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Site Coefficient and Design Spectral Acceleration Evaluation of New Indonesian 2019 Website Response Spectra

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Abstract. Calculation of site coefficient and design response spectral acceleration are two important steps in the seismic design of buildings. According to Indonesian Seismic Code 2019, two information requirements for site coefficient calculations are the site soil class and Risk-targeted Maximum Considered Earthquake (MCE_R-S_S for short and MCE_R-S_1 for long period) spectral acceleration. Three different hard/SC, medium/SD and soft/SE are typically site soil classes used for building designs. Two different site coefficients (Fa for MCE_R-S_S and Fv for MCE_R-S_1 spectral acceleration) are used for surface and design response spectral acceleration calculations. The Indonesian Seismic Code provides two (Fa and Fv) tables for calculating site coefficients. If the MCE_R-S_S or MCE_R-S_1 values developed for a specific site are not exactly equal to the values in Fa or Fv tables, the site coefficients can then be predicted using straight-line interpolation between the two closest Fa or Fv values within the tables. When the straight-line interpolation is adjusted for Fa or Fv calculation, different results were observed in comparison to the values developed using website-based software (prepared by Ministry of Public Works and Human Settlements). This study evaluates site coefficients and design response spectral acceleration predictions in Semarang City, Indonesia, according to straight-line interpolation method and website software calculations. The study was conducted at 203 soil boring positions in the study area. The site soil classes were predicted using average standard penetration test values (N-SPT) of the topmost 30 m soil deposit layer (N30). Three different site soil classes were observed in the study area. On average, the largest differences between the two analysis (linear interpolation and website) methods in the site coefficient values and design response spectral acceleration calculation were observed for the SD and SE classes. However, for the SC site soil class, the difference was small, with their values approximately similar.

Keywords: Design response spectral acceleration; MCE_R; N-SPT; Site coefficient; Straight-line interpolation

1. Introduction

The new National Seismic Code of Indonesia (SNI 1726:2019, 2019) was announced in

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2019. Some of the information introduced in this new seismic code was partially adopted from the American Standard Code for Seismic Design ASCE/SEI 7-16, specifically the site coefficient values and design response spectral acceleration calculation methods. Additional information for developing the site coefficients was adopted from Stewart and Seyhan (2013). Due to the improved methods described in ASCE/SEI 7-16 for developing site coefficients for site soil classes SD and SE, not all the information described in the American Code was adopted by SNI 1726:2019. Specifically, the site coefficients for the SD and SE classes presented in SNI 1726:2019 were completely adopted from Stewart and Seyhan (2013).

Following the SNI 1726:2019, the Ministry of Public Works and Human Settlements announced a new website software (online facility) for site coefficient and design response spectral acceleration calculation. Site or building position coordinates (in terms of longitude and latitude) and site soil class are two information requirements for design response spectral acceleration calculations. Risk-targeted Maximum Considered Earthquake (MCE_R) acceleration, MCE_R-S_S for short and MCE_R-S_1 for long periods, (Luco et al., 2007; Allen et al., 2015; Sengara et al., 2020), and two design response spectral acceleration, S_{DS} and S_{D1}, are four important values calculated by the website facility software. However, no information related to site coefficients F_a for short and F_v for long periods can be obtained from the new website. Thus, these values can be calculated using Equation 1 and Equation 2. All S_{DS}, S_S (MCE_R-S_S), S_{D1}, and S_1 (MCE_R-S_1) values can be obtained from the website.

