Selected and scaled ground motions for the Transportation Systems Research Program

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Motivation

The goal of this project is to select a standardized set of ground motions for the TSRP that

- Can be used to analyze a variety of bridge and geotechnical systems
- Are appropriate for a variety of locations in California

Because these are not structure-specific and site-specific goals, ground motion selection techniques developed in previous PEER projects are not directly applicable here

Today I will present my plan for addressing this challenge, and solicit input from you regarding your needs

Issues relevant to this effort

- There is no single site of interest, but we are generally interested in high-seismicity sites in California (i.e., mid- to large-magnitude shallow crustal earthquakes at distances of less than 40 km)

- Some sites of interest may be located nearby active faults, such that they have the potential to experience near-fault directivity pulses

- The systems of interest may be sensitive to excitation at a wide range of periods

Presentation outline

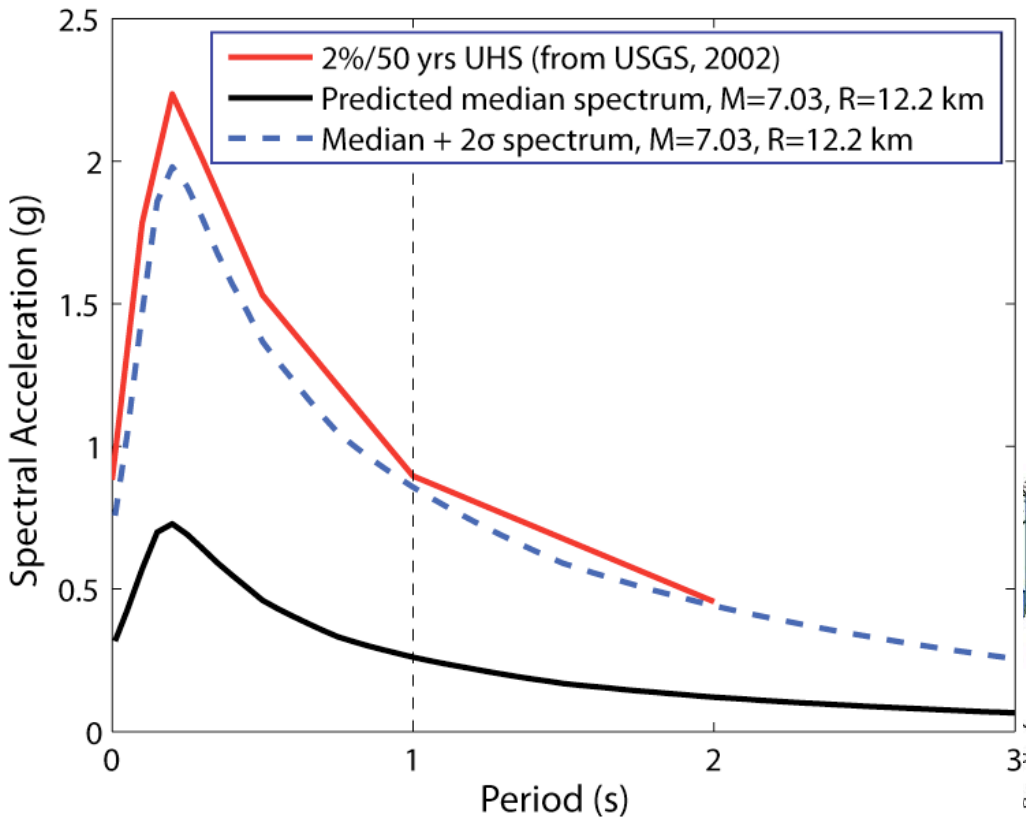
1. Background: latest thoughts on structure-specific and site-specific record selection (i.e., "why isn't code-based ground motion selection sufficient?").
   - "Conditional Mean Spectrum" concept, versus a Uniform Hazard Spectrum
   - Near-fault directivity pulses

2. Proposal for the TSRP ground motion sets

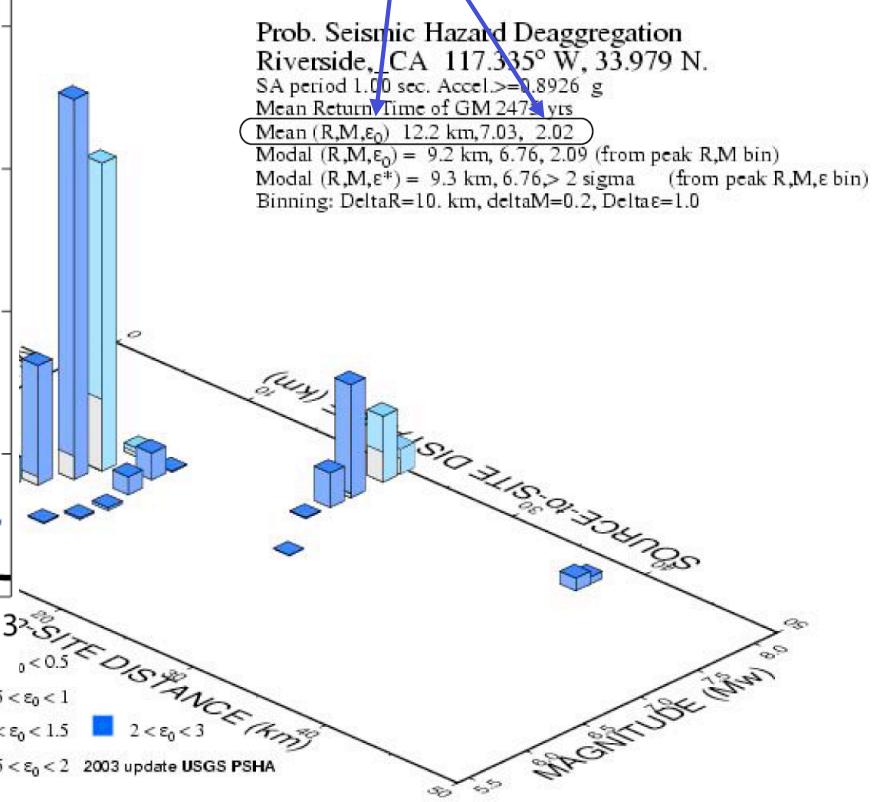
3. Documentation of the selected ground motion sets

