



DOI: doi.org/10.21009/SPEKTRA.061.06

SIMULATION OF PEAK GROUND ACCELERATION AND PSEUDO SPECTRAL ACCELERATION OF PALU EARTHQUAKE SEPTEMBER 28TH 2018

Amalia Nasrurroh^{1,*}, Bambang Sunardi², Muhammad Fikri Hayqal Hiola³, Hendri Subakti⁴

¹Tangerang Geophysics Station, BMKG, jl. Meteorologi no 5 Tangerang, Banten, Indonesia

²Research and Development Center, BMKG, jl. Angkasa I no 2 Kemayoran, Jakarta Pusat, Indonesia

³Gowa Geophysics Station, BMKG, jl. Poros Malino, Sungguminasa, Gowa, Indonesia

⁴State Collage of Meteorology Climatology and Geophysic (STMKG), jl. Perhubungan I no 5 Pondok Betung, Tangerang Selatan, Indonesia

*Corresponding Author Email: amalianasrurroh@gmail.com

Received: 1 May 2020

Revised: 2 February 2021

Accepted: 16 February 2021

Online: 29 April 2021

Published: 30 April 2021

SPEKTRA: Jurnal Fisika dan Aplikasinya

p-ISSN: 2541-3384

e-ISSN: 2541-3392



ABSTRACT

The devastating earthquake Mw 7.4 hit Palu City, Central Sulawesi on September 28th, 2018, at 17:02:44 WIB. A high tsunami followed it. More than 2000 people died as a result of the earthquake and tsunami disaster. The latest evidence shows that the earthquake was categorized as a rare super shear earthquake. The earthquake shaking that hit Palu City is relatively large. Acceleration data are not available at the study site due to the lack of instrumentation in the area. The Authors present a simulation of peak ground acceleration (PGA) and pseudo-spectral acceleration (PSA) due to the earthquake in three locations Tatura Mall, Roa-Roa Hotel, and Antapura Hospital. PGA describes the maximum acceleration on the ground, while pseudo-spectral acceleration describes the acceleration of earthquake shaking from buildings with various floor numbers. Simulation of PGA and PSA to the three sites used three different Ground Motion Prediction Equation (GMPE) functions, BSSA14, CB14, and CY14, with the weighting of each Next Generation Attenuation (NGA) GMPE functions. The results of PGA simulation is about 0.22-0.23 g and show that in the three study site, it is more vulnerable to spectral acceleration period $T=0.3$ s or building with three floors or about 1-15 floors. These correlate with the level of damage caused by earthquakes which is more impact to relatively higher buildings.

Keywords: peak ground acceleration, pseudo-spectral acceleration, GMPE, Palu earthquake

INTRODUCTION

The Indonesian region has a very high level of natural disasters; those are due to the geographical location of Indonesia, which influences climate factors or seismic activity. According to Law No. 24 of 2007, natural disasters can be interpreted as disasters caused by events or a series of events caused by nature [1]. One of the natural disasters that often occur in the Indonesian region is earthquakes. An earthquake is a significant release of elastic energy due to sudden displacement in the fault plane [9].

Seismic activity in the Indonesian region is strongly influenced by meeting the world's large plates, namely Indo-Australia, Eurasia, and Pacific [5]. In addition to causing megathrust pathways, the collision activity of these plates raises the local seismic sources. One of Indonesia's regions with a high level of seismic risk is Palu City, Central Sulawesi. Several factors cause the seismic risk of Palu City, one of those is a hazard of activities Palu-Koro fault [3]. This fault has a sinistral strike-slip mechanism extending from North to South, dividing the Palu City with depth fault down to 40 km. This fault has four segments, and the maximum magnitude that has been mapped each segment are Makassar Strait M_{max} 7.1, Moa M_{max} 7.1, Hammer M_{max} 6.8, and Saluki M_{max} 6.9. Shallow faults cause shallow earthquakes to occur, and a large magnitude potential can cause strong shakes on the ground [11]; however, there are some unknown segments with potential earthquake strength that are not yet identified. Besides seismic activity, the exposure level of Palu City is very high. As the Central Sulawesi Province capital, Palu has a larger population than other regions in Central Sulawesi. Based on the population census conducted by the Central Statistics Agency (BPS) in 2010, Palu City had a population of 336.532 with a density of 852 inhabitants/km², and the highest percentage of the population distribution 36.48 percent, is on the South Palu District [2]. Besides population, Palu also has a level of infrastructure and building construction higher than other regions in Central Sulawesi.

