Site-Specific Analysis to Investigate Response and Liquefaction Potential during the Megathrust Earthquake at Banten Province Indonesia

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Article

Site-Specific Analysis to Investigate Response and Liquefaction Potential during the Megathrust Earthquake at Banten Province Indonesia

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Abstract. The megathrust earthquake affiliated with several activities in the Java subduction zone is predicted to be the main trigger of the earthquake in Indonesia which is located in the world ring of fire. Therefore, this study aims to determine the seismic soil response and investigate the seismic liquefaction potential in the specific area in Banten Province. A computational simulation was performed to analyze soil response and earthquake data from Pacific Earthquake Engineering Research (PEER) database were adjusted based on the attenuation model. The results show that the site passes through amplification up to two times and the peak of spectral acceleration occurs at a low-medium period, namely 0.3 seconds. This indicated that the resonance effect can occur in buildings with up to 3 floors. Furthermore, the site dominated by sandy soil has the potential to undergo liquefaction, especially once peak ground acceleration reaches 0.1g. This investigation shows significant progressive results for understanding and practice related to the assessment of seismic site response and preliminary soil liquefaction study.

Keywords: Megathrust, earthquake, seismic response, attenuation model, liquefaction potential.

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1. Introduction

Many cities around the world are severely affected economically and socially by earthquakes. The earthquake phenomenon often occurs in Indonesia because the country is located on the world's ring of fire [1]. Earthquakes with a magnitude more than M_w 6 could be causing much structural damage. Therefore, it is necessary to carry out a comprehensive analysis to determine the potential for future damage and appropriate treatment.

Earthquakes have caused enormous damage to several cities. These include the M_w 6.7 Northridge Earthquake (USA) in 1994 [2], the M_w 6.9 Kobe Earthquake (Japan) in 1995 [3], the M_w 6.2 Yogyakarta Earthquake (Indonesia) in 2006 [4], the M_w 8.6 Bengkulu-Mentawai Earthquake (Indonesia) in 2007 [5], and recently the M_w 7.4 Palu Earthquake (Indonesia) in 2018 [6]. In Indonesia, near the capital city, there is an active tectonic zone, namely the Java Megathrust. It is an active plate boundary that can converge between the Australian and Southeast Asian plates at a rate of 68mm/year as shown in Fig. 1. This subduction zone is characterized by the presence of large megathrust earthquakes (magnitudes more than M_w 8) [7]. Meanwhile, two major events have been recorded during the instrument period, namely the M_w 7.9 earthquake in 1994 and the M_w 7.8 Pangandaran earthquake in 2006 [8]. Models and sequences of these phenomena show that extensional mechanisms followed the main fracture. These two earthquakes generated a devastating tsunami on the island of Java [9].

Previous studies have shown that the damage caused by these earthquakes is increased by the influence of local geological conditions [11, 12, 13], especially site characteristics. It was also reported that seismic waves are significantly affected by ground conditions on shallow surfaces [14]. Geological materials with low resistivity in the soil, indicated by small shear wave velocities (V_s) at shallow depths, play an essential role in amplifying motion [15]. The influence of these local conditions significantly on seismic main factors such as amplitude, frequency, and duration has also been identified [16].

The earthquake causes liquefaction according to soil damage and its impact on the structure's foundation [17]. Liquefaction relates to geological conditions and tectonic settings [18]. During an earthquake, pore water pressure in saturated sandy soils increases and reduces soil effective stress. The effective stress is a bearing capacity parameter that supports overburden pressure and external loads. Therefore, once the effective stress reaches zero, the bearing capacity disappears, and soil mass behaves as liquid material.

The liquefaction potential in an area is highly dependent on soil penetration and geological condition. The soil strength is presented in V_s [19]. It was also discovered that a site with V_s less than 180 m/s and dominated by saturated sandy soil can be very vulnerable to liquefaction [18]. Furthermore, a site with a low value of time-averaged of shear wave velocity for the first 30 m depth (V_{s30}) tends to be more vulnerable to seismic impact, which indicates that it can also experience liquefaction [20]. A sandy soil site experiencing earthquake shaking with peak ground acceleration (PGA) of more than 0.3g could undergo liquefaction [21].

In line with the importance of site investigation and the geotechnical impact of earthquakes, there is a need to study the ground response effect and liquefaction potential. Therefore, this study was carried out to investigate ground amplification, spectral acceleration (SA), and liquefaction potential in Banten.

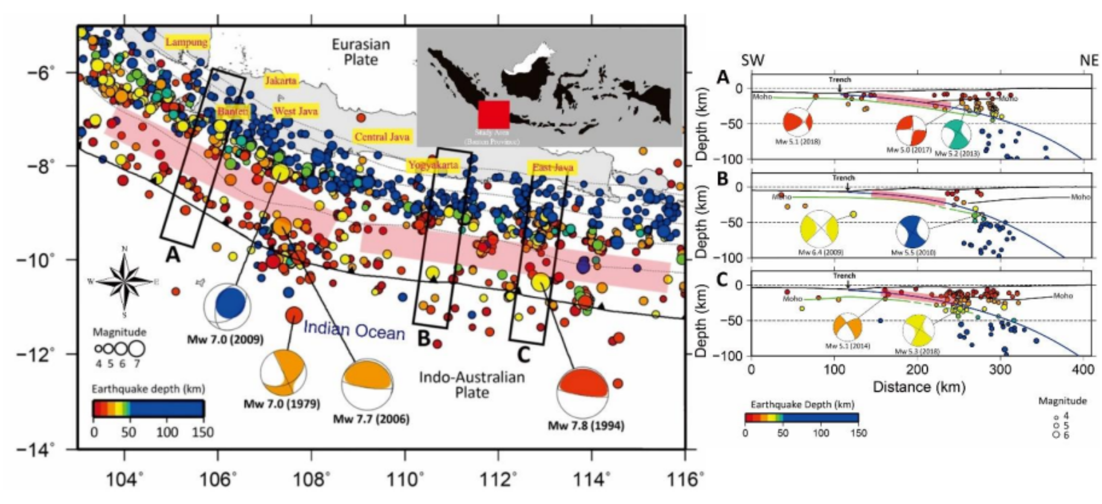

Fig. 1. Distribution of earthquake epicenters with magnitude ≥ 4.0. from 2009–2020, black rectangles (A–C) show the location of vertical cross sections (modified from [10]).

