# Parametric Study of One-Dimensional Seismic Site Response Analyses Based on Local Soil Condition of Jakarta

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**Abstract.** Seismic site response analysis is used to estimate the response of soil deposits during seismic loading at any depth of interest and to interpret time histories as well as response spectra. This type of analysis involves many parameters that can affect the character of ground shaking. It is important to know the effect of these parameters in order to perform reliable seismic hazard evaluation at a site. This paper presents the effects of several parameters toward the characteristics of surface response spectra based on the local soil conditions of Jakarta using a one-dimensional (1-D) site response model with total stress approach. A parametric study was performed on two cohesive soil deposit profiles with a different site class, namely medium clay (site $S_D$) and soft clay (site $S_E$). The bedrock layers of both profiles were located at a depth of 300 m. In this study, the analytical methods implemented were the equivalent-linear method and the non-linear method. Several different dynamics soil models were also implemented. In addition, variation of property parameters, such as depth of bedrock, shear wave velocity of bedrock, layer thickness, etc., were studied. The results of this study indicate that all of the studied parameters have a significant effect on the response spectra at the ground surface.

**Keywords**: *1-D site response model; response spectra; seismic hazard evaluation; seismic site response analysis; site class; total stress approach.*

## 1 Introduction

Site response analysis can be used to predict seismic wave characteristics propagation from the underlying bedrock to the ground surface. The characteristics of seismic ground motion at any depth of interest are strongly influenced by local soil conditions, as reflected by the corresponding time histories and response spectra. Ultimately, this analysis estimates the response of the soil surface due to seismic loading, which is crucial for structural and geotechnical designs. Surface response spectra describe an envelope of the peak responses of many single degree of freedom (SDoF) systems that can be used to

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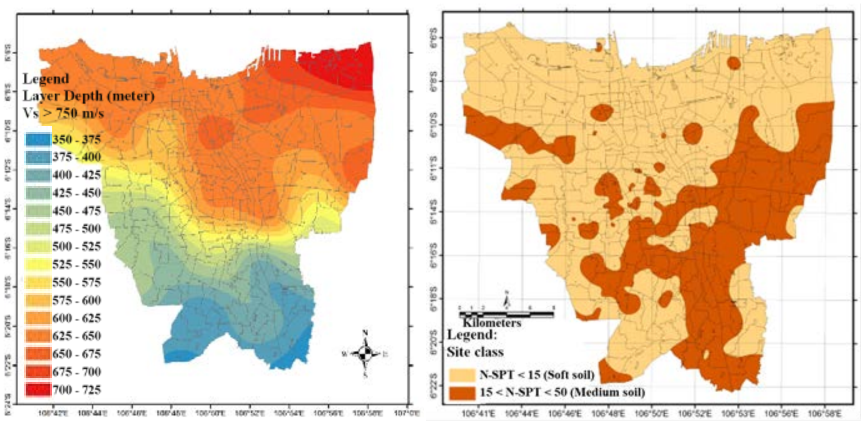
design earthquake-resistant structures. Jakarta, the capital of Indonesia, is the center of governance and economic activities. The city is supported by various vital infrastructure facilities. Jakarta is located in the northern part of Java and is the most densely populated area in Indonesia, with a population density of approximately 15,000 people/km$^2$.

The seismic condition of Jakarta has been investigated in several studies. Generally, the previous studies performed by Irsyam, *et al.* [1] and Ridwan, *et al.* [2] suggest that Jakarta is situated in an active tectonic region. Irsyam, *et al.* [1] have identified that, within a radius of about 250 km, Jakarta is influenced by megathrust subduction at the south of Java island and several shallow crustal faults such as the Sunda Fault, the Semangko Fault, the Cimandiri Fault, and the Lembang Fault.

Several researchers, for example Irsyam, *et al.* [3], Ridwan, *et al.* [2], and Ridwan, *et al.* [4], have identified the local site conditions of Jakarta. The interpretation of site class and bedrock depth in Jakarta is presented in Figure 1. Generally, these studies were performed by using site investigation and geophysical survey. The results of these studies indicate that Jakarta is dominated by two site classes, namely soft soil (SE), with an average SPT value for the first 30 m of depth (N-SPT30) of less than 15, and medium soil (SD), with an N-SPT30 value ranging from 15 to 50. 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. For engineering practice, N-SPT30 can be used to classify the local site class, which is summarized by SNI 03-1726-2012.




(a) (b)

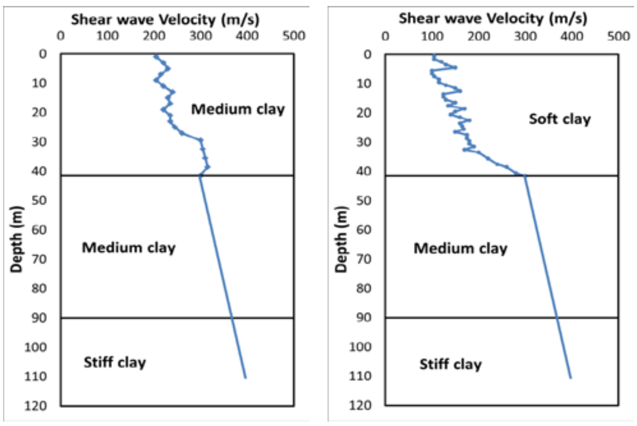
**Figure 1** Contour map of Jakarta: (a) depth of bedrock based on microtremor array measurement conducted by Ridwan *et al.* [4], (b) site classification based on SNI-1726-2012 by Irsyam *et al.* [3].

