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Seismic Site Response Simulation of Jakarta subsoils due to 5.4 M_W Banten Earthquake on July 7^{th} 2020

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ABSTRAK

Potensi kerusakan akibat gempa bumi jarak jauh dapat menimbulkan amplifikasi getaran selama perambatan gelombang. Pada tanggal 7 Juli 2020, gempa 5.4 MW terjadi di Provinsi Banten yang berfiliasi dengan aktifitas intraslab dimana Lempeng Indo-Australia yang menunjam di bawah Lempeng Eurasia. Pusat gempa relatif jauh dari pusat kota Jakarta, yaitu sekitar 95 km. Namun, sebagian warga Jakarta sempat merasakan guncangan saat gempa. Hal tersebut menunjukkan bahwa guncangan dalam jangka waktu lama bisa saja terjadi pada saat gempa. Sejalan dengan fenomena tersebut, penelitian ini bertujuan untuk menginterpretasikan efek amplifikasi yang terjadi Jakarta. Model Next Generation Attenuation (NGA) diimplementasikan untuk menghasilkan response tanah terhadap lokasi penelitian yang diselidiki. Simulasi respons tanah seismik nonlinier satu dimensi diaplikasikan untuk mengamati perilaku tanah dan parameter getaran tanah di Jakarta. Secara umum, hasil tersebut dapat menggambarkan efek amplifikasi pada kondisi tanah di Jakarta. Hasil tersebut juga ditujukan untuk menyadarkan masyarakat akan gempa bumi.
Kata kunci: gempa bumi, amplifikasi, kecepatan gelombang geser, NGA, percepatan tanah

ABSTRACT

The potential descruction could be affected by long-distance earthquakes since the vibrations could appear amplification of ground shake during the wave propagation. On July 7^{th} 2020, the 5.4 Mw earthquake happened at Banten Province affiliated with intraslab activities where the Indo-Australian Plate is submerged beneath the Eurasian Plate. The earthquake epicenter is relatively far away from the downtown Jakarta, i.e. about 95 km. However, some people in Jakarta could feel the shaking during the earthquake. It indicates that the long-period shaking could happen during the earthquake. Futhermore, this study aims to interpret the amplification effect in Jakarta. The next generation attenuation (NGA) model is implemented to generate the ground motion for the investigated sites. Simulation of nonlinear one-dimensional seismic site response is then performed to observe the soil behavior and ground motion parameters on the investigated sites. In general, the results could describe the amplification effect on Jakarta subsoils. The results are also addressed to make the awareness of the earthquakes for people of Jakarta and Indonesia in general.
Keyword : earthquake, amplification, shear wave velocity, NGA, Peak Ground Acceleration

1. INTRODUCTION

Jakarta as the capital city of Indonesia treaten by routine tectonic activity in the surounded area of Jakarta. Meteorological, Climatological, and Geophysical Agency (BMKG) reported mild seismicity affecting Jakarta. Several earthquakes could be felt in Jakarta even though the earthquake's epicenter lies hundreds of kilometers away, such as the 5.4 Mw Banten earthquake on July 7th 2020. This earthquake has epicenter about 95 km from downtown in Banten Province. The issue that becomes a concern because Banten is relatively close to Jakarta. Seismic activity in Jakarta is influenced by the Sunda Arc subduction zone and the shallow crustal fault zone. There are 3 major faults around the city of Jakarta, namely the Semangko fault, the Cimandiri fault, and the Lembang fault (Irsyam, et al., 2017).

Subsurface investigations were conducted using geophysical and geotechnical methods (e.g. seismic refraction, seismic downhole test, standard penetration test (SPT)), but these are difficult to undertake in urban areas, particularly for deep layers. The microtremor array method by Ridwan et al. (2013) was applied in this study to obtain subsurface shear wave velocity profiles underneath Jakarta. This method has been used widely, not only for scientific but also for engineering purposes, owing to its simplicity of operation and the fact that it does not require an active source. According to National Earthquake Hazard Reduction Program (NEHRP) (1998), the local site classification of Jakarta by microtremor measurement by Ridwan et al. (2013) research, concluded that Jakarta was classified as NEHRP Site Class D and E generally.

The study points are shown in Figure.1. Four location are selected such as Ancol (ANCL) that is one of the tourism place in the North of Jakarta, Istana Negara (ISTN) that is the presidential palace, Kuningan

(KNGN) that is one of the business district in Central Jakarta, and Universitas Indonesia (UI) that is the one of the biggest public university in Indonesia.

