Comparison of earthquake design parameters of low rise building structures based on SNI-1726-2002 and SNI 1726:2012 at 23 districts in Aceh Province, Indonesia

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Abstract. This paper presents a comparison of earthquake design parameters, i.e. response spectrum, modal mass contribution, base shear and natural vibration period, of low rise building structures based on SNI-1726-2002 and SNI 1726:2012 at 23 districts in Aceh Province, Indonesia. A four-story reinforced concrete frame structure is analyzed. The results show that the maximum spectral acceleration based on SNI 1726:2012 is higher than based on SNI-1726-2002 for 15 districts in Aceh. The modal mass participation for those two standards is almost the same. The base-shear force of SNI 1726:2012 is much higher than of SNI-1726-2002. The structural natural period of both SNI-1726-2002 and SNI 1726:2012 is in a good agreement.

1. Introduction
The Indonesian Government has issued several special regulations to anticipate the effects of the earthquake on buildings and minimize the damage of buildings due to an earthquake. One of the regulations is SNI-1726-2002 concerning Earthquake Resistance Design Standards for Building Structures [1]. This standard uses the Indonesian earthquake zoning map which is divided into 6 zones from the lowest zone (zone 1) to the highest zone (zone 6) of seismic intensity.

Since the issuance of SNI-1726-2002, there have been a couple of major earthquake events in Indonesia that have magnitudes greater than the maximum magnitude of previous estimates, such as the Sumatra-Andaman Earthquake in 2004 (Mw = 9.2) and Nias Earthquake in 2005 (Mw = 8.7) ([2], [3], [4]). The earthquakes have caused death of thousands of lives, collapsed and damaged thousands of infrastructures, and trillions of rupiah for rehabilitation and reconstruction. In the last few years a new analytical method has been developed that can accommodate a three-dimensional earthquake source attenuation model (3-D). It can better illustrate the wave propagation attenuation compared to the 2-D model used for the preparation of SNI-1726-2002 earthquake maps. Further intensive research on current attenuation functions and recent studies of active faults in Indonesia further strengthens the need to improve Indonesia's current earthquake map. Therefore in 2012, the government issued the latest regulations/standards namely SNI 1726:2012 concerning Design Procedures for Earthquake Resistance of Building and Non-Building Structures [5].

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In this standard the earthquake zoning map is made based on the bedrock acceleration of the short period (0.2 seconds) "Sd" and the bedrock acceleration of 1 second period "S1". Furthermore, in design of building structures, it was agreed that the new Indonesian earthquake map would be prepared based on the most recent seismicity data, the latest research results on seismotectonic conditions in Indonesia, and using the 3-D model with reference to International Building Code (IBC) 2009 ([2], [6]).

One of the areas with high earthquake intensity in terms of earthquake zoning maps in both SNI-1726-2002 and SNI 1726:2012 is Aceh Province. This makes the engineers need a special attention when designing building structures in Aceh Province. The difference in earthquake zoning maps in both standards for each district causes a difference in the maximum spectral response value so that a separate analysis is needed to determine the effect on the structure response behavior in the form of basic shear force (V) and natural vibration period (T). This research was conducted with the aim to get a comparison of the spectra response graph, natural vibration period and basic shear force from the three-story building structures which is calculated based on the two regulations at 23 districts in Aceh Province.

2. Literature Review

2.1 Earthquake map

The earthquake design load in SNI-1726-2002 uses a 10% probability value exceeded in 50 years or had a 475 year return period. Whereas SNI 1726:2012 uses earthquake maps with a probability value of 2% exceeded in 50 years or has a return period of 2475 years. In SNI 1726-2002, earthquake maps are divided into 6 regions. Region 1 represents the lowest seismic value and region 6 represents the highest seismic value while the earthquake area according to SNI 1726:2012 is determined based on the parameter value of the bedrock acceleration of short period (0.2 seconds) Sd and bedrock acceleration period of 1 second S1 ([1], [5]).

2.2 Soil Classification

Ideally an initial study to define the seismic site classification must be carried out prior to the analysis as shown in [7] and [8]. There are many factors contributed to seismic site classification i.e. basin geometry [9]. Due to some constraints, the used seismic site classification of this study is based on the adopted standards. Based on SNI 03-1726-2002, the soil is classified into hard soil, medium soil, soft soil and special soil [1]. On the contrary SNI 03-1726-2012 classifies the soil into several site classes, as the basis for determining the Fv site coefficient (amplification factor at 2s) and site coefficient Fv (amplification factor at 1s) [5].

2.3 Response Spectrum

According to SNI-1726-2002 design response spectrum C-T is divided into 6 earthquake areas with 3 types of soil namely hard soil, medium soil and soft soil. In the design response spectrum the value of C is the earthquake response factor expressed in gravitational acceleration (g) and T is the vibration natural period expressed in seconds. For T = 0 the value of C becomes the same as spectrum acceleration A∞. Base rock acceleration and peak ground acceleration values are also determined as minimum accelerations that must be taken into account in designing the building structures to ensure minimum robustness of the building structures.

