SITE-SPECIFIC UNIFORM HAZARD SPECTRUM FOR SEISMIC PRA OF KOREAN NUCLEAR POWER PLANTS

In-Kil Choi[1] , Masato Nakajima[2], Young-Sun Choun[1], Yasuki Ohtori[2]

[1] *Principal Researcher, Integrated Safety Assessment Division ,Korea Atomic Energy Research Institute, Daejeon, Korea Email: cik@kaeri.re.kr*

[2] *Researcher, Central Research Institute of Electric Power Industry, Abiko, Chiba-ken, Japan*

ABSTRACT :

A site-specific median spectrum has generally been used for the seismic fragility analysis of structures and equipments in Korean nuclear power plants. The site-specific response spectrum, however, does not represent the same probability of an exceedance over an entire frequency range of interest. A uniform hazard spectrum is more appropriate for use in a seismic probabilistic risk assessment than a site-specific spectrum. In this study, the uniform hazard spectra were developed using available seismic hazard data for Korean NPP sites.

KEYWORDS: Probabilistic Seismic Hazard Analysis, Uniform Hazard Spectrum, SPRA, SMA

1. INTORDUCTION

A seismic analysis and design have been performed based on a design basis earthquake. A design basis earthquake ground motion is generally specified as a design response spectrum. However the seismic safety of a nuclear power plant can not be secured by only considering a design basis earthquake, since the seismological situation of a nuclear power plant site is changed during the development of geosciences.

A seismic probabilistic risk assessment (SPRA) methodology has been used to evaluate a seismic safety of a nuclear power plant beyond design earthquake intensity. A probabilistic seismic hazard analysis is an important part of the SPRA, and has a significant effect on the final result of the SPRA for a nuclear power plant. In the SPRA, the seismic risk of a nuclear power plant is estimated by the convolution of a seismic hazard and a system fragility.

For the probabilistic seismic hazard analysis, the seismic source models for the Korean nuclear power plant sites were developed based on a historical and instrumental earthquake catalog. However, most of the strong earthquake data in the historical earthquake records are described simply in these historical documents. This causes a large uncertainty in the seismic hazard curves. Due to this reason, the site specific uniform hazard spectrum has not been used for the SPRA, even though the probabilistic seismic hazard analyses for the Korean nuclear plant sites have been performed as a part of the SPRA study.

In this study, the site-specific uniform hazard spectra for 4 nuclear plant sites in Korea were developed by using the available seismic source maps which were used for the past PRA study and a recently developed ground motion attenuation equation.

2. PROBABILISTIC SEISMIC HAZARD ANALYSIS

2.1. Seismic Source Map

In Korea, the active faults have not been identified as seismic sources which generate earthquakes at the present time, and the historical data on the recurrence time for a specific earthquake has not been obtained. Therefore, the Poisson typed PSHA (Probabilistic Seismic Hazard Analysis) method has been used in Korea, in which all the earthquakes are assumed to occur according to a stationary Process in the time domain (Choi et al., 2005).

In this study, four seismic source models were used for the seismic hazard analysis. Figure 1 shows the seismic source models used in this study. These seismic source models were developed based on a historical and

instrumental earthquake catalog.
The team approach was adopted for developing the seismic source models. The seismicity expert teams proposed the seismic source maps for the probabilistic seismic hazard analysis. Especially, at least one non-seismologist was included in each seismicity team to reduce the resultant uncertainty (Seo et al., 1999).

