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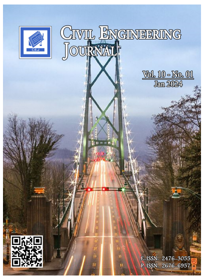

# Evolution and Implications of Changes in Seismic Load Codes for Earthquake Resistant Structures Design

Abdul Kadir [1], Ahmad Syarif Sukri [1*], Nini Hasriani Aswad [1], Masdiana [1], Nasrul [1]

[1] *Department of Civil Engineering, Halu Oleo University, Kendari 93232, Indonesia.*

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**Abstract**

Seismic load is a critical load that can trigger damage or collapse of structures, especially in earthquake-prone areas. The susceptibility of structures to seismic loads is influenced by factors related to soil characteristics and structural behavior. This paper comprehensively examines the development of Indonesian seismic code design parameters and their comparison with the current seismic code. The results of the analysis showed that the design spectral acceleration of short-period AD and long-period A1 SKBI 1987 and SNI 2002 increased with increasing PGA values, with a consistent pattern of SC < SD < SE. Unlike the previous two codes, design spectral acceleration AD and A1 SNI 2012 and SNI 2019 experience fluctuations in all types of soil. The ratio design spectral acceleration of AD and A1 SNI 2019 to KBI 1987 and SNI 2002 varies; there are up, fixed, and down for SC, SD, and SE soil conditions. The ratio of design spectral acceleration AD and A1 SNI 2019 to SNI 2012 designs also varies; this condition is due to changes in site coefficients. There were significant changes to the SKBI 1987 and SNI 2002 structural systems, especially the low and medium seismic levels. The increase in the seismic influence coefficient ratio of some cities varies for each type of soil and code. The increase in the 1970 PMI seismic coefficient was < 30% for all soil types, and the highest percentage increase occurred in SC soil types. The increase in seismic coefficient in SKBI 1987, SNI 2002, and SNI 2012 is more dominant in SE soil types.

*Keywords:* Code; Parameter and Design Load; Seismic; Base Shear; Comparative.

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## 1. Introduction

Indonesia is one of the most earthquake-prone countries in the world due to its geographical location on the Pacific Ring of Fire. Its existence on the borders of active tectonic makes Indonesia often the target of strong earthquakes. Earthquake shaking occurs almost every day with a magnitude of 5 or 6. Earthquake shaking also increases the frequency of events and their intensity. Based on USGS data from 1900–2022, Indonesia has experienced more than 150 earthquakes with a magnitude of more than 7 magnitudes. The earthquakes caused serious damage to infrastructure buildings, as well as threatening the safety of the community. Therefore, the review and development of relevant earthquake load standards is a must to mitigate earthquake risk in Indonesia.

The concept of earthquake-resistant building planning was pioneered by Boen & Wangsadinata (1971) [1]. In 1970, the government officially issued the first earthquake regulations under the name Indonesian Loading Regulations (PMI 1970) [2]. The earthquake load uses a seismic coefficient approach following the earthquake regulations of several countries at that time [3, 4]. The seismic coefficient approach is relatively simple, and there is not yet an adequate understanding of the seismic characteristics of the Indonesian region.

* Corresponding author: ahmad.syarif.sukri@uho.ac.id

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The 1976 Bali tectonic earthquake caused many casualties, damage or collapse of infrastructure, and loss of property [5]. This event prompted Indonesian seismologists to revisit the seismic characteristics of the earthquake region and the design philosophy of earthquake-resistant structures. Four years later, in 1981, the Government of Indonesia released the first modern earthquake regulation entitled Indonesian Earthquake Resistant Design Regulations for Buildings (1981) [6], which refers to New Zealand regulations. This regulation already uses response spectra to determine earthquake acceleration and first introduced the concept of planning that relies on the distribution of energy through the occurrence of plastic joints. Many new things are also addressed in this regulation, such as (1) the concept of structural ductility; (2) the concept of collapse by the formation of plastic joints at the ends of the beam (beam side sway mechanism), which requires a strong column weak beam (*strong column weak beam*) and (3) the concept of capacity design.

In 2002, Indonesia re-published the 2002 SNI earthquake standard [7]. This standard provides more detailed and specific guidance for the planning and design of earthquake-resistant buildings. However, a growing understanding of seismology and experience from other major earthquakes continues to motivate improvements in earthquake load standards. Over time, Indonesia has undergone updated earthquake load standards for buildings that reflect updated seismic data, more accurate mapping of earthquake zones, as well as a deeper understanding of regional earthquake characteristics. Newer earthquake load standards, such as SNI 2012 [8] and SNI 2019 [9], reflect a commitment to improving earthquake resilience and protecting infrastructure and communities from earthquake risk.

The development of seismic standards has an important meaning in anticipating structural collapse due to future earthquakes and ensuring that buildings that have been built with previous codes are safe against earthquake loads according to the latest earthquake codes. Evaluations of developments as well as comparative studies of earthquake parameters and forces against standards have been carried out by several researchers. A Comparative Study of Indonesian Spectra Response Parameters for Buildings According to 2002 and 2012 Seismic Codes [10]. General assessment on earthquake resistance spectral design load criteria for buildings and infrastructure associated with the recent development of Indonesian seismic hazard maps [11]. Comparison of base shear forces on tall, medium, and low buildings in cities representing zones 1, 2, 3, 4, 5, and zone 6 according to Standards PMI 1971, SKBI 1987, SNI 2002, SNI 2012, and SNI 2019 [12]. A Comparative Study of Indonesian Spectra Response Parameters for Buildings According to 2012 and 2019 Seismic Codes [13–18] Some of the studies above evaluate all codes but are general and not comprehensive. The focus of his studies concerns the provisions and design criteria as well as the comparison of base shear forces in cities representing each zone. Others evaluate partial codes, comparing the design behavior of earthquake acceleration response or comparing base shear forces in one city or another.

This paper presents the development of Indonesian earthquake loads and earthquake design parameters from International Codes or publications adopted and become references in the preparation of Indonesian loading standards. Also, exposure to the behavior of soil types with increasing PGA, changes in seismic level comprehensively related to seismic risk, design categories, and comparison of base shear forces can be considered in strengthening structures in several major cities in Indonesia. This research reflects developments in earthquake knowledge that can provide benefits in the context of earthquake disaster mitigation and community protection.

## 2. Development of Indonesia's Seismic Code

Indonesia has experienced five changes in the seismic code. The history of the development of seismic codes that have been implemented in Indonesia are:

### 2.1. Indonesian Loading Code PMI 1970

PMI 1970 is a regulation governing earthquake loading for buildings that was first officially published before the issuance of the 1970 PMI. Several normalization sheets on cargo were applied in Indonesia, namely translations of normalized sheets in Dutch such as NI 02006 "for fixed loads" and NI 02007 "for net loads". The earthquake hazard used is an earthquake with a 200-year return period. The earthquake map contained in PMI 1970 only divides the territory of Indonesia into three earthquake areas. The design of the building structure is carried out by the elastic method. Since the combination of earthquake loading with dead loads and reduced live loads is considered a temporary load. The allowable stress can be increased.

### 2.2. Earthquake Resistance Design Guideline for Houses and Buildings SKBI 1987

SKBI 1987 [19] is a change of name from the two previous codes, namely the Indonesian Earthquake Resistant Design Regulations for Buildings 1981 and the Indonesian Earthquake Resistant Design Provisions Code for Buildings 1983 [20]. In Code SKBI 1987, a seismic zone is defined as an area where the expected structural risk of structural and non-structural damage due to an earthquake is nearly uniform [21]. The spectral response used for seismic hazards is based on a return period of 200 years (10% probability of occurrence in a period of approximately 20 years). This regulation was later renamed again to SNI 03-1726-1989 [22] without any changes.

### 2.3. Earthquake Resistance Design Standards for Building Structures SNI-1726-2002

This regulation updates the existing earthquake map in the previous code (SKBI 1987). Indonesia is divided into six earthquake areas. SNI 2002 adopted the Uniform Building Codes (UBC) 1997 [23] with minor changes. In SNI 2002, spectral determination of the target acceleration was carried out using the 2002 earthquake-prone map of Indonesia. The site conditions in SNI 2002 are grouped into 3 categories, namely hard, medium, and soft sites. The spectral response used is the spectral response of an earthquake with a probability of occurring at 10% within 50 years, which is an earthquake with a repeat period of 500 years.

### 2.4. Earthquake Resistance Planning Procedures for Building and Non-Building Structures SNI-1726-2012

The SNI 2012 standard was motivated by several major earthquake events after SNI 2002 and the development of world design codes, especially in the United States. Major earthquakes that occurred in the range of 2002–2012 were Aceh in 2004 (Mw = 9.2), the Nias earthquake in 2005 (Mw = 8.7), the Yogyakarta earthquake in 2006 (Mw = 6.3), the Bengkulu earthquake in 2007 (Mw = 8.4), and the Padang earthquake in 2009 (Mw = 7.6) [24, 25]. Some fundamental changes in SNI 2012 are the renewal of earthquake hazard maps, the determination of earthquake spectrum response, and the earthquake return period. In addition, new analytical methods have been developed that can accommodate 3D earthquake source attenuation models. The seismic design criteria for the SNI 2012 follow ASCE 7–10 [26], developed by Luco et al. (2007) [27]. The design earthquake load is calculated as the risk-targeted maximum considered by the earthquake. According to FEMA P-749 [28], this earthquake is expected to cause a small probability (10% or smaller) that a structure with a common-use function will collapse from earthquake shaking. In SNI 2012 design, seismic events are defined as earthquakes with a probability of exceeding their magnitude during the life of the 50-year building structure by 2% or earthquakes with a 2475-year return period. The earthquake map was developed using ground movement predictive equations (GMPE) based on seismic zone characteristics and Next Generation Attenuation (NGA) by Power et al. (2008) [29], as well as a representative PSHA methodology.

### 2.5. Earthquake Resistance Planning Procedures for Building and Non-Building Structures SNI-1726-2019

SNI 2019 is an update to SNI 2012. This revision was made to adjust to the last few earthquake events and the American Code, which changes periodically. Some of the earthquake events between 2012 and 2019 were the Mentawai Earthquake in 2016 (Mw = 5.8), the Tasikmalaya Earthquake in 2017 (Mw = 5.1), and the Lombok Earthquake in 2018 (Mw = 7.0) [30, 31]. There is no fundamental difference between SNI 2012 and 2019. The seismic design criteria follow ASCE 7-16 [32], where the seismic design load is the maximum risk-targeted considered earthquake. Design seismics are defined as earthquakes with a probability of exceeding their magnitude during the life of the 50-year building structure of 2% or earthquakes with a 2475-year return period. The earthquake map was updated based on attenuation models developed by Boore-Atkinson NGA West-2 (2013) [33], Campbell-Bozorgnia NGA West-2 (2013) [34], and Chiou-Youngs NGA West-2 (2014) [35].

