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3D PROBABILISTIC PHYSICS-BASED SEISMIC HAZARD MAPS FOR REGIONAL RISK ANALYSIS

Allocation: Exploratory/50 Knh
PI: Paolo Gardoni[1]
Co-PI: Roberto Guidotti[1]

[1]University of Illinois at Urbana-Champaign

EXECUTIVE SUMMARY

Disastrous earthquakes have revealed the extreme vulnerability to seismic hazards of highly populated areas. This exploratory project contributed toward a reliable seismic risk evaluation, substantiating a future proposal for the development of site-specific seismic scenarios through physics-based 3D models of seismic wave propagation. To be reliable, those models require a high computational burden, with a significant level of parallelization and high-performance computing resources. That is why the leading-edge capability of Blue Waters is necessary. The exploratory project and the requested resources have been used to: 1) evaluate and tune the SPEED (SPectral Elements in Elastodynamics with Discontinuous Galerkin) software for Blue Waters, and 2) demonstrate its readiness for use in a future proposal submission. The next-generation work will be a proposal for a general allocation aimed at developing 3D probabilistic physics-based hazard maps.

RESEARCH CHALLENGE

A seismic event affecting a densely populated area could lead to severe damage and economic losses. The chain of disastrous earthquakes that have occurred recently, from Chile (Maule, Mw 8.8) to Japan (Tohoku Mw 9.0) to New Zealand (Darfield Mw 7.1, Christchurch Mw 6.2), revealed the extreme vulnerability of modern society to seismic hazards and the need to better estimate seismic scenarios. A reliable seismic risk evaluation, able to assess and reduce earthquake-induced damage and loss, is clearly needed, and is, therefore, a challenge of paramount significance. To improve hazard assessment through the definition of site-specific physics-based seismic scenarios will help emergency managers, planners, and the public to be prepared for future earthquakes. It will also help civil engineers to develop cost-effective mitigation measures and practices in structure design, construction, and planning. This will allow researchers and the risk-management industry to tackle the challenging task of analyzing seismic wave propagation with increased accuracy.

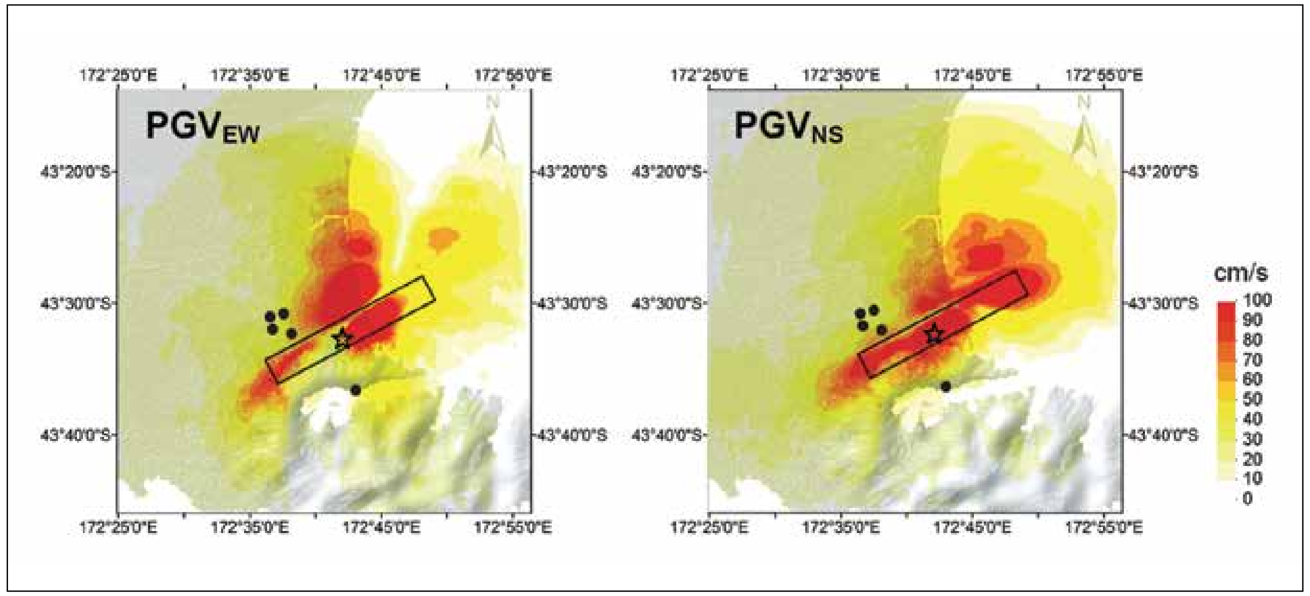

Figure 1: Spatial variability of peak ground velocity as estimated by 3D numerical simulation referring to the February 22, 2011, Christchurch, New Zealand, earthquake (Mw 6.2).

