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RE-EVALUATION OF SEISMIC HAZARD IN TASIKMALAYA CITY USING PROBABILISTIC APPROACH

*Bambang Sunardi[1], Supriyanto Rohadi[1], Anisa Dila Indriyani[2], Sulastri[1], Dwikorita Karnawati[1]

[1]Meteorological Climatological and Geophysical Agency, Indonesia
[2]Department of Science, Sumatera Institute of Technology, Indonesia

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ABSTRACT: Tasikmalaya is one of the earthquake-prone cities in Indonesia as a result of collision of the Indo-Australian and the Eurasian plate. Earthquake mitigation efforts are needed to reduce the impact of future earthquakes. One of the mitigation efforts that can be proposed is a re-evaluation of the seismic hazard of the city. The main objective of this study was to re-evaluate seismic hazard expressed in Peak Ground Acceleration (PGA) and spectral acceleration at bedrock level based on a probabilistic approach, particularly in Tasikmalaya City. We first processed the earthquake data then adopted the new 22 seismogenic structures as the earthquake sources. Furthermore, we determined the characterization of each earthquake sources, selected, and adjusted the ground motion attenuation, and logic tree processed to manage the uncertainty of earthquake recurrence, magnitude distribution, and ground motion attenuation. Using Probabilistic Seismic Hazard Analysis (PSHA), PGA and spectral acceleration at bedrock level corresponding to 2% exceedance of 50 years' probability were calculated. The seismic hazards were quantified in terms of PGA and spectral acceleration at two fundamental periods of 0.2 and 1.0 s. The results showed that the subduction interface zones in southern Java and background seismicity significantly contributed to the seismic hazard in Tasikmalaya City. If compared with the 2010 Indonesian earthquake hazard maps, the results have relatively higher values in the three hazard maps which might due to the different characterization of earthquake sources, earthquake catalogs, and the GMPE to be used.

Keywords: Seismic hazard, PSHA, PGA, Spectral acceleration, Tasikmalaya

1. INTRODUCTION

Geographically, Tasikmalaya City is located in the southeastern part of West Java province, Indonesia, located between $108^{0}08'38''$ - $108^{0}24'02''$ E and $7^{0}10'$ - $7^{0}26'32''$ S. Tasikmalaya City covers an area of 183.85 Km^2 which is divided into 10 districts namely Cihideung, Cipedes, Tawang, Mangkubumi, Kawalu, Indihiang, Bungursari, Tamansari, Purbaratu, and Cibeureum as seen in Figure 1.

Tasikmalaya City is one of the Indonesia city's most often earthquakes experienced in Indonesia which has a high level of seismic hazard due to its location near Indo Australia and Eurasian plate collision. In the last nine years, at least two devastating earthquakes occurred in Tasikmalaya City, i.e. the September 2, 2009, M 7.5 and December 15, 2017, M 6.5 earthquakes. The September 2, 2009 earthquake caused 1,260 houses heavily damaged and 5,784 others slightly damaged [1]. Likewise, the December 15, 2017 earthquake caused damages in Tasikmalaya City, although not as big as 2009 one. These two disasters caused significant social and economic loss and disrupted many years' development efforts.

Earthquake disaster mitigation becomes indispensable to reduce the hazards caused by earthquake events. Generally, most of the damaged buildings are due to their inadequate design and construction. A well-engineered construction will reduce earthquake risk. One effort to minimize the impact of the earthquake disaster is by assessing the seismic hazard. Seismic hazard assessment is useful for development planning purposes, preparedness, emergency response, risk calculation of life and economic loss, and to increase public awareness.

The seismic hazards assessment in Indonesia has improved in line with the knowledge of seismotectonics in the region. Seismic hazard maps for a wider scale covering the entire territory of Indonesia already existed and several times underwent revised, consisting of the Indonesian earthquake hazard map of PPTI-UG as a result study of Beca Carter in Indonesia-New Zealand bilateral cooperation [2], Indonesian earthquake hazard map of SNI 03-1726-2002 [3], Indonesian earthquake hazard map of 2010 [4], and earthquake hazard map of 2017 [5].

Re-evaluation of seismic hazard is an important need to be done. Some countries such as the United States are updating earthquake hazard maps every three years following the renewal cycle of the building code of the International Building Code [6].

