Low Frequency Examination of Synthetic Reno-Area Basin Amplification from M3 Earthquakes at a Variety of Azimuths

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Abstract

Seismic waves travel with greater amplitude and slower speeds when moving through soft sedimentary rock, relative to hard bedrock. Seismic hazard in the Reno area is increased due to the city's location within a thin (<1 km) sedimentary basin, where energy from seismic waves can be trapped and ground motion amplified. In order to study the extent to which ground motion in the basin is amplified compared to the bedrock, we are using the SW4 code from LLNL/geodynamics.org to simulate seismic wave propagation through the Reno area for six different M3 earthquakes, to a maximum frequency of 1.11 Hz. After compiling SW4 for the first time under MacOS Big Sur for Apple's new M1 chip, we ran SW4 on personal laptops for about 16 hours to complete each scenario. We are using Eckert's 3D community velocity model for the basin, on which he based the M6.3 Reno ShakeOut Scenario computation to 3.125 Hz. At a grid spacing of 120 m, this velocity model has a minimum shear-wave velocity of 609 m/s, yielding at least 4.57 grid points per minimum wavelength. PGV maps produced from these models will allow us to compare shaking at basin versus bedrock sites, and how it changes based on the location of the earthquake. Preliminary indications are that the standard deviation of basin-over-bedrock ground-motion ratios will be a substantial proportion of the average ratio. These results will help in determining the basin's amplification effects when assessing seismic hazard in the Reno area, and other urban basins.

Introduction and Methods

Ground-motion modeling is useful for areas where earthquake-shaking records are sparse, helping reveal variability and trends. Eckert et al. (2021) at UNR recently published the Reno ShakeOut Scenario, showing with 3D SW4 computations to 3.125 Hz that a M6.3 quake below the urban area could produce unexpected effects:

- Severe shaking with peak ground velocities (PGV) >0.3 m/s over a wide swath of the urban area.
- Extreme shaking, PGV >1.5 m/s in very limited areas, with great variations in shaking intensity across distances <0.1 km.

Developed at Lawrence Livermore National Lab (LLNL), SW4 is a node-based finite difference wave-equation solver with 4th order accuracy in time and space (Sjogreen & Petersson, 2012; Petersson & Sjogreen, 2012; Petersson & Sjogreen, 2015; Petersson & Sjogreen, 2017). LLNL has tuned SW4 to run on the world's largest clusters.

Eckert's Reno ShakeOut Scenario is only one earthquake at one location. SCEC SOURCES interns modeled small earthquakes at additional locations, at low frequency. The additional scenarios begin to explore the non-ergodic variability in shaking, and its amplification by the basin sediments, produced by a variety of earthquake sources.

We compiled LLNL's SW4 on our personal Apple M1 laptops and used it to simulate seismic wave propagation for six M3 earthquakes at various locations in the Reno area. Each run took about 16 hours.

	EQ1	EQ2	EQ3	EQ4	EQ5	EQ6
Magnitude	3.2	3.9	3.1	3.1	3.6	3.0
Depth, km	9.2	1.5	7.5	6.7	2.6	6.7
Date	2015-12-23	2008-06-08	2018-06-06	2016-07-31	2008-05-08	2018-06-06
Strike	200°	167°	73°	49°	27°	126°
Dip	54°	44°	58°	57°	77°	68°
Rake	-74°	-96°	35°	-91°	-8°	132°
Location	Below Basin	Basin Edge	Outside Basin	Below Basin	Basin Edge	Outside Basin

Table 1: Earthquakes simulated by SW4 and their parameters.

Using a source-time function central frequency of 0.37 Hz, the highest frequency at which substantial wave energy propagates is 0.74 Hz. The calculation is free of grid dispersion up to 1.11 Hz. Grid spacing was 120 m, with a minimum velocity of 609 m/s.

Basin Thickness Model

We used basin thickness derived from gravity surveying and drilling logs (Abbott & Louie, 2000) to explore the relationship between basin amplification and basin thickness at 24 stations. Eckert et al. (2021) used the same 3D velocity model.

