

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

SCEC Annual Meeting 2013

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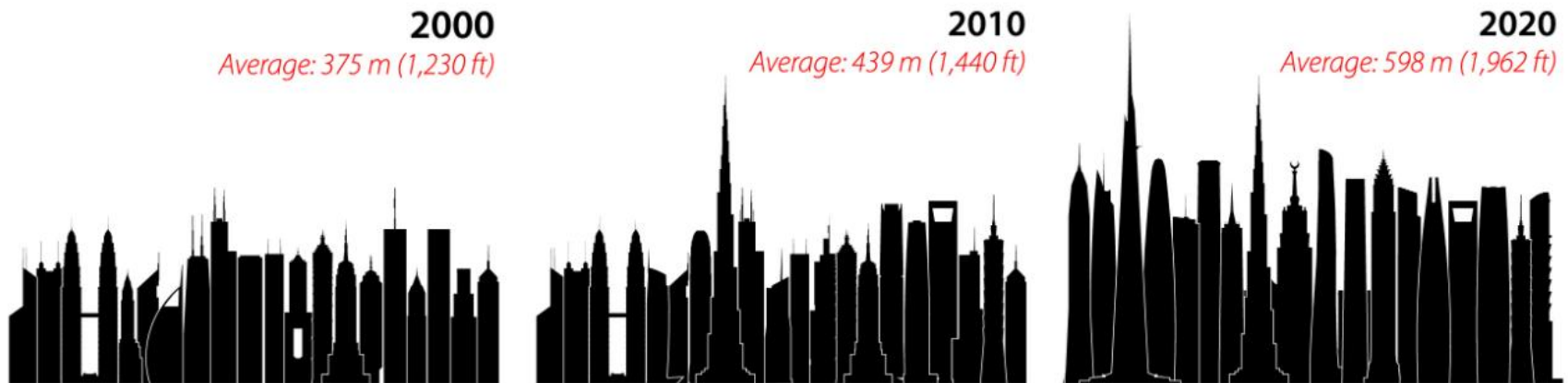
Stanford University

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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)



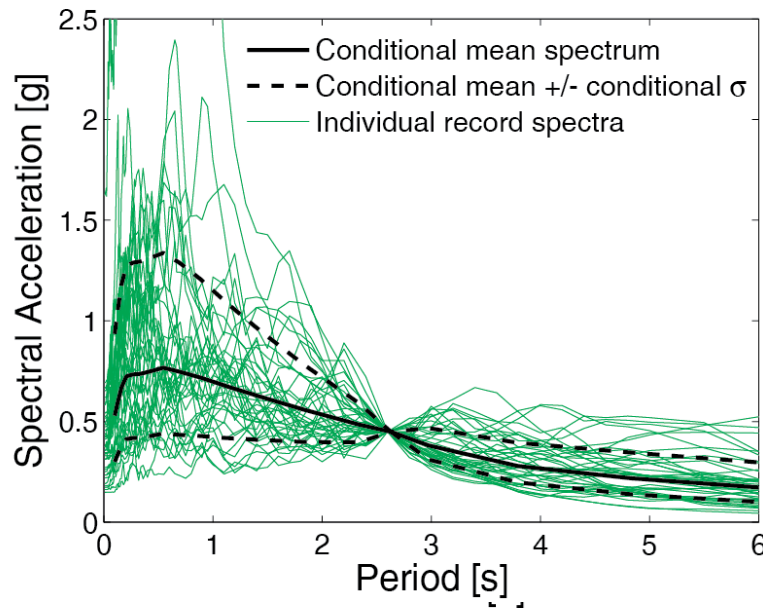
A study of tallest 20 buildings per decade (credit: CTBUH)

