Validation of Earthquake Simulations and Their Effects on Tall Buildings Considering Spectral Shape and Duration

SCEC Annual Meeting 2013

Ting Lin

Marquette University

Greg Deierlein

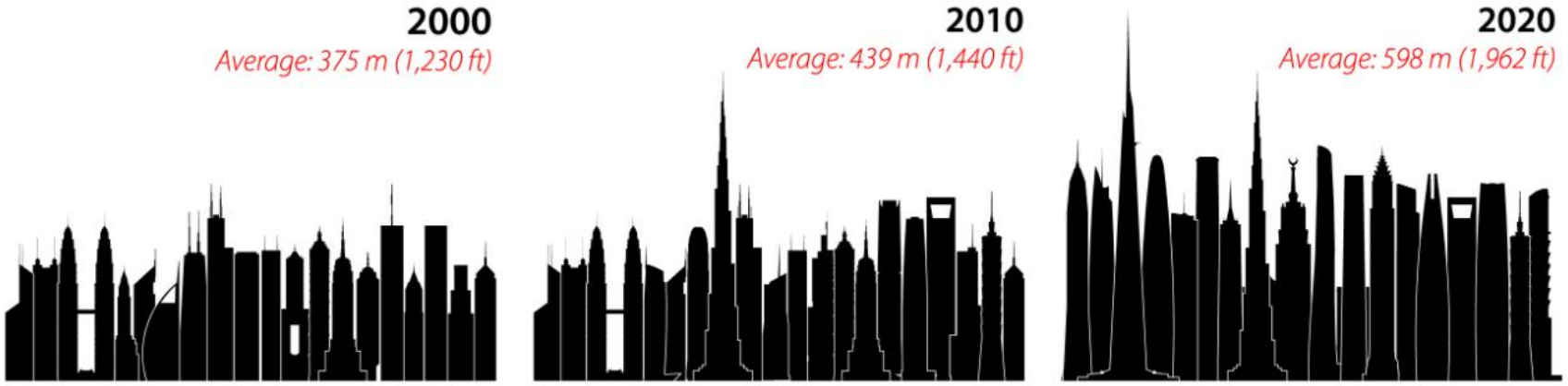
Nenad Bijelic

Stanford University

September 8, 2013

Motivation

- Simulations from the earth science community (e.g., Mai and Beroza, 2003; Aagaard et al., 2010 ; Graves et al., 2011) provide an attractive alternative that incorporates site-specific characteristics not accurately captured by GMPEs
- Reasonable agreement between simulated and recorded ground motions in the low frequency (long period) range is especially promising for the study of long-period structures such as tall buildings
- This study is motivated by a growing interest in tall buildings in seismically active regions, including major cities in the western US, Japan, China and other Pacific rim countries (e.g., Hall et al., 1995; TBI, 2010; Moehle et al., 2011; Krishnan and Muto, 2012; Galasso et al., 2013; Lu et al, 2013)



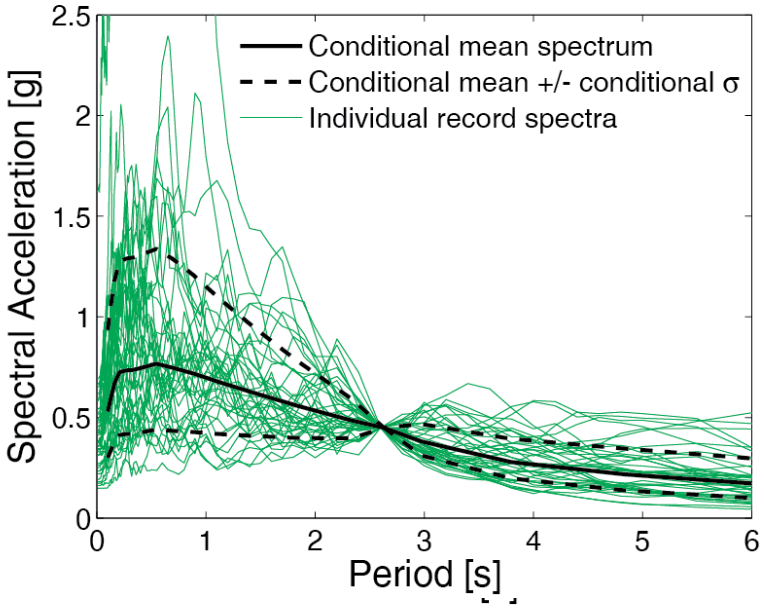
A study of tallest 20 buildings per decade (credit: CTBUH)

