2016 SCEC PROJECT REPORT

HIGH-FREQUENCY PATH AND SOURCE PARAMETERS
DETERMINED FROM RECORDED GROUND MOTION IN CENTRAL CALIFORNIA

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Abstract
The main objective of this work was to determine Q for coda and direct S-waves, as well as κ in the coastal region between Paso Roble and San Luis Obispo. For this we determined the smoothed Fourier spectra for each ground motion recording, and used a non-parametric to invert for both path and source parameters. From the inverted source spectra, we determined κ, which in average was ~ 35 ms. We also determined coda Q values, where intrinsic Q_i is ~315, 720, 890 and 1100 at 1-2, 2-4, 4-8, and 8-16 Hz frequency bands. Scattering Q_s is ~ 1000.

Intellectual Merit
We have determined important seismic parameters which are useful to quantify seismic hazard in the Central California Coastal region. To our knowledge, there have been no prior attempts to calculate regional κ values in this region, which are important to simulate ground motion and to estimate response spectra for engineering purposes. Also, during the term of the project, we developed a new method to estimate smooth Fourier amplitude spectra using a continuous wavelet transform.

Broader Impacts
During this project, we where able to determine important seismic parameters such as Q and regional κ values, which will be useful for the Central California Coastal region in terms of hazard determination.
An outcome of the project was a Python code to determine Q and κ values, that in the future will be used to teach students on how to determine these important parameters. We plan to make this code freely available at a computer code repository.

Problem Setup
First, we computed the Morlet continuous wavelet transform (CWT) for each horizontal acceleration recording. We then proceeded to integrate the CWT along the time domain between the onset of the S-wave and the end of this phase. This was done to estimate the Fourier amplitude spectrum of acceleration. The advantage of first computing the Morlet CWT and integrating along the time domain is to naturally smooth the Fourier spectrum between frequencies. This method does not need to window the S-wave with a taper function, which is another advantage. In Figure (2) the recorded ground motion produced by a 2010 M_w4.0 earthquake in Parkfield, and it's smoothed horizontal average spectrum is shown in Figure (3).

Once the spectra are estimated, we compute the geometrical average of the two horizontal spectra. We use the non-parametric method of Castro et al. (1990) and Oth *et al*. (2008) to invert for both path and source parameters at each frequency. We perform this by solving the linear problem:

$$\log\left(U_{ij}(f, r_{ij})\right) = \log\left(A_i(f, r_{ij})\right) + \log\left(\hat{S}_j(f)\right)$$

where U_{ij} are the recordings at an i^{th} distance and produced by source j. A_i are the path variables and $\hat{S}_j$ are the source variables with site condition included. We end up with more than 80 linear equations, 32 path variables and 23 source variables for each frequency. This system of equations is solved using SVD.

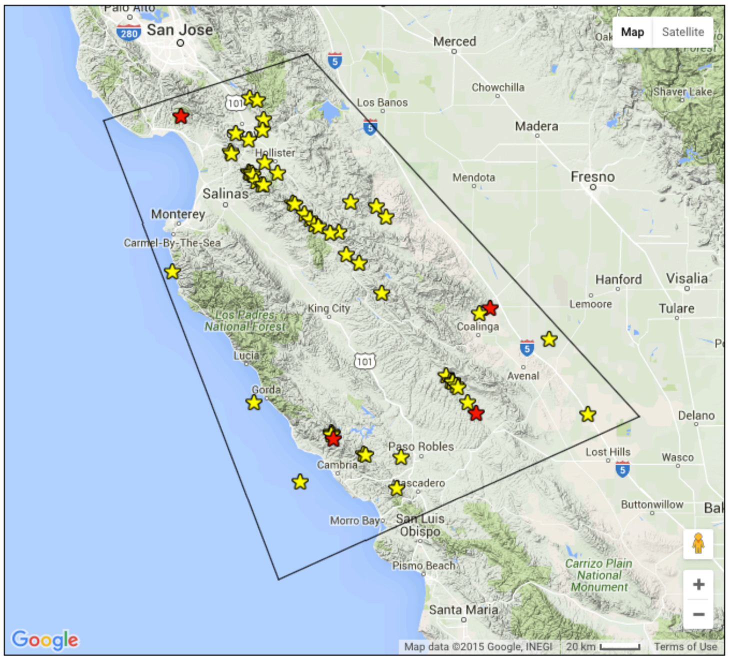

Figure 1: Map view of the earthquakes we used to constrain the source and path models with a non-parametric approach.

