

NATURAL HAZARDS

EQSIM: High-Performance, Multidisciplinary Simulation for Regional-Scale Earthquake Hazard and Risk Assessments

Large earthquakes present a significant risk around the world and are a major issue across the DOE mission space ranging from the safety of DOE’s own inventory of one-of-a-kind mission critical facilities to all major US energy systems. Beyond the DOE enterprise, addressing earthquake risk, both from the standpoint of life safety and damage/economic impact, is a major societal challenge for virtually every element of the built environment including transportation, health, data/commerce, and all urban infrastructure. EQSIM is tapping the tremendous developments occurring in high performance computing, data collection, and data exploitation to help advance earthquake hazard and risk assessments. EQSIM application codes are removing the reliance on simplifying idealizations, approximations, and sparse empirical data; instead, they focus on resolving with the fundamental physics uncertainties in earthquake processes. Through EQSIM, regional-scale ground motion simulations are becoming computationally feasible, and simulation models that connect the domains of seismology and geotechnical and structural engineering are becoming within grasp.

The EQSIM application development project is focused on creating an unprecedented computational toolset and workflow for earthquake hazard and risk assessment. Starting with a set of the existing codes, SW4 (a fourth-order, 3-D seismic wave propagation model), NEVADA (a nonlinear, finite displacement program for building earthquake response), and ESSI (a nonlinear finite-element program for coupled soil-structure interaction), EQSIM is building an end-to-end capability to simulate from the fault rupture to surface ground motions (earthquake hazard) and ultimately to infrastructure response (earthquake risk). The ultimate goal of the EQSIM development is to remove computational limitations as a barrier to scientific exploration and understanding of earthquake phenomenology, as wells as to practical earthquake hazard and risk assessments.

Traditional earthquake hazard and risk assessments for critical facilities have relied on empirically based approaches that use historical earthquake ground motions from many different locations to estimate future earthquake ground motions at a specific site of interest. Given the fact that ground motions for a particular site are strongly influenced by the physics of the specific earthquake

processes including the fault rupture mechanics, seismic wave propagation through a heterogeneous medium, and site response at the location of a particular facility, earthquake ground motions are very complex with significant spatial variation in both frequency content and amplitude. The homogenization of many disparate records in traditional empirically based ground motion estimates cannot fully capture the complex site-specificity of ground motion. Over the past decade, interest in utilizing advanced simulations to characterize earthquake ground motions (earthquake hazard) and infrastructure response (earthquake risk) has accelerated significantly. However, the extreme computational demands required to execute hazard and risk simulations at the regional scale have been prohibitive. A fundamental objective of the EQSIM application development project is to advance regional-scale ground motion simulation capabilities from the historical computationally limited frequency range of ~0–2 Hz to the frequency range of interest for a breadth of engineered infrastructure of ~0–10 Hz. A second fundamental objective of this project is to implement an HPC framework and workflow that directly couples earthquake hazard and risk assessments through an end-to-end simulation

framework that extends from earthquake rupture to structural response, thereby capturing the complexities of interaction between incident seismic waves and infrastructure systems.

To achieve the overall goals, two fundamental challenges must be addressed. First, regional-scale forward ground motion simulations must be effectively executed at an unprecedented frequency resolution with much larger, much faster models. Achieving fast earthquake simulations is essential to allowing the parametric variations necessary to span critical problem parameters (e.g., multiple fault rupture scenarios). Second, as the ability to compute at higher frequencies progresses, there will be a need for better characterization of subsurface geologic structure at finer and finer scales; thus, a companion schema for representing fine-scale geologic heterogeneities in massive computational models must be developed. For the purpose of evaluating regional-scale simulations and assessing progress on the application developments of this project, a representative large regional-scale model of the San Francisco Bay Area (SFBA) has been created for the domain. This model includes all necessary geophysics modeling features (3D geology, earth surface topography, material attenuation, nonreflecting boundaries, fault rupture models). For a 10 Hz simulation, the computational domain includes approximately 203 billion grid points in the finite difference domain. The SFBA model provides the basis for testing and evaluating both advanced physics algorithms and computational implementations.

Progress to date

- Porting of SW4 to CORI and implementation of optimized loops and a hybrid MPI/OpenMP implementation.
- Successful porting of SW4 to GPU-based platforms including Sierra and Summit; this included utilization of the RAJA libraries to enable platform independence.
- Implementation of a capability to overlay statistically representative stochastic geology variations across a large SW4 geologic model to represent fine-scale geologic variability.

EQSIM will use exascale to help scientists understand the fundamental geologic physics of earthquakes that will inform civil engineering and emergency response on better ways to counter threats from these potential natural disasters.

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