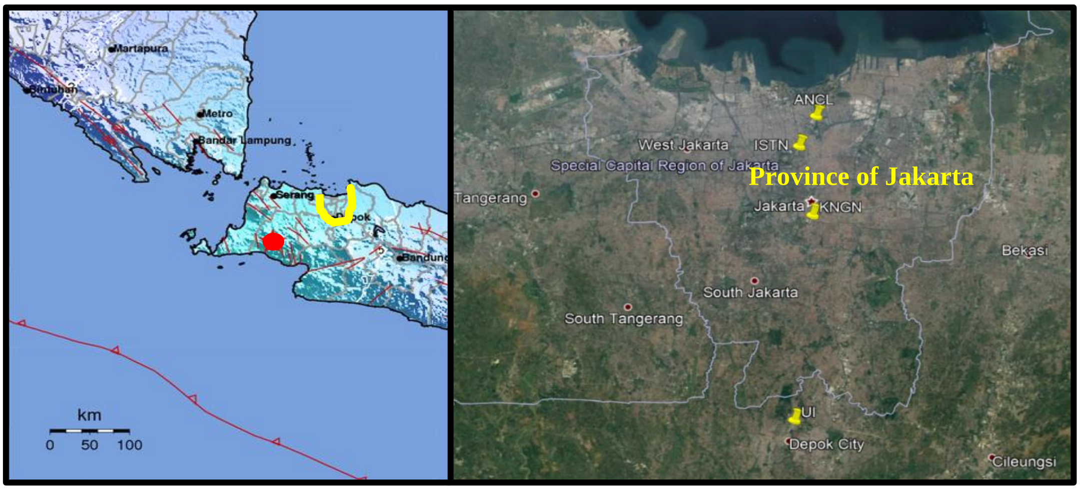

Figure 1. *(1) Epicenter of Banten earthquake on July 7th 2020 (2) Research point in Jakarta subsoil*

2. GEOLOGICAL CONDITION

Turkandi et al. (1992) had conducted previous geological studies in the Jakarta area. According to those studies, Jakarta is situated near the northwest tip of the island of Java, with its northern edge facing the Java Sea. The city lies within an altitude of 0–78 m above sea level, that is relatively flat topography. This represents the prevailing phase of deposition in which northward-flowing rivers such as Cisadane, Angke, Ciliwung and Bekasi that have transported material from the chain of volcanoes at the south of Jakarta to alluvial deposits that fill the Jakarta basin. In general, the lithology consists of quaternary sedimentary units, including alluvium, beach ridge and alluvial fan deposits, as well as Banten Tuff as shown in Figure 2.

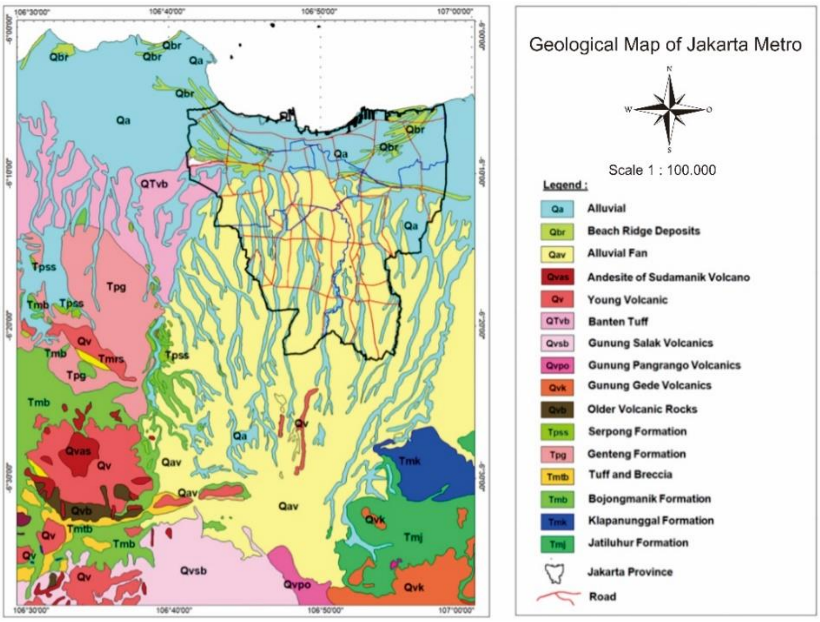

Figure 2. *Geological Map of Jakarta (modified Turkandi et al. 1992; Ridwan et al. 2016)*

Ridwan et al. (2013, 2014) performed microtremor measurements and established the shear wave and the depth of engineering bedrock in the Jakarta area as shown in Figure 3. The results of these studies also suggest that the depth of the bedrock in the north-south direction ranges from 300 m to 600 m and show the soil profile as shown in Figure 4. For engineering practice, Vs30 can be used to classify the local site class, which is summarized by SNI-1726-2012.