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Banten is located in the western part of Java Island, which is very close to the Java Megathrust. This area is also known as one of the industrial places in Indonesia. Therefore, this study aims to observe the site's characteristics during the earthquake and the possible impact. It was initiated by conducting subsurface investigations at the location using the standard penetration test (SPT) method. The soil sampling was also carried out for laboratory tests. Site response is required in this area to establish seismic hazard analysis and minimize the future risk associated with ground amplification and liquefaction.

2. Seismic Condition in The South Java Area

In South Java, the Jurassic seafloor contains thick sediments and subducts beneath the edge of the Sunda land Margin in the Java Trench. Historical records of earthquakes in the Sunda-Andaman subduction zone indicate the possibility of a catastrophic megathrust earthquake in the Java subduction zone [1]. Some earthquakes with long duration had occurred in this area. The earthquake focus is possibly found at both shallow and deep depths. One of the events that occurred under this scenario is the M_w 7.8 Banyuwangi Earthquake. This earthquake is categorized as a normal-faulting event. Meanwhile, another earthquake called the M_w 7.7 Pangandaran Earthquake in 2006 occurred within the area, and is categorized as a short-duration event [22]. The difference between these two earthquakes is the complexity of subduction features such as turbidity and obstruction that affect the rupture propagation [23]. In this study, three earthquake sources were used, namely the 5.3 M_w Banten, the 7.7 M_w Pangandaran, and the 7.3 M_w Tasikmalaya in 2020, 2006, and 2009, respectively, with detailed information shown in Fig. 2.

3. Soil Condition and Shear Wave Velocity

The geological condition of the location consisted of some rock formations called Bayah Formation, which is divided into Limestone Members (Tebl), Claystone Members (Tebm), and Conglomerate Members (Teb) [24]. The study area is located in a specific area in Banten Province and the soil condition is a product of rock weathering. Figure 3 shows site investigation results in the study area. The soil was dominated by silty sand at a depth range of 0 to 10. According to the National Earthquake Hazard Reduction Program (NEHRP), the soil condition in the area is classified as NEHRP into D (stiff soil) with V_{s30} of 180 to 240 m/s. Moreover, earthquake is related to ground amplifications, which can change the stiffness of soil at shallow depths, with the most influential factor of V_{s30}.

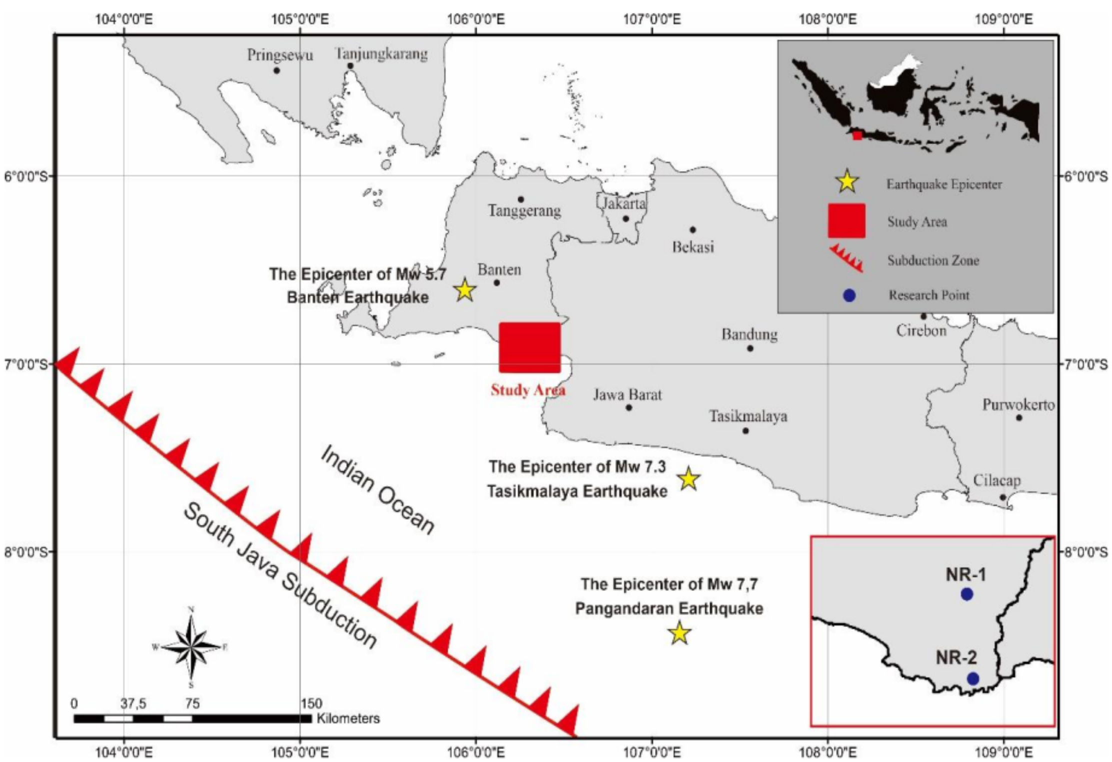

Fig. 2. Research Area.

