Spatial Statistics of the Clark County Parcel Map, Trial Geotechnical Models, and Effects on Earthquake Ground Motions in Las Vegas Valley

Report on the Project

"Spatial Variability in Geotechnical Velocities and Effects on Ground Motions"

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When deterministically modeling the propagation of seismic waves, shallow shear-wave velocity plays a crucial role in predicting measures of shaking intensity such as peak ground velocity (PGV; Borcherdt and Glassmoyer, 1992; BSSC, 1997; Field, 2001) and duration (Olsen, 2000; Stephenson, 2005; Gvirtzman and Louie, 2010; Shani-Kadmiel et al., 2012). The Clark County Parcel Map provides us with a data set of >10,000 geotechnical velocities in and around Las Vegas Valley (Figure 1; Louie et al., 2011a), measured with SeisOpt® ReMi™ by Optim SDS. This is an unprecedented level of geotechnical detail, achieved in the past only over small areas, such as by Kaiser and Louie (2006). Las Vegas Valley is a geologic basin having similar geologic and geotechnical properties to some areas of Southern California (Scott et al., 2006; Thelen et al., 2006; Louie et al., 2008; Thompson, 2010).

We analyze elementary spatial statistical properties of the Parcel Map, and calculate its spatial variability. To calculate the fractal dimension of a data set using its spatial power spectrum, Mela and Louie (2001) use, following Carr (1995):

$$D = \frac{5 - \beta}{2} \tag{1}$$

where D is the fractal dimension and β represents the absolute value of the slope obtained from the power-law fit to the power spectrum of the data set. Plotting a histogram of the Parcel Map's 30-meter depth-averaged shear velocity (Vs30) values shows the data to approximately fit a bimodal normal distribution with μ_1 = 400 m/s, σ_1 = 76 m/s, μ_2 = 790 m/s, σ_2 = 149 m/s, and p = 0.49, where μ is the mean, σ is standard deviation, and p is the probability mixing factor for the bimodal distribution. Based on plots of spatial power spectra (Figure 2), the Parcel Map appears to be fractal between 0.1 and 10 cycles/km spatial frequency, or 0.1 to 10 km wavelengths. The 1-d spatial spectra exhibit the same fractal dimension in the N-S and the E-W directions, D=1.668 versus 1.656 respectively, indicating isotropic scale invariance for the 2-d spatial spectra.

We then analyze the same spatial statistics from PGV maps computed using two geotechnical models that incorporate the Parcel Map as input. Louie et al. (2011b) and Savran et al. (2011) outlined the Nevada ShakeZoning process we use to predict earthquake ground motions in Las Vegas Valley. The finite-difference code E3D, by Larsen et al. (2001) of Lawrence Livermore National Laboratories, solves the elastic wave equation in three dimensions from kinematic representations of earthquake ruptures. Our Nevada ShakeZoning models use E3D to propagate the waves, and ModelAssembler (Louie, 2008) to configure model parameters specific to Las Vegas Valley, such as lithologic information, basin thickness, and geotechnical velocities; all from external data sets such as the Parcel Map. ModelAssembler implements a Community Velocity Model (CVM) such as SCEC's (Magistrale et al., 2000) for Nevada and anywhere else. For each of the scenarios the basin thickness data are assembled by overlying

Langenheim et al. (1999) results at high resolution in Las Vegas Valley atop the Saltus and Jachens (1995) results for basin-floor topography across the Intermountain West. Nevada ShakeZoning assembles geotechnical velocity maps in the same fashion. The Parcel Map (Louie et al., 2011a) is overlain on the IBC default geotechnical velocities to produce the input geotechnical layer, Figure 1. Each earthquake scenario will be calculated twice, once using the stochastic model and the other using the Parcel Map. Flinchum et al. (2012) provide validation of Nevada ShakeZoning synthetics against recordings of the 1992 M5.5 Little Skull Mountain earthquake in southern Nevada.