A few years ago, a significant earthquake occurred on September 28th, 2018, at 17:02:45 WIB with parameters magnitude 7.4, epicenter at 0.20° S and 119.89° E, 25 km North of Donggala, Central Sulawesi and depth 11 km [4]. The earthquake produced a bigger magnitude than predicted by the PuSGen (2017). The strength of the large earthquake and shallow depth causes earthquake shakes on the ground extremely strong that cause severe damage such as road cracks, landslides, liquefaction, and tsunami. Based on data from the National Disaster Management Agency (BNPB) recorded 1,663 people died, 652 were missing, and 65,733 houses were damaged in Palu City [10]. The high level of seismic risk happens in Palu City and the massive impact caused by the major September 28th, 2018 earthquake, so it needs earthquake disaster mitigation, more specifically in Palu City. One form of mitigation is earthquake-resistant buildings by considering the acceleration to buildings during an earthquake, both in low and high periods. The authors used several formulations of Ground Motion Prediction Equation (GMPE) to calculate the acceleration value and produce a pseudo response spectral on the ground generated by the September 28th, 2018 earthquake Mw 7.4 in several affected locations, Tantura mall and Roa-Roa hotel in South Palu and Antapura Hospital in West Palu. Mall Tatura and Antapura Hospital are four floors (0.4 ss period) while the Roa-Roa hotel is eight floors (0.8 ss period). The locations are a public area where the

number of people will concentrate more. In addition, based on BNPB's report, the buildings were damaged so badly that the Tatura Mall collapsed. At the same time, the Antapura Hospital was split into two, and one part collapsed to leave 1.5 floors and Roa-Roa Hotel almost flat with the ground so that the impact of large casualties during the earthquake occurred.

Spectral acceleration research as earthquake mitigation already due at some region in Indonesia caused by a significant earthquake like Hiola and Sunardi, 2019 [16] identified spectral acceleration compare with acceleration design from SNI 2002 and SNI 2012 caused Lebak Earthquake 2018 M6.1 used empirical equation on short period 0.2 s dan long period 1 s to see how they shake and impact to a building during the earthquake. The authors hope this research can be used as a consideration for the construction of earthquake-resistant buildings in Palu City.

METHOD

The data used in this research are BMKG's parameter data from the Donggala earthquake on September 28th, 2018 [4] at 17:02:44 WIB. The parameters required are Mw7.4, epicenter locations 0.20 S and 119.89 E, and fault information of strike (358°) and dip (71°) from BMKG reports[4]. Local site conditions are also needed, represented by the value of Vs30 from previous studies [19] as input for GMPE calculated.

This research area focuses on peak ground acceleration (PGA) and pseudo-spectral acceleration (PSA) analysis at three locations, Tatura mall in South Palu, Roa-Roa hotel in East Palu, and Antapura hospital in West Palu, shown in FIGURE 1. PGA and PSA are parameters that could explain how the level of shake on the ground and the building during the earthquake[17]. The authors calculate the distance parameters between sites to earthquake sources such as R_X , R_{JB} , and R_{RUP} . Distance parameters calculated using the following formula [18].

$$\begin{aligned}
 R_X &= \text{horizontal distance from the fault measured perpendicular to fault strike} \\
 &\quad (\text{look for the relationship between longitude and latitude site and source}) \\
 R_{JB \text{ (final)}} &= \text{offset} \\
 R_{RUP \text{ (final)}} &= \sqrt{(R_{RUP})^2 + (\text{Offset})^2} \quad (1)
 \end{aligned}$$

with,

- R_{JB} is the closest distance to surface projection of the fault
- Offset is an additional measurement, measured perpendicular to surface projection of fault or extension
- R_{RUP} is closest distance to fault

