Estimation of Cumulative Absolute Velocity Threshold Level Using Current Earthquake Records

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1. Introduction

The cumulative absolute velocity (CAV) has been considered an efficient indicator for the earthquake potential damage. The CAV, which is estimated by the area under the absolute acceleration time history of the ground motion, is used for determining the exceedance of the operating basis earthquake (OBE) at nuclear power plants (NPPs) according to U.S. NRC regulatory guide 1.166 [1]. The threshold CAV, which defines the damage for NPP structures and equipment, was estimated to be 0.16 g·s [2]. The threshold value is associated with a negligible level of the observed damage to a building of good design and construction, and was determined based on the 1987 Whittier earthquake (M_L=5.9) occurred in California. In general, the damage to the equipment does not begin until the buildings are also damaged, and the damage to a building of good design and construction does not occur until reaching Modified Mercalli Intensity (MMI) VIII.

The CAV is sensitive to potentially damaging low-frequency ground motions. The CAV threshold level is estimated using the local earthquakes records that include high-frequency dominant motions.

2. Standardized CAV

The standardized CAV for each component of the free-field ground motion is given by [3]

$$CAV = \sum_{i=1}^{N} H(PGA_i - 0.025) \int_{t=t_i}^{t_{i+1}} |a(t)|\, dt \qquad (1)$$

where N is the number of non-overlapping 1-s time intervals, PGA_i is the peak ground acceleration (g) in time interval i, $H(x)$ is the Heaviside function defined as $H(x)$ = 0 for $x < 0$ and 1 otherwise, and $|a(t)|$ is the absolute value of acceleration at time t.

The standardized CAV restricts the integration to 1-s time-interval, which has amplitudes of at least 0.025g to exclude low-amplitude non-damaging ground motions from the value of CAV.

3. Background of Threshold CAV

In a review of earthquake experience with equipment at conventional power plants and heavy industrial facilities, the conclusion was reached that there is reasonable engineering assurance that equipment at an NPP will not fail at an intensity of less than MMI VIII [4]. In addition, it was concluded that an assumption that the potential for damage to NPP equipment and structures occurs at intensities of larger than MMI VI is conservative. The damage threshold CAV value is determined based on the observed negligible structural damage associated with MMI VII for buildings of a good design and construction.

The threshold CAV value of potential damage, 0.16 g·s, was chosen as the lowest CAV value associated with the site intensity of MMI VII, which is the record closest to the Pasadena Power Plant in the 1987 Whittier earthquake [2]. The plant had no damage for the earthquake. The threshold CAV value of 0.16 g·s can be conservative, because power plants have been subjected to earthquake ground motions with an intensity level of MMI VIII and have remained functional.

4. Ground Motion Database

Table I shows a summary of the earthquake ground motion database. The earthquakes that have a magnitude of greater than 4.5 and occurred within a distance of 50 km around the NPP site are included. The 60 ground motions within an epicentral distance of 80 km are selected. Fig. 1 shows the relation between the PGA and CAV values for the recorded ground motions. The PGA value associated with the threshold CAV value of 0.16 g·s is estimated as 0.27 g.

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

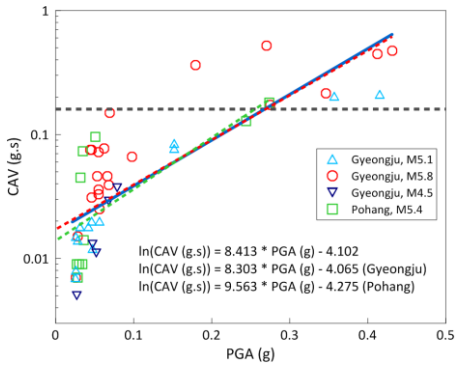

Fig. 1. Relation between PGA and CAV for the recorded motions.

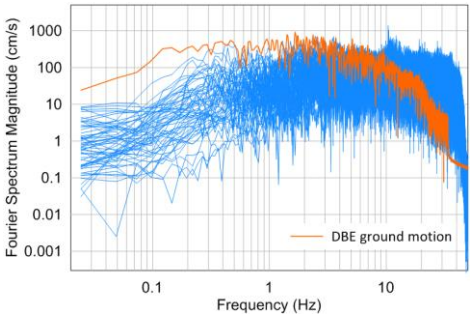

Fig. 2. Comparison of Fourier spectra for the recorded motions and for an artificial ground motion from design spectrum.

Fig. 2 shows that recorded ground motions are rich in high frequencies greater than 10 Hz in comparison with the ground motion used for the seismic design of NPPs.

5. Correlation between MMI and CAV

Figs. 3 and 4 show the relations between PGA and MMI, and between CAV and MMI obtained from the KMA reports [5, 6] and the recorded ground motions. For the intensity of MMI VII, the PGA and CAV values are estimated as 0.25 g and 0.24 g·s, respectively, using regression formulas. Because a regression formula used to compute CAV is quite different for the Gyeongju and Pohang earthquakes, normalized ground motions were used for CAV.

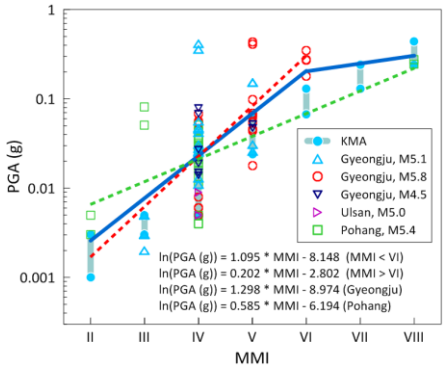

Fig. 3. Relation between PGA and MMI based on the KMA reports.

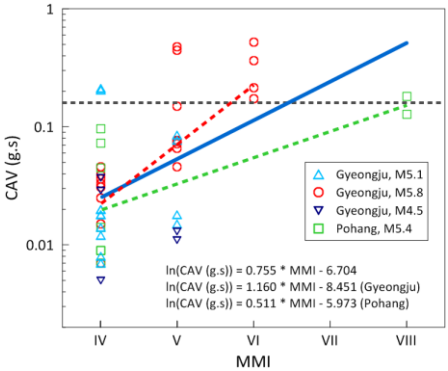

Fig. 4. Relation between CAV and MMI based on the recorded motions.

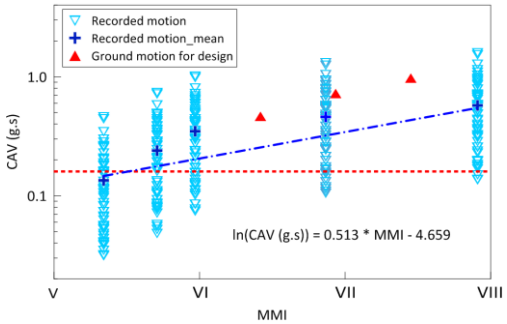

Fig. 5. Relation between CAV and MMI using normalized motions.

From Fig. 5, for the intensity of MMI VII, CAV is estimated as 0.34 g·s for the recorded motions, but 0.72 g·s for the design ground motion.

6. Conclusions

The CAV threshold value of 0.16 g·s, specified in the U.S. regulatory guide, is conservative for NPP structures and equipment. The analysis results of the recorded ground motions show that the CAV threshold level for Korean plants can be greater than 0.30 g·s because of the dominant high-frequency earthquakes.

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