Evaluation of seismic site amplification factors in Yogyakarta using One-Dimensional site response analysis

M. Irfan Marasabessy[1,*], Elvis Saputra[1], Yuamar I Basarah[2]

[1]Department of Civil Engineering, Faculty of Civil Engineering and Planning, Islamic University of Indonesia
[2]Faculty of Civil and Environmental Engineering, Bandung Institute of Technology, Bandung, Indonesia

Article Info
***Article history*:**
Received:
March 1, 2025
Revised:
May 24, 2025
Accepted:
May 24, 2025
Available online:
June 23, 2025

***Keywords*:**
Site response analysis
Seismic amplification
Ground motion
Yogyakarta

Corresponding Author:
M. Irfan Marasabessy
irfanmarssy@uii.ac.id

Abstract
This study evaluates seismic site amplification in Yogyakarta using one-dimensional (1D) nonlinear site response analysis. Subsurface conditions were characterized using borehole and Standard Penetration Test (SPT) data from four different locations. Ground motion records were selected and matched to the seismic hazard target spectrum at the bedrock level in Yogyakarta. The nonlinear site response analysis was then used to propagate the seismic waves to the ground surface using the DEEPSOIL program. The results show de-amplification at short periods (T < 0.5 s) and amplification at longer periods (T > 1 s), The highest amplification is observed at T = 0.15 s, with an average factor of 3.47. A comparison with the Indonesian seismic design code SNI 1726:2019, which shows that the code provides more conservative estimates than the site-specific analysis in this study. The analysis also shows that lower input motion intensity at bedrock (PGA = 0.02g) leads to higher amplification, while higher PGA (up to 0.72g) results in reduced response. This study highlights the need for site-specific analysis and consideration of input motion variability.

Introduction

The Mw 6.2 tectonic earthquake that struck Yogyakarta and its surrounding areas in 2006 was both a tragic event and a crucial learning experience regarding the importance of disaster mitigation preparedness. The earthquake resulted in approximately 5,048 fatalities and the destruction of 430,374 houses, leading to economic losses estimated at IDR 29.1 trillion at the exchange rate at that time (USD 1 = IDR 9,000) (Pramumijoyo, 2009). Following this event, extensive evaluations were conducted, including revisions to the National Seismic Hazard Map in 2010 and most recently in 2017 (PuSGeN, 2017). The seismic hazard map provides ground motion acceleration values at bedrock level. However, to determine surface-level acceleration, an amplification factor is required. According to the Indonesian National Standard (SNI) for seismic load planning in building structures (Indonesian Standard Code, 2019), amplification values are based on site class categories that describe local soil conditions. Several recent studies have been conducted to obtain site-specific seismic amplification factors for Yogyakarta, such as those by (Saputra, 2023; Pawirodikromo et al., 2019; Marasabessy & Widodo, 2017; and Wibowo & Huda, 2020). While previous studies have made important contributions, the integration of detailed nonlinear dynamic soil properties has been relatively limited, leaving aspects such as shear modulus degradation, strain-dependent damping behavior, and variations in soil thickness above the bedrock less explored. This presents opportunities for further refinement in site-specific seismic response analyses. Meanwhile, This gap contrasts with more advanced studies conducted in Jakarta (Delfebriyadi et al., 2019; Misliniyati et al., 2019) and in Surabaya (Marasabessy et al., 2024), where nonlinear site response analyses have revealed the significant role of these parameters in influencing seismic amplification. Furthermore, the novelty of this study expected to produce more reliable amplification values and support better earthquake-resistant design and seismic risk evaluation, specifically in Yogyakarta.

Soil Profile Modelling

The soil investigation samples were collected from four different locations, as shown in the table 1 below

Table 1. Sample of soil investigation

No	Name	Coordinates		Total Depth	Site Class
		Latitude	Longitude		
1	SP-1	-7.7768	110.3866	30.00	SD
2	SP-2	-7.7690	110.3875	30.00	SD
3	SP-3	-7.7717	110.3876	30.00	SD
4	SP-4	-7.7978	110.3833	30.00	SD

The soil investigation conducted in this study was based on borehole log data obtained from the Standard Penetration Test (NSPT) up to a total depth of 30 m, as illustrated in figure 1. The subsurface profile primarily consists of sand with consistency ranging from loose to very dense. However, the bedrock was assumed to be present at a depth of 50 m, in accordance with the findings of Naing et al., (2015), who reported that bedrock depths in Yogyakarta vary between 20 m and 50 m. Although variations in bedrock depth can also affect wave propagation results, this research merely adopts a single bedrock depth for simplification purposes. Therefore, to estimate the soil parameters between the SPT-derived data and the bedrock, the linear extrapolation method proposed by Boore (2004) was employed. This method has also been implemented numerically in previous studies by (Misliniyati et al., 2019; and Marasabessy et al., 2024). The linearly extrapolated parameters include the shear wave velocity (Vs) and soil shear strength (Su), as illustrated in figure 2. The shear wave velocity was assumed to be 760 m/s in the bedrock, while the shear strength was set at 1500 kPa.

