2014 SCEC Annual Report
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Evaluation of Attenuation Models (*Q-Vs* Relationships) used in Physics-Based Ground-Motion Earthquake Simulation through Validation with Data

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1 Project Summary

Durign the course of this project we performed a series of deterministic earthquake ground-motion simulations to assess the influence that different attenuation models have on the quality of the synthetics when these are compared with recorded data. The main objective of the project was to characterize the level of sensitivity of the ground motion to the attenuation relationships. Here, by attenuation relationships we refer to the relationships used to define the quality factor Q_S as a function of the shear wave velocity V_S. To accomplish this we proposed a new and simple Q_S-V_S relationship that is defined in terms of only 3 parameters. This new Q_S-V_S function is sufficiently flexible to allow one to duplicate almost all other relationships used in previous simulations and thus allowed us to conduct a systematic study on the influence of its parameters on the simulation validation results. Our initial results for the case of simulations up to 1 Hz for the 2008 Chino Hills earthquake indicate that it is possible to significantly improve validation goodness-of-fit results with a more appropriate selection of the Q_S-V_S relationship. Further analysis of our results will allow us to propose adequate parameter for other simulations.

2 Background and Description of Work

Physics-based earthquake simulations are a key element to SCEC's mission and its primary science goal of developing a comprehensive understanding of earthquake phenomena through the integration of a multidisciplinary study of the ground motion and the seismic hazard in Southern California. In physic-based earthquake ground-motion simulation, the attenuation of seismic waves is typically treated by means of viscoelastic models (Graves and Day, 2003; **?**). Internally, the properties of a given attenuation model are set based on the material's quality factor Q, and the most common approach is to define the quality factors associated with P- and S-waves, Q_P and Q_S, based on the values of the seismic velocities V_P and V_S obtained from any particular velocity model. The value of Q_S, for instance, is usually defined based on rules that depend on the value of V_S, and the value of Q_P is commonly defined based on Q_S (e.g., Brocher, 2005; Taborda and Bielak, 2013). Table 1 shows a collection of different Q_S-V_S and Q_P-Q_S relationships used in simulations and other related studies.

As it can be seen from Table 1, currently there is no consensus on the most appropriate set of relationships. Here we proposed a new and simple relationship that is defined in terms of only 3 (constant) parameters, c, α, and β:

$$Q_S = c + \alpha V_S^{\beta} \quad . \tag{1}$$

This new Q_S-V_S function is sufficiently flexible to allow one to duplicate almost all other relationships shown in Table 1 used in previous simulations and thus allowed us to conduct a systematic study on the influence of its parameters on the validation of simulations.

3 Results and Future Work

We conducted a series of simulations for different combinations of the parameters c, α, and β in Equation 1. In all cases we considered

Table 1: Examples of Q_S-V_S and Q_P-Q_S relationships used in past physics-base simulations. Most of these correspond to the region of southern California and to past earthquakes, unless noted differently. FD and FE superscripts indicate when a publication is cited specifically in reference to results published therein using a particular method.

Publication	**Simulation**	$V_{S_{min}}$ **(m/s)**	f_{max} **(Hz)**	$Q_S = g(V_S)$ **(V_S in km/s, z in km)**		$Q_P = h(Q_S)$
Olsen et al. (2003)	1994 Northridge	500	0.5	$20V_S$	$V_S < 1.5$	$1.5Q_S$
				$100V_S$	$V_S \geq 1.5$	
Bielak et al. (2010)[FD]	ShakeOut*	500	0.5	$50V_S$		$2Q_S$
Cui et al. (2010)	M8*	400	2.0			
Graves et al. (2011)	CyberShake*	500	0.5			
Komatitsch et al. (2004)	2001 Hollywood	670	0.5	90	Sediments	∞
	2002 Yorba Linda			∞	Bedrock	
Taborda et al. (2007)[§]	ShakeOut*	200	1.0	$50V_S$		
Bielak et al. (2010)[FE,§]	ShakeOut*	500	0.5			
Graves (2008)	2001 Big Bear	250	1.0	$60V_S$		$2Q_S$
Aagaard et al. (2008)[FD]	1989 Loma Prieta	330–760	0.5–1.0	$50V_S$	$V_S < 0.9$	
				$60{V_S}^{1.5}$	$0.9 \leq V_S < 3.4$	
				500	$V_S \geq 3.4$	
Brocher (2008)[¶]	–	–	–	13	$V_S < 0.3$	
				$-16 + 104.13V_S$ $-25.225{V_S}^2$ $+8.2184{V_S}^3$	$0.3 \leq V_S < 5$	
Chaljub et al. (2010)[†]	2003 Lancey, and Event S1*	300	2.0	50	$z < 1$	$3/4(V_P/V_S)^2 Q_S$
				∞	$z \geq 1$	∞
Taborda and Bielak (2013)	2008 Chino Hills	200	4.0	$10.5 - 1.6V_S + 153V_S^2 - 103V_S^3$ $+34.7V_S^4 - 5.29V_S^5 + 0.31V_S^6$		$3/4(V_P/V_S)^2 Q_S$

