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# A Korean ground motion simulation model comprising of stochastic point-source and shaping window models

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## ABSTRACT

The aim this study is to develop a ground motion simulation model for the Korean peninsula to simulate ground motions propagated from scenario-based earthquakes. The proposed numerical model can be used to construct ground motion prediction equations and to perform probabilistic seismic hazard analyses. The model consists of stochastic point-source and shaping window model. The model parameters of these models are calibrated based on ground motions recorded at various bedrock site stations during 10 earthquakes with $M_L$>3.5 occurred in the Korean peninsula from 2015 to 2019. To confirm accuracy of ground motion simulation model, 5% damped pseudo spectral acceleration with T = 0.1s-10s of recorded and simulated ground motions are compared.

## 1. INTRODUCTION

According to Schulte and Mooney (2005), the Korean peninsula is classified as a stable continent region with considered with an earthquake-safe zone. However, three earthquakes (the 2016 Gyeongju foreshock, mainshock, and the 2017 Pohang mainshock earthquakes) with $M_L$>5.0 caused building damaged with economic losses and human casualties in the south-eastern area of the Korean peninsula. These three earthquakes are ranked as top three in Korea since start of digitized seismic stations by Korea Meteorological Administration (KMA) in 1990s. After these earthquakes occurred, importance of future earthquake hazard has grown in the Korea region.

To deal with economic losses and human casualties from future earthquake hazard, accurate seismic hazard prediction with regional earthquake characteristics should be developed. Therefore, this study developed regional ground motion simulation model to reproduce ground motions from the Korean Peninsula by using recorded ground motions. Here, the information of those earthquake events used in this study summarized in Table 1.

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Table 1. Information of the earthquake events catalogue from NECIS

| Event No. | Local Date Time | Longitude (East) | Latitude (North) | Focal depth (km) | $M_L$ |
|---|---|---|---|---|---|
| 1 | 2015Dec22 04:31 | 126.95° | 36.02° | 11 | 3.9 |
| 2 | 2016Sep12 19:44 | 129.19° | 35.77° | 19 | 5.1 |
| 3 | 2016Sep12 20:32 | 129.19° | 35.76° | 19 | 5.8 |
| 4 | 2016 Sep19 20:33 | 129.18° | 35.74° | 19 | 4.5 |
| 5 | 2017Nov15 14:29 | 129.37° | 36.11° | 9 | 5.4 |
| 6 | 2017Nov15 16:49 | 129.36° | 36.12° | 10 | 4.3 |
| 7 | 2017Nov16 09:02 | 129.37° | 36.12° | 8 | 3.6 |
| 8 | 2017Nov20 06:05 | 129.36° | 36.14° | 12 | 3.6 |
| 9 | 2018Feb11 05:03 | 129.33° | 36.08° | 14 | 4.6 |
| 10 | 2019Jul21 11:04 | 128.10° | 36.50° | 14 | 3.9 |

Regional ground motion simulation model consists of two models with stochastic point-source and shaping window models. Boore (2003) proposed stochastic point-source model with three main earthquake characteristics (i.e. source, path, and site effects) in the frequency domain. Saragoni and Hart (1974) proposed shaping window model with two main regional earthquake characteristics (i.e. duration and shape envelope of ground motion) in the time domain.

## 2. DEVELOPMENT OF GROUND MOTION SIMULATION MODEL

Regional ground motion simulation model consists of two models (stochastic point-source and shaping window models). This study used calculated shaping window model proposed by Han and Jee (2020). Therefore, the stochastic point-source was additionally estimated step-by-step with path, site, and source effects with Fourier amplitude spectrum (FAS) from recorded ground motions at bed rock site. The stochastic point-source model $[FAS(f,R)]$ is as shown in Eq. (1).

$$FAS(f) = Source(f, M_0, f_c) \times Path(f, R_H) \times Site(f, \kappa_0) \quad (1)$$

where $Source(f, M_0, f_c)$ is source function, $Path(f, R_H)$ is path function, $Site(f, \kappa_0)$ is site function. More detail summary of this model is in Table 2. Before develop the stochastic point-source model, $V_{SH}$ and $\rho$ in Table 2 were firstly determined from crustal structure modeling map calculated by Tao et al., 2018.

