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Acceleration Response Spectra for M 7.4 Donggala Earthquake and Comparison with Design Spectra

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Abstract. A 7.4 magnitude earthquake have strucked Donggala on September 28th 2018, followed by tsunami and liquefaction which hit Palu, Central Sulawesi, a few minutes later. This event had resulted in damage to buildings, and caused more than 2,000 people were killed and injured. Indonesia already have a building code in form of SNI 1726:2002 which had been updated to SNI 1726:2012. This paper analyses the hazard level caused by the 2018 Donggala earthquake compared to the existing design spectra, as mentioned in SNI 1726:2002 and SNI 1726:2012. A simple analysis was carried out by comparing Donggala earthquake's acceleration response spectra with the existing design spectra, at the MPSI accelerograph station. The site class at MPSI station is hard soil (*SC*). The seismic hazard in Palu and Donggala refers to SNI 1726:2002 is included in the earthquake area 4. The maximum earthquake response factor for earthquake area 4 is about 0.6 for hard soil type (*SC*). The MPSI station recorded peak ground acceleration of Donggala earthquake around 0.14 g. The acceleration response spectra recorded at the MPSI station showed a peak value of around 0.71 g for the N component. This value is actually still below the design spectra referring to SNI 1726:2012, which the peak value is 0.88 g for *SC*, but, it exceeded the design spectra of SNI 1726:2002.

1. Introduction

Central Sulawesi Province is one of Indonesian earthquake prone area. The known earthquake source is originated from the North Sulawesi subduction, which is located in the north of Sulawesi Island. Another earthquake source is the active fault on the mainland, one of which is Palu Koro fault (Supartoyo et al., 2014). The Palu Koro fault is the main fault on Sulawesi Island, with a sinistral movement and classified as an active fault (Bellier et al., 2001). Palu Koro is the most prominent fault in Sulawesi and is very important because it is straddled by Palu city that is inhabited by population of more than 368,000 (BPS, 2018). The Palu Koro fault appears to pass from the South West corner of the Celebes Sea to a diffuse termination onshore at the northern end of Bone Bay, a distance of 500 km, of which 220 km is onshore (Watkinson and Hall, 2017).

Activities in the Palu Koro fault were quite active so it results high seismic hazard in the area around the fault, including Donggala District and Palu City. Earthquake history showed that the Donggala and Palu had experienced strong earthquakes. From 1910 to 2013, they had experienced at least 19 destructive earthquakes (Figure 1). Some of these destructive earthquakes were located on land (Supartoyo et al., 2014).

One of the earthquakes generated by the Palu Koro fault activity is a magnitude 7.4 earthquake that strucked Donggala on September 28th 2018. An earthquake with a magnitude of 7.4 accompanied by liquefaction and tsunami disasters that hit Palu and its surroundings, has resulted in thousands of casualties and injuries. In the interim estimates, the loss and damage caused by these disaster were estimated at more than 18.4 trillion rupiah (CNN, 2018). The devastating earthquakes that have happened a lot lately in Indonesia require our hard work to keep on updating our knowledge, one of which is in the seismic engineering field. Efforts to understand the behavior of earthquakes have meaning to improve earth science as well as to reduce the earthquake risk.

Indonesia already have national building code included in Indonesian National Standard (SNI), i.e. SNI 1726:2002 which had been updated to SNI 1726:2012. The differences in the hazard level caused by the 2018 Donggala earthquake compared to the Indonesia's existing national building code, can be done, which one of them is comparing the Donggala earthquake acceleration value and response spectra with the Indonesian National Standard (SNI 1726:2002 and SNI 1726:2012).

Indonesian seismic hazard maps or more popular with Indonesian earthquake map is prepared using the Probabilistic Seismic Hazard Analysis (PSHA) approach. Although it has never been validated with objective testing, PSHA has been widely and officially used by various countries in making national earthquake hazard maps, as well as developing requirements for building code (Mulargia, et al., 2017). PSHA is used to quantify the probability of exceeding various ground motion levels in a given location by all possible earthquakes that could be occured. This method is largely based on Cornell (1968). Generally, the maximum ground acceleration or better known as the Peak Ground Acceleration (PGA) is used to measure the ground motion in PSHA. However, the preferred parameter is the acceleration response spectra. The concept of acceleration response spectra was first incorporated into US building code in the late 1950s (Freeman, 2007).

This research analyses the hazard level of Donggala earthquake compared with the existing design spectra, as mentioned in SNI 1726:2002 and SNI 1726:2012. The acceleration response spectra of an earthquake is one of the useful tools for experts in measuring the demands of ground motion on the building capacity in an effort to withstand earthquake loads.