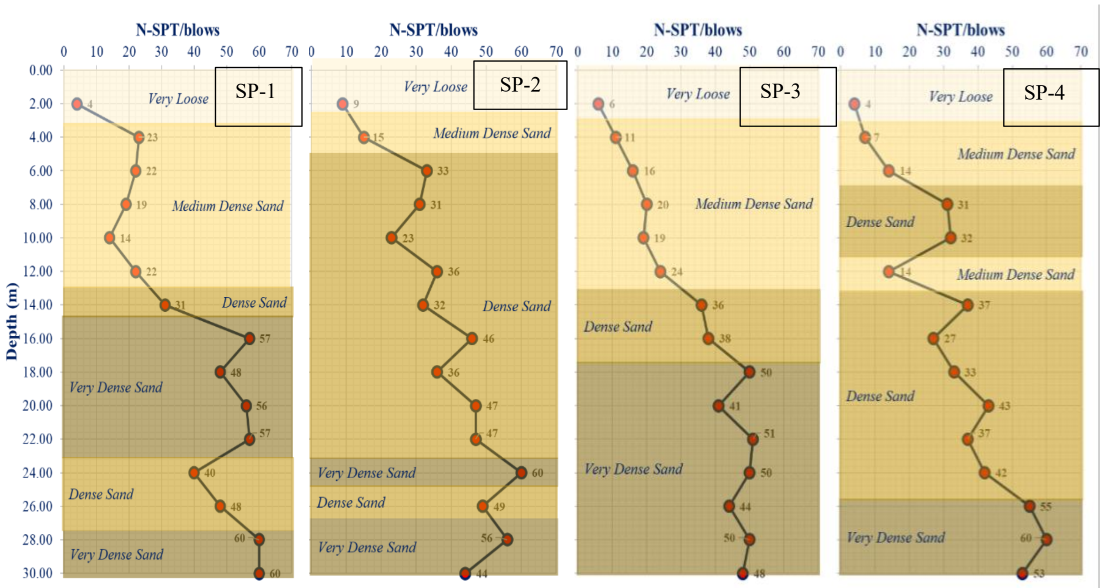

Figure 1. Bor-log NSPT and soil description

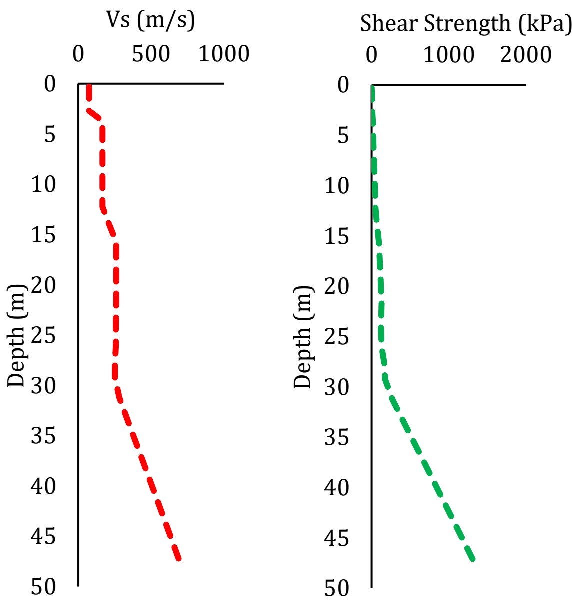

Figure 2. Linear extrapolation from a depth of 30 m to the bedrock level for SP-1

The shear wave velocity can be determined using the equation proposed by Wair et al., (2012), as follows:

$$V_s = 30 \times N^{0.215} \times \sigma'_{ov}{}^{0.275} \quad (1)$$

Where, N represents the NSPT value, and σ'_{ov} denotes the overburden pressure.

Ground Motion at Bedrock

Ground motion at the bedrock level serves as a key input for acceleration time history to propagate seismic waves through soil layers. The selection of earthquake records requires a spectrum-matching procedure (Indonesian Standard Code, 2020), which is adjusted based on the seismic conditions in Yogyakarta, considering the magnitude (M_w) and the closest distance (R) to the seismic sources, as derived from Deagregation Map (PuSGeN, 2022). The target spectrum is generated using the probabilistic seismic hazard analysis (PSHA) method that produce uniform hazard spectrum (UHS) at bedrock in Yogyakarta City, as shown in figure 3. This spectrum was then used as a reference for performing spectrum matching with various collected earthquake records.

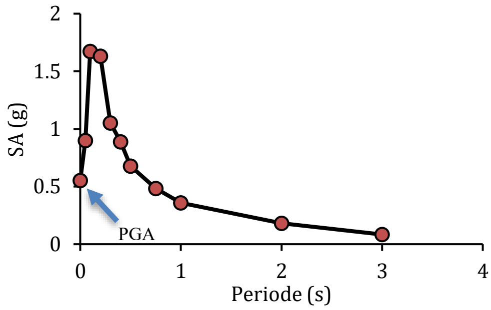

Figure 3. Uniform hazard spectrum (UHS) as target spectrum at bedrock

In this study, earthquake recordings were limited to shallow crustal events to simplify the analysis process. According to Indonesian Standard Code, (2020) a minimum of five pairs of earthquake records at the bedrock level is required for conducting seismic wave propagation analysis. Each pair is presented in table 2 below, where EW denotes East-West and NS represents North-South. These earthquake records were selected based on the Indonesian Deaggregation Map (PuSGeN, 2022), considering a moment magnitude (Mw) of 5.8–6 and a source-to-site distance (R) of 20–30 km for a 2,500-year return period in Yogyakarta.

Table 2. List of original record ground motion

No	Code	Ground Motion Name	PGA (g)
1	GM-1	SantaBarbara_1978_EW	0.08
2	GM-2	SantaBarbara_1979_NS	0.04
3	GM-3	Livermore1_1980 EW	0.07
4	GM-4	Livermore1_1980 NS	0.06
5	GM-5	TaiwanSmart_1981 EW	0.09
6	GM-6	TaiwanSmart_1981 NS	0.13
7	GM-7	Northridge_1994_EW	0.04
8	GM-8	Northridge_1994_NS	0.05
9	GM-9	Parkfield_2004_EW	0.02
10	GM-10	Parkfield_2004_NS	0.02

Based on table 2 above, the maximum Peak Ground Acceleration (PGA) was initially 0.13g. However, it will be adjusted to match the target spectrum, with the final expected PGA reaching approximately 0.6g.