Main Results

In Figure (4) we show seismic attenuation for different log-spaced frequency bins. The distance bins reach up to 160 km in epicentral distance, and each bin is 5 km in size. Our preliminary results show that at ~100-120 km of distance, there is a sharp attenuation increase. This might be due to the Moho post-critical reflections. In Figure (5) we show four different inverted earthquake source functions. Because our analysis did not include the parameterization of κ (Anderson, 1985), this effect is included in the source, making the spectrum diminish considerably after ~6Hz. We have estimated the parameter κ from each earthquake source with the method of Oth *et al*. (2011). This analysis yields a mean value of κ ~35 ms, a value consistent with other studies of κ in California (Kilb *et al*., 2012; Zandieh et al., 2016).

We have also determined coda Q values (scattering and intrinsic Q) with the proposed method of Frankel and Wennerberg (1987), which consists in fitting the in two steps the scattering and intrinsic Q model to the energy flux envelope of recorded data. This is at different frequency bands, which we chose to be between 1-2, 2-4, 4-8, and 8-16 Hz. In these bands we filtered with an acausal

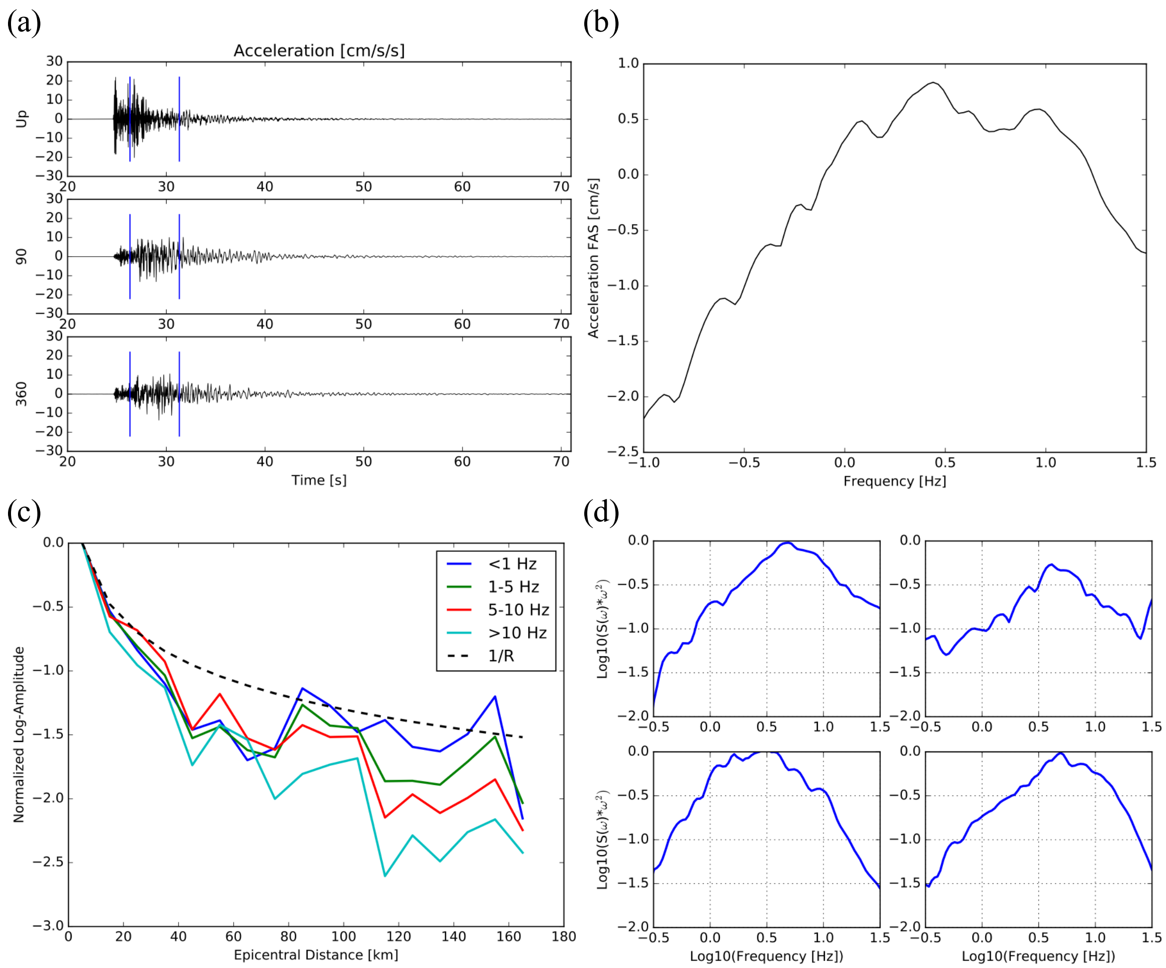

