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5	Editor-in-Chief File	Comments Online.docx	23.37 KB		2021-07-22
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7	Manuscript Acceptance Receipt	Dr. Kencanawati.pdf	384.79 KB		2022-03-07

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May 21th, 2021

Dear Editor in Chief of Scientia Iranica,

We wish to submit an original research article entitled “Two Approaches on Structural Seismic Responses in Mataram City: Based on the Spectral Acceleration of Lombok Earthquake Series and the Newest Seismic Codes” for consideration by Scientia Iranica.

We confirm that this work is original and has not been published elsewhere, nor is it currently under consideration for publication elsewhere.

In this paper, we report that the seismic parameters due to recent Lombok 2018 earthquakes lead to higher seismic demands structures than those of the current seismic code. This is significant because it is urgent to update the existing seismic codes by accommodating the acceleration of ground motion due to Lombok 2018 earthquake. We believe that this manuscript is appropriate for publication by Scientia Iranica because it is in the civil engineering field to support the risk reduction of earthquake disasters in the future.

We have no conflicts of interest to disclose.

Please address all correspondence concerning this manuscript to me at nkencanawati@unram.ac.id.

Thank you for your consideration of this manuscript.

Sincerely yours,

Ni Nyoman Kencanawati

Research Highlight

- Response spectrum of Lombok earthquake ground motion in 2018
- Some approaches on determination of structural seismic responses in Mataram city
- Spectral accelerations due to recent strong earthquake are the greatest
- Improvement on the current national seismic code to be more preparedness on the future earthquakes

“Editors’ Comments to the Author/s”

The Editorial Board of the journal has requested you to:

1- Update the references of your manuscript to include at least 10 references published from 2014 to 2018,

2- To include at least 2 references published in *Scientia Iranica*.

Reviewer 1

Ref. No: SCI-2105-5702

"Comments to the Authors"

Based on response spectrum method, this paper compares the two codes and the affected by Lombok Earthquake 2018. And their influence on the seismic response analysis of a building structure in Mataram city are studied here.

This research provides a new method for earthquake response analysis in Indonesia. However, the authors have to address all the following issues before recommending it for publication:

1-Title. The seismic response analysis of structure based on SNI 1726-2019 was not proposed by the author. For this reason, it is opinion of this reviewer, that it would be better to modify the paper’s title as follows: A New Approach on Structural Seismic Responses in Mataram City: Based on the Spectral Acceleration of Lombok Earthquake Series.

2-Section 2. The following words’ Figure (a)’ and ’ Figure (b)’ appear twice each in this section. However, there are no Figure (a) and Figure (b) in this paper. Please correct them.

3- Section 2. In this section, the author gives a building configuration with reference to the three earthquake acceleration maps. However, it does not reflect the influence of the SNI 1726-2019 and the spectral acceleration of 2018 Lombok earthquake on its design.

4- Section 3. The digital parts of Figures 8 and 9 are not blackened.

Reviewer 2

Ref. No: SCI-2105-5702

"Comments to the Authors"

My main concern is related to the comparison between building code provisions which are constructed on the basis of probabilistic seismic hazard analysis (PSHA) performed in different periods of time (2012, 2017, and after 2018). On one hand, probabilistic seismic hazard mapping and characterization of design ground motion parameters are the continuous procedures. The development of seismic hazard maps is related to accumulation of new information, enhance of procedures of interpretation of the data, development of sophisticated models and adequate treatment of uncertainty in seismic process. The last estimations of seismic hazard in the studied area were stipulated by a series of earthquakes occurred in 2018 at the northern part of Lombok Island caused the death of hundreds of people and ruined thousands of buildings. Unfortunately, there is no comparison between the observed ground motion data and results of PSHA, therefore the difference between the results of different PSHA may be considered only as manifestation of epistemic uncertainty, or uncertainty caused by application of different input models and methods.

On the other hand, many recent earthquakes caused ground motions amplitudes of which that are much higher than the design limits provided by seismic hazard maps. These high amplitudes may be caused by local site effects, peculiarities of rupture propagation, and so on. The PSHA produces an integrated description of seismic hazard representing numerous seismic events. There is always a considerable probability that the design threshold will be exceeded, especially in the area close to a source, due to high positive values of ground motion variability. Also, it is necessary to bear in mind, that many buildings (may be the majority of the building stock) were not built in accordance with most recent building code provisions. That is why these buildings may be strongly damaged, and it seems that the Lombok earthquake consequence is the case. As can be seen from Fig. 5, the last two PSHAs (Code SNI 1726-2019 and those obtained after 2018 earthquake) show almost similar high-frequency estimations of ground motion, i.e. the latter short period spectral acceleration is only 4% larger than the former. I don't think that this negligible difference may be a reason for necessity to improve of current seismic code provisions. Bearing in mind overall uncertainty of PSHA, it would be reasonable concluding that considering the current knowledge and given new models for PSHA constructed after the 2018 Lombok earthquakes, the Code SNI 1726-2019 adequately represents seismic hazard in the area.

Specific comments

1. Introduction.

Page. 2. A map showing general features of tectonic and seismicity of the entire region (Indonesia) should be provided highlighting the area where the Lombok earthquakes were occurred.
Page 4, second paragraph. Please specify what was the difference between the model of seismicity created by NCES in 2017 and new model developed after the Lombok earthquakes – new source zonation, another ground motion equations, consideration of earthquake records, etc.

Materials and Methods

Figures 1 and 2. It would be better to rearrange plots joining the SNI 2012 and SNI 2019 maps for similar parameter in the same Figure. In this case the differences (if any) will be clearly seen. Also, area shown in Figure 3 should be outlined at these maps.

Figure 3. I suggest to show here (1) location of the Lombok earthquakes and (2) corresponding area of the SNI 2019 map.

Building configuration

Why this four-story reinforce concrete building is considered here? Is it typical construction for the area? Or there are enough data to create the building model for further analysis? Actually, it seems that the next step in development of building code will be risk-targeted hazard maps that are based on probability of collapse. In this case characteristics (fragility curve) of typical construction are considered.

4 Conclusion

Bearing in mind negligible difference between high-frequency amplitudes of the SNI 2019 design spectrum and the design spectrum based on the hazard maps constructed after the 2018 Lombok earthquakes, why did the authors call for the update of existing seismic codes ? Please specify.

Technical comments

Abstract
Line 7 "..as well as the spectral acceleration affected by Lombok earthquake 2018". Do you mean the results of PSHA obtained after occurrence of the 2018 earthquakes?
Line 9. ".. the seismic parameters of recent Lombok 2018 earthquakes lead to higher…".

Again, not observed ground motion records were used, but the results of PSHA obtained after occurrence of the 2018 earthquakes. Please specify it later in the text – not “Lombok ground motion”, or “2018 Lombok seismic map", but “PSHA results obtained after Lombok earthquakes”

Introduction

Page 3, first paragraph, first line – not “seismic map” but “seismic hazard map” Third and fifth lines (and later in the text) – “response design spectrum”

I believe that the language editing is absolutely necessary.

TABLES OF AUTHOR'S RESPONSES

Responses to Editor's Comments

No	Editor's Comments	Author's Responses
1	Update the references to include at least 10 references published from 2014 to 2018	In order to fit Editor's suggestion, authors have included 11 references published from 2014 to 2018 used in this manuscript
2	To include at least 2 references published in Scientia Iranica	Authors have added 3 references published in Scientica Iranica used in the manuscript as follows: [17] J. P. Amezquita-Sanchez, M. Valtierra-Rodriguez, and H. Adeli, "Current efforts for prediction and assessment of natural disasters: Earthquakes, tsunamis, volcanic eruptions, hurricanes, tornados, and floods," *Sci. Iran.*, vol. 24, no. 6, pp. 2645–2664, 2017, doi: 10.24200/sci.2017.4589. [34] H. Beiraghi, A. Kheyroddin, and M. A. Ka_fi, "Effect of record scaling on the behavior of reinforced concrete core-wall buildings subjected to near-fault and far-fault earthquakes," *Sci. Iran.*, vol. 24, no. 3, pp. 884–899, 2017, doi: 10.24200/sci.2017.4073. [41] M. Mahsuli, "Resilience of Civil Infrastructure by Optimal Risk Mitigation," *Sci. Iran.*, vol. 23, no. 5, pp. 1961–1974, 2016, doi: 10.24200/sci.2016.2263.

Responses to Reviewer#1's Comments

No	Reviewer's Comments	Author's Responses
1	Title. The seismic response analysis of structure based on SNI 1726-2019 was not proposed by the author. For this reason, it is opinion of this reviewer, that it would be better to modify the paper's title as follows: A New Approach on Structural Seismic Responses in Mataram City: Based on the Spectral Acceleration of Lombok	Based on the explanation from the reviewer, authors accepted to modify the title as recommended by the reviewer.

	Earthquake Series.	
2	Section 2. The following words' Figure (a)' and ' Figure (b)' appear twice each in this section. However, there are no Figure (a) and Figure (b) in this paper. Please correct them	According to your suggestion, the figures and the citation in the text of the acceleration maps have been revised to make it clearer. In addition, the highlight of Lombok Island location has been added to the figures.
3	Section 2. In this section, the author gives a building configuration with reference to the three earthquake acceleration maps. However, it does not reflect the influence of the SNI 1726-2019 and the spectral acceleration of 2018 Lombok earthquake on its design.	Authors would like to explain the building configuration related to the three earthquake acceleration maps. The configuration of the Mataram State Islamic University building was used as an example case in comparing the application of the response design spectra from SNI 2012, SNI 2019, and the Lombok earthquake ground motion to the seismic responses of the building. The three response design spectrums were generated from each earthquake map described in **Subsection 2.1**, which was from SNI 2012, SNI 2019, and Lombok earthquake ground motion. These response design spectrums are then applied during the structural analysis to obtain the seismic responses in terms of lateral loads and displacements experienced by the building. Thus, it can be analyzed the influence of each spectrum response from SNI 2012, SNI 2019, and the Lombok earthquake 2018 on the seismic responses of this building. It was found that in the building seismic response in terms of lateral forces and displacements on medium soil is larger when analyzed using the response spectrum due to the 2018 Lombok earthquake.
4	Section 3. The digital parts of Figures 8 and 9 are not blackened.	The digital parts of Figure 8 and Figure 9 have already been changed in a blackened style.

Note: The author's responses to the Reviewer#1's comments are presented in grey highlight in the revised manuscript

Responses to Reviewer#2's Comments

No	Reviewer's Comments	Author's Responses
1	Introduction. A map showing general features of tectonic and seismicity of the	According to the reviewer's suggestion, a map providing the features of tectonic activities in Indonesia and Lombok, including the location of Lombok major earthquakes 2018 and the distribution of aftershocks, has

	entire region (Indonesia) should be provided highlighting the area where the Lombok earthquakes were occurred.	been provided in Figure 1 and Figure 2, respectively.
2	Page 4, second paragraph. Please specify what was the difference between the model of seismicity created by NCES in 2017 and new model developed after the Lombok earthquakes – new source zonation, another ground motion equations, consideration of earthquake records, etc.	Authors have inserted some differences between the model of the seismicity produced by the National Center for Earthquake Studies in 2017 and the new model developed after the Lombok earthquakes in the intended paragraph in the text as following: The sources used in the National Center for Earthquake Studies are subduction, back-arc, and strikes slip faults for Lombok and surroundings, meanwhile in 2018 Lombok earthquake used only subduction and back-arc because they are the most dominant. The earthquake data records used in the Lombok earthquake model are until 2018, while the data used in National Center for Earthquake Studies model is until 2016. Thus, the *a* and *b* values are more updated in the recent Lombok earthquake, 2018 model. However, the ground motion equations according to National Center for Earthquake Studies and the Lombok earthquake 2018 are nearly the same.
3	Materials and Methods Figures 1 and 2. It would be better to rearrange plots joining the SNI 2012 and SNI 2019 maps for similar parameter in the same Figure. In this case the differences (if any) will be clearly seen. Also, area shown in Figure 3 should be outlined at these maps. Figure 3. I suggest to show here (1) location of the Lombok earthquakes and (2) corresponding area of the SNI 2019 map.	Reviewer's suggestions have been accommodated. The same period is included in one figure by displaying maps from SNI 2012 and 2019 side by side. In addition, the location of Lombok island has been marked on the maps. In the seismic acceleration maps affected by the Lombok earthquake ground motion, the location of the epicenter of Lombok Earthquake 2018 has also been marked on the map. The writing of the manuscript has also been adjusted according to your suggestion as follows: The seismic design maximum acceleration maps of the bedrock for the short period (T = 0.2 s (SS)) and for the long period (T = 1 s (S1)) with the probability of 2% exceeded in 50 years are provided by the codes: SNI 1726-2012 and SNI 1726-2019 presented in **Figure 1-2** respectively. **Figure 1** presents spectral acceleration maps in bedrocks for the short period, T = 0.2 s from SNI 1976-2012 and SNI 1976-2019. Meanwhile, **Figure 2** shows spectral acceleration maps in bedrocks for the long period, T = 1 from SNI 1976-2012 and SNI 1976-2019. In **Figures 1** and **2**, the location of Lombok and its surroundings are marked with a blue box shape. The seismic acceleration map in bedrock affected by the 2018 Lombok earthquake is illustrated in **Figure 3**, which consists of maps for the

		short and long periods. The epicenter location of the series of earthquakes that occurred on Lombok in 2018 is marked with a blue circle on the map.
4	Building configuration Why this four-story reinforce concrete building is considered here? Is it typical construction for the area? Or there are enough data to create the building model for further analysis? Actually, it seems that the next step in development of building code will be risk-targeted hazard maps that are based on probability of collapse. In this case characteristics (fragility curve) of typical construction are considered.	Relating to the building configuration. The two-five story reinforced concrete structures are common in this area. This paper considered a four-story building to represent the building construction. Furthermore, the performance-based pushover analysis has been added to perform the building capacity, as shown in **Section 3.4**. According to the analysis, when the three response design spectrum of the medium soil was applied clearly, SNI 1726-2019 gives the higher base shear and displacement. However, according to the performance level, the three response design spectrums show the same level of performance, namely immediate occupancy. Immediate occupancy means the structure is safe in the occurrence of an earthquake but with minimal damage. Strength and stiffness are approximately equal to pre-earthquake conditions. In addition, the vertical and lateral structural resisting systems are still capable sustain earthquake load.
5	4 Conclusion Bearing in mind negligible difference between high-frequency amplitudes of the SNI 2019 design spectrum and the design spectrum based on the hazard maps constructed after the 2018 Lombok earthquakes, why did the authors call for the update of existing seismic codes ? Please specify.	Authors agreed with the Reviewer’s comment; therefore, some explanation has been added into the final paragraph of the text to specify the recommendation as follows: All efforts to reduce earthquake hazards need to be carried out with preventive measures for disaster management. One of the efforts made is updating the Earthquake Hazard Map, which is usually updated every year or after such a strong earthquake stroke. For Indonesia, it is attempted no later than every five years [26]. In this paper, although there is only a 4% increase in the short period bedrock's acceleration, it is necessary to update the map because it has existed for five years. Moreover, the design response spectrum after the Lombok earthquake shows an increase in the seismic building responses. In addition, some new fault characterizations have been studied after the sequence of the Lombok 2018 earthquake [39], [40]. Therefore, updating the earthquake map is suggested to the next Indonesian code to this area to improve seismic mitigation.
6	Technical comments Abstract Line 7 “..as well as the spectral acceleration affected by Lombok earthquake 2018”. Do you mean the results of PSHA obtained after occurrence of	 Authors agreed with the Reviewer's suggestions. Lombok ground motion, or the 2018 Lombok seismic map, has been replaced with PSHA results obtained after Lombok earthquakes in entire the manuscript.

	the 2018 earthquakes? Line 9. ".. the seismic parameters of recent Lombok 2018 earthquakes lead to higher…". Again, not observed ground motion records were used, but the results of PSHA obtained after occurrence of the 2018 earthquakes. Please specify it later in the text – not "Lombok ground motion", or "2018 Lombok seismic map", but "PSHA results obtained after Lombok earthquakes"	
	Introduction Page 3, first paragraph, first line – not "seismic map" but "seismic hazard map" Third and fifth lines (and later in the text) – "response design spectrum"	The seismic map has been replaced with the seismic hazard map, and the response spectrum has been replaced with the response design spectrum in the entire text.
	I believe that the language editing is absolutely necessary.	Authors accepted the Reviewer's suggestion. The language editing has been improved using *Grammarly* Application.

Note: The author's responses to the Reviewer#2's comments are presented in yellow highlight in the revised manuscript except for the number 3 comment revision are presented in grey highlight because it is answering simultaneously with the reviewer#1 inquiry.

A New Approach on Structural Seismic Responses in Mataram City: Based on the PSHA Results Obtained after Lombok Earthquakes 2018

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Abstract

In the last few years, several major earthquakes in Indonesia have prompted an update of the building seismic resistance code. SNI 1726-2019 is the newest Indonesia seismic code. However, the change of PSHA results due to the 2018 Lombok Earthquake has not been accommodated in this code because it adopts the 2017 seismic maps from National Center for Earthquakes Studies. This paper studied spectral acceleration parameters according to the previous seismic codes (SNI 1976-2012) and current seismic code (SNI 1976-2019) and the PSHA results obtained after the Lombok earthquakes in 2018.The spectral accelerations were applied to a building structure located in Mataram City to analyze the seismic building responses. The results indicate that the seismic parameters of the PSHA result obtained after Lombok earthquakes lead to higher seismic demands structures than the codes either SNI 1726- 2012 or SNI 1726- 2019, especially for structures located in medium soil type. The current code needs to be immediate improved for the sake of earthquake mitigation resilience in this area.

Keywords: Spectral acceleration, Lombok earthquake series, seismic codes, seismic responses

1. Introduction

A series of Lombok earthquake events in 2018 were triggered by upward fault activity in the north of Lombok. The activity generated six earthquakes which had magnitudes greater than 5.5. Furthermore, apart from earthquakes of relatively smaller magnitude, the National Agency for Meteorology, Climatology, and Geophysics recorded that the aftershocks with lower magnitude were more than 2000 events. The first earthquake started with a magnitude of 6.4 on July 29, 2018. Then on August 5, 2018, an earthquake with a magnitude of 6.9 at a hypocenter depth of 34 km again hit northern Lombok. Four days later, on August 9, 2018, an earthquake with a magnitude of 5.9 occurred, with the center moved to the west. Ten days later, on August 19, 2018, two large earthquakes with a magnitude of 6.3 occurred in the afternoon with a hypocenter depth of 7.9 km, and a magnitude 7.0 (later updated to a magnitude 6.9) occurred at night with a hypocenter depth of 25 km with a position to the east. The sixth earthquake with a magnitude of 5.5 occurred on August 25, 2018, centered on the east of Lombok. **Figure 1** shows the topography and tectonic areas of Indonesia, where the island of Lombok is indicated by a red circle [1]. Then the six major earthquakes occurrence are explained in **Figure 2** as a black circle and blue inside; meanwhile, the red circle provides the distribution of aftershocks that occurred from July 29–September 10, 2018. The mechanism of earthquake focus and hypocenter data was obtained from the USGS catalog [2]. According to the national disaster management agency, this series of earthquakes damaged buildings as many as 71962 damaged houses, 671 damaged educational facilities, 52 health facilities, 128 prayer facilities. They even collapsed in some areas, including Mataram City [2]–[6].

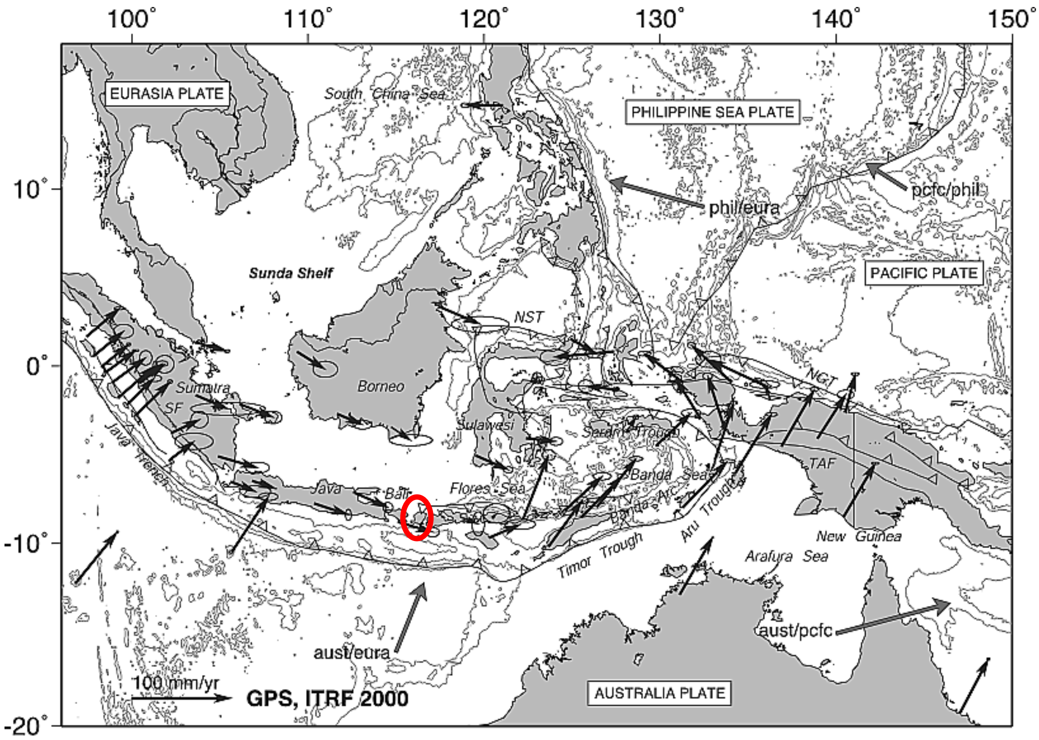


Figure 1 Topography and tectonics of the Indonesia region with the Island of Lombok in a red circle [1]

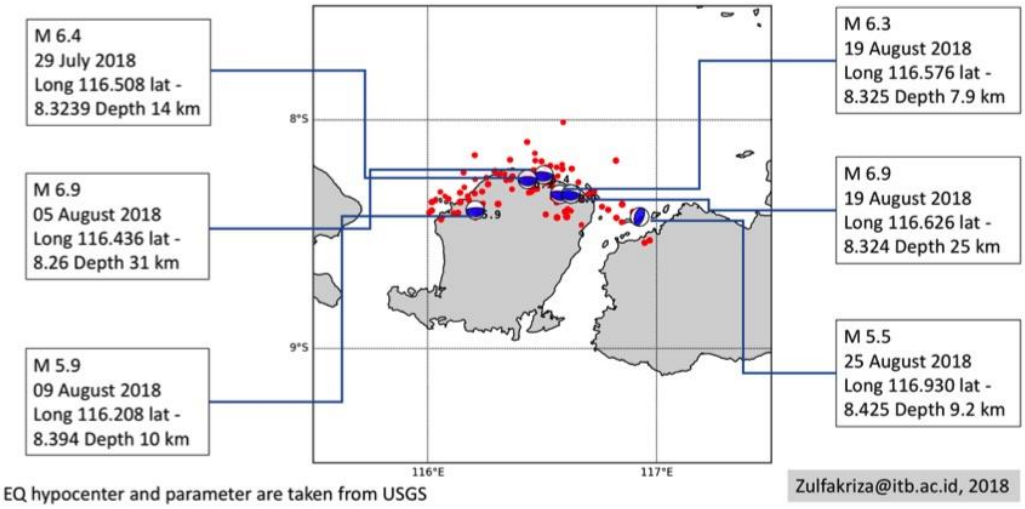


Figure 2 Distribution of Lombok earthquake occurrence [2]

A large amount of damage to building structures caused by strong earthquakes has inevitably urged the government to renew the existing building seismic resistance design code. Changes in the code carried out by the government worldwide are intended to accommodate the latest earthquake events [7], [8], [17], [9]–[16]. This includes evaluating the seismic performances on existing structures after such large earthquakes stroke the countries [18]–[22]. In Indonesia, one of the government's seismic codes was SNI 1726-2002 [23], and then updated it to SNI 1726-2012 [24]. The latest version was published in 2019 [25].

In SNI 1726-2002, the seismic hazard map was divided into six earthquake zones, where each zone was classified based on the peak acceleration of the bedrock and had the same response design spectrum. However, based on the latest geological studies of the earth's plate, which influenced the earthquake region, improved the code into SNI 1726- 2012. According to this code, each region or location had a different response design spectrum because it was determined based on the ground motion parameters Ss and S_1. The peak ground acceleration (PGA) of SNI 1726-2002 was based on a 10% probability of being exceeded in 50 years. The return period was 500 years. After several great earthquakes, there was a change in the Indonesian seismic hazard map; therefore, this code was replaced by SNI 1976-2012. This replacement seismic code had a peak ground motion with a 2% probability of being exceeded in 50 years or a return period of 2475 years for the spectral acceleration. Updating the seismic hazard map has been carried out and produced the latest seismic code, SNI 1976-2019. The seismic spectral acceleration is based on the 2017 seismic hazard map National Earthquake Center [26], [27].

The National Center for Earthquake Studies updated the National Earthquake Map in 2017. The series of research results, studies, and publications related to Indonesia's latest earthquake source parameters, including geology in some areas and earthquake relocation data, have contributed significantly to updating the source maps and the hazards. Therefore, SNI 1726-2012 was renewed to SNI 1726-2019 and has been becoming the current seismic code in Indonesia. In this code, some major earthquake-prone areas show increased spectral acceleration [27], [28]. However, change is not significantly found for the area that has not been much affected by the seismic occurrence, such as Mataram City. In fact, Lombok area was stroke by strong earthquakes in 2018. The increase is not so sharply seen in Lombok because SNI 1976-2019 has accommodated the 2017 earthquake map.