2. Data And Method

The response spectrum is a fundamental tool in earthquake engineering research and practice (Copra, 2007), because it shows the maximum dynamic response of single degree of freedom (SDOF) system subjected to specified earthquake ground motion and its time period and damping ratio (Slocum et al., 2018). Maximum dynamic response could be in the form of maximum displacement, maximum velocity, or maximum acceleration of structure mass with a single degree of freedom SDOF (Widodo, 2001).

2.1. Spectral Acceleration Due to The Donggala Earthquake

The strong motion data closest to the epicenter of Donggala earthquake can be obtained at MPSI (Mapaga, Donggala) station. Based on the site characterization, the site class for MPSI is categorized as hard soil type *SC* (BMKG engineering seismology division, 2018). The strong motion data of the Donggala earthquake on September 28th 2018 recorded at the MPSI station were processed to obtain PGA and acceleration response spectra due to the earthquake.

2.2. Spectra Design Refers to SNI 1726:2002 and SNI 1726:2012

The SNI 1726:2002 referred to the Uniform Building Code-97 (UBC 97). The earthquake map was developed based on a 10% probability of exceedance in 50 years, or earthquake with a return period of about 500 years. Map of bedrock PGA based on SNI 1726:2002 for Indonesian is shown in Figure 2. Referring to these SNI, Palu and Donggala are included in region 4 (yellow color area). SNI 1726:2002 classified the design spectra into earthquake area 1 to earthquake area 6.

Design spectra in SNI 1726:2012 referred to the development of modern earthquake regulations in the United States such as FEMA P-750 (Building Seismic Safety Council, 2009) and ASCE/ SEI 7-10 (2010). Design spectra in SNI 1726:2012 can be determined by referring to Figure 3. The response spectra is a modification of the ASCE 7-10 design spectra, where the long period transition T_L on ASCE 7-10 are not defined in SNI 1726:2012 (Arfiadi and Satyarno, 2013). For periods smaller than T_0, the spectral acceleration is calculated using equation (1).

$$S_a = S_{DS} = \left(0.4 + 0.6\frac{T}{T_0}\right) \quad (1)$$

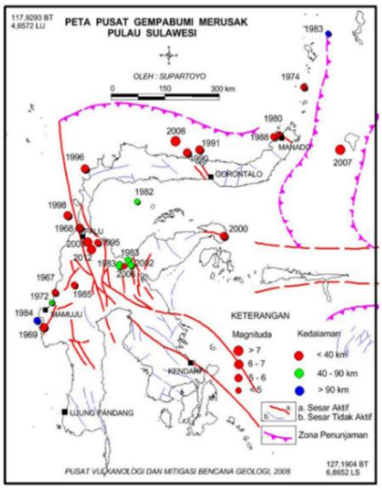

Figure 1. Destructive earthquakes and the year of occurrences on Sulawesi Island (Supartoyo et al., 2014)

For periods greater than or equal to T_0 and smaller or equal to T_s, the spectral acceleration S_a is equal to S_{DS}. For periods greater than the T_s, the spectral response acceleration S_a is taken based on equation (2).

$$S_a = \frac{S_{D1}}{T} \quad (2)$$

S_{DS} is an acceleration response spectra parameter in short period, S_{D1} is an acceleration response spectra parameter at a period of 1 second, T is a fundamental vibration period of structure, $T_0 = 0.2\frac{S_{D1}}{S_{DS}}$ and $T_s = \frac{S_{Ds}}{S_{D1}}$. The design spectra acceleration parameters in the short period S_{DS} and the period of 1 second S_{D1} are determined by equations (3) and (4).

$$S_{DS} = \frac{2}{3}S_{MS} \quad (3)$$

$$S_{D1} = \frac{2}{3}S_{M1} \quad (4)$$

The acceleration response spectra parameters in short period S_{MS} and a period of 1 second S_{M1} that are adjusted for site classification effect are determined by equations (5) and (6). S_s is the mapped of risk targeted maximum considered earthquake (MCE$_R$) spectral acceleration parameter at short periods and S_1 is the mapped of MCE$_R$ spectral acceleration parameter for a period of 1 second. The values of S_s and S_1 are determined using the PSHA approach, while the *Fa* and *Fv* coefficients follow the Table in SNI 1726:2012.

$$S_{MS} = F_a S_s \quad (5)$$

$$S_{M1} = F_v S_1 \quad (6)$$

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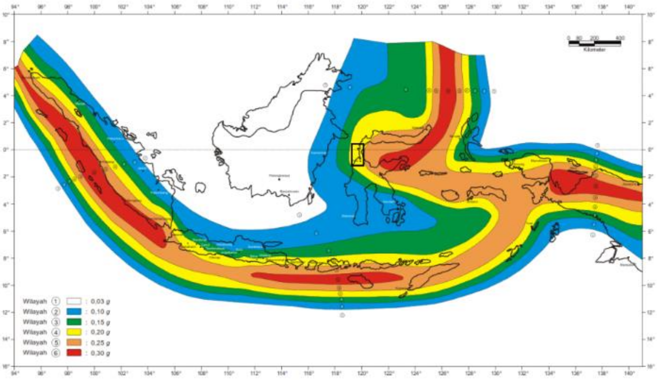

