Toward development of physics-based coherency models using deterministic broad-band earthquake ground motion simulations

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1. Introduction

- Wave passage, scattering and attenuation results in spatially varying seismic ground motions (SVSGMs).
- SVSGMs and differential deformations can cause damages to the distributed infrastructure (Figure 1).
- Current understanding of the coherency of SVGMs relies significantly on:
  - empirical models are based on a few dense arrays (e.g., LSST, SMART1 arrays – Figure 2);
  - simple (semi-)analytical models with plane wave assumptions.
- No physics-based coherency model exists that can translate source, path and site effects into SVSGMs.
- **Overarching goal** is to study the effects of physical parameters -- such as subsurface heterogeneity, topography, seismic source type, and spatial distance -- on the coherency of simulated ground motions, and develop a three-dimensional physics-based model that can be used for the generation of SVSGM fields in earthquake engineering applications, e.g., performance-based engineering of distributed infrastructure.

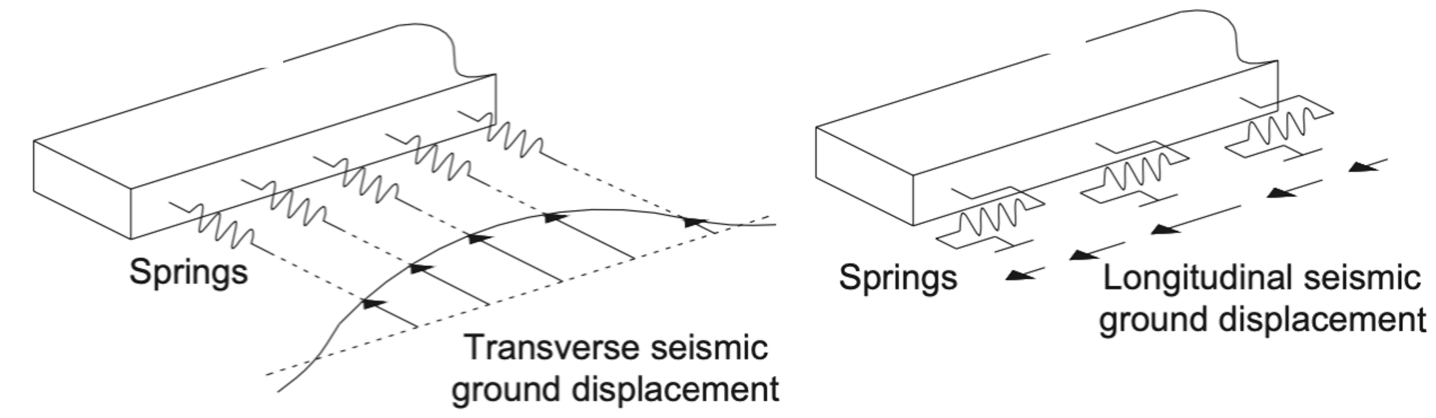


Figure 1: Schematic of displacement field along by long infrastructure.

