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Generation of a Pilot GMRS through Probabilistic Site Response Analysis

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1. Introduction

There is a growing interest in earthquakes after the occurrence of domestic earthquakes(Gyeongju and Pohang) and various attempts have been made to more accurately evaluate the effects of earthquakes in Korea. In the field of seismic design and evaluation for nuclear facilities, more rigorous approaches are required. The related studies have been conducted in the United States(US) and then in Korea too. For the United States, seismic performance evaluation and seismic design are unified and implemented by performance-based design method systematically. In Korea, there is conflict between seismic design codes which are originated from the DC(Design Certification) process of the United States and the recent seismic performance evaluation standards. The standards are based on a target performance(e.g., Seismic Design Category-5: 1×10^{-5})[1] and are divided into seismic demand and seismic capacity. The seismic demand is defined as the design response spectrum(DRS) and corresponding acceleration time histories. In the case of domestic seismic design for nuclear power plants, it is based on US NRC R.G. 1.60[2] design response spectrum. However, in the performance-based seismic design, a site-specific ground motion response spectrum(GMRS) should be used.

GMRS is applied for CP(Construction Permit), OL(Operating License), ESP(Early Site Permits) and COL(Combined Licenses)[3]. GMRS can be divided into the procedures to determine the annual frequencies of maximum acceleration and to obtain appropriate response spectrums at the free-field ground surface reflecting seismic wave transmission(site amplification). These procedures correspond to a Probabilistic Seismic Hazard Analysis(PSHA) and a Probabilistic Site Response Analysis(PSRA), and all processes are performed being consistent with the seismic performance goal. Also, in order to consider SSI effect a seismic response analysis should be performed statistically so as to include disturbed soil properties through the probabilistic site response analysis.

2. Methods and Results

2.1 Probabilistic Site Response Analysis

The PSRA is constructed for seismic wave transmission from bedrock to the surface level at a site. The detailed process is described in U.S. NRC. Reg. Guide 1.208[3] and ASCE 4-16[4]. Reg. Guide 1.208 describes site amplification in the process of developing the GMRS and NUREG/CR-6728[5] provides technical basis on the selection for design ground motions and detailed approaches. ASCE 4-16 also describes the part of the probabilistic seismic analysis more detailed on geotechnical characteristics. However, the motion information and statistical models for geotechnical characteristics in NUREG/CR-6728[5] are for the US and some other countries, not for Korea.

The probabilistic site response analysis is an interpretation that realizes site amplification of earthquakes from bedrock to near the surface. Each probabilistic site response analysis is performed for UHRS(Uniform Hazard Response Spectrum) with the annual frequencies of 10^{-4} and 10^{-5} deaggregated by earthquake magnitude, distance, and frequency ranges. The US NRC. Reg. Guide 1.208 describes as follows:

Analysis of multiple ground motion levels are used to obtain a more complete understanding of the earthquake characteristics (i.e., mean magnitudes and distances) that contribute to the high-frequency(5 and 10 Hz) and low-frequency (1 and 2.5 Hz) hazard, than could be obtained from a single ground motion level (e.g., 1 E-05/yr).

Since the probabilistic site response analysis requires at least 60 convolution analyses and it is performed for each seismic scenario, hundreds or thousands of probabilistic analyzes should be performed to define the mean and the standard deviation of the site response. Therefore, it cannot be done without an statistical models for the soil properties an automation program supporting it. STRATA is a representative program which is being applied to various fields and it is being used in the project of the Wylfa nuclear power plant in the UK. STRATA is used in this research for the probabilistic site response analysis.

In the PSRA, the soil parameters, i.e., shear wave velocity, shear modulus, damping, and layer thickness (V_s, G, ξ, and layer thickness) should be defined in terms of statistical variation. 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[6].

Fig. 1 shows randomized soil layer profiles and disturbed layer profiles through the PSRA and Fig. 2 shows randomly generated damping curves and shear modulus ratio curves of sand. Fig. 3 includes the results of Mean Amplification Functions for 10^{-4} and 10^{-5}

mean annual probability of exceedance through 60 simulations respectively.

