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SEISMIC BASE SHEAR ANALYSIS IN ACEH PROVINCE: A COMPARISON BETWEEN SNI 03-1726-2012 AND SNI 03-1726-2019

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Abstract

Indonesia, being one of the earthquake-prone countries, faces the constant threat of seismic events with varying intensities. With four surrounding tectonic plates, earthquakes impact the region frequently, resulting in significant structural damage and casualties. To mitigate these damages, the Indonesian government revised the seismic resistant design code in 2019, replacing the previous version issued in 2012. This update was necessitated by the seismic events over the years, which exposed the need for incorporating the latest seismic design technologies and global standards.

The Sumatera region, particularly Aceh, is significantly influenced by two major earthquake sources: the megathrust zone beneath the west Sumatera ocean and the Sumatera Great Fault. The devastating Aceh earthquake and tsunami in 2004 had a profound impact on seismic activity in the region, generating tectonic forces that trigger earthquakes in various epicenters. Subsequent earthquakes, such as those in Singkarak, West Sumatera, Padang, and Kerinci, further emphasized the need for comprehensive seismic analysis and updated design codes.

Considering the differences between the seismic design codes, SNI 03-1726-2012 and SNI 03-1726-2019, specifically concerning spectrum response data, a comparative study is essential to analyze the seismic base shear and its impact on building structures in Aceh. This study aims to assess the required cross-sectional area of columns, beams, and ring beams in low-rise building structures across 23 regencies/cities in Aceh Province using the aforementioned seismic design codes.

In this research, seismic data from various earthquake events, including the 2016 Pidie Jaya earthquake, the 2013 Takengon Lot Tawar lake area earthquake, and historical events dating back to 1967 and 1942, will be analyzed. The seismic base shear and the impact on building elements' dimensions will be evaluated based on both SNI 03-1726-2012 and SNI 03-1726-2019, providing valuable insights for seismic-resistant construction in Aceh.

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1. Introduction

Indonesia is one of the earthquake-prone countries in the world where mild to high intensity earthquakes might occur in its region [1]. The country is surrounded by four tectonic plates, namely the Eurasian Plate, the Indo-Australian Plate, the Philippine Plate, and the Pacific Plate which is frequently struck by more than 10% earthquakes each year[2], [3]. Earthquake shocks can cause great damage to building structures resulting in many casualties [4]. Structural damages are related with the level of seismic intensity, low material quality and so on [5], [6]. To reduce damages in building structures, the Indonesian government has updated the seismic resistant design code for building and non-building structures in SNI 1726-2019 [7]

In 2012, the Indonesian government has issued a seismic design code for building and non-building structures in SNI 03-1726-2012 [8]. However, major seismic events over the decades in Indonesia showed that several issues must be updated and developed to reflect the current development technology used in seismic practice and to consider the latest changes in seismic design codes worldwide. Thus, the government of Indonesia has issued SNI 03-1726-2019 in 2019 [9] to replace the SNI 03-1726-2012 seismic design code.

The Sumatera region, including Aceh, is typically driven by two major earthquake sources: the megathrust zone beneath the west Sumatera ocean and the Sumatera Great Fault [10]. Seismic activity in the Sumatera region increased drastically after the great Aceh earthquake and tsunami in 2004 [11]. This is due to the fact that big seismic occurrences continually produce tectonic forces in the surrounding region, causing earthquakes at other epicenters in the region. Numerous earthquakes have occurred since the 2004 Aceh earthquake and tsunami, including the Singkarak, and West Sumatera earthquakes (M6.3 and M6.4), the Padang earthquake (M7.6), and the Kerinci earthquake (M6.7), which happened 12 hours after the Padang earthquake [6]. In the Aceh region, an earthquake occurred in the Takengon Lot Tawar lake area in 2013 with a magnitude of M6.4. This earthquake caused fatalities and extensive damage to structures and infrastructure. The 2016 M6.4 earthquake in Pidie Jaya, Indonesia [12], [13]. The earthquakes in Pidie Jaya have occurred in the past few decades such as in 1967 (M6.1) and 1942 (M6.8).

