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Challenges on Probabilistic Site Response Analysis for the Generation of GMRS in Korea

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1. Introduction

Recently, due to the Gyeongju and Pohang earthquakes, interest in safety of nuclear facilities is increasing. Several researches are being carried out at the national level for seismic design and seismic performance evaluation of nuclear power plants. The criteria for them are based on the performance target and are divided into seismic demand and seismic capacity. The seismic demand is defined as the design load transferred to the surface level of structure by the design response spectrum(DRS) and corresponding acceleration time histories. The performance goal is defined as probability (e.g., Seismic Design Category-5: 1×10^{-5}) and the seismic design load is obtained through a probabilistic seismic analysis by multiple seismic input motions. Also, probabilistic methods such as a probabilistic seismic hazard analysis(PSHA) and a probabilistic site response analysis(PSRA) are performed in estimating a site-specific, performance-based ground motion response spectrum(GMRS). All of these processes are carried out in correspondence with each other in order to achieve the seismic performance. Among them, a probabilistic site response analysis is performed with bedrock motions derived from the PSHA and a uniform hazard response spectra(UHRS). Their results become surface motions and the disturbed soil properties and serve as an intermediary for inputs to a soil-structure interaction(SSI) analysis. Therefore, a procedure for the probabilistic seismic analysis is needed to carry out its role as a link in the performance-based seismic design as well as the methodology of the probabilistic site response analysis itself. An automated program is essential as hundreds of site response analyzes performed in a probabilistic way. In this paper, we describe challenges on the probabilistic site response analysis for the generation of GMRS in Korea and focuses on the development of its program, PSHAKE which stands for Probabilistic SHAKE.

2. Methods and Results

2.1 Ground Motion Response Spectrum in Korea

The process of obtaining a site-specific, performance-based GMRS starts from finding a hazard curve through PSHA and converting the hazard curve into the UHRS at bedrock location to obtain the UHRS at the surface location. In order to obtain the design response spectrum of the site where an actual nuclear power plant is located, the site amplification effect should be calculated. The final GMRS is obtained by probabilistically considering uncertainty of the site. Fig. 1, the process is as follows.

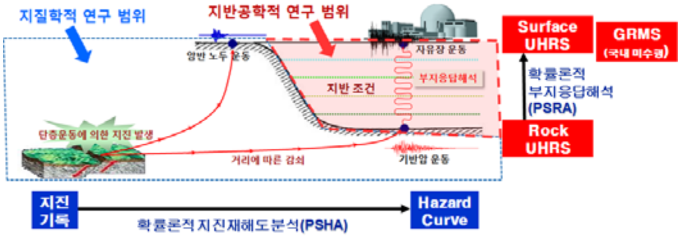


Fig. 1. Hazard Curve, UHRS, and GMRS

The PSRA is constructed for seismic wave transmission from bedrock to the surface level at the site. The detailed process is described in U.S. NRC. Reg. Guide 1.208 [1] and ASCE 4-16 [2]. Reg. Guide 1.208 describes site amplification in the process of developing the GMRS and ASCE 4-16 also describes the part of a probabilistic seismic analysis more detailed on the PSRA. The selection of bedrock motions(i.e., controlling motions) is done through deaggregation for review of the PSHA and NUREG/CR-6728 [3] includes technical basis on the selection for design ground motions. However, the motion information in NUREG/CR-6728 [3] is for the US and some other countries, not for Korea.

The PSRA is constructed for the variation of a soil profile such that a minimum of 60 realizations shall be generated [1] due to the nonlinear nature of the analyses. To determine the surface-level of UHRS through the PSRA, the probabilistic models which are constructed by regression based on reliable data are needed for the generation of the site-specific soil profile but those are not available in Korea.

2.2 Probabilistic site response analysis

The PSRA is performed for UHRS return periods for each magnitude scale, distance, and high- of low-frequency range of earthquakes, and therefore requires at least 60 probabilistic analyzes (generally more than 360) varying soil profiles. Without algorithms and an automated program to support it, it is impossible to do manually, easily, or reliably. In the PSRA, the dispersion of the four soil parameters, i.e., shear wave velocity, shear modulus, damping, and layer thickness (V_s, G, ξ, and layer thickness) should be considered.

