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Probabilistic Seismic Hazard Assessment Method for Nonlinear Soil Sites based on the Hazard Spectrum of Bedrock Sites

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1. Introduction

For the probabilistic safety assessment of the nuclear power plants (NPP) under seismic events, the rational probabilistic seismic hazard estimation should be performed. Generally, the probabilistic seismic hazard of NPP site is represented by the uniform hazard spectrum (UHS) for the specific annual frequency. In most case, since that the attenuation equations were defined for the bedrock sites, the standard attenuation laws cannot be applied to the general soft soil sites. Hence, for the probabilistic estimation of the seismic hazard of soft soil sites, a methodology of probabilistic seismic hazard analysis (PSHA) coupled with nonlinear dynamic analyses of the soil column are required.

Two methods are commonly used for the site response analysis considering the nonlinearity of sites. The one is the deterministic method [1] and another is the probabilistic method [2, 3]. In the analysis of site response, there exist many uncertainty factors such as the variation of the magnitude & frequency contents of input ground motion, and material properties of soil deposits. Hence, nowadays, it is recommended that the adoption of the probabilistic method for the PSHA of soft soil deposits considering such uncertainty factors [4, 5].

In this study, we estimated the amplification factor of the surface of the soft soil deposits with considering the uncertainties of the input ground motions and the soil material properties. Then, we proposed the probabilistic methodology to evaluate the UHS of the soft soil site by multiplying the amplification factor to that of the bedrock site. The proposed method was applied to four typical target sites of KNGR & APR1400 NPP site categories.

2. Methods and Results

For the evaluation of the UHS of soft soil sites considering the uncertainties, we introduced the uncertainty of input ground motion by selecting the database of 15 strong ground motions. Each acceleration response spectrum of input ground motion is plotted in Fig.1. It can be seen that the governing spectral acceleration spreads in wide range from about 1.0 Hz to over 10 Hz.

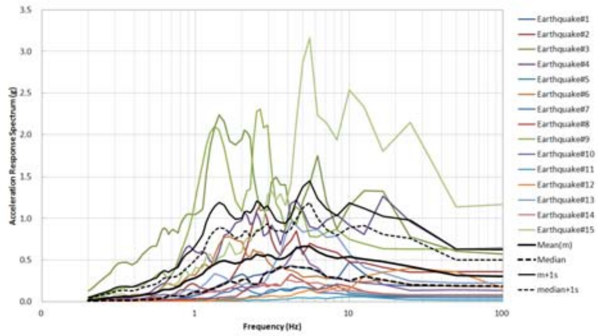
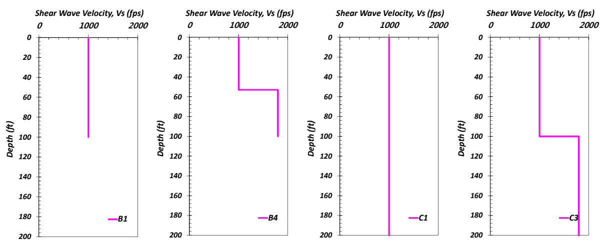


Fig. 1. Acceleration response spectrum of input ground motions (5% damping).

For the evaluation of the seismic response at surfaces of soil deposits, firstly, we selected four target sites (B1, B4, C1 & C3) from KNGR & APR 1400 site categories. Main difference of each category is shear wave velocity profiles. In Fig.2, the shear wave velocity profiles of target soil deposits are depicted. Site B4 & C3 has discontinuous surface at 53ft & 100ft, respectively.



B1, Sand (gravel) | B4, Sand & weathered rock | C1, Sand (gravel) | C3, Sand & weathered rock

Fig. 2. Shear wave velocity profiles of target soil deposits.

To consider the uncertainty of the material properties of soil deposits, we sampled 30 sets of combination of shear wave velocity & unit weight. It is assumed that each random variable has lognormal distribution & coefficient of variance (COV) of 0.25. Fig.3 shows the histograms & target probability density functions (green lines) of sampled random variables.

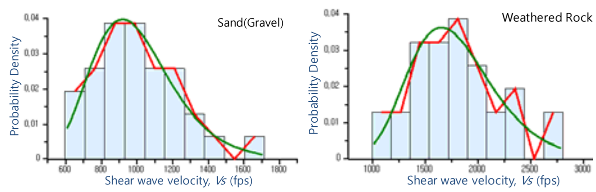
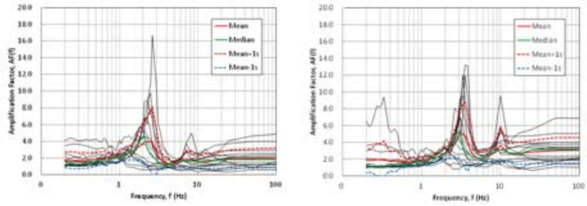
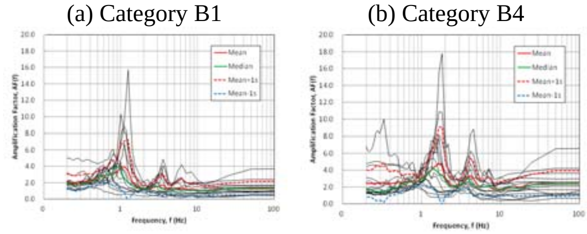


Fig. 3. Histograms of sampled random variable & target probability density functions.