Based on the frequency and intensity of recent earthquakes, Aceh is a highly earthquake-prone region. As there are differences between SNI 03-1726-2012 and SNI 03-1726-2019 regarding the type of spectrum response data, a comparative study of the seismic base shear is required for the analysis of buildings in the Aceh region. Using SNI 03-1726-2012 and SNI 03-1726-2019, this study will analyses the seismic base shear and the required cross-sectional area of columns, beams, and ring beams in low-rise building structures in 23 regencies/cities in Aceh Province.

2. Methods

In conducting this research, it begins with data collection including as built drawing of structures and loading data. A five-story office building with medium-type soil is used in the study. A special moment resistant frame is also considered for structural analysis.

2.1. Determination of Response Spectra

The location and coordinates of the 23 regencies/cities in Aceh will be utilized in SNI 03-1726-2012 and SNI 03-1726-2019 to calculate the design response spectra.

The determination of the design response spectra in SNI 03-1726-2012 is carried out by using coordinates and soil types through the website "indo spectra" [14]. Similarly, using the indo spectra programs that are also available on the website, one can obtain response spectra of SNI 03-1726-2019[15].

2.2. Preliminary Design

According to SNI 2847-2019 article 18.7.2[16], the smallest cross section's dimensions cannot be smaller than 300 mm, and the smallest dimensions cannot be smaller than 0.4 of the perpendicular dimensions. Meanwhile, Table 9.3.1.1 and article 18.6.2 of SNI 2847-2019 outline the restrictions on the design of beam dimensions.

This study involved the measurement of a set of structural elements, including columns, beams, and tie beams. Based on the maximum design response spectra acceleration (Sa) values at SNI 03-1726-2012 and SNI 03-1726-2019, dimensions of structural elements was estimated as shown in Tables 1 and 2.

Table 1: Dimensions of structural elements based on SNI 03-1726-2012

Dimension Groups	Dimensions based on SNI 03-1726-2012		
	Column, TOS (cm)	Beam, BL (cm)	Tie Beam, RB (cm)

1	60 x 60	35 x 60	30 x 55
2	50 x50	35 x 50	30 x 45

Table 2: Dimensions of structural elements based on SNI 03-1726-2019

Dimension Groups	Dimensions based on SNI 03- 6-2019		Tie Beam, RB (cm)
	Column, TOS (cm)	Beam, BL (cm)	
1	70 x 70	35 x 70	30 x 65
2	60 x 60	35 x 60	30 x 55
3	50 x50	35 x 50	30 x 45

2.3. Structural Modeling

Modeling of building structures is carried out using ETABS 18.1.1 [17]. The following shows floor plans of office building and the 3dimensional view of the building model in Figure 1.

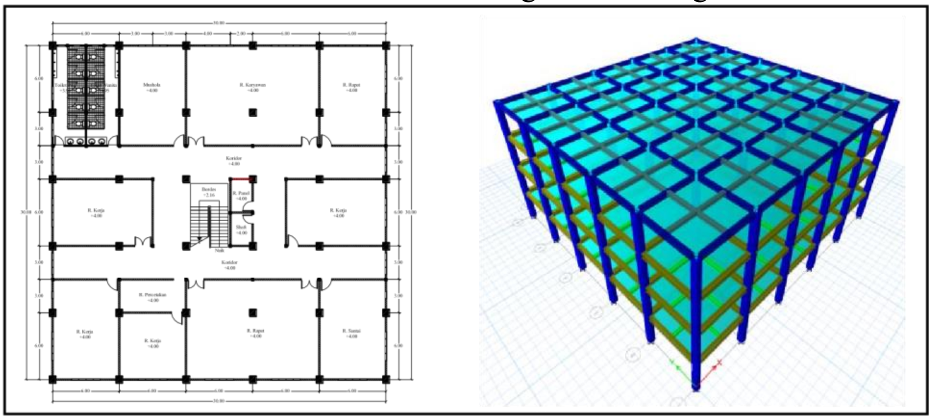

Fig 1: Structural model building used in this study

2.4 . Loading Input

The types of loads used in this study are dead loads, additional dead loads, and live loads. Based on SNI 1727-2020 [18], the dead load is the weight of all installed building construction materials, including walls, floors, roofs, ceilings, stairs, fixed partition walls, finishing, building cladding, and other architectural and structural components as well as other installed service equipment including tap weight. Additional dead loads used in this study are:

a. Additional dead load on beams and tie beams
   - Load of brick walls on beams = 9.81 kN/m
   - Load of brick walls on tie rings = 1,962 kN/m

b. Additional dead load on the plate
   - Additional dead load supported by floor slabs 2-4 = 1,511 kN/m2
   - Additional dead load supported by the roof slab = 0.667 kN/m2 The live load used is as follows:
   - Load on the roof deck of the building = 0.96 kN/m2
   - Load on office space = 2.40 kN/m2
   - Load on the corridor above the first floor = 3.83 kN/m2
   - Load on the meeting room = 4.79 kN/m2

