An Investigation of Building Seismic Design Parameters

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An Investigation of Building Seismic Design Parameters in Mataram City Using Lombok Earthquake 2018 Ground Motion

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Highlights:

- Spectral acceleration using the Lombok earthquake 2018 was analyzed
- The spectral acceleration is greater than the existing seismic code acceleration
- The seismic response coefficient is higher than the existing seismic code
- Existing seismic building standards need to be improved

Abstract. Mataram is the capital of West Nusa Tenggara. West Nusa Tenggara is made up of two islands, Lombok and Sumbawa. The 2018 earthquake on Lombok undoubtedly affected spectral acceleration. This is an important factor to be addressed in structural design. Short period spectral acceleration, S_S, increases 18.323% compared to the value listed in seismic code SNI 1976:2012, corresponding to a 2500-year return period. However, even if the S_S value increases, the design category of the building does not change and remains in the D category. In general, the acceleration value in this study was found to be relatively greater than that of the existing code for periods of less than 0.462 s for site class D, and in periods of less than 0.830 s in site class E. In addition, the seismic response coefficient, C_S, for medium soil, increases by 10.782% compared to the C_S calculated using of the current code. This effect is more severe in soft soil areas where the increase reaches 13.168%. Improving existing codes with seismic design parameters for new buildings affected by the ground motion of recent strong earthquakes will lead to more preparedness and will be an important part of local disaster risk reduction.

Keywords: *building seismic coefficient; Lombok earthquake 2018; spectral acceleration; seismic design parameters; seismic code.*

1 Introduction

The West Nusa Tenggara region is an area of high seismic activity, surrounded by two active seismic sources. In the south is the subduction zone of the Indo-Australia Sea Plate and in the north is the back-arc thrust zone. According to the

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Indonesian Agency for Meteorology, Climatology and Geophysics (BMKG), a 6.2 magnitude earthquake on June 9, 2016, occurred in Mataram and Central Lombok and caused some damage. Later, in 2017, several quakes hit at a scale of II-III MMI in Mataram City, as reported by Taruna, Banyunegoro, and Daniarsyad in [1]. In addition, officials reported that there were 3699 earthquake events in 2018 and 215 events were felt. One of a series of Lombok earthquakes on August 5, 2018, with a magnitude of 7.0, caused severe damage to a number of buildings and houses, some even collapsed in the Lombok area, including the city of Mataram, as announced by BMKG in [2] and published by Pomonis *et al.* in [3] and Asmirza and Sofian in [4].

In the past, some countries have changed their seismic codes after large earthquakes that caused various damage to structures and buildings. As studied by Okamura in [5] and Karakostas *et al*. in [6], seismic codes have been improved with a new response spectrum based on recent ground accelerations. Similarly, Indonesia has a current code for seismic structures, namely SNI 1726:2012 in [7]. The ground motion is calculated with a 2% probability of being exceeded within 50 years. The return period of the spectral acceleration is 2500 years. It replaced SNI 1726:2002 in [8]. SNI 1726:2002 provided spectral acceleration by dividing all areas of Indonesia into six seismic zones. The current Seismic Building Code has been improved by providing spectrally accelerated design values at each coordinate point in Indonesia. Seismic acceleration maps are also attached for spectral accelerations at T = 0 s (PGA), T = 0.2 s (short period), and T = 1 s (long period).

The previous seismic design code, SNI 1726:2002, has been reviewed by Sengara *et al*. [9]. In addition, compared to the previous seismic code SNI 1726:2002 presented by Arfiadi and Satyarno in [10], some of the Indonesian short-period design spectral accelerations, S_{DS}, were significantly increased in current seismic code SNI 1726:2012. Significant increases in S_{DS} are evident in some areas, such as Aceh, Palu, Yogyakarta, and Padang, which were affected by major earthquakes during the time when the previous code was applied. Therefore, the values have been modified in the current code. In Palu, S_{DS} had the largest increase, with 116.7%, 85.7% and 41.2% in hard, medium, and soft soils, respectively. This region was hit by a 7.7 magnitude earthquake in 2008, and the 2012 seismic code changed the spectral acceleration. In the other earthquake prone areas mentioned above, the S_{DS} of three types of soil were increased from 10% to 80%. Conversely, Lombok did not show significant seismic activity during that period. Therefore, the 2012 seismic code shows little change in acceleration.

