IJE TRANSACTIONS B: Applications Vol. 33, No. 5, (May 2020) 784-790

International Journal of Engineering

Journal Homepage: www.ije.ir

Comparative Analysis of Two Seismic Response Analysis Programs in the Actual Soft Field

X. Fei Li

School of Architecture Engineering, Binzhou University, Binzhou, China

PAPER INFO

Paper history:
Received 14 January 2020
Received in revised form 21 February 2020
Accepted 07 March 2020

Keywords:
Soft Soil Site
Seismic Response Analysis Program
KiK-net
Calculation Results
Measured Records

ABSTRACT

SHAKE2000 and DEEPSOIL are the two most important programs to calculate the response analysis of soil layer. In order to analyze the similarities and differences between them, and to guide the improvement of the method and program of seismic response analysis of soil layer, 25 KiK net seismic records from 9 stations were selected as the research objects in this paper, from the aspects of surface acceleration, acceleration response spectrum and maximum shear strain of the surface. SHAKE2000 and DEEPSOIL are used to calculate the soft soil site.The results showed that when the soil nonlinearity is not obvious, most of the differences of PGA results calculated by SHAKE2000 and DEEPSOIL can be ignored. The error of the maximum value of soil shear strain calculated by SHAKE2000 and DEEPSOIL is less than 20%. When the soil nonlinearity is obvious, only a few of the differences of PGA results can be ignored, and the error of the maximum value of soil shear strain calculated by SHAKE2000 and DEEPSOIL is less than 20%. In most cases, the acceleration response spectra calculated by SHAKE2000 and DEEPSOIL are not different. Based on the measured records, there are great differences between the calculated results of SHAKE2000 and DEEPSOIL and the measured records, but generally, the calculation method of SHAKE2000 is better than DEEPSOIL and SHAKE2000 is closer to the strong earthquake records.

doi*: 10.5829/ije.2020.33.05b.09*

1. INTRODUCTION

As an indispensable part of seismic design, soil layer seismic response analysis has a history of nearly 80 years. It can determine the ground motion quickly and accurately, which directly affects the seismic safety of engineering structures [1-2]; also has a significant impact on the project cost. Therefore, it is of great significant to study soil layer seismic response analysis [3-4].

With the enrichment of seismic data and in-depth study of seismic engineering, there are many methods of site seismic response analysis [5-6]. From the dimension of mechanical model, there are one-dimensional, two-dimensional and three-dimensional soil model. At present, one-dimensional seismic response analysis of soil layer is widely used in engineering field [7-8]. This method regards soil as horizontal layered structure, which has the advantages of fast calculation speed and simple principle [9-10].

The current international programs for seismic response analysis of one-dimensional soil layer mainly include SHAKE series, DEEPSOIL, LSSRLI-1, EERA, DYNEQ, etc. These programs have been widely used in practical projects in different regions at home and abroad, among which SHAKE series and DEEPSOIL programs are relatively mature and most widely used. SHAKE 2000 is the latest version of SHAKE series [11], representing the advanced level of frequency-domain equivalent linearization method in the world. SHAKE 2000 assumes that the response in the soil layer is mainly caused by the upward propagation of shear wave from the rock layer, and its theory is the vertical propagation of shear wave in the online elastic system. Based on this theory, SHAKE 2000 has been verified in a large number of field tests.

DEEPSOIL is a program developed by UIUC, which can calculate not only the frequency-domain equivalent linearization method but also the time-domain nonlinear method one-dimensional soil layer seismic response analysis program, representing the advanced level of the time-domain equivalent linearization method in the world [12]. Besides the equivalent linearization model,

*Corresponding Author Email: *lxf2011iem@126.com* (X. Fei Li)

Please cite this article as: X. Fei Li, Comparative Analysis of Two Seismic Response Analysis Programs in the Actual Soft Field, International Journal of Engineering (IJE), IJE TRANSACTIONS B: Applications Vol. 33, No. 5, (May 2020) 784-790

there are also hyperbolic model and pressure hyperbolic model, including many research results of UIUC. In the selection of time-domain nonlinear method, DEEPSOIL can transform the nonlinear parameters of input soil into the required fitting parameters by using the built-in model inside the program. Therefore, the parameters required by DEEPSOIL are the same as those required by SHAKE2000, which is also an important basis for the comparison of the two programs.

