Spectral correlations, polarization, and near-fault pulses in simulated ground motions

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Ground motion properties for validation

Properties we have studied:

- Spectral correlations
- Velocity pulses in near-fault motions
- Polarization of response spectra

} To be discussed today

- Inelastic response spectra
- Simple structural model collapse capacities

We have targeted properties with the following characteristics:

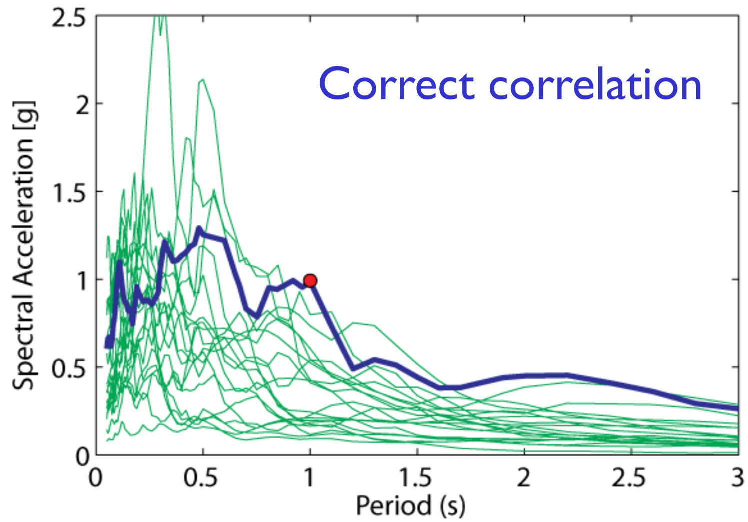
- Simple and general, but of engineering relevance
- Relatively stable in recorded ground motions (so that we know the "correct" answer even for large or unusual events)

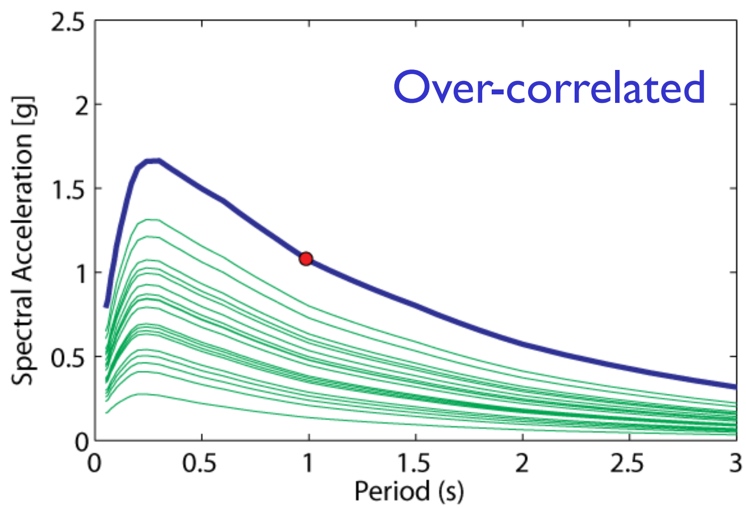
  Stable:

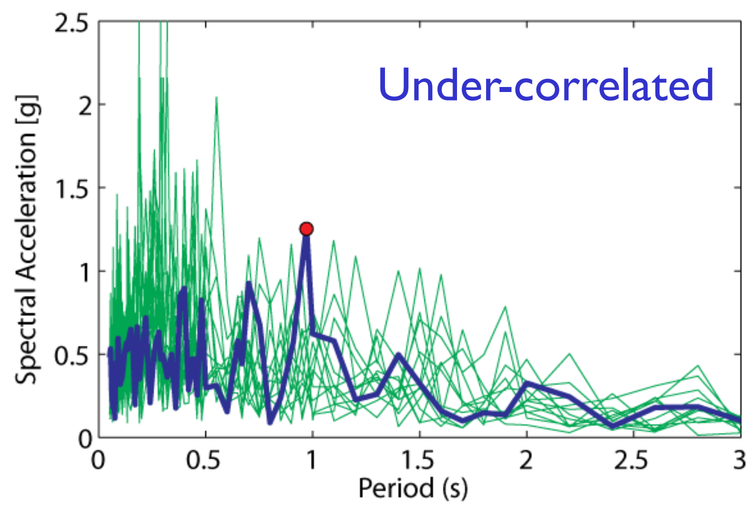
  - Little variation in empirical models across a range of magnitude/distance/site conditions
  - Little variation among models from multiple researchers

Spectral correlations

Hypothetical response spectra having the same means and standard deviations.



