Preliminary Results of
*Spectral Decomposition of Ground Motions in New Zealand using the Generalized Inversion Technique*

NSHM GIT Team

Chuanbin Zhu
University of Canterbury

QuakeCoRE: The Centre for Earthquake Resilience
DT1 Meeting
30 March 2023
Outline

- Data Selection/Processing
- Results for Crustal Events
Initial Data Selection

('chan' == 'HN') | ('chan' == 'BN') | ('chan' == 'HH') | ('chan' == 'EH')

'mag' >= 3.0

'tect_class' == 'Crustal' & ‘r_rup’ <= 300.0
| ‘tect_class’ == ‘Interface’ & ‘r_rup’ <= 500.0
| ‘tect_class’ == ‘Slab’ & ‘r_rup’ <= 500.0

‘focal depth’<=200

max(‘PGA_x’, ‘PGA_y’) <= 0.2g & max(‘PGA_x’, ‘PGA_y’) >= 0.0002g
Initial Data Selection

Minimum usable frequency:
\[ \max(f_{\text{min}_x}, f_{\text{min}_y}) \leq 1.0 \text{ Hz} \]

Quality score:
\[ \min('\text{score\_mean\_x}', '\text{score\_mean\_y}') \geq 0.5 \]

No multiple wave trains:
\[ \max('\text{multi\_mean\_x}', '\text{multi\_mean\_y}') \leq 0.1 \]

No clipped recordings:
\[ \text{clip\_clip\_prob} \leq 0.2 \]

SNR check on each waveform will be conducted in following steps.
Windowing

We used $D_{S20-80}$ and impose a minimum and maximum window length of 10 and 40 s, respectively. However, longer-window versions $D_{S05-95}$ and $D_{S03-97}$ are also prepared.

For LF stability, we only use frequencies:

$$f > \frac{n}{Ds}, \ n=3 \ (at \ least \ three \ circles)$$

A noise window with the same length as signal is cut out.

5% cosine taper to both ends and KO with $b=40$ to both signal and noise windows;

Spectral SNR ($\geq 3$)

Courtesy of Dino Bindi, GFZ
Final Selection

\[
EAS(f) = \sqrt[2]{\left[\frac{1}{2} FAS_{HC1}(f)^2 + FAS_{HC2}(f)^2\right]}
\]

**Usable frequency range:**
- **Lower-bound:** \(\max (f_{\text{min}_x}, f_{\text{min}_y}, \frac{3}{D_s})\)
- **Upper-bound:** \(\min (f_{\text{max}_x}, f_{\text{max}_y}, 0.9\cdot\text{Nyquist})\)

- **must be usable between 0.5-18 Hz**
- **no. of records per station & per event >= 3**
Crustal Events

No. of records: 20,813
No. of events: 1,200
No. of stations: 693
No. of unique stations: 439

Path coverage is the same for $f=0.5$-18 Hz
Outline

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Nonparametric Generalized Inversion Technique

We apply the nonparametric GIT to the above selected records in the Fourier domain.

For a surface recording during earthquake $i$ at site $j$, the Fourier amplitude spectrum (FAS) of its horizontal component, $H_{i,j}(f)$, can be represented by the convolution of the source $E_i(f)$, path $P_{i,j}(f)$, and site $S_j(f)$:

$$\ln H_{i,j}(f) = \ln E_i(f) + \ln P_{i,j}(f, R) + \ln S_j(f)$$

Tectonic class-
(and region)
dependent

If a seismic network which recorded many different events, the above system of linear equations can be solved as a general-inverse problem in the least-squares sense (e.g., Andrews, 1986; Castro et al., 1990).