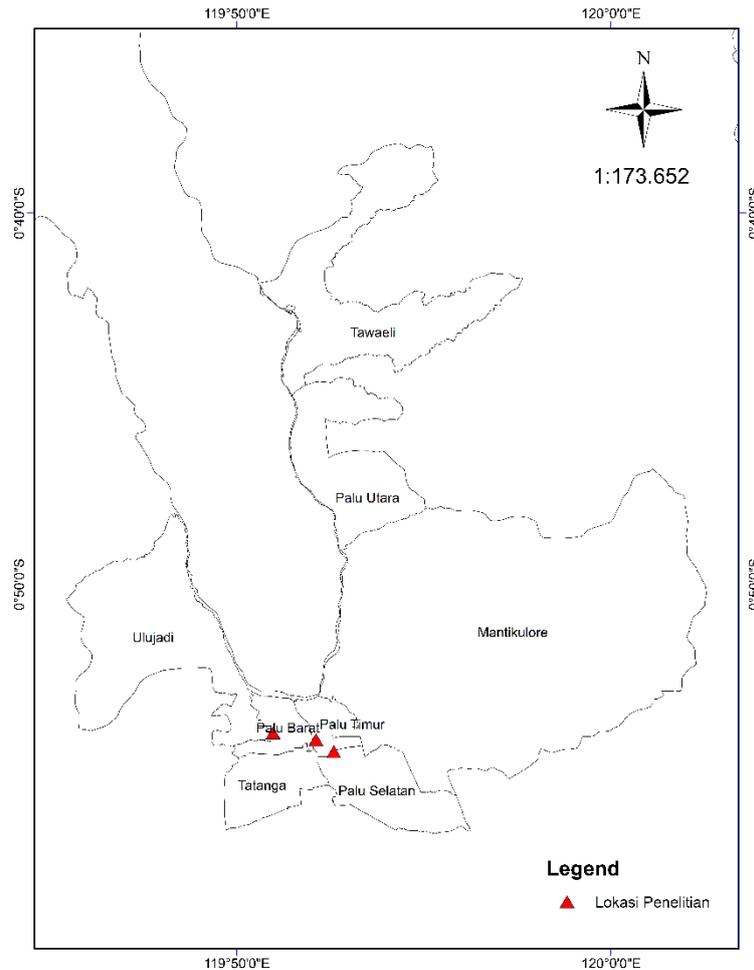


FIGURE 1. Study site

The estimated value of PGA and PSA are calculated using three Ground Motion Prediction Equation (GMPE) functions, BSSA14, CB14, and CY14, by weighting each of the GMPE Next Generation Attenuation (NGA) functions after distance parameters and V_{s30} available. The authors use three GMPE formulations based on the PuSGen reference used in Indonesia for shallow crustal earthquake sources [11].

GMPE Boore-Stewart-Seyhan-Atkinson NGA (BSSA14) function [6].

$$\ln Y = F_E(M, mech) + F_p(R_{JB}, M, region) + F_S(V_{s30}, R_{JB}, M, Region, z_1) + \varepsilon_n \sigma(M, R_{JB}, V_{s30}) \quad (2)$$

with,

- Y is PGA (g)
- F_E is source function
- F_p is the distance function
- F_S is site function
- $\varepsilon_n \sigma$ is the standard deviation

GMPE Campbell-Bozorgnia NGA (CB14) function [7].

$$\ln Y = \begin{cases} \ln PGA; & PSA < PGA \text{ and } T < 0,25 \text{ s} \\ f_{mag} + f_{dis} + f_{flt} + f_{hng} + f_{site} + f_{sed} + f_{hyp} + f_{dip} + f_{atn}; & \text{otherwise} \end{cases} \quad (3)$$

with,

- Y is PGA (g)
- f_{mag} is magnitude function
- f_{dis} is the distance function
- f_{flt} is style faulting function
- f_{hng} is hanging wall effect function
- f_{site} is site condition function
- f_{sed} is basin condition function
- f_{hyp} is the hypocentral distance function
- f_{dip} is dip angle function
- f_{atn} is unelastic attenuation function