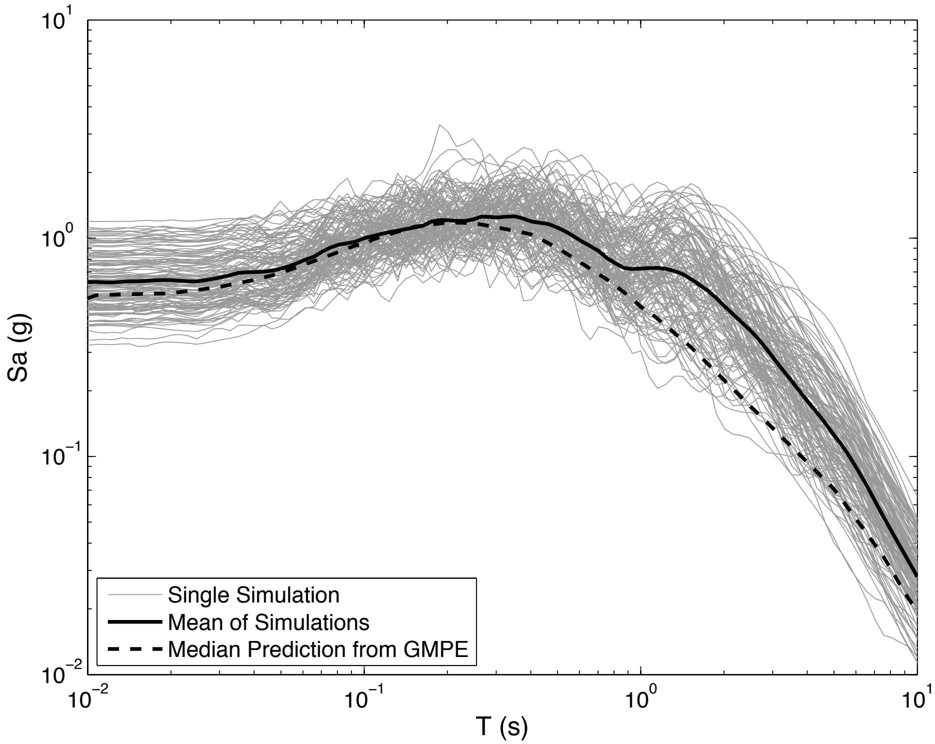




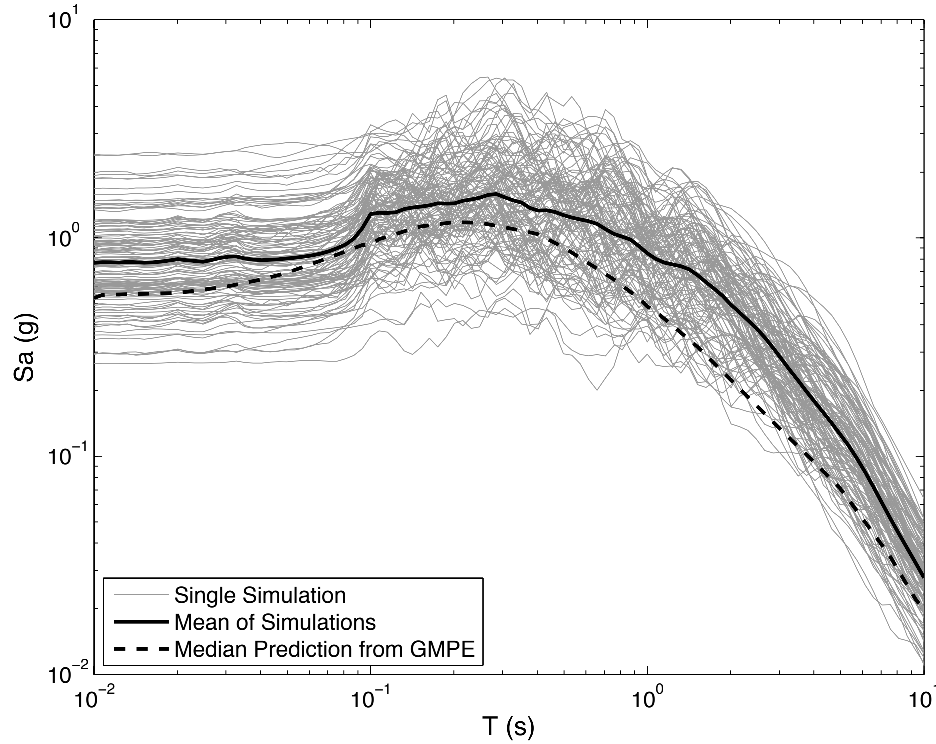
Response spectra (max direction orientation)