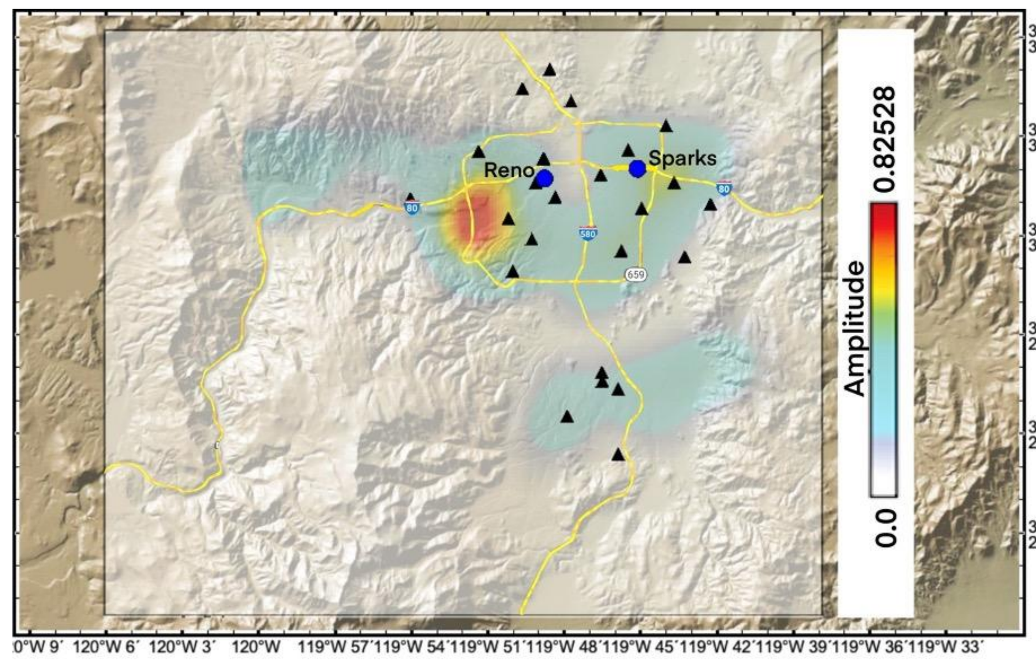

Figure 1: Thickness of Truckee Meadows basin from Abbott & Louie (2000). Basin thickness is less than 0.5 km in most of the Truckee Meadows, reaching a maximum of 0.9 km in the west Reno sub-basin.

Peak Ground Velocity Maps for Earthquakes 1-6

The PGV maps suggest ground-shaking variability depends on quake location relative to the basin. Quakes in similar areas produce similar PGV maps. EQs 2 and 5, on the NW edge of the basin, produce high PGV in the northern part of the basin, with the southern part less affected. These events had unusually shallow depths of 1.5 km and 2.6 km respectively, resulting in a much larger peak PGV value than the other earthquakes. EQs 1 and 4, within the basin, have peak PGV values at stations nearest the earthquakes' epicenters. EQs 3 and 6, located southwest of the basin, produce large PGV values at the maximum thickness of the basin.

