Microzonation of The Earthquake Hazard

by Herry Riswandi

Microzonation of The Earthquake Hazard as A Disaster Mitigation Effort in The Special Region of Yogyakarta

Herry Riswandi[1], Ikhsan[2], Yohana Noradika Maharani[3,a)], Wijayanto[2], Bambang Sunardi[2], Ayu Krisno Ekarsti[2], Yody Rizkianto[4], Muhamad Syaifudin[5]

[1]*Geomatics Engineering, Universitas Pembangunan Nasional Veteran Yogyakarta*
[2] *Indonesian Agency for Meteorological Climatological and Geophysics*
[3]*Disaster Management, Universitas Pembangunan Nasional Veteran Yogyakarta*
[4,5]*Geology Engineering, Universitas Pembangunan Nasional Veteran Yogyakarta*

[a)] Corresponding author: yohananm@upnyk.ac.id

Abstract The Special Region of Yogyakarta is tectonic with a high level of risk of earthquake disasters. This condition is due to the location of Yogyakarta which is closer to the subduction zone of the Indo-Australian Plate to the Eurasian Plate in the Indian Ocean in the South of Java Island and there is a very active Opak fault on land. The history of destructive earthquakes in Yogyakarta due to the Opak fault activity last occurred on 27 May 2006. The earthquake caused 5,782 deaths, dozens were injured, and hundreds of thousands of houses were damaged. This study aims to identify potential earthquake hazards using the microzonation method to evaluate and map areas that have a high earthquake risk based on the calculation of the maximum soil acceleration (PGA) value in bedrock and Vs30 data as a site characterization due to the influence of local soil conditions. In this study, the methods used are the calculation of Probabilistic Seismic Hazard Analysis (PSHA), the HVSR inversion method and the Multichannel Analysis of Surface Waves (MASW). Based on the calculations, a map of the maximum ground acceleration (PGA) in the bedrock and a map of the maximum ground acceleration at the ground surface are generated which can be used as considerations in determining the rules regarding the design/standard of earthquake-resistant buildings as an effort to mitigate earthquakes.

Keywords: Earthquake, Microzonation, PSHA, PGA, HVSR, Yogyakarta

1. INTRODUCTION

The Special Region of Yogyakarta is tectonically one of the most active regions in Indonesia. This condition is caused by the location of Yogyakarta which is closer to the subduction zone of the Indo-Australian Plate to the Eurasian Plate in the Indian Ocean south of Java Island. Besides being very prone to earthquakes due to plate subduction activities, the Special Region of Yogyakarta and its surroundings are also very prone to earthquakes due to local fault activities.

The history of destructive earthquakes in Yogyakarta based on the BMKG Damaging Earthquake Data Catalog (Setiyono, et al., 2019) occurred in 2006, 1981, 1943, 1937, and 1867 (Figure 1). The 2006 earthquake occurred on 27 May 2006 in the morning at 05:53:57 WIB, the source of the earthquake at coordinates 8.26 South Latitude and 100.31 East Longitude with a depth of 33 km and a strength of 5.9 M, felt in Bantul and Klaten with an intensity of IX MMI, Sleman and Yogyakarta. VIII MMI, Surakarta V MMI, Salatiga and Blitar IV MMI, Surabaya II MMI and Denpasar. The earthquake caused the death toll in Bantul, Klaten, Yogyakarta and Central Java to reach 5,782 people, dozens of people were injured, and hundreds of thousands of houses were damaged.