2.5 . Modal Analysis (Modal Participation Mass Ratio)

A significant number of variations must be included in the analysis of the spectrum responses based on SNI 03-1726-2012 in order to obtain mass participation of at least 90% of the total mass. According to SNI 03-1726-2019, the spectrum analysis must take into account a sufficient number of variations to obtain the combined variety mass of 100% of the structure's mass.

2.6 . Natural Period

The length of time it takes to reach one vibration is known as the vibrating period. Knowing the structure's natural vibration period will help prevent resonance in the structure [19]. Structural resonance is a state where the natural frequency in the structure is close to the imposed frequency caused by external load so that it can cause a collapse in the structure [20].

Based on SNI 03-1726-2012 and SNI 03-1726-2019 article 7.8.2, there are two limit values for the building period, namely the minimum value of the building period ($T_{a\ min}$) and the maximum value of the building period ($T_{a\ max}$).

2.7 . Seismic Base Shear

The seismic base shear is the total of all lateral forces due to the earthquake subjected to the building and so the total of the lateral force subjected to each floor[21].

$$V = Cs \cdot W \quad (1)$$

The value of *Cs* must be determined by the following equation:

$$C_{s\ maximum} = \frac{S_{DS}}{\left(\frac{R}{Ie}\right)} \quad (2)$$

The *value of* C_s calculated above must not exceed the following:

$$C_{s\ count\ result} = \frac{S_{D1}}{T\left(\frac{R}{Ie}\right)} \quad (3)$$

The value of C_s must be not less than:

$$C_{s\ minimum} = 0.044\ S_{DS}\ I_e \geq 0.01 \quad (4)$$

Structures located in S_1 that are equal to or greater than 0.6*g*, then C_s should be not less than:

$$C_{s\ additional\ minimum} = \frac{0{,}5\ S_1}{\left(\frac{R}{Ie}\right)} \quad (5)$$

Where,

Cs = Seismic response coefficient

W = Total weight of the building

S_{DS} = Short-period design response spectra acceleration parameter

R = Seismic reduction factor

Ie = Important factor

S_{D1} = response spectra acceleration design parameter at period 1 second

T = Fundamental vibrating period of the structure

S_1 = MCE_R response spectra acceleration parameter mapped for a period of 1 second

2.8 Story Drift

Based on SNI 03-1726-2012 and SNI 03-1726-2019 article 7.8.6, it requires story drift only to determine the performance at the ultimate state. The determination of story drift (Δ) should be calculated as the difference in drifts at the center of mass above and below the level of the structure. The deflection of the center of mass at the level of x (δx) in mm, must be determined by,

$$\delta_x = \frac{C_d\ \delta_{xe}}{I_e} \quad (6)$$

where:

Cd = Deflection magnification factor

δ_{xe} = Deflection at the required location and determined according to the elastic analysis I_e = Important factor

Table 3: Allowable Story Drift Δ_a

Structure	Risk categories		
	I or II	III	IV
Structures, unless shear wall structures, 4 levels or less with interior walls, partitions, ceilings and exterior wall systems that have been designed to accommodate story drift.	$0.025\ h_{sx}$[c]	$0.020\ h_{sx}$	$0.015\ h_{sx}$
Brick cantilever shear wall structure	$0.010\ h_{sx}$	$0.010\ h_{sx}$	$0.010\ h_{sx}$
Other brick shear wall structures	$0.007\ h_{sx}$	$0.007\ h_{sx}$	$0.007\ h_{sx}$
All other structures	$0.020\ h_{sx}$	$0.015\ h_{sx}$	$0.010\ h_{sx}$

3. Results and Discussion

The results of the study include the comparison of the seismic shear forces and the required cross-sectional areas of the building structures in 23 Regencies/Cities of Aceh Province using SNI 03-1726-2012 and SNI 03-1726-2019. It has a significant impact on the outcomes of structural analysis, including seismic base shear, mass participation ratio, lateral displacement, and story drift, because there are discrepancies in the response spectra between the two standards.