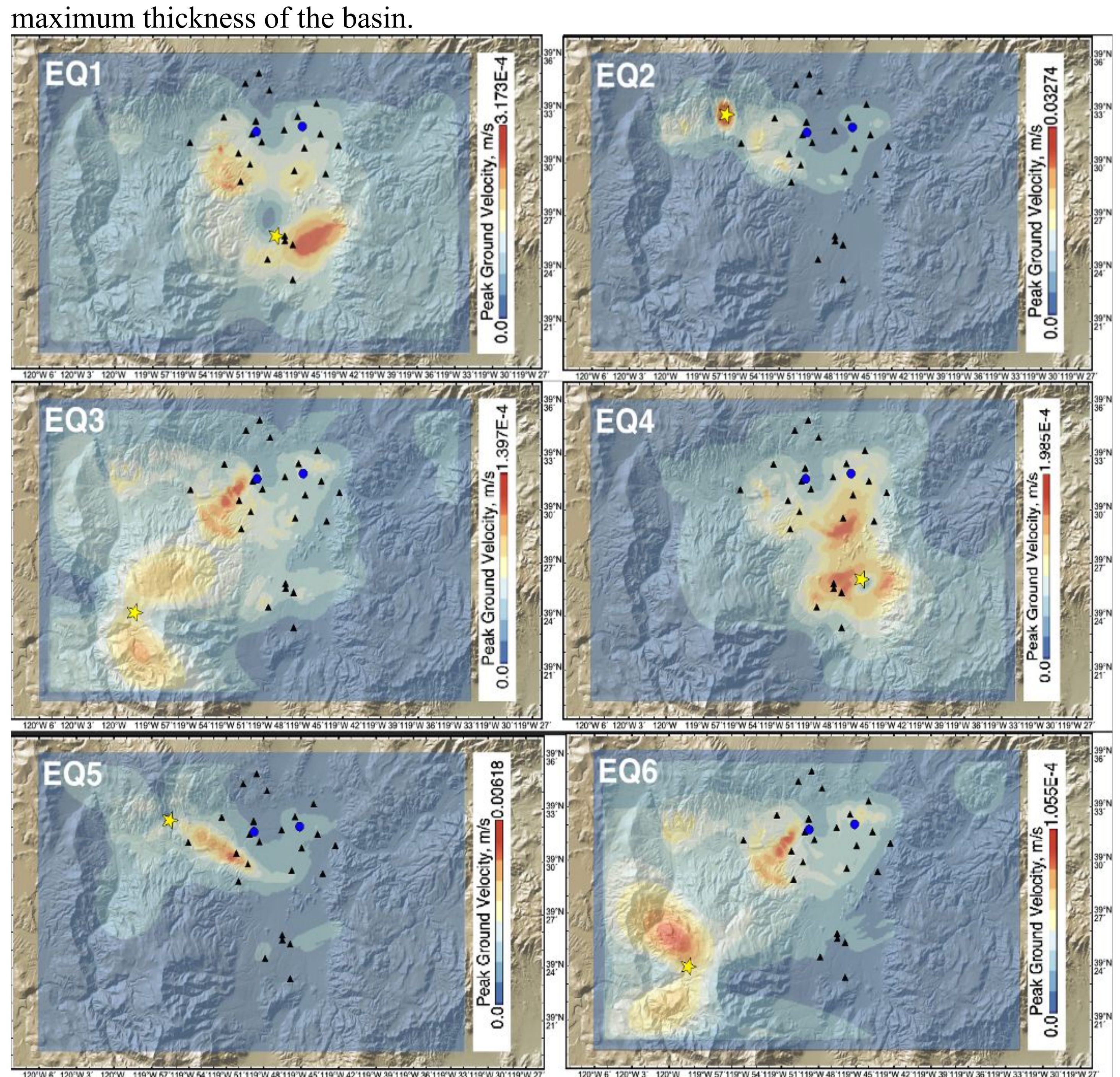

Figure 2: Peak ground velocity computed to 0.74 Hz for six minor earthquakes in the Reno area. Earthquake numbers correspond to those in Table 1. Station locations marked by black triangles; yellow stars indicate quake epicenters. Note each quake has a different color scale.

References

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Petersson, N.A. and B. Sj¨ogreen (2017). SW4 v2.0. Computational Infrastructure of Geodynamics, Davis, CA

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Multi-Scenario, Non-Ergodic PGV Summary Maps

We normalized the PGV maps for each earthquake to a modeled moment equivalent to that of the largest-magnitude EQ2, with M3.9. For each point on the maps, we computed the arithmetic average and standard deviation of PGV across the six normalized maps. This normalization assumes that these small quakes are point sources.