However, we need to apply two additional constraints.
Nonparametric Generalized Inversion Technique

Reference distance:
\[ \log A(f, R_0) = 0 \text{ with } R_0 = 2 \text{ km}; \]

Reference site(s):
\[ \log \text{Amp}(f, \text{subset}) = 0, \ \text{subset} = [\text{HUNS}_\text{HN}, \text{RPZ}_\text{HN}, \text{MRZ}_\text{HN}]. \]
logAmp(f, global) = 0

$V_{S30}$: 680 m/s (Foster et al., 2019 & Perrin et al., 2015), 1000 m/s (NSHM, 2021), and 800 m/s (NSHM, 2021)
Reference Sites

Other studies:
- Van Houtte et al. (2012): STKS, HUNS
- Oth and Kaiser (2014): RPZ, MQZ
- Kaiser et al. (2016): RPZ, MQZ, D14C
- Ren et al. (2018): POTS, LTZ
Reference Sites

subset 1

subset 2

subset 3

subset 4

subset 5

subset 6
Site Responses

Reference sites:
- "HUNS_HN"
- "RPZ_HN"
- "MRZ_HN"
Path Attenuation & Source Spectra

\[ \log A(f, R_0) = 0 \text{ with } R_0 = 2 \text{ km}; \]

No. of events: 1200
Site Responses

Reference sites:
- "HUNS_HN"
- "RPZ_HN"
- "MRZ_HN"
Lee et al. (2022): Full site response $= F_s(V_{S30}) + dS2Ss$
Some mismatch is expected due to different reference site conditions;
Site term = site response + uncorrected instrumental response + building response + ... geological/geotechnical profile
Site-Response Map: National

For sites with multiple sensors, only one sensor is used (HN>BN>HH>EH);
439 point-based observations;
These inverted site responses can be used to generate maps for forward prediction;
AI is promising in interpolation;
Between-Site Variability in Site Response

- JP_1830 (Nakano et al., 2015)
- CA_630 (Bora et al., 2019)
- EU_821 (Kotha et al., 2021)
- NZ_616 (Zhu et al., 2023)

Standard deviation of FAS-based site responses across many sites in a given region;
Between-Site Variability in Site Response

Correlation between site response with average S-wave velocity $V_{sz}$, Japan

☑ HF site response is correlated with deeper structures;
Between-Site Variability in Site Response

- JP_1830 (Nakano et al., 2015)
- CA_630 (Bora et al., 2019)
- EU_821 (Kotha et al., 2021)
- NZ_616 (Zhu et al., 2023)

- Standard deviation of FAS-based site responses across many sites in a given region;
Randomness in site response at a given site over different events and is stable across regions;
- within-site is lower than between-site variability: site-specific (impedence, resonance and attenuation) before event-specific site effects (nonlinear, topo. and basin effects);

after Zhu et al., (2021, GJI)
Source Terms

Crustal

No. of crustal events.: 1200
Source Parameters

Brune source model (Brune, 1970 and 1971):

\[ E(f, M) = \frac{R_{\theta} VF}{4\pi \beta^3 R_0} \times \frac{M_0(2\pi f)^2}{1 + \left(\frac{f}{f_c}\right)^2} \]

For larger events (> 5.0), magnitude (or \(M_0\)) in spectral fitting (non-linear least squares) is anchored to \(M_w\) from GMDB.

Assuming a circular crack model, stress drop:

\[ \Delta \sigma = 8.5 M_0 \left(\frac{f_c}{\beta}\right)^3 \]
Source Parameters: Stress

- Same source model but different windowing, smoothing, reference site conditions;
- It is a global challenge to have consistent estimates of stress parameters across studies;
- Community Stress Drop Validation Study (Baltay et al., 2021, SSA)
Source Parameters: Stress

The mean and variability of stress parameter for crustal events are comparable to those for Japan: 0.8 MPa ±log_{10}0.34 (Nakano et al., 2015).
Source Parameters: Stress

- Stress drop increases with $M_0$ for large events;
- Stress drop increases with focal depth;
Source Parameters: Stress

Lee et al. (2022)
Source Parameters: Stress

Spatial distribution of stress drop

Lee et al. (2022)
Source Parameters: $M_0$-$f_c$ Scalling

- The slope between $M_0$ and $f_c$ is -0.324, indicating only a slight departure from self-similarity (-0.333).
Source Parameters: $M_0-f_c$ Scalling

Japan (Nakano & Kawase, 2019)

Central Italy (Bindi et al., 2020)
Next Step: Path Attenuation

Geometrical spreading:

\[ G(R) = R^{-\gamma} \]

\[ D(f, R) = \exp \left[ \frac{-\pi f R}{Q(f) V_Q} \right] = \exp \left[ \sum_{i=1}^{L} \frac{-\pi f r_i}{Q_i V_{Q,i}} \right] \]
Thanks for your attention!