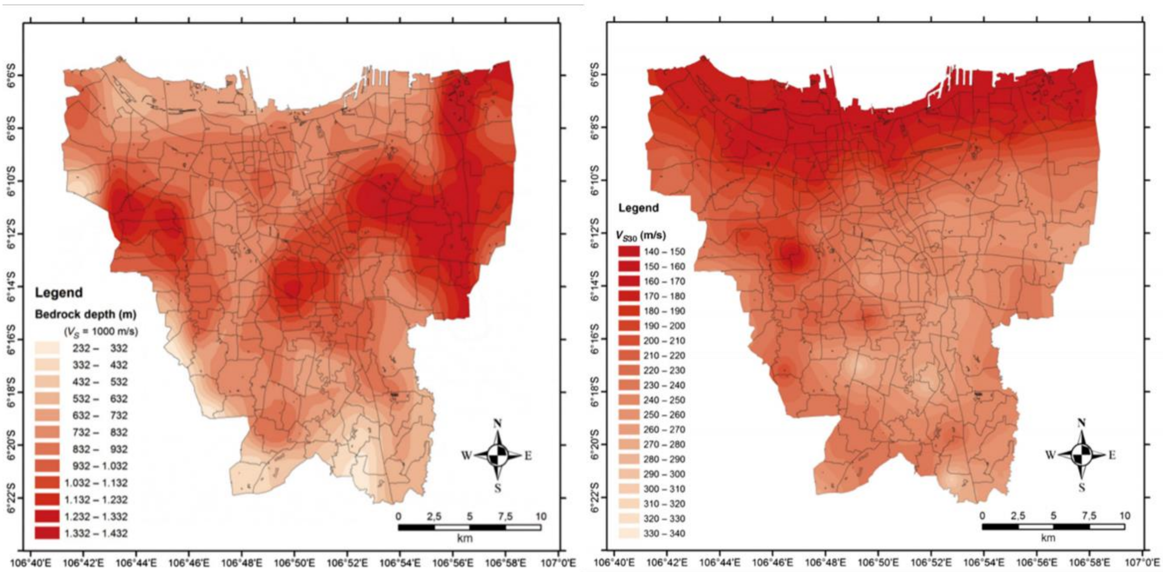

Figure 3. *(1) Bedrock depth map of Jakarta based on microtremor (2) Shear wave velocity on 30 meters depth of Jakarta Ridwan et al. (2013).*