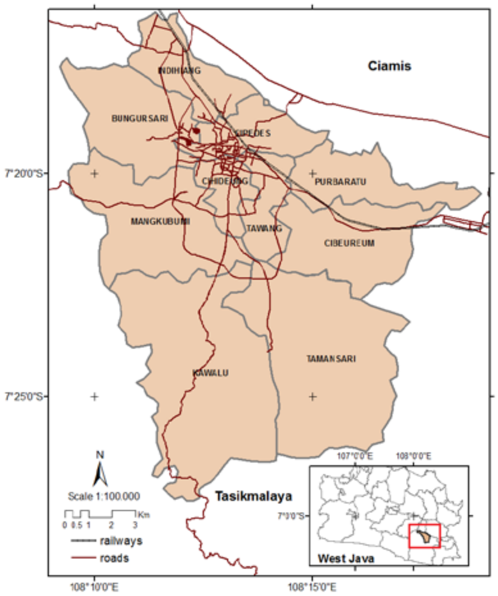

Fig.1 Location of Tasikmalaya City

This paper presented the research results about re-evaluating the seismic hazard in Tasikmalaya City. Seismic hazard assessment was conducted more locally by considering the parameters of current earthquake sources based on recent research results such as earthquake relocation data [7] - [8], geology in Java [9], Lembang fault [10] - [11], earthquake potential in West Java based on GPS data [12], geodetic slip rates in Java [13], and other studies contributing to re-evaluation of seismic hazards.

We used a probabilistic approach to calculate seismic hazards with a 2% exceedance in 50 years probability by using updated earthquake catalogs until 2017 and adopted new earthquake sources including the subduction interface (megathrust zones), shallow crustal and background seismic zone. A more recent model of Ground Motion Prediction Equations (GMPE) was also applied to assess the seismic hazard of the earthquake sources.

2. METHODS

We used the Probability Seismic Hazard Analysis (PSHA) method developed by Cornel [14] as our base in evaluating the seismic hazard of Tasikmalaya City. The first step taken in the PSHA process is using geological data and history of seismicity to model and characterize each earthquake source. The next step is to estimate the ground motion generated by the earthquake sources of Tasikmalaya City using the latest GMPE. A logic tree approach was used to manage the uncertainty factors in PSHA.

2.1 Seismicity and Earthquake Sources

In this study, we considered three potential of earthquake sources, including the subduction interface (megathrust zones), shallow crustal, and background earthquake sources. Two subduction zones to be considered were the Sunda Strait and West-Central Java megathrusts. The shallow crustal earthquake sources included Ujungkulon B, Cimandiri, Nyalindung-Cibeber, Rajamandala, Lembang, Tampomas, Subang, Ciremai, Cirebon 1, Cirebon, Cirebon 2, Brebes, Ajibarang, Rakutai, and Kencana faults. The other sources are backgrounds which including shallow and 4 deep background models. Figure 2 showed seismicity around Tasikmalaya City based on BMKG and USGS earthquake catalogs until 2017, while Figure 3 showed earthquake sources considered for a re-evaluation of the seismic hazard in Tasikmalaya City.

2.2 Earthquake Sources Characterization

In the characterization of earthquake sources, it took several input parameters such as a and b-values, the maximum magnitude (Mmax), and slip rate. Characterization of earthquake sources was done in megathrust zones, shallow crustal, and backgrounds. In this study, we used the latest characterization of earthquake sources from National Earthquake Study Center [5]. The following Table 1 and Table 2 were examples of characterization of shallow crustal and subduction interface sources.

2.3 Attenuation Models

The seismic wave attenuation of site distance from earthquake source can be predicted using Ground Motion Prediction Equations (GMPE) model which developed from many strong ground motion recordings by applying a statistic regression method. GMPE is a simple mathematical equation that connects seismic parameters at an earthquake center location, including Magnitude (M) and distance (R), with ground movement parameters (spectral acceleration) at the site under study. In this study, we adopted the attenuation model from other regions that have seismotectonic conditions similar to Indonesia, because there is no attenuation model yet that have been made in Indonesia.

We picked 3 different attenuation models for each earthquake sources, based on the best similarity. For subduction interface (megathrust), we used Zhao et al., variable Vs30 interface [15], BC Hydro 2012 modified [16], and Atkinson-Boore Global subduction [17]. We used the same attenuation models for shallow crustal and shallow background because their characteristics are similar.

The attenuation model for both of shallow sources are Boore et al NGA West2-Atkinson [18], Chiou-Youngs NGA West2 [19], and Campbell-Bozorgnia NGA [20]. For the last earthquake source, the deep background, it were used Geomatrix slab seismicity rock intraslab [21], Atkinson-Boore intraslab, Worldwide [22], and Atkinson-Boore intraslab, Cascadia [22].