According to [29], theoretically, one reason for the uncertainty of building collapse due to earthquakes is spectral acceleration. The structures can resist without collapsing, depending on the spectral acceleration produced according to ground motion characteristics. In the case of the Lombok earthquake in 2018, many damaged structures were found, even in Mataram City, the major city in Lombok Island, which was located around 47 km away from the largest epicenter of the earthquake series. PSHA results obtained after the Lombok earthquakes have strongly influenced the spectral acceleration as studied by [30], [31].

Considering the 2018 Lombok earthquakes, an analysis is conducted based on a probabilistic seismic hazard analysis using a detailed tectonic background and the appropriate ground motion equations. The analysis is aimed to determine the seismic parameters that are more suitable with the ground motion that occurs due to a strong earthquake that has occurred and comparing it with the model published by the National Center for Earthquake Studies in 2017. The sources used in the National Center for Earthquake Studies are subduction, back-arc, and strikes slip faults for Lombok and surroundings, meanwhile in 2018 Lombok earthquake used only subduction and back-arc because they are the most dominant. The earthquake data records used in the Lombok earthquake model are until 2018, while the data used in National Center for Earthquake Studies model is until 2016. Thus, the *a* and *b* values are more updated in the recent Lombok earthquake 2018 model. However, the ground motion equations of the National Center for Earthquake Studies and the Lombok earthquake 2018 are nearly identical. Furthermore, it was found that Lombok and its surrounding islands show a significant seismic hazard than the model published by the National Earthquake Study Center in 2017. This is because the model was estimated before the 2018 earthquake. Therefore, updating the seismic hazard map for Lombok and surrounding islands are proposed by considering the effect of the strong earthquakes [30].

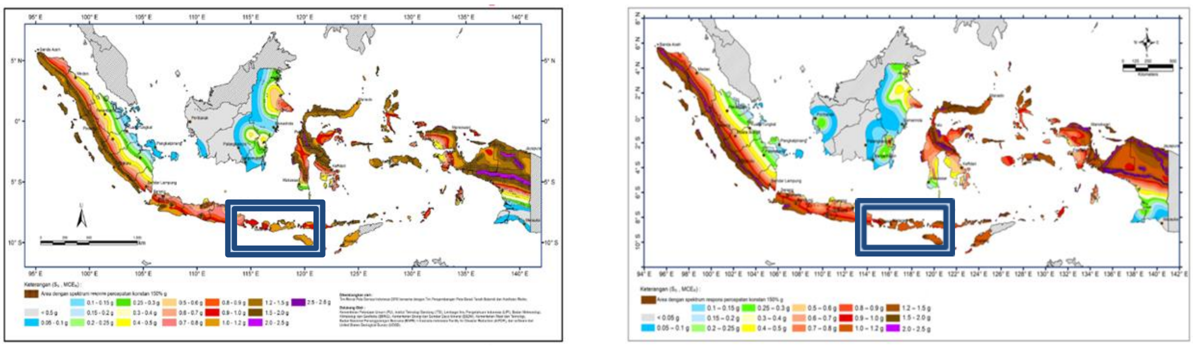
Furthermore, the effect of the 2018 Lombok earthquake PSHA results on the seismic coefficient C_S of buildings has been reported in [31]. It was described that due to the effect of the large earthquake, C_S increased in Mataram City by 10.8% for medium soil compared to the C_S calculated using the applicable SNI at that time, namely SNI 1976-2012. The increase in C_S was found much greater for soft soil, which was 13.2%. It is recommended to update the seismic code by considering the ground motion due to the Lombok earthquake.

In this paper, the seismic design parameters of the spectral acceleration due to the Lombok 2018 earthquake are compared with the latest code, namely SNI 1976-2019. The change in spectral acceleration must definitely affect the building seismic demand parameters. A comprehensive overview of the performance of the structures due to the change of spectral acceleration is discussed in terms of lateral force and building displacement of a four-story building located in Mataram City. The approaches from previous national seismic codes, SNI 1976-2012, are also included.

2. Materials and Methods

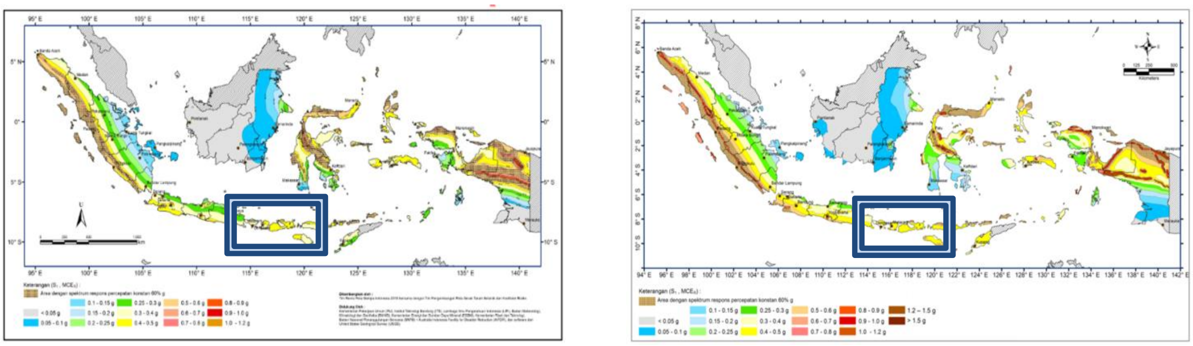
2.1. Seismic acceleration map

The seismic design maximum acceleration maps of the bedrock for the short period (T = 0.2 s (S_S)) and for the long period (T = 1 s (S_1)) with the probability of 2% exceeded in 50 years are provided by the codes: SNI 1726-2012 and SNI 1726-2019 are presented in **Figures 1-2,** respectively. **Figure 1** illustrates spectral acceleration maps in bedrocks for the short period, T = 0.2 s from SNI 1976-2012 and SNI 1976-2019. Meanwhile, **Figure 2** shows spectral acceleration maps in bedrocks for the long period, T = 1 from SNI 1976-2012 and SNI 1976-2019. In **Figures 1** and **2**, the location of Lombok and its surroundings are marked with a blue box shape. The seismic acceleration map in bedrock based on the PSHA results obtained after the Lombok earthquake is illustrated in **Figure 3** which consists of maps for the short and long periods. The epicenter locations of the series of earthquakes that occurred on Lombok in 2018 is marked with a blue circle on the map. The earthquake data set was collected from United States Geological Survey (USGS), the International Seismological Centre (ISC), and the Indonesian Centre for Meteorology, Climate and Geophysics (BMKG) for a period range between 1922 and 2018. The earthquake with a magnitude M_w of 4.5 was considered for the spectral acceleration calculation because this magnitude is a standard for earthquakes related to seismic disaster risk.



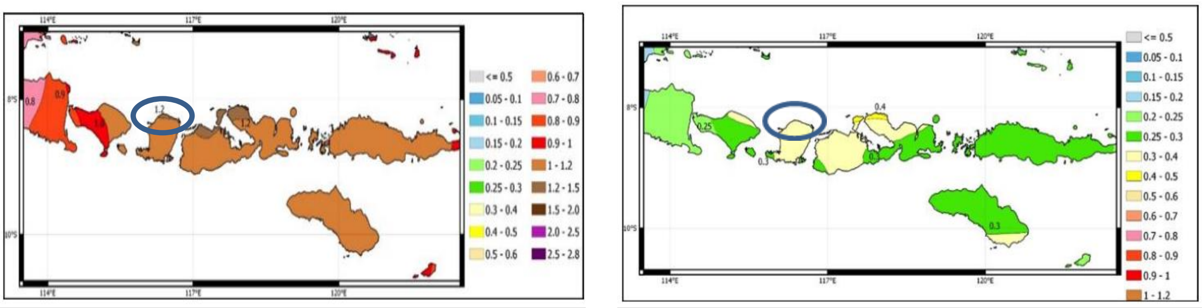
SNI 1976-2012 SNI 1976-2019

Figure 1 Spectral acceleration maps in bedrocks for the short period, T = 0.2 s from SNI 1976-2012 [24] and SNI 1976-2019 [25].



(a) SNI 1976-2012 (b) SNI 1976-2019

Figure 2 Spectral acceleration maps in bedrocks for the long period: T = 1 from (a) SNI 1976-2012 [24] and (b) SNI 1976-2019 [25].



(a) short period, T = 0.2 s (b) long period, T = 1 s

Figure 3 Lombok earthquake spectral acceleration maps in bedrocks for Mataram and surroundings: (a) for short period, T = 0.2 s and (b) for long period, T = 1 s [30], [31].

Based on the spectral acceleration maps in bedrocks described using the three approaches described earlier and the soil amplification factor of the building site location, the maximum consideration spectral acceleration was calculated for the short period (S_{MS}) and the long period (S_{M1}). Once the SMS and SM1 were obtained, the design spectral acceleration: SDS and SD1 were calculated respectively for the short and long periods. Furthermore, the response spectrum curve was generated according to S_{DS} and S_{D1}. The designed response spectrum was then applied to evaluate the seismic responses of the intended building.

2.2. Building configuration

The designed response spectrum was produced using three earthquake acceleration maps: SNI 1726-2012, SNI 1726-2019, and PSHA results obtained after Lombok earthquakes mentioned earlier. The differences of the design spectral acceleration were considered and applied as the parameter for analyzing the seismic response coefficient and structural responses.

Seismic coefficient and structural responses were observed in Mataram State Islamic University, which is located in Mataram City at the coordinates of latitude: -8.610232 and longitude: 116.100845. This educational building is a four-story reinforced concrete structure. The height of each story is 3.9 meters. The longitudinal direction consists of 8 spans with a total length is 44.28 meters. Meanwhile, four spans are in the transversal direction, with a total span length of 24.5 meters. The overview frame in longitudinal and transversal directions used for the seismic structural analysis is shown in **Figure 4**.

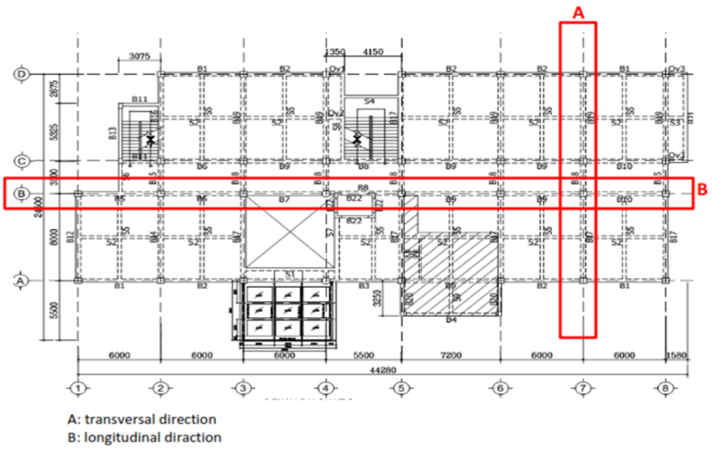
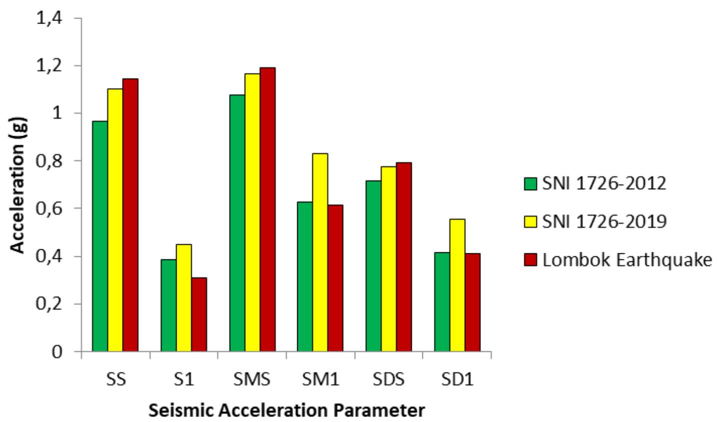


Figure 4 Plan of building in each story and the overview frame.

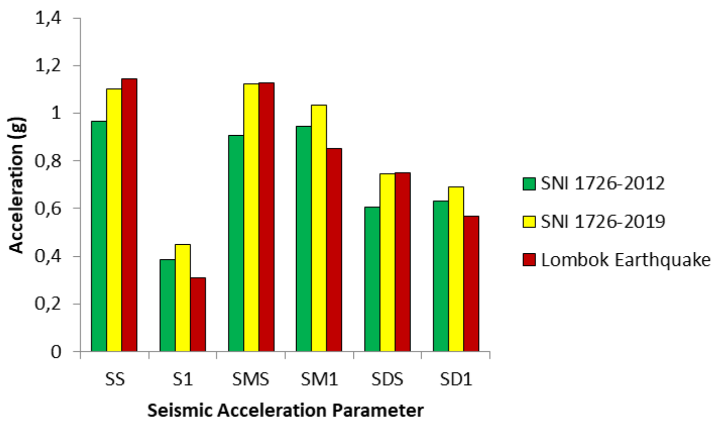
3. Results and Discussion

3.1. Spectral acceleration parameter

According to research in [32], the shear wave velocity of the surface sediment layer in Mataram City ranged between 135 m/s and 201 m/s. Therefore, based on the shear wave propagation velocity, Mataram City is included in the SD site class (medium soil) and SE site class (soft soil). The spectral acceleration of this area calculated based on SNI 1726-2012, SNI 1726-2019, and Lombok earthquake 2018 PSHA results are presented in **Figure 5 (a)** for medium soil, SD, and **Figure 5 (b)** for soft soil, SE.



a Medium Soil, SD



b Soft soil, SE

Figure 5 Spectral acceleration parameters.

From the seismic acceleration map of SNI 1726-2012, it is obtained that the bedrock acceleration parameters for T = 0.2 s, S_S is 0.966 g, and for T = 1 s, S_1 is 0.386 g. Meanwhile, based on SNI 1726-2019, S_S and S_1 values increase to 1.1 g and 0.45 g, respectively. The escalations are about 14% for S_S and 17% for S_1. The acceleration value at SNI 1726-2019 is more significant than SNI1726-2012 because some major earthquakes occurred in some areas in Indonesia between 2012 and 2017. As described earlier, SNI 1726-2019 adopted 2017 seismic acceleration maps from the National Center of Earthquake Studies. However, when the effect of the 2018 Lombok earthquake is considered, the S_S value changes to 1.143 g. This value increased by 18% against the S_S value on SNI 1726-2012 and increased by 4% compared to the S_S value from SNI 1726-2019. Meanwhile, the S1 value changed to 0.309 g, which decreased compared to the S1 value on both seismic codes.

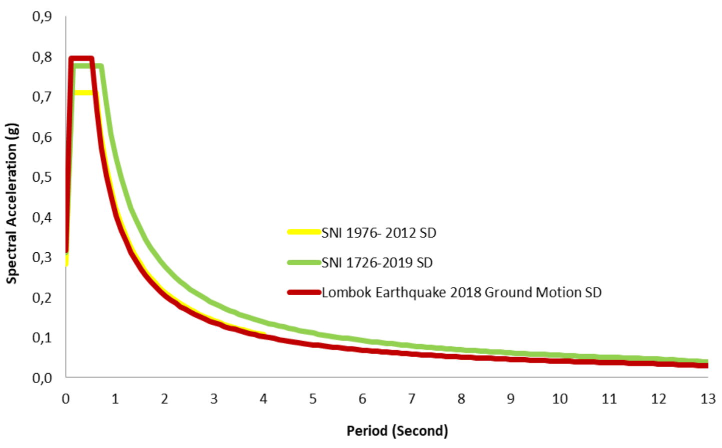
Furthermore, the short-period maximum acceleration value (S_{MS}) and short-period design acceleration (S_{DS}) due to the Lombok earthquake 2018 PSHA results effect are found to be greater than those calculated based on SNI 1976-2019. However, for the period T = 1 s, namely S_{M1} and S_{D1} are more generous in SNI 1726-2019. This occurs in both medium and soft soils.

The 2018 Lombok earthquake PSHA result has a more significant effect on short-period spectral acceleration; otherwise, both seismic codes have a more significant effect on the long-period spectral acceleration. This is because the acceleration in the long period is more influenced by far-field earthquakes, while the short period due to the PSHA results obtained after the 2018 Lombok earthquakes is more dominantly by near-field earthquakes. The near-field earthquakes tend to occur in shorter periods with higher acceleration. Meanwhile, the far-field earthquakes are in the more extended period [33], [34]. The difference in the value of spectral acceleration for the short period, S_{DS}, and for the long period, S_{D1}, can affect the seismic design category of the building [35], [36]. However, either the codes or the Lombok earthquake 2018 show the S_{DS} value greater than 0.5 g, and the S_{D1} was more significant than

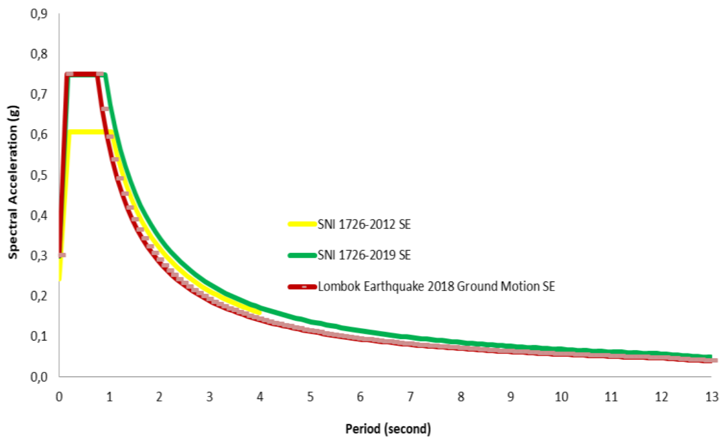
0.2 g. Thus there is no change for the seismic design category of the three approaches, namely remaining in the D-seismic design category. A building in this category needs a more detailed design in reinforcement due to possible severe ground shaking [35].

3.2. Response design spectrum curve

In principle, the typical shape of the response design spectrum between both codes and the 2018 Lombok earthquake PSHA results is substantially similar as illustrated in **Figure 6**. **Figure 6 (a)** describes medium soil, and **Figure 6 (b)** describes soft soil. SNI 1726-2019 has considered the existence of a more extended period on the spectral response curve. In both medium and soft soils, PSHA results obtained after Lombok earthquakes has a higher spectral acceleration value in short periods. For medium soils, the highest acceleration of SNI 1726- 2019 response design spectrum curve is 0.777 g, observed in a range of 0.143 s to 0.714 s. A higher acceleration is found in the Lombok earthquake's response design spectrum, namely 0.795 g over a more extended period, from 0.103 s to 0.516 s. The outdated code, SNI 1726-2012, gives the lowest acceleration on the curve peak.



a Medium soil, SD



b Soft soil, SE

Figure 6 Response spectrum curve.

Considering the spectral acceleration of the soft soil, it is observed that the acceleration peaks of the curve are lower than those that occurred in medium soil among the three response design spectrum curves. The spectral acceleration value on soft soil is generally more significant than the spectral acceleration value on medium soil. This aspect is found in the Mataram City spectral acceleration only for the long period. However, in the short period, the spectral acceleration value in soft soil is observed to be lower. This anomaly occurs because the short-period amplification factor in medium soils is lower than those in soft soils. The anomaly phenomena in which the SNI-1726-2019 spectral acceleration design of soft soil is lower than that of medium soil has been observed in 17 regions; even it is found that the spectral acceleration of site class of hard soil (SC) is higher in earthquake-prone areas [28].

3.3. Seismic response coefficient, C_S

Seismic response coefficient (C_S) is used to calculate the building's base shear during static equivalent analysis. This coefficient is a function of several buildings parameters, consists of spectral acceleration design, building fundamental period of vibration, building importance factor related to the building occupancy category, and building response modification factor which is determined by building type of seismic force resisting system [24], [25], [36], [37].

In this study, The C_S value is determined under several conditions: risk category for educational facilities = 4, importance factor = 1.5, and response modification factor = 8. As shown **in Figure 7**, the determined C_S and minimum C_S values are lower than the maximum C_S values for medium soils. Meanwhile, on soft soil, the maximum C_S is greater than the determined C_S and minimum C_S. The S_{DS} affects the determined C_S and the maximum C_S, while the S_{D1} affects the maximum C_S. The S_{DS} on medium soil is higher than soft soil so that it generates a higher determined C_S and minimum C_S. Likewise, the S_{D1} is found to be greater on soft soil, so the maximum C_S is found to be greater on soft soil. This trend occurs on both codes and also due to the 2018 Lombok earthquake.

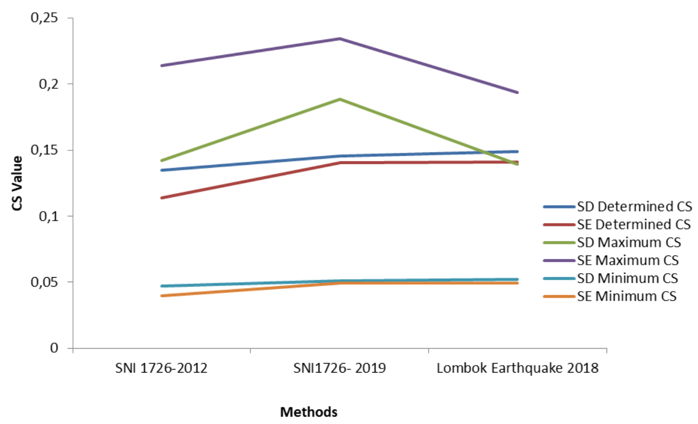


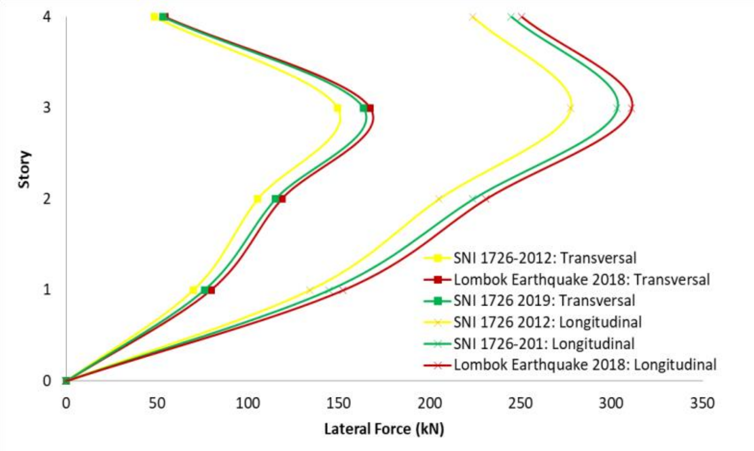
Figure 7 C_S Value Based On Three Approaches.

Due to S_{DS}'s effect by the 2018 Lombok earthquake, which is the highest among the three methods, this method has the highest value on the determined C_S and minimum C_S. However, the highest S_{D1} is found in SNI 1726-2019, so that the greatest value of maximum C_S is found in this method. In principle, the determined C_S cannot be greater than the maximum C_S and it cannot be less than the minimum C_S. The determined C_S due to the 2018 Lombok earthquake is slightly greater than the determined C_S on SNI 1726-2019 for both medium and soft soil.

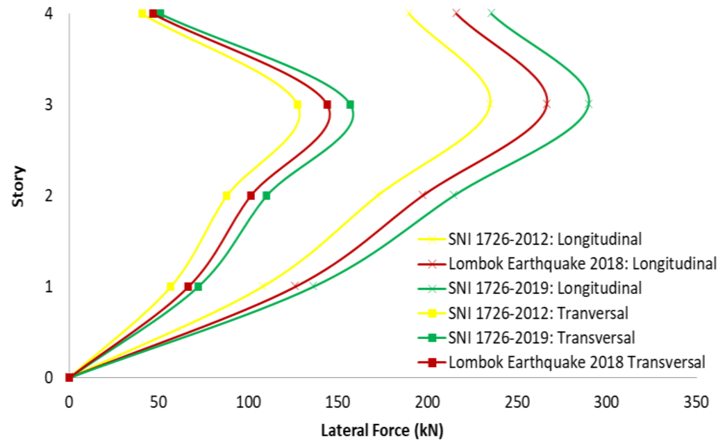
3.4. Building seismic responses

The lateral forces, shown in **Figure 8**, are calculated at the overviewed frame section of each longitudinal and transverse direction of the building. On medium soils, as illustrated in **Figure 8 (a)**, it can be seen that the most significant lateral force occurs when calculated based on the acceleration of the PSHA results obtained after the 2018 Lombok earthquakes. Minor lateral forces are obtained when calculated by the old code, namely SNI 2012. The lateral force calculated based on the 2018 Lombok earthquake's spectral acceleration is also more remarkable than the lateral force calculated based on SNI 1726-2019. This difference ranges from 2.3% to 5.4%, depending on the story height and direction of the building overviewed.

However, in soft soil (**Figure 8 (b)**), the largest lateral forces are found when calculated using SNI 1726-2019 Compared with the lateral force calculated by considering the acceleration of the PSHA results due to the 2018 Lombok earthquake, this value is 8%-9% greater depending on the storey height and direction of the building review. Soft soil generates a long-period response more than medium soils [38]. Therefore, the lateral force of SNI 1726-2019 is more significant because the spectral acceleration of soft soil at SNI 1726-2019 is greater than the spectral acceleration of soft soil due to the 2018 Lombok earthquake.