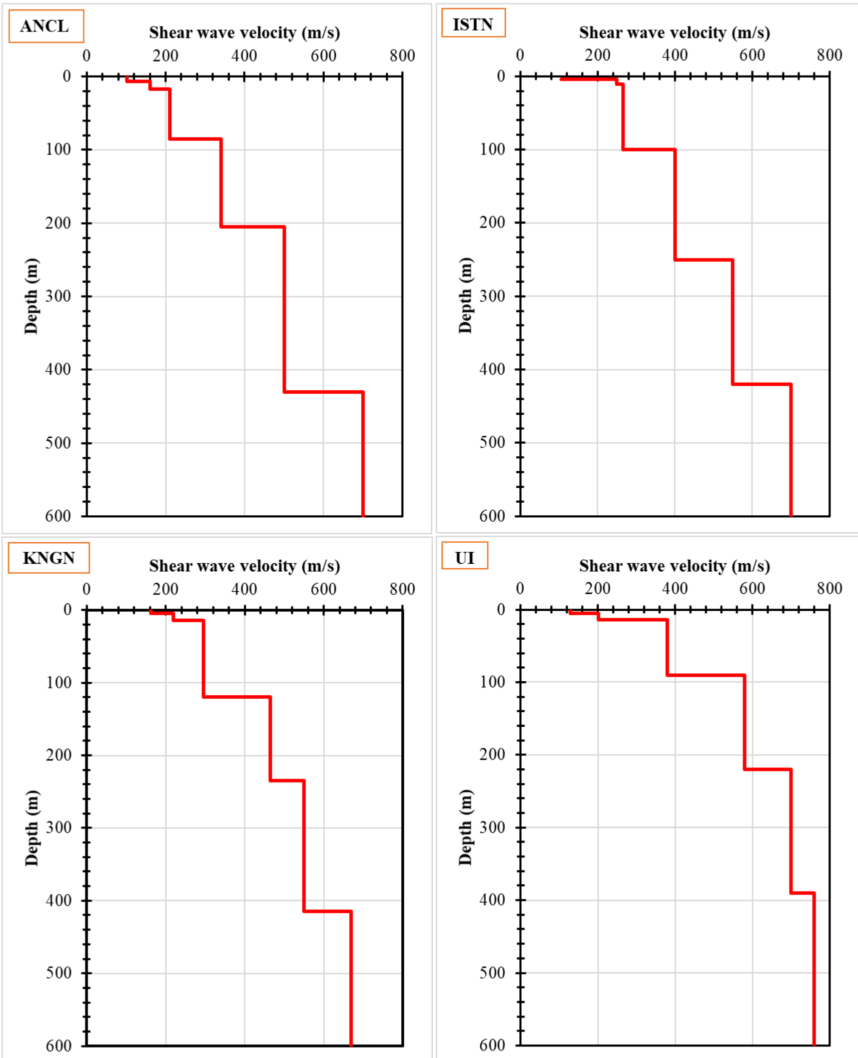

Figure 4. *Soil profile according to the microtremor measurement by Ridwan et al. (2019).*

Table 1. Detail Information of Research Area

Site	Vs30	Site Class	Bedrock
ANCL	140-150	E	532-632
ISTN	200-210	D	532-632
KNGN	200-210	D	432-532
UI	210-220	D	332-432

3. SEISMIC ACTIVITIES AROUND JAKARTA

Jakarta lies in a very active tectonic region. A series of active faults surround the study area. The Indo-Australia Subduction Zone, Cimandiri fault, Baribis Fault, Sunda Fault and Lembang Fault are the most important sources of earthquakes in the study region (Irsyam et al, 2019). The 5.4 Mw Banten earthquake in 2020 affiliated with Indo-Australia Subduction Zone where the Indo-Australian Plate is submerged beneath the Eurasian Plate as reported by BMKG (2020). The general state of the tectonic features of the mayor was shown in Figure 5.

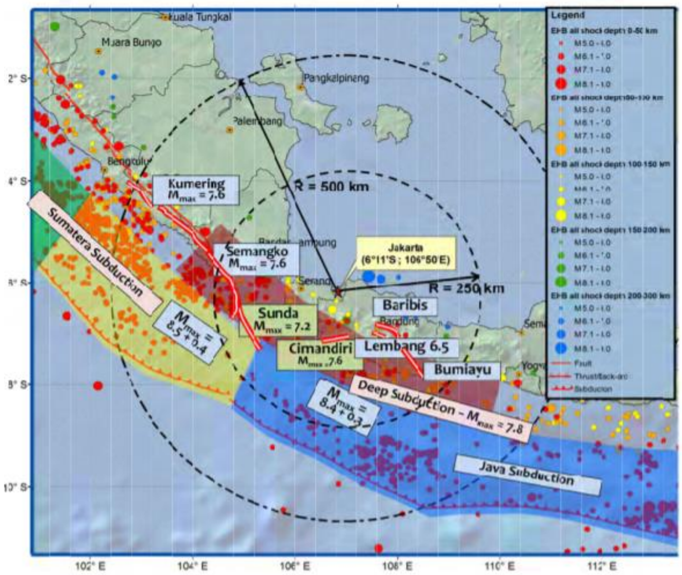

Figure 5. *Seismic Activity around Jakarta (Irsyam et al, 2019)*

4. METHOD

4.1. Deterministic Seismic Hazard Analysis

Determinitic Seismic Hazard Analysis is used to produce motion from the Banten earthquake. The 5.4 Mw Banten earthquake is used to assess the parameter. In addition, the next generation attenuation (NGA) model of Abrahamson et al. (2014) is used for ground motion prediction (GMP) due to the Banten earthquake and resulted in spectral acceleration as shown in Figure 6.

Subduction zone, which is a zone of earthquake occurrences that occur near the boundary of the meeting between oceanic plates that sinks under the continental plates. Earthquakes due to thrust faults, normal faults, reverse slips and strike slips that occur along plate joints can be classified as subduction zones. In this study, the subduction zone referred to is the megathrust zone, which is the source of a subduction earthquake from the surface to a depth of 50 km. Subduction sources with a depth of more than 50 km (benioff zone) will be modeled as deep background sources. Spectral acceleration at the sites under investigation is consistent with many earthquakes from Pacific Earthquake Engineering Studies or PEER Database (2018). Earthquakes affect to the city that have relatively similar geological condition to Jakarta region. Moreover, the Chici earthquake from PEER database is selected.

The Chichi earthquake incident on September 21th, 1999 has provided important lessons on the form of earthquake damage related to shock characteristics such as amplitude, frequency content and duration of earthquakes felt at ground level. Most of the damage caused by the earthquake, occurred in an area dominated by thick deposits of soft clay (Qodri, 2019). This event clearly shows that in an earthquake hazard study the influence of local soil deposit conditions must be considered in order to see in detail the dynamic response behavior of the soil due to the earthquake.