In SNI 03-1726-2012, the response spectrum C-T is calculated based on the following parameters:

(a) Bedrock acceleration. Bedrock acceleration is determined respectively for acceleration response of 0.2 seconds (Sd) and 1 second (S1) in seismic ground motion maps and expressed in decimal numbers on gravitational acceleration (g).

(b) Site classes. Land site classes are determined whether they are included in SA, SB, SC, SD, SE and SF

(c) Site coefficient. Site coefficients and response parameters of the maximum earthquake acceleration spectra considered risk-targeted (MCER) at the ground surface required a seismic amplification factor for a period of 0.2 seconds and a 1 second period. SNI 1726:2012 Article 6.2 states that the
amplification factor includes vibration amplification factors related to the acceleration that represent short period vibrations \( F_a \) and vibration amplification factors related to the acceleration that represent vibrations of 1 second period \( F_v \). Spectra response parameters in short periods \( S_{MS} \) and 1 second period \( S_{M1} \) adjusted to the influence of site classification must be determined by the following formula:

\[
S_{MS} = S_S F_a \\
S_{M1} = F_v S_I
\]

where \( S_S = \) MCER earthquake acceleration response parameters are mapped for short periods; \( S_I = \) MCER earthquake acceleration response parameters are mapped for a period of 1 second.

(d) Design spectra acceleration. The design spectra acceleration parameters for short periods \( S_{DS} \) and 1 second period \( S_{D1} \) must be determined through the following formula:

\[
S_{DS} = \frac{2}{3} S_{MS} \\
S_{D1} = \frac{2}{3} S_{M1} \\
T_S = \frac{(S_{D1})}{S_{Ds}} \\
T_0 = 0.2 \frac{(S_{D1})}{S_{Ds}}
\]

where: \( S_{DS} = \) design spectrum acceleration parameter in short periods, \( S_{D1} = \) design spectrum acceleration response parameter for a period of 1 second, \( T_S = \) fundamental period of structures in short periods (0.2seconds)

(e) Design response spectrum acceleration. The \( S_a \) value for periods smaller than \( T_0 \) is calculated by the following equation:

\[
S_a = S_{DS} (0.4 + 0.6 \frac{T}{T_0})
\]

In periods greater than or equal to \( T_0 \) and smaller than or equal to \( T_S \), the \( S_a \) value is equal to \( S_{DS} \). For periods larger than \( T_S \), the response spectrum of the design acceleration is taken based on the following equation:

\[
S_a = \frac{(S_{D1})}{T}
\]

where: \( T = \) fundamental period of structures and \( S_a = \) design response spectrum acceleration.

All parameters are plotted into the graph and produced a design response spectrum. The acceleration of the bedrock at 0.2 seconds and 1.0 second is first set. The acceleration of the bedrock is then amplified so that it becomes acceleration at ground level or below the building structures for \( T_0 \), 0.2 seconds, \( T_S \), and 1.0 second. These values are used as earthquake loads in building structure design [10].

3. Method

3.1 Aceh earthquake map and analytical model

This study uses an earthquake map that is juxtaposed with the administrative map of the Aceh Province so that it can be determined in an outline of the boundaries of each district in both earthquake maps SNI-1726:2002 and SNI 1726:2012. The analytical model used in this study is a four-floor reinforced concrete building structure that has been built in Banda Aceh.

3.2 Stage of research

The stages of research in this study can be described [11], as follows:

1) Collecting Aceh Province Administration Maps and Indonesian Earthquake Maps;
2) Comparing the Aceh Province Administration Map to the Indonesian Earthquake Map so that the boundaries of each district are known in the earthquake map;
3) Determine the earthquake area of each district to choose the response of SNI-1726-202 spectra and determine the $S_s$ and $S_l$ values to calculate the response of SNI 1726:2012 spectra;
4) Make the graph of the response spectra for 23 districts based on SNI-1726-2002 using data from the earthquake area that has been determined;
5) Graph the response spectra for 23 districts based on SNI 1726:2012 using the help of Indo spectra software;
6) Model the building structure into SAP2000 software;
7) The input load is evenly distributed, centralized and the response spectra as a dynamic load structure in SAP2000 in accordance with the provisions of SNI-1726-2002 and SNI 1726:2012;
8) Analyze and make a comparison of earthquake design parameters.

4. Results and Discussion

4.1 Response spectra
Response spectra for all 23 district in Aceh Province is shown in Table 1. The higher in response spectra in SNI 1726:2012 is due to adjustments to the large earthquakes those occurred after SNI 03-1726-2002 was set, as well as changes in the value of the earthquake return period from the 475 year return period to a 2475 year return period. In addition, the lower in SNI-1726-2002 response spectra is due to that SNI-1726-2002 still uses a calculation method of decreasing earthquake intensity (attenuation) in 2 dimensions by assuming that the entire region has the same depth of earthquake propagation rock so that the resulting earthquake map is still lacking in detail. In contrast SNI 1726-2012 uses the attenuation method in 3 dimensions so that each point being reviewed will have a different spectral value even though it is in one type of earthquake zone, depending on the extent and depth of the media of earthquake propagation. As results, there are several districts that experienced a decline in SNI 1726:2012 spectra values. In the case of Banda Aceh, the used response spectra in this study is lower than the response proposed by [12].

