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SEISMIC MICROZONATION OF SEMARANG, INDONESIA, BASED ON PROBABILISTIC AND DETERMINISTIC COMBINATION ANALYSIS

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ABSTRACT

Research and development of seismic hazard maps of Indonesia has already finished on 2017. One of the most important information obtained from this research related with new seismic source which is crossed the city of Semarang, Indonesia. Based on the new Indonesian Seismic Hazard Maps 2017, Semarang fault is to be categorized as the new dangerous seismic source and should be taken into account for seismic mitigation of this city. This paper describes the result of seismic microzonation of Semarang by conducting a combination of probabilistic and deterministic hazard analysis. The purpose of this research is for developing risk map for Semarang by conducting one percent of building collapse in 50 years. The analysis was performed by conducting the same method proposed for developing risk targeted Maximum Considered Earthquake (MCER) maps 2012 by improving beta (logarithmic standard deviation) value equal 0.65 and direction factor 1.1 and 1.3 for short and long period spectral acceleration respectively. Compare with the previous result conducted on 2012 the maximum MCER spectral acceleration was identified on the eastern part of the city due to the existing of Lasem fault. However due to the new developed Semarang fault source the maximum MCER spectral acceleration was distributed on the western part of the study area. The differences of those two MCER distribution results caused by the location of Lasem fault and Semarang fault seismic sources. Lasem fault is located on the eastern part however Semarang fault is located on the northwestern part of the city.

Keywords: Seismic microzonation, shallow crustal fault, probabilistic, deterministic, MCER

INTRODUCTION

The new Indonesian seismic hazard maps were already developed on 2017 by National Research Center for Earthquake Disaster (PUSGEN) [1] by conducting probability seismic hazard analysis (PSHA). Eight different maps with different probability of exceedance, from 20% of exceedance in 10 years (50 years of return periods) until 1% of exceedance in 100 years (10000 years of return periods), were implemented during 2017. Major improvements on historical earthquakes data, earthquakes faults assessments data, seismotectonic maps data and minor improvements on ground motion prediction equations were implemented for developing those eight seismic hazard maps [2]. One of the important seismic hazard maps used for developing Indonesian Seismic Code for Building Resistance is 2500 years of return periods seismic hazard map (2% probability of exceedance in 50 years). Development of seismic hazard maps for building design is still ongoing and following the same procedures implemented for developing 2012 Indonesian Seismic Code (**SNI:1726-2012**) [3]. The proposed seismic hazard maps for SNI will be developed using a combination of probabilistic (2% of exceedance in 50 years) and deterministic hazard analysis and conducting risk targeted ground motion (RTGM) analysis of probabilistic seismic hazard analysis to produce 1% probability of building collapse in 50 years [3], [4]. The RTGM analysis was performed by conducting beta (β), logarithmic standard deviation, value equal to 0.65 and direction factor 1.1 and 1.3 for 0.2 second and 1 second respectively. The RTGM analysis was performed for the whole area of the country from 94° to 142° east longitude and from 8° north latitude to 12° south latitude and conducting 0.1 degrees grid spacing on both directions longitude and latitude.

A combination of probabilistic seismic hazard (RTGM) analysis and deterministic seismic hazard analysis was then implemented for developing maximum considered earthquake (MCE) for the whole area of the country. Two risk targeted maximum considered earthquake (MCER) ground motion maps, short period (0.2 second) and long period (1 second), were then developed for the whole area of Indonesian country.

This paper describes the development of seismic microzonation of Semarang, Indonesia, by conducting a combination of probabilistic (RTGM) and deterministic seismic hazard analysis in terms of short period (MCES) and long period (MCES1). The development of seismic microzonation of the city was implemented at 288 boring locations by conducting weighting interpolation of four closest points of MCES and MCES1 result calculations. All boring investigations were performed from 2009 until 2017 with minimum 30 meters depth. Average shear wave velocity (Vs30) were already calculated using standard penetration test data (N-SPT) and conducting three empirical formulas proposed by [5], [6] and [7]. A comparative study was implemented in this study to evaluate all MCES and MCES1 values calculated at 288 boring locations using 2018 and 2012 data. Fig. 1 shows Vs30 maps of Semarang, boring locations and two fault traces

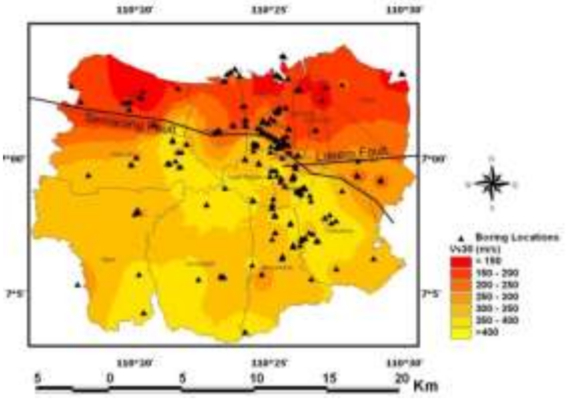

Fig. 1 Vs30 map and boring positions.

SEISMIC HAZARD ANALYSIS

Seismotectonic Data for Seismic Hazard Analysis

Major improvement of seismotectonic data was conducted for seismic hazard analysis. Seismotectonic data for 2010 seismic hazard analysis was dominated by 5 (five) shallow crustal fault sources (Cimandiri, Lembang, Yogya, Lasem and Opak) and 1 (one) subduction source (Java Megathrust). However for 2017 seismic hazard analysis 8 (eight) shallow crustal fault data (Cimandiri, Lembang, Baribis-Kendeng, Ciremai, Ajibarang, Opak, Merapi-Merbabu and Pati) have been clearly identified and located within a radius of 500 Km from the city of Semarang. All crustal fault data are divided into 26 (twenty-six) fault segments. Table 1 shows the seismotectonic data of 26 fault segments used for seismic hazard analysis. Seismic parameters SR, SM, D, L and M on this table represents Slip Rate **(mm/year)**, Seismic Mechanism, Dip (degree), Long (Km) and Maximum Magnitude (Mw).

For 2017 seismic hazard analysis 1 (one) subduction source (Java Megathrust) was clearly identified and located on the southern part of Java island. For seismic hazard analysis Java subduction megathrust source is divided into two segment, i.e. Jabar (West Java) and Jateng-Jatim (**Central** Java and East Java) segments. Table 2 shows all parameter data used for Java subduction megathrust source. L, W, SR and M represents Long (Km), Width (Km), Slip Rate (cm/year) and Maximum Magnitude (Mw) respectively. Fig. 2 shows seismotectonic of Java Island used for developing seismic hazard map. Fault number on this figure related with segment fault number as can be seen on Table 1.

Seismic hazard analysis was performed by conducting earthquake databases from 1901 until 2014 [2]. All earthquake data were collected from Meteorological Climatological and Geophysical Agency (BMKG), focal mechanism from International Seismological Commission (ISC) databases, EHB catalog and Preliminary Determination of Epicenters (PDE) [2]. In order to obtain complete and correct positions of earthquake data all hypocenter earthquake data have been relocated to the correct positions [2].

Table 1 Shallow crustal fault parameter data [1]

No	Fault Segments	SR	SM	D	L	M
1	Cimandiri	0.55	RS	45	23	6.7
2	Cibeber	0.40	RS	45	30	6.5
3	Rajamandala	0.1	SS	90	45	6.6
4	Lembang	2.0	SS	90	29.5	6.8
5	Subang	0.1	RS	45	33	6.5
6	Cirebon-1	0.1	RS	45	15	6.5
7	Cirebon-2	0.1	RS	45	18	6.5
8	Karang Malang	0.1	RS	45	22	6.5
9	Brebes	0.1	RS	45	22	6.5
10	Tegal	0.1	RS	45	15	6.5
11	Pekalongan	0.1	RS	45	16	6.5
12	Weleri	0.1	RS	45	17	6.5
13	Semarang	0.1	RS	45	34	6.5
14	Rawapening	0.1	RS	45	18	6.5
15	Demak	0.1	RS	45	31	6.5
16	Purwodadi	0.1	RS	45	38	6.5
17	Cepu	0.1	RS	45	100	6.5
18	Waru	0.05	RS	45	64	6.5
19	Surabaya	0.05	RS	45	25	6.5
20	Blumbang	0.05	RS	45	31	6.6
21	Ciremai	0.1	SS	90	20	6.5
22	Ajibarang	0.1	SS	90	20	6.5
23	Opak	0.75	SS	60	45	6.6
24	Merapi-Merbabu	0.1	SS	90	28	6.6
25	Pati	0.1	SS	90	69	6.5
26	Lasem	0.5	SS	90	114.9	6.5

Note: RS: Reverse-Slip, SS: Strike-Slip.

Table 2 Subduction parameter data [1]

No	Segment	L	W	SR	M
1	Jabar	320	200	4.0	8.8
2	Jateng-Jatim	400	200	4.0	8.9

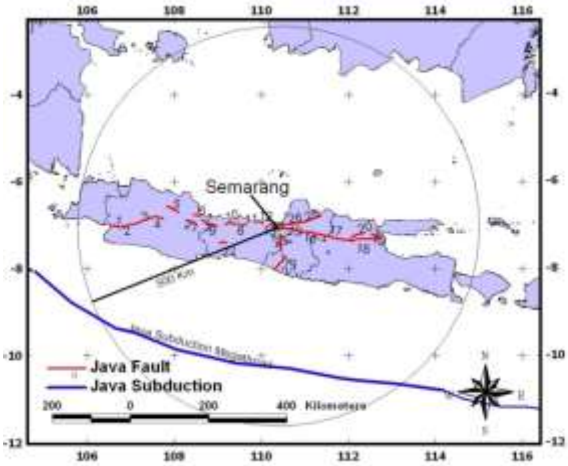

Fig. 2 Seismotectonic map of Java Island.

Ground Motion Prediction Equations

Selection of ground motion prediction equation (attenuation function) is important for calculating or predicting spectral acceleration at specific site. Following the same method implemented for 2010 seismic hazard maps of Indonesia all attenuation function used for 2017 seismic hazard maps are divided into four different seismic source mechanism, i.e. shallow crustal fault, shallow background, subduction megathrust (Interface) and deep background (Benioff). Compare to 2010 seismic hazard maps a minor improvement of attenuation function was conducted for 2017 seismic hazard maps. BCHydro [8] attenuation function was conducted for subduction interface to replace Young's 1997 attenuation function [9]. Table 3 shows all attenuation functions used for developing 2017 seismic hazard maps.