Background issue #1: structure-specific record selection using PSHA

UHS for Riverside, California

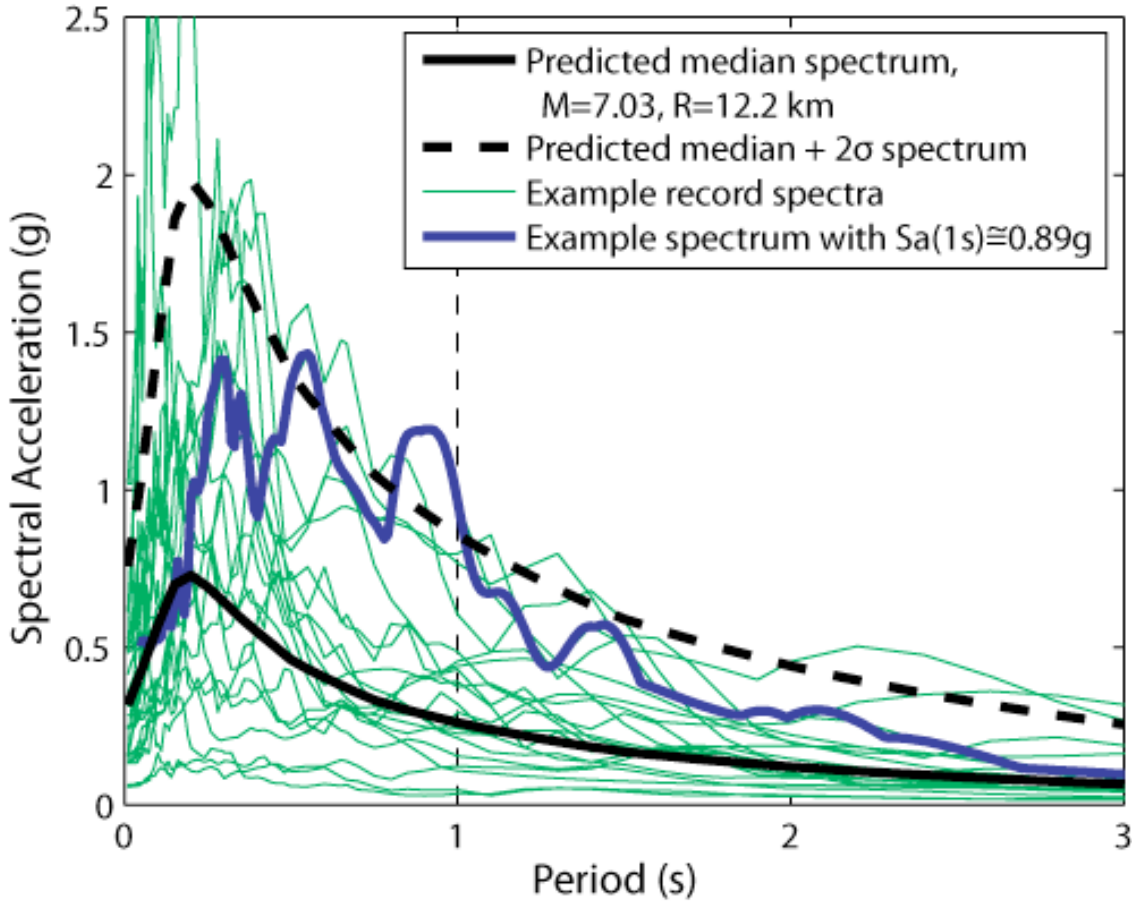


# of standard deviations above median Sa

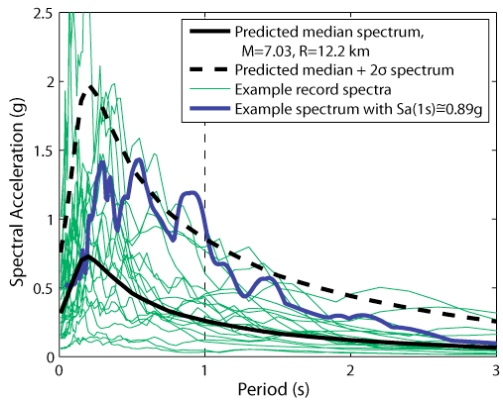


This " ε effect" is a real phenomenon

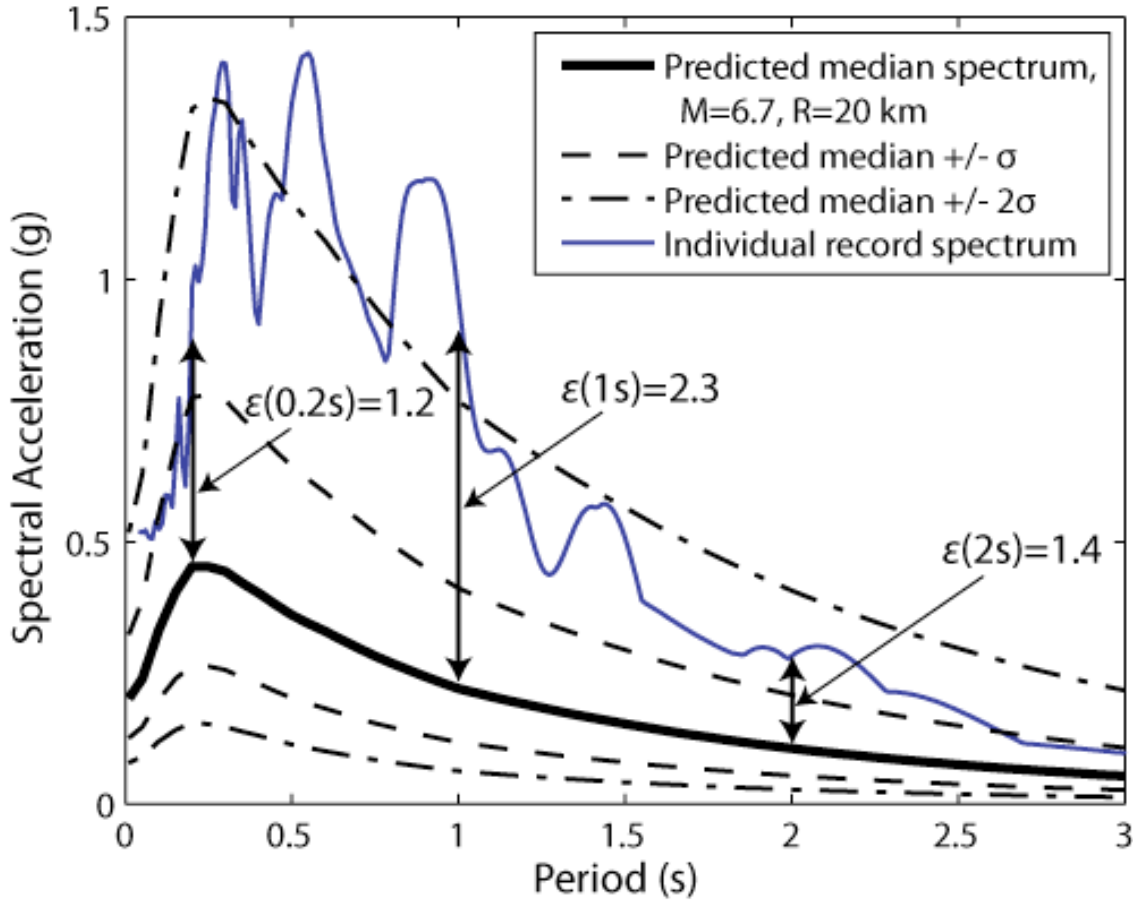
Response spectra from real ground motions having approximately magnitude = 7 and distance = 12 km



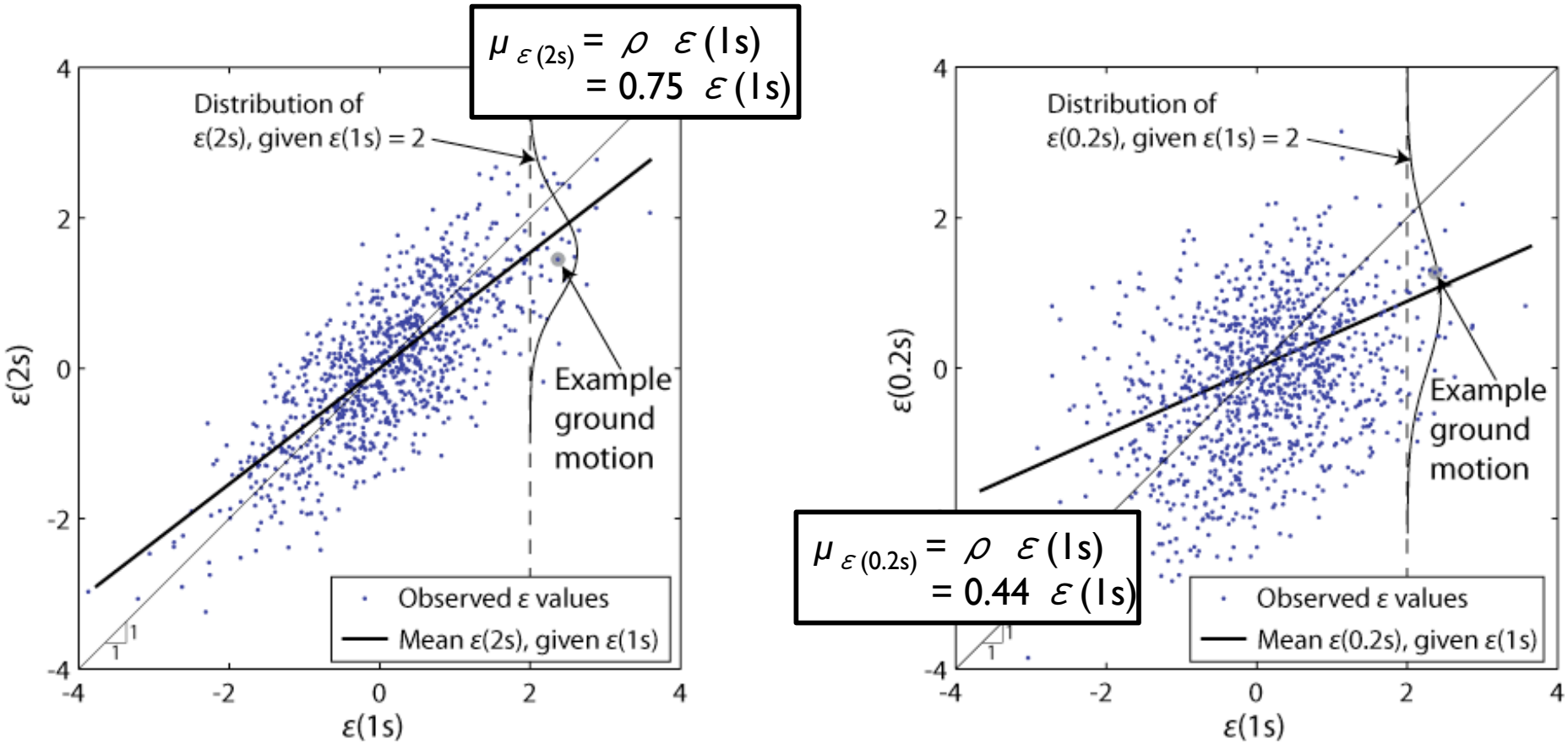
Calculation of ε values at three periods



