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Ground Motion Response Spectra Considering Soil Amplification

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1. Introduction

The seismic design of the nuclear power plants (NPPs) has been based on a design earthquake which is consistent with the standard design response spectra [1]. After the concept of safe shutdown earthquake ground motion, which is based on the probabilistic seismic hazard analysis, was introduced, the existing deterministic method to evaluate design ground motions began to be changed into the probabilistic method [2]. With the introduction of performance based design, it is recommended that deign ground motions be consistent with uniform risk response spectra (URRS) or ground motion response spectra (GMRS), in which seismic risk has an annual probability of exceedance of 10^{-5}, rather than the uniform hazard response spectra (UHRS) [3]. Thus, the conversion of UHRS to URRS has been studied [4-6].

Earthquake responses of nuclear power plants are greatly affected by soil-structure interaction. Therefore, it has been studied how to obtain UHRS/GMRS at soil sites from those at the bedrock level considering soil-amplification effects. In this study, GMRS at soil sites will be computed from those at the bedrock level and the effects of soil amplification will be investigated.

2. Seismic Hazard Curves at Soil Sites

First, seismic hazard curves at soil sites are computed from those at the bedrock level considering the effects of soil amplification. The soil amplification is described by a amplification function, AF(f), where f is a generic oscillator frequency. AF(f) is defined as the ratio of the spectral acceleration at soil sites, , to that at the bedrock level, . The spectral acceleration is calculated using the iterative equivalent-linear site analysis code, ProSHAKE 2.0. From the calculations with various ground motions, the statistics of the amplification function are estimated. The seismic hazard at soil sites is computed by convolving the site-specific hazard curve at the bedrock level with the probability distribution of the amplification function AF(f).

The above methodology is applied in order to calculate seismic hazard curves at the generic soil sites in Table I. The hazard curves at the bedrock level is shown in Figure 1. It can be observed that the seismic hazard at 10 Hz is dominant. In this application, a total of 59 strong ground motions are considered for the calculation of statistics of the amplification function. Their spectral accelerations at the bedrock level are shown in Fig. 2. The spectral accelerations at the soil surfaces are calculated. The amplification functions for the considered 59 motions are shown in Fig. 3. The

Table I: Generic Soil Sites

(a) Profile

Depth (ft)	Generic soil								
	1	2	3	4	5	6	7	8	9
0 ~ 55	P1	P1	P2	P1	P3	P2	P2	P4	P4
55 ~ 100	P1	P1	P2	P2	P3	P3	P3	P4	P4
100 ~ 200	P1	P2	P2	P3	P4	P3	P4	P4	P5
200 ~ 500	P2	P3	P3	P4	P4	P5	P5	P5	P5
500 ~ 1000	P3	P4	P5	P5	P5	P5	P5	P5	P5
1000 ~	P5	P5	P5	P5	P5	P5	P5	P5	P5

(b) Properties

Generic soil	S-wave velocity (ft/sec)	Specific weight (lb/ft^3)
P1	1200	125
P2	2000	130
P3	4000	135
P4	6000	145
P5	9200	155

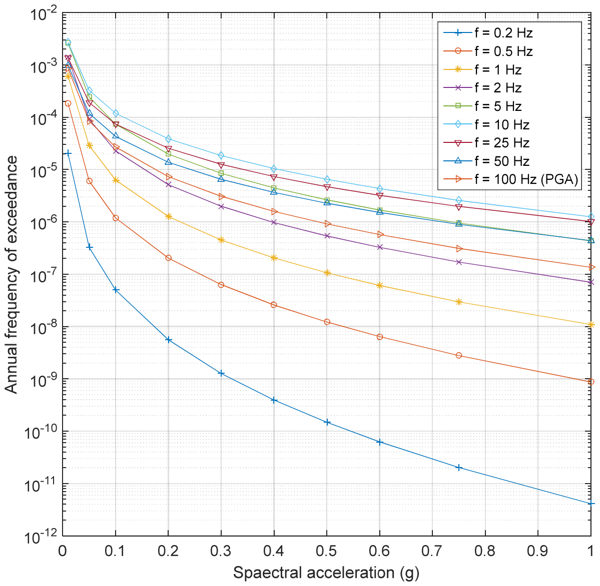


Fig. 1. Hazard curves at the bedrock level

amplification functions are regressed in terms of the spectral accelerations at the bedrock level and their statistics are determined assuming log-normal probability distributions. The regressions at 1 Hz and 10 Hz are shown in Fig. 4. Then, the seismic hazard curves at soil sites are obtained. Those at 1 Hz and 10 Hz are shown in Fig. 5. It can be observed that the soil amplifications at 1 Hz are not large for the generic soils 5 to 9 in Fig. 4(a). Thus, the hazard curves at the soil surfaces are very close to that at the bedrock level as shown in Fig. 5(a).