To obtain a new spectral acceleration that includes the site amplification factor, strong ground motions after the earthquake must be considered. This is compared to the existing spectral acceleration provided by the existing code to make sure there is a sufficient design to face strong earthquakes that may occur in the future, as reported by Panzera *et al.* in [11] and Mase, Likitlersuang and Tobita in [12]. Furthermore, evaluation of seismic codes after earthquakes has been carried out in some countries. Their earthquake code has been updated to consider recent ground accelerations due to earthquakes. In addition to the response spectrum, details of the structural design have been improved further, as given by Okamura in [5], Karakostas *et al.* in [6], Sezen *et al.* in [13], Ergün, Kiraç and Bacsaran in [14], Mosleh *et al.* in [15] and Baros and Santa-Maria in [16].

The current analysis describes the seismic hazard in Mataram city using seismic data up to 2017 with a 2% probability of being exceeded in 50 years (return period of 2500 years). The short period of bedrock acceleration S_S (T = 0.2 s) and the long period of bedrock acceleration S_1 (T = 1 s) were reported to be in the range of 0.37-0.45 g ($g = 9.81 \text{m/s}^2$) and 0.16-0.18 g, respectively. Furthermore, the values of S_S and S_1 in the northern region of Mataram are higher than those in the southern region of Mataram. This is due to the superiority of the Back Arc Thrust activity in northern Lombok, as given in [1]. The 2018 earthquake on Lombok is an important consideration in spectral acceleration. This is an important factor to be addressed in structural design. Improving the calculation of parameters will lead to the reproduction of the structural design under seismic loading, which is part of disaster risk reduction. It could potentially save millions of lives and reduce major risks in the region in the future. Therefore, a new spectral acceleration needs to be approached using the recent 2018 seismic data, which apply to some seismic parameters that will help achieve better seismic structures.

2 Related Research and Theory

According to Agustawijaya, Sulistyono and Elhuda [17], Lombok is classified as moderate to high seismic activity. Before the strong earthquake of 2018, this study stated that the South Subduction Megathrust and the North Back-Arc Thrust have established the tectonic pattern of Lombok Island as an effect of compression between the Australian continental plate and Eurasia. Then in 2018, a series of earthquakes occurred in North Lombok, triggered by the Flores back arc trust. The ground motion initially began on July 28 with an M_w 6.4 earthquake in the northern part of Lombok. Aftershocks with M_w<5 followed the first earthquake a few hours later. On August 5, a larger shock of M_w 7.0 occurred. Then, in the following two weeks, an M_w 6.9 earthquake hit the island on August 19, 2018. The sequences of Lombok ground motions have been studied in detail in [18,19].

As reported by Marjiyono in [20], in general, the plains of Mataram City are dominated by alluvial deposits with sandy materials, either the product of the eastern river process or marine products from the West Side. The alluvium fills an ancient form in the form of a basin in the western part of Mataram. Physically, alluvial sediments are soft and are indicated by low shear wave velocity values. This condition is potential for areas that experience such wave amplification during an earthquake [21]. In addition, the average measurement of shear wave velocity (V_s) shows a value in the range of 135-201 m/s in Mataram city. This value is included in site class D (SD) and site class E (SE) of the current building seismic code.

S_S and S_1 must be determined at $T = 0.2$ s and $T = 1$ s, respectively, provided in the ground motion map of the SNI 1726:2012 code, and may exceed 2% in 50 years. By multiplying the S_S and S_1 values by the amplification factor from each site class, the short-period, S_{MS}, and long-term S_{M1} surface maximum ground acceleration can be calculated directly [22,23]. The amplification factor F_a is related to the acceleration of the short-period S_S, while the amplification factor associated with S_1 is F_v. Furthermore, the S_{MS} and S_{M1} values are used to calculate the design spectral acceleration parameters for short period, S_{DS} and long period S_{D1}, as described by in SNI 1726:2012 [7].

3 Method

3.1 Ground Acceleration Data

The ground acceleration data used in this study were based on previous works [24,25]. Earthquake data were obtained from Engdahl ISC (EHB), USGS, and BMKG for 1922-2018. The data were taken at a latitude of 7°-12° and a longitude of 113.5°-122.5°, or about 300 km from Mataram city, with magnitude $M_w \geq 4.5$. This magnitude is assumed to be the standard for earthquakes related to the risk of seismic disaster. In this study, the values of peak ground motion in the bedrock soil layer from the previous studies were used. Ground motion or maximum acceleration were adopted as the parameters used in this study. These parameters, S_S and S_1, are related to the technical design of earthquake-resistant structures, as shown in Figures 1 and 2.

