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Simulation of ground motion propagation during the 2016 Gyeongju Earthquake in Korea

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ABSTRACT

In low and moderate seismic areas, only limited recorded ground motion data is available. In Korea, the Gyeongju earthquake (M=5.8) occurred on September 12, 2016, which was the largest earthquake since earthquake recording was started in Korean peninsula. During this earthquake, valuable information on ground motions was collected by various recording stations distributed widely in Korean peninsula. In this study, a point source model is constructed to accurately simulate ground motions recorded at different recording stations with different soil conditions during the Gyeongju earthquake. Using this model, ground motions are generated at all grid locations of Korean peninsula. Each grid size has $0.1° \times 0.1°$. Then a contour hazard map is constructed using the peak ground acceleration of the simulated ground motions.

Keywords: Earthquake, ground motion, recording station, soil condition, point source model

1. Introduction

Korea is located in a low and moderate seismic regions that seismic activities have not been well defined. The most earthquakes with magnitudes less than 4 occupy in past history earthquake list or instrument earthquake list of Korea. Since the first observation of the domestic instrument earthquake in 1905, however, the earthquakes with magnitudes greater than 5 was observed 20 times in total. Six of these earthquakes occurred after 2000. According to the Meteorological Agency statistics, a total of 1,060 earthquakes have been observed in the past 36 years (1978 to 2013), with an average annual occurrence rate of 29. And also annual occurrence rate have been increasing with magnitudes greater than 3. In particular, the Gyeongju earthquake was the largest recorded earthquake in Korea that occurred on September 12, 2016 and caused the largest economic damages in the nearby area.

For seismic design of structures against earthquakes, equivalent static analysis,

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response spectrum analysis, or time history analysis can be used according to current seismic design criteria. If the seismic design category of the target area is high and the structure has non-uniformity according to the standard, or the structure to which the damping system is applied, dynamic analysis such as nonlinear time history analysis should be used.

In KBC 2016, the time history analysis shall be performed using the selected instrument earthquake recording or artificial earthquake recording corresponding to the ground conditions of the target area and adapted to the design spectrum. Korea has a short history of seismic observations and the number of available strong-earthquakes is very limited. Most of them are used for dynamic analysis by correcting the recorded ground motions. Even if the recorded ground motions are corrected in the area with similar ground conditions, however, very different results can be obtained when the waveform, frequency component, and duration of the strong earthquake do not match the conditions of the target area.

For this reason, there have been many studies on the artificial ground motion simulation method reflecting the dynamic characteristics of the soil. Many studies have been carried out on the model of ground motion simulation in overseas countries. However, this model can not be used in Korea because the geotechnical conditions, the damping effect and the ground amplification effect of each periods the seismic wave are very different.

In this study, ground motion model was constructed to simulate ground motions caused by the Gyeongju earthquake using point earthquake source model. In order to consider the geotechnical conditions in Korea, the parameters of point seismic source model are proposed by Noh and Lee (1995) and Jo and Baag (2001) were simulated. In order to consider the ground amplification effect of each site, ground amplification factor was calculated based on existing soil profiles in Korea and then reflected in the simulation of artificial ground motion. In order to evaluate the accuracy of the proposed method, we compared the actual ground motions measured by the Gyeongju earthquake on September 12, 2016 and the ground motions generated by the proposed model for several recording stations.

