The 2019 World Congress on
Advances in Structural Engineering and Mechanics (ASEM19)
Jeju Island, Korea, September 17 - 21, 2019

Equations of Path Effects to simulate ground motions in Korean Peninsula using Point-source model

*Hyun Woo Jee[1] and Sang Whan Han[2]

[1), 2)] *Department of Architectural Engineering, Hanyang University, Seoul 04763, Korea*
[2)] *swhan@hanyang.ac.kr*

ABSTRACT

The point source model has been widely used in generating artificial ground motions, which can be used to develop the ground motion prediction equation and to evaluate the seismic risks of structures. This model mainly consists of three different functions representing source, path, and site effects. The path effect is used to emulate decay in ground motion according to distance from the source. In the point source model, the path effect is taken into account by using the geometrical attenuation effect and the anelastic attenuation effect. The aim of this study is to develop accurate equations of quality factor and geometrical spreading for the Korean peninsula. It is shown that the proposed equations play an important role in simulating ground motions reflecting local geological properties and travel path of earthquakes.

1. INTRODUCTION

Since the Korean peninsula is low-to-moderate seismicity region, rate of large-scaled earthquake occurrence is lower than the rate in the seismically active regions such as Japan, Taiwan, and Western North America. However, several historical large-sized earthquake events with magnitude 6 or large were recorded in Korean historical documents from 2 to 1904 A.D. (Lee and Yang, 2006). Since seismological observation network started by Korea Meteorological Administration (KMA) in 1997, 1st and 2nd ranked earthquake events (2016 Gyeongju earthquake and 2017 Pohang earthquake) also caused building structure damages and economic losses nearby areas within the Korean peninsula. Here, the information of those earthquake events used in this study summarized in Table 1.

Therefore, research for threats of earthquake is worth considering for the Korean peninsula. There are developments of probabilistic seismic hazard analysis (PSHA), ground motion prediction equations (GMPEs), and ground motion simulation model associated with the research.

For reliability and accuracy of results, those researches need to properly consider

---

[1)] Graduate Student
[2)] Professor

key seismological characteristics such as source, path, site effects. One widely used model to estimate the characteristics is the point-source model (Atkinson and Mereu, 1992; Noh and Lee, 1994; Park et al., 2000; Jo and Baag, 2001; 2003; Junn et al., 2002; Zandieh and Pezeshk, 2010; Jeong and Lee, 2017; Jee and Han, 2019). Among those characteristics, this research only focused on the path attenuation effect propagated from earthquake source.

Table 1. Information of the earthquake events catalogue from KMA

Event	Type of event	Local Date-Time	Longitude (East)	Latitude (North)	Focal depth (km)	M_L
1	Foreshock of the 2016 Gyeongju earthquake	2016Sep12-19:44	129.19°	35.77°	19	5.1
2	Mainshock of the 2016 Gyeongju earthquake	2016Sep12-20:32	129.19°	35.76°	19	5.8
3	Aftershock of the 2016 Gyeongju earthquake	2016Sep19-20:33	129.18°	35.74°	19	4.5
4	Mainshock of the 2017 Pohang earthquake	2017Nov15-14:29	129.37°	36.11°	9	5.4
5	Aftershock of the 2017 Pohang earthquake	2017Nov15-16:49	129.36°	36.12°	10	4.3
6	Aftershock of the 2017 Pohang earthquake	2018Feb11-05:03	129.33°	36.08°	14	4.6

2. PATH EFFECT ESTIMATION

For the path effect, geometrical attenuation effect and anelastic attenuation effect were used together in the frequency domain (Boore, 2003). It needs to analyze two effects simultaneously because there is a trade-off relation between those effects (Atkinson and Merou, 1992). Previous researches (Atkinson and Merou, 1992; Zandieh and Pezeshk, 2010) proposed estimation procedure for path effect itself using the point-source model with smoothed Fourier amplitude spectrum (FAS) of observed ground motion recordings from rock site stations. This study also similarly applied this procedure using the point-source model [$A(f,R)$] as shown in Eq. (1).

$$\log A(f,R) = \log Source(f) + \log Path(f,R) + \log Site(f) \tag{1}$$

where $Source(f)$ is source effect function, $Path(f,R)$ is path effect function, $Site(f)$ is site effect function, R is hypo-central distance for this study, and f is frequency. More detail explanation of the model is summarized in Table 2.

