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SEISMIC MICROZONATION STUDIES CONSIDERING LOCAL SITE EFFECTS FOR YOGYAKARTA CITY, INDONESIA

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ABSTRACT: An Mw 6.3 earthquake hit Yogyakarta, Indonesia in 2006, causing massive damage in this densely populated area. As a consequence, risk reduction efforts in terms of local seismic response and peak ground acceleration (PGA) mapping is needed to improve the spatial planning and early assessment before another disastrous earthquake. The determination of PGA for microzonation study was conducted by referring to the Indonesian seismic code and empirical prediction by examining attenuation relationships considering the local site effects. The site investigation was conducted at 87 locations, comprising 13 core drillings and 74 microtremor measurements. Further, the nonlinear earthquake site response analyses were conducted to calculate the local seismic response occurring in a layered soil. Referring to the seismic code with a 2% probability of exceedance in 50 years and site characteristics, the maximum considered earthquake geometric mean PGA for Yogyakarta City is 0.50-0.57g, while the southern area has higher PGA. The empirical prediction by attenuation relationships that considers the 6.3 Mw Yogyakarta earthquake 2006 with 50-100 year return period resulted in PGA of 0.14g to 0.21g. Meanwhile, the empirical prediction based on soil predominant period resulting from microtremor measurements shows that the southern part of the city has higher PGA of 0.2g to 0.3g whereas the northern part has lower PGA of 0.1g to 0.2g. The result of nonlinear earthquake site response analyses shows that the PGA at the southern part and the northern part of the city have higher PGA up to 0.38g. The results show the significance of local site effects and site response analysis in determining the earthquake characteristics in comparison to the present simplified empirical approach.

Keywords: Peak ground acceleration, seismic code, attenuation relationship, microtremor, site response

1. INTRODUCTION

Peak ground acceleration (PGA) represents the acceleration at the ground surface that will occur in the aftermath of an earthquake with a certain magnitude in a certain area. It is difficult to determine PGA as the time, location, and magnitude of the earthquake cannot be predicted accurately; therefore, it must be determined based on past earthquake catalogues and fault studies. PGA depends on the local site characteristics, ground amplification, earthquake magnitude, and hypocenter distance [1]. Several methods frequently used in the PGA determination are historical earthquake, maximum probable earthquake, seismic code in every country and earthquake maps [2].

The Yogyakarta earthquake on May 27, 2006 with the magnitude of Mw 6.3 and hypocenter depth of 10 km [3] has proven the necessity of a proper microzonation study. It destroyed 60,000 houses and 393 school buildings, with total casualties of 6,736 people killed, 45,210 people injured and 33,345 internally displaced persons in 95 temporary shelters [4]. The level of damage was not only influenced by the structural integrity and durability of the building but also by the level of soil amplification to the earthquake [5] and PGA distribution in the affected area [4]. Therefore, the local seismic response and PGA mapping are very critical to determine the building design, to improve spatial planning and to conduct an effective emergency response and assessment before another disastrous earthquake [6], [7].

The Indonesian seismic code describes earthquake prone areas and response spectrums for regions in Indonesia [8]. The earthquake map is based on the probabilistic seismic hazard analysis taking into account bedrock condition and active fault distribution [9]. Considering the scale of the national map, there is a necessity to provide seismic microzonation studies in determining the PGA taking into account the local site effects of geological conditions based on the actual site investigation and field measurement, especially for densely populated areas [10], [11], [12]. Previously, single observation of microtremors to estimate the site-dependent amplification characteristics and microtremor array investigation to gain the soil condition of subsurface structures have been conducted in Padang [13] and Palu [14] of Indonesia.

The determination of PGA in this research uses past earthquake references and results of the site investigation by core drillings, seismic downhole tests, and microtremor measurements. The result of the study is in the form of PGA microzonation that shows the hazard susceptibility level caused by the earthquake. Through this microzonation study, it is expected that the building code and spatial planning in earthquake prone areas can be properly developed and implemented.

2. GEOLOGICAL CONDITION

Yogyakarta is located in a depression area in the region of the volcanic arc of the Central Java and the Java Trench, surrounded by several fault zones [15]. The city is located at the foot of Mt. Merapi volcano that is bordered by two mountains in the eastern and western part, and a coast in the southern part [16]. The Yogyakarta metropolitan area is a graben filled by young volcanic debris deposited by various ways (fluvial, lahar, and pyroclastic) [17].

The sedimentation occurring in Yogyakarta is controlled by three main rivers, namely the Code River, Gajah Wong River, and Opak River (Fig. 1). Those rivers originate from Mt. Merapi; flowing down in wider and meandering streams to the south. The rivers transport and deposit volcanic sediment to the lower land of Yogyakarta. The fluvial process occurs in balance with natural erosion, transportation, and sedimentation.

In general, the volcanic deposit comprises thick medium to dense sand with a good bearing capacity for building foundations. As a graben, it is filled with thick quaternary sedimentary rock while several parts of the southern area have a basement of tertiary clastic sedimentary rocks such as marlstone/mudstone, limestone, and a reef belonging to the Sentolo Formation [18].