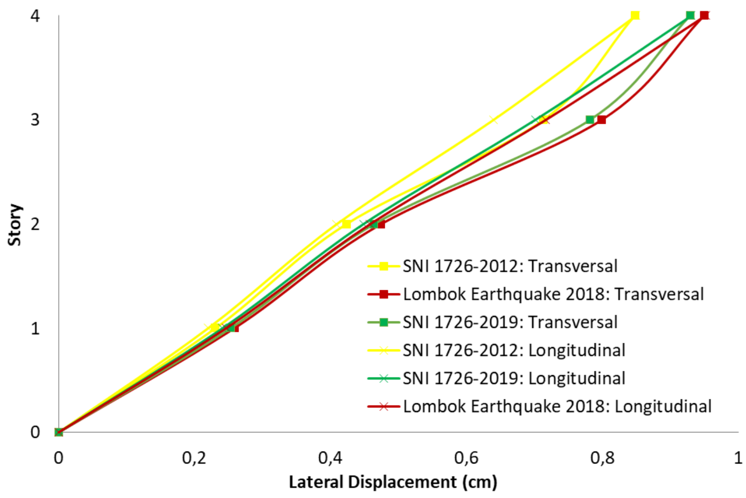
a Medium soil, SD



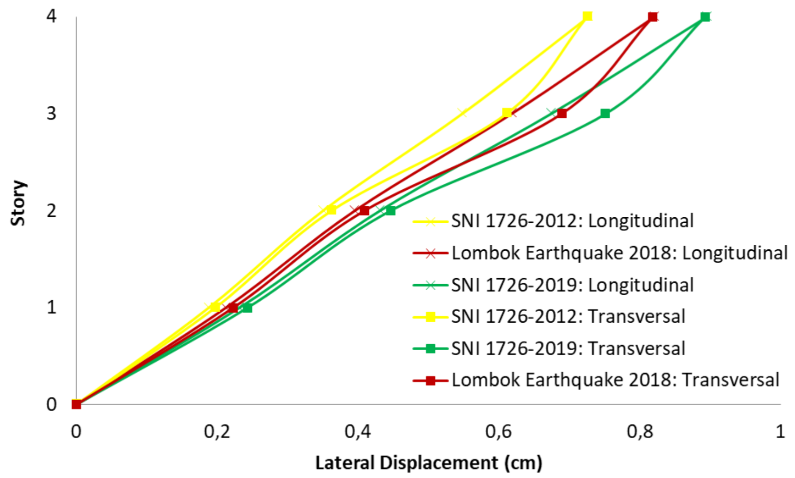
b Soft soil, SE

Figure 8 Lateral forces of overviewed frame section.

A similar phenomenon occurs in the building response in the form of a lateral displacement, as shown in **Figure 9**. On medium soil (**Figure 9 (a)**), the most significant lateral displacement occurred in the calculation with the 2018 Lombok earthquake. However, on soft soil (**Figure 9(b)**), the lateral displacement value calculated by the SNI 2019 response design spectrum is the greatest. Meanwhile, the smallest building lateral displacement was found when using the 2012 response design spectrum.



a Medium soil, SD



b Soft soil, SE

Figure 9 Lateral displacement of the overviewed frame section.

The seismic response of buildings on medium soil is being found to be greater if the response design spectrum for the PSHA results of the 2018 Lombok earthquake is used in the calculation compared to the two seismic codes in Indonesia.

Furthermore, the performance-based using pushover analysis has been added to perform the building capacity. According to the analysis, when the three response design spectrum of the medium soil was applied, clearly SNI 2019 gives the higher base shear and displacement.

However, according to the performance level, the three response design spectrums show the same level of performance, namely immediate occupancy. Immediate occupancy means the structure is safe in the occurrence of an earthquake but with minimal damage. Strength and stiffness are approximately equal to pre-earthquake conditions. In addition, the vertical and lateral structural resisting systems are still capable sustain earthquake load [36].

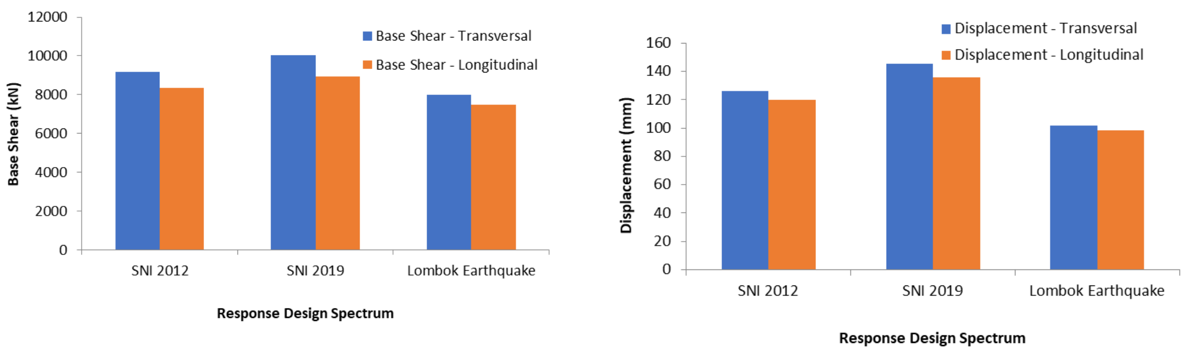


Figure 10. Performance Point for Base Shear and Displacement

All efforts to reduce earthquake hazards need to be carried out with preventive measures for disaster management. One of the efforts made is updating the Earthquake Hazard Map, which is usually updated every year or after such a strong earthquake stroke. For Indonesia, it is attempted no later than every five years [26]. In this paper, although there is only a 4% increase in the short period bedrock's acceleration, it is necessary to update the map because it has existed for five years. Moreover, using the PSHA results obtained after the Lombok earthquakes, the design response spectrum increases the seismic building responses. In addition, some new fault characterizations have been studied after the sequence of the Lombok 2018 earthquake [39], [40]. Therefore, updating the earthquake map is suggested to the next Indonesian code to this area to improve seismic mitigation. Seismic code updates provide preparedness for either new buildings or strengthen existing buildings towards better structural seismic responses for future earthquakes. Similar recommendations related to seismic disaster risk reduction in this area have been proposed by other studies [5], [6], [30], [31], [41].

4. Conclusions

The bedrock acceleration in the short period (S_S), respectively from the greatest to the smallest, is 1.143 g based on the PSHA results obtained after the 2018 Lombok earthquakes, 1.1 g based on the SNI 1726-2019 seismic map, and 0.966 g based on the SNI 1726-2012 earthquake map. Meanwhile, the highest value of bedrock acceleration in the long period (S_1) is found in SNI 1726-2019. The old, outdated code, SNI 1726-2019, provides the lowest value of bedrock acceleration.

In principle, the typical shape of the response spectrum between both codes and the 2018 Lombok earthquake ground motion is similar. In both medium and soft soils, Lombok earthquake PSHA results have a higher spectral acceleration value in the short period, while SNI 1726-2019 has superior existence of the long period on the response design spectrum curve.

Due to the effect of the higher value of S_{DS}, either on medium or soft soil, the determined seismic response coefficient, C_S, due to the PSHA results of the 2018 Lombok earthquake is slightly more significant than the determined C_S analyzed by SNI 1726-2019. In addition, the building seismic response in terms of lateral forces and displacements on medium soil is more enormous when analyzed using the response spectrum due to the PSHA results obtained after the Lombok earthquakes. Furthermore, it is essential to update the seismic codes by accommodating the effect of the Lombok 2018 earthquake to support risk reduction of earthquake disasters in the future.

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Ref. No: SCI-2105-5702

"Comments to the Authors"

Section 3.4, paragraph below Fig.10 Caption. "All efforts to reduce earthquake hazards need to be carried out with preventive measures..." Actually, earthquake hazard cannot be reduced, because the term "Earthquake Hazard" relates to any physical phenomenon associated with an earthquake. As a rule, the term is applied to indicate level of ground motion. However, it may be possible to reduce earthquake damage and risk - probability of that specified loss will exceed some level. Please revise the text.

TABLES OF AUTHOR'S RESPONSES

Comments to the Authors	Author's Responses
Section 3.4, paragraph below Fig.10 Caption. "All efforts to reduce earthquake hazards need to be carried out with preventive measures..." Actually, earthquake hazard cannot be reduced, because the term "Earthquake Hazard" relates to any physical phenomenon associated with an earthquake. As a rule, the term is applied to indicate level of ground motion. However, it may be possible to reduce earthquake damage and risk - probability of that specified loss will exceed some level. Please revise the text.	The authors would like to appreciate the valuable comment and apologize for setting the wrong term. The revision has been made to the intended text. Earthquake hazard has been replaced with earthquake damage and risk. Thus the sentence changes to: "All efforts to reduce earthquake damage and risk need to be carried out with preventive measures for disaster management." Please kindly refer to the yellow highlighted text for the revision in the manuscript.

A New Approach on Structural Seismic Responses in Mataram City: Based on the PSHA Results Obtained after Lombok Earthquakes 2018

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Abstract

In the last few years, several major earthquakes in Indonesia have prompted an update of the building seismic resistance code. SNI 1726-2019 is the newest Indonesia seismic code. However, the change of PSHA results due to the 2018 Lombok Earthquake has not been accommodated in this code because it adopts the 2017 seismic maps from National Center for Earthquakes Studies. This paper studied spectral acceleration parameters according to the previous seismic codes (SNI 1976-2012) and current seismic code (SNI 1976-2019) and the PSHA results obtained after the Lombok earthquakes in 2018.The spectral accelerations were applied to a building structure located in Mataram City to analyze the seismic building responses. The results indicate that the seismic parameters of the PSHA result obtained after Lombok earthquakes lead to higher seismic demands structures than the codes either SNI 1726- 2012 or SNI 1726- 2019, especially for structures located in medium soil type. The current code needs to be immediate improved for the sake of earthquake mitigation resilience in this area.

Keywords: Spectral acceleration, Lombok earthquake series, seismic codes, seismic responses

1. Introduction

A series of Lombok earthquake events in 2018 were triggered by upward fault activity in the north of Lombok. The activity generated six earthquakes which had magnitudes greater than 5.5. Furthermore, apart from earthquakes of relatively smaller magnitude, the National Agency for Meteorology, Climatology, and Geophysics recorded that the aftershocks with lower magnitude were more than 2000 events. The first earthquake started with a magnitude of 6.4 on July 29, 2018. Then on August 5, 2018, an earthquake with a magnitude of 6.9 at a hypocenter depth of 34 km again hit northern Lombok. Four days later, on August 9, 2018, an earthquake with a magnitude of 5.9 occurred, with the center moved to the west. Ten days later, on August 19, 2018, two large earthquakes with a magnitude of 6.3 occurred in the afternoon with a hypocenter depth of 7.9 km, and a magnitude 7.0 (later updated to a magnitude 6.9) occurred at night with a hypocenter depth of 25 km with a position to the east. The sixth earthquake with a magnitude of 5.5 occurred on August 25, 2018, centered on the east of Lombok. **Figure 1** shows the topography and tectonic areas of Indonesia, where the island of Lombok is indicated by a red circle [1]. Then the six major earthquakes occurrence are explained in **Figure 2** as a black circle and blue inside; meanwhile, the red circle provides the distribution of aftershocks that occurred from July 29–September 10, 2018. The mechanism of earthquake focus and hypocenter data was obtained from the USGS catalog [2]. According to the national disaster management agency, this series of earthquakes damaged buildings as many as 71962 damaged houses, 671 damaged educational facilities, 52 health facilities, 128 prayer facilities. They even collapsed in some areas, including Mataram City [2]–[6].

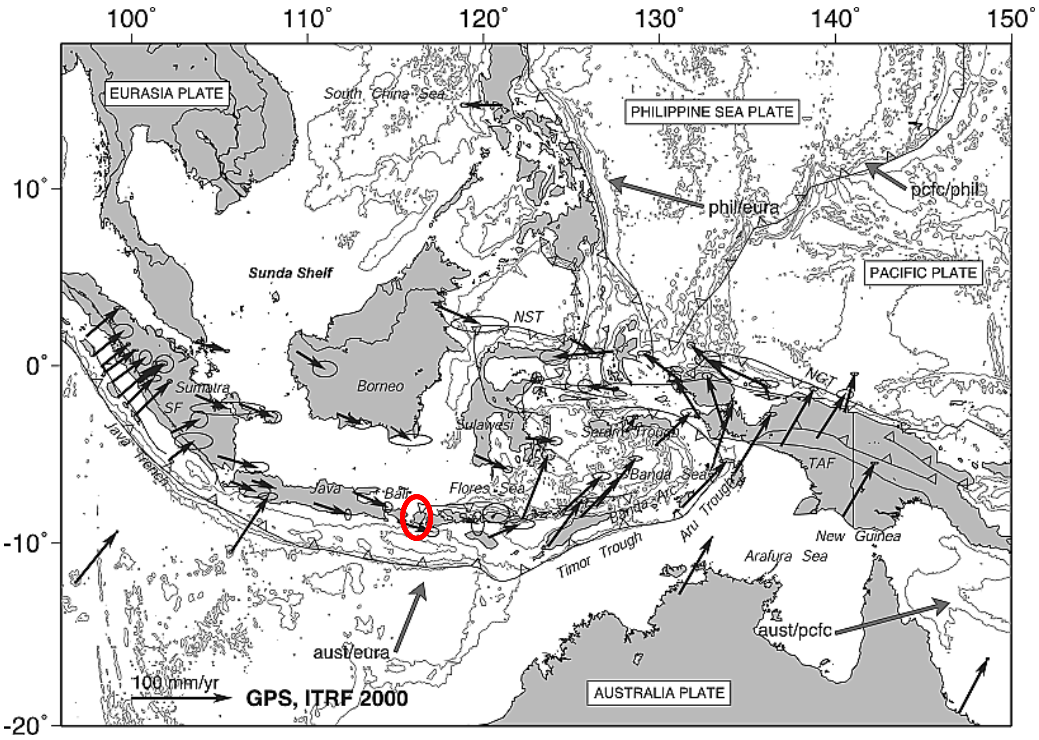


Figure 1 Topography and tectonics of the Indonesia region with the Island of Lombok in a red circle [1]

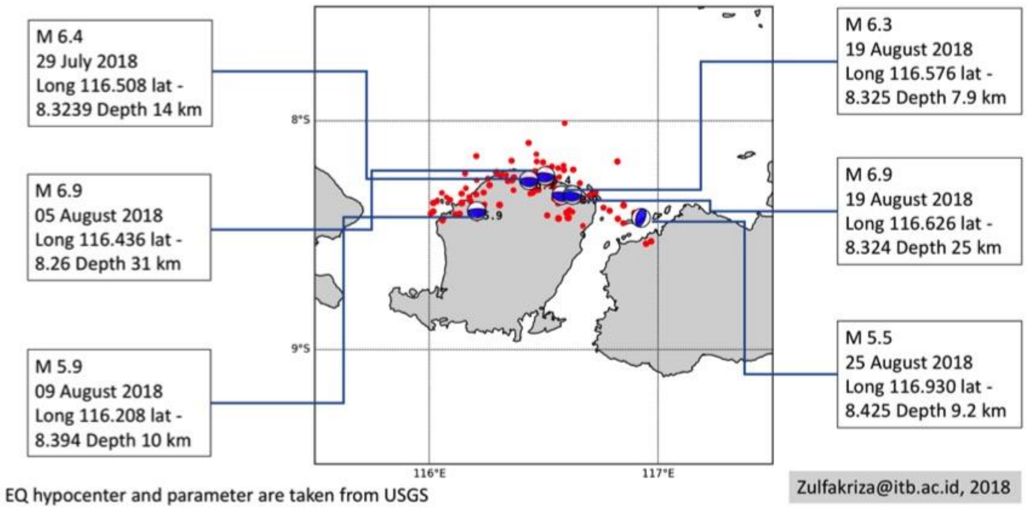


Figure 2 Distribution of Lombok earthquake occurrence [2]

A large amount of damage to building structures caused by strong earthquakes has inevitably urged the government to renew the existing building seismic resistance design code. Changes in the code carried out by the government worldwide are intended to accommodate the latest earthquake events [7], [8], [17], [9]–[16]. This includes evaluating the seismic performances on existing structures after such large earthquakes stroke the countries [18]–[22]. In Indonesia, one of the government's seismic codes was SNI 1726-2002 [23], and then updated it to SNI 1726-2012 [24]. The latest version was published in 2019 [25].

In SNI 1726-2002, the seismic hazard map was divided into six earthquake zones, where each zone was classified based on the peak acceleration of the bedrock and had the same response design spectrum. However, based on the latest geological studies of the earth's plate, which influenced the earthquake region, improved the code into SNI 1726- 2012. According to this code, each region or location had a different response design spectrum because it was determined based on the ground motion parameters Ss and S_1. The peak ground acceleration (PGA) of SNI 1726-2002 was based on a 10% probability of being exceeded in 50 years. The return period was 500 years. After several great earthquakes, there was a change in the Indonesian seismic hazard map; therefore, this code was replaced by SNI 1976-2012. This replacement seismic code had a peak ground motion with a 2% probability of being exceeded in 50 years or a return period of 2475 years for the spectral acceleration. Updating the seismic hazard map has been carried out and produced the latest seismic code, SNI 1976-2019. The seismic spectral acceleration is based on the 2017 seismic hazard map National Earthquake Center [26], [27].

The National Center for Earthquake Studies updated the National Earthquake Map in 2017. The series of research results, studies, and publications related to Indonesia's latest earthquake source parameters, including geology in some areas and earthquake relocation data, have contributed significantly to updating the source maps and the hazards. Therefore, SNI 1726-2012 was renewed to SNI 1726-2019 and has been becoming the current seismic code in Indonesia. In this code, some major earthquake-prone areas show increased spectral acceleration [27], [28]. However, change is not significantly found for the area that has not been much affected by the seismic occurrence, such as Mataram City. In fact, Lombok area was stroke by strong earthquakes in 2018. The increase is not so sharply seen in Lombok because SNI 1976-2019 has accommodated the 2017 earthquake map.

According to [29], theoretically, one reason for the uncertainty of building collapse due to earthquakes is spectral acceleration. The structures can resist without collapsing, depending on the spectral acceleration produced according to ground motion characteristics. In the case of the Lombok earthquake in 2018, many damaged structures were found, even in Mataram City, the major city in Lombok Island, which was located around 47 km away from the largest epicenter of the earthquake series. PSHA results obtained after the Lombok earthquakes have strongly influenced the spectral acceleration as studied by [30], [31].

Considering the 2018 Lombok earthquakes, an analysis is conducted based on a probabilistic seismic hazard analysis using a detailed tectonic background and the appropriate ground motion equations. The analysis is aimed to determine the seismic parameters that are more suitable with the ground motion that occurs due to a strong earthquake that has occurred and comparing it with the model published by the National Center for Earthquake Studies in 2017. The sources used in the National Center for Earthquake Studies are subduction, back-arc, and strikes slip faults for Lombok and surroundings, meanwhile in 2018 Lombok earthquake used only subduction and back-arc because they are the most dominant. The earthquake data records used in the Lombok earthquake model are until 2018, while the data used in National Center for Earthquake Studies model is until 2016. Thus, the *a* and *b* values are more updated in the recent Lombok earthquake 2018 model. However, the ground motion equations of the National Center for Earthquake Studies and the Lombok earthquake 2018 are nearly identical. Furthermore, it was found that Lombok and its surrounding islands show a significant seismic hazard than the model published by the National Earthquake Study Center in 2017. This is because the model was estimated before the 2018 earthquake. Therefore, updating the seismic hazard map for Lombok and surrounding islands are proposed by considering the effect of the strong earthquakes [30].

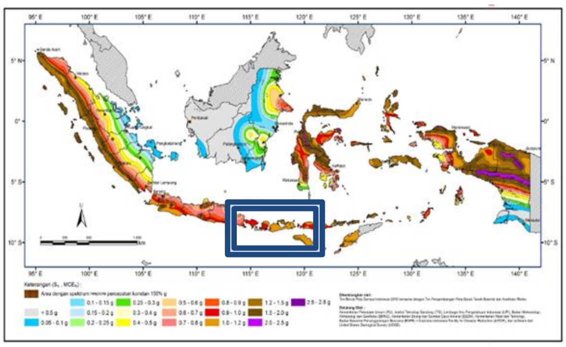
Furthermore, the effect of the 2018 Lombok earthquake PSHA results on the seismic coefficient C_S of buildings has been reported in [31]. It was described that due to the effect of the large earthquake, C_S increased in Mataram City by 10.8% for medium soil compared to the C_S calculated using the applicable SNI at that time, namely SNI 1976-2012. The increase in C_S was found much greater for soft soil, which was 13.2%. It is recommended to update the seismic code by considering the ground motion due to the Lombok earthquake.

In this paper, the seismic design parameters of the spectral acceleration due to the Lombok 2018 earthquake are compared with the latest code, namely SNI 1976-2019. The change in spectral acceleration must definitely affect the building seismic demand parameters. A comprehensive overview of the performance of the structures due to the change of spectral acceleration is discussed in terms of lateral force and building displacement of a four-story building located in Mataram City. The approaches from previous national seismic codes, SNI 1976-2012, are also included.

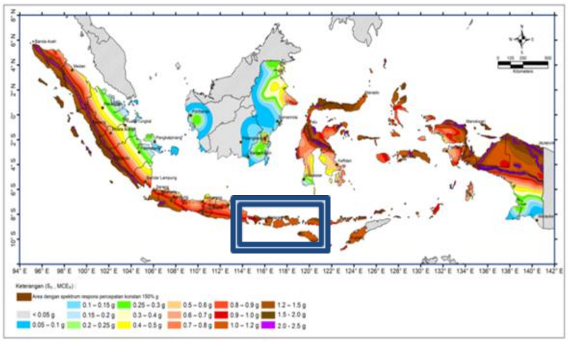
2. Materials and Methods

2.1. Seismic acceleration map

The seismic design maximum acceleration maps of the bedrock for the short period (T = 0.2 s (S_S)) and for the long period (T = 1 s (S_1)) with the probability of 2% exceeded in 50 years are provided by the codes: SNI 1726-2012 and SNI 1726-2019 are presented in **Figures 1-2,** respectively. **Figure 1** illustrates spectral acceleration maps in bedrocks for the short period, T = 0.2 s from SNI 1976-2012 and SNI 1976-2019. Meanwhile, **Figure 2** shows spectral acceleration maps in bedrocks for the long period, T = 1 from SNI 1976-2012 and SNI 1976-2019. In **Figures 1** and **2**, the location of Lombok and its surroundings are marked with a blue box shape. The seismic acceleration map in bedrock based on the PSHA results obtained after the Lombok earthquake is illustrated in **Figure 3** which consists of maps for the short and long periods. The epicenter locations of the series of earthquakes that occurred on Lombok in 2018 is marked with a blue circle on the map. The earthquake data set was collected from United States Geological Survey (USGS), the International Seismological Centre (ISC), and the Indonesian Centre for Meteorology, Climate and Geophysics (BMKG) for a period range between 1922 and 2018. The earthquake with a magnitude M_w of 4.5 was considered for the spectral acceleration calculation because this magnitude is a standard for earthquakes related to seismic disaster risk.

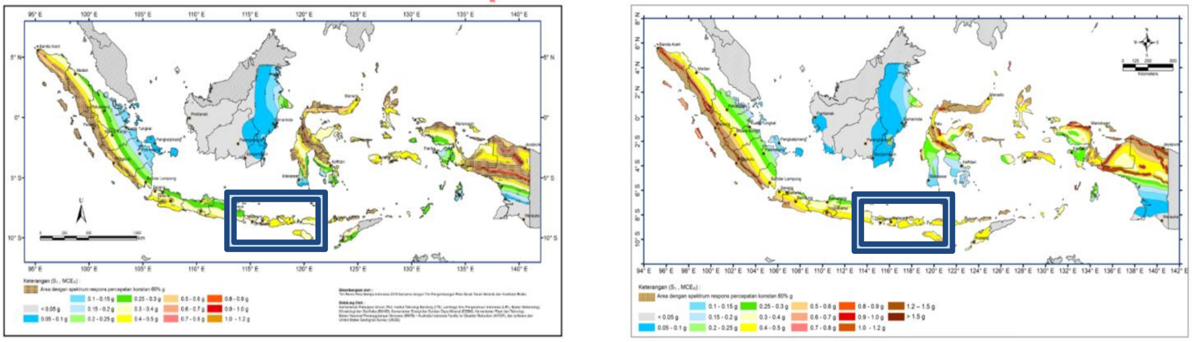


SNI 1976-2012



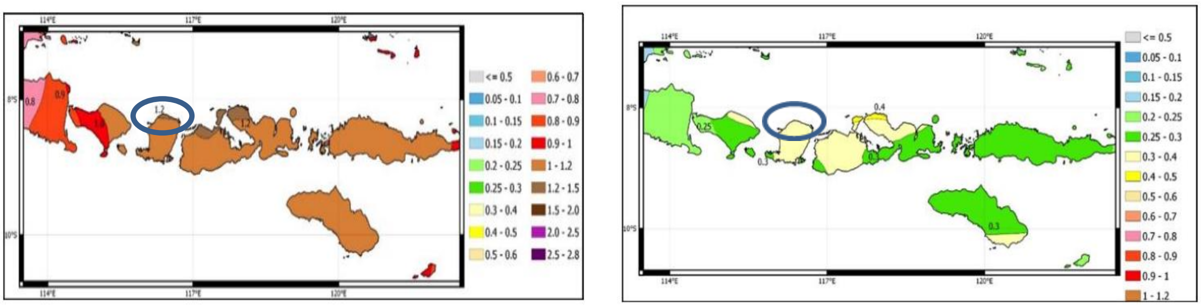
SNI 1976-2019

Figure 1 Spectral acceleration maps in bedrocks for the short period, T = 0.2 s from SNI 1976-2012 [24] and SNI 1976-2019 [25].