2. Ground motion model

Since information on fault structures is very limited in Korea, seismic sources for Korean peninsula are modeled using the point source model developed Boore and Atkinson(1987). Ground motions can be simulated from the point source simulation using the SMSIM software (2002). Eq. (1) is a functional form of the Fourier amplitude spectrum of the point source model.

$$A(f) = C \cdot S(f) \cdot D(f) \cdot I(f) \tag{1}$$

where C is the scaling factor that defines the spectral amplitude, and $S(f)$ is the source spectral function that defines spectral shape of earthquake ground motions at a site, $D(f)$ is the diminution function of spectral amplitudes as waves propagate to a site, $I(f)$ is the type of motion being computed: acceleration, velocity, or displacement, and

f is the frequency. the parameters of the point source model for the Korean peninsula as follows:

$$C = \frac{R_{\theta\phi} \cdot F \cdot V}{4\pi\rho\beta^3} \cdot \frac{1}{\gamma} \tag{2}$$

$$S(f) = \frac{M_0}{1 + (f/f_c)^2} \tag{3}$$

$$D(f) = \exp(-\pi\kappa_q f \cdot r \cdot) \exp(-\pi\kappa_s f), \quad \kappa_s = 1.4\times10^{-2}(\pm3.8\times10^{-3}), \quad \kappa_q = 1.6\times10^{-4}(\pm3.9\times10^{-5}) \tag{4}$$

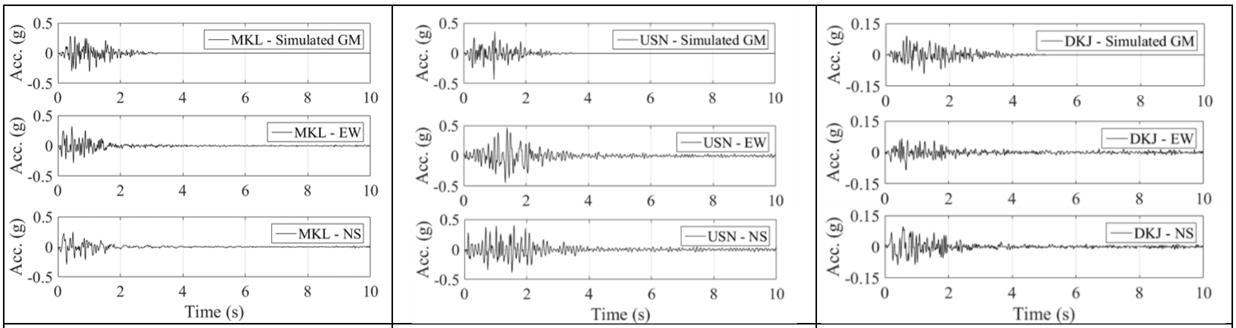
$$I(f) = (2\pi f)^p \tag{5}$$

where $R_{\theta\phi}$ is the average radiation pattern ($=0.63$), F is the free surface effect ($=2$), V is the partition factor of the horizontal component ($=0.71$), ρ is the soil density ($=2.7\text{g/cm}^3$), β is the shear wave velocity ($=3.5\text{km/s}$) and r is the distance scaling factor accounting for geometric spreading of body waves radiated from a point source, M_0 is the seismic moment, f_c is the corner frequency ($=4.9\times10^6\beta(\Delta\sigma/M_0)^{1/3}$), $\Delta\sigma$ is the stress drop($=100\text{bar}$), and p is 0, 1, and 2 for displacement, velocity and acceleration, respectively.

3. Simulation of ground motions

Earthquake ground motions recorded at different sites (MKL station, USN station, DKJ station) during the 2016 Gyeongju earthquake are simulated using the point source model with SMSIM software. Fig. 1 shows the acceleration of simulated sample and recorded ground motions at different recording stations. Table 1 summarizes peak ground accelerations (PGA) extracted from simulated and actual ground motions. It is observed that the PGAs of simulated ground motions match those of actual ground motions. Since ground motions are generated randomly using the SMSIM software, it is better compare multiple generated ground motions with actual ground motion rather than single simulated ground motion. Thus, the median response spectrum is constructed using 200 generated ground motions, and compared with actual response spectrum of corresponding ground motion recorded during the Gyeongju earthquake (Fig. 2). From this figure, the median response spectrum of the 200 generated ground motions matches the actual ground motion fairly accurately. This indicates that the point source model can be used for simulating ground motions for a particular earthquake event to conduct regional seismic risk analyses.

