Simulation and Validation of Topographic Effects on Mt Pleasant, Christchurch, New Zealand

Kami Mohammad\textsuperscript{a}, Seokho Jeong\textsuperscript{b}, Domniki Asimaki\textsuperscript{a}, and Brendon A. Bradley\textsuperscript{c}

\textsuperscript{a} Department of Mechanical and Civil Engineering, California Institute of Technology. \textsuperscript{b} QuakeCoRE, University of Canterbury. \textsuperscript{c} Department of Civil and Natural Resources Engineering, University of Canterbury

Abstract

Damage distribution maps from strong earthquakes and recorded data from field experiments have repeatedly shown that the ground surface topography and subsurface stratigraphy play a decisive role in shaping the ground motion characteristics at a site. Published theoretical studies qualitatively agree with observations from past seismic events and experiments; quantitatively, however, they systematically underestimate the absolute level of topographic amplification up to an order of magnitude or more in some cases. We have hypothesized in previous work that this discrepancy stems from idealizations of the geometry, material properties, and incident motion characteristics that most theoretical studies make. In this study, we perform numerical simulations of seismic wave propagation in heterogeneous media with arbitrary ground surface geometry, and compare results with high quality field recordings from a site with strong surface topography. Our goal is to explore whether high-fidelity simulations and realistic numerical models can – contrary to theoretical models – capture quantitatively the frequency and amplitude characteristics of topographic effects. For validation, we use field data from a linear array of nine portable seismometers that we deployed on Mount Pleasant and Heathcote Valley, Christchurch, New Zealand, and we compute empirical standard spectral ratios (SSR) and single-station horizontal-to-vertical spectral ratios (H/V SSR). The instruments recorded ambient vibrations and remote earthquakes for a period of two months (March-April 2017). We next perform two-dimensional wave propagation simulations using the explicit finite difference code FLAC. We construct our numerical model using a high-resolution (8m) Digital Elevation Map (DEM) available for the site, an estimated subsurface stratigraphy consistent with the geomorphology of the site, and soil properties estimated from invulsive and non-destructive tests. We subject the model to incident and out-of-plane incident motions that span a broadband frequency range (0.1-20Hz). Numerical and empirical spectral ratios from our blind prediction are found in very good agreement for stations on the slope of Mount Pleasant and on the surface of Heathcote Valley, Christchurch, across a wide range of frequencies that reveal the role of topography, soil amplification and basin edge focusing on the distribution of ground surface motion.

Prelude

Temporal Characteristics

Spectral Characteristics

Wavefield Snapshots

Postlude

- The characteristic length ($L_{ch}$) of the scatterer (topography + basin) normalized by incident wavelength – aka dimensionless frequency ($f_{ch}$) – determines the response of the feature. We may define three different types of response over the whole range of frequency:

  1. $R_{c}$: Incident SV wave reaches the scatterer (i.e., the basin).
  2. $R_{t}$: Rayleigh wave of the same scattering pattern as that of irregular homogenous basin.
  3. $R_{s}$: Scattering at the basin.

- The characteristic length ($L_{ch}$) of the scatterer (topography + basin) normalized by incident wavelength – aka dimensionless frequency ($f_{ch}$) – determines the response of the feature. We may define three different types of response over the whole range of frequency:

  1. $R_{c}$: Incident SV wave reaches the scatterer (i.e., the basin).
  2. $R_{t}$: Rayleigh wave of the same scattering pattern as that of irregular homogenous basin.
  3. $R_{s}$: Scattering at the basin.

- This study shows that using a simple 2D model – whose material properties and geometry are carefully extracted from in-situ and non-destructive tests as well as DEM data – can reliably determine the true response of the topographic feature over the entire frequency range.

- This study shows that using a simple 2D model – whose material properties and geometry are carefully extracted from in-situ and non-destructive tests as well as DEM data – can reliably determine the true response of the topographic feature over the entire frequency range.

- This study shows that using a simple 2D model – whose material properties and geometry are carefully extracted from in-situ and non-destructive tests as well as DEM data – can reliably determine the true response of the topographic feature over the entire frequency range.

- This study shows that using a simple 2D model – whose material properties and geometry are carefully extracted from in-situ and non-destructive tests as well as DEM data – can reliably determine the true response of the topographic feature over the entire frequency range.

- This study shows that using a simple 2D model – whose material properties and geometry are carefully extracted from in-situ and non-destructive tests as well as DEM data – can reliably determine the true response of the topographic feature over the entire frequency range.

- This study shows that using a simple 2D model – whose material properties and geometry are carefully extracted from in-situ and non-destructive tests as well as DEM data – can reliably determine the true response of the topographic feature over the entire frequency range.

- This study shows that using a simple 2D model – whose material properties and geometry are carefully extracted from in-situ and non-destructive tests as well as DEM data – can reliably determine the true response of the topographic feature over the entire frequency range.

- This study shows that using a simple 2D model – whose material properties and geometry are carefully extracted from in-situ and non-destructive tests as well as DEM data – can reliably determine the true response of the topographic feature over the entire frequency range.

- This study shows that using a simple 2D model – whose material properties and geometry are carefully extracted from in-situ and non-destructive tests as well as DEM data – can reliably determine the true response of the topographic feature over the entire frequency range.

- This study shows that using a simple 2D model – whose material properties and geometry are carefully extracted from in-situ and non-destructive tests as well as DEM data – can reliably determine the true response of the topographic feature over the entire frequency range.

- This study shows that using a simple 2D model – whose material properties and geometry are carefully extracted from in-situ and non-destructive tests as well as DEM data – can reliably determine the true response of the topographic feature over the entire frequency range.

- This study shows that using a simple 2D model – whose material properties and geometry are carefully extracted from in-situ and non-destructive tests as well as DEM data – can reliably determine the true response of the topographic feature over the entire frequency range.

- This study shows that using a simple 2D model – whose material properties and geometry are carefully extracted from in-situ and non-destructive tests as well as DEM data – can reliably determine the true response of the topographic feature over the entire frequency range.

- This study shows that using a simple 2D model – whose material properties and geometry are carefully extracted from in-situ and non-destructive tests as well as DEM data – can reliably determine the true response of the topographic feature over the entire frequency range.

- This study shows that using a simple 2D model – whose material properties and geometry are carefully extracted from in-situ and non-destructive tests as well as DEM data – can reliably determine the true response of the topographic feature over the entire frequency range.

- This study shows that using a simple 2D model – whose material properties and geometry are carefully extracted from in-situ and non-destructive tests as well as DEM data – can reliably determine the true response of the topographic feature over the entire frequency range.

- This study shows that using a simple 2D model – whose material properties and geometry are carefully extracted from in-situ and non-destructive tests as well as DEM data – can reliably determine the true response of the topographic feature over the entire frequency range.