Verification and Validation of High-Frequency (f_max = 5 Hz) Ground Motion Simulations of the 2014 M_w 5.1 La Habra, California, earthquake


Abstract

The Southern California Earthquake Center (SCEC) High-F frequency project seeks to advance physics-based, deterministic, earthquake simulation with the long-term objective of improving ground motion prediction and seismic hazard models. An important aspect of this involves the validation of models and simulation methods, and the validation of synths with respect to data. The present study describes a recent concerted effort to verify different simulation methods, and attempts to reproduce the ground motions from the 2014 M_w 5.1 La Habra, California, earthquake in the greater Los Angeles region over a simulation domain of 100 km × 135 km and 60 km in depth. The simulations are done using three high-performance computing codes; two of them implement the finite difference method and the third one implements a finite element approach. The models are tailored to satisfy a maximum frequency of 5 Hz and a minimum shear wave velocity of 500 m/s. We rely on the latest version of the community velocity model CVM-S, version 4.26.1, and use a point source and two finite source models. The point source model is defined by a mechanism derived from strong-motion data and a slip-time signal obtained from a dynamic rough-fault rupture model. The two finite source models come from (i) an independent source inversion study, and (ii) a simulation done with a kinematic rupture generator also used in the SCEC Broadband Platform. At the verification stage, we compared synthetics from the three codes for the point source model, using the 3D regional structure and frequency independent attenuation (Q) models. The comparisons between the three codes exhibit very good agreement. For the validation stage, we compared seismograms collected at 350+ recording stations from different strong-motion accelerometers monitoring networks with synthetics obtained for the three different source models. Initial results indicate that extended source models, even for a moderate-size earthquake like the one considered here, tend to lead to better fits with data. Current and future efforts concentrate on defining the best possible source model based on goodness-of-fit comparison metrics, and testing the influence of other parameters such as a frequency dependent Q model and small-scale heterogeneities. Simulations have been carried out on NCSA Blue Waters and on OLCF Titan.

Event and Region of Interest

- Name: La Habra
- Date: 03-29-2014
- Time: 04:09:41-97
- Magnitude: M_w 5.1
- Latitude: 33.8058°
- Longitude: 117.8582°
- Depth: 5.0 km
- Strike/Dip/Rake: 239/70/30 (Lee et al., 2014)
- Large Simulation Domain: 180 km × 135 km × 61.875 km
- Small Simulation Domain: (green): 28 km × 28 km × 14 km
- Large Domain Bounding Box: -117.85 to 118°E, 33.88 to 34.41°N, -117.80 to 118°E, 33.83 to 34.40°N
- Rotation Angle: 39°
- Avail. Records: 350+ stations

Material Models

- a) Halfspace Model: Vs = 1.0 km/s, ξ = 0.1 km/s, Density = 2.1 g/cm³
- b) 1D Crustal Model: Based on the Los Angeles basin model used in the SCEC Broadband Platform (BBP) - linearly smoothed, Vs = 550 m/s
- c) 3D Crustal Model: SCEC CVM-S 26.041
- d) Attenuation Parameters: Qs = 250 (frequency-independent code)

Point Source Model

- Obtained from a dynamic rupture simulation using SDG. The simulation corresponded to a truck-fault model used in a previous study, not directly linked to the La Habra earthquake. The selected slip function was rich in frequency content above 4 Hz. For our simulations, the slip function was low-pass filtered at f = 5 Hz (Buttersworth, N = 4, 2 passed).

Finite Fault Models

- We consider two finite-fault models. The first of these models (left) corresponds to the frequency dependent inversion by Wei et al. (2014). The second model (right) corresponds to a kinematic rupture generated using the method introduced by Gregves and Rialha (2016). The latter method is one of the rupture generators implemented in the SCEC Broadband Platform.

3D Simulation Codes

- We compute ground motions using three simulation codes. Two of these codes implement the finite difference method (FDM) and the other implements the finite element method (FEM) to solve wave propagations problems in anisotropic media. All three codes have been extended extensively in the past for large-scale ground motion earthquake simulations at low frequencies (< 1 Hz) and in a reduced number of simulations at higher frequencies (> 1 Hz). This study evaluates their performance—through verification and validation—for the case of simulations in the 0.5-5 Hz frequency range. For some verification purposes we also used the wavenumber (f-K) code developed by Lupei Zhu (LSU).

Comparison Criteria and Software

- We quantify the goodness-of-fit between synthetics and data using the traditional goodness-of-fit (GOF) maps (Anderson, 2004), the simulation performance assessment (SPA) (Anderson, 2004), and the structural dynamic error (SDE) (Gaiser, 2008).

Simulation Verification and Validation Plan

- We have designed a plan of simulations intended to verify the codes with various modeling setups and learn about the influence of parameters associated to the simulation codes. Those runs already used in validation are indicated by the red frame.

Lessons Learned

- Although codes have been verified before with respect to each other, a systematic approach was necessary, including simple models such as halfspace and one-dimensional layered models.
- Validation results for small-magnitude events are appropriate for low-frequency simulations but not so for high-frequency simulations, especially in the vicinity of the epicenter. For moderate and large-magnitude events, extended fault models are necessary even for low frequencies.
- It is critical to build the necessary software infrastructure for seismic processing, and independent verification and validation with standard procedures.

Relevant References