Another history of destructive earthquakes is the earthquake on March 14, 1981. This earthquake occurred at 06:22:35 WIB, the source of the earthquake at coordinates 8.76 South Latitude and 110.43 East Longitude, a depth of 51 km and a strength of M 5.6 was felt in Yogyakarta with an intensity of VII MMI. The earthquake caused cracks in the walls of the Ambarukmo hotel. The earthquake on July 24, 1943 with coordinates 8.6 South Latitude and 109 East Longitude was felt in Yogyakarta VIII MMI, Garut, and Surakarta. The earthquake caused 213 people died, 2096 people were injured, and 2800 houses were badly damaged. The earthquake on 27 September 1937 at coordinates 8.7 South Latitude and 110.8 East Longitude was felt in Yogyakarta VIII-IX MMI, Klaten, Klumpit, Central Java, to East Lombok. There were one-person dead in Klumpit and 1 house split open, a total of 326 Prambanan temple stones collapsed, 2,200 houses were damaged, and underground pipes were damaged in several places. The earthquake on June 10, 1867 was felt in Yogyakarta and Surakarta VIII-IX MMI. As a result of the earthquake, 5 people died, and 372 houses collapsed and partially damaged.

The Special Region of Yogyakarta has a high level of risk for earthquake disasters because it has a relatively high population density and the development of public infrastructure and housing is growing rapidly. Physiographic conditions affect the distribution of the population, the availability of regional infrastructure and facilities, and the socio-economic activities of the population, as well as the progress of development between regions. In relatively flat areas, such as fluvial plains covering Sleman Regency, Yogyakarta City, and Bantul Regency, these are areas with high population density, and have high socio-economic activities.

When earthquake prediction efforts have not been successful, the best effort to anticipate the disaster is through earthquake mitigation. Earthquake mitigation can be carried out in three stages, namely before, during, and after an earthquake. The first step in mitigation efforts before an earthquake occurs is by microzoning the earthquake hazard. This mapping is needed to identify areas that have a high earthquake risk. By knowing areas that have a high earthquake risk, anticipation to reduce the impact of disasters that may arise in these areas can be done as early as possible.

The Special Region of Yogyakarta has a high level of risk for earthquake disasters. Therefore, mitigation efforts through microzonation of earthquake hazards need to be carried out comprehensively. Earthquake hazard microzonation is an attempt to evaluate and describe the potential for earthquake disasters in an area, which are generally caused by strong vibrations during an earthquake. Earthquake hazard microzonation activities include, among others, site characterization due to the influence of local soil conditions, as well as seismic-hazard microzonation analysis by considering the amplification due to the influence of local soil conditions. Earthquake microzonation activities can provide output in the form of studies, maps, and various detailed information on potential earthquake hazards. This is needed as input for authorities at both central and regional levels in spatial planning, practitioners in the initial design of earthquake-resistant structures and infrastructure, earthquake mitigation priorities, and contingency plans for earthquake disasters.

2. MATERIALS AND METHODS

2.1 Case study delineation

The special area of Yogyakarta, Indonesia is the administrative area chosen in the case study in this study, this is considering the potential high risk of earthquake hazard caused by opaque fault activity which is an active fault on land in the Yogyakarta area. The Yogyakarta earthquake that occurred on 27 May 2006 was a major earthquake in Yogyakarta caused by the movement of the opaque fault, the magnitude of the earthquake was quite large, namely M= 6.4 which resulted in 6234 fatalities with 36,299 people injured and 1.5 million people lost their homes and resulted in infrastructure damage as many as 616,458 units of residential buildings.

The areas selected for the research include all regencies and cities in D.I Yogyakarta which include the City of Yogyakarta, Sleman Regency, Bantul Regency, Kulonprogo Regency, and Gunung Kidul Regency. In this study, PGA and Vs30 mapping were carried out for the entire Special Region of Yogyakarta, while surface PGA mapping was carried out for each Regency/City obtained by using microtremor data processing, HVSR inversion, Vs30 data obtained from the MASW and USGS methods so that PGA was obtained. bedrock and surface PGA with a probability of exceeding 2% in 50 years.

