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A Study on the Site-Specific Response Spectrum in Korea

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Abstract

Safe shutdown earthquakes (SSE) of four existing nuclear power plant sites were evaluated by using a probabilistic method. It turned out that the SSE's of the two sites are smaller than those of the rest. Site-specific response spectra were developed for two sites of which SSE's show a comparatively large difference. The result shows that the site-specific response spectrum of one site is higher by a factor of 1.5 than that of the other. The comparison of uniform hazard spectrum and site-specific response spectrum at one of the two sites shows that the both spectra are consistent with each other.

I. Introduction

The response spectra of RG 1.60[1] have been widely used in the design of nuclear facilities, especially in Korea and U.S.A.. With RG 1.60 response spectra, one can easily construct design response spectra of a site. The required parameter is only one: the peak ground acceleration (PGA) at the site. Design response spectra of the site is constructed simply by scaling RG 1.60 response spectra with the PGA at that site. This procedure does not discriminate the locations and magnitudes of the earthquakes which produce that PGA. Both a large earthquake at large distance and a small earthquake at small distance can cause the same PGA at a site. In this case, however, the frequency contents of seismic energy transported to the site are not same due to the characteristics of source spectra and crustal attenuation. The high-frequency energy transported from the small earthquake occurred at small distance from the site is richer than that from the large earthquake at large distance. This fact necessitates the development of site-specific response spectrum (SSRS).

The SSRS considers the location and magnitude of the earthquake that most affects the site. This earthquake is called *controlling earthquake* of the site by US NRC[2]. The controlling earthquake can be determined either by a deterministic method or by probabilistic method. In a seismically stable region such as Korea and eastern part of US, the probabilistic method can be more adequate than the deterministic method because earthquake phenomena in these regions are little known.

Recently US NRC[3] revised Federal Codes related to nuclear facilities to allow the probabilistic method. The regulatory guide, RG 1.165[2] describes detailed procedures to evaluate controlling earthquake(s) and to develop SSRS. According to these procedures, Noh *et al.*[4] evaluated controlling earthquakes of four existing nuclear power plant (NPP) sites in Korea. The present study is a continuation of the study of Noh *et al.*.

II. Evaluation of Safe Shutdown Earthquakes and Controlling Earthquakes

RG 1.165[2] defines the safe shutdown earthquake (SSE) as a spectral acceleration that corresponds to so called, the *reference probability*. The reference probability is a median probability of exceedance averaged for 5 and 10 Hz. Although Noh *et al.*[4] analyzed the reference probability based on the current SSE's of four existing NPP's, they did not recommended any preferred values for Korean NPP's. This is because that the reference probability is fairly sensitive to the attenuation formulas, while proper attenuation formulas are not provided yet. Therefore, they applied the reference probability of 10^{-5}/yr that is recommended by NRC[3] for central and eastern parts of US.

Table 1 shows the SSE's of four existing NPP sites in Korea, which are evaluated in the present study. Also shown in the last column are the controlling earthquakes recopied from Noh *et al.*[4]. The controlling earthquake is, in its meaning, equivalent to the modal earthquake[6,7]. The SSE's and controlling earthquakes of Site 2 and 3 are almost identical, but are different from those of the rest.

Table 1. Safe shutdown earthquakes and controlling earthquakes of four NPP sites in Korea (for 5 and 10 Hz)

Site No.	Safe shutdown earthquake (gal)	Controlling earthquake
1	274.8	M=5.74, D=22.8 km
2	408.5	M=5.99, D=14.0 km
3	399.1	M=5.96, D=13.2 km
4	338.4	M=6.05, D=25.5 km

III. Development of Site-Specific Response Spectra

Once the controlling earthquake is evaluated, development of SSRS is straightforward. The first step is to collect a suite of time histories recorded from those earthquakes of which magnitudes and distances are close to those of controlling earthquake. But in practice, rare are the cases that, even in seismically active regions, such earthquake records are sufficient enough to develop a statistically meaningful SSRS. It should also be studied how much close the magnitude and distance shall be chosen. In the present study, we used the same attenuation formula and magnitude-distance bins as those used in the seismic hazard deaggregation in Noh *et al.*[4]. The attenuation model[5] used in the present study and Noh *et al.* is

$$\log y = c_0 + c_1 r - \log r \qquad (1)$$

where r is the hypocentral distance, and c's are constants that depends on the magnitude of an earthquake and natural frequency of a structure.