The objective of this study was to evaluate the effect of the analysis parameters on the characteristics of response spectra at the ground surface by using one-dimensional seismic site response analysis. This study compared two analytical methods, i.e. the equivalent-linear (EQL) method and the non-linear (NL) method.

To compare the performance of the non-linear model, several non-linear models are presented. In addition, the variation of physical properties and geological characteristics was observed. In general, this paper describes the effect of dominant parameters in the Jakarta site. The results of this study suggest that the Indonesian Government should reconsider the seismic hazard in Jakarta.

## 2 Methodology of Parametric Study

A parametric study of seismic site response analysis using local soil conditions in Jakarta was performed based on a 1-D wave propagation model with total stress approach, implemented in Equivalent Linear Method, as performed in several previous studies, such as Mase, *et al.* [5]. Figure 2 presents the two soil column models analyzed in this study. In Figure 2, these two site models were underlain by a cohesive soil deposit of 300 m thickness. In Figure 2, based on SNI 03-1726-2012, the first 40 m of depth was varied into two soil types, i.e. medium clay, where the shear wave velocity ($V_s$) is in the range of 175 to 350 m/s, and soft clay ($V_s$ < 175 m/s).




(a) Site $S_D$ for depth up to 40 m (b) Site $S_E$ for depth up to 40 m

**Figure 2** Profiles of shear wave velocity and site class in two reference sites with a bedrock depth of 300 m.

Furthermore, extrapolation was performed up to 300 m depth. This assumption was implemented due to the limited available site investigation data. In this study, the extrapolation was conducted proportionally by extending $V_s$ at 40 m depth to 300 m depth. It should be noted that at 300 m, the $V_s$ of the site is about 760 m/sec. This value is based on the result of Ridwan, *et al.* [4]. The implementation of the extrapolation method for a 1-D seismic site response analysis can be found in Mase, *et al.* [6]. For the extrapolated layers, the soils were assumed to be medium soil and stiff soil (350 m/s $\leq V_s \leq$ 750 m/s).

This study began by evaluating the influence of analytical methods and soil constitutive models on the characteristics of the surface response spectra. The effect of the analytical methods was reviewed by comparing the surface response spectra of the EQL and the NL approach. Because the EQL approach in available codes typically applies the same computation procedure, this study only employed the computer program STRATA, as proposed by Kottke and Ratjhe [7], to analyze the effect of this method on the surface response spectra. The different available NL codes have different analytical methods and soil constitutive models. For this reason, two NL codes were used in this study. The DEEPSOIL 6.1 code by Hashash, *et al*. [8] considers two NL soil models, i.e. Extended MKZ, developed by Hashash & Park [9], and GQ/H, developed by Groholski, *et al*. [10].

The MKZ model is an extended hyperbolic model that emphasizes the non-linear behavior of the soil. This model adds two parameters to adjust the shape of the backbone curve to depict the appropriate shear stress ($\tau$) and shear strain ($\gamma$), consistent with the laboratory test. Therefore, a realistic hysteresis loop could be generated by this model. The GQ/H model was developed on the basis of capturing small strain and large strain behavior. In GQ/H, a quadratic/hyperbolic model is implemented to define a continuous curve. This model is also able to depict pore pressure generation. The IM model was originally developed by Iwan [11] and Mroz [12]. IM uses several mechanical elements (piecewise elements) with different stiffnesses to depict the non-linear behavior of soils. The IM model is implemented in programs such as NERA, introduced by Bardet and Tobita [13]. These models have been used in several studies, such as Mase [14] and Mase, *et al*. [15].

The microtremor array measurement conducted by Ridwan, *et al*. [2] indicates that Jakarta has variation in the depth of the bedrock ranging from 300 m to 600 m. This variation was subsequently analyzed to observe its impact on the surface response spectra. To observe the effect of $V_s$ at the bedrock, the $V_s$ of the bedrock was also varied using several magnitudes (760 m/s, 1000 m/s, 1500 m/s, and 2000 m/s).

The layer thickness ($H$) used in this analysis was determined by the correlation between the maximum frequency ($f_{max}$) that the soil layer can propagate and the shear wave velocity ($V_s$) of the layer, where $f_{max} = V_s/4H$. Hashash *et al.* [8] proposes that $f_{max}$ should be at least 30 Hz. This means that the thickness of a layer should be designed to be able to propagate a maximum frequency of 30 Hz. A maximum frequency of 30 Hz is expected to capture large-frequency motion generated by an earthquake. Therefore, thin layers should be provided in the model in a simulation to accommodate the applicability of a maximum frequency of 30 Hz. Implementation of this recommendation has been performed by Mase [6]. A detailed explanation of the frequency and layer thickness is presented in Hashash, *et al*. [8].