The seismic responses at site surfaces are computed by using the ProShake [6, 7] code, and the amplification factors ($AF(f)$, equals to $S^s_a(f)$ / $S^r_a(f)$) are estimated (Fig.4). $S^s_a(f)$ & $S^r_a(f)$ represent spectral acceleration at surface & bedrock, respectively.



(a) Category B1 (b) Category B4



(c) Category C1 (d) Category C3

Fig. 4. Amplification factor at each site category w.r.t. frequency profiles.

From the previous research [3], it was revealed that the amplification factor has strong correlation with the spectral acceleration at bedrock, $S^r_a(f)$. Hence, to evaluate the UHS of the surface of the soft soil deposit, the regression analysis of amplification factor with respect to $S^r_a(f)$ are performed. Fig. 5 is an example of the regression results at some frequency points.

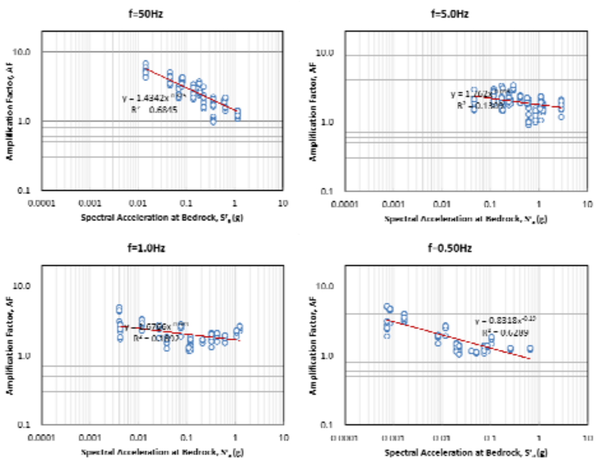
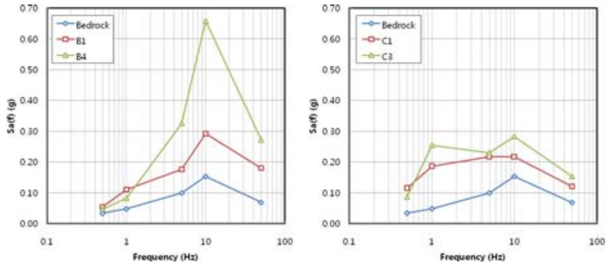
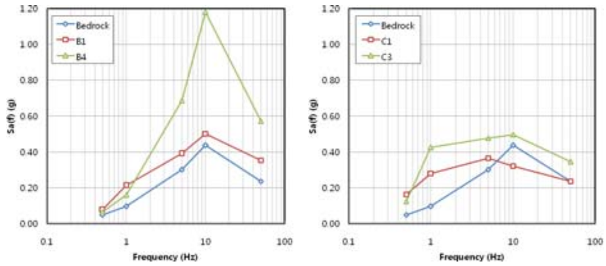


Fig. 5. Example of regression analysis results between amplification factor and spectral acceleration of input ground motion at bedrock (case of category B4).

In Fig.6, the UHS at the surface of the soft soil deposits are presented. It can be seen that the UHS at bedrock is most significantly amplified around of the frequency range of 10Hz in B4 category site. In the UHS of annual frequency 1.0E-5, it should be noted that the magnitude of the UHS at the surface of C1 site are reduced within some frequency range compared to that of the surface of bedrock. We suppose that the cause of this phenomenon is the nonlinear behavior of the soil deposit under strong level of ground motions.



(a) Annual frequency of 1.0E-4



(b) Annual frequency of 1.0E-5

Fig. 6. Uniform hazard spectra (UHS) at each site surface w.r.t. annual frequencies of 1.0E-4 & 1.0E-5.

3. Conclusions

The UHS of soft soil site were evaluated considering the uncertainties of soil deposits and input ground motions. In most case, the UHS are amplified at the surface of soft soil deposits. However, at category C1 site, it was observed that the reduction of the UHS in some frequency range due to the nonlinear behavior of the soil deposit under strong level of ground motions.

REFERENCES

[1] Schnabel, P.B., Seed, H.B., and Lysmer, J., "Modification of Seismograph Records for Effect of Local Soil Conditions", Bulletin of Seismological Society of America, Vol.62, pp.1649-1664, 1972.

[2] Faccioli, E., "A Stochastic Approach to Soil Amplification", Bulletin of Seismological Society of America, Vol. 66, No. 4, pp.1277-1291, August, 1976.

[3] Bazzurro, P., "Probabilistic Seismic Demand Analysis", Ph.D. Thesis, Stanford University, 1998.

[4] USNRC, "SRP 3.7.2 : Seismic System Analysis", U.S. Nuclear Regulatory Commission, 2007.

[5] ASCE, "Seismic Analysis of Safety-Related Nuclear Structure and Commentary", ASCE 4-98, 1999.

[6] Idriss, I.M., and Sun, J.I., “SHAKE91: A computer program for conducting equivalent linear seismic response of horizontally layered soil deposits”, User’s Guide, UC Davis, California, 1992.

[7] Schnabel, P.B., Lysmer, J., and Seed, H.B., “SHAKE: A computer program for earthquake response analysis of horizontally layered sites”, Report No. EERC 72-12, Earthquake Engineering Research Center, UC Berkeley, California, 1972.