Comparison of the RSNI 1726:2018 and the SNI 1726:2012 design response spectra of 17 major cities in Indonesia

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Abstract. Based on the 2017 Indonesian Seismic Map and the ASCE 7-16, the proposed Indonesian Seismic Design Code - RSNI 1726:2018, was developed to renew the current SNI 1726:2012 code. Taking a sampling of 17 major cities representing all regions in Indonesia, this paper presents the comparison of the RSNI 1726:2018 and the SNI 1726:2012 design response spectra. All cities located in high seismic areas have an anomaly characteristic, where the design response spectra of site class SE (soft soil) is less than that of site class SD (medium soil), or even less than that of site class SC (hard soil), contrary to what Structural and Geotechnical Engineers think so far, that the design response spectra of site class SE is always higher than that of site classes SD and SC.

1. Introduction
The construction industry always welcomes the revised Indonesian Seismic Design Code with great enthusiasm. They always want to know immediately, how much the load difference and the changes in the provisions relating to the design and construction. Commercial building developers may immediately take a decision to speed up the project design and construction process if it turns out that the seismic design load rises and/or the requirements are more stringent. On the contrary, they may postpone the project until the new code is implemented if the seismic design load decreases.

As a revision of the current Indonesian seismic design code SNI 1726:2012 [7], the proposed RSNI 1726:2018 [4] was developed based on the 2017 Indonesian Seismic Map [3] and the provisions of the ASCE 7-16 [1] which was adopted with several modifications adapting the conditions of Indonesia.

This paper is intended as a "preview" which shows the difference of the design response spectra according to the RSNI 1726:2018 and the SNI 1726:2012 of 17 major cities which are considered to represent the entire territory of Indonesia, based on verified data provided.

In addition, an observation on the possibility of an anomaly in which the condition of the design response spectra at short periods of the site class SC (hard soil), SD (medium soil) and SE (soft soil) do not increase sequentially, is also presented in this paper. This anomalous phenomenon occurs in earthquake-prone areas with relatively high spectral response acceleration at short periods ($S_S$) related to the application of the site coefficient $F_a$, which in fact decreases (de-amplifies).

2. Design response spectra
Figure 1 shows a schematic illustration of developing a design response spectrum according to the RSNI 1726:2018 or the ASCE 7-16. In principle, the spectral response acceleration values, $S_S$ and $S_1$, are obtained from the MCE$_R$ maps for 0.2 seconds periods (figure 2) and a 1-second period (figure 3),...
which are then multiplied by the seismic amplification factors $F_a$ and $F_v$ producing the spectral response acceleration parameters corresponding to the soil site class, namely $S_{MS}$ and $S_{M1}$. The value of the design spectral response acceleration at short periods, $S_{DS}$, is $2/3$ of the $S_{MS}$ value, and the value of the design spectral response acceleration at a 1-second period, $S_{D1}$, is $2/3$ of the $S_{M1}$ value.

Figure 1. Developing design response spectra process.

The Risk-Targeted Maximum Considered Earthquake (MCER) spectral response acceleration maps with a 5% critical damping and a 1% probability of collapse within a 50 years, which were adjusted for the soil site class between SB and SC, for short periods (0.2 seconds) and a 1-second period according to the ASCE 7-16, as shown in figures 2 and 3, were developed based on hazard maps with a 2% probability of exceedance within 50 years (2,475-year earthquake return period) compiled by the National Earthquake Study Center Team in the 2017 Earthquake Source and Hazard Maps.

Figure 2. MCER map for 0.2-second spectral response acceleration (5% damping - site class SB/SC).
Figure 3. MCER map for 1-second spectral response acceleration (5% damping - site class SB/SC).

The MCER maps were developed with a grid interval of 0.10 and consist of approximately 96,000 data for each spectral response acceleration at short periods, $S_S$, and for spectral response acceleration at a 1-second period, $S_1$. In order to obtain $S_S$ and $S_1$ values at given latitude and longitude coordinates, an interpolation calculation of 4 points on the closest grids is carried out. This MCER map will be refined and posted on the Puskim PU website to be freely used by public.