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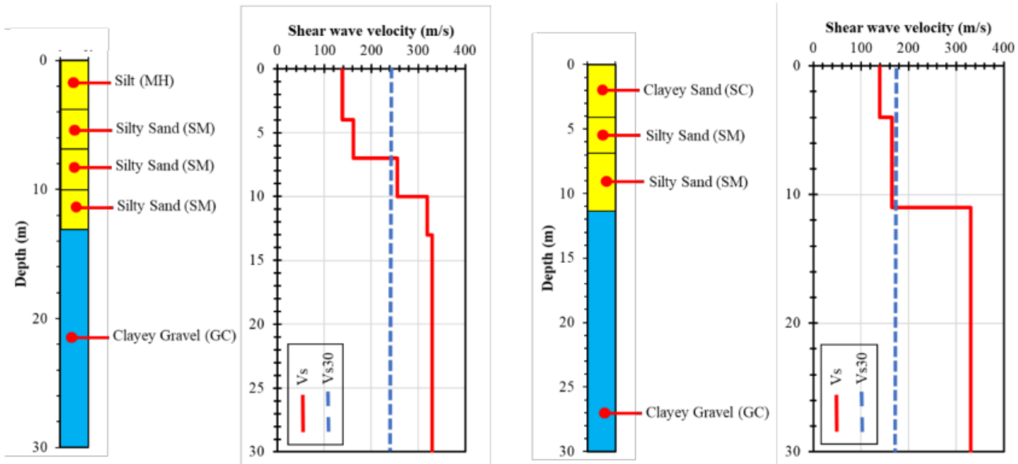

Fig. 3. SPT investigation results (a) NR-1 and (b) NR-2.

4. Deterministic Seismic Hazard Analysis

Seismic hazard analysis is an approach for explaining the potential shaking of future earthquakes. The hazard analysis can be estimated by a deterministic (DSHA) or probabilistic (PSHA) approach. The deterministic approach evaluates the amplitude of the intensity measurement [24]. DSHA uses the maximum magnitude and shortest distance between the source and the site to assess seismic intensity in the worst-case scenarios. The basic steps include (1) Identifying all possible fault sources of earthquakes around a specific location, (2) Defining the maximum magnitude and minimum distance of each fault, (3) Calculating the seismic intensity based on the attenuation relationship, (4) Taking the maximum intensity amplitude as the final DSHA estimate. The earthquake source model and the seismic motion prediction equation (GMPE) are essential inputs to DSHA. From Fig. 4, the attenuation model [27] is used for a large earthquake. The attenuation model from PEER seismic database consists of global primary seismic records. Based on the current database version, the most comprehensive set of metadata is suitable for remote sources and locations [27]. After choosing the decay model; time history selection, scaling, and fitting are performed. The M_w 6.9 Loma Prieta 1989 earthquake provided the basis for the seismic motion to investigate the seismic response because of its similar characteristics, in terms of V_{s30} to the study area.

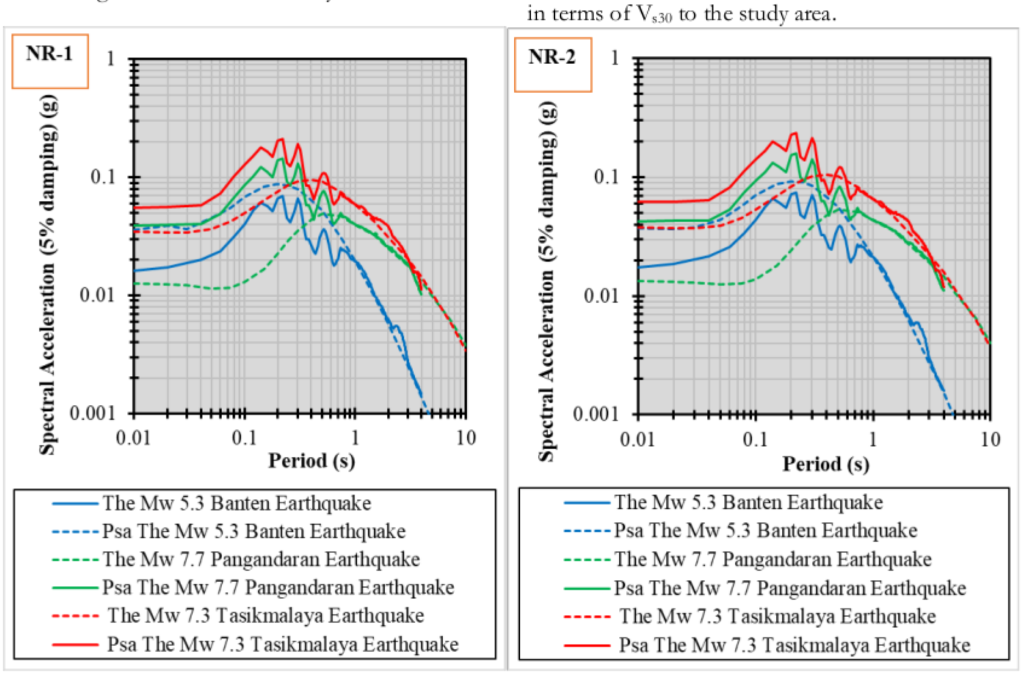

Fig. 4. Spectral acceleration after adjusting to the attenuation model (Psa).

