Methods for Incorporating Soil Nonlinearity in Ground Motion Simulation

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1. Background

This poster discusses several possible approaches by which the nonlinear response of surficial soils can be explicitly modelled in physics-based ground motion simulations, focusing on the relative advantages and limitations of the various methodologies. These methods include fully-coupled 3D simulation models that directly allow soil nonlinearity in surficial soils, the domain reduction method for decomposing the physical domain into multiple subdomains for separate simulation, conventional site response analysis uncoupled from the simulations, and finally, the use of simple empirically-based site amplification factors

We provide the methodology for an ongoing study to explicitly incorporate soil nonlinearity into hybrid broadband simulations of the 2010-2011 Canterbury, New Zealand earthquakes.

2. Ongoing and future study

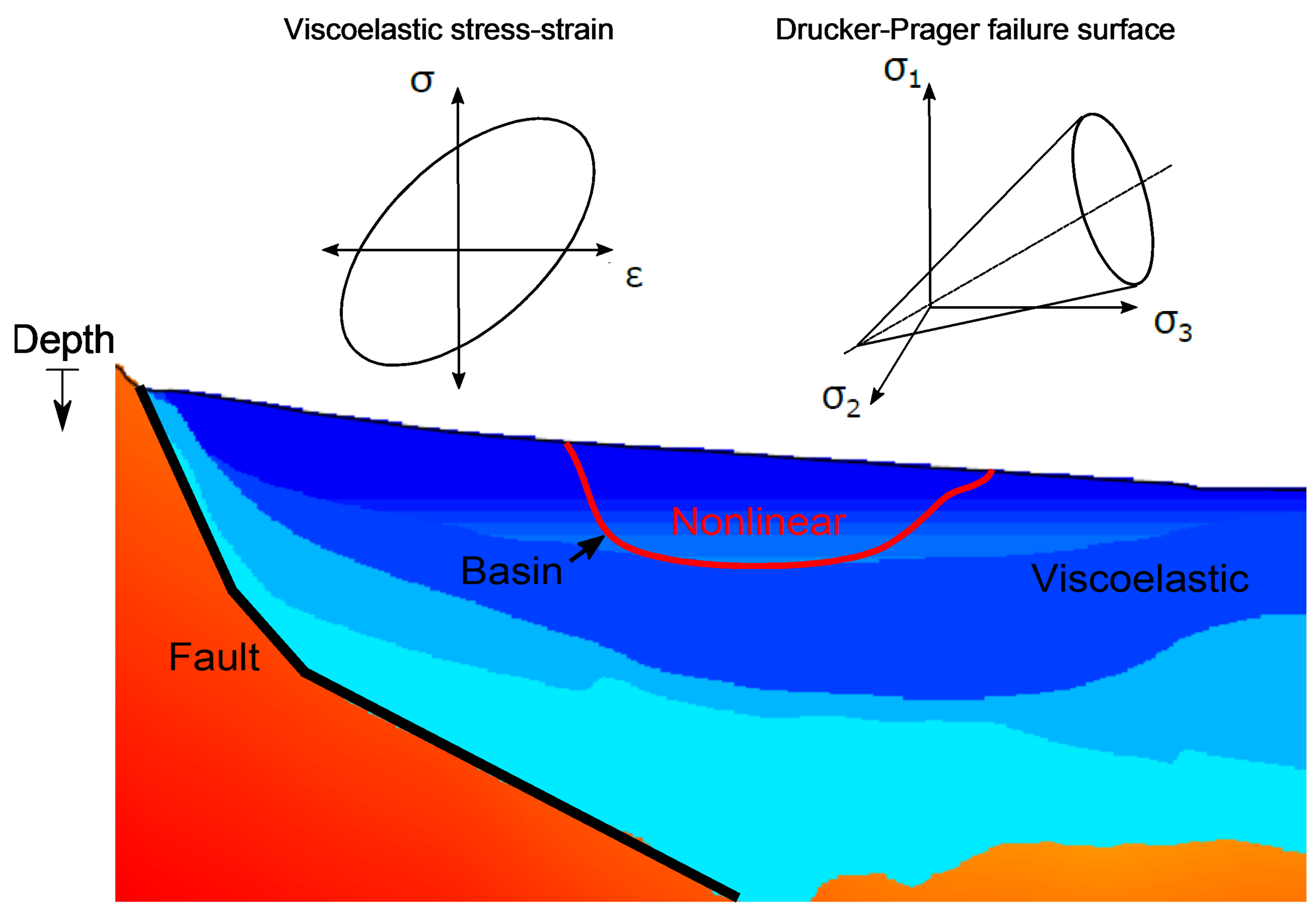
To incorporate soil nonlinearity into simulations of the Canterbury earthquakes we will follow the uncoupled approach with 1D-3D (i.e., 1D wave propagation and 3D soil response) total- and effective-stress site response analysis. Unlike previous studies, which have only considered a 1D and 2D soil stress state in the site response analysis, we will utilize 3D soil constitutive models.