2.2 Methods

2.2.1 Processing of Microtremor, HVSR Inversion, and Vs30

The microtremor signal from the measurement results was analyzed using Geopsy software. The first step is the windowing process. Window selection is done manually with a window length of 25-50 seconds. Each windowis then fourier transformed, so that every window that was originally in the time domain is transformed into a window in the frequency domain. Each window is then compared with the horizontal direction spectrum with the vertical direction spectrum to produce an HV curve for each window. The curves are then stacked so that the average value of the HVSR curve is obtained from one microtremor recording data. In the HVSR curve, information is obtained from the dominant frequency value and the peak amplitude of the HVSR. Microtremor data processing is done using Geopsy software. The results of microtremor processing are then stored in .hv format.

The HVSR curve was then analyzed again using the OpenHVSR program to obtain a 1D profile of shear wave velocity (Vs). The data needed in this process is the HVSR curve in .hv format and the initial model in .txt format in the form of Vp, Vs, density, layer thickness, Qp, and Qs. HVSR inversion processing is carried out using the OpenHVSR program. The results of further processing are used to calculate the value of Vs30 with the formulation of equation (2). In this study, the Vs30 value used is a combination of the results of HVSR inversionprocessing, and from secondary data, namely the Vs30 value from the MASW method and Vs30 from the USGS.

2.2.2 Soil Acceleration Microzonation Process

Earthquake microzonation is carried out by estimating the maximum ground acceleration (PGA) value in the bedrock. In this study, the PGA value in the bedrock used refers to the results of the 2017 Indonesia Earthquake Source and Hazard Map (Pusgen, 2017). Local soil conditions will affect the amount of PGA on the soil surface. Local soil conditions will affect the amplification of earthquake waves. The representative soil dynamics parameter that can be used to estimate the PGA on the surface is the value of Vs30.

2.2.3 Mapping of Processing Results and Modeling

After processing the data processing process, the parameter values obtained are then mapped to make it easier to interpret. The results of processing the mapped data are the value of Vs30, PGA in bedrock, and surface PGA with a probability of exceeding 2% in 50 years. In this study, mapping the results of data processing using ArcMap 10.8. software

3. RESULTS AND DISCUSSIONS

3.1. Site Characterization of the Special Region of Yogyakarta

Based on the results of data processing combined HVSR inversion, MASW secondary data, and Vs30 USGS, the average shear wave velocity to a depth of 30 m (Vs30) in the Special Region of Yogyakarta varies with values from less than 175 m/s to 900 m/s. Relatively low values of Vs30 were found in most parts of Bantul Regency and Yogyakarta City, southern and eastern Kulonprogo, southern Sleman and parts of Gunungkidul.

Site characterization in the Special Region of Yogyakarta based on site class classification in SNI 1726:2019 shows that this area has four types of site classes, namely soft soil (SE), medium soil (SD), hard soil, very dense and soft rock (SC), and rock (SB). Soft soil has a value of Vs30 < 175 m/s, medium soil 175 - 350 m/s, hard soil 350 - 750m/s, and rock 750 - 1500 m/s.

3.2. Potential Earthquake Hazards in Bedrock

The potential for earthquake hazard in bedrock in the Special Region of Yogyakarta (DIY) refers to the 2017 Indonesia Earthquake Source and Hazard Map from the National Earthquake Study Center (PuSGeN). Based on the calculation of the Probabilistic Seismic Hazard Analysis (PSHA), the maximum soil acceleration (PGA) map for engineering bedrock is generated with a shear wave velocity of Vs 760 m/s. This map can be used to determine the maximum ground acceleration value probabilistically or to identify potential seismic hazard probabilistically. This map becomes the official reference map for PGA values in bedrock for building design in a city or certain coordinates. The PGA map in the bedrock of the Special Region of Yogyakarta shown in Figure 1.