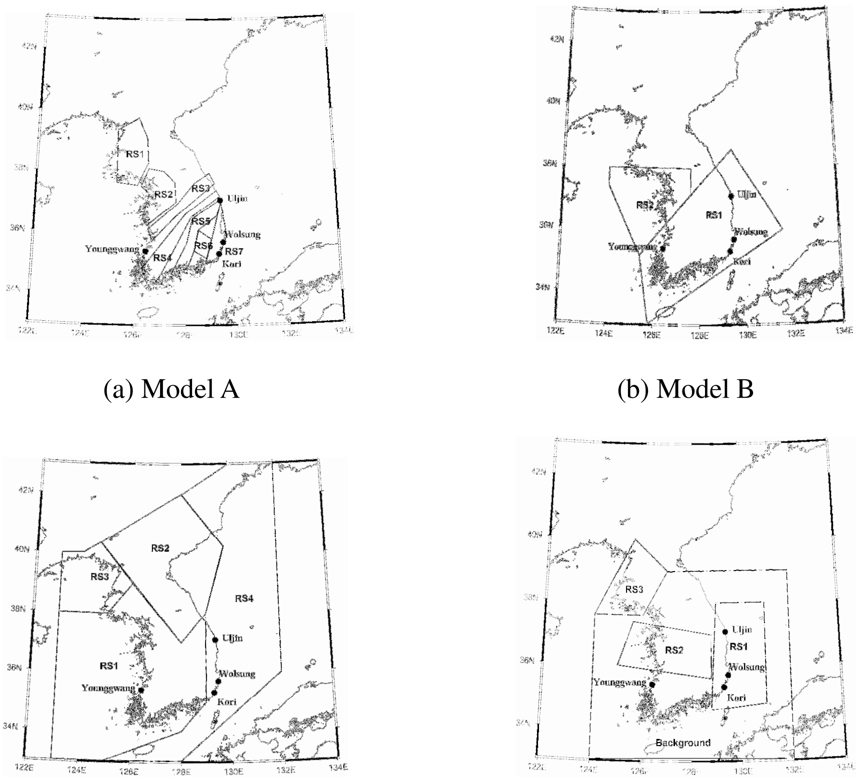
2.2. Attenuation Equation for the Korean Peninsula

The ground motion attenuation equation developed by Yun (Yun et al., 2005) was used in this study. The site specific attenuation equations were developed by regression analyses for the multiple simulations of the PGA (Peak Ground Acceleration) values obtained by the RVT (Random Vibration Theory) simulation method (Yun, 2006). The spectral acceleration can be estimated by the following equation.

$$\begin{aligned}\ln\left(Y(S_A(g))\right) = C_1 + C_2 * M_w + \left(C_3 + C_4 * M_w\right) * a\log\left(R_{\mathrm{epi}} + \exp(C_5)\right) \\ + C_6 * \left(M_w - 6.0\right) * \left(M_w - 6.0\right) + C_7 * \ln\left(\min(R,50)\right) + C_8\left(\max(R,50)\right)\end{aligned} \tag{1}$$

$$\begin{aligned} R &= \sqrt{R_{epi}^2 + 9.8^2} && (Mw \le 6.5) \\ &= \sqrt{R_{epi}^2 + 9.8^2 * \exp\left(2.0 * (-1.25 + 0.227 * Mw)\right)} && (Mw > 6.5)\end{aligned}$$

where, M_w and R_{epi} denote the earthquake magnitude and the epicentral distance (km), respectively. $C_1 \sim C_8$ are the constants for the attenuation equation.



(a) Model A

(b) Model B

(c) Model C

(d) Model D

Figure 1 Seismic source models for the probabilistic seismic hazard analysis

2.2.Probabilistic Seismic Hazard Curves

Using the proposed seismic source maps and a recently developed ground motion attenuation equation, the probabilistic seismic hazard analyses were performed for 4 Korean nuclear plant sites, Wolsung, Youngkwang, Kori and Unchin site. Figure 2 shows the characteristics of the ground motion attenuation equation for the Wolsung nuclear plant site. Figure 3 and 4 show the seismic hazard curves for the peak ground acceleration and the spectral hazard curves according to the frequencies for the Wolsung site.

