SIMULATING LARGE CALIFORNIA EARTHQUAKES BEFORE THEY OCCUR

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EXECUTIVE SUMMARY

The Southern California Earthquake Center (SCEC) used Blue Waters to develop the CyberShake probabilistic seismic hazard analysis (PSHA) method and to apply this method to all major urban areas in California. SCEC's CyberShake [1] hazard models use detailed earthquake fault and seismic velocity models and high-performance software to calculate physics-based probabilistic ground motion forecasts. SCEC is actively collaborating with geo-scientific groups, national seismic hazard map developers [2], and civil engineering groups [3] to verify and validate the CyberShake California seismic hazard models for use in broad impact engineering and public seismic hazard applications and to apply the CyberShake method to other national and international regions.

RESEARCH CHALLENGE

PSHA earthquake forecast models [4] are the scientific basis for many engineering and social applications: performance-based design, seismic retrofitting, resilience engineering, insurance rate setting, disaster preparation and warning, emergency response, and public education. The U.S. Geological Survey (USGS) currently uses PSHA for promoting seismic safety engineering and disaster preparedness across the United States, including California, through its National Seismic Hazard Mapping Project [5]. During the last year, researchers with the SCEC used the high-performance computing capabilities of Blue Waters to calculate physics-based PSHA models for northern California to better understand earthquake hazards and to better inform civil engineering organizations as they develop earthquake-resilient societal infrastructure.

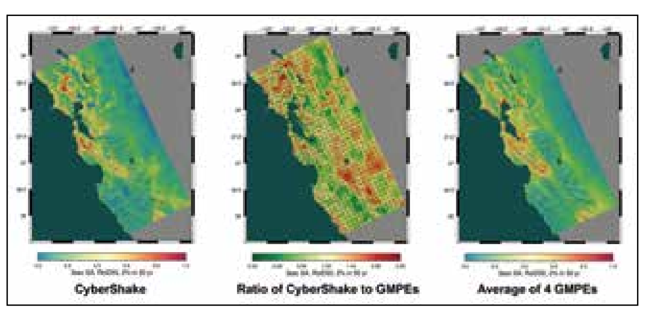

Figure 1: These maps show the CyberShake Study 18.8 model and compare the results to current standard methods based on ground motion prediction equations. This CyberShake seismic hazard model provides multiple layers of information that include hazard maps, hazard curves for selected sites, rupture models, seismograms, and site-specific seismic intensity and shaking duration measurements.

METHODS & CODES

The SCEC earthquake system science program requires a collection of interoperable earth models and open-source scientific application programs including OpenSHA [6], UCVM [7], Hercules [8], and AWP–ODC [9]. SCEC's CyberShake seismic hazard model calculations use a workflow system based on HT–Condor [10] and Pegasus–WMS [11] to perform large regional-scale seismic hazard studies. CyberShake extends existing PSHA methods to produce site-specific seismic hazard curves and other seismic hazard information such as duration of shaking, which is not available from earlier methods. In 2018, SCEC performed CyberShake Study 18.8, which used NCSA's Blue Waters and OLCF's Titan to calculate PSHA hazard curves up to 1 Hz for 869 locations in central and northern California, producing a physics-based PSHA hazard model for a large Northern California region that includes the San Francisco Bay Area.

RESULTS & IMPACT

Regional PSHA hazard models are used by engineers, seismologists, and governmental organizations in building design, urban planning, community earthquake awareness, and disaster preparation. During the last year, SCEC completed CyberShake Study 18.8, the first physics-based PSHA model for the San Francisco Bay region. This study used over 3.8 million Blue Waters node hours to calculate a PSHA seismic model for northern California, using deterministic wave propagation simulations in 3D seismic velocity models, combining estimates of hazard curves from 869 locations in California. CyberShake data products show the effects of basin structures and rupture directivity on hazard, improve upon standard attenuation-based methods of calculating seismic hazard, and identify research targets to further improve PSHA estimate accuracy. As a result, the scientific and computational advancements in CyberShake work can help reduce the total uncertainty in long-term hazard models, which has important practical consequences for the seismic provisions in building codes and especially for critical-facility operators.

