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Sensitivity Analysis of Seismic Hazard Curve Conversion by the Probabilistic Distribution of Soil Amplification Factor

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1. Introduction

For seismic design of nuclear power plant structures, it is recommended to use Uniform Hazard Spectrum (UHS) developed by Probabilistic Seismic Hazard Analysis (PSHA) based on Reg.Guide 1.165 [1]. The UHS is prepared for the bedrock using the rock attenuation equation, but a site-specific UHS is needed in consideration of the amplification of seismic response due to the site characteristics of the nuclear power plant. However, it is difficult to determine a certain design response spectrum due to the lack of earthquake data and attenuation equation on the soil. Several studies are being conducted on the developments of site-specific design response spectrum, such as estimating UHS using the attenuation equation of the CEUS site like the domestic site or converting site-specific UHS from rock UHS. Based on the rock UHS, the Amplification Factor (AF) obtained from the site response analysis is applied when converting to site-specific UHS. In this study, a probabilistic method considering the distribution of the AF was used. By performing sensitivity analysis according to parameters such as the slope and frequency of the seismic hazard curve, we want to find out how much the AF value by site response analysis is amplified in UHS.

2. Site-Specific UHS Conversion Methods

To obtain a site-specific UHS, the most appropriate approach would be to develop a site-seismic hazard using attenuation equation at a specific nuclear power plant site for various earthquake magnitudes and epicenter distances. However, since the attenuation equation is generally determined from earthquake data measured at various sites with similar ground conditions, it is difficult to apply it in reality because there is not enough data to obtain the attenuation equation for a specific nuclear power plant site. Therefore, a method for converting site-specific UHS based on rock UHS is widely used.

2.1 Approaches of NUREG/CR-6728

NUREG/CR-6728 [2] presents approaches that can be converted to soil UHS based on rock UHS and shows the results of implementing the proposed approaches using the WUS and CEUS sites as an example. The criteria are largely classified into two approaches: to calculate the soil hazard curve by integrating multiple over multiple rock amplitudes, or to use the rock UHS as annual probability to derive the soil UHS with the same probability. Because of the attenuation equation lacks in soil, an alternative method of calculating the seismic hazard curve on the soil by scaling the ground motion by the AF is widely used.

2.2 The site-specific UHS conversion

Figure 1 [3] shows two approaches to obtaining soil UHS. The traditional approach is to obtain the soil UHS by scaling the rock UHS by the AF. However, because AF is estimated through empirical data based on site characteristics, it is highly variable, and conservative results may not be obtained due to the frequency dependent characteristics of site amplification and variability of the site. Therefore, it is effective to obtain a soil UHS considering the variability of site amplification by developing a soil seismic hazard curve by convoluting the distribution or variability of the AF derived from the site response analysis with the rock seismic hazard curve. In this study, the soil seismic hazard curve was converted through this probabilistic method and the sensitivity analysis was performed accordingly.

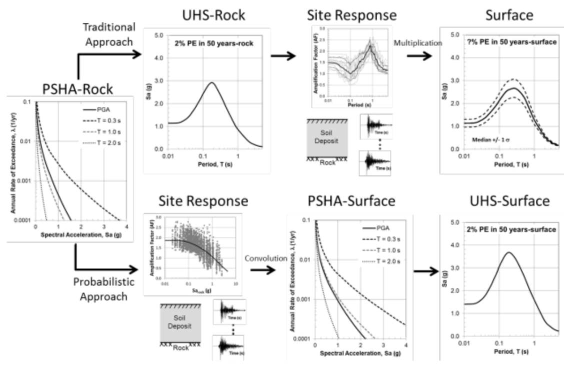


Fig. 1. Approaches for developing soil UHS (Rathje et al, 2015).

3. The Sensitivity Analysis and Results

3.1 Seismic hazard curve model

In this study, sensitivity analysis was performed through a simple example to see the tendency of the soil seismic hazard curve converted through the probabilistic method to the rock seismic hazard curve to be amplified by the distribution of the AF. The seismic hazard curve was prepared by the approximate Equation (1) expressed in ASCE 43-05 [4].

$$H(a) = K_1 a^{-K_H} \quad (1)$$

$$K_H = \frac{1}{\log(A_R)} \quad (2)$$

$$A_R = \frac{SA_{0.1H_D}}{SA_{H_D}} \quad (3)$$

$H(a)$ is the annual frequency of exceedance of ground motion level a, K_1 is the constant, and K_H is the slope parameter that determines the slope of the hazard. A_R is a slope factor that means the ratio of UHS spectral acceleration of a specific annual frequency of exceedance and frequency equivalent to 0.1 times. The factor has a value of 1.5 to 3.0 in the WUS, but it can change to 2.0 to 6.0 in the CEUS, so the amplification tendency was analyzed by varying A_R by referring to the data of the CEUS, which are like conditions of the domestic earthquake occurrence.