5. Seismic Ground Response

One-dimensional (1D) analysis of site response is used to analyze the influence of ground conditions during earthquakes under certain assumptions. Firstly, the soil response caused by V_s is horizontally polarized and propagated vertically upward from the underlying elastic soil layer [16]. The second assumption is that the wave propagates vertically. Based on a previous report [15], all soil sediments are treated as single-degree-of-freedom (SDOF) systems during earthquakes. The nonlinear method is the time domain for solving the equation to estimate SDOF. The equivalent linear analysis is the frequency domain, which is caused by the ease of adoption and common use. However, the site response is significantly influenced by the nonlinear alternative approach that a computationally convenient. It is the actual nonlinear process and provides results, which are similar to the real conditions [28].

In terms of dynamic analysis, the nonlinear model shows essential factors, such as stress-strain of soil. This indicates that the shear modulus of the soil changes continuously during seismic activity [29]. However, the soil stiffness and damping properties are the main factors that directly affect soil response [30]. The nonlinear method is responsible for the change in shear modulus and damping ratio during an earthquake with ground hysteresis stresses [31].

A computational simulation by the DEEPSOIL application is used to determine the response of the soil [32]. In this study, 1D soil response analysis was performed. The data were obtained from the results of the SPT test boring log. DEEPSOIL generates wave propagation models for the analysis, namely nonlinear analysis. Several calculations that were carried out include shear modulus, strain, and stress, as well as vertical effective stress, damping ratio, and acceleration in each sub-layer. For these analyses, information about the earthquakes, soil profiles, and material types is required. The parameters that must be taken for soil profile properties are shear wave velocity (V_s), initial shear modulus (G_{max}), unit weight (γ), and other important parameters. For soft clay, medium stiff clay, stiff to very stiff clay, and very stiff clay, the shear-ratio modulus G/G_{max}-ε relationship from [33] was used, while the G/G_{max}-ε relationship from [34] was used for sand.

The determination of bedrock assuming half elastic space with V_s is 760 m/s [35], γ for rock is 22 kN/m^3 and damping ratio (ξ) is 5%. Moreover, a general engineering bedrock value of approximately 760 m/s has been identified [35]. The value is used as a baseline in several investigations [36, 37]. The attenuation model was determined to obtain data on earthquake events. This study originated from the Loma Prieta earthquake after being matched with the attenuation model. The ground motion propagation was analyzed using input wave motion at the base of each location (rock layer).

6. Results

In this study, 1D nonlinear soil response analysis in Banten was carried out using DEEPSOIL software. The dynamic parameters obtained from SPT data are used for SA and PGA calculations. Seismic parameters based on a megathrust earthquake in South Java were used in the soil response analysis. From these analyses, the main results including amplification and spectral acceleration are discussed. The preliminary analysis of liquefaction potential is also a part of the discussions in this study.

6.1. Amplification

The results of amplification factors are summarized in Fig. 5. During wave propagation, these factors were determined based on the comparison of the surface site and the input motion PGAs [38]. In general, it was discovered that underground conditions can affect the amplification factor of wave propagation. Furthermore, the NR-1 of the Pangandaran earthquake produced the highest factor from all locations investigated, while the NR-2 showed the lowest. The soil is classified as medium (Class D) with a relatively low V_{s30} (200-250 m/s), which is important in determining the amplification factor. The earthquake acceleration amplified from 1.9 to 2.7 times based on the three megathrust earthquakes, with an average of approximately 2.8 times.

6.2. Spectral Acceleration

The ground surface spectral acceleration due to earthquakes at each location is shown in Fig. 6. The acceleration at the ground surface has the highest value, especially at the site with the input of the Tasikmalaya and Pangandaran earthquakes. Meanwhile, SA at the ground surface reaches its maximum in period (T) varying from 0.3 to 0.6 seconds. It indicates that a resonance effect can occur in buildings having 3 to 6 floors in height (estimated from T = 0.1n, with n being the number of building stories). The results also showed that the designed SA released by the Indonesian National Standard [39] can accommodate the spectral acceleration of earthquakes.

The result of spectral acceleration obtained on the ground surface is higher than the input motion, which indicates that the input motion is amplified. At the shallow depth, the study area is dominated by silty sand. In this state, liquefaction due to an earthquake is very possible [40, 41], therefore, further investigations are recommended to perform.