Objective

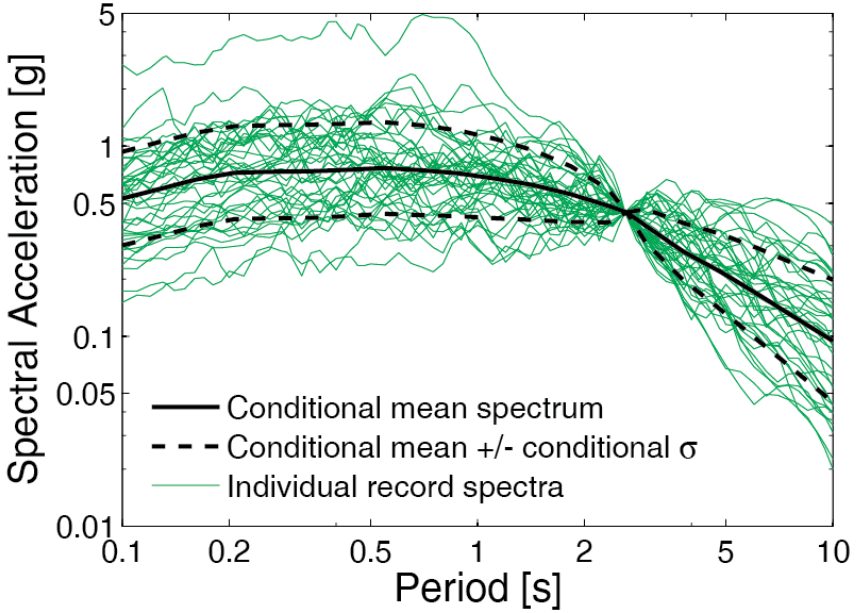
- Validate earthquake simulations from an engineering perspective through assessment of structural performance of tall buildings subjected to recorded and simulated ground motions
- Examine effects of spectral shape and duration on structural response
- Provide insights regarding the use of simulations for nonlinear dynamic analysis of tall buildings

Conditional Spectrum, Conditional Mean Spectra, and Uniform Hazard Spectrum

The spectral shapes of Conditional Mean Spectra (mean of Conditional Spectra) change with amplitudes



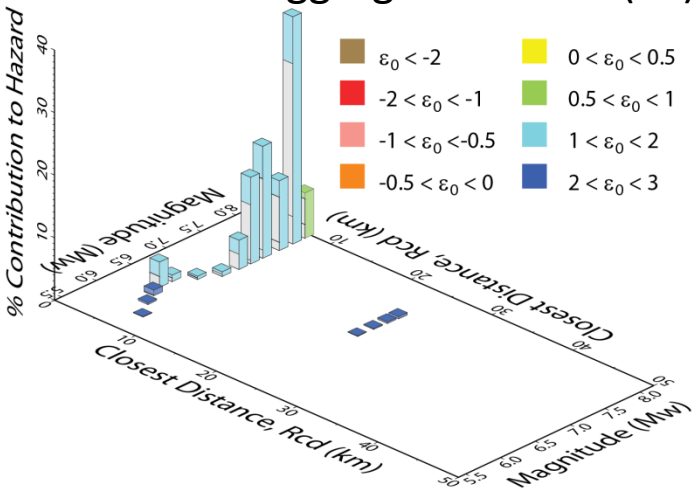
Uniform Hazard Spectrum is the envelope of Conditional Mean Spectra at various periods



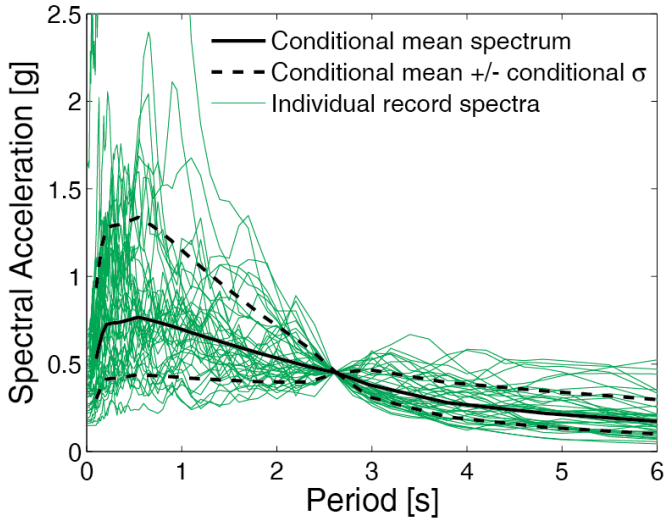
Lin, T., C. B. Haselton, & J. W. Baker (2013b). Conditional-Spectrum-based ground motion selection. Part II: Intensity-based assessments and evaluation of alternative target spectra. Earthquake Engineering & Structural Dynamics,, 42(12), 1867-1884. doi:10.1002/eqe.2303.

Ground motion selection and structural analyses

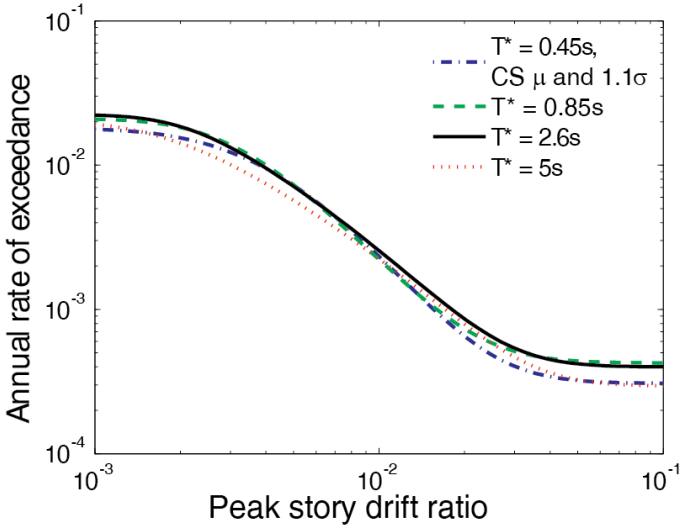
Hazard deaggregation for *Sa*(*T**)