Although SHAKE2000 and DEEPSOIL are widely used, due to the lack of previous actual site records, the inspection work of SHAKE2000 and DEEPSOIL using the actual site is less. The existing research shows that when the site is a hard site, the errors of the calculation results of SHAKE2000 and DEEPSOIL can be ignored; but when it is a soft soil site, whether the calculation results of SHAKE2000 and DEEPSOIL are reasonable has not been a representative conclusion. Therefore, this paper chooses soft site as the research object, and the result is reliable [13-14]. Zhan et al. [15] conducted the nonlinear seismic response analysis of large scale deep soft ground under the action of large earthquake by use of SHAKE. Chen et al. [16] studied the seismic response characteristics of the deep and weak site in the middle and lower reaches of the Yangtze River in China using SHAKE91. Based on the exponential dynamic constitutive model of soil, a new nonlinear seismic response analysis method of one-dimensional soil layer was proposed by Qi et al. [17]. However, they only conducted comparative analysis for specific sites, lacking of representativeness.

KiK-net in Japan can record the underground bedrock acceleration and surface acceleration time history at the same time [18]. Recently, many underground site records have been obtained, and these data are open to the public, which provides a basis for testing the existing seismic response program.

In this paper, based on the strong earthquake records of KiK-net in Japan, the soil response analysis of soft site is carried out by using SHAKE2000 and DEEPSOIL programs, respectively. The difference between SHAKE2000 and DEEPSOIL and the difference between the calculation results of the two programs and the measured records were compared and analyzed from the aspects of calculation peak acceleration, measured peak acceleration, acceleration response spectrum and maximum shear strain of soil layer, which provides the basis for improving the method and program of seismic response analysis of soil layer. The research method of this paper is shown in Figure 1.

2. STATION DATA

In this paper, 9 stations and 25 KiK-net seismic records are selected to verify the applicability of SHAKE2000 and DEEPSOIL seismic response analysis programs in soft site [19]. Figure 2 shows the distribution of KiK-net stations.

The selected station has complete borehole profile data, underground bedrock acceleration record and surface acceleration record. The soil profile , specific coordinate positions and equivalent shear wave velocity information of 9 stations are listed in Table 1. In the calculation, the soil is divided into layers according to the soil type, and each soil type is divided into layers according to one meter.

The frequency and amplitude of seismic wave have certain influence on the seismic response of soil layer [20]. In order to make the working condition more representative, 25 KiK-net strong earthquake records of 9 stations are selected as the input ground motion in this paper. The input acceleration peak range is between 6gal-214gal, and the input seismic wave part is shown in Figure 3. Two programs, SHAKE2000 and DEEPSOIL, are used to calculate the selected seismic waves, respectively. The differences between the two programs and between the calculation results of the two programs and the measured records are compared and analyzed from the aspects of surface acceleration, acceleration response spectrum and the maximum shear strain of the surface.

3. DYNAMIC PARAMETERS

In addition to the information of ground motion, shear wave velocity, soil section thickness, soil stratification and soil type, the dynamic shear modulus ratio and damping ratio of soil need to be input for program calculation. In order to simplify the calculation, according to literature [21], three kinds of nonlinear conditions are adopted, which are defined as weak nonlinear condition, mean value condition and strong nonlinear condition, respectively. As shown in Figure 4.

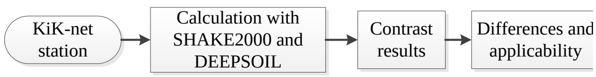


Figure 1. Flowchart of research methodology

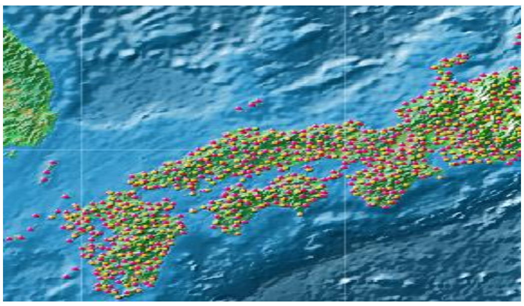


Figure 2. KiK-net station distribution

TABLE 1. Drilling data

Number	The equivalent shear wave velocity (m/s)	Depth (m)	Geographic coordinates	
			Longitude	Latitude
AKTH19	237.58	180	140 °28′28.0″	39 °11′18.0″
NMRH05	173.94	220	144 °48′22.0″	43 °23′15.0″
KSRH02	172.98	105	144 °7′37.0″	43 °6′42.0″
SZOH42	126.83	203	138 °54′57.2″	34 °58′20.3″
KSRH07	160.31	222	144 °19′53.0″	43 °7′60.0″
KSRH01	141.18	106	144 °5′18.0″	43 °26′1.0″
KSRH04	162.79	240	144 °41′4.0″	43 °12′41.0″
KSRH09	185.92	100	143 °59′17.0″	42 °58′59.0″
TCGH16	172.84	112	140 °4′42.0″	36 °32′42.0″