(a) SNI 1976-2012 (b) SNI 1976-2019

Figure 2 Spectral acceleration maps in bedrocks for the long period: T = 1 from (a) SNI 1976-2012 [24] and (b) SNI 1976-2019 [25].



(a) short period, T = 0.2 s (b) long period, T = 1 s

Figure 3 Lombok earthquake spectral acceleration maps in bedrocks for Mataram and surroundings: (a) for short period, T = 0.2 s and (b) for long period, T = 1 s [30], [31].

Based on the spectral acceleration maps in bedrocks described using the three approaches described earlier and the soil amplification factor of the building site location, the maximum consideration spectral acceleration was calculated for the short period (S_{MS}) and the long period (S_{M1}). Once the SMS and SM1 were obtained, the design spectral acceleration: SDS and SD1 were calculated respectively for the short and long periods. Furthermore, the response spectrum curve was generated according to S_{DS} and S_{D1}. The designed response spectrum was then applied to evaluate the seismic responses of the intended building.

2.2. Building configuration

The designed response spectrum was produced using three earthquake acceleration maps: SNI 1726-2012, SNI 1726-2019, and PSHA results obtained after Lombok earthquakes mentioned earlier. The differences of the design spectral acceleration were considered and applied as the parameter for analyzing the seismic response coefficient and structural responses.

Seismic coefficient and structural responses were observed in Mataram State Islamic University, which is located in Mataram City at the coordinates of latitude: -8.610232 and longitude: 116.100845. This educational building is a four-story reinforced concrete structure. The height of each story is 3.9 meters. The longitudinal direction consists of 8 spans with a total length is 44.28 meters. Meanwhile, four spans are in the transversal direction, with a total span length of 24.5 meters. The overview frame in longitudinal and transversal directions used for the seismic structural analysis is shown in **Figure 4**.

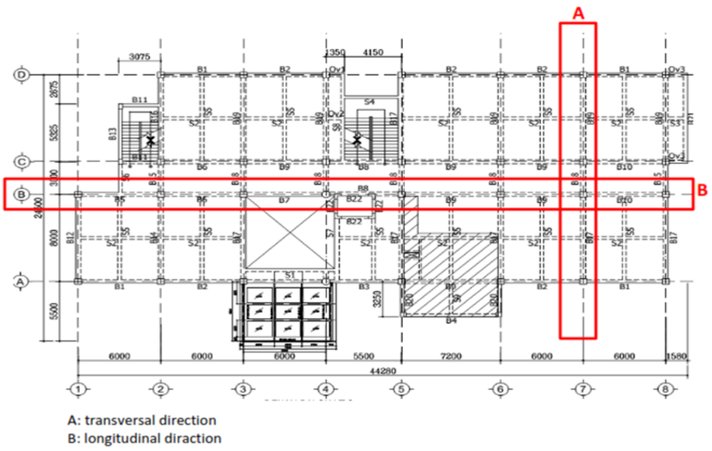
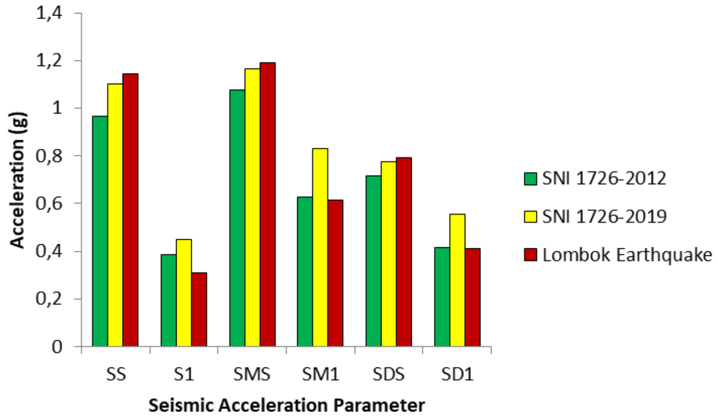


Figure 4 Plan of building in each story and the overview frame.

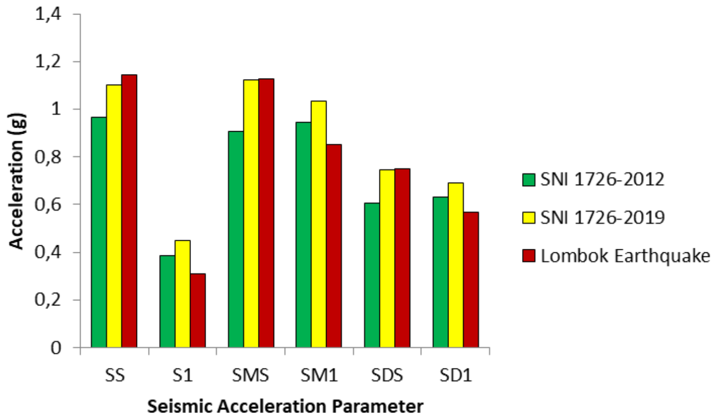
3. Results and Discussion

3.1. Spectral acceleration parameter

According to research in [32], the shear wave velocity of the surface sediment layer in Mataram City ranged between 135 m/s and 201 m/s. Therefore, based on the shear wave propagation velocity, Mataram City is included in the SD site class (medium soil) and SE site class (soft soil). The spectral acceleration of this area calculated based on SNI 1726-2012, SNI 1726-2019, and Lombok earthquake 2018 PSHA results are presented in **Figure 5 (a)** for medium soil, SD, and **Figure 5 (b)** for soft soil, SE.



a Medium Soil, SD



b Soft soil, SE

Figure 5 Spectral acceleration parameters.

From the seismic acceleration map of SNI 1726-2012, it is obtained that the bedrock acceleration parameters for T = 0.2 s, S_S is 0.966 g, and for T = 1 s, S_1 is 0.386 g. Meanwhile, based on SNI 1726-2019, S_S and S_1 values increase to 1.1 g and 0.45 g, respectively. The escalations are about 14% for S_S and 17% for S_1. The acceleration value at SNI 1726-2019 is more significant than SNI1726-2012 because some major earthquakes occurred in some areas in Indonesia between 2012 and 2017. As described earlier, SNI 1726-2019 adopted 2017 seismic acceleration maps from the National Center of Earthquake Studies. However, when the effect of the 2018 Lombok earthquake is considered, the S_S value changes to 1.143 g. This value increased by 18% against the S_S value on SNI 1726-2012 and increased by 4% compared to the S_S value from SNI 1726-2019. Meanwhile, the S1 value changed to 0.309 g, which decreased compared to the S1 value on both seismic codes.

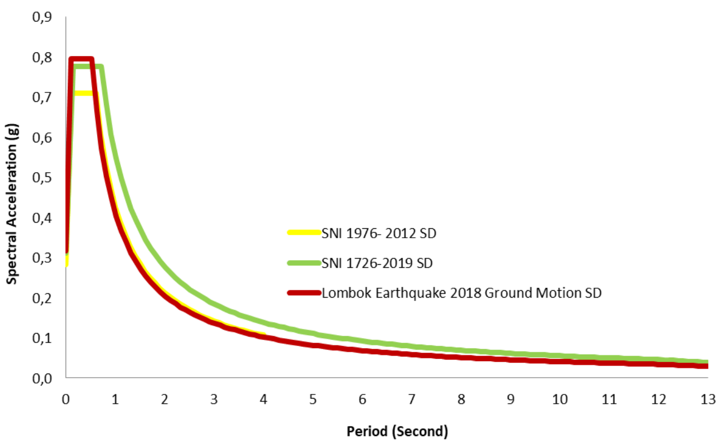
Furthermore, the short-period maximum acceleration value (S_{MS}) and short-period design acceleration (S_{DS}) due to the Lombok earthquake 2018 PSHA results effect are found to be greater than those calculated based on SNI 1976-2019. However, for the period T = 1 s, namely S_{M1} and S_{D1} are more generous in SNI 1726-2019. This occurs in both medium and soft soils.

The 2018 Lombok earthquake PSHA result has a more significant effect on short-period spectral acceleration; otherwise, both seismic codes have a more significant effect on the long-period spectral acceleration. This is because the acceleration in the long period is more influenced by far-field earthquakes, while the short period due to the PSHA results obtained after the 2018 Lombok earthquakes is more dominantly by near-field earthquakes. The near-field earthquakes tend to occur in shorter periods with higher acceleration. Meanwhile, the far-field earthquakes are in the more extended period [33], [34]. The difference in the value of spectral acceleration for the short period, S_{DS}, and for the long period, S_{D1}, can affect the seismic design category of the building [35], [36]. However, either the codes or the Lombok earthquake 2018 show the S_{DS} value greater than 0.5 g, and the S_{D1} was more significant than

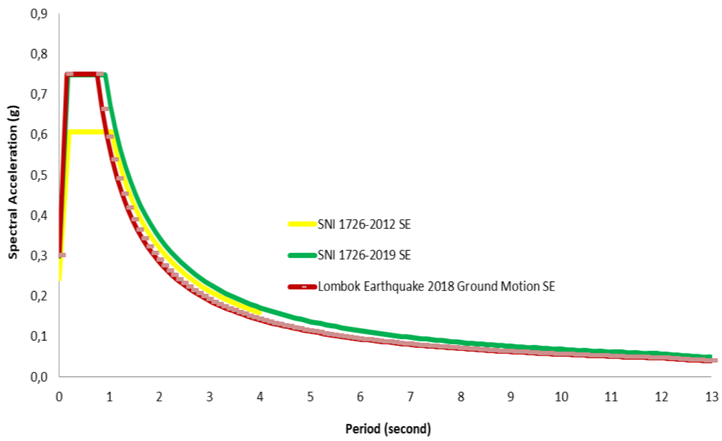
0.2 g. Thus there is no change for the seismic design category of the three approaches, namely remaining in the D-seismic design category. A building in this category needs a more detailed design in reinforcement due to possible severe ground shaking [35].

3.2. Response design spectrum curve

In principle, the typical shape of the response design spectrum between both codes and the 2018 Lombok earthquake PSHA results is substantially similar as illustrated in **Figure 6**. **Figure 6 (a)** describes medium soil, and **Figure 6 (b)** describes soft soil. SNI 1726-2019 has considered the existence of a more extended period on the spectral response curve. In both medium and soft soils, PSHA results obtained after Lombok earthquakes has a higher spectral acceleration value in short periods. For medium soils, the highest acceleration of SNI 1726- 2019 response design spectrum curve is 0.777 g, observed in a range of 0.143 s to 0.714 s. A higher acceleration is found in the Lombok earthquake's response design spectrum, namely 0.795 g over a more extended period, from 0.103 s to 0.516 s. The outdated code, SNI 1726-2012, gives the lowest acceleration on the curve peak.



a Medium soil, SD



b Soft soil, SE

Figure 6 Response spectrum curve.

Considering the spectral acceleration of the soft soil, it is observed that the acceleration peaks of the curve are lower than those that occurred in medium soil among the three response design spectrum curves. The spectral acceleration value on soft soil is generally more significant than the spectral acceleration value on medium soil. This aspect is found in the Mataram City spectral acceleration only for the long period. However, in the short period, the spectral acceleration value in soft soil is observed to be lower. This anomaly occurs because the short-period amplification factor in medium soils is lower than those in soft soils. The anomaly phenomena in which the SNI-1726-2019 spectral acceleration design of soft soil is lower than that of medium soil has been observed in 17 regions; even it is found that the spectral acceleration of site class of hard soil (SC) is higher in earthquake-prone areas [28].

3.3. Seismic response coefficient, C_S

Seismic response coefficient (C_S) is used to calculate the building's base shear during static equivalent analysis. This coefficient is a function of several buildings parameters, consists of spectral acceleration design, building fundamental period of vibration, building importance factor related to the building occupancy category, and building response modification factor which is determined by building type of seismic force resisting system [24], [25], [36], [37].

In this study, The C_S value is determined under several conditions: risk category for educational facilities = 4, importance factor = 1.5, and response modification factor = 8. As shown **in Figure 7**, the determined C_S and minimum C_S values are lower than the maximum C_S values for medium soils. Meanwhile, on soft soil, the maximum C_S is greater than the determined C_S and minimum C_S. The S_{DS} affects the determined C_S and the maximum C_S, while the S_{D1} affects the maximum C_S. The S_{DS} on medium soil is higher than soft soil so that it generates a higher determined C_S and minimum C_S. Likewise, the S_{D1} is found to be greater on soft soil, so the maximum C_S is found to be greater on soft soil. This trend occurs on both codes and also due to the 2018 Lombok earthquake.

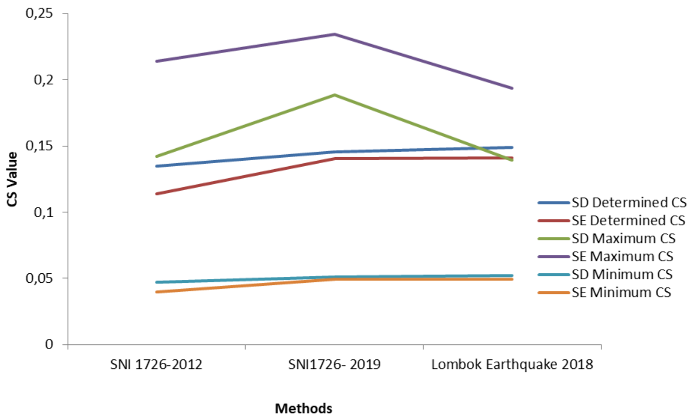


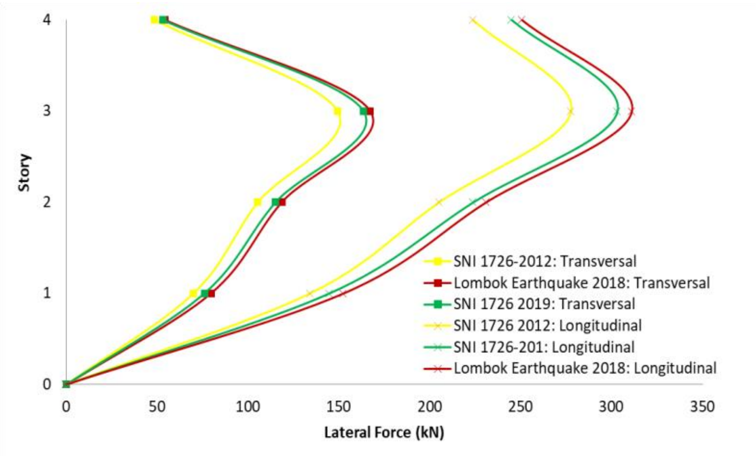
Figure 7 C_S Value Based On Three Approaches.

Due to S_{DS}'s effect by the 2018 Lombok earthquake, which is the highest among the three methods, this method has the highest value on the determined C_S and minimum C_S. However, the highest S_{D1} is found in SNI 1726-2019, so that the greatest value of maximum C_S is found in this method. In principle, the determined C_S cannot be greater than the maximum C_S and it cannot be less than the minimum C_S. The determined C_S due to the 2018 Lombok earthquake is slightly greater than the determined C_S on SNI 1726-2019 for both medium and soft soil.

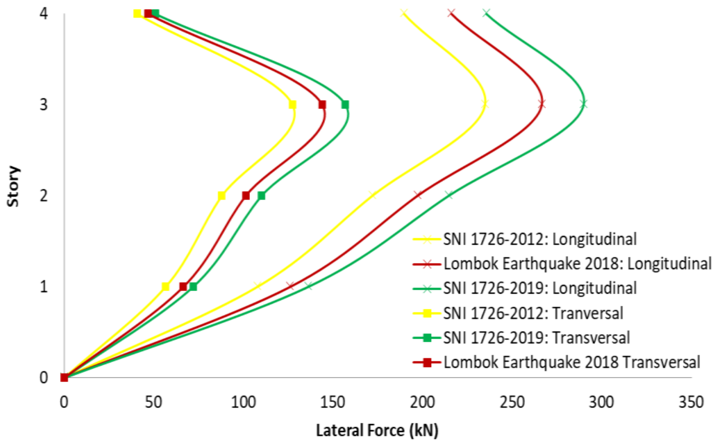
3.4. Building seismic responses

The lateral forces, shown in **Figure 8**, are calculated at the overviewed frame section of each longitudinal and transverse direction of the building. On medium soils, as illustrated in **Figure 8 (a)**, it can be seen that the most significant lateral force occurs when calculated based on the acceleration of the PSHA results obtained after the 2018 Lombok earthquakes. Minor lateral forces are obtained when calculated by the old code, namely SNI 2012. The lateral force calculated based on the 2018 Lombok earthquake's spectral acceleration is also more remarkable than the lateral force calculated based on SNI 1726-2019. This difference ranges from 2.3% to 5.4%, depending on the story height and direction of the building overviewed.

However, in soft soil (**Figure 8 (b)**), the largest lateral forces are found when calculated using SNI 1726-2019 Compared with the lateral force calculated by considering the acceleration of the PSHA results due to the 2018 Lombok earthquake, this value is 8%-9% greater depending on the storey height and direction of the building review. Soft soil generates a long-period response more than medium soils [38]. Therefore, the lateral force of SNI 1726-2019 is more significant because the spectral acceleration of soft soil at SNI 1726-2019 is greater than the spectral acceleration of soft soil due to the 2018 Lombok earthquake.



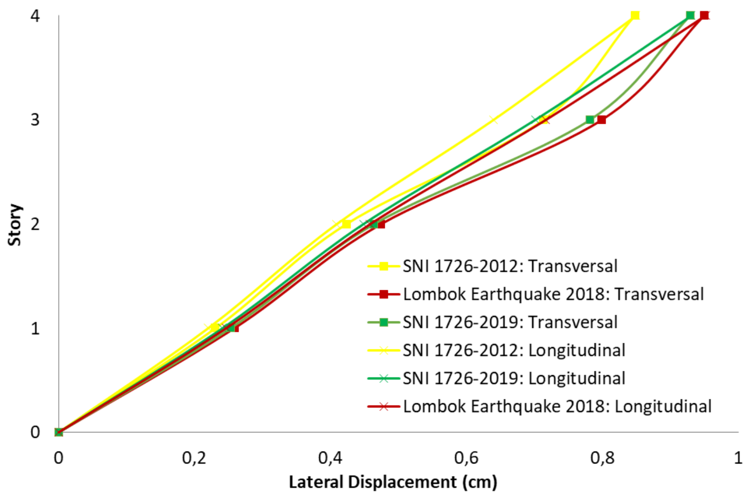
a Medium soil, SD



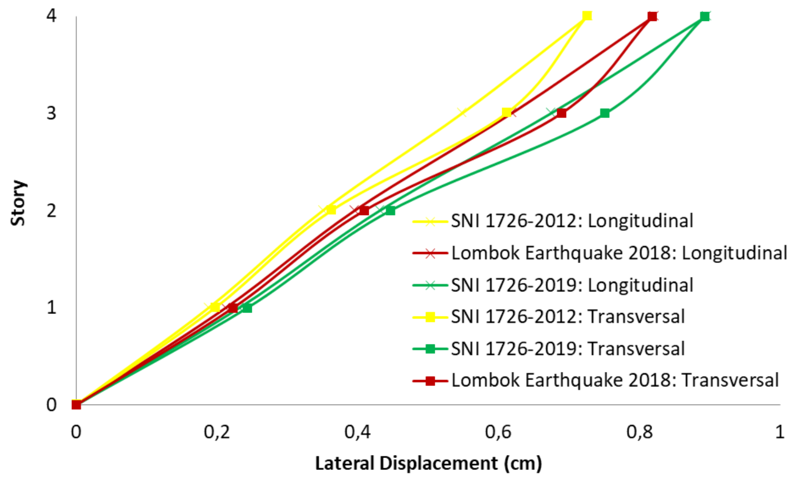
b Soft soil, SE

Figure 8 Lateral forces of overviewed frame section.

A similar phenomenon occurs in the building response in the form of a lateral displacement, as shown in **Figure 9**. On medium soil (**Figure 9 (a)**), the most significant lateral displacement occurred in the calculation with the 2018 Lombok earthquake. However, on soft soil (**Figure 9(b)**), the lateral displacement value calculated by the SNI 2019 response design spectrum is the greatest. Meanwhile, the smallest building lateral displacement was found when using the 2012 response design spectrum.



a Medium soil, SD



b Soft soil, SE

Figure 9 Lateral displacement of the overviewed frame section.

The seismic response of buildings on medium soil is being found to be greater if the response design spectrum for the PSHA results of the 2018 Lombok earthquake is used in the calculation compared to the two seismic codes in Indonesia.

Furthermore, the performance-based using pushover analysis has been added to perform the building capacity. According to the analysis, when the three response design spectrum of the medium soil was applied, clearly SNI 2019 gives the higher base shear and displacement.

However, according to the performance level, the three response design spectrums show the same level of performance, namely immediate occupancy. Immediate occupancy means the structure is safe in the occurrence of an earthquake but with minimal damage. Strength and stiffness are approximately equal to pre-earthquake conditions. In addition, the vertical and lateral structural resisting systems are still capable sustain earthquake load [36].

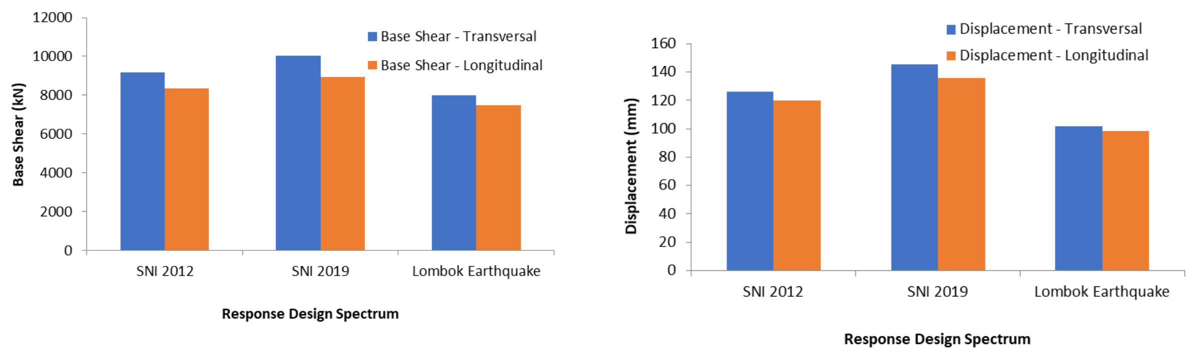


Figure 10. Performance Point for Base Shear and Displacement

All efforts to reduce earthquake damage and risk need to be carried out with preventive measures for disaster management. One of the efforts made is updating the Earthquake Hazard Map, which is usually updated every year or after such a strong earthquake stroke. For Indonesia, it is attempted no later than every five years [26]. In this paper, although there is only a 4% increase in the short period bedrock's acceleration, it is necessary to update the map because it has existed for five years. Moreover, using the PSHA results obtained after the Lombok earthquakes, the design response spectrum increases the seismic building responses. In addition, some new fault characterizations have been studied after the sequence of the Lombok 2018 earthquake [39], [40]. Therefore, updating the earthquake map is suggested to the next Indonesian code to this area to improve seismic mitigation. Seismic code updates provide preparedness for either new buildings or strengthen existing buildings towards better structural seismic responses for future earthquakes. Similar recommendations related to seismic disaster risk reduction in this area have been proposed by other studies [5], [6], [30], [31], [41].

4. Conclusions

The bedrock acceleration in the short period (S_S), respectively from the greatest to the smallest, is 1.143 g based on the PSHA results obtained after the 2018 Lombok earthquakes, 1.1 g based on the SNI 1726-2019 seismic map, and 0.966 g based on the SNI 1726-2012 earthquake map. Meanwhile, the highest value of bedrock acceleration in the long period (S_1) is found in SNI 1726-2019. The old, outdated code, SNI 1726-2019, provides the lowest value of bedrock acceleration.

In principle, the typical shape of the response spectrum between both codes and the 2018 Lombok earthquake ground motion is similar. In both medium and soft soils, Lombok earthquake PSHA results have a higher spectral acceleration value in the short period, while SNI 1726-2019 has superior existence of the long period on the response design spectrum curve.

Due to the effect of the higher value of S_{DS}, either on medium or soft soil, the determined seismic response coefficient, C_S, due to the PSHA results of the 2018 Lombok earthquake is slightly more significant than the determined C_S analyzed by SNI 1726-2019. In addition, the building seismic response in terms of lateral forces and displacements on medium soil is more enormous when analyzed using the response spectrum due to the PSHA results obtained after the Lombok earthquakes. Furthermore, it is essential to update the seismic codes by accommodating the effect of the Lombok 2018 earthquake to support risk reduction of earthquake disasters in the future.

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A New Approach on Structural Seismic Responses in Mataram City: Based on the Probabilistic Seismic Hazard Analysis (PSHA) Results Obtained after Lombok Earthquakes 2018

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Abstract

In the last few years, several major earthquakes in Indonesia have prompted an update of the building seismic resistance code. SNI 1726-2019 is the newest Indonesia seismic code. However, the change of PSHA results due to the 2018 Lombok Earthquake has not been accommodated in this code because it adopts the 2017 seismic maps from National Center for Earthquakes Studies. This paper studied spectral acceleration parameters according to the previous seismic codes (SNI 1976-2012) and current seismic code (SNI 1976-2019) and the probabilistic seismic hazard analysis (PSHA) results obtained after the Lombok earthquakes in 2018.The spectral accelerations were applied to a building structure located in Mataram City to analyze the seismic building responses. The results indicate that the seismic parameters of the PSHA result obtained after Lombok earthquakes lead to higher seismic demands structures than the codes either SNI 1726- 2012 or SNI 1726- 2019, especially for

structures located in medium soil type. The current code needs to be immediate improved for the sake of earthquake mitigation resilience in this area.