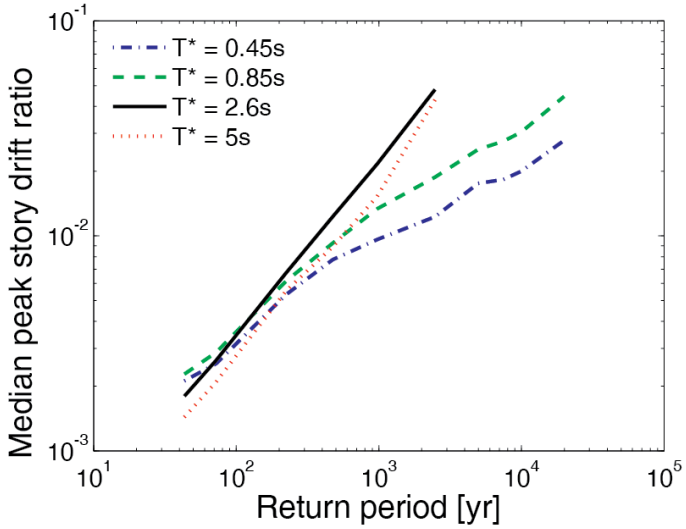
Target spectrum computation and ground motion selection



Risk-based assessments



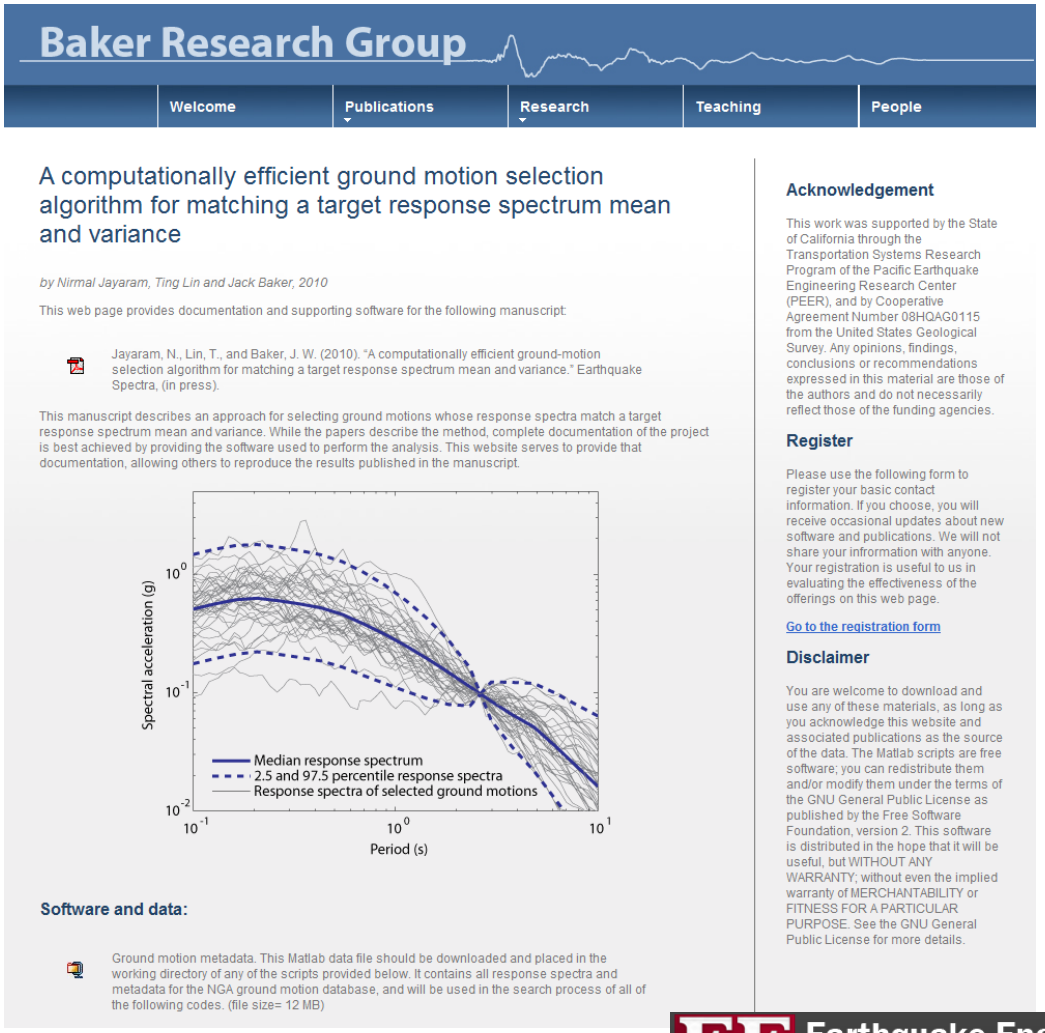
Intensity-based assessments



Lin, Harmsen, Baker, & Luco (2013) Lin, Haselton, Baker (2013a) Lin, Haselton, & Baker (2013b)

Software tool for ground motion selection

http://www.stanford.edu/~bakerjw/gm_selection.html



Matlab source code

User provides:

- Target spectrum or deaggregation information
- Desired limitations on magnitude, distance, site conditions, scale factor, …

Software produces:

- Selected and scaled ground motions from the PEER NGA database

Jayaram, Lin, and Baker (2011)

Earthquake Engineering Research Institute
Dedicated to reducing earthquake risk

Web-based algorithm

Duration

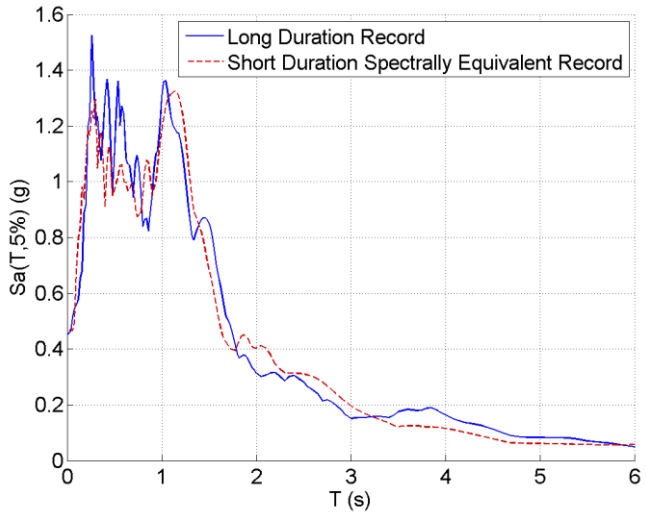
- The detection of ground motion duration effects requires the use of a realistic numerical model that accurately captures component deterioration.
- The 5-95% significant duration appears to be a promising duration metric according to a list of desired properties for engineering applications

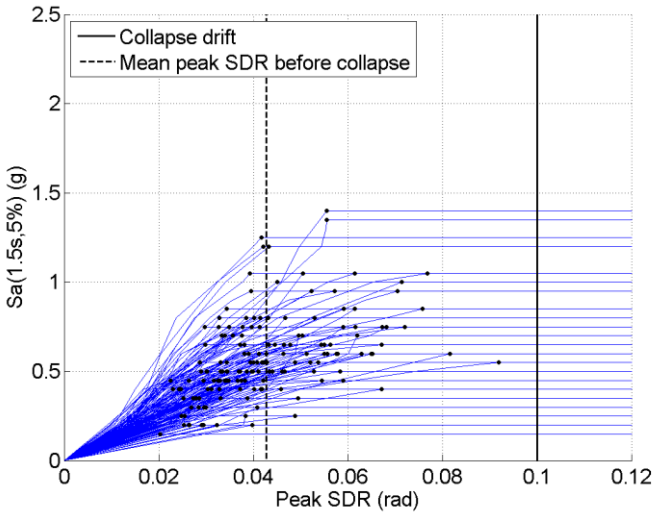
Desired properties	Bracketed duration	Significant duration	Arias Intensity	CAV	I_D
Uncorrelated to common IMs like PGA and Sa(1s)	✓	✓	✗	✗	✓
Unaffected by scaling	✗	✓	✗	✗	✓
Does not bias spectral shape	✓	✓	✓	✓	✗

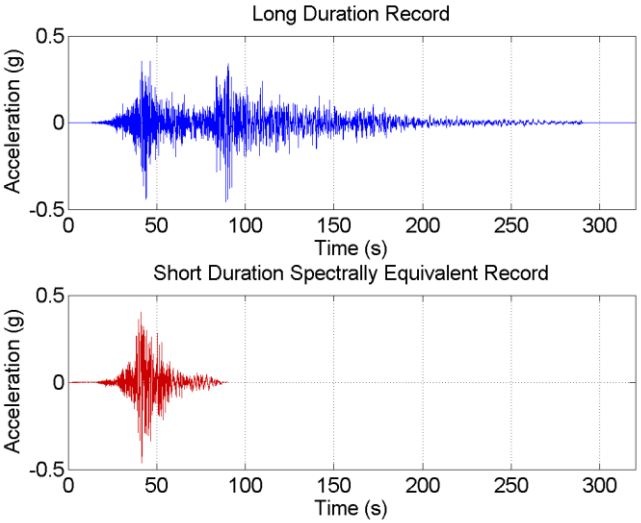
- ***Run good-of-fit algorithms on simulations*** on 5-95% significant duration?
- This project utilizes significant duration, explores other metrics and study their effects on structural response in the context of simulations, in conjunction with ongoing PEER center research on duration

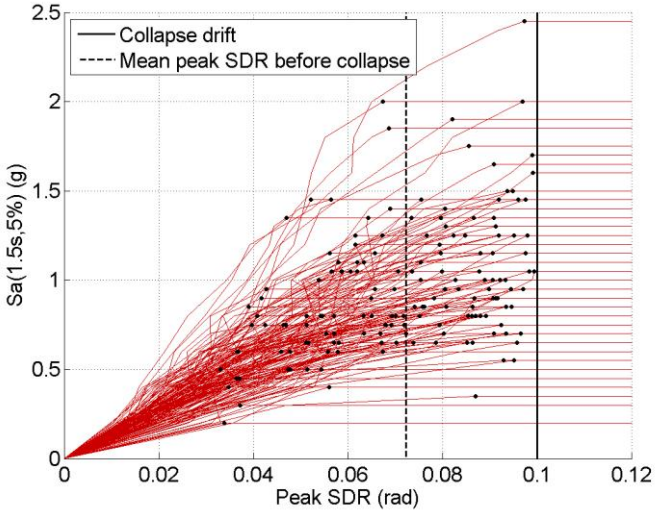
Foschaar, Baker, and Deierlein (2012) Chandramohan, Lin, Baker, and Deierlein (2013)

