Criteria for Exceedance of Operating Basis Earthquake Based on the Characteristics of Site-Specific Ground Motions

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1. Introduction

The 2016 Gyeongju earthquake of magnitude 5.8 caused a shutdown of all operating units of the Wolsong nuclear power plant (NPP), which is located about 28 km from the epicenter, for the first time in Korea. The peak ground acceleration (PGA) of the free-field ground motions at the Wolsong NPP site was 0.12 g, which exceeds the operating basis earthquake (OBE) acceleration of 0.1 g [1]. According to the Korean regulatory guidelines, four units at the site were shutdown manually. Although the OBE was exceeded, however, no damage was found in structures, systems, and components (SSCs) during a plant walkdown. Based on recent earthquake experiences, it is necessary to review the shutdown criteria of operating NPPs.

This study reviewed current criteria of the OBE exceedance using the site-specific ground motions, and discussed a suitability of the guideline for Korean NPPs.

2. OBE Exceedance Criteria

The evaluation to determine whether the OBE was exceeded should consist of a check of the PGA, a check of the response spectrum, and a check of the cumulative absolute velocity (CAV). The Korean regulatory guideline [2] requires a check of the PGA and response spectrum. When either check exceeds the OBE exceedance criterion, the plant must be shutdown. The U.S. NRC regulatory guide 1.166 [3] requires a check of the response spectrum and CAV. When both the response spectrum check and CAV check are exceeded, the OBE was exceeded and an operating plant must be shutdown. If either check does not exceed the criterion, the OBE was not exceeded.

2.1 PGA Check

The PGA check is exceeded if any one of three PGA values of the three components for the free-field ground motion is greater than the PGA value of the OBE ground motion.

2.2 Response Spectrum Check

The OBE response spectrum is exceeded if any one of the three components of the 5 % of the critical damping response spectra generated using the free-field ground motion is larger than the following:

(1) the corresponding design response spectral acceleration, or 0.2 g, whichever is greater, for frequencies between 2 to 10 Hz, or
(2) the corresponding design response spectral velocity, or a spectral velocity of 6 inches/s, whichever is greater, for frequencies between 1 and 2 Hz.

2.3 CAV Check

The CAV check is exceeded if any CAV calculations are greater than 0.16 g·s. The CAV for each component of the free-field ground motion should be calculated as follows: (1) the absolute acceleration time-history is divided into 1-second intervals, (2) each 1-second interval that has at least one exceedance of 0.025g is integrated over time, and (3) all integrated values are summed together to arrive at the CAV.

3. Check of OBE Exceedance for Site-Specific Ground Motions

3.1 Ground Motion Database

Table I shows a summary of the earthquake ground motion database used in this study. Earthquakes that have a magnitude of greater than 4.5 and occurred within a distance of 50 km around the NPP site are included. Sixty ground motions within an epicentral distance of 80 km are selected. Fig. 1 presents the relationship between PGA and CAV values for the ground motions. Fig. 2 plots the 5% damped acceleration response spectra scaled to PGA = 0.1 g for the ground motions. The OBE response spectrum is also plotted. As shown, there are significantly different characteristics between the site-specific response spectra and the OBE spectrum. The spectral acceleration of the site-specific response spectra is much lower than that of the OBE spectrum except at a high frequency range of greater than around 10 Hz. The site-specific ground motions are rich in high frequencies.

Table I: Summary of earthquake database

Earthquake	Mag.	Number of ground motions	Epicentral distance (km)		PGA (g)	
			max	min	max	min
Ulsan	5.0	2	59	59	0.009	0.005
Gyeongju	5.1	14	57	6	0.415	0.011
Gyeongju	5.8	16	58	7	0.431	0.026
Gyeongju	4.5	6	26	7	0.079	0.014
Pohang	5.4	22	78	8	0.274	0.004

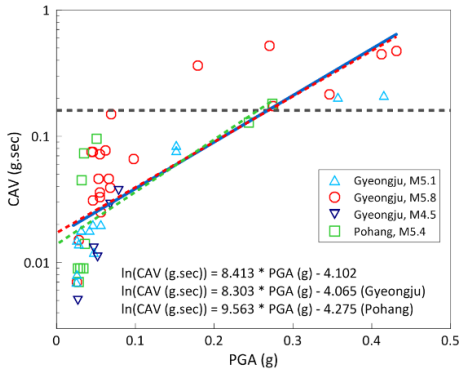

Fig. 1. Relationship between PGA and CAV for the site-specific ground motions.

