Additional Remarks and Setting the Stage for the Session

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Typical Approach for Design Time Histories

- Specified Design Event
  - M, R, Site, Spectrum
- Engineers Request: Provide small set of representative ground motions time series
  - e.g. 1-7 sets of time series
- Ground Motion Analyst
  - Select ground motions with similar M, R, site, directivity condition
  - Modify the ground motion to be consistent with the design spectrum
  - Preference for less scaling

What is Unsaid in Engineer's Request

- Use of small number of time histories
  - Implies engineer is after average response
  - Too few records to define variability
- Non-linear engineering analysis
  - Ground motion analyst should find recordings that give an average response when put into a non-linear system
    - Non-linear soil
    - Non-linear structure

Summary from the 2004 Meeting

- Large variability of non-linear response of structures from recordings with similar M,R
  - For small number of time series (e.g. 3-7), results sensitive to the selection of the time series
- No well founded objective criteria for selecting time series
  - Left to judgment
  - Problem is getting worse as the number of recordings grows
- Can't develop an objective selection criteria until the intended use of the time series is specified.
  - Need more interaction between ground motion analyst and engineer evaluating the structure

Summary from the 2004 Meeting

- Need to decide if we are after average response or variability of response
  - Most participants agreed we are after the average response given the design spectrum, not the variability of the response
  - The design spectrum already has the return period of the ground motion in it
- If we are after average response, we can do better than just randomly selecting records from similar magnitude-Distance bin
  - Epsilon value (Cornell's approach)
  - Simplified non-linear system
- PEER DGML
  - Records selected to capture variability of the response

Summary from the 2004 Meeting

- Modification of time series
  - Scaling by a constant factor
    - Large scale factors can lead to a bias in the response if random records in M-R bin are used
    - Large scale factors can lead to unbiased results for some time series
      - Need to consider additional parameters to be able to identify records that can be scaled by large factors
  - Spectrum compatible
    - Not considered in 2004 meeting
    - To be addressed in 2005 meeting

Recommendations for Selection and Scaling of Ground Motion Records to Satisfy Code Requirements Including Spectrum Compatible Scaling

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Scaling vs Spectrum Compatible

- Spectrum compatible reduces variability of response
  - Requires fewer sets of time histories to get same accuracy in mean response of structure
    - Spectrum compatible reduces the standard deviation of the non-linear response by about a factor of 2
    - One spectrum compatible = about 4 scaled records for determining the mean values
  - Does not capture variability of response
- Scaling preserves variability of response
  - Need to consider effect of “epsilon” in selecting records
  - Bias if scaling up spectral troughs to UHS level

Objections to Spectrum Compatible Ground Motions

- Spectrum compatible leads to a smooth spectrum. Since earthquakes don't have smooth spectra, then spectrum compatible time series are unrealistic by definition
  - Objective is to reduce the variability in response from realistic ground motions, but preserving the median response

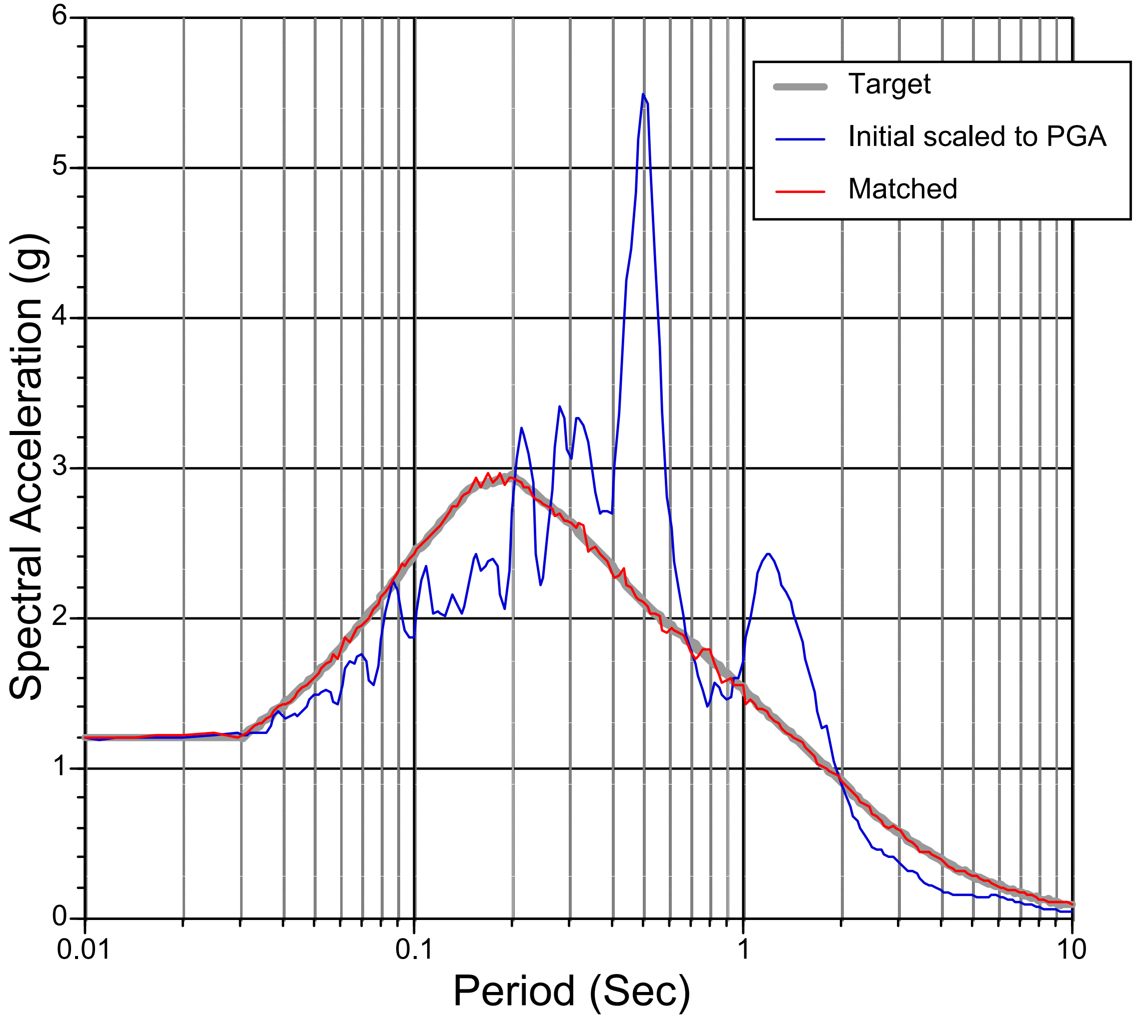
Objections to Spectrum Compatible Ground Motions