Influence of duration on seismic collapse risk



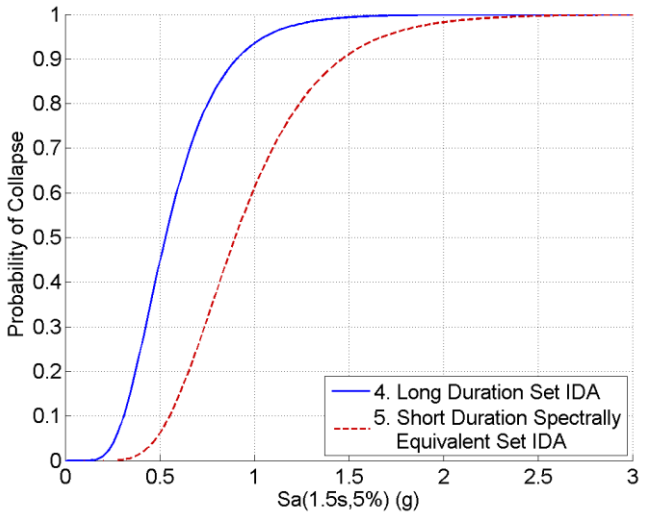


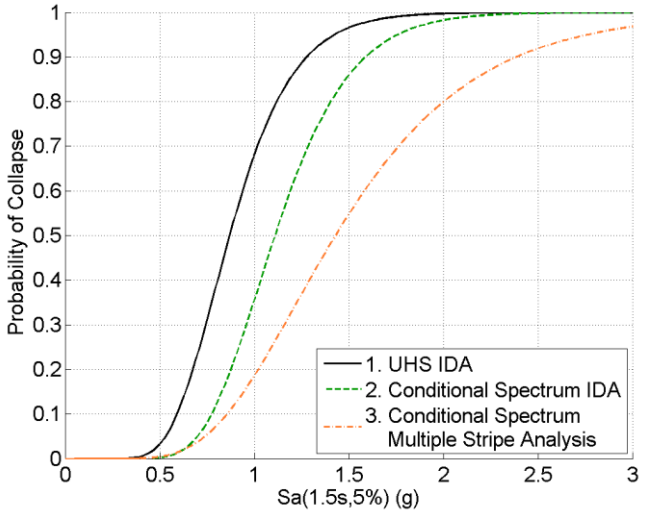




Chandramohan, Lin, Baker, and Deierlein (2013)

