A model for simulating ground motions for the 2017 Pohang earthquake occurred in Korean peninsula

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Abstract

The 2017 Pohang earthquake ($M_L = 5.4$) induced the largest economic loss and human casualties in Korea among earthquakes recorded in Korean peninsula since the Korean Metrological Administration started instrumental recording in 1978. Ground motions were recorded during the Pohang earthquake by recording stations widely distributed in Korean peninsula, which contained valuable geophysical and seismological information. In this study, a model for simulating ground motions was proposed based on a point source model and shaping window model. The domestic geological characteristics and site effects were considered. Using the proposed model, ground motions recorded during the Pohang earthquake are simulated. Based on the simulation results, contour maps are constructed, which represent the degree of peak ground acceleration at individual grid locations in Korean peninsula.

Keywords: point source model, shaping window model, simulation, ground motion, contour map

1. INTRODUCTION

The Korean peninsula is within the Eurasian plate, and it is an area with less possibility of strong motions because of the low-to-moderate seismic activity. After domestic digital observations, the 2017 Pohang earthquake caused the most casualties and economic damage in Korea. So, in order to prevention for this, much attention has been paid to the prediction of earthquake characteristics and the study of seismic design.

According to current seismic design criteria (ASCE 7-16), it is recommended that the design should be performed by time history analysis using input seismic waves in case of high rise buildings and irregular buildings. However, if the wave shape, duration, frequency shape, and site effects of the input seismic waves do not proper target site conditions, it may lead to biased analysis results. Since the Korean peninsula does not have many accumulated strong motion, the number of observed seismic waves to perform seismic design is very small. In order to replace this, it is important to study artificial ground motion simulation with proper domestic geological conditions.

Based on the source displacement amplitude model (ω^{-2} model) proposed by Brune (1970; 1971), Boore and Atkinson (1987) were proposed point source model for ground motion simulation. And based on the method proposed by Saragoni and Hart (1974), Boore (2003) constructed shaping window model for ground motion simulation.

And, if the target area is a soil site with a large site effect, it is necessary to consider the site amplification. As a previous study, Zhao et al. (2006) evaluated site effect by improving the horizontal to vertical spectral ratio proposed by Nakamura (1989).

In this study, the characteristics of the 2017 Pohang earthquake were evaluated using the point source model considering site effect and the shaping window model. And proposed the model for artificial ground motion simulation.

2. Simulation models for the 2017 Pohang earthquake

In order to evaluate the 2017 Pohang earthquake, the point source-based Fourier amplitude spectrum model proposed by Boore and Atkinson (1987) was used in the frequency domain. And for considering the site effect in the target area, the site amplification term ($Z(f)$) is added to the point source model.

$$A(M_o, R, f) = C \times G(R) \times S(M_o, f) \times D(f) \times I(f) \times Z(f) \tag{1}$$

Table 1. Point source model parameters

Terms		Parameters	values
Scaling factor	$C = \frac{\langle R_{\theta\phi} \rangle \times F \times V}{4\pi\rho\beta^3}$	$\langle R_{\theta\phi} \rangle$: average body-wave radiation coefficients for SH wave (Boore and Boatwright, 1984)	0.44
		F : amplification due to the free surface effect (Boore and Atkinson, 1987)	2
		V : reduction factor that accounts for the partitioning into two components (Boore and Atkinson, 1987)	0.7071
		ρ : source crustal density (Kim, 1995)	$2.7\ \mathrm{g/cm^3}$
		β : source crustal shear velocity (Kim, 1995)	$3.36\ \mathrm{km/s}$
Geometrical spreading factor	$G(R) = R^{-1}$	R : Hypocentral distance	Input value
Source spectral function	$S(M_o, f) = \frac{M_o}{1+(f/f_c)^2}$	$M_o = 10^{1.5(M_W+10.7)}$: Seismic moment (Hanks and Kanamori, 1979)	Input value
		$f_c = 4.9\times10^6 \times \beta \times (\Delta\sigma/M_o)^{1/3}$: corner frequency (Boore and Atkinson, 1987)	Estimated value from Table 2
Diminution function	$D(f) = \exp(-\pi\kappa f)$	$\kappa = \kappa_1 + \kappa_2 \times R$: decay parameter (Anderson and Hough, 1984)	Estimated value from Table 2
Ground Motion type function	$I(f) = (2\pi f)^p$	$p = 0,\ 1,$ or 2 for displacement, velocity, or acceleration (Boore and Atkinson, 1987)	2
Site amplification function (Zhao et al., 2006)	$Z(f) = \frac{RSA_H(f)}{RSA_V(f)}$	$RSA_H(f)$: 5% damped response spectrum for horizontal component	Estimated value from each recording station
		$RSA_V(f)$: 5% damped response spectrum for vertical component	Estimated value from each recording station

Table 2. Estimated point source model parameters for the 2017 Pohang earthquake

Earthquake	Decay factor, κ	Corner frequency, f_c	Seismic moment, M_o	Moment magnitude, M_W	Local magnitude, M_L	Stress drop, $\Delta\sigma$
Main shock	$0.0093 + 0.000043R$	0.58 Hz	1.8×10^{24} dyn-cm	5.5	5.4	56 bar
After shock		1.53 Hz	7.0×10^{22} dyn-cm	4.5	4.6	77 bar

The description of the individual parameters for this model are shown in Table 1. Due to the lack of research related with the geometrical spreading factor for Korean peninsula, it is assumed to be the reciprocal of the hypocentral distance.

