Sensitivity Tests of Detailed Shear-Wave Velocity Profiles to 95 m Depth in 3D Numerical Simulations of Wave Propagation to 15 Hz Frequency, Clark County, Nevada

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Wednesday, June 27th, TT026. Ground Motion Simulations for Engineering
MOTIVATION:

• Including small-scale heterogeneous structures (meter-scale) is important for high frequency numerical methods based simulations (> 10 Hz)

• Vs30 has a “smoothing” effect - underestimates ground motion amplification
OBJECTIVE:

1. Simulate ground motions up to 15 Hz frequency for:

   • **DETAILED VELOCITY MODELS** that contain 3D small-scale heterogeneous velocity structures down to 30 m and 95 m depth

   • **Vs30 VELOCITY MODEL** that incorporates Vs30

2. Perform sensitivity tests using Fourier Spectral Ratio (FSR) between the **DETAILED** and **Vs30** models
BACKGROUND: 3D numerical methods

We used the SW4 (Sjögreen and Petersson, 2012; Petersson and Sjögreen, 2014)

- **Advantage:** Material models include the spatial distribution of 3D geology

- **Disadvantage:** Hampered by computational restrictions at high frequency

Higher frequency calculations can be obtained with the same computational effort, simply by reducing the grid spacing over a reduced volume (Larsen et al., 2001)

An example of an SW4 simulation: Black Hills Fault, M6.5 Scenario (waveform displacement on left) and (basin depth form gravity on right) (Louie, 2011)
BACKGROUND: site class at parcel level

Clark County Parcel Map (CCPM), Pancha et al. (2017)

- > 10,700 1D Vs Profiles
- Site class was modeled over a 1500 Km² area
- data-density = 1/20 acres
- Available to the public at http://gisgate.co.clark.nv.us/openweb/

Modified from Pancha et al. (2017)
METHODS: Project Site and Criteria

• Sensitivity tests based on subset of CCPM
• Vs profiles = 27
• Vs30 = 318 to 445 m/s
• 3m grid spacing = 143E6 nodes
  Frequency range = 0.6Hz - 15Hz

Depth to basement from (Langenheim et al 1998; 2001)
METHODS: Three material models

Three separate models:

Vs30 - includes the Vs30 as a laterally variable geotechnical layer with a constant thickness of 30 m.

(top 30 m of the model space)

Geo30 - includes the 3D heterogeneous velocity structure interpolated from the SWVPs down to 30 m.

(top 30 m of the model space)

Geo95 - includes the 3D heterogeneous velocity structure interpolated from the SWVPs down to 95 m.

(top 95 m of the model space)
METHODS: Material model: RockWorks17® generated Vs-volume (95 m depth)
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METHODS: Simulations: Geo95, Geo30 and Vs30

All simulations use the C6SmoothBump source time-function as a single-point-source double-couple with a 10º strike, 70º dip, and -90º rake, for the Eglington normal fault #1733. Central frequency of 7.5 and Mw -3.01 correlating to a seismic moment M0 of 3,800 N-m.
METHODS: Simulations: Geo95, Geo30 and Vs30

Legend
- Station
- Hypocenter

Wave energy being channeled and focused by the complex basement structure
RESULTS: Sensitivity Tests: Fourier spectral ratio (FSR)

Smoothed Fourier Amplitude Spectra (FAS) are calculated for the X and Y component at each station for each model type, resulting in 6 total separate FAS

Fourier spectral ratio (FSR) combinations:
1-Geo95/Vs30 x-component
2-Geo95/Vs30 y-component
3-Geo30/Vs30 x-component
4-Geo30/Vs30 y-component

Effectively a qualitative analysis
RESULTS: Sensitivity Tests: Fourier spectral ratio (FSR)

Average FSR all stations Geo95/Vs30 X-components

Average FSR all stations Geo95/Vs30 Y-components

Average FSR all stations Geo30/Vs30 X-components

Average FSR all stations Geo30/Vs30 Y-components
RESULTS: Sensitivity Tests: Fourier spectral ratio (FSR)

detailed models amplifying ground motions at high frequency
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Vs30 resonance frequencies

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RESULTS: Sensitivity Tests: Fourier spectral ratio (FSR)

- **Average FSR all stations Geo95/Vs30 X-components**
- **Average FSR all stations Geo30/Vs30 X-components**
- **Average FSR all stations Geo95/Vs30 Y-components**
- **Average FSR all stations Geo30/Vs30 Y-components**

**Vs30 resonance frequencies**

**Only slight SA at Vs30 resonant frequencies**

**detailed models amplifying ground motions at high frequency**

Legend:
- Standard deviation of FSR
- Average of 27 FSR
RESULTS: Sensitivity Tests: Fourier spectral ratio (FSR)

Extra 45 m causes trough at Vs30 resonant frequencies

Only slight SA at Vs30 resonant frequencies

detailed models amplifying ground motions at high frequency

Vs30 resonance frequencies
Conclusions

• Including small-scale heterogeneous structures in the near surface is essential for high frequency numerical simulations and can be achieved over reduced computational grids

• FSR trends of amplification establish that the detailed models increase ground motions by roughly 50% above the simple Vs30-layer model at frequencies higher than 4.6 Hz

• FSR analysis demonstrates that when the Vs30 layer is replaced with the full detailed Vs profile information there is no effect below and only limited effect at the 30-meter resonance frequencies

• The extra 45 m of detailed velocity structure is causing the Vs30 models to amplify ground motions beyond the detailed models at the Vs30 resonance frequencies, while having the opposite effect below.
Future work and considerations:

- Implement a more realistic source (i.e. a vertically propagating plane wave from the bottom of the volume)
- Perform finite element simulations such as SPECFEM 3D
- Validate against recorded empirical data
Questions?