Table 3 Attenuation functions used for developing 2017 seismic hazard maps

Seismic Mechanism	Attenuation Functions
Shallow Crustal Fault and Shallow Background	[10] - [12]
Interface Megathrust	[9], [13], [14]
Benioff Subduction Intraslab	[9], [14]

Probabilistic and Deterministic Hazard Analysis

Two seismic hazard, probabilistic (PSHA) and deterministic (DSHA), analysis were performed for obtaining spectral acceleration at bedrock elevation. PSHA was implemented using total probability theorem [15]. Equation 1 shows the basic formula for obtaining the total average rate of exceedance of earthquake (λa^*) with acceleration greater than specific acceleration value a*. P_m (m) and P_r(r) on this equation represents probability distribution function of magnitude (m), distance (r) respectively and v represents mean rate of exceedance. DSHA was implemented using 84th percentile or equal to 150% of median spectral acceleration.

$$\lambda a^* = v \int_m \int_r (Pa > a^* | m, r) P_m(m) P_r(r)\, dr\, dm \qquad (1)$$

Following the same steps conducted for developing 2010 national seismic hazard maps and 2012 seismic code, integrating of PSHA and DSHA was implemented for developing 2018 MCER maps for the whole area of the country. Compare to 2012 seismic code two basic improvements were performed, i.e. β (logarithmic deviation standard) value and direction factor for short and long periods spectral acceleration. The β value was improve from 0.7 for 2012 seismic code to 0.65 for 2018 MCER maps. The direction factor used for 2018 MCER maps **are** 1.1 for short period (0.2 second) and 1.3 for long period (1 second). Two direction factors used for 2012 seismic code are 1.05 and 1.15 for short period and long period respectively. By implementing new β value and direction factor integrating analysis for combining PSHA and DSHA was implemented for developing 2018 MCER maps. Fig. 3 shows illustrated procedure for developing 2018 MCER maps [16] and [17].

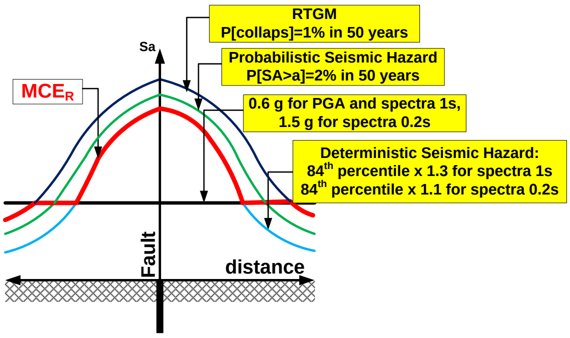

Fig. 3 **MCER 2018 design procedure** (modified from [16] and [17].

REUSLTS AND DISCUSSIONS

Seismic microzonation of Semarang was developed based on MCER analysis by combining risk targeted ground motion analysis (RTGM) with 1% probability of collapse in 50 years and 84th percentile deterministic seismic hazard analysis with adjusting direction factor 1.1 for 0.2 second period and 1.3 for 1 second period spectral acceleration. Fig. 4 shows MCEG map for peak ground acceleration, Fig. 5 shows MCER map for 0.2 second period (MCES) and Fig. 6 shows MCER map for 1 second (MCES1) spectral accelerations. As can be seen on Fig. 4 and Fig. 5 MCEG and MCES maximum acceleration are identified on the western part of the city with maximum MCEG is 0.45g and maximum MCES is 0.95g. As can be seen on Fig. 6 maximum MCES1 is **0.4g**.

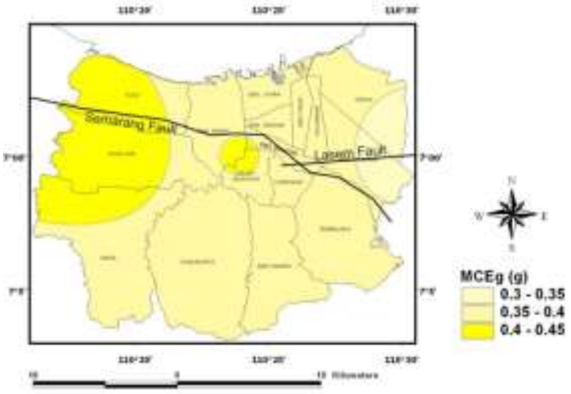

Fig. 4 MCEG map for Semarang.

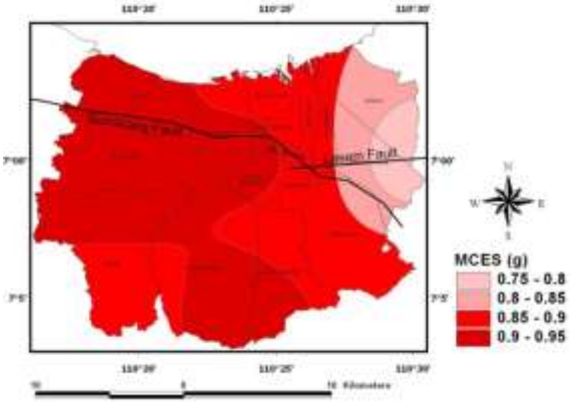

Fig. 5 MCES map for Semarang.

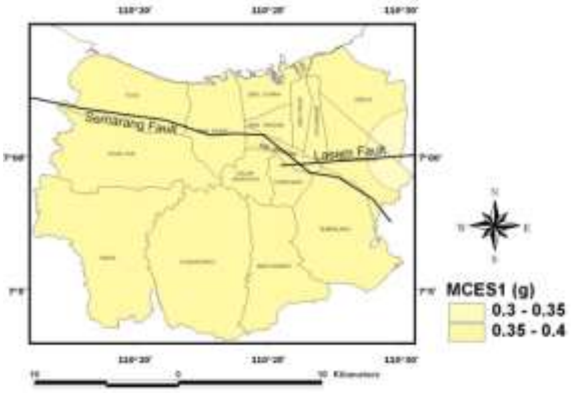

Fig. 6 MCES1 map for Semarang.

MCER calculation for evaluating the MCEG, MCES and MCES1 distributions in terms of Vs30 was conducting at 288 boring locations. The purpose of the analysis is to obtain the correlation between Vs30 and MCEG, MCES and MCES1 values. The analysis was performed by conducting weighting interpolation for each boring position with four closest data from MCER analysis results. The MCER (MCEG, MCES and MCRS1) values at boring position were interpolated by using equation 2 and equation 3 where M_b is MCER value at specific boring position. Mi is MCER value at point 'i' where i = 1 to 4, di is minimum distance of boring position to point i and wi is weight factor of boring position to point number i. Fig. 7 shows MCER distribution values calculated at 288 boring positions in terms of Vs30.

$$wi = \frac{1/di}{\sum\limits_{i=1}^{4} 1/di} \qquad (2)$$

$$M_b = \sum_{1}^{4}(wi * Mi) \qquad (3)$$

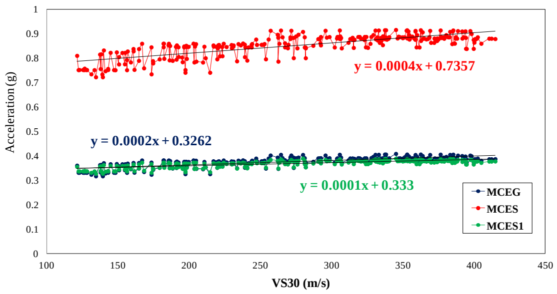

Fig. 7 MCEG, MCES and MCES1 ditribution in terms of Vs30.

Comparative analysis of 2018 MCER values to 2012 MCER values was implemented at 288 boring locations. The purpose of the analysis is to obtain the difference between 2018 MCER and 2012 MCER distribution for Semarang. Fig. 7 shows the distribution of 2012 MCES values and Fig. 8 shows the distribution of 2012 MCES1 values. As can be seen on Fig. 8 the maximum MCES values were identified on the eastern part the city. Maximum MCES value is 1.4 g. ~~**Fig. 9 shows the distribution of 2012 MCES1 values.**~~ Maximum 2012 MCES1 values were identified on the small area of eastern part of the study area. Maximum 2012 MCES1 value is 0.5 g.

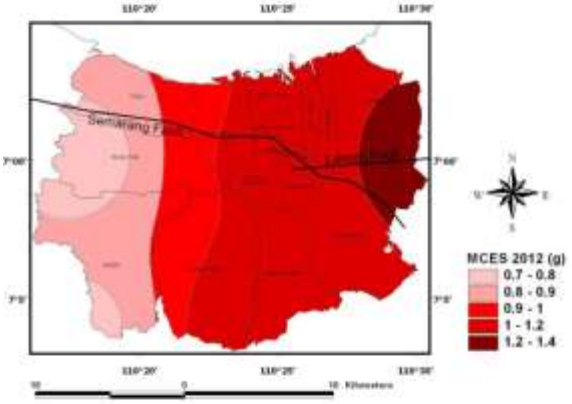

Fig. 8 MCES map 2012.

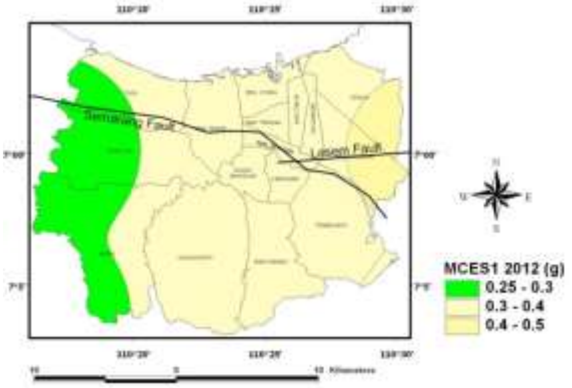

Fig. 9 MCES1 map 2012.

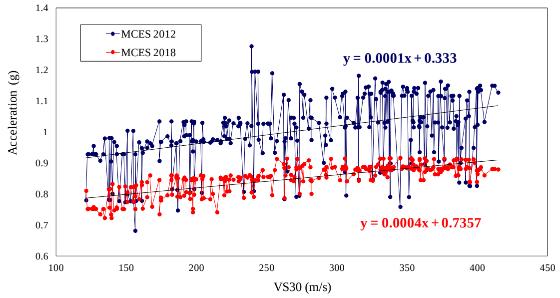

Fig. 10 Two MCES distribution (2018 and 2012) in terms of Vs30.

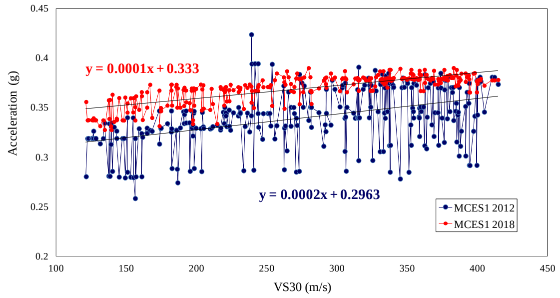

Fig. 11 Two MCES1 distribution (2018 and 2012) in terms of Vs30.

Fig. 9 shows the difference between 2018 and 2012 MCES values. All MCES values are distributed in terms of Vs30 values. As can be seen on this figure the 2012 MCES values in average are relatively greater than 2018 MCES values. Fig. 10 shows the difference between 2018 and 2012 MCES1 values. It can be seen in this figure the 2018 MCES1 values are relatively greater than the 2012 MCES1 values. Although the maximum 2018 MCES1 value as can be seen on Fig. 6 less than the maximum 2012 MCES1 value on Fig. 9, the maximum 2012 MCES1 values are distributed on the small area of the eastern part of Semarang.