Notes:
- * Denotes scenario events
- § Rayleigh damping instead of a visco-elastic model
- ¶ Empirical relations (no simulation) for Northern California
- † Simulations for Grenoble Valley, France
- FE Finite-element simulation therein
- FD Finite-element simulation therein

$$Q_P = 3/4(V_P/V_S)^2 Q_S \quad , \tag{2}$$

which derives from the assumption of neglecting dilational attenuation. The simulations where done first for $f_{max} = 0.5$ Hz and then repeated for $f_{max} = 1$ Hz, and $V_{S_{min}} = 200$ m/s. All simulations correspond to the case of 2008 M_w 5.4 Chino Hills, California, earthquake in a volume domain of 180 km × 135 km × 62 km. This earthquake has become a canonical reference case in simulations due to the large number of records available for validation. Figures 1 and 2 show results for the attenuation of peak ground velocity with hypocentral distance for different Q_S-V_S relationships as given by parameters c, α, and β in Equation 1 for f_{max}= 0.5 and 1 Hz, respectively. These comparisons are quantified in Figures 3 and 4, which show goodness-of-fit final score results using the criteria proposed by Anderson (2004) following Taborda and Bielak (2013).

Based on these initial results, we found that relationships yielding higher values of Q_S seem to follow better the attenuation observed in the data and thus yield higher GOF scores. In the following months we will continue to refine these findings and analyze the results at different frequencies and in contrast to empirical attenuation relationships (NGAs).

4 Intellectual Merit

Initial results from this project provide valuable insight about the choice of appropriate attenuation models for low-frequency simulations. This will help better constrain simulation parameters for simulation efforts at large, but more important, it will help build a more robust set of parameters for SCEC projects such as CyberShkae and High-F. While we are well-aware that material quality factors are frequency and depth dependent, we believe that the results obtained thus far within this project help define a baseline or reference framework that will facilitate further improvements in modeling intrinsic attenuation in anelastic wave propagation simulations. This, in turn, will help advance the use of simulations in engineering applications.

5 Broader Impacts, Education and Outreach

This project provided direct funds and research opportunities two Ph.D. students at the University of Memphis: Naeem Khoshnevis (Geophysics) and Shima Azizzadeh-Roodpish (Civil Engineering). Both these students are