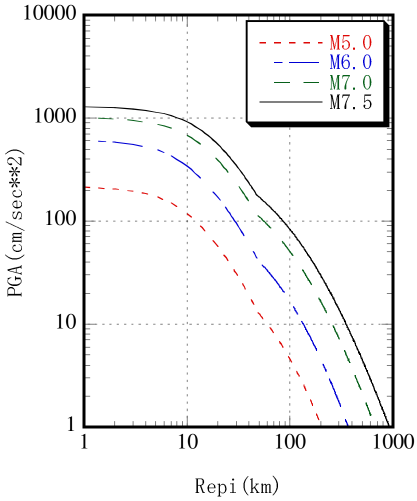


Figure 2 Characteristics of an attenuation equation

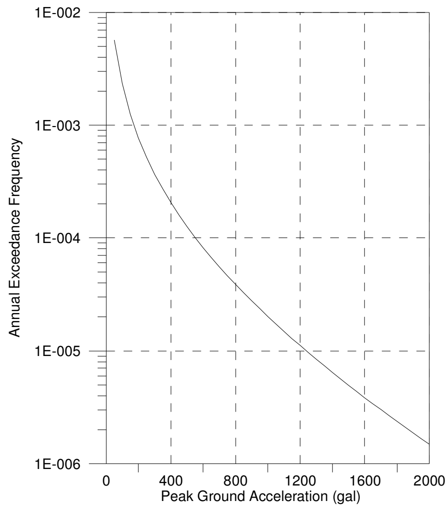


Figure 3 Seismic hazard curve

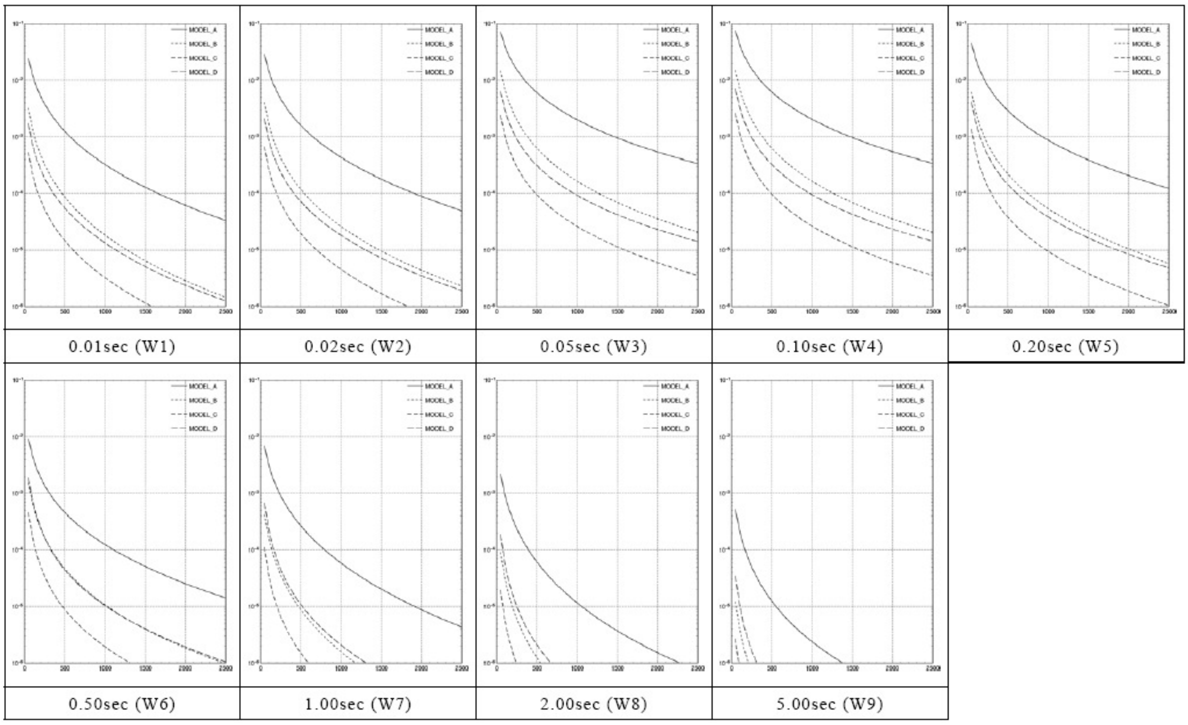


Figure 4 Spectral hazard curves for the Wolsung site

3. UNIFORM HAZARD SPECTRUM

3.1.Evaluation Response Spectrum for the SPRA

The safety factor method has been used for the seismic fragility analysis in a previous SPRA study. The safety factor for a response spectrum shape was one of the most important safety factors affecting the seismic fragility of a nuclear plant component. Table 1 shows the safety factors for the seismic fragility of a containment structure (KEPCO, 2001). As shown in this table, the spectrum shape factor has an important role in the final result.