3.1. Response Spectra

Based on data analysis, the maximum design acceleration response spectra value (Sa) at the time of occurrence of an earthquake (T) for each Regency/City with a time interval of T = 0 second to T = 4 seconds in both SNI are obtained. The difference in the average Sa maximum value between two standards in all districts/cities are shown in Table 4.

Table 4: The difference between the average maximum value of Sa between two standards in all Regencies/Cities

No.	Districts/Cities	Maximum Acceleration Design Response Spectrum (*Sa*) SNI 1726:2012	SNI 1726:2019	Difference (%)
1	Gayo Lues	0.984	1.621	64.70%
2	Sabang	0.814	1.537	88.84%
3	Aceh Besar	0.911	1.316	44.55%
4	Southeast Aceh	1.045	1.244	19.06%
5	South Aceh	0.963	1.003	4.20%
6	Subulussalam	0.831	1.000	20.34%
7	Aceh Singkil	1.000	1.000	0.00%
8	Simeulue	1.000	1.000	0.00%
9	Banda Aceh	0.899	0.967	7.55%
10	Central Aceh	0.695	0.947	36.22%
11	Nagan Raya	0.907	0.945	4.18%
12	West Aceh	0.986	0.909	-7.82%
13	Aceh Jaya	0.985	0.902	-8.47%
14	Pidie Jaya	0.630	0.899	42.58%
15	Southwest Aceh	0.902	0.829	-8.05%
16	Pidie	0.680	0.792	16.55%
17	Bener Meriah	0.664	0.779	17.23%
18	Lhokseumawe	0.550	0.749	36.21%
19	North Aceh	0.549	0.615	12.20%
20	Bireuen	0.576	0.590	2.42%
21	Langsa	0.577	0.566	-1.88%
22	Aceh Tamiang	0.571	0.566	-0.99%
23	East Aceh	0.546	0.536	-1.90%

According to Table 4, Aceh Jaya Regency has not significant reduction of Sa in SNI 03-1726-2012 compared to other districts/cities, for about 8.47% of the maximum acceleration design (Sa response) spectra value based on SNI 03-1726-2019. The maximum response spectra values also decreased in 5 other regencies/cities, with successive drops in West Aceh, Southwest Aceh, Langsa, Aceh Tamiang, and East Aceh of 7.82%, 8.05%, 1.88%, 0.99%, and 1.90%, respectively. The maximum response spectra for SNI 03-1726-2019 is higher than SNI 03-1726-2012 in other districts and cities. The Regencies/Cities of Pidie Jaya, Aceh Besar, Gayo Lues, and Sabang have significant increase of 42.58%, 44.55%, 64.70%, and 88.84%, respectively. The city with the highest percentage improvement in maximum response spectra is Sabang City. Additionally, in the Aceh

Singkil and Simeulue Regencies, the maximum response spectra value was reached the same values based on SNI 03-1726-2012 and SNI 03-1726-2019.

3.2. Seismic Base Shear

Based on SNI 03-1726-2012, the seismic base shear force value cannot be less than 85% of static seismic base shear. It cannot be less than 100% static seismic base shear based on SNI 03-1726-2019. The scale factor is used to increase the calculated seismic base shear if it has not met the second condition. For each regency/city, Table 5 shows dynamic base shear in directions x and y for SNI 03-1726-2012 and SNI 03-1726-2019.

According to Table 5, the seismic base shear values of direction x and direction y for all districts/cities for SNI 03-1726-2019 are greater than those for SNI 03-1726-2012. This is due to three factors: firstly, an increase in the dynamic seismic shear force of SNI 03-17262019 by 25% of the static seismic base shear compared to SNI 03-1726-2012; secondly, an increase in the response spectra value of SNI 03-1726-2019 resulting in a higher load on the structure; and thirdly, the division of the dimensional groups of structural elements based on the response spectra values resulting in the seismic base shear values are different.

