Simulation and Validation of Long-Period Earthquake Ground Motion in the Kanto Basin in Japan

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Objective

- Part of SCEC’s VISES project with ERI and DPRI
- Verification and validation of earthquakes in Japan since 2000 (dense coverage)
- Beroza et al: Impulse response from ambient seismic field
- Use Hercules for simulating long-period earthquakes
- First use point sources and then extended faults
- Part of High-F project: To achieve realistic simulations from 0 to 10 Hz
Basic question

• How do seismic waves propagate from the rupture to produce strong shaking at the Earth’s surface?

• Study the basin amplification effects in the Kanto region
Ambient Seismic Field

New view of this “noise” as a useful signal

Courtesy of Greg Beroza
Green’s Function

Used to solve linear differential equations subject to specific initial conditions and/or boundary conditions.

For the wave equation, the Green’s function is the response to an idealized force localized in space and time.

*Fundamental* to construct more general solutions to the wave equation to study Earth structure and seismic sources.

Courtesy of Greg Beroza
(1) Record weakly coherent background.

(2) Extract surface impulse response.

(3) Correct for depth & mechanism.

(4) Large Magnitude via superposition.

The Virtual Earthquake Approach

 Courtesy of Greg Beroza
Virtual Earthquake Approach validated by 4 moderate earthquakes.

Basin amplification is apparent.

It works.

Courtesy of Greg Beroza

Denolle et al. (2012)
2008 M5.4 Chino Hills Earthquake with Region of Interest Validation

Simulation Domain: 180 x 135 x 62 km$^3$
Material Model: CVM-S v4.1
Minimum Vs: 200 m/s
Maximum Frequency: 4 Hz
Software: Hercules
Processors: 24,000
Time: 31 hrs

Source model

» Shao et al. (2012)
J. Geophys. Res. 117:B07307
Our octree-based finite element tool for modeling earthquake ground motion* (Tu et al., SC2006)

Hercules has been used for verification and validation studies (Bielak et al, GJI 2010; Taborda et al, CiSE 2011)

- TeraShake (2005–2007) SCEC
- Chino Hills (2008–2011) SCEC

* and simplified building models
Simulation Stages

- Mesh Generation (Produces a discrete mesh)
- Source Generation
- Solving
- 4D Wavefield

Solving Algorithm

- For each time step:
  - Add EQ Forces
  - Compute stiffness contribution
  - Communication send
  - Communication adjust
  - Communication send
  - Compute new displacements
  - Communication send
  - Communication adjust
  - Communication send
  - Write output
  - Next

For each mesh element:
- Compute $K^e u_n$
- Next

For each mesh node:
- Compute $u_{n+1}$
- Next

Octree-based FEM mesh tailored to shear wave length
Observations vs synthetics

Red – data
Blue - simulations

Anderson, 2004
Observations vs synthetics
Observations vs synthetics

GOF criteria

John Anderson (2009)
Geotechnical layers

Soil Profile

Depth (m)

Velocity (m/s)

Energy (cm²/s)

Fourier Amp. (cm)

Borehole

Depth (m)

Velocity (m/s)

Time (s)

Freq. (Hz)
Global score for PGV
Goodness-of-fit PGV

0.1 – 0.25 Hz
Table 2. Earthquakes since 2000 selected for simulation validation

<table>
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<tr>
<th>YEAR</th>
<th>REGION</th>
<th>EQ NAME</th>
<th># RECORDS &lt; 200 km</th>
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Epicenter of Tottori earthquake is out of the available material model

Velocity model, NIED; Ichimura

Table is taken from Virtual Institute for the Study of Earthquake Systems (VISES) Proposal
### Material Model --- Layer Properties

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**Layer 3**

**Layer 14**

**Layer 11**
MATERIAL MODEL (KANTO-BASIN)