2.4 Logic Tree Approach

The logic tree introduced by Kulkarni [23] is a method that becomes a standard feature of PSHA. The purpose of the logic tree is to capture and measure the epistemic uncertainty associated with the input to the PSHA, thereby allowing the uncertainty estimation resulting in hazard [24].

The logic tree is modeled by a nodal sequence representing the model points to be explained and branching representing the variation of the model to be used. The logic tree model used adapted to the considered source of the earthquake. In the current study, the alternative hypothesis is used mainly for the calculation of maximum magnitude (Mmax) and GMPE. Therefore, the logic tree consists of two branched components and the weight of each branch reflects the relative trust in each branch. The logic tree we used in the data analysis could be seen in Figure 4 – 5.

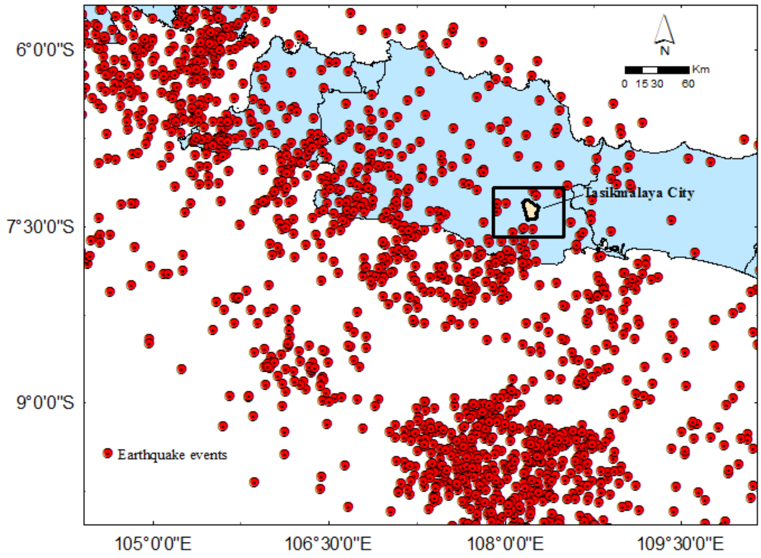

Fig.2 Seismicity map in the research area and surrounding

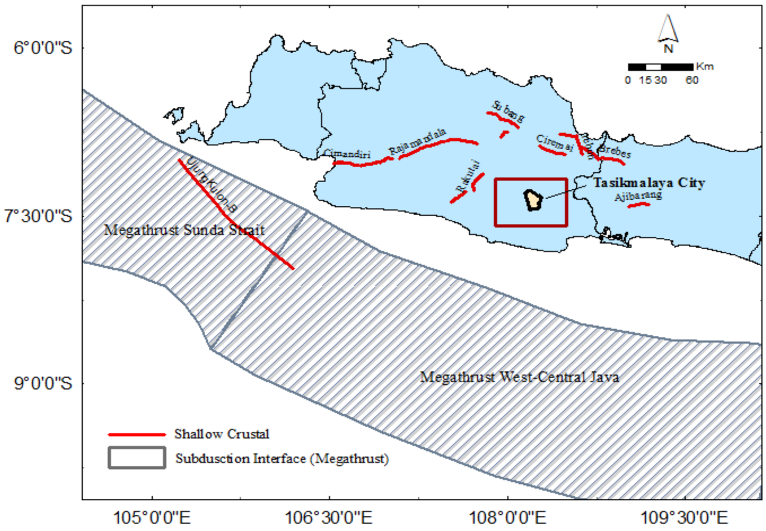

Fig.3 Earthquake sources considered for a re-evaluation of seismic hazard in Tasikmalaya City

Table 1 Characterization of shallow crustal earthquake sources [5]

No	Earthquake Sources	Sense Mechanism	Slip Rate (mm/yr)	Dip	Top (km)	Bottom (km)	L (km)	M_{max}
1	Cimandiri	Reverse	0.55	45S	3	18	23	6.7
2	Nyalindung-Cibeber	Reverse	0.4	45S	3	18	30	6.5
3	Rajamandala	Strike Slip	0.1	90	3	18	45	6.6
4	Lembang	Strike Slip	2.0	90	3	18	29.5	6.8
5	Tampomas	Reverse	0.1	45S	3	18	22	6.5
6	Subang	Reverse	0.1	45S	3	18	33	6.5
7	Ciremai	Strike Slip	0.1	90	3	18	20	6.5
8	Cirebon 1	Reverse	0.1	45S	3	18	15	6.5
9	Cirebon	Reverse	0.5	45S	3	18	23	6.2
10	Cirebon 2	Reverse	0.1	45S	3	18	18	6.5
11	Brebes	Reverse	0.1	45S	3	18	22	6.5
12	Ajibarang	Strike Slip	0.1	90	3	18	20	6.5
13	Garsela Rakutai	Normal	0.1	60E	3	18	19	6.5
14	Garsela Kencana	Strike Slip	0.1	90	3	18	17	6.5
15	Ujung Kulon B	Strike Slip	10	90	3	20	150	7.6