Objective

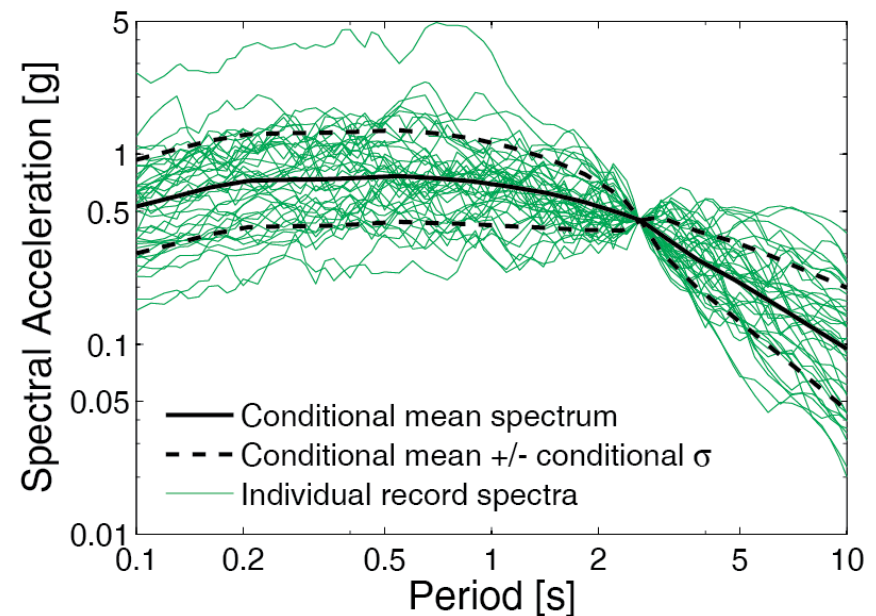
- Validate earthquake simulations from an engineering perspective through assessment of structural performance of tall buildings subjected to recorded and simulated ground motions
- Examine effects of spectral shape and duration on structural response
- Provide insights regarding the use of simulations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

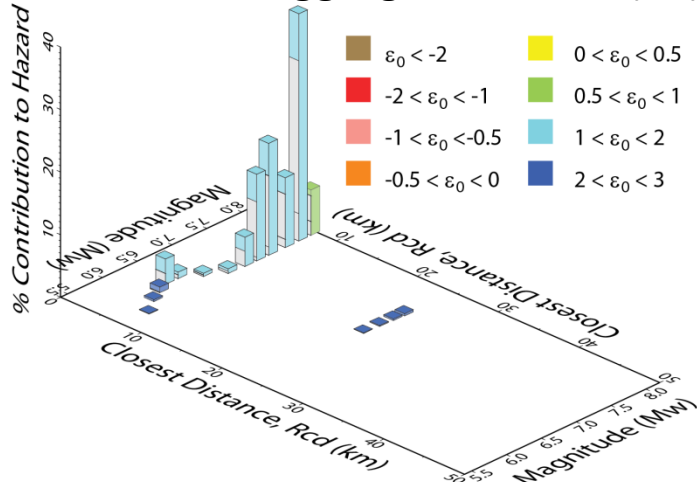


Uniform Hazard Spectrum is the envelope of Conditional Mean Spectra at various periods