Table 2. Point-source model parameters

Terms		Parameters
Source effect function	$Source(f)$	Estimated values [$\overline{\log Source_i(f)}$] for each earthquake event used in this study referred from Eq. (3)
Path effect function	$Path(f,R) = G(R)\cdot\exp(-\pi fR/Q_S(f)\beta_S)$	$G(R)=\begin{cases} R^{b_1} & (R\le R_1) \\ R_1^{b_1}\cdot(R/R_1)^{b2} & (R_1<R\le R_2) \\ R_1^{b_1}\cdot(R_2/R_1)^{b2}\cdot(R/R_2)^{b3} & (R>R_2)\end{cases}$: hinged-trilinear geometrical attenuation function
		$Q_S(f)=Q_0 f^{\eta}$: quality factor of anelastic attenuation function for S-wave
		β_S : source crustal shear wave velocity for S-wave in the Korean peninsula (= 3.56; Cho et al., 2011)
Site effect function	$Site(f) = Z(f)\cdot\exp(-\pi\kappa_0 f)$	$Z(f)=\frac{RS_H(f)}{RS_V(f)}$: site amplification function where $RS_H(f)$ is geometric mean of 5% damped response spectrum for horizontal component of ground motion recordings, and $RS_V(f)$ is 5% damped response spectrum for vertical component of ground motion recordings.
		κ_0 : site attenuation factor

The site amplification function [$Z(f)$] was estimated using horizontal-to-vertical spectral ratio (HVSR) technique, and ground motion recordings from station with the amplification values of near unity (= rock site for site class B of NEHRP (BSSC, 2009)) were used (Nakamura, 1989; Zhao et al., 2006). Therefore, the site amplification function is negligible. Except this function, Eq. (1) can be arranged as shown in Eq. (2).

$$\log Source_{ij}(f)=\log A_{ij}(f,R)-\log Path_{ij}(f,R)-\log\exp(-\pi\kappa_0 f) \quad (2)$$

where $Source_{ij}(f)$ is estimated source effect function for earthquake event i at station j, $A_{ij}(f,R)$ is geometric mean FAS of horizontal ground motion recordings for earthquake event i at station j and $Path_{ij}(f,R)$ is estimated path effect function for earthquake event i at station j.

This study analyzed parameter combination (b_1, b_2, b_3, R_1, R_2, $Q_S(f)$) of the path effect using object function minimization technique from previous researches (Atkinson and Merou, 1992; Zandieh and Pezeshk, 2010) as shown in Eq. (3).

$$\text{Objective Function}(f)=\frac{1}{M}\frac{1}{N}\sum_{i=1}^{M}\sum_{j=1}^{N}\left|\log Source_{ij}(f)-\overline{\log Source_i(f)}\right| \quad (3)$$

where N is number of stations, M is number of earthquake events, and $\overline{\log Source_i(f)}$ is mean value of $\log Source_{ij}(f)$ for earthquake event i. $\overline{\log Source_i(f)}$ is also used for representative source effect for each earthquake event. Here, $\exp(-\pi\kappa_0 f)$ is negligible for analysis because κ_0 can be assumed same value for ground motion recordings from rock site stations (Anderson and Hough, 1984; Hashash et al, 2014).

As a result, the geometric attenuation parameters b_1, b_2, b_3, R_1, and R_2 are estimated values of -1.3, 0.3, -0.5, 70 km, 100 km. Quality factor [$Q_S(f) = 348 f^{0.48}$] of anelastic attenuation function was also estimated. Fig. 1 shows the proposed path effect, observed path effects, and mean residuals between those path effects in the logarithmic scale. The values of mean residuals are near zero for each frequency. Therefore, the proposed path effect function is valid.