$$\varepsilon(T) = \frac{\ln Sa(T) - \mu_{\ln Sa(T)}}{\sigma_{\ln Sa(T)}}$$

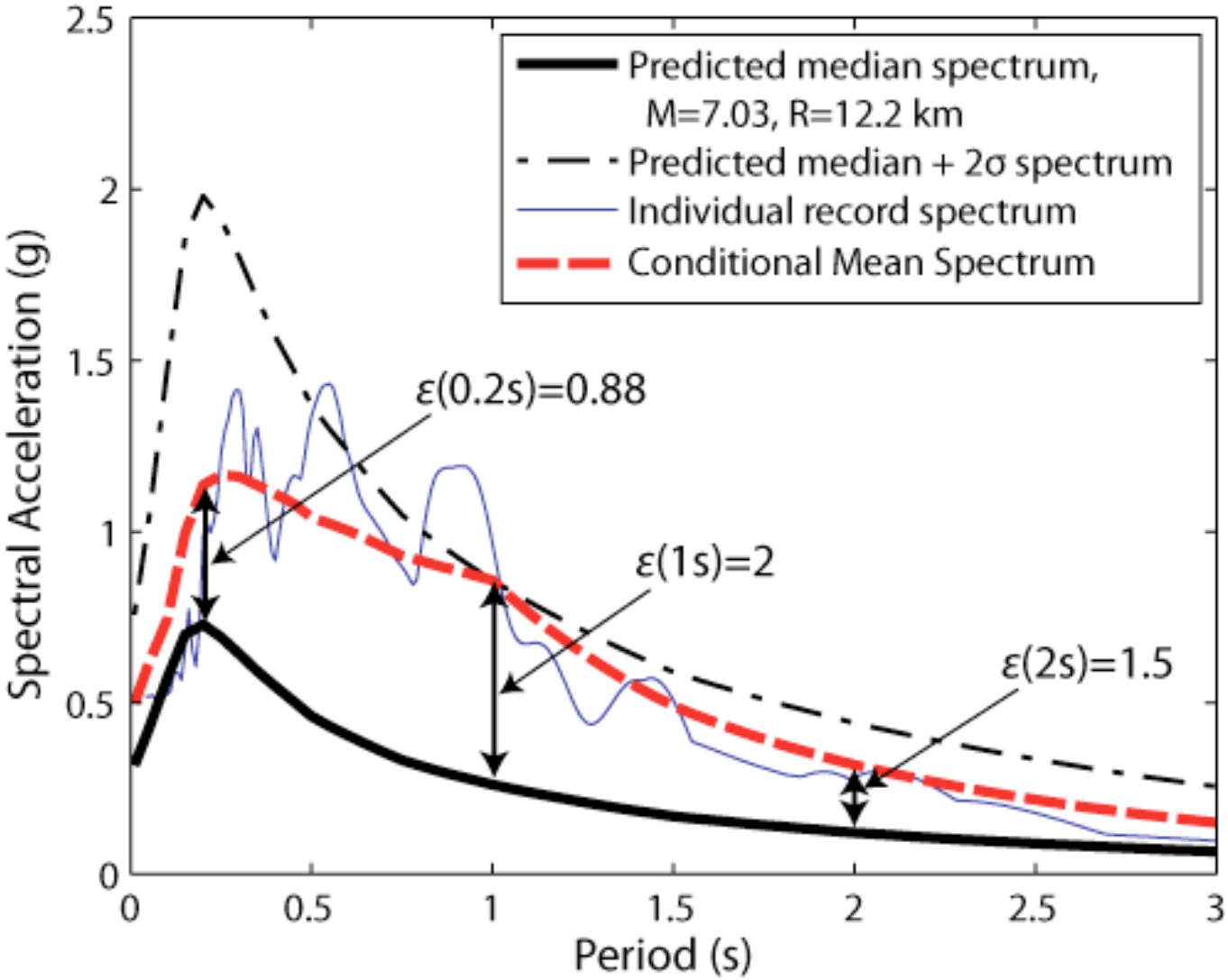


ε values at varying periods, from many ground motions

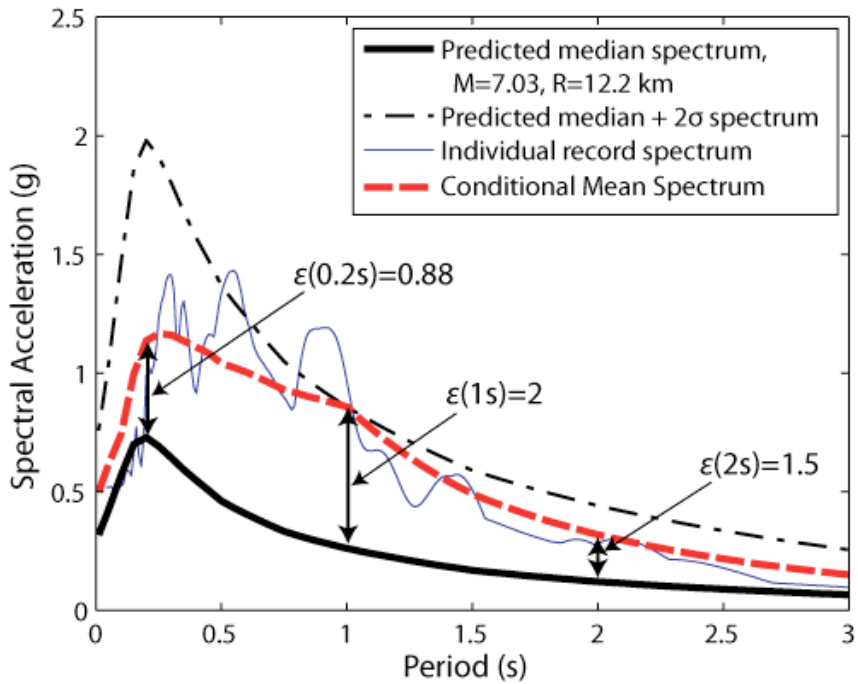


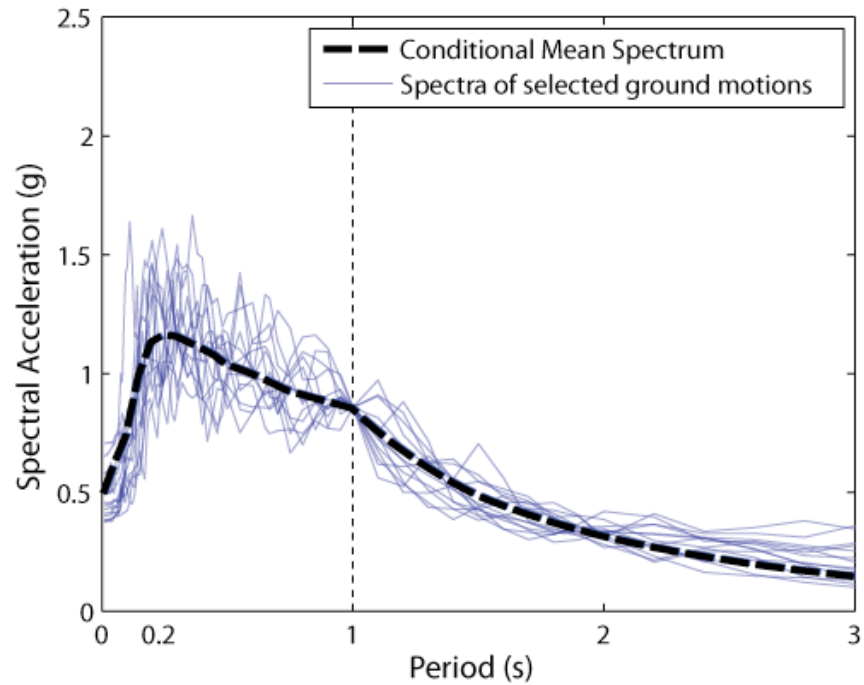
Using this information, we can find the "expected" (mean) ε at all periods, given a target ε at T_1, the period of primary interest

Conditional mean values of spectral acceleration at all periods, given the target *Sa*(1s)