3.2 Seismic Amplification Factor

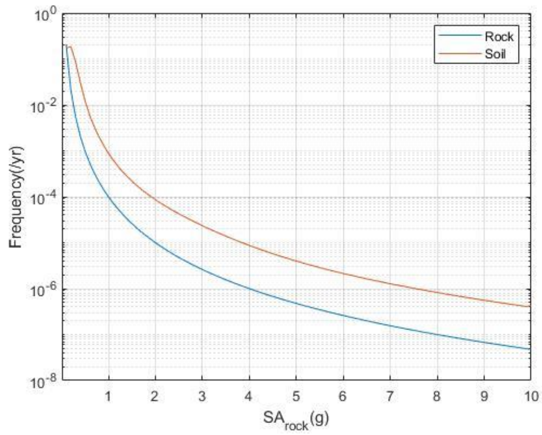
For the AF, an arbitrary value was used by referring to the AF of the $S_2 \sim S_5$ site presented in the KDS 17 00 00 [5] (Table 1). It was classified into short-period AF from 0.1 to 0.9 seconds and a long-period AF from in the range of 1.0 to 10 seconds and applied respectively. Because the variability of the AF can show a large deviation depending on the ground characteristics, a random value was fixed and applied for all accelerations.

Table. 1: The short and long period AF by ground type (KDS 17 00 00)

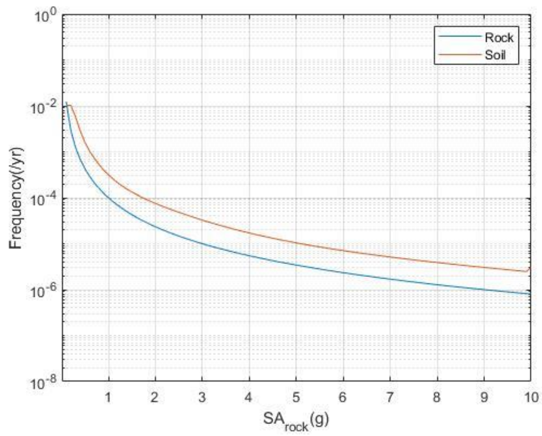
Ground type	AF of the short period (0.2 sec)	AF of the long period (1.0 sec)
S_2	1.3~1.4	1.3~1.5
S_3	1.3~1.7	1.5~1.7
S_4	1.2~1.6	1.8~2.2
S_5	1.3~1.8	2.4~3.0

3.3 The sensitivity analysis

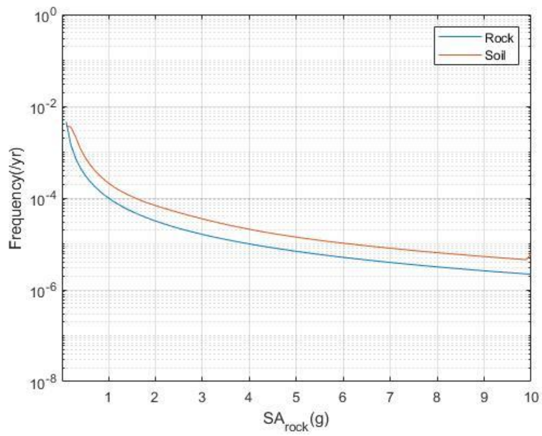
Figure 2 shows the soil hazard curve calculated by convoluting the hazard curve by Equation (1) and the AF of the S_2 ground which is set by referring to the domestic seismic design standard. Because AF has a value of 1.2 or more for all accelerations, it tends to be amplified overall in the entire acceleration range. As can be seen from Equation (2), as the A_R value increases, the slope parameter decreases, and the hazard curve shows a gradual shape. Also, it can be confirmed visually that the amplification decreases for the same annual frequency of exceedance. Table 2-3 shows the amplification ratios for the accelerations corresponding to the 10^{-4} and 10^{-5} frequencies used as representative frequencies. Here, the amplification ratio is defined as SA_{soil}/SA_{rock}. The amplification ratio according to the annual frequency of exceedance shows almost similar results, which is presumed to be the result because the set AF values are similar in all acceleration ranges. In addition, in all cases except when the slope factor is 6, the value is lager than the AF value corresponding to each acceleration, which means that it can have a larger amplification than expected from the site response analysis. Therefore, it may be more effective to obtain site-specific UHS through a probabilistic method using AF distribution than to directly apply AF to rock UHS for conservative results when determining design ground motion.