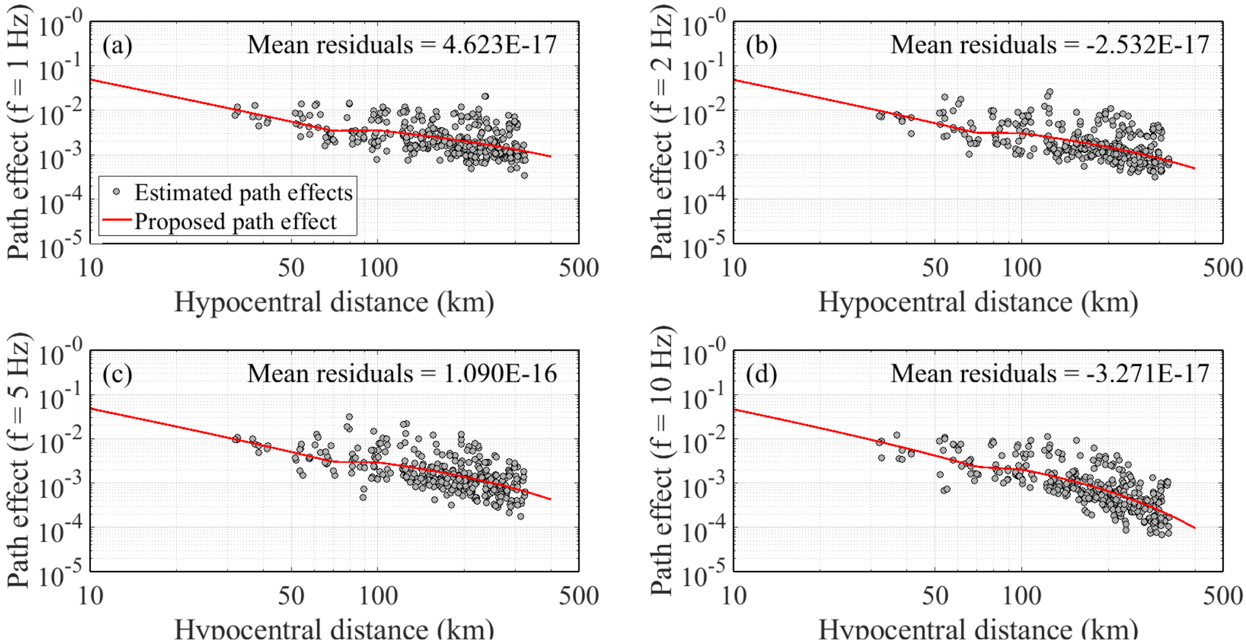

Fig. 1 Proposed path effect and estimated path effects for each observed ground motion recording: (a) 1 Hz, (b) 2 Hz, (c) 5 Hz, (d) 10 Hz.

3. CONCLUSIONS

In this study, the path effect was estimated for the Korean peninsula. And the results are as follows.

1. The point-source model and ground motion recordings from rock site stations from the 2016 Gyeonju earthquake and the 2017 Pohang earthquake are used for estimation of path effect function for the Korean peninsula.
2. Estimated path effects were compared with proposed path effect line, the result is valid.
3. Proposed path effect can be applied point-source model for the Korean peninsula, and is to contribute ground motion simulation model, GMPEs, and PSHA.

ACKNOWLEDGMENTS

The research was supported by grants from Ministry of Land, Infrastructure and Transport of Korean government (19CTAP-C152179-01).

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.

Atkinson, G.M., and Mereu, R.F. (1992), "The Shape of Ground Motion Attenuation Curves in Southeastern Canada," *Bulletin of the Seismological Society of America*, **82**, 2014-2031.

Building Seismic Safety Council (BSSC) (2009), "NEHRP Recommended Seismic Provisions for New Buildings and Other Structures (FEMA P-75) (2009 Edition)," *Building Seismic Safety Council*, Washington, D.C.

Hashash, Y.M.A., Kottke, A.R., Stewart, J.P., Campbell, K.W., Kim, B., Moss, C., Nikolaou, S., Rathje, E.M., and Silva, W.J. (2014), "Reference Rock Site Condition for Central and Eastern North America," *Bulletin of the Seismological Society of America*, 104, 684–701.

Jee, H.W., and Han, S.W. (2019), "Development of Simulation Model for the 2017 Pohang Earthquake and Construction of Hazard Map based on its Scenario," *Journal of the Korean Society of Hazard Mitigation*, **19**, 289-301.

Jeong, G.H., and Lee, H.S. (2017), "An earthquake ground motion model (GMM) for Korean Peninsula," *The 2017 World Congress on Advances in Structural Engineering and Mechanics (ASEM17)*, Ilsan, Korea.

Jo, N.D., and Baag, C.E. (2001), "Stochastic Prediction of Strong Ground Motions in Southern Korea," *Journal of Earthquake Engineering Society of Korea*, **5**, 17-26.

Jo, N.D., and Baag, C.E. (2003), "Estimation of Spectrum Decay Parameter x and Stochastic Prediction of Strong Ground Motions in Southeastern Korea," *Journal of Earthquake Engineering Society of Korea*, **7**, 59-70.

Juun, J.G., Jo, N.D., and Baag, C.E. (2002), "Stochastic Prediction of Ground Motions in Southern Korea," *Geosciences Journal*, **6**, 203-214.

Lee, K., and Yang, W.S. (2006), "Historical Seismicity of Korea, *Bulletin of the Seismological Society of America*," **96**, 846-855.

Nakamura, Y. (1989), "A Method for Dynamic Characteristics Estimation of Subsurface Using Microtremor on the Ground Surface," *Quarterly Report of Railway Technical Research*, **30**, 25-33.

Noh, M.H., and Lee K.H. (1994), "Estimation of Peak Ground Motions in the Southeastern Part of the Korean Peninsula (I): Estimation of Spectral Parameters," *Journal of the Geological Society of Korea*, **30**, 297-306.

Park, D.H., Lee, J.M., and Kim, S.K. (2000), "Attenuation and Source Parameters of Earthquakes in the Southeastern Part of the Korean Peninsula," *Journal of the Earthquake Engineering Society of Korea*, **4**, 99-105.

Zandieh, A., Pezeshk, S. (2010), "Investigation of Geometrical Spreading and Quality Factor Functions in the New Madrid Seismic Zone," *Bulletin of the Seismological Society of America*, **100**, 2185-2195.

Zhao, J.X., Irikura, K., Zhang, J., Yoshimitsu, F., Somerville, P.G., Asano, A., Ohno, Y., Oouchi, T., Takahashi, T., and Ogawa, H. (2006), "An Empirical Site-Classification Method for Strong-Motion Stations in Japan Using H/V Response Spectral Ratio," *Bulletin of the Seismological Society of America*, **96**, 914–925.