- Spectrum compatible excites all periods in one earthquake (e.g. broadband) which will lead to significant over-estimation of the response.
  - This is not the case for modern spectrum compatible methods

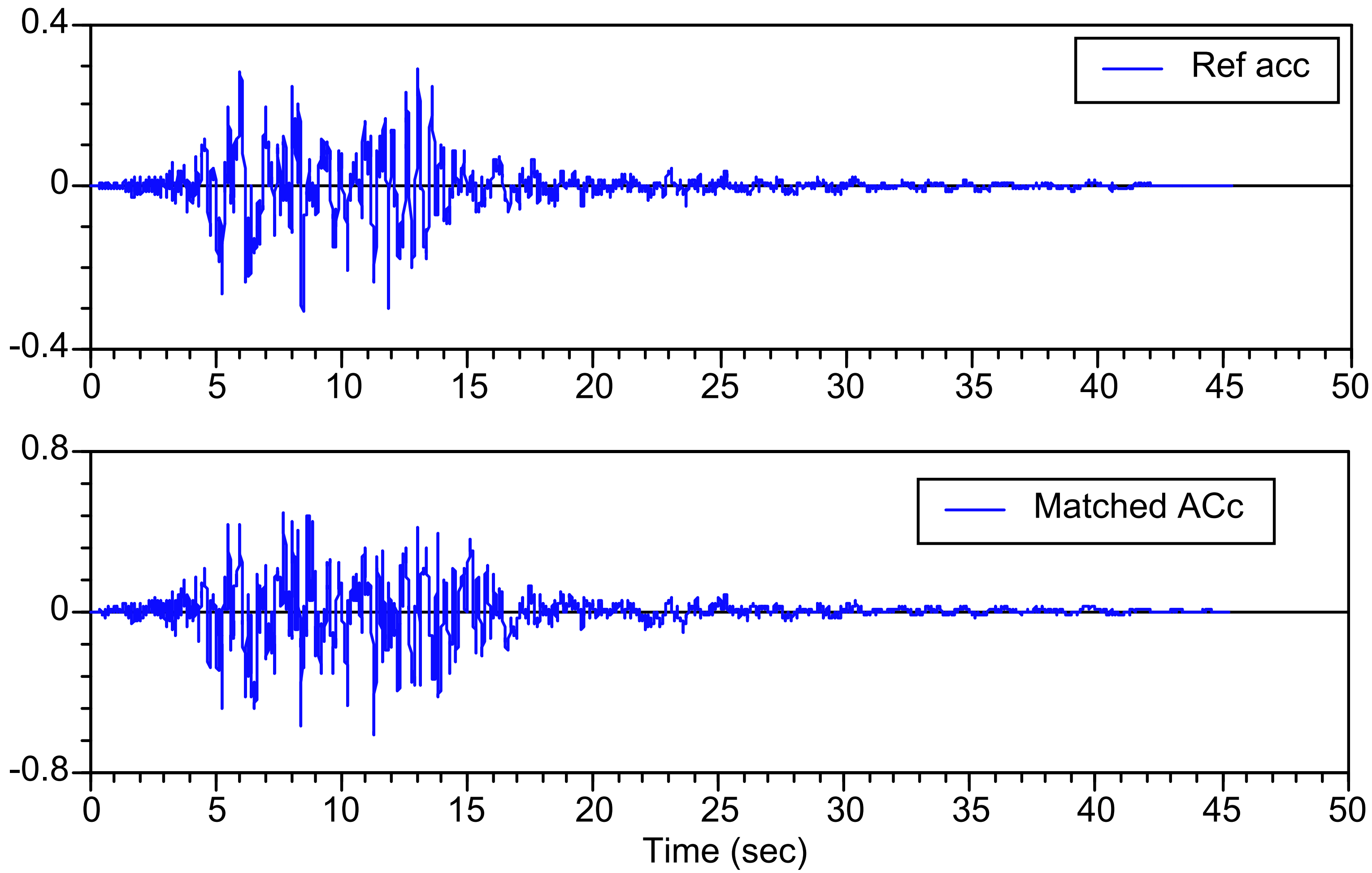
Objections to Spectrum Compatible Ground Motions

- Spectrum compatible time series aren’t realistic (e.g. white noise)
  - White noise methods are obsolete and should not be used
  - Two approaches work well preserving the general non-stationary characteristics of the reference time series
    - Time domain method (wavelets)
      - e.g. RSPMATCH
    - RVT methods (if the change in response spectral shape is not too large)
      - e.g. RASCAL
  - Still somewhat of an art. Ongoing work to make the process more automated