Table 2 Characterization of subduction interface (megathrust zones) [5]

Earthquake Sources	a-value	b-value	M_{max}
Sunda Strait	5.99	1.15	8.7
West - Central Java	5.55	1.08	8.7

2.5 Probabilistic Seismic Hazard Analysis

The probabilistic approach used in most seismic hazard studies followed the methodology described by Algermissen and Perkins [25], based on theoretical calculations made by Cornell [14]. The model and concept of this analysis still be used today. However, the models of analysis and calculation techniques are constantly being developed.

In this approach, it was assumed that the magnitude M and the distance R from source to the city as a continuous independent random variable. The general form of the total probability theory can be expressed in equation (1).

$$P[I \ge i] = \int_r \int_m P[I \ge i | m \& r] f_M(m). f_r(r) dmdr \tag{1}$$

With f_M is the function of the magnitude distribution, f_r is the hypocenter distance distribution function, P[I ≥ i | m and r] is an intensity random probability condition (I) that exceeds the value of (i) at a location due to magnitude (M) and the hypocenter distance (R). In this study, PSHA calculations for re-evaluation the seismic hazard of Tasikmalaya City using the validated Crisis 2015 software [26].

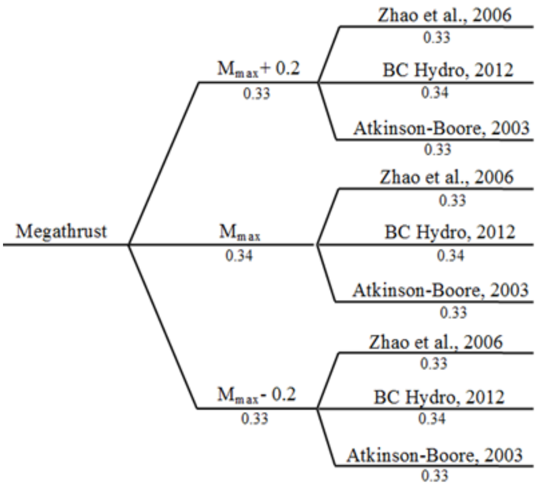

Fig.4 Logic tree for the megathrust source

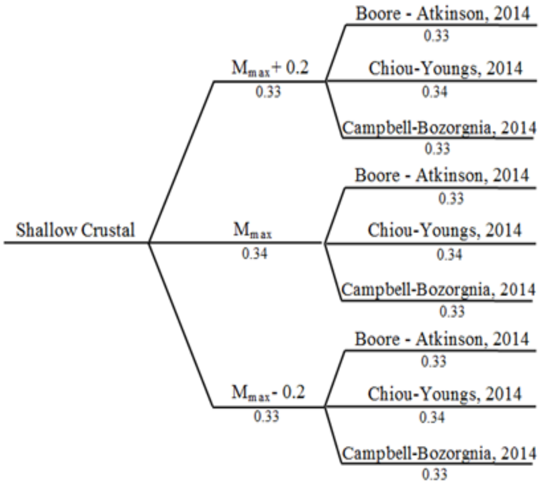

Fig.5 Logic tree for the shallow crustal source

3. RESULT AND DISCUSSION

In this study, the re-evaluation of seismic hazard in Tasikmalaya City was conducted by considering some new earthquake sources. The result of a re-evaluation of seismic hazard in Tasikmalaya City is presented in the form of acceleration map in bedrock for 2% exceedance in 50 years. Acceleration maps in the bedrock are the maximum ground acceleration hazard (PGA) and spectral acceleration in T = 0.2 second (s) and T = 1 s.

3.1 Hazard PGA

The PGA values in bedrock range from 0.47 to 0.53 g as shown in Figure 6. Indihiang Subdistrict, northern Tasikmalaya City has a relatively lower PGA value of about 0.47 g, while the southern part of Tasikmalaya City mainly in Kawalu and Tamansari gained the most PGA values up to 0.53 g. The high PGA value is probably due to the fact that the southern area of Tasikmalaya City is closer to the megathrust earthquake source.