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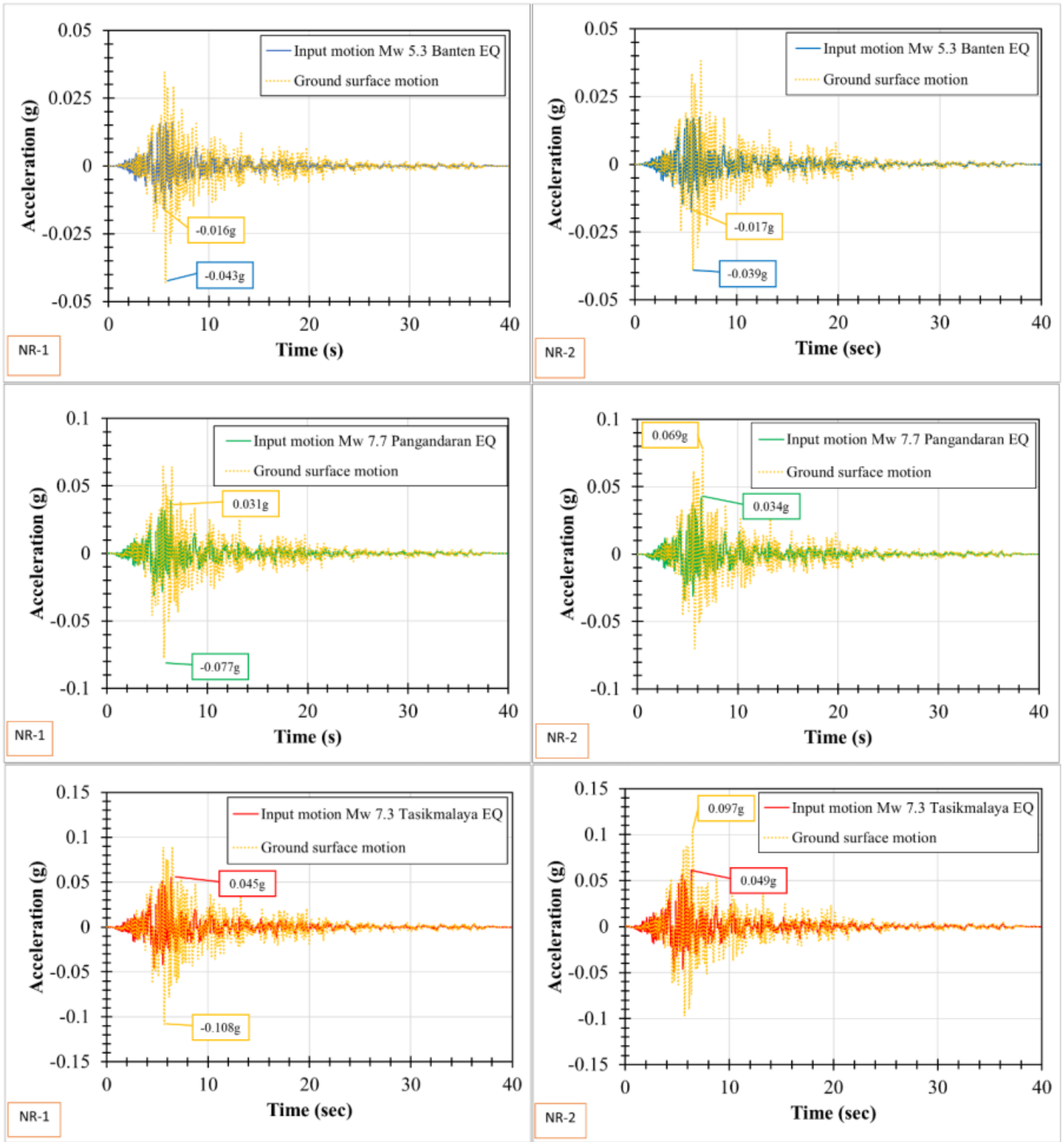

Fig. 5. Result of input motion and ground surface motion in the study area.

6.3. Overview of Liquefaction Potential

The liquefaction potential of the study area was also evaluated. From Fig. 7, several sand layers were discovered on the site on a shallow surface. Sand layers have shear wave velocity (V_s) less than 180 m/s. According to a previous study [18, 19], sand layers having V_s of approximately 180 m/s tend to be more vulnerable to liquefaction. Furthermore, based on seismic ground response analysis, PGA from the Tasikmalaya earthquake is larger than 0.1g at the ground surface. PGA greater than 0.1g with a magnitude of earthquake more than M_w 5 can trigger liquefaction in sand layers [42]. It means that it is important to observe liquefaction potential in the study area. Moreover, a detailed explanation related to liquefaction potential in the study area will be presented in further investigation.

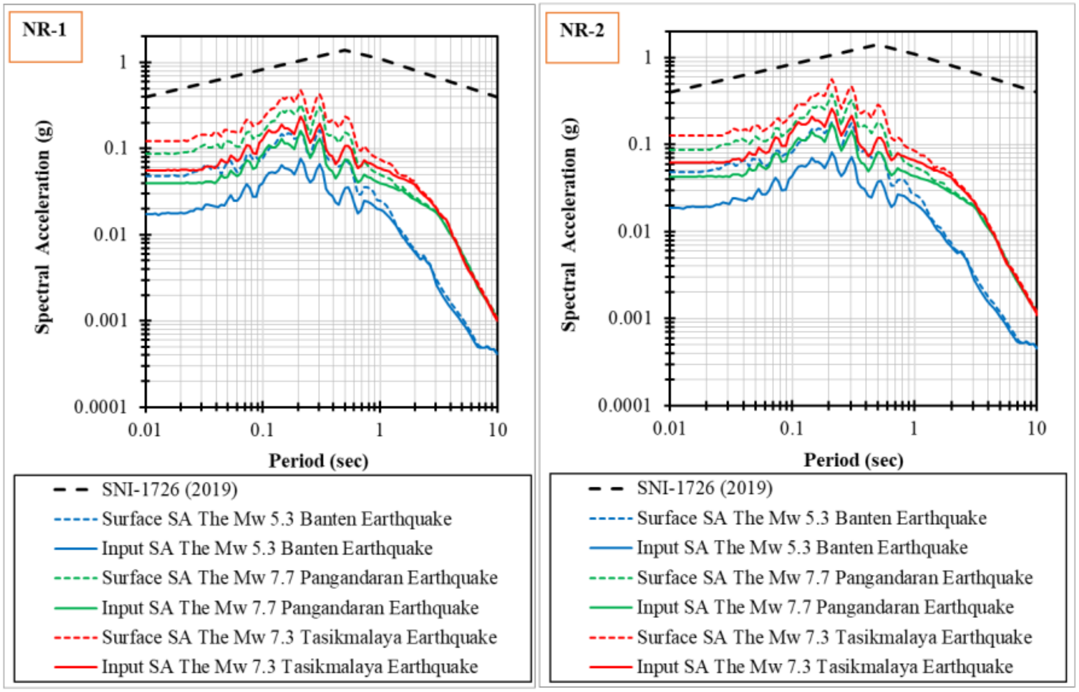

Fig. 6. Result of spectral acceleration in the study area.