GMPE Chiou-Youngs NGA (CY14) function [8].

$$\ln(y_{ij}) = \ln(y_{refij}) + \eta_i + \phi_1 \min\left(\ln\left(\frac{V_{s30j}}{1130}\right), 0\right) + \phi_2 \left(e^{\phi_3(\min(V_{s30j}, 1130) - 360)} - e^{\phi_3(1130 - 360)}\right) \\ \ln\left(\frac{y_{refij} e^{\eta_i + \phi_4}}{\phi_4}\right) + \phi_5(1 - e^{-\Delta Z_{1.0j}/\phi_6}) + \varepsilon_{ij} \quad (4)$$

with,

- y_{ij} is PGA (g)
- y_{refij} is source functions
- V_{s30j} is the average shear speed for topsoil depth of 30 m (m/s)

To clarify, the flow of research methods can be illustrated in the following flowchart that can be seen in FIGURE 2.

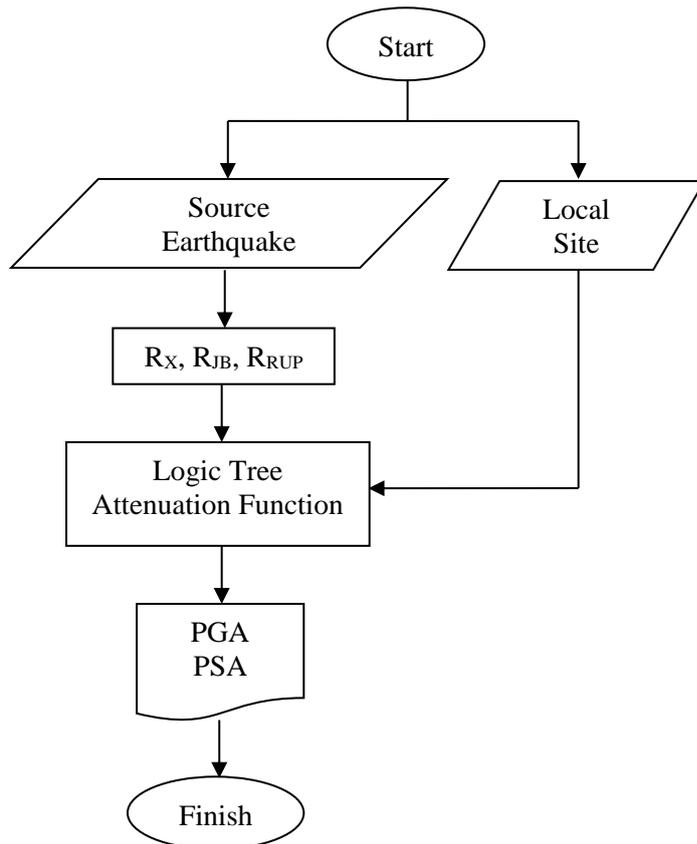


FIGURE 2. Flowchart

RESULTS AND DISCUSSION

Peak ground acceleration can describe earthquake shakes that occur on the ground. The greater the value of the PGA, the greater the perceived shake. Based on TABLE 1, Antapura General Hospital has the highest PGA 0.23 g while for Tatura Mall and Roa-Roa Hotel 0.22 g. It means Antapura Hospital gets a stronger shake on the ground level. The difference is influenced by the location of Antapura Public Hospital, which is the nearer epicenter of the earthquake than the other two locations[13].

TABLE 1. Result of peak ground acceleration (PGA) at the study site

Study site	PGA (g)
Tatura Mall	0.22
Roa-Roa Hotel	0.22
Antapura Hospital	0.23

PGA values about 0.2 g or 196 gals can be categorized on VII-VII MMI or IV SIG. FIGURE 3 shows that it can be moderately damaged with this level of shake, which causes cracks and even collapses in simple buildings on the level ground.