## 3. Parameter Seismic

### 3.1. Response Spectra Design

The response spectrum is a value that describes the maximum response of a system of single degrees of freedom at various natural frequencies (natural periods) damped due to ground shaking. Indonesia has experienced five changes in seismicity codes, where the last four codes (SKBI 1987, SNI 2002, SNI 2012, and SNI 2019) use spectral response in calculating earthquake acceleration. The SKBI 1987 spectral response used the results of joint research with New Zealand; the SNI 2002 spectral response adopted the UBC 1997 spectral response model; and the SNI 2012 and SNI 2019 spectral responses adopted the ASCE 7-10 and ASCE 7-16 spectral response forms. The shape of the SKBI 1987 spectrum response curve consists of three linear lines, as shown in Figure 1. The shape of the SNI 2002, 2012, and 2019 spectrum response curves in Figure 2 is identical, consisting of an ascending curve that is a flat curve and a descending curve in the form of a parabolic line. The response parameters of the spectrum are presented in Tables 1 and 2.

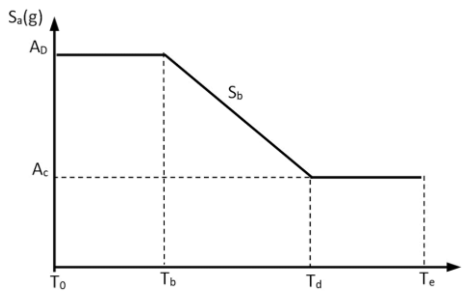


**Figure 1. Forms of Spectral Response SKBI 1987 code**

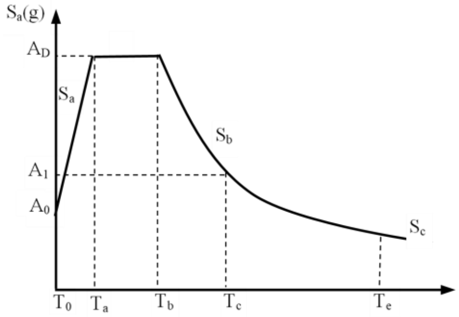


**Figure 2. Forms of Spectral Response SNI 2002 SNI 2012 and SNI 2019 code**

**Table 1. Indonesian seismic code spectral response parameters**

| Parameter | SKBI 1987 | SNI 2002 | SNI 2012 | SNI 2019 |
|---|---|---|---|---|
| $A_D$ | Table 2 | Table 2 | $2/3F_aS_s$; $F_a$ dari (Table 3) | $2/3F_aS_s$; $F_a$ dari (Table 3) |
| $A_1$ | - | $A_DT_b$ | $2/3F_vS_1$; $F_v$ dari (Table 4) | $2/3F_vS_1$; $F_v$ dari (Table 4) |
| $A_C$ | Table 2 | - | - | - |
| $A_0$ | $A_D$ | $0.4A_D$ | $0.4A_D$ | $0.4A_D$ |
| $S_a$ | - | $A_D(0.4+T/T_a)$ | $A_D(0.4+0.6T/T_a)$ | $A_D(0.4+0.6T/T_a)$ |
| $S_b$ | $A_C+(A_D-A_C)(T_d-T)/(T_d-T_b)$ | $A_DT_b/T$ | $A_1/T$ | $A_1/T$ |
| $S_c$ | - | - | $A_1T_e/T^2$ | $A_1T_e/T^2$ |
| $T_a$ | $T_0$ | 0.2 | $0.2A_D/A_1$ | $0.2A_D/A_1$ |
| $T_b$ | SC(0.5); SE(1) | SC(0.5); SD(0.6); SE(1) | $A_D/A_1$ | $A_D/A_1$ |
| $T_c$ | - | 1 | 1 | 1 |
| $T_d$ | 2 | - | - | - |
| $T_e$ | 3 | 3 | $T_L$ | $T_L$ |

**Table 2. Spectrum response parameters of SKBI 1987 and SNI 2002 Code**

| SKBI 1987 | | | | SNI 2002 | | | |
|---|---|---|---|---|---|---|---|
| Zone | $A_D/A_C$ | | | Zone | $A_D$ | | |
| | SC | SD | SE | | SC | SD | SE |
| 5 | 0.01/0.01 | - | 0.03/0.02 | 1 | 0.10 | 0.13 | 0.20 |
| 4 | 0.03/0.015 | - | 0.05/0.025 | 2 | 0.30 | 0.38 | 0.50 |
| 3 | 0.05/0.025 | - | 0.07/0.035 | 3 | 0.45 | 0.55 | 0.75 |
| 2 | 0.07/0.035 | - | 0.09/0.045 | 4 | 0.60 | 0.70 | 0.85 |
| 1 | 0.09/0.045 | - | 0.13/0.065 | 5 | 0.70 | 0.83 | 0.90 |
| | | | | 6 | 0.83 | 0.90 | 0.95 |

**Table 3. $F_a$ values for SNI 2012 and SNI 2019 codes**

| Type of soil | SNI-2012/2019 | | | | | |
|---|---|---|---|---|---|---|
| | $S_s \leq 0.25$ | $S_s = 0.5$ | $S_s = 0.75$ | $S_s = 1$ | $S_s = 1.25$ | $S_s \geq 1.5$ |
| SC | 1.2/1.3 | 1.2/1.3 | 1.1/1.2 | 1.0/1.2 | 1.0/1.2 | 1.0/1.2 |
| SD | 1.6/1.6 | 1.4/1.4 | 1.2/1.2 | 1.1/1.1 | 1.0/1.0 | 1.0/1.0 |
| SE | 2.5/2.4 | 1.7/1.7 | 1.2/1.3 | 0.9/1.1 | 0.9/0.9 | 0.9/0.8 |

**Table 4. $F_v$ values for SNI 2012 and SNI 2019 codes**

| Type of soil | SNI-2012/2019 | | | | | |
|---|---|---|---|---|---|---|
| | $S_s \leq 0.1$ | $S_s = 0.2$ | $S_s = 0.3$ | $S_s = 0.4$ | $S_s = 0.5$ | $S_s \geq 0.6$ |
| SC | 1.7/1.5 | 1.6/1.5 | 1.5/1.5 | 1.4/1.5 | 1.3/1.5 | 1.3/1.4 |
| SD | 2.4/2.4 | 2.0/2.2 | 1.8/2.0 | 1.6/1.9 | 1.5/1.8 | 1.5/1.7 |
| SE | 3.5/4.2 | 3.2/3.3 | 2.8/2.8 | 2.4/2.4 | 2.4/2.2 | 2.4/2.0 |

One of the parameters of the response spectrum is the type of soil. In the SKBI 1987, the soil is grouped into two types, namely hard soil and soft soil. The SNI 2002 divides soil types into six categories: hard rock (SA), rock (SB), hard soil (SC), stiff soil (SD), soft soil (SE), and special soil (SF). The SNI 2019 groups soil types into six classes as per the classification of soil types in UBC 1997 and ASCE 7-16, namely hard rock (SA), rock (SB), very dense soil and soft rock (SC), stiff soil (SD), soft clay soil (SE), and soil that requires site response analysis (SF). SA and SB soil types in UBC 1997, ASCE 7-10, and ASCE 7-16 are not found in Indonesia, so they are not used in SNI 2002, SNI 2012, and SNI 2019.

Two important parameters in the SNI 2012 and SNI 2019 design spectral responses are spectral parameters ($S_s$, $S_1$) and amplification parameters ($F_a$, $F_v$). $S_s$ is the spectral parameter of maximum acceleration of $MCE_R$ mapped at a short period of 0.2 s with 5% critical damped in bedrock, and $S_1$ is the maximum spectral parameter of $MCE_R$ mapped at a period of 1 s with 5% critical damped in bedrock. The values of $S_s$ and $S_1$ for SNI 2012 can be obtained from the 2012 SNI earthquake map or the Indonesian spectral design (*http://puskim.pu.go.id/Aplikasi/desain_spektra indonesia_2011/*). While the $S_s$ and $S_1$ values for SNI 2019 can be obtained from the 2019 SNI Earthquake map or the website (*http://rsapuskim2019.litbang.pu.go.id*).

The amplification parameters consist of parameters $F_a$ and $F_v$. The parameter $F_a$ is the site coefficient for the short period (at a period of 0.2 s). And $F_v$ is the site coefficient for a long period. The values of coefficient sites $F_a$ and $F_v$ listed in SNI 2012 adopt directly from the ASCE/SEI 07-10 code. In SNI 2019, the values of the $F_a$ and $F_v$ site coefficients were adopted from ASCE 7–16, developed by Stewart & Seyhan (2013) [36]. FEMA-749 [37] no longer uses site coefficients because they are less accurate, especially for soft soils.

### 3.2. Level of Seismic Risk or Seismic Design Category (SDC)

The seismic design category (SDC) is intended to define systems and detailing structures that meet the requirements according to the estimated earthquake intensity. SDC is concerned with earthquake hazard levels, soil type, and building use and function [38]. ACI-318-19 [39] describes the relationship between seismic design categories. Seismic risk and seismic zones, Codes or standards relevant to this paper are only mentioned in Table 5.

**Table 5. Correlation between seismic level of seismic risk, design categories, and seismic zone in model codes [39]**

| Code or standard | Level of seismic risk or design categories as defined in the Code | | |
|---|---|---|---|
| ASCE 7-98. 7-02. 7-05. 7-10. 7-16; NEHRP 1997. 2000. 2003. 2009. 2015 | SDC A. B | SC C | SDC D. E. F |
| ACI 318-05 and previous editions | Low seismic risk | Moderate seismic risk | High seismic risk |
| Uniform Building Code 1991. 1994. 1997 | Seismic zone 0. 1 | Seismic zone 2 | Seismic zone 3. 4 |

The SNI 2002 code classifies the category or level of earthquake risk based on seismic zones as UBC 1997. Zone 1-2 is a low-risk category; zones 3–4 are a medium-risk category; and zones 5–6 are a strong-risk category. SNI 2012 and SNI 2019 as ASCE-7-10 and ASCE-7-16 specifically determine SDC based on: (1) building risk categories and designing spectral response acceleration at 0.2-second periods or short periods ($A_D$) and (2) risk categories and designing spectral response acceleration at 1-second periods or long periods ($A_1$). Each designed building should be specified with the most decisive SDC from Tables 6 and 7. SDC "A" is the lightest SDC. While SDC "F" is the SDC with the most stringent requirements. Structures with risk categories I, II, or III built on sites with $S_1 \geq 0.75$(g) should be designated as SDC "E". Structures with risk category IV located in areas with $S_1 \geq 0.75$ (g) should be designated as SDC "F".

**Table 6. Level of seismic risk and SDC based on $A_D$ value**

| $A_D$ value | Seismic design categories (SDC) | |
|---|---|---|
| | Risk categories | |
| | I or II or III | IV |
| $A_D < 0.167$ | A | A |
| $0.167 \leq A_D < 0.33$ | B | C |
| $0.33 \leq A_D < 0.50$ | C | D |
| $A_D \geq 0.50$ | D | D |

**Table 7. Level of seismic risk and SDC based on $A_1$ value**

| $A_1$ value | Seismic design categories (SDC) | |
|---|---|---|
| | Risk categories | |
| | I or II or III | IV |
| $A_1 < 0,067$ | A | A |
| $0,067 \leq A_1 < 0,133$ | B | C |
| $0,133 \leq A_1 < 0,20$ | C | D |
| $A_1 \geq 0,20$ | D | D |

### 3.3. Seismic Reduction Factors

The seismic reduction factor represents a structure's ability to dissipate energy through inelastic forces [40, 41]. In the development of the Indonesian seismicity code, there are two terms used as seismic reduction factors: structure type factor (K) and response modification (R). The structure type factor (K) is used in SNI 1987, and response modification is used in SNI 2002, SNI 2012, and SNI 2019 codes. The structure type factor (K) is the reduction factor related to ductility ($R_\mu$). Studies of the relationship between reduction factors and response modification have been carried out by many researchers [42–46]. The relationship between ductility reduction factor (Rμ), response modification (R), and overstrength factor (Ωo) is shown in Figure 3 [47]. For the special moment-resisting frame, the response modification value ranges from 3–8.5, UBC 1997, ASCE 7–10, and ASCE 7–16.