In the western part of Yogyakarta, an andesite basement belonging to Old Andesite Formation is found. Quaternary sediment filling of the Yogyakarta depression comprises the Sleman Formation, Yogyakarta Formation, and Wates Formation (Fig. 1). The Yogyakarta Formation consists of sand, gravel, silt and clay coming from the Sleman Formation located in the north. The Sleman Formation is the base for the Yogyakarta Formation, consisting of 20-40 meters of layers of sand, volcanoclastic, gravel and boulders of rocks. From Fig. 1, the study area is located in the Yogyakarta Formation with the upper lithology formed by young Merapi deposits. This formation spreads from the middle flank of Mt. Merapi to the south of Bantul and has a fine grain size gradation.

There are two main faults that are relatively directed to the north-south and east-west. The Opak fault is a normal fault directed to north-south along Opak River and the biggest fault is located in the eastern part of Yogyakarta [18]. Based on the drilling data, some normal faults are also found in the east-west direction across Yogyakarta city.

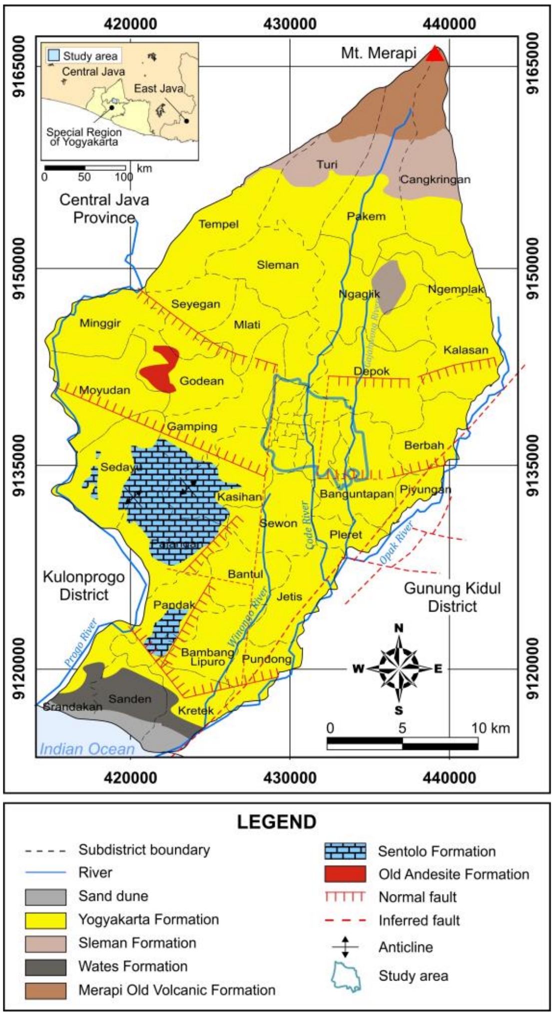

Fig. 1 Geological map of the Yogyakarta depression area, modified from [18]

3. METHOD

At the preliminary stage of this research, PGA determination in Yogyakarta City was conducted by referring to Indonesian seismic code [8] and by empirical prediction with attenuation equations considering local site effects. The Indonesian seismic code considers the soil characteristics from the results of Standard Penetration Test (SPT), seismic downhole surveys and laboratory tests. It determines the earthquake zonation based on the PGA for design earthquake with 2500 year return period (2% probability of exceedance in 50 years). The determination of PGA is based on past earthquakes, maximum probable earthquake, and the soil condition.

The empirical prediction with attenuation relationship formulates the PGA based on the earthquake magnitude and the hypocenter distance. The attenuation relationship for Indonesia has never been developed; therefore, equations from other countries with similar tectonic and geological condition are used [1], [19], [20], [21].

In the next phase, the PGA determination using nonlinear earthquake site response analyses was conducted by calculating the seismic site responses occurring in a layered soil. The main input in the calculation is the profile of soil layers, shear wave velocity, and the maximum PGA using ground motion sources from the past earthquakes. The analysis was carried out at 87 locations in the research area, comprising 13 core drillings and 74 microtremor measurements. At two boreholes (B12 and B13), the seismic downhole test was performed. The location of boreholes and microtremor measurement in the research area is shown in Fig. 2.