BMKG SIG Scale	Color	Simple Description	Detailed Description	MMI Scale	PGA (gal)
I	White	(Not Felt)	Not felt or felt by only a few people but recorded by a tool.	I-II	<2.9
II	Green	(Felt)	Feeled by many people but does not cause damage. Light objects hanging shook and the glass window shook.	III-V	2.9-88
III	Yellow	(Slight Damage)	Non-structural parts of the building suffered minor damage, such as hair cracks on the wall, the roof shifted down and partly fell.	VI	89-167
IV	Orange	(Moderate Damage)	Many cracks occur in the walls of simple buildings, some collapse, broken glass. Some of the wall plaster is loose. Most of the roof is sliding down or falling. The building structure has mild to moderate damage.	VII-VIII	168-564
V	Red	(Heavy Damage)	Most of the walls of the permanent building collapsed. The building structure suffered heavy damage. Railroad arches.	IX-XII	>564

FIGURE 3. Relationship between PGA, MMI, and SIG [12]

The calculation results using three GMPE formulations produce Pseudo Spectral Acceleration (PSA) output at the three sites. Generally, from the three sites, the largest PSA is in the period of 0.3 s with the peak PSA value for each site are Tantura mall 0.52 g, Roa-Roa Hotel 0.51 g, and Antapura Hospital 0.53 g. FIGURE 4a, 4b, 4c show that the PSA value starts to increase approach period 0.1 s until getting the peak on period 0.3 s and decrease away after that period. Periods with the highest PSA or dominant period show the highest acceleration occurs to the building or indicate that the most strong shakes will be felt in buildings with a certain period describe by the floors[13]. In this case, a high strong shake will occur on building around three floors, and the worst shakes to buildings with three floors.

Overall based on previous PSA results, there is no significant difference among the Tatura Mall building (FIGURE 4a), Roa-Roa Hotel (FIGURE 4b), and Antapura Hospital (FIGURE 4c). The three figures show the same curve pattern, which the curve flat on the period before 0.04 s then increase until it reach the peak PSA on period 0.3 s and get the decrease. Only a little different for the value of PSA about 0.01 g - 0.03 g for each period of each building

(TABLE 2), with the highest Antapura Hospital 0.53 g (FIGURE 4c) and the lowest Roa-Roa Hotel 0.51 g (FIGURE 4b), the difference is not big but no with the damage. Tatura Mall (FIGURE 4a) and Antapura Hospital (FIGURE 4c) have the peak PSA 0.52 g and 0.53 g should have the worst damage on the building, especially because the period of two building approach the dominant period of earthquake 0.3 s. However, the Roa-Roa hotel with building period 0.8 s far from the dominant period of the earthquake, 0.3 s, and has peak PSA smaller than the two previous buildings, 0.51 g, but collapsed to almost flat to the ground, not like Tatura Mall and Antapura Hospital even get major damage but still stand on the ground. The authors conclude that there is a fatal structural failure in the building, especially on Roa-Roa Hotel. Overall, the Antapura General Hospital has less damage than the other two buildings, even though the Antapura General Hospital is in the largest acceleration and PSA area. This proves that Antapura General Hospital has a better building structure compared to the other two buildings.

TABLE 2. Pseudo spectra acceleration (PSA) results at study site

Periode (s)	Pseudo Spectral Acceleration (g)		
	Tantura Mall	Roa-Roa Hotel	Antapura Hospital
0.01	0.22	0.23	0.23
0.02	0.22	0.22	0.23
0.03	0.22	0.23	0.24
0.05	0.25	0.26	0.27
0.075	0.30	0.31	0.32
0.1	0.35	0.37	0.38
0.15	0.43	0.44	0.45
0.2	0.48	0.49	0.50
0.25	0.51	0.51	0.52
0.3	0.52	0.51	0.53
0.4	0.50	0.49	0.51
0.5	0.48	0.46	0.47
0.75	0.37	0.35	0.36
1	0.30	0.28	0.29
1.5	0.22	0.20	0.20
2	0.17	0.15	0.15
3	0.11	0.10	0.10
4	0.08	0.07	0.07
5	0.05	0.05	0.05
7.5	0.03	0.02	0.03
10	0.01	0.01	0.01