$$F_a = \frac{S_{DS}}{\frac{2}{3} S_S} \tag{1}$$

$$F_v = \frac{S_{D1}}{\frac{2}{3} S_1} \tag{2}$$

To verify the F_a and F_v site coefficients estimated using Equations 1 and 2, straight-line interpolation can be conducted using the S_S and S_1 website calculations and applying site coefficient (F_a and F_v) table data provided by SNI 1726:2019. F_a and F_v are then estimated following the procedure described by SNI 1726:2019. Equation 3 shows a simple formula for F_a and F_v site coefficients calculation. Figure 1 shows a diagram of the straight-line interpolation of the F_a and F_v calculation. F and M_w represent the site coefficient to be estimated and the MCE_R value obtained from the website, respectively; M_{1S} and M_{2S} represent two boundary MCE_R values close to M_w; F_{1S} and F_{2S} represent the site coefficients for M_{1S} and M_{2S}, respectively; and M_{1S}, M_{2S}, F_{1S}, and F_{2S} are the four values obtained from the SNI 1726:2019 tables. F_a and F_v are estimated separately using Equation 3.

$$F = \left(\frac{F_{2S} - F_{1S}}{M_{2S} - M_{1S}}\right)(M_W - M_{1S}) + F_{1S} \tag{3}$$

This paper describes the site coefficients and design response spectral acceleration verification calculated using the website facility and the straight-line interpolation described in SNI 1726:2019. The objective of the study was to evaluate whether or not the website performed the analysis following the same procedures used by SNI 1726:2019. The study was performed in Semarang City, Indonesia, and conducted at 203 soil boring investigation positions. The study was performed as part of seismic microzonation research of the city. One of the important information requirements for seismic microzonation is the development of soil amplification or site coefficient distribution map at the study area. In this study, the standard penetration test (N-SPT) data observed during boring investigation were used for site class calculation. All boring investigations in this study were conducted at a minimum depth of 30 m and a maximum depth 60 m. The average standard penetration test (N-SPT) of the topmost 30 m soil deposit layer (N_{30}) of every boring position was used for site soil class interpretation (Moghaddam, 2011; Partono et al., 2019; Syaifuddin et al., 2020). Figure 2a shows the 203 boring positions and the N_{30} distribution within the study area. Figure 2b shows the distribution of the site soil classes developed based on the N_{30} data (Partono et al., 2021). The maximum N-SPT data obtained from the boring investigation was 60. Following the procedure described by SNI 1726:2019, the N_{30} value was estimated using Equation 4, where d_i and N_i represent the thickness and N-SPT value of any soil layer "i", respectively.

The parameter that can also be used for site interpretation is the average shear wave velocity (V_S) of the topmost 30 m soil deposit (V_{S30}) (Naji et al., 2020). The V_{S30} value can be calculated using the same method as that shown in Equation 4 and replacing the N_i value with V_{Si}. The V_S value can be observed using seismic refraction multichannel analysis of surface waves (MASW) or seismometer array investigations. Prakoso et al. (2017) described a comparative study of V_S value obtained from MASW investigation and soil boring (N-SPT) data. The V_S value developed using MASW was more reliable compared to that developed based on the N-SPT data. Pramono et al. (2020) described the predominant frequency investigation at Lombok Island following the 2018 earthquake event. The greater the V_{S30} value used, the greater the predominant frequency obtained from the wavelet analysis of the ground motion. Additionally, development of V_{S30} and predominant frequency correlation was also conducted by Pramono et al. (2017) in the Palu area.

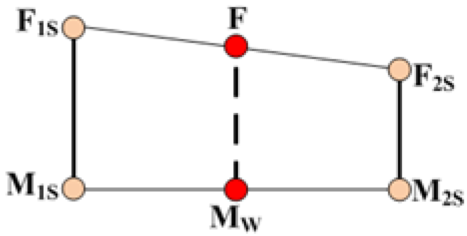


Figure 1 Straight-line interpolation for F_a and F_v calculations

$$N_{30} = \frac{\sum_{i=i}^{i=n} d_i}{\sum_{i=i}^{i=n} \frac{d_i}{N_i}} \tag{4}$$

2. Methods

The evaluation of the site coefficients from the study area was conducted following five basic steps:

- Site class interpretation;
- MCE_R (S_S and S_1) and design response spectral acceleration calculation using the website;
- Site coefficient calculation based on the website output;
- Site coefficient calculation based on SNI 1726:2019 tables and procedures;

