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Research Article

Nonlinear Seismic Response Based on Different Site Types: Soft Soil and Rock Strata

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Site condition is an important part of urban underground space development and construction. The seismic fortification of the site plays an important role in the safety of the whole project. To study the seismic dynamic response of the site under different geological conditions, seismic waves of different intensities (Chichi wave and Kobe wave) were input to a rock site with good geological conditions and a soft soil site, respectively. In this paper, the dynamic responses of these two types of free sites were calculated and analyzed using DEEPSOIL numerical simulation software. The dynamic responses of different types of sites under strong shock and persistent earthquakes are discussed under the equivalent linear and nonlinear conditions, and the related dynamic parameters are studied. The results show that the equivalent linear method is more effective than the nonlinear method, especially in the calculation of the strong nonlinear soft soil response induced by strong earthquakes. The amplification effect is more obvious in rock layer sites under strong earthquakes, and the "weakening" effect of soft soil sites is more obvious. Arias's strength values show that both types of sites are safe under the incident of the two waves, but soft soil sites have better seismic performance. The results calculated by the equivalent linear method are larger and more unsafe; in particular, in the case of a strong earthquake with a stronger nonlinear Kobe wave, the results are more inaccurate. The purpose of this study is to provide a reference for seismic design and reinforcement measures of underground engineering.

1. Introduction

Site seismic response analysis is an important part of site seismic safety evaluation. It is of great reference value to the design of seismic-sensitive dynamic parameters of sites and structures, which will affect the subsequent design and construction of underground space and structure. In recent years, the macroscopic seismic damage data and the observation records of strong earthquakes have proved that the site conditions not only have an important influence on the peak acceleration and spectral shape of ground motion but also have a very close relationship with the seismic response and earthquake damage mechanism of different types of engineering structures. Some scholars have studied the seismic response of soft soil sites. Huang et al. [1] adopted the one-dimensional equivalent linearized frequency domain analysis method to study the seismic response of the site in the deep soft soil overburden area of Shanghai and established a dynamic analysis model. Taking El Centro seismic wave as an example, the acceleration response and spectral characteristics of the seismic response of the soil in the Shanghai area are analyzed. The results show that the surface peak ground acceleration (PGA) of the soft soil site has amplification characteristics when the seismic category is 7°; that is, the site peak ground acceleration (PGA) is equal to 0.1 g. The spectral composition of surface acceleration has the characteristics of low-frequency amplification and high-frequency filtering. The preeminent period of the response spectrum of ground motion acceleration also tends to move towards the long period direction. Huang et al. (2000)

conducted an experimental study on the site seismic response of soft soil sites with soft interlayers in Hong Kong. Through analysis, they found that the weak interlayer magnified the long period of response spectrum and reduced the dynamic intensity of the earthquake. In addition, they also proposed a normalized design response spectrum for such sites. Cao et al. [2] constructed a seismic response analysis model for various soil layers based on soft soil sites in the Jianghuai region of China. They analyzed the effects of the buried depth and thickness of the soft layer on the peak surface acceleration of soft soil under three kinds of strong earthquake conditions. The results show that the peak surface acceleration and the amplification coefficient of the soil layer decrease with the increase of the buried depth and thickness of the soft layer. When the buried depth and thickness of the soft interlayer exceed a certain value, the site begins to have a shock absorption effect. The deeper the buried depth and thickness of the soft layer are, the higher the ground vibration intensity is, and the more obvious the shock absorption effect is. Ma et al. [3] conducted a series of large-scale drainage dynamic triaxial tests to study the dynamic characteristics of saturated sand and gravel soil in Nanning and established a model which can accurately predict the dynamic deformation characteristics of saturated round gravel.

Numerical analysis and model test methods are often used to analyze site seismic response. One-dimensional site response methods are commonly used nonlinear methods and equivalent linear methods. The equivalent linear method approximates the nonlinear problem and is not as accurate as the nonlinear method in calculating the seismic induced site dynamic response. DEEPSOIL (Hashash et al. [4]) is one-dimensional site seismic response analysis software that allows linear, equivalent linear, and time-domain nonlinear analyses of the site and considers the effects of pore water pressure. From the engineering practical point of view, DEEPSOIL numerical software provides the best time-domain nonlinear elastoplastic calculation. Sun et al. [5] proposed the method of global equivalent shear strain and compiled the calculation program of seismic response of soil layer based on equivalent linearization, which can be used to simulate the amplification of strongly nonlinear site earthquakes under strong earthquakes. Wang et al. compared and verified the computational results of weakly coupled nonlinear site response simulated by Abaqus and one-dimensional liquefaction site seismic response calculated by DEEPSOIL v6.0, and obtained more accurate propagation characteristics of high-frequency seismic waves and filtering effect of liquefaction site. Zhang et al. [6] established a soft soil site model with DEEPSOIL software and analyzed the seismic response of a typical III type soft soil site (according to Chinese industry standards). They studied the sensitivity of fitting parameters and the effects of equivalent linear method and time-domain nonlinear method on response spectrum of peak acceleration and surface acceleration and pointed out the shortcomings of equivalent linear method in analyzing the seismic response of soft soil sites. Gao et al. [7] used the FLUSH finite element analysis program to calculate the surface acceleration peak value and acceleration response spectrum under three different input waves and different replacement rates in the two-dimensional reinforced composite foundation site. Based on some site conditions in the loess area, Liao et al. [8] obtained the dynamic parameters of soil: dynamic shear modulus G and equivalent viscous damping ratio D, through dynamic triaxial tests. A heterogeneous soil layer model considering the wave velocity and the depth of weak interlayer was established. El Centro wave was input to the bottom of bedrock for experimental simulation. The results show that the soft interlayer in the loess stratum will reduce the maximum acceleration of seismic response and the ground acceleration. Ou et al. studied the dynamic response of concrete dam of large mud dump reservoir induced by artificial synthetic seismic waves and simulated it with viscoelastic artificial boundary.