CONCLUSION

Seismic microzonation of Semarang, Indonesia, was already implemented based on the combination analysis of probabilistic seismic hazard and deterministic seismic hazard analysis. Risk targeted ground motion (RTGM) analysis by conducting β value 0.65 and directivity factor 1.1 for 0.2 second spectral acceleration and 1.3 for 1 second spectral acceleration was implemented in this study. The purpose this study is to evaluate the distribution of maximum considered earthquake (MCER) values based on the new seismic hazard maps 2017. Comparative study to 2012 MCER values which has already used for 2012 Indonesian seismic code was also implemented in this study.

The maximum 2018 MCER (MCEG, MCES and MCES1) values for Semarang are distributed on the western part of the city. The maximum 0.45 g for MCEG, 0.95 g for MCES and 0.4 g for MCES1 values were identified for 2018 MCER. The opposite condition was identified for MCER distribution values of 2012 MCER. The maximum 2012 MCES and MCES1 values are identified on the eastern part of the city.

Comparative analysis was implemented in this study by comparing 2018 and 2012 MCER values. The analysis was performed for MCES and MCES1 values at 288 boring locations. Graphical analysis was implemented for comparing both MCES and MCES1 values. On average the 2018 MCES values are smaller than 2012 MCES values. However the 2018 MCES1 values on average are greater than the 2012 MCES1 values.

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free software for PSHA.

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3. Authors' Contributions (Please write all authors' contribution here)

Dr. Ir. Windu Partono MSc,: analysis and map design of seismic microzonation of Semarang and main author.

Prof. Ir. Masyhur Irsyam, MSE., PhD.: critical and final reviewing of MCER analysis and results and reviewing the manuscript.

Prof. Ir. I Wayan Sengara. MSEM, PhD.: seismic hazard and MCER analysis and reviewing the MCER analysis and reviewing the manuscript.

Dr. Ir. Muhammad Asrurifak, MT.: seismic hazard analysis and the contribution of seismic hazard and and reviewing the manuscript

4. Ethics (Please provide ethical issues that may arise after the publication of your paper)

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and no ethical issues involved.

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3. 1 Juli 2018 (First review)

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8323.pdf
24.2kB

GEOMATE Conference Review & Evaluation

Submission Date	2018-06-25 19:08:15
Paper ID number	8323
Paper Title	SEISMIC MICROZONATION OF SEMARANG, INDONESIA, BASED ON PROBABILISTIC AND DETERMINISTIC COMBINATION ANALYSIS
i. Originality	3
ii. Quality	3
iii. Relevance	4
iv. Presentation	4
v. Recommendation	4
Total (sum of i to v)	18
General comments	This paper presented very interesting results on the seismic hazard maps of Indonesia. The purpose of this research is for developing risk map for Semarang by conducting one percent of building collapse in 50 years. The analysis was performed by conducting the same method proposed for developing risk targeted Maximum Considered Earthquake (MCER) maps 2012 by improving beta (logarithmic standard deviation) value equal 0.65 and direction factor 1.1 and 1.3 for short and long period spectral acceleration respectively. Compare with the previous result conducted on 2012 the maximum MCER spectral acceleration was identified on the eastern part of the city due to the existing of Lasem fault. The differences of those two MCER distribution results caused by the location of Lasem fault and Semarang fault seismic sources. Lasem fault is located on the eastern part however, Semarang fault is located on the northwestern part of the city. The reviewer recommend this paper for acceptance with the following change.
Mandatory changes	1. Gradation of acceleration values should be drawn more clearly on Fig. 4, 5 and 6. 2. Equation (3) should be rewritten. 3. “1nd” is false in title of Fig. 10. Is it “and”? 4. “Fig. 9” and “Fig. 10” are false in last paragraph of “RESULTS AND DISCUSSION”. Maybe “Fig. 10” and “Fig. 11”.
Suggested changes	It is suggested that the authors should describe some reasons of the relationship between accelerations and Vs30 values. And it is considered that statistical dispersion of Fig 10 and 11 should be evaluated quantitatively compared with Fig. 7.
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4. 23 Oktober 2018 (Revised paper)

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7. 20 Desember 2018 (Submission after First Review and Proofreading)

8323: Journal Revised paper

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8323: Journal Revised paper

Paper ID number	8323
Revised Title	SEISMIC MICROZONATION OF SEMARANG, INDONESIA, BASED ON PROBABILISTIC AND DETERMINISTIC COMBINATION ANALYSIS
Title/Position	Dr.
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SEISMIC MICROZONATION OF SEMARANG, INDONESIA, BASED ON PROBABILISTIC AND DETERMINISTIC COMBINATION ANALYSIS

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*Corresponding Author, Received: 00 Oct. 2018, Revised: 00 Nov. 2018, Accepted: 00 Dec. 2018

ABSTRACT: One of the most important pieces of information obtained from the new Indonesian seismic hazard maps completed in 2017 was the identification of a fault that crosses the city of Semarang. This fault can be categorized as a new dangerous seismic source and should be taken into account in future seismic mitigation planning of this city. This paper describes the seismic microzonation of Semarang carried out via a combination of probabilistic and deterministic hazard analysis. The purpose of this research was to develop a risk map for Semarang based on one percent building collapse in 50 years. Analysis was performed using the same method employed in developing risk targeted Maximum Considered Earthquake (MCE_R) maps in 2012, with an improved beta (logarithmic standard deviation) value of 0.65 and adjusted direction factors of 1.1 and 1.3 for short- and long-period spectral acceleration, respectively. Whereas the 2012 maximum MCE_R spectral acceleration was distributed in the north-east of the study area due to the presence of Lasem fault, the 2018 maximum is located in the north-western part of the city as a result of the newly developed Semarang fault.

Keywords: Seismic microzonation, shallow crustal fault, probabilistic, deterministic, MCE_R

1. INTRODUCTION

The new Indonesian seismic hazard maps were developed in 2017 by the National Center for Earthquake Studies [1]. All maps were produced based on probabilistic seismic hazard analysis (PSHA). Eight different maps with varying probabilities of exceedance, ranging from 20% probability of exceedance in 10 years (50-year of return period) through to 1% probability of exceedance in 100 years (10000-year return period). Major improvements were made regarding historical earthquakes data, earthquake fault assessment data and seismotectonic map data, and minor improvements in ground motion prediction equations [2]. One of the most important seismic hazard maps used in developing the Indonesian Seismic Code for Building Resistance is the 2500-year return period seismic hazard map (2% probability of exceedance in 50 years).

However, the development of new seismic hazard maps for building design remains on-going and following the same procedures implemented in developing the 2012 Indonesian seismic code for building and other structure design [3]. The new seismic hazard maps for Indonesian Seismic Code are being developed using a combination of probabilistic (2% probability of exceedance in 50 year) and deterministic hazard analysis, as well as risk targeted ground motion (RTGM) analysis of probabilistic seismic hazard to determine 1% probability of building collapse in 50 years [3, 4]. The new RTGM analysis includes modified beta (β), logarithmic standard deviation, values and a modified of direction factor for 0.2 second and 1 second spectral acceleration. RTGM analysis is being applied to the whole area of the country from East longitude 94° to 142° and from North latitude 8° to South latitude 12° with 0.1 degree grid spacing on both directions longitude and latitude.

As part of this research, a combination of probabilistic and deterministic seismic hazard analysis are to be implemented for developing maximum considered earthquake (MCE) for the whole area of the country. Three risked targeted maximum considered earthquake ground motion (MCE_R) maps, Peak ground acceleration (PGA), short period (0.2 second) and long period (1 second), are developed for the whole area of Indonesian country.

This paper describes the development of seismic microzonation of Semarang, Indonesia, by conducting a combination of probabilistic and deterministic seismic hazard analysis in the development of three MCE_R maps (MCES for 0.2-second period, MCES1 for 1-second period and MCEG for peak ground acceleration). Seismic microzonation of the city was implemented on 288 borehole locations by conducting weighted interpolation of the four closest points of the national MCES, MCES1 and MCEG result calculations. All borehole investigations were conducted during the period from 2009 until 2017 at a minimum of 30 m depth. Average shear wave velocity (V_S30) were previously calculated using standard penetration test data (N-SPT) and conducting three empirical formulas proposed by [5], [6] and [7]. A comparative analysis was then carried out in this study to evaluate all MCES and MCES1 values calculated at 288 borehole locations based on 2018 and 2012 data. Fig. 1 shows a V_S30 map of Semarang, the borehole locations and two fault traces (Semarang and Lasem fault).

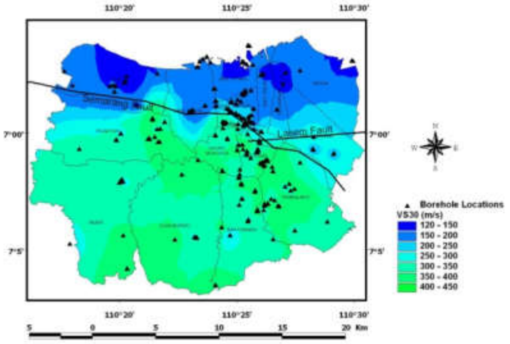

Fig.1 V_S30 map of Semarang, borehole locations and two fault traces

2. SEISMIC HAZARD ANALYSIS

2.1 Seismotectonic Data

Major improvements to the seismotectonic data for the Semarang region were made for seismic hazard analysis. Seismotectonic data for the year 2010 seismic hazard analysis are dominated by 5 (five) shallow crustal fault sources (Cimandiri, Lembang, Yogya, Lasem and Opak) and 1 (one) subduction source (Java Megathrust). In contrast, the 2017 seismic hazard analysis data [1] are characterised by 8 (eight) shallow crustal fault data (Cimandiri, Lembang, Baribis-Kendeng, Ciremai, Ajibarang, Opak, Merapi-Merbabu and Pati) clearly identified and located within a 500 Km radius of Semarang. The eight shallow crustal fault data can be divided into 26 (twenty-six) fault segments. Table 1 displays the seismotectonic data for the 26 fault segments used for seismic hazard analysis. Seismic parameters SR, SM, D, M, RS and SS in this table represent the slip rate (mm/year), seismic mechanism, dip (degree), maximum magnitude (Mw), reverse-slip and strike-slip, respectively.

In the 2017 seismic hazard analysis, 1 (one) subduction source (Java Megathrust) was clearly identified and located on the southern part of Java island. For further 2018 seismic hazard analysis Java subduction megathrust source can be divided into two segments: West and Central-East Java. Table 2 displays all parameter data used to analyse the Java subduction megathrust source, where L, W, SR and M stand for length (Km), width (Km), slip rate (cm/year) and maximum magnitude (Mw), respectively. Fig. 2 shows the seismotectonic map of Java Island used in PSHA development; the fault numbers displayed in Fig. 2 are related to the segment fault number listed in Table 1.