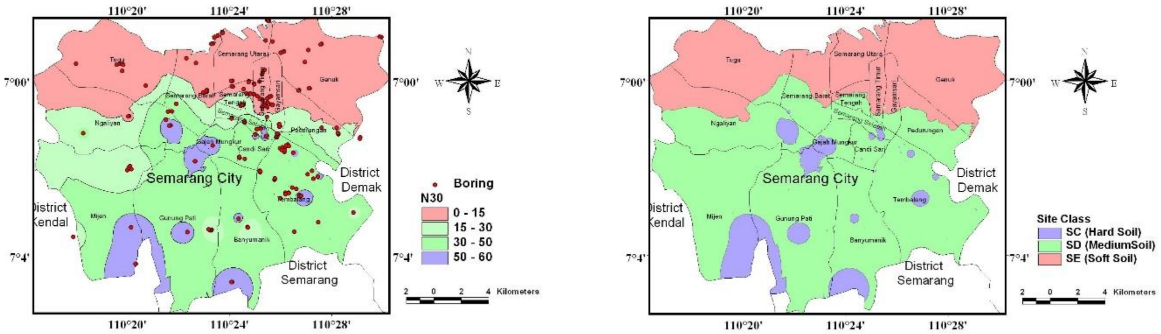
- Comparative analysis of the two different approaches in terms of their calculated site coefficients and design response spectral acceleration: the website output and straight-line interpolation.

2.1. Site Soil Class Interpretation

Site soil class interpretation (Figure 2b) was conducted for the 203 boring positions using N_{30} data, with the site soil classes interpreted according to SNI 1726:2019. Table 1 shows the basic classification criteria for each site soil class. Only three different site soil classes are presented in this table, site classes SA/hard rock, SB/rock, and SF/specific soil unavailable. Figure 2b shows the corresponding site soil class distribution according to the site classification information in Table 1. The site class distribution in the study area is dominated by the SD and SE classes; meanwhile, site class SC was observed in small areas in the middle and southern parts of the city (Partono et al., 2021).

Table 1 Site classification

Site Class	N_{30}
SC	> 50
SD	15–50
SE	< 15



(a) (b)

Figure 2 (a) Boring investigation and N_{30}; and (b) site soil classes distribution maps

2.2. MCE_R and Design Response Spectral Acceleration Calculation

MCE_R calculations were performed for the 203 boring positions using the website. According to the site class distribution of the study area, different MCE_R-S_S and MCE_R-S_1 distributions were also observed in the study area. Table 2 shows the total data for each site class as well as the distribution of the minimum and maximum MCE_R-S_S, MCE_R-S_1, S_{DS}, and S_{D1} for the three different site classes developed using the website.

Table 2 S_S, S_1, S_{DS}, and S_{D1} spectral acceleration values obtained from the website

Site Class	Total Data	MCE_R-S_S(g)		S_{DS} (g)		MCE_R-S_1 (g)		S_{D1} (g)	
		Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
SC	34	0.8459	0.9668	0.68	0.77	0.3653	0.4097	0.37	0.41
SD	90	0.8098	0.9579	0.63	0.71	0.3546	0.4071	0.46	0.51
SE	79	0.696	0.9274	0.64	0.71	0.3185	0.3936	0.58	0.63

2.3. Website-calculated Fa and Fv values

F_a and F_v site coefficient calculations were performed according to the MCE_R-S_S, MCE_R-S_1, S_{DS}, and S_{D1} values obtained from the website. The site coefficients were then estimated using Equations 1 and 2. Table 3 shows the distribution of the minimum and maximum F_a and F_v values using these four values. According to the boundary values of F_a and F_v described in the SNI 1726:2019 tables, the minimum and maximum F_a values developed in the study area were divided into two different boundary values. A few MCE_R-S_S values were lower than 0.75 g; however, most of the MCE_R-S_S values were between 0.75 and 1 g.