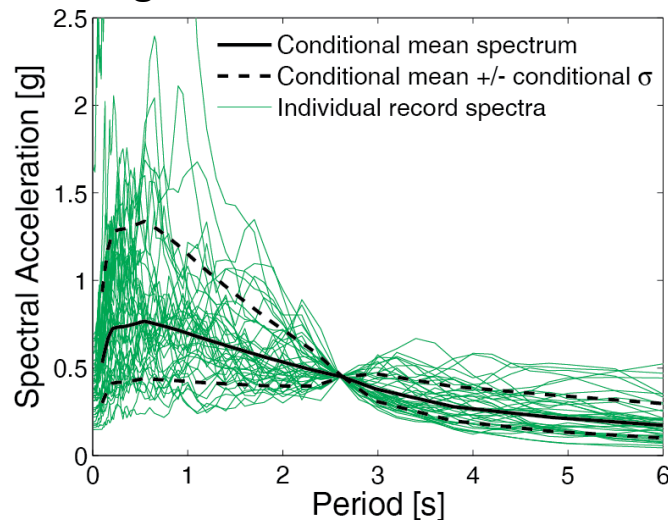


Ground motion selection and structural analyses

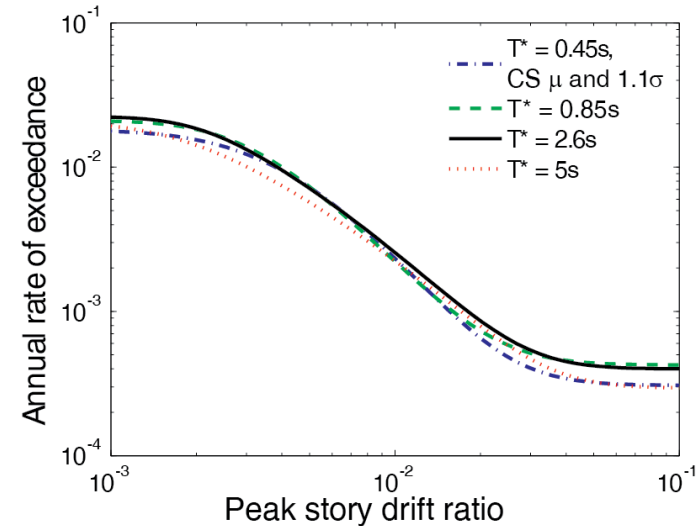
Hazard deaggregation for $S_a(T^*)$



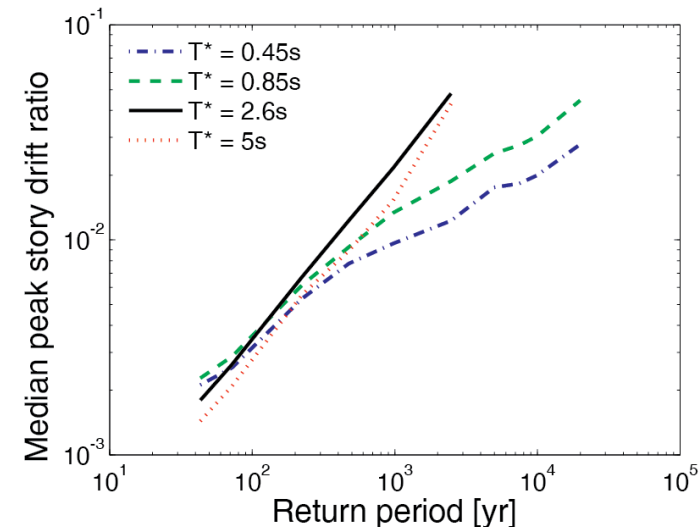
Target spectrum computation and ground motion selection



Risk-based assessments



Intensity-based assessments



Software tool for ground motion selection

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


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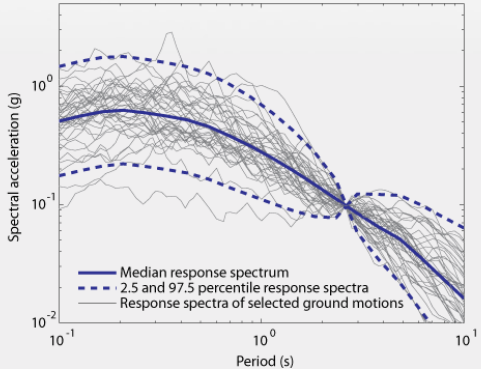
A computationally efficient ground motion selection algorithm for matching a target response spectrum mean and variance

by Nirmal Jayaram, Ting Lin and Jack Baker, 2010


This web page provides documentation and supporting software for the following manuscript:

 Jayaram, N., Lin, T., and Baker, J. W. (2010). "A computationally efficient ground-motion selection algorithm for matching a target response spectrum mean and variance." *Earthquake Spectra*, (in press).

This manuscript describes an approach for selecting ground motions whose response spectra match a target response spectrum mean and variance. While the papers describe the method, complete documentation of the project is best achieved by providing the software used to perform the analysis. This website serves to provide that documentation, allowing others to reproduce the results published in the manuscript.



Software and data:

 Ground motion metadata. This Matlab data file should be downloaded and placed in the working directory of any of the scripts provided below. It contains all response spectra and metadata for the NGA ground motion database, and will be used in the search process of all of the following codes. (file size= 12 MB)

Acknowledgement

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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



