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Uniform Hazard Response Spectra of Korea Considering Uncertainties in Ground Properties

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UNIFORM HAZARD RESPONSE SPECTRA OF KOREA CONSIDERING UNCERTAINTIES IN GROUND PROPERTIES

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ABSTRACT

The seismic site coefficients derived deterministically are often used with ground motion parameters determined by probabilistic seismic hazard analysis in construction of the design response spectrum. There is, therefore, an inherent incompatibility between two approaches. New methods have been developed to resolve this incompatibility by developing probabilistic seismic site coefficients. In such approaches, the uncertainties in the properties of the ground were not systematically accounted for due to lack of measurements of the ground. In this study, an integrated probabilistic seismic hazard analysis which can quantify the nonlinear seismic site effects and account for the uncertainties in soil properties is developed and used to generate the uniform hazard response spectra in Korea. The procedure used an extensive database of measured shear wave velocity profiles and dynamic curves, which included more than 114 shear wave velocity profiles and more than 15 dynamic curves. The calculated uniform hazard response spectra were compared to the design spectra. Comparisons show significant discrepancy between two spectra, and highlight the need to revise the current design guideline.

INTRODUCTION

Probabilistic seismic hazard analysis (PSHA) is widely used to quantify the hazard originating from future earthquakes (Frankel et al., 2002; Cramer et al., 2002; Kramer, 1996). The result of a PSHA is most often represented in the form of the seismic hazard map, which depicts the contours of a ground motion parameter for various probability levels.

The seismic site effects is known to have an important influence on the characteristics of the ground motion and need to be considered in the characterization of the seismic hazard. A traditional PSHA method, however, cannot account for the seismic site effects. It is a common practice to link the probabilistically determined ground motion parameter(s) calculated from the PSHA with deterministically derived site coefficients in developing the design acceleration response spectrum (DS), thus neglecting the inherent incompatibility (MOCT, 1997; FEMA, 1997).

Park and Hashash (2005) developed a new PSHA procedure (PSHA-NL) that can incorporate the seismic site effects within the probabilistic framework. PSHA-NL, which is based on the work of Wen and Wu (2001), generated fully probabilistic and depth-dependent site coefficients of the Mississippi Embayment that are compatible with the USGS seismic hazard maps. In the development, uncertainties in the ground properties were not taken into account.

This paper applied the PSHA-NL approach in developing the uniform hazard response spectra (UHRS) of Korea. An extensive database of measured site profiles was used to model the uncertainties in the site profile. In addition, a series of site-specific and generic dynamic curves were used to account for the variability in the dynamic soil behavior. The probabilistically derived UHRS were compared to the Korean seismic design code (MOCT, 1997).

SEISMIC HAZARD OF KOREA AND DESIGN CODE

The probabilistic seismic hazard maps (MOCT, 1997) depict variations of the peak ground acceleration (PGA) for various mean annual rates of exceedance. The PGA of Korea can also be determined from the seismic zone classification system (MOCT, 1997).

Table 1. Site classification of Korean seismic design guideline (MOCT, 1997)

Site class	Description	$\overline{v}_s$	$\overline{N}$ or $\overline{N}_{ch}$	$\overline{s}_u$
S_A	Hard rock	> 1500 m/s	N.A.	N.A.
S_B	Rock	760 to 1500 m/s	N.A.	N.A.
S_C	Very dense soil and soft rock	360 to 760 m/s	> 50	> 100 kPa
S_D	Stiff soil	180 to 360 m/s	15 to 50	50 to 100 kPa
S_E	Soft soil	< 180 m/s	< 15	< 50 kPa
S_F	Soils requiring site-specific evaluations			

Table 2. Comparison of site coefficients of MOCT (1997) and 1997 NEHRP (FEMA, 1997)