2.4. Site Coefficients F_a and F_v SNI 1726:2019

Straight-line interpolation was also performed for F_a and F_v calculation using Equation 3 and the F_a and F_v tables provided by SNI 1726:2019. According to the MCE_R-S_S and MCE_R-S_1 values obtained from the website, the minimum and maximum boundaries for these two site coefficients could be estimated. Thus, Table 3 shows the boundaries of the F_a and F_v values used for the straight-line interpolation calculations. The F_a and F_v boundary values displayed in Table 3 were obtained from SNI 1726:2019.

Table 3 F_a and F_v distribution developed using the website and SNI 1726:2019 tables

Site Class	Total Data	Linear Interpolation (SNI)					Website				Diff. > 0.01 (%)	
		F_a			F_v		F_a		F_v		F_a	F_v
		MCE_R-S_S(g)			MCE_R-S_1 (g)		Min.	Max.	Min.	Max.		
		0.5	0.75	1.0	0.3	0.4						
SC	34	1.2	1.2	1.2	1.5	1.5	1.19	1.21	1.478	1.519	0	58.82
SD	90	1.4	1.2	1.1	2.0	1.9	1.112	1.167	1.879	1.949	3.41	56.82
SE	79	1.7	1.3	1.1	2.8	2.4	1.148	1.4	2.401	2.732	13.92	50.63

3. Results and Discussion

The MCE_R-S_S values for the SC site class (Table 2) range from 0.8459 to 0.9668 g, while the F_a values for the SC site class developed according to the website (Table 3) range between 1.19 and 1.21. All the F_a values developed from the website are consistent with and almost equal to those from SNI 1726:2019 (Table 3). As can be seen in Table 3, the F_a values from SNI 1726:2019 are constant and equal to 1.2. The difference between the F_a values developed using the website data and those from SNI 1726:2019 is less than 0.01. According to Table 3, for all 34 data, the percentage of total data with a minimum difference of 0.01 is 0%. Figure 3a shows the distribution of the F_a site coefficients for the SC site class in terms of the MCE_R-S_S values. The linear and website legends inside this figure represent the straight-line interpolation following SNI 1726:2019 and the website data acquisition. The R^2 (coefficient of determination) value for site class SC is close to 0, because the F_a values estimated using these two models are nearly constant for all MCE_R-S_S values. The R^2 value is used for evaluation of the fitting line (linear fit model) performance. The evaluation was performed for the distribution of F_a or F_v to the linear regression line model. The minimum and maximum R^2 values are 0 and 1 (100%), respectively. The higher the R^2, the better the linear fitting model difference for the F_a or F_v data distribution.

The distribution of the MCE_R-S_S values for the SD site class in the study area was almost equal to that of the SC site class. Table 2 shows the distribution of MCE_R-S_S for the SD site class, with the values ranging from 0.8098 to 0.9579 g. Following the same procedure as that of the SC site class, the F_a site coefficients for the SD site class in the study area range between 1.2 and 1.1. Due to the MCE_R-S_S being distributed around 1, the F_a values obtained from the study area are close to 1.1: As shown in Table 3, the F_a values range between 1.112 and 1.167. The total percent of data with a minimum difference of 0.01 are 3.41%. Figure 3b shows the distribution of the F_a values for site class SD in terms of the MCE_R-S_S values.