METHODS & CODES

The numerical simulations tested on Blue Waters within the allocated exploratory project have been carried on with SPEED [1], an existing open-source high-performance software package. The code belongs to the family of the spectral element method (SEM), a powerful, well-established, numerical technique naturally suited for three-dimensional seismic wave propagation analyses. SPEED allows seismic wave propagation modelling through viscoelastic heterogeneous three-dimensional media, both on the local and regional scale. SPEED reproduces the propagation path of the seismic wave through complex geological structures and localized superficial irregularities such as alluvial basins and civil engineering infrastructures. The code is written in Fortran90 using its pseudo-object-oriented features. It takes advantage of the hybrid parallel programming based on the Message Passing Interface (MPI) library and relies on the domain decomposition paradigm and the OpenMP library for multi-threading operations on shared memory.

RESULTS & IMPACT

The allocated resources have been used to: 1) set up the SPEED software on Blue Waters, 2) evaluate/tune the SPEED code with short tests (tutorials), and 3) evaluate/tune the SPEED code with tests at full machine scale.

Fig. 1 shows results of tests at full-machine scale. The spatial variability of peak ground east-west and north-south velocity has been estimated by a 3D numerical simulation of the February 22, 2011, Christchurch, New Zealand (Mw 6.2), earthquake, based on the available numerical model for that area [2]. The allocated resources in the exploratory project have been used to evaluate how the SPEED code utilizes the major systems elements of Blue Waters; e.g., the memory hierarchy, the communications network, the computational elements, the GPU nodes, and the I/O subsystem. We evaluated and tuned the SPEED code for Blue Waters and demonstrated the readiness of SPEED for use in a future proposal submission. In addition, the tests performed on Blue Waters confirmed the excellent scalability features of the code.

For our next work, we are developing a proposal for a general allocation aimed at developing 3D probabilistic physics-based hazard maps. These maps will help address seismic risk, contributing to a comprehensive understanding of earthquake physics and effects. The general proposal will consist of two main steps. First, we will develop a 3D physics-based seismic model of the Metro Memphis Statistical Area, which is near one of the highest seismic hazard areas in the central and eastern United States—the New Madrid Seismic Zone. This model is intended to give a comprehensive understanding of seismic wave propagation through complex media over a large area, leading to more accurate, physics-based and site-specific seismic hazard maps for use in assessing the resilience of spatially distributed large networks. Second, we will investigate the predictive power of physics-based methods in seismic hazard analysis, introducing a probabilistic procedure based on the development of a suitable surrogate model. Based on the chosen 3D physics-based seismic scenarios, the surrogate model will allow the generation of a new set of scenarios with a significant reduction in computational burden.

WHY BLUE WATERS

Among the most appealing features of physics-based 3D models of seismic wave propagation is the possibility of capturing in its entirety the complex coupling of: 1) directivity pulses; 2) 3D basin effects (Fig. 1); 3) topographic effects; 4) wave scattering; and 5) nonlinear soil response, especially near the source of an earthquake. Accounting for all these features within a single computational model requires a high computational burden (in terms of CPU time and RAM usage), with a significant level of parallelization and high-performance computing resources. That is why the leading-edge capability of Blue Waters was necessary to address this research. To perform our 3D seismic wave propagation simulation would have been infeasible without Blue Waters' resources. Blue Waters, allowing the running of hundreds of simulations, is essential in a future work to generate the predictions needed for 3D probabilistic physics-based hazard maps.

PUBLICATIONS AND DATA SETS

Guidotti, R., A. Contento, and P. Gardoni, 3D Probabilistic Physics-based Seismic Hazard Assessment via Metamodels. *16th European Conference in Earthquake Engineering*, Thessaloniki, Greece, June 18–21, 2018.

Tian, S., R. Guidotti, and P. Gardoni, Simulation of seismic wave propagation in the Metro Memphis Statistical Area (MMSA), *11th U.S. National Conference on Earthquake Engineering*, Los Angeles, Calif., June 25–29, 2018.