Development of Design Acceleration Response Spectrum for Building Based on New Indonesian Seismic Hazard Maps 2017

Windu Partono, Masyhur Irsyam, I. Wayan Sengara, Asrurifak, Frida Kistiani and Undayani Cita Sari

Abstract Research and development of Indonesian Seismic Hazard Maps in 2017 (IHSM-2017) have a direct impact on the development of seismic resistance code for building design in Indonesia. The development of new Indonesian seismic code for building and non-building design is still on-going, following the development of ASCE/SEI 7-16. This paper describes the development of design acceleration response spectrum (DARS) for building design. DARS-2019 is developed following the same method describes in the Indonesian seismic code [9] and ASCE/SEI 7-16. The study for developing DARS-2019 was performed at 35 cities in Central Java and Yogyakarta Provinces, Indonesia. A comparative study with 2012 seismic code (DARS-2012) was also performed in this study to evaluate the improvement of the DARS at those 35 cities. The analysis was performed for three different site soil classes (hard soil/SC, medium soil/SD and soft soil/SE). The purpose of this study is to evaluate the direct impact of the new ISHM-2017 on DARS-2019. Based on the analysis conducted at 35 cities, the improvement of DARS-2019 compared to DARS-2012 for site classes SC, SD and SE are less than 0.1 g except for site class SC at five cities located close to Opak fault trace.

Keywords Hazard map · Seismic code · Acceleration spectrum · Site soil class

W. Partono (✉) · F. Kistiani · U. C. Sari
Engineering Faculty, Civil Engineering Department, Diponegoro University, Semarang 50275, Indonesia
e-mail: windu_bapake_dila@yahoo.com

M. Irsyam · I. W. Sengara
Civil Engineering Department, Faculty of Civil and Environmental Engineering, Bandung Institute of Technology, Bandung 40132, Indonesia

Asrurifak
Research Center for Disaster Mitigation, Bandung Institute of Technology, Bandung 40132, Indonesia

F. Mohamed Nazri (ed.), *Proceedings of AICCE'19*, Lecture Notes in Civil Engineering 53, https://doi.org/10.1007/978-3-030-32816-0_6

1 Introduction

The development of seismic code for building design based on seismic hazard maps research was already conducted in 2012. The 2012 Indonesian Seismic Code [8] for building and non building design was developed based on seismic hazard map research carried on 2010. The research for 2010 Indonesian Seismic Hazard Maps (ISHM) was conducted by the Team for Revision of Seismic Hazard Maps 2010. The new ISHM-2017 was developed by The National Center for Earthquake Studies 2017 [5]. One of the most important information obtained from this research related with the new seismic sources that are detected and spread at the whole area of the country especially the additional of shallow crustal fault sources. A good example of additional shallow crustal fault sources from 5 (ISHM-2010) to 33 (ISHM-2017) are detected at the Java Island. There has been no significant improvement of 2017 subduction sources surrounding the Java Island.

SNI 1726:2012 [8] was developed based on the development of ISHM-2010. The improvement of SNI 1726 is still on-going, following the development of the new ISHM-2017. One of the important pieces of information needed for building resistance design is the design acceleration response spectrum (DARS) at the building location. Based on SNI 1726:2012 the DARS at the building location can be developed by conducting three basic steps: development of the maximum considered risk targeted acceleration spectrum (MCE_R) at the bedrock position; development of the surface acceleration spectrum (SM_S, SM_1 and PGA_M); calculation of the DARS using SM_S and SM_1 surface spectral acceleration and following the same method described by SNI 1726:2012 and ASCE/SEI 7-16 [1].

The MCE_R spectral accelerations is divided into three: short period (Ss), long period (S_1) and PGA (Peak Ground Acceleration) [4, 6]. All three acceleration spectra are calculated by combining Risk Targeted Ground Motion (RTGM) for a 1% probability of collapse in 50 years with 84th percentile deterministic seismic hazard analysis. Following the same method proposed by ASCE/SEI 7-16 [1], the new S_S and S_1 acceleration spectra are calculated by adjusting direction factors 1.1 and 1.3 for short and long period respectively. The logarithmic standard deviation (β) used for the S_S and S_1 acceleration spectrum calculation is 0.65.

The surface acceleration S_{MS}, S_{M1} and PGA_M are calculated by multiplying the three acceleration spectra Ss, S_1 and PGA with site coefficients F_a, F_v and F_{PGA}, respectively. For the new Indonesian seismic code, the three site coefficients are developed using the same values proposed by Stewart and Seyhan [9]. For a specific site or building location, the three site coefficients are calculated based on site class data and following the same method described by SNI 1726:2012.