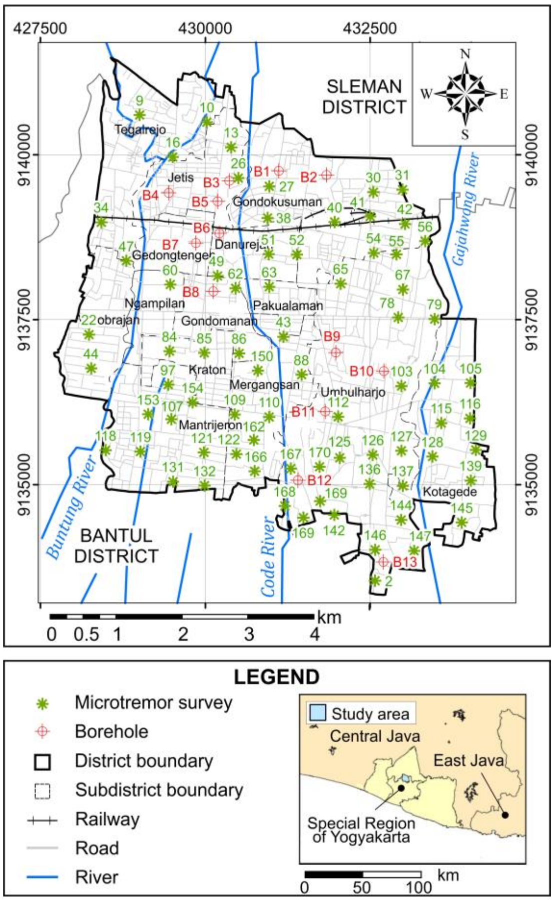

Fig. 2 Location of boreholes and microtremor measurement in Yogyakarta City

4. DETERMINATION OF PEAK GROUND ACCELERATION

The soil characteristic of the Yogyakarta City is determined using the results of site investigation and laboratory tests. The upper lithology of the Yogyakarta depression area consists of an interlayer of sand, silt and clay, while in general the soil layer is dominated by sand. The correlation of boreholes B6, B11 and B13 from the north to south of Yogyakarta City is shown in Fig. 3. The cross section shows the thickness of silt and clay layer increases to the south direction. The silt-clay layer has an internal friction of lower than 25^o, the cohesion of 0.14 to 0.35 kg/cm^2 with the average N-SPT value less than 15. Meanwhile, the sand layer has the internal friction angle of 35^o to 43.5^o, the cohesion of 0.1 to 0.01 kg/cm^2, and the average N-SPT value of 17 to 45.

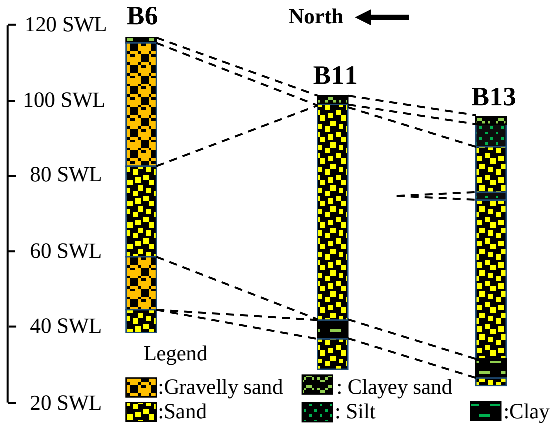

Figure 3. Cross section of soil layer from the north to south direction of the Yogyakarta City

Considering the soil layer characteristic at the study area, the following section analyzes the determination of peak ground acceleration (PGA) using various methods i.e. (1) referring to Indonesian seismic code; (2) empirical prediction by incorporating the attenuation equations considering local site effects; and (3) site response analyses in layered soil.

4.1 PGA Determination based on Seismic Code

PGA is obtained by determining seismic zones based on the Indonesian seismic code (Fig. 4) and soil types depending on the average shear wave velocity ($\bar{v}_s$), the average standard penetration test ($\bar{N}$), and the average undrained shear strength ($\bar{s}_u$), as shown in Table 1. The PGA is determined by combining the earthquake zonation (Fig. 4) and soil types (Table 1) to determine the maximum considered earthquake geometric mean PGA of every soil type using Eq. (1).

$$PGA_M = F_{PGA} PGA \quad (1)$$

where PGA_M = maximum considered earthquake geometric mean PGA adjusted for site class effects; PGA = peak ground acceleration using Fig. 4; and F_{PGA} = site coefficients (Table 2).

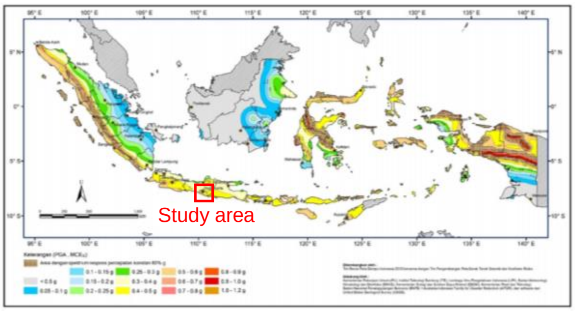

Fig 4. Indonesian earthquake zonation map with peak bedrock acceleration of earthquake with a 2% probability of exceedance in 50 years (2500 year return period) [8]

Table 1 Site classification based on Indonesian seismic code [8]

Site class	$\bar{v}_s$ (m/s)	$\bar{N}$	$\bar{S}_u$ (kPa)
SA (hard rock)	>1500	N/A	N/A
SB (rock)	750 to 1500	N/A	N/A
SC (hard/very dense soil and soft rock)	350 to 750	>50	≥100
SD (medium soil)	175 to 350	15 to 50	50 to 100
SE (soft soil)	<175	<15	<50
	or, any soft soil profile where the total thickness > 3 m with PI > 20%, $w_n \geq$ 40% and $\bar{S}_u$ < 25 kPa		
SF (special soil)	Required specific geotechnical investigation and site response analysis on every site		

Table 2 Site coefficients (F_{PGA})

Site class	PGA≤ 0.1g	PGA= 0.2g	PGA= 0.3g	PGA =0.4g	PGA≥ 0.5g
SA	0.8	0.8	0.8	0.8	0.8
SB	1.0	1.0	1.0	1.0	1.0
SC	1.2	1.2	1.1	1.0	1.0
SD	1.6	1.4	1.2	1.1	1.0
SE	2.5	1.7	1.2	0.9	0.9
SF	Required specific site response analysis				

Since 2002 and then revised in 2010, the Indonesian seismic code has been using the probabilistic seismic hazard analysis to determine the PGA for the bedrock with the probability of exceedance of 10% in 50 years (500 year return period). However, the newly published code considers a 2% probability of exceedance in 50 years (2500 year return period) [8]. From Fig. 4, it is shown that Yogyakarta City is located in the zone with PGA of 0.50g to 0.60g. According to the results of site investigation, the average N-SPT values ($\bar{N}$) in 13 boreholes are 15 to 50. At 2 seismic downhole surveys, the average value of shear wave velocity up to 30 meter in B13 is 198.81 m/s with $\bar{N}$ = 30, while in B12 is 240.38 m/s with $\bar{N}$ = 26. As seen in Table 1 and 2, the soil in Yogyakarta City can be classified as medium soil (SD). Therefore, the city has the maximum considered earthquake geometric mean PGA of 0.50-0.57g, while the southern area has higher PGA. Meanwhile, the previous code gives the peak bedrock acceleration value of 0.25g and PGA for medium soil of 0.32g.