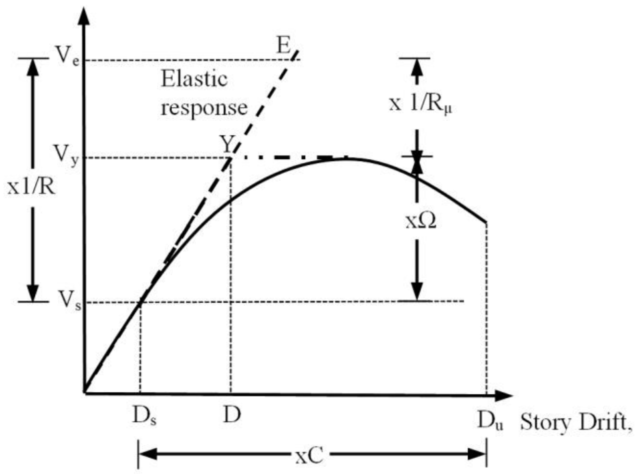


**Figure 3. Relationship of strength reduction factor and response modification [47]**

According to Elnashai & Sarmo (2008) [48], the value of the overstrength factor structure is in the range of 1.8–6.5 for long and short periods. According to Malhotra (2005) [49], the value of the overstrength factor (Ωo) = 1.5 is generally acceptable. If the value of Ωo is taken as 1.5, then the value of R in SNI 1987 = 1.5×4=6. The values of the seismic reduction factor for the Indonesian code are shown in Table 8.

**Table 8. Seismic reduction factor values for Indonesian code**

| System Structure | System Structure | Seismic Reduction | |
|---|---|---|---|
| | | K | R |
| SKBI 1987 | Elastic (E) | 4 | 6 |
| | Limited ductility (L) | 2 | 3 |
| | Full ductility (F) | 1 | 1.5 |
| SNI 2002 | Ordinary moment-resisting frame (O) | | 3.5 |
| | Intermediate moment-resisting frame (I) | | 5.5 |
| | Special moment-resisting frame (S) | | 8.5 |
| SNI 2012/SNI 2019 | Ordinary moment-resisting frame (O) | | 3 |
| | Intermediate moment-resisting frame (I) | | 5 |
| | Special moment-resisting frame (S) | | 8 |

### 3.4. Fundamental Period

Until now, there have been no methods or analysis techniques that can be used to calculate the fundamental periods of vibration in a building structure. The building structure is known as the building plan, view, section, and cross-sectional dimensions. Therefore, to determine the fundamental period of building structures, a simple empirical approach is used. These empirical estimates produce a relatively small value, thus yielding a conservative base earthquake coefficient (C). The fundamental period calculated by the formula has been validated with the natural vibration time recorded by several buildings during the 1971 San Fernando and Northridge earthquakes [50], and it turns out to show satisfactory natural vibration time values as estimates.

The fundamental period approach ($T_e$) used in SKBI 1987 and SNI 2002 adopts the NEHRP formula (1997) [51] and UBC 1997, which define T empirical ($T_e$) as the average fundamental natural period. T empirical ($T_e$) is calculated using the form $T = Ct.H^{3/4}$, where H is the height from the ground to the highest floor and Ct is the numerical coefficient. The vibrating time approach used in SNI 2012 and SNI 2019 adopts the ASCE 7-10 and ASCE 7-16 formulas developed by Chopra and Goel in 1997 (Table 9) [50].

**Table 9. Fundamental period (Tempirical) and limit conditions Indonesian seismic code**

| Code | T empirical ($T_e$) | Limit conditions |
|---|---|---|
| SKBI 1987 | $0.06H^{3/4}$ | $T_e \leq 1.2T_{Rayliegh}$; $T_{Rayliegh}=6.3\sqrt{\frac{\sum_{i=1}^{n} W_i d_i^2}{g\sum_{i=1}^{n} F_i d_i}}$ |
| SNI 2002 | $0.0731H^{3/4}$ | $0.8T_{Rayliegh} \leq (T_e$ or T from vibration 3D) $\leq 1.2\ T_{Rayliegh.}$ and $\leq \zeta$ n;<br>$\zeta$= Numerical coefficient depending on the earthquake zone. n = number of levels |
| SNI 2012 | $0.0466H^{0.9}$ | $T_e \leq$ Vibration 3D $\leq C_u T_e$; $C_u$ = Coefficient dependent on design spectral parameters 1s |
| SNI 2019 | $0.0466H^{0.9}$ | $T_e \leq$ Vibration 3D $\leq C_u T_e$; $C_u$ = Coefficient dependent on design spectral parameters 1s |

## 4. Design Base Shear and Seismic Influence Coefficients (SIC)

The design base share is the maximum lateral force on the building during seismic activity. Base share can increase or decrease depending on several factors, such as site characteristics, building importance, and seismic load resistance systems (types of structures). The factors that affect the design of the base shear are called Seismic Influence Coefficients (SIC), expressed by the V/W ratio [52]. The base shears in PMI 1970, SKBI 1987, SNI 2002, SNI 2012, and SNI 2019 are:

***PMI 1970***; The total horizontal base shear V that should be in design against seismic load, is determined by;

$$V = a_i.W \tag{1}$$

where $a_i$ is the acceleration of the earthquake formulated by;

$$a_i = k_{ih} k_d k_t \tag{2}$$

where, $k_{ih}$ is the earthquake coefficient at height I, $k_d$ is the area coefficient depending on the area where the structure is built, and $k_t$ is the soil coefficient depending on the type of soil (hard, medium, soft, very soft) and type of construction (steel, reinforced concrete, wood)

***SKBI 1987***; The total horizontal base shear *V* that should be in design against seismic load, is determined by;

$$V = C.I.K.W_t \tag{3}$$

where *C* = the base earthquake coefficient obtained from the spectral response for the fundamental natural period T, *I* = Importance factor, *K* = structure type factor which depends on the ductility of the type of structure used, and $W_t$ is the total weight of the building.

***SNI 2002***; The total horizontal base shear V that should be in design against seismic load, is determined by;

$$V=\frac{C.I}{R}W_t \tag{4}$$

where *C* = the base earthquake coefficient obtained from the spectral response for the fundamental natural period T, *I* = Importance factor, *R* = response modification factors, and $W_t$ is the total weight of the building.

***SNI 2012***; The total horizontal base shear *V* that should be in design against seismic load, is determined by;

$$V = C_s.W_t \tag{5}$$

where $C_s$ is seismic response coefficient calculated by;

$$C_s=\frac{A_D}{(R/I)} \tag{6}$$

The value of $C_s$ in Equation 7 above does not need to be greater than:

$$C_s=\frac{A_I}{T(R/I)} \tag{7}$$

The minimum $C_s$ value is determined by the equation:

$$C_s min=0.044A_D I\geq 0.01 \tag{8}$$

for areas with $S_1 \geq 0.6$g, the minimum $C_s$ value should be taken at;

$$C_s min=\frac{0.5S_1}{(R/I)} \tag{9}$$

**SNI 2019**; The total horizontal base shear $V$ is the same as SNI 2012.

## 5. Research Method

The research method used in this study is a literature review, which is specifically focused on the in-depth analysis and synthesis of literature relevant to our research topic. In this context, we will explore and evaluate various existing literature sources to develop a more comprehensive understanding of the problem we are researching. This literature review approach allows us to identify similarities and differences and compare the various earthquake load standards that apply. This research method is carried out in the following stages (Figure 4):

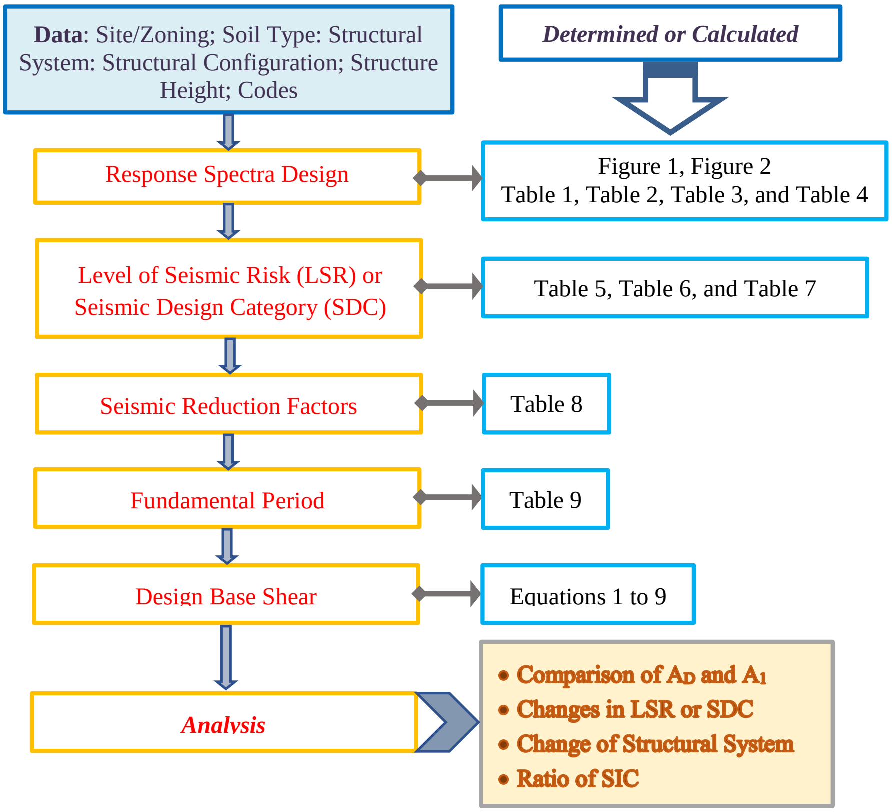


**Figure 4. Flowchart of the research methodology**

## 6. Results and Discussions

### 6.1. Design Spectral Response Acceleration

The design spectral accelerations $A_D$ and $A_1$ of SKBI 1987 and SNI 2002, as shown in Figures 5 and 6, increase linearly and parabolically with increasing peak ground acceleration (PGA). The design spectral acceleration for soil conditions appears to be consistent and uniform, with an SC < SD < SE pattern at each level of peak ground acceleration.