The DARS for building resistance design is developed using two S_{DS} and S_{D1} values which represent short and long period design spectra acceleration respectively. S_{DS} and S_{D1} are equal to two third of S_{MS} and S_{M1} values and are calculated using the same method described in SNI 1726:2012. The new Indonesian seismic code introduces a long transition period (T_L) for developing the new DARS-2019. T_L is a period on DARS-2019 which is separating the constant displacement and constant velocity and usually greater than 4 s [2, 3, 7]. DARS-2019 with T_L values is developed using the same procedure proposed by ASCE/SEI 7-16 [1].

The MCE_R (S_S, S_1 and PGA) and T_L data of Indonesia (national data) are developed by PUSGEN which are spread from (94° longitude, 8° latitude) through (142° longitude, −12° latitude) with a 0.1° interval (±11.05 km) in both directions. The S_S, S_1, PGA and T_L at specific positions are usually obtained from the same values at the closest distance points (national data positions). Figure 1 shows the S_S map and Fig. 2 shows the S_1 map and the positions of national data surroundings the study area.

This paper presents the development of MCE_R and T_L values at specific location (cities) by conducting three different methods. The first method (method-1) for developing MCE_R and T_L values is conducted by calculating the average of MCE_R and T_L at the four closest points. The second method (method-2) is conducted by adjusting the MCE_R and T_L values at the closest point. The final method (method-3) is conducted by using the weighting factor calculated from the four closest points. The weighting factor is calculated using four distance values at the four closest points. The MCE_R and T_L values are calculated at 35 cities in Central Java and Yogyakarta regions. The positions of all cities can be seen in Figs. 1 and 2. The DARS-2019 for site class SC, SD and SE at specific city are then developed based on the MCE_R (S_S and S_1) and T_L values at the specific point and calculated based on ASCE/SEI 7-16.

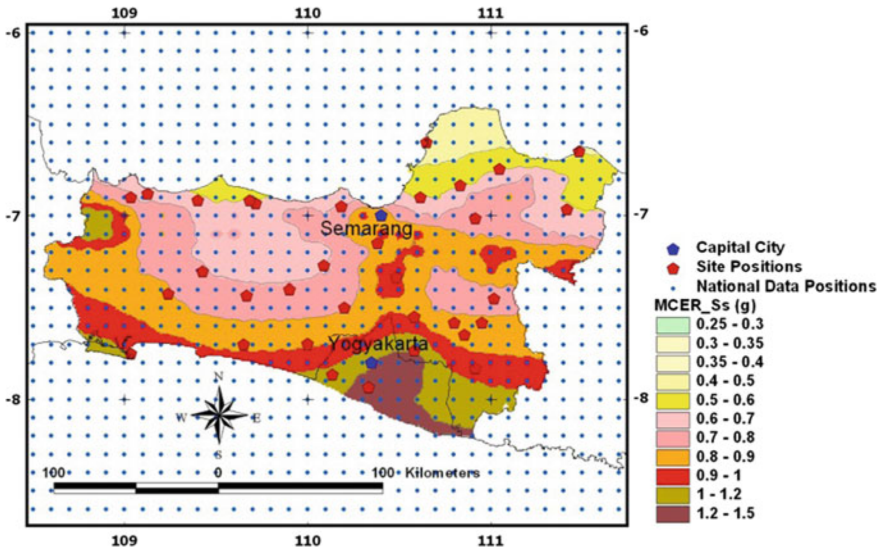

Fig. 1 MCE_R–S_S map of Central Java and Yogyakarta Provinces

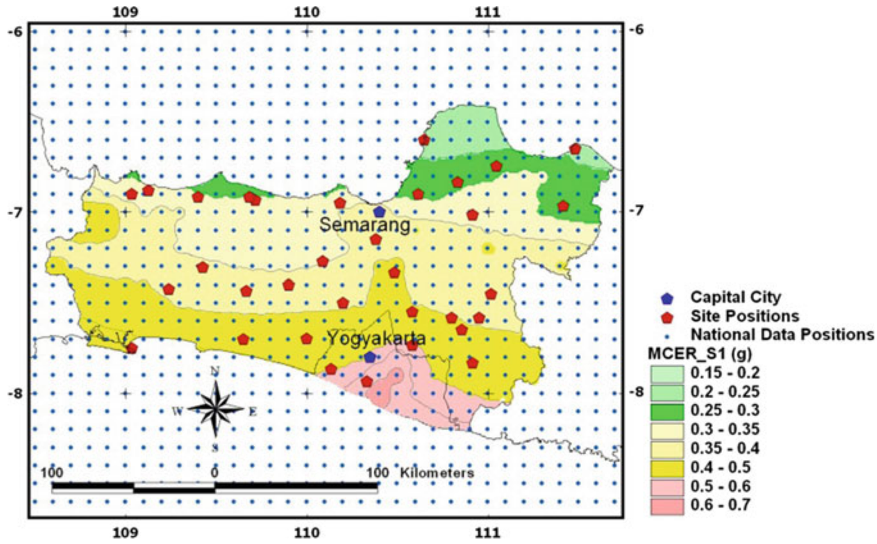

Fig. 2 MCE_R–S_1 map of Central Java and Yogyakarta Provinces

2 Methodology

The development of DARS-2019 for site class SC, SD and SE at specific locations or sites is carried out using the following algorithms:

1. Find the MCE_R acceleration spectrum (S_S, S_1 and PGA) and T_L from national data points.
2. Find all points with a maximum 15 km distance from the site position and then find 4 closest points to the site position.
3. Find the MCE_R (S_S, S_1 and PGA) and T_L values of the four closest points.
4. Sort the MCE_R and T_L data of four points based on the distance of each point to the site position from minimum to maximum.
5. Find the average of MCE_R and T_L values of all four points (method-1).
6. Find the MCE_R and T_L values of the closest point (method-2).
7. Find the MCE_R and T_L values of site based on the weighting factor of four points (method-3) following "Eqs. (1)–(3)". The "w(i)" in Eq. 1 is the weighting factor of points number "i" where i = 1–4. The d(i) value is the distance of point no "i" to the site position. The $MCE_R(i)$ and $T_L(i)$ are MCE_R and T_L value at point no "i".
8. Calculate the SM_S, SM_1 and PGAM following the same method proposed by SNI 1726:2012 and utilizing the site factor proposed by [9].
9. Calculate the S_{DS} and S_{D1} using the same method proposed by SNI 1726:2012.
10. Develop the DARS-2019 based on ASCE/SEI 7-16 [1].

$$w(i) = \frac{1/d(i)}{\sum_{i=1}^{i=4} 1/d(i)} \tag{1}$$

$$MCER = \sum_{i=1}^{i=4} w(i) * MCER(i) \tag{2}$$

$$T_L = \sum_{i=1}^{i=4} w(i) * T_L(i) \tag{3}$$

Table 1 shows an example of MCE_R and T_L calculation for Yogyakarta, the capital city of Yogyakarta Province, with coordinates (110.35, −7.8). Based on the distance of the site to national data points there are six points with a distance less than 15 km to Yogyakarta. Based on method-1 the S_S, S_1, PGA and T_L values of Yogyakarta are 1.2635 g, 0.54475 g, 0.53 g and 13 s respectively. By applying the second method (method-2) the S_S, S_1, PGA and T_L values of Yogyakarta are 1.069 g (1 g = 9.81 m/s^2), 0.493 g, 0.465 g and 20 s respectively. Finally by conducting method-3 the S_S, S_1, PGA and T_L values of Yogyakarta are 1.211384 g, 0.533551 g, 0.516982 g and 13 s respectively. Table 2 shows another example of MCE_R and T_L calculation for Semarang, the capital city of Central Java Province, with coordinates (104.0, −7.0). Following the same steps conducted for Yogyakarta, there are 5 (five) closest points to Semarang. Table 3 shows three different pair of S_S and S_1 results calculated at Semarang using three different methods.

Table 1 MCER-S_S. S_1, PGA and TL example calculation for Yogyakarta

Point No	Longitude	Latitude	Distance (Km)	S_S (g)	S_1 (g)	PGA (g)	T_L (sec)
1	110.3	−7.8	5.5148	1.069	0.493	0.465	20
2	110.4	−7.8	5.5148	1.238	0.538	0.527	6
3	110.3	−7.9	12.3578	1.247	0.548	0.528	20
4	110.4	−7.9	12.3578	1.5	0.6	0.6	6
5	110.3	−7.9	12.3583	0.941	0.45	0.408	20
6	110.4	−7.9	12.3583	1.006	0.465	0.432	20

Table 2 MCER-S_S. S_1, PGA and TL example calculation for Semarang

Point No	Longitude	Latitude	Distance (Km)	S_S (g)	S_1 (g)	PGA (g)	T_L (sec)
1	104.0	−7.0	0	0.911	0.391	0.406	6
2	110.3	−7.0	11.05	0.936	0.395	0.419	6
3	110.5	−7.0	11.05	0.774	0.344	0.337	20
4	110.4	−6.9	11.05	0.658	0.305	0.289	20
6	110.4	−7.1	11.05	0.919	0.383	0.402	20

Table 3 S_S and S_1 acceleration spectrum calculated using three different methods

City	Method-1		Method-2		Method- 3	
	S_S (g)	S_1 (g)	S_S (g)	S_1 (g)	S_S (g)	S_1 (g)
Yogyakarta	1.264	0.555	1.069	0.493	1.221	0.534
Semarang	0.8198	0.3588	0.911	0.391	0.911	0.391

By using S_S and S_1 values and applying site factor proposed by [9] and following ASCE/SEI 07-2016, the DARS-2019 for site class SC, SD and SE for Yogyakarta are presented in Fig. 3. Figure 4 shows an example of DARS-2019 for site class SC, SD and SE for Semarang. All DARS-2019 as can be seen in Figs. 3 and 4 are developed from S_S and S_1 results calculated using method-3.