4.2 Empirical Prediction of PGA by using Attenuation Relationships

PGA is calculated using the empirical equations based on the earthquake magnitude and hypocenter distance or active faulting that happened in the past. The attenuation relationships used in the calculation are the Boore et al. equation [19] and Bozorgnia et al. equation [20] taking into account site characteristics. The Yogyakarta earthquake on May 27 2006 is considered as the strongest earthquake that hit Yogyakarta in the past. According to USGS [3], this earthquake had the magnitude of Mw 6.3 and epicenter coordinate of 440265.66E; 9119863.97N with the hypocenter depth of 10 km. Considering the historical earthquakes around Yogyakarta compiled from [3], [17], [22], and [23], the Yogyakarta earthquake 2006 is estimated to have a 50-100 year return period.

Boore et al. [19] developed an attenuation relationship based on the earthquake data in the northeast of America with earthquake magnitude from 5.0 to 7.7 and the distance from the active fault less than 100 km as shown in Eq. (2).

$$\log a = b_1 + b_2(M_w - 6) + b_3(M_w - 6)^2 + b_4 R + b_5 \log R + b_6 G_B + b_7 G_C \quad (2)$$

where a = PGA (g), $R = (d^2+h^2)^{0.5}$; d = distance from observed site to the nearest active fault; b, h = coefficient determined by [19]; G_B = 0 for observed point A and C class, and 1 for B class; G_C = 1 for observed point A and B class, and 0 for C class. The level of observed class is determined based on shear wave velocity ($\bar{v}_s$) resulted from the seismic downhole test, where A class is $\bar{v}_s$ >750 m/s; B class is $\bar{v}_s$ 360–750 m/s; and C class is $\bar{v}_s$ 180–360 m/s.

The map of active faults in Yogyakarta was developed using data integration after the occurrence of earthquake ground motion, Cenozoic geo-history, and tectonic geomorphology [16]. The active fault close to Yogyakarta is part of the Opak Fault and classified as a normal fault. The calculation result using the Boore et al. attenuation relationship at 87 observed sites has PGA of 0.14g to 0.21g.

Bozorgnia et al. [20] developed an attenuation relationship based on the earthquake data occurring throughout the world, i.e. 2800 of uncorrected PGA from 48 earthquakes, and more than 1300 response spectra data from 33 earthquakes that can be elaborated as follows.

$$
\begin{aligned}
\ln a &= c_1 + c_2 M_w + c_3(8.5 - M_w)^2 + c_4 \ln(\{R_s^{\,2} \\
&+ [(c_5 S_{HS} + c_6\{S_{PS} + S_{SR}\} + c_7 S_{HR})\exp(c_8 M_w \\
&+ c_9\{8.5 - M_w\}^2)]^2\}^{1/2}) + c_{10} F_{SS} + c_{11} F_{RV} \\
&+ c_{12} F_{TH} + c_{13} S_{HS} + c_{14} S_{PS} + c_{15} S_{SR} + c_{16} S_{HR}
\end{aligned} \tag{3}
$$

where M_w = moment magnitude; R_s =distance from observed point to the nearest active fault; S_{HS} = 1 for Holocene soil; S_{PS} = 1 for Pleistocene soil; S_{SR} = 1 for soft rock; S_{HR} = 1 for hard rock; $S_{HS} = S_{PS} = S_{SR} = S_{HR} = 0$ for other type of soil; F_{SS} = 1 for strike slip faulting; F_{RV} = 1 for reverse faulting; F_{TH} = 1 for thrust faulting; $F_{SS} = F_{RV} = F_{TH} = 0$ for other fault types; $c_1 - c_{16}$ = regression coefficient.

The result of the calculation using the deterministic approach [20] shows that the 87 observed points are classified into the zone with PGA value of 0.16g to 0.19g. The most influencing factor for PGA in this equation is the distance from the observed point to the active fault and the magnitude of the earthquake.

4.3 PGA Determination based on Microtremor Measurement

Microtremor measurement is often used to determine the local site effects in the earthquake prone areas with limited ground motion records, in order to develop a seismic microzonation [24]. The resonance frequency obtained from microtremor measurement theoretically has a closer value to the frequency directly measured in the big magnitude earthquake. This study used the attenuation equation proposed by Kanai [21], which correlates the PGA, soil predominant period (T_g) from microtremor recording, earthquake magnitude, and the distance from hypocenter (Eq. 4).

$$
a = \frac{5}{\sqrt{T_g}} 10^{0.61M - \left(1.66 + \frac{3.6}{R}\right)\log R + 0.167 - \frac{1.83}{R}} \tag{4}
$$

where a = PGA at the observed site (cm/sec^2); T_g = dominant period (s); R = the closest distance from observed point to the hypocenter or active fault (km); M = earthquake magnitude in Richter scale.