The remaining parameter values (κ, f_c, M_o) of the point source model were evaluated with methods proposed by Anderson and Hough (1984) and Joshi et al. (2016) based on Brune (1970; 1971)'s model after removing the site effect ($Z(f)$) for the 2017 Pohang earthquake (Table 2).

In order to simulate artificial ground motions according to the magnitude and hypocentral distance using the point source model, appropriate windowed white gaussian noise should be determined in the time domain. Boore (2003) used the modified form of window model proposed by Saragoni and Hart (1974), and Atkinson and Boore (1995) proposed seismic wave duration. However, this is not a good fit when compared with the domestic recorded ground motions. Therefore, shape window model was proposed for the Korean Peninsula, as shown in Eq. (2 - 3).

$$\ln\left(W\left(t,T_D\right)\right)=1.96+0.78\times\ln\left(t/T_D\right)-3.51\times t/T_D \tag{2}$$

$$T_D=\frac{1}{f_c}+\begin{bmatrix}2.75+0.375R & \left(10km<R\le 50km\right)\\ 14.1+0.038R & \left(50km<R\right)\end{bmatrix} \tag{3}$$

where t is time and T_D is duration. To account for the duration, the Arias Intensity energy method was used to evaluate the time between the arrival of the S wave and 95% of the total energy reached.

3. Artificial ground motion generation using simulation models

Earthquake ground motions recorded at 3 sites (PHA2 station, YODB station, USN2 station) during the 2017 Pohang earthquake are simulated using the proposed simulation model with MATLAB software. Figure 1 shows the comparison of artificial ground motion acceleration generated along with the horizontal ground motion observed at each station. The response spectra of observed ground motions are estimated to be reproducible because they are evaluated within the maximum standard deviation ($=2\sigma_{\log}$) considered. Figure 2 shows the peak ground acceleration (PGA) hazard map constructed using generated artificial ground motions at all locations in Korean peninsula due to the 2017 Pohang earthquake. And most region of error values between the actual record and the artificial record are within the maximum standard deviation ($=2\sigma_{\log}$) considered. These indicate that the ground motion simulation model can be used for the Pohang earthquake event to conduct regional seismic risk analyses.