In this study, the effect of layer thickness on the characteristics of surface response spectra was analyzed using thickness variation following the criteria of Hashash. This variation was only modeled for the layers below 40 m depth up to the underlying bedrock since site investigation data were only available for the first 40 m of depth. In addition, modeling of the soil below 40 m depth was expected to be able to reduce the uncertainty of the extrapolated depth, as recommended by Mase, *et al*. [15]. In general, the geological conditions of the Jakarta Basin are dominated by alluvial fan deposits. Cipta, *et al.* [16] mention that these geologic materials are generally composed of clayey material. Therefore, at the depth below 40 m can be estimated as clay layers.

The plasticity index (*PI*) for site $S_E$ in this study was selected based on site classification per the SNI-1726-2012 standard when *PI* is higher than 20. However, the plasticity index for $S_D$ and $S_C$ is not specified in the SNI-1726-2012. Hence, determination of *PI* for these classes was carried out according to the classification of plastic soil by Burmister [17]. Based on this classification, $S_D$ and $S_C$ were assumed identical to medium and low plasticity, respectively. In other words, site $S_D$ was assumed to have a *PI* value between 10-20%, and $S_C$ had a *PI* in the range of 5-10%. Furthermore, these variations of *PI* were evaluated to understand their effect on the surface response spectra.

The curve models of $G/G_{max}$ and $D$ used as the input parameters in these analyses are shown in Figure 3. These curves describe the relation between shear modulus reduction, or damping ratio, and shear strain. Curve models based on Vucetic and Dobry [18], Sun, *et al*. [19], Idriss [20], and Darendeli [21] were used to evaluate their effects on the surface response spectra.

The seismic ground shaking used as input motion in this study consisted of recorded acceleration time histories on bedrock that were modified based on an earthquake scenario for Jakarta for a return period of 2500 years. These motions were obtained from a probabilistic seismic hazard analysis modified from

Delfebriadi *et al*. [22]. Delfebriadi, *et al*. [22] also performed de-aggregation to define the most credible earthquake for the study area.

The most credible earthquake was further used to determine the reliable ground motions that are relevant for the study area. The details of the de-aggregation procedure can be found in Irsyam, *et al*. [23].

These input motions were modified from the de-aggregation work by Delfebriadi, *et al.* [22] as shown in Figure 4. The variations of the seismic sources represent the difference in input motion characteristics, i.e. amplitude, frequency content, and duration of motion. Kramer [24] mentions that these parameters are important since they significantly influence the intensity of the earthquake.

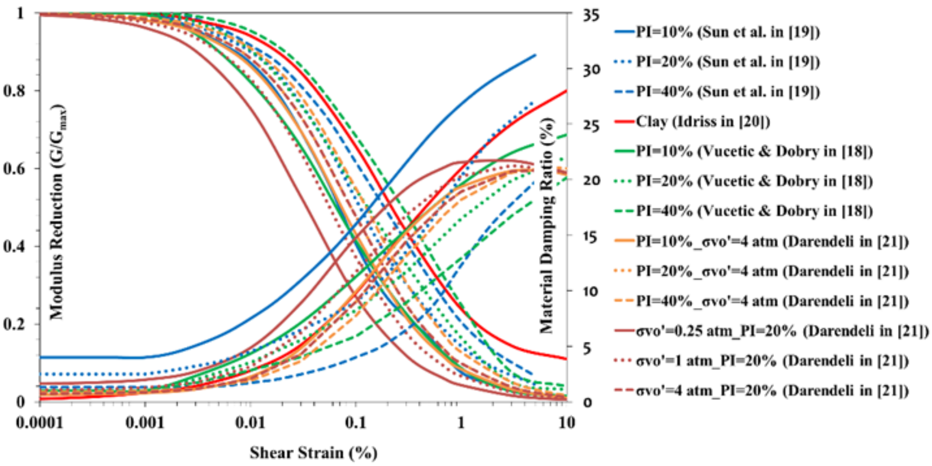



**Figure 3** Curve models of shear modulus reduction and damping ratio for cohesive soils from several references.

Several model assumptions were applied in this study. For example, the NL approach using the MKZ soil model on DEEPSOIL 6.1 code was implemented for all parameters that were not reviewed. The elastic half space assumption was considered for the layer below 300 m with a $V_s$ value of 760 m/s. The layer thickness was designed to be able to propagate a maximum frequency of at least 30 Hz, as recommended by Hashash, *et al.* [8]. The plasticity index for site $S_E$, site $S_D$ and site $S_C$ was assumed to be 40%, 20%, and 10%, respectively.

For dynamic soil properties, the curve models of reduction shear modulus and damping ratio for clayey soils were selected based on Vucetic & Dobry [18]. In Figure 4, three earthquake sources are presented. In this study, the largest magnitude of acceleration and the longest duration were the basis for determining the input motion in the simulation. Therefore, in this study, the acceleration time histories used as input motion were taken from a megathrust earthquake for a return period 2500 years, scaled to acceleration at a spectral period of 0.0 s.