As shown in Figure 2, the higher increase in the value of seismic shear force is in Sabang (192.05 %). This result is consistent with the increase response spectra value of SNI 03-1726-2019 compared to SNI 03-1726-2012, as well as the difference in the dimensions of the structural elements used in Sabang City based on SNI 03-1726-2012 (e.g., column dimensions of 50x50 cm) and SNI 03-1726-2019 (e.g., column dimensions of 70x70 cm), so that the value of the seismic base shear obtained is significantly different. The smallest increase in the value of seismic base shear was found in Southwest Aceh Regency (8.16 %).

Table 5: Dynamic seismic base shear based on SNI 2012-1726-1726 and SNI 03-1726-2019

No.	Districts/Cities	Dynamic seismic base shear (tons)			
		SNI 03-1726-2012		SNI 03-1726-2019	
		Direction *X*	Direction *Y*	Direction *X*	Direction *Y*
1	Gayo Lues	414.231	414.232	899.864	899.867
2	Sabang	289.180	289.180	853.227	853.224
3	Aceh Besar	404.694	404.694	731.072	731.070
4	Southeast Aceh	431.945	431.945	690.723	690.725
5	South Aceh	408.782	408.781	525.897	525.898
6	Subulussalam	316.873	316.874	524.150	524.150
7	Aceh Singkil	408.781	408.782	524.150	524.150
8	Simeulue	408.781	408.782	524.152	524.150
9	Banda Aceh	400.679	400.679	507.029	507.029
10	Central Aceh	244.494	244.493	496.546	496.544
11	Nagan Raya	403.946	403.945	495.147	495.148
12	West Aceh	408.782	408.782	476.278	476.278
13	Aceh Jaya	408.781	408.781	472.783	472.785
14	Pidie Jaya	226.655	226.655	471.036	471.037
15	Southwest Aceh	401.867	401.865	434.675	434.675
16	Pidie	240.899	240.898	415.264	415.265
17	Bener Meriah	233.952	233.952	408.304	408.304
18	Lhokseumawe	198.356	198.357	392.297	392.297
19	North Aceh	197.547	197.547	297.624	297.623
20	Bireuen	210.536	210.536	292.236	292.235
21	Langsa	204.247	204.247	279.028	279.028
22	Aceh Tamiang	207.257	207.257	280.286	280.286
23	East Aceh	190.867	190.867	252.035	252.035

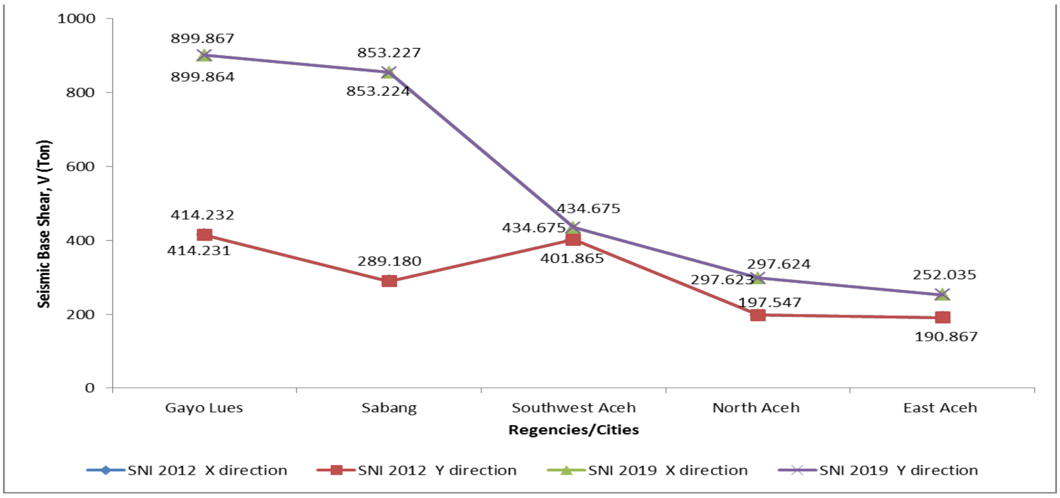

Fig 2: Comparison of seismic base shear based on SNI 03-1726-2012 and SNI 03-1726-2019 in several regencies/cities

3.3. Cross-Sectional Area of Structural Elements

The required cross-sectional area of the structural elements observed is in columns, beams, and tie beams. The difference in the percentage of the required cross-sectional area of structural elements in several regencies / cities representing each group of dimensions of structural elements can be seen in Figure 3 to Figure 5. Based on Figure 3, it can be seen that the higher increase in column crosssectional area obtained in Sabang (96%). Meanwhile, there was no increase in the cross-sectional area of the column in several regencies/cities including South Aceh, Aceh Singkil, Simeulue, Banda Aceh, Nagan Raya, West Aceh, Aceh Jaya, Southwest Aceh, North Aceh, Bireuen, Langsa, Aceh Tamiang, and East Aceh.

