Broadband Nonparametric Ground-Motion Evaluation of Horizontal Shear-Wave Fourier Spectra

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on seismic input motions, incorporating recent geological studies
by

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Introduction

- Parametric method
  - Assume path functions
    - e.g. $Q_0 f^n + \text{Geometrical spreading (bilinear, trilinear linear segments)}$
  - Adopted in most of the previous studies due to small number of available earthquake data
    - there are wide variety of Q models reported in Korea
  - Need to verify the parametrically inverted path functions and determine the best model to simulate strong GM models

- Nonparametric method
  - Independent of physical models $\rightarrow$ capable of being used as a reference GM attenuation
  - Large earthquake dataset accumulated from nation-wide seismic networks
  - Provide additional information of the observed data $\rightarrow$ complement the parametric method
Nonparametric method

\[ Y(f_c)_{ij} = \log \text{(Horizontal Fourier Amp.)} \]
\[ = \left[ E'(f_c)_i + F(f_c) \right] + \text{Site}(f_c)_j + \sum_{k=0}^{n} L_k(R)D_k(f_c) \]

* i, j = index for source (excitation) and sites
L_k(R) = linear interpolation function for a path term D_k(f_c)
F(f_c) = a dummy factor common to all the eqk. events

Obtain a least-square solution by matrix inversion with constraints
- \[ \sum_{j} \text{Site}(f_c)_j = 0 \]
- Smoothness of D_k terms
- D(R_{ref}, f_c) = 0
Earthquake Database

- 253 shallow crustal events from 1992('99) to 2003 ($M_L > 2.0$)
- 6,203 records, 134 stations
- Catalogs of earthquake source parameters to calculate the hypocentral distances
  - KMA, KIGAM, ISC

Earthquake data resources

- Domestic major seismic networks
  - KMA, KIGAM, KEPRI, KINS, universities, NPPs
- Foreign seismic networks
  - KSRS Array (U.S. Air Force)
  - IRIS (INCN, SEO), PASSCAL (XI, XL)
  - F-net (IZH), JMA (JTU), PS (TJN, PHN)
Data Processing

Preprocessing

- screening seismic records
- S wave-train windowing (5% tapering)
  → $V_g = 2.6-3.6 \text{km/sec}$ used for automatic windowing at distances > 100km
- instrumental correction for short-period seismometer
- calculation of Fourier spectra for horizontal acceleration components and vector summation (1024pts, df=0.05Hz)
- select available frequency band (S/N > 3 - 4)
  → mainly between 2.0 ~ 30.0 Hz
- No smoothing
- using velocity (for low frequency), acceleration (for high frequency) data
Numerical validation

- Nonparametric method applied to artificial dataset generated by using inverted stochastic GM model parameters (Boore, ‘03)

- Possible bias of the inverted path terms was investigated by numerical simulation

  ➡ There are more earthquake records from small earthquakes at short distance ranges
Inversion of stochastic GM model parameters

- Parametric inversion of stochastic GM model parameters was previously performed (’02, OECD/NEA Workshop)

- Stochastic GM model parameters:
  - Source: Brune’s omega-2 model (’70, 71)
  - Path: Q(f), trilinear G(R), crustal amp (=1.67 at high frequencies)
  - Site: site-dependent kappa (Anderson, ’04)

- Simultaneous nonlinear inversion of the model parameters performed by using the modified Levenberg-Marquardt’s method
Inversion results

Path

Source

Site

Trilinear Geo. Att. model Normalized to 21.54km

1/R

(1/R)^1

(1/65)^1(65/R)^0.5

(1/65)^1(65/117)^0.5(117/R)^0.5

Stress Drops (bars)

Mw

Kappa (sec)

Site ID
Evaluation of path bias terms (1)

- Generated two types of artificial dataset by using inverted stochastic GM model parameters and perform nonparametric inversion.

\[ D_k^{\text{inv}}(M, SD, \kappa_0) \]

**Type 1 path terms**

\[ D_k^{\text{inv}}(M_0, SD_0, \kappa_0) \]