Furthermore, to assess the impact of input motion intensity, the original ground motion records GM-6 (PGA 0.13g) and GM-10 (PGA 0.02g) will be used as comparisons.

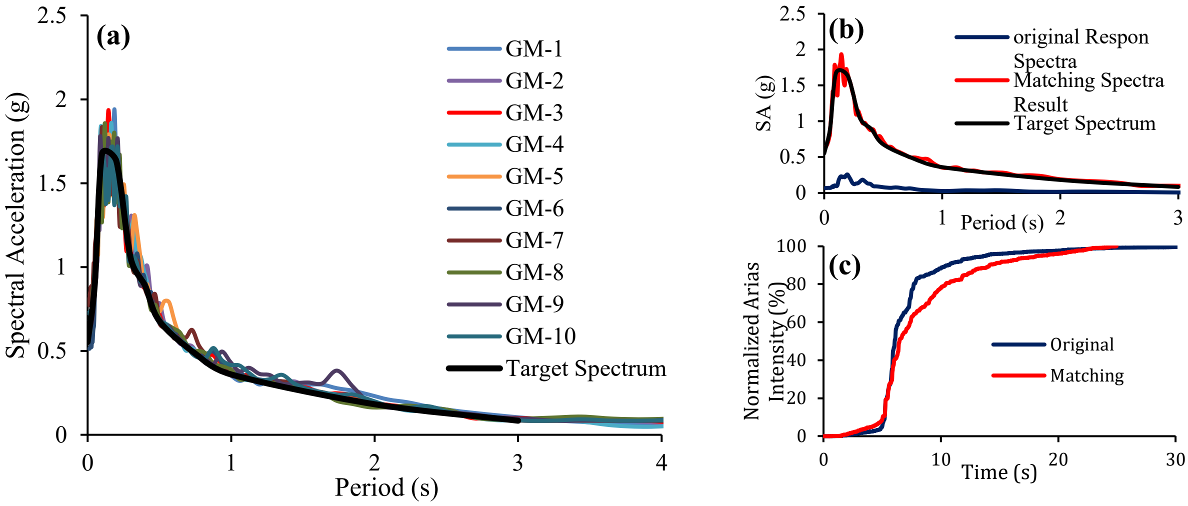

Figure 4. (a) Spectral matching to the target spectrum for each of the five pairs of ground motions (b) Spectral matching for GM-1 (c) normalized arias intensity (%) for GM-1

Figure 4(a) illustrates the spectral matching results of five pairs of earthquake records against the target spectrum, showing that the PGA values for each record increased to approximately 0.6g. Figure 4(b) presents a comparison of the spectra before and after the matching process for GM-1, which was further verified by examining the normalized arias intensity of both, as shown in figure 4(c). The comparison of Arias intensity aims to assess whether significant differences exist in the earthquake records after spectral matching, as the process is intended to preserve the original characteristics of the ground motion.

The spectral matching of earthquake records to the target response led to a significant increase in PGA values, as illustrated in figure 5, which presents acceleration time histories for both the original and matched records. The highest acceleration (PGA = 0.82g) was observed in GM-7 (Northridge 1994 earthquake, East-West direction), while the lowest acceleration (PGA = 0.51g) occurred in GM-6 (Taiwan 1981 earthquake, North-South direction).

1-D Site Response Analysis

All matched seismic records will subsequently be propagated from the bedrock using the one-dimensional (1D) wave propagation program DEEPSOIL (Y. M. A. Hashash et al., 2020). The one-dimensional approach is commonly used because, based on the theory of seismic wave propagation, waves traveling upward through horizontal soil layers tend to refract toward a vertical path (Kramer, 1996). However, this study also neglects the basin effects in which the influence of basin effects still requires further investigation using 2D or 3D methods, as demonstrated in previous studies McGann et al., (2021). Therefore, the nonlinear method will be employed to evaluate wave propagation at the surface. This method was chosen based on extensive research conducted over the past 60 years, which has demonstrated that soil exhibits highly nonlinear behavior even under both small and large strain conditions (Y. M. a Hashash & Groholski, 2010).

The two key parameters that characterize the nonlinear behavior of soils are the modulus reduction curve and the damping curve. Several previous studies have formulated modulus reduction and damping curves, including Vucetic & Dobry (1991), Seed & Idriss (1970), and Darendeli (2001). Moreover, the research conducted by Guerreiro et al., (2012) indicated that the family curves derived by Darendeli (2001) seem to effectively account for all major influences across the full range of strains.