Influence of spectral shape and duration on seismic collapse risk



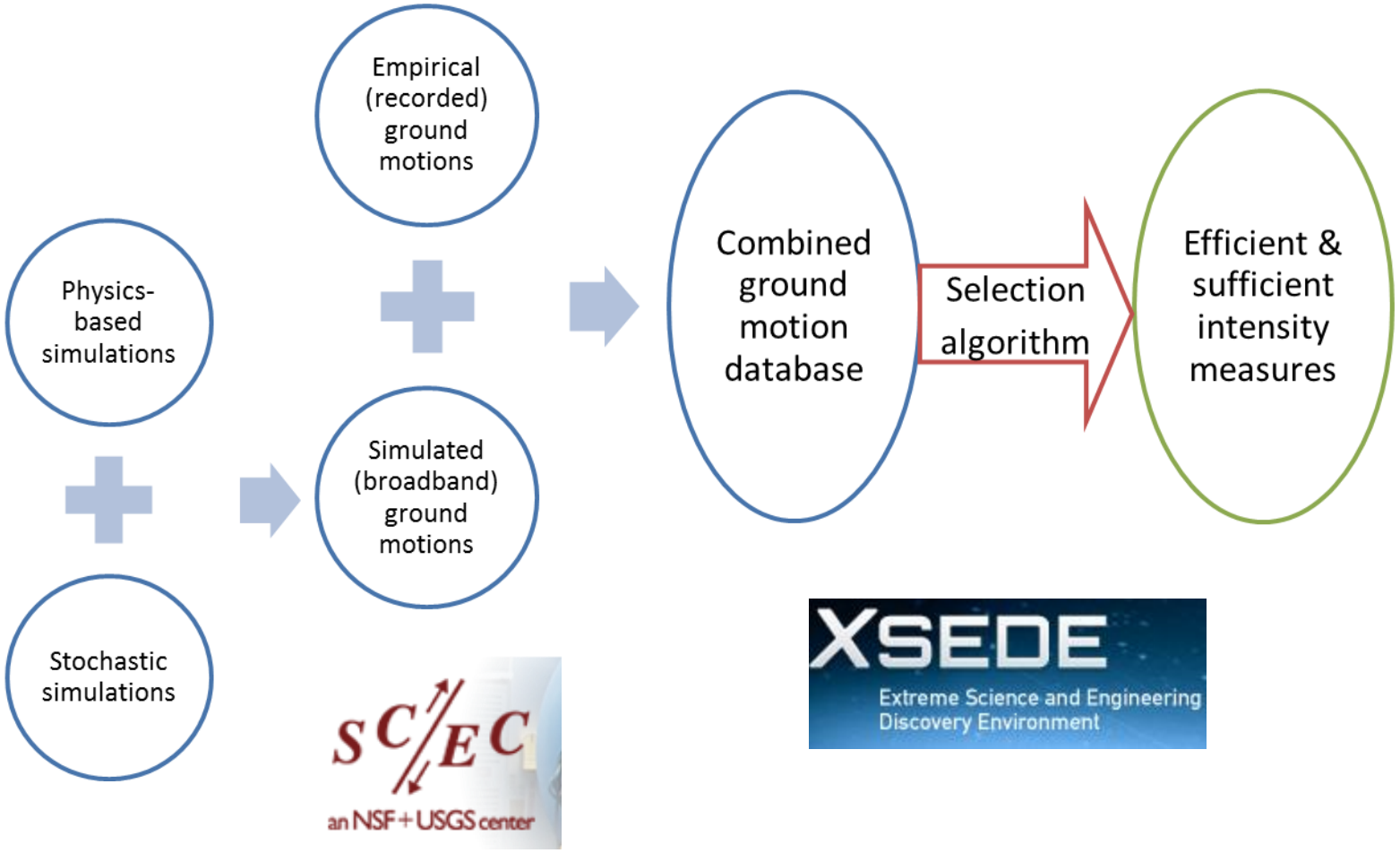


Analysis number	Ground Motion set(s) used	Type of analysis performed	Geometric mean of predicted collapse capacity (g)	Lognormal standard deviation of predicted collapse capacity
1	2% in 50 year matched set	Incremental Dynamic Analysis	0.87	0.30
2	2% in 50 year Conditional spectrum matched set	Incremental Dynamic Analysis	1.11	0.28
3	Conditional spectrum matched set at each intensity level	Multiple Stripe Analysis	1.43	0.40
4	Long duration set	Incremental Dynamic Analysis	0.53	0.42
5	Short duration spectrally equivalent set	Incremental Dynamic Analysis	0.90	0.38

This project examines impact of spectral shape and duration for simulations

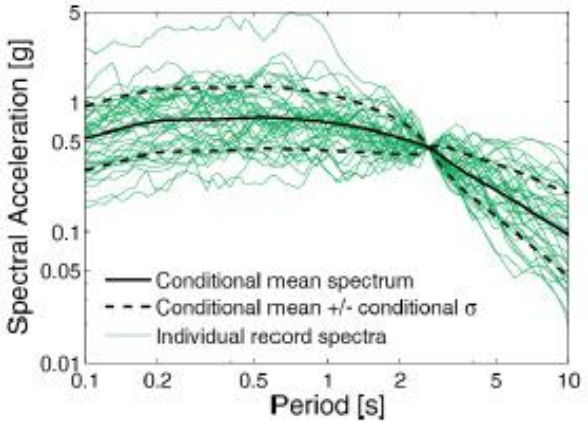
Chandramohan, Lin, Baker, and Deierlein (2013)

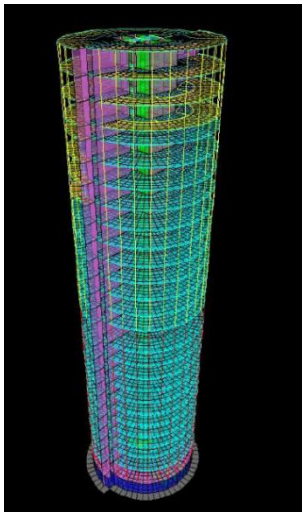
The future of ground motion selection



Project tasks

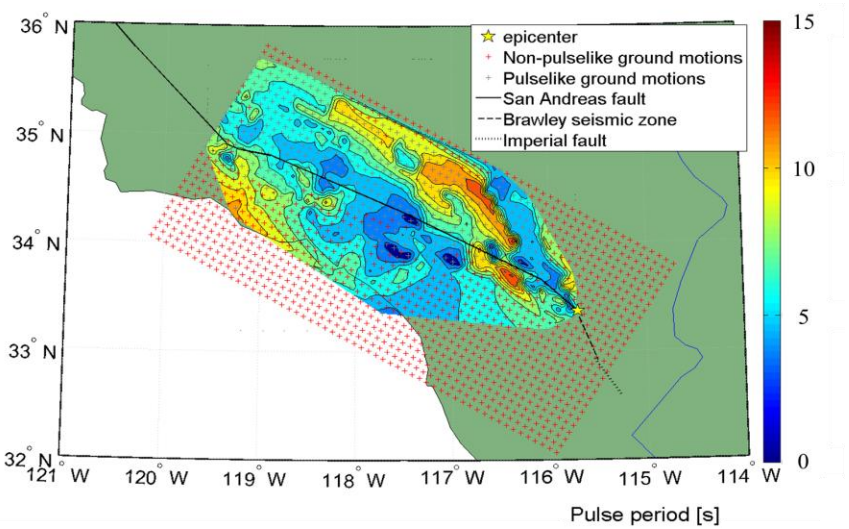
- Examine ground motion properties
  - Consider (independently and jointly) spectral shape, duration and pulse-like characteristics
  - Select ground motions that satisfy a specified set of criteria or generate motions via direct simulations
- Develop archetype classes of tall buildings
  - Include different structural systems, height ranges and layouts
  - Capture important structural behavior such as structural collapse, cumulative damage and “in-cycle” strength and stiffness degradation
- Evaluate structural response subjected to simulated motions
  - Investigate sufficient and efficient intensity measures through nonlinear response history analyses
  - Provide recommendations on use of simulated motions

