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 dimensions greater than R is proportional to R². 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 wave-number method in a 3D horizontally layered crustal model. An estimation of subevents’ stress drop is based on fitting empirical attenuation relations for PGA and PVD, as they represent robust information on strong ground motion caused by earthquakes, including both path and source effects. 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.

Composite source model
The strong motion synthesis is performed according to Burjánek (2002) with following features:
- Composite model with Fractal Subevent Size Distribution - number of subevents with characteristic dimensions greater than R is proportional to R²
- 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 propagates over entire fault, with constant velocity, reaches prescribed point of subevent

Determination of stress drop
- We want to find the constant of proportionality between subevent size and duration (inversely proportional to corner freq.). Having L and W the length and width of subevent and R the equivalent radius:
  \[ A = \frac{R}{\sqrt{LW}} \]
- Value of A is related to stress release. For Brune model with effective radius R:
  \[ A = \left(\frac{R}{\sqrt{LW}}\right) = \frac{a}{LW} \]
- R is equivalent radius R for Brune model
- Assuming \( a = 0.6-0.9 \) Brune model gives A from 0.41 to 0.62, our aim is to compare these values with values obtained from data.
- We show procedure of A estimation (i.e., Stress drop estimation) in the case of 1999 Athens \( M_w = 5.9 \) earthquake.
- Optimal value of parameter A is found by fitting PGA and PVD empirical attenuation relations, taken from Mercier et al. (2002).
- Calculation is performed for two crustal models. Model A was taken from Nortey et al. (2001) and model B was built up by adding low velocity layers (Brune and Joyner, 1997) to represent NEHRP soil class B

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., 1995)
- 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 positions)
- A set of output consists of 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…)

We have found optimal values of A between 0.71-0.95, corresponding to stress drops of 12-20MPa, and thus equivalent radius \( R = 2 \) times larger than the Brune’s effective source radius. Brune model gives stress drop of 3.2MPa only. Such inconsistency indicates heterogeneous stress drop distribution

References

Conclusions
- 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 \( a = 1.03 \), for Tottori earthquake \( a = 0.85 \)
- We have found strong ground prediction for two crustal earthquakes
- Key parameter of strong motion prediction - position of asperity with respect to hypocenter is implicitly included in fractal realizations.
- Present composite model is very effective tool for predicting strong ground motion, convenient for e.g., real-time generation of shaking maps.

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Key parameters of strong motion prediction
- Parameterization of presented composite source model is done using single parameter \( a \)
- This parameter was retrieved for these earthquakes \( a = 0.71-0.95, a = 1.03 (7) \)
- Key parameter of strong motion prediction - position of asperity with respect to hypocenter is implicitly included in fractal realizations.
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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 dilatational model
- homogeneous slip proportional to dimension of subevent
- basin 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:

1997 Kagoshima Earthquake
- 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 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).