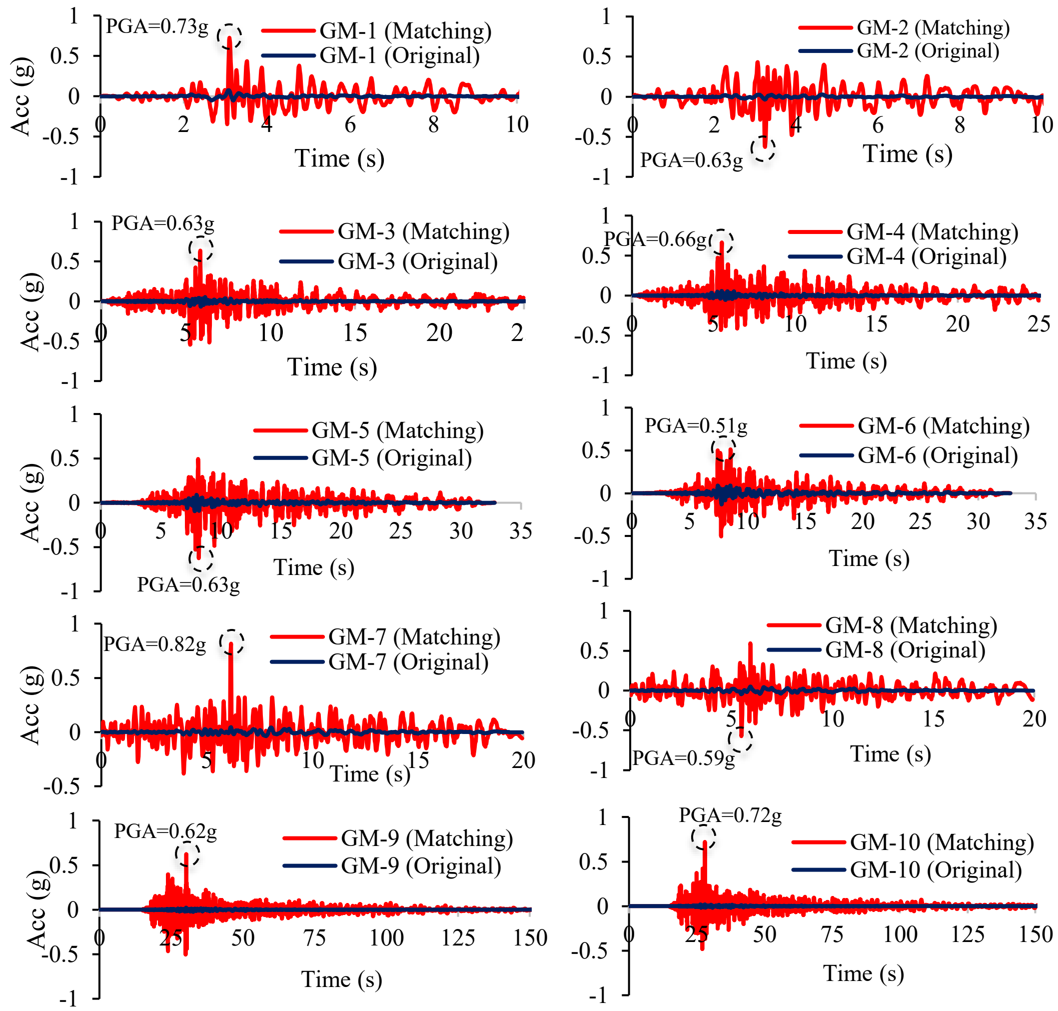

Figure 5. Acceleration time history of five pairs record ground motion at bedrock

Effect of Soil Shear Strength

The study from Phillips & Hashash, (2009) that has been mentioned in Marasabessy et al., (2024) reveal that at large strain levels, soil shear strength can be either underestimated or overestimated. A key limitation of laboratory experiments is that they cannot accurately capture the decrease in damping ratio curves at very high strain levels. To improve the accuracy of shear strength representation in these conditions, applying a shear strength correction is necessary. Thus, to accomodate this problem, then Groholski et al., (2016) proposed a simplified nonlinear constitutive model, commonly known as the General Quadratic/Hyperbolic (GQ/H) model. This model employs curve-fitting procedures that automatically adjust the shear strength based on reference curves available in the DEEPSOIL program. To understand the concept of shear strength correction and its role in determining dynamic parameters such as G/Gmax and the damping curve, Figure 6 illustrates that shear strength increases with increasing shear strain. As previously mentioned, laboratory experiments cannot accurately capture the reduction in damping ratio curves at very high strain levels. Therefore, shear strength adjustments are necessary at these strain levels.

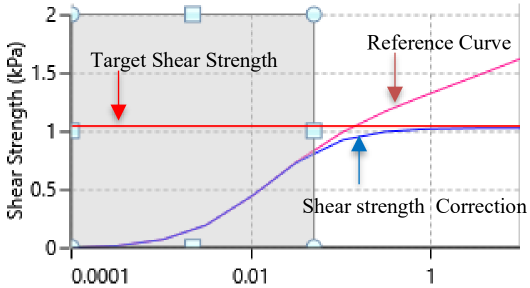

Figure 6. Fitting curve for shear strength correction at top layer using UIUC reduction factor

Based on figure 6, the target shear strength at the top surface is around 1.04 kPa, which was obtained from previous soil investigation data using the following equation:

$$S = c + \sigma'_{ov} tan\phi \quad (2)$$

Where c represents cohesion, ϕ is the internal friction angle, and σ'_{ov} is the vertical overburden stress at the specific depth under consideration. Furthermore, the shear strength values obtained from the reference curves in the modulus reduction and damping model must be calibrated against experimental data. This phenomenon occurs because the Darendeli, (2001) model is based on laboratory tests, which are generally limited to shear strains below 0.1–0.3%. However, its nonlinear property curves are often extrapolated to shear strains up to 10% using the model's hyperbolic equation. To improve the accuracy of the soil's large-strain response, shear strength can be applied to refine the upper segment of the modulus reduction curve (Zalachoris & Rathje, 2015). This calibration ensures a more realistic soil behavior while considering specific boundary parameters in dynamic modeling. The curve-fitting calibration method follows the UIUC reduction factor to capture the non-masing behavior of the soil (Y. M. A. Hashash et al., 2020). The corrected shear strength values are then used to refine the modulus reduction and damping curves, as shown in figures 7. This procedure is performed for each soil layer individually with the assistance of the DEEPSOIL software.