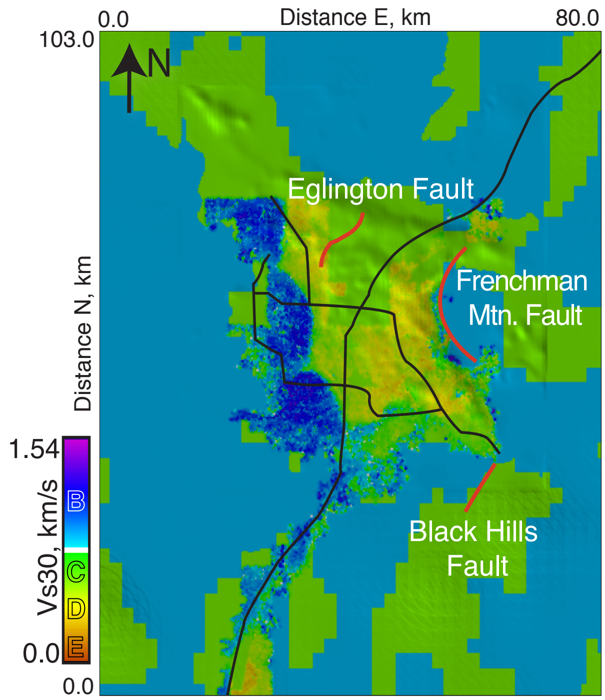

Figure 1. Map showing a portion of the >10,000 Vs30 data points of the Clark County Parcel Map (Louie et al., 2011a) plotted on top of IBC default geotechnical velocities (BSSC, 1997) for rock (blue) and soil (green) areas. The cooler areas on the map represent areas that have higher Vs30 and should see lower ground motions; whereas the warmer areas have lower Vs30 and represent a higher expected ground motion. This entire region comprises the top surface of the model grid for the Black Hills fault scenario computation (Louie et al., 2011b).

We configured finite-difference wave propagation models at 0.5 Hz with LLNL's E3D code, utilizing the Parcel Map as input, to compute a PGV map of the shaking intensity expected from scenario earthquakes (Black Hills M6.5 and Frenchman Mtn. M6.7; Louie et al., 2011b; Savran et al., 2011). Rupture properties are estimated from the Qfaults database (USGS and NBMG, 2012). The resulting PGV map, Figure 3 for Frenchman Mtn., is fractal over the same spatial frequencies as the Vs30 maps associated with their respective models. The fractal dimension is systematically lower in all of the PGV maps as opposed to the Vs30 maps, showing that the PGV maps are richer in lower spatial frequencies. This is potentially caused by seismic waves averaging through spatial heterogeneities as they propagate.

Finally, we develop a method to produce a comprehensive and adaptable Vs30 geotechnical model containing the Parcel Map overlain on stochastically generated Vs30 values. This model preserves the spatial statistics across the entire modeled map, and implements the deterministic features discovered by the Parcel Map. Our goal is to replicate the same spatial statistics discovered in the Parcel Map, as well as any other non-deterministic features discovered in our analysis. We try and replicate the stochastic spatial variance seen using white, pink, and Brownian noise generators across a model map. The generated random noise is smoothed using a square kernel of adjustable dimension on the map, and then scaled to add a pre-specified percentage of noise to a background Vs30 model map. In order to produce a model map similar to the Parcel Map and uphold the deterministic features, we first produce the deterministic background model containing IBC default velocities (BSSC, 1997; Louie, 2008) based on the Saltus and Jachens (1995) and Langenheim et al. (1998) geologic maps for southern Nevada, in the area of Figure 1. In our models, the IBC default geotechnical velocities are 500 m/s for sediment or basin sites, and 760 m/s for bedrock sites. The Saltus and Jachens (1995) and Langenheim et al. (1998) maps distinguish basin from bedrock, producing the blocky deterministic basin (green) and bedrock (blue) areas at the edges of Figure 1, outside the coverage of the Clark County Parcel Map. The background maps provide no site-specific regions of higher or lower velocity within any basin or bedrock area, such as the high-velocity caliche-cemented soils in the western portion of Las Vegas Valley noted by Louie et al. (2011a). However, when we run earthquake scenarios through a model built from a stochastic geotechnical map having the statistics of the Parcel Map, but not the actual Parcel Map data, the resulting PGV map has the same statistics as the PGV from a run including the Parcel Map (such as Fig. 3).