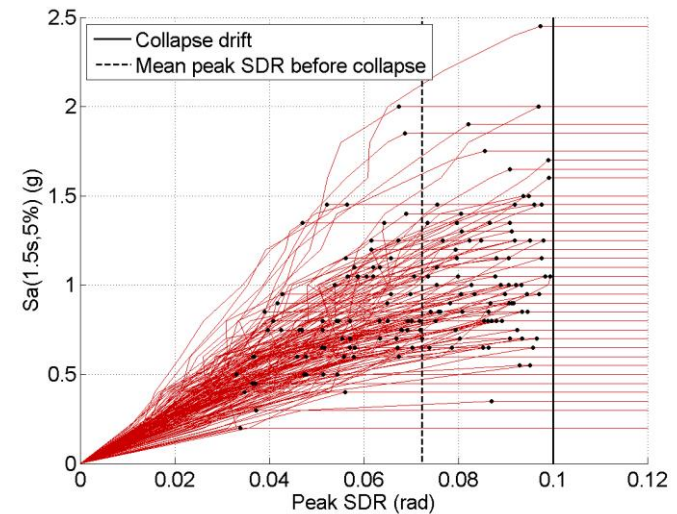
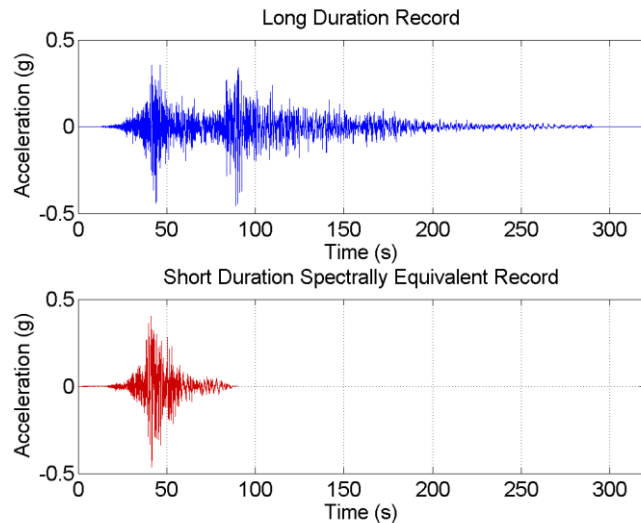
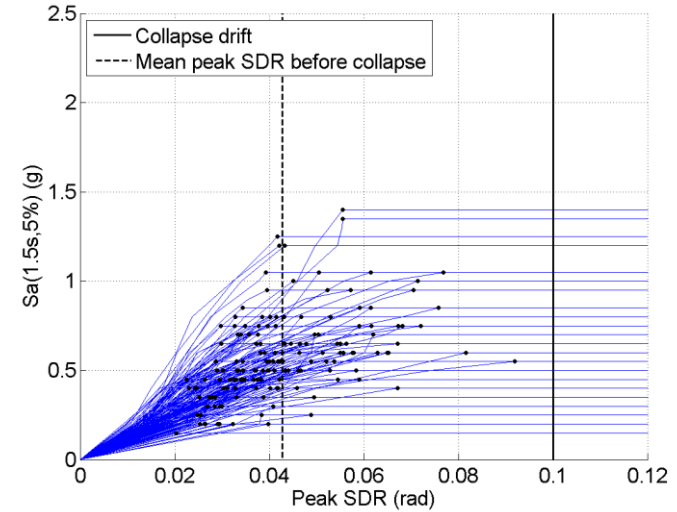
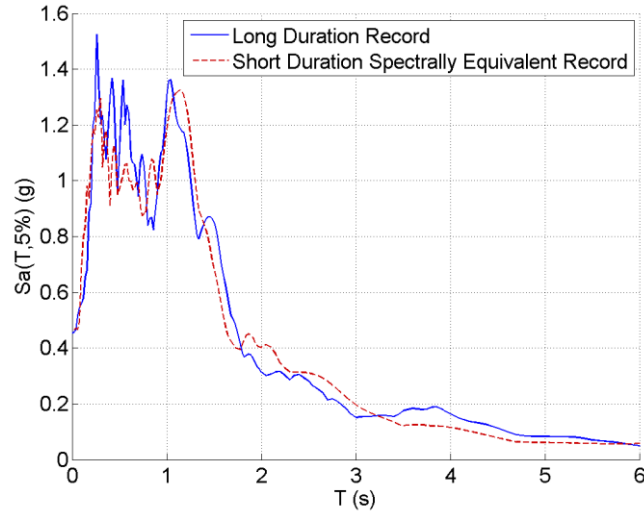
Duration

