



Strong Motion Prediction By Composite Source Model

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Abstract

A composite source model, incorporating different sized subevents, provides a possible description of complex rupture processes during earthquakes. The number of subevents with characteristic dimension greater than R is proportional to R^2 . The subevents do not overlap with each other, and the sum of their areas equals to the area of the target event (e.g. mainshock). The subevents are distributed randomly over the fault. Each subevent is modeled either as a finite or point source, differences between these choices are shown. The final slip and duration of each subevent is related to its characteristic dimension, using constant stress-drop scaling. Absolute value of subevents' stress drop is free parameter. The synthetic Green's functions are calculated by the discrete-wavenumber method in a 1D horizontally layered crustal model. An estimation of subevents' stress drop is based on fitting empirical attenuation relations for PGA and PGV, as they represent robust information on strong ground motion caused by earthquakes, including both path and source effect. We use the 2000 M6.6 Western Tottori and the 1997 M6.1 Kagoshima Japan, earthquakes as validation events, providing comparison between predicted and observed data.

Determination of stress drop

- We want to find the constant of proportionality α between subevent's size and duration (inversely prop. to corner freq.). Having L and W the length and width of subevent and R the equivalent radius:

$$R = \sqrt{\frac{LW}{\pi}} \quad f_c = \frac{v}{R}$$

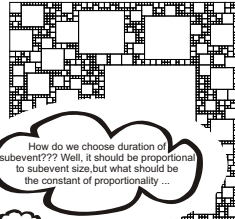
- Value of α is related to stress release. For Brune model with effective radius R_e

$$\Delta\sigma = \left(\frac{f_c}{0.49}\right)^3 M_0 \quad R_e = 0.37 \frac{\beta}{f_c}$$

- R_e is equivalent radius R for Brune model
- Assuming v equal to **0.6-0.9** Brune model gives α from **0.41 to 0.62**, our aim is to compare these values with values obtained from data.
- We show procedure of α estimation (i.e., Stress drop estimation) in the case of 1999 Athens $M_w=5.9$ earthquake.
- Optimal value of parameter α is found by fitting PGV and PGA empirical attenuation relations, taken from Margaritis *et al.* (2002).
- Calculation is performed for two crustal models. Model **A** was taken from Novotný *et al.* (2001) and model **B** was built up by adding low velocity layers (Boore and Joyner, 1997) to represent NEHRP soil class B

Composite source model

The strong motion synthesis is performed according to Burjánek (2002) with following features:



How do we choose duration of subevent??? Well, it should be proportional to subevent size, but what should be the constant of proportionality ...

- Composite model with Fractal Subevent Size Distribution - number of subevents with characteristic dimension greater than R is proportional to R^2
- Both amplitude and duration of slip are proportional to R
- Subevents are distributed randomly over the entire fault
- Subevents are triggered as the rupture front propagating over entire fault, with constant velocity, reaches prescribed point of subevent

How should we model time histories of subevents? Should we use point-source approx. or some simple finite-source model?

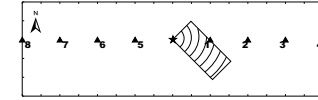
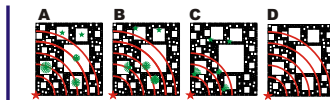
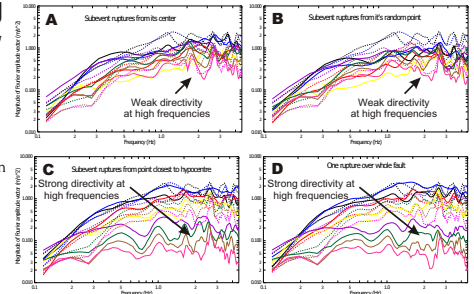
Strong motion prediction

- Input parameters: moment magnitude, focal mechanism, hypocentral depth would be also helpful, but not necessary (set of various depths can be checked), crustal model (i.e., set of 1D layered models)
- Other source parameters are obtained from empirical relations (e.g., Somerville *et al.*, 1999).
- Calculation is calibrated by using empirical attenuation relations.
- Set of calculations is performed for different spatial distributions of subevents (which implicitly includes scenarios of different asperity position).
- As an output we get set of time histories for each site, which can serve for further analysis of predicted strong ground motion (e.g., peak values, response spectra, duration ...)