Table 1 Shallow crustal fault parameter data [1]

No	Fault Segments	SR	SM	D	M
1	Cimandiri	0.55	RS	45	6.7
2	Cibeber	0.40	RS	45	6.5
3	Rajamandala	0.1	SS	90	6.6
4	Lembang	2.0	SS	90	6.8
5	Subang	0.1	RS	45	6.5
6	Cirebon-1	0.1	RS	45	6.5
7	Cirebon-2	0.1	RS	45	6.5
8	Karang Malang	0.1	RS	45	6.5
9	Brebes	0.1	RS	45	6.5
10	Tegal	0.1	RS	45	6.5
11	Pekalongan	0.1	RS	45	6.5
12	Weleri	0.1	RS	45	6.5
13	Semarang	0.1	RS	45	6.5
14	Rawapening	0.1	RS	45	6.5
15	Demak	0.1	RS	45	6.5
16	Purwodadi	0.1	RS	45	6.5
17	Cepu	0.1	RS	45	6.5
18	Waru	0.05	RS	45	6.5
19	Surabaya	0.05	RS	45	6.5
20	Blumbang	0.05	RS	45	6.6
21	Ciremai	0.1	SS	90	6.5
22	Ajibarang	0.1	SS	90	6.5
23	Opak	0.75	SS	60	6.6
24	Merapi-Merbabu	0.1	SS	90	6.6
25	Pati	0.1	SS	90	6.5
26	Lasem	0.5	SS	90	6.5

Table 2 Subduction parameter data [1]

No	Segment	L	W	SR	M
1	West	320	200	4.0	8.8
2	Central-East	400	200	4.0	8.9

Seismic hazard analysis was performed using earthquake data covering the period from 1901 to 2014 [2] collected from the Meteorological Climatological and Geophysical Agency (BMKG) with focal mechanism from the International Seismological Commission (ISC) databases, the EHB catalogue and Preliminary Determination of Epicenters (PDE) [2]. All hypocenter earthquake data have been relocated to the correct positions [2].

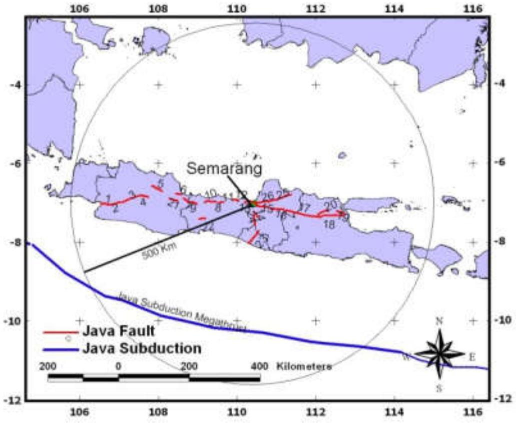

Fig.2 Seismotectonic map of Java Island

2.2 Ground Motion Prediction Equations

The selection of an appropriate ground motion prediction equation (attenuation function) is essential for calculating or predicting spectral acceleration at a specific site. Following the same method implemented for the 2010 Indonesian seismic hazard maps, all attenuation function used for the 2017 seismic hazard maps were divided into four different seismic source mechanism: shallow crustal fault, shallow background, subduction megathrust (Interface) and deep background (Benioff). Compare to the 2010 seismic hazard maps, a minor improvement in attenuation function was applied for the 2017 seismic hazard maps, with a new attenuation function employed specially for the subduction interface [8] to replace attenuation function [9]**.** Table 3 shows all attenuation functions used in developing the 2017 Indonesian seismic hazard maps.

2.3 Probabilistic and Deterministic Hazard Analyses

Both seismic hazard analyses, probabilistic (PSHA) and deterministic (DSHA), were performed to obtain spectral acceleration at bedrock elevation. PSHA was implemented using the total probability theorem [15]. Eq. (1) shows the basic formula to obtain the total average rate of exceedance of an earthquake (λa^*) with acceleration greater than the specific acceleration value a*. P_m (m) and P_r(r) in this equation represent the probability distribution function for magnitude (m) and distance (r), respectively and v represents the mean rate of exceedance. DSHA was implemented using 84th percentile, equal to 180% of median spectral acceleration.

Table 3 Attenuation functions used for developing 2017 seismic hazard maps

Seismic Mechanism	Attenuation Functions
Shallow Crustal Fault	[10] - [12]
Shallow Background	[10] - [12]
Interface Megathrust	[8], [13], [14]
Benioff Subduction Intraslab	[9], [14]

$$\lambda a^* = v \int_{m} \int_{r} (Pa > a^* \,|\, m,r)\, P_m(m)\, P_r(r)\, dr\, dm \qquad (1)$$

Following the same steps conducted in developing the 2010 national seismic hazard maps and 2012 national seismic code [3], integration of PSHA and DSHA was implemented to develop new 2018 MCE_R maps for the entire territory of Indonesia. MCE_R values was calculated by combining risk targeted ground motion analysis (RTGM) for a 1% probability of collapse in 50 years and 84th percentile deterministic seismic hazard analysis, with adjusted direction factors of 1.1 for 0.2 second period and 1.3 for 1 second period spectral acceleration, and conducting β (logarithmic standard deviation) equal to 0.65. The 2012 seismic code used a β value equal to 0.7, direction factors of 1.05 and 1.15 for short-period and long-period spectral acceleration, respectively. Eq. (2) and Eq. (3) express the log-normal distribution functions of building collapse capacity [3, 4] used in developing the RTGM maps, with 'c' representing spectral acceleration and $c_{10\%}$ the 10th percentile collapse capacity.

$$f_F(c) = \frac{1}{c\beta\sqrt{2\pi}} \exp\left[-\frac{\ln c - (\ln c_{10\%} + 1.28\,\beta)^2}{2\beta^2} \right] \qquad (2)$$

$$P[collaps] = \int_{0}^{\infty} f_F(c)\; P[S > c]\; dc \qquad (3)$$

The schematic approach employed in combining PSHA and DSHA was first illustrated by [16], with this model adopted in the present study to calculate the MCE_R values (2018). Fig. 3 shows the graphical procedure used in developing the new 2018 MCE_R values based on combining RTGM and 84th percentile deterministic seismic hazard [3, 16 and 17].

Seismic microzonation of Semarang was carried out based on the obtained national MCE_R analysis results by combining risk targeted ground motion analysis (RTGM) for a 1% probability of collapse in 50 years and 84th percentile deterministic seismic hazard analysis with an adjusted direction factor of 1.1 for 0.2 second period and 1.3 for 1 second period spectral acceleration.

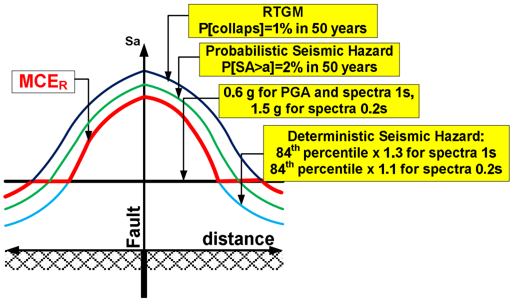

Fig.3 MCE_R 2018 design procedure

The analysis at 288 borehole locations was performed by conducting weighting interpolation for each borehole location to the four closest positions of national MCE_R data. MCE_R (MCEG, MCES and MCRS1) values at each borehole location was interpolated using Eq. (4) and Eq. (5), where M_b represents MCE_R value at each borehole location. Mi is the national MCE_R value at point 'i' where i = 1 to 4, 'di' represents minimum distance from borehole location to point number 'i' and 'wi' is weight factor of each borehole location to point number 'i'.

$$wi = \frac{1/di}{\sum_{i=1}^{4} 1/di} \tag{4}$$

$$M_b = \sum_{1}^{4} (wi * Mi) \tag{5}$$

3. REUSLTS AND DISCUSSIONS

The analysis of MCEG, MCES and MCES1 were performed at 288 borehole locations. Fig. 4, 5 and 6 show the produce 2018 MCEG, MCES and MCES1 maps, respectively. As it can be seen on Fig. 4 and Fig. 5 maximum MCEG and MCES spectral acceleration values were identified in the western part of the city, with maximum MCEG is 0.45 g and maximum MCES is 0.95 g (g is gravitational acceleration). As can be seen in Fig. 6, the MCES1 values ranging between 0.35 g to 0.4 g are identified across the whole part of the city.

MCEG, MCES and MCES1 distributions in terms of V_S30 (i.e. their correlation) were applied for all 288 borehole locations. The purpose of the analysis is to obtain the correlation between V_S30 and MCEG, MCES and MCES1 values. The V_S30 value was implemented in the present study due to the important correlation between V_S30 and site class in developing surface spectral accelerations [17].

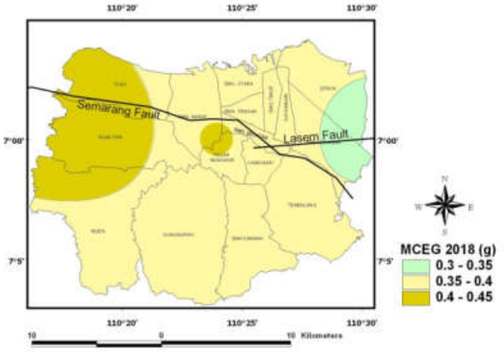

Fig.4 MCEG 2018 map for Semarang

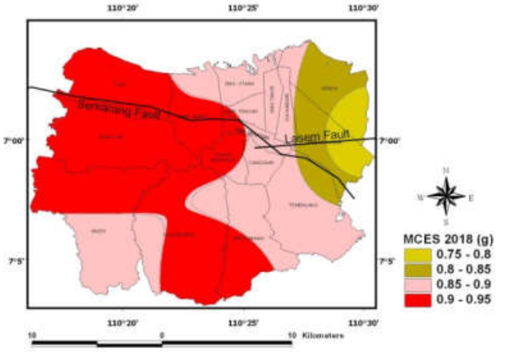

Fig.5 MCES 2018 map for Semarang

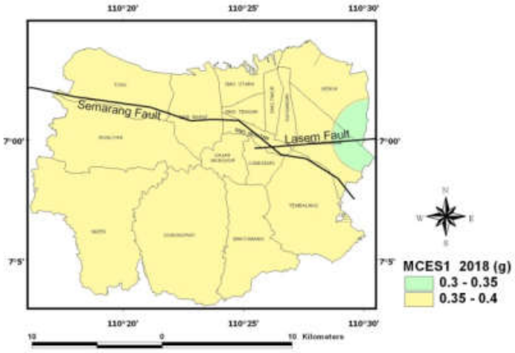

Fig.6 MCES1 2018 map for Semarang

The distributions of MCE_R 2018 values

(MCEG, MCES and MCES1) at the 288 borehole locations were thus developed based on V_S30 values producing the scatter distribution chart shown in Fig. 7. Analysis of this figure clearly reveals that MCEG, MCES and MCES1 show to a slight increase with increasing V_S30 values from 120 m/s to 420 m/s. Table 4 displays the distribution of average MCE_R (2018) values in terms of V_S30 and site soil class [18], where SE, SD and SC on this table represent soft, medium and hard soil, respectively.

