Using Spatial Variation of kappa to Develop Site-Specific Attenuation Model for Improved Broadband Simulations

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ABSTRACT

This study aims to improve upon Broadband simulations to account for site-specific surface response to an earthquake. For this purpose, we have developed velocity and attenuation profiles for Wildlife Liquefaction Array (WLA) in Southern California using kappa (Anderson et al., 1984), which are later incorporated into source-to-site Broadband simulations. The WLA site is carefully chosen for the significant number of ground motions recorded there at different depths (Fig.1). We have selected 22 earthquakes ranging from moderate (M_w=4.0) to strong (M_w=6.6) ground motions recorded at WLA, post year 2000.

The research was divided into 3 phases to determine vertical and longitudinal velocity and attenuation profiles:

Task 1: Calculating kappa for all considered ground motions

Task 2: Development of velocity and Q profiles in the upper 100m

Task 3: Development of velocity and Q profiles in the waveguide

Finally, we incorporated these profiles in Broadband simulations based on Composite Source Model (Anderson, 2015) because this method retains full wave propagation solutions at high frequencies, which will be used to calculate the attenuation profiles again for validation of this research.

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TASK 1: CALCULATION OF KAPPA

Studies have shown that the rapid decay of a Fourier spectrum of an accelerogram at high frequencies is characteristic of the ground attenuation, or Q-value profile at the site. Assuming a Brune source model (1970), an attenuation parameter, kappa (Anderson et. al., 1984), is identified beyond a corner frequency, f_{max} (Hanks, 1982). When seismic phases are modeled as rays, the attenuation time (Cormier, 1982) becomes equal to kappa (κ) under the assumption of a frequency independent quality factor, Q. Anderson (et. al. 1984) noted that the exponential decay observed on a log-log plot of acceleration spectrum, transforms into a straight line on a semi-log plot of the same. Based on this trend, the first order shape of acceleration spectrum can be described by the equation,

$$A = A_0 e^{-\pi\kappa f} \qquad \text{(i)}$$

where, κ is the attenuation parameter, kappa = $\frac{x}{Qc}$, f is the spectral frequency, x=distance travelled by the ray, Q is the quality factor, and c is speed of the seismic wave. Equation (i) follows that the spatial variation of kappa can be given as:

$$\frac{d\kappa}{dx} = \frac{1}{Qc} \qquad \text{(ii)}$$

We identify the first arrivals of P- and S-waves separately using cosine windows for all events recorded at every depth considered in the study, and fit a linear regression between 10-25Hz on the corresponding acceleration spectrum (Fig.2). While the data recorded at WLA is good up to 80Hz, we limit ourselves to 25Hz because that is the Nyquist frequency of our synthetic simulations, so that we can make apple-to-apple comparison of kappa with the synthetics. The acceleration spectrums are smoothed and the effect of smoothing and uncertainties not dealt with in the current scope of study.