The Result of PSA (TABLE 2) shows that on period 0.1 s – 0.4 s, the highest PSA occurs on Antapura Hospital but on the period of higher or equal to 0.5 s, the highest PSA change into Tatura Mall. It is also shown in FIGURE 4a, that in the period above 0.4 seconds, the curve is slightly higher than that of the other sites (FIGURE 4b and FIGURE 4c), although the difference is not very clear at only about 0.01 g - 0.03 g. This could be due to the distance between the epicenter and location. The farther the distance between the epicenter and the location will make the characteristics of the earthquake frequency lower, meaning that the period is higher [14]. In accordance with FIGURE 1, Tartura Mall has a farther epicenter

distance from other locations, so it has a higher period and will have a higher PSA than other sites [14].

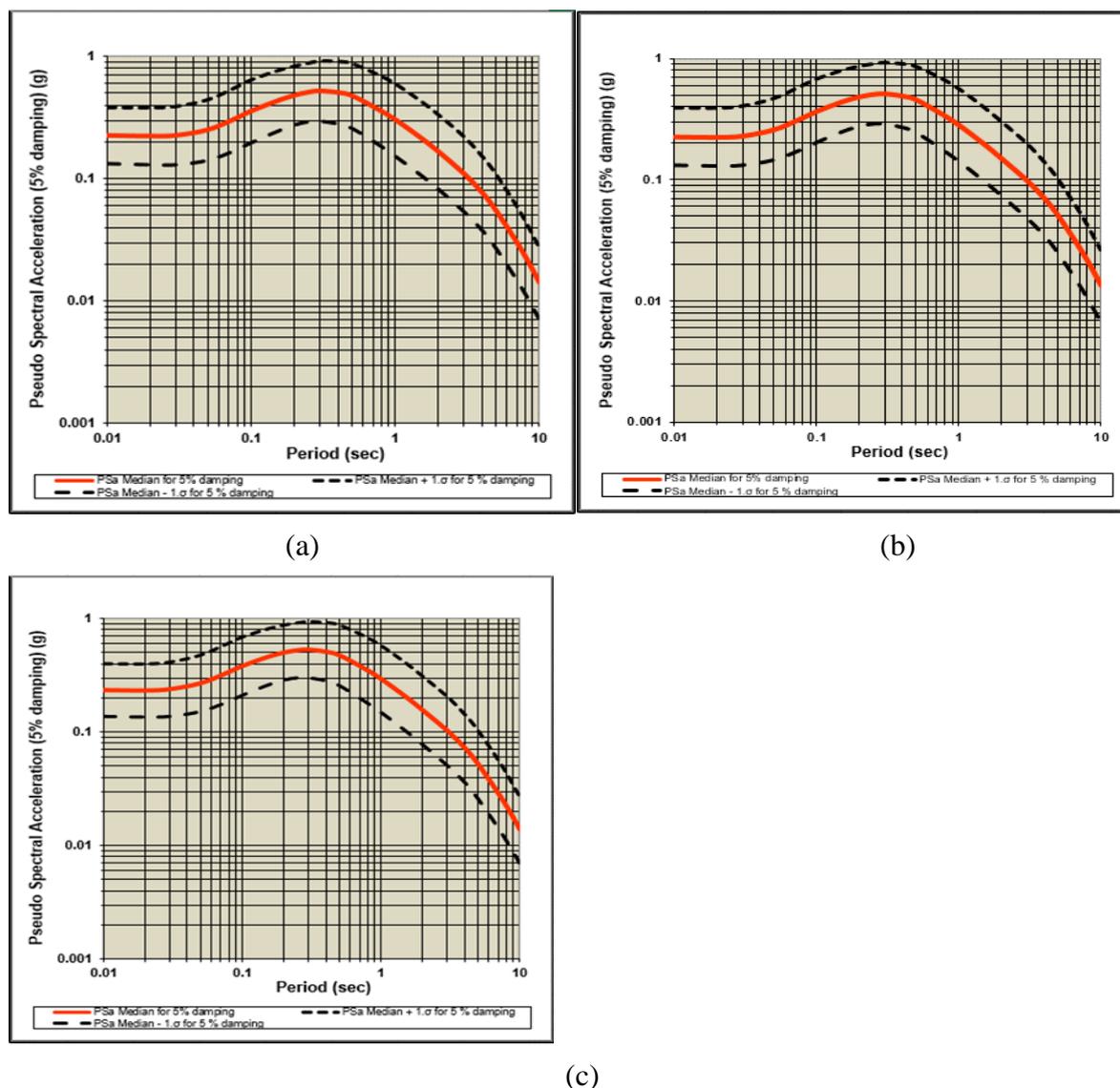


FIGURE 4. Pseudo spectra acceleration (PSA) at the study site (a) Tatura mall, (b) Roa-Roa hotel dan (c) Antapura hospital.

The PSA value in the 0.1 s - 1.5 s period indicates that the building was hit by a strong earthquake due to the Palu Mw7.4 earthquake on September 28th, 2018. If PSA is changed to vibration intensity in the 0.1 s - 1.5 s period, it will be categorized as very strong shocks to severe shocks, while the period of more than 1.5 seconds is considered a strong shock. It is understandable if we look at the magnitude of the shocks and earthquake damage that occurred in the Palu area.

These results are in line with the research results of Sunardi etc., 2019[15], which studied the comparison of design spectral acceleration of SNI 2002 and 2012 with the spectral acceleration of Donggala-Palu earthquake September 28th, 2018, as well as M7.4, but the focus of the area was in the Donggala region using a three-component accelerograph. They got a dominant period of about 2.4 seconds on the N component with the highest PSA of 0.71 g in the N