PSHA users including scientific, engineering, and governmental agencies such as the USGS, are evaluating the new information provided by CyberShake results. For seismologists, CyberShake provides new information about the physics of earthquake ground motions, the interaction of fault geometry, 3D earth structure, ground motion attenuation, and rupture directivity. For governmental agencies responsible for reporting seismic hazard information to the public, CyberShake represents a new source of information that contributes to their understanding of seismic hazards, which they may use to improve the information they report. For building engineers, CyberShake represents a refinement of existing seismic hazard information that reduces some of the uncertainties in current empirical ground motion attenuation models.

CyberShake PSHA estimate simulations for Southern California are under review as inputs to a new Los Angeles urban seismic hazard map under development by the USGS [2]. The SCEC committee for Utilization of Ground Motion Simulations (UGMS) is working within the framework of the Building Seismic Safety Council activities to develop long-period, simulation-based response spectral acceleration maps for the Los Angeles region. CyberShake hazard maps are under consideration for inclusion in the National Earthquake Hazards Reduction Program and the American Society of Civil Engineers (ASCE) 7–10 Seismic Provisions, and for the Los Angeles City Building Codes. The UGMS group is using CyberShake simulations to quantify the effects of sedimentary basins and other 3D crustal structures on seismic hazard, information that is difficult to obtain with traditional empirical methods. Prototype risk-targeted maximum considered earthquake response spectra have been mapped using a combination of the empirical approach and the CyberShake model and are being integrated into the ASCE Project 17 recommendations for tall buildings [3].

WHY BLUE WATERS

SCEC used Blue Waters to perform large-scale, complex scientific computations involving thousands of large CPU and GPU parallel jobs, hundreds of millions of short-running serial CPU tasks, and hundreds of terabytes of temporary files. SCEC scientists and technical staff have worked closely with the Blue Waters staff to achieve a series of breakthroughs including integration of new physics into wave propagation software [12], optimization of production calculations using GPU code improvements [13], and optimization of the CyberShake runtime performance.

Using the well-balanced system capabilities of Blue Waters' CPUs, GPUs, disks, and system software, together with scientific workflow tools, SCEC's research staff can now complete CyberShake calculations in weeks rather than months, improvements that were made during years of Blue Waters access and operations. Blue Waters has enabled SCEC scientists to improve their seismic hazard methodology at a rapid pace.

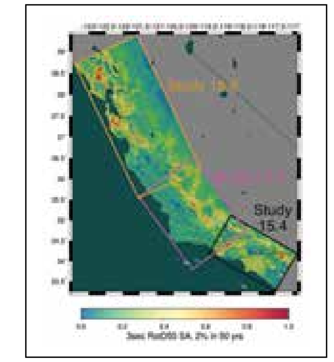

Figure 2: This California map shows three CyberShake probabilistic seismic hazard models calculated using Blue Waters including southern California (CyberShake Study 15.4), central California (CyberShake Study 17.3), and northern California (CyberShake Study 18.8), showing the CyberShake hazard estimates that have now been calculated for the most densely populated regions in the state.

PUBLICATIONS & DATA SETS

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C. Crouse, T. H. Jordan, K. R. Milner, C. A. Goulet, S. Callaghan, and R. W. Graves, "Site-specific MCER response spectra for Los Angeles Region based on 3D numerical simulations and the NGA West2 equations," presented at the 11th Nat. Conf. Earthquake Eng., Los Angeles, CA, U.S.A., June 25–29, 2018, Paper 518.

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D. Roten, K. B. Olsen, S. M. Day, and Y. Cui, "Quantification of fault-zone plasticity effects with spontaneous rupture simulations," *Pure Appl. Geophys.*, vol. 124, no. 9, pp. 3369–3391, 2017, doi: 10.1007/s00024-017-1466-5.

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