The study of urban underground space often involves the interaction and response of soil and structure, mainly considering the dynamic response of structures (Ma et al. [9], Chen et al. [10], Han et al. [11], Wang et al. [12]). However, the nonlinear problem of the site under earthquake and the amplification effect of the site are also very important. In this paper, the seismic dynamic response of the actual engineering sites was analyzed on the basis of the theory of seismic engineering, combined with the geological exploration data in the two actual engineering sites. In order to study the seismic dynamic response of the site under different geological conditions, seismic waves of different intensities (Chichi wave and Kobe wave) were input to a rock site with good geological conditions in Nanning City, Guangxi Province, China, and a soft soil site with bad geological conditions in the coastal area of Guangdong Province, China. Moreover, the effects of different types of earthquakes and site geological conditions on the dynamic parameters of site seismic response were discussed using the DEEPSOIL v7.0 numerical simulation software, and the site safety and amplification effects were also analyzed.

2. Engineering Projects

Baoneng City Square Project of Nanning Wuxiang New Area is located in Yongning District, Nanning City. The site belongs to the denuded hilly remnant geomorphic unit. The site is near Yongjiang River. No surface water is found on the site. The groundwater is mainly upper stagnant water, and the surface roughness is of class B (according to Chinese industry standards). Field earthquake basic intensity is 7°, and seismic fortification intensity is 7°. The soil of the building site is classified as II (according to Chinese industry standards). The basic seismic acceleration of the design is 0.10 g. The surface bearing capacity is high, and the upper stagnant water mainly occurs in the plain fill, red clay, and gravel. The stable water level depth is 0.50 m–20.40 m, and the stable water level elevation is 74.16 m–105.79 m. The main replenish source is surface water, which is greatly affected by the season. The bedrock fissure water mainly occurs in strongly weathered argillaceous siltstone, strongly weathered calcareous siltstone, strongly weathered siliceous rock, and moderately weathered calcareous siltstone (the local limestone sections are manifested as karst cave fissure water). During the survey, the stable water level elevation is 65.27 m–98.98 m, and the water quantity is relatively stable. The equivalent shear wave velocity of the overlying soil of the site is 170.00–200.00 m/s. Through sorting out the geological prospecting data of Baoneng City Square in Wuxiang New District of Nanning and the headquarter base of Nanning Qianhai Life Insurance, unified stratigraphic parameters are selected for calculation after statistical analysis. The soil parameters are shown in Table 1, and the parameters in this table will be used to represent the specific geological types in part areas of Nanning in the subsequent seismic dynamic response analysis.

The soft soil site is based on a geological survey report of the data of 384 boreholes drilled in an engineering site in the coastal soft soil area of Guangzhou. Most of the strata in the coastal areas of Guangzhou are mainly composed of silt, with a thickness of about 10–30 m. According to the geological origin, the site strata are successively divided into quaternary system (Q^{ml}), grain filling soil <1-3>, marine and continental strata (Q^{mc}), silt layer <2-1>, diluvial layer (Q^{al+pl}), fine sand layer <3-1>, medium sand layer <3-2>, eluvial soil (Q^{el}), and hard plastic sandy clay layer <4-1>; the bedrock is mainly Yanshanian granite (γ), strongly weathered layer <5>, moderately weathered layer <6>, and slightly weathered layer <7>. The physical and mechanical parameters of soil in each layer are shown in Table 1. Soil parameters of soft soil base are shown in Table 2.

3. Calculation Model and Analysis Method

3.1. Theory and Model. The MRDF pressure-dependent hyperbolic model [13], a non-Masing model inherent in DEEPSOIL software, was used to describe the hysteretic behavior of media loading and unloading. By introducing the reduction factor, the modulus reduction curve and damping curve can be fitted simultaneously. The damping performance is improved as follows:

$$\xi_{\text{MasingHysteretic}} = F(\gamma_{\text{Max}}) * \xi_{\text{Masing}}, \tag{1}$$

where $F(\gamma_m)$ is the reduction factor calculated by the function of γ_m, γ_m is the maximum shear strain experienced by the soil at any given moment, and ξ_{Masing} is the hysteretic damping calculated by Masing rule based on the modulus reduction curve.

In this calculation, we adopted the MRDF-Darendeli model, which was proposed by Darendeli in 2001 and improved the reduction coefficient on the basis of the MRDF pressure-dependent hyperbolic model. This formula is a modified hyperbolic model based on experience, which is used to predict the nonlinear dynamic response of different types of soil. The developed model is implemented as a simplification factor in the following form:

$$F(\gamma_m) = P_1\left(\frac{G(\gamma_m)}{G_0}\right)^{P2}, \tag{2}$$

where γ_m is the maximum shear strain experienced at any given time; $G(\gamma_m)$ is the shear modulus at γ_m; and P_1, P_2, and P_3 are the fitting parameters. By setting $P_1 = 1$ and $P_2 = 0$, the reduction factor is equal to 1 (regardless of the value of P_3), and the model is reduced to the extended Masing criteria.

Figure 1 shows the models established under two different geological conditions. Model 1 is the model under geological conditions in Nanning area, and model 2 is the model under soft soil conditions. The profile of model 1 has a total depth of 115 m, a natural frequency of 0.9646 (Hz), and a natural period of 1.037 seconds. Model 2 has a total depth of 62 m, a natural frequency of 0.8071 (Hz), and a natural period of 1.239 seconds. It can be seen that model 1 is dominated by relatively hard rock strata, while model 2 has poor geological conditions and is dominated by silt.

3.2. Input Parameters. Figures 2 and 3 show acceleration time history curves of two different types of input seismic waves. The peak acceleration of the first type of seismic wave is no more than 0.2 g, while the peak acceleration of the second type of seismic wave is no more than 0.8 g. The first type of seismic wave lasts longer than the second, which can be described as a short, strong earthquake.