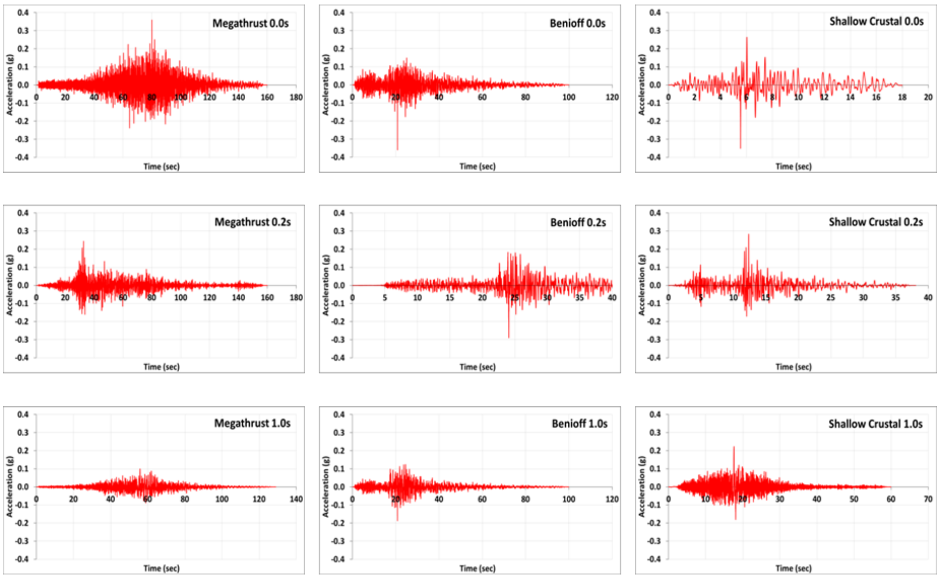



**Figure 4** Modified acceleration time histories on bedrock for Jakarta from megathrust, benioff, and shallow crustal earthquake sources for a return period of 2500 years (modified from Delfebriadi, *et al*. [22]).

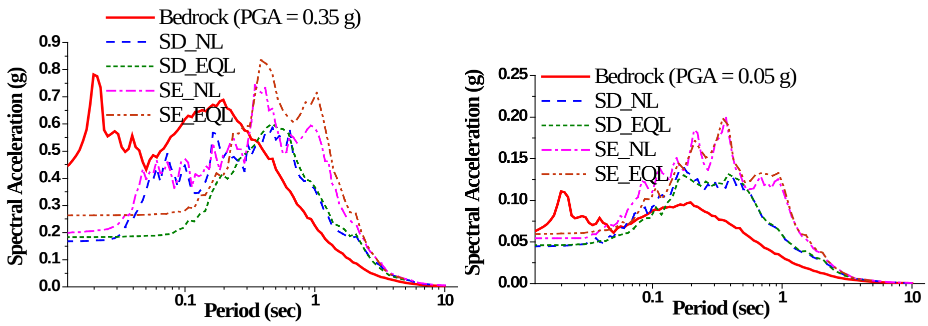
## 3 Results and Discussion

The parametric study of the Jakarta seismic site response analyses resulted in surface response spectra on two reference profiles, i.e. site $S_D$ and site $S_E$. These profiles refer to site classification for a depth up to 40 m. In this study, analytical methods were implemented, i.e. equivalent linear and non-linear models. Several dynamics soil models were implemented in this study. In addition, variation of several properties parameters, i.e. depth of bedrock, shear wave velocity of bedrock, layer thickness, plasticity index, and the characteristics of input motion, was studied.

### 3.1 Analytical Method

The effect of the analytical methods on the surface response spectra was evaluated using the NL and EQL approaches. Both analyses were performed using time histories on bedrock with maximum acceleration (*peak base* *acceleration*/*PBA*) at 0.35 g and 0.05 g. The use of these time histories aims to represent the difference in shear strain conditions in the soil column due to seismic loading. Input motion with an intensity *PBA* level of 0.35 g results in a larger shear strain on the soil column compared to the shear strain attributed to a time history with a *PBA* of 0.05 g. The NL method was applied using the Extended MKZ soil model available in the DEEPSOIL 6.1 code. Furthermore, the results of this method were compared to those of the EQL method using STRATA code.

Figure 5 shows the surface response spectra of the NL and EQL methods at different shear strain conditions. In the sites of $S_D$ and $S_E$, the input motion with *PBA* at 0.35 g produced maximum shear strains of 0.08% and 0.23%, respectively (high strain levels). Meanwhile, the input motion with *PBA* at 0.01 g gave maximum shear strains on the site $S_D$ and site $S_E$ of 0.01% and 0.03%, respectively (low strain levels). In high-strain conditions, the characteristics of the surface response spectra yielded by these two methods were relatively different for both sites.



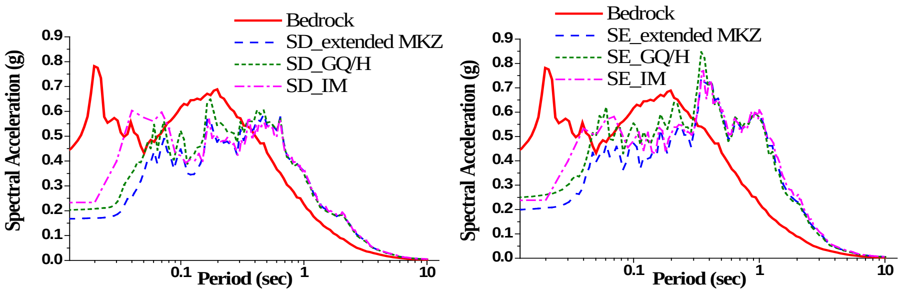

(a) Surface response spectra for PGA 0.35 g (b) Surface response spectra for PGA 0.05 g

**Figure 5** The surface response spectra of non-linear and equivalent-linear approaches for a megathrust earthquake with a return period of 2500 years scaled at a spectral period of 0.0 s.

