Incorporation of Site-Specific Attenuation Model using Kappa in Broadband Simulations

Swasti Saxena¹, John Anderson², Ramin Motamed³

¹ Graduate Student, ² Professor, ³ Assistant Professor
Presentation Outline

- Introduction
- Site Description
- Data used in study
- Calculation of kappa
- Developing Q-profiles
- Validations of Q-profiles via BB Simulations
- Improved Broadband Simulations
- Conclusion
Introduction

Goal: Source to site calculations using wave propagation to high frequencies. Incorporate site response & Q in the Green’s functions. Match surface and downhole seismograms over complete frequency range of interest.

\[ \kappa_0 = \sum \frac{h_i}{Q_i c_i} \]

\[ \tilde{\kappa}(x) = \frac{x}{Q c} \]

\[ \kappa = \kappa_0 + \tilde{\kappa}(x) \]

Seismic basement  
\( V_s > 3000 \text{ m/s} \)  
\( V_p > 6000 \text{ m/s} \)

Conceptual model for the relationship between Q and \( \kappa \).
Location: Imperial Valley, southernmost end of San Andreas Fault system

- 6 stations, at depths of 0m, 2.5m, 5.5m, 7.7m, 30m and 100m respectively

- 22 recorded events considered: $M >= 4.0$ since year 2000

Model earthquake:
- $M_w = 4.1$
- 13 km WNW of Calipatria, California, on May 21, 2015

Representation of Depths (vertical) and Station-IDs (horizontal) of accelerometers at WLA, adopted from NEES@UCSB website
Histograms representing frequency versus Magnitude, Depth and Distance of WLA from epicenter for the 22 earthquakes considered in the study.
Calculation of kappa

- Identification of separate first P- and S-wave cosine windows
- Semi-logarithmic plot of Fourier spectrum of each
- Fitting a linear regression between 10-25 Hz for each

Fourier amplitude spectrum of acceleration and subsequent kappa calculation for vertical component recorded at WLA at the downhole on 31 August, 2005
Calculation of Q in the waveguide

Plots of kappa versus epicentral distance for 22 earthquakes for P-waves (left) and S-waves (right)
The slope of the previous semi-log plot can be used to calculate Q for P- and S-waves, using their respective speeds in equation below-

$$\frac{dk}{dx} = \frac{1}{Qc}$$

Final simplified velocity and Q profiles at 0-200m depth (left), and 0-40km depth (right)
Final Q-profiles

- Minimum value of $Q=50$ maintained to prevent introduction of noise in simulations
- $Q_S > Q_P$ in shallow crustal layers, up to 500 m
- $Q_S = Q_P$ for depth $>500$ m and depth $<3$ km
- $Q_P > Q_S$ for deeper sediments

- Frequency independent Q-profiles, here, represent anelastic attenuation only, not scattering
Validation of Q profiles via BB Simulations

- Compared Q values determined from 22 recordings with those recorded from 12 simulations
- Qp profile could not be validated. Reason: Large surface amplification
- Qs profile is more than 85% match

kappa versus epicentral distance plots for $\kappa_p$ (left) and $\kappa_s$ (right), derived from Broadband simulations at 12 stations for the model $M_w=4.1$ earthquake
Broadband Simulations Using Composite Source Model

Fourier amplitudes of acceleration for horizontal components (a), (b) and vertical component (c). Red line represents the recorded data, grey represents synthetics and the bold black line is the average of synthetics.
Conclusions

- Downhole calculations encountered unexpected numerical noise, so this approach to estimate Q in the shallow layers was not successful.
- The exercise was successful in predicting a Qp and Qs in the waveguide, so calculations reproduce observed distance-dependence of kappa.
- In a separate modeling exercise using data from Japan by J. Anderson, synthetics at the surface are also significantly improved at frequencies up to 20 Hz by combining site-specific profile with an appropriate single flat-layered velocity model.
Acknowledgements

- This study was partially funded by Southern California Earthquake Center under award # 16165

- Dr. J. Steidl of UCSB for help with Wildlife Liquefaction Array