Keywords: Spectral acceleration, Lombok earthquake series, seismic codes, seismic responses**,** building structures

1. Introduction

A series of Lombok earthquake events in 2018 were triggered by upward fault activity in the north of Lombok. The activity generated six earthquakes which had magnitudes greater than 5.5. Furthermore, apart from earthquakes of relatively smaller magnitude, the National Agency for Meteorology, Climatology, and Geophysics recorded that the aftershocks with lower magnitude were more than 2000 events. The first earthquake started with a magnitude of 6.4 on July 29, 2018. Then on August 5, 2018, an earthquake with a magnitude of 6.9 at a hypocenter depth of 34 km again hit northern Lombok. Four days later, on August 9, 2018, an earthquake with a magnitude of 5.9 occurred, with the center moved to the west. Ten days later, on August 19, 2018, two large earthquakes with a magnitude of 6.3 occurred in the afternoon with a hypocenter depth of 7.9 km, and a magnitude 7.0 (later updated to a magnitude 6.9) occurred at night with a hypocenter depth of 25 km with a position to the east. The sixth earthquake with a magnitude of 5.5 occurred on August 25, 2018, centered on the east of Lombok. **Figure 1** shows the topography and tectonic areas of Indonesia, where the island of Lombok is indicated by a red circle [1]. Then the six major earthquakes occurrence are explained in **Figure 2** as a black circle and blue inside; meanwhile, the red circle provides the distribution of aftershocks that occurred from July 29–September 10, 2018. The mechanism of earthquake focus and hypocenter data was obtained from the USGS catalog [2]. According to the national disaster management agency, this series of earthquakes damaged buildings as many as 71962 damaged houses, 671 damaged educational facilities, 52 health facilities, 128 prayer facilities. They even collapsed in some areas, including Mataram City [2]–[6].

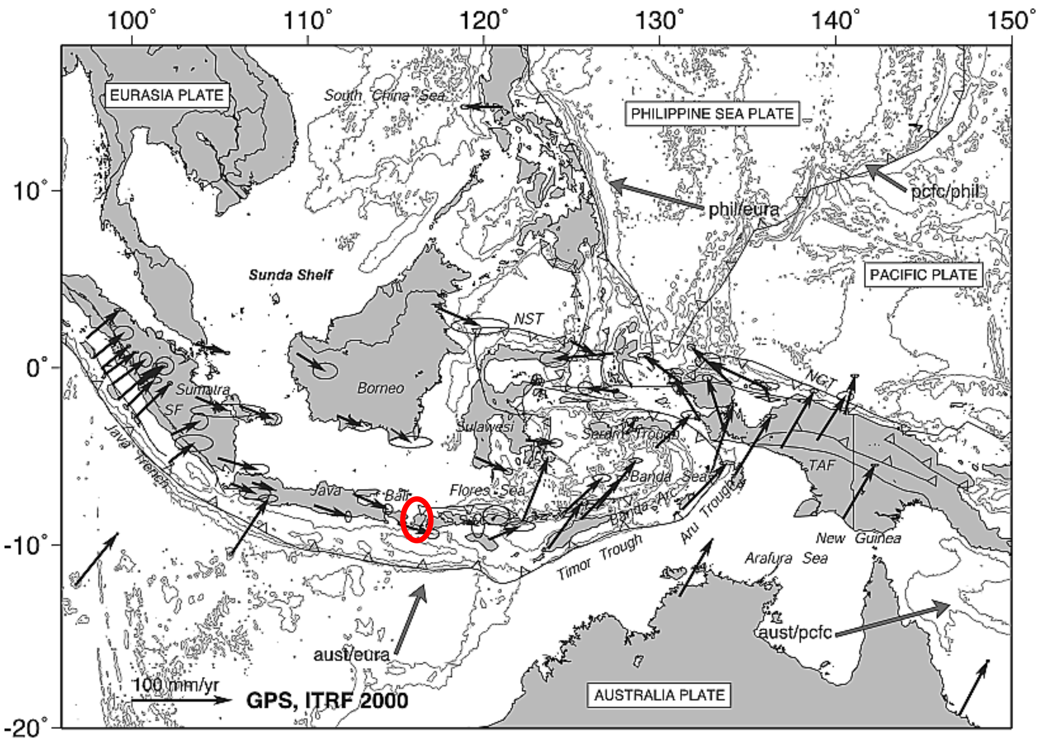


Figure 1 Topography and tectonics of the Indonesia region with the Island of Lombok in a red circle [1]

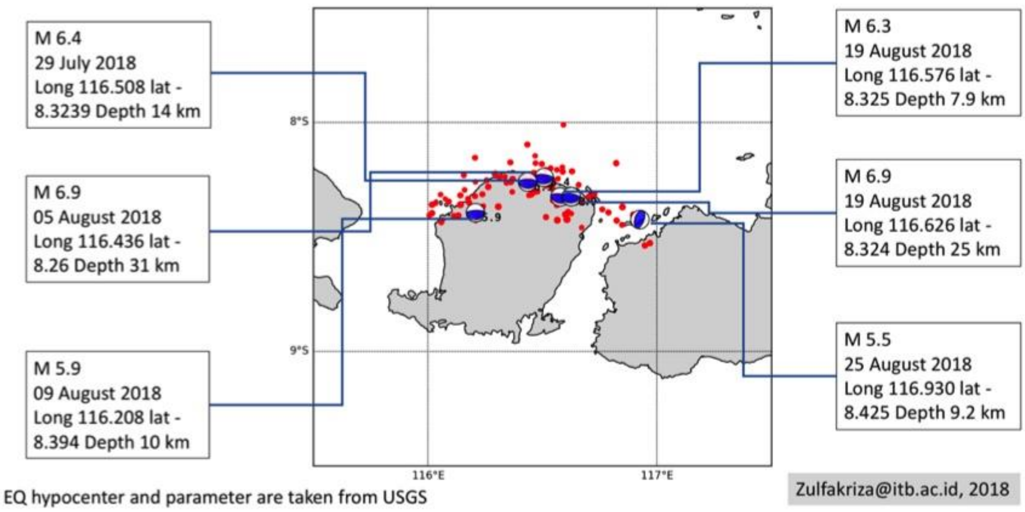


Figure 2 Distribution of Lombok earthquake occurrence [2]

A large amount of damage to building structures caused by strong earthquakes has inevitably urged the government to renew the existing building seismic resistance design code. Changes in the code carried out by the government worldwide are intended to accommodate the latest earthquake events [7], [8], [17], [9]–[16]. This includes evaluating the seismic performances on existing structures after such large earthquakes stroke the countries [18]–[22]. In Indonesia, one of the government's seismic codes was SNI 1726-2002 [23], and then updated it to SNI 1726-2012 [24]. The latest version was published in 2019 [25].

In SNI 1726-2002, the seismic hazard map was divided into six earthquake zones, where each zone was classified based on the peak acceleration of the bedrock and had the same response design spectrum. However, based on the latest geological studies of the earth's plate, which influenced the earthquake region, improved the code into SNI 1726- 2012. According to this code, each region or location had a different response design spectrum because it was determined based on the ground motion parameters S_S and S_1. The peak ground acceleration (PGA) of SNI 1726-2002 was based on a 10% probability of being exceeded in 50 years. The return period was 500 years. After several great earthquakes, there was a change in the Indonesian seismic hazard map; therefore, this code was replaced by SNI 1976-2012. This replacement seismic code had a peak ground motion with a 2% probability of being exceeded in 50 years or a return period of 2475 years for the spectral acceleration. Updating the seismic hazard map has been carried out and produced the latest seismic code, SNI 1976-2019. The seismic spectral acceleration is based on the 2017 seismic hazard map National Earthquake Center [26], [27].

The National Center for Earthquake Studies updated the National Earthquake Map in 2017. The series of research results, studies, and publications related to Indonesia's latest earthquake source parameters, including geology in some areas and earthquake relocation data, have contributed significantly to updating the source maps and the hazards. Therefore, SNI 1726-2012 was renewed to SNI 1726-2019 and has been becoming the current seismic code in Indonesia. In this code, some major earthquake-prone areas show increased spectral acceleration [27], [28]. However, change is not significantly found for the area that has not been much affected by the seismic occurrence, such as Mataram City. In fact, Lombok area was stroke by strong earthquakes in 2018. The increase is not so sharply seen in Lombok because SNI 1976-2019 has accommodated the 2017 earthquake map.

According to [29], theoretically, one reason for the uncertainty of building collapse due to earthquakes is spectral acceleration. The structures can resist without collapsing, depending on the spectral acceleration produced according to ground motion characteristics. In the case of the Lombok earthquake in 2018, many damaged structures were found, even in Mataram City, the major city in Lombok Island, which was located around 47 km away from the largest epicenter of the earthquake series. Probabilistic seismic hazard analysis *(*PSHA) results obtained after the Lombok earthquakes have strongly influenced the spectral acceleration as studied by [30], [31].

Considering the 2018 Lombok earthquakes, an analysis is conducted based on a PSHA using a detailed tectonic background and the appropriate ground motion equations. The analysis is aimed to determine the seismic parameters that are more suitable with the ground motion that occurs due to a strong earthquake that has occurred and comparing it with the model published by the National Center for Earthquake Studies in 2017. The sources used in the National Center for Earthquake Studies are subduction, back-arc, and strikes slip faults for Lombok and surroundings, meanwhile in 2018 Lombok earthquake used only subduction and back-arc because they are the most dominant. The earthquake data records used in the Lombok earthquake model are until 2018, while the data used in National Center for Earthquake Studies model is until 2016. Thus, the *a* and *b* values are more updated in the recent Lombok earthquake 2018 model. However, the ground motion equations of the National Center for Earthquake Studies and the Lombok earthquake 2018 are nearly identical. Furthermore, it was found that Lombok and its surrounding islands show a significant seismic hazard than the model published by the National Earthquake Study Center in 2017. This is because the model was estimated before the 2018 earthquake. Therefore, updating the seismic hazard map for Lombok and surrounding islands are proposed by considering the effect of the strong earthquakes [30].

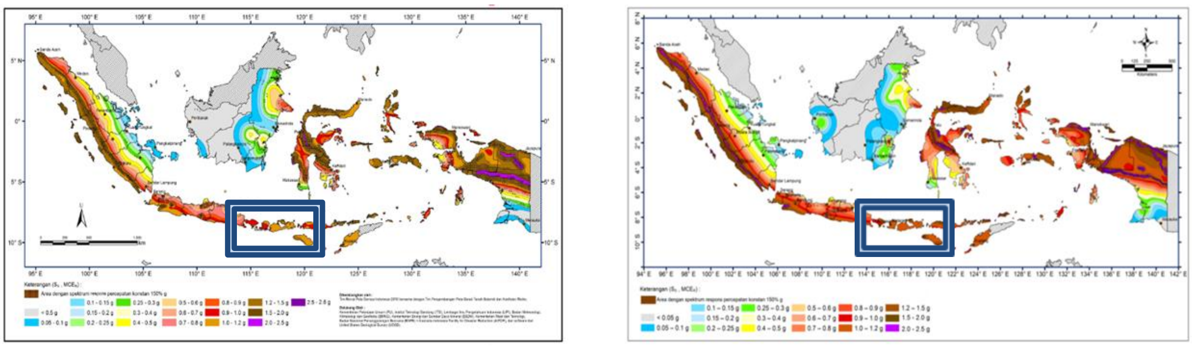
Furthermore, the effect of the 2018 Lombok earthquake PSHA results on the seismic coefficient C_S of buildings has been reported in [31]. It was described that due to the effect of the large earthquake, C_S increased in Mataram City by 10.8% for medium soil compared to the C_S calculated using the applicable SNI at that time, namely SNI 1976-2012. The increase in C_S was found much greater for soft soil, which was 13.2%. It is recommended to update the seismic code by considering the ground motion due to the Lombok earthquake.

In this paper, the seismic design parameters of the spectral acceleration due to the Lombok 2018 earthquake are compared with the latest code, namely SNI 1976-2019. The change in spectral acceleration must definitely affect the building seismic demand parameters. A comprehensive overview of the performance of the structures due to the change of spectral acceleration is discussed in terms of lateral force and building displacement of a four-story building located in Mataram City. The approaches from previous national seismic codes, SNI 1976-2012, are also included.

2. Materials and Methods

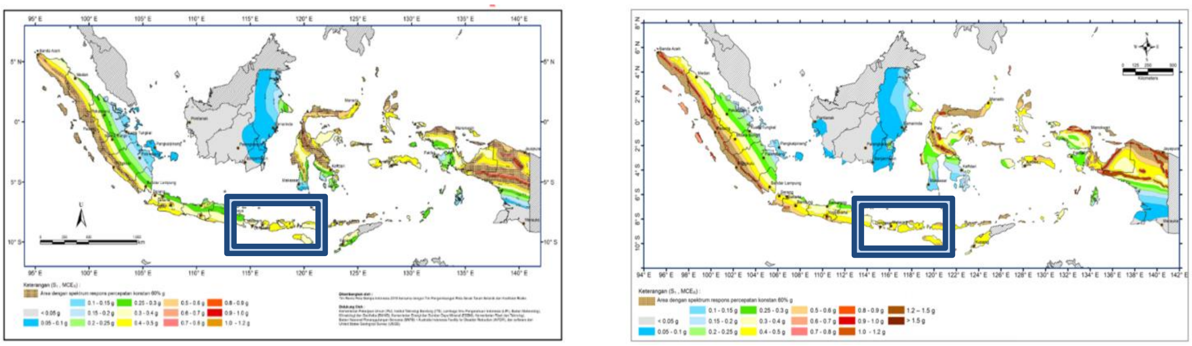
2.1. Seismic acceleration map

The seismic design maximum acceleration maps of the bedrock for the short period (T = 0.2 s (S_S)) and for the long period (T = 1 s (S_1)) with the probability of 2% exceeded in 50 years are provided by the codes: SNI 1726-2012 and SNI 1726-2019 are presented in **Figures 3-4,** respectively. **Figure 3** illustrates spectral acceleration maps in bedrocks for the short period, T = 0.2 s from SNI 1976-2012 and SNI 1976-2019. Meanwhile, **Figure 4** shows spectral acceleration maps in bedrocks for the long period, T = 1 from SNI 1976-2012 and SNI 1976-2019. In **Figures 3** and **4**, the location of Lombok and its surroundings are marked with a blue box shape. The seismic acceleration map in bedrock based on the PSHA results obtained after the Lombok earthquake is illustrated in **Figure 5** which consists of maps for the short and long periods. The epicenter locations of the series of earthquakes that occurred on Lombok in 2018 is marked with a blue circle on the map. The earthquake data set was collected from United States Geological Survey (USGS), the International Seismological Centre (ISC), and the Indonesian Centre for Meteorology, Climate and Geophysics (BMKG) for a period range between 1922 and 2018. The earthquake with a magnitude M_w of 4.5 was considered for the spectral acceleration calculation because this magnitude is a standard for earthquakes related to seismic disaster risk.



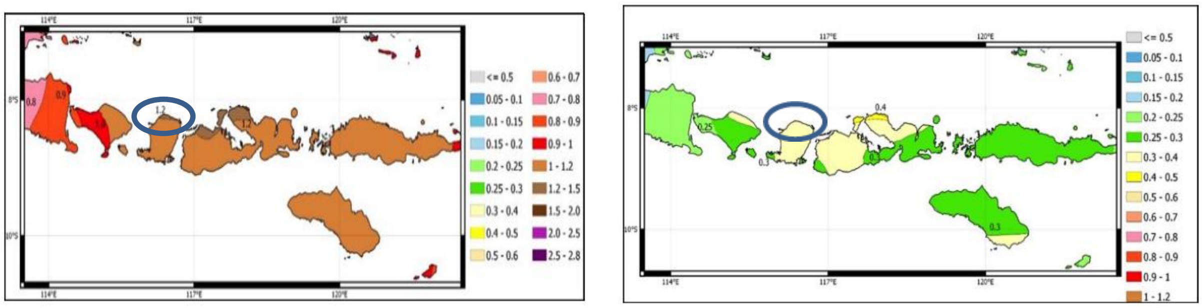
SNI 1976-2012　　　　　　　　　　SNI 1976-2019

Figure 3 Spectral acceleration maps in bedrocks for the short period, T = 0.2 s from SNI 1976-2012 [24] and SNI 1976-2019 [25]



(a) SNI 1976-2012　　　　　　　　　　(b) SNI 1976-2019

Figure 4 Spectral acceleration maps in bedrocks for the long period: T = 1 from (a) SNI 1976-2012 [24] and (b) SNI 1976-2019 [25]



(a) short period, T = 0.2 s　　　　　　　　　　(b) long period, T = 1 s

Figure 5 Lombok earthquake spectral acceleration maps in bedrocks for Mataram and surroundings: (a) for short period, T = 0.2 s and (b) for long period, T = 1 s [30], [31]

Based on the spectral acceleration maps in bedrocks described using the three approaches described earlier and the soil amplification factor of the building site location, the maximum consideration spectral acceleration was calculated for the short period (S_{MS}) and the long period (S_{M1}). Once the SMS and SM1 were obtained, the design spectral acceleration: SDS and SD1 were calculated respectively for the short and long periods. Furthermore, the response spectrum curve was generated according to S_{DS} and S_{D1}. The designed response spectrum was then applied to evaluate the seismic responses of the intended building.

2.2. Building configuration

The designed response spectrum was produced using three earthquake acceleration maps: SNI 1726-2012, SNI 1726-2019, and PSHA results obtained after Lombok earthquakes mentioned earlier. The differences of the design spectral acceleration were considered and applied as the parameter for analyzing the seismic response coefficient and structural responses.

Seismic coefficient and structural responses were observed in Mataram State Islamic University, which is located in Mataram City at the coordinates of latitude: -8.610232 and longitude: 116.100845. This educational building is a four-story reinforced concrete structure. The height of each story is 3.9 meters. The longitudinal direction consists of 8 spans with a total length is 44.28 meters. Meanwhile, four spans are in the transversal direction, with a total span length of 24.5 meters. The overview frame in longitudinal and transversal directions used for the seismic structural analysis is shown in **Figure 6**.

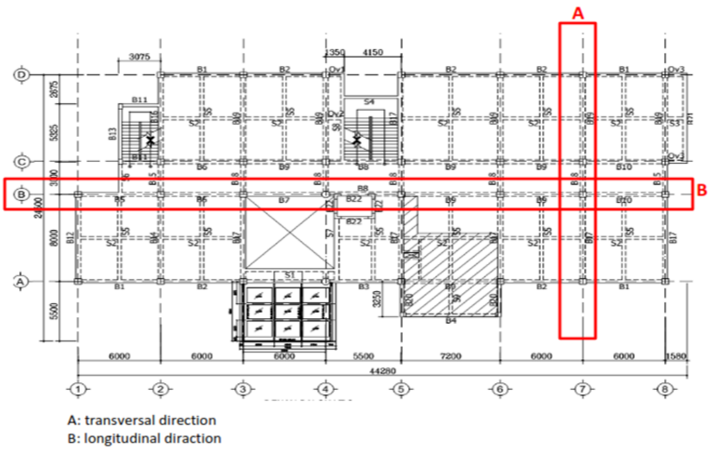
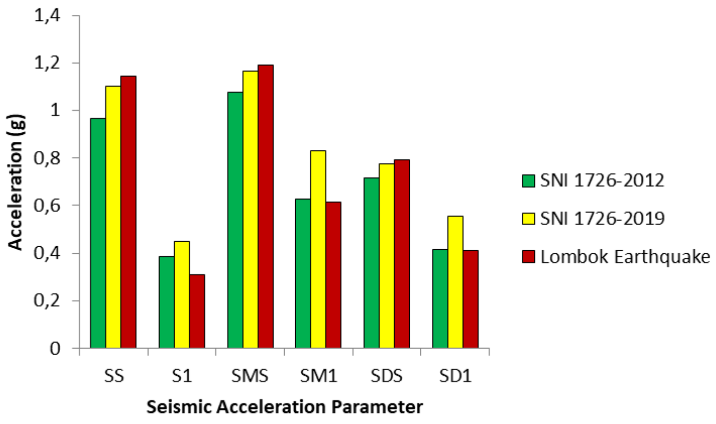


Figure 6 Plan of building in each story and the overview frame

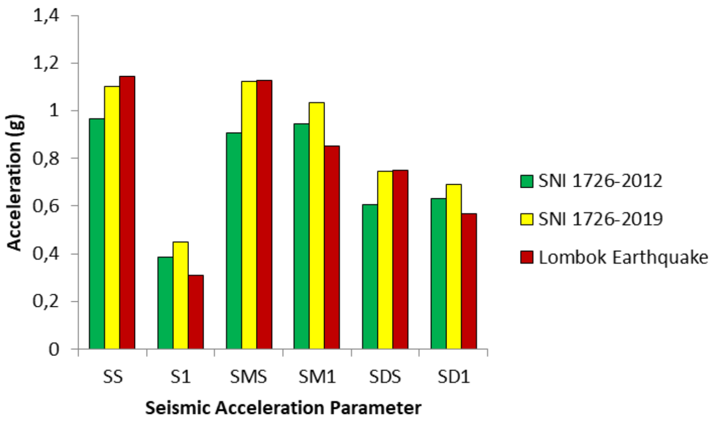
3. Results and Discussion

3.1. Spectral acceleration parameter

According to research in [32], the shear wave velocity of the surface sediment layer in Mataram City ranged between 135 m/s and 201 m/s. Therefore, based on the shear wave propagation velocity, Mataram City is included in the SD site class (medium soil) and SE site class (soft soil). The spectral acceleration of this area calculated based on SNI 1726-2012, SNI 1726-2019, and Lombok earthquake 2018 PSHA results are presented in **Figure 7 (a)** for medium soil, SD, and **Figure 7 (b)** for soft soil, SE.



a Medium Soil, SD



b Soft soil, SE

Figure 7 Spectral acceleration parameters

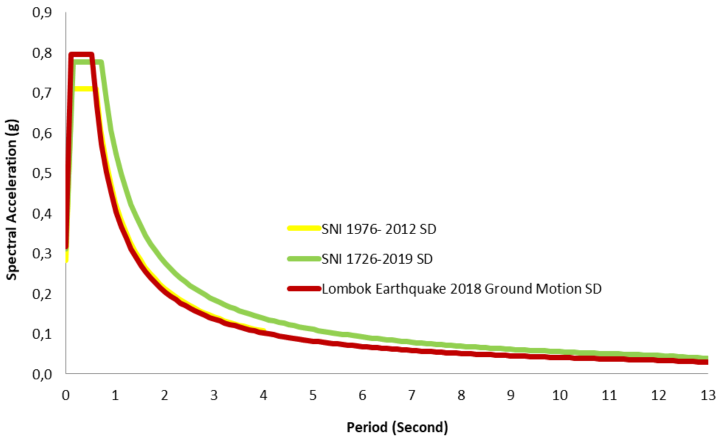
From the seismic acceleration map of SNI 1726-2012, it is obtained that the bedrock acceleration parameters for T = 0.2 s, S_S is 0.966 g, and for T = 1 s, S_1 is 0.386 g. Meanwhile, based on SNI 1726-2019, S_S and S_1 values increase to 1.1 g and 0.45 g, respectively. The escalations are about 14% for S_S and 17% for S_1. The acceleration value at SNI 1726-2019 is more significant than SNI1726-2012 because some major earthquakes occurred in some areas in Indonesia between 2012 and 2017. As described earlier, SNI 1726-2019 adopted 2017 seismic acceleration maps from the National Center of Earthquake Studies. However, when the effect of the 2018 Lombok earthquake is considered, the S_S value changes to 1.143 g. This value increased by 18% against the S_S value on SNI 1726-2012 and increased by 4% compared to the S_S value from SNI 1726-2019. Meanwhile, the S1 value changed to 0.309 g, which decreased compared to the S1 value on both seismic codes.

Furthermore, the short-period maximum acceleration value (S_{MS}) and short-period design acceleration (S_{DS}) due to the Lombok earthquake 2018 PSHA results effect are found to be greater than those calculated based on SNI 1976-2019. However, for the period T = 1 s, namely S_{M1} and S_{D1} are more generous in SNI 1726-2019. This occurs in both medium and soft soils.

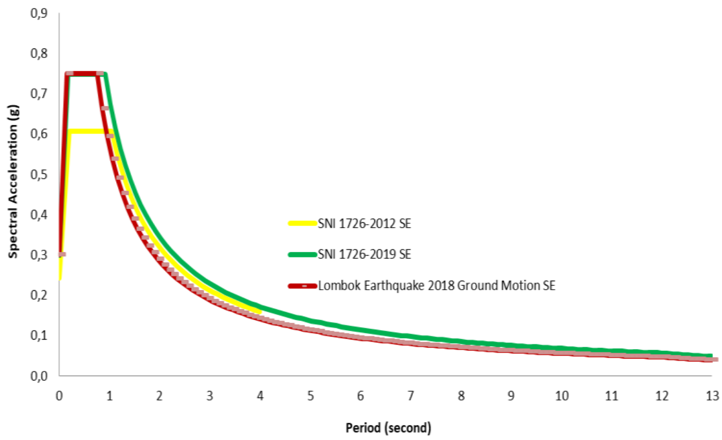
The 2018 Lombok earthquake PSHA result has a more significant effect on short-period spectral acceleration; otherwise, both seismic codes have a more significant effect on the long-period spectral acceleration. This is because the acceleration in the long period is more influenced by far-field earthquakes, while the short period due to the PSHA results obtained after the 2018 Lombok earthquakes is more dominantly by near-field earthquakes. The near-field earthquakes tend to occur in shorter periods with higher acceleration. Meanwhile, the far-field earthquakes are in the more extended period [33], [34]. The difference in the value of spectral acceleration for the short period, S_{DS}, and for the long period, S_{D1}, can affect the seismic design category of the building [35], [36]. However, either the codes or the Lombok earthquake 2018 show the S_{DS} value greater than 0.5 g, and the S_{D1} was more significant than 0.2 g. Thus there is no change for the seismic design category of the three approaches, namely remaining in the D-seismic design category. A building in this category needs a more detailed design in reinforcement due to possible severe ground shaking [35].