Table 1 Safety factors for an example fragility analysis

Variable		Factor of Safety
Capacity	Strength	7.4
	Inelastic energy absorption	1.4
Response	Spectrum shape	1.3
	Damping	1.0
	Modeling	1.0
	Modal combination	1.0
	Earthquake component combination	1.0
	Horizontal earthquake direction	1.0
	Soil-structure interaction	1.0
Combined		13.5

Several kinds of input motions, site-specific response spectrum, uniform hazard spectrum, site independent standard spectrum such as NUREG/CR-0098, in terms of a specific earthquake magnitude with a specific epicentral distance, were used for the previous SPRA studies.
When the seismic information of a site is available it is preferable to use a site-specific response spectrum. This will lower the uncertainty for the ground response spectrum shape variability (EPRI, 1994). For cases when the site-specific data is not well understood, the use of a site independent standard response spectrum may be more appropriate. As mentioned before, the probabilistic seismic hazard analysis for a Korean nuclear plant site was performed based on a historical and small magnitude earthquake catalog, since there are only a few medium size (greater than magnitude 5.0) earthquake records. It makes it difficult to define a site-specific response spectrum for the SPRA. So, it is reasonable to use the uniform hazard spectrum for the SPRA in Korea.
The reference response spectrum anchored to the peak ground acceleration should be selected for the SPRA and the seismic margin analysis (SMA). In Korea, the site-specific response spectrum developed for the Kori site has been used for all the nuclear plant sites in the past SPRAs. Figure 5 shows the Kori site-specific median spectrum with the US NRC Regulatory Guide 1.60 spectrum (US NRC, 1973) which has been used for the design of Korean nuclear power plants. It is noted that the site-specific response spectrum does not present the same probability of an exceedance over the full frequency range of interest. So the present trend is to develop spectrum that represents a uniform probability of an exceedance over an entire frequency range of interest (Loh et al., 1994). This is so-called a uniform hazard spectrum (UHS).
The uniform hazard spectrum is established by generating the first set of seismic hazard curves, each of which expresses an annual frequency of an exceedance as a function of an acceleration response spectral value for a specified discrete value of a frequency and damping (Figure 6 (a)). With these sets of spectral hazard curves, the response spectra for a specified probability of an exceedance over an entire frequency range of interest are obtained directly (Figure 6 (b)).

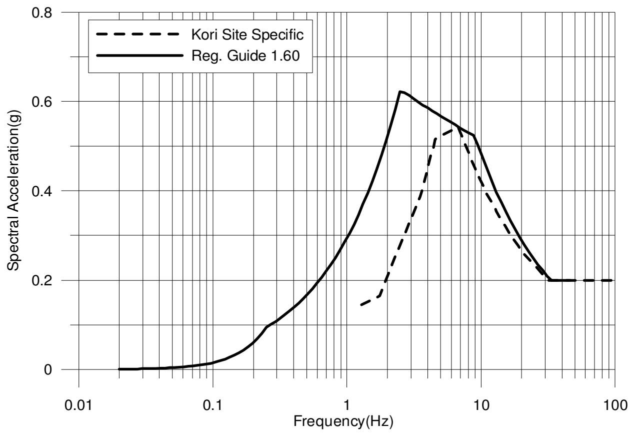
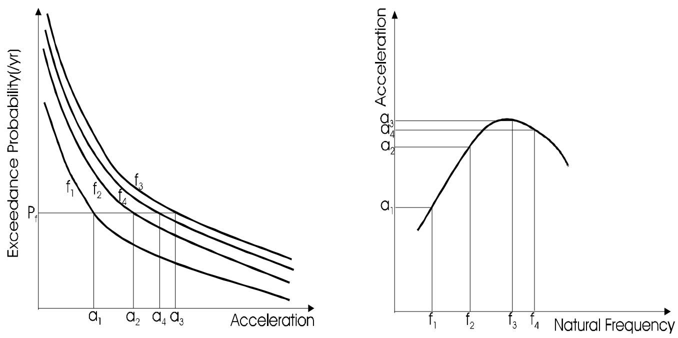


Figure 5 Median site-specific response spectrum for past SPRA studies



(a) Spectral Hazard Curves (b) UHS

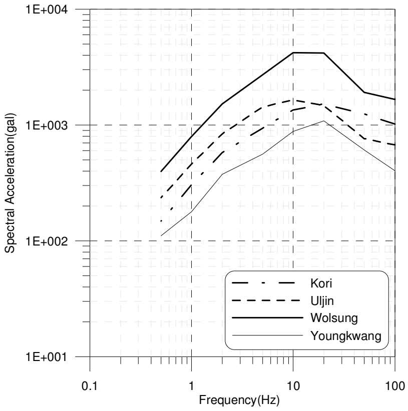
Figure 6 Procedure for developing a uniform hazard spectrum