- 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

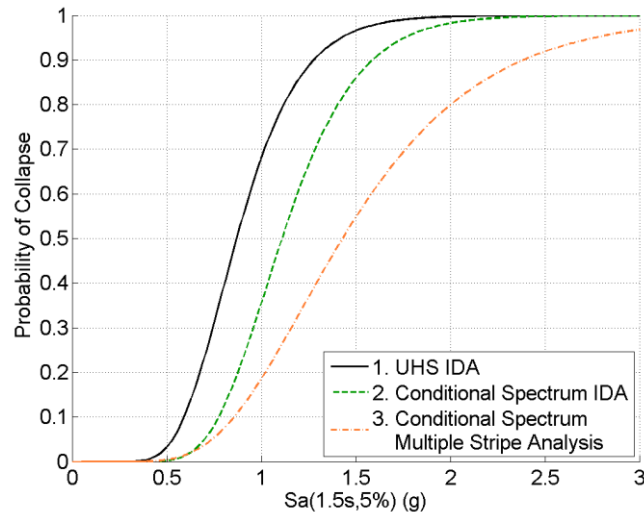
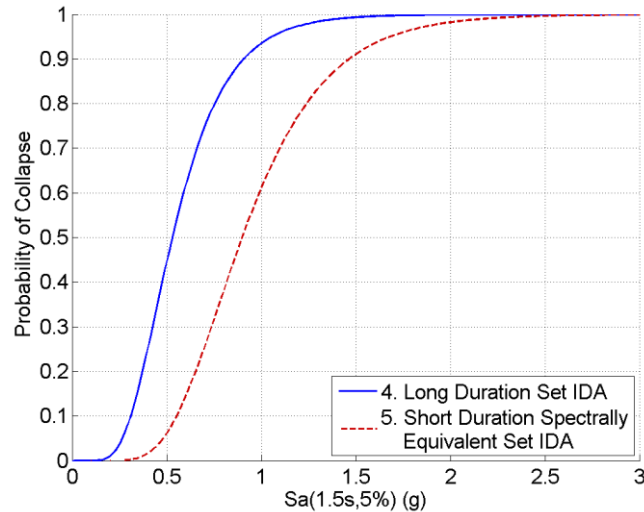
Desired properties	Bracketed duration	Significant duration	Arias Intensity	CAV	I_D
Uncorrelated to common IMs like PGA and $S_a(1s)$	✓	✓	✗	✗	✓
Unaffected by scaling	✗	✓	✗	✗	✓
Does not bias spectral shape	✓	✓	✓	✓	✗

- ***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

Influence of duration on seismic collapse risk



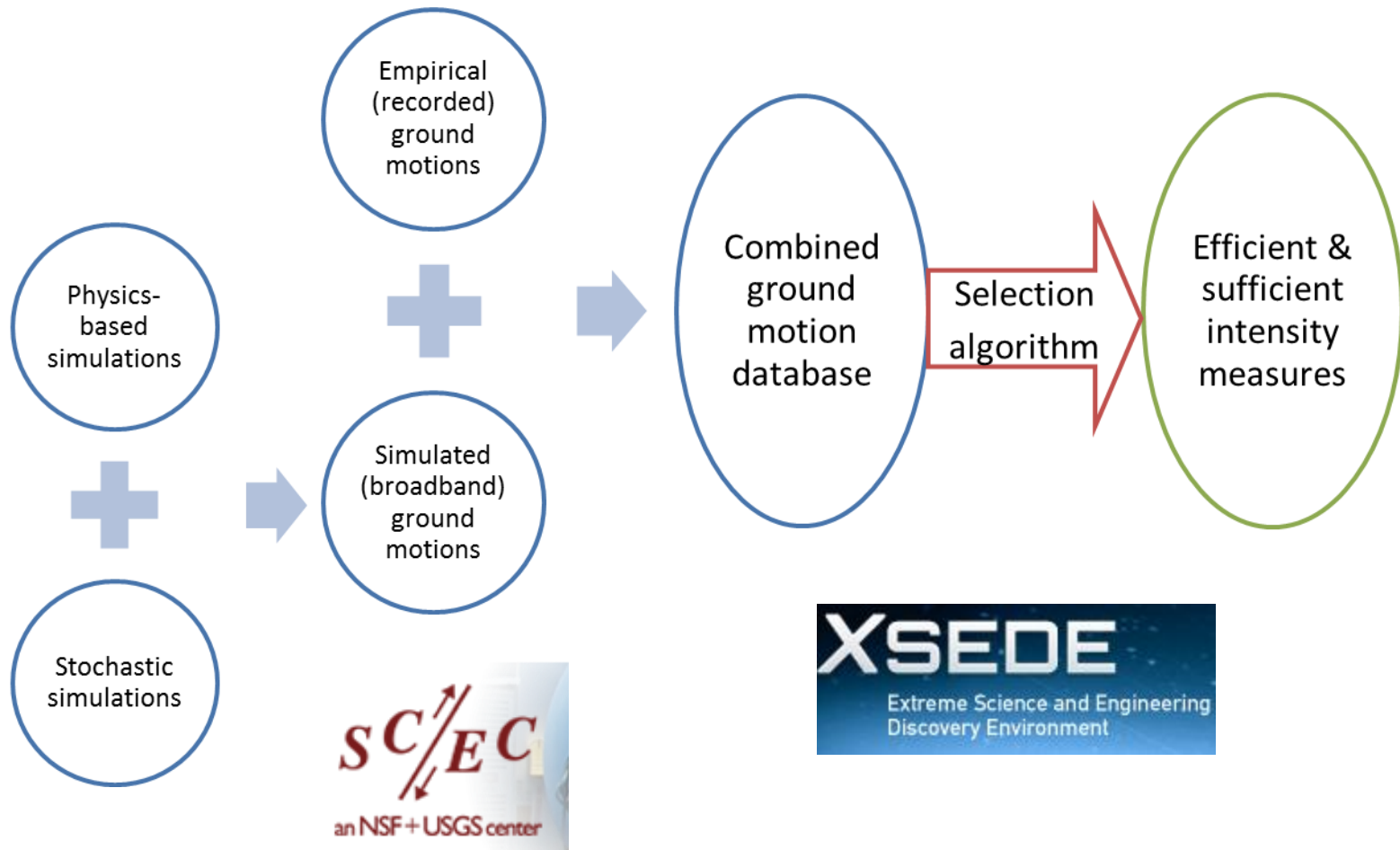
Influence of spectral shape and duration on seismic collapse risk