Figure 2: Indonesian earthquake area with bedrock PGA for earthquake return periods of 500 years

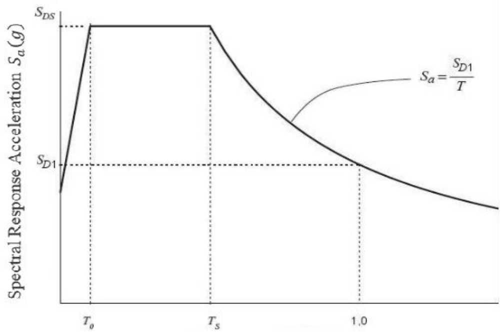

Figure 3: Design spectra refers to SNI 1726:2012

Furthermore, the acceleration and acceleration response spectra due to September 28th 2018 Donggala earthquake at the MPSI station were compared with the design spectra in the same location referring to SNI 1726:2002 and SNI 1726:2012.

3. Results and Discussion

Review of seismic hazards in Palu City and Donggala by referring to the SNI 1726:2002 showed that Palu and Donggala are included in earthquake area 4 with a PGA value of around 0.2 g (Figure 2). Meanwhile, the results of the PSHA calculation for the 2% exceedance probability in 50 years or equivalent to earthquake return periods of 2500 years, referring to SNI 1726:2012, showed that Palu and Donggala have a PGA range of 0.45 - 0.87 g. The spectral response acceleration parameter (MCE_R) for short period S_s ranges from 0.8-2.2 g and MCE_R for period of 1 second S_1 is around 0.45 - 0.85 g (Figure 4).

The recording of the strong motion data of Donggala earthquake at the nearest epicenter station that can be obtained until now is at the MPSI station. The site class of the MPSI station is *SC* (hard soil). The results of strong motion data processing at the MPSI station showed the PGA value for component Z is around 95.057 gal (0.1 g), component N is around 138.871 gal (0.14 g) and component E is around 84.377 gal (0.09 g), as shown in (Figure 5 and Table 1). The results of the spectral acceleration data recorded at the MPSI station can be seen in Figure 6. The maximum spectral acceleration value for component N was reached in the period 0.24 sec with a Peak Spectral Acceleration (PSA) of around 0.71 g. For component E, the PSA value is around 0.51 g in the period 0.22 sec and for component Z, the PSA value is around 0.35 g in the period 0.16 sec.

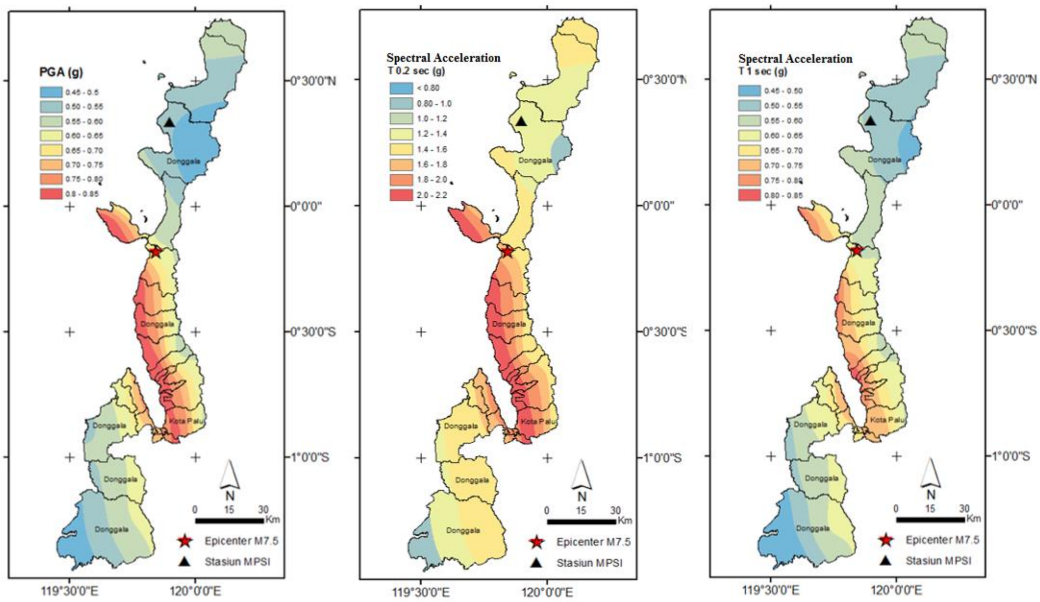

Figure 4: Results of PGA and MCE_R for short periods S_s and MCE_R for period of 1 sec S_1