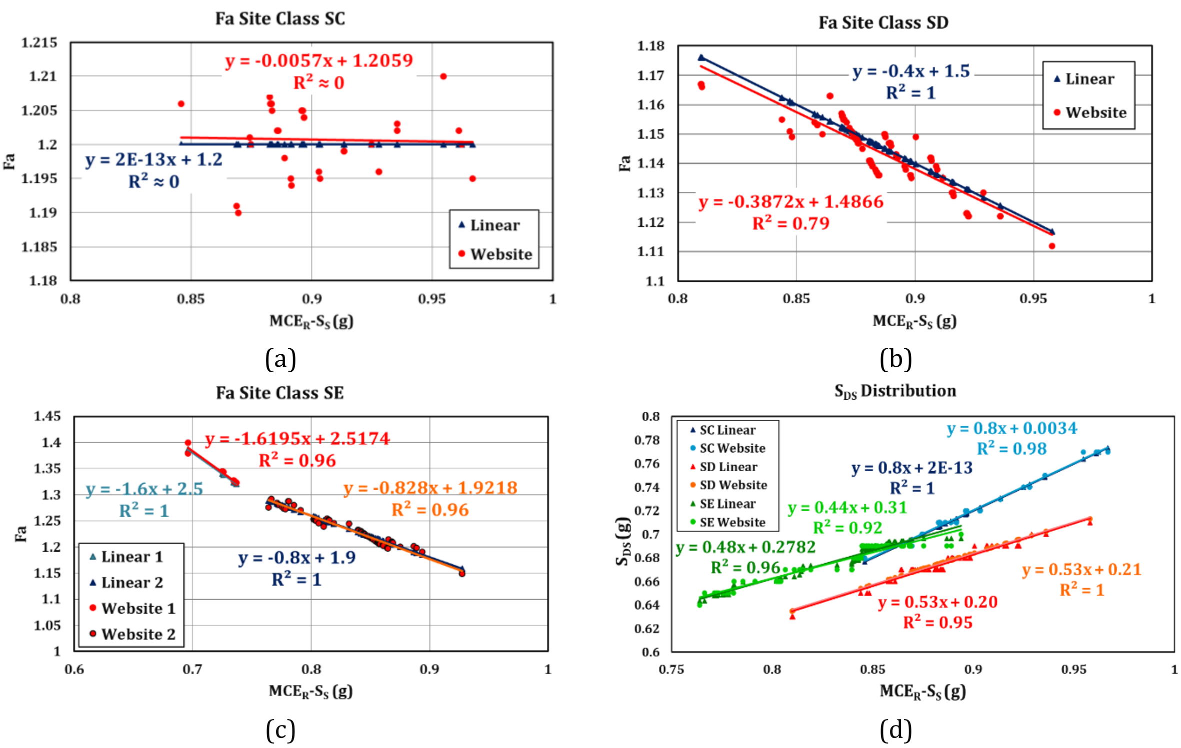


Figure 3 F_a distributions in terms of MCE$_R$-S_S values for: (a) SC; (b) SD; and (c) SE site classes; and (d) the correlation of S_{DS} and MCE$_R$-S_S from the linear interpolation and website software

As can be seen in Figure 3b, the R^2 value obtained from the regression analysis is 0.7858, or less than 1. The straight-line interpolation values developed according to the SNI 1726:2019 data and tables were better compared to the F_a values developed using the website. However, on average, the absolute difference in the F_a values developed between these two models was 0.0105, and the line distributions were almost identical (i.e., coincided).

The MCE$_R$-S_S distribution of the SE site class values estimated from the website ranged between 0.696 and 0.9274 g. According to SNI 1726:2019, all MCE$_R$-S_S for site class SE were distributed between two different boundary values, from 0.5 through 0.75 g for the first boundary and from 0.75 through 1 g for the second boundary. The straight-line interpolation for all MCE$_R$-S_S was also separated into two different boundary values. The first F_a boundary values (6 data) were distributed between 1.4 and 1.323; however, the second F_a (73 data) site coefficients were distributed between 1.292 and 1.148. Figure 3c shows the distribution of the F_a values for the SE site class. Two different straight-line interpolations can be observed in this figure in accordance with the two different boundary values from SNI 1726:2019. The absolute average difference in F_a for site class SE is 0.029. As can be seen in Table 3, 13.92% of the 79 data have a minimum difference of 0.01.