Fig. 5 shows the result of PGA calculation using the Kanai equation [21] considering the Mw 6.3 Yogyakarta earthquake. Based on the soil predominant period resulting from microtremor measurement, the PGA at the research area varies from 0.05g to 0.30g. It is clarified that the southern part of Yogyakarta City has higher PGA, mostly 0.2g to 0.3g, whereas the northern part of Yogyakarta has lower PGA of 0.1g to 0.2g.

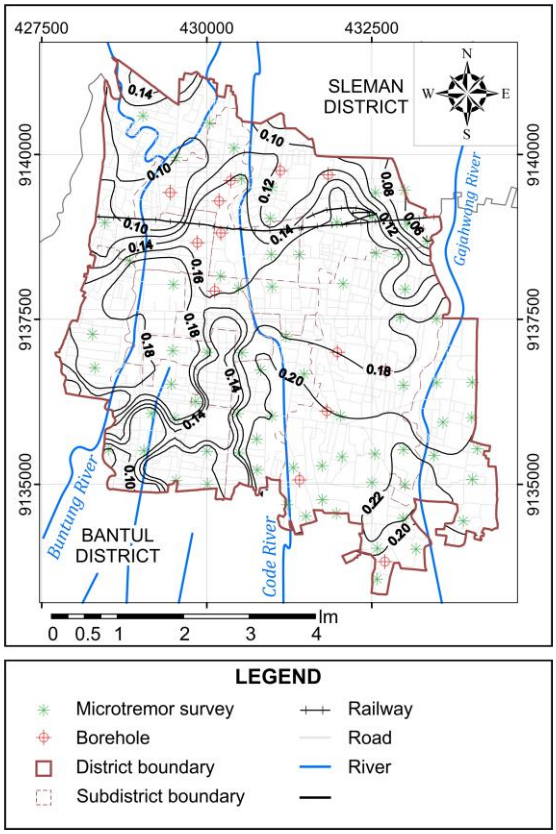

Fig. 5 PGA distribution map using attenuation relationship by Kanai [21] based on microtremor measurements

4.4 Nonlinear Earthquake Site Response Analysis

Nonlinear Earthquake site Response Analyses (NERA) calculate the site response in layered soil by taking into consideration the soil layering profile, shear wave velocity, and the PGA value [25]. The ground motion recorded in the past can be used as source ground motion in this calculation. In addition, source ground motion will be scaled based on the maximum PGA. Layered soil in the observed site is connected to the value of shear wave velocity that plays a significant role in determining the accuracy of the calculation.

Shear wave velocity can be obtained from the seismic downhole test, the use of Bunsanf-HV Matsuo program or by using empirical equation. In this research, the shear wave velocity was determined using empirical equation. Numerous researchers have developed the empirical correlation of shear wave velocity and the N-SPT value considering the soil types at the observed site [26]. The empirical correlation between shear wave velocity and N-SPT value was developed based on geotechnical and geoseismic data [27] and has shown better results compared to the other empirical equations. This equation takes into account the soil types at the observed site, as shown in the following equations:

$$V_s = 90 \times N^{0.309} \quad \text{for all soils} \qquad (5)$$

$$V_s = 90.8 \times N^{0.319} \quad \text{for sandy soils} \qquad (6)$$

$$V_s = 97.9 \times N^{0.269} \quad \text{for clayey soils} \qquad (7)$$

where V_s = shear wave velocity (m/s); N = number of blows of N-SPT.

In the above equations, the N-SPT value is very critical for calculating shear wave velocity while the soil type is not too critical. The equation based on uncorrected N-SPT values shows better results than the equation based on corrected N-SPT values. Therefore, it is suggested to use the equation developed for all soil types based on uncorrected N-SPT value in the calculation [27]. The above equations are used to obtain shear wave velocity of the existing borehole data.

In the analysis at 87 observed sites (Fig. 2), the soil profile was estimated and interpolated from the boreholes data nearby. The soil profile in every observed site was determined based on the result of borehole test combined with the laboratory test.

The determination of ground motion based on 4 source ground motions was performed to reduce the uncertainty of the observed location. The Indonesian seismic code requires that 4 recorded accelerograms of 4 different earthquakes must be observed at the minimum, one of which is El Centro N-S. The source ground motions used in the PGA calculation are:

1. Loma Prieta Earthquake at South California
2. Imperial Valley Earthquake, May 18 1940, 2037 PST N-S Corrected El Centro N-S,
3. Parkfield, COMP N65E,
4. Taft Earthquake July 21 1952 N69W.

The source ground motion scaling was conducted by taking into account the Yogyakarta earthquake amplification map [5], the geological condition, historical earthquakes and site effects. In the measurements located in the medium amplification zone, the source ground motion was scaled at 0.25g while the measurements in very high and high amplification zone, the source ground motion was scaled at 0.275g and 0.30g. This scaling was determined to be compared to the results deterministic approach by attenuation relationships considering the Yogyakarta earthquake 2006. Fig. 6 shows the result of the ground motion scaling used in the calculation.