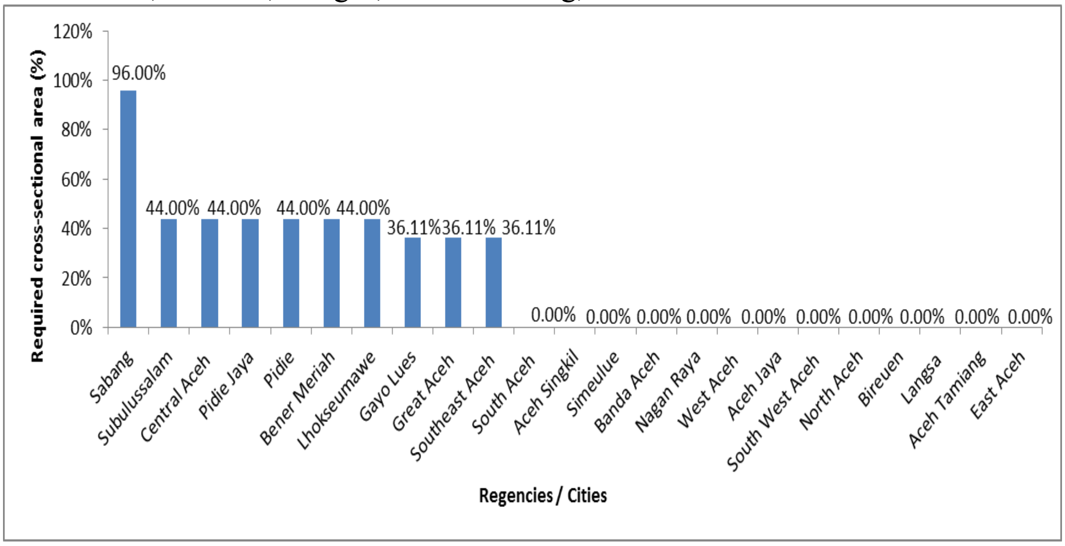

Fig 3: Comparison of the required cross-sectional area of the column based on SNI 03-1726-2012 and SNI 03-1726-2019

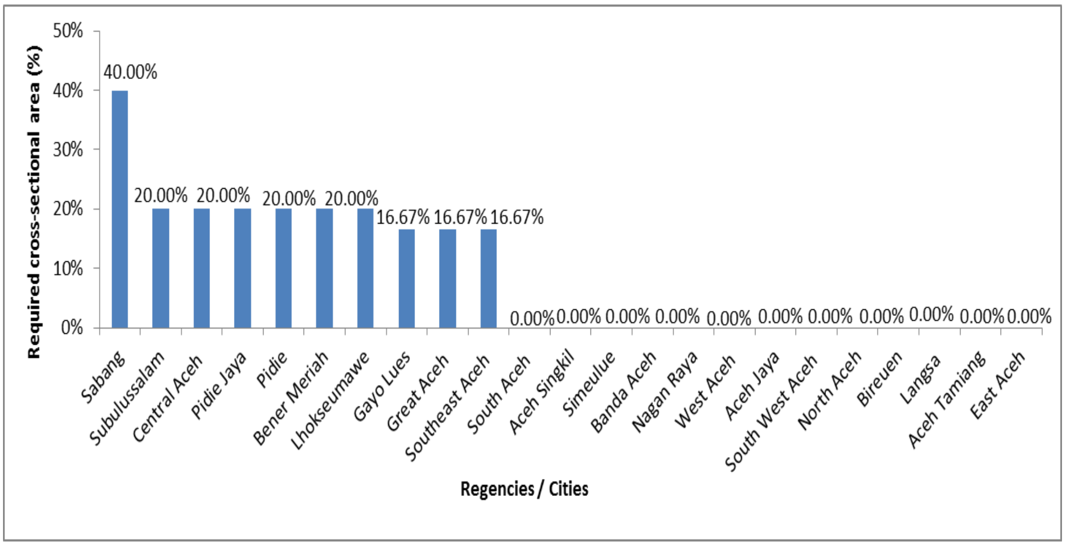

Fig 4: Comparison of the required cross-sectional area of the beam based on SNI 03-1726-2012 and SNI 03-1726-2019

