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The study of Peak Ground Acceleration with probabilistic seismic hazard analysis (PSHA) method in the Tolnaku Landslide Area of Kupang Regency - NTT

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ABSTRACT

This paper reviews the value of *peak ground acceleration* (PGA), the *spectra response* value compared to the Earthquake Resilience Planning Procedure for Building and Non-Building Structures(SNI-1726-2002 and SNI-1726-2012) in the area of Kupang Regency and obtain the earthquake zone map in the similar region by using the *Probabilitic Seismic Hazard Analysis* (PSHA) method. Data used are seismic catalog data of ISC, USGS / NEIC, and the Meteorology, Climatology and Geophysics Agency (BMKG) from 1918 to 2015 periods with magnitude of $M \geq 5$ on the Richter Scale and earthquakes epicenter distance of ≥ 500 km. Results of the *spectra response* based on the IndonesianNational Standards (SNI) with calculation results on measuring point 1 is 0.3010 g and 0.4736 g based on the calculation results, whilethe peak ground acceleration on rock surface based onthe Indonesian National Standard (SNI) is 0.7530 g and amounting to 1.1840 g based on the calculation results. While *spectra response* based on the Indonesian National Standard (SNI) with calculationon all measuring points is 0.4736 g; the lowest *peak ground acceleration* based on the Indonesian National Standard (SNI) is amounting to 0.2990 g and 0.2363 g based on the calculation results. The highest *peak ground acceleration* on rock surface based on the Indonesian National Standard (SNI) is amounting to 0.7625 g and based on the calculation results is 1.1840 g, while the lowest *peak ground acceleration* based on the Indonesian National Standard (SNI) is 0.7475 g and 0.5908 g based on the calculation results.

Key words : *Ground Acceleration, Probabilitic Seismic Hazard Analysis (PSHA), Spectra Response*

Introduction

Timor Island has tectonics which is part of the Banda arc. Timor Island is a zone which is formed of interaction between the continental plates of northwestern Australia and subduction zones that are no longer active. At first, Timor island zone was a subduction zone which then evolved into a collision zone (Harris, 2006; Standley and Harris, 2009).

The collision process causes the accretion prims at the sub-duction zone to be folded and pushed to the surface to form a non-volcanic island (Harris, 2006). The propulsion continues to occur so that the Australian continental plate rises and covers the folded accretion prism in the southeast region. In some zones on the northeast to southwest

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part of Timor Island, there are hills of Flores-Wetar sub duction zone rocks that are folded, broken, and cover the accretion prism (Standley and Harris, 2009).

Geological structures that reflect the compressive force of the tectonics that occur are evenly distributed along Timor Island. In a small part of the northern zone and most of the southern zone of Timor island bordering waters, there are Baucau-Soe-Kupang basins formed by intensive compression of collisions between Australian continental plates and the Flores-Wetarsubduction zone (Standley and Harris, 2009).

Several factors which correlated to earthquake risk reduction include: soil dynamics response, building design, structural strength, disaster management, land use, government regulations on disaster management and land use as well as community awareness and active participation in disaster risk reduction. Regarding to many factors associated with disaster risk reduction, the scope of this research is limited to the study of soil dynamics responses in relation to seismic microzonation and land use plans in Kupang Regency, East Nusa Tenggara.

Probability of Exceedance, a Procedure for Planning Earthquake Resilience for Building and Non Building Structures

An earthquake risk is the probability of exceedance of an earthquake with certain intensity over a building's economic life, which is expressed in the formula as follows:

$$R_N = [1-(1-R_A)^t] \quad .. (1)$$

$$R_A = \frac{1}{T} \quad .. (2)$$

R_N, R_A, t and T each states the earthquakes risk during the plan life, the annual risk, the planned building life and the return period of the earthquake. R_N is the probability of an earthquake occurring at least 1 time with a return period T; it can be expressed in normal distribution:

$$R_A = P_{(t<T)} = -e^{-Nt} \quad .. (3)$$

$$N = -\frac{1}{t} Ln\left(1 - \left(\frac{R_N}{100}\right)\right) \quad ..(4)$$

with N as the economic life of the building.