After producing spectral acceleration, the motion is analyzed and matched to the spectral acceleration of the locations. Seismosoft (2020) is used to produce motion when combined with spectra acceleration using the spectra matching technique.

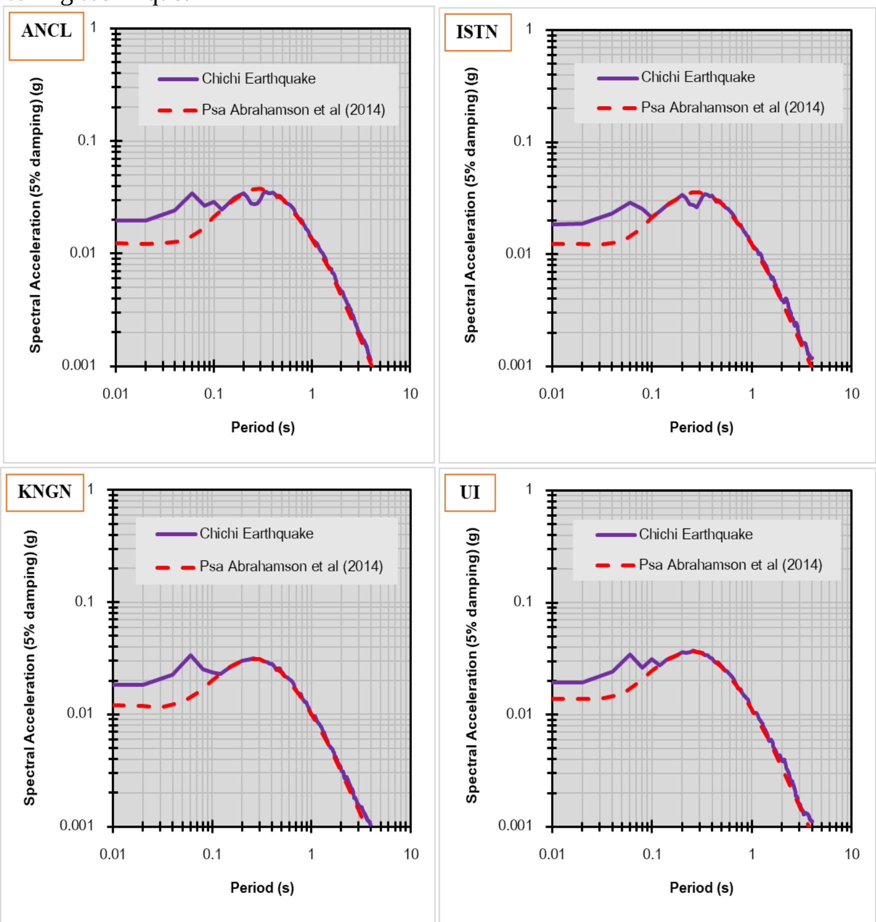

Figure 6. *The spectral matching on each site*

4.2. Seismic Site Response Analysis

A computer program called "DEEPSOILS" created by Hashash et al (2016) was used in this analysis. The software uses non-linear pressure dependent hyperbolic to model non-linear soil activity during the earthquake. Several input parameters, including unit weight (average weight), soil thickness (h), shear wave velocity (V_S), Plasticity Index and shear modulus ratio-shear strain curve (G/Gmax-ε) are needed. For soft clay, medium stiff clay, stiff to very stiff clay and very stiff clay use the G/Gmax-ε relationship from Vucetic and Dobry (1991) and for sand use the G/Gmax-ε relationship from Seed and Idriss (1971). The plasticity index (PI) for this research site was assumed based on site class of soil from NEHRP (1998). According to SNI-1726 (2012), the PI for site class S_E is higher than 20. However, the PI for S_D and S_C was assumed to have a PI value between 10-20% and 5-10% respectively. Moreover, these variations of PI were evaluated to understand their effect on the surface response spectra

The motions are applied at rock layer as engineering bedrock. According to Miller et al. (1999), the engineering bedrock value in general about 760 m/s, the weight unit is about 22 kN/m^3 and the damping ratio is 5%. This value also was used as basic value in several researcher, i.e Mase (2018), and Adampira et al. (2014). In jakarta subsoil, the depth of engineering bedrock is about 500 m (Sinsakul, 2000).

