1D seismic site response analysis for a soil deposit at Baoding city

Qijun Jia1, Duguo Wang2*, Fenlou Zhai3 and Xiaoyu Liu3

1China road&bridge corporation, Beijing City, 100013, China
2China earthquake disaster prevention center, Beijing City, 100029, China
3Beijing Computing center, Beijing City, 100094, China
*Wangduguo@163.com

Abstract. Based on 1D equivalent linear method, the effect of a soil deposit at Baoding city on wave propagation was analyzed. Firstly, probabilistic seismic hazard analysis (PSHA) was performed, and the peak acceleration and response spectrum of outcrop with exposure rate over 63%, 10% and 2% in 50 years are obtained; secondly, the artificial earthquake ground motions used as input motion of soil deposit were synthesized; lastly, 1D equivalent linear analysis was performed to evaluate the effect of soil deposit on wave propagation. Results show that soil deposit has a great influence on wave propagation. The intensity of input motion also plays an important role on the properties of seismic ground motion.

1. Introduction
For engineering structures, one essential job is evaluation of earthquake ground motion at the engineering site. The presence of deep soil deposits is especially complex for estimating the seismic ground motions [1-3]. Generally, 1D equivalent linear method is widely used for studying seismic motions propagation. 1D equivalent linear method is first introduced by Schnabel [4], then improved by Kausel [5] and Yoshida [6]. Also, various nonlinear site response methods [7-11] are developed in the past years. However, due to its convenience and efficiency, 1D equivalent linear method is still the most popular method for estimation of seismic ground motions.

In this paper, the seismic site response of one deep soil site over 50 m thick located at Baoding City is performed. This paper includes 3 main sections: 1) PSHA for the site; 2) Synthesization of artificial seismic motions of outcrop; and 3) 1D equivalent linear seismic site analysis for the site.

2. Probabilistic seismic hazard analysis
PSHA aims to estimate the probability that a specified level of ground motion will be exceeded or to estimate the level of ground motions that will occur at a specified exceedance probability, and it integrates hazard from all significant potential seismic sources and incorporates the frequency of earthquakes from each potential seismic source. PSHA has its roots originated in the seminal papers by Cornell [12] and Milne and Davenport [13].

The potential sources and the ground motion prediction equations used by Seismic ground motion parameters zonation map of China (GB 18306-2015) are applied to the site studied in this paper. The PSHA was performed and the results of probability of exceeding of 63%, 10% and 2% in 50 years (damp ratio 0.05) are listed in table 1, and the curves of exceeding probability in 1, 50 and 100 years for the peak acceleration are shown in figure 1.
| Period (s) | Acceleration values of probability of Exceedance in 50 years (cm s⁻¹) | 63% | 10% | 2% |
|-----------|------------------------------------------------------------------|-----|-----|----|
| 0         |                                                                  | 41.0| 97.8| 154.3|
| 0.04      |                                                                  | 46.7| 113.6| 182.1|
| 0.05      |                                                                  | 53.9| 131.3| 211.5|
| 0.07      |                                                                  | 69.3| 168.2| 268.8|
| 0.10      |                                                                  | 88.1| 212.3| 338.3|
| 0.12      |                                                                  | 93.7| 225.9| 360.1|
| 0.16      |                                                                  | 110.6| 267.5| 429.6|
| 0.20      |                                                                  | 109.6| 266.0| 427.2|
| 0.24      |                                                                  | 101.5| 247.5| 397.6|
| 0.26      |                                                                  | 94.2| 231.6| 373.1|
| 0.30      |                                                                  | 86.9| 216.6| 352.3|
| 0.34      |                                                                  | 80.9| 201.8| 327.4|
| 0.40      |                                                                  | 67.3| 173.3| 285.7|
| 0.50      |                                                                  | 56.1| 146.9| 245.1|
| 0.60      |                                                                  | 46.2| 126.0| 216.2|
| 0.80      |                                                                  | 33.8| 96.7| 170.5|
| 1.00      |                                                                  | 26.5| 80.5| 147.2|
| 1.20      |                                                                  | 21.2| 66.5| 123.7|
| 1.50      |                                                                  | 14.2| 47.4| 91.1|
| 1.70      |                                                                  | 11.4| 38.3| 74.4|
| 2.00      |                                                                  | 8.6| 29.7| 58.8|
| 2.40      |                                                                  | 6.0| 20.8| 42.9|
| 3.00      |                                                                  | 3.8| 13.4| 30.4|
| 4.00      |                                                                  | 2.3| 7.8| 18.5|
| 5.00      |                                                                  | 1.6| 5.0| 12.2|
| 6.00      |                                                                  | 1.2| 3.3| 8.3|
3. Synthesization of artificial seismic motions
The input seismic ground motions for deposit soil were generated through trigonometric series method. 80 period points with log uniform distribution between 0.04-6.0 seconds are chosen as the target spectrum points. The errors between the target spectrum and the synthesized spectrum generated by simulated grounded motions are supposed to be below 5%. Figure 2 shows three sample timehistories of probability of exceeding of 63% in 50 years.

