Local scale numerical simulations of shallow site effects: A case study of Christchurch, New Zealand

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Overview

• Shallow Site Effect at Heathcote Valley, Christchurch

• Shallow Site Effect at Mt Pleasant, Christchurch

• Incorporating Soil Nonlinearity into Physics-Based Ground Motion Simulation

• SeisFinder: A web interface for extracting simulated motions

• Refinement to the NZVM in Canterbury

• Ongoing development of NZVM
Shallow Site Effect at Heathcote Valley, Christchurch

Observed ground motions: M7.2 2010 Darfield Earthquake

Source: Earthstar Geographics
Shallow Site Effect at Heathcote Valley, Christchurch

Site characterisation

- 15 sCPT, 15 ambient noise HVSR, 5 surface wave tests
- Lidar-based DEM to account for topography
- Soil thickness profile from CPT refusal depths and the estimated depths from H/V spectral ratios

Numerical model

- 2D finite element simulations using OpenSees; $f_{\text{max}} \approx 25\text{Hz}$
- Deconvolved LPCC motion as plane wave input
- Non-reflective boundaries; equivalent force input at the base of the model
- PDMY model (UCSD) for soils and the linear elastic model for rocks
- Soil: $\rho = 1.8\text{Mg/m}^3$, $V_S = 207z^{0.25}\text{m/s}$, $\phi = 36^\circ$, $\nu = 0.25$
- Weathered rock: $\rho = 2.4\text{Mg/m}^3$, $V_S = 800\text{m/s}$, $\nu = 0.25$
- Rock: $\rho = 2.4\text{Mg/m}^3$, $V_S = 1500\text{m/s}$, $\nu = 0.25$
Shallow Site Effect at Heathcote Valley, Christchurch

**Result and Discussions**

- **Good agreement**
- **Strong amplification due to a high impedance contrast**
- **Large variability in f > f_0, due to the soil nonlinear response**

\[ r = \log(\frac{SA_{\text{Obs}}}{SA_{\text{Sim}}}) \]

- Empirical model shows large residuals; regional-scale ground motion simulations show improved residuals in long periods, but still poor in short periods
- The 2D local-scale Heathcote Valley site response model outperforms the empirical model and the regional-scale ground motion simulation
Shallow Site Effect at Heathcote Valley, Christchurch

Result and Discussions

- Strong nonlinear soil response affects the motions in $T < T_0 = 0.3$ s
Shallow Site Effect at Mt Pleasant, Christchurch

**Instrumentation**
Nine portable seismometers in Mt Pleasant and Heathcote Valley, for March-April 2017, recording more than ten distant earthquakes

**Site Characterisation**
Basin geometry estimated from HVSR; Basin Vs from sCPT; Rock Vs from published data

**Numerical Simulation**
2D finite difference method using FLAC2D; Linear elastic material models; Vertically and obliquely incident plane waves

Mohammadi et al. (Poster #243)
Shallow Site Effect at Mt Pleasant, Christchurch

Result

• **Demonstration of the topographic effect** in Mt Pleasant, and its potential role in the localised damage observed in Port Hills; observed and simulated topographic amplification comparable to previous studies

• **Good predictability through quantitative validation** of the numerical model against the observed data

• **Challenge in finding a good reference station**: the apparent amplification (up to a factor of 2) at f=1.6Hz is combined effect of crest amplification and the toe de-amplification
Incorporating Soil Nonlinearity into Physics-Based Ground Motion Simulation

The workflow

Step 1: 3D viscoelastic simulation

Step 2: Viscoelastic deconvolution

Step 3: Nonlinear site response

de la Torre et al. (2017)
Incorporating Soil Nonlinearity into Physics-Based Ground Motion Simulation

Three representative sites in Christchurch

- **Stiff Site**
  - No Improvement over the empirical approach

- **Intermediate Site**
  - Moderate Improvement

- **Large Impedance Contrast**
  - Significant Improvement

![Graph showing residuals and periods for CACS, RHSC, and HVSC sites]
SeisFinder: A web interface for extracting simulated motions

- Allows users to extract simulations on an event- or site-specific basis

- Higher-resolution site characterisation is likely obtained as part of infrastructure projects

- SeisFinder allows subsurface extraction so that site-specific near-surface simulation using this additional characterisation is possible after the 3D regional GM simulation
Refinement to the NZVM in Canterbury

Typical Vs profile in Canterbury

Fitted power law models

Thomson et al. (2017)
Refinement to the NZVM in Canterbury

**Kriged surfaces of between-site residuals**

Step by step for generating Vs profile

1) Applying the baseline power models to each geologic layer

2) Interpolate to obtain spatial residual (site correction factor – the between site residual) at the site and correcting the baseline power model by this value

3) Generate a covariance matrix using the vertical semivariogram. Apply the covariance matrix to generate random correlated velocity perturbations with depth

Thomson et al. (2017)
Ongoing development of NZVM

Development and refinement of the velocity models, using geophysical and geotechnical testing methods, existing well logs and geology maps, in addition to the existing model by Eberhart-Phillips et al. (2010).
Thank you!