The EQL method estimated higher spectral accelerations on the ground surface than the NL method at short periods, particularly in site $S_E$, as shown in Figure 5(a). For low strain conditions (Figure 5(b)), the NL and EQL methods tended to give a similar response for sites $S_D$ and $S_E$. Both methods yielded similar estimates of acceleration across the spectral period. A similar trend has also been observed by other researchers (Mase, *et al*. [5] and Mase, *et al*. [15]).

## 3.2 Soil Constitutive Models

The soil constitutive models used in this parametric study were the Extended MKZ, GQ/H, and IM models. The surface response spectra of the two site profiles that were generated by these three soil models are presented in Figure 6.



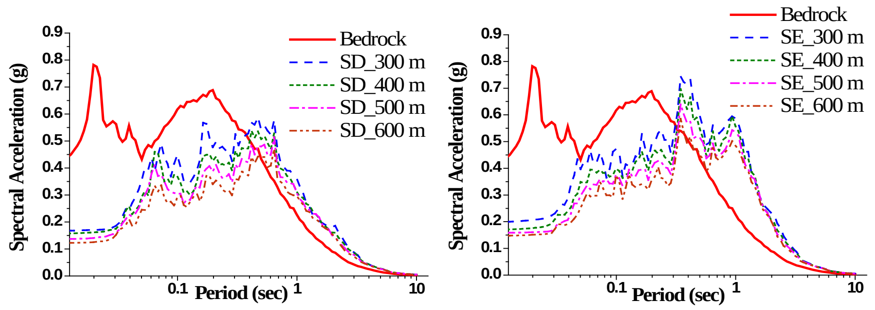

(a) Surface response spectra for site $S_D$ (b) Surface response spectra for site $S_E$

**Figure 6** Surface response spectra of the three soil models for a megathrust earthquake with a return period of 2500 years scaled at spectral a period of 0.0 s.

The results of this study show that all soil models gave relatively different predictions of the surface response spectra at short periods. This is due to the fact that the overestimation of the spectral acceleration at short periods is strongly controlled by the soft layer. For this condition, the IM model, which implements piecewise elements to predict the spectral acceleration at short periods, yields relatively high values. This is due to the fact that the IM model predicts the non-linear behavior with piecewise linear assumption.

Therefore, the spectral acceleration controlled by the soft layer tends to be higher at short periods. This in contrast with the MKZ and the GQ/H models, which use a hyperbolic model to reduce the linear assumption for estimating the non-linear behavior of soils.

The same trend has also been found in several other studies (for example in Mase, *et al.* [5]). However, at longer periods (spectral period greater than one second), the models tend to give similar predictions of spectral acceleration. This is due to the fact that at long periods, the spectral acceleration is relatively lower than at short periods. For seismic wave propagating through horizontally layered soils, the spectral acceleration is related to the stiff material. For this condition, all models and NL are able to capture the nonlinear behavior at the stiff layer. Therefore, at long periods, the prediction resulted from all models is relatively consistent. This trend was also observed in other studies (for example Kumar, *et al.* [25]).




(a) Surface response spectra for site $S_D$ (b) Surface response spectra for site $S_E$

**Figure 7** The effect of depth of bedrock on the surface response spectra for a megathrust earthquake with a return period of 2500 years scaled at a spectral period of 0.0 s.

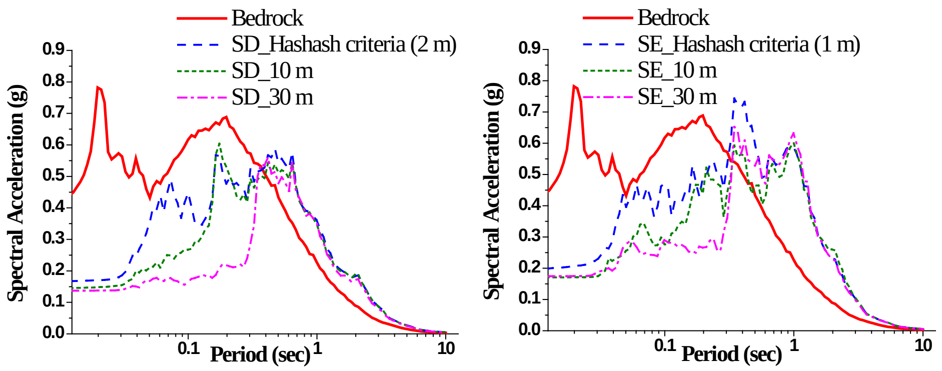
## 3.3 Layer Thickness

Layer thickness variation of the two soil columns was carried out on the soil deposit below 40 m depth, where the shear wave velocity of this deposit was extrapolated proportionally toward the shear wave velocity of bedrock of 760 m/s. The thickness of the extrapolation layer was varied into three models, i.e. (1) with the thickness modeled following the criteria recommended by Hashash, *et al*. [8], (2) with a layer thickness of 10 m, and (3) with a layer thickness of 30 m.