Peak ground acceleration is determined by:

$\alpha = AN^b$

$$A = \frac{n\ \sum(\ln N\ x \ln \alpha) - \sum \ln N\ x\ \sum \ln \alpha}{n\ \sum(\ln N)^2 - (\sum \ln N)^2}$$

$$B = \frac{\sum(\ln N)^2\ x\ \sum \ln \alpha - \sum \ln N\ x\ \sum(\ln N - \ln \alpha)}{n\ \sum(\ln N)^2 - (\sum \ln N)^2} \quad .. (5)$$

With α, N dan n each is the *peakground acceleration* (gal), *annual exceedance rate* and data amount. Indonesian building regulations for earthquake resistant buildings use earthquake hazard maps with an exceeded risk of 10% (SNI-1726-2002) and 2 % (SNI-1726-2012) during the building's economic life of 50 years.

Attenuation function

The selection of attenuation function is based on the similarity of geological and tectonic conditions in the region where attenuation functions will be used. The attenuation function used in this study is the attenuation function of Youngs, where it is an empirical attenuation function that can be used to predict peak ground acceleration and acceleration of spectra responses to *interface* and *interslab* subduction zones of earthquake events. The attenuation function of Youngs uses a greater value of moment magnitude of 5.0 on the Richter Scale and the distance from the area to the earthquake source takes form a 10-500 km repture distance. This attenuation correlation was developed using regression analysis. Figure 1 illustrates the graph of the response spectra resulted by Youngs by looking at the rupture distance and magnitude.

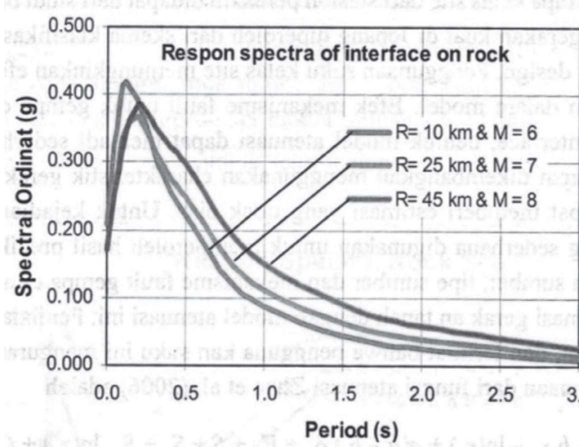

Fig. 1. Attenuation Spectra of Youngs (Makrup, 2013)

According to Youngs (1997), the form of the attenuation function equation for rocks is:

$$\text{Log } \alpha = 0.2418 + 1.414\ M + c_1 + c_2\ (10-M)^3 + c_3 \ln (R_{rup} + c_m) + 0.00607\ h + 0.3846\ z_r \quad .. (6)$$

with c_m value = $1.7818\ e^{(0.554\ M)}$ .. (7)
and the value of deviation standard (σ) is:

$c_4 + c_5 M$ .. (8)

α, M, h, Z_r, R_{rup} and c each are the acceleration of *spectra* (g), *magnitude* (M ≥ 5) (Richter Scale), depth (km), source type (= 0 for *interface* events and 1 for *interslab* events), the nearest distance to *rupture* (km) (10 km ≤ 500 km) and attenuation coefficient of Youngs (1997), respectively.

Research Methods

The data used are earthquake catalog data of ISC, USGS / NEIC and the Meteorology, Climatology and Geophysics Agency (BMKG) from 1918 to 2015 periods with magnitudes M ≥ 5 on the Richter Scale and the earthquake epicenter of ≤ 500 km; while the steps are classifying the main earthquake from the preliminary earthquake and follow-up using Gardner and Knopoff's time window and distant window criteria; determining the rate of assurance; determining the magnitude of the recurrence correlation by using the Gutenberg-Richter (1994) model; calculating the annual exceedance rate with the exceeded value a= 20 cm/dt^2 to 500 cm/dt^2 by using the attenuation function of Youngs; determining the event rate of magnitude (; determining the peak ground acceleration and the spectra response graph which is the result of the attenuation function; comparing the spectra response graph as an attenuation function with earthquake resistance planning procedures for building and non-building structures (SNI-1726-2012) to find out the difference between the attenuation functions of Youngs *et al.*, (1997) and SNI-1726-2012 and later mapping the Tolnakul and slide region based on the results of the spectra response for the value of ground acceleration on the bedrock (a_{bd}) and ground acceleration at land surface (a_{pm}).