Subevent modelling

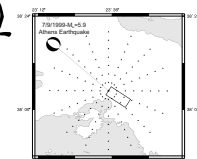
We model time-histories of subevents kinematically either as a finite-source or in point-source approximation:

- point-source:
 - source time function is Brune's pulse
- finite-source:
 - kinematic dislocation model
 - homogeneous slip proportional to dimension of subevent
 - box-car slip velocity function with rise-time proportional to dimension of subevent
 - radial rupture propagation with constant rupture velocity
 - we study four alternative choices of such triggering points:



- Cases **A** and **B** produce very similar results - strong directivity effect even at high frequencies connected - very different from point-source approximation
- Cases **C** and **D** produce very similar results even similar with point-source approximation - weak directivity at high frequencies.
- We prefer point-source approximation, because existing observations do not indicate strong directivity at high frequencies.
- There is another alternative: The source directivity is strong but it is not observed since the source effect is masked by propagation effects (e.g., scattering effects, site effects). But as we don't account for these effects in our strong motion simulation, it is reasonable to use a model of weak directivity by using point-source approximation (or **A,B**).

Source-receiver geometry



Crustal model A

$\rho(km/s)$	$v_p(km/s)$	$v_s(km/s)$	$\nu(km/s^2)$	Q_p	Q_s
0.0	2.67	1.58	2.50	300	300
1.0	4.45	2.50	2.50	300	300
2.0	5.70	3.20	2.50	300	300
5.0	6.00	3.37	2.50	300	300
10.0	6.30	3.60	2.50	300	300
30.0	7.00	4.11	3.28	1000	1000

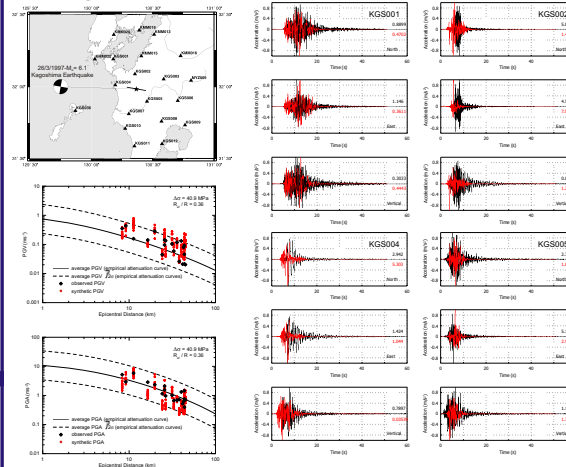
Crustal model B

$\rho(km/s)$	$v_p(km/s)$	$v_s(km/s)$	$\nu(km/s^2)$	Q_p	Q_s
0.00	0.02	0.05	2.50	8	5
0.01	1.09	0.62	2.50	27	13
0.02	1.32	0.76	2.50	20	15
0.05	1.47	0.85	2.50	29	17
0.01	1.66	0.96	2.50	33	19
0.05	1.81	1.05	2.50	36	21
0.05	1.05	1.13	2.50	30	25
0.07	2.08	1.20	2.50	42	24
0.08	2.19	1.27	2.50	44	25
0.09	2.29	1.33	2.50	46	27
0.12	2.50	1.49	2.50	52	30
1.00	4.45	2.50	2.50	300	300
2.00	5.70	3.20	2.50	300	300
5.00	6.00	3.37	2.50	300	300
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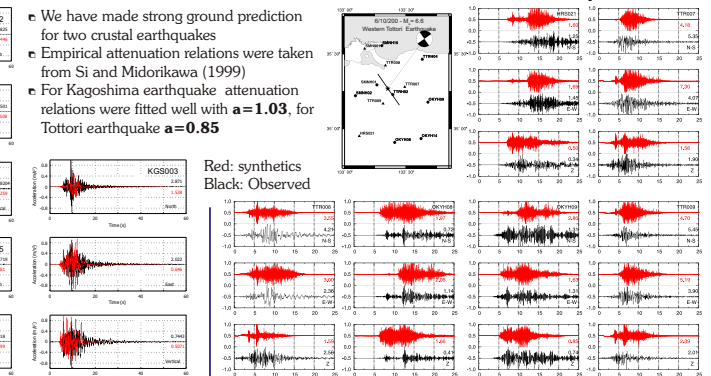
Source parameters

strike	123°
dip	55°
rake	-84°
M_0	$7.8 \cdot 10^{17} Nm$
L	1100 m
W	8000 m
v_r	$2800 m/s$

1997 Kagoshima Earthquake



2000 Western Tottori Earthquake



- We have made strong ground prediction for two crustal earthquakes
- Empirical attenuation relations were taken from Si and Midorikawa (1999)
- For Kagoshima earthquake attenuation relations were fitted well with $\alpha=1.03$, for Tottori earthquake $\alpha=0.85$

Red: synthetics
Black: Observed

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Conclusions

- Parametrization of presented composite source model is done using single parameter α .
- This parameter was retrieved for three earthquakes ($\alpha=0.71-0.95$, $\alpha=1.03(?)$, $\alpha=0.85$) - significantly differs from Brune's one!
- Key parameter of strong motion prediction - position of asperity with respect to hypocenter - is implicitly included in fractal realizations.
- Presented composite model is very effective tool for predicting strong ground motion, convenient for e.g., real-time generation of shaking maps.