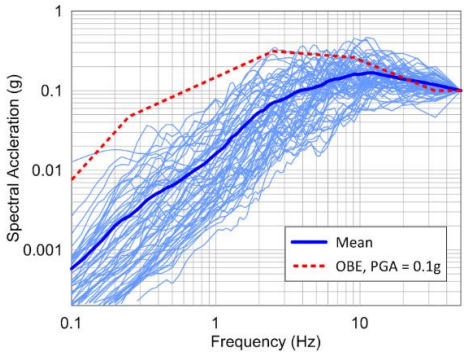

Fig. 2. Response spectra for PGA = 0.1 g (5% damping).

3.2 Check of OBE Exceedance

Fig. 3 plots the spectral acceleration values at 10 Hz of the 5 % damped response spectra scaled to PGA = 0.1 g shown in Fig. 2. The mean value of the spectral acceleration values is estimated as 0.21 g, which is lower than that of the OBE spectrum of 0.24 g.

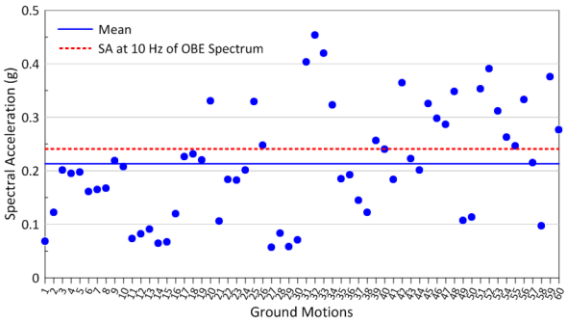

Fig. 3. Spectral acceleration values at 10 Hz for PGA = 0.1 g.

Fig. 4 plots the CAV values for the ground motions scaled to PGA = 0.1 g. The mean value of CAV is estimated to be 0.13 g·s, which is lower than the threshold value specified in the US regulatory guide, namely, 0.16 g·s. Because the CAV value for an artificial time-history generated from the OBE spectrum is estimated to be 0.47 g·s, the threshold CAV is conservative for Korean NPPs.

According to the Korean guidelines, any ground motions with PGA > 0.1 g exceeds the OBE, regardless of a check of the response spectrum. The mean values of spectral acceleration and CAV for the site-specific ground motions are lower than the threshold specified in the US regulatory guide. According to the US regulatory guide, only eight ground motions exceed OBE. For the M5.8 Gyeongju earthquake, no damage was found in the SSCs even though the PGA of the free-field ground motion at the site is up to 0.12 g. As shown in Fig. 1, the CAV value for PGA = 0.12 g is smaller than 0.16 g·s because of the characteristics of high-frequency ground motions.

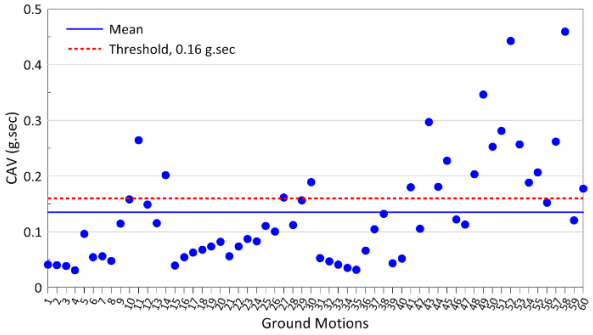

Fig. 4. CAV for the ground motions with PGA = 0.1g.

4. Conclusions

The OBE exceedance criteria were discussed using the site-specific ground motions. High-frequency earthquakes have occurred around the NPP sites in Korea. For high-frequency ground motions, the PGA is not an efficient indicator of the potential damage of SSCs. It was found that CAV is a more efficient damage indicator than the PGA. The CAV threshold value of 0.16 g·s, specified in the US regulatory guide, is conservative for Korean NPPs. An in-depth review is required to determine a CAV threshold value.

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