3.2 Spectral Acceleration at 0.2 s

The result of acceleration with T = 0.2 s condition is a pattern resembling PGA result, were south of Tasikmalaya City has bigger acceleration value compared to the northern part. The spectral acceleration in the short period (T = 0.2 s) for 2% exceedance in 50 years' probability indicated the range of values of 1.04 to 1.14 g as shown in Figure 7. The spectral acceleration values in the southern part of Kawalu were the highest overall sub-districts. Overall, the values of ground acceleration spectra at bedrock at T = 0.2 s is higher than the PGA value.

The re-evaluation of earthquake hazard in Tasikmalaya City showed that the southern Java subduction interface (Megathrust zones) and background seismicity significantly contribute to the seismic hazard in Tasikmalaya City.

3.3 Spectral Acceleration at 1 s

Map of spectral acceleration in bedrock at T = 1 s as shown in Figure 8. Acceleration value at spectral condition T = 1 s for 2% exceedance in 50 years' probability showed a range of values between 0.47 - 0.52 g. The southeast part of Kawalu and Tamansari district got higher ground acceleration than other districts. The resulting pattern was almost identical to the result of PGA and spectral acceleration at T = 0.2 s whereas to the north of Tasikmalaya City, the acceleration values of the ground acceleration will be smaller.

The results showed that the bedrock PGA of this study (Figure 6), relatively higher when compared to the 2010 Indonesian earthquake hazard map [27] which showed PGA values between 0.47 - 0.49 g (Figure 9). In the T = 0.2 s spectral condition, the re-evaluation results showed a range of values between 1.04 - 1.14 g (Figure 7). The value is also relatively higher than the 2010 Indonesian earthquake hazard map which showed the values of 0.98 – 1.04 g (Figure 10).

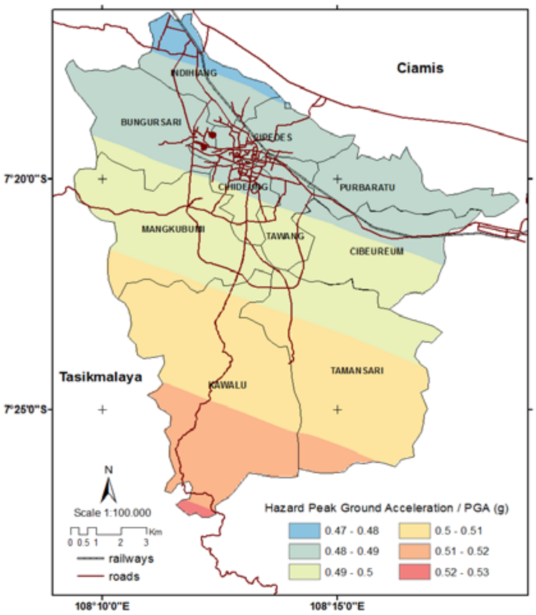

Fig.6 Map of hazard Peak Ground Acceleration (PGA) of Tasikmalaya City

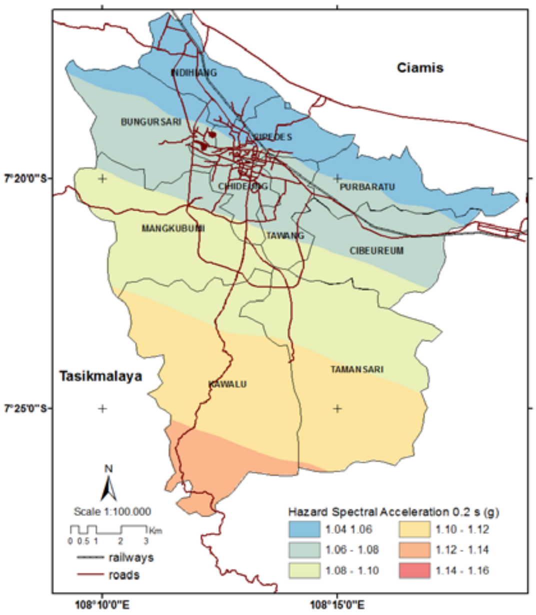

Fig.7 Map of hazard spectral acceleration 0.2 s of Tasikmalaya City

In the T = 1 s spectral condition, the re-evaluation of seismic hazard for 2% probability exceedance in 50 years with the values of 0.47 - 0.52 g (Figure 8) were also relatively higher than 2010 Indonesian earthquake hazard map [27], which showed values of 0.38 - 0.41 g (Figure 11).