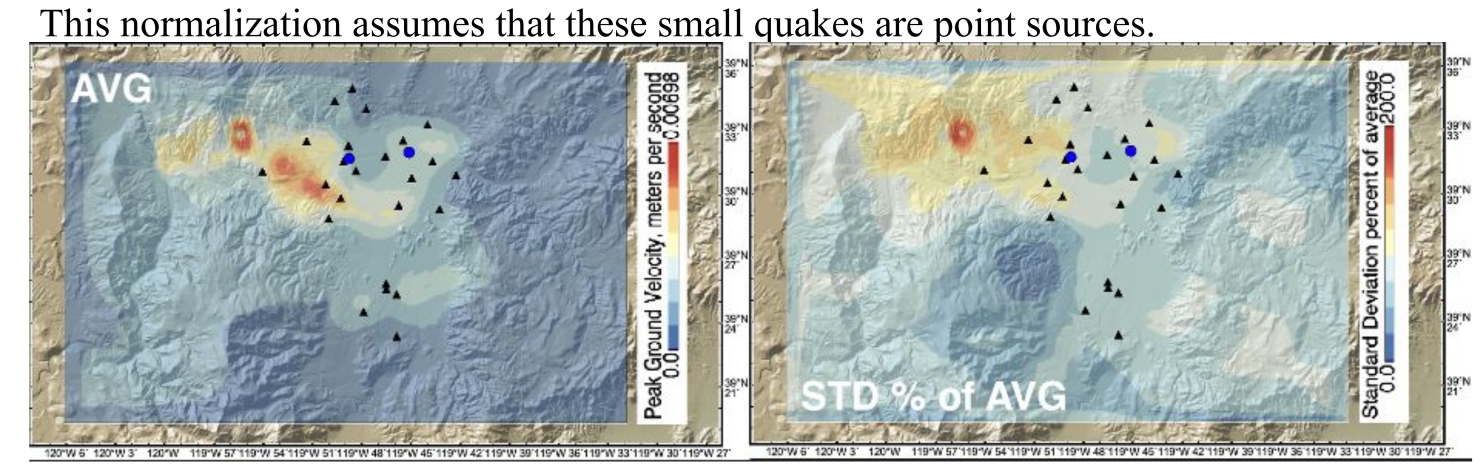

Figure 3: Maps of the arithmetic PGV average and standard deviation for EQs 1-6 after normalizing to M3.9.

The average and standard-deviation of PGV maps are dominated by the shallowest quakes (EQ2 and EQ5). Shaking from these quakes is concentrated close to their epicenters. 22 of the 24 stations have a standard deviation greater than 50% of the average. This suggests that earthquake location relative to the basin strongly influences ground shaking.The shaking variability for these minor earthquakes is proportionally the same as the variability of the earthquakes if they occurred with greater magnitude. These results inform estimates of hazards associated with larger earthquakes that are expected in the Reno area.

Synthetic Basin Amplification Ratios Compared to Basin Thickness

Taking computed PGV values at seismic station locations around the Reno area from the PGV maps of Fig. 2, we computed the basin amplification ratio at all basin stations, relative to all five rock stations WDEM, NOAA, RFNV, REDF, and SWTP. Figures 4 and 5 represent the two end members of geometric-mean basin amplification ratios vs. basin thickness plots for each earthquake.