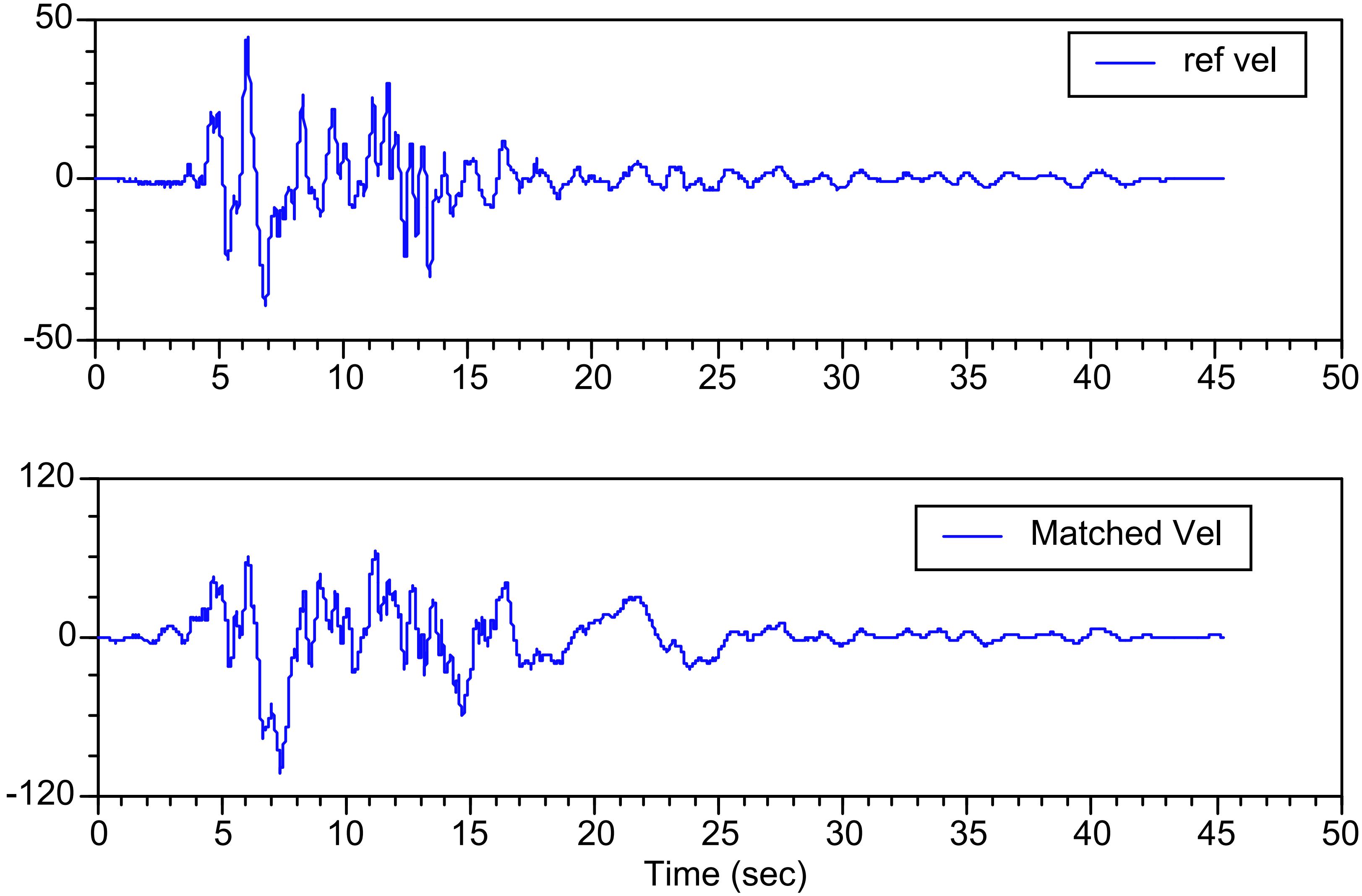
Example Spectral Matching



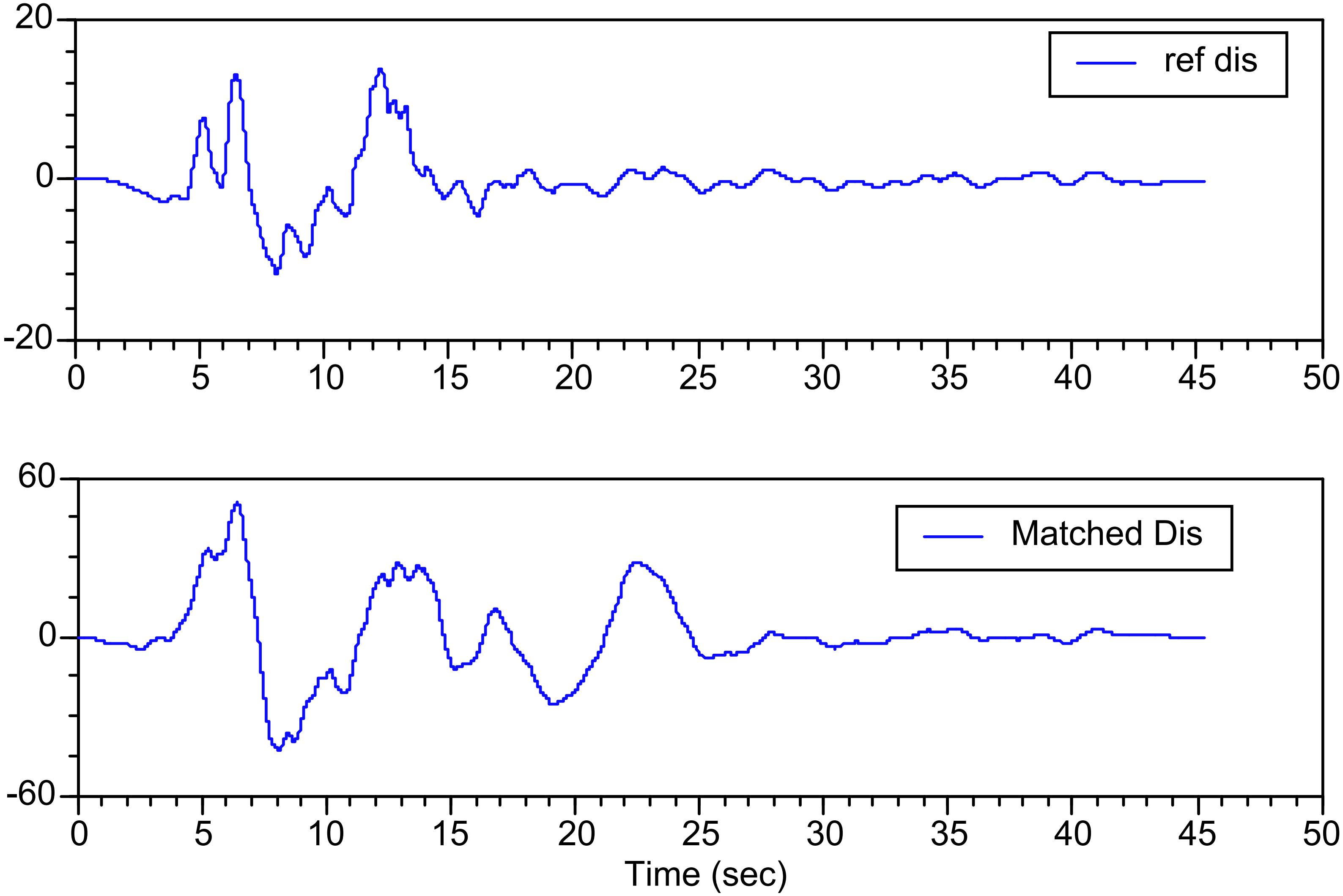
Acceleration Time Series



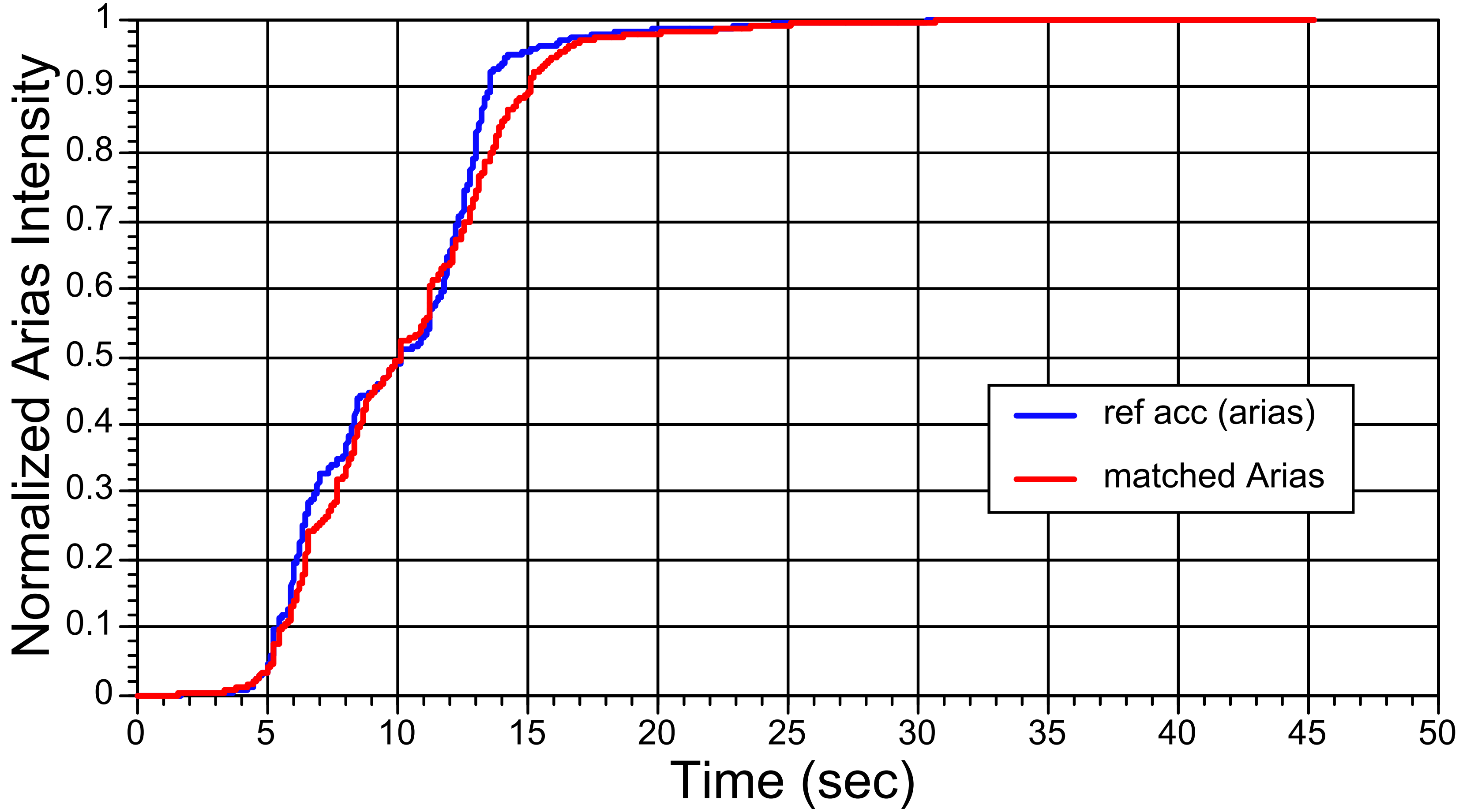