3. Site coefficient $F_a$ and $F_v$

As shown in table 1 and table 2, the site coefficient values (which are also commonly known as the amplification factors) $F_a$ and $F_v$ were changed in RSNI 1726:2018 by adopting the recommendation from Pacific Earthquake Engineering Research (PEER) that are slightly different from the ones set on the ASCE 7-16. This is to avoid having to conduct site-specific response analysis for the soft soil (SE) site class when the values of spectral response acceleration $S_S \geq 1$ g, and $S_1 \geq 0.2$ g, as required in ASCE 7-16.

| Site Class | $S_S \leq 0.25$ | $S_S = 0.5$ | $S_S = 0.75$ |
|------------|-----------------|-------------|-------------|
| SA         | 0.8 0.8 0.8     | 0.8 0.8 0.8 | 0.8 0.8 0.8 |
| SB         | 1.0 0.9 0.9     | 1.0 0.9 0.9 | 1.0 0.9 0.9 |
| SC         | 1.2 1.2 1.2     | 1.2 1.2 1.2 | 1.2 1.2 1.2 |
| SD         | 1.6 1.6 1.6     | 1.4 1.4 1.4 | 1.2 1.2 1.2 |
| SE         | 2.5 2.4 2.4     | 1.7 1.7 1.7 | 1.2 1.3 1.3 |
| SF         | Site-Specific  | Site-Specific| Site-Specific |

| Site Class | $S_S = 1.0$ | $S_S = 1.25$ | $S_S = 1.5$ |
|------------|-------------|--------------|-------------|
| SA         | 0.8 0.8 0.8 | 0.8 0.8 0.8 | 0.8 0.8 0.8 |
| SB         | 1.0 0.9 0.9 | 1.0 0.9 0.9 | 1.0 0.9 0.9 |
| SC         | 1.0 1.2 1.2 | 1.0 1.2 1.2 | 1.0 1.2 1.2 |
| SD         | 1.1 1.1 1.1 | 1.0 1.0 1.0 | 1.0 1.0 1.0 |
| SE         | Site-Specific | Site-Specific| Site-Specific |
| SF         | Site-Specific | Site-Specific| Site-Specific |
Table 2. Long-period site coefficient $F_v$.

| Site Class | $S_1 = 0.1$ | $S_1 = 0.2$ | $S_1 = 0.3$ |
|-----------|------------|------------|------------|
| $F_v$     |            |            |            |
| SNI 1726:2012 | ASCE 7-16 | PEER / RSNI 1726:2018 | SNI 1726:2012 | ASCE 7-16 | PEER / RSNI 1726:2018 | SNI 1726:2012 | ASCE 7-16 | PEER / RSNI 1726:2018 |
| SA        | 0.5        | 0.8        | 0.8        |
| SB        | 1.0        | 0.8        | 0.8        |
| SC        | 1.5        | 1.5        | 1.5        |
| SD        | 2.4        | 2.4        | 2.4        |
| SE        | 3.5        | 4.2        | 3.2        |
| SF        | Site-Specific | Site-Specific | Site-Specific |
| $F_v$     |            |            |            |

As stated by Crouse [2], the previous $F_a$ and $F_v$ values were considered to be too long have not been updated and are no longer compatible with the results of recent studies conducted by J Stewart et al [8]. This is the basis of the changes adopted by the RSNI 1726:2018.

According to the ASCE 7-16, the bed rock is no longer at the site class SB, but in between sites classes SB and SC. It should be noted that the MCE maps presented in figures 2 and 3 have been adjusted to this criterion. Next, in contrast to the SNI 1726:2012, the $S_1$ classification is added with "$\geq 1.5$" and the $S_1$ classification is added with "$\geq 0.6$", representing very high seismicity areas near the fault or earthquake source. It can be stated that $F_a$ and $F_v$ values variedly change, most of them rise, but some values remain the same as before, and some values go down, especially in the low seismicity areas. The occurrence of an anomaly in which the magnitude of the design response spectra for the hard soil (SC), medium soil (SD) and soft soil (SE) site classes did not increase sequentially as in the old standard due to fluctuations of $F_a$ values and will be discussed further in the other section of this paper.

4. Design response spectra of 17 major cities in Indonesia

In order to see the design response spectra comparison of the RSNI 1726:2018 and the SNI 1726:2012, 17 major cities, which were considered to represent the entire territory of Indonesia from West to East, and from North to South, were chosen as samplings.

Comparison of the spectral response acceleration at the bedrock of the 17 major cities is shown in table 3. $S_1$ and $S_1$ values derived from the MCE maps of the RSNI 1726:2018 had been verified by M Irsyam on May 23, 2018 Sub-Structures Technical Meeting in Jakarta, from the results of studies of W Sengara, Asrurifak and W Partono which were done separately.