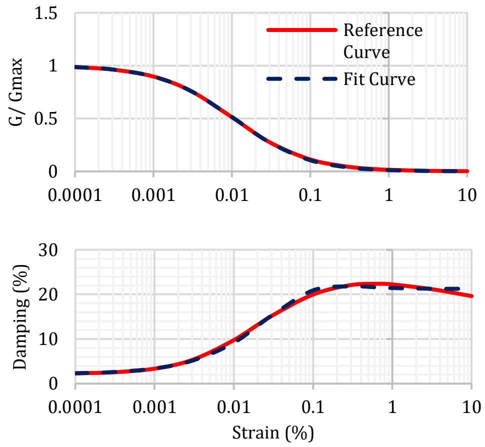

Figure 7. Fitting procedure for modulus reduction and damping curve

Result and Discussion

PGA and Maximum Strain Profile

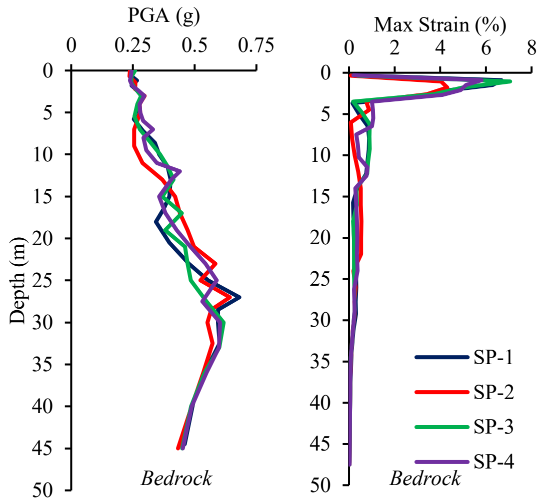

Figure 8. PGA and maximum strain profile

Figure 8 presents the average values from the five pairs of ground motions for each soil profile (1–4). The results indicate a decrease in PGA values at a depth of 30 meters, which continues to decline toward the ground surface. It is important to note that the PGA values at the bedrock level vary between approximately 0.5g and 0.7g across the five pairs of ground motions in this propagation analysis. Figure 9 show the results for the soil profiles and the maximum strain for each ground motion. On the other hand, the maximum strain levels range from 4% to 7% appears at depths of 2–4 meters. This result, as shown in Figure 1, corresponds to loose sand with an NSPT value of less than 5. It is well known that soft soils tend to exhibit large shear strain. Nevertheless, despite the lower strain at a depth of 30 meters, the PGA results already indicate a decrease towards its travel to the top surface.

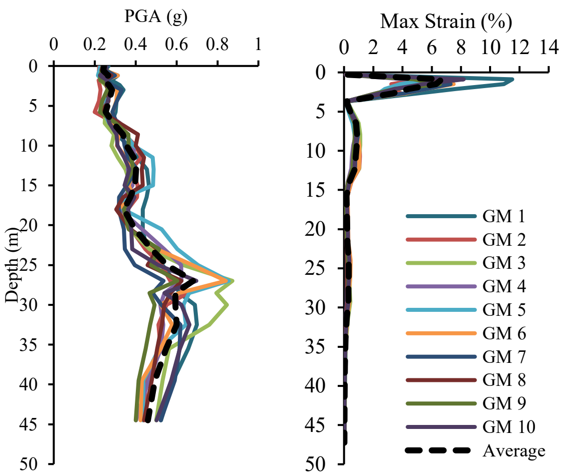

Figure 9. PGA and maximum strain profile for all pairs strong motion in SP-1

In general, the results from all soil profiles (1–4) across different locations show similar trends, as evidenced by the consistent response behavior in Figures 8 and 9.

Respon Spectra and Amplification

The response spectra at the ground surface for the four soil profiles exhibit a peak shift from the target spectrum at the bedrock level, as illustrated in Figure 10. These results also indicate de-amplification of the spectral response at the surface for short periods (T < 0.5 seconds), while an increase in response is observed for longer periods.

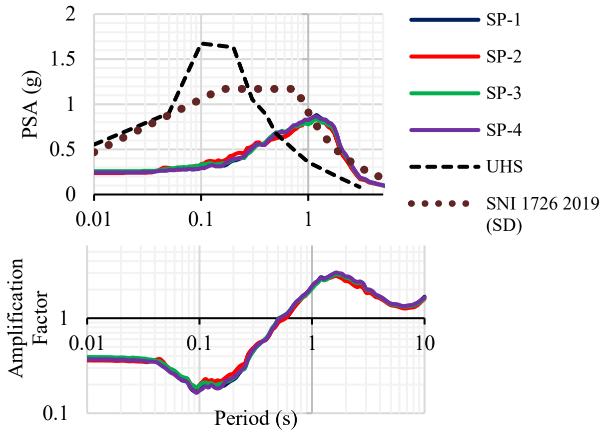

Figure 10. Respon Spctrum and Amplification factor for all soil profiles

The amplification factor quantifies the ratio between surface and bedrock responses, where values greater than one indicate amplification, and values less than one denote de-amplification. These results align with the acceleration time history observed at the surface, as shown in figure 12, where all pairs of earthquake records exhibit similar results.

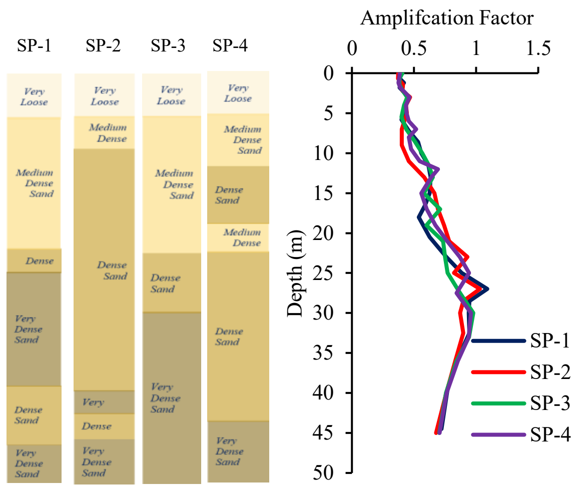

Figure 11. Factor of amplification at PGA for all samples location.

