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Three-Dimensional Finite Difference Simulation of Ground Motions from the August 24, 2014 South Napa Earthquake

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Introduction

The M_W 6.0 August 24, 2014 South Napa earthquake is the largest seismic event in the San Francisco Bay Area since the 1989 M_W 6.9 Loma Prieta earthquake (Brocher et al., 2015). This recent event was recorded by more numerous and modern instruments, including sensors operated and archived by the Northern California Earthquake Data Center operated by BSL.

We performed three-dimensional (3D) anelastic ground motion simulations of the South Napa earthquake to investigate the performance of different finite rupture models and the effects of 3D structure on the observed wavefield. We considered rupture models reported by Dreger et al. (2015), Ji et al., (2015), Wei et al. (2015) and Melgar et al. (2015). We used the SW4 anelastic finite difference code developed at Lawrence Livermore National Laboratory (Petersson and Sjogreen, 2013) and distributed by the Computational Infrastructure for Geodynamics. This code can compute the seismic response for fully 3D sub-surface models, including surface topography and linear anelasticity. We use the 3D geologic/seismic model of the San Francisco Bay Area developed by the United States Geological Survey (Aagaard et al., 2008, 2010). Evaluation of earlier versions of this model indicated that the structure can reproduce main features of observed waveforms from moderate earthquakes (Rodgers et al., 2008; Kim et al., 2010). Simulations were performed for a domain covering local distances (< 25 km) and resolution providing simulated ground motions valid to 1 Hz.

Simulation Results and Waveform Comparisons

The waveforms for the South Napa earthquake show significant variability due to rupture details, path and site effects. We started by computing the response at local distance seismic stations (strong motion and broadband) for the rupture model developed by Dreger et al. (2015). This model shows that the rupture propagated from the hypocenter (11 km depth) up dip and to the north. Consequently directivity to the north sent seismic energy into the sedimentary structure underlying the Napa Valley.

We have compared waveforms for four reported finite rupture models and synthetics based on the 1D and 3D models and generally find that 3D effects on the waveforms are significant, especially for sites in sedimentary basins or whose paths interact with basins or other material heterogeneity. Figure 1 shows a snapshot of the ground velocity as the rupture evolves (color coded with the ShakeMap scheme). Also shown are comparisons of the observed and synthetic waveforms at two stations (NC.N016 in Napa Valley and NC.NSP across the Sonoma Valley). Synthetics were computed for the 1D (GIL7, Stidham et al., 1999) and 3D models. Note that the 3D model clearly fits the amplitudes and late arriving scatetred surface waves.

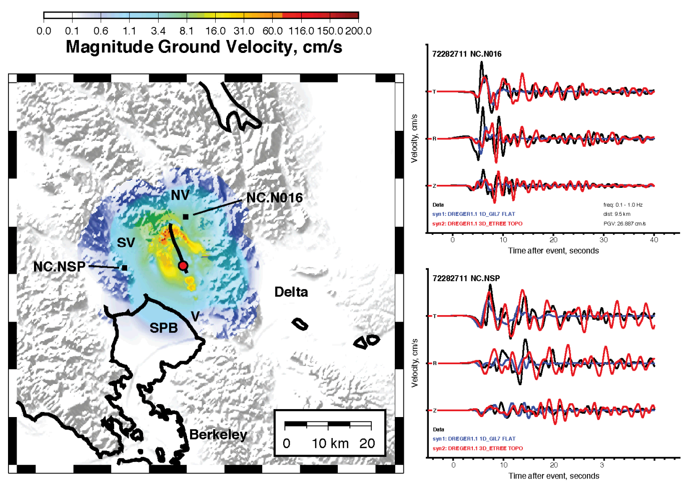

Figure 1. (left) Snapshot of the ground motion from the South Napa earthquake, with the magnitude of ground velocity (centimeters per second, scaled with color scale). The event initiated at the epicenter (red circle) and ruptured along the fault (thick black line). Squares mark the locations of two seismic stations from which waveforms are shown on the right. Place names are Napa Valley (NV), Sonoma Valley (SV), Vallejo (V), and San Pablo Bay (SPB). (right) Three-component seismograms for the event contrast the observed (black) ground motions with those computed with a 3D model and topography (red) and for a 1D model (blue).

Response Spectra

In order to evaluate the ground motion parameters of interest for engineering seismology, we computed the RotD50 spectral responses of the data and synthetics and formed the natural logarithmic ratio of data/synthetic as a function of period. This ratio measures the bias such that for values of 0 the synthetic predicts exactly the response spectrum at that period and positive/negative bias indicates the data is larger/smaller than the data at that period.

Figure 2 shows the response spectral bias for three of the rupture models considered for 1D (left) and 3D structural models (right) based on 24 local distance stations (<25 km). The response spectra are generally biased high for the 1D model compared to the 3D model, probably due to the relatively high near-surface wavespeeds of the 1D model (1500 m/s) compared to the lower wavespeeds of the 3D models (~400 m/s). Note that the scatter in the response spectral bias is lower for the 3D model suggesting that 3D wave propagation effects are properly accounted for in the USGS 3D model.

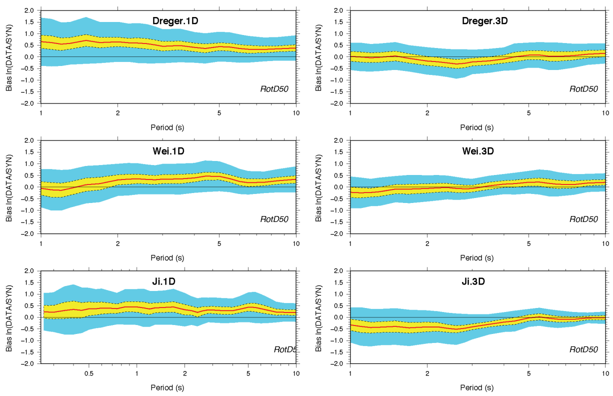

Figure 2. Rotd50 bias (logarithm of data/synthetic) for three rupture models for 1D (left) and 3D (right) structural models. The average (red line) and spread are based on 24 local distance stations.

Conclusions and Recommendations

This study indicates that 3D seismic simulations on high-performance computers using the reported rupture models and the USGS 3D geologic/seismic model of the San Francisco Bay Area can accurately model observed ground motions.

Clearly the model can be improved and simulations performed at high frequency. Model improvements could be obtained by waveform-based adjoint tomography using moderate earthquakes already recorded. Advances in computing and access to more powerful computers will enable higher frequency simulations.

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