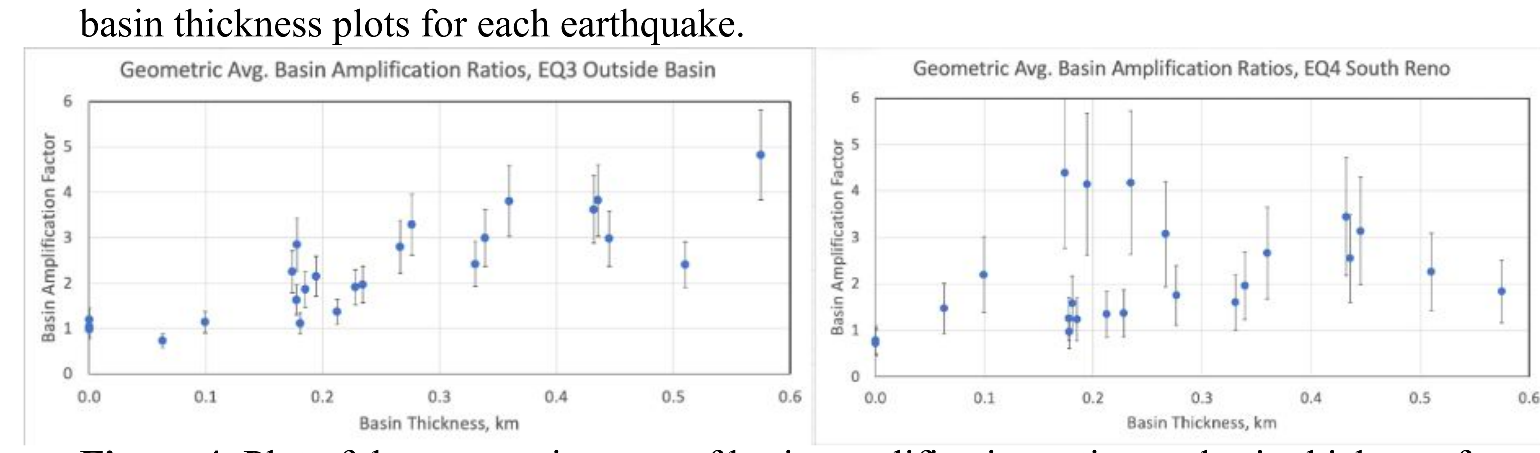

Figure 4: Plot of the geometric mean of basin amplification ratios vs. basin thickness for EQ3 (left) and EQ4 (right). Error bars indicate the means +/- the standard deviations.

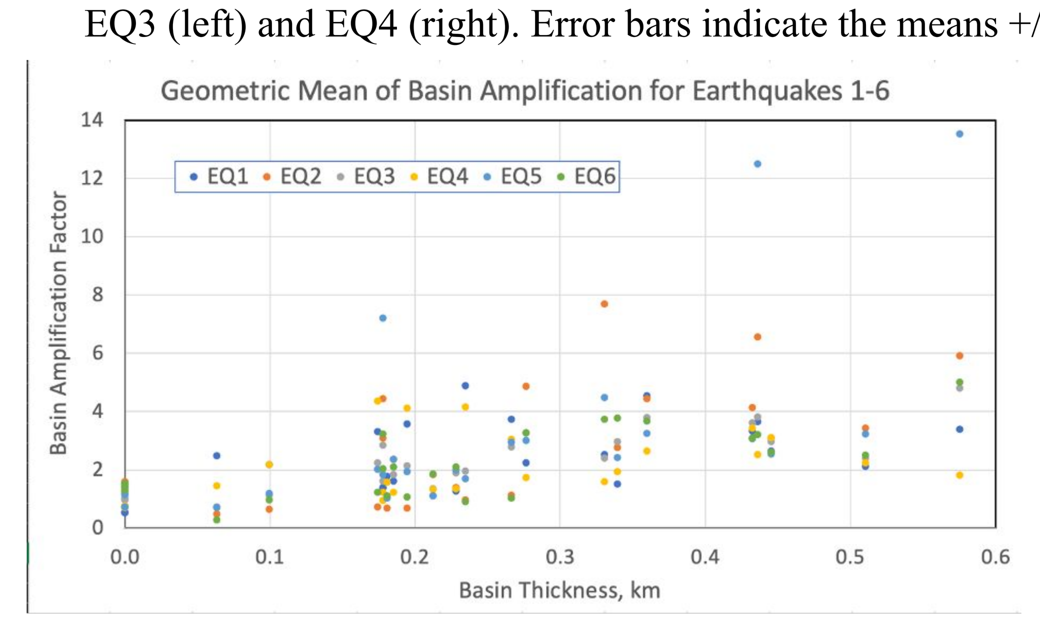

Figure 5: Synthetic geometric-mean basin-amplification factor vs. basin thickness for EQs 1-6. Many fewer recordings of these quakes exist, compared to how many stations we can model.

EQ3 synthetics suggests there could be a simple relationship between basin thickness and computed basin amplification, as the standard deviation is relatively small and the average generally increases with thickness (Fig. 4, left). There is little variation in azimuth for EQ3, as it occurred southwest of all stations. EQ4 occurred below the basin, with a wide variety of azimuth directions, and there is no indication that basin amplification increases with thickness. Amplification ratios at stations with similar values in basin thickness differ substantially, showing that variability depends greatly on earthquake proximity and azimuth (Fig. 4, right). Figure 5 shows that the average basin amplification factor at each station varies depending on earthquake. This denotes that variation is large and azimuth dependent, and that ground shaking amplification in the Reno basin cannot be generalized based on basin thickness.

Conclusions

3D synthetics suggest ground-shaking variability in the Reno basin is considerable and largely dependent on earthquake azimuth. Basin effects on ground shaking in the <1 km deep Reno-area basin, and other "thin" basins, should not be disregarded when considering seismic hazard, as they cannot be generalized based on the thickness of the basin.

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