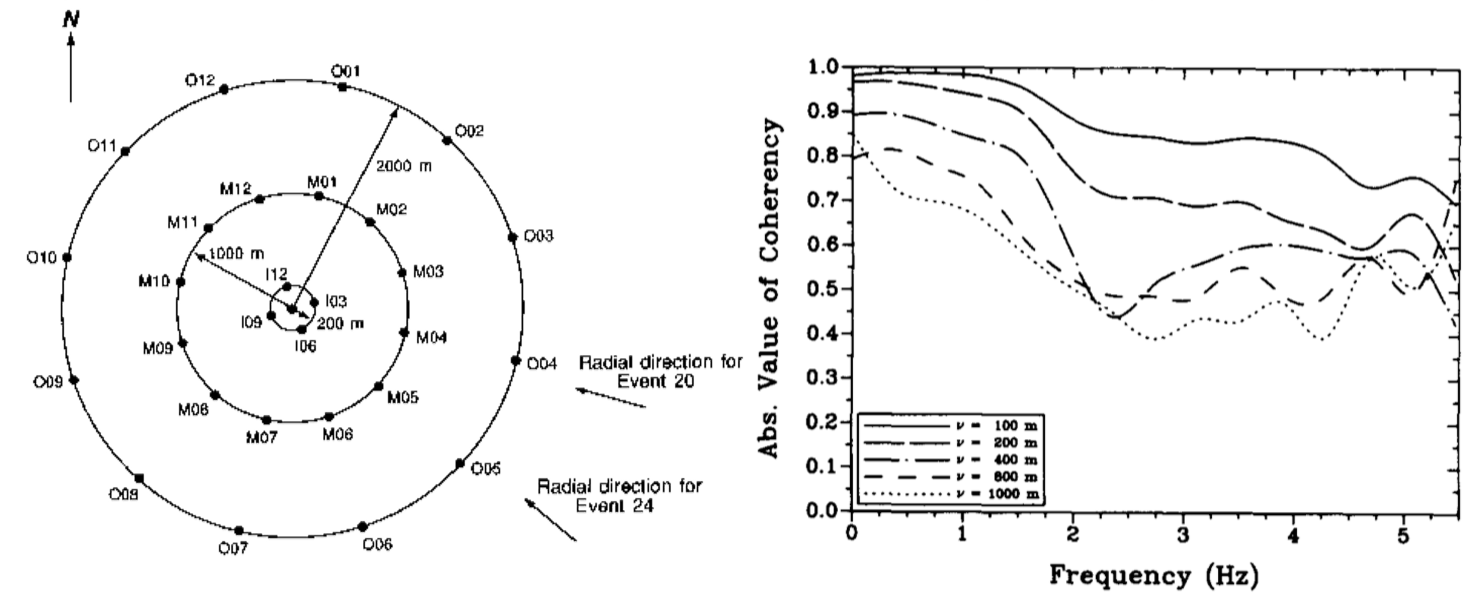
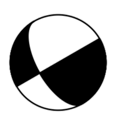


Figure 2: Smoothed coherency at SMART 1 array using Event 24 [1].

2. Deterministic Coherency Analysis in San Francisco (SF) Bay Area

- We perform a series of earthquake simulations up to 4 Hz in the SF Bay Area (Figure 3a) using the SW4 finite difference code. We use correlated stochastic perturbations (SP) in the upper 5km of the crust to model the small-scale geologic heterogeneity in the USGS 3D velocity model (USGS-3DVM) (Figure 3b).
- We simulate a magnitude 4.4 earthquake using a point source at a depth of 12km and with an epicenter shown as ★ in Figure 3a --  strike 60º, dip 90º, rake -40º.
- We define a dense array with 100 m spacing in an 8kmx6km region (black rectangle in Figure 3a) and compute the lagged coherency $|\gamma|$ as a function of both distance d and frequency ω:

$$|\gamma(d,\omega)| = \frac{S(\boldsymbol{x}_i,\boldsymbol{x}_j;\omega)}{\sqrt{S(\boldsymbol{x}_i,\boldsymbol{x}_i;\omega)S(\boldsymbol{x}_j,\boldsymbol{x}_j;\omega)}}, \quad d = |\boldsymbol{x}_i - \boldsymbol{x}_j|$$

where $S(x_i, x_j; \omega)$ is the cross power spectral density of acceleration time series between $\boldsymbol{x}_i$ and $\boldsymbol{x}_j$.