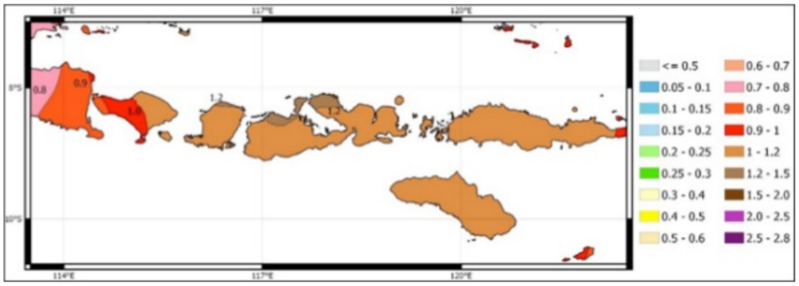

Figure 1 Spectral acceleration at T = 0.2 s in bedrock with a probability exceeding 2% in 50 years for the Bali-West Nusa Tenggara region, Taruna in [24].

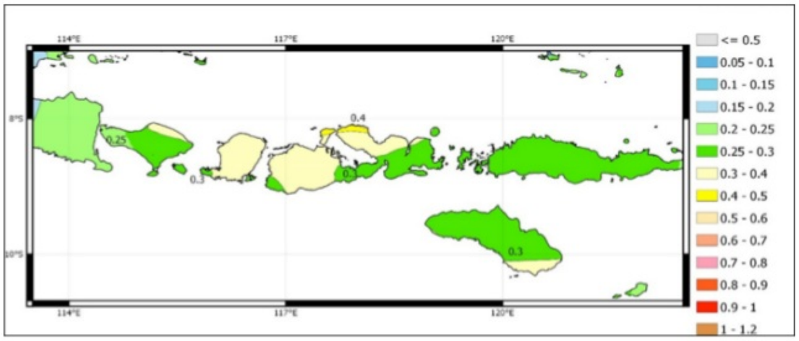

Figure 2 Spectral acceleration at T = 1 s in bedrock with a probability exceeding 2% in 50 years for the Bali-West Nusa Tenggara region, Taruna in [24].

As shown in Figure 1, in most Lombok regions, S_S ranges from 1-1.2 *g*, while in North Lombok the values are over 1.2 *g*. S_S values tend to be larger than the 0.9-1.2 *g* values for Lombok calculated in SNI 1726:2012 (Figure 3). This could be caused by the large earthquake data used in previous studies, especially the increase in the 2018 Lombok earthquake series. On the other hand, the maximum acceleration of S_1 is 0.25 to 0.4 *g*. The S_1 values in the Lombok region used in this study were lower than those of SNI 1726:2012 (Figure 4). In SNI 1726:2012, Lombok's S_1 values range from 0.3 to 0.5 *g*, with the maximum seen in the north.

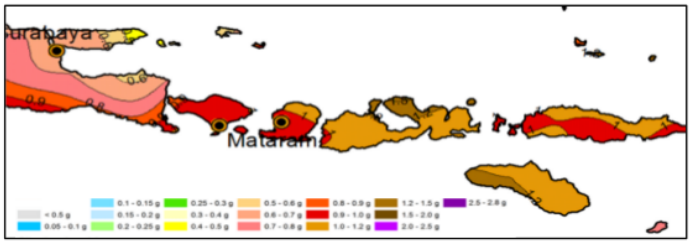

Figure 3 Spectral acceleration at T = 0.2 s in bedrock with a probability exceeding 2% in 50 years for the Bali-West Nusa Tenggara region, SNI 1726:2012 in [7].

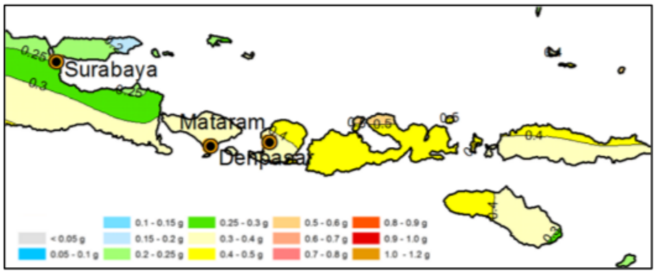

Figure 4 Spectral acceleration at T = 1 s in bedrock with a probability exceeding 2% in 50 years for the Bali-West Nusa Tenggara region, SNI 1726:2012 in [7].