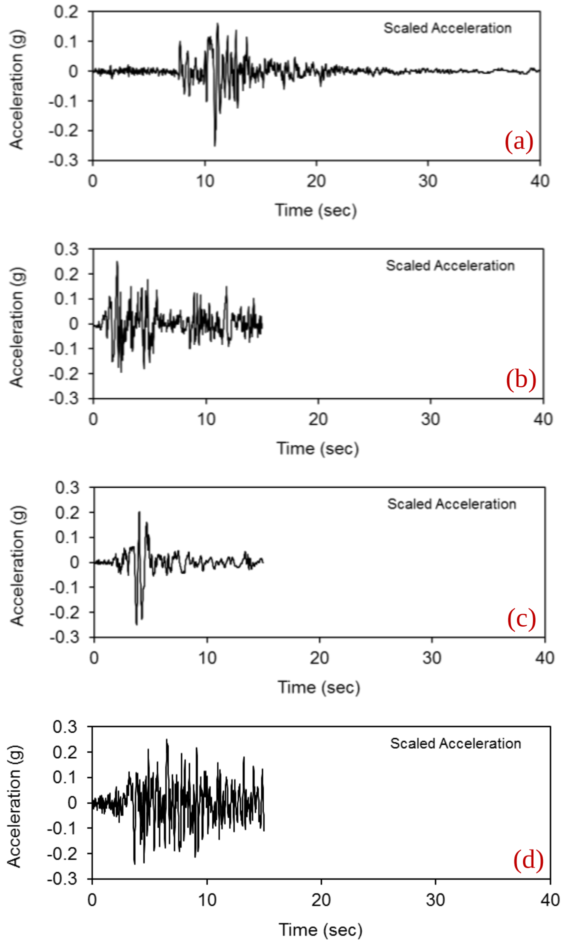

Fig. 6 Scaled ground motion (max. acceleration 0.25g): (a) Loma Prieta earthquake; (b) El Centro earthquake; (c) Parkfield earthquake; (d) Taft earthquake

The profile of soil layer in the borehole needs to be adjusted into input data specified in the program, namely inputting soil types, layer thickness, total unit weight and shear wave velocity. Table 3 shows the example of input data for soil profile in B13 at the South most Yogyakarta City (see Fig. 2) where the groundwater table is at layer No. 5. Soil material type needs to be defined in the next step. Data input is the value of strain and comparison of G/G_{max}. This data is used to illustrate the shear modulus graphic and damping ratio (Fig. 7).

The calculation requires input data for earthquake, soil profile and soil material type. The next phase is the calculation of maximum shear modulus and vertical effective stress, damping, maximum shear strain, maximum shear stress, maximum acceleration, and acceleration in each sub layer. Table 4 shows the result of the calculation in worksheet iteration in order to obtain the maximum acceleration in every depth.

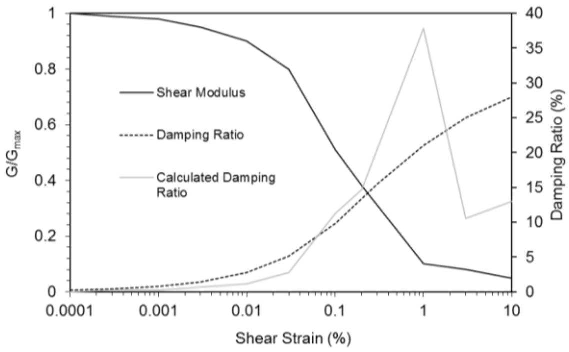

Fig. 7 Correlation between shear strain, G/G_{max} and damping ratio at B13

Table 3 Input data of soil profile at B13

Layer No.	Soil type	Layer thickness (m)	Max shear modulus (MPa)	Total unit weight (kN/m^3)	Shear wave velocity (m/sec)	Depth at top layer (m)	Vertical effective stress (kPa)
1	1	1.0	23.6	17.95	113.6	0.0	0.0
2	2	1.0	72.5	19.23	192.3	1.0	17.9
3	3	1.5	456.7	22.56	445.6	2.0	37.1
4	2	0.7	29.2	19.23	122.0	3.5	71.0
5	3	5.2	131.1	22.56	238.7	4.2	84.4
6	2	1.2	19.0	19.23	98.5	9.4	150.8
7	3	4.4	168.9	22.56	270.9	10.6	162.1
8	4	5.0	59.5	17.56	182.3	15.0	218.2
9	5	3.6	129.2	16.68	275.7	20.0	256.9
10	6	2.9	227.8	19.77	336.2	23.6	281.6
11	7	3.0	188.6	16.38	336.1	26.5	310.5
12	8	5.5	697.5	23.54	539.1	29.5	330.2

Table 4 The result of NERA calculation at B13

Layer No.	Middle Depth (m)	Max Strain (%)	Max stress (kPa)	Max accel. (g)	Max relative velocity (cm/s)	Max relative displ. (cm)
1	0.50	0.014	3.04	0.31	67.69	19.46
2	1.50	0.013	8.51	0.26	67.33	19.45
3	2.75	0.004	14.86	0.23	67.21	19.44
4	3.85	0.176	19.59	0.26	67.18	19.44
5	6.80	0.033	30.33	0.26	67.13	19.34
6	10.00	11.593	41.97	0.30	67.50	19.18
7	12.80	0.082	57.30	0.52	41.10	7.24
8	17.50	1.162	77.19	0.41	38.31	6.89
9	21.80	0.291	89.26	0.59	19.87	1.63
10	25.05	0.105	115.48	0.58	10.00	0.65
11	28.00	0.115	130.53	0.57	6.59	0.35
12	29.50	0.020	137.31	0.41	0.00	0.00

In the calculation using 4 types of source ground motion, Uniform Building Code [28] was used to determine the soil profile based on shear wave velocity recorded in the observed soil layer. The result shows that the measurement of 147 (location of mircrotremor survey) at the east part of B13 obtained the highest PGA of 0.384g in the calculation by using source ground motion Parkfield earthquake, while the lowest PGA was obtained in the calculation using source ground motion El Centro earthquake in the observer point No. 47 (western part of Yogyakarta) with the PGA of 0.189g.