**Type 2 path terms**

\[ \kappa_0 = (0.016, \ldots, 0.016) \]

Crustal amp.(f) \( = 0 \)

\[ \text{Mw} = (3.5, \ldots, 3.5) \]

SD(bars) \( = (50, \ldots, 50) \)
Evaluation of path bias terms (2)

- Calculated biases between estimated and exact path terms
  - \( B_k = D_k^{\text{inv}}(M, SD, \kappa_0) - D_k^{\text{inv}}(M_0, SD_0, \kappa_0) \) \( (B_k(\text{ref}) = 0) \)
  - \( D_k^{\text{inv}}(M_0, SD_0, \kappa_0) \) is considered to be exact path terms

- 6 frequency bands & 17 discrete distances to calculate \( D_1(fc) \)

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Frequency weighting function

\[
\begin{align*}
\text{Frequency weighting function} &
\end{align*}
\]
Calculation of path bias terms

\[ B_k = D_k^{\text{inv}}(M, SD, \kappa_0) - D_k^{\text{inv}}(M_0, SD_0, \kappa_0) \quad (B_k(\text{ref}) = 0) \]
$D_k^{\text{inv}}(M, SD, \kappa 0)$ terms

Comparison of bias-corrected path terms with exact path terms

Correction with $B_k$

Normalization

$\log(FS) + \log(R_{hyp}/21.54)$ (cm/sec)

Rhyp (km)

$D_k^{\text{inv}}(M, SD, \kappa 0)$ terms

Comparison of bias-corrected path terms with exact path terms

Correction with $B_k$

Normalization

$\log(FS) + \log(R_{hyp}/21.54)$ (cm/sec)

Rhyp (km)
An example of raw data of Fourier acceleration spectrum between 2.97-3.46Hz according to the moment magnitude ranges.

- Mw 2.2-2.5
- Mw 2.8-3.1
- Mw 3.4-3.7
- Mw 4.0-4.3
- Mw 4.6-4.9

Frequency (Hz): 2.97 - 3.46
Nonparametric inversion results

- Trilinear type of change is observed
- Avg. of Log standard deviation = 0.024 for fq3
Comparison of Q(f) function with nonparametrically inverted Q’s values for R>200km where R^{-0.5} attenuation is justified.

Parametrically inverted Q(f) function validated for Fq’s between 3-30Hz

\[
Q(f) = 168(1+(f/0.3)^{2.55})/(f/0.3)^2
\]
Comparison with two types of parametric results

"Par. path function" = Q(f) + G(R)

"Par. path residuals" = Obs. F.S. – Source (Mw, SD, R_{ref}) – Site (kappa)

Good agreement!!
For Fq > 3Hz and R > 100km
- **Par. path residual** better fits the nonparametric results.

- **Par. path function** is overestimated for short distance ranges less than 100km for fq1.

- Abrupt increase of nonparametric path terms and par. path residuals observed at greater than 200km.
  - Presence of more than two phases.

- Explains the misfit for the frequencies below 3Hz.
Steeper than $R^{-1}$ observed for short distances less than 50km

Less rapid attenuation for higher $Fq$’s than for lower $Fq$’s.

reverse of what *par. path function* predicts
Conclusion(1)

- The inverted path terms with the bias correction show three distinct linear regions roughly divided by hypocentral distances of 65km and 117km.

- The use of parametrically inverted Q functions was validated over the frequency band between 3-30Hz and distance range beyond 200km.

- Mixing of more than two wave phases was found in the low frequency band within the time window for spectral calculation beyond 200km in hypocentral distances.

- Parametrically estimated Q at 1Hz is overestimated because of fitting to the spectral data at the far distance range.
Conclusion(2)

- Steep attenuation comparable to $R^{-1.3}$ geometrical spreading is found at distances less than 50km.

- Unresolved phenomena is found that implies possible change of $Q$ according to distances and different geometrical spreading according to the frequencies at short distances less than 100km.

- Parametric and nonparametric method should be used in complementary way to reduce the uncertainty in simulating strong GM