3.2.Site-Specific Uniform Hazard Spectra

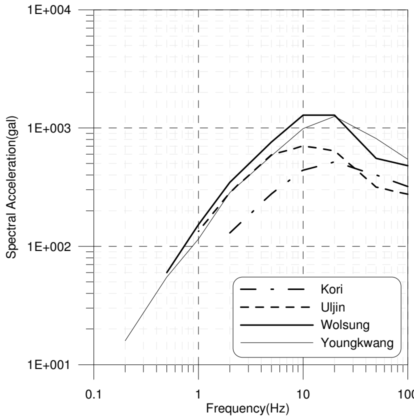
In this study, four seismic source models and one ground motion attenuation equation were used for the probabilistic seismic hazard analysis. Figure 7 shows the uniform hazard spectra for the 4 nuclear plant sites according to the used seismic source models. Model A gives the highest seismic hazard for all the sites and model D gives the lowest seismic hazard. It is shown from this figure that the seismic hazard for a site is strongly dependent on the seismic source model.

For a comparison of the uniform hazard spectrum, the average uniform hazard spectrum for a 10^{-4} exceedance probability level was calculated. Figure 8 shows a comparison of the average uniform hazard spectra for the four NPP sites. As shown in this figure, the seismic hazard of the Wolsung NPP site has the highest seismic hazard. The spectral shapes show rich high frequency contents similar to the frequency contents of the earthquake records in Korea.

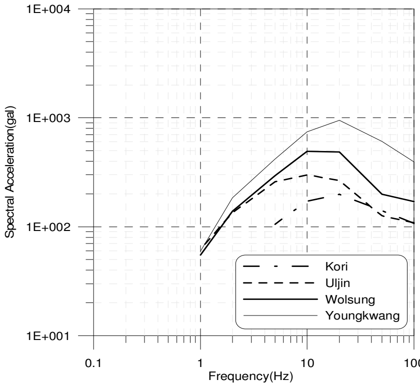
Mean ground response spectra obtained from 270 earthquake records with a magnitude of 3 to 5 which have occurred in Korea are shown in Fig. 9 (Seo et al., 2002). As shown in the figure, these spectra have relatively large high-frequency spectral acceleration contents. The fluctuation in the spectrum for the magnitude 5 earthquakes is due to the very limited number of data. It is noted from Fig. 7 and Fig. 8 that the shapes of the uniform hazard spectra are very similar to the mean response spectrum developed from the real earthquake data that have occurred in Korea.



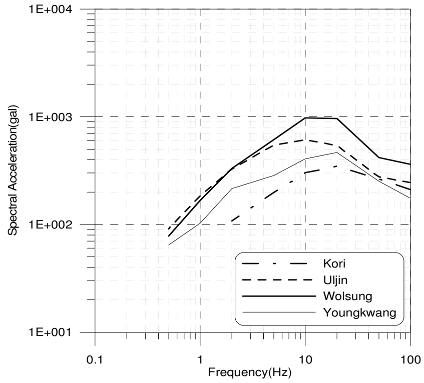
(a) Model A



(b) Model B



(a) Model C



(b) Model D

Figure 7 Uniform hazard spectra for the 4 NPP sites according to the seismic source models