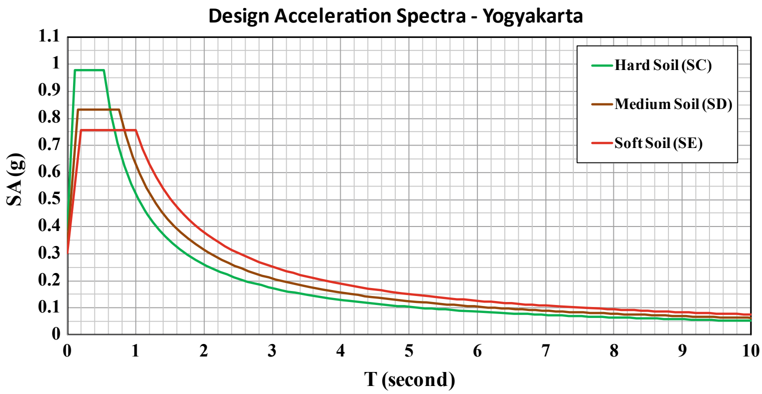

Fig. 3 DARS-2019 of Yogyakarta for site class SC, SD and SE calculated based on S_S and S_1 method-3

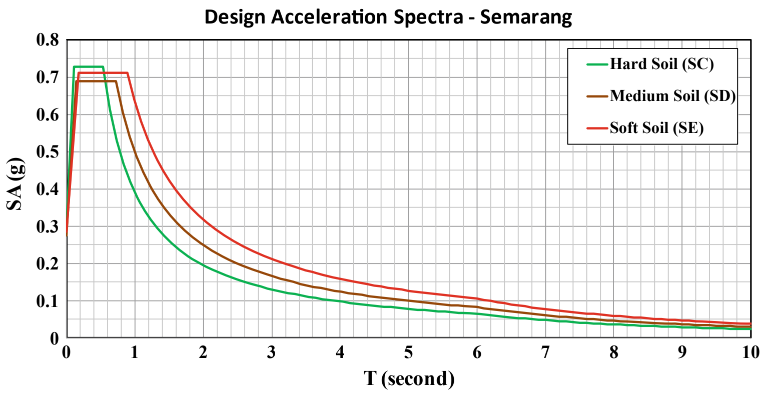

Fig. 4 DARS-2019 of Semarang for site class SC, SD and SE calculated based on S_S and S_1 method-3

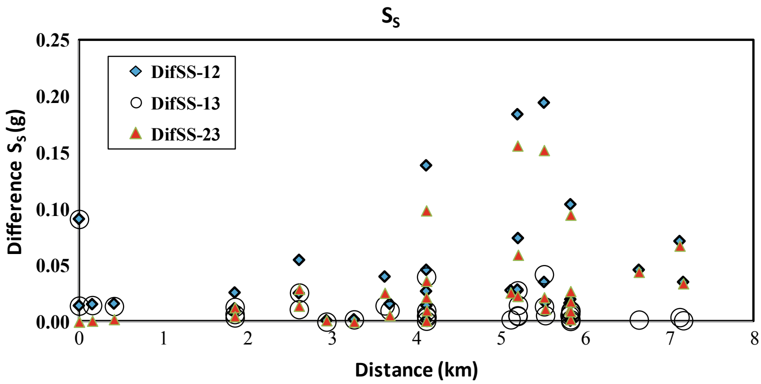

Fig. 5 Difference of S_S values in terms of closest site distance calculated using three methods

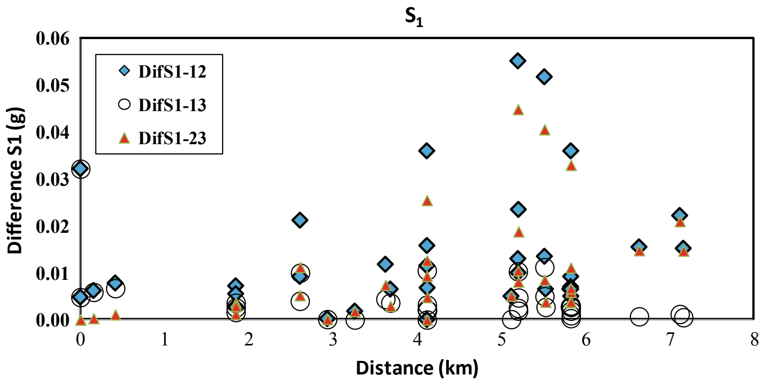

Fig. 6 Difference of S_1 values in terms of closest site distance calculated using three methods