Figures 4 and 5 show variation of peak spectral acceleration with the period (response spectrum) and the relationship between Fourier amplitude and frequency (Fourier amplitude spectrum) after input of different seismic waves, respectively. It can be seen that the peak spectral acceleration of Kobe input seismic wave exceeds 2.5 g at low period and that of Chichi input seismic wave is about 0.5 g. As shown in Figure 5, the Fourier amplitude of the two seismic waves is very large at low frequencies, and the maximum value of Kobe input wave is 0.6 g-s, which is twice that of Chichi's input wave 0.3 g-s.

Figure 6 shows Fourier amplitudes and 5% damped spectral acceleration of the two input seismic waves. It shows that the amplitude of the two kinds of seismic waves is higher at low frequency and low periods. The 5% damping spectrum acceleration amplitude of the Kobe input wave is more than 2.5 g, and that of the Chichi input wave is about 0.5 g.

4. Numerical Analysis

The simplification of some parameters is involved in time-history analysis and spectrum analysis, and the meaning of parameter representation is explained as follows: peak spectrum acceleration (PSA); peak spectrum acceleration (PSV); peak ground acceleration (PGA); equivalent linear (EL).

Arias intensity I_a is a quantity proposed by the American scientist Arias to calculate the total intensity of ground motion using strong earthquake records. It is an important dynamic parameter that can be used to judge the degree of the earthquake disaster. It describes the overall energy released by the observed field point vibration, that is, vibration amplitude, frequency, and other information. Compared with other ground motion parameters, it can reflect the whole situation of the vibration more comprehensively. Wang et al. [14] studied the dynamic influencing factors of a landslide triggered by the Wenchuan earthquake and

Table 1: Soil parameters of a project in Nanning area.

Order	Name	H (m)	f_{ak} (kPa)	ρ (g/cm^3)	Vs (m/s)
1-3	Plain fill	5	\	1.80	130
2-1	Hard plastic red clay	15	200	1.90	320
2-2	Plastic red clay	4	160	1.82	200
2-3	Gravel	2	300	2.21	600
3-1	Broken limestone	6	700	2.12	550
4-2	Highly weathered argillaceous siltstone	13	450	1.95	520
4-3	Strongly weathered calcareous siltstone	11	600	1.96	530
4-4	Highly weathered siliceous rock	20	420	1.98	580
5-1	Limestone	12	5000	2.23	610
5-2	Moderately weathered calcareous siltstone	6	2600	2.45	620
5-3	Breccia	21	1200	2.50	700

Table 2: Soil parameters of soft soil base.

Order	Name	H (m)	f_{ak}/f_a (kPa)	ρ (g/cm^3)	Vs (m/s)
1-1	Plain fill	1	\	1.8	130
2-1	Silt	25	40	1.62	110
3-1	Fine silt	3	100	1.80	230
3-2	Medium-coarse sand	3	180	1.90	300
4-1	Hard plastic sandy clay	2	250	1.93	550
5	Intensely weathered granite	2	500	2.10	520
6	Moderately weathered granite	6	2500 ~ 3000	2.40	550
7	Breezy granite	20	8000 ~ 10000	2.50	600

discussed the influence relationship between the Arias intensity parameters and the degree of the earthquake disaster. In that paper, the severity of landslides is differentiated by Arias intensity I_a. Taking the unidirectional Arias intensity $I_a = 2$ m/s as the boundary, I_a values in the two horizontal directions of the key disaster area and the sub-key disaster area are all greater than 2 m/s, while those in the general area and other areas are almost less than 2 m/s. When the sum of the two horizontal energy releases is taken as the criterion, $I_a = 4$ m/s can be taken as the criterion. Dong et al. [15] discussed the simulation accuracy of seismic liquefaction of sandy soil foundation, by carrying out shaking table test and using OpenSees software for numerical simulation, and verified the accuracy of Arias strength in the horizontal direction as anti-liquefaction strength. However, Arias intensity is closely related to the seismic records in the specific region, and the amplitude of Arias intensity may vary significantly in different areas of the same disaster zone due to the influence of earthquake source, propagation path, and local site conditions. Therefore, the seismic damage level of specific sites still needs to be analyzed by combining Arias strength with other site dynamic parameters and relevant data.

4.1. Output Time-History Analysis. According to Figure 7, the value of acceleration calculated by the equivalent linear method is larger than that calculated by the nonlinear method. In the nonlinear calculation results, the amplitude of acceleration of the two types of seismic waves is similar, and the acceleration duration of the output of the Chichi wave is longer. By comparing the output PGA value in Figure 7 with the acceleration input in Figures 2 and 3, it can be seen that the acceleration peak value in Figure 7 is greater than those in Figures 2 and 3, in both model 1 and model 2 when input in both Kobe wave and Chichi wave. The actual output values are amplified, indicating that the sites have a magnifying effect. In model 1, the acceleration amplitude of Kobe's output wave is obviously much smaller than that of the input wave, while the peak values of Chichi's input wave and output wave are similar. Model 2 weakens both the Chichi wave and the Kobe wave. However, the weakening of the Kobe wave is more serious. Therefore, affected by the site conditions, seismic waves will be magnified and reduced to varying degrees. The site amplification effect of model 1 rock site is more obvious than that of model 2 soft soil site. The results of the equivalent linear calculation of site acceleration are too large. The results of nonlinear calculation considering the nonlinear behavior of soil materials are more accurate, especially in the dynamic response analysis of soft soil and clay sites. The equivalent linear method is more inaccurate in calculating the result of soft field than that of sites in good soil conditions.