Results and Discussion

The determination of peak ground acceleration in Tolnakulandslide region of Kupang Regency was conducted in 63 measuring points with distance between points of 2 km. The distribution of main eqrthquake data with Mb ≥ 5 SR and epicenter distance of 500 km from the measuring point which is the result of *clustering window time* and *window distant* is illustrated on Figure 2 below:

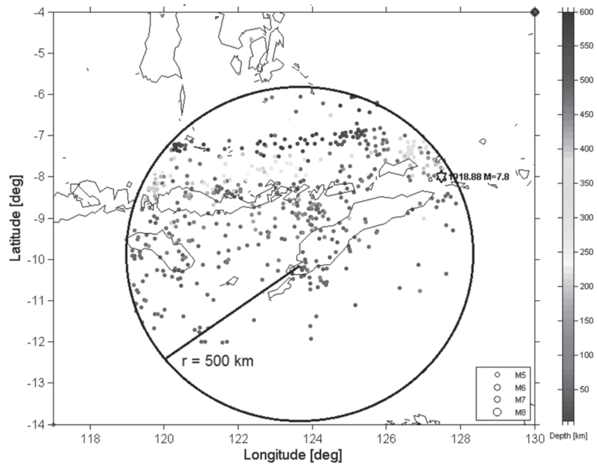

Fig. 2. Earthquake events around the measuring point 1 as the result of *clustering window time* and *window distant.*

Determination of rate of insurance from earthquake events with "M = 0.5 or earthquake data with magnitudes which are not multiples of 0.5 will be integrated to the nearest multiplication. Data of clustering results on magnitude, distance, time and rate of assurance are earthquake data that are used to be analyzed for seismic hazard at each measuring point. The model used is the Gutenberg-Richter model. The Gutenberg-Richter equation model needs to determine the values of *a* and *b* which are the results of linear regression of the correlation between the magnitude and total earthquakes in a region with a certain period of time that is close to magnitude (N(M)). The earthquake data used is data during the 97 years period. Examples of the correlation between Gutenberg-Rich at point 1 are can be seen in Table 1.

The results from Table 1 are described in graphical form which is the correlation between the magnitude and total earthquakes in areas around the measuring point which is close to the magnitude (M_i). The linear regression correlation between Gutenberg-Rich at point 1 is shown in Figure 3.

The correlation of the magnitude and natural logarithm of the total probability of earthquakes in the area of measuring point 1 (is re-entered into the Gutenberg-Richter equation:

$$\text{Log } N(M) = \alpha - bM \text{ or } N(M) = 10^{a-bm} = e^{\beta-\gamma m} \quad .. (9)$$

The linear regression results of Gutenberg-Richter correlation are as follows:

a = 5,266 b = -0,876

Thus, log N(M) = a – bM = 5.266 – 0.876 M. The

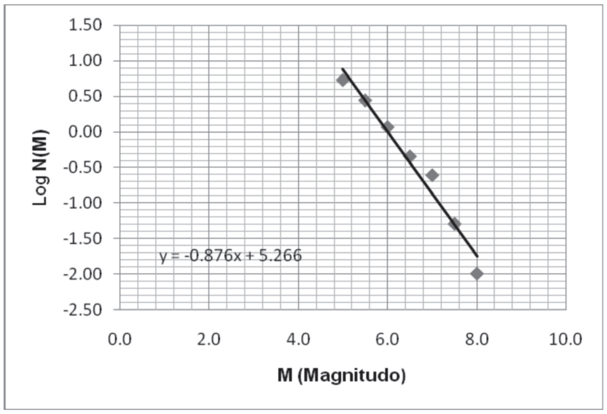

Fig. 3. Linear Regression of Gutenberg - Linear for Measuring Point 1

correlation ofand of Gutenberg-Richter results in parameter bandg. Parameter bandg can be searched using the formula below:

$$\beta = \ln (10)\ x\ a = \ln(10)\ x\ 5.266 = 12.125 \quad .. (10)$$

$$\gamma = \ln (10)\ x\ b = \ln(10)\ x\ (–0876) = –2{,}017 \quad .. (11)$$

Based on the results of *linear magnitude recurrence* relationship from Gutenberg-Richter for measuring point 1, the calculation can be rewritten into the Gutenberg-Richter equation as follow:

$$log\ N(M) = 5.266 – 0.876\ M\ atau\ N(M) = e^{12125–2{,}017M} \quad .. (12)$$

Earthquake Event Rate

The linear regression results from the correlation curve between and λ_m that have been obtained will be analyzed for its cumulative probability of magnitude by determining the number of earthquake events with a certain amount of magnitude. The calculation results of events on measurement point 1 are shown in Table 3 with the following data:

Latitude : $9^0$54′29,89" LS atau 9,98303 LS
Longitude : 123^0 42′30,06" BT atau 123,78906 BT
: 4,5 of Richter Scale
: 8,0 of Richter Scale

The event rate calculation as one example of calculating the earthquakes occurrence with magnitude (m_i)= 7,0 Richter Scale at point 1 is showed below:

F_M calculation for M_i = 7,0 Richter Scale

$$F_M\left(M_i - \frac{\Delta M}{2}\right) = \frac{1-e^{-\beta\left(M_i-\frac{\Delta M}{2}\right)-M_0)}}{1-e^{-\beta(M_u-M_0)}} = \frac{1-e^{-2{,}017\left(7-\frac{0.5}{2}\right)-4{,}5)}}{1-e^{-2{,}017\,(8-4.5)}} = 0{,}9902$$

$$F_M\left(M_i + \frac{\Delta M}{2}\right) = \frac{1-e^{-\beta\left(M_i+\frac{\Delta M}{2}\right)-M_0)}}{1-e^{-\beta(M_u-M_0)}} = \frac{1-e^{-2{,}017\left(7+\frac{0.5}{2}\right)-4{,}5)}}{1-e^{-2{,}017\,(8-4.5)}} = 0{,}9970$$

G_M calculation for M_i= 7
$G_M\ (M) = 1–F_M(M)$

$$G_M\ (M) = \left(M_i - \frac{\Delta M}{2}\right) = 1 – 0.9902 = 0.0098$$

Table 1. Gutenberg-Richtercorrelation to obtainvalue and value

No	Data number	Cummulative	Average depth	M_i	N(M)	Log N(M)
1	248	515	183.36	5.0	5.31	0.73
2	154	267	166.01	5.5	2.75	0.44
3	69	113	152.00	6.0	1.16	0.07
4	20	44	148.35	6.5	0.45	-0.34
5	19	24	133.00	7.0	0.25	-0.61
6	4	5	204.25	7.5	0.05	-1.29
7	1	1	190.00	8.0	0.01	-1.99

Table 2. The Calculation of *Event Rate*value on Measuring Point 1

M_i	$F_M\left(M_i-\frac{\Delta M}{2}\right)$	$F_M\left(M_i+\frac{\Delta M}{2}\right)$	$G_M\left(M_i-\frac{\Delta M}{2}\right)$	$G_M\left(M_i+\frac{\Delta M}{2}\right)$	Event Rate
5,0	0.3964	0.7804	0.6036	0.2196	2.039
5,5	0.7804	0.9204	0.2196	0.0796	0.386
6,0	0.9204	0.9715	0.0796	0.0285	0.060
6,5	0.9715	0.9902	0.0285	0.0098	0.008
7,0	0.9902	0.9970	0.0098	0.0030	0.002
7,5	0.9970	0.9994	0.0030	0.0006	0.000
8,0	0.9994	1.0003	0.0006	-0.0003	0.000

$$G_M(M) = \left(M_i - \frac{\Delta M}{2}\right) = 1 - 0.9970 = 0{,}0030$$

The event rate value is the distribution value of cumulative probability of the total earthquakes probability in the measuring point area:

$$P\left(M > M_i + \frac{\Delta M}{2}\right) - P\left(M > M_i - \frac{\Delta M}{2}\right)\lambda_m(m_0)$$

event rate =

$$\left(F_m\left(m_i + \frac{\Delta m}{2}\right) - F_m\left(m_i - \frac{\Delta m}{2}\right)\right) x\ \lambda_m(m_o)$$

= (0,9902 – 0,9970) x 0,25

= 0,002

Annual Exceedance Rate

The acceleration cumulative values of annual axceedance rate that probably occured for each particular PTM are showed in Table 3. Determination of annual axceedance rate from a certain PTM value for measuring point 1 with PTM 20 cm/sec^2 to PTM 500 cm/sec^2. The natural value of PTM is the cumulative value of M_i with "$R_{rupture}$= 100 km. Calculation of N_a values are can be seen in Table 3.