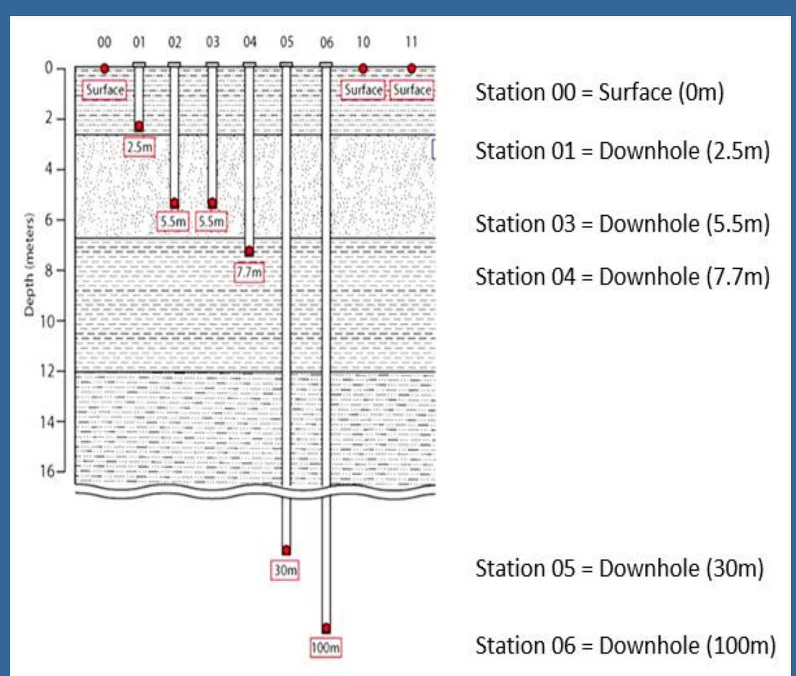

Figure 1. Representation of Depths (vertical) and Station-IDs (horizontal) of accelerometers at WLA, adopted from NEES@UCSB website

TASK 2: DEVELOPMENT OF PROFILES IN THE UPPER 100m

Ground motions recorded at the geotechnical array at surface and five more depths give us an opportunity to carefully study spatial variations of kappa, vertically. For the upper 100m, we stack the response of a flat layered velocity model to an SH-wave (in short, shstack) vertically incident at each of the downhole depths, separately. We then calculate surface-to-downhole spectral ratios, and compare them with the respective spectral ratios calculated from recorded data. We start from the shallowest downhole and proceed to the deeper ones, matching the peak response and respective frequencies on the way (Fig.3). The frequency of maximum amplitude of the ratio depends on the velocity profile, and the amplitude on the Q-profile, in the upper 100m. The Q-profile developed here is compared with the target Q-profile obtained from the exponential decay of spectral ratios of recorded data (Fig.4), using equations (i) and (ii).