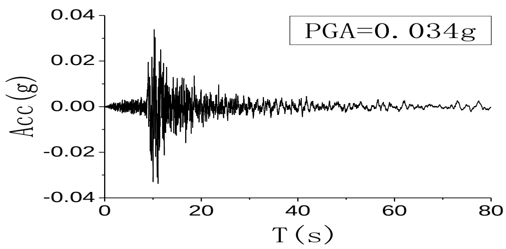
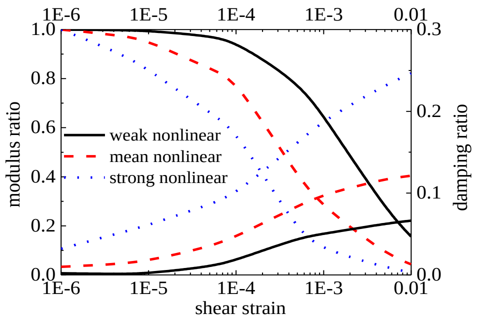
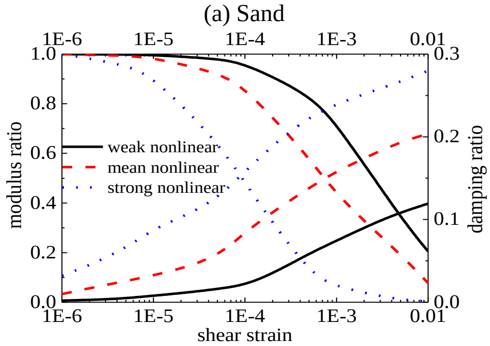


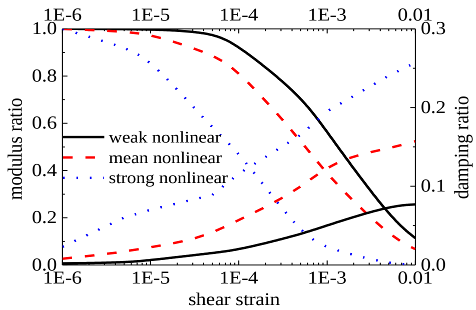
Figure 3. Input wave (NMRH05 station wave 1)



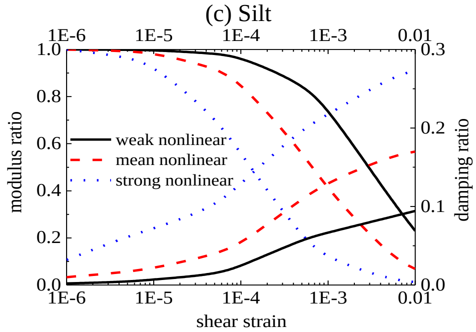
(a) Sand



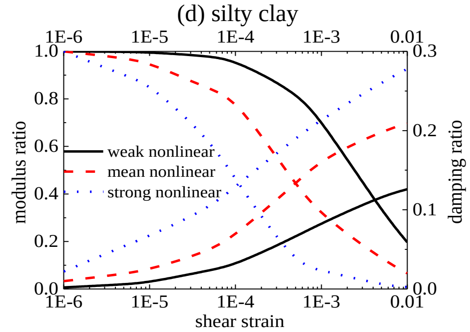
(b) Clay



(c) Silt



(d) silty clay



(e) mucky soil

Figure 4. Relationship curves between dynamic shear modulus ratio and damping ratio versus shear strain

4. PEAK ACCELERATION

In this paper, the acceleration calculated by SHAKE2000 and DEEPSOIL and the comparison between the calculated acceleration and the measured surface acceleration are analyzed. There are 150 calculation conditions in total. The conditions that the peak acceleration error is less than 20% are counted. The results are shown in Figure 5.