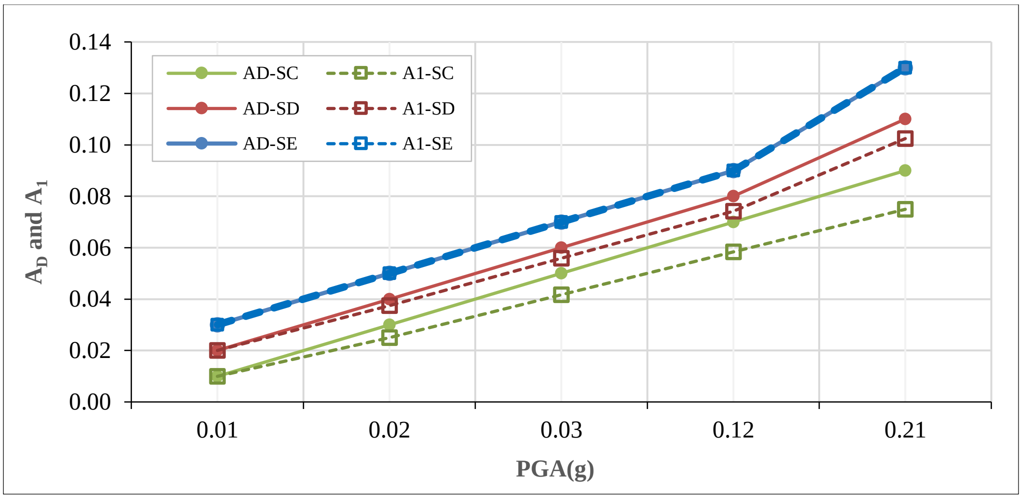


**Figure 5. Design acceleration spectrum $A_D$ and $A_1$ SKBI 1987**

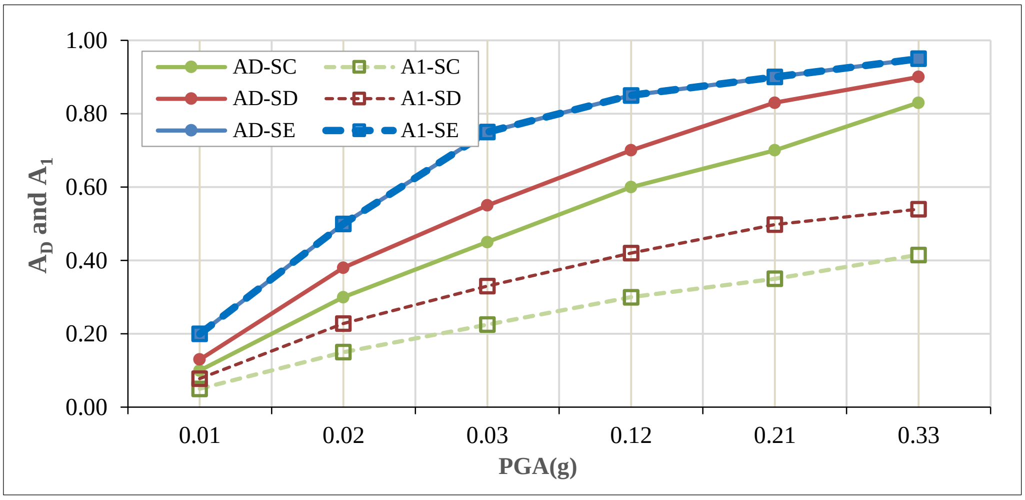


**Figure 6. Design acceleration spectrum $A_D$ and $A_1$ SNI 2002**

In SNI 2012, as shown in Figure 7, the values of $A_D$ and $A_1$ no longer follow the same pattern as in SKBI 1987 and SNI 2002. The values of $A_D$ and $A_1$ of the three soil types (SC, SD, and SE) tend to fluctuate with increasing PGA. The value of $A_D$ soil type changes or shifts with 4 variations, namely 1) SC < SD < SE, 2) SE < SC < SD, 3) SE < SD < SC, 4) SE < SD = SC, while the value of condition $A_1$ is consistent SC < SD < SE. The value of $A_D$ is in the PGA range of 0.0g to 0.35g, or the cities of Pontianak, Palangkaraya, Banjarmasin, Makassar, Medan, Surabaya, and Jakarta have fast conditions, namely SC < SD < SE. In cities such as Bengkulu, Manado, Semarang, and Denpasar, spectral design conditions are SE<SC<SD. In Mataram and Yogyakarta regions, the condition of design acceleration is SE < SD < SC. The design spectral acceleration of the cities of Padang, Aceh, Bandung, Jaya Pura, and Palu is SE < SD = SC.

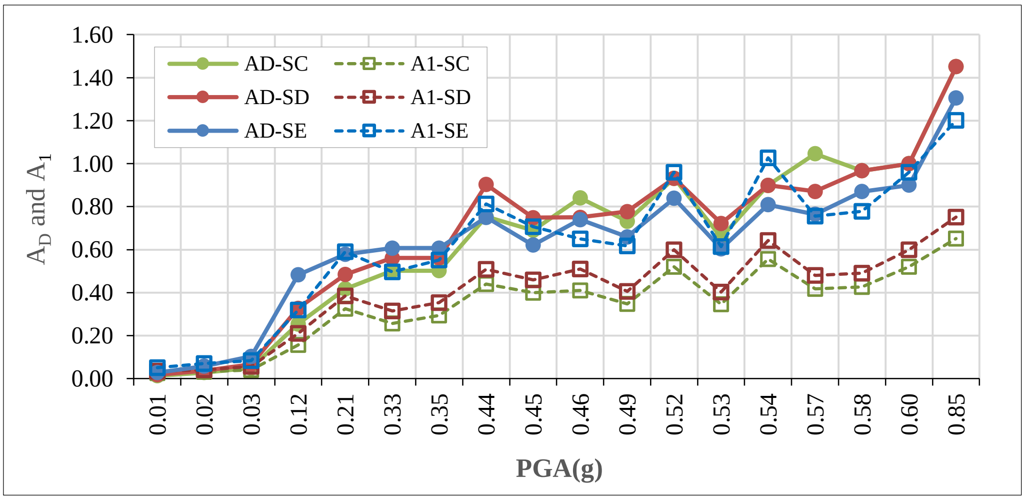


**Figure 7. Design acceleration spectrum $A_D$ and $A_1$ SNI 2012**

The design spectral acceleration of $A_D$ and $A_1$ SNI 2019 is shown in Figure 8. It appears that the three types of soil appear to increase more consistently than SNI 2012. Fluctuations in the spectral value of acceleration occur only at PGA 0.39, with an insignificant difference in value. The increase in $A_D$ values for SC types appears to be greater than for SD and SE soil types. The value of $A_D$ soil type also changes or shifts with 4 variations with different patterns with SNI 2012, namely 1) SC < SD < SE, 2) SD < SC < SE, 3) SE = SD < SC, 4) SE < SD < SC, while the value of condition $A_1$ is SC < SD < SE. $A_D$ values with SC < SD < SE conditions occur at low PGA 0.03g to medium PGA 0.32g, namely in the cities of Palangkaraya, Banjarmasin, Pontianak, Makassar, Medan, and Surabaya. $A_D$ values with SD < SC < SE conditions occurred in the 0.38g transition PGA in Semarang and Jakarta. $A_D$ values with SE = SD < SC conditions occur in Denpasar City with PGA 0.43g. $A_D$ values with SE < SD < SC conditions occurred at PGA 0.46-0.77g in Mataram City, Manado, Bandung, Yogyakarta, Aceh, Jayapura Bengkulu, Palu, and Padang.

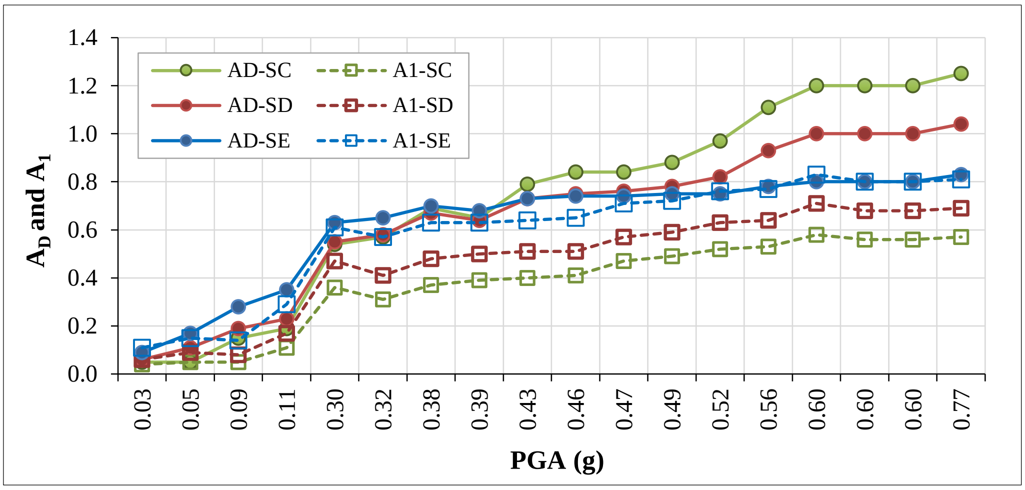


**Figure 8. Design acceleration spectrum $A_D$ and $A_1$ SNI 2019**

Fluctuations in the spectral value of acceleration occur only at PGA 0.39, with an insignificant difference in value. The increase in $A_D$ values for SC types appears to be greater than for SD and SE soil types. The value of $A_D$ soil type also changes or shifts with 4 variations with different patterns with SNI 2012, namely 1) SC < SD < SE, 2) SD < SC < SE, 3) SE = SD < SC, 4) SE < SD < SC, while the value of condition $A_1$ is SC < SD < SE. $A_D$ values with SC < SD < SE conditions occur at low PGA 0.03g to medium PGA 0.32g, namely in the cities of Palangkaraya, Banjarmasin, Pontianak, Makassar, Medan, and Surabaya. $A_D$ values with SD < SC < SE conditions occurred in the 0.38g transition PGA in Semarang and Jakarta. $A_D$ values with SE = SD < SC conditions occur in Denpasar City with PGA 0.43g. $A_D$ values with SE < SD < SC conditions occurred at PGA 0.46-0.77g in Mataram City, Manado, Bandung, Yogyakarta, Aceh, Jayapura Bengkulu, Palu, and Padang.

The design spectral acceleration of $A_D$ and $A_1$ that occurs in the 1987 SKBI Code and 2002 SNI Code, as shown in Figures 5 and 6, is caused by amplification in SD and SE soil types. Amplification of short and long periods has been adopted by several codes, such as UBC 1997, NZS 2004 [53], and Eurocode 8 (1998) [54]. Long-period amplification has also been described by several researchers [55, 56]. Pitilakis et al. (2012, 2013) [57, 58] and Kim et al. (2019) [59] recommend a spectrum form that is identical to SNI SKBI 1987 and SNI 2002.

In SNI 2012 and 2019, as shown in Figures 7 and 8, there is amplification and de-amplification in the $A_D$ acceleration spectral. Amplification of SNI 2012 tends not to show a consistent pattern, and international codes are rarely adopted. In SNI 2019, the design spectral acceleration of $A_D$ amplification occurs at low PGA and de-amplification occurs at high PGA. Amplification at low PGA is in line with SKBI 1987 and SNI 2002. The opposite phenomenon that occurs is de-amplification, which occurs in short periods [60, 61] and has not been accommodated by the International Code.

### 6.2. Comparison of Design Spectral Acceleration $A_D$ and $A_1$

Comparison of design spectral acceleration $A_D$ and $A_1$ SNI 2019 codes to the 3 previous codes for hard soil (SC), stiff soil (SD), and soft soil (SE) soil types is as follows:

#### 6.2.1. Comparison of Design Spectral Acceleration $A_D$ and $A_1$ for Hard Soil (SC) Type

SNI 019 provides consequences for the design spectral accelerations $A_D$ and $A_1$ in previous codes. Some have increased and decreased, and some have not changed. The $A_D$ and $A_1$ values for the 18 major cities for the SC site class are shown in Figure 9. It appears that the increase in spectral value of SKBI 1987 occurred in 16 cities. Average increase in design spectral acceleration ($A_{DSNI\ 2019}/A_{DSKBI\ 1987}$) = 2.321. The highest increase occurred in Semarang City, with a design acceleration ratio = 3.833. The decrease in design acceleration occurred in the cities of Palangkaraya and Banjarmasin with a ratio = 0.833.