3.2 Equivalent Lateral Load Factor

The dynamic properties of seismic loads were simplified to horizontal forces with an equivalent lateral load procedure. For the analysis, the seismic response coefficient C_S was determined. SNI 1726:2012 provides instructions for obtaining C_S. It depends on spectral acceleration, the S_{DS} and S_{D1} values and parameters such as seismic design category, importance factor, structural fundamental period, response modification factor, etc.

4 Result and Discussion

4.1 Spectral Acceleration

As shown in Figures 5 to 6, the strong earthquake in Lombok in 2018 increased the spectral acceleration S_S of Mataram by 1.143 *g*. This value represents the location of Mataram latitude: -8.5606 and longitude: 116.0707. This is an increase of 18.323% from the value listed in SNI 1976:2012. Approximately the same increase as the spectral acceleration in Padang city provided in the previous seismic code compared to the current code (SNI 1976:2012). This is because Padang experienced a major earthquake in 2009, the transition period between the previous code and the current code. The following Indonesian seismic code assumed that the acceleration of Mataram would potentially be higher due to the 2018 Lombok earthquake, as this study shows. Meanwhile, Sharma *et al.* in [26] reported that after the Nepal earthquake (M_w 7.9) ground motion, existing spectral accelerations were still applicable to seismic structural engineering design.

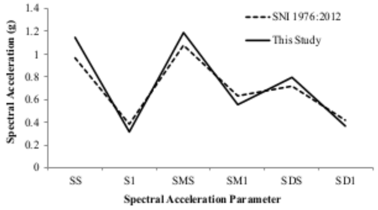

Figure 5 Spectral acceleration parameters in medium soil.

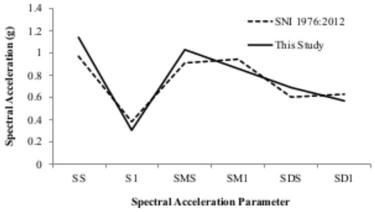

Figure 6 Spectral acceleration parameters in soft soil.

Figures 5 and 6 also shows the spectral acceleration of the maximum considered and design basis earthquakes on the surface at T = 0.2 s (S_{MS} and S_{DS}) and T = 1 s (S_{M1} and S_{D1}) on medium soil (Figure 5), whereas the parameters for soft soil are illustrated in Figure 6. The acceleration of the surface is calculated for site class D (SD) and site class E (SE), because Mataram city is made up of medium and soft soils as given by Marjiyono in [20]. The spectral acceleration provided by SNI 1726: 2012 is also shown for comparison.

Contrary to the acceleration of T = 0.2 s, the acceleration of T = 1 s used in this study was smaller than that of SNI 1726:2012 because the constant attenuation equation is not the same between S_S and S_1. Furthermore, theoretically, S_1 is a long period spectrum affected by far-field earthquakes, whereas this study was more dominantly about near earthquakes.

4.2 Building Seismic Design Category

Considering the ground motion of recent earthquakes, the S_{DS} and S_{D1} values for Mataram are 0.795 *g* and 0.367 *g* for medium soil and 0.686 *g* and 0.569 *g* for soft soil, respectively. According to SNI 1976:2012, buildings at sites with an S_{DS} greater than 0.5 *g* are designed as D category for all risk categories I-IV (shown in bold in Table 1). Similarly, for S_{D1}, as shown in Table 2, Mataram has values greater than 0.2 *g* in both medium and soft soils. Therefore, it is included in the D seismic design category (shown in bold in Table 2). S_{DS} values exceed 0.5 *g* and S_{D1} values exceed 0.2 *g*. This is similar to the value in the current code. Thus, even though the results of this study's spectral acceleration appear larger than those present in the current seismic code, there is no change in the seismic design category between the current seismic code and the results of this study.

The D-design seismic category is intended for structures built on sites with potential for severe and damaging earthquakes, but not located close to major faults. As given by Giouncu and Mazolani in [22] and Duggal in [23], structures on poor soils generally fall into the D class for seismic design. According to Sharma *et al*. [26], as mentioned above, there was no change in the spectral acceleration between the existing code and the spectral acceleration after the Nepal earthquake, however, it is recommended to implement the existing code to develop mitigation strategies and structures.