Fig. 8 shows the distribution map of PGA in Yogyakarta City developed from the result of nonlinear earthquake site response analyses using Parkfield source ground motion. The result shows that the southern part and the northern part of Yogyakarta have higher PGA up to 0.38g. The analyses were conducted at 47 observed points and considered adequate to represent the earthquake condition of Yogyakarta as the locations were spread evenly in the research area.

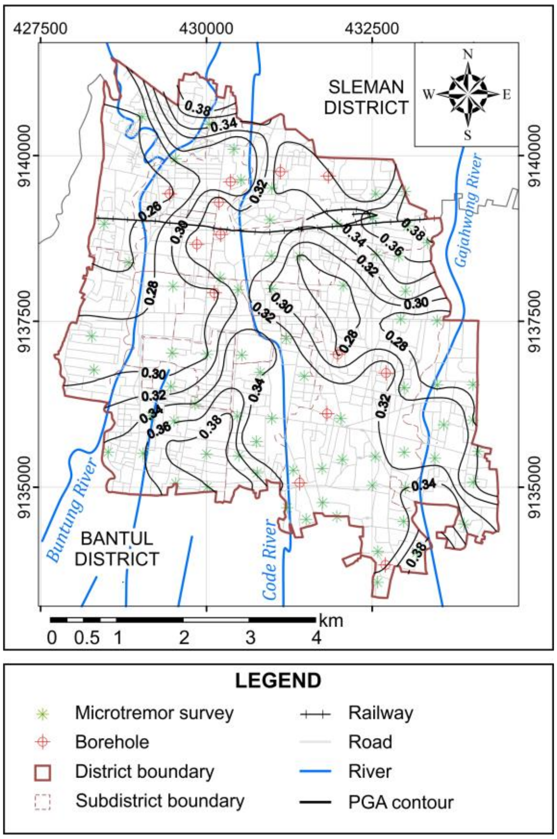

Fig. 8 PGA distribution map of Yogyakarta City based on the calculation using NERA

5. CONCLUSION

In the determination of PGA using the deterministic approach by attenuation relationships, each method resulted in different PGA. In this research, the earthquake data from the 6.3 Mw Yogyakarta earthquake 2006 is used as a reference of the earthquake magnitude and distance from hypocenter. According to the seismic history, this earthquake has a 50-100 year return period. The PGA can also be calculated using probabilistic seismic hazard analysis that needs earthquake catalogues surrounding the observed area.

The highest PGA is obtained from the calculation using Kanai equation [21] by using the predominant period from microtremor measurement. The average peak bedrock acceleration based on seismic code is 0.25g with PGA for medium soil is 0.32g. The Bozorgnia et al. equation [20] results in PGA between 0.16g to 0.19g, while the Boore et al. equation [19] results in PGA value of 0.14g to 0.21g. The result of microtremor measurement obtains the highest PGA compared to the other two methods. The PGA varies from 0.05g to 0.30g.

The newly published seismic code (SNI-1726-2012) considers a 2% probability of exceedance in 50 years or 2500 year return period. This procedure resulted in much higher PGA values for medium soil (SD) of 0.50-0.57g in Yogyakarta City, almost twice as high as PGA calculated by the previous codes in 2002 and 2010, which used a 10% probability of exceedance in 50 years or 500 year return period.

The PGA calculation using nonlinear earthquake site response analyses obtains the highest PGA at the southern area that is 0.384g using source ground motion Parkfield earthquake while the lowest PGA of 0.189g is obtained in the calculation using source ground motion El Centro earthquake at the eastern part of the city.

The result of the research shows that the number and the distribution of microtremor measurement have represented the local site effects. However, to improve the accuracy of PGA calculation, the number and the depth of core drilling should be increased so that the soil layer profile and physical properties can illustrate the real condition more accurately. The downhole test in several other measurements should be performed to obtain more representative value of shear wave velocity in each layer. The above methods can be applied in the microzonation studies in other areas by having an appropriate site investigation and by applying attenuation equations suitable to the site characteristics of the areas.

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7. REFERENCES

[1] Campbel KW and Bozorgnia Y, Updated near-source ground motion (attenuation) relations for the horizontal and vertical components of peak ground acceleration and acceleration response spectra, Bull. of the Seismological Society of America: Vol. 93, No. 1, 2003, pp. 314-331.

[2] Day RW, Geotechnical earthquake engineering handbook, McGraw-Hill, New York, 2002.

[3] United States Geological Survey (USGS), M6.3 Java Earthquake of May 2006, National Earthquake Information, 2006.

[4] Fathani TF, Adi AD, Pramumijoyo S, and Karnawati D, The determination of peak ground acceleration at Bantul Regency, Yogyakarta Province, Indonesia, The Yogyakarta Earthquake of May 27, 2006, Star Publishing, California, 2008, pp. 12.1-12.15.