Site	C_a	F_a (MOCT)	F_a (NEHRP)	C_v	F_v (MOCT)	F_v (NEHRP)
S_A	0.09	0.81	0.80	0.09	0.81	0.80
S_B	0.11	1.00	1.00	0.11	1.00	1.00
S_C	0.13	1.17	1.20	0.18	1.62	1.69
S_D	0.16	1.44	1.58	0.23	2.07	2.36
S_E	0.22	1.98	2.42	0.37	3.33	3.47

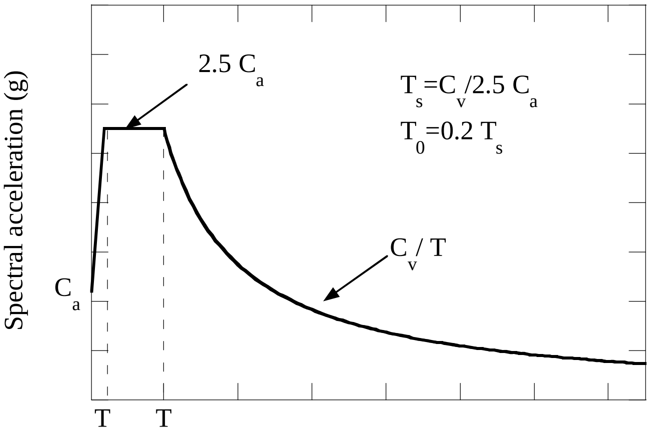


Fig. . 1 Design response spectrum characterization (MOCT, 1997).

The system divides South Korea into two zones (termed Seismic Zone I and II), at which PGAs of 0.11g and 0.07g are assigned for an earthquake with a return period of 500 years, respectively. After selecting the PGA, it is used with site coefficients to develop the DS. The site classification system used in the Korean seismic design guideline (MOCT, 1997) is summarized in Table 1 and the corresponding site coefficients are listed in Table 2. The procedure of developing the DS is illustrated in Fig. 2.

Korean site classification system is identical to 1997 NEHRP Provisions (FEMA, 1997) and 1997 UBC, which classifies the soil column into six categories based on the average shear wave velocity (often termed Vs30), standard penetration resistance, or undrained shear strength of the upper 30 m of the soil profile, as shown in Table 1. Table 2 lists the site coefficients Ca and Cv for all site classes. Ca represents the PGA, while Cv represents the 1.0 sec spectral acceleration. Also shown in Table 2 are the calculated Fa and Fv, which are not specifically defined in the design code (MOCT, 1997), but calculated in this study to compare with the 1997 NEHRP coefficients (FEMA, 1997), also listed in Table 2. Table 2 demonstrates that the MOCT (1997) and 1997 NEHRP (FEMA, 1997) coefficients are very similar. When developing the DS at other return periods, both site coefficients are simply multiplied by the Safety factor, which are defined as 1.4 and 2.0 for 1000 and 2400 year return periods, respectively.