3 Results and Discussion

The calculation of S_{DS} and S_{D1} for the development of DARS-2019 depends not only on the S_S and S_1 values but also depends on the site factor Fa and Fv values. The Fa and Fv values for specific site soil class (SC, SD and SE) are usually developed by linear interpolation and depends on the S_S and S_1 values. Table 4 shows the S_S and S_1 at 35 cities in the study area. As can be seen in Table 4 the difference of S_S and S_1 values are obtained due to different methods used for calculating S_S and S_1. The analysis for evaluating the probability best performance of three methods is conducted at 35 different cities. Figures 5 and 6 show the results of S_S and S_1 performance calculations using the three different methods.

Figure 5 shows the distribution of the S_S difference values calculated using method-1 and method-2 (DifSS-12), the difference between method-1 and

Table 4 Improvement of S_{DS} and S_{D1} for site class SC

City	Closest Distance (Km)	Method-1		Method-2		Method-3	
		S_S (g)	S_1 (g)	S_S (g)	S_1 (g)	S_S (g)	S_1 (g)
Banjarnegara	5.2035	0.7348	0.3760	0.7070	0.3660	0.7298	0.3741
Bantul	5.2005	1.4312	0.6032	1.247	0.548	1.4034	0.5929
Batang	4.1192	0.631	0.3098	0.585	0.294	0.6212	0.3066
Blora	4.1224	0.5938	0.2812	0.608	0.288	0.598	0.2832
Boyolali	5.8286	0.8892	0.4188	0.909	0.428	0.8819	0.4169
Brebes	3.6839	0.7318	0.3335	0.716	0.327	0.7217	0.3299
Cilacap	6.6404	1.01	0.4655	1.056	0.481	1.0118	0.4662
Demak	1.8457	0.6018	0.2908	0.59	0.288	0.5951	0.2892
Jepara	5.5293	0.477	0.2425	0.46	0.236	0.4713	0.2398
Karanganyar	5.8184	0.7995	0.3845	0.816	0.391	0.8052	0.3873
Kebumen	5.5161	0.9122	0.4465	0.877	0.433	0.8986	0.4415
Kendal	5.8293	0.6948	0.321	0.799	0.357	0.7040	0.324
Klaten	4.1178	1.2648	0.537	1.126	0.501	1.2248	0.5265
Pekalongan	2.611	0.6398	0.3152	0.585	0.294	0.614	0.3052
Kudus	5.2068	0.6222	0.2925	0.548	0.269	0.6074	0.2878
Magelang	0.1562	0.8025	0.3972	0.787	0.391	0.7878	0.3913
Pati	7.1242	0.5975	0.2772	0.526	0.255	0.5935	0.2760
Pemalang	1.8468	0.6268	0.3072	0.601	0.3	0.6137	0.3036
Purbalingga	2.9347	0.7058	0.3548	0.707	0.355	0.7058	0.3549
Purwodadi	2.6081	0.7602	0.3382	0.735	0.329	0.7491	0.3342
Purwokerto	5.12	0.8142	0.394	0.842	0.399	0.8162	0.3939
Purworejo	0.4146	0.873	0.4312	0.889	0.439	0.8868	0.4379
Rembang	5.8296	0.4962	0.24	0.512	0.245	0.4942	0.2391
Salatiga	4.1185	0.9335	0.416	0.932	0.416	0.9327	0.416
Semarang	0	0.8198	0.3588	0.911	0.391	0.911	0.391
Solo	1.8469	0.8235	0.3985	0.832	0.404	0.8272	0.4011
Sragen	5.8278	0.7795	0.367	0.781	0.374	0.7789	0.3673
Sukoharjo	7.1664	0.8562	0.4122	0.821	0.397	0.855	0.4117
Tegal	3.6256	0.634	0.3042	0.674	0.316	0.6484	0.3086
Temanggung	3.2612	0.697	0.3482	0.695	0.35	0.695	0.3482
Ungaran	5.8291	0.8522	0.3715	0.853	0.378	0.8622	0.3742
Wates	5.2007	1.0385	0.49	1.067	0.503	1.0441	0.4925
Wonogiri	4.1177	0.961	0.4545	0.934	0.443	0.9556	0.4523
Wonosobo	0	0.7242	0.3708	0.71	0.366	0.71	0.366
Yogyakarta	5.5148	1.2635	0.5448	1.069	0.493	1.2214	0.5336