According to Figure 5, there are 29 peak acceleration errors calculated by SHAKE 2000 and DEEPSOIL that are less than 20%, accounting for 43.94% of the total working condition. Among them, there are 14 cases of weak nonlinearity, accounting for 56% of the total cases of weak nonlinearity; 12 cases of average, accounting for 50% of the total cases of average; 3 cases of strong nonlinearity, accounting for 17.65% of the total cases of strong nonlinearity. The least error is the weak nonlinear condition of NMRH05 site wave 1, with an error of 0.15%. The biggest error is the strong nonlinear condition of NMRH05 field ground wave 4, and the error is 3.967 times. For weak nonlinear and mean value conditions, in most cases, the difference of peak acceleration calculated by the two methods can be ignored; for strong nonlinear conditions, in a few cases, the difference of peak acceleration calculated by the two methods can be ignored, in the rest cases, there are some differences, in a few cases, there are significant differences.

See Figure 6 for the calculation and measured peak acceleration error less than 20%.

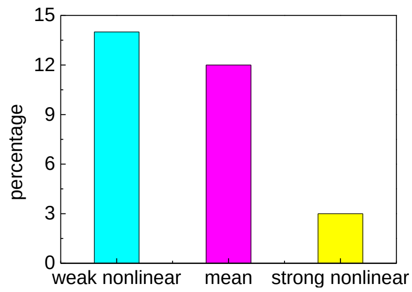


Figure 5. The peak acceleration errors of SHAKE2000 and DEEPSOIL

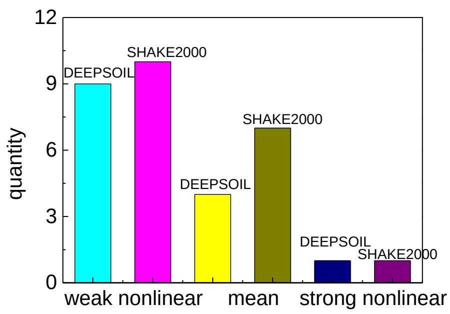


Figure 6. The peak acceleration errors of the calculated and the measured conditions

It can be seen from Figure 4 that there are 32 working conditions with the error less than 20% between the calculated acceleration and the measured acceleration, accounting for 22.7% of the total working conditions, and the error range is 0-7.2.

In 32 cases where the error between the calculated and measured peak acceleration is less than 20%, there are 14 DEEPSOIL methods, accounting for 18.67% of the total DEEPSOIL conditions, including 9 weak nonlinear conditions, accounting for 36% of the total weak nonlinear conditions; 4 average conditions, accounting for 16% of the total average conditions; 1 strong non-linear condition, accounting for 4% of the strong nonlinear conditions. There are 18 SHAKE 2000 methods, accounting for 27.27% of the total number of SHAKE 2000 conditions, of which 10 are weak nonlinear conditions, accounting for 40% of the total number of weak nonlinear conditions; 7 are average conditions, accounting for 29.17% of the total number of average conditions; 1 is strong nonlinear conditions, accounting for 5.88% of the total number of strong nonlinear conditions. It can be seen from the above that for the weak non-linear and mean conditions, a few differences between DEEPSOIL and SHAKE 2000 and the measured results can be ignored; for the strong non-linear conditions, individual differences between DEEPSOIL and SHAKE 2000 and the measured results can be ignored. Although the calculated results of the two programs are quite different from the measured results, the results of SHAKE 2000 are slightly better than those of DEEPSOIL.

5. ACCELERATION RESPONSE SPECTRUM

Based on literature [22], the ratio of the response spectrum is taken as logarithm to express the residual between the calculated results and the measured results. The same method is used to compare the response spectrum calculated by SHAKE2000 and DEEPSOIL with the measured response spectrum based on the measured response spectrum, and the error between the calculated result and the measured record is determined quantitatively by the average spectral value ratio. The calculation formula of the average spectral value ratio is:

$$\overline{R(T)} = \frac{\sum_1^n \left(ln\left[S_{a,p}(T_i)\right] - ln\left[S_{a,m}(T_i)\right] \right) \bullet \Delta T_i}{\sum_1^n \Delta T_i} \tag{1}$$

where, $\overline{R(T)}$ is the average spectral value ratio; $S_{a,p}(T_i)$ is the calculated response spectra; $S_{a,m}(T_i)$ is the measured response spectra; ΔT_i is cycle interval (s).

The spectral ratio between the calculated and measured response spectra of SHAKE2000 and DEEPSOIL is shown in Figure 7.

The differences between the calculation results and the surface records are listed in Table 2. In order to make the two comparable, the conditions that cannot be calculated in SHAKE2000 are not considered in DEEPSOIL.

