SPEED: a new numerical code for 3D modeling of the site-city interaction effect

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Introduction

New Zealand *Canterbury Plains* *Christchurch*

Between September 2010 and December 2011 the Canterbury Plains and, in particular, the city of Christchurch, in the South Island of New Zealand, experienced four major earthquakes with $M_W \geq 6.0$ and a huge number of aftershocks. The most damaging and deadliest of the seismic sequence, a M_W 6.2 earthquake, happened on 22 February 2011, struck the city and the suburbs of Christchurch, causing extensive destruction and more than 180 victims

The availability of an unprecedented dataset of near fault strong ground motion, combined with the peculiar geological configuration of the Christchurch area, makes the 22nd February M_W 6.2 Christchurch earthquake a relevant benchmark to test the effectiveness of 3D numerical tools for the prediction of the variability of strong ground motion in near fault conditions..

Objectives

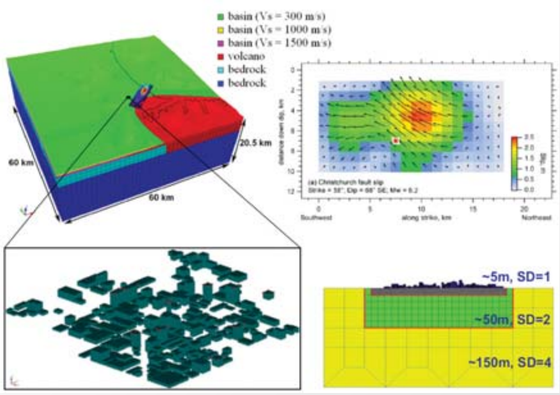
The main objective of this work is to tackle the multi scale wave propagation problem of the 22 February 2011 Christchurch earthquake. The computational model includes the coupled effects of the seismic source, the propagation path through complex geological structures and localized superficial irregularities, such as alluvial basins or/and man-made infrastructures. Accounting for all these features within a single model still poses challenging demands on computational methods and resources due to the coexistence of very different spatial scales, from a few tens of kilometers, with reference to the seismic fault, up to a few meters, or even less, when considering some structural elements. Relying on discontinuous Galerkin techniques, the numerical code SPEED (https://speed.mox.polimi.it) allows us to deal with a non-uniform polynomial degree distribution (*p-adaptivity*), as well as a locally varying mesh size (*h-adaptivity*). Such a flexibility can be used in seismic wave propagation problems to remove the constraint that element faces should have the same shape and size in regions characterized by different mechanical properties, saving computational time and preserving the accuracy. Understanding and quantifying these effects in a fully coupled 3D numerical model is an open problem that has been addressed only by a few studies. This application, made possible by the performance features of the code SPEED, represents a step further in promoting a novel "from-the-seismic-source-to-the-structure" multi-scale computing approach for seismic risk assessment.

From Canterbury Plains to Christchurch Business District (CBD)

The regional model of the Canterbury Plains combines:
i) a horizontally layered crustal model;
ii) a simplified model for the alluvial plain;
iii) a description of the transition between the alluvial sediments and the volcano materials;
iv) a kinematic finite fault model for the seismic source.

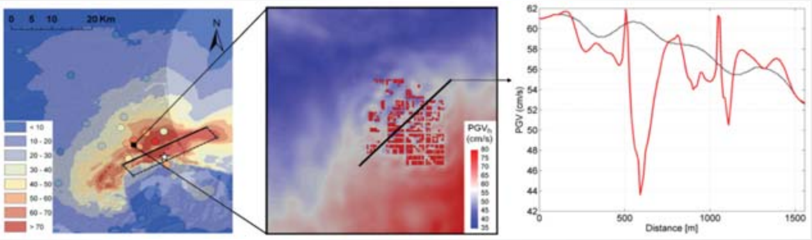
The regional model has dimension of 60x60x20 km, including the city of Christchurch, part of the Canterbury Plains and of the Banks Peninsula. The mesh (designed by CUBIT software https://cubit.sandia.gov) consists of about 1 million of elements, with size ranging from a minimum of about 150 m, at surface, up to 1,500 m, at bedrock.

The CBD has been modeled, taking information on height and floor-plan dimensions of the cluster of about 150 buildings, in an area having dimension of 1 x 1 km. Also the foundations, for a depth of 10 m, and the soil around foundations, for a depth of 50 m, have been considered.



3D model of the Canterbury Plains with the seismic source model adapted from a press release by the GNS (New Zealand Institute of Geological and Nuclear Sciences).

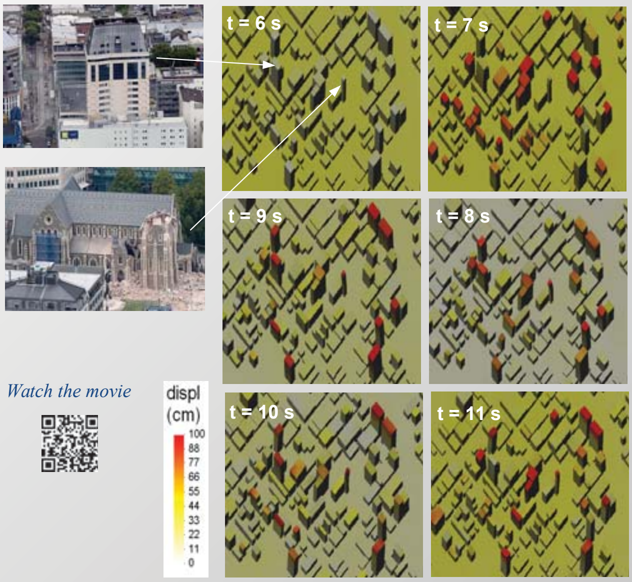
Results



Recorded (filled dots) vs. synthetic peak ground velocity (PGV) map, with zoom on the Christchurch CBD. In the chart peak ground velocity taken along the South-West, North-East direction across the CBD, considering (red line) or not (black line) the presence of the city

The simulations have been done with the software package SPEED. The complexity of the seismic wave propagation is fully considered at a Site-City scale, where the Central Business District (CBD) of Christchurch is geometrically represented and numerically modeled.

Looking at the spatial variability of the peak ground motion, the cluster of buildings plays not only a passive role, but active, as source area, consisting of a large number of closely spaced sources of translational and rotational motions. The wave passage effect, characterized by a strong ground motion differing from point to point, produces translational and rotational motions at the bases that could be in counter phase, with high level of damage in pounding-prone compounds of buildings. This work allowed us to highlight the role of numerical simulations in seismic hazard assessment studies and about the future development of this topic, fostered by new advancements in numerical and computational fields.



Watch the movie

Displacements are considered in their absolute values. On the ground, between buildings, is visible the displacement wave-field.

References

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