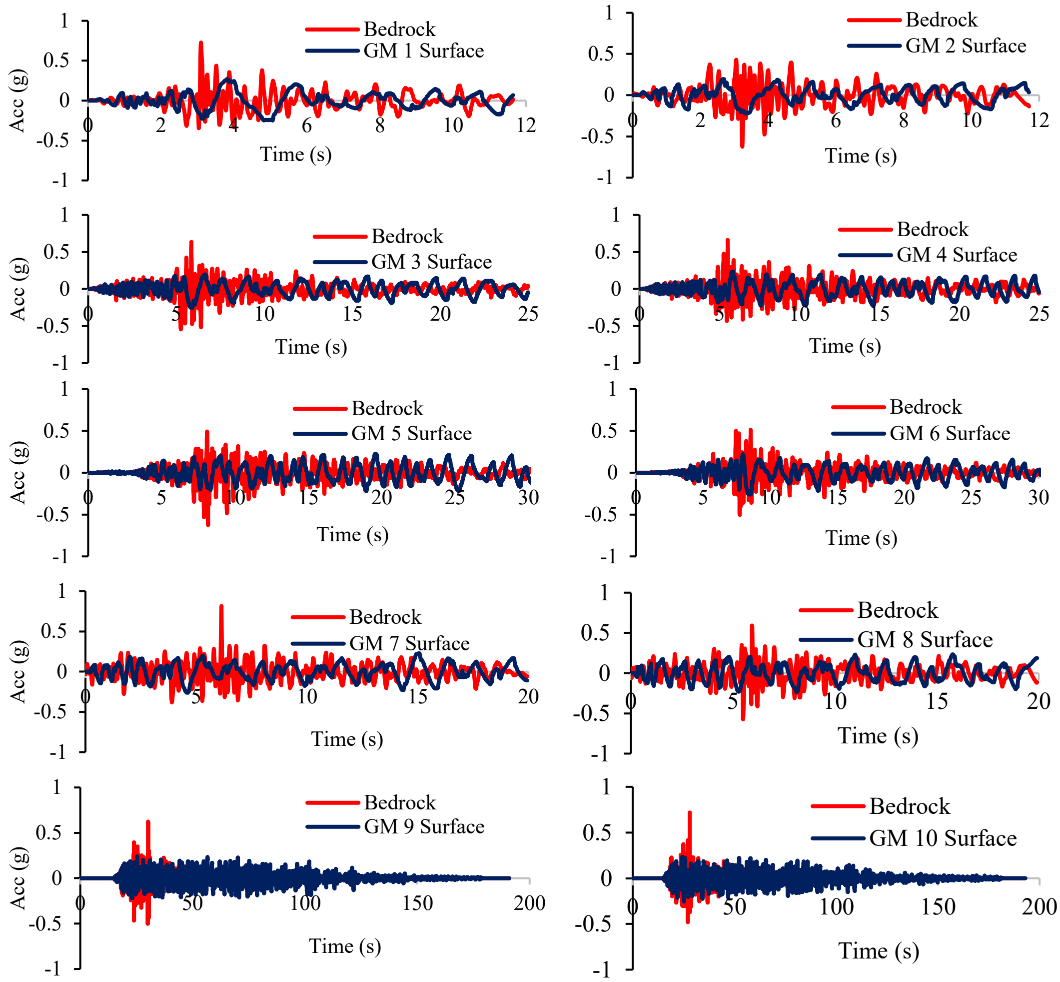

Figure 12. Comparison between acceleration time history at surface level and bedrock

In Figure 10, when the surface spectral response is compared with the Indonesian Standard Code, (2019) method for site class SD, it is observed that similar results are only found at periods (T > 1 second). Meanwhile, at shorter periods, SNI provides a higher response than the numerical analysis in this study (see table 3). In addition, figure 11 shows the amplification factor at a period of 0 seconds, where the surface values for all four soil profiles are approximately 0.4 (de-amplification). The response reduction begins to be noticeable at a depth of 30 meters. This phenomenon may require further investigation to understand the reasons behind the decrease in response at this depth.

Table 3. Comparison of surface pseudo spectral acceleration with SNI 1726:2019

Period (s)	**PSA (g)**		**Ratio**
	SNI 1726 2019 (D)	**This Study Average value**	
(i)	(ii)	(iii)	(ii) / (iii)
0.01	0.47	0.25	1.89
0.15	1.17	0.34	3.47
1	0.89	0.83	1.08
2	0.45	0.46	0.97
3	0.30	0.18	1.66

Effect of Ground Motion Intensity at Bedrock

The effects of ground motion intensity at the bedrock level have been previously studied in several research works, including those by Afacan et al., (2014) and Zhou et al., (2017). Both studies employed centrifuge test modeling in the laboratory, producing results that closely reflect real-world conditions and were also validated through numerical analysis. The study conducted by Afacan et al., (2014). demonstrated that when the peak base acceleration at the bedrock exceeds 0.1g, a response reduction or de-amplification tends to occur, particularly in the short-period range. Similar trend was also observed in the study conducted by Zhou et al., (2017). Based on those explanation, this study will attempt to propagate seismic waves from the bedrock using the original ground motion inputs before spectral matching, where the PGA values are approximately 0.02g (GM-10) and 0.13g (GM-6). This propagation experiment is conducted on soil sample 1 (SP-1), with the results shown in figure 13 below.

