by ASCE 7-10. The approach is based on Leyendecker et al. (1995) and The National Earthquake Hazards Reduction Program (NEHRP) 2003.

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 preliminary results of new Indonesia Seismic Hazard Map for several return periods of earthquake, such as 475 years and 2,475 years are already developed in the early 2017. The example of peak ground acceleration maps for 475 years return period of earthquakes is shown in Figure 11.

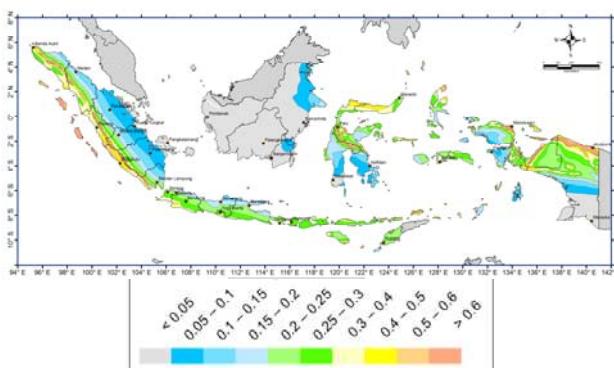


Figure 11. Preliminary maps of peak ground acceleration at bedrock (S_B) for 10% probability of exceedance in 50 years

6 CONCLUSION

This paper presents the development for updating Indonesia seismic hazard maps 2017. The updated maps were developed

based on the latest researches and investigations such as recent active-fault studies utilizing trenching, carbon dating, epicenter relocation, strain analysis (GPS) as well as availability of basic data including the SRTM-30, IFSAR, LiDAR and other data that is just recently available.

Major different between the previous model (used in SNI 1726-2012) and the updated seismotectonic model were described briefly in this paper. The preliminary Indonesia Seismic Hazard Map for several return periods of earthquake, such as 475 years and 2,475 years are already developed.

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