According to Figure 1 the PGA value of bedrock in the Special Region of Yogyakarta varies from 0.35 to more than 0.6 g. The areas with the highest PGA values for bedrock are distributed in most of Bantul Regency, western Gunungkidul Regency (which is adjacent to the Opak Fault line), Sleman Regency with the closest orientation to the Opak Fault line (Berbah and Prambanan Districts), Yogyakarta City with the closest orientation. with the Opak Fault line (Kota Gede District, Umbulharjo). Meanwhile, the lowest bedrock PGA values were distributed in Sleman District (Cangkringan, Pakem, Turi, Tempel), and Kulonprogo Districts (Kalibawang District, Samigaluh).

3.3. Potential Earthquake Hazards at Ground Surface

The results of mapping the potential for earthquake hazards on the ground surface in this report are initial information which is divided into preliminary reports for Bantul Regency, Yogyakarta City, Kulonprogo Regency, Sleman Regency, and Gunungkidul Regency. Based on PSHA calculations, PGA is generated for engineering bedrock with Vs 760 m/s (Figure 2). These results were further analyzed by considering the condition of the sediment at a depth of 0-30 meters from the surface to produce a map of the maximum soil acceleration (PGA) at the ground surface. This surface PGA map is very necessary to calculate the maximum acceleration of earthquake vibrations when passing certain types of soil that are mapped in the range of 0-30 meters from the surface. Based on the calculation of the surface PGA described above, the resulting vibration levels on the ground surface, as shown in Figure 2.