We can select and scale ground motions to match this Conditional Mean Spectrum

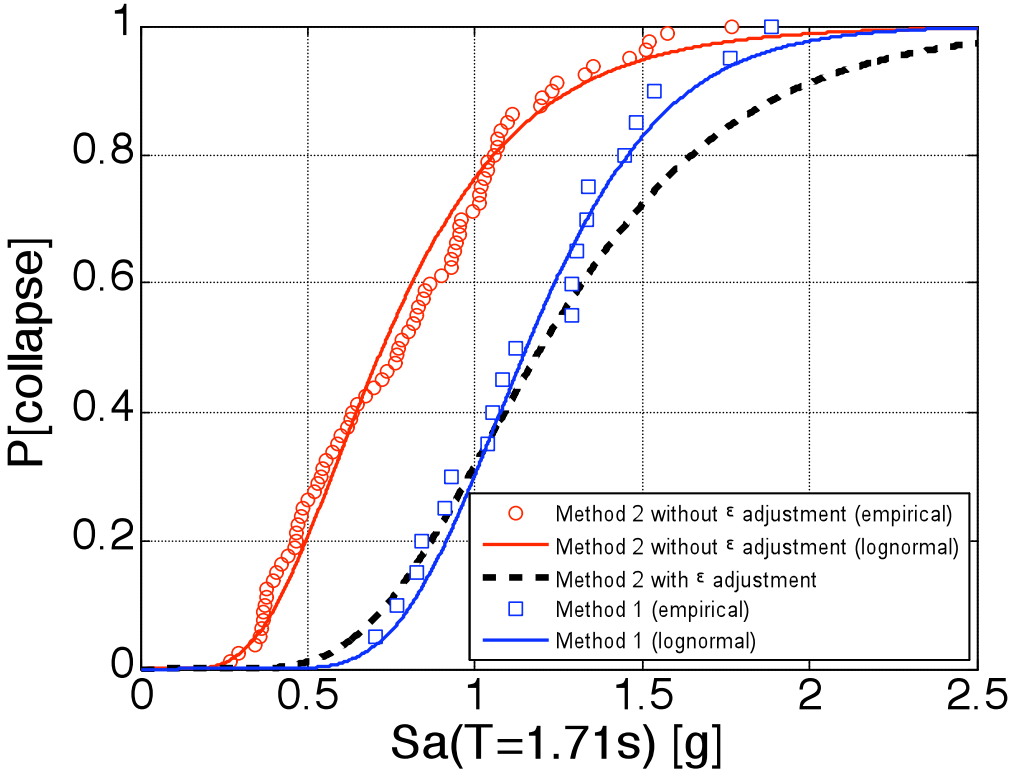




Ground motions selected and scaled while accounting for this ε effect have been shown to be most appropriate for PEER-framework assessments

An important issue: at what period to we do the conditioning?

The ε effect and collapse fragility functions (ATC-63 results)



Collapse fragility functions for a modern eight-story reinforced concrete frame studied by Haselton et al. in the ATC-63 project

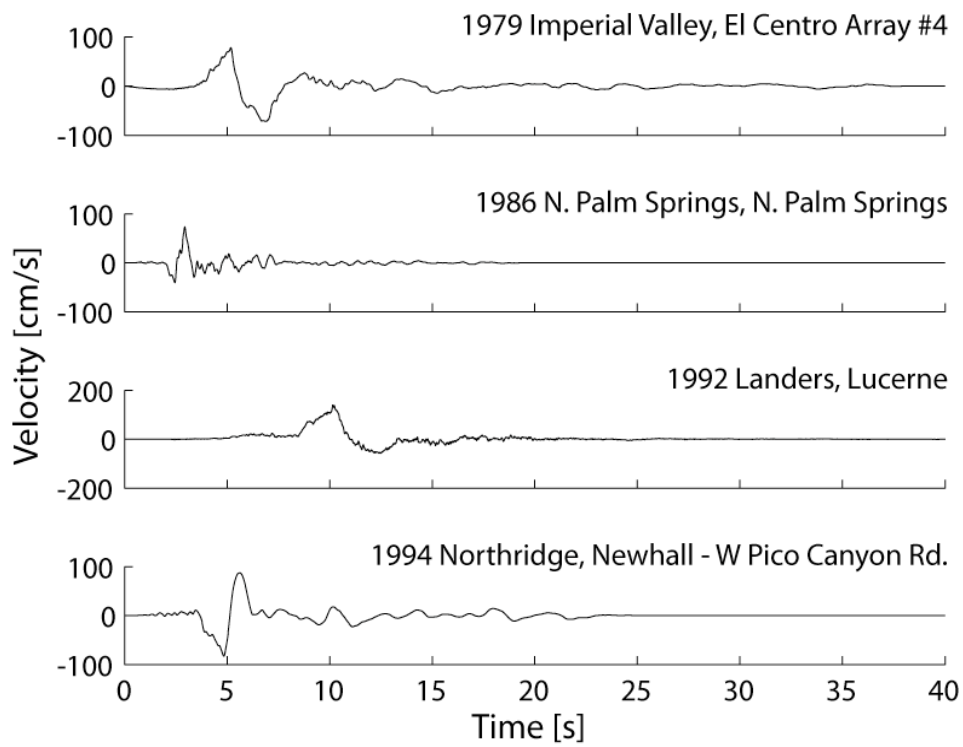
Haselton, C. B., Baker, J. W., Liel, A. B., and Deierlein, G. G. (2009). "Accounting for ground motion spectral shape characteristics in structural collapse assessment through an adjustment for epsilon." *ASCE Journal of Structural Engineering*, (In press).

Background issue #2: Near-fault directivity

Near-fault directivity pulses can have an important effect on structural and geotechnical response

Many bridges in California are located near active faults and may thus experience these pulses

A key parameter is the period of the velocity pulse, relative the period of the structure being analyzed



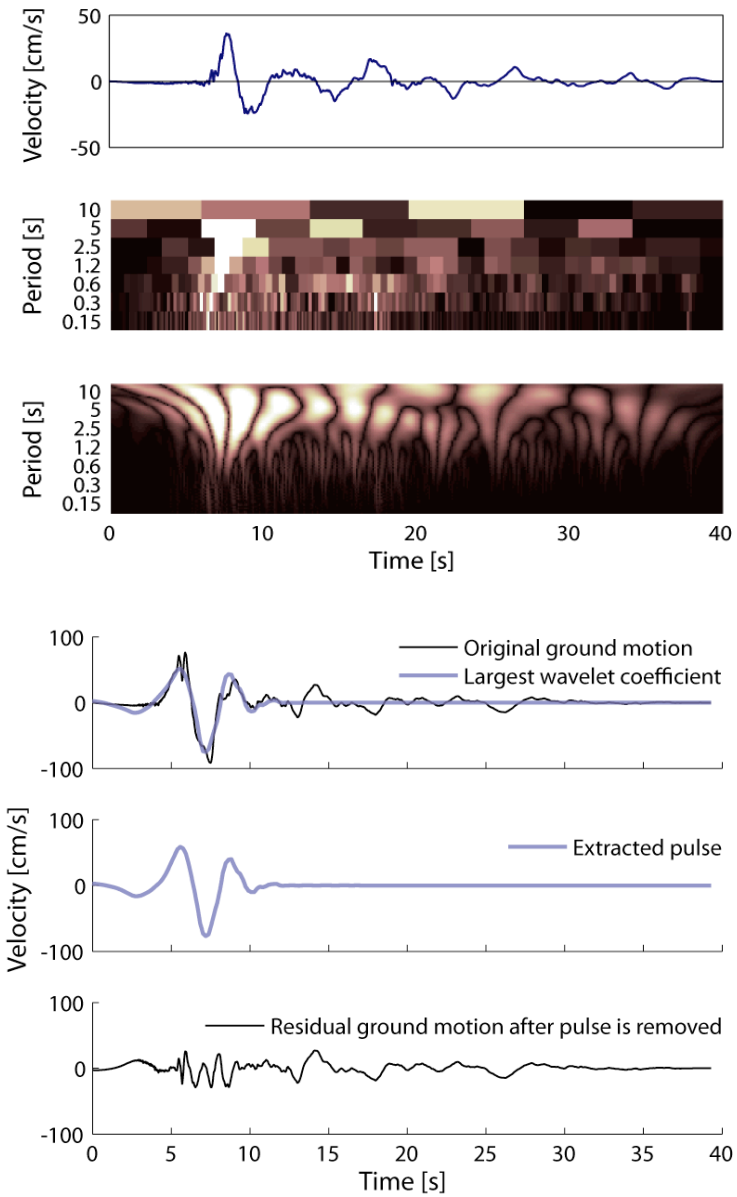
Pulse identification and extraction

Here I propose to utilize my previous work that quantitatively identified pulses by decomposing ground motions into wavelets

If the largest wavelet coefficient is associated with a large portion of the record, a ground motion is identified as containing a pulse (91 fault-normal pulses in the NGA library)