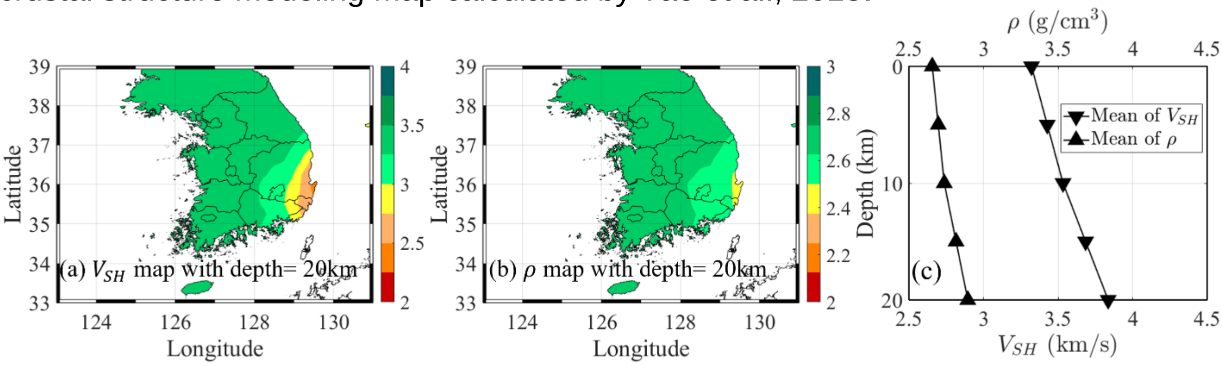


Fig. 1 Crustal structure modeling map for the Korean Peninsula (Tao et al., 2018)

Table 2. Stochastic point-source model parameters for ground motion acceleration

| Terms | | Parameters |
|---|---|---|
| Source effect function | $Source(f, M_0, f_c) = \frac{M_0 \times (2\pi f)^2}{1+(f/f_c)^2} \times \frac{\langle R_{\theta\phi} \rangle FV}{4\pi\rho V_{SH}^3 R_{ref}}$ | $f$ : frequency<br>$M_0$ : seismic moment<br>$f_c$ : corner frequency<br>$\langle R_{\theta\phi} \rangle$ : averaged radiation pattern value (=0.63; Boore and Boatwright, 1984)<br>$F$ : free surface effect value (=2; Boore, 1983)<br>$V$ : vector partition value for horizontal component (0.7071; Boore, 1983)<br>$\rho$ : source crustal density for S-wave in the Korean peninsula<br>$V_{SH}$ : source crustal shear wave velocity for S-wave in the Korean peninsula<br>$R_{ref}$ : reference hypocentral distance (= 1 km) |
| Path effect function | $Path(f, R) = G(R) \cdot \exp(-\pi fR / Q_S(f) V_{SH})$ | $G(R) = \begin{cases} R^{-1.3} & (R \le 70 \text{ km}) \\ 70^{-1.3} \cdot (R/70)^{0.3} & (70 \text{ km} < R \le 100 \text{ km}) \\ 70^{-1.3} \cdot (100/70)^{0.3} \cdot (R/100)^{-0.5} & (R > 100 \text{ km}) \end{cases}$<br>: geometrical attenuation function (Jee and Han, 2019) |
| | | $Q_S(f) = 348 f^{0.48}$ : quality factor of anelastic attenuation function for S-wave (Jee and Han, 2019) |
| Site effect function | $Site(f, \kappa_0) = AMP(f) \cdot \exp(-\pi\kappa_0 f)$ | $Z(f)$ : site amplification function |
| | | $\kappa_0$ : site attenuation factor |

Firstly, this study used calculated path effect function [$Path(f, R)$] proposed by Jee and Han (2019), as shown in Table 2. Secondly, site effect function [$Site(f, \kappa_0)$] was determined, which consists of site amplification function [$AMP(f)$] and site attenuation function [$\exp(-\pi\kappa_0 f)$]. Here, site amplification function [$AMP(f)$] is assumed as a unity because recorded ground motions used in this study are at bedrock site. Site attenuation function [$\exp(-\pi\kappa_0 f)$] was measured for effective range with 10 Hz – 30 Hz as follows procedure from Anderson and Hough (1984). Thirdly, source effect function [ $Source(f, M_0, f_c)$ ] was determined with key parameters $M_0$ and $f_c$ for each earthquake events. Frankel (1994) reported stress drop, $\Delta\sigma$ is consistent with moderate-to-high earthquake magnitude in stable continent region. And, $\Delta\sigma$ consists of $M_0$ and $f_c$ (Boore, 1983). Therefore, $M_0$ and $f_c$ are measured with fixed stress drop, $\Delta\sigma$ as shown in Eq. (2).