Table 1 Seismic design categories for short period response acceleration S_{DS} [5].

S_{DS} (*g*)	Risk Category	
	I or II or III	**IV**
$S_{DS} < 0{,}167$	A	A
$0.167 \leq S_{DS} \leq 0.133$	B	C
$0.133 \leq S_{DS} \leq 0.50$	C	D
$\mathbf{0.50 \leq S_{DS}}$	**D**	**D**

Table 2 Seismic design categories for long period response acceleration S_{D1} [5].

S_{D1} (*g*)	Risk Category	
	I or II or III	**IV**
$S_{D1} < 0{,}067$	A	A
$0.067 \leq S_{D1} \leq 0.133$	B	C
$0.133 \leq S_{D1} \leq 0.20$	C	D
$\mathbf{0.20 \leq S_{D1}}$	**D**	**D**

4.3 Response Spectrum Curve

The spectral acceleration parameters previously obtained in Subsection 4.1 are described using the response spectrum, which is important for building design, as presented in Figures 7 and 8, intended for medium soil (SD) and soft soil (SE) respectively. For comparison, the dashed line also shows the spectral acceleration graph based on the current earthquake code SNI 1726:2012. In general, the acceleration in this work was found to be relatively greater than that in the current code for periods of less than 0.462 s for D site class (SD) and for periods less than 0.830 s in E site class (SE). The maximum acceleration in SD is 0.795 *g* in the period of 0.092-0.462 s. Meanwhile, in site class E, the maximum spectrum acceleration value is 0.686 *g* in the period of 0.1166-0.830 s. Also, it can be seen that over this period, medium soils amplify the spectral acceleration response more than soft soils.

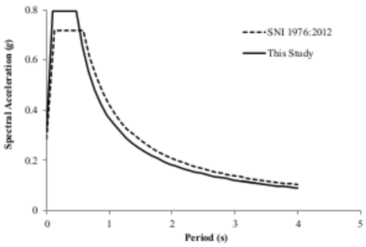

Figure 7 Response spectrum for SD.

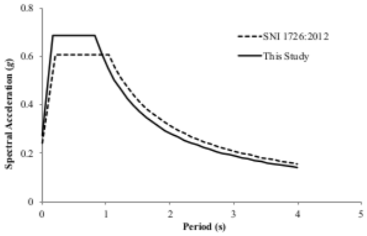

Figure 8 Response spectrum for SE.

However, soft soils generate the long period response more than the medium soils. For a period of T = 1 s, the spectral acceleration for medium soil is 0.367 *g* and for soft soil 0.569 *g*. This trend is consistent with that found in existing building seismic standards, where the medium soil spectrum has an acceleration of 0.386 *g* and soft soils of 0.606 *g* each in the long period. During this period, SNI 1726:2012 shows a slightly higher acceleration than the results of this study.

Primarily, a similar shape of the response spectrum curve is seen between the results of this study and the current code. The trend is similar when medium soil (SD) has higher spectral acceleration than soft soil (SE) in the short period, but the higher effect of soft soil on spectral acceleration is seen over a longer period, as shown in Figure 9. Such findings have also been reported by Dhakal *et al.* [27]. During the calculation of seismic loads, the response spectrum is very important. Short period spectral acceleration values are used for an equivalent static analysis to calculate the seismic response factor C_S. Therefore, the effects of the 2018 Lombok earthquake, which produced higher spectral accelerations in a short period of time, may increase the safety of structural designs and improve seismic resistance.

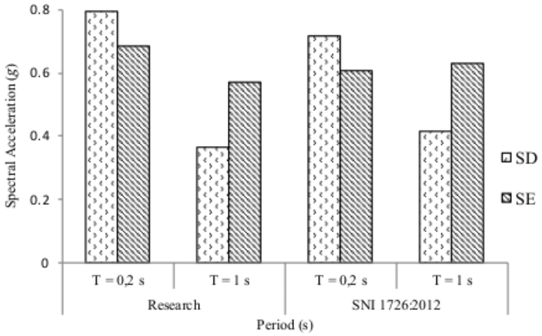

Figure 9 Spectral acceleration at T = 0.2 s and T = 1 s for different soil types.