At the end, spectral acceleration at ground surface and amplification factor as site response including are presented in this study. The spectral acceleration results are also compared spectral acceleration design by SNI-1726 (2012). This is very important to predict the potential of earthquake impact in Indonesia especially in Jakarta

5. RESULT AND DISCUSSION

5.1. Peak Ground Acceleration

The results of PGA input and PGA at ground surface in each site in different input motion as shown in Table 2 and Figure 7. Those can be calculated of the amplification factor (AF) with the following formula

$$Amplification\ Factor = \left| \frac{\text{PGA at ground surface}}{\text{PGA input}} \right| \quad (1)$$

The highest amplification among all ground PGA at ground surface surface is ANCL site and the lowest amplification among all ground surface is KNGN site in all input motions. The amplification factor in all the sites research is about 1.2-2.4.

Table 2. The results of maximum PGA and amplification factor on each site

Site	PGA input	PGA at ground surface	Amplification factor
ANCL	0.019	0.032	1.6
ISTN	0.018	0.024	1.3
KNGN	0.018	0.022	1.2
UI	0.013	0.032	2.4

Based on the previous research by Ridwan (2019), the amplification factor in Jakarta subsoil reaching 5 times. According to Yoshida (2015), the existence of soft soil is the main role that control the amplification. The same statement also coming from Choi and Stewart (2005) that the soil layer with Vs30<180 m/s can increase the earthquake power. The results of the research are corresponding with the previous study that Jakarta Metropolitan area could happen the amplification for low intensity input motion Considering the different Vs30 on each station, Vs30 is not always consistent with the amplification factor. The different trend between the result of amplification and Vs30 is caused by differences the thickness and abundance of soft soil in every site.

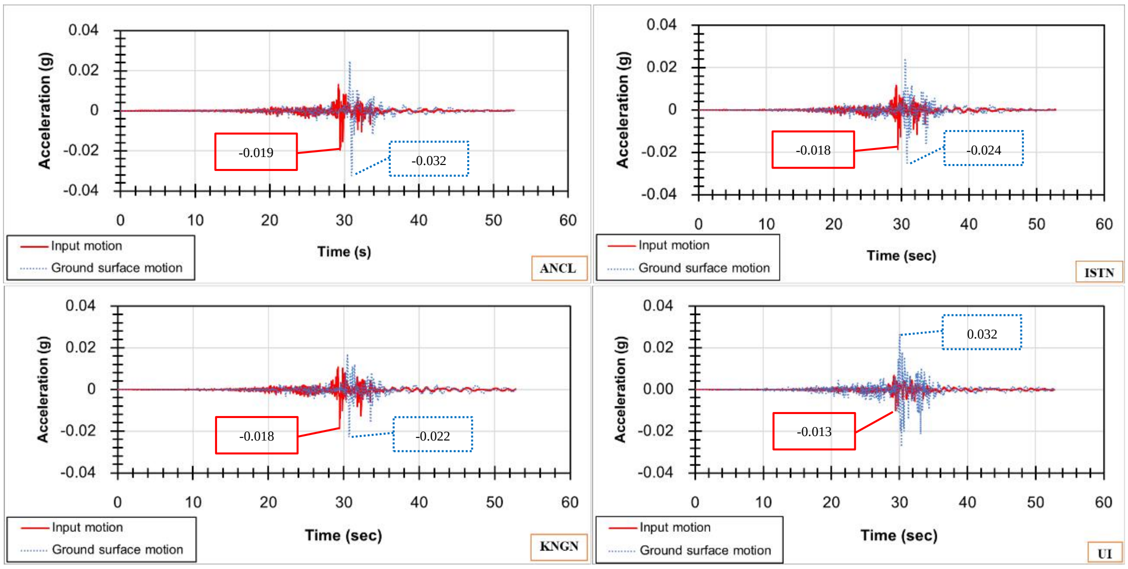

Figure 7. *The comparison of input ground motion and surface ground motion on each site*

5.1. Spectral Acceleration

The result of spectral accelerations due to the earthquake on each site are presented in Figure 8. In general, the spectral acceleration at the surface of UI site has the highest value. The spectral acceleration of the motions at ground surface reaches the maximum of spectral acceleration at period of 0.2 to 0.3 sec. The ranges are reflecting the building natural period of 2 to 3 stories building of concrete building based on the equation 2 below. That mean the ground motion can make serious damage to the low stories building in Jakarta.