From the observations of table 3, the values of spectral response acceleration at short periods ($S_3$) according to the RSNI 1726:2018 in ten cities, namely: Banda Aceh, Denpasar, Jakarta, Manado, Manokwari, Medan, Padang, Palembang, Pontianak and Surabaya, increase with ratios between 1.01 - 6.65 from the values of spectral response acceleration at short periods according to the SNI 1726:2012; one city, namely Jayapura, has no change; and six cities, namely Ambon, Balikpapan, Bandung, Kupang, Makassar and Semarang, in fact decrease with ratios ranging from 0.52 - 0.94.

The values of spectral response acceleration at a 1-second period according to the RSNI 1726:2018 in twelve cities increase with ratios between 1.01 - 2.14, namely: Balikpapan, Bandung, Denpasar, Jakarta, Kupang, Manado, Manokwari, Medan, Palembang, Pontianak, Semarang and Surabaya; two cities, Jayapura and Padang, have no change; and three cities, Ambon, Banda Aceh and Makassar, decrease with ratios of 0.79 - 0.93, compared to the values of spectral response acceleration at a 1-second period according to the SNI 1726:2012.
Table 3. Spectral response acceleration parameters at short periods and 1-second period based on MCE_{eq} map of 17 major cities in Indonesia.

| No. | City       | Coordinate Latitude | Longitude | S_{Y} 1.0 sec | S_{1} 1.0 sec |
|-----|------------|---------------------|-----------|---------------|--------------|
| 1   | Ambon      | -3.654               | 128.190   | 1.380         | 1.085        | 0.799       | 0.400 | 0.393 | 0.80 |
| 2   | Balikpapan | -1.2379              | 116.852   | 0.235         | 0.123        | 0.52        | 0.082 | 0.083 | 1.01 |
| 3   | Banda Aceh | 5.5483               | 95.3238   | 1.349         | 1.510        | 1.12        | 0.642 | 0.600 | 0.93 |
| 4   | Bandung    | -6.9175              | 107.6191  | 1.450         | 1.176        | 0.81        | 0.486 | 0.510 | 1.05 |
| 5   | Depok      | -8.0705              | 115.2126  | 0.977         | 0.984        | 1.01        | 0.360 | 0.397 | 1.10 |
| 6   | Jakarta    | -6.1751              | 106.8650  | 0.664         | 0.779        | 1.17        | 0.203 | 0.379 | 1.20 |
| 7   | Jayapura   | -2.5916              | 140.6690  | 1.500         | 1.500        | 1.00        | 0.600 | 0.600 | 1.00 |
| 8   | Kupang     | -10.1772             | 123.6070  | 1.113         | 1.049        | 0.94        | 0.296 | 0.380 | 1.28 |
| 9   | Makassar   | -5.1477              | 119.4327  | 0.317         | 0.222        | 0.70        | 0.142 | 0.112 | 0.79 |
| 10  | Manado     | 1.4748               | 124.8421  | 1.035         | 1.052        | 1.02        | 0.442 | 0.470 | 1.06 |
| 11  | Manokwari  | -0.8615              | 134.0620  | 1.454         | 1.500        | 1.03        | 0.561 | 0.600 | 1.07 |
| 12  | Medan      | 3.5952               | 98.6722   | 0.526         | 0.652        | 1.24        | 0.332 | 0.360 | 1.08 |
| 13  | Palembang  | -0.5471              | 110.4172  | 1.398         | 1.481        | 1.06        | 0.600 | 0.600 | 1.00 |
| 14  | Pontianak  | -2.9761              | 104.7754  | 0.262         | 0.292        | 1.11        | 0.164 | 0.248 | 1.51 |
| 15  | Pontianak  | -0.0063              | 109.3425  | 0.017         | 0.113        | 0.65        | 0.022 | 0.047 | 2.14 |
| 16  | Semarang   | -7.0051              | 110.4381  | 1.098         | 0.880        | 0.80        | 0.364 | 0.379 | 1.04 |
| 17  | Surabaya   | -7.2575              | 112.7521  | 0.665         | 0.710        | 1.07        | 0.247 | 0.315 | 1.28 |

Table 4 and table 5 present a comparison of the design response spectrum value for the site class categories of hard soil (SC), medium soil (SD) and soft soil (SE) of the 17 major cities in Indonesia at short periods (0.2 seconds), S_{DS}, and at a 1-second period, S_{DI}.