4.2. Acceleration Spectrum Analysis. Figure 8 shows the surface response spectra of model 1 and model 2, respectively. As can be seen, when the equivalent linear calculation is adopted, the output results of the Kobe seismic wave differ greatly, and the results are not accurate. The two different sites reduced the Kobe wave more than the Chichi wave. In model 2, due to the damping effect of the soil, the soft soil site has a more obvious weakening effect on the peak spectral acceleration, especially for the sudden strong earthquake like the Kobe wave. Because the intensity of the Kobe wave is larger than that of the Chichi wave, the nonlinear

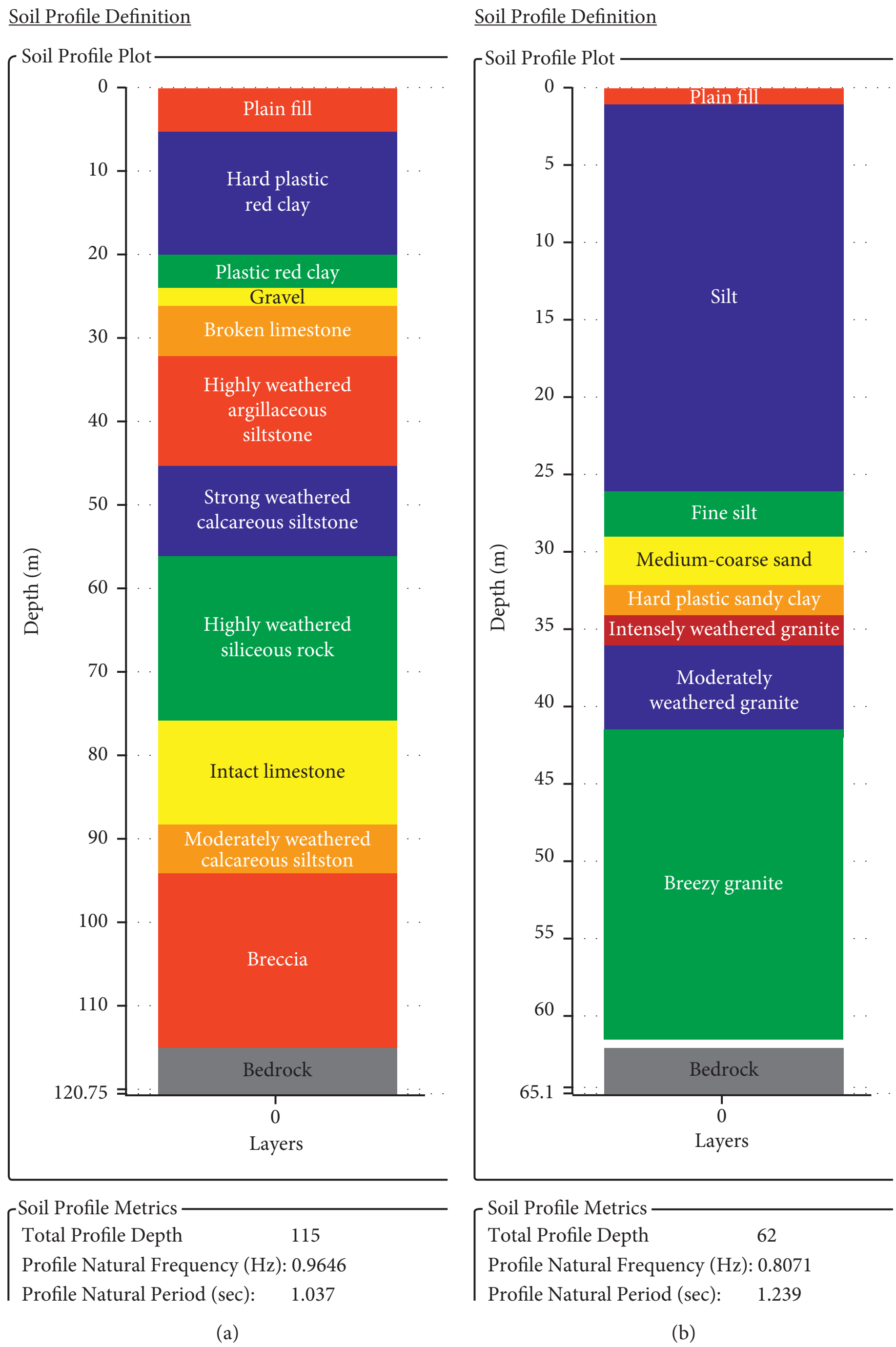


FIGURE 1: Establishment of the model: (a) model 1 and (b) model 2.

characteristic is stronger. Therefore, the error in performing equivalent linear calculations is larger. Furthermore, this error is amplified in the rock strata with larger elastic modulus and better soil conditions. In model 2, the calculation error of the soft soil layer is very large, partly because of its stronger nonlinearity. In addition, the amplification effect of the site is also reflected in Figure 8. The PSA values in Figure 8 are all larger than the acceleration values of Chichi and Kobe wave input in Figures 2 and 3. The peak acceleration at the surface is magnified by the site more obviously.

4.3. Time-History Response to Arias Strength. Figure 9 shows the variation of Arias intensity with time when the seismic waves recorded by Chichi and Kobe were input. The results show that the damage degree caused by different types of seismic wave input is also very different in various types of sites. The results of the equivalent linear calculation are different from those of nonlinear calculation. There is a great difference between the equivalent linear and nonlinear calculations when using the Kobe seismic wave. The calculation result of the linear equivalent of the two seismic waves is generally larger than that of the nonlinear one.

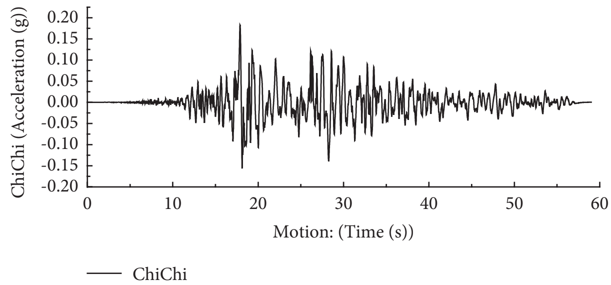


Figure 2: Acceleration time history of Chichi motion.