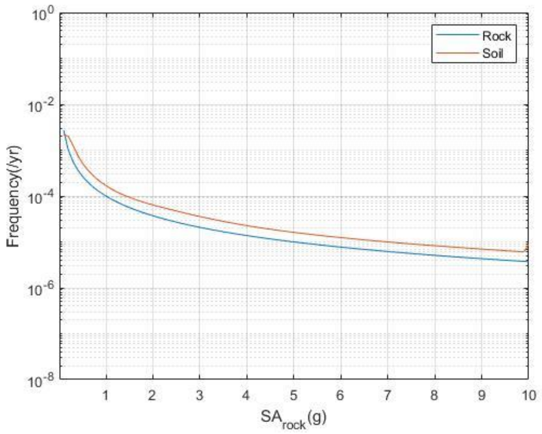
(a) $A_R = 2.0$



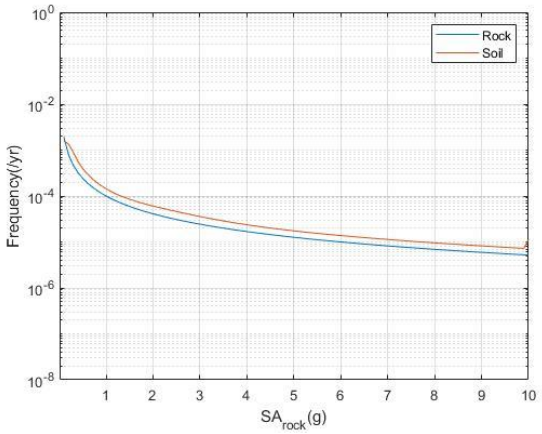
(b) $A_R = 3.0$



(c) $A_R = 4.0$



(d) $A_R = 5.0$



(e) $A_R = 6.0$

Fig. 2. The result of the seismic hazard curve of S_2 according to A_R

Table. 2: The acceleration and amplification ratio corresponding to 10^{-4} annual frequency of exceedance

A_R	SA_{rock} (g)	SA_{soil} (g)	Amplification Ratio	AF
2.0	1.0	1.9	1.9	1.46
3.0	1.0	1.7	1.7	1.46
4.0	1.0	1.6	1.6	1.46
5.0	1.0	1.4	1.4	1.46
6.0	1.0	1.3	1.3	1.46

Table. 3: The acceleration and amplification ratio corresponding to 10^{-5} annual frequency of exceedance

A_R	SA_{rock} (g)	SA_{soil} (g)	Amplification Ratio	AF
2.0	2.0	3.8	1.9	1.44
3.0	3.0	5.0	1.67	1.32
4.0	4.0	6.1	1.53	1.34
5.0	5.0	7.0	1.4	1.32
6.0	6.0	7.7	1.28	1.48

3. Conclusions

In this study, a sensitivity analysis was performed in the process of converting a rock seismic hazard curve through a probabilistic method using the distribution of the ground amplification factor, AF. The hazard curve equation presented in ASCE 43-05 was used as a model, and the AF referred to the amplification factor presented in the domestic seismic design standard. Because the hazard curve is sensitive to the slope factor, the amplification tendency according to the slope factor was analyzed. As a result, as the slope factor increased, the hazard curve became more gradual, and the amplification ratio tended to decrease. When comparing accelerations corresponding to 10^{-4} and 10^{-5}, which are representative annual frequency of exceedance, there was no significant change in the amplification ratio according to annual frequency of exceedance. However, the amplification ratio of the analysis result was larger than the AF of the corresponding rock spectral acceleration.

This study was conducted by assuming a simple hazard curve and arbitrary AF distribution for sensitivity analysis. In the future, it is expected that a more detailed sensitivity analysis will be performed and analyzed through actual data to identify the amplification effect on UHS and to be the basis for determining the site-specific design ground motion.

Acknowledgements

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