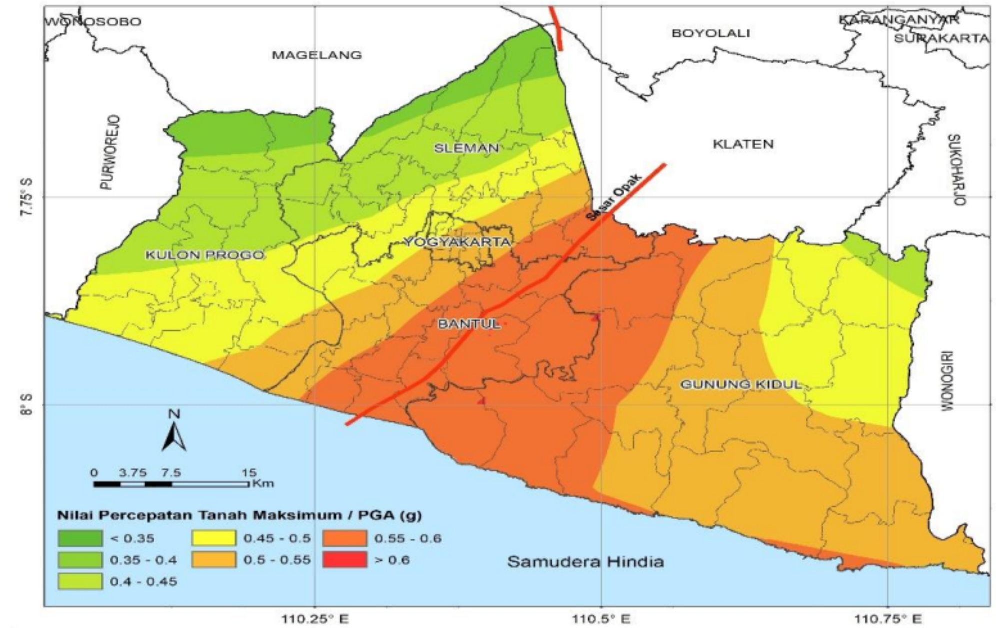

Figure 1. PGA map of bedrock in the Special Region of Yogyakarta

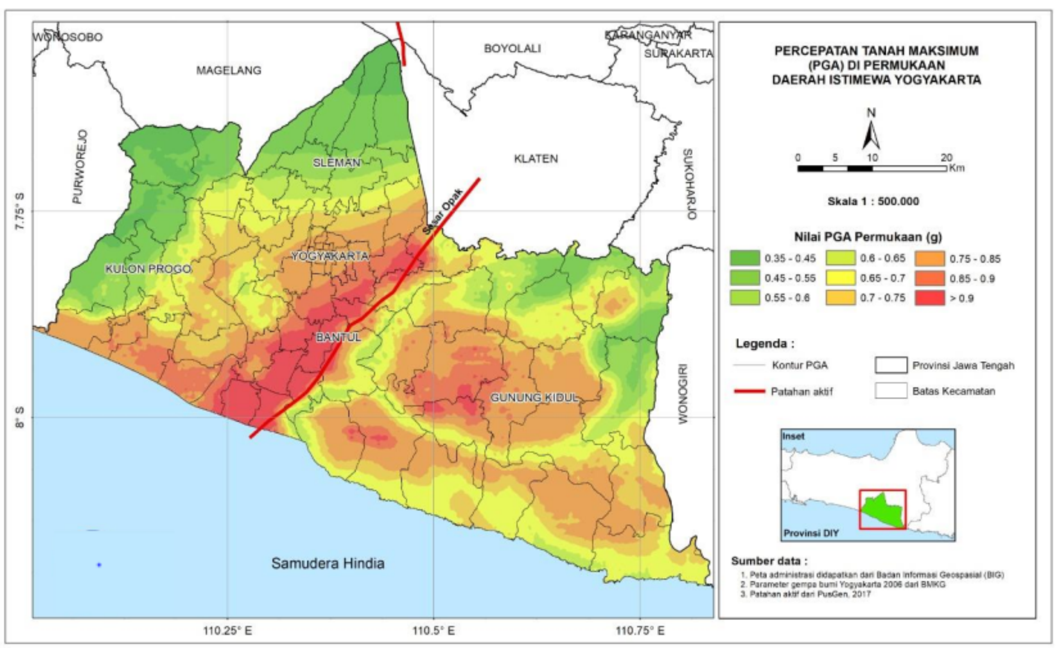

Figure 2. The surface PGA map in the Special Region of Yogyakarta

3.3.1. Bantul Regency Area

The surface PGA map in Bantul Regency is shown in Figure 2. The maps in this report are preliminary information. The surface PGA value in Bantul Regency varies from 0.6 g to > 0.9 g or if converted in the MMI scale it varies between VIII – IX MMI. The potential damage and impacts caused by the earthquake range from minor damage to buildings with strong construction, cracks in buildings with poor construction, walls can be separated from the frame of the house to damage to strong buildings, the frames of the house are not straight, and lots of cracks. Based on Figure 2, the sub-districts with acceleration values of 0.75 g to > 0.9 g or IX MMI are distributed around the Opak Fault line, namely Srandakan, Pandak, Kretek, Sanden, Pundong, Bambanglipuro, Jetis, Bantul, Pleret, Sewon, Piyungan and Banguntapan sub-districts. The area is dominantly located on the east side of the Opak Fault with the predominance of sedimentary material originating from the Qmi Formation (Mount Merapi Muda Sediment) which is composed of tuff, ash, breccia, agglomerates and lava flows. Areas with surface PGA varying from 0.6 9 – 0.75 g or VIII MMI are found in Sedayu, Pajangan, Kasihan, Imogiri, and Dlingo sub-districts.

3.3.2. Yogyakarta City Area

Based on Figure 2. The maps in this report are preliminary information. The surface PGA value in Yogyakarta City varies from 0.65 to 0.85 g or if converted on the MMI scale it varies between VIII – IX MMI. The potential damage and impacts caused by the earthquake range from minor damage to buildings with strong construction, cracks in buildings with poor construction, walls can be separated from the frame of the house to damage to strong buildings, the frames of the house are not straight, and lots of cracks. Based on Figure 3, the sub-districts with acceleration values of 0.75 g to 0.85 g or IX MMI are located in the southeast of Yogyakarta City with the orientation closest to the Opak Fault Line, namely Kota Gede, Umbulharjo, Mergangsang, Mantrijeron, and Kraton Districts. Geologically, the area is located in the Qmi Formation (Young Mount Merapi Sediment) which is composed of sedimentary material in the form of tuff, ash, breccia, agglomerates and lava flows. Areas with surface PGA varying from 0.65 – 0.7 g or VIII MMI are found in the Districts of Wirobrajan, Ngampilan, Gondomanan, Pakualaman, Gondokusuman, Danurejan, Gedongtengen, Jetis and Tegalrejo.