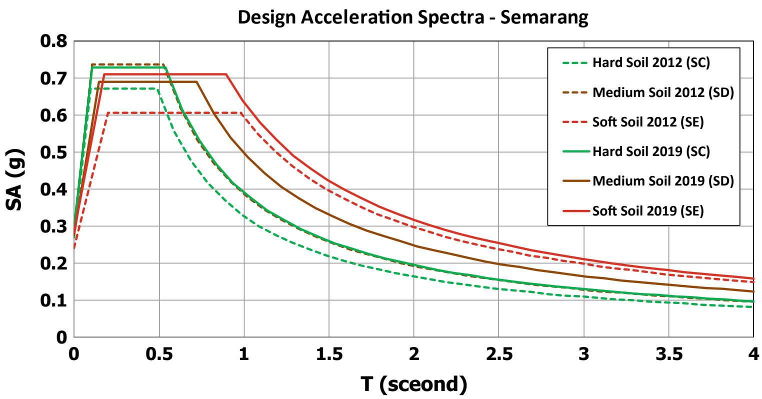

Fig. 7 DARS for Semarang

method-3 (DifSS-13) and the difference between method-2 and method-3 (DifSS-23). The S_S difference distribution is developed in terms of closest site distance to national data positions. As can be seen in Fig. 5 when the distance of the site position to national data positions less than 2 km, there is no significant difference in S_S values calculated using three different methods. However, when the distance of the site to national data greater than 2 km the S_S values calculated using method-1 and method-3 are almost equal while the S_S values calculated using method-2 is differ from the two other methods. It seems that the S_S values calculated using method-3 have a better performance compared to another two methods.

Figure 6 shows the distribution of S_1 difference values DifS1-12, DifS1-13 and DifS1-23. In terms of site distance, the distribution of DifS1-12, DifS1-13 and DifS1-23 are almost equal with DifSS-12, DifSS-13 and DifSS-23 distributions. The performance of the S_1 values calculated using mehod-3 is better than method-1 or method-2.

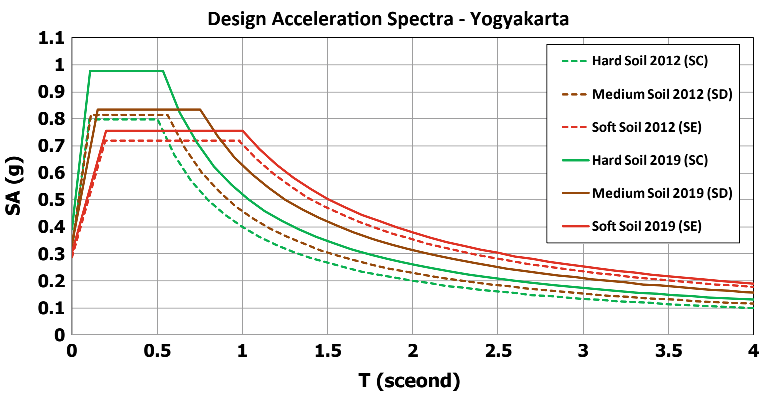

Fig. 8 DARS for Yogyakarta

A comparative study was conducted to evaluate the improvement of DARS calculated using [8] (DARS-2012) and DARS-2019. The analysis was conducted for 35 cities in Central Java and Yogyakarta Provinces for three different site classes (SC, SD and SE). DARS-2019 is developed using method-3. Figures 7 and 8 show the DARS-2019 and DARS-2012 for Semarang and Yogyakarta respectively. The maximum period of DARS-2019 display in Figs. 7 and 8 are equal to 4 s and is adjusted to the same period used by SNI 1726:2012.