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

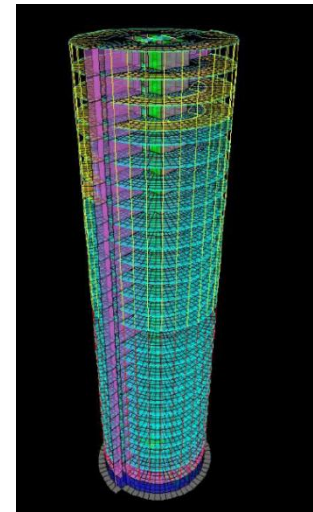
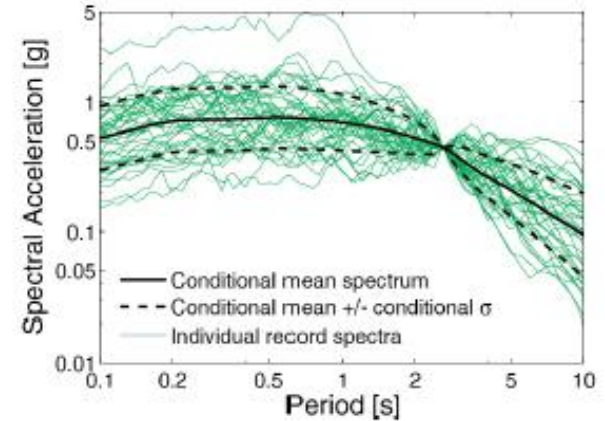
This project examines impact of spectral shape and duration for simulations