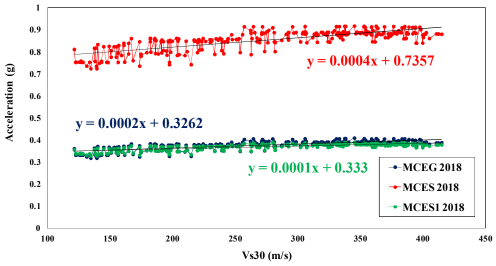

Fig.7 MCEG, MCES and MCES1 (2018) distribution in terms of V_S30

Table 4 Average MCEG, MCES and MCES1 (2018) values

V_S30 (m/s)	Site Class	MCEG (g)	MCES (g)	MCES1 (g)
<175	SE	0.35	0.78	0.35
175 - 350	SD	0.38	0.86	0.37
350 - 750	SC	0.39	0.88	0.38

Comparative analysis was then undertaken between 2012 and 2018 MCES and MCES1 values at 288 borehole locations. The purpose of the analysis is to obtain the difference between 2012 and 2018 MCES and MCES1 distribution in Semarang. Fig. 8 shows the distribution of 2012 MCES values and Fig. 9 shows the distribution of 2012 MCES1 values. As it can be seen on Fig. 8 the maximum 2012 MCES values were identified on the eastern part of the city with maximum 1.4 g. Maximum 2012 MCES1 values were identified in the small eastern part of the study area with maximum 0.5 g.

The difference between 2018 and 2012 MCES and MCES1 distribution values in terms of V_S30 is depicted in Fig. 10 and Fig. 11, respectively. Fig. 10 shows the difference between MCES (2018) and MCES (2012) values. As it can be seen on this figure average MCES (2012) values are relatively greater than in MCES (2018) values. Table 5 shows the improvement of MCES values. As it can be seen on this table the MCES (2018) is 84.33% to 86.41% lower than in MCES (2012) values.

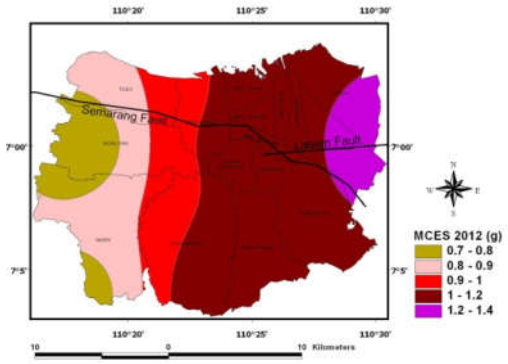

Fig.8 MCES 2012 map of Semarang

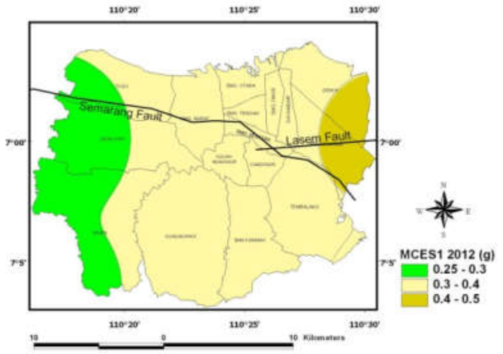

Fig.9 MCES1 2012 map of Semarang

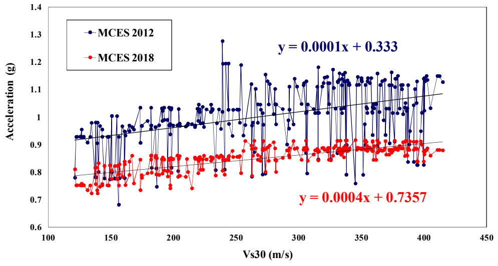

Fig.10 MCES 2018 and MCES 2012 distributions in terms of V_S30

Table 5 The difference between MCES (2018) and MCES (2012)

V_S30 (m/s)	MCES (2012) (g)	MCES (2018) (g)	+ / -
<175	0.90	0.78	-86.41%
175 - 350	1.02	0.86	-84.33%
>350	1.04	0.88	-84.93%

+: increase; -: decrease

Fig. 11 shows the difference between MCES1 (2018) and MCES1 (2012) values. As it can be seen in this figure the MCES1 (2012) values are relatively smaller than in MCES1 (2018) values. Table 6 shows the improvement of MCES1 values. As it can be seen on this table the MCES (2018) is 108.21% to 110.79% greater than in MCES1 (2012).

All MCES values on Table 5 and MCES1 values on Table 6 are divided into three different V_S30 categories which representing three different site soil classes [18]. Based on Fig 10 and Fig 11, MCES and MCES1 values exhibit a positive linear relationship with V_S30 values. All MCES and MCES1 2018 and 2012 values are calculated at 288 borehole locations.

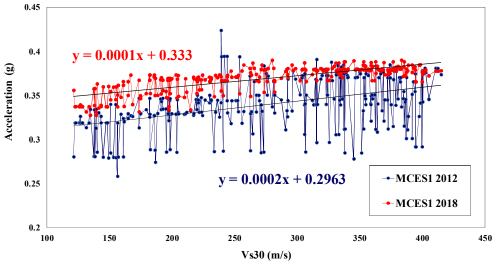

Fig.11 MCES1 (2018) and MCES1 (2012) distributions in terms of V_S30

Table 6 The difference between MCES1 (2018) and MCES1 (2012)

V_S30 (m/s)	MCES1 (2012) (g)	MCES1 (2018) (g)	+ / -
<175	0.31	0.35	+110.79%
175 - 350	0.34	0.37	+108.21%
>350	0.35	0.38	+108.29%

+: increase; -: decrease

4. CONCLUSIONS

Seismic microzonation of Semarang, Indonesia, was implemented based on the combination of probabilistic and deterministic seismic hazard analyses. Risk targeted ground motion (RTGM) analysis was conducted using a β value of 0.65 and adjusted direction factors of 1.1 for 0.2 second period spectral acceleration and 1.3 for 1 second period spectral acceleration was implemented in this study. The purpose of this study was to evaluate the distribution of maximum considered earthquake (MCE$_R$) values across Semarang based on the new 2017 seismic hazard maps. Comparative analysis was then undertaken with MCE$_R$ (2012) values, which were used previously in the development of the 2012 Indonesian seismic code.

Maximum 2018 MCE$_R$ (MCES and MCES1) values for Semarang are distributed in the north-western part of the city at a maximum 0.45 g for MCEG, 0.95 g for MCES and 0.4 g for MCES1. This pattern is the opposite of that identified in 2012 MCE$_R$ distribution values, with 2012 MCES and MCES1 maximum are identified on the north-eastern part of the city.

Comparative analysis was also implemented in this study by comparing 2018 and 2012 MCE$_R$ values. The analysis was performed for MCES and MCES1 values at 288 borehole locations. On average the MCES (2018) values are 84.33% to 86.41% lower than the MCES (2012) values. However the MCES1 (2018) values are 108.21% to 110.79% greater than the MCES1 (2012) values.

5. ACKNOWLEDGEMENTS

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Response by Authors to Reviewer's Remarks/Comments

Seismic Microzonation of Semarang, Indonesia, Based on Probabilistic and Deterministic Combination Analysis

Authors: **W. Partono, M. Irsyam, M. Asrurifak, I.W. Sengara, A. Mulia, M. Ridwan and L. Faizal**

The authors have summarized their replies to the Reviewers' comments in this response letter in a two column format. A revised manuscript is submitted addressing all the comments to the Journal of GEOMATE for possible publication.

	Reviewer Comments	*Authors Response*
1	Gradation of acceleration values should be drawn more clearly on Fig. 4, 5 and 6.	Gradation of acceleration values has already redrawn, see Fig4, 5 and 6 on page 4.
2	Equation (3) should be rewritten.	Equation (3) has already rewritten, see equation (3) on page 3. For clearly explanation and understanding on the implementation of b value and direction factor, additional two functions has already added in the paper (equation (2) and (3)).
3	"1nd" is false in title of Fig. 10. Is it "and"?	The authors appreciate the comments from the reviewer. Miss typing in the title of Fig. 10 has already changed from "1nd" to "and" see page 5.
4	"Fig. 9" and "Fig. 10" are false in last paragraph of "RESULTS AND DISCUSSION". Maybe "Fig. 10" and "Fig. 11".	The authors appreciate the comments from the reviewer. Miss typing of Fig. 9 and Fig. 10 in last paragraph of "RESULTS AND DISCUSSION" has already changed to Fig. 10 and Fig. 11. See page 5.
5	It is suggested that the authors should describe some reasons of the relationship between accelerations and Vs30 values.	MCE_R calculation for evaluating the MCEG, MCES and MCES1 distributions in terms of Vs30 was conducting at 288 boring locations. The purpose of the analysis is to obtain the correlation between Vs30 and MCEG, MCES and MCES1 values. The V_S30 value was implemented in this study due to the important correlation between V_S30 and site class for developing surface spectral accelerations based on Indonesian seismic code.
6	It is considered that statistical dispersion of Fig 10 and 11 should be evaluated quantitatively compared with Fig. 7.	Based on Fig 7, Fig 10 and Fig 11 all 2012 and 2018 MCES and MCES1 values tend to be linearly scattered. The 2018

		MCES and MCES1 distributions are slightly better (well distributed) compare to 2012 MCES and MCES1 distributions.

The authors appreciate the valuable comments from the Reviewers.

Prof. Ir. Masyhur Irsyam, MSE., PhD. is professor in Geotechnical Engineering, Faculty of Civil and Environmental Engineering, Bandung Institute of Technology, Indonesia, email is masyhur.irsyam@yahoo.co.id.

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3. Authors' Contributions (Please write all authors' contribution here)

Dr. Ir. Windu Partono MSc,: analysis and map design of seismic microzonation of Semarang and main author.

Prof. Ir. Masyhur Irsyam, MSE., PhD.: critical and final reviewing of MCER analysis and results and reviewing the manuscript.

Prof. Ir. I Wayan Sengara. MSEM, PhD.: seismic hazard and MCER analysis and reviewing the MCER analysis and reviewing the manuscript.

Dr. Ir. Muhammad Asrurifak, MT.: seismic hazard analysis and the contribution of seismic hazard and and reviewing the manuscript

4. Ethics (Please provide ethical issues that may arise after the publication of your paper)

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and no ethical issues involved.