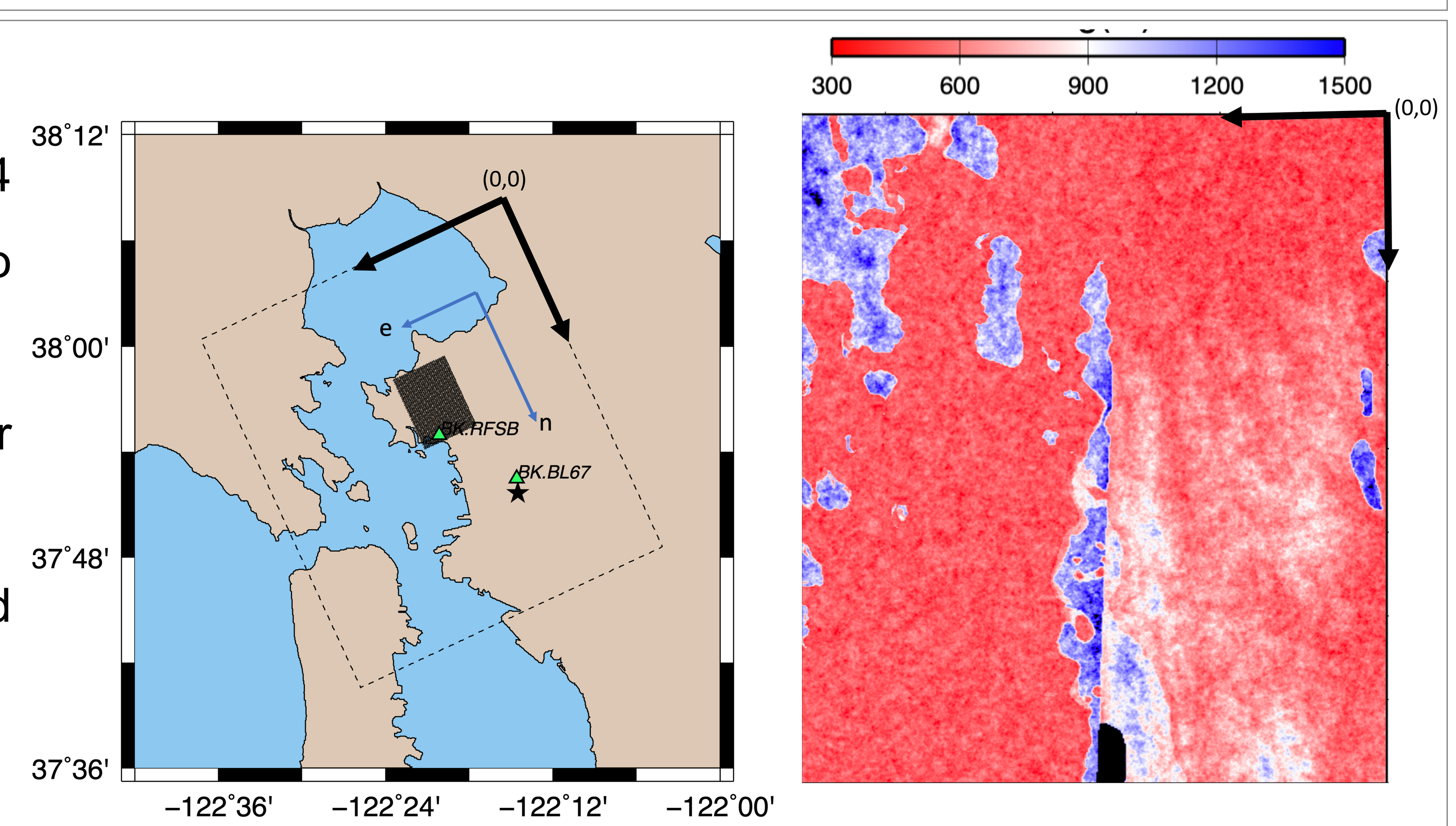
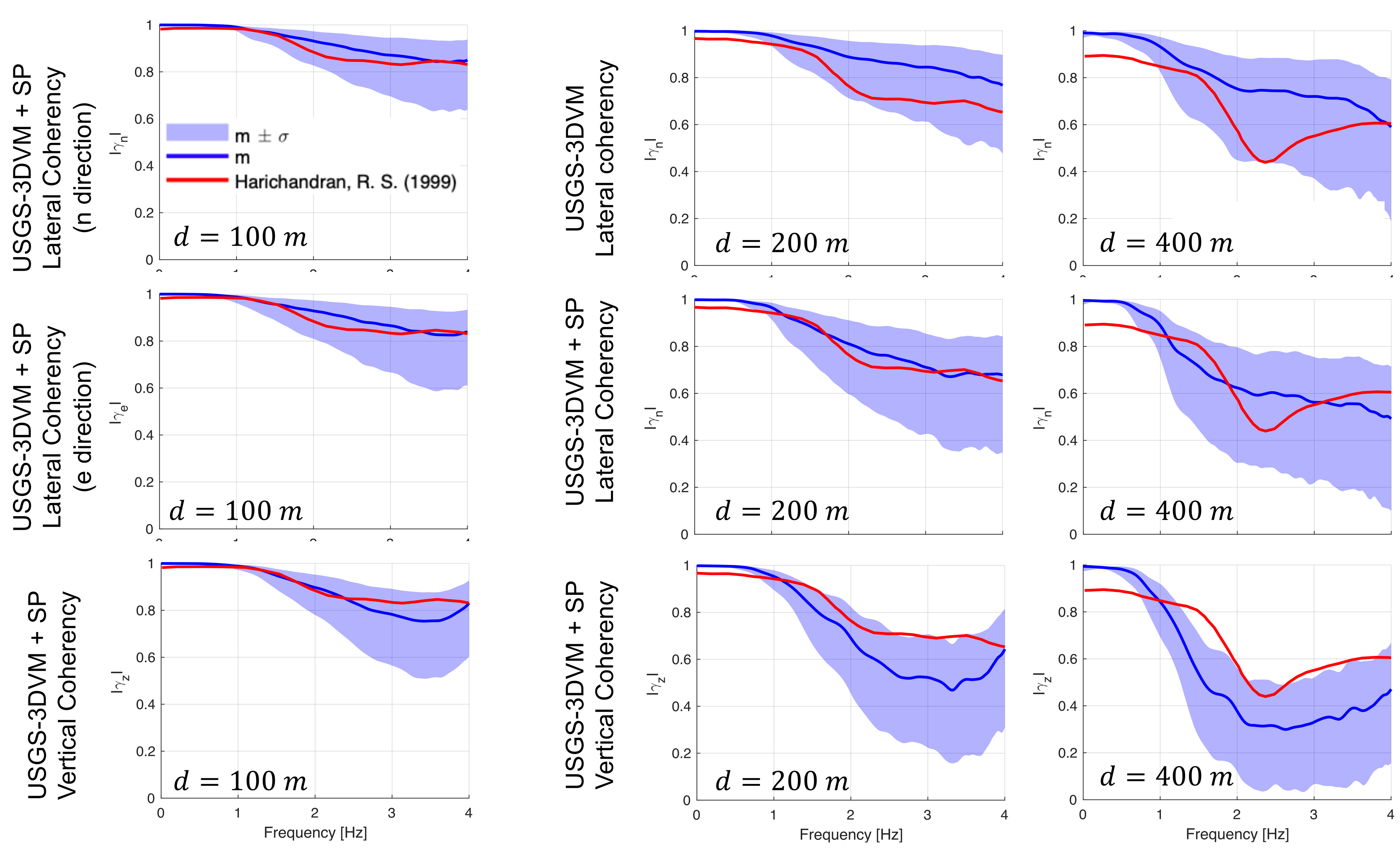


