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
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

- 2%/50 yrs UHS (from USGS, 2002)
- Predicted median spectrum, $M=7.03$, $R=12.2$ km
- Median + 2σ spectrum, $M=7.03$, $R=12.2$ km

# of standard deviations above median $S_a$

Prob. Seismic Hazard Deaggregation
Riverside, CA 117.335° W, 33.979° N.
SA period 1.00 sec. Accel.$>0.8926$ g
Mean Return Time of GM 247 yrs

Mean ($R, M, e$) = 12.2 km, 7.03, 2.02
Modal ($R, M, e$) = 9.2 km, 6.76, 2.59 (from peak $R, M$ bin)
Modal ($R, M, e^*$) = 9.3 km, 6.76 > 2 sigma (from peak $R, M, e$ bin)
Binning: Delta$R=10$. km, delta$M=0.2$, Delta$e=1.0$
This “$\varepsilon$ effect” is a real phenomenon.

Response spectra from real ground motions having approximately magnitude $= 7$ and distance $= 12$ km.
Calculation of $\varepsilon$ values at three periods

$$\varepsilon(T) = \frac{\ln Sa(T) - \mu_{\ln Sa(T)}}{\sigma_{\ln Sa(T)}}$$
values at varying periods, from many ground motions

Using this information, we can find the “expected” (mean) $\varepsilon$ at all periods, given a target $\varepsilon$ 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 do we do the conditioning?
The $\varepsilon$ 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

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.

Velocity pulse observations from past earthquakes

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 $\text{Sa}(T_1)$

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
Group 1: 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 $\varepsilon$.

(figures 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.
Narrow-band ground motions

- Below are the means of the three record sets, versus the envelope of all CMS spectra ($M = 7$, $R = 12$, $\varepsilon = 2$)
- 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
  - $\varepsilon$ values
Data Format: Summary Flatfile and Time Histories

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<thead>
<tr>
<th>Record #</th>
<th>NGA #</th>
<th>Earthquake</th>
<th>Station</th>
<th>Magnitude</th>
<th>Rg Distance (km)</th>
<th>Mechanism</th>
<th>Scale Factor</th>
<th>Pulse?</th>
<th>Pulse Period [s]</th>
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Text file `rec_1_comp_1.acc`:

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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

1979 Imperial Valley-06, El Centro Array #7

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?