Fig. 3 shows the contour hazard map constructed using PGAs of ground motions simulated at all locations in Korean peninsula due to the Gyeongju earthquake. It is assumed that soil condition is assumed as S_B (normal rock, soil amplification factor = 1).

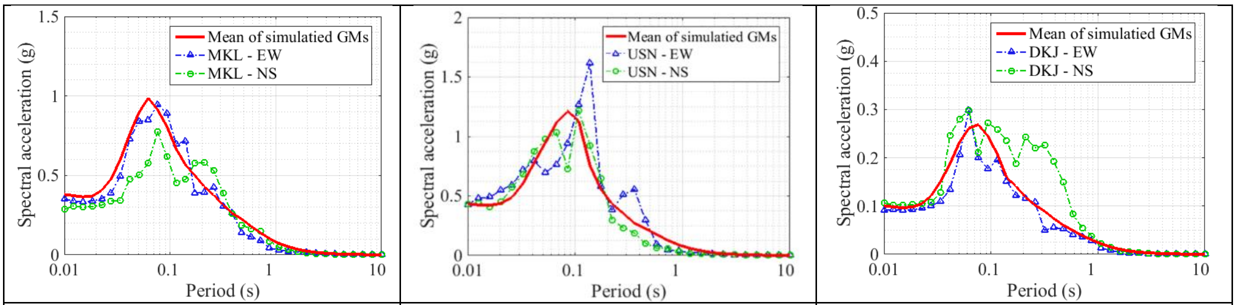


(a) MKL | (b) USN | (c) DKJ

Fig. 1 Response spectra of simulated and recorded ground motions

Table 1 PGAs for simulated and recorded ground motions

Station name	Site	PGA(g)		
		Simulated ground motion	Recorded ground motion	
			EW component	NS component
MKL	Myeonggye-ri	0.2881	0.3437	0.2644
USN	Ulsan	0.4398	0.4649	0.4042
DKJ	Deokjeong-ri	0.0813	0.0729	0.1068
MIYA	Miryang	0.0263	0.0333	0.0309



(a) MKL | (b) USN | (c) DKJ

Fig. 2 Response spectra of simulated and recorded ground motions

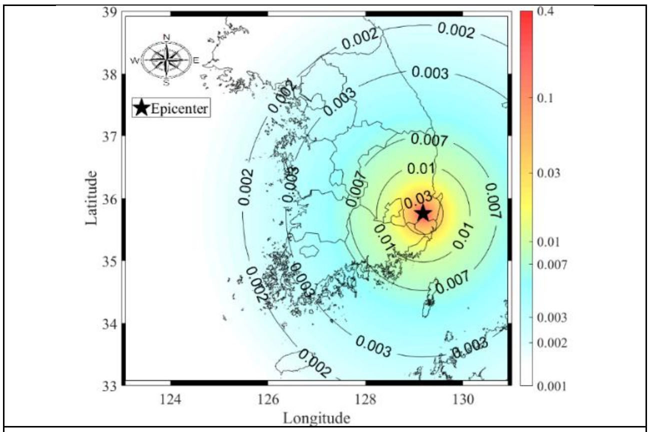


Fig. 3 Contour hazard map constructed using the peak ground acceleration of the simulated ground motions

4. Conclusions

In this study, ground motions recorded during the Gyeongju earthquake were simulated using the point source model. The following are the conclusions obtained from this study.

1. Ground motions occurred during the 2016 Gyeongju earthquake were accurately simulated using the point source model. It is observed that local site condition could properly accounted for by this model.
2. The response spectra of generated ground motions matched the actual response spectrum of ground motions recorded during the 2016 Gyeongju earthquake. This indicates that the model used in this study accurately reflect site condition as well as the intensity of ground motions over all period ranges.
3. Seismic hazard contour map was constructed, which is associated with the Gyeongju earthquake. Such maps can be used when seismic risk analyses are to be conducted for existing and new structurers.

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