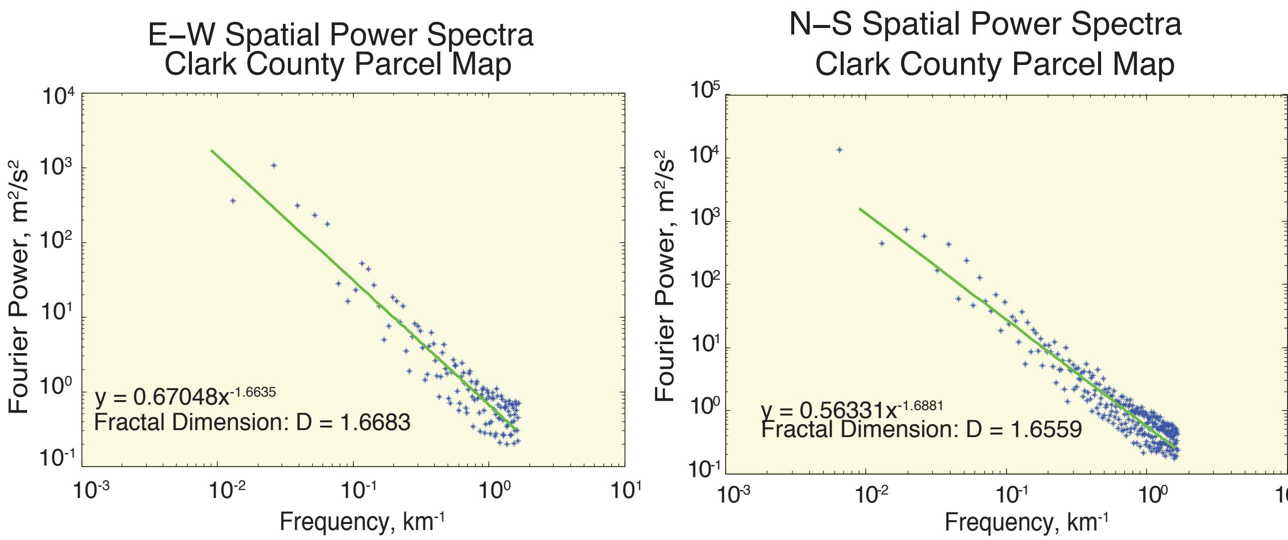

Figure 2. Spatial power spectra taken from the assembled geotechnical model of Parcel Map measurements (Louie et al., 2011a) superimposed over IBC default Vs30 values assigned according to geology (BSSC, 1997; Louie, 2008). The summed EW spectra are on the left, summed NS spectra on the right. Fractal dimensions are computed from the sloping green fit lines, using Mela and Louie (2001).

The white noise generator produces evenly distributed random noise (Figure 3, left), with no decrease in power at the higher-spatial-frequency part of the spectrum. The white noise modulates the IBC default geotechnical velocities at every grid point. White noise does not replicate natural processes as well as pink or Brownian noise (Mela and Louie, 2001); however, we include it to better understand the spatial statistics of the Parcel Map. Theoretically, white noise should display equal power across all frequencies, resulting in physically unrealistic variance in the Parcel Map.

To model the stochastic variation with pink noise the random variance in velocity must fit a Gaussian distribution. This is most simply accomplished using the Central Limit Theorem to approximate the Gaussian distribution. Pink noise decays as 1/f on the spectrum whereas white noise decays as $1/f^0$ and Brownian or red noise decays as $1/f^2$. Brownian noise has a fractal dimension of 1.5, and pink noise has a fractal dimension of 2, from Mela and Louie (2001). Based on the observations of Louie et al. (2008) and Thompson (2010), a fractal dimension of 1.5 to 1.8 would indicate the randomness as some type of fractional Brownian motion. In order to obtain this fractional component, a square-smoothing kernel is applied to the model map. The dimensions of the kernel can be chosen by the analyst, and is expressed in kilometers. For our stochastic geotechnical models, we smoothed the random noise over scenario-modeled seismic wavelength, or 3.0 km, producing the map in Figure 3 (right).