Pulse periods are also obtained

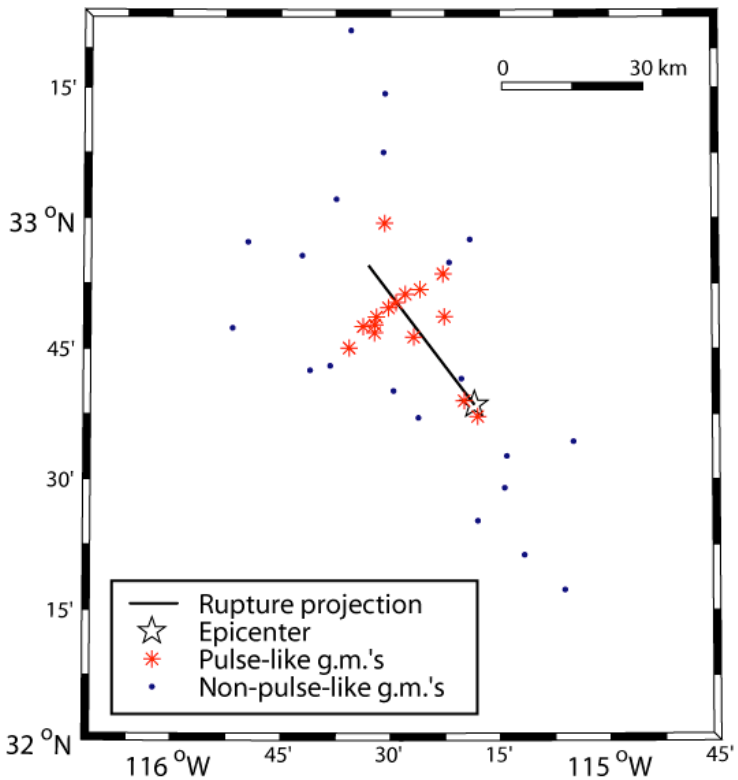
This technique utilized in the PEER Design Ground Motion Library project



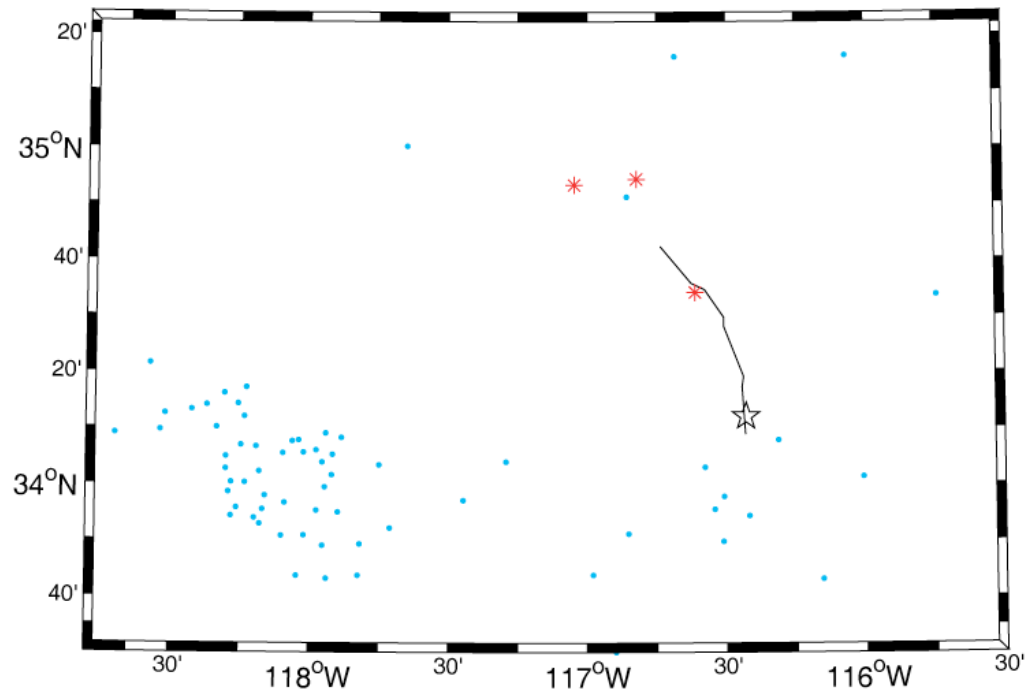
Baker, J.W. (2007). "Quantitative Classification of Near-Fault Ground Motions Using Wavelet Analysis." *Bulletin of the Seismological Society of America*, 97(5), 1486-1501.

Velocity pulse observations from past earthquakes

1979 Imperial Valley



1992 Landers



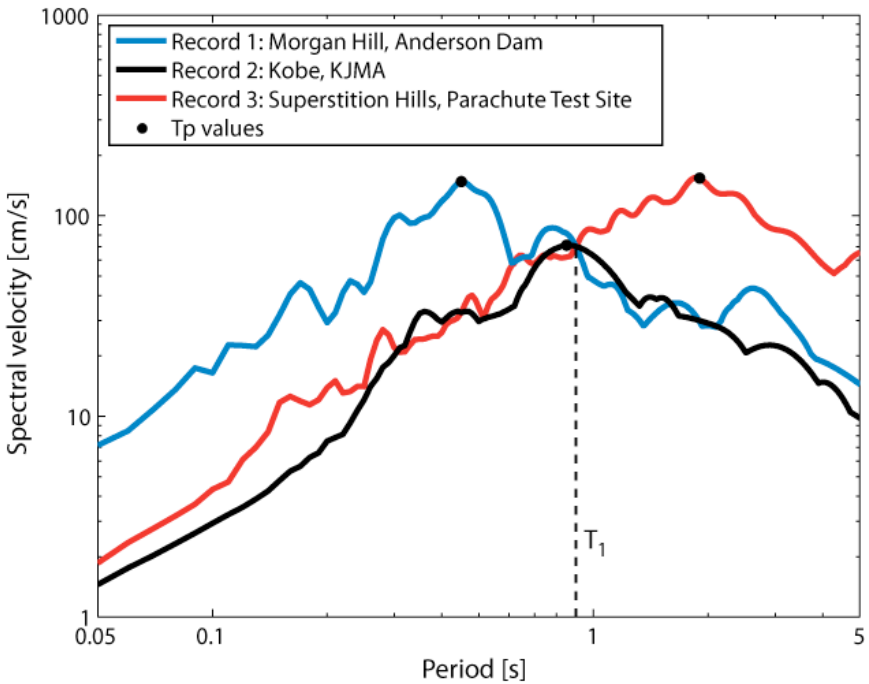
The algorithm identifies ground motions with clear pulses, and the identified motions are generally from locations where directivity is expected

Velocity pulses and structural response

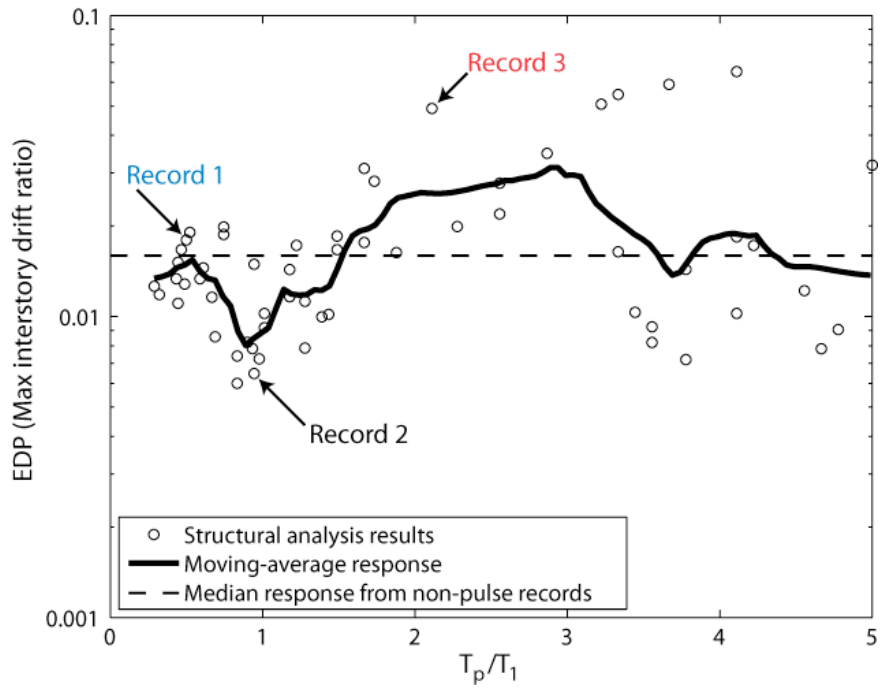
The velocity pulse periods typically correspond to peaks in the velocity spectra