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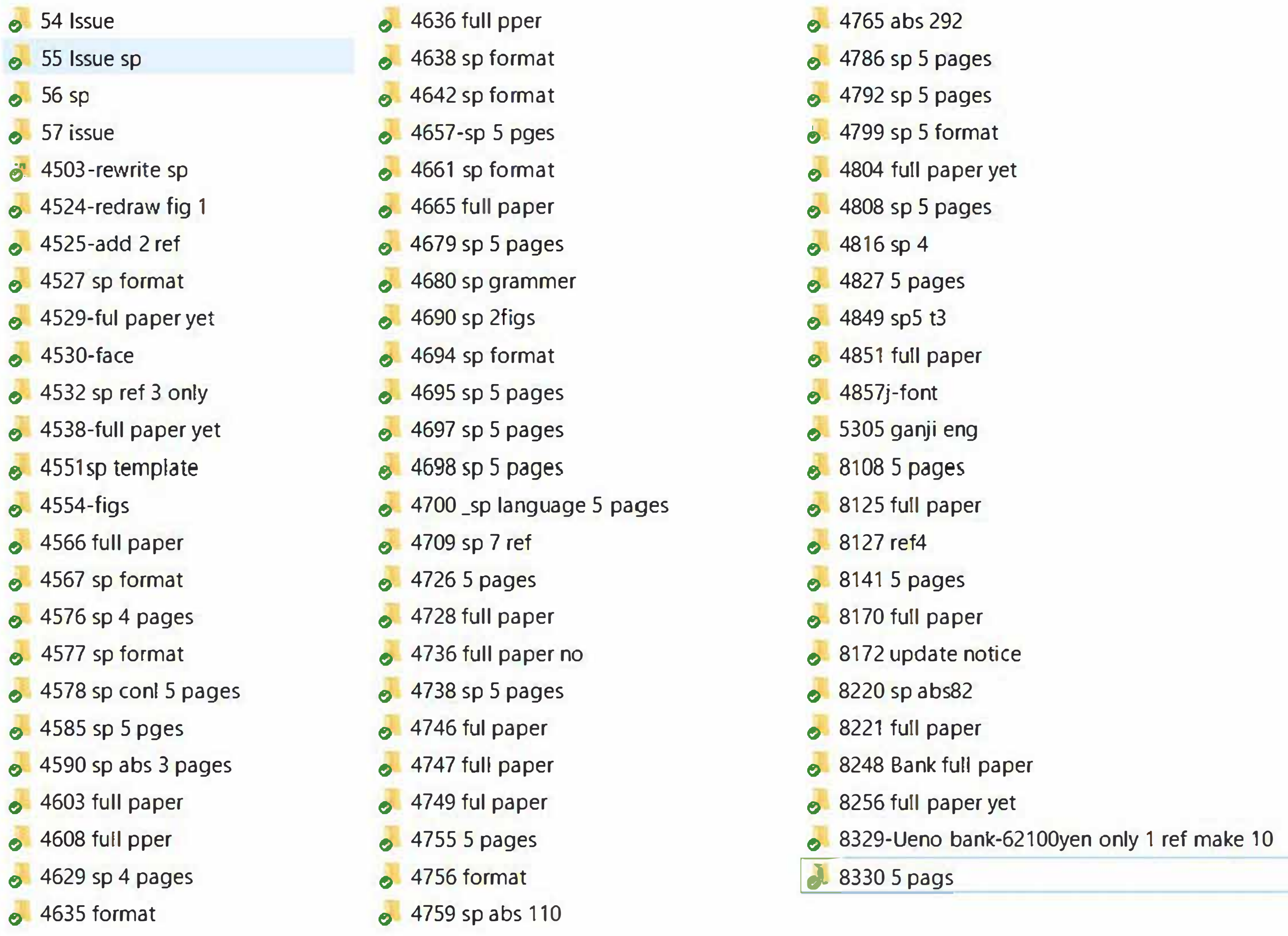

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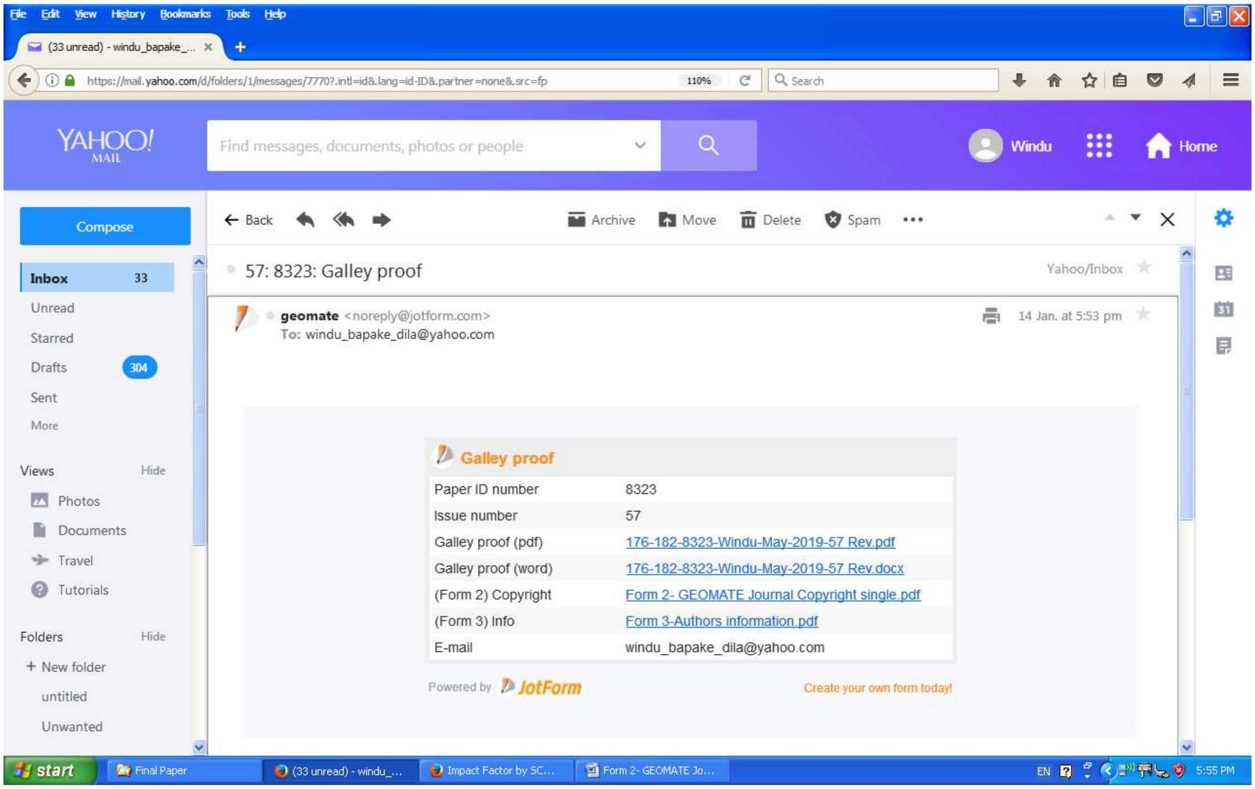

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SEISMIC MICROZONATION OF SEMARANG, INDONESIA, BASED ON PROBABILISTIC AND DETERMINISTIC COMBINATION ANALYSIS

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*Corresponding Author, Received: 30 Oct. 2018, Revised: 20 Dec. 2018, Accepted: 11 Jan. 2019

ABSTRACT: One of the most important pieces of information obtained from the new Indonesian seismic hazard maps completed in 2017 was the identification of a fault that crosses the city of Semarang. This fault can be categorized as a new dangerous seismic source and should be taken into account in future seismic mitigation planning of this city. This paper describes the seismic microzonation of Semarang carried out via a combination of probabilistic and deterministic hazard analysis. The purpose of this research was to develop a risk map for Semarang based on one percent building collapse in 50 years. The analysis was performed using the same method employed in developing risk targeted Maximum Considered Earthquake (MCE_R) maps in 2012, with an improved beta (logarithmic standard deviation) value of 0.65 and adjusted direction factors of 1.1 and 1.3 for short- and long-period spectral acceleration, respectively. Whereas the 2012 maximum MCE_R spectral acceleration was distributed in the north-east of the study area due to the presence of Lasem fault, the 2018 maximum is located in the north-western part of the city as a result of the newly developed Semarang fault.

Keywords: Seismic microzonation, Fault, Probabilistic, Deterministic, MCE_R

1. INTRODUCTION

The new Indonesian seismic hazard maps were developed in 2017 by the National Center for Earthquake Studies [1]. All maps were produced based on probabilistic seismic hazard analysis (PSHA). Eight different maps with varying probabilities of exceedance, ranging from 20% probability of exceedance in 10 years (50-year of return period) through to 1% probability of exceedance in 100 years (10000-year return period). Major improvements were made regarding historical earthquakes data, earthquake fault assessment data and seismotectonic map data, and minor improvements in ground motion prediction equations [2]. One of the most important seismic hazard maps used in developing the Indonesian Seismic Code for Building Resistance is the 2500-year return period seismic hazard map (2% probability of exceedance in 50 years).

However, the development of new seismic hazard maps for building design remains on-going and following the same procedures implemented in developing the 2012 Indonesian seismic code for building and other structure design [3]. The new seismic hazard maps for Indonesian Seismic Code are being developed using a combination of probabilistic (2% probability of exceedance in 50 year) and deterministic hazard analysis, as well as risk targeted ground motion (RTGM) analysis of probabilistic seismic hazard to determine 1% probability of building collapse in 50 years [3, 4]. The new RTGM analysis includes modified beta (β), logarithmic standard deviation, values and a modified of direction factor for 0.2 seconds and 1-second spectral acceleration. RTGM analysis is being applied to the whole area of the country from East longitude 94^o to 142^o and from North latitude 8^o to South latitude 12^o with 0.1-degree grid spacing on both directions longitude and latitude.

As part of this research, a combination of probabilistic and deterministic seismic hazard analysis is to be implemented for developing maximum considered earthquake (MCE) for the whole area of the country. Three risked targeted maximum considered earthquake ground motion (MCE_R) maps, Peak ground acceleration (PGA), short period (0.2 seconds) and long period (1 second), are developed for the whole area of Indonesian country.

This paper describes the development of seismic microzonation of Semarang, Indonesia, by conducting a combination of probabilistic and deterministic seismic hazard analysis in the development of three MCE_R maps (MCES for the 0.2-second period, MCES1 for the 1-second period and MCEG for peak ground acceleration). Seismic microzonation of the city was implemented on 288 borehole locations by conducting weighted interpolation of the four closest points of the national MCES, MCES1 and MCEG result calculations. All borehole investigations were conducted during the period from 2009 until 2017 at a minimum of 30 m depth. Average shear wave velocity (V_S30) were previously calculated using standard penetration test data (N-SPT) and conducting three empirical formulas proposed by [5], [6] and [7]. A comparative analysis was then carried out in this study to evaluate all MCES and MCES1 values calculated at 288 borehole locations based on 2018 and 2012 data. Fig. 1 shows a V_S30 map of Semarang, the borehole locations and two fault traces (Semarang and Lasem fault).