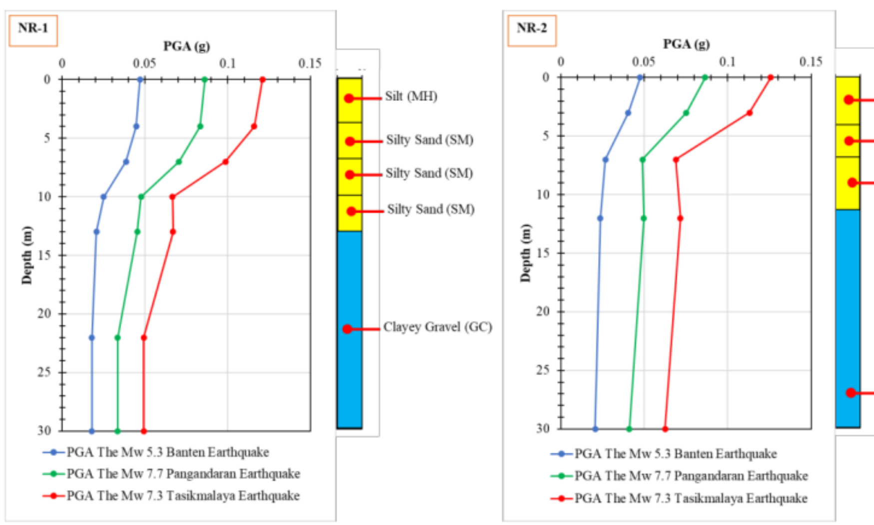

Fig. 7. Profile of peak ground acceleration due to seismic ground response analysis.

7. Conclusions

This study used the concept of deterministic seismic hazard analysis (DSHA) and analyzed the soil response to obtain PGA and SA as a form of soil response at both sites NR-1 and NR-2 to Megathrust earthquakes. According to seismic history, the earthquake has a return period of 50-100 years. The soil type is classified as medium soils (site classes D) with a relatively low V_{s30} (200-250 m/s), which is important in determining PGA on bedrock and surface to identify the amplification factor at the site. PGA in bedrock is observed to enlarge with the variation from 1.9 to 2.7 times on the surface based on the three-megathrust earthquake in South Java Island, with an average of approximately 2.8 times. The newly issued seismic code by Indonesian National Standard [37] considers the probability of exceeding 2% in a return period of 50 years or 2500 years. This procedure gave a significantly high SA value for medium soils at the study site, which is twice as high as the SA calculated from the soil response. The newly issued seismic code can still restrain earthquakes. Since there is an existence of sand layers at the shallow surface with low soil penetration, liquefaction potential needs to be considered. Meanwhile, the elaboration related to liquefaction potential in the study area will be presented in further study.

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References

[1] K. R. Newcomb and W. R. McCann, "Seismic history and Seismotectonics of the Sunda Arc," *Journal of Geophysical Research: Solid Earth*, vol. 92, no B1, pp. 421-439, 1987. [Online]. Available: https://doi.org/10.1029/JB092iB01p00421

[2] D. K. Miller, "Lessons learned from the Northridge earthquake," *Journal of Engineering Structures*, vol. 20, no. 4-6, pp. 249-260, 1998. [Online]. Available: https://doi.org/10.1016/S0141-0296(97)00031-X

[3] L. Z. Mase, S. Likitlersuang, and T. Tobita. "Cyclic behaviour and liquefaction resistance of Izumio sands in Osaka, Japan," *Marine Georesources & Geotechnology*, vol. 37, no. 7, pp. 249-260, 2019. [Online]. Available: https://doi.org/10.1080/1064119X.2018.1485793

[4] L. Z. Mase, T. F. Fathani, and A. D. Adi, "A simple shaking table test to measure liquefaction potential of Prambanan Area, Yogyakarta, Indonesia," *ASEAN Engineering Journal*, vol. 11, no. 3, pp. 89-108, 2021. [Online]. Available: https://doi.org/10.11113/aej.v11.16874

[5] L. Z. Mase, "Seismic hazard vulnerability of Bengkulu City, Indonesia, based on deterministic seismic hazard analysis," *Geotechnical and Geological Engineering*, vol. 38, no. 5, pp. 5433-5455, 2020. [Online]. Available: https://doi.org/10.1007/s10706-020-01375-6

[6] Y. Wang, W. Feng, K. Chen, and S. Samsono, "Source characteristics of the 28 September 2018 Mw 7.4 Palu, Indonesia, earthquake derived from the advanced land observation satellite 2 data," *Remote Sensing*, vol. 11, no. 17, pp. 1999, 2019. https://doi.org/10.3390/rs11171999

[7] A. Koulali, S. McClusky, P. Cummins, and P. Tregoning, "Wedge geometry, frictional properties and interseismic coupling of the Java megathrust," *Tectonophysics*, vol. 734, pp. 89-95, 2018. [Online]. Available: https://doi.org/10.1016/j.tecto.2018.03.012

[8] A. Koulali, S. McClusky, S. Susilo, Y. Leonard, P. Cummins, P. Tregoning, I. Meilano, J. Efendi, and A. B. Wijanarto, "The kinematics of crustal deformation in Java from GPS observations: Implications for fault slip partitioning," *Earth and Planetary Science Letters*, vol. 458, pp. 69-79, 2017. [Online]. Available: https://doi.org/10.1016/j.epsl.2016.10.039