In the second step, a shape of response spectrum corresponding to the controlling earthquake is developed by using a suite of time histories, attenuation formulas, or others. For convenience' sake, we call the ground motions on this response spectrum the *modal ground motions*, after the meaning of the controlling earthquake. The modal ground motions are generally smaller than the ground motions corresponding to the reference probability that are called the *target ground motions*. Chapman[6] showed that this is entirely due to the uncertainty in the attenuation formula. The second step develops only the shape of the SSRS.

Naturally, the last step is to match the modal ground motion to the target ground motion, at a selected frequency. In RG 1.165[2], this is achieved simply by scaling the modal ground motion at 7.5 Hz for the average of median seismic hazards for 5 and 10 Hz. On the other hand, McGuire[7] developed a different matching procedure. In his procedure, the ground-motion uncertainty, ε is adjusted until the modal ground motion at the frequency of interest replicates the target ground motion at the same frequency. Then the adjusted ε is applied to all the attenuation formulas of natural frequencies being considered. Though McGuire's procedure seems quite different from that of RG 1.165, the results are same as long as logarithmic attenuation model like equation (1) is used. The present study revealed that the scaling factors for four NPP sites range 2.2~3.1 which, in terms of ε in common logarithms, amounts to 0.35~3.1.

We selected Sites 1 and 2, as an example, to see the site-dependent variation of SSRS's. Figure 1 (a) compares the SSRS's of 5 % critical damping. The SSRS of Site 2 is higher than that of Site 1 by the factor of about 1.5 at frequencies considered. Therefore, Sites 1 has a larger seismic safety margin than Site 2 because a same SSE of 0.2 g (in peak ground acceleration) had been assigned to all Korea NPP sites. Figure 1 (b) shows the comparison of the SSRS and the UHS (uniform hazard spectrum) of Site 1. The UHS of the Figure 1 (b) corresponds to the same critical damping (5 %) and reference probability (10^{-5}/yr). The difference between the SSRS and the UHS increases as decreasing frequencies because the SSRS was adjusted at 7.5 Hz to replicate the target ground motion. In case that the difference at low frequencies is significant, additional controlling earthquake should be evaluated to modify the shape of SSRS at low frequencies. We consider that this is not such a case.

IV. Conclusion

The probabilistic analysis for four existing NNP sites revealed that the SSE's and