[5] Karnawati D, Husein S, Pramumijoyo S, Ratdomopurbo A, Watanabe K, and Anderson R, Earthquake microzonation and hazard maps on Bantul Area, Yogyakarta, Indonesia, The Yogyakarta Earthquake of May 27, 2006, Star Publishing, California, 2008, pp. 6.1-6.16.

[6] Wu YM, Shin TC, and Chang CH, Near real-time mapping of peak ground acceleration and peak ground velocity following a strong earthquake, Bull. of Seismological Society of America, Vol. 91, No. 5, 2001, pp. 1218-1228.

[7] Bradley BA and Cubrinovski M, Near-source strong ground motions observed in the 22 Feb 2011 Christchurch Earthquake, Seismological Res Lett., Vol. 82, No. 6, 2011, pp. 853-865.

[8] National Standardization Agency of Indonesia, National standard for designing earthquake resistance buildings, SNI-1726-2012.

[9] Iryam M, Hendriyawan, Asrurifak M, Ridwan M, Aldiamar F, Sengara IW, Widiyantoro S, Triyoso W, Hilman D, Kertapati E, Meilano I, Suhardjono, and Firmanti A, Past earthquakes in Indonesia and new seismic hazard maps for earthquake design of buildings and infrastructures, Geotechnical Predictions and Practice in Dealing with Geohazards, Springer, 2013, pp. 33-46.

[10] Ansal A, Kurtulus A, and Tonuk G, Seismic microzonation and earthquake damage scenarios for urban areas, J Soil Dynamics and Earthquake Eng., Vol. 30, 2010, pp. 1319-1328.

[11] Ganapathy GP, First level seismic microzonation map of Chennai city – a GIS approach, Nat. Hazards Earth Syst. Sci., Vol. 11, 2011, pp. 549-559.

[12] Grasso S and Maugeri M, The seismic microzonation of the City of Catania (Italy) for the Etna Scenario Earthquake (M = 6.2) of 20 Feb 1818, Earthquake Spectra Vol. 28, No. 2, 2012, pp. 573-594.

[13] Rusnardi R and Kiyono J, Estimation of earthquake ground motion in Padang, Indonesia, Int. J. of GEOMATE, Oct. 2011, Vol. 1, No. 1, pp. 71-77.

[14] Rusnardi R, Kiyono J, Yoshimoto Y, Ono Y, and Syahril, Determined soil characteristic of Palu in Indonesia by using microtremor observation, Int. J. of GEOMATE, April 2016, Vol. 10, No. 2, pp. 1737-1742.

[15] Thant M, Pramumijoyo S, Hendrayana H, Kawase H, and Adi AD, Evaluation of strong ground motion for Yogyakarta depression area, Indonesia. J. of South East Asian Appl. Geol., Vol. 2, No. 2, 2010, pp. 81-94.

[16] Setiadji LD, Darianto DH, Watanabe K, Fukuoka K, and Ehara S, Searching for the active fault of the Yogyakarta Earthquake of 2006 using data integration on aftershocks, Cenozoic geo-history, and tectonic geomorphology, The Yogyakarta Earthquake of May 27, 2006, Star Publishing, California, 2008, pp. 4.1-4.23.

[17] Van Bemmelen RW, The geology of Indonesia, 2nd Eds, Martinus Nijhoff, The Haque, Govrn. Printing Office, 1970, pp. 732.

[18] McDonald M and partners, Greater Yogyakarta groundwater resources study, Vol. 3 Groundwater, Groundwater Development Project (P2AT), 1984, pp. 116.

[19] Boore DM, Joyner WB, and Fumal TE, Equations for estimating horizontal response spectra and peak acceleration from Western North American Earthquakes: a summary of recent work, Seismological Research Letters, Vol. 68, No. 1, 1997, pp. 128-153.

[20] Bozorgnia Y, Campbell KW, and Niazi M, Observed spectral characteristics of vertical ground motion recorded during worldwide earthquakes from 1957 to 1995, 12 WCEE, 2000, 2761.

[21] Kanai K, Improved empirical formula for the characteristic of strong earthquake motion, Proc. of Japan Earthquake Engineering Symposium, Tokyo, 1966, pp. 1-4.

[22] Newcomb KR and McCann WR, Seismic History and Seismotectonics of the Sunda Arc. J. of Geophysical Research 92, B1, 1987.

[23] Utsu T, A list of deadly earthquakes in the World: 1500-2000, in International Handbook of Earthquake and Engineering Seismology Part A, Eds. Lee WK, Kanamori H, Jennings PC, and Kisslinger C, Academic Press, San Diego, 2002, pp. 691-717.

[24] Bour M, Fouissac D, Dominique P, and Martin C, On the use of microtremor recordings in seismic microzonation, J Soil Dynamics and Earthquake Eng.:17 (7-8), 1998, pp. 465-474.

[25] Bardet JP and Tobita T, NERA: A computer program for nonlinear earthquake site response analyses of layered soil deposits, Dep. of Civil Eng., University of Southern California, 2001.

[26] Fauzi A, Irsyam M, and Fauzi UJ, Empirical correlation of shear wave velocity and N-SPT value for Jakarta, Int. J. of GEOMATE, Sept. 2014, Vol. 7, No. 1, pp. 980-984.

[27] Hasancebi N and Ulusay R, Empirical correlations between shear wave velocity and penetration resistance for ground shaking assessments, Bull. Eng. Geol. Environ: 66, 2006, pp. 203-213.

[28] Structural Engineering Design Provisions, Uniform Building Code Volume 2, 1997.