Broadband ground motions from 3D hybrid simulations will be deconvolved, and used as input to the site response analysis. We will analyze 17 well-characterized strong motion stations in Christchurch that recorded the earthquakes. With a large dataset of recorded strong ground motions, we are able to compare observed ground motions to the ground motion simulations based on site response analysis as well as conventional empirical site effects modeling via 30m-averaged shear wave velocity.

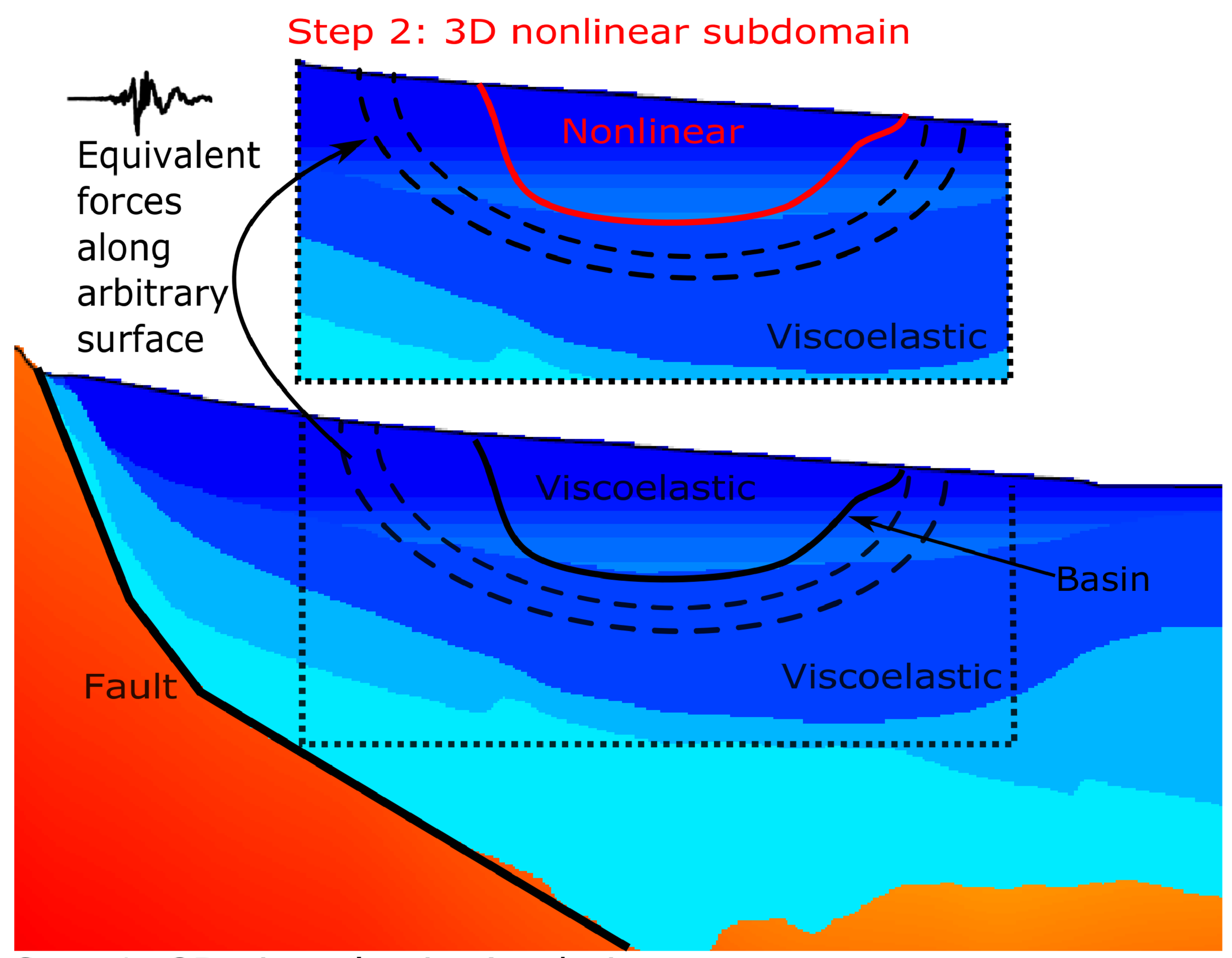
3. Comparison of physics-based methods for explicitly considering nonlinear site response