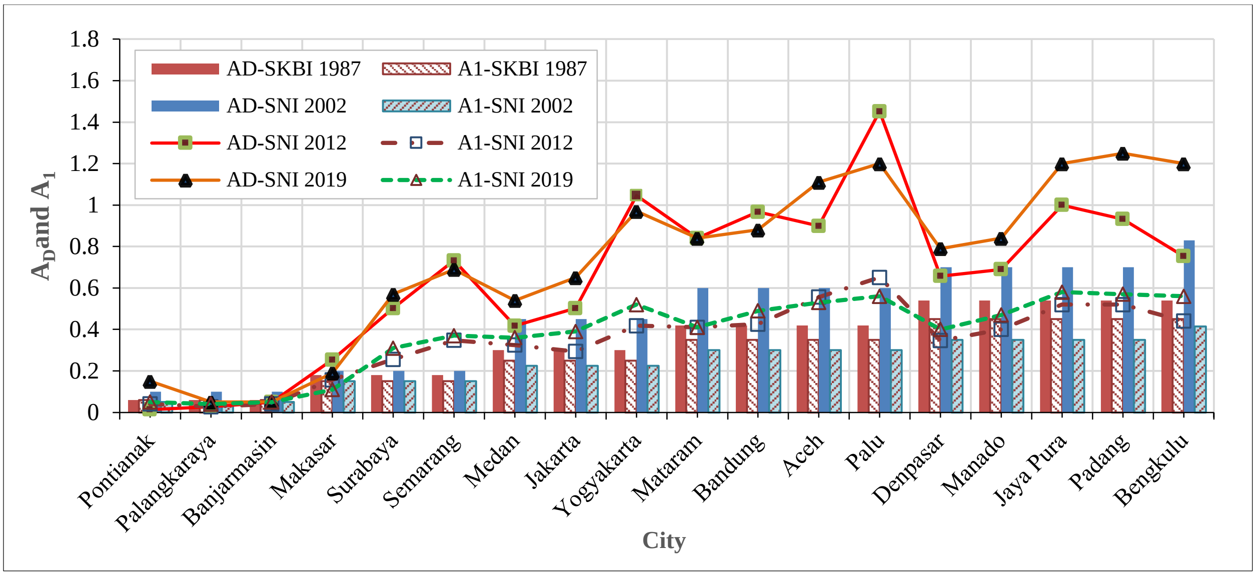


**Figure 9. The design acceleration spectrum $A_D$ and $A_1$ soil type SC SKBI 1987, SNI 2002, SNI 2012, and SNI 2019**

The increase in the value of $A_D$ SNI 2002 occurred in 15 cities, with an average increase in design spectral acceleration ($A_{DSNI\ 2019}/A_{DSNI\ 2002}$) = 1.773. The highest increase occurred in the city of Semarang, with an acceleration spectral design ratio = 3.450. The smallest increase occurred in the city of Denpasar, with an increased ratio = 1.129. The decrease in spectral value occurred in 3 cities, with an average decrease = 0.65. The largest decrease occurred in the cities of Palangkaraya and Banjarmasin, with a spectral ratio = 0.5. The smallest decrease in spectral design acceleration occurred in the city of Makassar, with a design spectral acceleration ratio = 0.9.

The $A_D$ values of SNI 2012 against SNI 2019 are up and down, and some have not changed. The increase in design spectral acceleration value occurred in 12 cities, with an average increase in acceleration ($A_{DSNI\ 2019}/A_{DSNI\ 2012}$) = 2.111. The highest increase occurred in the city of Pontianak, with a ratio of $A_D$ = 11.029. The smallest increase occurred in the city of Banjarmasin, with an increase ratio = 1.008. The decrease in $A_D$ values occurred in 5 cities, with an average decrease = 0.706. The largest decrease occurred in the city of Makassar, with a ratio of $A_D$ = 0.748. The smallest $A_D$ decrease occurred in the city of Yogyakarta, with a spectral ratio = 0.927. The city that did not experience any change in its spectral value was Mataram.

The increase in $A_1$ SKBI 1987 value occurred in 13 cities, with an average spectral increase = 1.549. The highest increase in $A_1$ occurred in Semarang City, with an acceleration ratio = 2.467. The smallest increase in $A_1$ occurred in the city of Manado, with a ratio of 1.044. The decrease in $A_1$ value occurred in 5 cities, with a decrease in average ratio = 0.791. The highest decrease in $A_1$ occurred in the city of Palangkaraya, with a ratio of 0.667. The smallest decrease in $A_1$ occurred in Denpasar city, with a ratio of 0.889.

The increase in $A_1$ SNI 2002 value occurred in 14 cities, with an average increase of ($A_{1SNI\ 2019}/A_{1SNI\ 2002}$) = 1.709. The highest $A_1$ increase occurred in Semarang City, with a ratio of 2.467. The smallest $A_1$ increase occurred in the city of Denpasar, with a ratio of 1.143. The decrease in $A_1$ value occurred in 2 cities, with a decrease in average ratio = 0.767. The highest decrease in $A_1$ occurred in the city of Makassar, with a ratio of 0.733. The smallest decrease in $A_1$ occurred in Palangkaraya city, with a ratio of 0.8. Two cities have not experienced changes in $A_1$ values, namely Pontianak and Banjarmasin.

The increase in $A_1$ SNI 2012 value occurred in 14 cities, with an average increase (ratio $A_{1\ SNI\ 2019}/A_{1SNI\ 2012}$) = 1.2. The highest increase in $A_1$ occurred in Palangkaraya city, with a ratio of 1.43. The smallest $A_1$ increase occurred in Semarang City, with a ratio of 1.06. The decrease in $A_1$ value occurred in 3 cities, with a decrease in average ratio = 0.84. The highest decrease in $A_1$ occurred in the city of Makassar, with a ratio of 0.7. The smallest decrease in $A_1$ occurred in Aceh City, with a ratio of 0.9. There is 1 city that has not experienced a change in $A_1$ value, namely the city of Mataram.

### 6.2.2. Comparison of Design Spectral Acceleration $A_D$ and $A_1$ for Stiff Soil (SD) Type

The $A_D$ and $A_1$ values for 18 major cities for the SD site class are shown in Figure 10. It appears that the increase in the value of $A_D$ SKBI 1987 occurred in 15 cities, with an average increase ($A_{DSNI\ 2019}/A_{DSKBI\ 1987}$) = 1.763. The highest increase occurred in Semarang City, with a ratio of 2.792. The smallest increase occurred in Denpasar city, with a ratio of 1.106. The decrease in $A_D$ values occurred in 3 cities, with an average decrease of 0.792. The biggest decrease occurred in Palangkaraya City, with a ratio of 0.5. The lowest decrease occurred in Makassar City, with a ratio of 0.958.

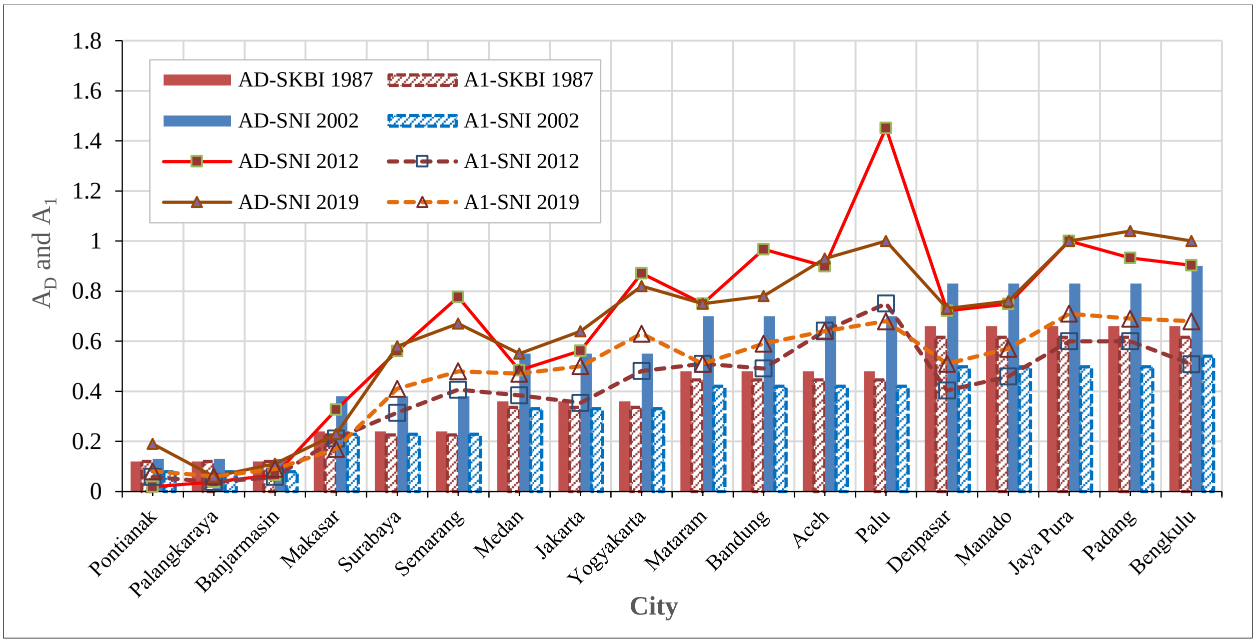


**Figure 10. The design spectral acceleration of $A_D$ and $A_1$ soil type SD SKBI 1987, SNI 2002, SNI 2012, and SNI 2019**

The increase in $A_D$ SNI 2002 value occurred in 12 cities, with an average increase of 1.326. The highest increase occurred in Semarang City, with a ratio of 1.763. The smallest increase occurred in Mataram City, with a ratio of 1.071. The decrease in $A_D$ values occurred in 5 cities, with an average decrease of 0.742. The biggest decrease occurred in Palangkaraya City, with a ratio of 0.462. The lowest decrease occurred in Manado City, with a ratio of 0.916. One city that does not experience changes in $A_D$ value is the city of Medan.

The increase in $A_D$ SNI 2012 value occurred in 11 cities, with an average increase of 1.945. The highest increase occurred in Pontianak City, with a ratio of 10.478. The smallest increase occurred in Denpasar City, with a ratio of 1.011. The decrease in $A_D$ values occurred in 5 cities, with an average decrease of 0.742. The biggest decrease occurred in Palu City, with a ratio of 0.689. The lowest decline occurred in Yogyakarta City, with a ratio of 0.941. The two cities that did not experience changes in $A_D$ values were Mataram and Jaya Pura.

The increase in the $A_1$ SKBI 1987 value occurred in 12 cities, with an average increase of ($A_{1SNI\ 2019}/A_{1SKBI\ 1987}$) = 1.463. The highest increase occurred in Semarang City, with a ratio of 2.133. The smallest increase occurred in Bengkulu City, with a ratio of 1.106. The decrease in $A_1$ value occurred in 3 cities, with an average decrease of 0.738. The largest decrease occurred in Palangkaraya City, with a ratio of 0.5. The lowest decline occurred in Manado City, with a ratio of 0.927.