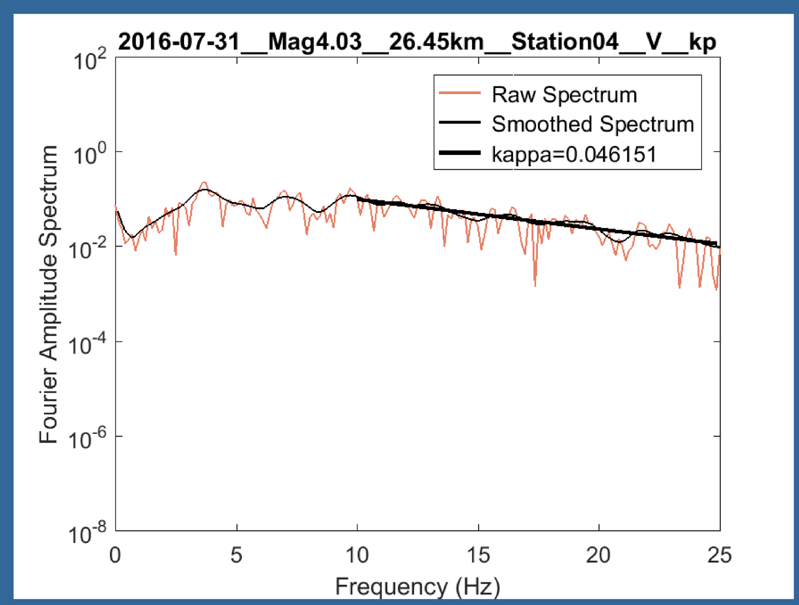

Figure 2. Calculation of kappa from an acceleration spectrum

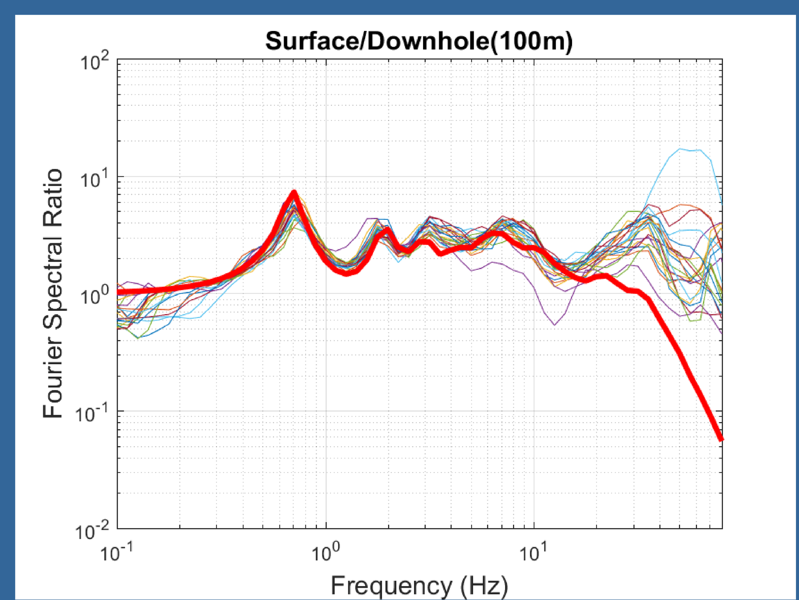

Figure 3. Comparing spectral ratios obtained from shstack (thick red) with those obtained from recorded data, at 100m depth (similar plots are developed for other 4 downhole depths also)

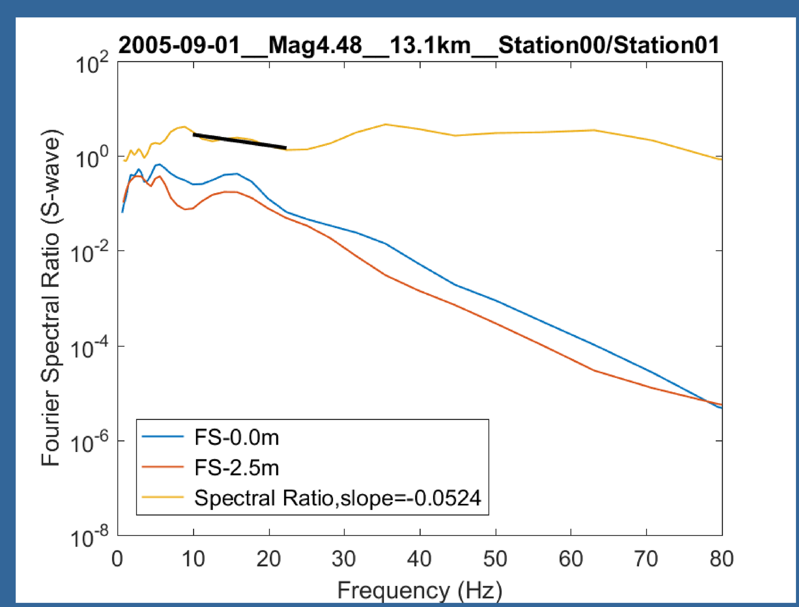

Figure 4. Calculation of kappa from spectral ratios

TASK 3: DEVELOPMENT OF PROFILES IN THE WAVEGUIDE

For velocities in the waveguide, we refer to various in-depth studies undertaken in the past for Imperial Valley basin and the depth of Mohorovicic Discontinuity (Moho), which suggest that the basin observes a very shallow depth of Moho, at about 22km. This changes the wave propagation and the effect of reflections at the Moho as compared to the generic models for Imperial Valley used in preliminary studies.

In order to develop a Q-profile in the waveguide, we plot kappa values calculated from each station recording of the 22 earthquakes used in the study, against respective epicentral distances (Fig.5). Using equation (ii), we calculate Q-values in the waveguide. The final profiles that are used in simulations are shown in Fig.6. Very low Q-values were obtained in upper 100m, but the simulations cannot handle Q<50 without creating multiple reflections, hence minimum 50 value is used for Q.