4. Seismic site response
1D seismic site response analysis is performed to evaluate the effect of soil deposit on wave propagation. Based on borehole data and experiment results, 1D simulation soil profile is illustrated in figure 3. The curves of shear modulus regression versus shear strain and damp ration versus shear strain are shown in figure 4.
Figure 3. 1D simulation soil profile

Figure 4. Shear modulus regression versus shear strain and damping ratio versus shear strain curves

The comparison of site response results and PHSA results is shown in figure 5. It can be seen that soil deposit has a great influence on wave propagation. The peak of site response results is higher than that of PHSA results for all cases. However, with the increment intensity of input motion, the site response results changes from higher to lower than that of PHSA results for short periods between 0.04-6s.

(a) Probability of exceedance of 63% in 50 years  
(b) Probability of exceedance of 10% in 50 years
5. Conclusion
The effect of soil deposit on wave propagation is studied in this paper. Results show that soil deposit has a great influence on the properties of earthquake ground motions. Seismic site response results for certain period bands are higher than that of PSHA results. The intensity of input motions also affects the results. As the intensity becomes strong, PSHA results are closer to seismic site response results, and even higher for certain period bands. Seismic site response is supposed to be performed for evaluation of the effect of soil deposit on wave propagation.

Acknowledgments
This research was funded by Beijing Municipal Science & Technology Major Project (Grant No. Z181100003918005) and the Innovation Team Plan of Beijing Academy of Science and Technology (Grant No. IG201802 N). The financial support mentioned above is gratefully acknowledged.

References
[1] Park, D., Hashash, Y.M.A. (2005) Evaluation of seismic site factors in the Mississippi Embayment. II. Probabilistic seismic hazard analysis with nonlinear site effects. Soil Dyn Earthq Eng, 25(2):145-156.
[2] Street, R., Woolery, E. W., Wang, Z., et al. (2001) NEHRP soil classifications for estimating site-dependent seismic coefficients in the Upper Mississippi Embayment. Eng Geol, 62(1-3):123-135.
[3] Langston, C. A. (2003) Local earthquake wave propagation through Mississippi Embayment sediments, Part II: Influence of local site velocity structure on Qp-Qs determinations. Bull Seismol Soc Am, 93(6):2685-2702.
[4] Schnabel, P. B., Lysmer, J., Seed, H. B. (1972) SHAKE: A Computer Program for Earthquake Response Analysis of Horizontally Layered Sites[R]. Report EERC 72-12, University of California, Berkeley.
[5] Kause, E., Assimaki, D. (2002) Seismic simulation of inelastic soils via frequency-dependent moduli and damping. J Eng Mech, 128(1): 34-47.
[6] Yoshida, N., Kobayashi, S., Suetomi, I. (2002) Equivalent linear method considering frequency dependent characteristics of stiffness and damping. Soil Dyn Earthq Eng, 22(3): 205-222.
[7] Lee, M. K. W., Finn, W. D. L. (1975) DESRA-1 — Program for the dynamic effective stress response analysis of soil deposits including liquefaction evaluation[R]. Soils Mechanics Series Report No.36, Department of Civil Engineering, University of British Columbia, Vancouver, Canada.
[8] Idriss, I. M., Dobry, R. M., Doyle, E. H., Singh, R. D. (1976) Behavior of soft clays under earthquake loading conditions. In: Proceedings, Eighth Annual Offshore Technology Conference, Houston, pp: 605-616.

[9] Joyner, W. B. (1977) A FORTRAN program for calculating nonlinear seismic ground response[R]. US Geological Survey Open File Report No.77-671.

[10] Lam, I., Tsai, C-F., Martin, G. R. (1978) Determination of site dependent spectra using nonlinear analysis. In: Proceedings, Second International Conference on Microzonation, San Francisco, pp: 1089-1104.

[11] Lee, M. K. W., Finn, W. D. L. (1978) DESRA-2: Dynamic effective stress response analysis of soil deposits with energy transmitting boundary including assessment of liquefaction potential[R]. Soils Mechanics Series Report No. 38, Department of Civil Engineering, University of British Columbia, Vancouver, Canada.

[12] Cornell, C.A. (1968) Engineering seismic risk analysis. Bull Seismol Soc Am, 58(5): 1583-1606.

[13] Milne, W., Davenport, A. (1969) Distribution of earthquake risk in Canada. Bull Seismol Soc Am, 59(2): 729-754.