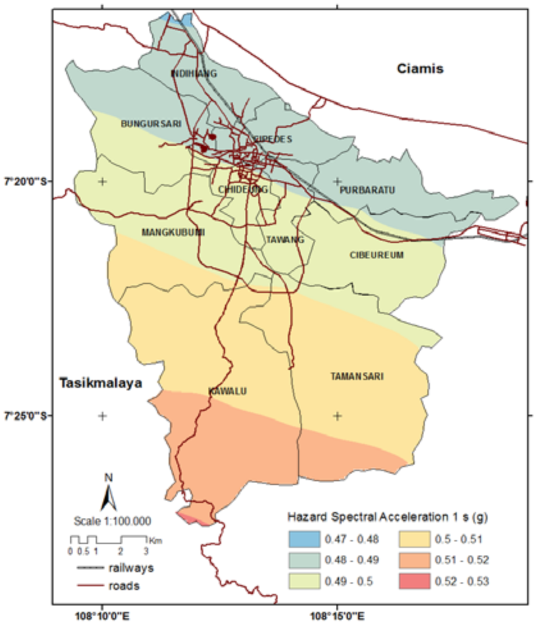

Fig.8 Map of hazard spectral acceleration 1 s of Tasikmalaya City

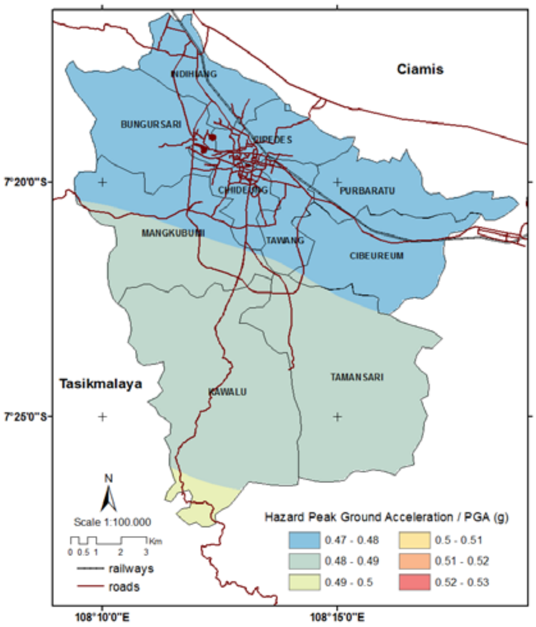

Fig.9 Peak Ground Acceleration (PGA) hazard map in the 2010 Indonesian earthquake hazard map [27]

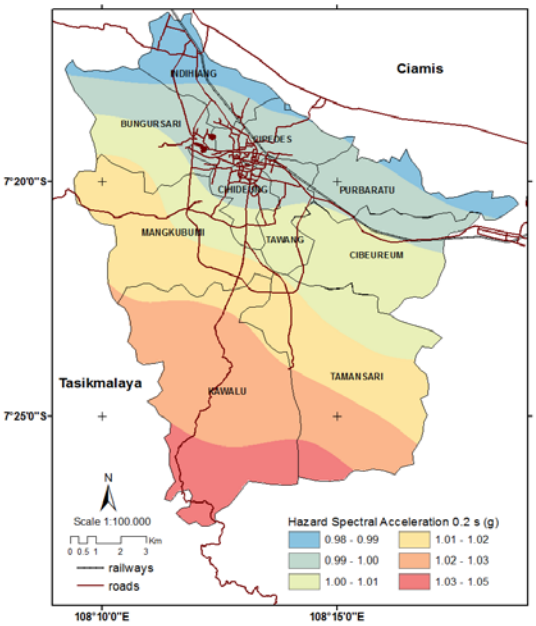

Fig.10 Spectral acceleration 0.2 s hazard map in the 2010 Indonesian earthquake hazard map [27]

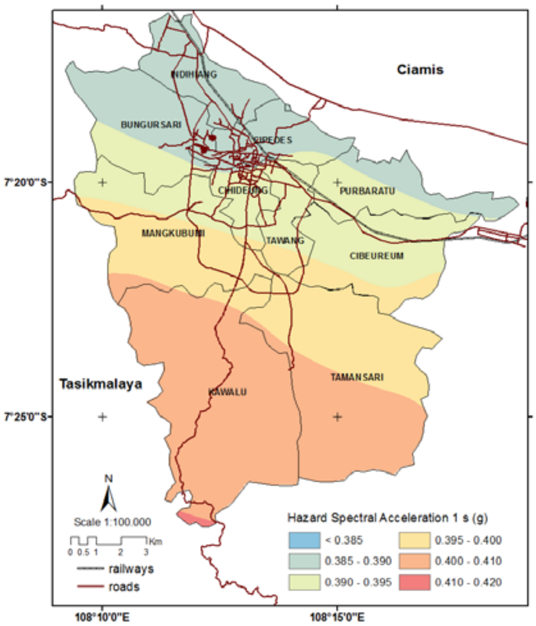

Fig.11 Spectral acceleration 1s hazard map in the 2010 Indonesian earthquake hazard map [27]