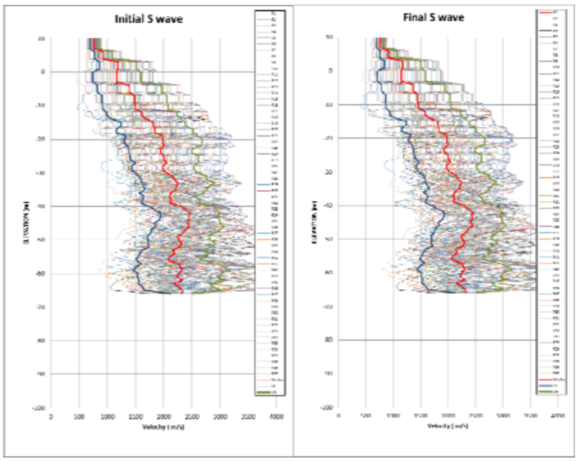

Fig. 1. Soil layer profile (randomly generated) and Disturbed layer profile

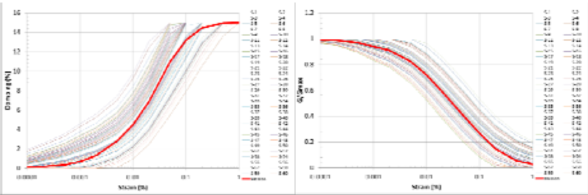

Fig. 2. Damping curves and shear modulus ratio curves of sand (randomly generated)

2.2 Pilot GMRS

Currently, GMRS is not used in seismic design or seismic performance evaluation in domestic nuclear industry in Korea. In order to apply this performance-based GMRS, a probabilistic seismic hazard analysis should be accompanied, but it was not implemented because of lack of information for detailed seismological data and following GMPEs and approaches. Also, the performance-based seismic design method is no implemented yet in the field of nuclear power plant design in Korea. Fortunately, as the survey of seismic sources in Korea is carried out by 2021, it is necessary to research engineering techniques for the generation of GMRS which can be used for seismic design and performance evaluation. In this study, the PSRA is performed for one site of nuclear power plants in Korea and a pilot GMRS is generated. Fig. 4 shows the generated GMRS, UHRSs at surface for 10^{-4} and 10^{-5} mean annual probability of exceedance with layer thickness variation and also the CSDRS(Certified Seismic Design Response Spectra) of the APR1400 for comparison.

3. Conclusions

The Pilot GMRS was derived through a probabilistic site response analysis in this study with Approach 1 in NUREG/CR-6728 to consider site amplification. As Approach 1 is known to show a relatively conservative result compared to Approach 2 or 3, there is a need for a more rigorous approach to consider site amplification in Korea. Concurrently, profound researches on PSHA should be accompanied so as to apply Approach 2 or 3 with a more complete understanding of the earthquake characteristics through deaggregation of seismic hazard in Korea. As a result, more rigorous and reliable GMRS of nuclear power plant sites in Korea can be developed.

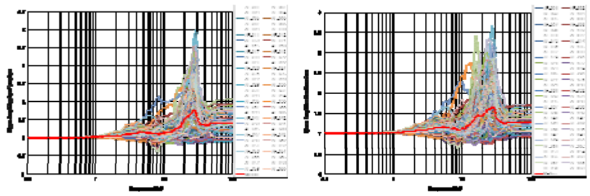

Fig. 3. Mean Amplification Functions for 10^{-4} and 10^{-5} mean annual probability of exceedance

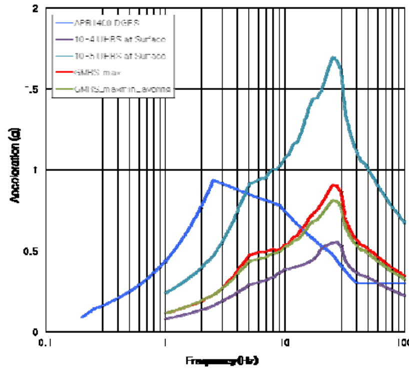

Fig. 4. GMRS, UHRSs at surface for 10^{-4} and 10^{-5} mean annual probability of exceedance with layer thickness variation

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