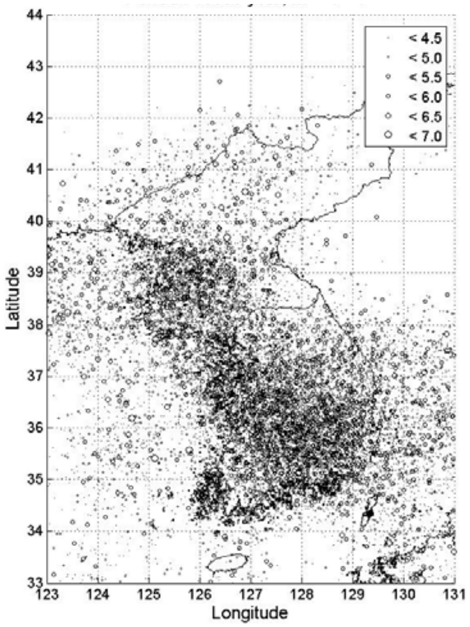
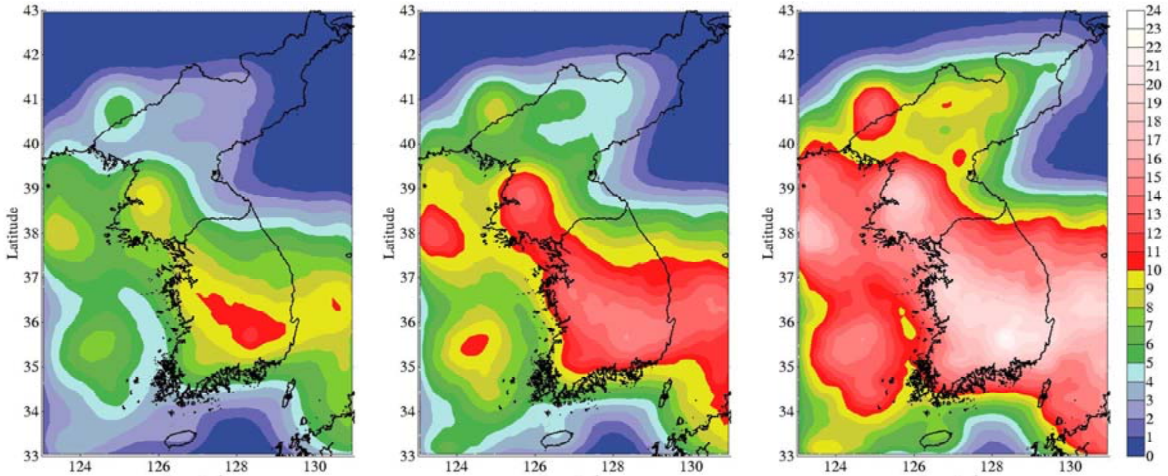


Fig. 2. Locations of epicenters simulated during a period 40,000 years.



(a) (b) (c)

Fig. 3. Seismic hazard maps developed from PSHA-NL (units in the legend: 0.01g): a) 500 year return-period, b) 1000 year return-period, a) 2400 year return-period.

PSHA WITH NONLINEAR SEISMIC SITE EFFECTS

PSHA-NL, developed by Park and Hashash (2003), integrates the PSHA with the site response analysis tool. PSHA-NL is performed in 3 steps, which are a) step 1: source characterization, b) step 2: generation of ground motions, and c) step 3: site response analysis. Before performing the PSHA-NL, the area is subdivided into 0.1° × 0.1° grids. The seismicity of each grid is defined according to the seismic design code.

In step 1 of the PSHA-NL, a random number which is uniformly distributed between 0 and 1 is generated within the grid. The generated number is related to the number of occurrence and magnitude during a 10-year simulation. Details on this process are presented in Park (2003). This process is repeated for a finite period until the aggregate of generated earthquakes corresponds to the seismicity of the grid.

In step 2, a site of interest is selected within the map. Among all earthquakes generated in step 1, earthquakes that occurs within a radius of 300 km are selected and the magnitudes – distances are recorded. A standard PSHA uses the attenuation relationship to estimate the ground motion parameter at the selected site. PSHA-NL uses a synthetic ground motion generation program to actually develop the acceleration time history.

In step 3, the generated motions are propagated through the site profiles of the site. By propagating all ground motions generated within 300 km from the site, the surface acceleration time histories and response spectra are obtained. The response spectra are used to develop the uniform hazard response spectrum (UHRS).

The accuracy of the PSHA-NL depends on the number of simulations. In this study, 4000 simulations of 10-year periods are performed, resulting in 40,000 years of earthquake record and 16,378 earthquake sources. The locations of the simulated sources are shown in Fig. 2. The ground motions were generated using SMSIM (Boore, 2002). SMSIM, which uses a point-source stochastic model in generating the earthquake scenario compatible synthetic motion, was used in development of the USGS hazard maps. The input parameters for SMSIM representative of the Korean seismic environment were proposed by Noh and Lee (1994) and used in the generation. The seismic hazard maps produced by the PSHA-NL are shown in Fig. 3. The calculated maps are almost identical to the maps in the seismic design code of Korea (MOCT, 1997), thus validating that step 1 and 2 of the PSHA-NL was performed correctly.