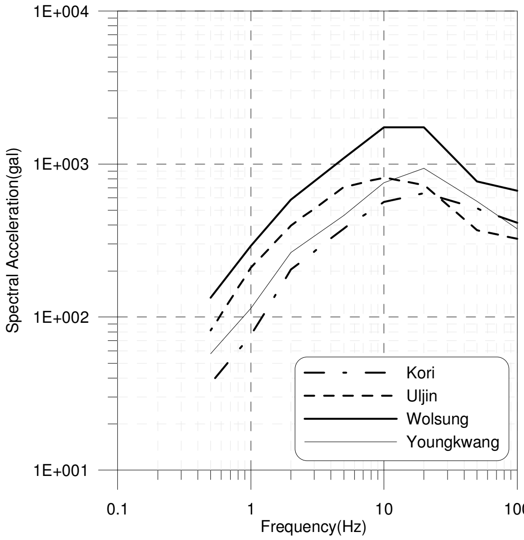


Figure 8 Comparison of the average uniform hazard spectrum for the 4 NPP sites

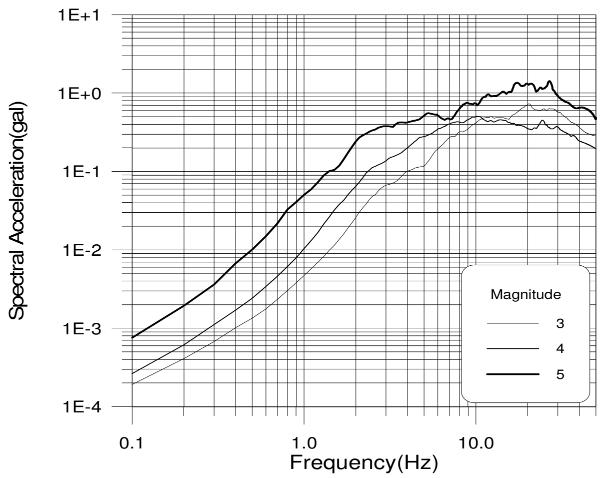


Figure 9 Mean response spectra for the earthquakes that have occurred in Korea

4. CONCLUSION

It is reasonable to use the uniform hazard spectrum developed from the probabilistic seismic hazard analysis for the SPRA to secure a consistency in the results of it.

The uniform hazard spectra for the Korean NPP sites was estimated using four seismic source models and one recently developed attenuation equation. The uniform hazard spectrum for the 4 NPP sites showed a different amplification for the whole frequency range and PGA values for the same occurrence probability. The shape and the frequency contents were similar to those of the real earthquake records in Korea.

For an accurate and reasonable estimation of a site specific spectrum, it is necessary to develop realistic and reliable seismic source models, and ground motion attenuation equations suitable for Korean NPP sites.

ACKNOWLEDGEMENT

This research was supported by the Mid- and Long-Term Nuclear Research & Development Program of the Ministry of Education, Science and Technology, Korea.

REFERENCES

Choi, In-Kil, Masato Nakajima, Young-Sun Choun, and Yasuki Ohtori. (2005). Evaluation of the current seismic zone of Korea based on the probabilistic seismic hazard analysis. *2005 KNS Spring Meeting*.

CRIEPI. (2006). Korea-Japan Joint Research on Development of Seismic Capacity Evaluation and Enhancement Technology Considering Near-Fault Effect (Final Report), KAERI/RR-2688/2006.

EPRI. (1994). Methodology for Developing Seismic Fragility. EPRI TR-103959.

KEPCO. (2001). External Event Analysis for Yonggwang Units 5 and 6 PSA. Korea Electric Power Company (in Korean).

Loh, Chin-Hsiung, Wen-Yu Jean, and Joseph Penzien (1994). Uniform-hazard response spectra-An alternative approach. *Earthquake Engineering and Structural Dynamics* 23, 433-445.

Newmark N. M. and W. J. Hall. (1978). Development of Criteria for Seismic Review of Selected Nuclear Power Plants. NUREG/CR-0098, Nuclear Regulatory Commission.

Seo, Jeong-Moon, Gyung-Shik Min, Young-Sun Choun, and In-Kil Choi. (1999) Reduction of Uncertainties in Probabilistic Seismic Hazard Analysis, KAERI/CR-65/99.

Seo, Jeong-Moon, Kwan-Hee Yun, and Sung-Kyu Lee. (2002). Seismic hazard of the Korean NPP sites: Recent innovation in the R&D and hazard results. *Proc. of the 7th Korea-Japan PSA Workshop,* Jeju, Korea.

US NRC Regulatory Guide 1.60. (1973). Design Response Spectra for Seismic Design of Nuclear Power Plants.

Yun, K.-H. and D.-H. Park. (2005). Development of site-specific ground motion attenuation relations in Korea – Examples for the nuclear power plant sites. *The 5th International Workshop on the Fundamental Research for Mitigating Earthquake Hazards*.

Yun, K.-H. (2006). Recent advances in developing site-specific ground motion attenuation relations for the nuclear plant sites in Korea. *OECD NEA Specialists Meeting on the Seismic PSA of Nuclear Facilities*, Jeju, Korea.