3.3.3. Kulonprogo Regency Area

The surface PGA map in Kulonprogo Regency is shown in Figure 2. The maps in this report are preliminary information. The surface PGA value in Kulonprogo Regency varies from 0.35 - 0.85 g or if converted in the MMI scale it varies between VII - IX MMI. The potential damage and impacts caused by the earthquake range from vibrations felt by all residents, residents leaving their homes, minor damage to buildings with good construction to damage to strong buildings, misaligned house frames, and lots of cracks. Based on Figure 4, the sub-districts with acceleration values of 0.75 g to 0.85 g or IX MMI are in the Southeast and South of Kulonprogo Regency with the orientation closest to the Opak Fault Line, namely Galur, Panjatan, Temon, Wates, Sentolo and Lendah Districts. Geologically, the area is located in the Qa (Aluvium) Formation which is composed of sedimentary material in the form of sand, cracal, silt and clay, and the Tmps Formation (Fromasi Sentolo) which is composed of limestone and marl sandstone.

Areas with Surface PGA varying from 0.45 – 0.7 g or VIII MMI are found in Kokap, Pengasih, Kalibawang and Nanggulan sub-districts. The area is located in the Menoreh hills which is composed of geological formations, namely the Tmok Formation (Kebobutak), Tmj (Jonggrangan) and andesite. The Tmok Formation is composed at the bottom in the form of well layered sandstone, siltstone, claystone, shale, tuff and agglomerates, with a thickness of more than650 meters with the top consisting of alternating sandstone and claystone with thin insertions of tuff, while the Tmj (Jonggrangan) Formation is composed of conglomerate rocks, tuffaceous marl, sandy limestone with lignite insertion and coral-coated limestone. Areas with surface PGA varying from 0.3 – 0.4 g or VII MMI are found in Girimulyo and Samigaluh Districts. The area is located in the Menoreh hills which is composed of geological formations, namely the Tmok Formation (Kebobutak), Tmj (Jonggrangan) and andesite.

3.3.4. Sleman Regency Area

The surface PGA map in Sleman Regency is shown in Figure 2. The maps in this report are preliminary information. The surface PGA value in Sleman Regency varies from 0.35 g to > 0.9 g or if converted in the MMI scale it varies between VII – IX MMI. The potential damage and impacts caused by the earthquake range from vibrations felt by all residents, residents leaving their homes, minor damage to buildings with good construction to damage to strong buildings, misaligned house frames, and lots of cracks. Based on Figure 5, the sub-districts with acceleration values of 0.75 g to 0.9 g or IX MMI are located in the Southeast and South of Sleman Regency with the orientation closest to the Opak Fault Line, namely Prambanan, Berbah, Depok, and Kalasan Districts. Geologically, the area is located in the Qmi Formation (Young Mount Merapi Sediment) which is composed of sedimentary material in the form of tuff, ash, breccia, agglomerates and lava flows.

Areas with surface PGA varying from 0.45 – 0.7 g or VIII MMI are found in Gamping, Godean, Moyudan, Minggir, Seyegan, Mlati, Ngaglik, Ngemplak, Sleman, Tempel, Turi, Pakem, and Cangkirngan sub-districts. The area is located in the Qmi Formation (Young Mount Merapi Sediment) and the Tmok Formation (Kebobutak). Areas with surface PGA varying from 0.35 – 0.4 g or VII MMI are found in the Mount Merapi area, namely in the Turi, Pakem and Cangkringan sub-districts with the Qmi Formation (Mount Merapi Young deposits).