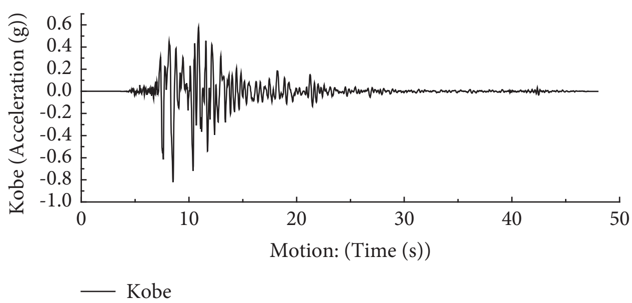


Figure 3: Acceleration time history of Kobe motion.

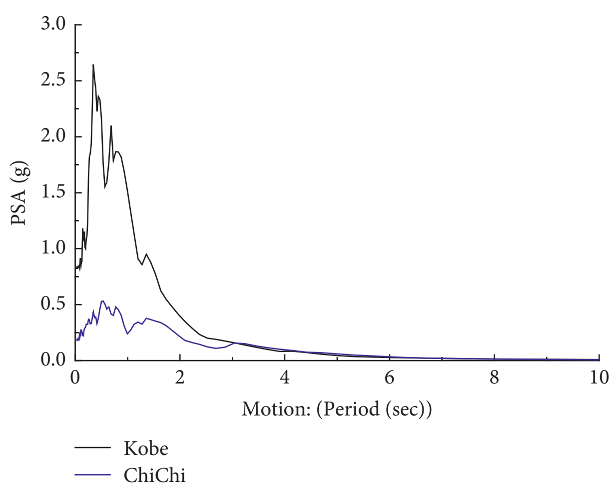


Figure 4: Response spectra of input motions.

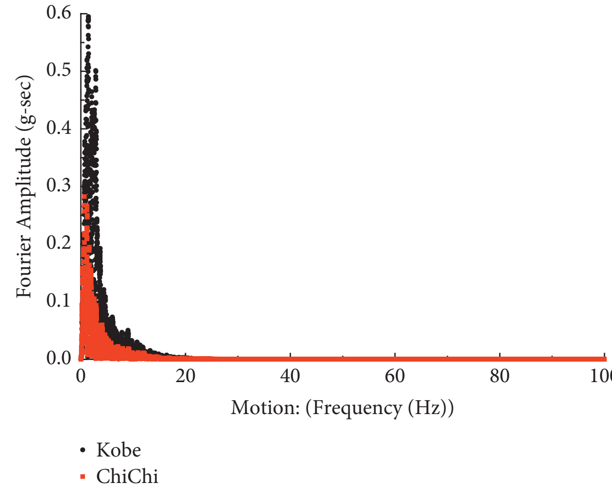


Figure 5: Fourier amplitude spectrum of input motions.

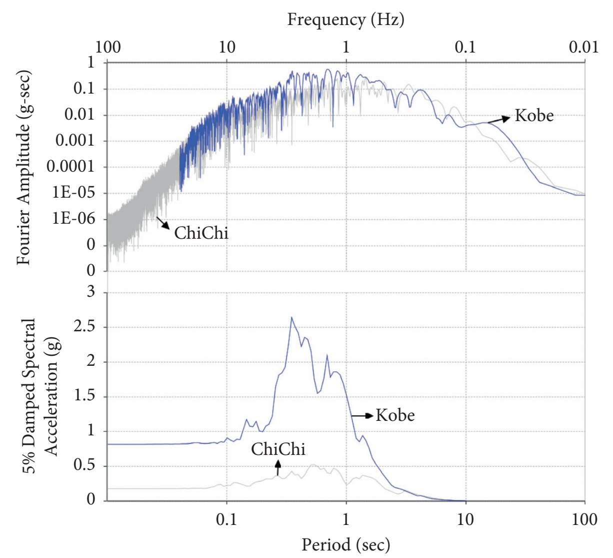


Figure 6: Fourier amplitudes and 5% damped spectral acceleration of two input seismic waves.

Except for the Chichi seismic wave input in model 1, the calculation results of the equivalent linearity are close to the results of the nonlinear Arias intensity. For strong earthquakes, the calculation accuracy of the equivalent linear method is low. For soft soil, the nonlinear nature of the soil itself is strong, and the error of the equivalent linear method is also large. Considering that the seismic wave and the soil are nonlinear, the results obtained by the nonlinear method are more reliable.

From the perspective of Arias strength value, the soft soil site can significantly reduce the sudden strong earthquakes. In contrast, persistent low-intensity earthquakes can dramatically reduce site safety. The intensity of Arias did not exceed 2 m/s after the input of two different types of earthquakes at the two sites; both sites are safe. In model 1, when Chichi wave is incident, Arias intensity results calculated by equivalent linearity and nonlinearity are very close. This is because the nonlinearity of the rock site is weak and the nonlinearity of the seismic wave is weaker than that of the Kobe wave. In Model 2, Arias's strength exceeds 2 m/s when Kobe wave is input into soft soil site for equivalent linear calculation, which deviates greatly from other calculation results. At this time, the Kobe wave belongs to a strong earthquake and has strong nonlinear characteristics. In addition, with the strong nonlinearity of the soft soil layer, the result of the equivalent linear calculation is more inaccurate. For strong earthquakes, the calculation accuracy of the equivalent linear method is low. For soft soil, the nonlinear property of soil is strong, and the calculation error of the equivalent linear method is too large. Because both seismic waves and soil are nonlinear, the results calculated by the nonlinear method are more reliable.