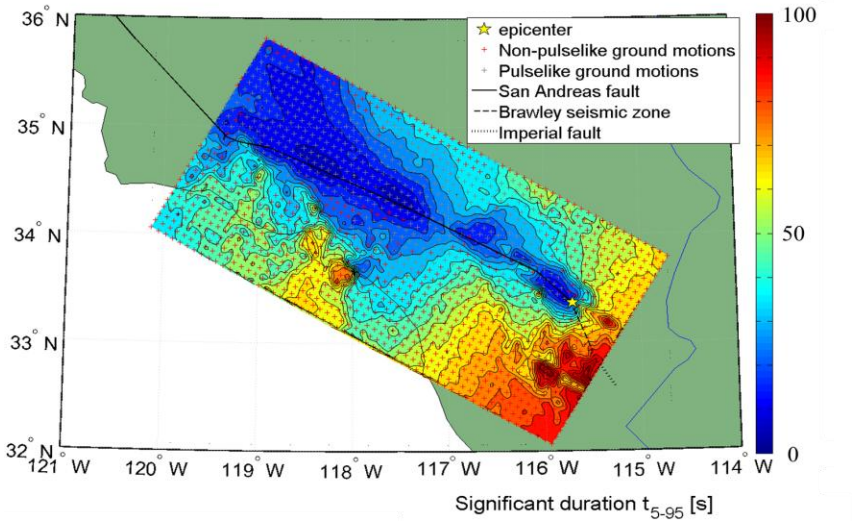


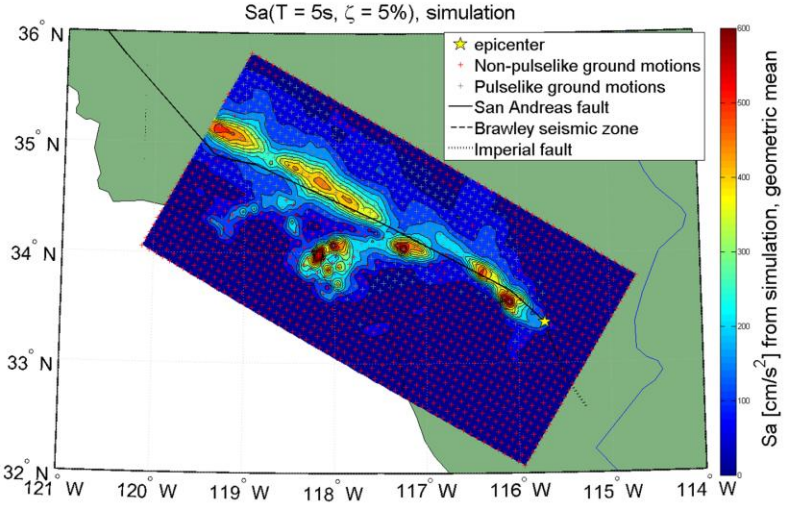


Ground motion screening example – Mw 7.8 ShakeOut Scenario HS1.2.0

- Set of broadband Mw 7.8 simulations
- Hypothetical earthquake on the southern San Andreas fault
- Southeast-to-northwest rupture with nucleation point at Bombay Beach
- Three-component waveforms for a 8km x 8km grid of sites covering Southern California
- Total of 1653 sites