3.3.5. Gunungkidul Regency Area

The surface PGA map in Gunungkidul Regency is shown in Figure 2. The maps in this report are preliminary information. Surface PGA values in Gunungkidul Regency vary from 0.45 g to 0.9 g or if converted in the MMI scale it varies between VIII – IX MMI. The potential damage and impacts caused by the earthquake range from minor damage to buildings with strong construction, cracks in buildings with poor construction, walls can be separated from the frame of the house to damage to strong buildings, the frames of the house are not straight, and lots of cracks. Based on Figure 6, the sub-districts with acceleration values of 0.75 g to 0.9 g or IX MMI are in the middle and south of Gunung Kidul Regency with the orientation closest to the Opak Fault Line, namely Playen, Purwosari, Panggang, Wonosari, Paliyan, Karangmojo, Semanu, Tepus sub-district, and Rongkop. The area is located in the Tmwl Formation (Wonosari - Punung Formation) and Tmpk Formation (Kepek). Areas with surface PGA varying from 0.45 – 0.7 g or VIII MMI were found in the Districts of Gedangsari, Nglipar, Ngawen, Semin, Ponjong, Girisubo, Tanjungsari and Saptosari. The area is located in the Tmwl Formation (Wonosari - Punung Formation).

The results of the surface PGA in Gunungkidul Regency are initial results because the Vs30 value used is still using Vs30 from USGS (based on topographic slope). It is necessary to re-examine using geotechnical methods and geophysical methods to obtain the actual value of Vs30.

4. CONCLUSIONS

Based on the results and analysis that has been carried out, the conclusions obtained are: (a) Based on the site characterization results, the Special Region of Yogyakarta has a site class of soft soil (SE), medium soil (SD), hard soil, very dense and soft rock (SC), and rock (SB). (b) The PGA value of bedrock in the Special Region of Yogyakarta varies from 0.35 to more than 0.6 g. The areas with the highest PGA values for bedrock are distributed in most of Bantul Regency, western Gunungkidul Regency (which is adjacent to the Opak Fault line), Sleman Regency with the closest orientation to the Opak Fault line (Berbah and Prambanan Districts), Yogyakarta City with the closest orientation. with the Opak Fault line (Kota Gede District, Umbulharjo). Meanwhile, the lowest bedrock PGA values were distributed in Sleman District (Cangkringan, Pakem, Turi, Tempel), and Kulonprogo Districts (Kalibawang District, Samigaluh). Surface PGA values in the Special Region of Yogyakarta varied between 0.35 - > 0.9 g or equivalent to VII – IX MMI. With the Highest Surface PGA in Bantul and Sleman Regencies 0.65 - > 0.9 g or equivalent to earthquake intensity VII - IX MMI and the lowest surface PGA in Kulonprogo Regency 0.35 - 0.85 g or equivalent to earthquake intensity VII - IX MMI (c) Preparation of ground acceleration maps Maximum soil acceleration (PGA) in bedrock, as well as maps of maximum soil acceleration on the surface of the Special Region of Yogyakarta have been carried out in five regencies/cities, namely Bantul Regency, Yogyakarta City, Kulonprogo Regency, Sleman Regency, and Gunungkidul Regency.