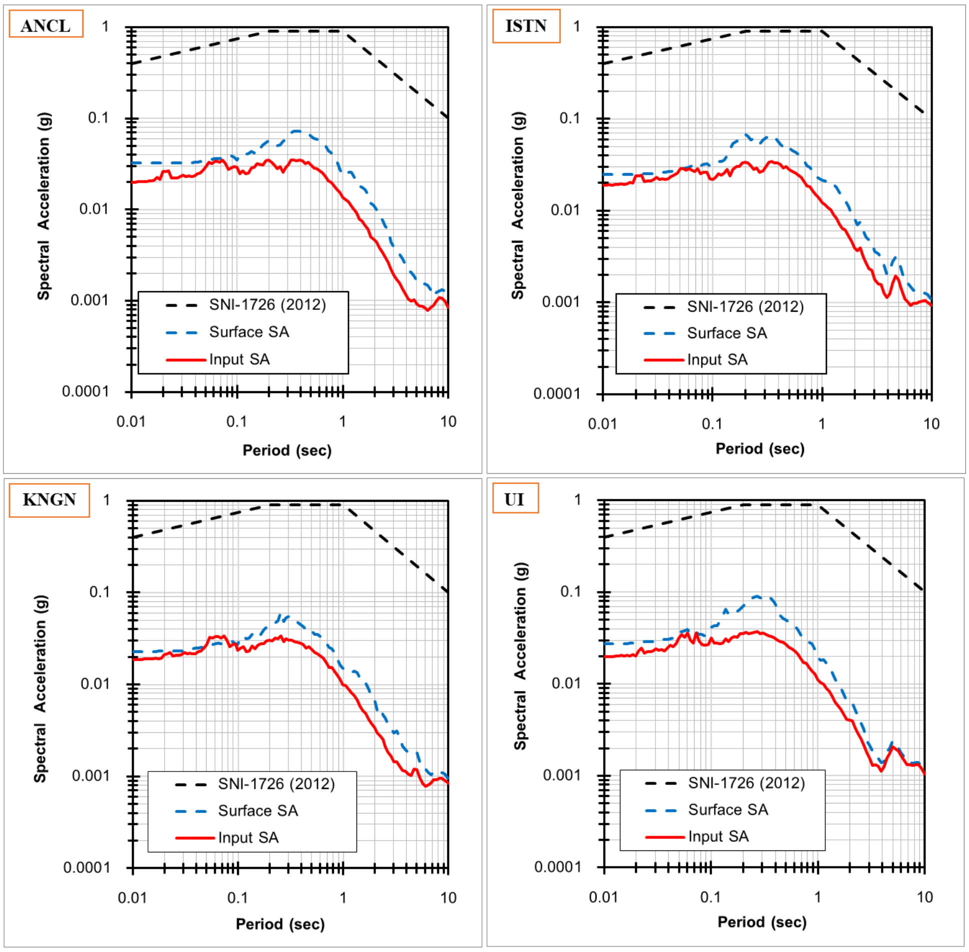

Figure 7. *Spectral acceleration comparison on each site*

According to the formula (2)

$$Tn = 0.1n \tag{2}$$

Figure 8 also compare the results of spectral acceleration in research area to the spectral acceleration design by SNI-1726 (2012). The results show there is no exceed by the spectral acceleration at the ground motion for the long period.

6. CONCLUSION

This research presents the one-dimensional site response study on several sites in Jakarta due to the seismic activity of the Banten earthquake on July 7th, 2020. A nonlinear site response analysis is conducted on the sites and combined with the principle of deterministic seismic hazard.

1. The results of the nonlinear one-dimensional site response study of the ground surface spectral acceleration are greater than that of the input motion. It represents the propagated amplification of the wave at each spot. Overall, the sites examined amplification factor is around 1.57-2.08.
2. According to spectral acceleration design by SNI-1726 (2012), the spectral acceleration from the result seismic ground response analysis is not exceeding. This indicates that the 5.4 Mw Banten earthquake triggering by the Si Sawat would not result in structural damage at the study area. However, the attention should be addressed to the medium high-rise building if the stronger earthquake from the closest distance fault occurs and affects to Jakarta. Generally, the results of this study warn the local engineer to reconsider earthquake on the structural design in Jakarta