Figure 1 shows one of the comparison of response spectrum according to SNI 1726-2012 and SNI 03-1726-2002 for Aceh Tengah District.

Figure 1. Comparison of the response spectrum of SNI-1726-2002 for Aceh Tengah District
Table 1. Comparison of SNI 1726:2012 and SNI-1726-2012 spectra value (1/2)

| District        | Maximum spectral acceleration (g) according to SNI 1726:2012 (A) | SNI-1726-2002 (B) | A/B   |
|-----------------|------------------------------------------------------------------|-------------------|-------|
| Banda Aceh      | 0.906                                                            | 0.830             | 1.092 |
| Aceh Besar      | 0.946                                                            | 0.830             | 1.140 |
| Pidie Jaya      | 0.733                                                            | 0.700             | 1.047 |
| Sabang          | 0.820                                                            | 0.700             | 1.171 |
| Pidie           | 0.897                                                            | 0.830             | 1.081 |
| Aceh Jaya       | 0.830                                                            | 0.830             | 1.000 |
| Bireuen         | 0.681                                                            | 0.700             | 0.973 |
| Aceh Barat      | 0.841                                                            | 0.830             | 1.013 |
| Lhokseumawe     | 0.578                                                            | 0.550             | 1.051 |
| Aceh Utara      | 0.611                                                            | 0.700             | 0.873 |
| Bener Meriah    | 0.683                                                            | 0.700             | 0.976 |
| Aceh Tengah     | 1.025                                                            | 0.700             | 1.464 |
| Gayo Lues       | 0.867                                                            | 0.830             | 1.045 |
| Nagan Raya      | 1.090                                                            | 0.830             | 1.313 |
| Aceh Barat Daya| 0.848                                                            | 0.830             | 1.022 |
| Aceh Tamiang    | 0.620                                                            | 0.700             | 0.886 |
| Aceh Selatan    | 0.821                                                            | 0.830             | 0.989 |
| Langsa          | 0.585                                                            | 0.550             | 1.064 |
| Aceh Tenggarra  | 1.003                                                            | 0.830             | 1.208 |
| Subulussalam    | 0.829                                                            | 0.830             | 0.999 |
| Aceh Timur      | 0.693                                                            | 0.700             | 0.990 |
| Aceh Singkil    | 1.000                                                            | 0.900             | 1.111 |
| Simeulue        | 1.000                                                            | 0.900             | 1.111 |

Figure 2. Effective modal mass participation based on SNI-1726-2002
4.2 Minimum effective modal mass participation

Based on the results obtained, the value of minimum effective modal mass participation in the model studied for all districts are 99.98% and 99.99% in X and Y directions, respectively as shown in Figure 2 and Figure 3. These values are satisfy the provisions of SNI-1726-2002 and SNI 1726:2012 which requires mass participation at least of 90%.

Figure 3. Effective modal mass participation based on SNI-1726-2002

4.3 Base shear force

Figure 6 and 7 show base shear force in the direction of X and Y directions for all districts according to SNI 1726:2012 and SNI-1726-2002. The increase in base shear force of SNI 1726:20012 is due to three reasons: firstly because of an increase in the response spectra value on SNI 1726:2012 so that the load received by the structure becomes larger, secondly because of the increase in the value of building safety factors for residential buildings which is 1.0 on SNI -1726-2002 becomes 1.5 in SNI 1726:2012, where
the greater the priority factor, the design base shear force of the building will also increase and the thirdly is the increased input combined load.

Figure 5. Base shear force in Y direction

4.4 Structure natural vibration period

Figure 6 and 7 show structure natural vibration periods for all districts and their comparison with requirement of SNI-1726-2002 and SNI 1726:2012, respectively. From those two figures, it can be seen that the structure natural vibration periods for all districts in Aceh Province are in accordance with the requirement of those two standards.

Figure 6. Structure natural periods and their comparison with SNI-1726-2002 requirement
5. Conclusions
Based on the results of this research, the following conclusions can be drawn:

1. Among 23 districts in Aceh Province, 15 of them which are Banda Aceh, Aceh Besar, Pidie Jaya, Sabang, Pidie, Aceh Barat, Lhokseumawe, Aceh Tengah, Gayo Lues, Nagan Raya, Aceh Barat Daya, Langsa, Aceh Tenggara, Aceh Singkil and Simeulue Districts have higher SNI 1726:2012 based maximum spectral accelerations compared to those of SNI-1726-2002. Aceh Jaya District has similar maximum spectral acceleration for both standards. The remaining 7 districts which are Bireun, Aceh Utara, Bener Meriah, Aceh Tamiang, Aceh Selatan, Subulussalam and Aceh Timur have lower SNI 1726:2012 based maximum spectral accelerations than those of SNI-1726-2002.

2. The modal mass participation and structure natural vibration period for all 23 districts satisfy the requirement of both SNI-1726-2002 and SNI-1726-2012 standards.

3. Base shear force for all districts calculated according to SNI 1726:2012 higher than that of SNI-1726-2002.

6. References
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