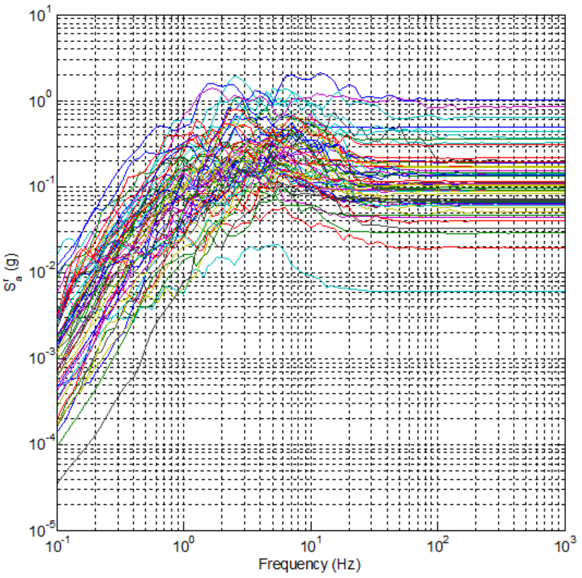


Fig. 2. Spectral accelerations at the bedrock level

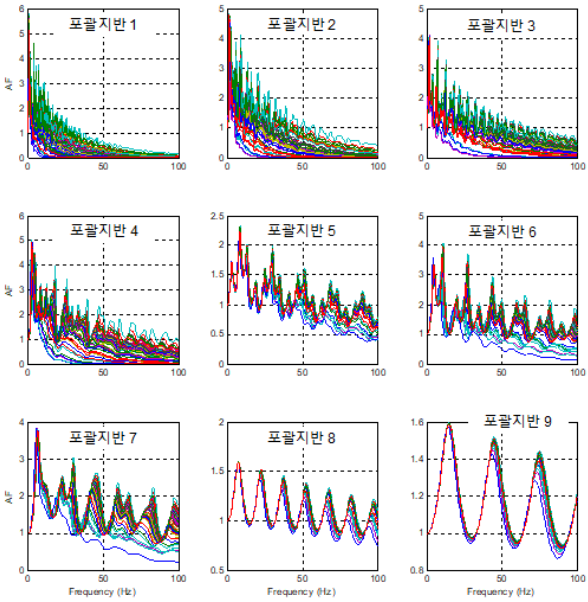
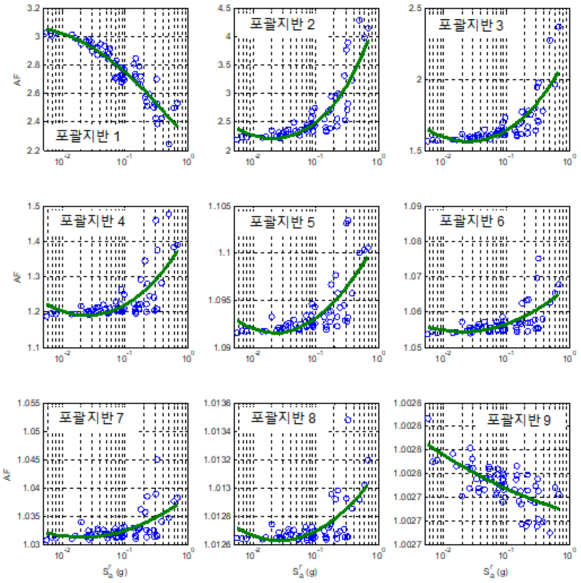
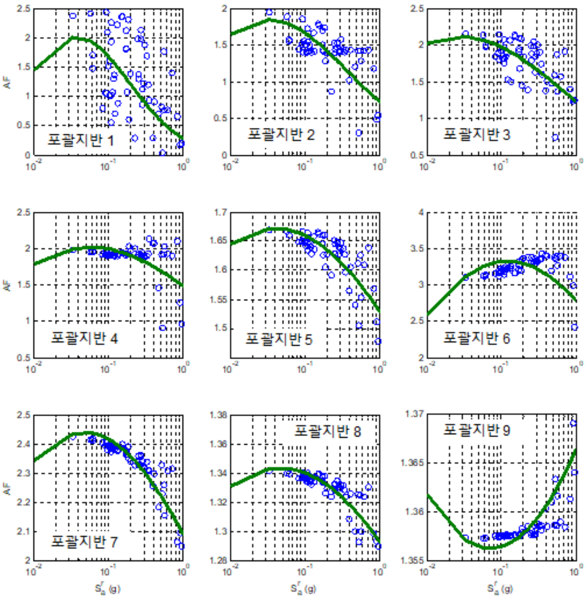