It can be seen from Table 2 that in the case of weak nonlinearity, the number of differences between the SHAKE2000 result and the measured record is the same as the number of DEEPSOIL; the number of significant differences between the SHAKE2000 and the measured record is less than the number of significant differences between the DEEPSOIL and the measured record. The SHAKE2000 calculation result is better than the DEEPSOIL result. In the mean case, the number of negligible differences between the results of SHAKE2000 and the measured records is more than that between DEEPSOIL and the measured records. There is no significant difference between the results of SHAKE2000 and the measured records; while, there is significant difference between the results of DEEPSOIL and the measured records. The calculated results of SHAKE2000 are better than that of DEEPSOIL. In the case of strong nonlinearity, the number of significant differences between the results of SHAKE2000 and the measured records is less than that of DEEPSOIL. The calculated results of SHAKE2000 are better than that of DEEPSOIL.

To sum up, SHAKE2000 and DEEPSOIL programs show that the weak nonlinear case is better than the mean case, and the mean case is better than the strong nonlinear case. There are differences between the two and the measured data in three nonlinear cases, but the calculation method of SHAKE2000 is better than DEEPSOIL.

6. SHEAR STRAIN

In order to determine the difference between SHAKE2000 and DEEPSOIL, the maximum shear strain of soil layer calculated by the two programs under the same calculation conditions is compared. Figure 8 shows the number of shear strain errors is less than 20% between SHAKE2000 and DEEPSOIL. From Figure 8, it can be concluded that there are 31 shear strains calculated by SHAKE 2000 and DEEPSOIL with error less than 20%, accounting for 68.89% of the total working conditions. Among them, there are 11 weak nonlinear conditions, accounting for 64.71% of the total; 11 mean conditions, accounting for 68.75% of the total; 9 strong nonlinear conditions, accounting for 75% of the total. For all working conditions, the error of the maximum shear strain calculated by SHAKE2000 and DEEPSOIL is less than 20% in most cases.

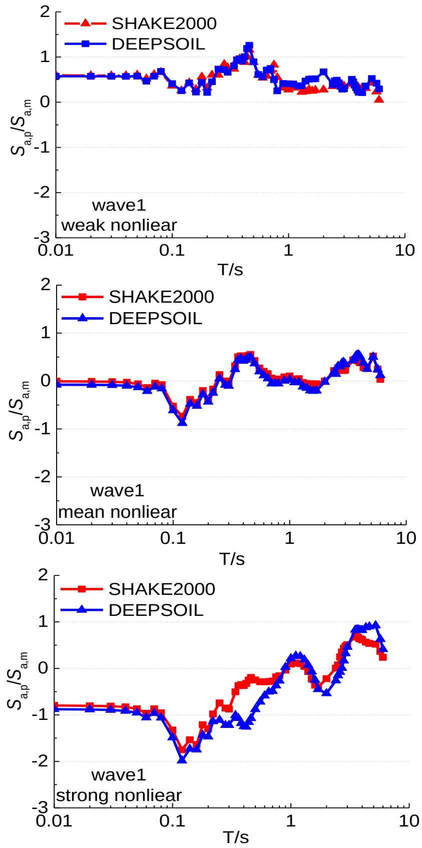


Figure 7. Spectral ratios (NMRH05 station wave1)

TABLE 2. Number of differences between calculation results and measured records

Degree of deviation		DEEPSOIL			SHAKE2000		
		Weak Nonlinear	Mean Nonlinear	Strong Nonlinear	Weak Nonlinear	Mean Nonlinear	Strong Nonlinear
Ignored	0-20%	6	4	0	4	5	0
Some	20-50%	13	13	3	15	13	10
Big	50-80%	5	6	12	4	6	6
Significant	Above 80%	1	1	2	2	0	1

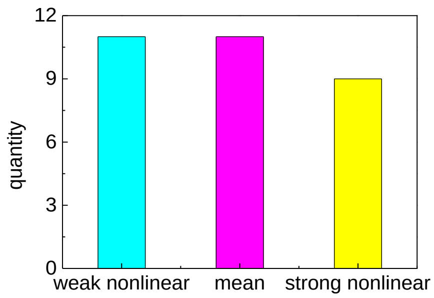


Figure 8. The error of maximum shear strain between SHAKE2000 and DEEPSOIL

7. CONCLUSIONS

Based on the measured data of 9 stations in KiK-net array, this paper uses two kinds of seismic response analysis programs, SHAKE2000 and DEEPSOIL, to carry out comparative calculation and analysis. The results show that:

(1) The nonlinearity of soil has great influence on the calculation results, and the stronger the nonlinearity is, the greater the influence is. Based on the peak acceleration, in most cases, the difference of peak acceleration calculated by SHAKE2000 and DEEPSOIL can be ignored in weak nonlinear and mean nonlinear conditions; in a few cases, the difference of peak acceleration calculated by the two methods can be ignored in strong nonlinear conditions.