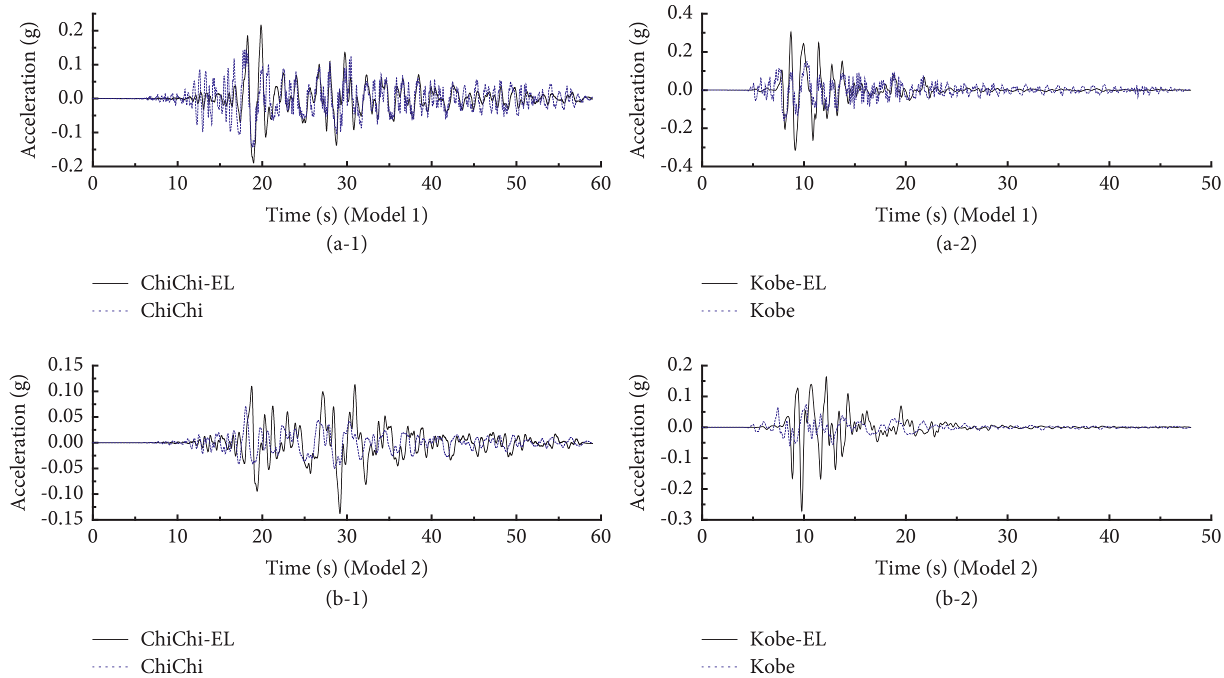


Figure 7: Surface time-domain acceleration response of (a) model 1 and (b) model 2.

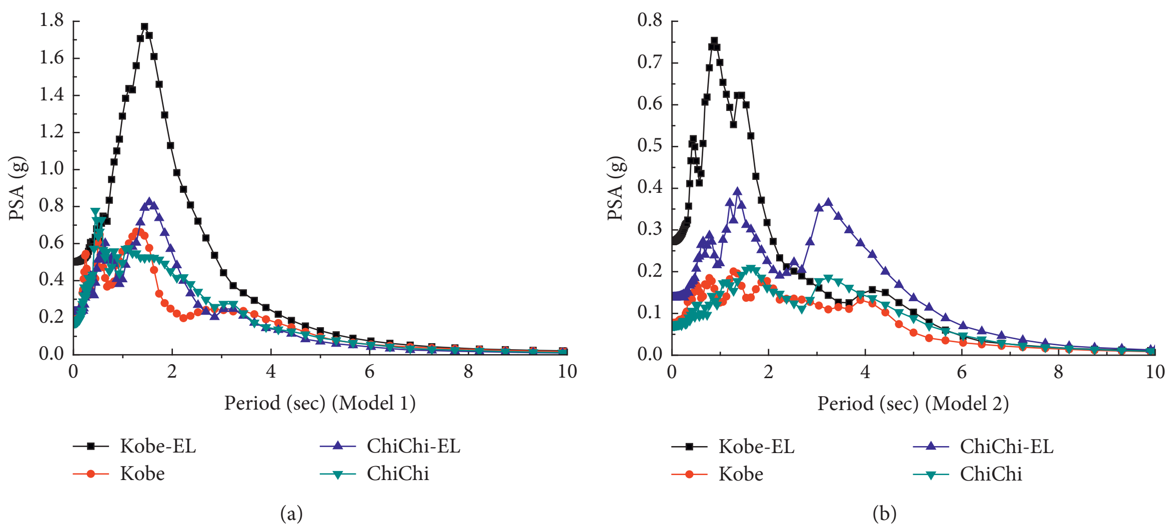
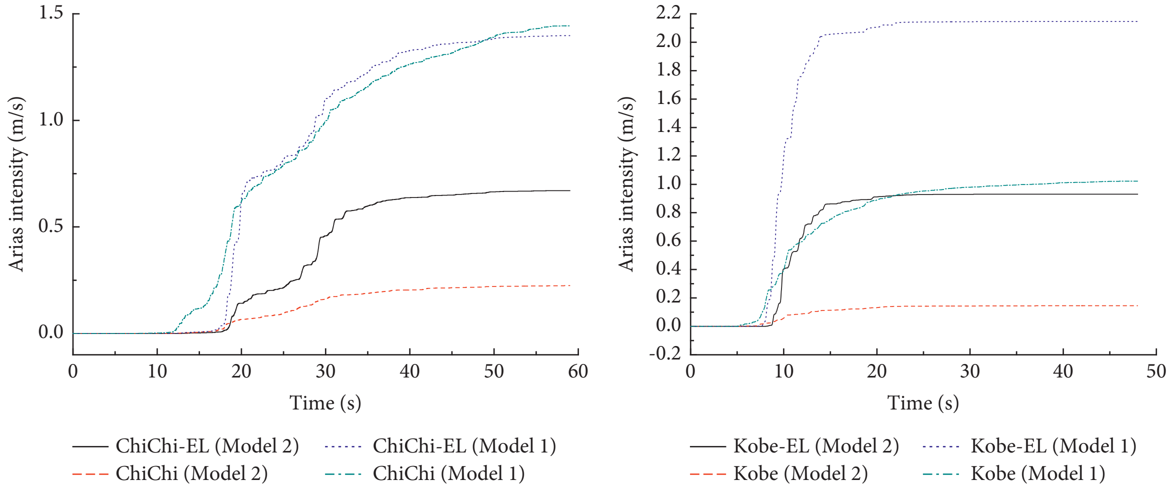


Figure 8: Surface response spectra of (a) model 1 and (b) model 2.