[9] S. L. Bilek and E. R. Engdahl. "Rupture characterization and aftershock relocations for the 1994 and 2006 tsunami earthquakes in the Java subduction zone," *Geophysical Research Letters*, vol. 34, no. 20, 2007. [Online]. Available: https://doi.org/10.1029/2007GL031357

[10] S. Widiyantoro, E. Gunawan, A. Muhari, N. Rawlinson, J. Mori, N. R. Hanifa, S. Susilo, P. Supendi, H. A. Shiddiqi, A. D. Nugraha, and H. E. Putra, "Implications for megathrust earthquakes and tsunamis from seismic gaps south of Java Indonesia," *Scientific Reports*, vol. 10, no. 1, pp. 1-11, 2020. [Online]. Available: https://doi.org/10.1038/s41598-020-72142-z

[11] H. Goto, S. Sawada, H. Morikawa, H. Kiku, and S. Ozalaybey, "Modeling of 3D subsurface structure and numerical simulation of strong ground motion in the Adapazari basin during the 1999 Kocaeli earthquake, Turkey," *Bull Seismology Soc Am*, vol. 95, no. 6, pp. 2197-2215, 2005. [Online]. Available: https://doi.org/10.1785/0120050002

[12] R. Misliniyati, L. Z. Mase, A. J. Syahbana, and E. Soebowo, "Seismic hazard mitigation for Bengkulu Coastal area based on site class analysis," in *IOP Conference Series: Earth and Environmental Science*, IOP Publishing, December 2018, vol. 212, no. 1, p. 012004. [Online]. Available: https://doi.org/10.1088/1755-315/212/1/012004

[13] L. Z. Mase, S. Likitlersuang, and T. Tobita, "Verification of liquefaction potential during the strong earthquake at the border of Thailand-Myanmar," *Journal of Earthquake Engineering*, vol. 26, no. 4, pp. 2023-2050, 2022. [Online]. Available: https://doi.org/10.1080/13632469.2020.1751346

[14] L. Z. Mase, S. Likitlersuang, and T. Tobita, "Ground motion parameters and resonance effect during strong earthquake in northern Thailand," *Geotechnical and Geological Engineering*, vol. 39, no. 3, pp. 2207-2219, 2021. [Online]. Available: https://doi.org/10.1007/s10706-020-01619-5

[15] S. L. Kramer, *Geotechnical Earthquake Engineering—Prentice-Hall International Series in Civil Engineering and Engineering Mechanics*. New Jersey: Prentice-Hall, 1996.

[16] H. Sana, S. K. Nath, and K. S. Gujral, "Site response analysis of the Kashmir valley during the 8 October 2005 Kashmir earthquake (Mw 7.6) using a geotechnical dataset," *Bulletin of Engineering Geology and the Environment*, vol. 78, no. 4, pp. 2551-2563,

2019. [Online]. Available: https://doi.org/10.1007/s10064-018-1254-1

[17] L. Z. Mase, "Shaking table test of soil liquefaction in Southern Yogyakarta," *International Journal of Technology*, vol. 8, no. 4, pp. 747-760, 2017. [Online]. Available: https://doi.org/10.14716/ijtech.v8i4.9488.

[18] L. Z. Mase, S. Likitlersuang, T. Tobita, S. Chaiprakaikeow, and S. Soralump, "Local site investigation of liquefied soils caused by earthquake in Northern Thailand," *Journal of Earthquake Engineering*, vol. 24, no. 7, pp. 1181-1204, 2020. [Online]. Available: https://doi.org/10.1080/13632469.2018.1469441

[19] R. D. Andrus, P. Piratheepan, B. S. Ellis, J. Zhang, and C. H. Juang, "Comparing liquefaction evaluation methods using penetration-Vs relationships," *Soil Dynamics and Earthquake Engineering*, vol. 24, no. 9-10, pp. 713-721, 2004. [Online]. Available: https://doi.org/10.1016/j.soildyn.2004.06.001

[20] E. Hartantyo, K. S. Brotopuspito, Sismanto, and Waluyo, "Predicting the liquefaction phenomena from shear velocity profiling: Empirical approach to 6.3 Mw, May 2006 Yogyakarta Earthquake," in *AIP Conference Proceedings*, April 2015, AIP Publishing LLC, vol. 1658, no. 1, p. 030017. [Online]. Available: https://doi.org/10.1063/1.4915025.

[21] J. D. Bray and J. Macedo, "6th Ishihara lecture: Simplified procedure for estimating liquefaction-induced building settlement," *Soil Dynamics and Earthquake Engineering*, vol. 102, pp. 215-231, 2017. https://doi.org/10.1016/j.soildyn.2017.08.026

[22] C. J. Ammon, H. Kanamori, T. Lay, and A. A. Velasco, "The 17 July 2006 Java tsunami earthquake," *Geophysical Research Letters*, vol. 33, no. 24, 2006. [Online]. Available: https://doi.org/10.1029/2006GL028005

[23] M. El Hariri, S. L. Bilek, H. R. DeShon, E. R. Engdahl, and S. Bisrat, "Along-strike variability of rupture duration in subduction zone earthquakes," *Journal of Geophysical Research: Solid Earth*, vol. 118, no. 2, pp. 646-664, 2013. [Online]. Available: https://doi.org/10.1029/2012JB009548

[24] S. Sujatmiko and S. Santosa, "Geologi Lembar Leuwidamar," Direktorat Geologi, Pertambangan and Energy Department, Republic of Indonesia. Bandung, 1992.