component. Their results make sense because it affects their closer focus area, it would make the acceleration bigger and the dominant period shorter, in contrast to our study had a longer epicenter distance [13] [14].

Hiola and Sunardi, 2019 [16] also identified spectral response from Lebak Earthquake 2018 using a comparison design response of spectral SNI 2002 and SNI 2012. They produce a spectral response from an earthquake with the seismo-signal software and response spectral design using calculating empirical mathematic with some variable of a coefficient site for a long period and short period. Their research result analyzed those PGA and PSA on short period will be higher on the site with the epicenter distance nearer. It happened with this research which the Antapura Hospital, as the nearest epicenter, has the highest PGA and PSA in a shorter period. These comparisons show that these research results reliable and supports each other with the principle of distance effect [13][14].

Based on the above discussion, it is necessary to pay close attention to the Palu's floors of buildings, especially for buildings with a number of floors about 3, and also the building reaches 15 floors. During this period, the PSA will experience a high enough value so that the perceived shake will be stronger. Damage to all three buildings is shown in FIGURE 5.



Damage at Tatura mall, source: tribunnews



Damage at Roa-Roa hotel, source: tribunnews



Damage at Anutapura Hospital, source: MNC Media

FIGURE 5. Damage at study site [4]

CONCLUSION

Based on PGA and PSA processing, the strongest shakes due to the September 28th, 2018 Donggala earthquake were, respectively, at the Antapura Hospital, Tatura mall, and Roa-Roa hotel with a maximum period of 0.3 ss. So that special attention is needed for the construction of buildings with a number of floors 2 to 5 in calculating earthquake shake loads as mitigation in earthquake-resistant buildings.

ACKNOWLEDGMENT

Thank you to the School of Meteorology, Climatology and Geophysics and also the Meteorology Climatology and Geophysics Agency.