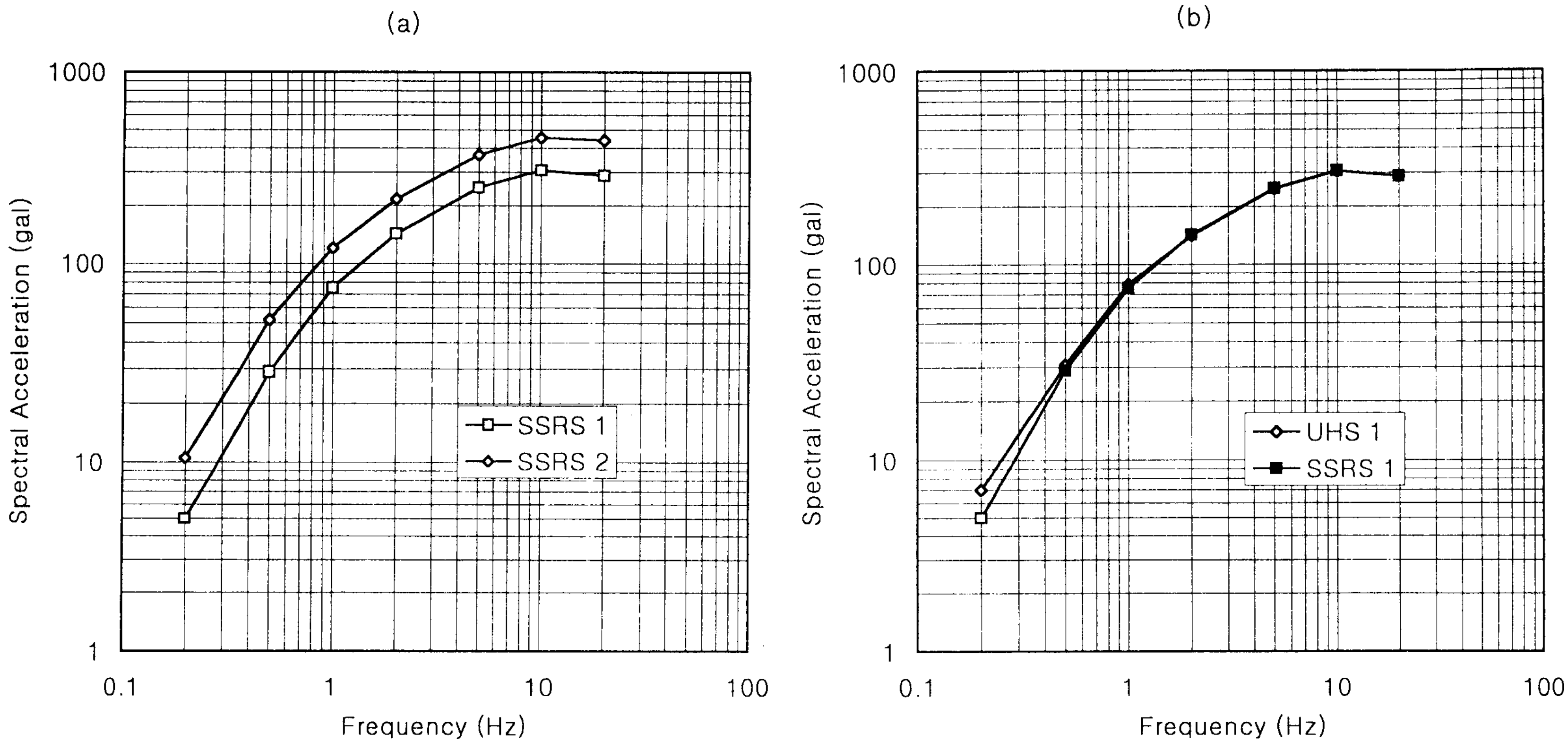

Figure 1. Comparison of site-specific response spectrum (SSRS). SSRS 1 and SSRS 2 are SSRS's of Site 1 and Site 2, respectively. UHS 1 is the uniform hazard spectrum of Site 1 that corresponds to the reference probability of 10^{-5}/yr.

controlling earthquakes of Sites 2 and 3 are almost identical, but are larger than those of Sites 1 and 4. From the SSE's and controlling earthquakes of Sites 1 and 2, the SSRS's of 5 % critical damping were developed by using attenuation formulas. In the comparison of the SSRS's of Sites 1 and 2, it was found that the SSRS of Site 2 is larger than that of Site 1, by a factor of about 1.5. This means that Site 1 has a larger seismic safety margin because a same SSE had been assigned to both sites.

A comparison of the SSRS and UHS of Site 1 was made. The UHS corresponds to the same critical damping (5 %) and reference probability (10^{-5}/yr). Since the SSRS is adjusted at the natural frequency of 7.5 Hz, they show increasing differences as decreasing frequencies. We consider that this differences are not significant and that the SSRS is consistent with the UHS.

References

[1] US NRC, 1973, Design Response Spectra for seismic Design of Nuclear power Plants, Regulatory Guide 1.60.

[2] US NRC, 1997, Identification and Characterization of Seismic Sources and Determination of Safe Shutdown Earthquake Ground Motion, Regulatory Guide 1.165.

[3] US NRC, 1996, Federal Register, Vol. 61, No. 239.

[4] Noh, M., C.-B. Im, and S.-K., Lee, 1997, A Preliminary Study on the Probabilistic Determination of Controlling Earthquakes for Nuclear Power Plant Sites in Korea, Proceedings of Earthquake Engineering Society of Korea, Seoul, Korea, Vol. 1, No. 1, pp. 62-66.

[5] Noh, M. and Lee, K., 1995, Estimation of Peak Ground Motions in the Southeastern Part of the Korean Peninsula (II): Development of Predictive Equations, Jour. Geol. Soc. Korea, Vol. 31, No. 3, pp. 175-187.

[6] Chapman, M. C., 1995, A Probabilistic Approach to Ground-Motion Selection for Engineering Design, Bull. Seism. Soc. Am., Vol. 85, No. 3, pp. 937-942.

[7] McGuire, R. K., 1995, Probabilistic Seismic Hazard Analysis and Design Earthquakes: Closing the Loop, Bull. Seism. Soc. Am., Vol. 85, No. 5, pp. 1275-1284.