(2) Based on the measured peak acceleration, there are few differences between SHAKE2000 and DEEPSOIL and the measured results under the condition of weak nonlinearity and mean nonlinearity, and some differences between SHAKE2000 and DEEPSOIL and the measured results under the condition of strong nonlinearity can be ignored.

(3) From the surface acceleration response spectrum, there is a big difference between SHAKE2000 and DEEPSOIL and the measured records under three kinds of nonlinearity, but generally, the calculation method of SHAKE2000 is better than DEEPSOIL.

(4) In most cases, the error between the maximum shear strain calculated by SHAKE2000 and DEEPSOIL is less than 20%.

(5) Although the calculated results of the two programs are quite different from the measured results, the SHAKE2000 is better than the DEEPSOIL. It can be seen from the comparison between the calculated results of the two programs and the measured results that SHAKE2000 is closer to the strong earthquake record.

8. ACKNOWLEDGEMENTS

The author would like to express her sincere appreciation for Shandong Provincial Natural Science Foundation, China (ZR2018PEE020) and Scientific Research Fund Project of Binzhou University (BZXYLG1916) for their supports.

9. REFERENCES

1. Yang, L., Iman, H. and Alec, M.M., "Performance-based Seismic Design of Flexible-Base Multi-Storey Buildings Considering Soil-Structure Interaction ", ***Engineering Structures***, Vol. 108, (2016), 90-103.
2. Yaghmaei-Sabegh, S., "A wavelet-based procedure for mining of pulse-like ground motions features in response spectra", ***International Journal of Engineering, Transactions A: Basics***, Vol. 25, No. 1, (2012), 39-50.
3. Emeka, A. E., Chukwuemeka, A. J. and Okwudili, M. B., "Deformation behaviour of erodible soil stabilized with cement and quarry dust", ***Emerging Science Journal***, Vol. 2, No. 6, (2018), 383-387.
4. Gamil, Y., Bakar, I. and Ahmed, K., "Simulation and development of instrumental setup to be used for cement grouting of sand soil", ***Emerging Science Journal***, Vol. 1, No. 1, (2017), 16-27.
5. Sun, L., "Effect of Variable Confining Pressure on Cyclic Triaxial Behaviour of K_0-consolidated Soft Marine Clay", ***Civil Engineering Journal***, Vol. 4, No. 4, (2018), 755-765.
6. Karkush, M. and Jabbar, A., "Improvement of Soft Soil Using Linear Distributed Floating Stone Columns under Foundation Subjected to Static and Cyclic Loading", ***Civil Engineering Journal***, Vol. 5, No. 3, (2019), 702-711.
7. Do, H. D., Nguyen, T. P. K. and Phan, K. H., "Physical Model Test for Soft Soil with or Without Prefabricated Vertical Drain with Loading", ***Civil Engineering Journal***, Vol. 4, No. 8, (2018), 1809-1823.
8. Qi, W., Bo, J., Liu, D., and Liu, H., (2005). "A test for three programs of soil layer seismic response analysis by strong earthquake record", ***Journal of Earthquake Engineering and Engineering Vibration***, Vol. 25, No. 5, (2005), 30-33.
9. Li, X., "Study on the Contrast between Two Seismic Response Analysis Programs of Soil Layer", ***International Journal of Engineering, Transactions A: Basics***, Vol. 32, No. 1, (2019), 46-53.
10. Li, X., Sun, R. and Yuan, X., "Comparative study on existing equivalent linear response analysis program based on KiK-net", ***China Earthquake Engineering Journal***, Vol. 37, No. 1, (2015), 144-151.
11. Ordonez, G.A., "Shake2000: A computer program for the 1d analysis of geotechnical earthquake engineering problems", ***Geomotions, LLC, USA***, (2000).
12. Hashash, Y., and Duhee, P., "Non-linear one-dimensional seismic ground motion propagation in the Mississippi embayment", ***Engineering Geology***, Vol. 62, No. 1-3, (2001), 185-206.
13. Mehdi, T. and Ganji, B.A., "Modelling of resonance frequency of MEMS corrugated diaphragm for capacitive acoustic Sensors", ***International Journal of Engineering, Transactions C: Aspects***, Vol. 27, No. 12, (2014), 1850-1854.
14. Habib, S., Changiz, G. and Amir, S., "Numerical and experimental study of soil-structure interaction in structures resting on loose soil using laminar shear box", ***International Journal of Engineering, Transactions B: Applications***, Vol. 30, No. 11, (2017), 1654-1663.
15. Zhan, J., Chen, G., and Liu, J., (2013). "Analysis of nonlinear seismic effects of large - scale deep soft site under far-field large