GROUND PROPERTIES

The uncertainties and variability in soil properties were accounted for by building a database of site profiles and randomly selecting from the database in performing the site response analysis. An extensive database consisting of 98 measured site profiles was used. For site classes S_C, S_D, and S_E, 52, 36, and 10 profiles were used, respectively. The stratigraphies were also available for all site profiles. The soil types of the layers of the soil columns were classified as one of four categories, which were clay, sand, gravel, and rock. The dynamic curves were assigned accordingly based on the layer information. The dynamic curves used in the analyses were also randomly selected from the sets of curves summarized in Table 3. Identical weights were assigned to all curves within the classified category.

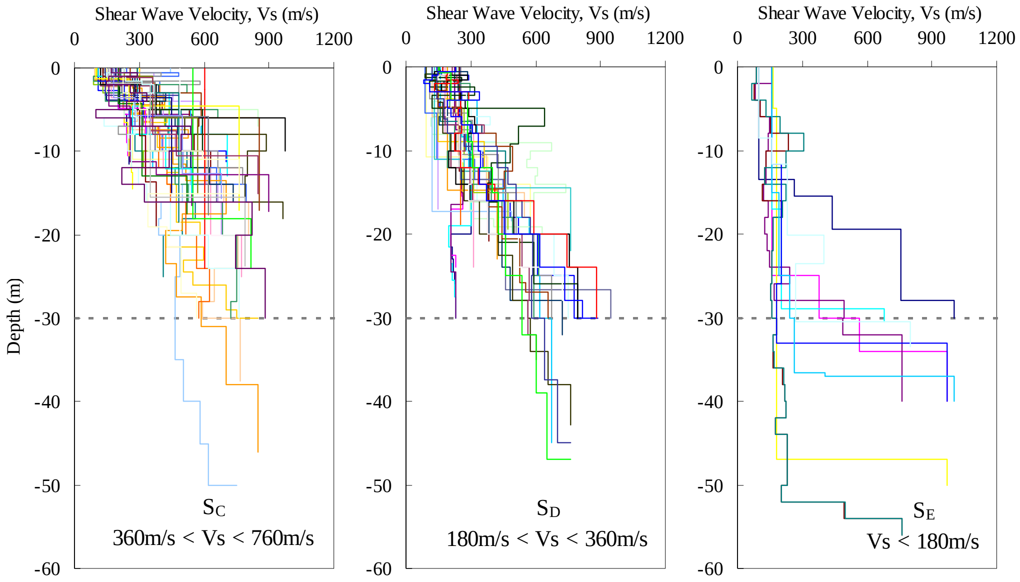


Fig. 4. Vs profiles categorized into site classes S_C, S_D, and S_E.

Table 3. Dynamic curves used in the analyses

Soil type	Developer	Selected curves
Clay	(Dobry and Vucetic, 1987)	PI=15, 30, 50
	(Sun et al., 1988)	Lower, Average, Upper
	(Kim and Choo, 2001)	Clay, Reclaimed soil
Sand	(Seed and Idriss, 1970)	Lower, Mean, Upper
	(Kim and Choo, 2001)	Alluvial soil, Weathered soil
Gravel	(Seed et al., 1986)	Gravel
Rock	(Schnabel, 1973)	Weak rock

UNIFORM RESPONSE SPECTRA

Equivalent linear analysis was used to propagate the suite of generated ground motions. The location selected in this study was 36.35° × 127.45°, at which the PGA for a return period of 500 years is 0.11g (identical to PGA at Seismic Zone I). The number of ground motions generated at this site was 850.