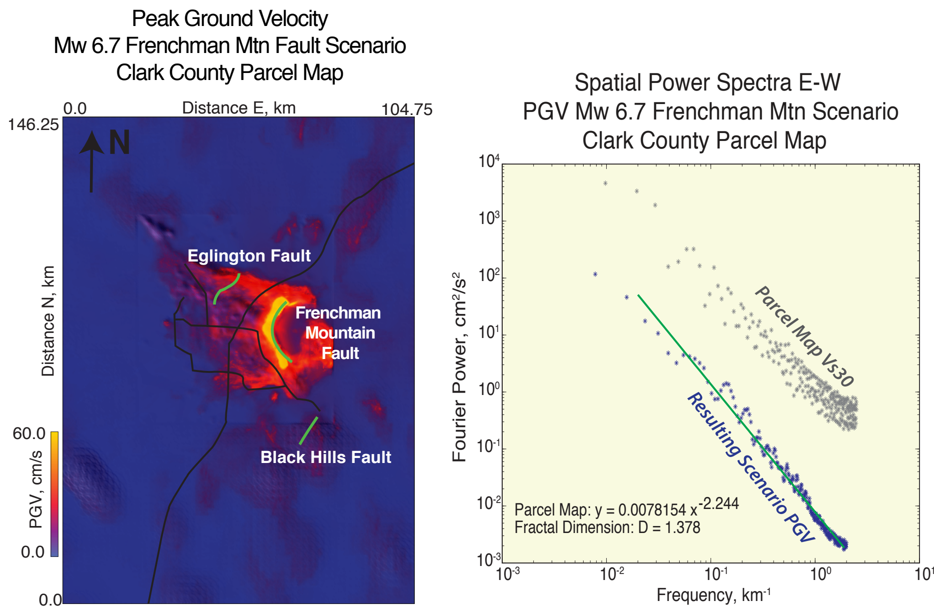

Figure 3. (Left). Peak Ground Velocity map calculated from an Mw 6.7 Frenchman Mtn. earthquake scenario, with the Parcel map data included. The maximum PGV of the scenario is 143 cm/s. (Right) Spatial power spectra from the scenario PGV map, indicating a fractal dimension of 1.378, and from the Parcel Map Vs30 data.

Red or Brownian noise is integrated white noise and can be modeled using a random walk approach, where the walker takes an equidistant step in a randomly determined direction until the walk is complete. As with the other two, the modeled Brownian noise will modulate the base map's deterministic default IBC values. The noise is scaled to an amount of noise selected by the analyst. The methods for generate the three different types of stochastic maps were integrated into Louie's (2008) ModelAssembler program for the Nevada ShakeZoning project. However, our Brownian noise generator did not perform as intended, so we will focus here on the pink noise models of the Parcel Map.

The stochastic noise modulating the background map containing the IBC default geotechnical velocities aims to preserve the spatial statistics of the Parcel Map. However, the method cannot account for the deterministic features of the Parcel Map. Our final method for creating model geotechnical maps is to overlay the Parcel Map measurements on top of the stochastic model. This overlay produces a model map accounting for the deterministic features in Las Vegas Valley as well as the preserved spatial statistics of the Parcel Map throughout the modeled data set, the "stochastically enhanced" Parcel Map of Figure 4.

Nevada ShakeZoning open-source model-assembly codes, data sets; and results including papers, presentations, and scenario wave-propagation animations are available at: http://crack.seismo.unr.edu/NSZ/

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SCEC Paper 1537. Flinchum, Brady A., John N. Louie, Kenneth D. Smith, William H. Savran, Satish K. Pullammanappallil, Aasha Pancha, 2012, Validation of Las Vegas Basin Response to the1992 Little Skull Mtn. Earthquake as Predicted by Physics-Based Nevada ShakeZoning Computations: *Proceedings of the 2012 Symposium on Engineering Geology and Geotechnical Engineering (EGGE)*, March 23, Reno, Nevada, 15 pp.