Figure (2): (a) Ground motion produced by a M_w earthquake. The blue lines are the time window in which the continuous wavelet transform integrated along the time domain to produce a smoothed spectrum of the S-wave, (b) smoothed Spectrum of the S-wave, (c) the total attenuation (geometric, anelastic and scattering) with distance at different frequency ranges. We also show a theoretical 1/R attenuation depicted as a dashed black line, and (d) source spectra for four earthquakes of the total earthquakes we analyzed.

2 pole Butterworth filter. We then computed the envelope and computed the energy flux at the different frequency bands. In Figure 6 we show the filtered velocity data of a M_w3.9 earthquake, recorded at ~12 km of distance away from the fault. In Figure (7) we show the fits of energy flux envelope to the data.

In average, the intrinsic Q_i for the region is ~315, 720, 890 and 1100 for the 1-2, 2-4, 4-8, and 8-16 Hz frequency bands respectively. The Scattering Q_s is quite insensitive to the data and was found to be ~1000.

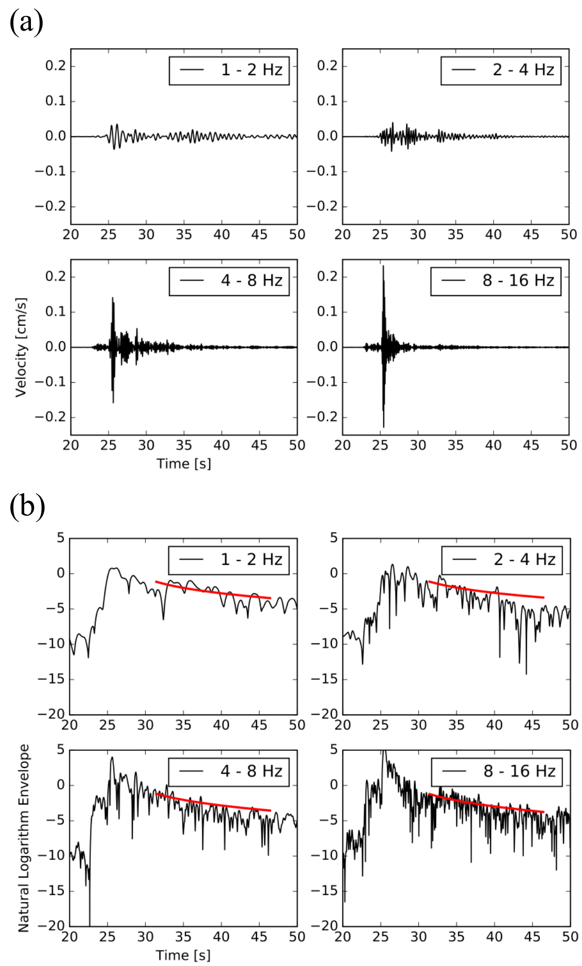

Figure (3): (a) Filtered ground motion velocity of a M_w3.9 earthquake recorded at ~12 km, and (b) Fits (in red) of the energy flux envelopes to the recorded ground motion of a M_w3.9 earthquake recorded at ~12

Conclusions

We have used ground motion data recorded in the Central Coastal California region to determine κ and Q estimates for direct coda and S-waves. We find values of ~ 35 ms for κ in this region. The parameters we have estimated will be useful to simulate ground motion in this region.

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