Velocity Time Series



Displacement Time Series



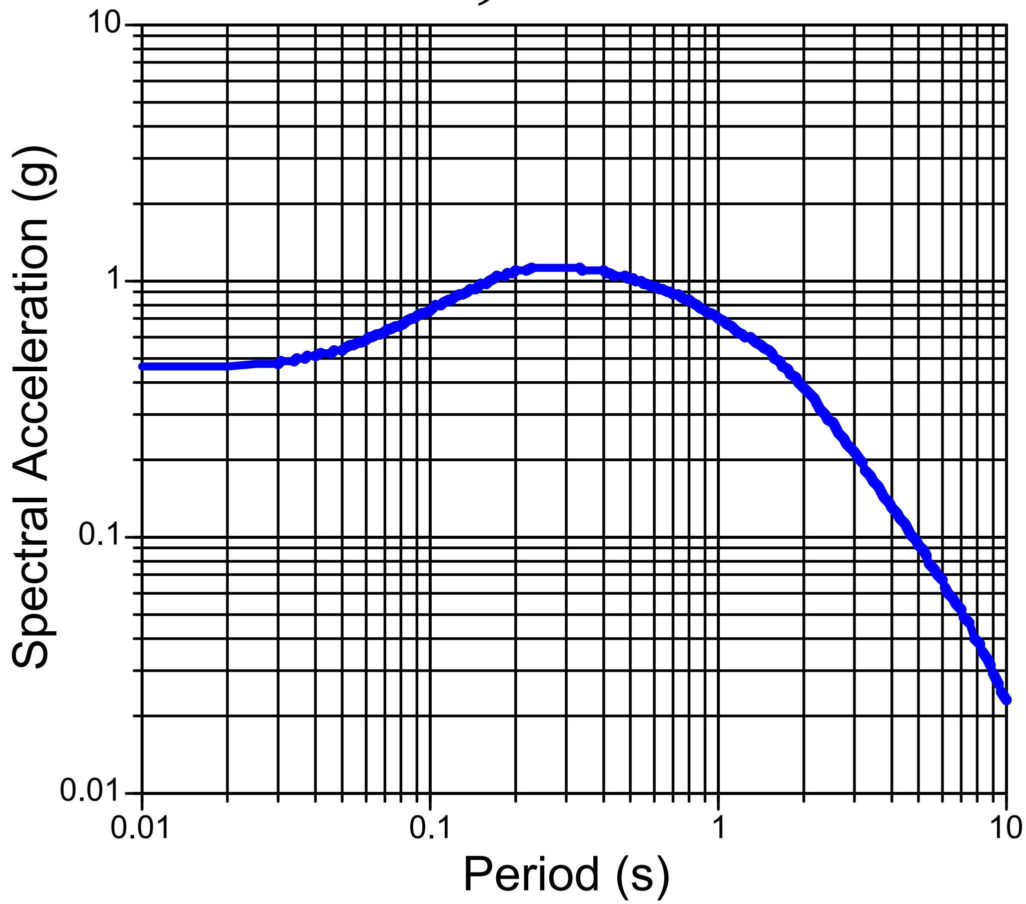
Check Husid Plot



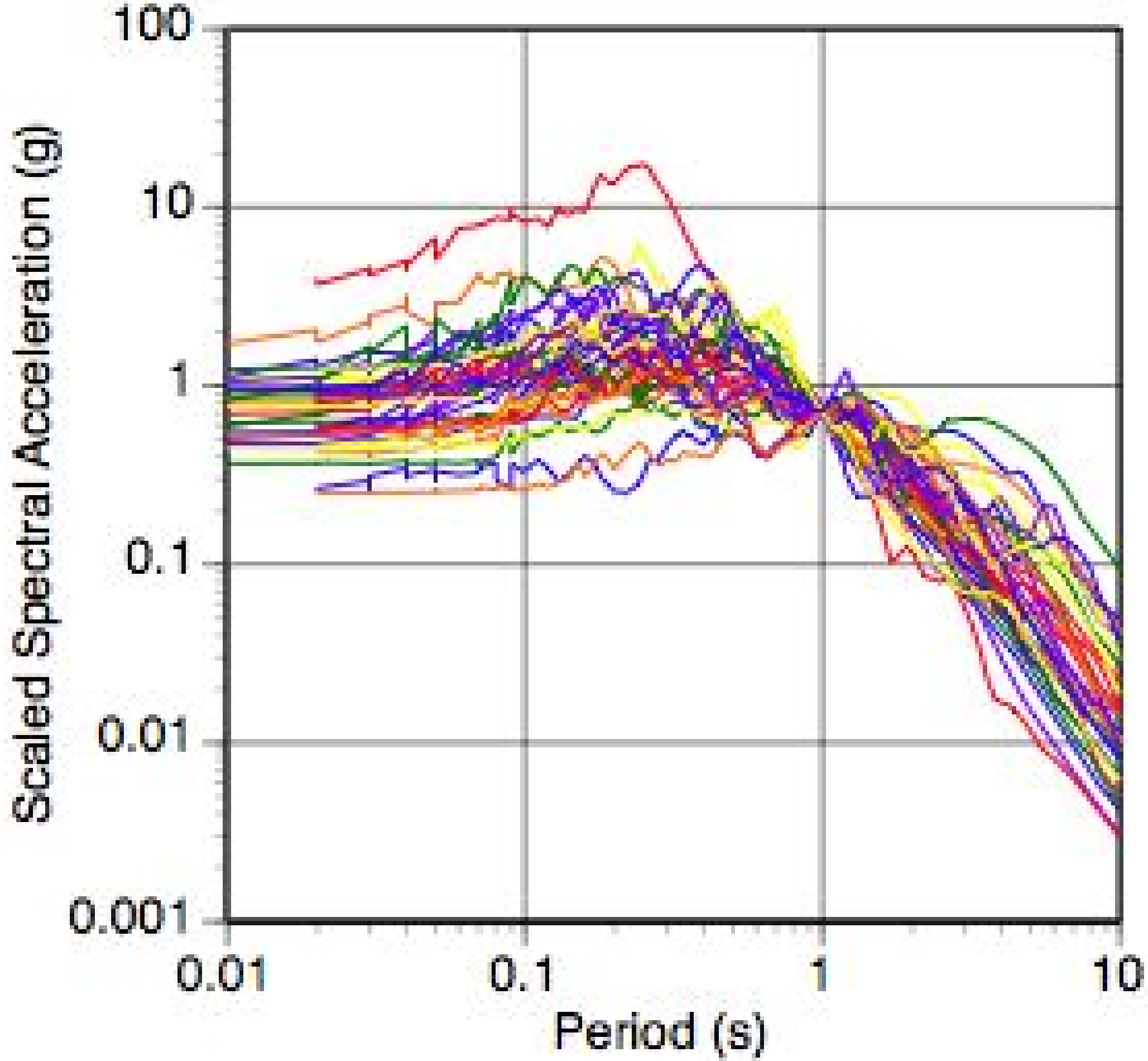
Example Using Inelastic Oscillators

- T = 1 sec
- 6 Cases
  - Yield displacement ratios: 4 and 10
  - Post yield stiffness ratio: 0.05, 0.10, 0.20