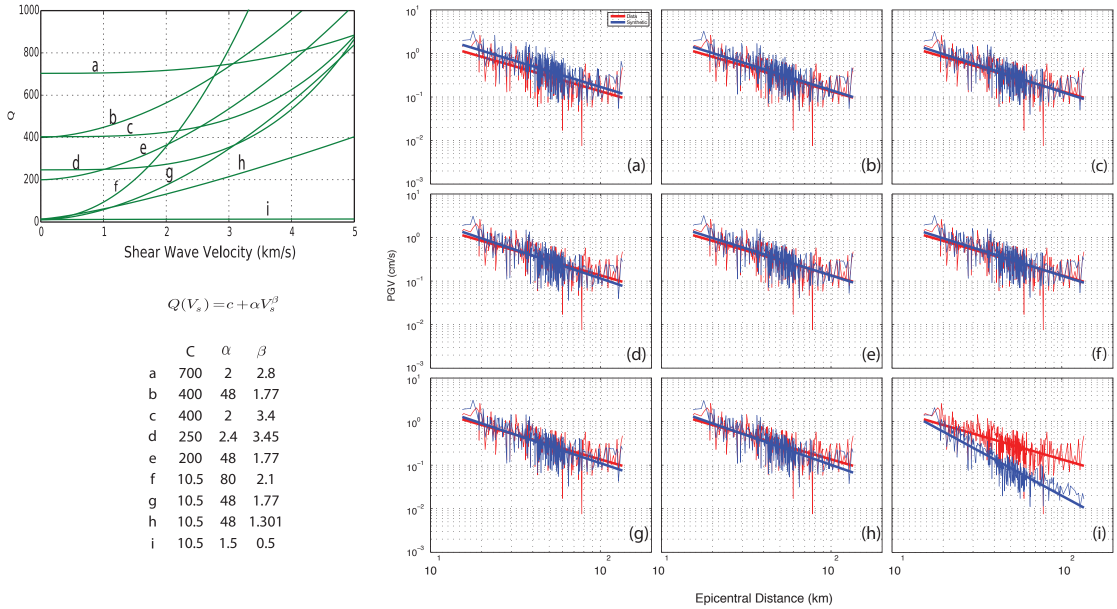

Figure 1: Comparisons of attenuation of peak ground velocity with hypocentral distance for different Q_S-V_S relationships as given by parameters c, α, and β in Equation 1. Values are measured at station locations for which we have records available. Red lines correspond to data (filtered at $f_{\max}$) and blue lines correspond to synthetics in the NS component of motion. These simulations were done for $f_{\max} = 0.5$ Hz.

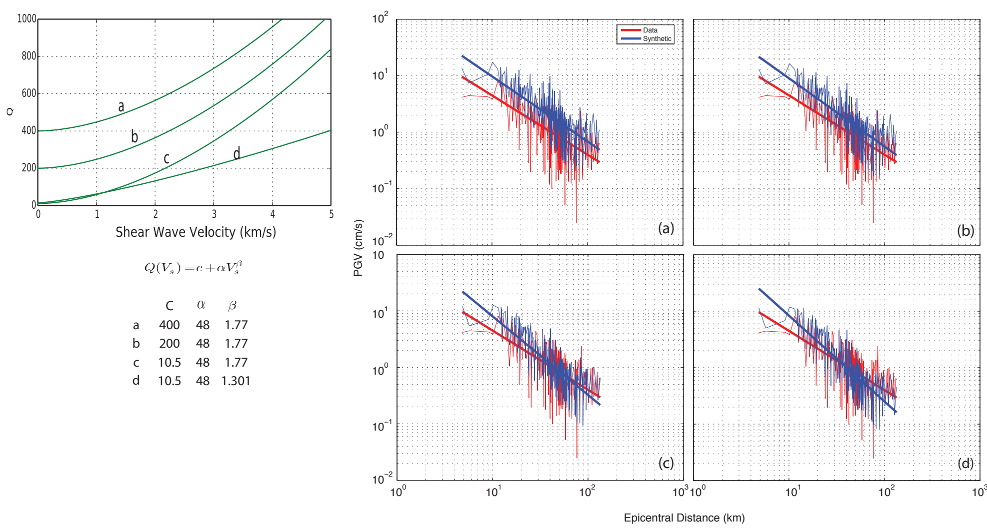

Figure 2: Similar to Figure 1 but for $f_{\max} = 1$ Hz.

affiliated with the Center for Earthquake Research and Information and work under the supervision of the PI. Initial results obtained for the specific purpose of the project will be presented this year at the 2015 SSA Annual Meeting. Details of the presentation are given in the next section. In addition, training of Khoshnevis toward the execution of the project research resulted in a spin-off research topic on the influence of signal processing (filtering) on the validation of ground motion simulations. Additional presentations on this topic are also listed below.

6 Presentations

Directly associated with the project:

- Khoshnevis and Taborda (2015a)