$$\Delta\sigma = M_0 \left( \frac{f_c}{4.906 \times 10^6 \times V_{SH}} \right)^3 \tag{2}$$

To measure proper $M_0$ and $f_c$, this study considered various $\Delta\sigma$ ranged with 10-1000 bar with object function as shown in Eqs. (3-4).

$$\text{Objective Function} = \frac{1}{M}\frac{1}{N}\sum_{i=1}^{M}\sum_{j=1}^{N}\left|\text{Residual}_i\left(T_j\right)\right| \tag{3}$$

$$\text{Residual}(T) = \log\left[PSA(T)_{simulataed}\right] - \log\left[PSA(T)_{recorded}\right] \tag{4}$$

where, $PSA(T)_{simulataed}$ and $PSA(T)_{recorded}$ are 5% damped pseudo spectral acceleration from simulated and recorded ground motions at period $T$. $M$ is the number of measured residuals at each period $T$ and these index is $i$ (=1-1378). $N$ is the number of periods ranged with 0.01s-10s and these index is $j$ (=1-31). In this study, the determined proper stress drop, $\Delta\sigma$ value is 215 bar for this study. Here, $\Delta\sigma$ this values would be sensitive values with different path effect function.

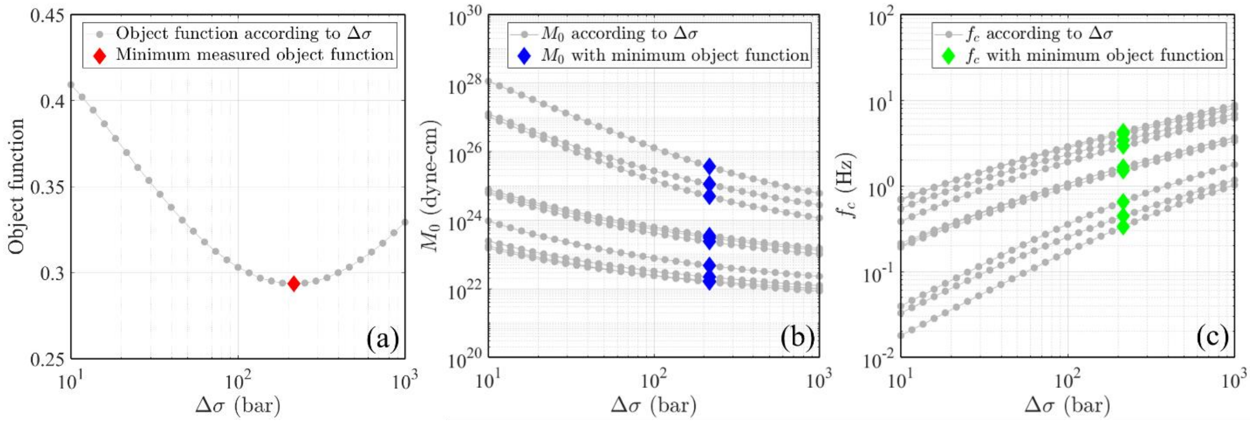


Fig. 2 Measured $M_0$ and $f_c$ with object functions

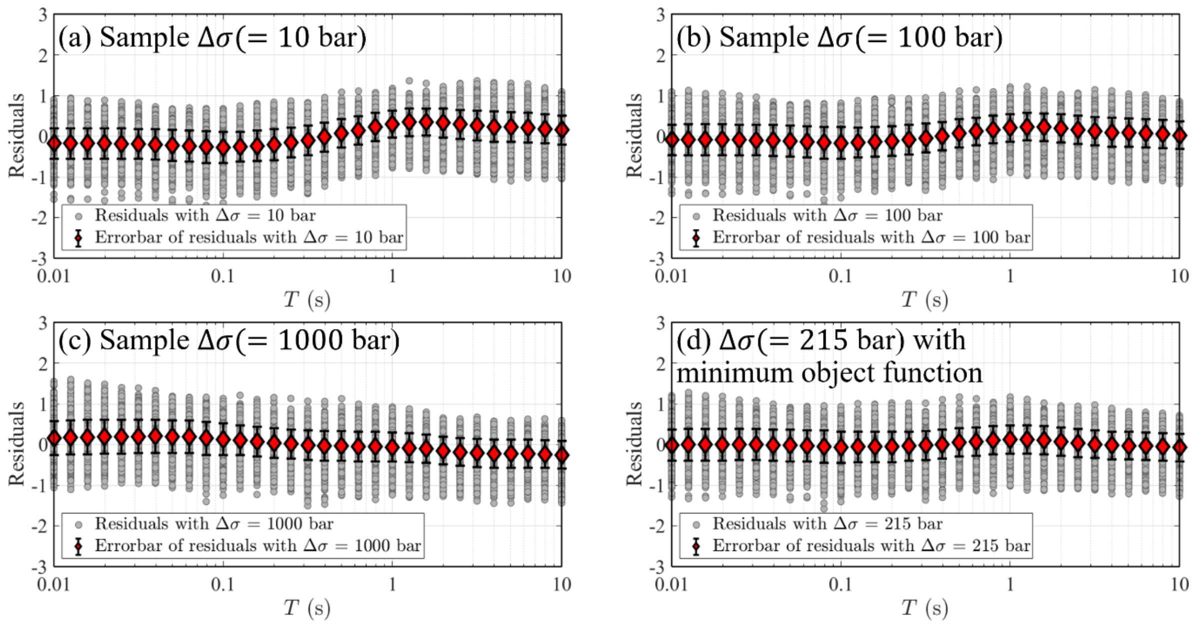

Fig. 3 Residuals between $PSA(T)$ with four $\Delta\sigma$ (10, 100, 1000, and 215 bar).

Figure 3 shows measured residuals $PSA(T)$ with four $\Delta\sigma$ (10, 100, 1000, and 215 bar). In Figure3d ( $\Delta\sigma = 215$ bar), mean and standard deviation of residuals are consistently near zero and stable values according to each period, $T$ different from other cases ($\Delta\sigma = 10$, 100, 1000 bar). Therefore, this study developed and verified the regional ground motion simulation model for the Korean peninsula.

## 3. CONCLUSIONS

In this study, the regional ground motion simulation model was developed for the Korean peninsula. And the results are as follows.

1. Stochastic point-source and shaping window models and recorded ground motions at bedrock site were used for development of the regional ground motion simulation model for the Korean peninsula.