Schematic

Fully-coupled nonlinear simulation

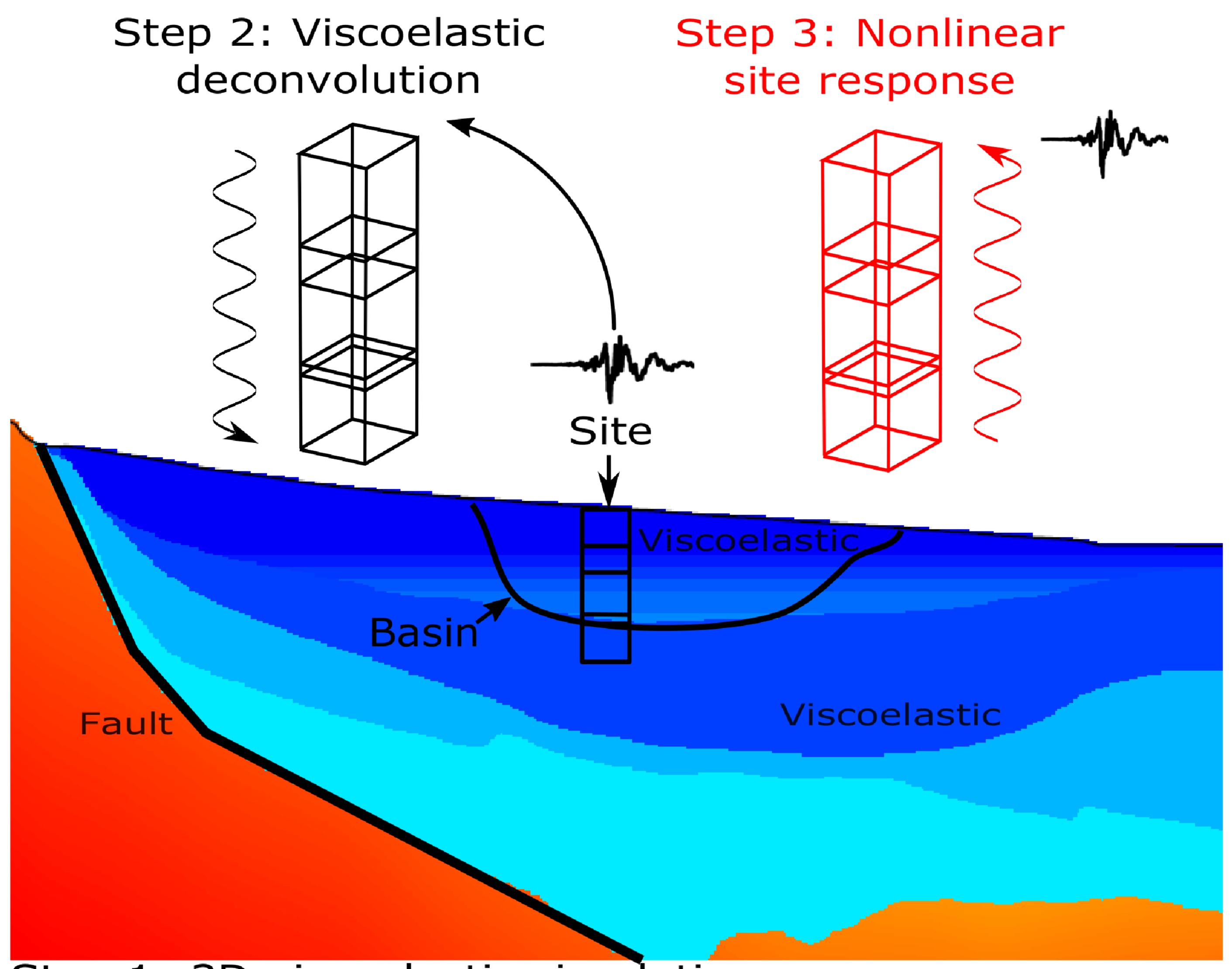


Domain reduction method



Step 1: 3D viscoelastic simulation

Uncoupled with 1D-3D surficial site response



Step 1: 3D viscoelastic simulation

Methodology

Fully-coupled nonlinear simulation
- Nonlinear modelling of soils above threshold depth or below threshold V_s within ground motion simulation model. [Xu et al (2003), Taborda and Bielak (2009), Taborda, Bielak and Restrepo (2012)].

Domain reduction method
- Decompose domain as: 1) viscoelastic model with the seismic source, and 2) subdomain with detailed nonlinear site conditions. Equivalent forces from Step 1 applied on arbitrary surface in subdomain. [Bielak et al (2003), Yoshimura et al (2003)].

Uncoupled with 1D-3D surficial site response
- Extract simulated ground motions from 3D model, deconvolve, and input into 1D-3D site response column (i.e., 1D wave propagation and 3D soil response). Existing applications are a subset of this generalized approach, and include equivalent linear, and total- and effective-stress nonlinear analyses. [Roten, Olsen, and Pechmann (2012), Hartzell et al (2002)].

Advantages

Fully-coupled nonlinear simulation
- Single model captures rupture physics, site-to-source path, and nonlinear site effects.
- Effect of soil nonlinearity on the 3D spatial variability of ground motion.

Domain reduction method
- Allows for iteration and sensitivity analysis of soil and geologic conditions in smaller subdomain.
- Effect of soil nonlinearity on the 3D spatial variability of ground motion.

Uncoupled with 1D-3D surficial site response
- Captures 3D effects and complex nonlinear soil behaviour (e.g., hardening, pore-pressure generation, and phase-transformation).
- Rapid iteration in 1D wave propagation using detailed constitutive models.
- Detailed geotechnical site investigation and characterization can be performed subsequent to simulations from Step 1.

Disadvantages

Fully-coupled nonlinear simulation
- A single modelling software generally does not have state-of-the-art models for all portions of the problem; often over-simplified soil constitutive models are used.
- Site-specific detailed geotechnical investigation and site characterization required before simulations are performed.

Domain reduction method
- Non-trivial to compute equivalent forces along arbitrary surface.
- Not effective for very large geologic features (e.g., deep basins).
- Complications with computational performance and scalability for regional-scale simulations.

Uncoupled with 1D-3D surficial site response
- Does not model effect of nonlinearity on 3D spatial variability of ground motion.
- Two separate analyses required with an intermediate step to deconvolve.