Table 3. Calculation of the natural value of PTM = =20 cm/sec^2 to PTM = 500 cm/sec^2 at Measuring Point 1

No	α (cm/sec^2)	N_α	Ln_α	Ln N_α
1	20	0.740	2.996	-0.301
2	40	0.250	3.689	-1.387
3	60	0.115	4.094	-2.164
4	80	0.062	4.382	-2.788
5	100	0.036	4.605	-3.317
6	120	0.023	4.787	-3.780
7	140	0.015	4.942	-4.194
8	160	0.010	5.075	-4.569
9	180	0.007	5.193	-4.915
10	200	0.005	5.298	-5.235
11	220	0.004	5.394	-5.533
12	240	0.003	5.481	-5.814
13	260	0.002	5.561	-6.078
14	280	0.002	5.635	-6.329
15	300	0.001	5.704	-6.567
16	320	0.001	5.768	-6.795
17	340	0.001	5.829	-7.012
18	360	0.001	5.886	-7.220
19	380	0.001	5.940	-7.421
20	400	0.000	5.991	-7.614
21	420	0.000	6.040	-7.800
22	440	0.000	6.087	-7.980
23	460	0.000	6.131	-8.154
24	480	0.000	6.174	-8.322
25	500	0.000	6.215	-8.485

The PTM and N_{PTM} logarithm values are calculated based on statistical calculation to obtain graphs a dan N_a which are made in the form of hazard curves as a result of natural PTM ratio of each M_i and natural logarithm of the exceeded PTM. In can be seen in Figure 4.

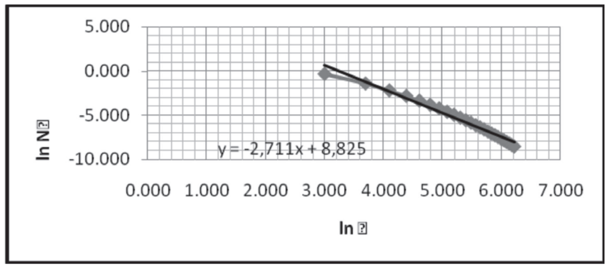

Fig. 4. Example of *hazard* curve on Measuring Point 1.

The linear regression results of hazard curve result in following parameters:

α = 8,825 b = -2,711 ln Na = 8,825 – 2,711 *lna*

Determination of *Peak Ground Acceleration*

By knowing equation for the hazard curve, an earthquake risk analysis can be conducted to determine the earthquake risk plan for a return period of a particular earthquake T during the economic life of building t. For strong earthquakes, SNI 1726-2012 requires that the return period of a strong earthquake plan is T = 2500 years and the building economic life is 50 years with a probability of 2%. The map of peak ground acceleration for the earthquake return period of T = 2500 years and the building economic life of 50 years for 63 measurement points are shown in Figure 6.

Spectra Response

By referring to SNI 1726-2002 of item 4.7.6 regarding to the method for determining the value of peak ground acceleration at the ground surface (a_{Pm}), then the peak ground acceleration in the bedrock (a_{bd}) is 2.5 x a_{bd} for hard soil type (Tc) of 0.5 seconds. An example of calculating the spectra response value was conducted at measuring point 1. The spectra response value can be calculated through the equation of peak ground acceleration in the bedrock (a_{bd}) and peak ground acceleration at the land surface (a_{Pm}):