2. Ground motion simulation model were verified with object function, and the result is valid.
3. Proposed model can simulate input ground motions, which are to contribute GMPEs, PSHA for the Korean peninsula.

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## REFERENCES

Anderson, J.G., and Hough, S.E. (1984), “A Model for the Shape of the Fourier Amplitude Spectrum of Acceleration at High Frequencies,” *Bulletin of the Seismological Society of America*, **74**, 1969-1993.
Boore, D.M., and Boatwright, J. (1984). “Average Body-wave Radiation Coefficients,” *Bulletin of the Seismological Society of America*, **74**(5):1615-1621.
Boore, D.M. (1983). “Stochastic Simulation of High-frequency Ground Motions Based on Seismological Models of the Radiated Spectra,” *Bulletin of the Seismological Society of America*, **73**(6A), 1865-1894.
Boore, D.M. (2003). “Simulation of Ground Motion Using the Stochastic Method,” *Pure and Applied Geophysics*, **160**(3-4), 635-676.
Han, S.W., and Jee, H.W. (2020). A Numerical Model for Simulating Ground Motions for the Korean Peninsula, *Applied sciences*, **10**(4), 1254.
Jee, H.W., and Han, S.W. (2019), “Equations of Path Effects to simulate ground motions in Korean Peninsula using Point-source model,” *The 2019 World Congress on Advances in Structural Engineering and Mechanics (ASEM19)*, Jeju, Korea.
Schulte, S.M., and Mooney, W.D. (2005). “An updated global earthquake catalogue for stable continental regions: Reassessing the correlation with ancient rifts,” *Geophysical Journal International*, **161**(3), 707-721.
Saragoni, G., and Hart, G. (1974). Simulation of Artificial Earthquakes, *Earthquake Engineering and Structural Dynamics*, **2**, 249-267.
Tao, K., Grand, S.P., and Niu, F. (2018). “Seismic Structure of the Upper Mantle Beneath Eastern Asia From Full Waveform Seismic Tomography,” *Geochemistry, Geophysics, Geosystems*, **19**(8), 2732-2763.