The increase in $A_1$ SNI 2002 value occurred in 16 cities, with an average increase of 1.433. The highest increase occurred in Semarang City, with a ratio of 2.105. The smallest increase occurred in Denpasar City, with a ratio of 1.024. The decrease in $A_1$ value occurred in 2 cities, with an average decrease of 0.757. The largest decrease occurred in Palangkaraya City, with a ratio of 0.769. The lowest decline occurred in Makassar City, with a ratio of 0.746.

The increase in $A_1$ SNI 2012 value occurred in 14 cities, with an average increase of 1.31. The highest increase occurred in Palangkaraya City, with a ratio of 1.61. The smallest increase occurred in Padang City, with a ratio of 1.15. The decrease in $A_1$ value occurred in 2 cities, with an average decrease of 0.96. The largest decrease occurred in Makassar City, with a ratio of 0.81. The lowest decline occurred in Palu City, with a ratio of 0.91. Two cities that did not experience changes in $A_1$ grades were the cities of Mataram and Aceh.

### 6.2.3. Comparison of Design Spectral Acceleration $A_D$ and $A_1$ for Soft Soil (SE) Type

The $A_D$ and $A_1$ values for 18 major cities for the SE site class are shown in Figure 11. It appears that the increase in the value of $A_D$ SKBI 1987 occurred in 14 cities, with an average increase ($A_{DSNI\ 2019}/A_{DSKBI\ 1987}$) = 1.495. The highest increase occurred in Semarang City, with a ratio = 2.333. The lowest increase occurred in Jaya Pura and Bengkulu cities, with a ratio of 1.026. The decrease in $A_D$ values occurred in 4 cities, with an average decrease of 0.832. The biggest decrease occurred in Palangkaraya City, with a ratio of 0.5. The lowest decline occurred in Jaya Pura City, with a ratio of 0.949.

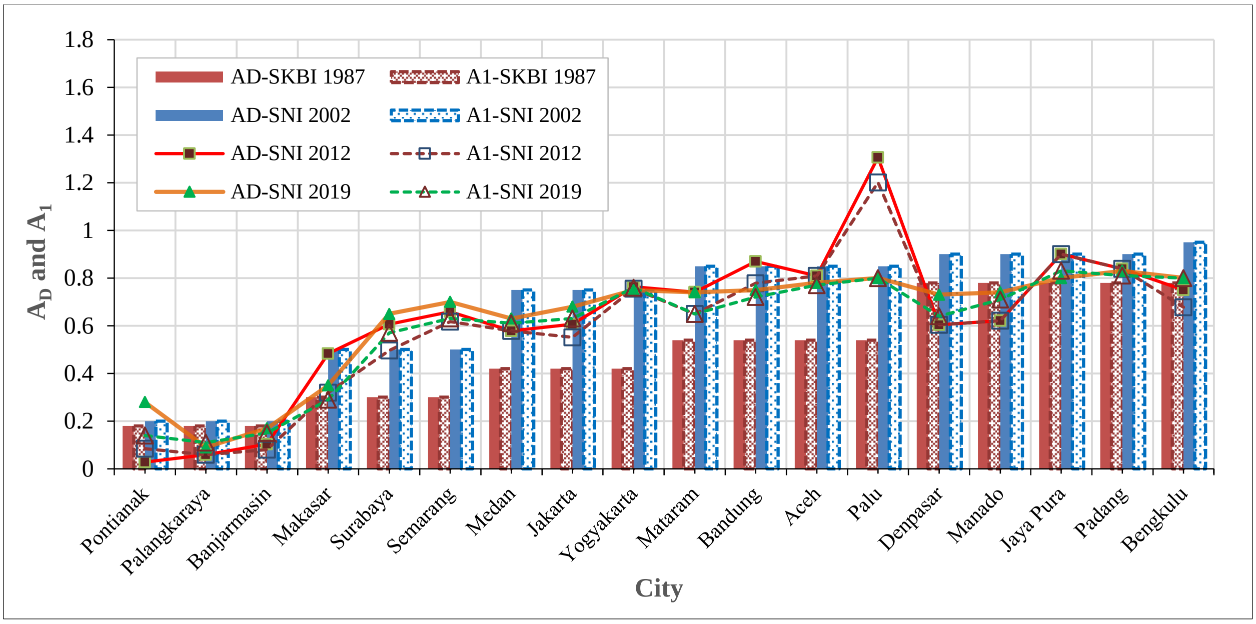


**Figure 11. Design spectral acceleration $A_D$ and $A_1$ type of soil SE SKBI 1987, SNI 2002, SNI 2012, and SNI 2019**

Different levels of earthquake risk with different return periods have implications for earthquake acceleration in the design of seismic loads. The ratio of the peak acceleration of seismic ground motion with a return period of 2500 years to 475 years ranges from 1.5–3, uake [62–65]. Figures 9 to 11 show that rather close amplification due to increased re-period occurs only in SC soil types; in SD and SE soil types, de-amplification occurs.

### 6.3. Level of Seismic Risk (LSR) or Seismic Design Categories (SDC)

With the implementation of SNI 2019, the level of seismic or design categories affects several cities; some have increased and some have not changed. Changes in LSR or SDC occurred at the low level (zones 5 and 1-2) and middle level (zones 4-3 and 3-4) (SKBI 1987 and SNI 2002). Changes in LSR and SDC occur in all types of soil or certain types only. Pontianak and Banjarmasin cities rose from low level to medium level, or SDC "C" and only occurred in SE soil types. While the city of Palangkaraya remains at the same level but changes the SDC level to "B". Makassar City, which is at a low level (zones 4 and 2), SKBI 1987 and SNI 2002 did not change the level for the SC type; they changed to the middle level, or SDC "C" for the SD type, and increased two levels to the high level, SDC "D" for the SE type. The cities of Surabaya and Semarang, which are at low levels (zones 4 and 2), SKBI 1987, and SNI 2002 increased 2 levels to SDC "D" for all SC, SD, and SE soil groups. Medan, Jakarta, Yogyakarta, Mataram, Bandung, Aceh, and Palu cities, which are at the middle level (zones 3-2 and 3-4), SKBI 1987 and SNI 2002 rose to the high level, or SDC "D" for all types of soil. The cities of Denpasar, Manado, Jaya Pura, Padang, and Bengkulu did not experience changes in the level of seismic risk, or SDC "D" for all soil types.

Changes in SDC SNI 2012 to SNI 2019 only occurred in 3 regions, namely Pontianak, Banjarmasin, and Makassar cities. Pontianak City with SDC "A" type SE rose to SDC "C". Banjarmasin City with SDC "A" and "B" rose to SDC and SDC "B" and "C" for SD and SE soil types. Makassar City with SDC "C" and "D" for SC and SD soil types dropped to SDC "B" and SDC "C".

### 6.4. Structure System

The structural system in SNI 2019 tends to have stricter criteria and requirements than the previous SNI, SKBI 1987, and SNI 2002. Changes to the system structure are shown in Table 10. It appears that many cities are experiencing changes in their structural systems, especially in cities with low and moderate seismic risk levels. Changes occur in all types of soil and in certain types of soil only. Palangkaraya City is the only city that has not experienced changes in its structural system. Pontianak and Banjarmasin cities experienced structural system changes where the elastic (E) system of SKBI 1987 and Ordinary Moment Resistance Frame (O) SNI 2002 were not allowed to be applied, especially to SE soil types. Makassar City experienced a structural system change where the (E) or (O) structure system was not allowed on SD soil types and only the S structure system was allowed on SE soil types. Cities that, by their standards, were previously at low seismic risk, such as Surabaya and Semarang, and cities with moderate seismic risk levels, such as Medan, Jakarta, Yogyakarta, Mataram, Bandung, Aceh, and Palu, can only use the (S) structure system. The cities of Denpasar, Manado, Jaya Pura, Padang, and Bengkulu did not experience structural system changes for all types of soil.

**Table 10. Change of Structural System**

| City | SKBI 1987 | SNI 2002 | SNI 2012 | | | SNI 2019 | | |
|---|---|---|---|---|---|---|---|---|
| | SC= SD=SE | SC= SD=SE | SC | SD | SE | SC | SD | SE |
| Pontianak | F/L/E | S/I/O | S/I/O | S/I/O | S/I/O | S/I/O | S/I/O | S/I |
| Palangkaraya | F/L/E | S/I/O | S/I/O | S/I/O | S/I/O | S/I/O | S/I/O | S/I/O |
| Banjarmasin | F/L/E | S/I/O | S/I/O | S/I/O | S/I/O | S/I/O | S/I/O | S/I |
| Makassar | F/L/E | S/I/O | S/I | S | S | S/I/O | S/I | S |
| Surabaya, Semarang | F/L/E | S/I/O | S | S | S | S | S | S |
| Medan, Jakarta, Yogyakarta | F/L | S/I | S | S | S | S | S | S |
| Mataram, Bandung, Aceh, Palu | F/L | S/I | S | S | S | S | S | S |
| Denpasar, Manado, Jaya Pura, Padang | F | S | S | S | S | S | S | S |
| Bengkulu | F | S | S | S | S | S | S | S |

In SNI 2012, structural system changes only occurred in 3 cities, namely Pontianak, Banjarmasin, and Makassar. The structural system in Pontianak and Banjarmasin cities changed, especially in SE soil types where the ordinary moment resistance frame (O) is no longer allowed. Makassar City underwent changes in the opposite structural system, where the structural system (O) was allowed on the SC soil type and the (I) structure system was allowed on the SD soil type.

## 6.5. Design Base Share (DBS) and Seismic Influence Coefficient (SIC)

Design base shear (V) and SIC (V/W) in a reinforced concrete building were analyzed based on PMI 1970, SKBI 1987, SNI 2002, SNI 2012, and SNI 2019. Considered a 5-story building, width X direction: 15 m, beam span: 5m. Width Y direction: 30 m, beam span: 6 m. Building height: 20 m with a 4m level height; beam dimension: 250 × 500 mm; column dimension: 500 × 500 mm; floor plate thickness: 130 mm; roof plate thickness: 120 mm. Only the types of full ductility (F) and special moment resistance frame (S) structures are analyzed in this paper.

### 6.5.1. Seismic Influence Coefficient (SIC)

The results of the SIC analysis of soil types SC Code PMI 1970, SKBI 1987, SNI 2002, SNI 2012, and SNI 2019 are shown in Figures 12 to 14. It appears that the SIC of PMI 1970 ranges from 0.025–0.075, SKBI 1987 ranges from 0.01–0.088, SNI 2002 ranges from 0.009–0.071, SNI 2012 ranges from 0.002–0.121, SNI 2019 ranges from 0.011–0.104.