3.2. Response design spectrum curve

In principle, the typical shape of the response design spectrum between both codes and the 2018 Lombok earthquake PSHA results is substantially similar as illustrated in **Figure 8**. **Figure 8 (a)** describes medium soil, and **Figure 8 (b)** describes soft soil. SNI 1726-2019 has considered the existence of a more extended period on the spectral response curve. In both medium and soft soils, PSHA results obtained after Lombok earthquakes has a higher spectral acceleration value in short periods. For medium soils, the highest acceleration of SNI 1726- 2019 response design spectrum curve is 0.777 g, observed in a range of 0.143 s to 0.714 s. A higher acceleration is found in the Lombok earthquake's response design spectrum, namely 0.795 g over a more extended period, from 0.103 s to 0.516 s. The outdated code, SNI 1726-2012, gives the lowest acceleration on the curve peak.



a Medium soil, SD



b Soft soil, SE

Figure 8 Response spectrum curve

Considering the spectral acceleration of the soft soil, it is observed that the acceleration peaks of the curve are lower than those that occurred in medium soil among the three response design spectrum curves. The spectral acceleration value on soft soil is generally more significant than the spectral acceleration value on medium soil. This aspect is found in the Mataram City spectral acceleration only for the long period. However, in the short period, the spectral acceleration value in soft soil is observed to be lower. This anomaly occurs because the short-period amplification factor in medium soils is lower than those in soft soils. The anomaly phenomena in which the SNI-1726-2019 spectral acceleration design of soft soil is lower than that of medium soil has been observed in 17 regions; even it is found that the spectral acceleration of site class of hard soil (SC) is higher in earthquake-prone areas [28].

3.3. Seismic response coefficient, C_S

Seismic response coefficient (C_S) is used to calculate the building's base shear during static equivalent analysis. This coefficient is a function of several buildings parameters, consists of spectral acceleration design, building fundamental period of vibration, building importance factor related to the building occupancy category, and building response modification factor which is determined by building type of seismic force resisting system [24], [25], [36], [37].

In this study, The C_S value is determined under several conditions: risk category for educational facilities = 4, importance factor = 1.5, and response modification factor = 8. As shown **in Figure 9**, the determined C_S and minimum C_S values are lower than the maximum C_S values for medium soils. Meanwhile, on soft soil, the maximum C_S is greater than the determined C_S and minimum C_S. The S_{DS} affects the determined C_S and the maximum C_S, while the S_{D1} affects the maximum C_S. The S_{DS} on medium soil is higher than soft soil so that it generates a higher determined C_S and minimum C_S. Likewise, the S_{D1} is found to be greater on soft soil, so the maximum C_S is found to be greater on soft soil. This trend occurs on both codes and also due to the 2018 Lombok earthquake.

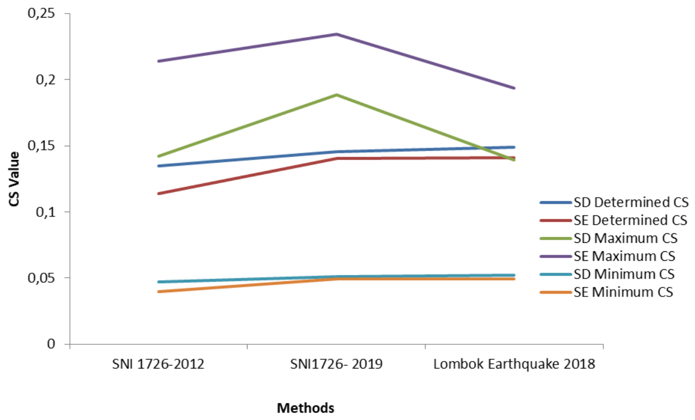


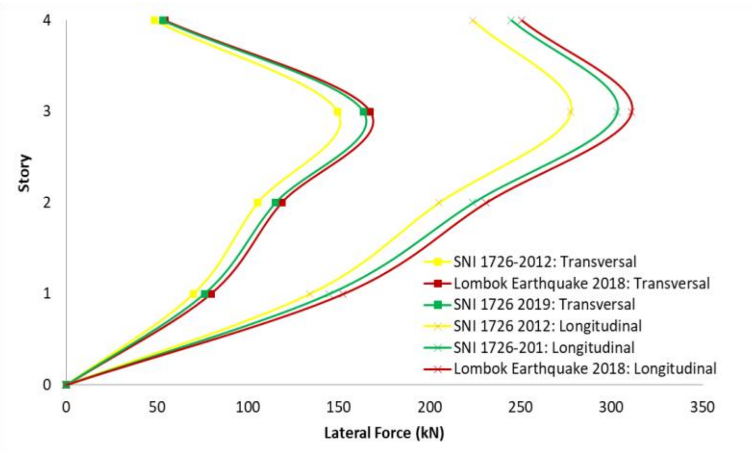
Figure 9 C_S value based on three approaches

Due to S_{DS}'s effect by the 2018 Lombok earthquake, which is the highest among the three methods, this method has the highest value on the determined C_S and minimum C_S. However, the highest S_{D1} is found in SNI 1726-2019, so that the greatest value of maximum C_S is found in this method. In principle, the determined C_S cannot be greater than the maximum C_S and it cannot be less than the minimum C_S. The determined C_S due to the 2018 Lombok earthquake is slightly greater than the determined C_S on SNI 1726-2019 for both medium and soft soil.

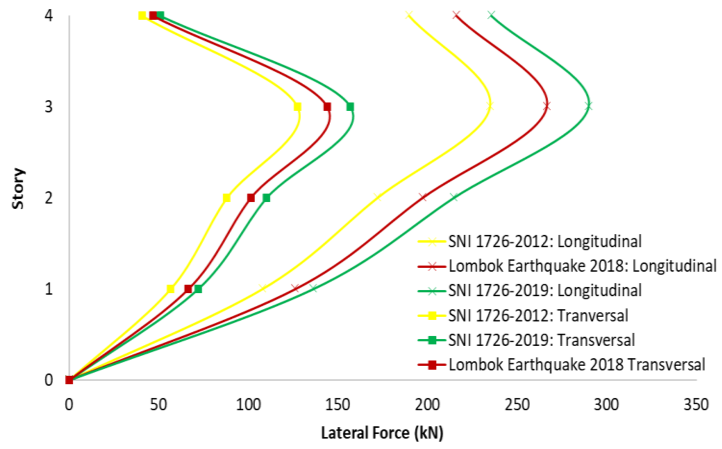
3.4. Building seismic responses

The lateral forces, shown in **Figure 10**, are calculated at the overviewed frame section of each longitudinal and transverse direction of the building. On medium soils, as illustrated in **Figure 10 (a)**, it can be seen that the most significant lateral force occurs when calculated based on the acceleration of the PSHA results obtained after the 2018 Lombok earthquakes. Minor lateral forces are obtained when calculated by the old code, namely SNI 2012. The lateral force calculated based on the 2018 Lombok earthquake's spectral acceleration is also more remarkable than the lateral force calculated based on SNI 1726-2019. This difference ranges from 2.3% to 5.4%, depending on the story height and direction of the building overviewed.

However, in soft soil (**Figure 10 (b)**), the largest lateral forces are found when calculated using SNI 1726-2019 Compared with the lateral force calculated by considering the acceleration of the PSHA results due to the 2018 Lombok earthquake, this value is 8%-9% greater depending on the storey height and direction of the building review. Soft soil generates a long-period response more than medium soils [38]. Therefore, the lateral force of SNI 1726-2019 is more significant because the spectral acceleration of soft soil at SNI 1726-2019 is greater than the spectral acceleration of soft soil due to the 2018 Lombok earthquake.



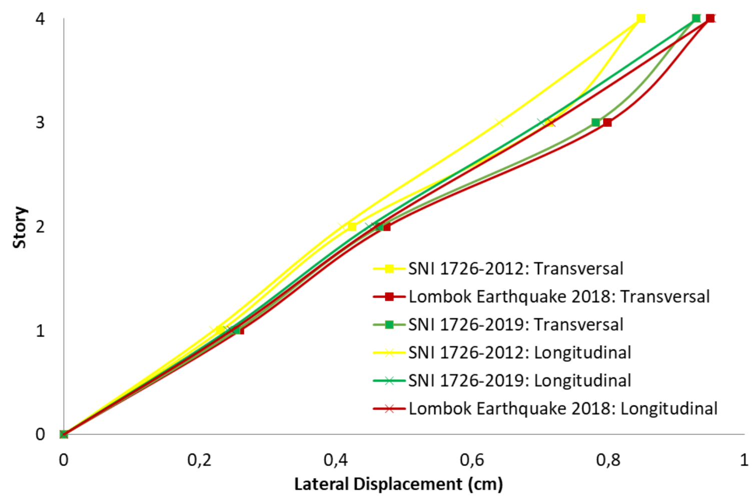
a Medium soil, SD



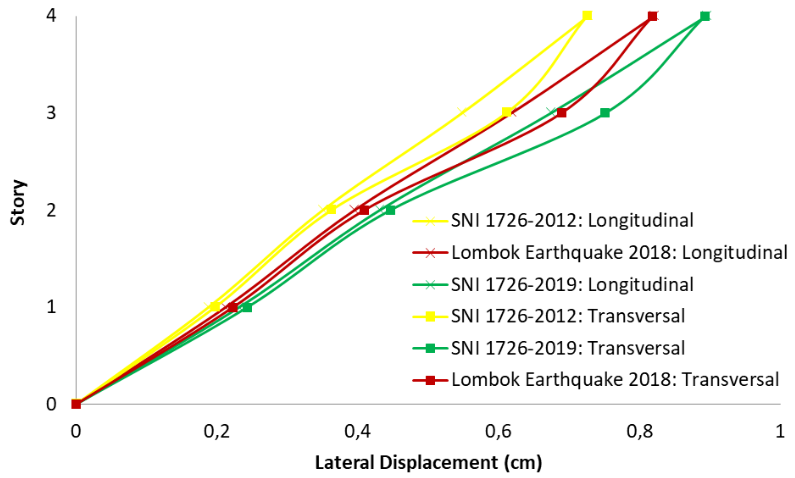
b Soft soil, SE

Figure 10 Lateral forces of overviewed frame section

A similar phenomenon occurs in the building response in the form of a lateral displacement, as shown in **Figure 11**. On medium soil (**Figure 11 (a)**), the most significant lateral displacement occurred in the calculation with the 2018 Lombok earthquake. However, on soft soil (**Figure 11 (b)**), the lateral displacement value calculated by the SNI 2019 response design spectrum is the greatest. Meanwhile, the smallest building lateral displacement was found when using the 2012 response design spectrum.



a Medium soil, SD



b Soft soil, SE

Figure 11 Lateral displacement of the overviewed frame section

The seismic response of buildings on medium soil is being found to be greater if the response design spectrum for the PSHA results of the 2018 Lombok earthquake is used in the calculation compared to the two seismic codes in Indonesia.

Furthermore, the performance-based using pushover analysis has been added to perform the building capacity. According to the analysis, when the three response design spectrum of the medium soil was applied, clearly SNI 2019 gives the higher base shear and displacement. However, according to the performance level as illustrated in **Figure 12**, the three response design spectrums show the same level of performance, namely immediate occupancy. Immediate occupancy means the structure is safe in the occurrence of an earthquake but with minimal damage. Strength and stiffness are approximately equal to pre-earthquake conditions. In addition, the vertical and lateral structural resisting systems are still capable sustain earthquake load [36].

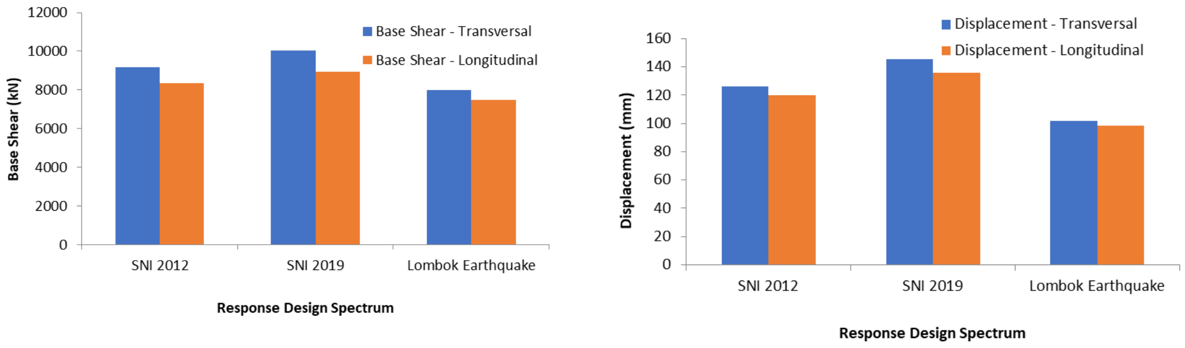


Figure 12 Performance point for base shear and displacement

All efforts to reduce earthquake damage and risk need to be carried out with preventive measures for disaster management. One of the efforts made is updating the Earthquake Hazard Map, which is usually updated every year or after such a strong earthquake stroke. For Indonesia, it is attempted no later than every five years [26]. In this paper, although there is only a 4% increase in the short period bedrock's acceleration, it is necessary to update the map because it has existed for five years. Moreover, using the PSHA results obtained after the Lombok earthquakes, the design response spectrum increases the seismic building responses. In addition, some new fault characterizations have been studied after the sequence of the Lombok 2018 earthquake [39], [40]. Therefore, updating the earthquake map is suggested to the next Indonesian code to this area to improve seismic mitigation. Seismic code updates provide preparedness for either new buildings or strengthen existing buildings towards better structural seismic responses for future earthquakes. Similar recommendations related to seismic disaster risk reduction in this area have been proposed by other studies [5], [6], [30], [31], [41].

4. Conclusions

The bedrock acceleration in the short period (S_S), respectively from the greatest to the smallest, is 1.143 g based on the PSHA results obtained after the 2018 Lombok earthquakes, 1.1 g based on the SNI 1726-2019 seismic map, and 0.966 g based on the SNI 1726-2012 earthquake map. Meanwhile, the highest value of bedrock acceleration in the long period (S_1) is found in SNI 1726-2019. The old, outdated code, SNI 1726-2019, provides the lowest value of bedrock acceleration.

In principle, the typical shape of the response spectrum between both codes and the 2018 Lombok earthquake ground motion is similar. In both medium and soft soils, Lombok earthquake PSHA results have a higher spectral acceleration value in the short period, while SNI 1726-2019 has superior existence of the long period on the response design spectrum curve.

Due to the effect of the higher value of S_{DS}, either on medium or soft soil, the determined seismic response coefficient, C_S, due to the PSHA results of the 2018 Lombok earthquake is slightly more significant than the determined C_S analyzed by SNI 1726-2019. In addition, the building seismic response in terms of lateral forces and displacements on medium soil is more enormous when analyzed using the response spectrum due to the PSHA results obtained after the Lombok earthquakes. Furthermore, it is essential to update the seismic codes by accommodating the effect of the Lombok 2018 earthquake to support risk reduction of earthquake disasters in the future.

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Figure and table captions

Figure 1 Topography and tectonics of the Indonesia region with the Island of Lombok in a red circle [1]

Figure 2 Distribution of Lombok earthquake occurrence [2]

Figure 3 Spectral acceleration maps in bedrocks for the short period, T = 0.2 s from SNI 1976-2012 [24] and SNI 1976-2019 [25]

Figure 4 Spectral acceleration maps in bedrocks for the long period: T = 1 from (a) SNI

Figure 5 Lombok earthquake spectral acceleration maps in bedrocks for Mataram and surroundings: (a) for short period, T = 0.2 s and (b) for long period, T = 1 s [30], [31]1976-2012 [24] and (b) SNI 1976-2019 [25]

Figure 6 Plan of building in each story and the overview frame

Figure 7 Spectral acceleration parameters

Figure 8 Response spectrum curve

Figure 9 C_S value based on three approaches

Figure 10 Lateral forces of overviewed frame section

Figure 11 Lateral displacement of the overviewed frame section

Figure 12 Performance point for base shear and displacement

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A new approach to structural seismic responses in Mataram City: Based on the Probabilistic Seismic Hazard Analysis (PSHA) results obtained after lombok earthquakes 2018

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KEYWORDS
Spectral acceleration;
Lombok earthquake series;
Seismic codes;
Seismic responses;
Building structures.

Abstract. In the last few years, several major earthquakes in Indonesia have provided enough reasons for updating the existing building seismic resistance code. SNI 1726-2019 is the latest Indonesia seismic code. However, the variation of Probabilistic Seismic Hazard Analysis (PSHA) results due to the 2018 Lombok Earthquake has been disregarded in this code because it adopts the 2017 seismic maps from National Center for Earthquakes Studies. This study investigated spectral acceleration parameters according to previous seismic codes (SNI 1976-2012) and current seismic codes (SNI 1976-2019) as well as the PSHA results obtained after the Lombok earthquakes in 2018. Spectral accelerations were applied to a building structure located in Mataram City to analyze the seismic building responses. The results indicate that seismic parameters of PSHA result associated with Lombok earthquakes yield structures of higher seismic demand than SNI 1726-2012 or SNI 1726-2019 codes, especially for structures located in medium soil type. The current code needs to be improved immediately to promote resilience and resistance against earthquakes in this area.

1. Introduction

A series of Lombok earthquake events in 2018 were triggered by upward fault activities in the north of Lombok. The activities generated six earthquakes that had a magnitude greater than 5.5. Furthermore, apart from earthquakes of relatively smaller magnitudes, the National Agency for Meteorology, Climatology, and Geophysics recorded that aftershocks with a lower magnitude were more than 2000 events. The first earthquake began with a magnitude of 6.4 on July 29, 2018. Then, on August 5, 2018, an earthquake with a magnitude of 6.9 at a hypocenter depth of 34 km again hit the northern part of Lombok. Four days later, on August 9, 2018, an earthquake with a magnitude of 5.9 occurred, with the center taken to the west. Ten days later, on August 19, 2018, two large earthquakes with a magnitude of 6.3 occurred in the afternoon at a hypocenter depth of 7.9 km and a magnitude of 7.0 (later updated to a magnitude of 6.9) occurred at night at a hypocenter depth of 25 km with a position to the east. The sixth earthquake with a magnitude of 5.5 occurred on August 25, 2018, centered on the east of Lombok. Figure 1 shows the topography and tectonic areas of Indonesia where the island of Lombok

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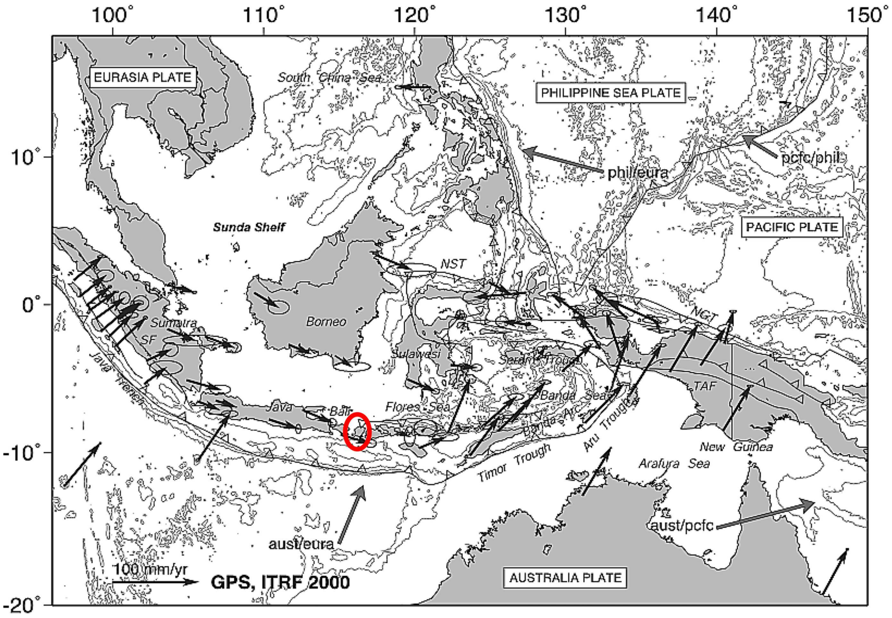

Figure 1. Topography and tectonics of the Indonesia region with the Island of Lombok in a red circle [1].

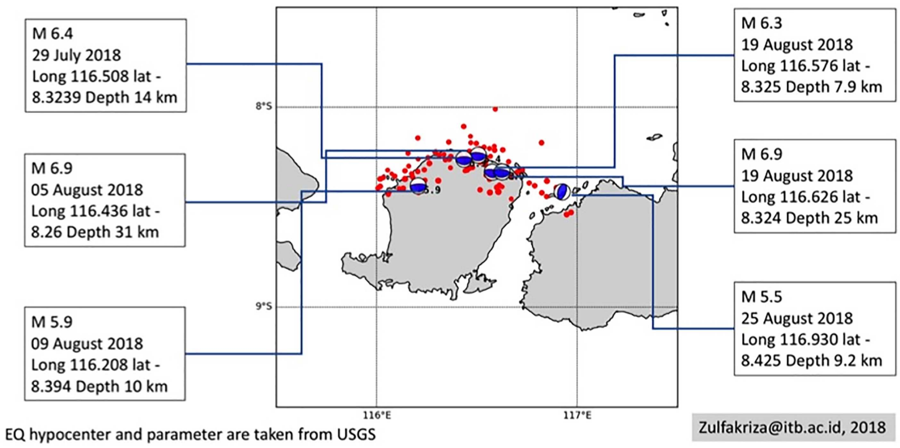

Figure 2. Distribution of Lombok earthquake occurrence [2].

is indicated by a red circle [1]. Then, the occurrence of six major earthquakes is explained in Figure 2 as a black circle and blue inside; meanwhile, the red circle provides the distribution of aftershocks that occurred from July 29 September 10, 2018. The USGS catalog presents the focal mechanism of earthquake and hypocenter data [2]. According to the national disaster management agency, this series of earthquakes damaged buildings including 71962 damaged houses, 671 damaged educational facilities, 52 health facilities, and 128 prayer facilities. They even collapsed in some areas including Mataram City [2–6].

The significant scope of damage to building structures caused by strong earthquakes has inevitably urged the government to renew the existing building seismic-resistant design code. Changes in the code carried out by the government worldwide are intended to accommodate the latest earthquake events [7–17]. This includes evaluation of seismic performances in existing structures after such large earthquakes stroke the countries [18–22]. In Indonesia, one of the government's seismic codes was SNI 1726-2002 [23] and then, it was updated to SNI 1726-2012 [24]. The latest version was published in 2019 [25].

In the case of SNI 1726-2002, the seismic hazard map was divided into six earthquake zones, each of which was classified based on the peak acceleration of the bedrock and had the same response design spectrum. However, based on the latest geological studies of the earth's plate, which influenced the earthquake region, the code was improved into SNI 1726-2012. According to this code, each region or location has a different response design spectrum because it was already determined based on the ground motion parameters, S_S and S_1. Peak Ground Acceleration (PGA) of SNI 1726-2002 is based on a 10% probability that it will be exceeded in 50 years. The return period was 500 years. After several great earthquakes, there was a change in the Indonesian seismic hazard map; therefore, this code was replaced by SNI 1976-2012. The replacement of the seismic code has a peak ground motion with a 2% probability of being exceeded in 50 years or with a return period of 2475 years for spectral acceleration. The seismic hazard map is updated and the latest seismic code, SNI 1976-2019, is produced. The seismic spectral acceleration is based on the 2017 seismic hazard map National Earthquake Center [26,27].

The National Center for Earthquake Studies updated the National Earthquake Map in 2017. A series of research results, studies, and publications related to Indonesia's latest earthquake source parameters, including geology in some areas and earthquake relocation data, have significantly contributed to updating the source maps and the cases of hazards. Therefore, SNI 1726-2012 was renewed Increase in what? it has become the current sei In this code, some major earthquake-prone areas exhibit increased spectral acceleration [27,28]. However, changes in spectral acceleration are not significantly detected for the area like Mataram City that has not been affected much through seismic occurrence. In fact, strong earthquakes in 2018 stroke Lombok area. The increase is not so sharply seen in Lombok because SNI 1976-2019 accommodated the 2017 earthquake map.

According to the referenced research [29], theoretically, spectral acceleration is the uncertainty associated with the building collapse caused by earthquakes. The structures exhibit resistance without collapsing, depending on the spectral acceleration produced according to ground motion characteristics. In the case of the Lombok earthquake in 2018, many damaged structures were found even in Mataram City, a major city in Lombok Island, which was located around 47 km away from the largest epicenter of the earthquake series. Probabilistic Seismic Hazard Analysis (PSHA) results obtained based on the Lombok earthquakes strongly influenced the spectral acceleration, as determined in [30,31].