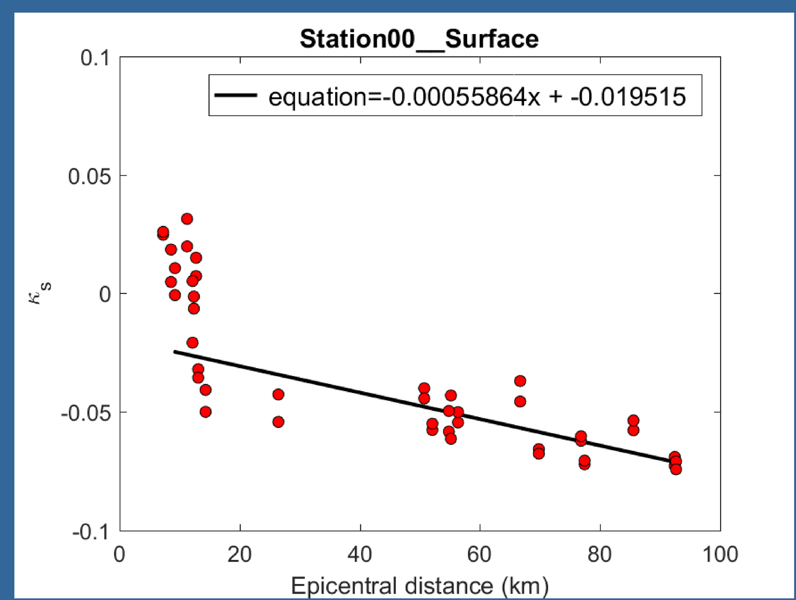

Figure 5. kappa versus epicentral distance plot κ_s derived from recorded events (similar plot is developed for κ_p also)