4.4. Analysis of Dynamic Parameters of Soil Profiles. The sections of two numerical simulation models with different geological conditions are analyzed. The variation of the maximum displacement, the maximum ground peak acceleration, and the ratio of maximum shear stress to vertical effective stress with soil depth were studied, and the calculated results are drawn in Figures 10–12.

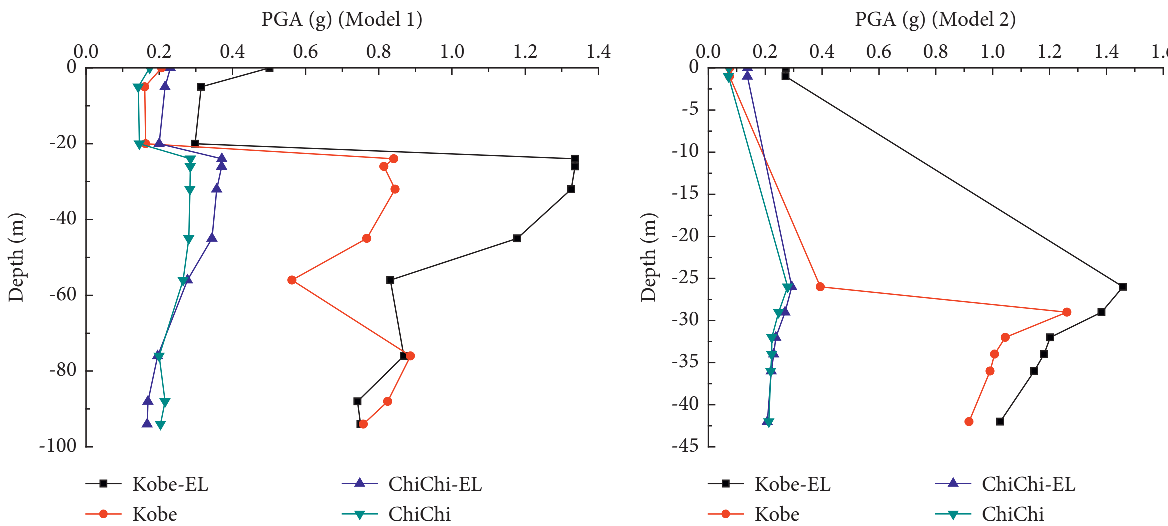
Figure 11 shows the variation of the maximum displacement of soil layer with depth in model 1 and model 2. Model 1 shows that different kinds of seismic waves have different influences on the deep soil, and the effect of the input Kobe seismic wave on the deep soil layer is greater than that of the Chichi wave. However, in model 2, where the soil layers are soft, the Kobe input wave has no special influence on the deep soil layer.

Figure 10 shows the variation of the maximum acceleration of soil layers with depth in model 1 and model 2. It shows that the stiff soil layer has a more obvious dynamic response to the Kobe input wave, and the ground peak acceleration is larger, while the soft soil layer is less sensitive to strong earthquakes. In the deep stiff stratum, the peak acceleration decreases with the increase of depth. In model 2,



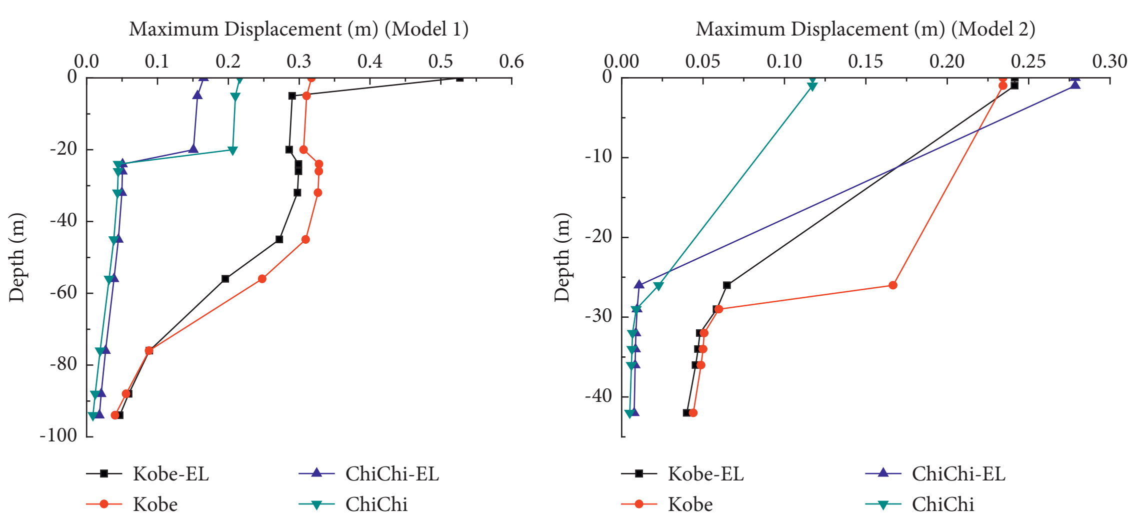
(a) (b)

Figure 9: Time-domain response of Arias strength: (a) Chichi and (b) Kobe.



