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Resilience Through Community Engagement and Technology

Development of a Unified Database of Hybrid Broadband Ground-Motion Simulations for Historical Mw 3.5-7.8 Crustal and Subduction Earthquakes in New Zealand

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ABSTRACT

Validating ground-motion simulations against observations from past earthquakes is essential to improve their accuracy and precision and enable their use in engineering applications. We present the development of a database of hybrid broadband ground-motion simulations for historical Mw 3.5-7.8 crustal and subduction earthquakes in New Zealand, with unified simulation input models and parameters. Based on an unprecedented amount of validation data, this open-access database enables a comprehensive examination of simulation residuals and systematic comparison with conventional empirical ground-motion models, representing a significant contribution to ongoing efforts to validate and improve ground-motion simulation methodologies.

Introduction

Ground-motion simulation can be used in seismic hazard and response-history analyses, offering significant potential advantages over empirical models currently used in practice to predict earthquake-induced ground motion. However, validation against observations from historical events is necessary to build confidence in the predictive capabilities of simulations and identify areas for modeling improvements.

Recent Validation Studies in New Zealand and Other Regions

Figure 1 summarizes recent validation studies conducted in New Zealand (NZ) using the Graves and Pitarka hybrid broadband simulation method (GP method [1]) and large datasets of recordings [2-7]. While these individual studies have provided valuable insights and improvements in simulations based on subsets of the available observational data, a large-scale dataset, based on unified simulation input models and parameters, is needed to fully assess and enhance simulation performance across a wider range of earthquake types and

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site conditions. The individual studies presented in Figure 1 have adopted several different input models and datasets, including different 3D velocity models, site amplification factors, and observational databases. For example, Lee et al. (2022) [2] used the New Zealand Velocity Model (NZVM) [8] v.2.02, which includes eight explicitly modeled sedimentary basins, while the most recent validation studies [5, 7] use v2.09, containing 45 modeled basins [9, 10].

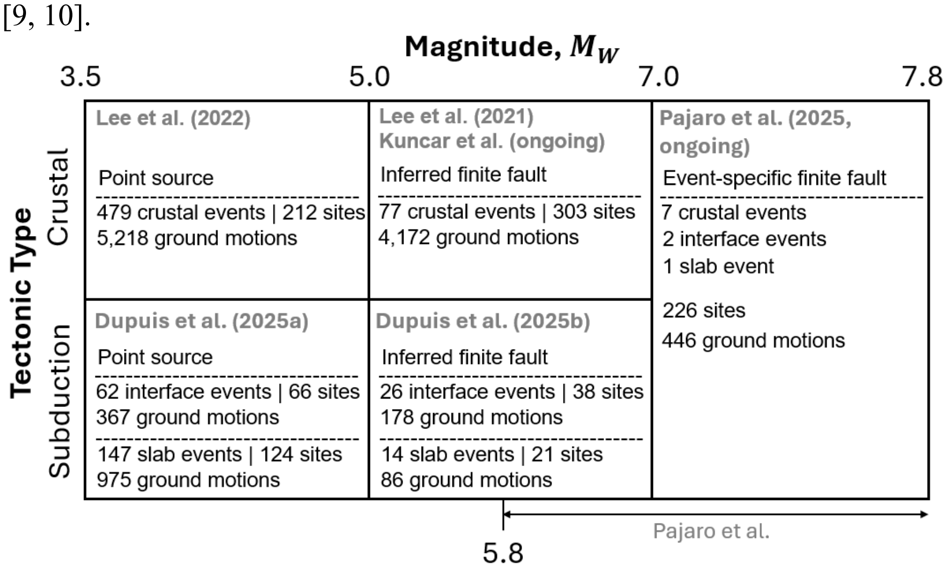

Figure 1. Recent validation studies in NZ using large recording datasets [2-7], spanning small to large magnitudes and both crustal and subduction events.

Similar validation studies have been performed in other regions, such as California and Italy [11-13]. However, these studies have been primarily focused on small-to-moderate crustal earthquakes and have generally included a significantly lower number of earthquakes and ground motions than those in NZ. For example, to the best of the authors' knowledge, the largest published validation study outside of NZ considered 30 Mw 3.6-5.4 events [11].

Selected Ground Motions for a Unified Database

In this work, we present the development of a unified database of ground-motion simulations for historical Mw 3.5-7.8 crustal and subduction earthquakes in NZ. The ground motions are selected from the latest version of the NZ ground-motion database (NZ GMDB v4.3, [14]); particularly, from the quality-screened dataset. In addition, several filters are applied to generate an appropriate dataset for simulation and validation. These filters are described in Table 1 along with the resulting number of events, sites, and ground motions after applying them. This filtering results in 1,690 events, with 45,764 recordings at 383 sites available for validation. The spatial distribution of these earthquake sources and strong-motion station sites is presented in Figure 2. The most significant feature of this simulated dataset is that it represents all events in NZ that are considered suitable for ground-motion model development from an engineering-oriented perspective. As a result, it will enable a comprehensive assessment of model predictive capability for both simulation-based and conventional empirical ground-motion models across all viable ground motion scenarios of interest (e.g., from Mw=3.5-7.8; R_{rup}=0-300 km, etc.). This will overcome a valid criticism of all prior ground-motion simulation validation studies to date, in that they considered significantly smaller datasets than are conventionally used in empirical ground-motion model development (e.g., number of ground-motions, events, and range of predictor variables of relevance).