α_{bd} = 0,4736 g or 464,6198 gal

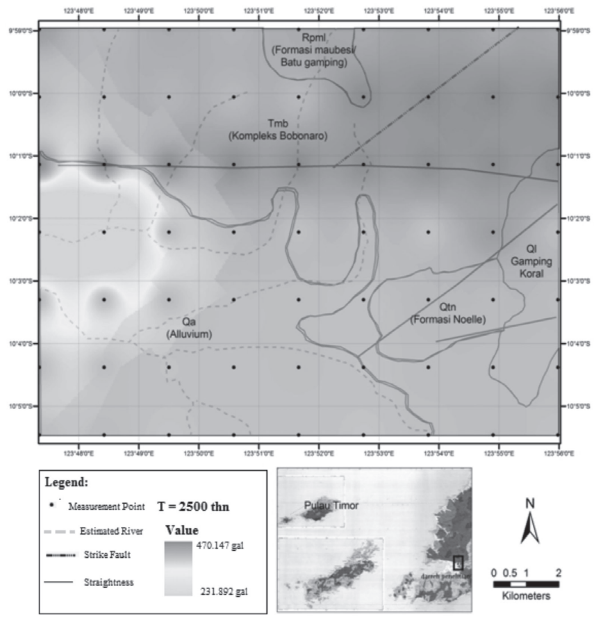

Fig. 6. Peak Ground Acceleration (g) for Building economic life (t = 50) and Earthquake Return Period (T = 2500 Years)

α_{pm} = 2,5 0,4736 = 1,1840 g or 1161,5040 gal
$\alpha_t = \alpha_{Pm} \ x$ Tc = 1,1840 x 0,5 = 0,5920 g
From the above values, it can be described the comparative value between the structure period and ground acceleration, to get a graph of responding spectra of the attenuation function. The result of spectra response is the ratio between the building period (T) versus the earthquake response factor (C) expressed through ground acceleration. Table 4 shows the comparison between the building period (T) and the earthquake response factor (C) in the form of ground acceleration for measuring point 1.

Examples of calculation to get comparisons between building periods (T) and earthquake response factors (C) are as follows:

For T = 0,000 then C = a_{bd} = 0,4736 g

For T = 0,2000to 0,5000 then C = a_{Pm}= 1,1840 g (where Tc = 0,5 second)

For T = 0,5500 then $C = \frac{\alpha_r}{T} = \frac{0,4736}{0,5500} = 0,8611\ g$

For T = 0,6000 then $C = \frac{\alpha_r}{T} = \frac{0,4736}{0,6000} = 0,7894\ g$

For T = 0,6500 then $C = \frac{\alpha_r}{T} = \frac{0,4736}{0,6500} = 0,7286\ g$

The next calculation to get a graph of spectra response on the measuring point 1 follows the existing calculation.

The comparison value between the building period (T) and the ground acceleration in the planned return period of strong earthquake is T = 2500 years and the economic life of the building of 50 years with a probability of 2% is depicted in the spectra response graph as shown in Figure 7. Spectra response for all measuring points from the results of probabilistic calculations of seismic hazards is com-

Table 4. Comparison between Building Periods (T) and Earthquake Response Factors (C) in the form of Ground Acceleration for Measuring Points 1

T (second)	C (g)	T(second)	C (g)	T(second)	C (g)
0.00	0.4736	1.30	0.3643	2.20	0.2153
0.20	1.1840	1.35	0.3508	2.25	0.2105
0.50	1.1840	1.40	0.3383	2.30	0.2059
0.55	0.8611	1.45	0.3266	2.35	0.2015
0.60	0.7894	1.50	0.3157	2.40	0.1973
0.65	0.7286	1.55	0.3056	2.45	0.1933
0.70	0.6766	1.60	0.2960	2.50	0.1894
0.75	0.6315	1.65	0.2870	2.55	0.1857
0.80	0.5920	1.70	0.2786	2.60	0.1822
0.85	0.5572	1.75	0.2706	2.65	0.1787
0.90	0.5262	1.80	0.2631	2.70	0.1754
0.95	0.4985	1.85	0.2560	2.75	0.1722
1.00	0.4736	1.90	0.2493	2.80	0.1691
1.05	0.4511	1.95	0.2429	2.85	0.1662
1.10	0.4306	2.00	0.2368	2.90	0.1633
1.15	0.4118	2.05	0.2310	2.95	0.1605
1.20	0.3947	2.10	0.2255	3.00	0.1579
1.25	0.3789	2.15	0.2203		