The future of ground motion selection



Project tasks

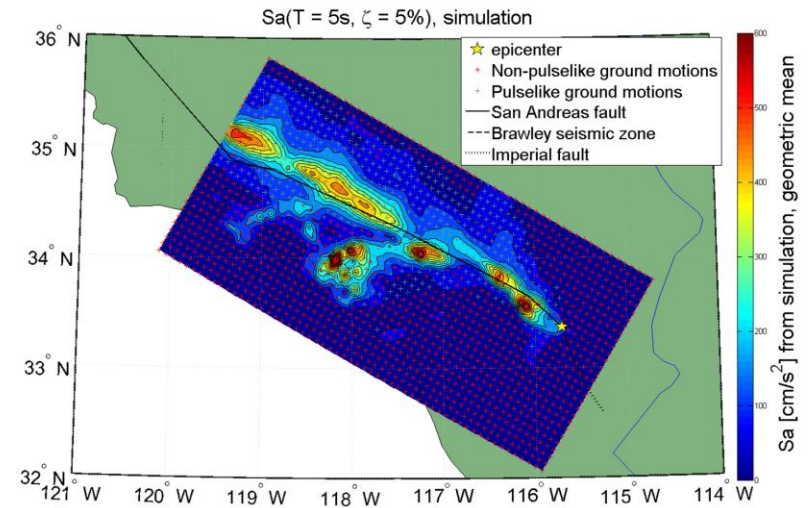
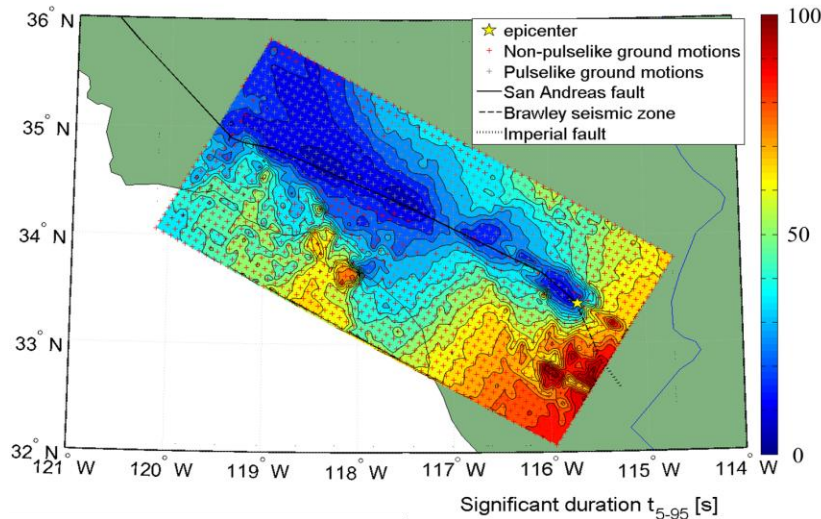
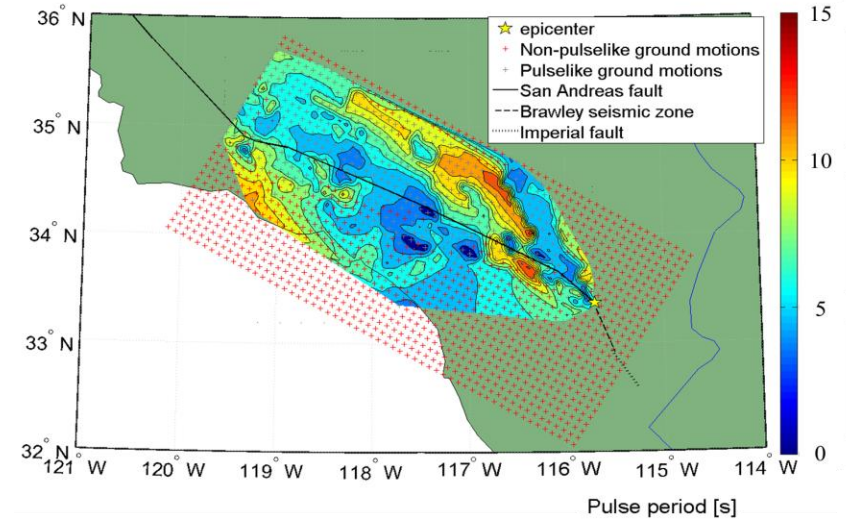
- Examine ground motion properties
 - Consider (independently and jointly) spectral shape, duration and pulse-like characteristics
 - Select ground motions that satisfy a specified set of criteria or generate motions via direct simulations
- Develop archetype classes of tall buildings
 - Include different 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