Differences in the range of acceleration values between the current study and the 2010 Indonesian earthquake hazard map [27] were attributed to several factors, such as the characterization of subduction interface (megathrust zones) earthquake sources in the south of the study area. In this re-evaluation study of the seismic hazard, the megathrust zones in the southern of Tasikmalaya City was designed with a maximum magnitude of

M 8.7 whereas the 2010 Indonesian earthquake hazard map using the maximum magnitude of M 8 [27]. The increasing of seismic hazard values was also influenced by the use of background earthquake sources model. In this study, it was used at least more complete 5 years' earthquake catalog if compared to the 2010 earthquake hazard map.

The re-evaluation of seismic hazard in Tasikmalaya City also considered the new earthquake sources, which have not been considered in the 2010 earthquake hazard map of Indonesia. The latest earthquake sources included Garsela Rakutai and Kencana, Ajibarang, Brebes, Cirebon 2, Cirebon 1, Cirebon, Ciremai, Subang and Tampomas faults. By considering the new earthquake sources, it can be an advantage over current research. In addition to considering the new earthquake sources, the re-evaluation of seismic hazards in Tasikmalaya City also uses some of the latest Ground Motion Prediction Equations (GMPE), not yet used in the 2010 Indonesian earthquake hazard map.

4. CONCLUSION

We already re-evaluation the seismic hazard in Tasikmalaya City using PSHA method. The maximum ground acceleration (PGA) values and the spectral accelerations at bedrock for 2% exceedance in 50 years probability in Tasikmalaya City were ranged from 0.47 - 0.53 g for PGA, from 1.04 to 1.14 g for the spectral acceleration for the short period (T = 0.2 s), and from 0.47 to 0.52 g for long period (T = 1 s). The results showed that PGA and spectral accelerations of this study are slightly bigger compared to 2010 Indonesia earthquake hazard maps, probably due to the addition in the calculation of several new earthquakes sources as well as the differences in the characterization of earthquakes sources and attenuation functions used in the study. In the future, Indonesia should have a detailed earthquake hazard map in all the cities, so the calculation of seismic hazard in the City Level still needs to do.

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6. REFERENCES

[1] The government of Tasikmalaya City, The September 2, 2009, earthquake disaster report, 2009.

[2] Beca Carter Hollings and Ferner, Indonesian Earthquake Study, New Zealand Bilateral Assistance Programme to Indonesia, Vol. 1-7, 1979.

[3] Indonesian National Standardization Agency, Earthquake Resistant Design Code for Building of Indonesia SNI 03-1726-2002, 2002.

[4] Indonesian Earthquake Map Revision Team, Study results of the 2010 Indonesian Earthquake Map Revision Team, Study Report, 2010.

[5] National Center for Earthquake Studies, Indonesian Earthquake Sources and Earthquake Hazard Maps 2017, Centre for Research and Development of Housing and Resettlement, Ministry of Public Works and Human Settlements, ISBN 978-602-5489-01-3, 2017, pp. 1-377.

[6] McCormac, J. C., Brown, R. H., Design of Reinforced Concrete, John Wiley & Sons, 2015.

[7] Shiddiqi, H. A., Relokasi Hiposenter Teleseismik Double-difference Gempa di Indonesia dengan Menggunakan Model Kecepatan Seismik 3D. Master Thesis. Institut Teknologi Bandung, 2015.

[8] Shiddiqi, H. A., Widiyantoro, S., Nugraha, A. D., Ramdhan, M., Wandono, Sutiyono, ... and Nugroho, H., Preliminary result of teleseismic double-difference relocation of earthquakes in the Molucca collision zone with a 3D velocity mode, in AIP Conference Proceedings, Vol. 1658, No. 1, 2015, p. 030011.

[9] Marliyani, G. I., Neotectonics of Java, Indonesia: Crustal deformation in the overriding plate of an orthogonal subduction system. Doctoral dissertation, Arizona State University, 2016.

[10] Meilano, I., Abidin, H. Z., Andreas, H., Gumilar, I., Sarsito, D., Hanifa, R., ... and Fukuda, Y., Slip rate estimation of the Lembang Fault West Java from geodetic observation. Journal of Disaster Research, 7 (1), 2012, 12-18.