[25] D. M. Boore, "Estimating Vs(30) (or NEHRP site classes) from shallow velocity models (depths< 30 m)," *Bulletin of the Seismological Society of America*, vol. 94, no. 2, pp. 591-597, 2004. [Online]. Available: https://doi.org/10.1785/0120030105

[26] Y. Huang and M. Xiong, "Probability density evolution method for seismic liquefaction performance analysis of earth dam," *Earthquake Engineering & Structural Dynamics*, vol. 46, no. 6, pp. 925-943, 2017. [Online]. Available: https://doi.org/10.1002/eqe.2837

[27] N. A. Abrahamson, W. J. Silva, and R. Kamai, "Summary of the ASK14 ground motion relation for active crustal regions," *Earthquake Spectra*, vol. 30, no. 3, pp. 1025-1055, 2014. [Online]. Available: https://doi.org/10.1193/070913EQS198M

[28] L. Z. Mase, S. Likitlersuang, and T. Tobita, "Non-linear site response analysis of soil sites in Northern Thailand during the Mw 6.8 Tarlay earthquake," *Engineering Journal*, vol. 22, no. 3, pp. 291-303, 2018. [Online]. Available: https://doi.org/10.4186/ej.2018.22.3.291

[29] H. Arslan and B. Siyahi, "A comparative study on linear and nonlinear site response analysis," *Environmental Geology*, vol. 50, no. 8, pp. 1193-1200, 2006. [Online]. Available: https://doi.org/10.1007/s00254-006-0291-4

[30] C. Phillips and Y. M. Hashash, "Damping formulation for nonlinear 1D site response analyses," *Soil Dynamics and Earthquake Engineering*, vol. 29, no. 7, pp. 1143-1158, 2009. [Online]. Available: https://doi.org/10.1016/j.soildyn.2009.01.004

[31] C. Bolisetti, A. S. Whittaker, H. B. Mason, I. Almufti, and M. Willford, "Equivalent linear and nonlinear site response analysis for design and risk assessment of safety-related nuclear structures," *Nuclear Engineering and Design*, vol. 275, pp. 107-121, 2014. https://doi.org/10.1016/j.nucengdes.2014.04.033

[32] Y. M. A. Hashash, M. I. Musgrove, J. A. Harmon, O. Ilhan, G. Xing, O. Numanoglu, D. R. Groholski, C. A. Phillips, and D. Park, *DEEPSOIL 7.0, User Manual.* Urbana, IL: Board of Trustees of University of Illinois at Urbana-Champaign, 2020.

[33] M. Vucetic and R. Dobry, "Effect of soil plasticity on cyclic response," *Journal of Geotechnical Engineering*, vol. 117, no. 1, pp. 89-107, 1991. [Online]. Available: https://doi.org/10.1061/(ASCE)0733-9410(1991)117:1(89)

[34] H. B. Seed and I. M. Idriss, "Simplified procedure for evaluating soil liquefaction potential," *Journal of the Soil Mechanics and Foundations Division*, vol. 97, no. 9, pp. 1249-1273, 1971. https://doi.org/10.1061/JSFEAQ.0001662

[35] R. D. Miller, J. Xia, C. B. Park, J. Ivanov, and E. Williams, "Using MASW to map bedrock in Olathe, Kansas," in *SEG Technical Program Expanded Abstracts 1999*, Society of Exploration Geophysicists, pp. 433-436. [Online]. Available: https://doi.org/10.1190/1.1821045

[36] L. Z. Mase, "Reliability study of spectral acceleration designs against earthquakes in Bengkulu City, Indonesia," *International Journal of Technology*, vol. 9, no. 5, 2018. [Online]. Available: https://doi.org/10.14716/ijtech.v9i5.621

[37] M. F. Qodri, L. Z. Mase, and S. Likitlersuang. "Non-linear site response analysis of Bangkok subsoils due to earthquakes triggered by Three Pagodas Fault," *Engineering Journal*, vol. 25, no. 1, pp. 43-52, 2021. [Online]. Available: https://doi.org/10.4186/ej.2021.25.1.43

[38] L. Z. Mase, S. Likitlersuang, and T. Tobita, "Analysis of seismic ground response caused during strong earthquake in Northern Thailand," *Soil Dynamic and Earthquake Engineering*, vol. 114, pp. 113-126, 2018. [Online]. Available: https://doi.org/10.1016/j.soildyn.2018.07.006

[39] *Tata Cara Perencanaan Ketahanan Gempa Struktur Bangunan Gedung dan Nongedung*, Standar Nasional Indonesia, SNI-1726, 2019

[40] L. Z. Mase, M. Farid, N. Sugianto, and S. Agustina, "The implementation of ground response analysis to quantify liquefaction potential index (LPI) in Bengkulu City, Indonesia," *J. Civ. Eng. Forum*, vol. 6, no. 3, p. 319, 2020. [Online]. Available: https://doi.org/10.22146/jcef.57466

[41] L. Z. Mase and S. Likitlersuang, "Implementation of seismic ground response analysis to estimate liquefaction potential in Northern Thailand," *Indonesian Journal of Geoscience*, vol. 8, no. 3, pp. 371-383, 2021. [Online]. Available: https://doi.org/10.17014/ijog.8.3.371-383

[42] R. Sukkarak, W. Tanapalungkorn, S. Likitlersuang, and K. Ueda, "Liquefaction analysis of sandy soil during strong earthquake in Northern Thailand," *Soils and Foundations*, vol. 61, no. 5, pp. 1302-1318, 2021. [Online]. Available: https://doi.org/10.1016/j.sandf.2021.07.003

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