F_a and F_v are the two site coefficients used for calculating surface spectral acceleration and design response spectral acceleration. The performance of the different values of these coefficients developed using the two different procedures (straight line interpolation and using website facility) can be neglected or avoided, since there was no significant difference in the design response spectral acceleration results between these two methods. The difference in the accuracy value used for both methods will sometimes produce different site coefficients and directly impact the performance of the S_{DS} and S_{D1} outputs for all site soil classes.

To verify the performance of the F_a and F_v values estimated using these two methods, design response spectral acceleration calculation was also conducted in this study. The purpose of this analysis was to verify the performance of the design response spectral acceleration S_{DS} and S_{D1} values according to the site coefficient values calculated using the two different methods. Figure 3d shows the performance of the S_{DS} design response spectral acceleration in terms of MCE_R-S_S developed from the website and straight-line interpolation. As can be seen in Figure 3d, a strong correlation between S_{DS} in terms of MCE_R-S_S was observed in this study. According to this figure, there are no significant differences in the S_{DS} performance estimated using the website versus SNI 1726:2019 straight line interpolation procedures for all three site classes (SC, SD, and SE).

The F_a distribution map developed from the 203 boring positions was also constructed based on the website and linear interpolation analysis. Figure 4a and 4b show the two F_a distribution maps, which are almost equal. Specifically, the F_a values from the study area range between 1.2 and 1.4, with the largest Fa values observed in a small north-eastern portion of the city.

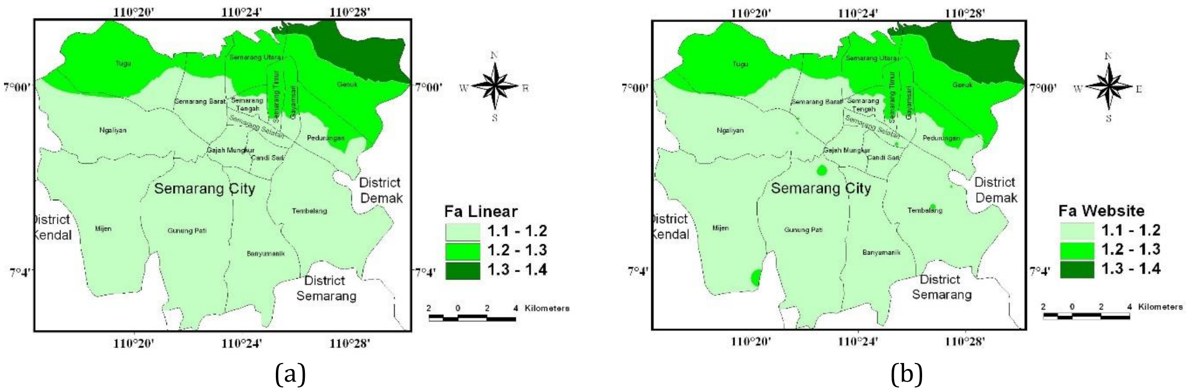


Figure 4 F_a distribution maps developed using: (a) website software; and (b) linear interpolation

Site coefficient evaluation was also conducted for long-period MCE_R-S_1 spectral acceleration. Using the same procedure as that used for MCE_R-S_S, the evaluation was performed for the SC, SD, and SE site classes. Based on the minimum and maximum MCE_R-S_1 values estimated using the website, all MCE_R-S_1 values in the study area were distributed between 0.3185 and 0.4097 g (see Table 2) or approximately between 0.3 and 0.4 g. For site classes SC and SD, there was one boring position with a MCE_R-S_1 value greater than 0.4 g. Figures 5a, b, and c show the distribution of the site coefficient F_v for the SC, SD, and SE site soil classes, respectively.