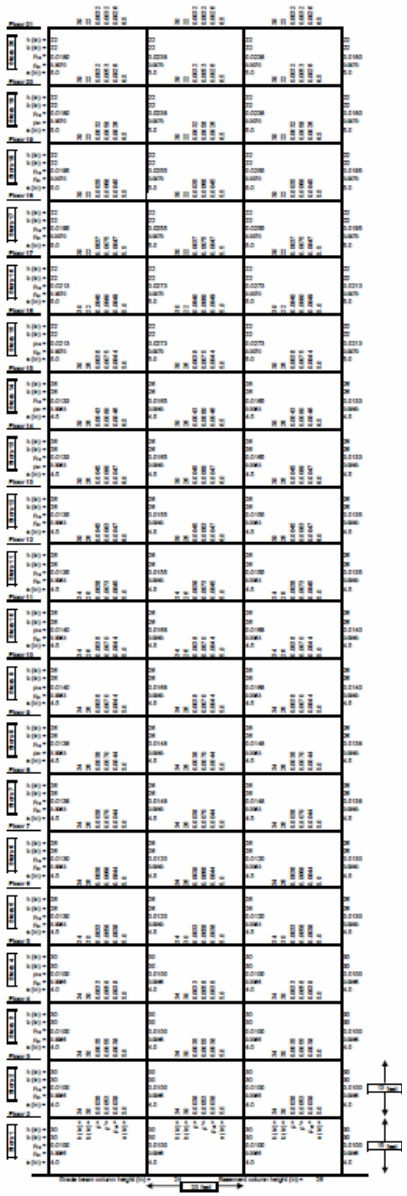


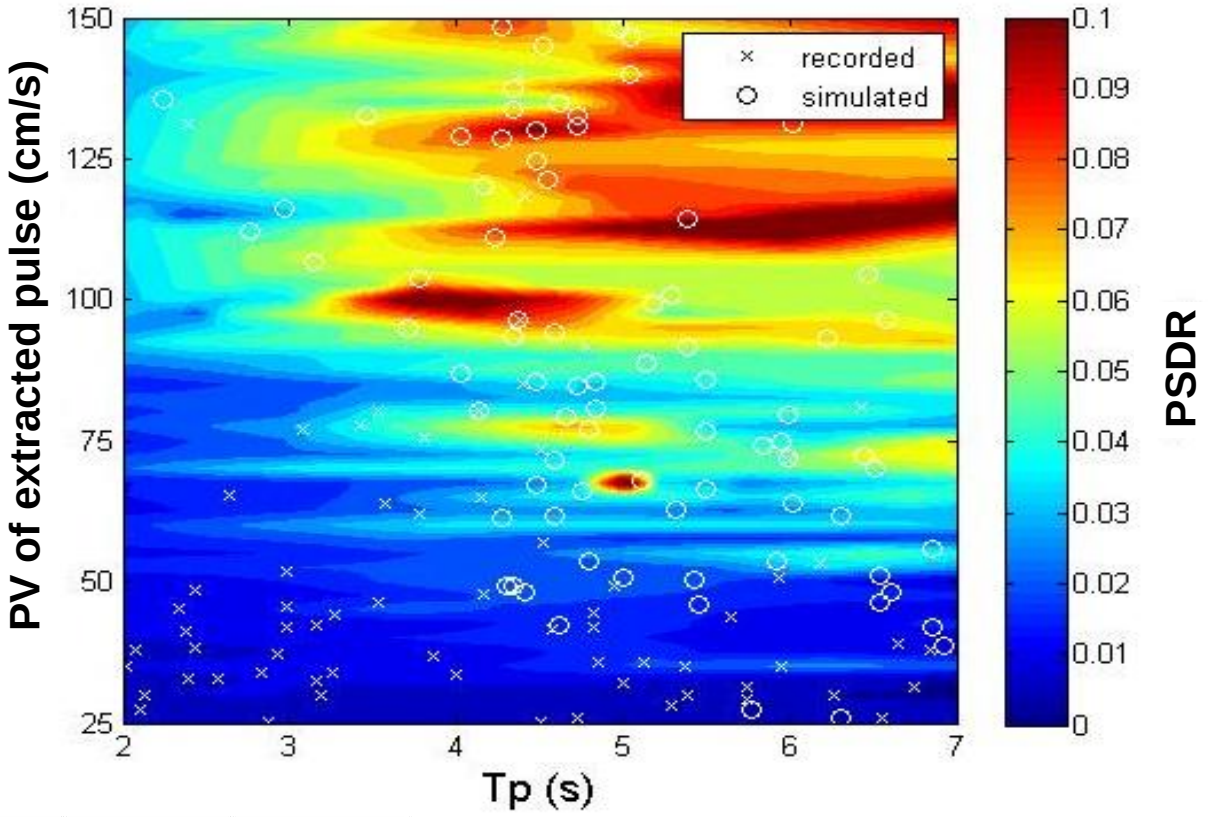


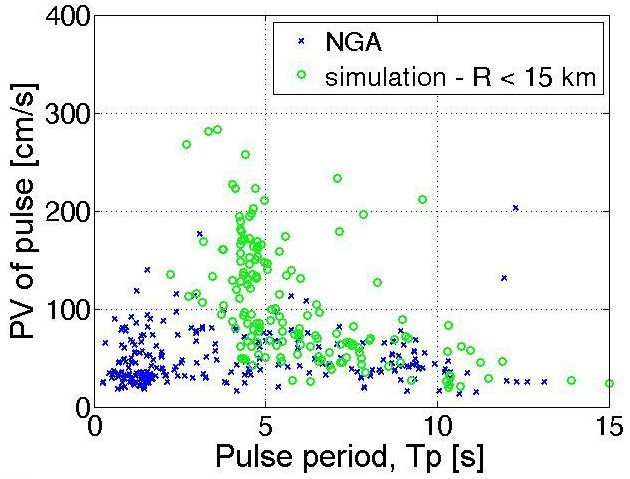


Simulations provided by Rob Graves

Pilot Study







- Structural model by Curt Haselton
- Earthquake simulations by Rob Graves
- NGA pulse-like motions by Shrey Shahi
- Pulse extraction following Baker (2007)
- EDP contour (on PV-Tp) for idealized velocity waveforms, recorded waveforms and simulated waveforms inspired by Krishnan and Muto (2013)

Thank you all!

Earth Science Day
@ Blume Earthquake Engineering Center
July 11, 2013

Poster 239/EEII: Tall building response to simulated pulse-like ground motions
Ting Lin, Nenad Bijelic, and Gregory Deierlein

www.stanford.edu/~tinglin

iSSEs2013 (ERI & SCEC):
The summer school on Earthquake Science in Japan
"Diversity of Earthquakes"
1. Huge earthquake
2. Transient phenomena
3. Fault zone

Acknowledgement:
SCEC, NSF XSEDE, Fulbright
Rob Graves
Marine Denolle, Eric Dunham & Greg Beroza
Broadband Platform simulators & validators
Arup/SOM partners
US/China tall building project
Stanford Seismic Resilience

www.eng.mu.edu/tinglin