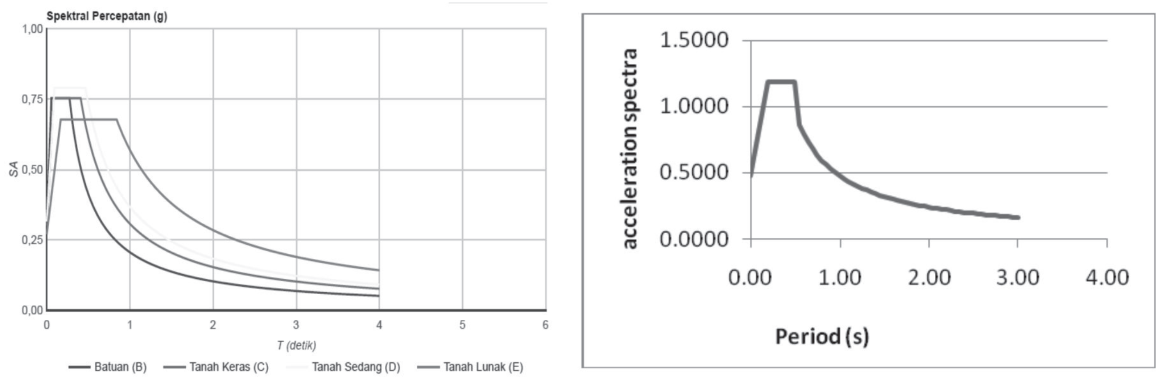

Fig. 7. Example of spectra response in the Measuring Point 1. (a) Spectra response according to the Indonesian National Standard (SNI-2012) and (b) Spectra response of calculation result

pared to the spectra response of SNI 2012 values with hard soil criteria. The results of spectra response of SNI-2012 were analyzed using *spectra Indonesia* software. The spectra response values of SNI-2012 on bedrock and earth surface are presented in Figure 7 and the spectra response value from the calculation results on the bedrock and earth surface are presented in Figure 7b. The comparison of spectra response for SNI-2012 with spectra response at point 1 is can be seen in Fig. 7.

The results of spectra response based on the Indonesian National Standard (SNI) with spectra response from the calculation results at measuring point 1 are very different, where the peak ground acceleration on bedrock based on the Indonesian National Standard (SNI) is 0.3010 g and 0.4736 g based on the calculation results; whilethe peak ground acceleration on surface rocks based on the Indonesian National Standard (SNI) is 0.7530 g and 1.1840 g based on the calculation results.

The results of spectra response based on the Indonesian National Standard (SNI) with thosefrom the calculation are very different, where the highest peak ground acceleration on bedrock based on the Indonesian National Standard (SNI) is 0.3050 g, whilebased on the calculation results, it is 0.4736 g. In addition, the lowest peak ground acceleration based on the Indonesian National Standard (SNI) of 0.2990 g and based on the calculation results of 0.2363 g. The highest peak ground acceleration on surface rocks based on the Indonesian National Standard (SNI) is 0.7625 g and based on the calculation results is amounting to 1.1840 g, while the lowest peak ground acceleration based on the Indonesian National Standard (SNI) is 0.7475 g and 0.5908 g based on the calculation results.

Conclusion

Based on the study results, several things can be concluded as follows:

a. The result of spectra response based on the Indonesian National Standard (SNI) with calculated spectra response on measuring point 1 is amounting to 0,3010 g while based on the calculation results is 0,4736 g. Thepeak ground acceleration on surface rocks based on the Indonesian National Standard (SNI) is 0, 7530 g and amounting to 1.1840 g based on the calculation resuls.

b. The result of spectra response based on the Indonesian National Standard (SNI) with Spectra response based on the calculation results on all measuring points is 0.4736 g. The lowest peak ground acceleration based on the Indonesian National Standard (SNI) is amounting to 0.2990 g and 0.2363 g based on the calculation results.

c. The highest peak ground acceleration on surface rocks based on the Indonesian National Standard (SNI) is 0.7625 g and based on the calculation results is 1.1840 g, while the lowest peak ground acceleration based on the Indonesian National Standard (SNI) is 0.7475 g and based on the calculation results is amounting to 0.5908 g.

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