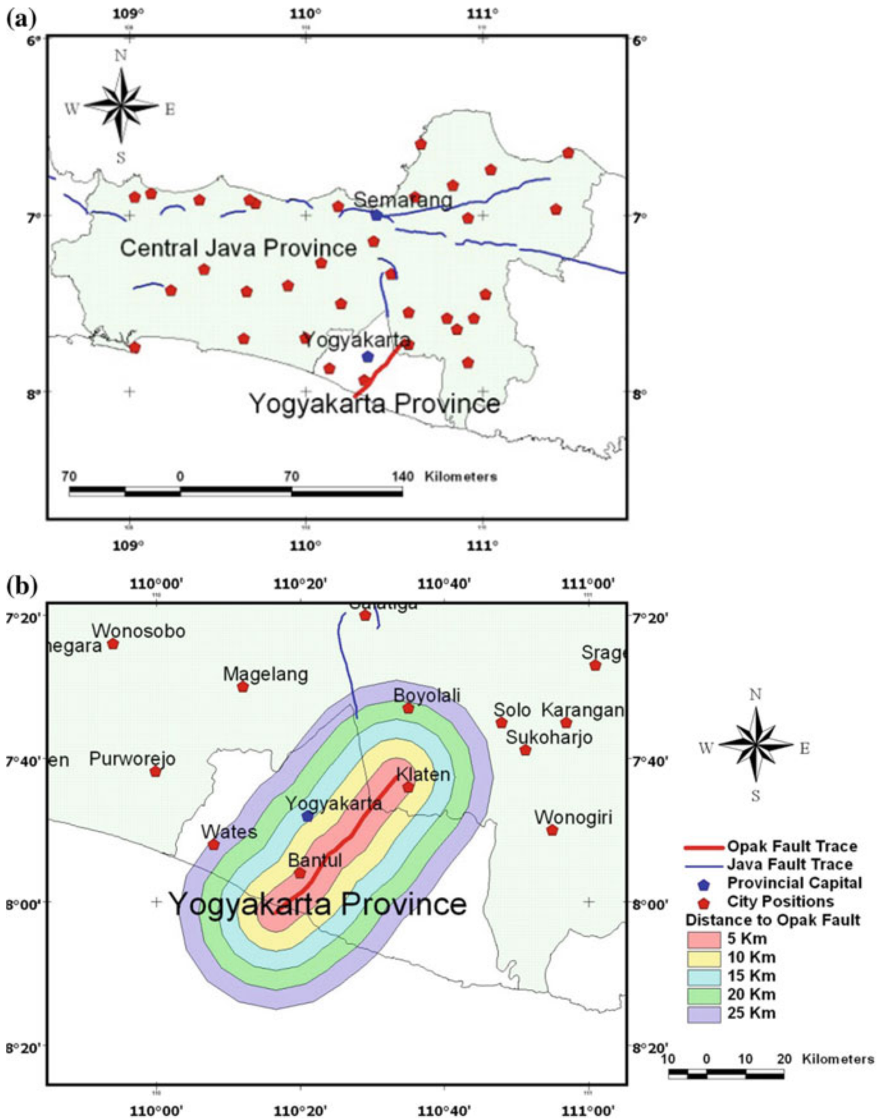

Fig. 9 The study area (**a**) and five cities with maximum improvement of S_{DS} and S_{D1} values (**b**)

As can be seen in Fig. 7, there is no significant improvement in the DARS for Semarang for site class SC, SD and SE. For site class SC and SE the DARS-2019 is slightly bigger than the DARS-2012. However, for site class SD, the DARS-2019 is slightly lower than the DARS-2012. The maximum improvement (increasing or decreasing) of DARS-2019 compared to DARS-2012 is less than 0.1 g. The improvement of DARS for Yogyakarta is slightly bigger than Semarang. As can be seen in Fig. 8, for site class SC and SD the DARS-2019 for Yogyakarta is slightly bigger than for DARS-2012. For site class SE the DARS-2019 of Yogyakarta is lower than the DARS-2012. The maximum improvement of the DARS-2019 compared to the DARS-2019 for site class SC is less than 0.2 g. However, the maximum improvement of DARS-2019 compared to Dars-2012 for site class SD and SE is less than 0.1 g.

Tables 5, 6 and 7 illustrate the improvement of S_{DS} and S_{D1} values for site classes SC, SD and SE respectively and calculated for developing DARS-2019 and DARS-2012 for Semarang and Yogyakarta. Positive or negative sign (±) inside this table represents increasing or decreasing of DARS-2019 compared to DARS-2012. Compared to S_{DS} 2012, the S_{DS} 2019 of Semarang city is increasing 8.32% and 17.33% for site classes SC and SE respectively. However, for site class SC the S_{DS} value for Semarang is decreases 6.50%. For Yogyakarta the S_{DS} 2019 value for site classes SC, SD and SE are decreased 22.43%, 2.33% and 5.29% respectively. Compared to DARS-2012, the S_{D1} values for site class SC, SD and SE of

Table 5 Improvement of S_{DS} and S_{D1} for site class SC

City	Spectrum-2019		Spectrum-2012		Improvement (±)	
	S_{DS} (g)	S_{D1} (g)	S_{DS} (g)	S_{D1} (g)	S_{DS}	S_{D1}
Semarang	0.729	0.391	0.673	0.328	8.32%	19.21%
Yogyakarta	0.977	0.520	0.798	0.399	22.43%	30.33%

Table 6 Improvement of S_{DS} and S_{D1} for site class SD

City	Spectrum-2019		Spectrum-2012		Improvement (±)	
	S_{DS} (g)	S_{D1} (g)	S_{DS} (g)	S_{D1} (g)	S_{DS}	S_{D1}
Semarang	0.69	0.498	0.738	0.387	−6.50%	28.68%
Yogyakarta	0.834	0.627	0.815	0.458	2.33%	36.90%