[11] Daryono, M. R., Paleoseismology Tropis Indonesia: Dengan Studi Kasus Di Sesar Sumatra, Sesar Palukoro-Matano, dan Sesar Lembang. Disertasi Program Doktor, Institut Teknologi Bandung, 2016.

[12] Hanifa, N. R., Interplate Earthquake Potential of Western Java, Indonesia, based on GPS data. Doctoral Dissertation at Nagoya University, Japan, 2014.

[13] Koulali, A., McClusky, S., Susilo, S., Leonard, Y., Cummins, P., Tregoning, P., & Wijanarto,

A. B., The kinematics of crustal deformation in Java from GPS observations: Implications for fault slip partitioning. Earth and Planetary Science Letters, 458, 2017, 69-79.

[14] Cornell, C. A., Engineering seismic risk analysis, B. Seism. Soc. Am., 58, 1968, 1583–1606.

[15] Zhao, J. X., Irikura, K., Zhang, J., Fukushima, Y., Somerville, P. G., Asano, A., Ohno, Y., Oouchi, T., Takahashi, T. and Ogawa, H., An empirical site-classification method for strong-motion stations in Japan using H/V response spectral ratio. Bulletin of the Seismological Society of America, 96(3), 2006, pp.914-925.

[16] Abrahamson, N. A., Gregor N., and Addo, K., BC Hydro Ground Motion Prediction Equations for Subduction Earthquakes, submitted to Earthquake Spectra, 2012.

[17] Atkinson, G. M., Boore, D. M., Empirical ground-motion relations for subduction zone earthquakes and their application to Cascadia and other regions, Bulletin of the Seismological Society of America, 93:4, 2003, 1703–1729.

[18] David M. Boore, Jonathan P. Stewart, Emel Seyhan, and Gail M. Atkinson, NGA-West2 Equations for Predicting PGA, PGV, and 5% Damped PSA for Shallow Crustal Earthquakes. Earthquake Spectra, Vol. 30, No. 3, 2014, pp. 1057-1085.

[19] Brian S. J. Chiou, and Youngs, R. R., Update of the Chiou and Youngs NGA Model for the Average Horizontal Component of Peak Ground Motion and Response Spectra, Earthquake Spectra, Vol. 30, No. 3, 2014, pp. 1117-1153.

[20] Campbell, K. W., and Bozorgnia, Y., NGA-West2 Ground Motion Model for the Average Horizontal Components of PGA, PGV, and 5% Damped Linear Acceleration Response Spectra. Earthquake Spectra, Vol. 30, No. 3, 2014, pp. 1087-1115.

[21] Youngs, R. R., Chiou, S. J., Silva, W. J., and Humphrey, J. R., Strong ground motion attenuation relationships for subduction zone earthquakes. Seismological Research Letters, 68 (1), 1997, 58–73.

[22] Atkinson, G. M., and Boore, D. M, Empirical Ground-Motion Relations for Subduction-Zone Earthquakes and Their Application to Cascadia and Other Regions, Bulletin of the Seismological Society of America, Vol. 93, No. 4, 2003, pp 1703-172.

[23] Kulkarni, R. B., Youngs, R. R., and Coppersmith, K. J., Assessment of confidence intervals for results of seismic hazard analysis, in Proceedings of the Eighth World Conference on Earthquake Engineering, San Francisco, Vol. 1, 1984, 263–270.

[24] Bommer, J. J., and Scherbaum. F., The Use and Misuse of Logic Trees in Probabilistic Seismic Hazard Analysis. Earthquake Spectra: November 2008, Vol. 24, No. 4, 2008, pp. 997-1009.

[25] Algermissen, S. T. and Perkins, D. M., A probabilistic estimate of maximum acceleration in rock in the contiguous Unites State, US Geological Survey Open-File Report, 1976.

[26] Meléndez, A. A, Ordaz Schroeder, M. G., De la Puente, J., González Rocha, S. N., Rodriguez Lozoya, H. E., Córdova Ceballos, A., ... & Campos Rios, A., Development and Validation of Software CRISIS to Perform Probabilistic Seismic Hazard Assessment with Emphasis on the Recent CRISIS2015. Computación y Sistemas, 2017, 21(1).

[27] Irsyam, M., Sengara, I.W., Asrurifak, M., Ridwan, M., Aldiamar, F., Widiyantoro, S., Triyoso, W., Natawijaya, D.H., Kertapati, E., Meilano, I., and Suhardjono, Summary: development of seismic hazard maps of Indonesia for revision of seismic hazard map in SNI 03-1726-2002. Research report submitted to the Ministry of Public Works by Team for Revision of Seismic Hazard Maps of Indonesia, 2010.