Considering the 2018 Lombok earthquakes, an analysis was conducted based on PSHA using a detailed tectonic background and appropriate ground motion equations. The analysis managed to determine the seismic parameters that are more suitable for the ground motion due to a strong earthquake, and the result was compared with the model outcome published by the National Center for Earthquake Studies in 2017. The sources used in the National Center for Earthquake Studies include subduction, back-arc, and strike-slip faults for Lombok and surroundings. Meanwhile, in 2018, the case of Lombok earthquake used only subduction and back-arc, given their dominance. The earthquake data records used in the Lombok earthquake model remained valid up to 2018, while the data used in National Center for Earthquake Studies model were valid up to 2016. Thus, a and b values were updated to a greater degree in the recent Lombok earthquake 2018 model. However, the ground motion equations of the National Center for Earthquake Studies and the Lombok earthquake 2018 are nearly identical. Furthermore, it was found that Lombok and its surrounding islands exhibited a significant seismic hazard compared to the model presented by the National Earthquake Study Center in 2017, because the model was estimated before the 2018 earthquake. Therefore, updating the seismic hazard map for Lombok and surrounding islands was proposed by considering the impacts of strong earthquakes [30].

Furthermore, the effect of the 2018 Lombok earthquake PSHA results on the seismic coefficient C_S of buildings was reported in [31]. It was described that due to the impact of the large earthquake, C_S increased in Mataram City by 10.8% for medium soil compared to the C_S calculated using the applicable SNI at that time, namely SNI 1976-2012. Increase in C_S was found to be much greater for soft soil, which was 13.2%. It is recommended that the seismic code be updated by considering the ground motion due to the Lombok earthquake.

In this paper, the seismic design parameters of the spectral acceleration due to the Lombok 2018 earthquake are compared with the latest code, namely SNI 1976-2019. The change in spectral acceleration must definitely affect the building seismic demand parameters. A comprehensive overview of the performance of the structures due to the change of spectral acceleration is done in terms of lateral force and building displacement of a four-story building located in Mataram City. The approaches established based on previous national seismic codes, SNI 1976-2012, are included.

2. Materials and methods

2.1. Seismic acceleration map

The seismic design maximum acceleration maps of the bedrock for a short time period ($T = 0.2$ s (S_S)) and a long time period ($T = 1$ s (S_1)) with a 2% probability of being exceeded in 50 years are provided by SNI 1726-2012 and SNI 1726-2019 codes, as presented in Figures 3 and 4, respectively. Figure 3 shows the spectral acceleration maps in bedrocks for a short

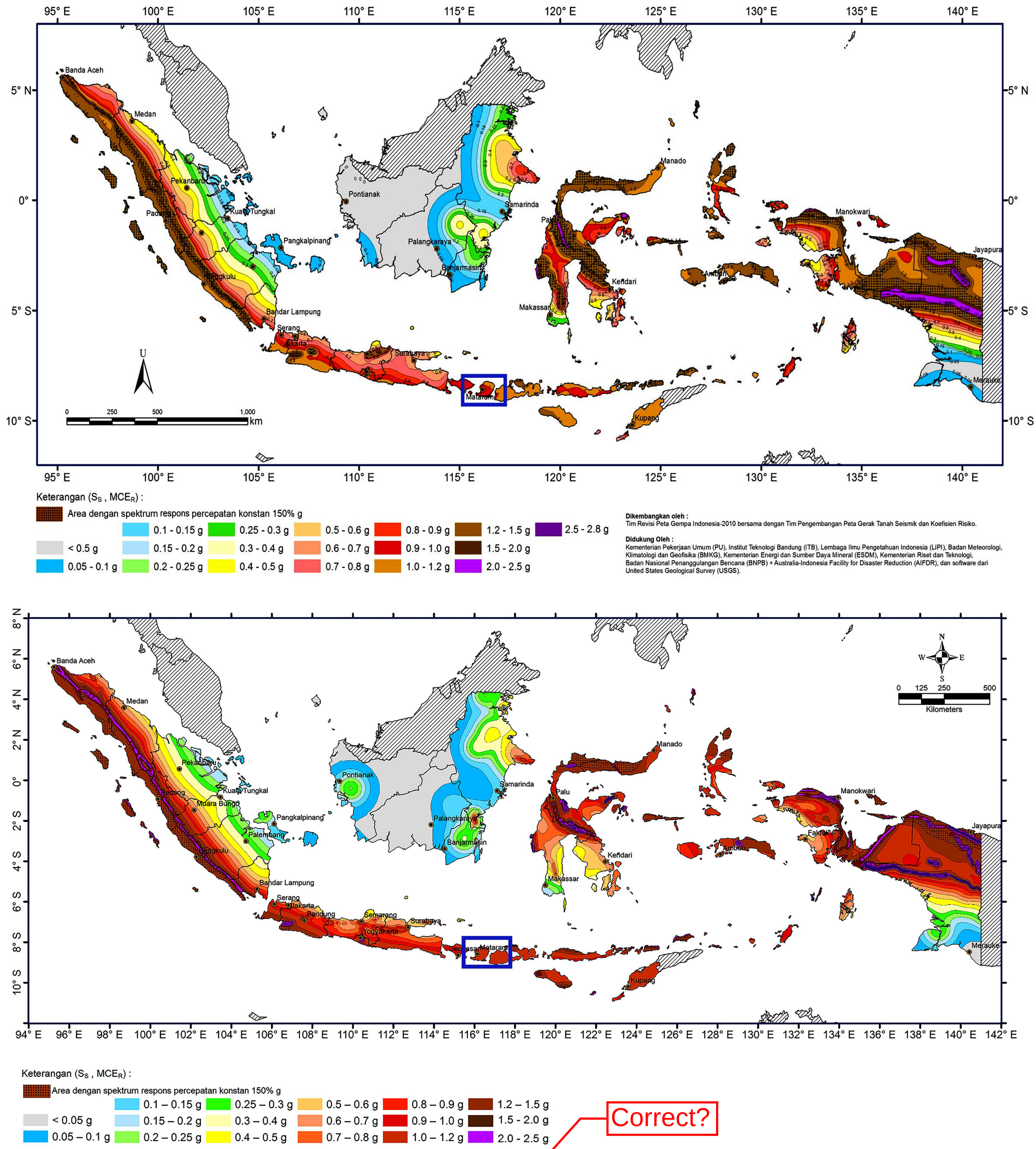

Figure 3. Spectral acceleration maps in bedrocks for the short period, $T = 0.2$ s, from SNI 1976-2012 [24] and SNI 1976-2019 [25].

period, $T = 0.2$ s, from SNI 1976-2012 and SNI 1976-2019. Meanwhile, Figure 4 shows spectral acceleration maps in bedrocks for a long period, $T = 1$ s, from SNI 1976-2012 and SNI 1976-2019. In Figures 3 and 4, the locations of Lombok and its surroundings are marked by a blue box shape. The seismic acceleration map in bedrock based on the PSHA results obtained after the Lombok earthquake is given in Figure 5 which consists of maps for short and long periods. The epicenter location of a series of earthquakes was in Lombok in 2018 and is marked by a blue circle on the map. The earthquake data set was collected from United States Geological Survey (USGS), International Seismological Centre (ISC), and Indonesian Centre for Meteorology,

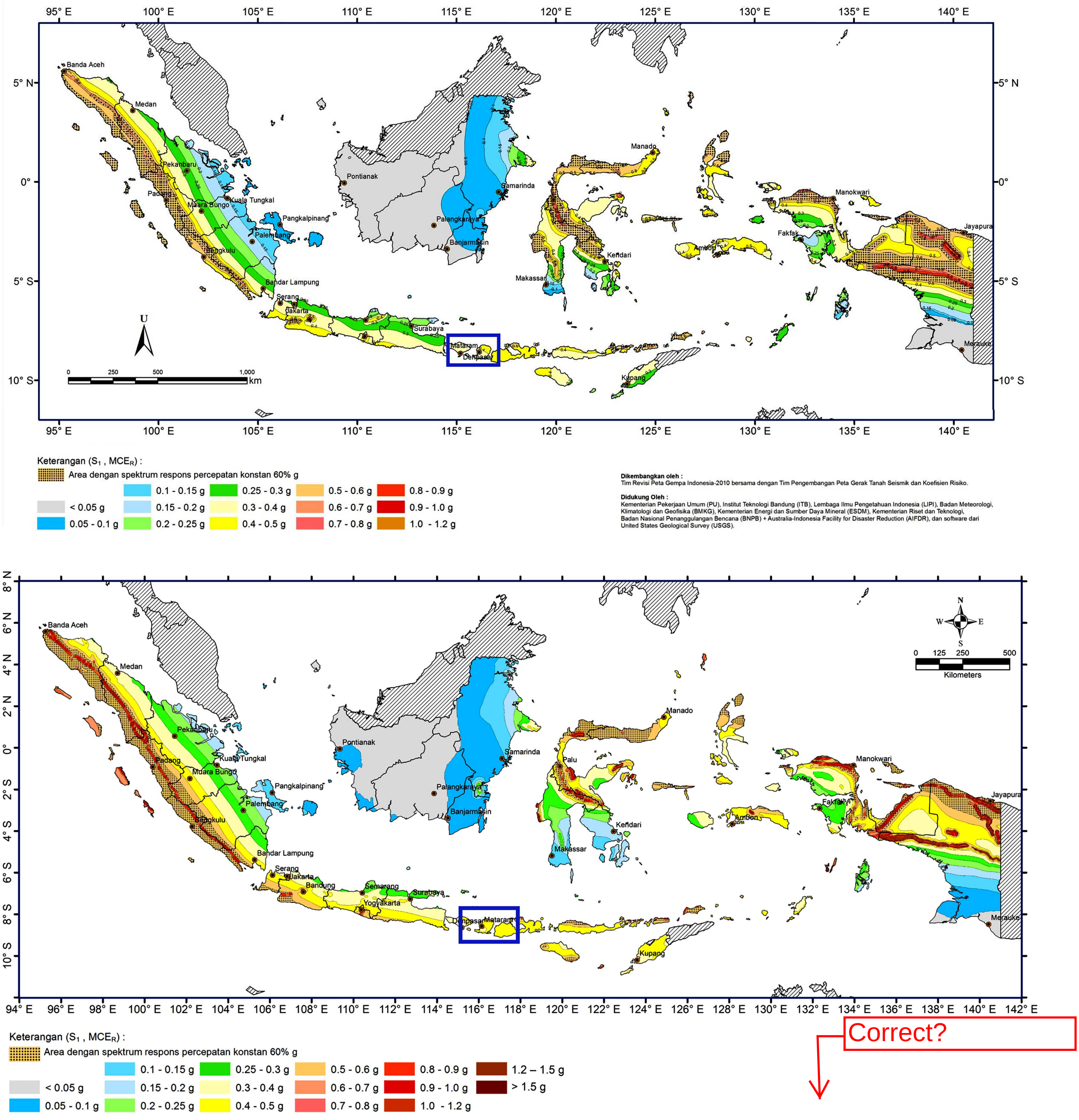

Figure 4. Spectral acceleration maps in bedrocks for the long period, $T = 1$ s, from SNI.

Climate and Geophysics (BMKG) for a period of 1922 to 2018. The earthquake with a magnitude M_w of 4.5 was considered for the spectral acceleration calculation because this magnitude is a standard for earthquakes related to seismic disaster risk.

Based on the spectral acceleration maps in bedrocks using the three approaches described earlier and the soil amplification factor of the building site location, the maximum spectral acceleration was calculated for short (S_{MS}) and long (S_{M1}) periods. Once the S_{MS} and S_{M1} were obtained, the design spectral accelerations, S_{DS} and S_{D1}, were calculated for the short and long periods, respectively. Furthermore, the response spectrum curve was generated according to S_{DS} and S_{D1}. The designed response spectrum was then applied to evaluate the seismic responses of the intended buildings.

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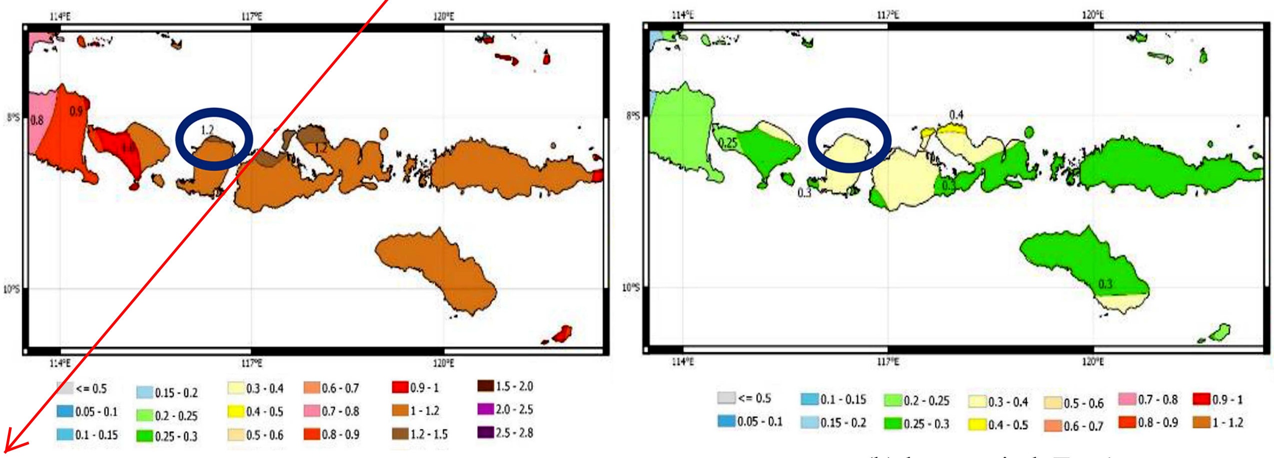

(a) short period, T = 0.2 s

(b) long period, T = 1 s

Figure 5. Lombok earthquake spectral acceleration maps in bedrocks for Mataram and surroundings: (a) for the short period, $T = 0.2$ s, from SNI 1976-2012 [24] and (b) for the long period, $T = 1$ s [30,31] from SNI 1976-2019 [25].

Correct?

2.2. Building configurat

The designed response spectrum was produced using three earthquake acceleration maps: SNI 1726-2012, SNI 1726-2019, and PSHA results obtained after Lombok earthquakes mentioned earlier. The differences in the design spectral acceleration were considered and applied as the parameter for analyzing the seismic response coefficient and structural responses.

Seismic coefficient and structural responses were observed at Mataram State Islamic University, which is located in Mataram City at coordinates of latitude: -8.610232 and longitude: 116.100845. This educational building represents a four-story reinforced concrete structure. The height of each story is 3.9 m. The longitudinal direction consists of 8 spans with a total length of 44.28 m. Meanwhile, four spans are in the transversal direction, with the total span length of 24.5 m. The overview frame in longitudinal and transversal directions used for seismic structural analysis is shown in Figure 6.

3. Results and discussion

3.1. Spectral acceleration parameter

According to the referenced study [32], the shear wave velocity in the surface sediment layer in Mataram City ranged between 135 m/s and 201 m/s. Therefore, based on the shear wave propagation velocity, Mataram City is included in the SD site class (medium soil) and SE site class (soft soil). The spectral accelerations of this area calculated based on SNI 1726-2012, SNI 1726-2019, and Lombok earthquake 2018 PSHA results are presented in Figure 7(a) for medium soil and SD and Figure 7(b) for soft soil, SE.

From the seismic acceleration map of SNI 1726-2012, it is found that the bedrock acceleration parameters for $T = 0.2$ s, S_S is 0.966 g while for $T = 1$ s, S_1 is 0.386 g. Meanwhile, based on SNI 1726-2019, S_S and S_1 values increase to 1.1 g and 0.45 g, respectively. The above increase rates are about 14% and 17% for S_S and S_1, respectively. The acceleration value in the case of SNI 1726-2019 is more significant than that in the case of SNI1726-2012 because some major earthquakes occurred in some areas in Indonesia between 2012 and 2017. As described earlier, the 2017 seismic acceleration maps from the National Center of Earthquake Studies were incorporated into SNI 1726-2019. However, when the effect of the 2018 Lombok earthquake was considered, the S_S value changed to 1.143 g. This value increased by 18% against the S_S value in the case of SNI 1726-2012 and increased by 4% compared to S_S value from SNI 1726-2019. Meanwhile, the S_1 value changed to 0.309 g, which decreased compared to the S_1 value on both seismic codes.

Furthermore, the values for short-period maximum acceleration (S_{MS}) and short-period design acceleration (S_{DS}) in the case of the Lombok earthquake 2018 PSHA results were found to be higher than those calculated based on SNI 1976-2019. However, at $T = 1$ s, S_{M1} and S_{D1} are more generous in the case of SNI 1726-2019. This finding holds in the case of both medium and soft soils.

The 2018 Lombok earthquake PSHA result has a more significant impact on short-period spectral acceleration, while both seismic codes have a more significant effect on the long-period spectral acceleration. This is because acceleration in the long period is more influenced by far-field earthquakes, while acceleration in the short period due to the PSHA results obtained from the 2018 Lombok earthquakes is highly affected by near-field earthquakes. The near-field earthquakes

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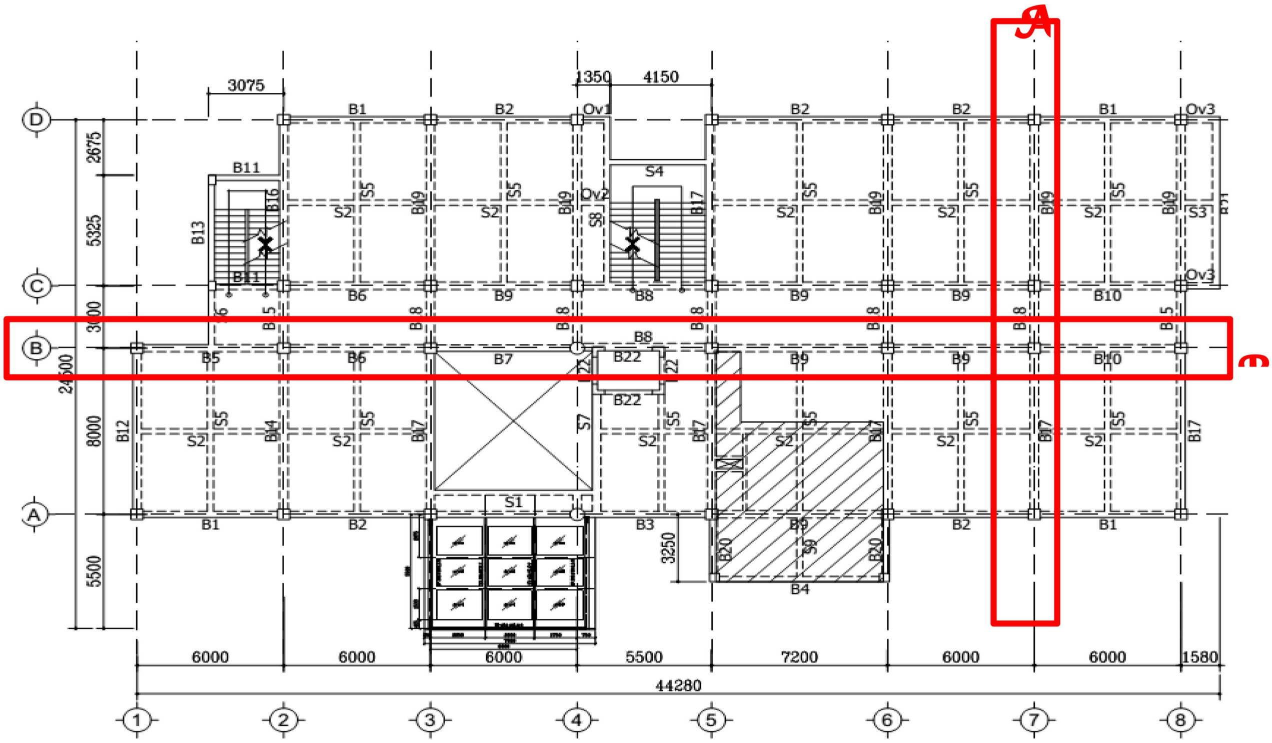
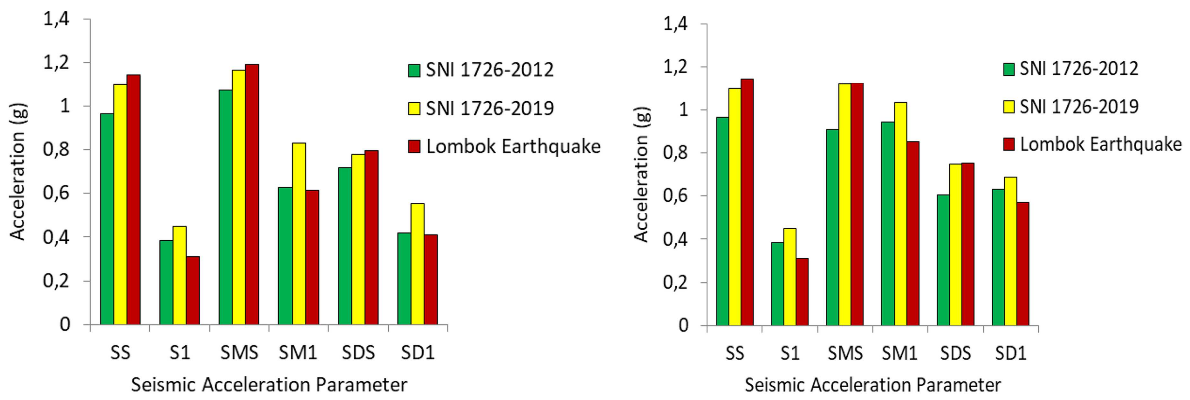


A: transversal direction
B: longitudinal direction

Figure 6. Plan of building in each story and the overview frame.



(a) Medium Soil, SD

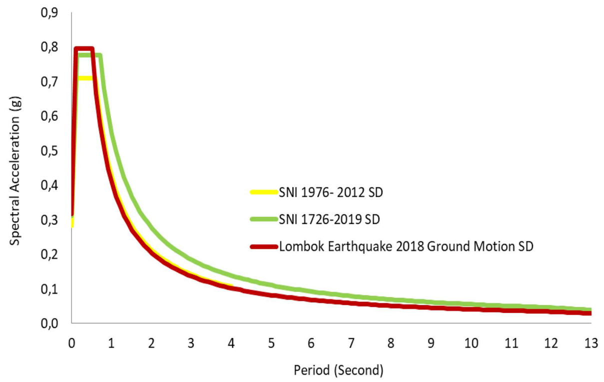
(b) Soft soil, SE

Figure 7. Spectral acceleration parameters.

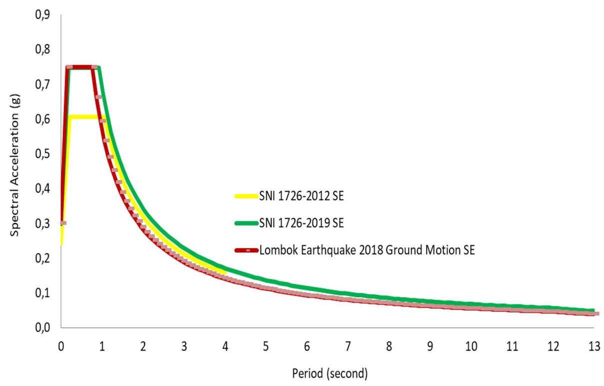
tend to occur in shorter periods with higher acceleration. Meanwhile, the far-field earthquakes occur in a more extended period [33,34]. The difference in the value of spectral acceleration for the short period, S_{DS}, and for the long period, S_{D1}, can affect the seismic design category of the building [35,36]. However, S_{DS} value was greater than 0.5 g in the case of either codes or the Lombok earthquake 2018 and the S_{D1} was more significant than 0.2 g. Thus, there is no change in the seismic design category of the three approaches, namely remaining in the D-seismic design category. A building in this category needs a more detailed design in reinforcement due to possible severe ground shaking [35].

3.2. Response design spectrum curve

In principle, the typical shape of the response design spectrum between both codes and the 2018 Lombok



(a) Medium soil, SD



(b) Soft soil, SE

Figure 8. Response spectrum curve.

earthquake PSHA results is substantially similar, as shown in Figure 8. Figure 8(a) describes medium soil, while Figure 8(b) describes soft soil. SNI 1726-2019 considered the existence of a more extended period on the spectral response curve. In both medium and soft soils, PSHA results obtained based on Lombok earthquakes had a greater spectral acceleration in short periods. For medium soils, the highest acceleration of the SNI 1726-2019 response design spectrum curve was 0.777 g, observed in the range of 0.143 s to 0.714 s. Higher acceleration was found in the Lombok earthquake's response design spectrum, i.e., 0.795 g, over a more extended period, from 0.103 s to 0.516 s. The outdated code, SNI 1726-2012, gives the lowest acceleration on the curve peak.

Considering the spectral acceleration of the soft soil, it is observed that the acceleration peaks of the curve are lower than those that occurred in medium soil among the three response design spectrum curves. The value of spectral acceleration in soft soil is generally significantly higher than that in medium soil. This finding holds in the case of Mataram City for the long-term period only. However, in the short period, the spectral acceleration value in soft soil is observed to be lower. This anomaly occurs because the short-period amplification factor in medium soils is lower than that in soft soils. The anomaly in which case the SNI-1726-2019 spectral acceleration design of soft soil is lower than that of medium soil was observed in 17 regions. It was found that even the spectral acceleration of the site class of hard soil (SC) was higher in earthquake-prone areas [28].

3.3. Seismic response coefficient, C_S

Seismic response coefficient (C_S) is used to calculate the building's base shear in static equivalent analysis. This coefficient is a function of several building parameters, consisting of spectral acceleration design, building fundamental period of vibration, building importance factor related to the building occupancy category, and building response modification factor which is determined based on the building type of seismic force-resisting system [24,25,36,37].

