Evaluation of vertical/horizontal ratio of earthquake ground motion in Korea using recorded motions from Gyeongju and Pohang earthquakes

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1. Introduction

The earthquake ground motion is expressed by three components: two horizontal and one vertical motions. Generally, the vertical motion has more high-frequency characteristics than the horizontal motion and can influence the seismic behavior of structures and equipment with high-frequency modes.

For the seismic analysis, there are two approaches to determine the vertical ground motion. One is directly performing a probabilistic seismic hazard assessment (PSHA), and the other is using a vertical/horizontal (V/H) ratio of the response spectrums. The V/H ratio is generally used due to the difficulty securing an attenuation equation for vertical earthquake motions and the difference between the controlling earthquake scenarios in the horizontal and vertical directions in the PSHA approach [1].

This study investigated the V/H ratio of earthquake ground motion in Korea based on the earthquake records observed during the 2016 Gyeongju earthquake and the 2017 Pohang earthquake.

2. Review of V/H ratio in Standards

In many early analyses, two-thirds of horizontal motion was assumed to be vertical motion. And recently, the V/H ratios have been suggested in various standards, and Fig. 1 compared those V/H ratios.

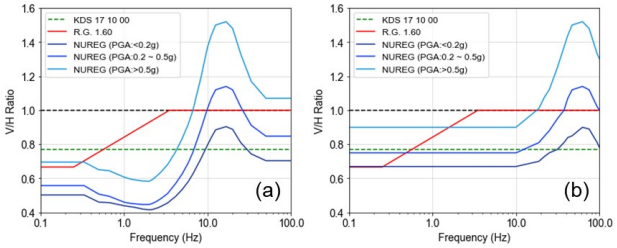

Fig. 1. V/H ratio ratios in previous studies (a) for the Western United States (b) for the Central and Eastern United States

The V/H ratio in the Korea Design Standard (KDS) [2] for general civil structure is 0.77 regardless of frequency. On the other hand, the V/H ratio changes according to the frequency in nuclear-related standards. Overall, the V/H ratio is more significant in the high-frequency region than in the low-frequency region. In NUREG/CR-6728 [4], the dominant frequencies of the maximum V/H ratio are about 20 Hz for the western US and about 60 Hz for the eastern US, respectively. When the peak ground acceleration of the horizontal ground motion is less than 0.2 g, Regulator Guide (RG) 1.60 [3] shows more conservative V/H ratio than NUREG/ CR-6728 [4]. However, when it exceeds 0.2 g, the V/H ratio of NUREG/ CR-6728 exceeds RG 1.60 at the high-frequency range.

3. Horizontal and Vertical Spectrum of Recorded Ground Motion

Among the earthquakes in the 2016 Gyeongju earthquake and the 2017 Pohang, the six most significant earthquake events were utilized. More than 1,200 seismic data recorded by the Korea Meteorological Administration (KMA), Korea Institute of Geoscience and Mineral Resources (KIGAM), and Korea Institute of Nuclear Safety (KINS) were used. For comparison, the seismic record data set from NGA-WEST built by the US Pacific Earthquake Engineering Research Center (PEER) was also evaluated. The NGA-WEST seismic data set consists of more than 3,000 seismic records and contains earthquake records of strong seismicity regions, unlike domestic conditions. A comparison with the NGA-EAST seismic data set, which is known to be similar to the domestic seismic condition, will be conducted through a follow-up study.

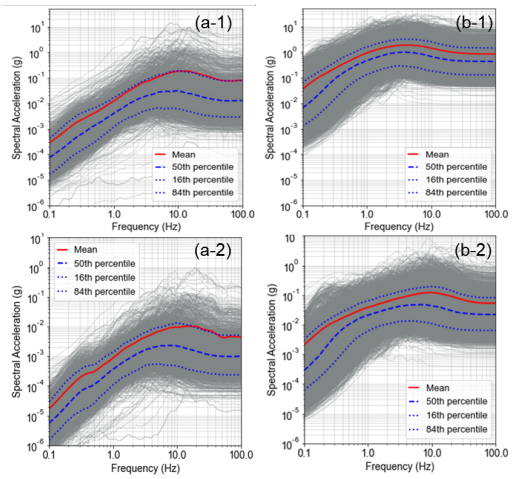

Fig. 2. Response spectrum of horizontal and vertical motions for all measurement record (a-1) Horizontal, Korea (a-2) Vertical, Korea (b-1) Horizontal, NGA-WEST (b-2) Vertical, NGA-WEST

The response spectra for horizontal and vertical motions for all seismic observation records are shown in Fig. 2. The representative horizontal motion of two bidirectional motions was defined as an orientation-

independent geometric mean spectrum (GMRotI50). The recorded motions in Korea relatively show the small intensity and the prominent high-frequency component larger than 10 Hz.