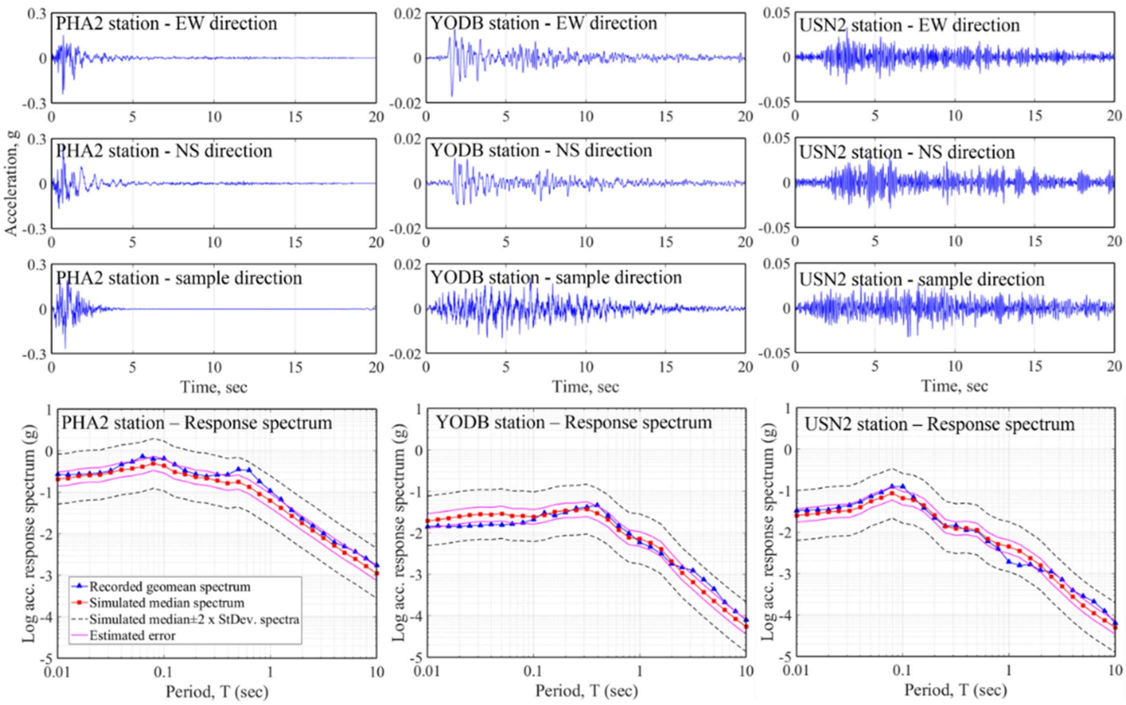

Figure 1. Simulated and recorded ground motions for the 2017 Pohang earthquake

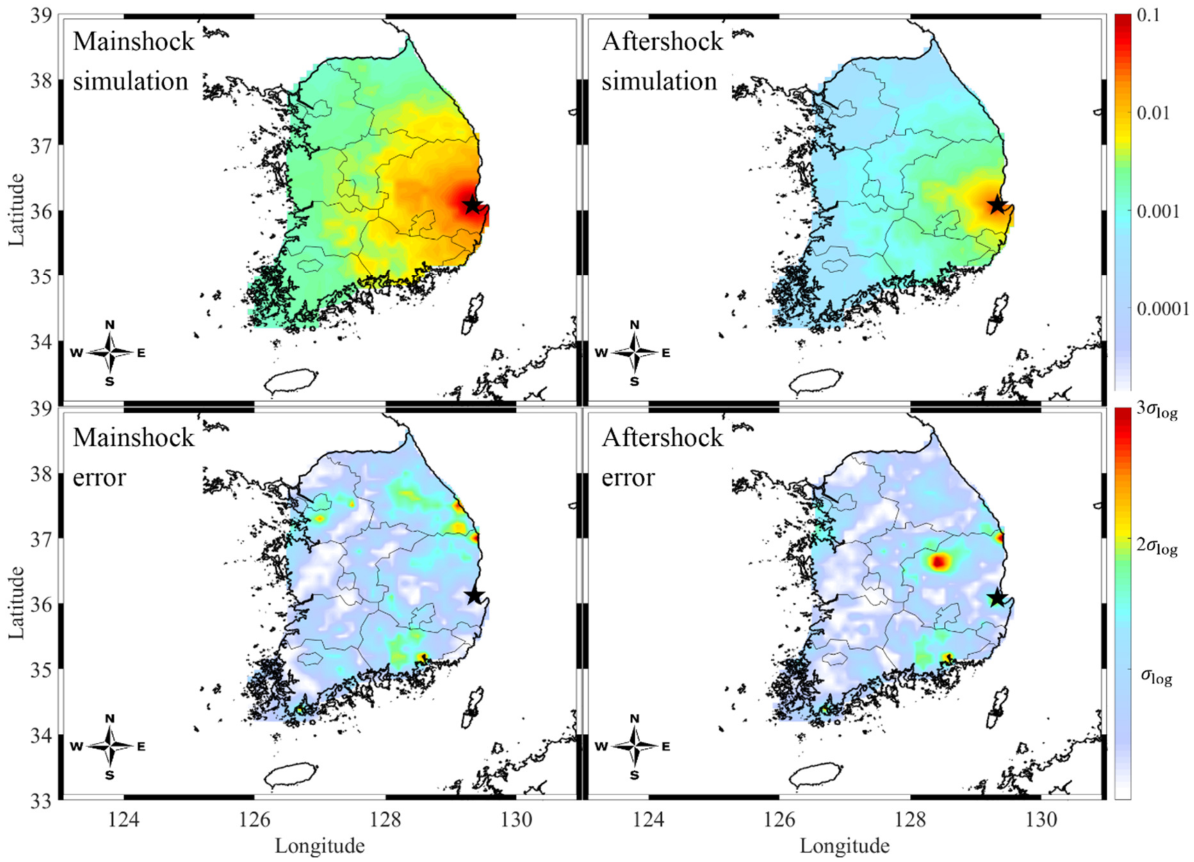

Figure 2. Peak ground acceleration (PGA) Hazard map for the 2017 Pohang earthquake

4. CONCLUSIONS

In this study, ground motions of the 2017 Pohang earthquake are simulated using the proposed simulation models. The following are the conclusions obtained from this study.

1. The proposed simulation model accurately simulated the recorded ground motions during the Pohang earthquake, which was developed based on proposed models.
2. The response spectra of simulated ground motions matched those of observed ground motions recorded at sites with various site conditions during the 2017 Pohang earthquake. This indicates that the model used in this study accurately reflected site effects as well as the intensity of ground motions.
3. Seismic PGA contour maps were constructed for the 2017 Pohang earthquake. Such maps can be used when seismic risk analyses are to be conducted for old and new structures.

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