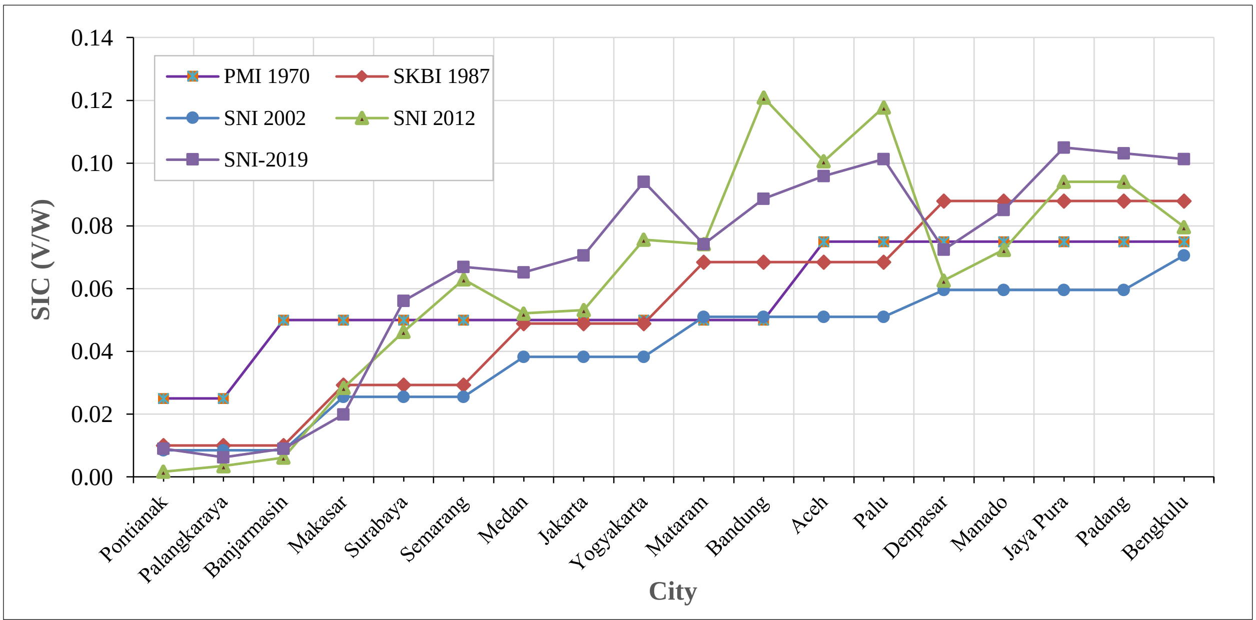


**Figure 12. Seismic Influence Coefficients (SIC) PMI 1970, SKBI 1987, SNI 2002, SNI 2012, and SNI 2019 soil types SC**

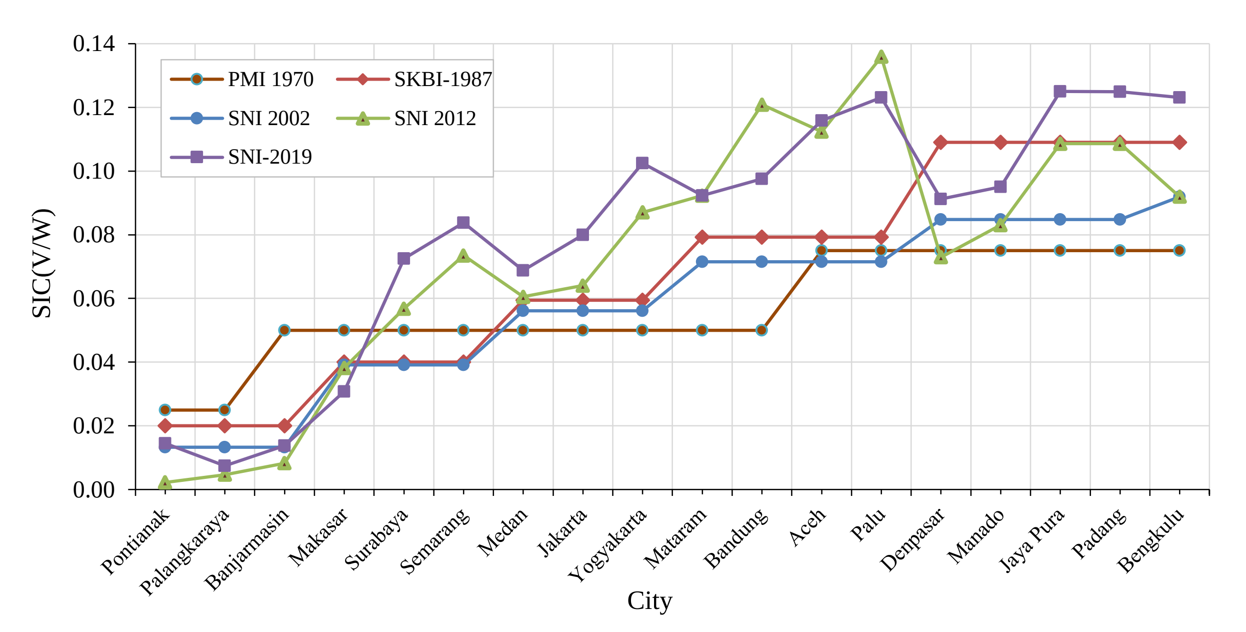


**Figure 13. The SIC PMI 1970, SKBI 1987, SNI 2002, SNI 2012, and SNI 2019 soil types SD**

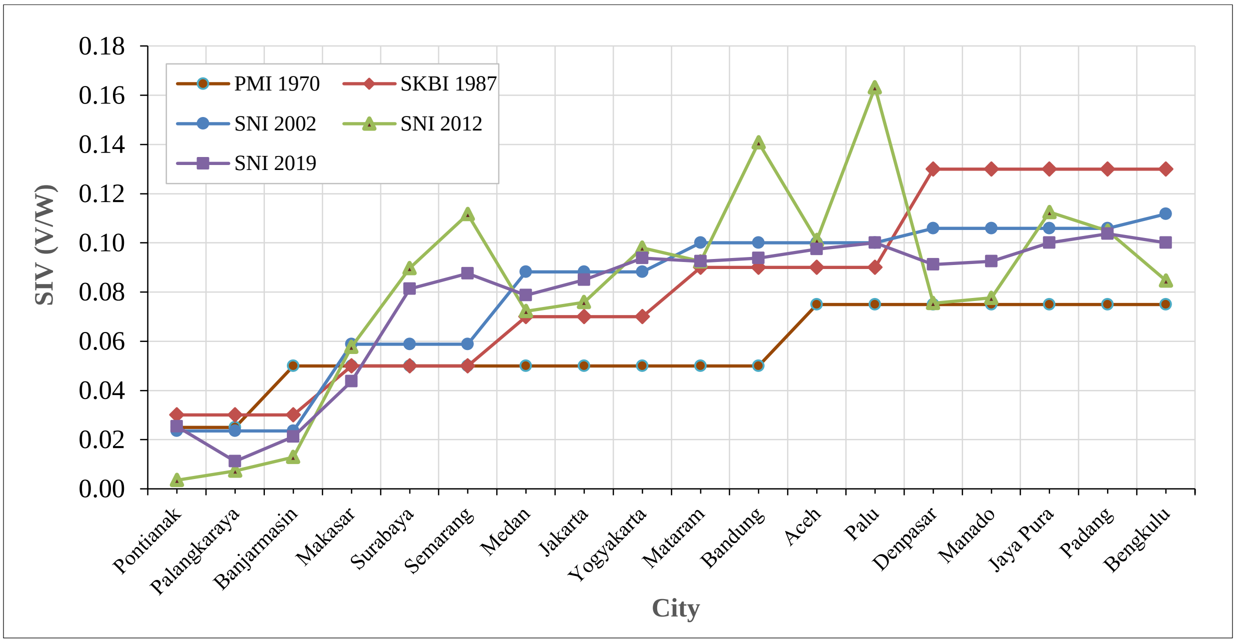


**Figure 14. The SIC PMI 1970, SKBI 1987, SNI 2002, SNI 2012, and SNI 2019 soil types SE**

The SIC of the SD soil type is shown in Figure 13. It appears that the SIC of PMI 1970 ranges from 0.025 – 0.075, SKBI 1987 ranges from 0.02 – 0.109, SNI 2002 ranges from 0.013 – 0.092, SNI 2012 ranges from 0.002 – 0.136, SNI 2019 ranges from 0.014 – 0.125.

The SIC of the SE soil type is shown in Figure 14. It appears that the SIC of PMI 1970 ranges from 0.025 – 0.075, SKBI 1987 ranges from 0.03 – 0.13, SNI 2002 ranges from 0.024 – 0.112, SNI 2012 ranges from 0.004 – 0.163, SNI 2019 ranges from 0.024 – 0.112.

### 6.5.2. Ratio Analysis of Seismic Influence Coefficient (SIC)

The results of the ratio of SIC analysis for the SC soil type are shown in Figure 15. It appears that based on the ratio of $SIC_{PMI\ 1970}/SIC_{SNI\ 2019}$, 4 cities experienced an increase or had a base shear force greater than SNI 2019, and 14 cities decreased. Average increases and decreases in base shear of 3.167 and 0.728. The highest increase of 5.526 and the lowest of 1.036 occurred in Banjarmasin and Denpasar. The highest decrease of 0.531 and the lowest of 0.891 occurred in the cities of Yogyakarta and Surabaya.

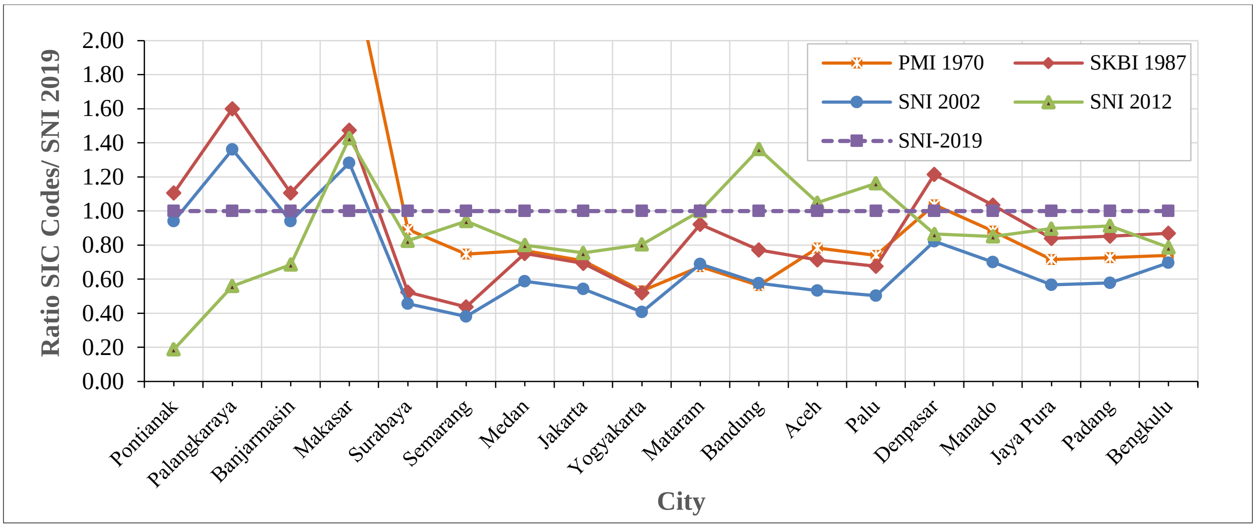


**Figure 15. The ratio of the SIC PMI 1970, SKBI 1987, SNI 2002, SNI 2012, and SNI 2019 soil types SC**

Based on the $SIC_{SKBI1987}/SIC_{SNI\ 2019}$ ratio for SC soil types, it shows that 6 cities experienced an increase and 12 cities experienced a decrease in base shear. The average increase and decrease in base shear were 1.256 and 0.714. The highest increase of 1.6 and the lowest of 1,034 occurred in Palangkaraya and Manado. The highest decrease of 0.438 and the lowest of 0.922 occurred in the cities of Semarang and Mataram.