In order to deal with the dispersion of the four soil parameters, a probability model for each parameter should be developed. The models are identified by a layering model, a velocity model, and nonlinear models for G/G_{max} and the damping.

First, the layering model is about the layer thickness and captures that layers tend to be thinner near the surface and thicker at depth. Toro [4] includes the layering model is modeled as a non-homogeneous Poisson process where the rate changes with depth. For a homogenous Poisson process, the depth rate is constant while for a non-homogeneous Poisson process, the rate varies. The approach of Toro [4] shows two methods assuming that the ground is homogeneous or nonhomogeneous. The model for layer thickness calculation is based on the Poisson cumulative distribution and the equation for layer thickness is given in the form of an inverse function. The formula assuming that the layer is a non-homogeneous is defined as a function of the depth of the layer thickness.

The velocity model is about shear wave velocity (V_s). It generally uses lognormal distribution and Toro [4] shows its approach well. The distribution of the shear wave velocity is determined by Z_i and it can be seen that it is greatly affected by the correlation ρ of the shear wave velocity. ρ is a function of the layer depth d and the layer thickness h, which means that as the depth of the layer becomes deeper, the thickness of the layer becomes thicker. Here, the other parameters ρ_0, Δ, d_0, and b are determined by regression based on the soil data of the site. The values in the US are described in detail in Toro [4] but this approach has not been implemented yet in Korea. Because the values are not presented, the models and the values from Toro [4] are used in this study.

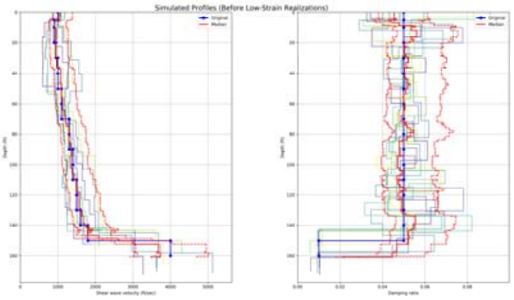
G/G_{max} curves and damping ratio curves, which are nonlinear soil properties, should also be considered additionally. The details are not shown in this paper but Toro [4] shows the procedure for those models.

2.3 Program PSHAKE

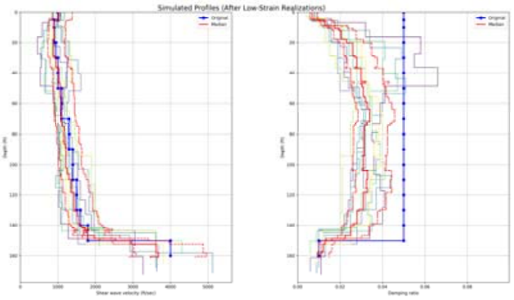
PSHAKE, a program for performing the PSRA, has been developed by constructing generation of the random variables and site response analyses through four soil models separately. It is based on the programming language Python. In the process of writing the program, the SHAKE91 also has been updated. PSHAKE adds an algorithm to automatically generate the input files (SASSI SITE data) for probabilistic SSI seismic analyses. The results of a preliminary analysis by the program PSHAKE are shown in Fig. 2.

3. Conclusions

This study includes the development of a program for a probabilistic seismic analysis of nuclear power plants and challenges in the middle of the generation of GMRS in Korea. It is expected that regulation related to the performance-based seismic design of nuclear power plants will be mandated afterwards, so that the requirements of domestic regulation will be increased. Therefore, this study includes a preliminary analysis to prepare the performance-based seismic design in Korea. In reality that seismic design of nuclear power plants is shifting to performance-based design all over the world, this study includes the development of a fundamental program and the preparation for it. Based on this probabilistic study, we expect to apply it to performance-based seismic design for domestic construction of nuclear power plants as well as to an emergency response building and the prototype of sodium fast reactor (SFR) design in Korea.



(a) Original soil property



(b) Disturbed soil property

Fig. 2. Generated shear wave velocity profiles.

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