In this study, C_S value is determined under several conditions: risk category for educational facilities = 4; importance factor = 1.5; and response modification factor = 8. According to Figure 9, the determined C_S and minimum C_S values are lower than the maximum C_S values for medium soils. Meanwhile, in soft soil, the maximum C_S is greater than the determined C_S and minimum C_S. S_{DS} affects the determined C_S and maximum C_S, while S_{D1} affects the maximum C_S. The S_{DS} in medium soil is higher than that in soft soil such that it generates a higher determined C_S and minimum C_S. Likewise, S_{D1} is found to be greater in soft soil; thus, the maximum C_S is found to be greater in soft soil. This trend occurs in both codes due to the 2018 Lombok earthquake.

Due to the effect of S_{DS} in the 2018 Lombok earthquake, which is the greatest among the three methods, this method has the highest value on the determined C_S and minimum C_S. However, the highest S_{D1} is found based on SNI 1726-2019 such that the greatest value of maximum C_S has been achieved using this method. In principle, the determined C_S cannot be greater than the maximum C_S and it cannot be lower

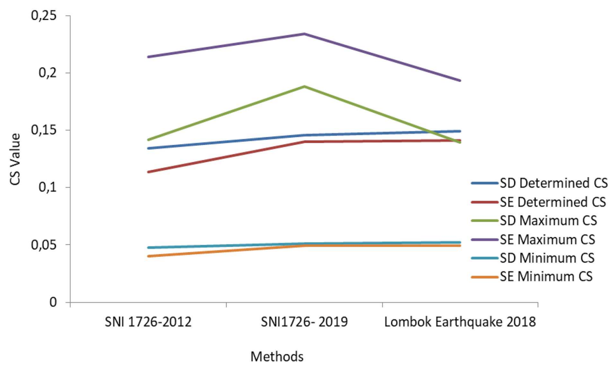
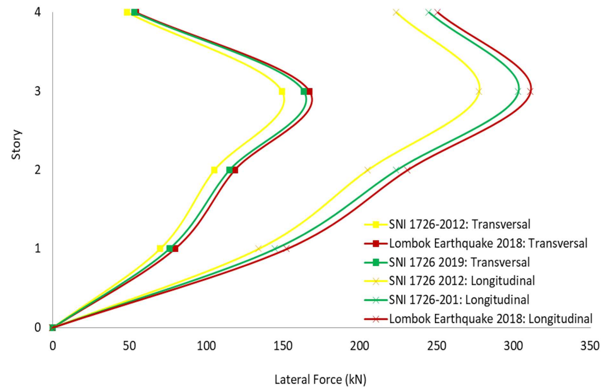
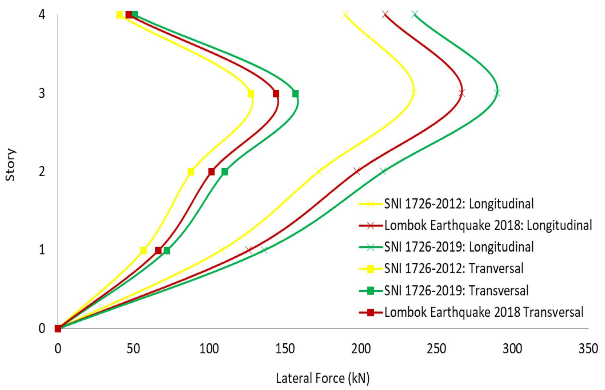


Figure 9. C_S value determined by the three approaches.



(a) Medium soil, SD



(b) Soft soil, SE

Figure 10. Lateral forces of the overviewed frame section.

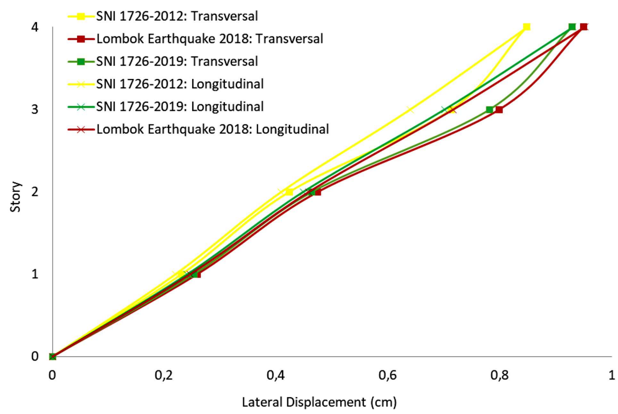
than the minimum C_S. The determined C_S due to the 2018 Lombok earthquake is slightly greater than the determined C_S in the case of SNI 1726-2019 for both medium and soft soils.

3.4. Building seismic responses

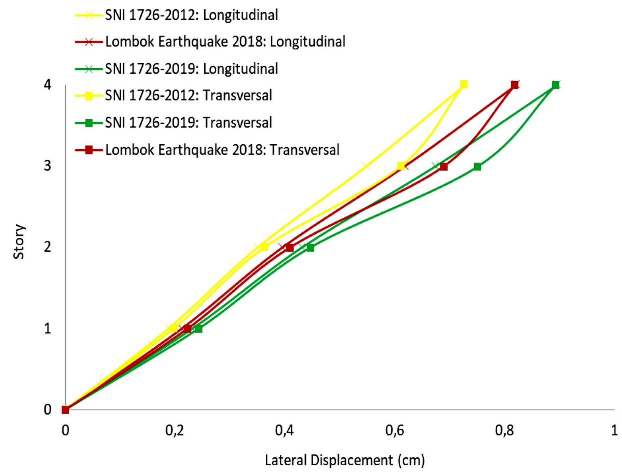
The lateral forces, shown in Figure 10, are measured in the overviewed frame section of longitudinal and transverse directions of the building. In medium soils, as illustrated in Figure 10(a), the most significant lateral force occurs when calculated based on the acceleration of the PSHA results associated with the 2018 Lombok earthquakes.

Minor lateral forces are obtained when calculated by the old code, namely SNI 2012. The lateral force calculated based on the spectral acceleration of the 2018 Lombok earthquake is also more remarkable than that calculated based on SNI 1726-2019. This difference ranges from 2.3% to 5.4%, depending on the story height and direction of the building reviewed.

However, in the case of soft soil (Figure 10(b)), the largest lateral forces are found using SNI 1726 – 2019 compared with the lateral force calculated based on the acceleration of the PSHA results due to the 2018 Lombok earthquake. This value is 8% – 9% greater



(a) Medium soil, SD



(b). Soft soil, SE

Figure 11. Lateral displacement of the overviewed frame section.

depending on the story height and direction of the building reviewed. Soft soil generates a long-period response greater than medium soils [38]. Therefore, the lateral force in the case of SNI 1726 – 2019 is more significant because the spectral acceleration of soft soil in SNI 1726 – 2019 is greater than the spectral acceleration of soft soil due to the 2018 Lombok earthquake.

A similar phenomenon occurs in the building response in the form of lateral displacement, as shown in Figure 11. On medium soil (Figure 11(a)), the most significant lateral displacement occurred in the calculation with the 2018 Lombok earthquake. However, in soft soil (Figure 11(b)), the lateral displacement value calculated by the SNI 2019 response design spectrum was the greatest. Meanwhile, the smallest building lateral displacement was found based on the 2012 response design spectrum.

The seismic response of buildings on medium soil was found to be greater if the response design spectrum for the PSHA results of the 2018 Lombok earthquake

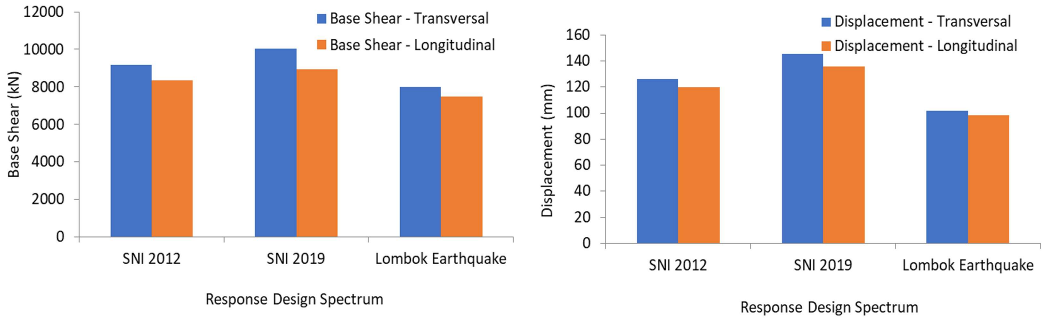


Figure 12. Performanc[...]displacement.

Perform the capacity? vague. Do we 'perform' a capacity?

was used in the calculation compared to the two sei[...] codes in Indonesia.

Furthermore, the performance-based design evaluated using pushover analysis was added in order to perform the building capacity. According to the analysis, upon the application of the three-response design spectrum of the medium soil, clearly SNI 2019 determined higher base shear and displacement. However, according to the performance level illustrated in Figure 12, the three-response design spectra exhibited the same performance level, called immediate occupancy. Immediate occupancy implies that the structure remains safe and only sustains minimal damage during the occurrence of an earthquake. Strength and stiffness are approximately equal to those in pre-earthquake conditions. In addition, the vertical and lateral structural resisting systems are still capable of sustaining earthquake load [36].

All efforts made to reduce earthquake damage and risk need to be carried out with preventive measures for disaster management. One of the efforts made is updating the Earthquake Hazard Map, which is usually updated every year or after such a strong earthquake stroke. For Indonesia, the updating attempt is made no later than every five years [26]. In this paper, although there is only a 4% increase in the short-period bedrock acceleration, it is necessary to update the map because it has existed for five years. Moreover, using the PSHA results obtained from the Lombok earthquakes, the design response spectrum increases the seismic building responses. In addition, some new fault characterizations have been studied following the sequence of the Lombok 2018 earthquakes [39,40]. Therefore, updating of the earthquake map is suggested for the next Indonesian code in this area to improve seismic mitigation. Seismic code updates provide preparation measures for new buildings and strengthen the existing one to ensure better structural seismic responses to future earthquakes. Other studies have made similar recommendations concerning the reduction of seismic disaster risk in this area [5,6,30,31,41].

[...]ns

The bedrock acceleration in the short period (S_S) in the order of the greatest to the smallest was obtained at 1.143 g based on the Probabilistic Seismic Hazard Analysis (PSHA) results from the 2018 Lombok earthquakes, 1.1 g from the SNI 1726-2019 seismic map, and 0.966 g based on the SNI 1726-2012 earthquake map. Meanwhile, the highest value of the bedrock acceleration in the long period (S_1) was found in the case of SNI 1726-2019. The outdated code, SNI 1726-2019, provided the lowest bedrock acceleration.

In principle, the typical shape of the response spectrum between both codes and the 2018 Lombok earthquake ground motion is similar. In both medium and soft soils, Lombok earthquake PSHA results had a higher spectral acceleration value in the short period, while SNI 1726-2019 had a prominent presence for the long period on the response design spectrum curve.

Given the effect of the higher value of S_{DS} on either medium or soft soil, the determined seismic response coefficient, C_S, due to the PSHA results of the 2018 Lombok earthquake was slightly more significant than the determined C_S analyzed by SNI 1726-2019. In addition, the building seismic response in terms of lateral forces and displacements on medium soil was greater when analyzed using the response spectrum due to the PSHA results obtained from the Lombok earthquakes. Furthermore, it is essential that the seismic codes be updated by considering the effect of the Lombok 2018 earthquake to support reducing the risk of earthquake disasters in the future.

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Biographies

Ni Nyoman Kencanawati is currently an Associate Professor at the Civil Engineering Department, University of Mataram, Indonesia. She received her BSc degree in Civil Engineering in 1999 from University of Mataram -Indonesia, MSc degree in Structural Engineering Engineering in 2001 from Gadjah Mada University-Indonesia, and PhD in Structural Engineering in 2011 from Kumamoto University-Japan. Her publications the form of several papers are published in national and international journals and conferences proceedings in the fields of structural engineering, concrete material, and seismic mitigation.

Hariyadi is currently an Associate Professor at the Civil Engineering Department, University of Mataram, Indonesia. He received his BSc degree in Civil Engineering in 1997 from University of Mataram-Indonesia, MSc degree in Strengthening and Maintenance of Civil Engineering Structures in 2002 from University of Leeds-UK, and PhD in Civil and Structural Engineering in 2015 from Kyushu University-Japan. His publications in either national and international journals or proceedings are highlighted in structural engineering, concrete material and structures, and earthquake-resistant structures.

Nurul Hidayati received her BSc degree in Civil Engineering in 2020 from Mataram University. Currently, she is also active in assisting research activities in the laboratory. Her research interest includes structural engineering and concrete material.

I Made Sukerta received his BSc degree in Civil Engineering in 2021 from Mataram University. Currently, he is also active in assisting research activities in the laboratory. His research interests include structural engineering and software application in Civil Engineering.

Ni Nyoman Kencanawati <nkencanawati@unram.ac.id>

Acknowledgement of Submission (#SCI-2105-5702)

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Manuscript ID: SCI-2105-5702

Manuscript Title: **Two Approaches on Structural Seismic Responses in Mataram City: Based on the Spectral Acceleration of Lombok Earthquake Series and the Newest Seismic Codes**

Authors: Ni Nyoman Kencanawati

Dear **Dr. Ni Nyoman Kencanawati**

This is to acknowledge the receipt of the above mentioned manuscript.

This manuscript will be reviewed for possible publication in Scientia Iranica.

Please be sure that the submitted manuscript has not been published previously and will not be submitted elsewhere prior to our decision.

Our editorial decision will be brought to your attention once the paper has been reviewed by the referees.

I wish to take this opportunity to thank you for sharing your work with us.

Sincerely Yours,

Parisa Morovati,

Senior Editorial Associate,

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Manuscript Needs Major Revision (#SCI-2105-5702 (R1))

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Authors: Ni Nyoman Kencanawati

Dear **Dr. Ni Nyoman Kencanawati**

Please find attached the review comments on your article entitled, "**Two Approaches on Structural Seismic Responses in Mataram City: Based on the Spectral Acceleration of Lombok Earthquake Series and the Newest Seismic Codes**"(Ref. No: SCI-2105-5702), which was submitted to Scientia Iranica for possible publication.

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"Editors' Comments to the Author/s"

The Editorial Board of the journal has requested you to:

1- Update the references of your manuscript to include at least 10 references published from 2014 to 2018,

2- To include at least 2 references published in Scientia Iranica.

Reviewer 1

Ref. No: SCI-2105-5702

"Comments to the Authors"

Based on response spectrum method, this paper compares the two codes and the affected by Lombok Earthquake 2018. And their influence on the seismic response analysis of a building structure in Mataram city are studied here.

This research provides a new method for earthquake response analysis in Indonesia. However, the authors have to address all the following issues before recommending it for publication:

1-Title. The seismic response analysis of structure based on SNI 1726-2019 was not proposed by the author. For this reason, it is opinion of this reviewer, that it would be better to modify the paper's title as follows: A New Approach on Structural Seismic Responses in Mataram City: Based on the Spectral Acceleration of Lombok Earthquake Series.

2-Section 2. The following words’ Figure (a)’ and ’ Figure (b)’ appear twice each in this section. However, there are no Figure (a) and Figure (b) in this paper. Please correct them.

3- Section 2. In this section, the author gives a building configuration with reference to the three earthquake acceleration maps. However, it does not reflect the influence of the SNI 1726-2019 and the spectral acceleration of 2018 Lombok earthquake on its design.

4- Section 3. The digital parts of Figures 8 and 9 are not blackened.

Reviewer 2

Ref. No: SCI-2105-5702

"Comments to the Authors"

My main concern is related to the comparison between building code provisions which are constructed on the basis of probabilistic seismic hazard analysis (PSHA) performed in different periods of time (2012, 2017, and after 2018). On one hand, probabilistic seismic hazard mapping and characterization of design ground motion parameters are the continuous procedures. The development of seismic hazard maps is related to accumulation of new information, enhance of procedures of interpretation of the data, development of sophisticated models and adequate treatment of uncertainty in seismic process. The last estimations of seismic hazard in the studied area were stipulated by a series of earthquakes occurred in 2018 at the northern part of Lombok Island caused the death of hundreds of people and ruined thousands of buildings. Unfortunately, there is no comparison between the observed ground motion data and results of PSHA, therefore the difference between the results of different PSHA may be considered only as manifestation of epistemic uncertainty, or uncertainty caused by application of different input models and methods.

On the other hand, many recent earthquakes caused ground motions amplitudes of which that are much higher than the design limits provided by seismic hazard maps. These high amplitudes may be caused by local site effects, peculiarities of rupture propagation, and so on. The PSHA produces an integrated description of seismic hazard representing numerous seismic events. There is always a considerable probability that the design threshold will be exceeded, especially in the area close to a source, due to high positive values of ground motion variability. Also, it is necessary to bear in mind, that many buildings (may be the majority of the building stock) were not built in accordance with most recent building code provisions. That is why these buildings may be strongly damaged, and it seems that the Lombok earthquake consequence is the case.

As can be seen from Fig. 5, the last two PSHAs (Code SNI 1726-2019 and those obtained after 2018 earthquake) show almost similar high-frequency estimations of ground motion, i.e. the latter short period spectral acceleration is only 4% larger than the former. I don’t think that this negligible difference may be a reason for necessity to improve of current seismic code provisions. Bearing in mind overall uncertainty of PSHA, it would be reasonable concluding that considering the current knowledge and given new models for PSHA constructed after the 2018 Lombok earthquakes, the Code SNI 1726-2019 adequately represents seismic hazard in the area.

Specific comments

1. Introduction.

Page. 2. A map showing general features of tectonic and seismicity of the entire region (Indonesia) should be provided highlighting the area where the Lombok earthquakes were occurred.

Page 4, second paragraph. Please specify what was the difference between the model of seismicity created by NCES in 2017 and new model developed after the Lombok earthquakes – new source zonation, another ground motion equations, consideration of earthquake records, etc.

Materials and Methods

Figures 1 and 2. It would be better to rearrange plots joining the SNI 2012 and SNI 2019 maps for similar parameter in the same Figure. In this case the differences (if any) will be clearly seen. Also, area shown in Figure 3 should be outlined at these maps.

Figure 3. I suggest to show here (1) location of the Lombok earthquakes and (2) corresponding area of the SNI 2019 map.

Building configuration

Why this four-story reinforce concrete building is considered here? Is it typical construction for the area? Or there are enough data to create the building model for further analysis? Actually, it seems that the next step in development of building code will be risk-targeted hazard maps that are based on probability of collapse. In this case characteristics (fragility curve) of typical construction are considered.

4 Conclusion

Bearing in mind negligible difference between high-frequency amplitudes of the SNI 2019 design spectrum and the design spectrum based on the hazard maps constructed after the 2018 Lombok earthquakes, why did the authors call for the update of existing seismic codes ? Please specify.

Technical comments

Abstract

Line 7 “..as well as the spectral acceleration affected by Lombok earthquake 2018”. Do you mean the results of PSHA obtained after occurrence of the 2018 earthquakes?

Line 9. “.. the seismic parameters of recent Lombok 2018 earthquakes lead to higher…”. Again, not observed ground motion records were used, but the results of PSHA obtained after occurrence of the 2018 earthquakes. Please specify it later in the text – not “Lombok ground motion”, or “2018 Lombok seismic map", but “PSHA results obtained after Lombok earthquakes”

Introduction

Page 3, first paragraph, first line – not “seismic map” but “seismic hazard map”

Third and fifth lines (and later in the text) – “response design spectrum”

I believe that the language editing is absolutely necessary.

Ni Nyoman Kencanawati <nkencanawati@unram.ac.id>

Acknowledgement of Revision (#SCI-2105-5702 (R1))

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Scientia Iranica <scientia@sharif.edu> 26 Agustus 2021 pukul 16.04
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Manuscript ID: SCI-2105-5702 (R1)

Manuscript Title: **A New Approach on Structural Seismic Responses in Mataram City: Based on the PSHA Results Obtained after Lombok Earthquakes 2018**

Authors: Ni Nyoman Kencanawati,Hariyadi Hariyadi,Nurul Hidayati,I Made Sukerta

Date: 2021-05-21

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Thank you for submitting the revised file of your manuscript to the **Scientia Iranica**

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Manuscript Title: **A New Approach on Structural Seismic Responses in Mataram City: Based on the PSHA Results Obtained after Lombok Earthquakes 2018**

Authors: Ni Nyoman Kencanawati,Hariyadi Hariyadi,Nurul Hidayati,I Made Sukerta

Dear **Dr. Ni Nyoman Kencanawati**

Please find attached comments on teh revised version of your article entitled, "**A New Approach on Structural Seismic Responses in Mataram City: Based on the PSHA Results Obtained after Lombok Earthquakes 2018**"(Ref. No: SCI-2105-5702 (R1)), which was submitted to Scientia Iranica for possible publication.

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"Comments to the Authors"

Section 3.4, paragraph below Fig.10 Caption. "All efforts to reduce earthquake hazards need to be carried out with preventive measures..." Actually, earthquake hazard cannot be reduced, because the term "Earthquake Hazard" relates to any physical phenomenon associated with an earthquake. As a rule, the term is applied to indicate level of ground motion. However, it may be possible to reduce earthquake damage and risk - probability of that specified loss will exceed some level. Please revise the text.

Ni Nyoman Kencanawati <nkencanawati@unram.ac.id>

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Authors: Ni Nyoman Kencanawati,Hariyadi Hariyadi,Nurul Hidayati,I Made Sukerta

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The manuscript has been revised according to the suggestions and the signed copyright form has been enclosed. We appreciate your kindness in guiding us to improve it for better presentation. We hope that the manuscript is now acceptable for publication.

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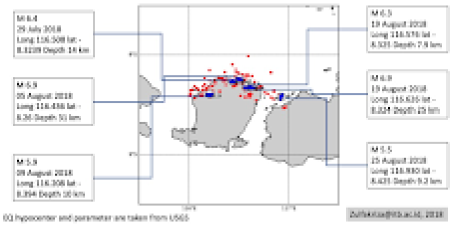

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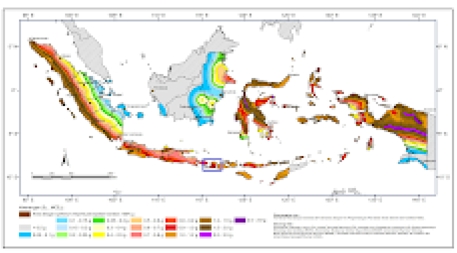

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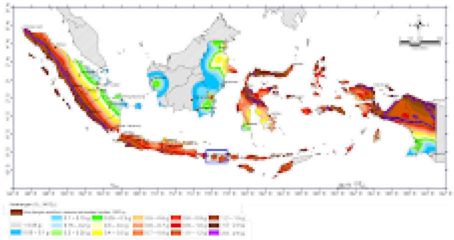
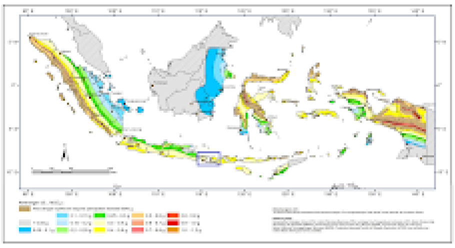
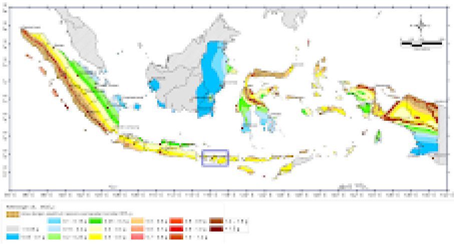


Original Fig 3 (b).png
933K



Original Fig 4 (a).png
1910K



Original Fig 4 (b).png
898K

Ni Nyoman Kencanawati <nkencanawati@unram.ac.id>

acceptance letter of your paper

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Balas Ke: scientiairanica@sharif.edu
Kepada: Ni Nyoman Kencanawati <nkencanawati@unram.ac.id>

Dear Dr. Kencanawati,

Please find attached the acceptance letter of your paper (Ref. No: SCI-2105-5702).

Sincerely Yours,

Office of Scientia Iranica

Dr.kencanawati.pdf
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Ni Nyoman Kencanawati <nkencanawati@unram.ac.id> 9 Maret 2022 pukul 09.09
Kepada: scientiairanica@sharif.edu

Dear Chief of Editor
Scientia Iranica,
I would like to express my deepest thank you for accepting our article in your journal.
Sincerely yours,
Ni Nyoman Kencanawati, Ph,D
Mataram University
[Kutipan teks disembunyikan]

Ni Nyoman Kencanawati <nkencanawati@unram.ac.id>

proof of 30.SCI.2105.5702

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Dear Dr. Kencanawati

Please find attached the PDF files of the proof and the edited version of your article entitled, "A New Approach on Structural Seismic Responses in Mataram City: Based on the PSHA Results Obtained after Lombok Earthquakes 2018" (Ref. 30.SCI.2105.5702) which you have submitted to Scientia Iranica.

I would be extremely grateful if you please examine the proof for typographical errors, paying special attention to editing, completeness and correctness of the text, tables, figures, formulae and references, and forward it to the office of Scientia Iranica, **within 3 days of the receipt**, in order to avoid delay in the publishing procedure of the article.

The edited version of your paper is also attached only for your consideration.

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9 Mei 2022 pukul 18.26

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Dear Mr. Roya Touiserkani,
Scientia Iranica Publishing Manager,

I would like to send my greatest thank you for improving my article comprehensively.
I have annotated the correction according to your inquiry in the PDF proof file.
In addition, the improved version of Figure 5 has been enclosed in this email.
Thank you very much for your cooperation.

Sincerely yours,
Ni Nyoman Kencanawati, Ph.D
Mataram University
[Kutipan teks disembunyikan]

Figure 5.docx
788K