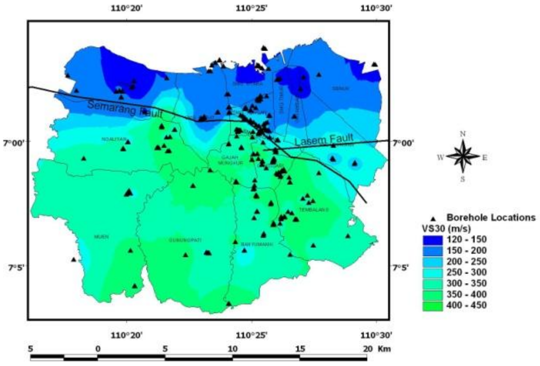

Fig.1 V_S30 map of Semarang, borehole locations and two fault traces

2. SEISMIC HAZARD ANALYSIS

2.1 Seismotectonic Data

Major improvements to the seismotectonic data for the Semarang region were made for seismic hazard analysis. Seismotectonic data for the year 2010 seismic hazard analysis are dominated by 5 (five) shallow crustal fault sources (Cimandiri, Lembang, Yogya, Lasem, and Opak) and 1 (one) subduction source (Java Megathrust). In contrast, the 2017 seismic hazard analysis data [1] are characterized by 8 (eight) shallow crustal fault data (Cimandiri, Lembang, Baribis-Kendeng, Ciremai, Ajibarang, Opak, Merapi-Merbabu and Pati) clearly identified and located within a 500 Km radius of Semarang. The eight shallow crustal fault data can be divided into 26 (twenty-six) fault segments. Table 1 displays the seismotectonic data for the 26 fault segments used for seismic hazard analysis. Seismic parameters SR, SM, D, M, RS and SS in this table represent the slip rate (mm/year), seismic mechanism, dip (degree), the maximum magnitude (Mw), reverse-slip and strike-slip, respectively.

In the 2017 seismic hazard analysis, 1 (one) subduction source (Java Megathrust) was clearly identified and located on the southern part of Java island. For further 2018 seismic hazard analysis, Java subduction megathrust source can be divided into two segments: West and Central-East Java. Table 2 displays all parameter data used to analyze the Java subduction megathrust source, where L, W, SR and M stand for length (Km), width (Km), slip rate (cm/year) and maximum magnitude (Mw), respectively. Fig. 2 shows the seismotectonic map of Java Island used in PSHA development; the fault numbers displayed in Fig. 2 are related to the segment fault number listed in Table 1.

Table 1 Shallow crustal fault parameter data [1]

No	Fault Segments	SR	SM	D	M
1	Cimandiri	0.55	RS	45	6.7
2	Cibeber	0.40	RS	45	6.5
3	Rajamandala	0.1	SS	90	6.6
4	Lembang	2.0	SS	90	6.8
5	Subang	0.1	RS	45	6.5
6	Cirebon-1	0.1	RS	45	6.5
7	Cirebon-2	0.1	RS	45	6.5
8	Karang Malang	0.1	RS	45	6.5
9	Brebes	0.1	RS	45	6.5
10	Tegal	0.1	RS	45	6.5
11	Pekalongan	0.1	RS	45	6.5
12	Weleri	0.1	RS	45	6.5
13	Semarang	0.1	RS	45	6.5
14	Rawapening	0.1	RS	45	6.5
15	Demak	0.1	RS	45	6.5
16	Purwodadi	0.1	RS	45	6.5
17	Cepu	0.1	RS	45	6.5
18	Waru	0.05	RS	45	6.5
19	Surabaya	0.05	RS	45	6.5
20	Blumbang	0.05	RS	45	6.6
21	Ciremai	0.1	SS	90	6.5
22	Ajibarang	0.1	SS	90	6.5
23	Opak	0.75	SS	60	6.6
24	Merapi-Merbabu	0.1	SS	90	6.6
25	Pati	0.1	SS	90	6.5
26	Lasem	0.5	SS	90	6.5

Table 2 Subduction parameter data [1]

No	Segment	L	W	SR	M
1	West	320	200	4.0	8.8
2	Central-East	400	200	4.0	8.9

Seismic hazard analysis was performed using earthquake data covering the period from 1901 to

2014 [2] collected from the Meteorological Climatological and Geophysical Agency (BMKG) with focal mechanism from the International Seismological Commission (ISC) databases, the EHB catalogue and Preliminary Determination of Epicenters (PDE) [2]. All hypocenter earthquake data have been relocated to the correct positions [2].

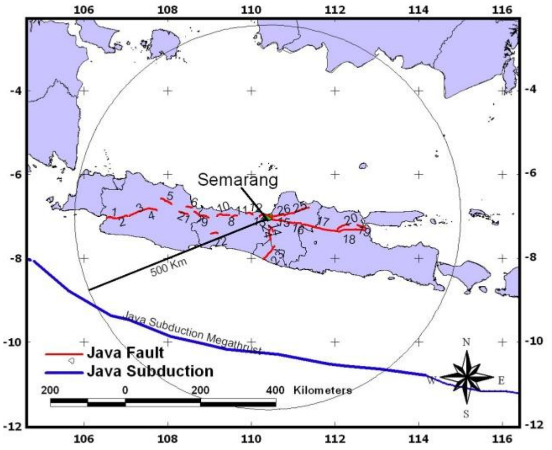

Fig.2 Seismotectonic map of Java Island

2.2 Ground Motion Prediction Equations

The selection of an appropriate ground motion prediction equation (attenuation function) is essential for calculating or predicting spectral acceleration at a specific site. Following the same method implemented for the 2010 Indonesian seismic hazard maps, all attenuation function used for the 2017 seismic hazard maps were divided into four different seismic source mechanism: shallow crustal fault, shallow background, subduction megathrust (Interface) and deep background (Benioff). Compare to the 2010 seismic hazard maps, a minor improvement in attenuation function was applied for the 2017 seismic hazard maps, with a new attenuation function employed especially for the subduction interface [8] to replace attenuation function [9]**.** Table 3 shows all attenuation functions used in developing the 2017 Indonesian seismic hazard maps.

2.3 Probabilistic and Deterministic Hazard Analyses

Both seismic hazard analyses, probabilistic (PSHA) and deterministic (DSHA), were performed to obtain spectral acceleration at bedrock elevation. PSHA was implemented using the total probability theorem [15]. Eq. (1) shows the basic formula to obtain the total average rate of exceedance of an earthquake (λa*) with an acceleration greater than the specific acceleration value a*. P_m (m) and P_r(r) in this equation represent the probability distribution function for magnitude (m) and distance (r), respectively and v represents the mean rate of exceedance. DSHA was implemented using 84th percentile, equal to 180% of median spectral acceleration.

Table 3 Attenuation functions used for developing 2017 seismic hazard maps

Seismic Mechanism	Attenuation Functions
Shallow Crustal Fault	[10] - [12]
Shallow Background	[10] - [12]
Interface Megathrust	[8], [13], [14]
Benioff Subduction Intraslab	[9], [14]

$$\lambda a^* = v \int_m \int_r (Pa > a^* | m, r) P_m(m) P_r(r) \, dr \, dm \tag{1}$$

Following the same steps conducted in developing the 2010 national seismic hazard maps and 2012 national seismic code [3], integration of PSHA and DSHA was implemented to develop new 2018 MCE_R maps for the entire territory of Indonesia. MCE_R values were calculated by combining risk targeted ground motion analysis (RTGM) for a 1% probability of collapse in 50 years and 84th percentile deterministic seismic hazard analysis, with adjusted direction factors of 1.1 for 0.2 second period and 1.3 for 1 second period spectral acceleration, and conducting β (logarithmic standard deviation) equal to 0.65. The 2012 seismic code used a β value equal to 0.7, direction factors of 1.05 and 1.15 for short-period and long-period spectral acceleration, respectively. Eq. (2) and Eq. (3) express the log-normal distribution functions of building collapse capacity [3, 4] used in developing the RTGM maps, with 'c' representing spectral acceleration and $c_{10\%}$ the 10th percentile collapse capacity.

$$f_F(c) = \frac{1}{c\beta\sqrt{2\pi}} \exp\left[-\frac{\ln c - (\ln c_{10\%} + 1.28\,\beta)^2}{2\beta^2} \right] \tag{2}$$

$$P[\text{collaps}] = \int_0^\infty f_F(c)\; P[S > c]\; dc \tag{3}$$

The schematic approach employed in combining PSHA and DSHA was first illustrated by [16], with this model adopted in the present study to calculate the MCE_R values (2018). Fig. 3 shows the graphical procedure used in developing the new 2018 MCE_R values based on combining

RTGM and 84th percentile deterministic seismic hazard [3, 16 and 17].

Seismic microzonation of Semarang was carried out based on the obtained national MCE_R analysis results by combining risk targeted ground motion analysis (RTGM) for a 1% probability of collapse in 50 years and 84th percentile deterministic seismic hazard analysis with an adjusted direction factor of 1.1 for 0.2 second period and 1.3 for 1 second period spectral acceleration.

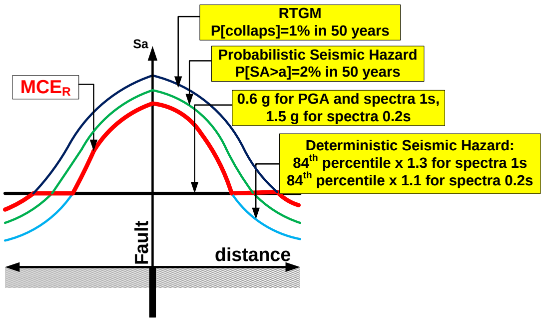

Fig.3 MCE_R 2018 design procedure

The analysis at 288 borehole locations was performed by conducting weighting interpolation for each borehole location to the four closest positions of national MCE_R data. MCE_R (MCEG, MCES, and MCRS1) values at each borehole location were interpolated using Eq. (4) and Eq. (5), where M_b represents MCE_R value at each borehole location. Mi is the national MCE_R value at point 'i' where i = 1 to 4, 'di' represents the minimum distance from borehole location to point number 'i' and 'wi' is weight factor of each borehole location to point number 'i'.

$$wi = \frac{1/di}{\sum_{i=1}^{4} 1/di} \tag{4}$$

$$M_b = \sum_{1}^{4} (wi * Mi) \tag{5}$$

3. RESULTS AND DISCUSSIONS

The analysis of MCEG, MCES, and MCES1 were performed at 288 borehole locations. Fig. 4, 5 and 6 show the produce 2018 MCEG, MCES and MCES1 maps, respectively. As can be seen in Fig. 4 and Fig. 5 maximum MCEG and MCES spectral acceleration values were identified in the western part of the city, with maximum MCEG are 0.45 g and maximum MCES is 0.95 g (g is gravitational acceleration). As can be seen in Fig. 6, the MCES1 values ranging between 0.35 g to 0.4 g are identified across the whole part of the city.

MCEG, MCES and MCES1 distributions in terms of V_S30 (i.e. their correlation) were applied for all 288 borehole locations. The purpose of the analysis is to obtain the correlation between V_S30 and MCEG, MCES and MCES1 values. The V_S30 value was implemented in the present study due to the important correlation between V_S30 and site class in developing surface spectral accelerations [17].