The pulse periods also relate to structural response results

Example velocity spectra, scaled to $Sa(T_1)$



Max IDR from an 8-story building



Proposal for TSRP ground motions:

I will provide three sets of ground motions, which can be used as needed

1. Broad-band set
   - Useful for general studies
   - Not site-specific
   - May require some post-processing for use in "PEER-Framework" analyses

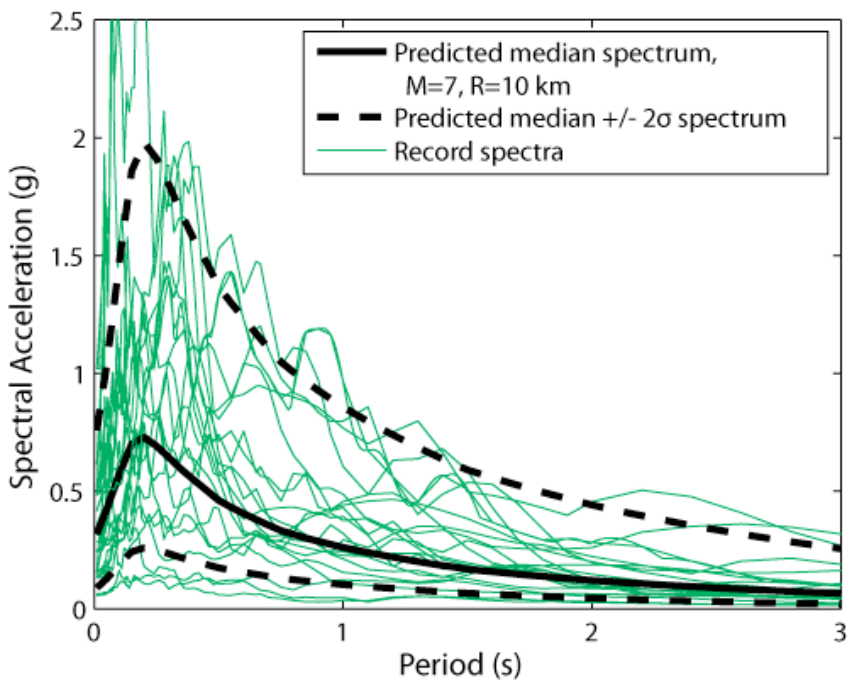
2. Narrow-band set
   - Ground motions approximating CMS-type target spectra
   - Semi-site-specific and building-specific
   - May require use of multiple sets (i.e., spectral peaks at multiple periods)

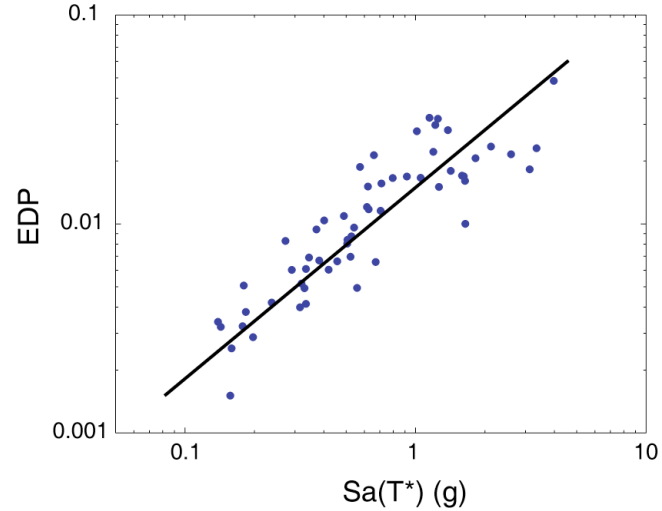
3. Near-fault set
   - Ground motions containing strong velocity pulses of varying periods

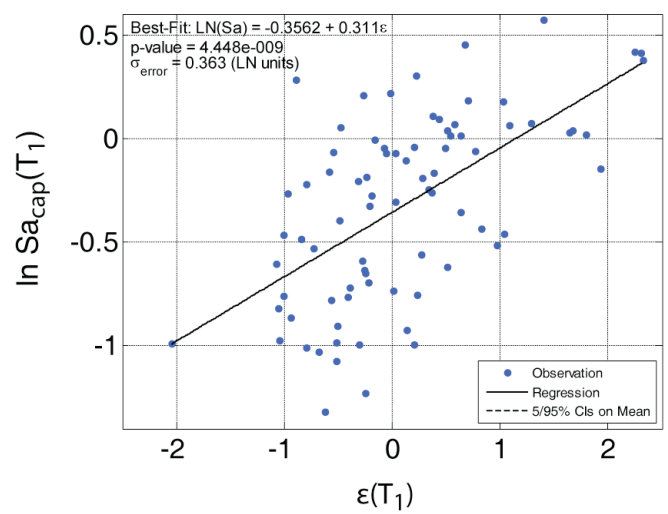
Group1: Broad-band ground motions

The spectra of these motions match the mean and standard deviation of response spectra expected from a magnitude 7 earthquake at 10 kilometers

EDP results can be post-processed to evaluate the effect of ground motion properties such as *Sa*(*T*) and ε





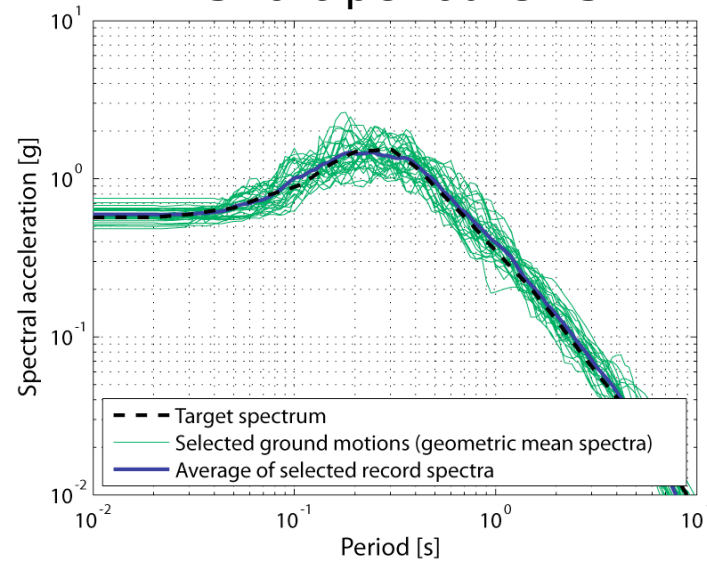


(figure adopted from Curt Haselton)

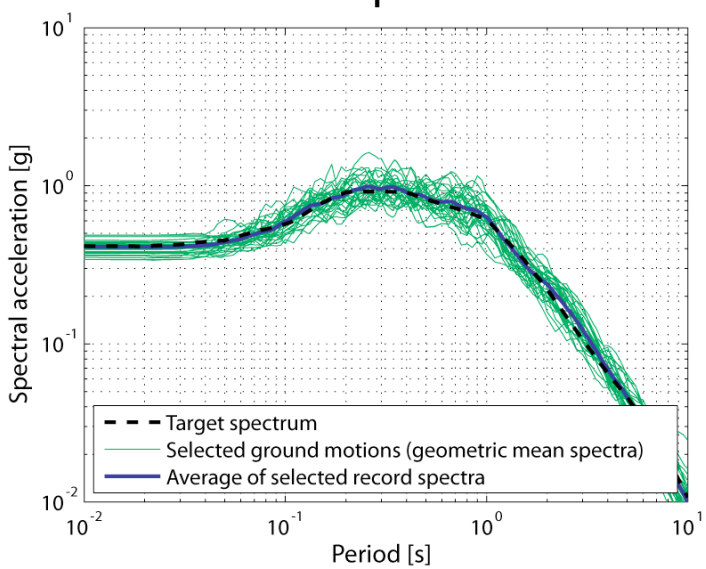
Group 2: Narrow-band ground motions

The schematic plan for this group is to have several sets of ground motions with high amplitudes at differing period ranges