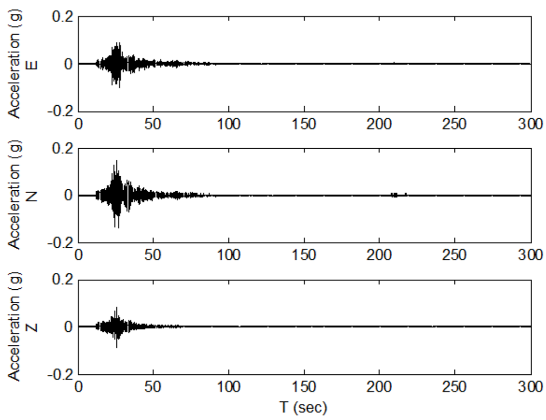

Figure 5: Strong motion data of Donggala earthquake at MPSI (Mapaga) station

Table 1: PGA due to the September 28th 2018 Donggala earthquake

No	Station	Long	Lat	Distance (km)	PGA-N (gal)	PGA-E (gal)	PGA-Z (gal)
1	MPSI	119.898	0.337	44	138.871	84.377	95.057
2	PMCI	120.65	-1.42	138	115.983	40.964	124.956
3	MRSI	121.941	0.477	218	4	2.524	4.963

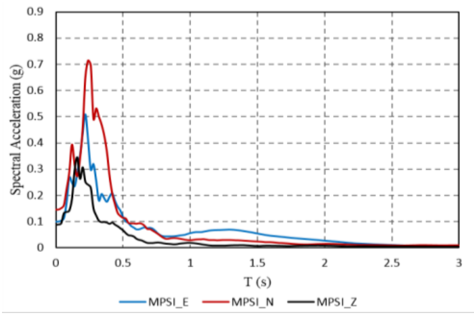

Figure 6: Spectral acceleration of the September 28th 2018 Donggala earthquake

The design spectra at the MPSI station location refers to SNI 1726:2002 is in the earthquake area 4, with the maximum earthquake response factor C value is about 0.6 for *SC*, while the design spectra in the same location refers to SNI 1726:2012 was developed according to the rules in Figure 3. The comparison of the spectral acceleration of the September 28th 2018 Donggala earthquake with the design spectra refers to SNI 1726:2002 and SNI 1726:2012 can be seen in Figure 7.

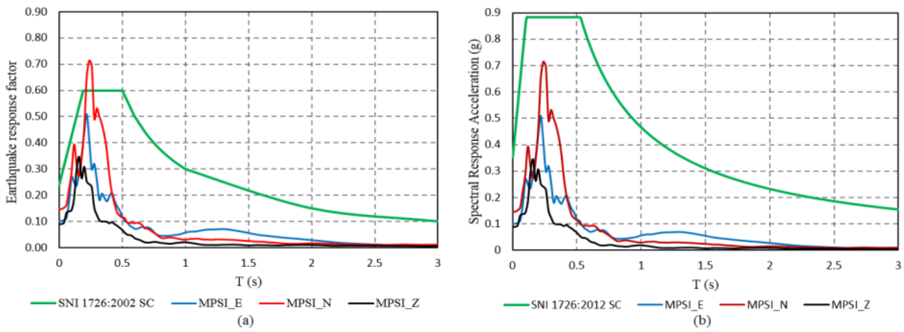

Figure 7: The comparison of earthquake spectral acceleration recorded at the MPSI station with design spectra in the same location refers to SNI 1726:2002 (a) and SNI 1726:2012 (b)

In general, the PGA value of the Donggala earthquake recorded at the MPSI station is still below the PGA value in SNI 1726:2002 and SNI 1726:2012. The earthquake acceleration spectra at the MPSI station showed the PSA value of around 0.71 g for N component. This value is actually still below the design spectra value referring to SNI 1726:2012, but it has exceeded the design spectra of SNI 1726:2002.

4. Conclusion

The MPSI station recorded PGA of Donggala earthquake at around 0.14 g, while the acceleration response spectra showed a peak value of around 0.71 g for the N component. MPSI station location, referred to SNI 1726:2002 is included in the earthquake area 4. The maximum earthquake response factor C for earthquake area 4 is about 0.6 for *SC*. The design spectra referring to SNI 1726:2012 has the peak value 0.88 g for *SC*. Acceleration response spectra for magnitude 7.4 Donggala earthquake recorded at the MPSI station was still below if compared with the design spectra referring to SNI 1726:2012, but it exceeded the design spectra of SNI 1726:2002.

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