Table 4. Design response spectra at short periods (S_{DS}) of 17 major cities in Indonesia.

| No. | City       | S_{DS} | S_{SD} | S_{SE} | Anomaly |
|-----|------------|--------|--------|--------|---------|
| 1   | Ambon      | 0.739  | 0.666  | 0.596  |         |
| 2   | Balikpapan | 0.567  | 0.549  | 0.509  |         |
| 3   | Banda Aceh | 0.699  | 1.206  | 1.134  |         |
| 4   | Bandung    | 0.467  | 0.941  | 0.907  |         |
| 5   | Depok      | 0.457  | 1.767  | 1.28   | 0.722   | 0.526   | 0.436   | 0.470   | 1.06 |
| 6   | Jakarta    | 0.582  | 0.623  | 0.256  | 0.856   | 0.47    | 0.406   | 0.730   | 1.21 |
| 7   | Jayapura   | 0.453  | 0.889  | 0.813  | 0.786   | 0.708   | 0.607   | 0.633   | 0.89 |
| 8   | Kupang     | 0.782  | 0.739  | 0.113  | 0.786   | 0.708   | 0.607   | 0.633   | 0.89 |
| 9   | Makassar   | 0.526  | 1.892  | 0.761  | 0.927   | 0.737   | 0.641   | 0.691   | 0.94 |
| 10  | Manado     | 0.600  | 0.882  | 0.222  | 0.749   | 0.707   | 0.632   | 0.742   | 1.20 |
| 11  | Manokwari  | 0.769  | 1.200  | 1.24   | 0.917   | 0.800   | 0.652   | 0.742   | 1.11 |
| 12  | Medan      | 0.637  | 0.859  | 0.218  | 0.848   | 0.514   | 0.458   | 0.641   | 0.89 |
| 13  | Palembang  | 0.932  | 1.185  | 1.27   | 0.932   | 0.800   | 0.652   | 0.742   | 1.20 |
| 14  | Pontianak  | 0.230  | 0.253  | 1.21   | 0.278   | 0.305   | 0.438   | 0.448   | 1.03 |
| 15  | Pontianak  | 0.014  | 0.996  | 0.728  | 0.918   | 0.121   | 0.627   | 0.663   | 0.86 |
| 16  | Semarang   | 0.732  | 0.708  | 0.904  | 0.777   | 0.437   | 0.438   | 0.707   | 1.00 |
| 17  | Surabaya   | 0.082  | 0.576  | 0.135  | 0.581   | 0.203   | 0.407   | 0.846   | 1.06 |

Table 5. Design response spectra at a 1-second period (S_{DI}) of 17 major cities in Indonesia.
In accordance with the new site coefficient $F_a$, the $S_{DS}$ values for the hard soil (SC) site class, 12 cities experience increases with ratios of 1.13 - 7.20, and 5 cities experience decreases with ratios ranging from 0.57 - 0.97. For the medium soil (SD) site class, 9 cities experience increases with ratios of 1.01 - 6.65, 2 cities have no change, and 6 cities experience declines with ratios of 0.52 - 0.97. For the soft soil (SE) site class, 9 cities experience increases with ratios of 1.03 - 6.38, and 8 cities experience decreases with ratios of 0.50 - 0.99.

With the application of the new site coefficient $F_v$, the $S_{DI}$ values in the hard soil (SC) site class, 14 cities experience increases with ratios between 1.01 - 1.89, and 3 cities experience decreases with ratios ranging from 0.71 - 0.92. For the medium soil (SD) site class, 16 cities experience increases with ratios of 1.01 - 2.14, and 1 city decreases with a ratio of 0.84. For the soft soil (SE) site class, 9 cities experience increases with ratios between 1.02 - 2.56, 1 city has no change, and 7 cities experience decreases with ratios of 0.78 - 0.96.

5. Design response spectrum anomaly

So far, Structural and Geotechnical engineers have a mindset where the design response spectra of hard soil (SC), medium soil (SD) and soft soil (SE) site classes increases sequentially. In other words, the softer the soil, the greater the design response spectrum value. As shown in figure 4, the SNI 1726-1989 [5] and the SNI 1726-2002 [6] design response spectra also adhere to this rule. However, studies carried out by S Sutjipto [9, 10] indicate that the application of site coefficients $F_a$ and $F_v$ according to the SNI 1726:2012 changes these sequences so that it is then referred to as an anomaly. In fact, it also occurs in the RSNI 1726:2018.