Fig. 3. Amplification functions



(a) *f* = 1 Hz

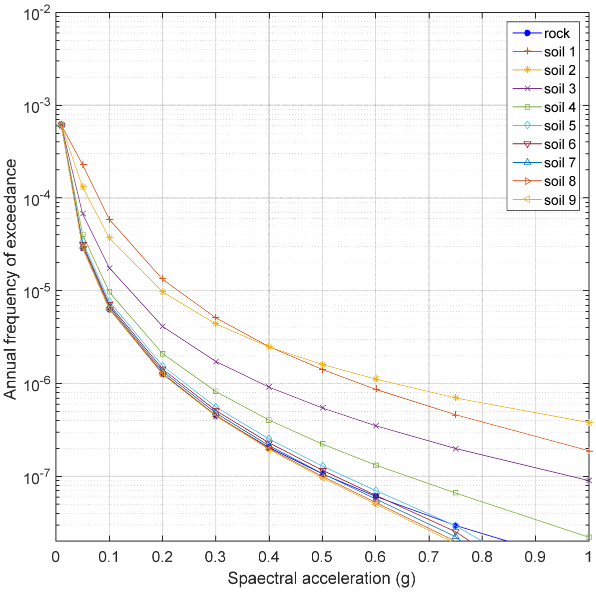


(b) *f* = 10 Hz

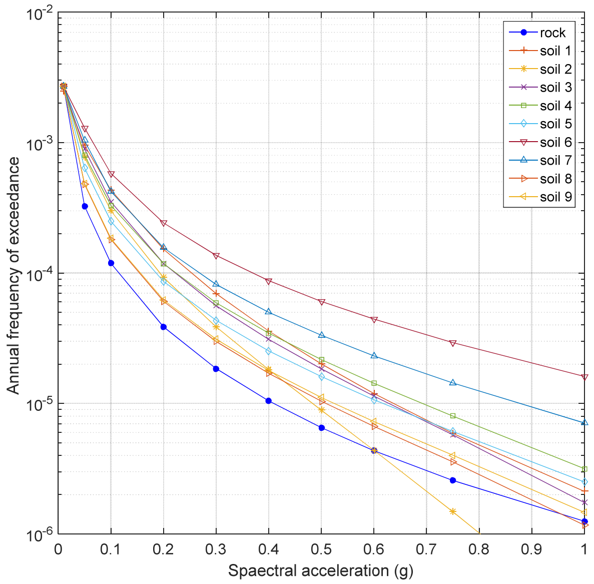
Fig. 4. Regressions of the amplification functions

3. Seismic Risk and GMRS at Soil Sites

Next, seismic risk at soil sites is calculated from the seismic hazard curves and fragility curves of structures, systems, and components (SSCs) in nuclear facilities. The fragility curves are given by cumulative distribution functions of logarithmic normal distributions. The medians and logarithmic standard deviations of the fragility curves are adjusted to achieve the two conservatisms in ASCE/SEI 43-05 [4]. Seismic risk at soil sites is calculated from the seismic hazard curves and fragility curves. Then, intensities of design earthquakes (DEs) and GMRS can be determined for a target performance goal.