REFERENCES

- [1] Badan Nasional Penanggulangan Bencana, "Definisi dan Jenis Bencana," 2017, diakses online <https://bnpb.go.id/potensi-bencana>.
- [2] Badan Pusat Statistik, "Sensus Penduduk 2010," 2019, diakses online <https://sp2010.bps.go.id/index.php/site?id=72&wilayah=SulawesiTengah>.
- [3] O. Bellier *et al.*, "High Slip Rate for a Low Seismicity along the Palu Koro Active Fault in Central Sulawesi (Indonesia)," Blackwell Science Ltd, Terra Nova, vol. 13, pp. 463-470, 2001.
- [4] Bidang Seismologi Teknik BMKG, "Ulasan Guncangan Tanah Akibat Gempa bumi Donggala 28 September 2018," Jakarta, 2018.
- [5] P. Bird, "An updated digital model of plate boundaries," *Geochem. Geophys. Geosyst.*, vol. 4, no. 3, pp. 1027, 2003, doi:10.1029/2001GC000252.
- [6] D. M. Boore *et al.*, "NGA-West2 Equations for Predicting PGA, PGV, and 5% Damped PSA for Shallow Crustal Earthquakes," *Earthquake Spectra*, vol. 30, no. 3, pp. 1057-1085, 2014.
- [7] K. W. Campbell and Y. Bozorgnia, "NGA-West2 Ground Motion Model for the Average Horizontal Components of PGA, PGV, and 5% Damped Linear Acceleration Response Spectra," *Earthquake Spectra*, vol. 30, no. 3, pp. 1087-1115, 2014.
- [8] B. S. J. Chiou and R. R. Youngs, "Update of the Chiou and Youngs NGA Model for the Average Horizontal Component of Peak Ground Motion and Response Spectra," *Earthquake Spectra*, vol. 30, no. 3, pp. 1117-1153, 2014.
- [9] Lowrie and William, "Fundamentals of Geophysics," Cambridge University Press, New York, 2007.
- [10] S. P. Nugroho, "Penanggulangan Bencana Gempa Bumi M7,4 dan Tsunami di Sulawesi Tengah," Badan Nasional Penanggulangan Bencana, 2018.
- [11] Peta Sumber dan Bahaya Gempa Indonesia Tahun 2017, "Pusat Studi Gempa Nasional (PuSGen)," Pusat Litbang Perumahan dan Pemukiman, Bandung, 2017.
- [12] Skala Intensitas Gempa bumi (SIG) BMKG, 2019, diakses online https://www.bmkg.go.id/gempa_bumi/skala-intensitas-gempa_bumi.bmkg.

- [13] M. D. Trifunac and A. G. Brady, "Correlations Of Peak Acceleration, Velocity and Displacement With Earthquake Magnitude, Distance and Site Conditions," *Earthquake Engineering And Structural Dynamics*, Vol. 4, pp. 455-471, 1976.
- [14] Y. Zheng *et al.*, "Magnitude and Rupture Duration from High Frequency Teleseismic P Wave with Projected Landweber Deconvolution," *Science China: Earth Sciences*, Vol. 56, pp. 13-22, 2013, doi: 10.1007/s11430-012-4557-2
- [15] B. Sunardi *et al.*, "Acceleration Response Spectra for M 7.4 Donggala Earthquake and Comparison with Design Spectra," *Journal of Sustainable Engineering*, Proceedings Series, vol. 1, no. 1, 2019, DOI: 10.35793/jseps.v1i1.3
- [16] M. F. H. Hiola and B. Sunardi, "The Acceleration Response Spectral And Effective Duration Of Lebak Earthquake January 23rd, 2018 In Jakarta Region," *SPEKTRA: Jurnal Fisika dan Aplikasinya*, vol. 4, no. 1, 2019, DOI: doi.org/10.21009/SPEKTRA.041.03
- [17] B. A. Bradly, "Empirical Correlation of PGA, Spectral Accelerations and Spectral Intensities From Active Shallow Crustal Earthquakes," *EARTHQUAKE ENGINEERING AND STRUCTURAL DYNAMICS*, 2011, DOI: 10.1002/eqe.1110
- [18] Division Of Engineering Services Geotechnical Services, "Methodology for Developing Design Response Spectral for Use in Seismic Design Recommendations," *CALTRANS*, 2012.
- [19] I. S. Putri, "Mikrozonasi Menggunakan Metode Multichannel Analysis Of Surface Waves dan Microtremor Array Measurement di Wilayah Palu," Skripsi, Program Diploma IV Geofisika, Sekolah Tinggi Meteorologi Klimatologi dan Geofisika, Tangerang Selatan, 2018.