Table 7 Improvement of S_{DS} and S_{D1} for site class SE

City	Spectrum-2019		Spectrum-2012		Improvement (±)	
	S_{DS} (g)	S_{D1} (g)	S_{DS} (g)	S_{D1} (g)	S_{DS}	S_{D1}
Semarang	0.711	0.635	0.606	0.595	17.33%	6.72%
Yogyakarta	0.756	0.757	0.718	0.705	5.29%	7.38%

Table 8 Improvement of S_{DS} and S_{D1} for site class SC at five cities

City	Spectrum-2019		Spectrum-2012		Improvement (±)		Improvement (±)	
	S_{DS} (g)	S_{D1} (g)	S_{DS} (g)	S_{D1} (g)	S_{DS} (g)	S_{D1} (g)	S_{DS} (%)	S_{D1} (%)
Bantul	1.123	0.56	0.948	0.441	0.175	0.119	18.5	27.0
Boyolali	0.706	0.417	0.562	0.313	0.144	0.104	25.6	33.2
Klaten	0.98	0.516	0.683	0.368	0.297	0.148	43.5	40.2
Wates	0.833	0.491	0.617	0.347	0.218	0.144	35.3	41.5
Yogyakarta	0.977	0.520	0.798	0.399	0.179	0.121	22.4	30.3

DARS-2019 for Semarang are increased 19.21%, 28.68% and 6.72% respectively. For Yogyakarta, the S_{D1} value for DARS-2019 increased by 30.33%, 36.90% and 7.38% for site classes SC, SD and SE respectively.

Base on the analysis conducted at 35 cities the largest improvement of S_{DS} and S_{D1} are detected at five cities located close to Opak Fault Trace Yogyakarta. The S_{DS} and S_{D1} of DARS-2019 at these five cities are larger than the S_{DS} and S_{D1} of DARS-2012. The S_{DS} values are increased in between 0.144 g and 0.297 g and the S_{D1} values are increased in between 0.104 and 0.148 g. The most significant improvement is detected at site class SC. However, the improvement of S_{DS} and S_{D1} for site classes SD and SE at five cities are smaller than for site class SC and less than 0.1 g. Table 8 shows the improvement of S_{DS} and S_{D1} values at five cities and Fig. 9 shows the position of all five cities. All five cities are located less than 25 km distance from the Opak fault trace. Klaten and Boyolali are located at Central Java Province. However, another three cities, Bantul, Wates and Yogyakarta are located at Yogyakarta Province. As can be seen in Table 8 the largest improvement of S_{DS} value at Klaten is close to 0.3 g (43.5%) and the improvement of S_{D1} value at this city is 0.144 g (40.2%).

4 Conclusions

The development of design acceleration response spectrum (DARS) for 35 cities in the Central Java and Yogyakarta Provinces, Indonesia, was performed in this study. The objective of this study was to evaluate the improvement of DARS-2019 compared to DARS-2012. The study was performed due to the improvement of the Seismic Hazard Maps of Indonesia 2017. The study was performed first by calculating the MCER acceleration spectra (S_S and S_1) and conducting three different methods. The DARS-2019 for site classes SC, SD and SE were then developed using the same method proposed by SNI 1726:2012 and ASCE/SEI 7-16.

Based on the analysis conducted at 35 different cities in Central Java and Yogyakarta Provinces, method-3 (weighting factor method) for developing of S_S

and S_1 values at specific location has a better performance compared to two different methods (method-1 and method-2). Method-1 is developed using the averages of four different values obtained from the four closest points. Method-2 is developed based on the value at the closest point. All three methods are conducted in this study because the site coordinate position not always equal to the coordinates of national data points (developed by PUSGEN).

On average the DARS-2019 developed at 35 cities in Central Java and Yogyakarta Provinces are almost equal compared to the DARS-2012. Based on the analysis conducted at 35 cities, the improvement of the DARS-2019 compared to the DARS-2012 for site classes SC, SD and SE are less than 0.1 g except for site class SC at five cities located close to Opak fault trace. All five cities are located less than 25 km distance toward Opak fault trace. The maximum improvement value is detected at Klaten with S_{DS} value close to 0.3 g (43.5%) and the improvement of S_{D1} value at this city is 0.144 g (40.2%).

Acknowledgements This research was financially supported by The Faculty of Engineering, Diponegoro University, Indonesia through Strategic Research Grant 2019. The Author also would like to thank to the Ministry of Public Works and Human Settlements Indonesia and National Center for Earthquake Studies (PUSGEN) for providing data and technical supports during the development of this research.

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