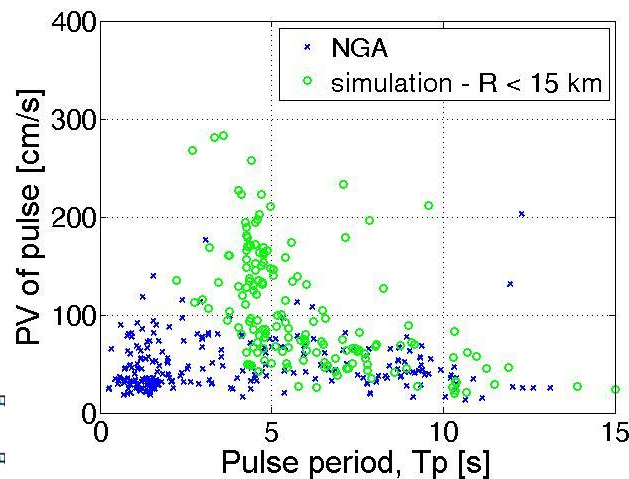
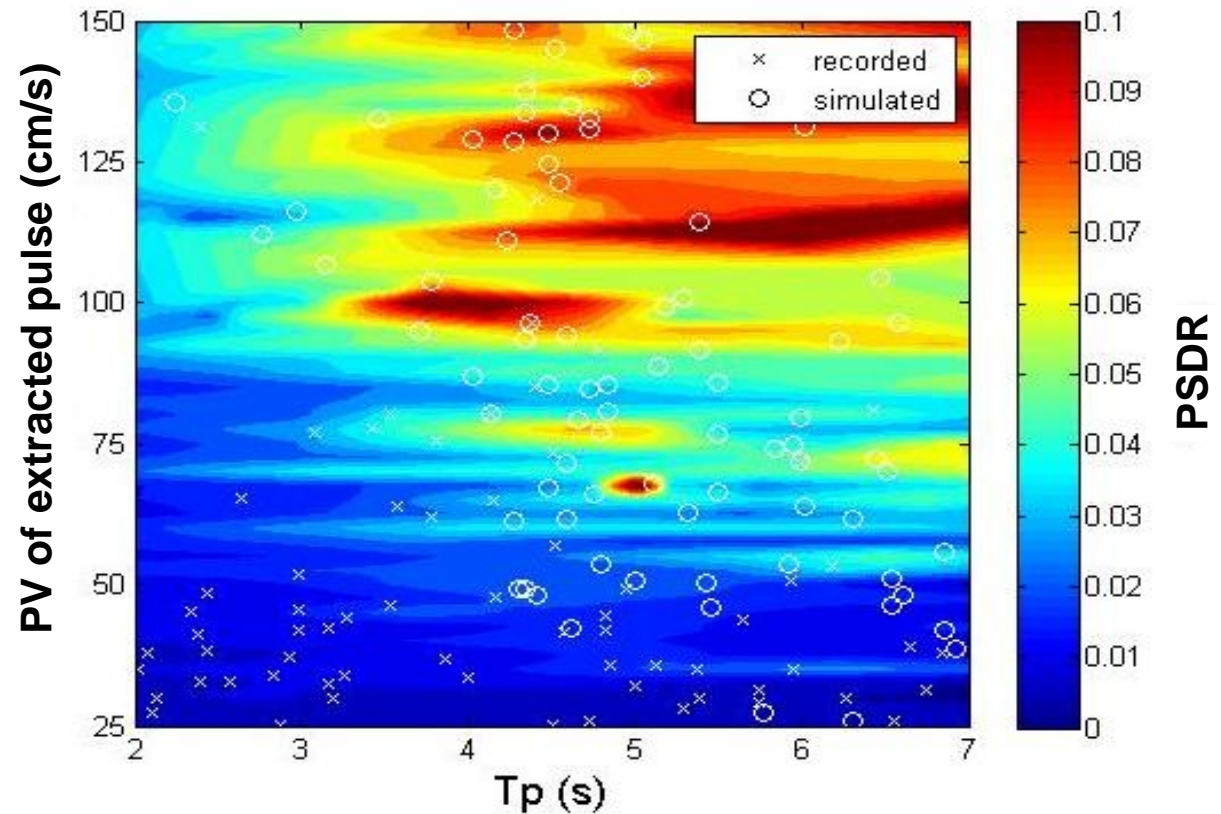
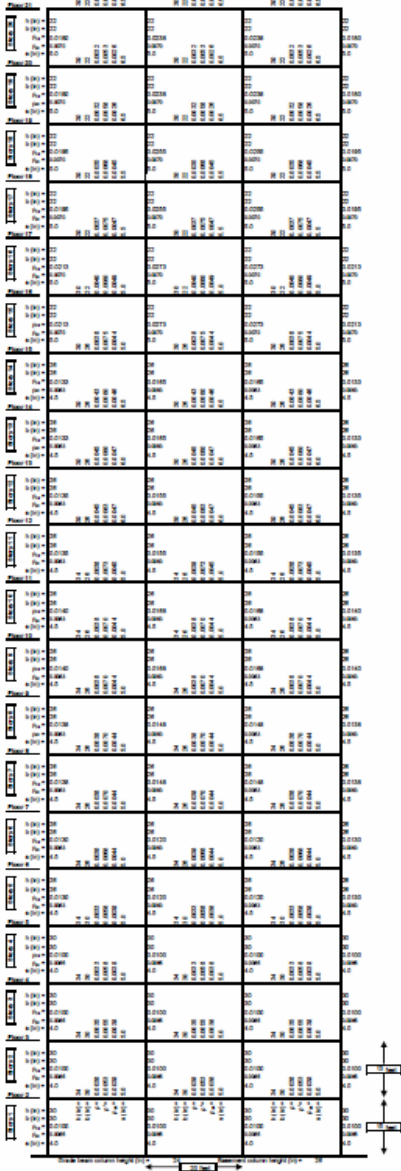
– Mw 7.8 ShakeOut Scenario HS1.2.0

- 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

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Broadband Platform
simulators & validators
Arup/SOM partners
US/China tall building project
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