The results of the analyses presented in Figure 8 show that the thicker the modeled soil layer, the smaller the amplitude of the spectral acceleration yielded at the soil surface. These results also show that the layer thickness modeled following the criteria Hashash, *et al*. [8] gave a higher predicted response compared to the other thickness variations. A thicker modeled soil layer provided a lower natural soil frequency. A soil layer with a lower natural frequency prevents the component of seismic wave motion with higher frequency from being captured during its propagation to the ground surface. Therefore, the analysis that modeled a soil layer with lower frequency (greater layer thickness) resulted in smaller surface response spectra, especially at short periods.

Hashash, *et al*. [8] mention that to determine the layer thickness, a wavelength analysis related to frequency and $V_s$ should be performed. This is because the maximum frequency is strongly related to the captured soil response. It indicates that to obtain a reliable soil response, a thin thickness layer would be suitable. The same procedure has been also implemented by several other studies, such as Bhardwaj and Anbazhagan [27] and Mase, *et al*. [28].

Therefore, for engineering practice, Hashash, *et al.*'s criteria could be considered for earthquake resistant designs.




(a) Surface response spectra for site $S_D$ (b) Surface response spectra for site $S_E$

**Figure 8** Surface response spectra due to the effect of layer thickness for a megathrust earthquake with a return period of 2500 years scaled at a spectral period of 0.0 s.

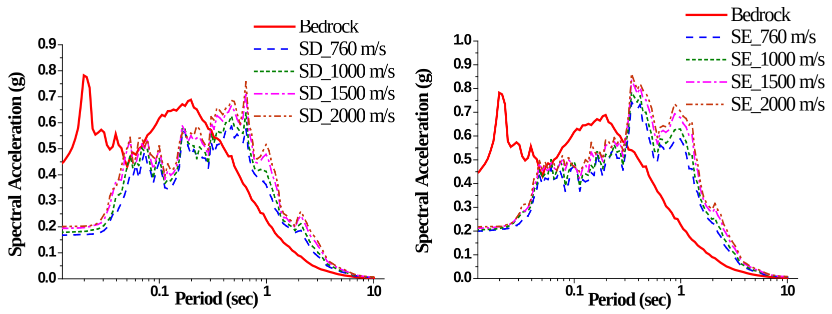
## 3.4 Shear Wave Velocity ($V_s$) of Bedrock

The influence of shear wave velocity of bedrock on surface spectrum response was evaluated by varying this parameter at 760 m/s, 1000 m/s, 1500 m/s, and 2000 m/s. Variations were only performed on $V_{s\ bedrock}$, while the $V_s$ parameter of the soil deposits was maintained constant, i.e. the same values as shown in Figure 2 were used.

This evaluation indicated that the surface spectral accelerations on two site profiles tended to have larger amplitudes as the $V_s$ of the bedrock increased (as shown in Figure 9).

A higher $V_s$ of the bedrock indicates that the seismic wave energy is also greater. This causes a larger shaking intensity at the ground surface. This result is consistent with Jakka & Roy [29], who state that an increase of bedrock $V_s$ means an increase of spectral acceleration at short periods.

Figure 9 shows that the difference in spectral acceleration is not significantly large. This indicates that the variation of $V_s$ of bedrock has little effect. Therefore, for reliable results, an accurate estimation of shear wave velocity from geophysical survey should be performed.

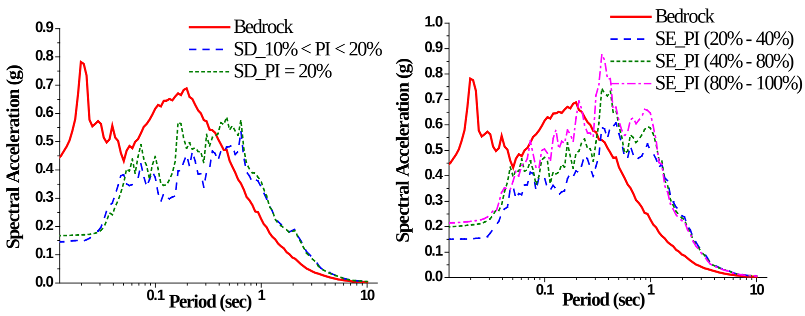



(a) Surface response spectra for site $S_D$ (b) Surface response spectra for site $S_E$

**Figure 9** Surface response spectra due to the effect of shear wave velocity of bedrock for a megathrust earthquake with a return period of 2500 years scaled at a spectral period of 0.0 s.

## 3.5 Plasticity Index (*PI*)

The effect of *PI* on the surface response spectra was evaluated through $G/G_{max}$ and Damping curves. For the purposes of this study, the reference curves proposed by Vucetic & Dobry [18] were used. Based on these reference curves, *PI* in the range 10% ≤ *PI* < 20% has different curves than *PI* at 20%. Therefore, the site profile of $S_D$ was modeled with these two *PI* values. Meanwhile, the $S_E$ profile was modeled with three variations of *PI* interval values, i.e. 20% ≤ *PI* < 40%, 40% ≤ *PI* < 80%, and 80% ≤ *PI* ≤ 100%.