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REFERENCES

1. Allen, T. I., and Wald, D. J., 2009, On the use of high-resolution topographic data as a proxy for seismic site conditions (Vs30), Bulletin of the Seismological Society of America, 99, no. 2A, 935-943.
2. BSN. 2019. Standar Nasional Indonesia 1726-2019 tentang Tata Cara Perencanaan Tahan Gempa untuk Struktur Bangunan Gedung dan Non Gedung. Jakarta: Badan Standarisasi Nasional (BSN).
3. Cornell, C. A. 1968. Engineering Seismic Risk Analysis. Bulletin of the Seismological Society of America, 1583–1606.
4. Heath, D., Wald, D. J., Worden, C. B., Thompson, E. M., and Scmocyk, G. (2020). A Global Hybrid VS30 Map with a Topographic-Slope-Based Default and Regional Map Insets”, Earthquake Spectra, vol. 36, 3: pp. 1570- 1584.
5. Herak, M. (2008). ModelHVSR — A Matlab tool to model horizontal-to-vertical spectral ratio of ambient noise.Computer and Geosciences, 34, 1514–1526.
6. McGuire, R. K. 1993. Computations of Seismic Hazards. Annali Di Geofisica XXXVI.
7. Nakamura, Y. (1989). A Method for Dynamic Characteristics Estimation of \ubsurface using Microtremor on the Ground Surface. QR of RTRI, 30(1), 25–33.

8. Nakamura, Y. (2000). Clear identification of fundamental idea of Nakamura's technique and its applications. Proceedings of the 12th World Conference on Earthquake Engineering, (May), Paper no. 2656. Retrieved from http://www.sdr.co.jp/papers/n_tech_and_application.pdf
9. Nakamura, Y. (2008). ON THE H/V SPECTRUM. World Conference on Earthquake Engineering, 14, 1–10.
10. Muzli, Mahesworo, R. P., Madijono, R., Siswoyo, Pramono, S., Dewi, K. R., Budiarta, Sativa, O., Sulistyo, B., Swastikarani, R., Oktavia, N., Moehajirin. 2016. Pengukuran Vs30 Menggunakan Metode MASW Untuk Wilayah Yogyakarta. Jurnal Meteorologi dan Geofisika, Vol. 17, No. 1, 25-32.
11. Nurrahmi, Efendi, R., Sandra. 2015. Analisis Kecepatan Gelombang Geser Vs30 Menggunakan Metode Refraksi Mikrotremor (Remi) Di Kelurahan Talise. Gravitasi, Vol. 14, No.1, 7-12.
12. Park, C. B., Miller, R. D., and Xia, J. (1999). Multichannel analysis of surface waves. Geophysics, 64(3), 800– 808.
13. Permana, D., Pramono, S., Rahmatullah, F. S., Sakti, A. P., Moehajirin, Reza, D. T., … Chelcea, A. (2019). Laporan Kegiatan Mikrozonasi Kota Besar (Pertama; B. S. Prayitno, Ed.). Jakarta: Seismologi Teknik BMKG.
14. Pusgen, 2017, Peta Sumber Dan Bahaya Gempa Indonesia Tahun 2017, Pusat Penelitian dan Pengembangan Perumahan dan Pemukiman Badan Penelitian dan Pengembangan Kementrian Pekerjaan Umum dan Perumahan Rakyat, Bandung, ISBN 978-602-5489-01-3, 400 p.
15. Setiyono, U., Gunawan, I., Priyobudi, Yatimantoro, T., Imananta, R. T., Ramdhan, M., … Kriswinarso, T. (2019). Katalog Gempabumi Siknifikan dan Merusak 1821-2018 (Pertama; T. Prasetya and Daryono, Eds.). Jakarta: Pusat Gempabumi dan Tsunami BMKG.
16. Thamarux, P., Matsuoka, M., Poovarodom, N., and Iwahashi, J. (2019). VS30 Seismic Microzoning Based on a Geomorphology Map: Experimental Case Study of Chiang Mai, Chiang Rai, and Lamphun, Thailand. International Journal of Geo Information, 8, 1–18.
17. Verdugo, R. (2019). Seismic site classification. Soil Dynamics and Earthquake Engineering, 124, 317–329.
18. Wald, D. J., and Allen, T. I. (2007). Topographic slope as a proxy for seismic site conditions and amplification.Bulletin of the Seismological Society of America, 97(5), 1379–1395

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