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REFERENCES

[1] Abrahamson, N. A., Silva, W. J., & Kamai, R. (2014). Summary of the ASK14 ground motion relation for active crustal regions. Earthquake Spectra, 30(3), 1025-1055.
[2] Adampira M, Alielahi H, Panji M, Koohsari H. (2014). Comparison of equivalent linear and nonlinear methods in seismic analysis of liquefiable site response due to near-fault incident waves: a case study. Arab J Geosci;8(5):3103–18.
[3] Badan Standardisasi Nasional (BSN) SNI 03-2002 (2002) Tata Cara Perencanaan Ketahanan Gempa untuk Bangunan Gedung, BSN, Jakarta
[4] Choi, Y., & Stewart, J. P. (2005). Nonlinear site amplification as function of 30 m shear wave velocity. Earthquake Spectra, 21(1), 1-30.
[5] Google Earth. 2019. Java Indonesia Region. ⟨www.google.com⟩.
[6] Hashash YMA, Musgrove MI, Harmon JA, Groholski DR, Phillips CA, Park D (2016) DEEPSOIL 6.1 User Manual. Urbana Campaign: USA.
[7] Irsyam, M., Hutapea, B. M., & Imran, I. (2017). Zonasi Hazard Gempa Bumi untuk Wilayah Jakarta. Jurnal Teknik Sipil, 24(2), 159-166.
[8] Irsyam, M., Hutapea, B. M., Imran, I., & Asrurifak, M. (2019). Determination of Site Amplification Deep Soil Layers using 1-D Site Response Analysis (Case Study: Jakarta City, Indonesia). Journal of Engineering & Technological Sciences, 51(6).
[9] Mase, L. Z., Likitlersuang, S., & Tobita, T. (2018). Non-linear Site Response Analysis of Soil Sites in Northern Thailand during the M w 6.8 Tarlay Earthquake. Engineering Journal, 22(3), 291-303
[10] Meteorological, Climatological, and Geophysical Agency (BMKG) (2020). Latest earthquake report 2020.
[11] Miller RD, Xia J, Park CB, Ivanov J. (1999). Using MASW to map bedrock in Olathe, Kansas (Exp.Abs). J Soc Explor Geophys 1:433–236.
[12] Misliniyati, R., Sahadewa, A., Hendriyawan, H., & Irsyam, M. (2019). Parametric Study of One-Dimensional Seismic Site Response Analyses Based on Local Soil Condition of Jakarta. Journal of Engineering and Technological Sciences, 51(3), 392-410.
[13] Naito, S., Azuma, H., Senna, S., Yoshizawa, M., Nakamura, H., Hao, K. X., . . . Yoshida, M. (2013). Development and testing of a mobile application for recording and analyzing seismic data. Journal of Disaster Research, 8(5).
[14] National Earthquake Hazards Reduction Program (NEHRP) (1998) Recommended provisions for seismic regulation for new buildings and other structures, 1997 Edition, FEMA 302, USA.
[15] PEER. (2018). PEER ground motion database. In: University of California Berkeley, California, USA.
[16] Qodri, M. F., Mase, L. Z., & Likitlersuang, S. (2019). Simulation of Seismic Ground Response at Bangkok Subsoil due to Si Sawat Fault. The 24th National Convention on Civil Engineering, .
[17] Ridwan, M., Cummins, P. R., Widiyantoro, S., & Irsyam, M. (2019). Site characterization using microtremor array and seismic hazard assessment for Jakarta, Indonesia. Bulletin of the Seismological Society of America, 109(6), 2644-2657.
[18] Ridwan, M., Widiyantoro, S., Irsyam, M. & Afnimar (2013) Identification of engineering bedrock in Jakarta by using array observations of microtremors. In: 3rd International Symposium on Earthquake and Disaster Mitigation 2013 (ISEDM 2013), Yogyakarta, Indonesia, 17– 18 December 2013.
[19] Ridwan, M., Afnimar, A., Widiyantoro, S., Irsyam, M., & Yamanaka, H. (2014). Estimation of S-wave velocity structures by using microtremor array measurements for subsurface modeling in Jakarta. Journal of Mathematical and Fundamental Sciences, 46(3), 313-327.
[20] Ridwan, M., Widiyantoro, S., Irsyam, M., & Yamanaka, H. (2017). Development of an engineering bedrock map beneath Jakarta based on microtremor array measurements. Geological Society, London, Special Publications, 441(1), 153-165.
[21] Seed HB, Idriss IM. (1991) Soil module and damping factors for dynamic response analyses. Berkeley, California, USA: Earthquake Engineering Research Center. University of California; [Report No. EERC 90–10].
[22] Seismosoft, (2020). A computer program for signal processing of strong-motion data and matching spectral. Seismosoft. Pavia. Italy
[23] Turkandi, T., Sidarto,, Agustiyanto, D.A. & Hadiwodjoyo, M.M.P (1992). Geological Map of Jakarta and Kepulauan Seribu Quadrangles Jawa. Geological Research and Development Centre
[24] USBSS. (1991). NEHRP recommended provisions for the development of seismic regulations for new buildings: Part 2: Commentary. In Earthquake Hazard Reductions Series (Vol. 65): US Federal Emergency Management Agency (FEMA).
[25] Vucetic, M., and Dobry, R. (1991). Effect of soil plasticity on cyclic response, Journal of geotechnical engineering, V. 117, No. 1, p. 89-107.
[26] Yoshida, N. 2015. Seismic Ground Response Analysis. Springer, Berlin, Germany.