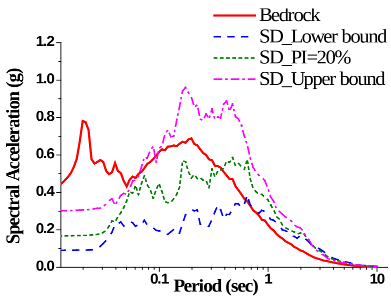



(a) Surface response spectra for site $S_D$ (b) Surface response spectra for site $S_E$

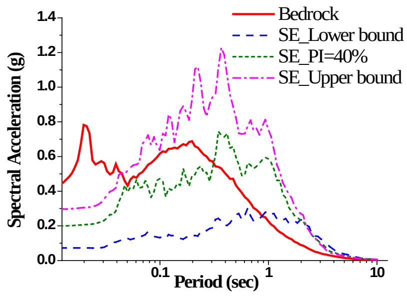
**Figure 10** The effect of *PI* values on the surface response spectra due to a megathrust earthquake with a return period of 2500 years scaled at a spectral period 0.0 s

Based on the characteristics of the surface response spectra presented in Figure 10, a higher *PI* causes greater acceleration on the ground surface at most spectral periods. This is attributed to degradation of the damping value when the *PI* of the soil increases. The lower damping causes the soil to absorb less energy. This means that more energy is allowed to propagate, which can consequently result in greater response intensity of the soil surface due to seismic loading. This observation is consistent with the investigations by Fatahi & Tabatabaiefar [30].

Figure 11 illustrates the effect of the boundary conditions of the shear modulus reduction and damping ratio curves on the surface response spectra. The curves used in this evaluation have been proposed by Vucetic & Dobry [18]. The upper bound curve represents the highest *PI* value for cohesive soil and the lower bound curve represents the lowest value. Figures 10 and 11 show that the *PI* values had a significant effect on the characteristics of the surface response spectra. When the *PI* value is unknown, the upper bound target curve in the site response analysis will produce the largest acceleration on the surface along spectral periods. This means that the use of this curve gives a more conservative result. However, the use of a target curve in the maximum range of *PI* of 20% for site $S_D$ produced a more accurate response compared to that of the upper bound curve, because *PI* values greater than 20% do not represent the characteristics of site $S_D$ exactly.




(a) Surface response spectra for site $S_D$

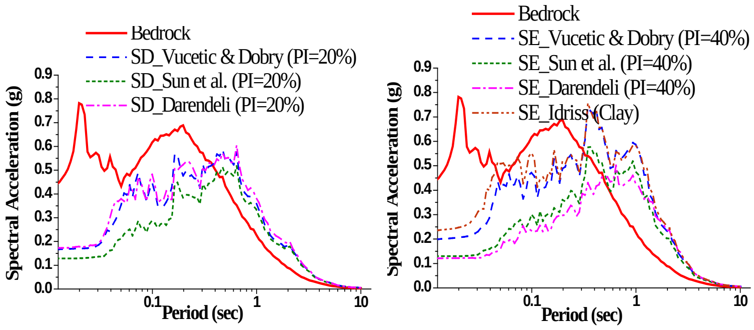



(b) Surface response spectra for site $S_E$

**Figure 11** The effect of boundary curves of $G/G_{max}$ and $D$ on the surface response spectra due to a megathrust earthquake with a return period of 2500 years scaled at a spectral period of 0.0 s.

### 3.6 Reference Curve Models of $G/G_{max}$ and Damping Ratio

The analysis for site $S_D$ was performed using three models of target curves, developed by Vucetic & Dobry [18], Sun, *et al*. [19], and Darendeli [21]. The site profile of $S_E$ was also analyzed using the three references of the curve models above and added to the target curves proposed by Idriss [20] for clay soil. The use of the Idriss curve was only applied to site $S_E$. Plotting the result against the other reference curves indicated that the Idriss curve for clay soil was similar to the curves with *PI* in the range of 40-80%.




(a) Surface response spectra for site $S_D$ (b) Surface response spectra for site $S_E$

**Figure 12** The effect of reference curve models of $G/G_{max}$ and Damping ratio on the surface response spectra due to a megathrust earthquake with a return period of 2500 years scaled at a spectral period 0.0 s.

Figure 12 shows that the use of the reference curve models from Vucetic and Dobry [18] and Darendeli [21] on the $S_D$ profile gave a similar response at the ground surface and a larger response compared to those from Sun, *et al*. [19].

Meanwhile, on site $S_E$, the curve models of Vucetic & Dobry [18] and Idriss [20] yielded surface response spectra that were similar to or greater than those of Sun, *et al*. [19] and Darendeli [21]. The use of the curve from Vucetic & Dobry [18] on these two site profiles yielded a larger surface acceleration than the other target curves. Generally, the soil properties contributed to the shear modulus and the damping ratio. Several parameters, such as plasticity index, and confining stress, can influence the shear modulus curve and damping ratio, Therefore, for reliable results, many parameters should be included in estimating the dynamic properties.