earthquake", ***Rock and Soil Mechanics***, Vol. 34, No. 11, (2013), 3229-3238.

16. Chen, J., Chen, G., and Shi, G., (2004). "Research on Seismic Response Characteristics of Sites with Deep and Soft Soils", ***Journal of Disaster Prevention and Mitigation Engineering***, Vol. 24, No. 2, (2004), 444-450.
17. Qi, W., Wang, z., and Bo, J., (2010). "Development and verification of a method for analysing the nonlinear seismic response of soil layers", ***Journal of Harbin Engineering University***, Vol. 31, No. 4, (2010), 444-450.
18. Wang, L., "The research of soil layer seismic characteristic based on Kik-Net strong-motion network", Institute of Engineering Mechanics, China Earthquake Administration, Harbin, (2014).
19. GB50011, C.S., "Code for seismic design of buildings", China Building Industry Press, Beijing, (2010).
20. GB/T 17742, C.S., "Chinese seismic intensity scale", Chinese Standard Press, Beijing, (2008).
21. Sun, R., Chen, H. and Yuan, X.M, "Uncertainty of non-linear dynamic shear modular ratio and damping ratio of soils", ***Chinese Journal of Geotechnical Engineering***, Vol. 32, No. 8, (2010), 1228-1235.
22. Annie, O. L. K., Jonathan, P. S. and Youssef, M. A. H., "Nonlinear ground-response analysis of turkey flat shallow stiff-soil site to strong ground motion", ***Bulletin of the Seismological Society of America***, Vol. 98, No. 1, (2008), 331-343.

Persian Abstract

چکیده

SHAKE2000 و DEEPSOIL دو برنامه مهم برای محاسبه تحلیل پاسخ لایه خاک هستند. به منظور تجزیه و تحلیل شباهت ها و تفاوت های بین آنها ، و راهنمایی در بهبود روش و برنامه تجزیه و تحلیل پاسخ لرزه ای لایه خاک ، ۲۵ پرونده لرزه نگاری خالص KiK از ۹ ایستگاه به عنوان اهداف تحقیق در این مقاله ، از جنبه های مختلف انتخاب شد. اثر شتاب سطح ، طیف پاسخ شتاب و حداکثر فشار برشی سطح. از SHAKE2000 و DEEPSOIL برای محاسبه محل خاک نرم استفاده می شود. نتایج نشان داد که وقتی غیرخطی بودن خاک آشکار نیست ، بیشتر تفاوت های نتایج PGA محاسبه شده توسط SHAKE2000 و DEEPSOIL قابل چشم پوشی است. خطای حداکثر مقدار کرنش برشی خاک توسط SHAKE2000 و DEEPSOIL محاسبه شده کمتر از ۲۰٪ است. هنگامی که غیرخطی بودن خاک آشکار است ، فقط برخی از تفاوتهای نتایج PGA قابل چشم پوشی است و خطای حداکثر مقدار کرنش برشی خاک که توسط SHAKE2000 و DEEPSOIL محاسبه شده است کمتر از ۲۰٪ است. در بیشتر موارد ، طیف پاسخ شتاب که توسط SHAKE2000 و DEEPSOIL محاسبه شده است ، متفاوت نیست. براساس سوابق اندازه گیری شده ، بین نتایج محاسبه شده SHAKE2000 و DEEPSOIL و سوابق اندازه گیری شده تفاوت های زیادی وجود دارد ، اما به طور کلی روش محاسبه SHAKE2000 بهتر از DEEPSOIL است و SHAKE2000 به سوابق قوی زلزله نزدیکتر است