All the F_v values estimated using the website and straight-line interpolation were almost equal or coincided except for site class SD. As shown in Figure 5b, most of the F_v values of the SD site class developed using the website are greater than those developed using straight-line interpolation. The R^2 value for this model was far from 1. The F_v values for site class SD from the website calculation were far from the linear model described by SNI 1726:2019. The R^2 for site class SC was not available (close to 0), because the F_v and MCE_R-S_1 correlations were nearly constant or almost equal. A good F_v and MCE_R-S_1 correlation was observed for site class SE (see Figure 5c) for the website output and straight-line interpolation methods. The R^2 obtained for this site class was nearly 1. On average the absolute differences between F_v were 0.015, 0.036, and 0.033 for the SC, SD, and SE site classes, respectively. According to Table 3, the percent of total data with a minimum difference of 0.01 for the SC, SD, and SE site classes is greater than 50%.

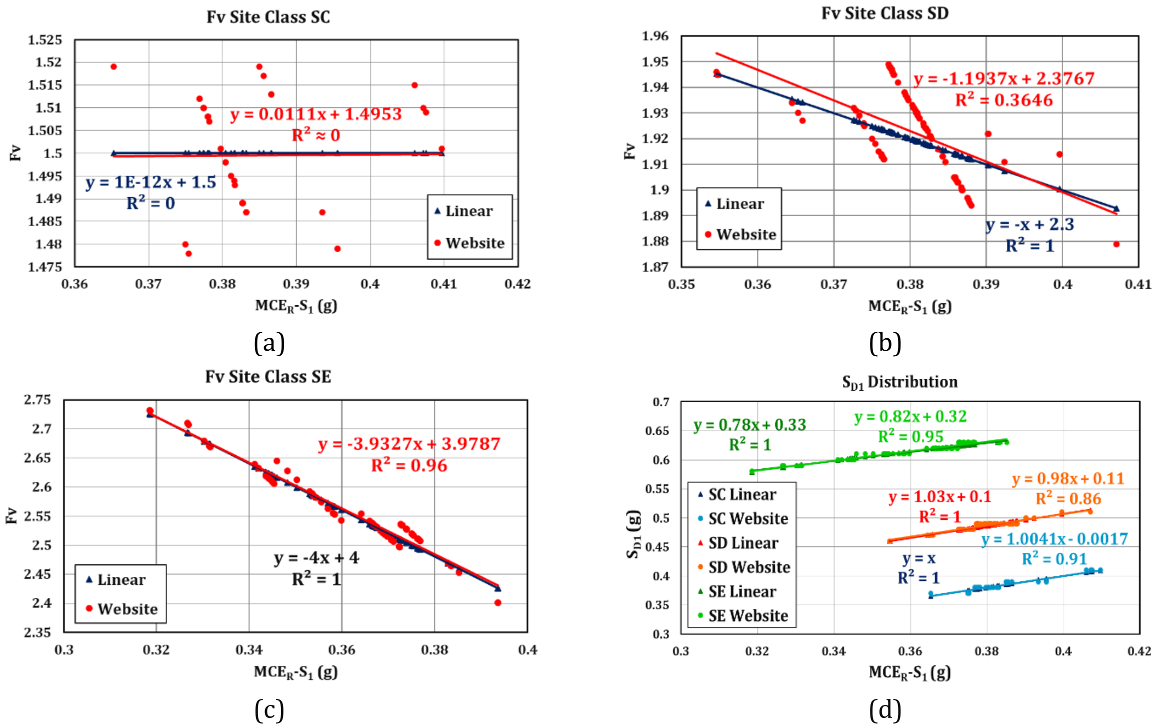


Figure 5 F_v distributions in terms of MCE_R-S_1 values for: (a) SC; (b) SD; (c) SE site classes; and (d) the correlation of S_{D1} and MCE_R-S_1 developed based on linear interpolation and website software