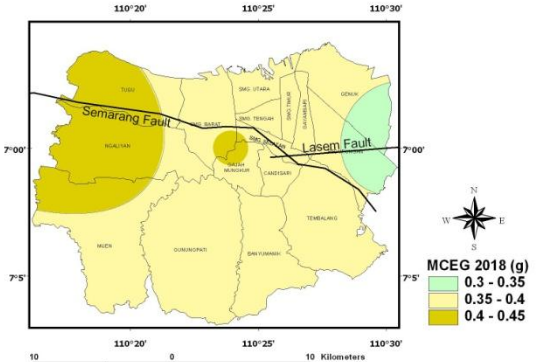

Fig.4 MCEG 2018 map for Semarang

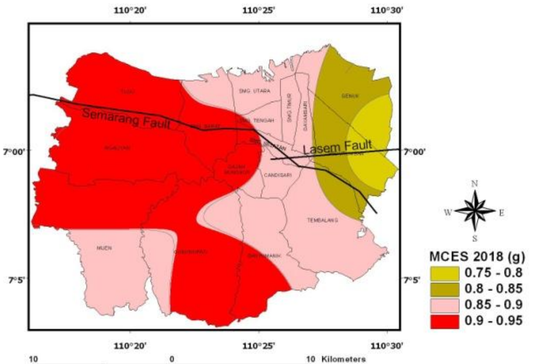

Fig.5 MCES 2018 map for Semarang

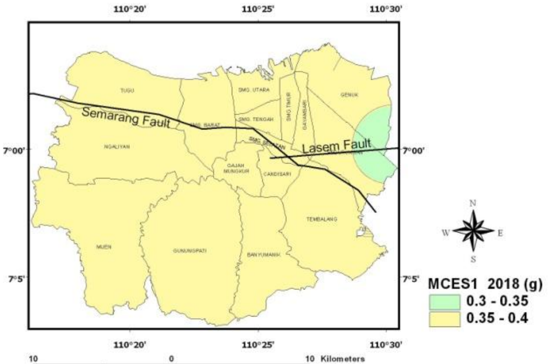

Fig.6 MCES1 2018 map for Semarang

The distributions of MCE_R 2018 values (MCEG, MCES and MCES1) at the 288 borehole locations were thus developed based on V_S30 values producing the scatter distribution chart shown in Fig. 7. Analysis of this figure clearly reveals that MCEG, MCES and MCES1 show to a slight increase with increasing V_S30 values from 120 m/s to 420 m/s. Table 4 displays the distribution of average MCE_R (2018) values in terms of V_S30 and site soil class [18], where SE, SD and SC on this table represent soft, medium and hard soil, respectively.

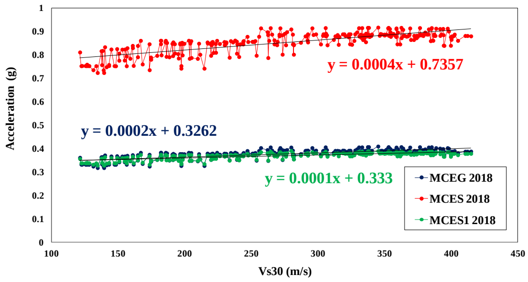

Fig.7 MCEG, MCES and MCES1 (2018) distribution in terms of V_S30

Table 4 Average MCEG, MCES and MCES1 (2018) values

V_S30 (m/s)	Site Class	MCEG (g)	MCES (g)	MCES1 (g)
<175	SE	0.35	0.78	0.35
175 - 350	SD	0.38	0.86	0.37
350 - 750	SC	0.39	0.88	0.38

Comparative analysis was then undertaken between 2012 and 2018 MCES and MCES1 values at 288 borehole locations. The purpose of the analysis is to obtain the difference between 2012 and 2018 MCES and MCES1 distribution in Semarang. Fig. 8 shows the distribution of 2012 MCES values and Fig. 9 shows the distribution of 2012 MCES1 values. As it can be seen in Fig. 8 the maximum 2012 MCES values were identified on the eastern part of the city with maximum of 1.4 g. Maximum 2012 MCES1 values were identified in the small eastern part of the study area with maximum of 0.5 g.

The difference between 2018 and 2012 MCES and MCES1 distribution values in terms of V_S30 is depicted in Fig. 10 and Fig. 11, respectively. Fig. 10 shows the difference between MCES (2018) and MCES (2012) values. As can be seen on this figure average MCES (2012) values are relatively greater than in MCES (2018) values. Table 5 shows the improvement of MCES values. As can be seen on this table the MCES (2018) is 84.33% to 86.41% lower than in MCES (2012) values.

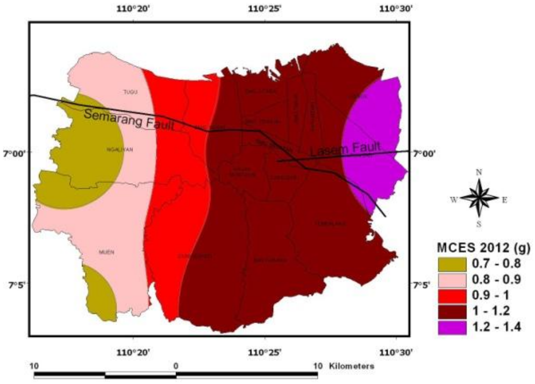

Fig.8 MCES 2012 map of Semarang

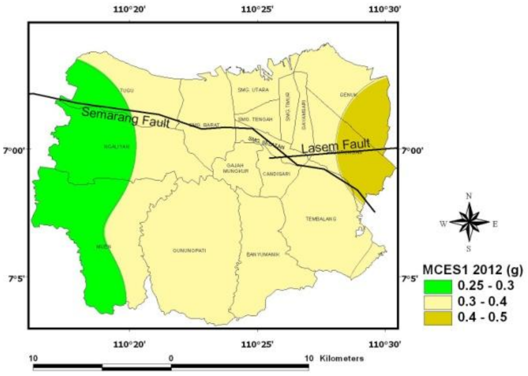

Fig.9 MCES1 2012 map of Semarang

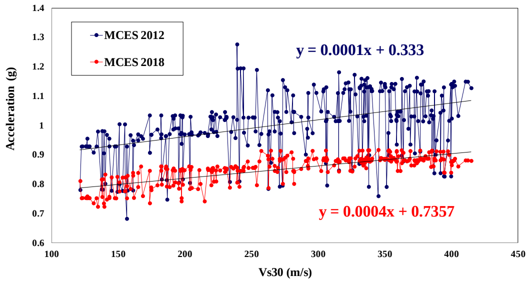

Fig.10 MCES 2018 and MCES 2012 distributions in terms of V_S30

Table 5 The difference between MCES (2018) and MCES (2012)

V_S30 (m/s)	MCES (2012) (g)	MCES (2018) (g)	+ / -
<175	0.90	0.78	-86.41%
175 - 350	1.02	0.86	-84.33%
>350	1.04	0.88	-84.93%

+: increase; -: decrease

Fig. 11 shows the difference between MCES1 (2018) and MCES1 (2012) values. As can be seen in this figure the MCES1 (2012) values are relatively smaller than in MCES1 (2018) values. Table 6 shows the improvement of MCES1 values. As can be seen on this table the MCES (2018) is 108.21% to 110.79% greater than in MCES1 (2012).

All MCES values in Table 5 and MCES1 values in Table 6 are divided into three different V_S30 categories which representing three different site soil classes [18]. Based on Fig 10 and Fig 11, MCES and MCES1 values exhibit a positive linear relationship with V_S30 values. All MCES and MCES1 2018 and 2012 values are calculated at 288 borehole locations.

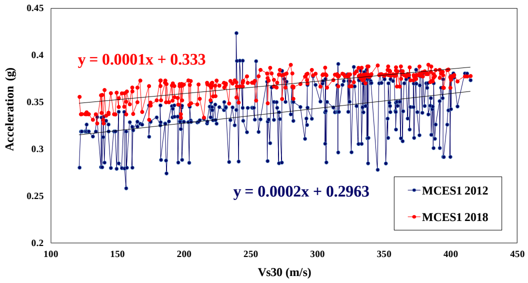

Fig.11 MCES1 (2018) and MCES1 (2012) distributions in terms of V_S30

Table 6 The difference between MCES1 (2018) and MCES1 (2012)

V_S30 (m/s)	MCES1 (2012) (g)	MCES1 (2018) (g)	+ / -
<175	0.31	0.35	+110.79%
175 - 350	0.34	0.37	+108.21%
>350	0.35	0.38	+108.29%

+: increase; -: decrease

4. CONCLUSIONS

Seismic microzonation of Semarang, Indonesia, was implemented based on the combination of probabilistic and deterministic seismic hazard analyses. Risk targeted ground motion (RTGM) analysis was conducted using a β value of 0.65 and adjusted direction factors of 1.1 for 0.2 second period spectral acceleration and 1.3 for 1 second period spectral acceleration was implemented in this study. The purpose of this study was to evaluate the distribution of maximum considered earthquake (MCE_R) values across Semarang based on the new 2017 seismic hazard maps. Comparative analysis was then undertaken with MCE_R (2012) values, which were used previously in the development of the 2012 Indonesian seismic code.

Maximum 2018 MCE_R (MCES and MCES1) values for Semarang are distributed in the north-western part of the city at a maximum of 0.45 g for MCEG, 0.95 g for MCES and 0.4 g for MCES1. This pattern is the opposite of that identified in 2012 MCE_R distribution values, with 2012 MCES and MCES1 maximum are identified on the north-eastern part of the city.

Comparative analysis was also implemented in this study by comparing 2018 and 2012 MCE_R values. The analysis was performed for MCES and MCES1 values at 288 borehole locations. On average, the MCES (2018) values are 84.33% to 86.41% lower than the MCES (2012) values. However the MCES1 (2018) values are 108.21% to 110.79% greater than the MCES1 (2012) values.

5. ACKNOWLEDGMENTS

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Dr. Ir. Windu Partono MSc,: analysis and map design of seismic microzonation of Semarang and main author.

Prof. Ir. Masyhur Irsyam, MSE., PhD.: critical and final reviewing of MCER analysis and results and reviewing the manuscript.

Prof. Ir. I Wayan Sengara. MSEM, PhD.: seismic hazard and MCER analysis and reviewing the MCER analysis and reviewing the manuscript.

Dr. Ir. Muhammad Asrurifak, MT.: seismic hazard analysis and the contribution of seismic hazard and and reviewing the manuscript

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Dr. Ir. Windu Partono MSc,: analysis and map design of seismic microzonation of Semarang and main author.

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Prof. Ir. I Wayan Sengara. MSEM, PhD.: seismic hazard and MCER analysis and reviewing the MCER analysis and reviewing the manuscript.

Dr. Ir. Muhammad Asrurifak, MT.: seismic hazard analysis and the contribution of seismic hazard and reviewing the manuscript

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