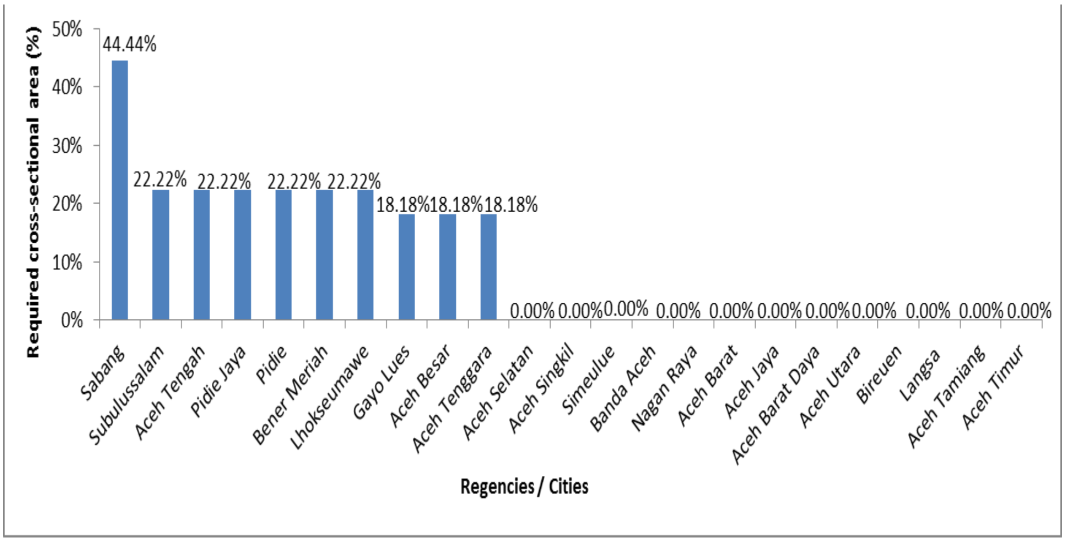

Fig 5: Comparison of the required cross-sectional area of tie beams based on SNI 03-1726-2012 and SNI 03-1726-2019

Based on Figure 4, it can be seen that the largest increase in the cross-sectional area of the beam occurred in Sabang Regency/City, which was 40%. Meanwhile, there was no increase in the cross-sectional area of the beams occurring in several regencies/cities, namely South Aceh, Aceh Singkil, Simeulue, Banda Aceh, Nagan Raya, West Aceh, Aceh Jaya, Southwest Aceh, North Aceh, Bireuen, Langsa, Aceh Tamiang and East Aceh.

Figure 5 demonstrates that the highest growth in tie beams cross-sectional area was found in the Sabang (44.44%). Several regencies/cities, including South Aceh, Aceh Singkil, Simeulue, Banda Aceh, Nagan Raya, West Aceh, Aceh Jaya, Southwest Aceh, North Aceh, Bireuen, Langsa, Aceh Tamiang, and East Aceh, exhibited no growth in the required cross-sectional area of the beams.

4. Conclusion

The dynamic seismic base shear based on SNI 03-1726-2019 compared to SNI 03-1726-2012 increased by 192.05 % in Sabang. The region with the smallest seismic base shear was found in Southwest Aceh (8.16 %). In Sabang, the higher increases in the required crosssectional area of the column elements, beams, and tie beams were 96%, 40%, and 44.44%, respectively. In several regencies/cities, including South Aceh, Aceh Singkil, Simeulue, Banda Aceh, Nagan Raya, West Aceh, Aceh Jaya, Southwest Aceh, North Aceh, Bireuen, Langsa, Aceh Tamaiang, and East Aceh, there was no significant increase in the required cross-sectional area of columns, beams, and tie beams.

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