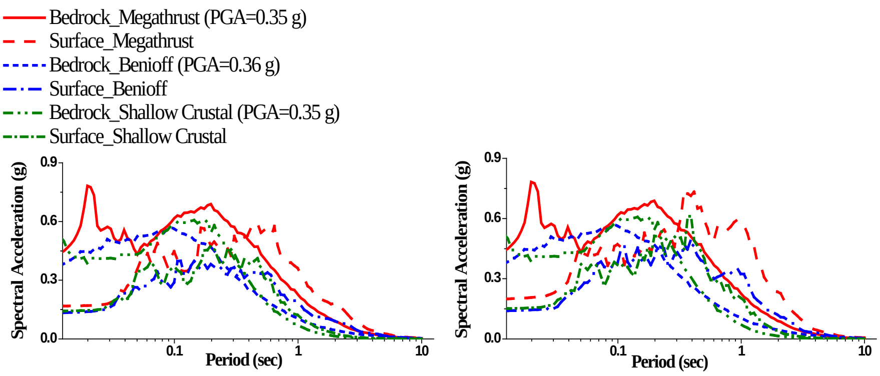
In this study, the model of Darendeli [21] required some soil property details as input to generate the dynamic properties. Since these parameters contribute to the seismic response, the spectral acceleration at short periods tends to be realistic, especially in connection with other considered parameters, such as site class. However, for engineering practice, the conservative models provided by Vucetic & Dobry [18] and Idriss [20] are still acceptable, as stated by Mase, *et al*. [5].

## 3.7 Seismic Ground Motion Characteristics

The acceleration time histories used as input motion in evaluating the effect of seismic ground motion characteristic on surface response spectra were derived from megathrust, benioff, and shallow crustal earthquakes with a return period of 2500 years scaled at a spectral period of 0.0 s as seismic sources. These three input motions have the same *PBA* amplitude of about 0.35 g. Although they are similar in terms of *PBA*, the characteristics of frequency content and duration are different.

The scaling of acceleration time history of a megathrust earthquake with a return period of 2500 years at different spectral periods was performed to get input motions that have different *PBA* amplitudes but still have the same frequency content and duration.

The scaling factors used in this study were based on the acceleration at spectral periods of 0.0 s, 0.2 s, and 1.0 s. These scaling factors generated the input motions with *PBA* were 0.35 g, 0.24 g, and 0.1 g, respectively. Furthermore, to describe very small strain conditions due to seismic loading, the input motion of the megathrust earthquake was scaled with a *PBA* of 0.05 g.

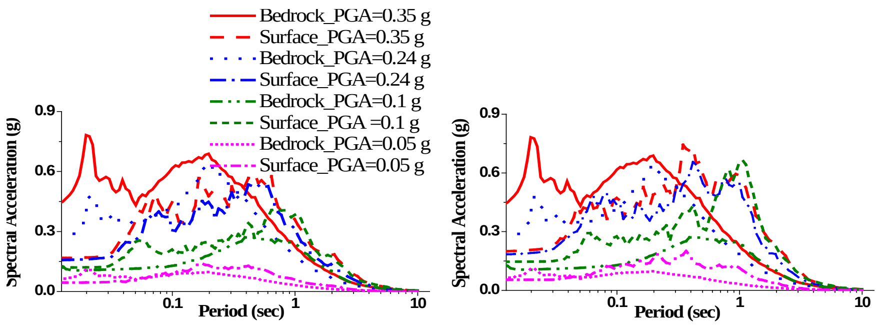



(a) Surface response spectra for site $S_D$ (b) Surface response spectra for site $S_E$

**Figure 13** Effect of frequency content and duration of the input motion on the surface response spectra due to megathrust, benioff, and shallow crustal earthquakes with a return period of 2500 years scaled at a spectral period of 0.0 s.

The result showed that the megathrust earthquake produced the highest spectral acceleration response on the ground surface compared to the benioff and shallow crustal earthquakes, as shown in Figure 13. It exhibited a long-period effect caused by the megathrust earthquake, which is significantly undergone by soft soil layers with low frequency (Ye, *et al.*, [31] and Mase, *et al.* [32]). This is attributed to the higher frequency content from megathrust earthquakes, which results in larger spectral acceleration values on the ground surface. Higher frequency content reflects the greater earthquake energy level of the earthquake compared to other seismic sources.

Figure 14 shows that input motions with a *PBA* of 0.35 g and 0.24 g experience deamplification of seismic acceleration on the ground surface at short to moderate periods. The amplification of these two input motions started to occur at spectral periods close to 1.0 s (long periods). Meanwhile, the amplification of input motions with a *PBA* of 0.1 g and 0.05 g occurred almost throughout the whole of the spectral periods. The input motion with a *PBA* of 0.35 g generally yielded the highest spectral acceleration on the ground surface. These results indicate that the amplitude of input motion has a significant effect on the surface response spectra.




(a) Surface response spectra for site $S_D$ (b) Surface response spectra for site $S_E$

**Figure 14** The surface response spectra of several *PBA*s of input motion due to a megathrust earthquake with a return period of 2500 years.

## 4 Conclusions

This paper presented a parametric study of one-dimensional seismic site response analysis based on the local seismic site conditions of Jakarta. The effect of the variation of parameters on spectral acceleration was observed. In general, several parameters, i.e. an increase of the *Vs* of the bedrock, plasticity index, amplitude of input motion, and frequency content of input motion tended to increase the spectral acceleration at the ground surface. This study also revealed that the spectral acceleration at the ground surface tended to decrease by the increase of the depth of the bedrock's layer thickness. Overall, the results depended strongly on the analytical method used, especially when comparing equivalent linear and non-linear methods. Different characteristics also appeared due to variation of the soil constitutive model. Therefore, the implementation of soil modeling in 1D seismic response analysis should consider the reliability of the data to obtain accurate predictions.

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