Figure 3: (a) Simulation region in SF Bay Area; (b) Velocity map [m/s] at surface (USGS-3DVM + SP).

3. Numerical Results



- The mean and standard deviations of the computed coherencies in directions n, e, and z are first evaluated in the log space and then transformed back to the linear space. The average results are compared to a set of empirically computed coherency values at SMART 1 array (Figure 2).

4. Discussion and Future Work

The analyses performed to-date suggest that:

- ✓ The coherency can decrease considerably in the frequency range of 0-4Hz and at a spatial distancing of less than 500m.
- ✓ Vertical components of the simulated ground motions show stronger incoherency compared to their horizontal counterparts.
- ✓ Inclusion of small-scale correlated stochastic perturbations in the velocity structure tend to reduce the ground motion coherency.

Future analyses will be focused on:

- expanding the parameter space to study the effects of (1) earthquake magnitude, (2) rupture to site distance, and (3) basin and topography structures on spatial variation of computed coherency at short distances.
- studying the changes in coherency as a function of depth, which are important for analysis of soil-structure interaction problems.

[1] Harichandran, R. S. (1999). Spatial variation of earthquake ground motion, what is it, how do we model it, and what are its engineering implications. Dept. of Civil and Environmental Engineering, Michigan State Univ., East Lansing, Mich.

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