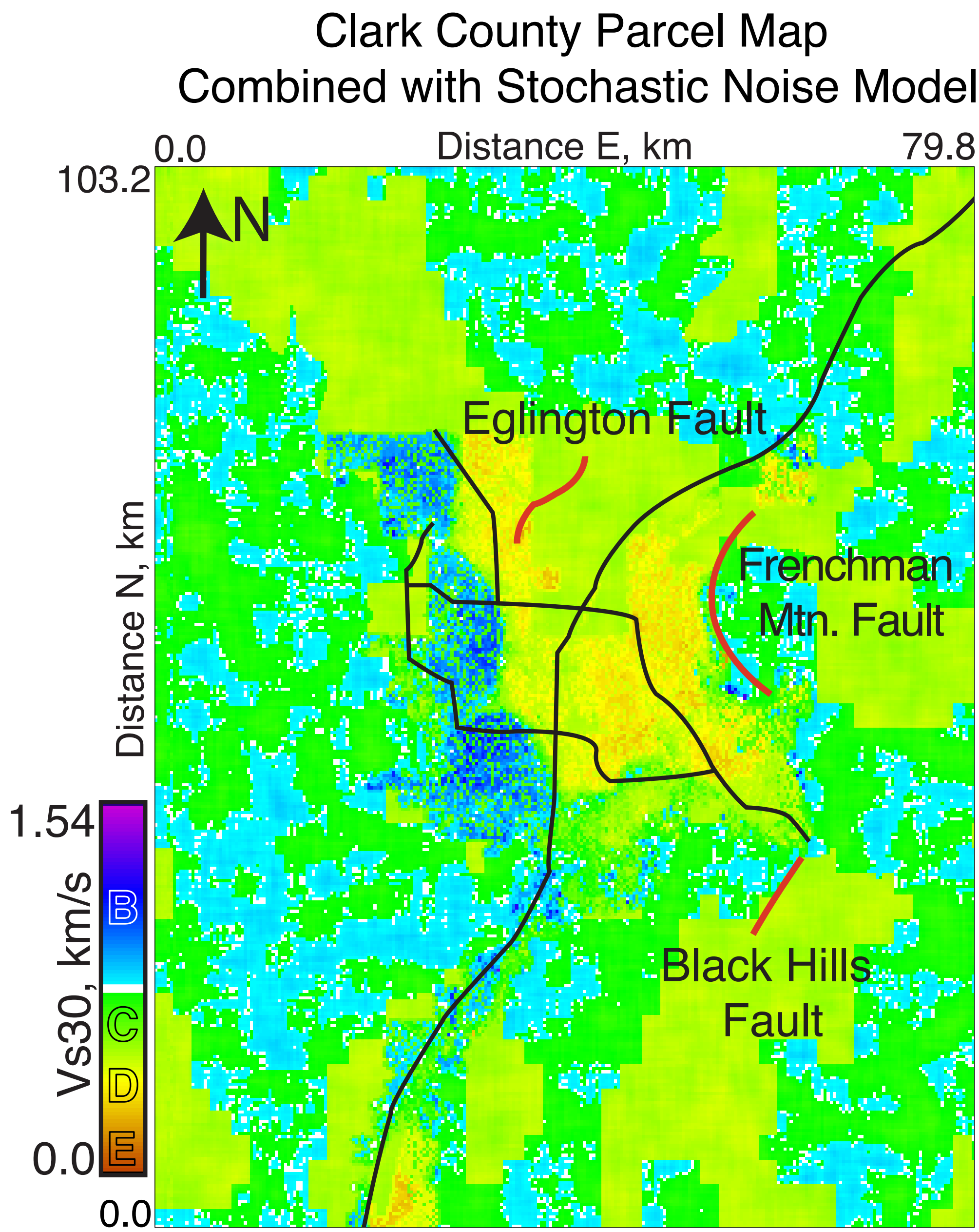

Figure 4. This map shows the combined model of geotechnical velocities in Las Vegas Valley and surrounds, plotted with the same color scale as Figure 1. Notice similar variance between the Vs30 values inside the valley as those in the surrounding bedrock. The white color represents a Vs30 of exactly 0.76 km/s. This model preserves the spatial statistics seen in the Parcel Map, and also implements the deterministic features discovered by it.

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