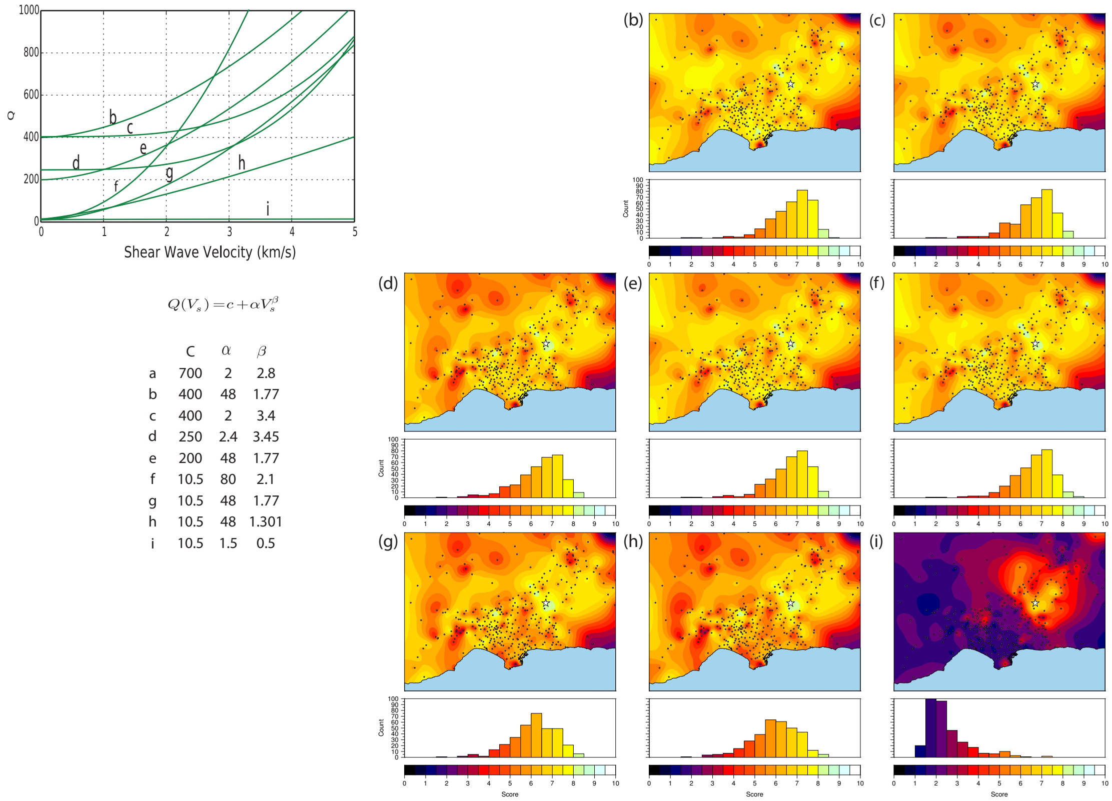

Figure 3: Goodness-of-fit final score results based on Anderson (2004) and following **?** for the different Q_S-V_S relationships as given by parameters c, α, and β in Equation 1 for simulations with $f_{\max} = 0.5$ Hz.

Spin-off research on filtering:

- Khoshnevis and Taborda (2015b)
- Khoshnevis and Taborda (2014b)
- Khoshnevis and Taborda (2014a)

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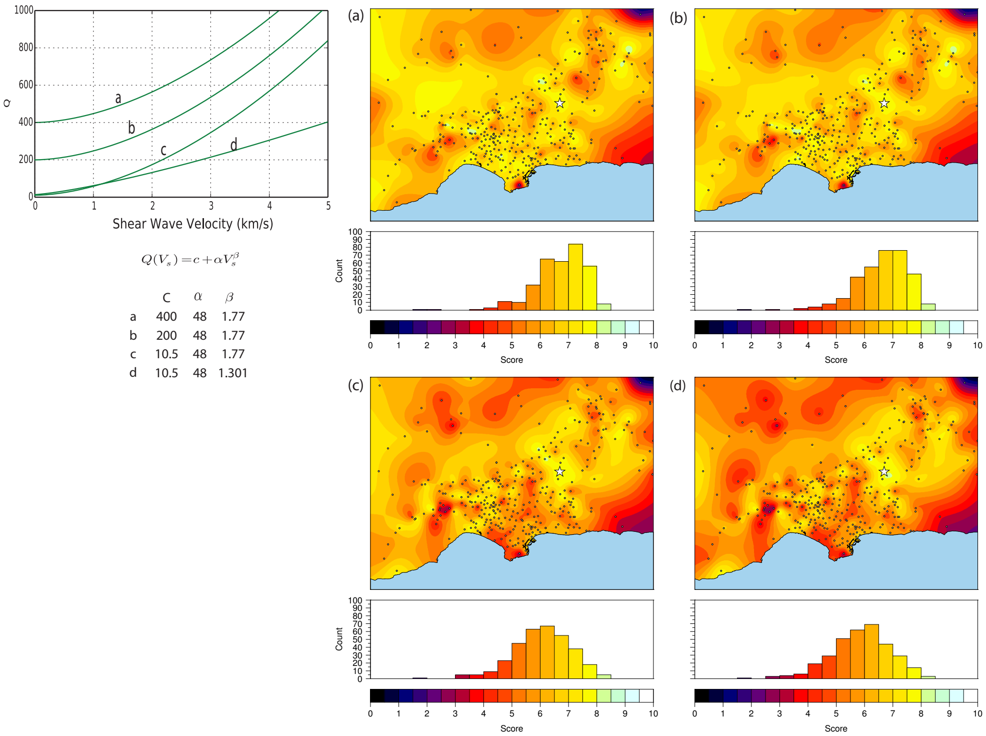

Figure 4: Similar to 3 but for $f_{\max} = 1$ Hz.

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