Based on the $SIC_{SNI\ 2002}/SIC_{SNI\ 2019}$ ratio for SC soil types, it shows that 2 cities experienced an increase and 16 cities experienced a decrease. Average increases and decreases in base shear of 1.322 and 0.62. The highest increase of 1,361 and the lowest of 1,282 occurred in Palangkaraya and Makassar City. The highest decrease of 0.381 occurred in Semarang, and the lowest decrease of 0.94 occurred in Pontianak and Banjarmasin.

Based on the $SIC_{SNI\ 2012}/SIC_{SNI\ 2019}$ ratio for SC soil types, it shows that 4 cities experienced an increase, 13 cities decreased, and 1 city did not change. The average increase and decrease in base shear were 1.256 and 0.759. The highest increase of 1,427 and the lowest of 1,049 occurred in Makassar and Aceh. The highest decrease of 0.188 and the lowest of 0.941 occurred in the cities of Semarang, Pontianak, and Surabaya.

The results of the SIC analysis for SD soil types are shown in Figure 16. It appears that based on the $SIC_{PMI\ 1970}/SIC_{SNI\ 2019}$ ratio, 4 cities experienced an increase and 14 cities experienced a decrease. The average increase and decrease in SIC ratios was 2.58 and 0.633. The highest increase of 3.636 and the lowest of 1.625 occurred in Banjarmasin and Makassar cities. The highest decrease of 0.488 and the lowest of 0.789 occurred in the cities of Yogyakarta and Manado.

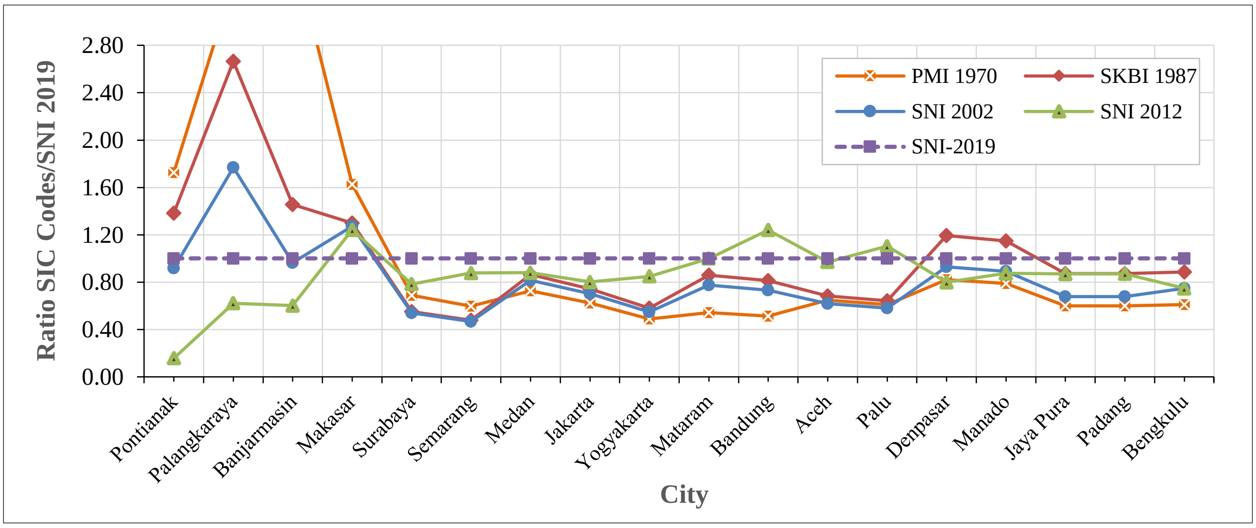


**Figure 16. The ratio of the SIC PMI 1970, SKBI 1987, SNI 2002, SNI 2012, and SNI 2019 soil types SD**

Based on the $SIC_{SKBI\ 1987}/SIC_{SNI\ 2019}$ ratio for SD soil types, it shows that 6 cities have increased and 12 cities have decreased. Average increases and decreases in SIC ratios were 1.524 and 0.737. The highest increase of 2.667 and the lowest of 1.30 occurred in Palangkaraya and Makassar City. The highest decrease of 0.478 and the lowest of 0.886 occurred in the cities of Semarang and Bengkulu.

Based on the $SIC_{SNI\ 2002}/SIC_{SNI\ 2019}$ ratio for SD soil types, it shows that 2 cities have increased and 16 cities have decreased. Average increases and decreases in SIC ratios were 1.521 and 0.724. The highest increase of 1.77 and the lowest of 1.272 occurred in Palangkaraya and Makassar City. The highest decrease of 0.467 and the lowest of 0.965 occurred in the cities of Semarang, Pontianak, and Banjarmasin.

Based on the $SIC_{SNI\ 2012}/SIC_{SNI\ 2019}$ ratio for SD soil types, it shows that 3 cities have increased, 14 cities have decreased, and 1 city has not changed. Average increases and decreases of 1.146 and 0.764. The highest increase of 1.241 and the lowest of 1.104 occurred in Makassar and Palu. The highest decrease of 0.157 and the lowest of 0.97 occurred in the cities of Pontianak and Aceh.

The results of the SIC analysis for SE soil types are shown in Figure 17. It appears that based on the $SIC_{PMI\ 1970}/SIC_{SNI\ 2019}$ ratio, 3 cities experienced an increase and 15 cities experienced a decrease. Average increases and decreases of 1.906 and 0.692. The highest increase of 2.353 and the lowest of 1.143 occurred in Banjarmasin and Makassar cities. The largest decrease of 0.533 occurred in Yogyakarta and Bandung, and the lowest decrease of 0.987 occurred in Pontianak.

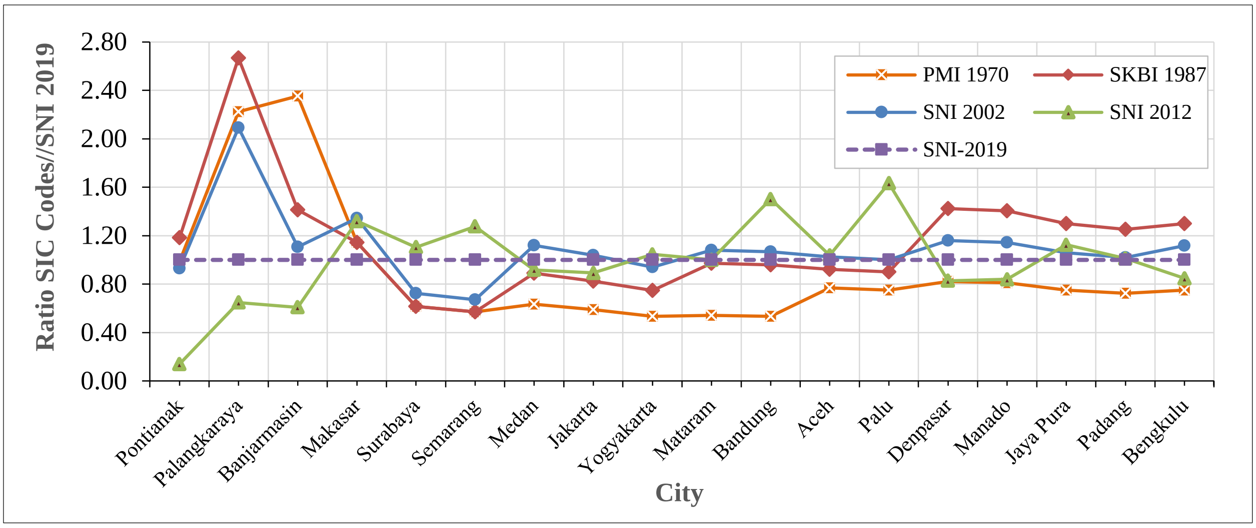


**Figure 17. The ratio of the SIC PMI 1970, SKBI 1987, SNI 2002, SNI 2012, and SNI 2019 soil types SE**

Based on the $SIC_{SKBI\ 1987}/SIC_{SNI\ 2019}$ ratio for SE soil types, it shows that 9 cities have increased and 9 cities have decreased. Average increases and decreases of 1.454 and 0.822. The highest increase of 2.667 and the lowest of 1.143 occurred in Palangkaraya and Makassar City. The largest decrease of 0.571 and the smallest decrease of 0.973 occurred in the cities of Semarang and Mataram.

Based on the $SIC_{SNI\ 2002}/SIC_{SNI\ 2019}$ ratio for SE soil types, it shows that 13 cities have increased, 3 cities have decreased, and 1 city has not changed. Average increases and decreases of 1.17 and 0.817. The highest increase of 2.092 and the lowest of 1,021 occurred in Palangkaraya and Padang City. The largest decrease of 0.672 and the smallest decrease of 0.941 occurred in Semarang and Yogyakarta.

Based on the $SIC_{SNI\ 2012}/SIC_{SNI\ 2019}$ ratio for SE soil types, it shows that 9 cities have increased, 8 cities have decreased, and 1 city has not changed. Average increases and decreases of 1.205 and 0.715. The highest increase of 1.502 and the lowest of 1,011 occurred in Bandung and Padang. The largest decrease of 0.14 and the smallest 0.917 occurred in the cities of Pontianak and Medan.

## 7. Conclusion

The design spectral acceleration $A_D$ and $A_1$ of SKBI 1987 and SNI 2002 for 18 major Indonesian cities increased with increasing PGA values, with a consistent pattern of SC < SD < SE. Unlike the previous two codes. The design spectral accelerations $A_D$ and $A_1$ of SNI 2012 and SNI 2019 experienced fluctuations with inconsistent patterns on all types of soil. SNI 2019 has an impact on changes to the design spectral acceleration of $A_D$ and $A_1$, the application of the structure system, and the design base shear to the previous 3 codes. Design spectral acceleration $A_D$ and $A_1$ SKBI 1987, SNI 2002, and SNI 2012 on soil conditions SC, SD, and SE vary; there are up, fixed, and down with a pattern that is not uniform. Changes to the structural systems of SKBI 1987 and SNI 2002 occurred in cities, especially those with low and medium seismic levels. All cities that, according to SKBI 1987 and SNI 2002, are at a moderate level of seismic risk are becoming at a high level of seismic risk, or SDC "D". The system structure, according to SNI 2012, is relatively fixed; changes in the system structure occur at low seismic levels. The increase in the ratio of seismic influence coefficient or design base shear in some cities varies for each type of soil and code. The increase in base shear design in PMI 1970 occurred more in SC soil types than in SD and SE. The increase in SIC in SKBI 1987, SNI 2002, and SNI 2012 is more dominant in SE soil types.

## 8. Declarations

### 8.1. Author Contributions

Conceptualization, A.K.; methodology. A.K., A.S.S., N.H.A., M., and N.; software, A.K. and A.S.S.; validation. A.K., A.S.S., N.H.A., M., and N.; formal analysis. A.K.; investigation. A.K., A.S.S., N.H.A., and N.; resources. A.K. and N.H.A.; data curation. A.K.; writing—original draft preparation, A.K.; writing—review and editing, A.K., A.S.S., N.H.A., M., and N.; visualization, A.S.S.; supervision. A.S.S. All authors have read and agreed to the published version of the manuscript.

### 8.2. Data Availability Statement

The data presented in this study are available in the article.

### 8.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

### 8.4. Conflicts of Interest

The authors declare no conflict of interest.

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