From table 4, it can be observed that the design response spectra at short periods ($S_{DS}$) of 17 selected cities experience 4 conditions and they can be grouped as follows:

- Normal : design response spectra SC < SD < SE
- Anomaly 1 : design response spectra SD < SC < SE
- Anomaly 2 : design response spectra SD < SE < SC
- Anomaly 3 : design response spectra SE < SD < SC

![SNI 1726-1989](image1)

![SNI 1726-2002](image2)

**Figure 4.** The SNI 1726-1989 and the SNI 1726-2002 design response spectra.
There are 6 cities with a normal condition, namely: Balikpapan, Makassar, Medan, Palembang, Pontianak and Surabaya. One city with Anomaly 1 condition is Jakarta. Two cities with Anomaly 2 condition are Denpasar and Semarang. And, 8 cities with Anomaly 3 condition are Ambon, Banda Aceh, Bandung, Jayapura, Kupang, Manado, Manokwari and Padang.

The observations in table 5 show the design response spectra at 1-second period ($S_{D1}$) of the 17 selected cities do not show anomalies, where the condition of the design response spectra SC < SD < SE. However, it should be noted that although the anomaly only occurs in short-periods response spectral, so it seems that it only affects the low-rise buildings, but in fact the impact can also affect the high-rise and medium-rise buildings due to the requirement of the minimum base shear $V = 0.044 S_{DS} I_e W$ according to the RSNI 1726:2018.

### 6. Plot of 17 selected cities design response spectra

The design response spectra plots based on the RSNI 1726:2018 and the SNI 1726:2012 for 17 selected cities are presented simultaneously in figure 5.

The design response spectra of the RSNI 1726:2018 are shown in solid curve lines, while the design response spectra of the SNI 1726:2012 are shown in intermittent curve lines. Green, yellow and red curves represent hard soil (SC), medium soil (SD) and soft soil (SE) site classes, respectively.

Plots without border show cities with Normal conditions (design response spectra SC < SD < SE). Plots with a single red line border indicate cities with Anomaly 1 condition (design response spectra SD < SC < SE), while plots with a double red line border indicate cities with Anomaly 2 condition (design response spectra SD < SE < SC), and plots with a triple red line border indicate cities with Anomaly 3 condition (design response spectra SE < SD < SC).

![Figure 5. Design response spectra of 17 major cities in Indonesia.](image-url)
Figure 5. Design response spectra of 17 major cities in Indonesia (continued).
7. Conclusion

Based on the data presented in this paper, it can be concluded that:

- The design response spectra of the 17 selected cities based on the RSNI 1726:2018, compared to that of based on the SNI 1726:2012, at short-periods mostly increase 10% on average, with an exception of Pontianak which increase approximately 6.5 times, and at 1-second period mostly increase 17% in average, except Pontianak which increase approximately 2.3 times.

- Based on the RSNI 1726:2018 site coefficient \( F_a \), three possibilities of anomaly conditions may occur in the cities located in earthquake-prone areas with a value of \( S_N \) above 0.75 g.

**Figure 5.** Design response spectra of 17 major cities in Indonesia (continued).
References

[1] ASCE/SEI 7-16 Minimum Design Loads and Associated Criteria for Buildings and Other Structures (VA: American Society of Civil Engineers)

[2] Crouse C B 2015 Site Coefficients $F_a$, $F_v$, and $F_{PGA}$ Proposed for ASCE 7-16. (CA: AECOM)

[3] Peta Sumber dan Bahaya Gempa Indonesia Tahun 2017 (Bandung: Pusat Litbang Perumahan dan Pemukiman)

[4] RSNI 1726:2018 Tata cara perencanaan ketahanan gempa untuk struktur bangunan gedung dan non gedung (Jakarta: Badan Standarisasi Nasional)

[5] SNI 1726-1989 Pedoman perencanaan ketahanan gempa untuk rumah dan gedung (Bandung: Departemen Pekerjaan Umum)

[6] SNI 1726-2002 Tata cara perencanaan ketahanan gempa untuk bangunan gedung (Jakarta: Badan Standarisasi Nasional)

[7] SNI 1726:2012 Tata cara perencanaan ketahanan gempa untuk struktur bangunan gedung dan non gedung (Jakarta: Badan Standarisasi Nasional)

[8] Stewart J P and Seyhan E 2013 Semi-Empirical Nonlinear Site Amplification and Its Application in NEHRP Site Factors (CA: PEERC)

[9] Sutjipto S and Sumeru I 2015 Anomali Spektrum Respons Desain SNI 1726:2012 (Jakarta: Seminar dan Pameran HAKI 2015)

[10] Sutjipto S 2016 An Overview of Design Response Spectra in the Indonesian Seismic Code - SNI 1726:2012 (Bali: International Conference on Earthquake Engineering and Disaster Mitigation III)