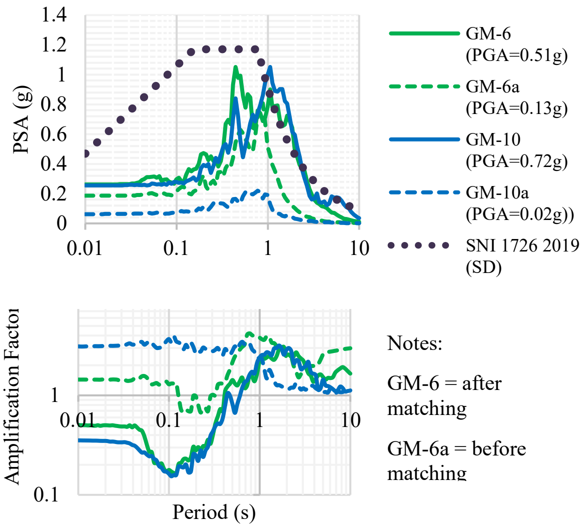

Figure 13. Response spectrum and amplification factor for two different intensity motions at bedrock

As shown in figure 13, a lower PGA at the bedrock level generally leads to increased response or amplification across all periods. GM-10a (PGA = 0.02g) exhibits significant amplification in the short-period range, although it gradually decreases for periods beyond 1 second without reaching de-amplification. In contrast, GM-10 (PGA = 0.72g) shows the opposite trend, where de-amplification occurs in the short-period range, nearly reaching 0.1, before amplification begins for periods greater than 0.7 seconds. Additionally, the results indicate that for short periods (T < 1 second), the spectral response based on SNI 1726:2019 (Indonesian Standard Code, 2019) is more conservative than the numerical analysis in this study, including variations in earthquake intensity at the bedrock level. Another finding is the relationship between input motion intensity at the bedrock and the corresponding amplification factor, as illustrated in Figure 14 below.

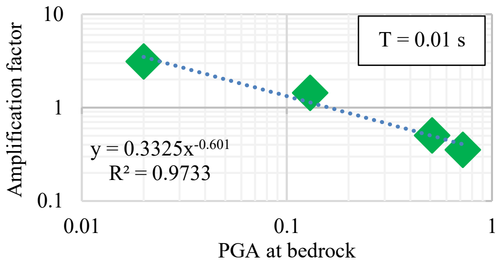

Figure 14. The correlation between the amplification factor and PGA at the bedrock level at period 0.01 second

Figure 14 above presents an equation that describes the relationship between peak acceleration intensity at the bedrock and the amplification factor at a period of T = 0.01 seconds. This result indicates that higher bedrock acceleration reduces surface wave propagation, while lower bedrock acceleration increases it.

Conclusion

Finally, this study demonstrates that the one-dimensional site response analysis using DEEPSOIL reveals a significant influence of local soil conditions on seismic amplification factors in Yogyakarta. The results indicate a de-amplification effect at short periods (T < 0.5 seconds), while greater amplification is observed at longer periods. Moreover, the peak ground acceleration (PGA) at the surface is generally lower than at the bedrock level, suggesting that seismic wave propagation undergoes energy attenuation due to site-specific soil characteristics. The study also highlights that soils with low standard penetration test (SPT) values exhibit higher shear strain, indicating greater susceptibility of soft soils to deformation under seismic loading.

Additionally, the analysis points out the substantial impact of ground motion intensity at the bedrock level on amplification factors. Lower PGA values at the bedrock (PGA = 0.02g) result in increased amplification at the surface, whereas higher PGA values (PGA = 0.72g) lead to de-amplification. This observation aligns with previous studies, which suggest that when base acceleration exceeds a certain threshold, the soil tends to reduce the propagation of seismic waves. Therefore, incorporating different levels of seismic intensity in site response modelling is crucial for accurately assessing potential structural damage in earthquake-prone regions.

Overall, this study provides critical insights into seismic amplification in Yogyakarta, offering valuable implications for improving earthquake-resistant infrastructure planning. Key factors such as soil characteristics, bedrock motion intensity, and shear strength correction methods significantly influence surface response estimates. Additionally, a comparison with the Indonesian Standard Code, (2019) highlights discrepancies at shorter periods, where SNI predicts higher responses than this study, and a notable de-amplification effect at a 30-meter depth. These results suggest the need for further study to improve seismic hazard analysis and strengthen design codes in geotechnically similar areas.

Acknowledgement

The authors would like to express their deepest gratitude to the Civil Engineering Department of Universitas Islam Indonesia for the research grant support, which has enabled this study to be successfully conducted.

References

Afacan, K. B., Brandenberg, S. J., & Stewart, J. P. (2014). Centrifuge Modeling Studies of Site Response in Soft Clay over Wide Strain Range. *Journal of Geotechnical and Geoenvironmental Engineering*, *140*(2), 1–13. https://doi.org/10.1061/(asce)gt.1943-5606.0001014

Darendeli, M. . (2001). *Development of A New Family of Normalized Modulus Reduction and Material Damping Curves*.

Delfebriyadi, 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 and Technological Sciences*, *51*(6), 824–838. https://doi.org/10.5614/j.eng.technol.sci.2019.51.6.6

Groholski, D. R., Hashash, Y. M. A., Kim, B., Musgrove, M., Harmon, J., & Stewart, J. P. (2016). Simplified Model for Small-Strain Nonlinearity and Strength in 1D Seismic Site Response Analysis. *Journal of Geotechnical and Geoenvironmental Engineering*, *142*(9). https://doi.org/10.1061/(asce)gt.1943-5606.0001496

Guerreiro, P., Kontoe, S., & Taborda, D. (2012). *Comparative Study Of Stiffness Reduction And Damping Curves*. 2–11.

Hashash, Y. M. A., Musgrove, M., Harmon, J., Ilhan, O., Xing, G., Numanoglu, O., Groholski, D. R., Phillips, C. A., & Park, D. (2020). *Deepsoil 7*. 1–170.