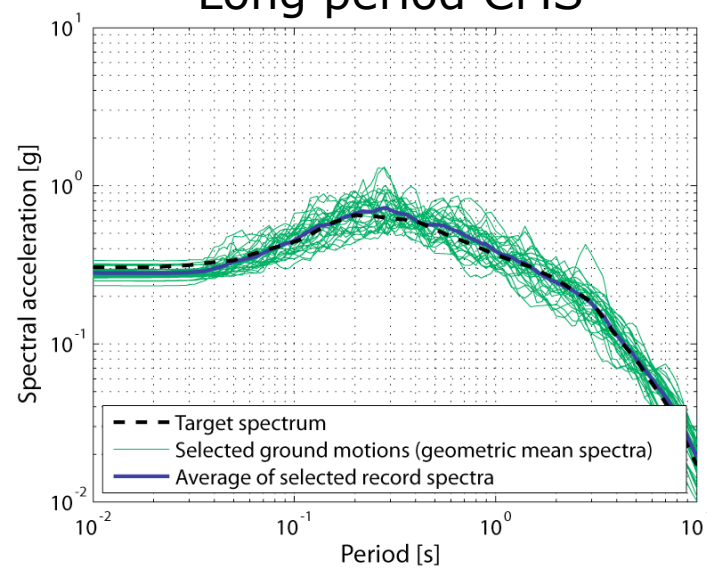
Short period CMS



Moderate period CMS

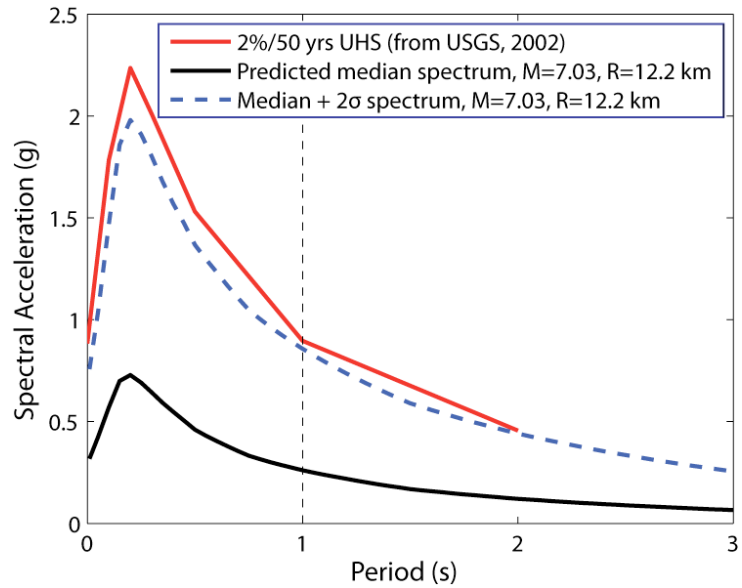


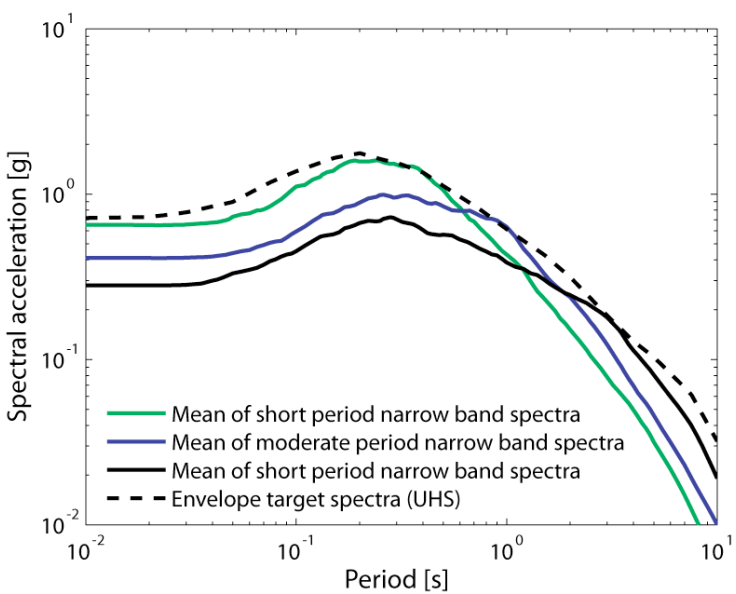
Long period CMS

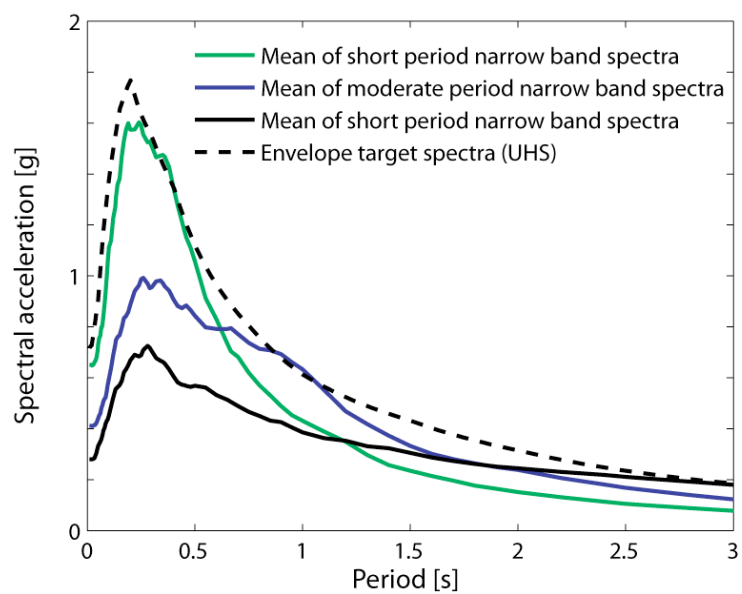


Narrow-band ground motions

- Below are the means of the three record sets, versus the envelope of all CMS spectra (M = 7, R = 12, ε = 2)
- We can significantly reduce the conditional target spectra at some periods with this approach, but we have also left some gaps



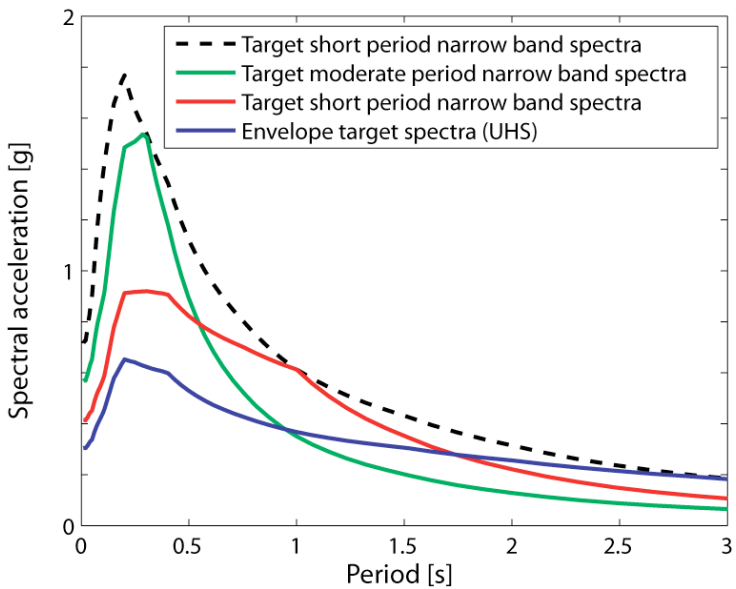




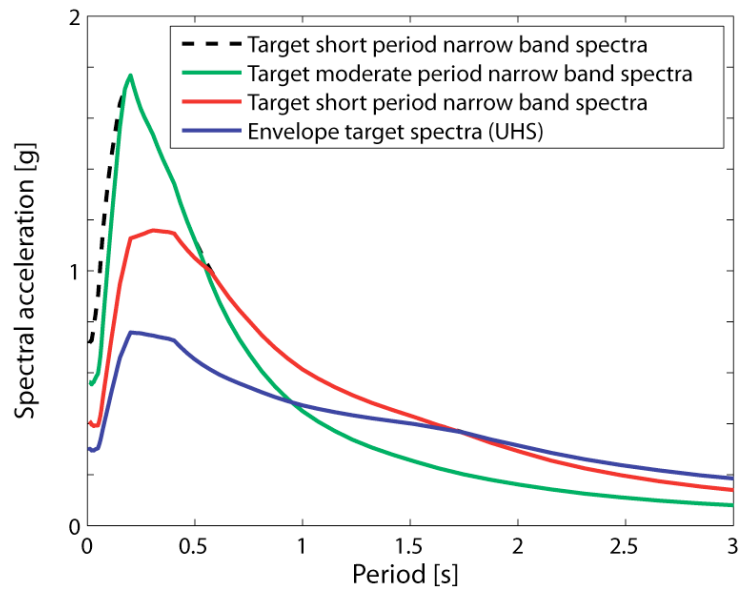
Modified concept for narrow-band records

- Retain some of the CMS benefit, while also avoiding unconservatism
- The more record sets we use, the less adjustment we must make