4.4 Seismic Response Coefficient, C_S

Using the procedure for determining the seismic response factors (C_S) specified by SNI 1726:2012 in [7], Table 3 shows the values for C_S, maximum C_S, and minimum C_S. The C_S value was calculated under several conditions: risk category = 2, importance factor = 1, response modification factor = 8, building height from base = 20 meters. Coefficients were implemented for both SD and SE types of site classes. The coefficient calculated based on the current code's spectral acceleration is also displayed for comparison.

Table 3 Seismic Response Coefficient, C_S

Seismic Parameter	Site Class D		Site Class E	
	SNI 1726:2012	This Study	SNI 1726:2012	This Study
S_{DS} (*g*)	0.717	0.795	0.606	0.686
S_{D1} (*g*)	0.418	0.367	0.631	0.569
C_S	0.090	0.099	0.076	0.086
C_S -maximum	0.766	0.673	1.156	1.044
C_S -minimum	0.032	0.035	0.027	0.030

All C_S values are between the minimum and maximum C_S values. In general, the C_S of site class D is higher than the C_S of site class E. This is because C_S depends on the value of the short period spectral acceleration, S_{DS}. As can be seen from Table 3, the S_{DS} for site class D is higher than the S_{DS} for site class E. Therefore, C_S increases in site class D. Conversely, the maximum C_S value for site class E is greater than the maximum value for site class D because of the large spectral acceleration value of S_{D1} at T = 1 s. The maximum value of C_S depends on the value of S_{D1}.

In this study, both sites had higher C_S results compared to SNI 1976:2012. After a strong Lombok earthquake, the seismic coefficient C_S increases by 10.782% when compared to C_S calculated using the current code. The effect is more severe in soft soil areas, with an increase of 13.168%. The higher C_S, the greater the seismic load on the building structure. It is recommended that current seismic regulations be revised to consider the effects of the last strong earthquake as this will have a significant effect on the increase in seismic loads experienced by the structure. Changes include enhancements to existing building structures so that new or old buildings may become more resistant to future earthquakes. A similar recommendation has also been given by Ramdani, Setiani and Setiawati [28], stating that studies on the Lombok earthquake could support the development of a robust mitigation system for the area. Other works related to the Lombok post-earthquake evidence showed that several concrete structures and steel structures were damaged, as evaluated by Salim *et al*. in [29]. Further improvements have been recommended to the structures by considering the basic requirements for earthquake resistant structures as given by Siswanto and Salim [30]. In addition, such a comprehensive structural design based on seismic risk has been introduced by Mangkoesoebroto, Prayoga and Parithusta [31] and Sidi [32]. It is suggested that the presented works should be considered for the next seismic code to achieve a better structural response against future earthquakes.

5 Conclusion

This paper presented the parameters of Mataram's seismic building design by considering the effects of the 2018 earthquake in Lombok. Short period spectral acceleration, S_S increased 18.323% compared to the values listed in SNI 1976:2012. However, the value of the spectral acceleration for the period $T = 1$ s, S_1, was smaller than the value described in the existing earthquake code.

Higher design spectral acceleration values shown in this study do not change the design of the Mataram earthquake category. According to the response spectrum curve, overall, the acceleration value in this study was found to be relatively greater than that of the existing code for periods shorter than 0.462 s for site class D, and for periods shorter than 0.830 s in site class E. The maximum acceleration in site class D from the results of the study is 0.795 *g* in the period from 0.092 to 0.462 s. For site class E, the maximum spectrum acceleration value is 0.686 *g* in the period from 0.1166 to 0.830 s. Soft soils react longer than medium soils. For the time period of $T = 1$ s, the spectral acceleration of medium soil is 0.346 *g*, while soft soil produces 0.553 *g*. Basically, a similar shape of the response spectrum curve is seen between the results of this study and recent codes. Medium soil (SD) has higher spectral acceleration than soft soil (SE) in a short period, but the higher effect of soft soil on spectral acceleration is seen over a longer period.

In this study, both site classes D and E have a higher seismic response coefficient compared to SNI 1976:2012. The seismic coefficient C_S after the Lombok strong ground motion increases by 10.782% compared to the C_S calculated using the current code. Soft soil is more prone to cause damage because C_S increases by 13.168%. Immediate revisions to current seismic building codes by considering the impact of the last strong earthquake to strengthen the preparation of seismic structures is recommended.

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