Hashash, Y. M. a, & Groholski, D. R. (2010). Recent advances in non-linear site response analysis. *Fifth Interantional Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics and Symposium in Honor of Professor I.M. Idriss*, *29*(6), 1–22. http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Remarks+on+site+response+analysis+by+using+Plaxis+dynamic+module#0

Indonesian Standard Code. (2019). SNI 1726:2019 - Tata cara perencanaan ketahanan gempa untuk struktur bangunan gedung dan nongedung. In *Tata Cara Perencanaan Ketahanan Gempa Untuk Struktur Bangunan Gedung dan Non Gedung* (Issue 8, p. 254).

Indonesian Standard Code. (2020). *SNI 8899:2020 Tata cara pemilihan dan modifikasi gerak tanah permukaan untuk perencanaan gedung tahan gempa*. 1–43.

Kramer, S. (1996). *Geotechnical Earthquake Engineering*. Prentice Hall.

Marasabessy, M. I., Masyhur Irsyam, & Yuamar I Basarah. (2024). Comparative Study of One-Dimensional Site Response Analysis on Deep Soft Clay Deposit using DEEPSOIL and NERA. *Indonesian Geotechnical Journal*, *3*(1), 1–14. https://doi.org/10.56144/igj.v3i1.81

Marasabessy, M. I., & Widodo. (2017). Pengaruh Interaksi Kinematik Massa Bangunan Terhadap Respons Non Linier Inelastik Lapisan Tanah. *Jurnal Teknisia*, *22*(1), 307–315.

McGann, C. R., Bradley, B. A., Wotherspoon, L. M., & Lee, R. L. (2021). Basin effects and limitations of 1D site response analysis from 2D numerical models of the thorndon basin. *Bulletin of the New Zealand Society for Earthquake Engineering*, *54*(1), 21–30. https://doi.org/10.5459/bnzsee.54.1.21-30

Misliniyati, R., Sahadewa, A., Hendriyawan, & 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. https://doi.org/10.5614/j.eng.technol.sci.2019.51.3.7

Naing, T., Pramumijoyo, S., & Kawase, H. (2015). Preliminary Evaluation of Local Site Conditon in Yogyakarta Basin. *Journal of Applied Geology*, *1*(1), 9–18. https://doi.org/10.22146/jag.7223

Pawirodikromo, W., Makrup, L., Teguh, M., Suryo, B., & Hartantyo, E. (2019). Site Coefficient of Short Fa and Long period Fv Maps Constructed from the Probabilistic Seismic Hazard Analysis in Yogyakarta Special Province. *MATEC Web of Conferences*, *280*, 01001. https://doi.org/10.1051/matecconf/201928001001

Phillips, C., & Hashash, Y. M. A. (2009). Damping formulation for nonlinear 1D site response analyses. *Soil Dynamics and Earthquake Engineering*, *29*(7), 1143–1158. https://doi.org/10.1016/j.soildyn.2009.01.004

Pramumijoyo, S. (2009). Road to earthquake mitigation: Lesson learnt from the Yogyakarta earthquake 2006. *Journal of Applied Geology*, *1*(2), 32–36. https://doi.org/10.22146/jag.6672

PuSGeN. (2017). PETA SUMBER DAN BAHAYA GEMPA INDONESIA TAHUN 2017. In *Kementerian Pekerjaan Umum dan Perumahan Rakyat*. https://doi.org/10.1002/9780470742341.ch7

PuSGeN. (2022). *PETA DEAGREGASI*

BAHAYA GEMPA INDONESIA UTUK PERENCANAAN DAN EVALUASI INFRASTRUKTUR TAHAN GEMPA.

Saputra, E. (2023). Penyusunan Peta Koefisien Amplifikasi Berdasarkan Rasio Spektra Percepatan. *Rekayasa Sipil*, *17*(3), 282–288. https://doi.org/10.21776/ub.rekayasasipil.2023.017.03.9

Seed, H. B., & Idriss, I. M. (1970). Soil Moduli and Damping Factors for Dynamic Analysis. *Earthquake Engineering Research Center, EERC*, *70–10*, 41.

Vucetic, M., & Dobry, R. (1991). Effect of Soil Plasticity on Cyclic Response. *Journal of Geotechnical Engineering*, *118*(5), 836. https://doi.org/10.1016/0148-9062(91)90820-c

Wair, B. R., Dejong, J. T., & Shantz, T. (2012). Guidelines for Estimation of Shear Wave Velocity Profiles. *Pacific Earthquake Engineering*, *8*(December), 68.

Wibowo, N. B., & Huda, I. (2020). Analisis Amplifikasi, Indeks Kerentanan Seismik Dan Klasifikasi Tanah Berdasarkan Distribusi Vs30 D.I.Yogyakarta Analysis Of Amplification, Seismic Vulnerability Index And Soil Clasification Based On Vs30 In Yogyakarta. *Buletin Meteorologi, Klimatologi, Dan Geofisika*, *1*(2), 21–31. http://usgs.maps.arcgis.com/apps/we

Zalachoris, G., & Rathje, E. M. (2015). Evaluation of One-Dimensional Site Response Techniques Using Borehole Arrays. *Journal of Geotechnical and Geoenvironmental Engineering*, *141*(12). https://doi.org/10.1061/(asce)gt.1943-5606.0001366

Zhou, Y. G., Chen, J., Chen, Y. M., Kutter, B. L., Zheng, B. L., Wilson, D. W., Stringer, M. E., & Clukey, E. C. (2017). Centrifuge modeling and numerical analysis on seismic site response of deep offshore clay deposits. *Engineering Geology*, *227*, 54–68. https://doi.org/10.1016/j.enggeo.2017.01.008