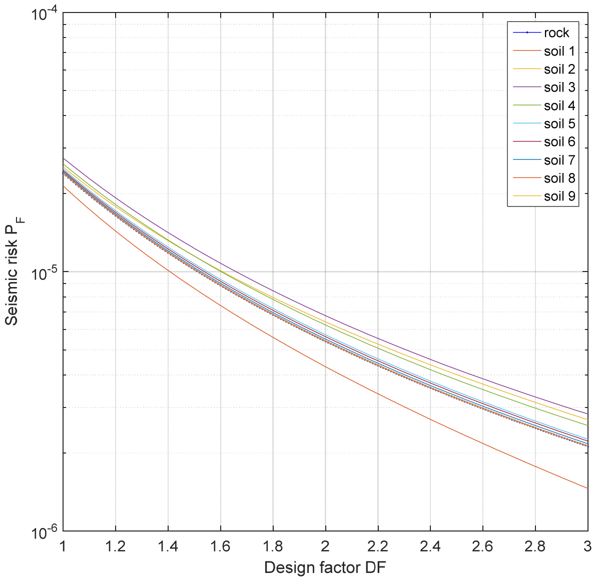
(a) *f* = 1 Hz



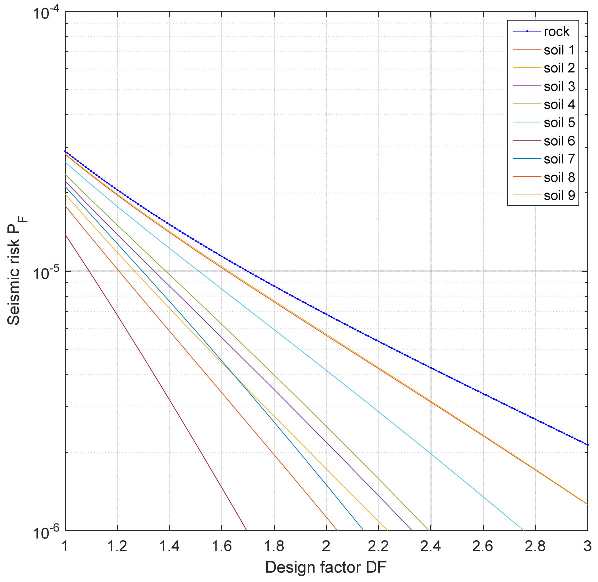
(b) *f* = 10 Hz

Fig. 5. Seismic hazard curves at the soil surfaces

The above methodology is applied in order to obtain GMRS at the generic soil sites in Table I. Seismic risk at the soil site is calculated for various values of design factors. The design factor (DF) is the ratio of DE to the UHRS. The values at 1 and 10 Hz are shown in Fig. 6. The values at which seismic risk is equal to a target seismic risk of 10^{-5} are determined. GMRS can be constructed from the values of DFs. The determined values of DFs and the GMRS are shown in Fig. 7.



(a) *f* = 1 Hz



(b) *f* = 10 Hz

Fig. 6. Seismic risk at the soil surfaces

4. Conclusion

In this study, seismic hazard curves and ground motion response spectra (GMRS) at soil sites were computed from those at the bedrock level. The soil simplification can influence them significantly. The GMRS will enhance the seismic safety of nuclear facilities.

Acknowledgements

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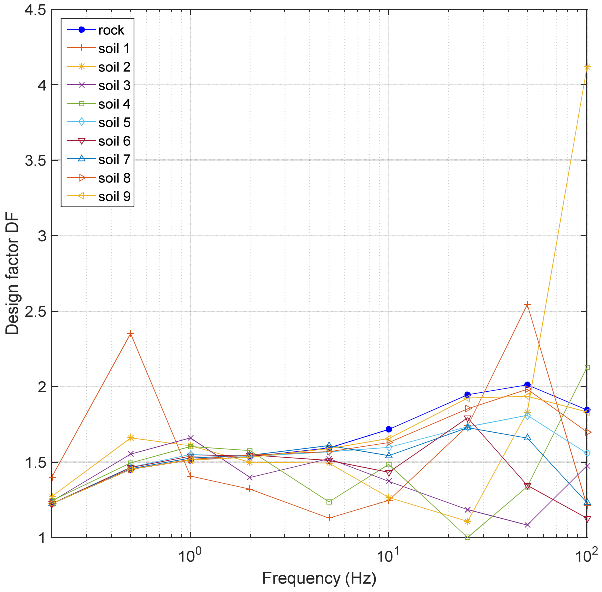
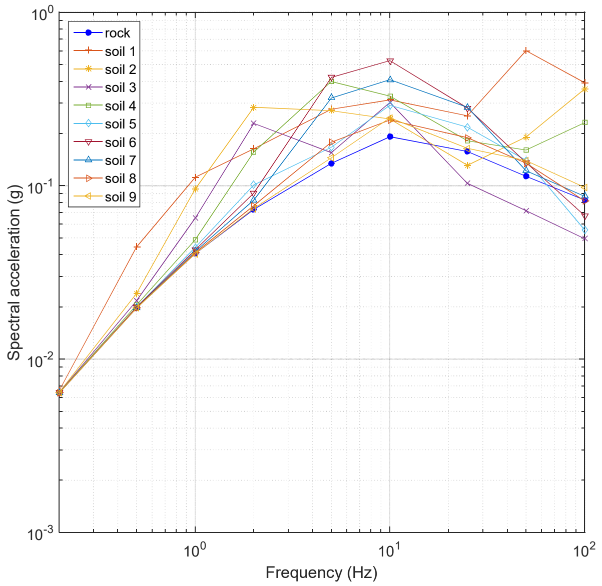


(a) Design factors for the target seismic risk



(b) GMRS

Fig. 7. Design factors for the target seismic risk and GMRS

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