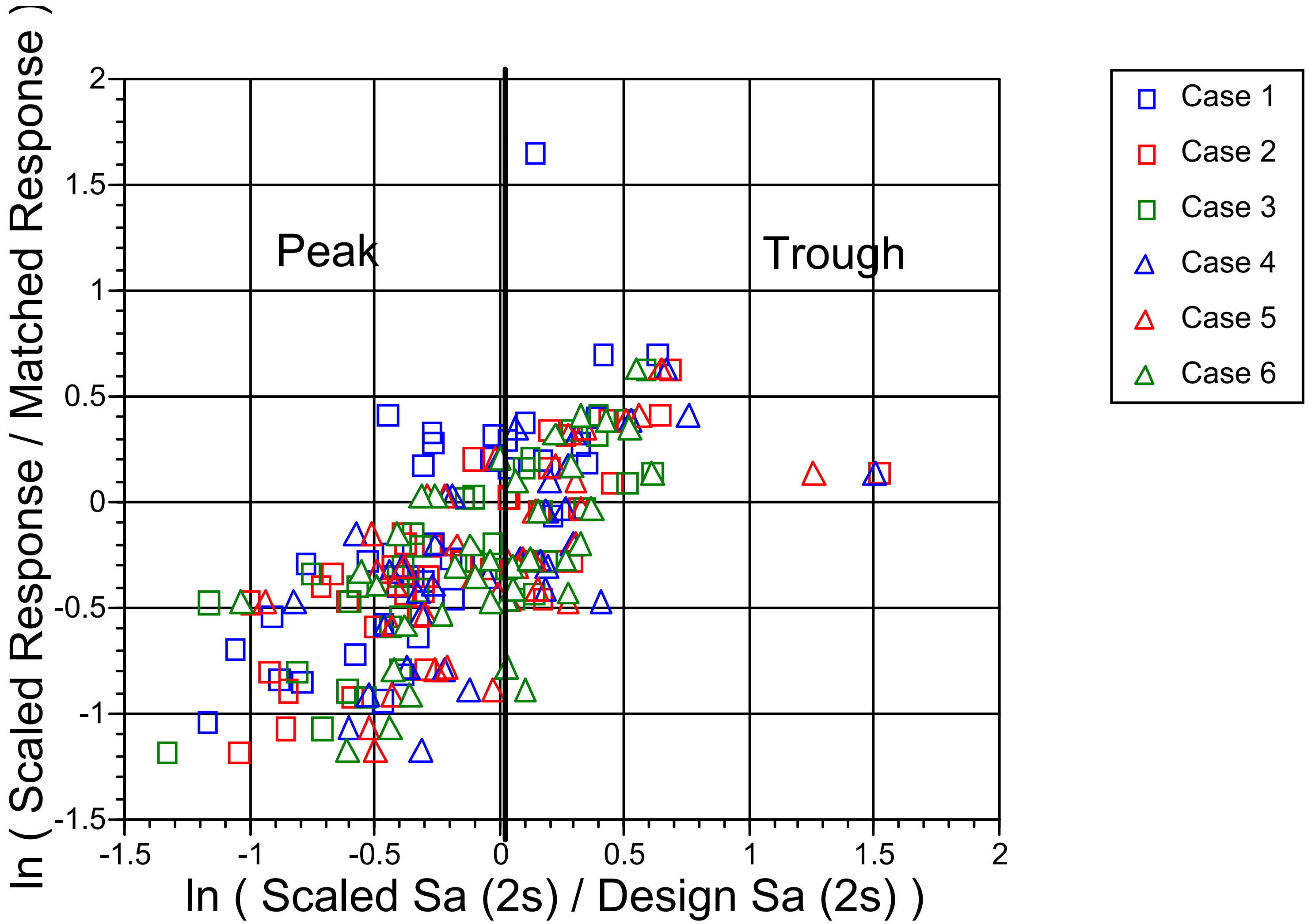
Example Design Spectrum M=6.75, R=10 km



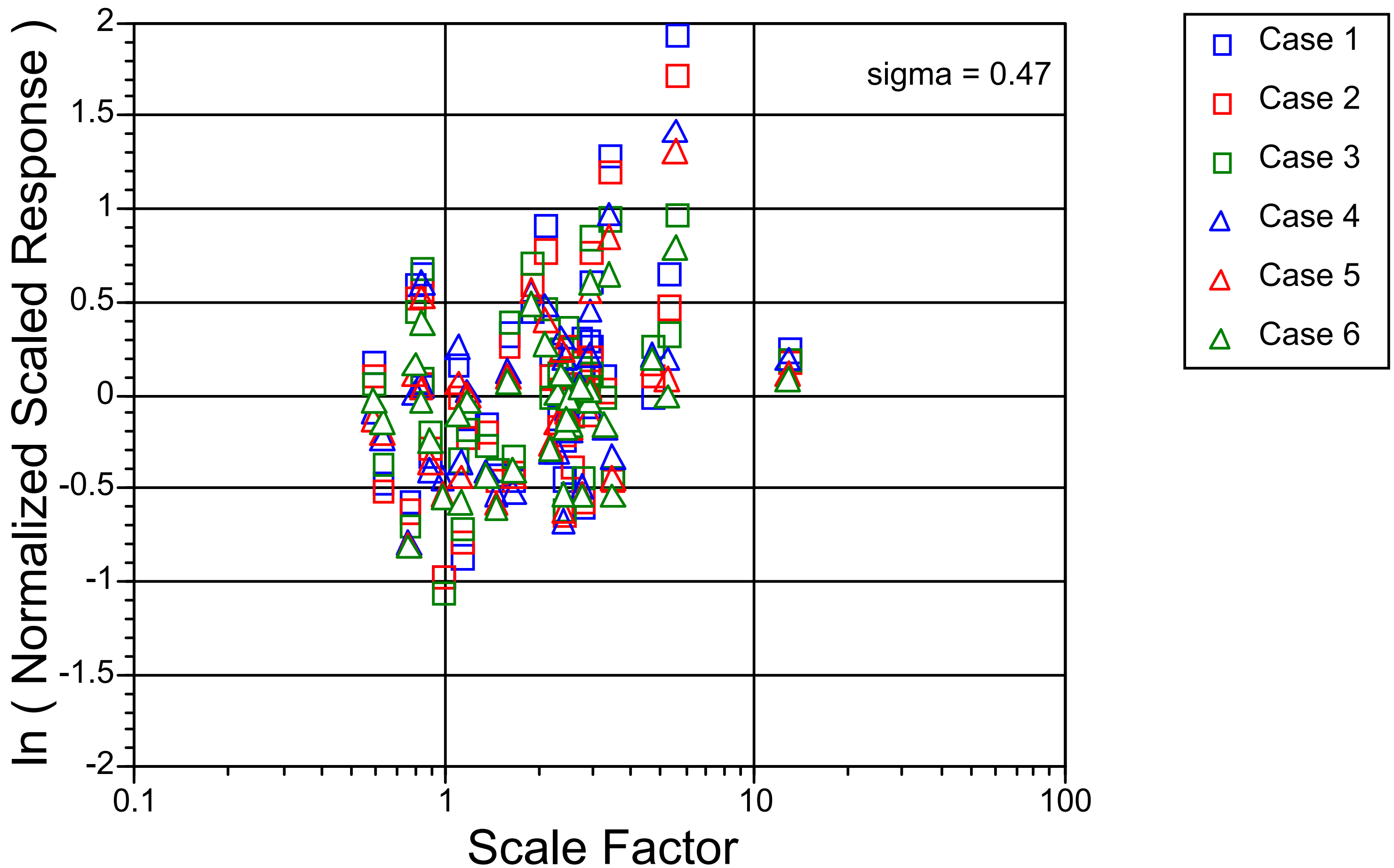
Scaled Records



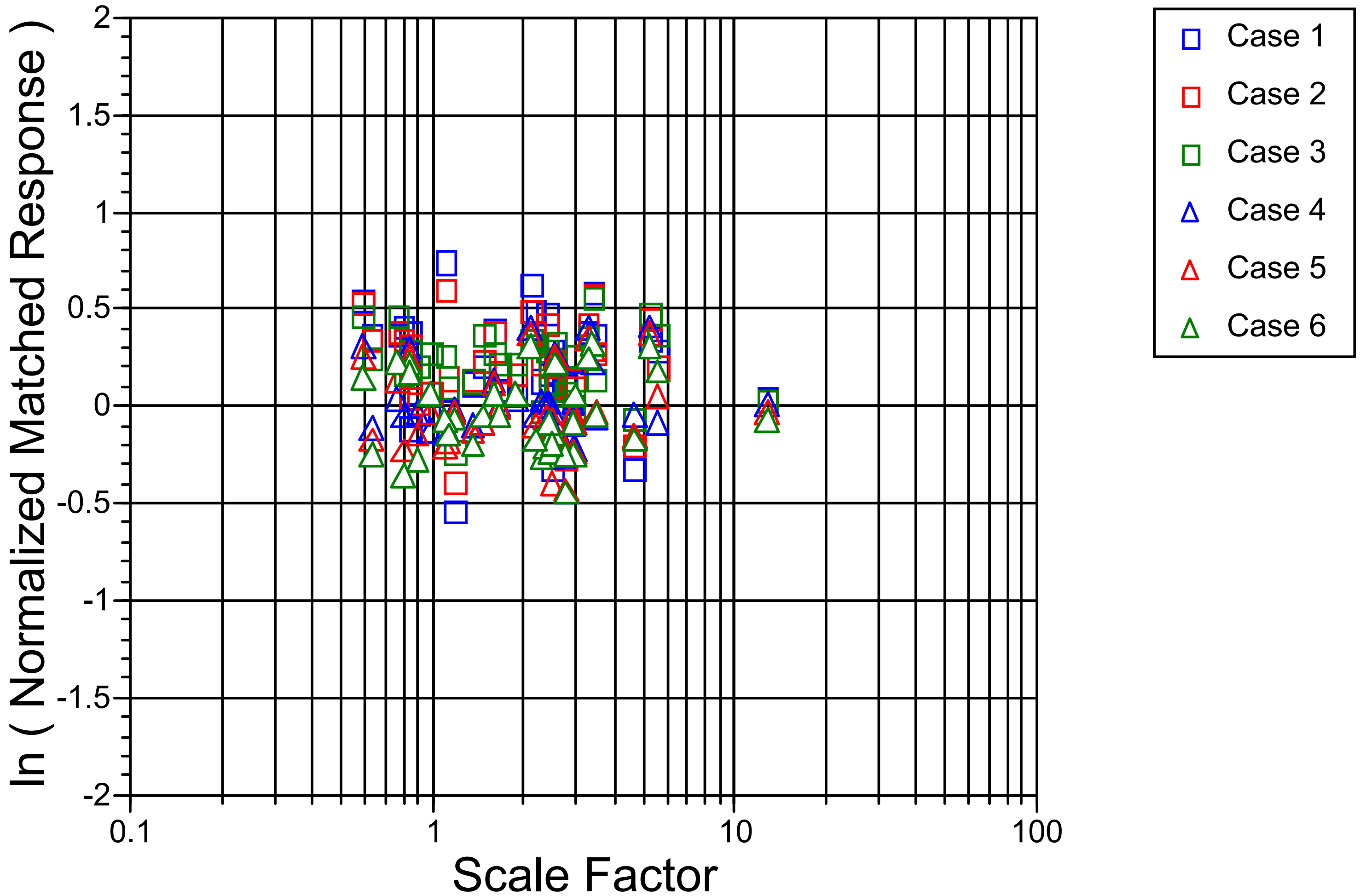
Scaled vs Spectrum Compatible



Scaled Records



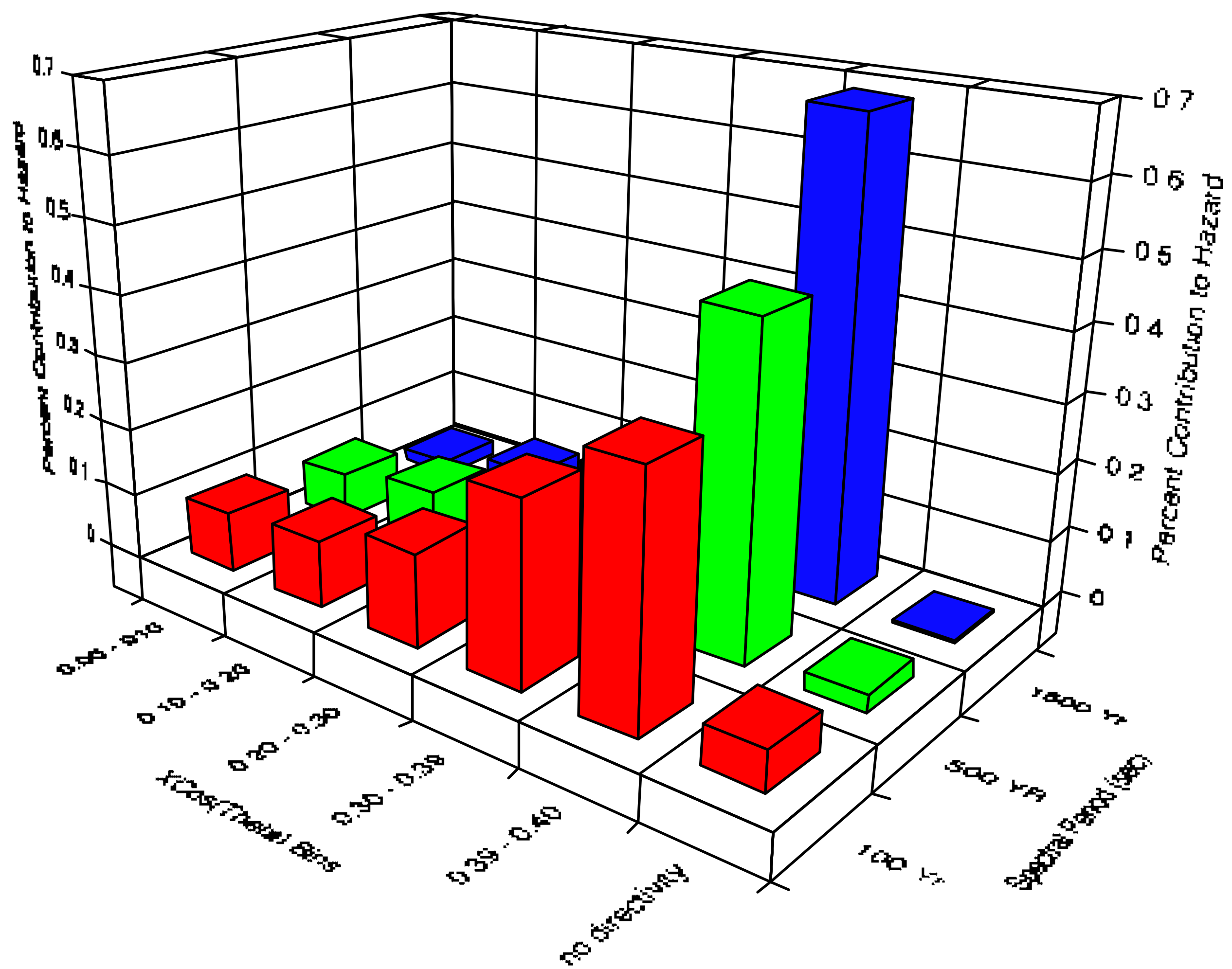
Spectrum Compatible



Recommendations

- For estimating median response given a design spectrum using spectrum compatible ground motions:
  - Select candidate records based on seismological properties
    - ± 0.5 magnitude (can be extended to ±1)
    - Wide distance range (e.g. 0-30 km)
    - All styles of faulting (crustal eqk)
    - Directivity condition
      - Forward, average, backward
    - Wide range of site classes
      - For hard-rock (Vs=2000 m/s), best to select hard-rock site for high frequency (> 10 hz)
    - No limits on the amount of scaling

Example: Caldecott Tunnel
T=2 sec