Original target CMS



Modified target CMS

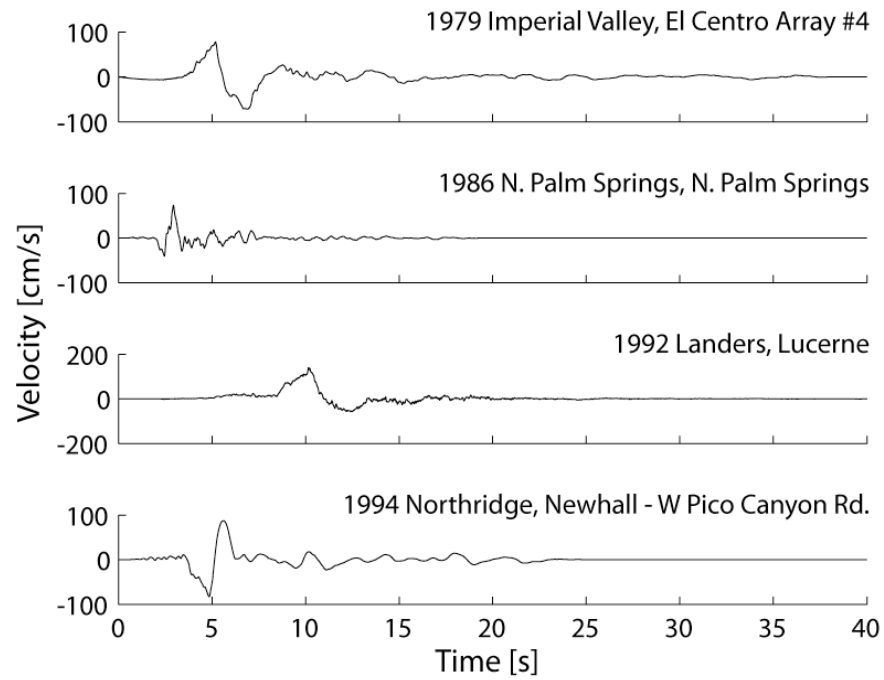


Group 3: pulse-like ground motions

These are strong ground motions, with distinct velocity pulses of varying periods

I will provide scaling so that response spectra are comparable to the non-pulse motions, to enable comparisons between pulse-like and non-pulse motions

Original orientation will be strike-normal and strike-parallel, and I will provide information about the range of angles over which a strong pulse is present



Comments on format and documentation

- All ground motions will come from the NGA database, and will be labeled for cross reference with the NGA Flatfile
- All ground motions will be three-component
- Ground motions will be pre-scaled
- Additional information not in the current NGA Flatfile will be included in a supplemental spreadsheet
  - Pulse periods
  - Scale factors
  - Response spectra of scaled motions
  - ε values

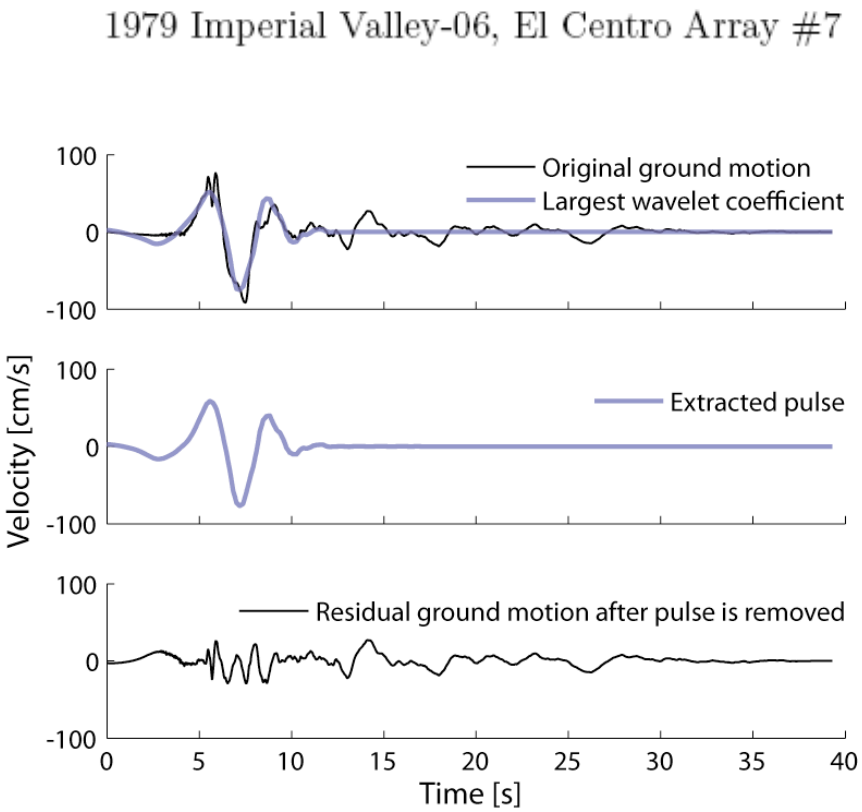
Data Format: Summary Flatfile and Time Histories

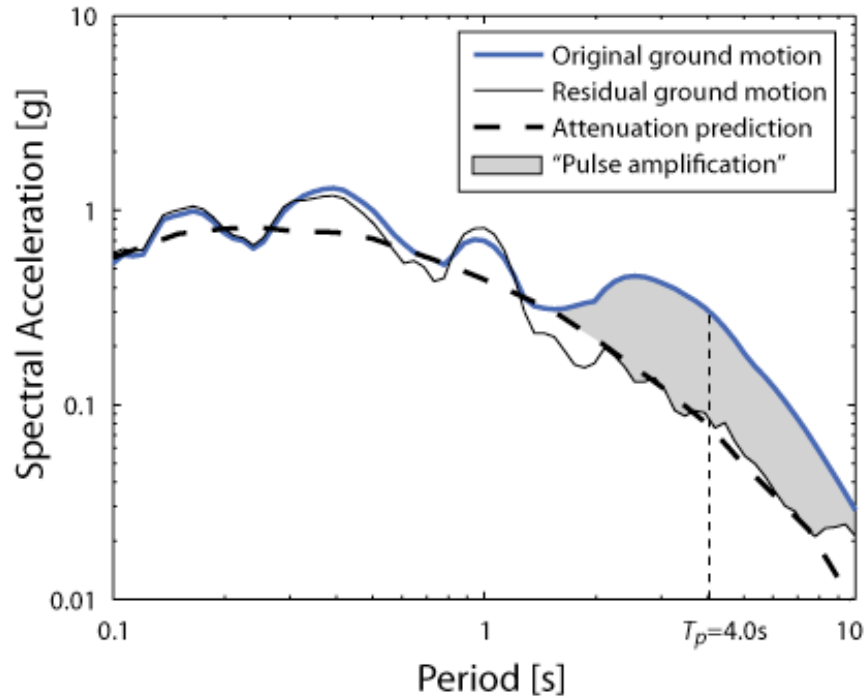
Record #	NGA #	Earthquake	Station	Magnitude	R_{jb} Distance (km)	Mechanism	Scale Factor	Pulse?	Pulse Period (s)	FN Filename	FP Filename
1	182	Imperial Valley-06	El Centro Array #7	6.5	0.6	SS	1.2	Yes	4.2	rec_1_comp_1.acc	rec_1_comp_2.acc
2	184	Imperial Valley-06	El Centro Diff. Array	6.5	5.1	SS	1.8	Yes	5.9	rec_2_comp_1.acc	rec_2_comp_2.acc
3	723	Superstition Hills-02	Parachute Test Site	6.5	1.0	SS	1.0	Yes	2.3	rec_3_comp_1.acc	rec_3_comp_2.acc
4	779	Loma Prieta	LGPC	6.9	3.9	RV-OB	1.1			rec_4_comp_1.acc	rec_4_comp_2.acc
5	821	Erzican, Turkey	Erzincan	6.7	4.4	SS	1.4	Yes	2.7	rec_5_comp_1.acc	rec_5_comp_2.acc
6	879	Landers	Lucerne	7.3	2.2	SS	1.8	Yes	5.1	rec_6_comp_1.acc	rec_6_comp_2.acc
7	1605	Duzce, Turkey	Duzce	7.1	6.6	SS	1.6			rec_7_comp_1.acc	rec_7_comp_2.acc

Text file *rec_1_comp_1.acc*:

```
Orig filename = IMPVALL/H-E07_233_FN.acc, Scale factor = 1.1908
7364 0.0050
0.004011
0.004948
0.003889
0.000887
0.000887
0.000840
0.000816
0.000791
0.000771
0.000755
0.000736
...
```

Additional documentation for Pulse-Like Ground Motions





All three "parts" of the ground motions will be available as plots and raw data files

Questions

- Is anything missing?
- What features will make these ground motions easiest to start using quickly?
- Is pre-scaling a good idea?
- What period ranges are most important to you?
- How important are vertical motions to you?