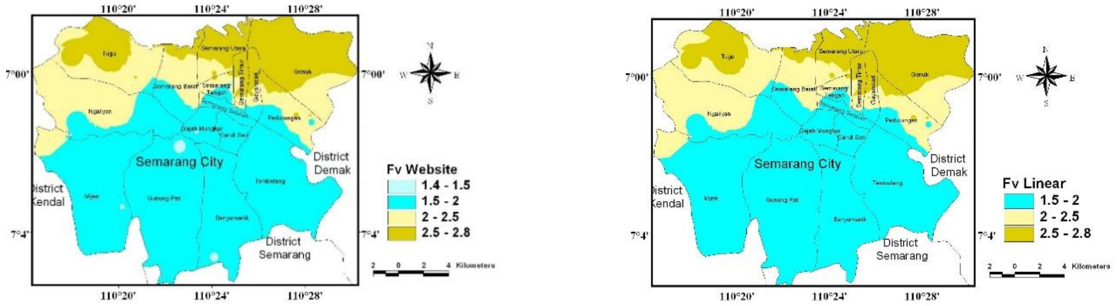
Figure 5d shows the S_{D1} design response spectral acceleration performance in terms of MCE_R-S_1 values estimated using the same methods as used in the S_{DS} calculation. As can be seen in Figure 5d, a good correlation between S_{D1} in terms of MCE_R-S_1 was observed in this study. Also, according to this figure, there are no significant differences in the S_{D1} performance for the SC, SD, and SE site class estimates between the website and straight-line interpolation of SNI 1726:2019 procedures.

F_v distribution maps were also developed based on the website and linear interpolation analysis. Figures 6a and 6b show two F_v distribution maps, which are almost equal. The F_v values developed using the website ranged between 1.4 and 2.8, while the F_v values developed using linear interpolation ranged between 1.5 and 2.8. The largest F_v values were observed in the northern part of the city.

The S_{DS} and S_{D1} developed for the study area using the website were acceptable according to the requirement criterion of SNI 1726:2019. Table 4 shows the minimum and maximum S_{DS} and S_{D1} values and the average difference in the S_{DS} and S_{D1} values between the two methods for the SC, SD, and SE site classes. As shown in Table 4, the average difference of S_{DS} and S_{D1} is the absolute values of S_{DS} and S_{D1}. The maximum average difference (ave. diff.) for S_{DS} and S_{D1}, 0.0224 g and 0.0153 g, respectively, were observed in the SD site class. However, the average differences in S_{DS} and S_{D1} for site classes SC and SE were less than 0.0073 g and 0.0044 g, respectively.

Table 4 S_{DS} and S_{D1} performance for all site classes

Site Class	S_{DS} (g)					S_{D1} (g)				
	Website		Linear		Ave. diff.	Website		Linear		Ave. diff.
	Min.	Max.	Min.	Max.		Min.	Max.	Min.	Max.	
SC	0.68	0.77	0.6767	0.7734	0.0067	0.37	0.41	0.3653	0.4097	0.0044
SD	0.63	0.71	0.6349	0.6925	0.0224	0.46	0.51	0.4599	0.4946	0.0153
SE	0.64	0.71	0.6433	0.706	0.0073	0.58	0.63	0.5788	0.6315	0.0027



(a) (b)

Figure 6 F_v distribution maps developed using website software (a) and linear interpolation (b)

4. Conclusions

Evaluations of site coefficients estimated using the website and straight-line interpolation methods were performed for 203 boring positions in Semarang City. No significant differences were found in the F_a and F_v site coefficients between the two methods. The largest difference in the F_a site coefficient calculations was observed for the SD and SE site classes. The difference in site coefficients for the SD and SE site soil classes was less than 0.03, while, for the SC site soil class, the difference was less than 0.01. In terms of site coefficient F_v, the largest difference was observed for the SD and SE site soil classes with a maximum of 0.04. However, the difference in site coefficient F_v for site class SC was less than 0.02. When calculating F_a and F_v site coefficients, the linear interpolation method from SNI 1726:2019 is better compared to the calculated using MCE_R-S_S, MCE_R-S_1, S_{DS}, and S_{D1} values obtained from the website.

No significant differences in the design response spectral acceleration S_{DS} and S_{D1} values were found for any of the site classes. The largest design response spectral acceleration difference in SD between the two methods was less than 0.02 g, while, for the SC and SE site classes, the differences were less than 0.005 g.

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