Methods and Database Output

Simulations are performed using the GP method, with a grid spacing of 100 m, a transition frequency of 1 Hz between the low-frequency (LF) and high-frequency (HF) simulation components, and the NZVM v2.09 [9, 10]. In addition to paired observed and simulated waveforms, the database includes several intensity measures of engineering interest computed for the simulations, the corresponding observations, and state-of-the-art empirical models. The database also provides all relevant input parameters used in the simulations.

Conclusions

We presented the development of an open-access database of ground-motion simulations for historical events in NZ. This database provides the most extensive set of simulated ground motions for observed events to date, enabling systematic validation of the hybrid ground-motion simulation method. It also facilitates testing of different modeling features, including alternative site adjustment approaches [e.g., 15], HF simulation methods [e.g., 12], and their parameters [e.g., 16]. This database will ultimately contribute to advancing the predictive capability of ground-motion simulations and their increasing adoption in engineering practice.

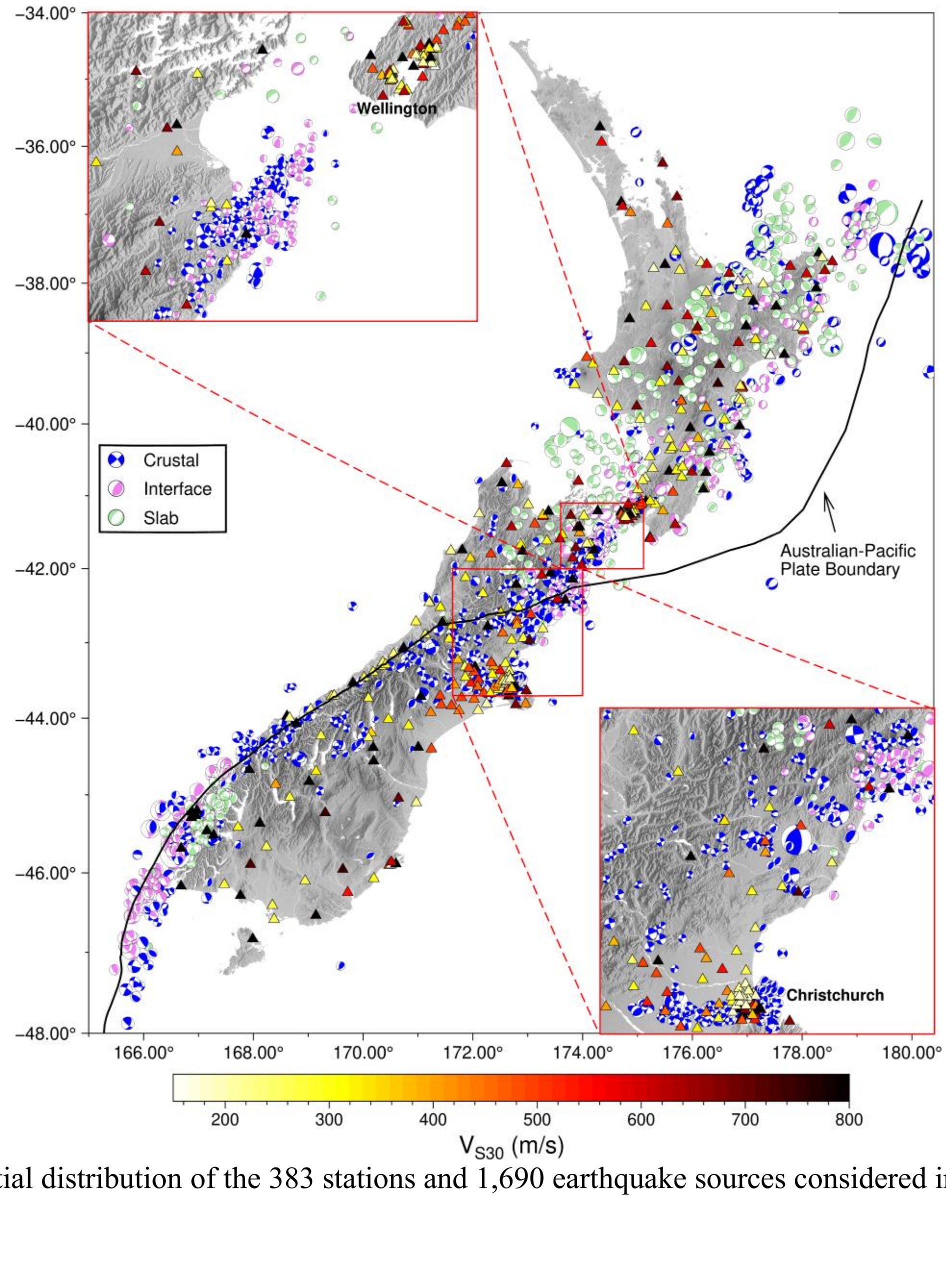

Figure 2. Spatial distribution of the 383 stations and 1,690 earthquake sources considered in the database.

Table 1. Selection of ground motions for simulation.

Filter	No. of Events	No. of Sites	No. of Ground Motions
High-quality recorded ground motions	3,928	389	77,318
Tectonic classification (Crustal, Interface, and Slab)	3,554	388	73,354
Earthquakes with a CMT solution	1,823	386	54,779
Mw ≥ 3.5	1,822	386	54,766
At least 1 record within the simulation domain	**1,690**	**383**	**45,764**

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