3. V/H ratio from Recorded Ground Motions

Fig. 3 shows the mean and percentile values of the V/H ratio for all seismic records. In Korea, the V/H ratio was large at low frequencies and converged to about 0.75 as the frequency increased. Although the change in the value according to the frequency was not large, the variation of the V/H ratio was significant in the low-frequency range. In the NGA-WEST records, the value was about 0.5 at low frequency, and the maximum value around 10 Hz was about 0.7. This trend is like V/H ratio suggested for the US western region in NUREG/CR-6728 [4].

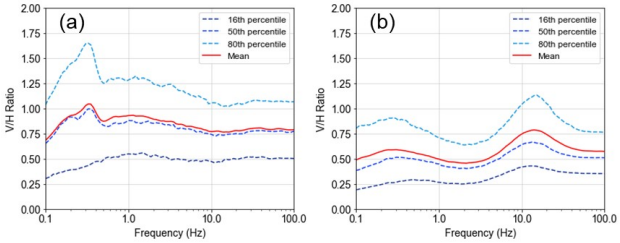

Fig. 3. V/H ratio from all measurement records (a) Korea (Gyeongju, Pohang) (b) NGA-WEST

Records with an epicentral distance less than 10 km were investigated separately. For comparison with domestic records, the NGA-WEST records limited the earthquake magnitude from 4 to 6. As shown in Fig. 4, the mean of the V/H ratios of the near-fault observation records for intermediate-magnitude earthquakes was less than 1 in all frequency ranges. It is constant at a value of 0.5 or less at low frequencies and shows amplification at high frequencies above 10 Hz. The dominant frequency of the V/H ratio appeared at about 25 Hz in the Korean earthquake data, which appeared in a higher frequency than in the NGA-West data. The variation of the V/H ratio for near-fault records in Korea was tiny due to the relatively small number of records.

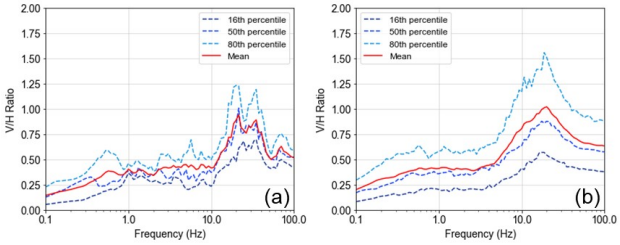

Fig. 4. V/H ratio from limited measurement records (R<10 km, 4<M<6) (a) Korea (Gyeongju, Pohang) (b) NGA-WEST

When the epicentral distance was limited to 10~30km, as shown in Fig. 5, the V/H ratio of the domestic earthquake records showed a constant value of around 0.75 regardless of the frequency. This V/H ratio of the domestic records shows a considerable difference from that of the foreign records in the low frequency. This is judged due to the small low-frequency energy of the horizontal motions in the domestic records and the different geological characteristics between Korea and the western US. For this, further analysis is required, along with the ground conditions of the observatory.

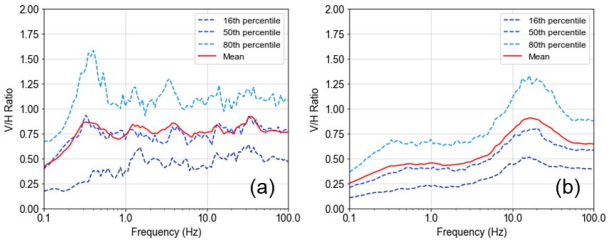

Fig. 5. V/H ratio from limited measurement records (R<10 km, 4<M<6) (a) Korea (Gyeongju, Pohang) (b) NGA-WEST

4. Conclusions

This study evaluated the V/H ratio of earthquake ground motion in Korea based on the observed earthquake records. The seismic records in Korea showed high-frequency characteristics than the seismic records in the western United States in horizontal and vertical directions. The V/H ratio was different according to the epicentral distance of the observatory. When the distance was less than 10 km, the peak value was about 0.9 near 25 Hz, and when the distance was greater than 10 km, it showed a constant value of about 0.75 regardless of the frequency. Although seismic records in Korea are still lacking, the results of this study are expected to be used as fundamental data for site-specific earthquake safety evaluation of nuclear power plants in consideration of domestic seismic conditions.

Acknowledgement

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