(a) (b)

Figure 10: Maximum acceleration of soil in model 1 and model 2.



(a) (b)

Figure 11: The maximum displacement of soil in (a) model 1 and (b) model 2.

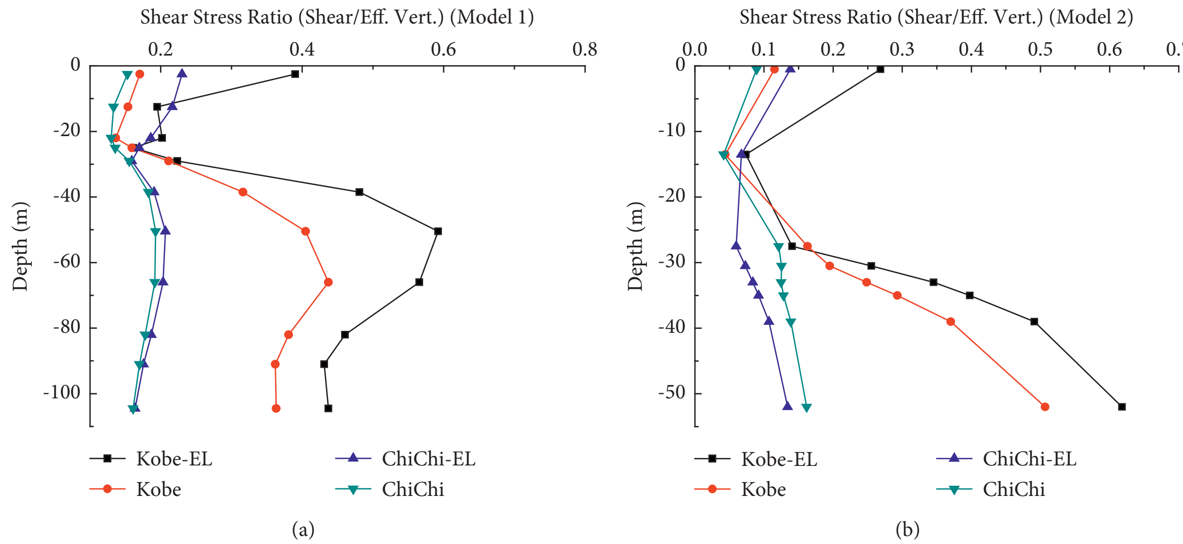


Figure 12: The ratio of maximum shear stress to vertical effective stress varies with depth in model 1 and model 2.

when two different seismic waves are input, the peak acceleration in the overlying soft soil layer increases with the depth, since the greater the vertical stress the soil is subjected to, the deeper the soil layer is. The vertical stress compacts and consolidates the weak soil layer, so the acceleration increases accordingly.

Figure 12 shows the variation of the ratio of maximum shear stress to vertical effective stress with soil depth under different site conditions. It can be seen from the figure that the ratio of the maximum shear stress to the vertical effective stress in model 1 is greater than that in model 2. Because the upper soil layer of model 2 is the silt layer, the soil damping is relatively large, and it is not sensitive to earthquake response. In model 2, the ratio of shear stress to vertical effective stress in the upper part of the soil layer is small, while the ratio of maximum shear stress to vertical effective stress in the bottom sandy bedrock layer is large, and it increases with the increase of depth. As the soil layer deepens, the degree of consolidation of soil deepens. Meanwhile, due to the constitutive characteristics of deep soil, the stress in the soil gradually increases with depth. As a result, the ratio of maximum shear stress to vertical effective stress turns with greater depth.

5. Conclusions

This paper studies the seismic response of different types of sites, aiming to provide the basis and data reference for the seismic fortification design of sites. The research results of this paper are summarized as follows:

(1) The soil itself is a nonlinear medium, so the nonlinear calculation method is more accurate than the equivalent linear calculation, especially for soft soil sites with more obvious nonlinear properties. In addition, seismic waves are not harmonics, and the nonlinear nature of seismic waves is simplified using the equivalent linear method, which leads to generally larger calculation results. Therefore, it is better to adopt the nonlinear method in the seismic dynamic calculation.

(2) The Kobe wave is stronger than the Chichi wave, but the main peak duration is shorter than the Chichi wave. Due to the large damping of soft soil, the weakening effect of soft soil is very obvious for sudden strong earthquakes, but for the continuous low-intensity earthquake, the acceleration response of soft soil will be greater. Harder soil and rock help the spread of earthquakes and therefore have greater acceleration. In addition, they are more sensitive to strong earthquakes, and the site amplification effect of earthquakes is more obvious.

(3) Acceleration, surface spectral acceleration, Arias strength, maximum acceleration of each layer of soil, and the ratio of maximum shear stress to vertical effective stress with depth are calculated using Kobe wave and Chichi wave; the equivalent linear calculation results are always larger than the nonlinear calculation results. However, the equivalent nonlinear calculation result of soil displacement with depth is not the maximum. The influence of Kobe wave on soil displacement is greater, and the influence on deep soil is also greater. In soft soil field with Kobe wave incident, the result of the equivalent linear calculation is more inaccurate because both seismic wave and field are highly nonlinear. However, the results of the equivalent linear calculation are close to those of nonlinear calculation in the rock field with Chichi wave incidence.

(4) From the perspective of Arias strength value, especially the soft soil site, sudden strong earthquakes are more obviously weakened by the site. Therefore, soft soil sites are safer than rock sites during strong earthquakes. However, the continuous low intensity earthquake will make the soft soil site safety factor

sharply decreased. The surface displacement caused by the earthquake is large, and the influence decreases with depth, which is related to the property of the soil layer and the vertical stress of soil increasing with depth. The deep soil in the rock layer is more significantly affected by a sudden strong earthquake [16–18].

Data Availability

Some or all data, models, or codes generated or used during the study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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