Fig. 5 compares the UHRS and the DS for site classes S_C, SD, and SE, respectively. Significant differences between the UHRS and the DS of MOCT (1997) are observed. The UHRS of S_C profiles is significantly larger and stiffer than the DS. For S_D, the UHRS is only slightly larger and stiffer than the DS. The DS is much larger than the UHRS for S_D. There are numerous reasons for this pronounced discrepancy. Firstly, the site coefficients in Korea are based on 1997 NEHRP (FEMA, 1997), which developed site coefficients mainly for soil profiles exceeding 30 m. The representative thickness of soil profiles in Korea are below 20 m. Secondly, the difference can be due to probabilistic and deterministic nature of the derived site coefficients. Other possible reasons include the use of different dynamic properties, soil profiles, and ground motions etc. Since the current study used extensive soil profiles measured in Korea, motions representative of seismic environment of Korea, and the UHRS are fully compatible with the seismic hazard map, the derived UHRS is considered to be more accurate than that of the design spectra of MOCT (1997).

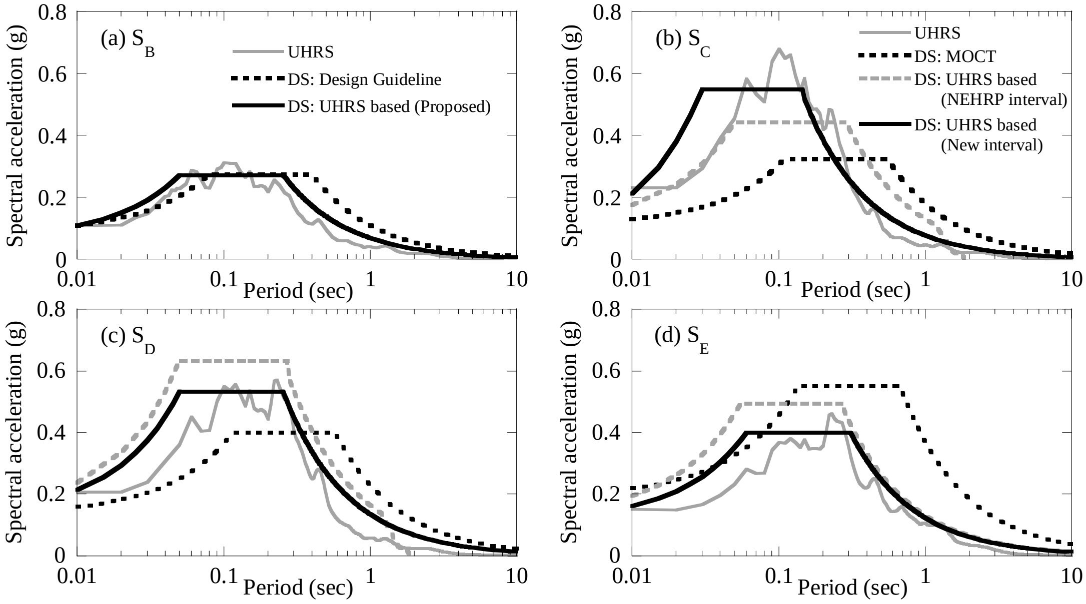


Fig. 5. UHRS, DS based on (MOCT, 1997), and proposed DS.

CONCLUSIONS

This paper applied the PSHA-NL, which integrates the traditional PSHA and seismic site effect characterization function, to develop uniform hazard response spectra (UHRS) of Korea.

To develop "truly" probabilistic UHRS, the uncertainties and randomness of the ground properties were accounted for by using extensive databases of measured shear wave velocity profiles - stratigraphies and dynamic curves for site classes considered in this study.

The calculated uniform hazard response spectra were compared to the design spectra. The comparisons indicate that the design spectra presented in the current design guideline are NEHRP based and are not suitable for soil profiles of Korea. The design response spectra of site classes S_C and S_D highly underestimates the seismic hazard, while it is overestimated for S_E.

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