Recommendations (cont)

- From the suite of candidate recordings:
  - Use a simple non-linear system as proxy for the more complicated full model of the structure
  - Select records that give closest to the average response of the simple non-linear system (e.g. non-linear oscillator)
- Modify records to be spectrum compatible
  - Prefer time domain approach
  - Simple to meet code requirements on spectral content without adding conservatism
- Results only good for the median response
- Use generic (university) studies to estimate the variability
- Check that spectrum compatible records lead to near median results for the simple non-linear system

Near Fault Effects

- Directivity
  - Related to the direction of the rupture front
    - Forward directivity: rupture toward the site
      (site away from the epicenter)
    - Backward directivity: rupture away from the site (site near the epicenter)
- Fling
  - Related to the permanent tectonic deformation at the site

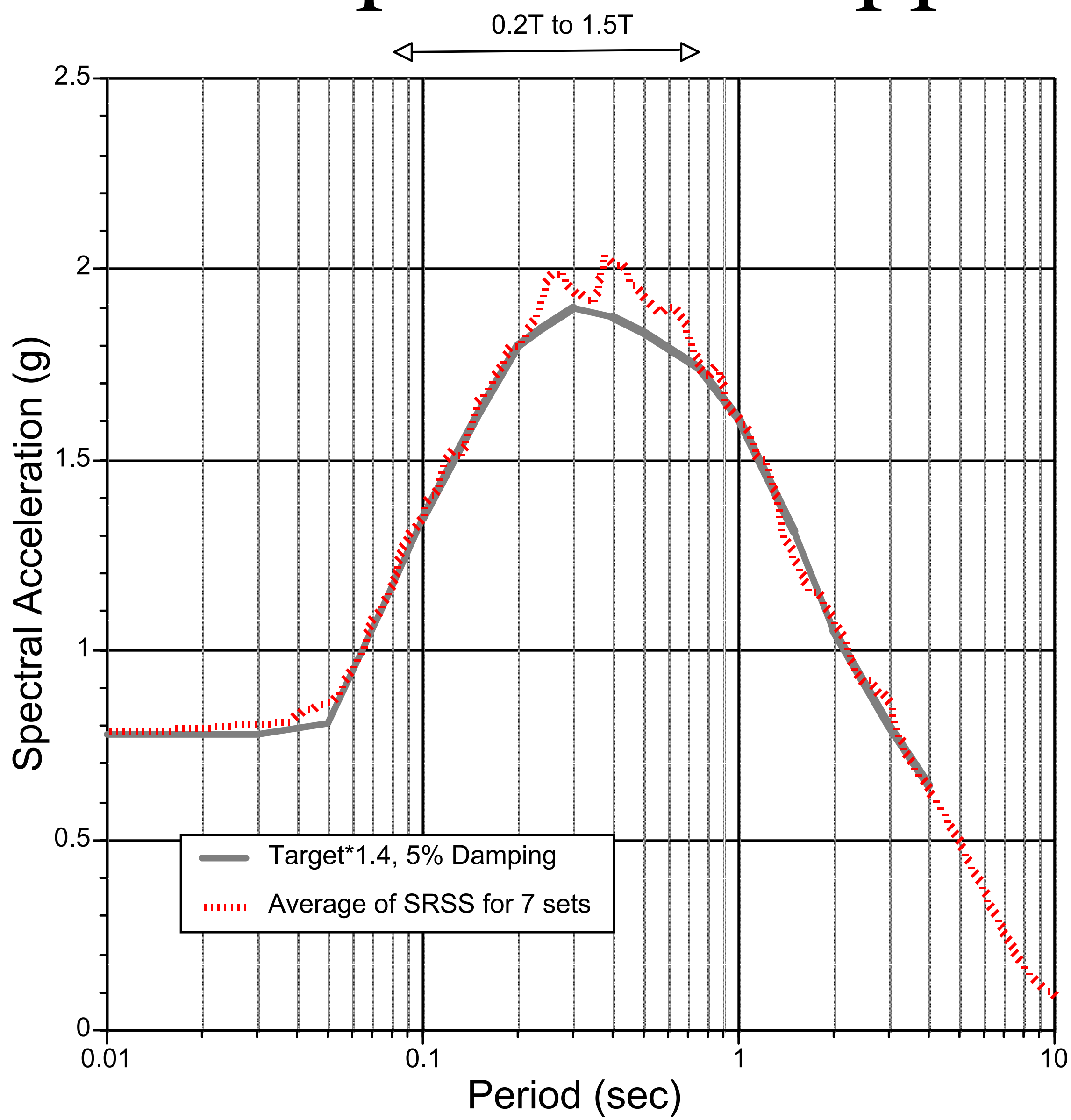
Velocity Pulses

- Forward Directivity
  - Two-sided velocity pulse due to constructive interference of SH waves from generated from parts of the rupture located between the site and epicenter
    - Constructive interference occurs if slip direction is aligned with the rupture direction
    - Occurs at sites located close to the fault but away from the epicenter for strike-slip
- Fling
  - One-sided velocity pulse due to tectonic deformation
  - Occurs at sites located near the fault rupture independent of the epicenter location

Observations of Directivity and Fling

Sense of Slip	**Directivity**	**Fling**
Strike-Slip	Fault Normal	Fault Parallel
Dip-Slip	Fault Normal	Fault Normal

Example Code Application



T=0.4-0.5sec