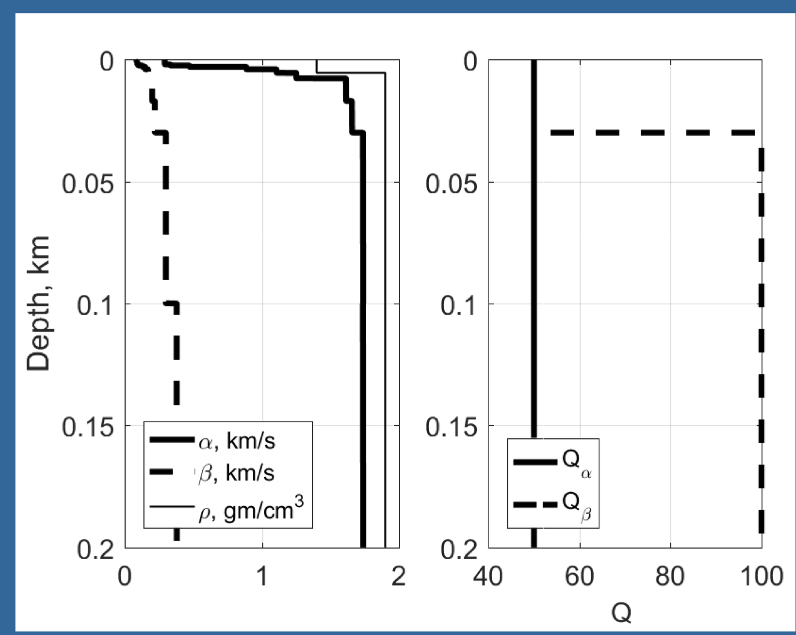

Figure 6. Final velocity and Q-profiles in the upper 200m

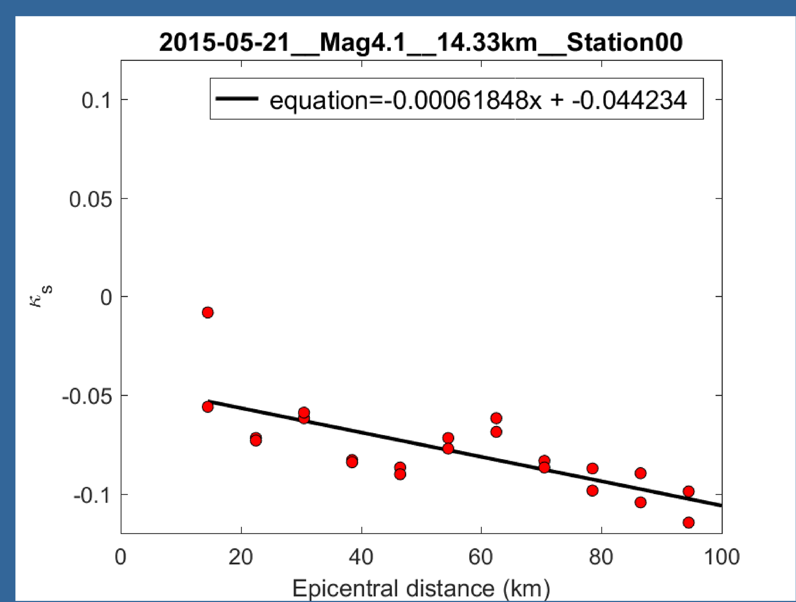

Figure 7. kappa versus epicentral distance plot κ_s derived from 12 station simulations

BROADBAND SIMULATIONS

Incorporating the latest velocity and Q-profiles, we execute a simulation of the seismic event of Mw=4.1, 13km WNW of Calipatria, CA, recorded at WLA on May 21, 2015, and compare the latest simulations with preliminary simulations, based on CSM approach, and the recorded data (Fig.8). We also use the same event to generate synthetics at 12 equidistant stations to develop kappa versus distance plots (Fig.7), and compare the value of kappa calculated with that obtained from the recorded earthquakes.

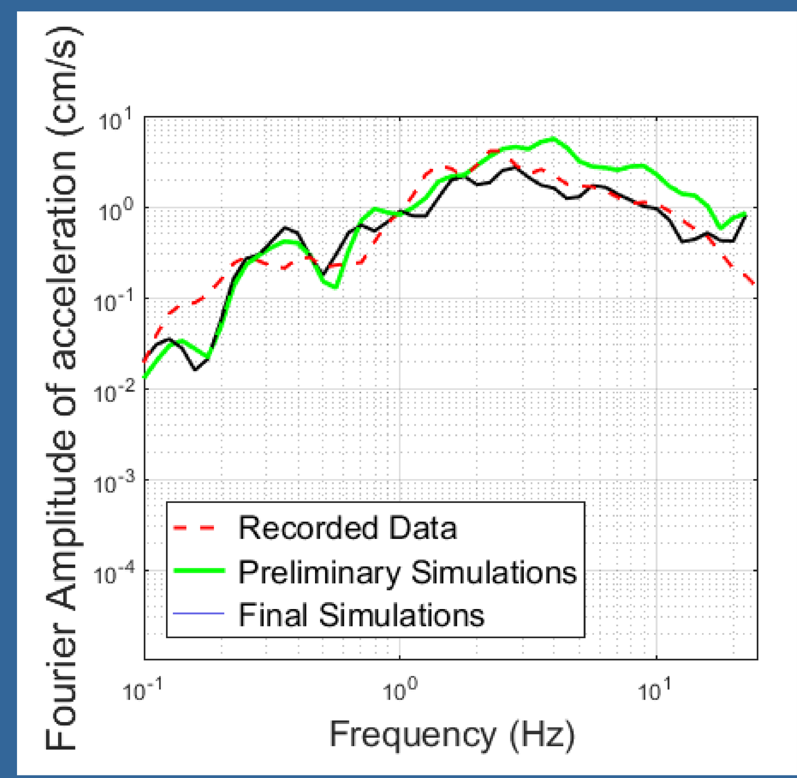

Figure 8. Comparison of Fourier amplitude spectrums for final and preliminary simulations' with that of recorded earthquake event (N-S component)

CONCLUSIONS

1. Spatial variation of kappa is a great tool to develop site-specific attenuation profiles.
2. Spectral ratios can be used to develop velocity profiles using simple stack of response of a flat layered velocity model to vertically incident SH-waves, which may need a little adjustment for non-vertical wave propagation in simulations.
3. Final simulations render distinctly different from preliminary simulations, highlighting the success of incorporation of local site effects using Composite Source Model approach.
4. The kappa values calculated from simulations are within 85% margin of those calculated from recordings, in the waveguide.
5. kappa values could not be verified in the upper 100m as the surface amplification effects tend to dominate the effect of exponential decay due to attenuation.

REFERENCES

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