An Overview of the SCEC CyberShake Project

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Meeting of the SCEC Committee for the Utilization of Ground Motion Simulations
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Probabilistic Seismic Hazard Model

Working Group on California Earthquake Probabilities (2007)

Uniform California Earthquake Rupture Forecast (UCERF2)

Earthquake Rupture Forecast

Ground Motion Model

Intensity Measures

\[ P(S_k) \quad P(Y_n / S_k) \quad P(Y_n) \]
**Probabilistic Seismic Hazard Model**

**Hazard Curve:**
- **Shaking intensity:** Peak Ground Acceleration (PGA)
- **Interval:** 50 years
- **Site:** Downtown LA

![Hazard Curve Diagram]

- **Peak Ground Acceleration (g)**
- **Probability of Exceedance in 50 yr**
  - 2% in 50 yr
  - 10% in 50 yr

Mathematical Expressions:

\[ P(S_k) \quad P(Y_n / S_k) \quad P(Y_n) \]
Probabilistic Seismic Hazard Model

Boore et al. (1997)
Empirical Ground Motion Prediction Equations (GMPEs)

Few data epistemic uncertainty
High scatter aleatory variability

Earthquake Rupture Forecast

Ground Motion Model

Intensity Measures

\[ P(S_k) \quad P(Y_n / S_k) \quad P(Y_n) \]
Probabilistic Seismic Hazard Analysis

- PSHA, as currently practiced, is based on empirical statistical models
- We seek to improve earthquake forecasting by incorporating more physics through numerical simulations

![Diagram showing the flow of information between different simulation tools and models.]

- **RSQsim**: Earthquake Rupture Simulator
- **CyberShake**: Ground Motion Simulator
- **Ground Motions**
- **Intensity Measures**

**UCERF2**

**NGA GMPEs**

**Physics-based simulations**

**Empirical models**
CyberShake Hazard Model 14.2

- **Sites:**
  - 289 sites in the greater Los Angeles region

- **Ruptures:**
  - All UCERF2 ruptures within 200 km of site (~14,900)

- **Rupture variations:**
  - 415,000 per site using Graves-Pitarka pseudo-dynamic rupture model

- **Seismograms:**
  - 240 million per model
NGA (2008) GMPEs used in the National Seismic Hazard Maps

Epistemic Uncertainties in GMPEs

- near-fault amplitudes
- basin effects
- SA-3s
  PE = 2%/50 yr
  UCERF2, no background seismicity
Comparison of 1D and 3D CyberShake Models for the Los Angeles Region

1. lower near-fault intensities due to 3D scattering
2. much higher intensities in near-fault basins
3. higher intensities in the Los Angeles basins
4. lower intensities in hard-rock areas
CyberShake Workflow

Kinematic rupture model

→ UCVM

Mesh generation
1 job per site
MPI, 320 cores

→ AWP-ODC

SGT computation
2 jobs per site
MPI, 10k CPUs or 100 GPUs

→ SeisSynth

Post-processing
415,000 jobs per site
serial

data transfer

→ Data Product Generation

Populate DB, construct queries
4 jobs per site

Uniform California Earthquake Rupture Forecast

Full-3D tomographic model of S. California

Scismograms

hazard curves

hazard maps
Conditional Slip Distribution
Graves-Pitarka Pseudo-Dynamic Rupture Models

GP07 used in CS11

GP10 used in CS13
Comparison of Basin Structures

Starting model: CVM-S4

26th Iterate: CVM-S4.26

$Z_{2500}$ : iso-velocity surfaces at $V_S = 2.5$ km/s
Test of CVM-S4.26 synthetics against data from the 03/28/14 La Habra Earthquake (M5.1)

Data in black, synthetics in red, low-passed at 0.2 Hz
NGA08-CyberShake Comparisons

Site SBSM
NGA14-CyberShake Comparisons

Site SBSM
CyberShake Research Issues

- Validation of long-period results
  - GMPE comparisons
  - Historical and new events
  - Virtual earthquakes synthesized from ambient noise

- Characterization of epistemic uncertainties
  - Earthquake rupture forecast
  - Pseudo-dynamic rupture model
  - 3D velocity structure
  - Site effects

- Push to shorter periods
  - Fault complexity
  - Near-fault plasticity
  - Frequency-dependent attenuation
  - Near-surface nonlinearity and small-scale heterogeneity
Averaging-Based Factorization
(Wang & Jordan, BSSA, 2014)

- **Representation of excitation functionals**
  Expected shaking intensities constructed by averaging over slip variations ($s$), hypocenters ($x$), sources ($k$), and sites ($r$)

\[
G(r, k, x, s) = A + B(r) + C(r, k) + D(r, k, x) + E(r, k, x, s)
\]

\[\uparrow \text{In (Y)} \quad \uparrow \text{level} \quad \uparrow \text{site effect} \quad \uparrow \text{path effect} \quad \uparrow \text{directivity effect} \quad \uparrow \text{slip complexity effect}\]

- **Representation of excitation variance**

\[
\text{Var}[G] = \sigma^2_G \equiv \left\langle [G(r, k, x, s) - A]^2 \right\rangle_{S, X, K, R}
\]

\[= \sigma^2_B + \left\langle \sigma^2_C(r) \right\rangle_R + \left\langle \sigma^2_D(r, k) \right\rangle_{K, R} + \left\langle \sigma^2_E(r, k, x) \right\rangle_{X, K, R}
\]

\[\equiv \sigma^2_B + \bar{\sigma}^2_C + \bar{\sigma}^2_D + \bar{\sigma}^2_E\]
A-values of CyberShake models

Amplitude reduction due to filtering
Dependence of Basin Effects on Velocity Structures
(SA corrected for $V_{S30}$ using BA08)

- **CVM-S4.26**
  - T=3.0s
  - T=5.0s
  - T=10.0s
  - Abrahamson & Silva (2008) NGA GMPEs
  - CS14b

- **CVM-H11**
  - T=3.0s
  - T=5.0s
  - T=10.0s
  - Abrahamson & Silva (2008) NGA GMPEs
  - CS13b
End