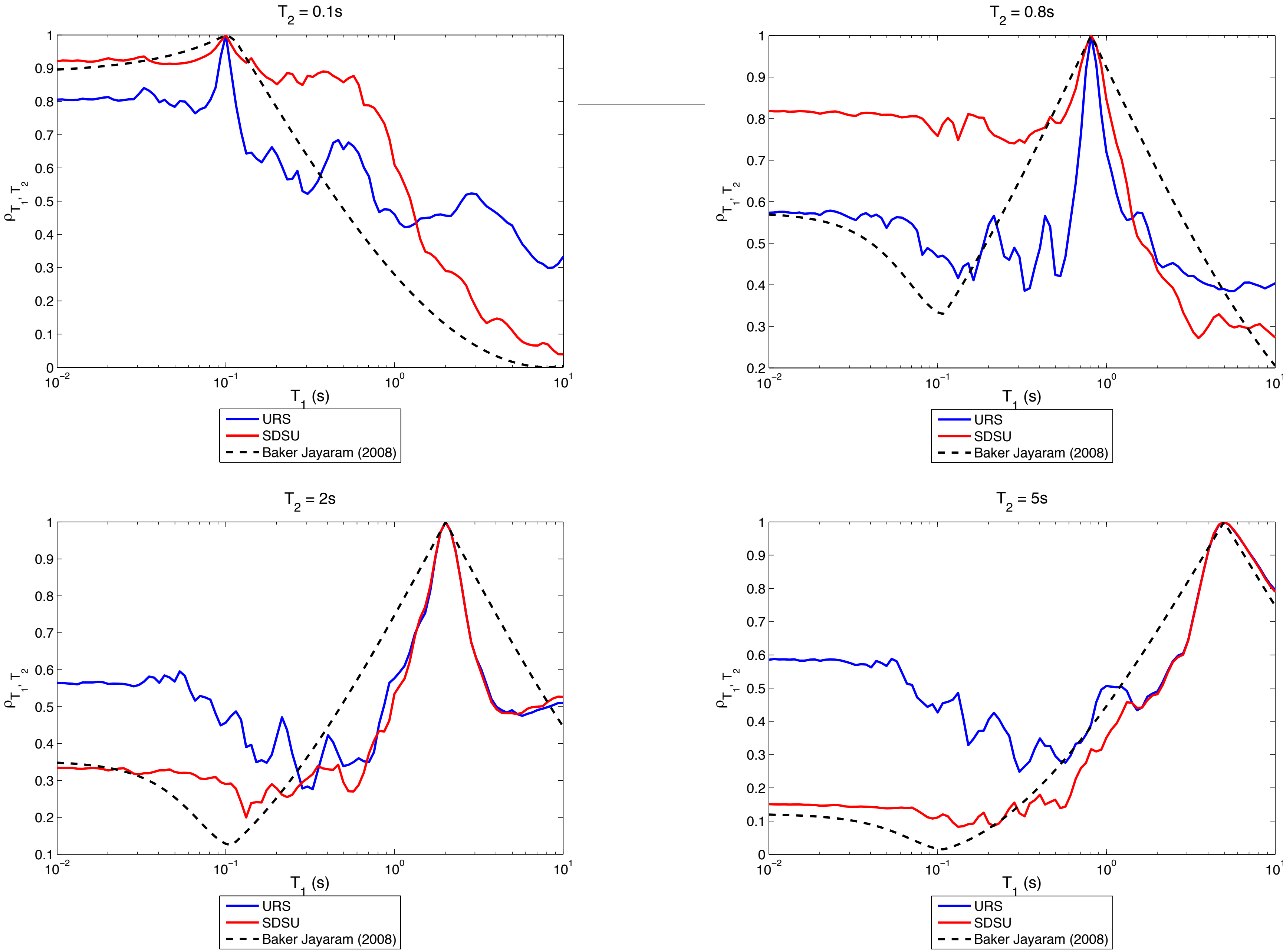
Broadband platform simulations of M=7 Hayward events at R_{rup} = 1km
URS rupture generator and low-frequency module

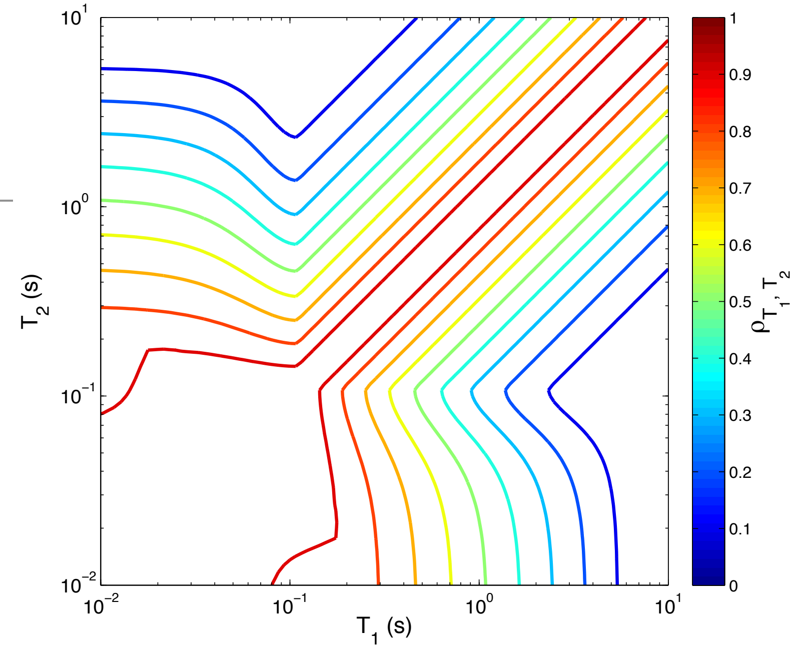
URS high-frequency module



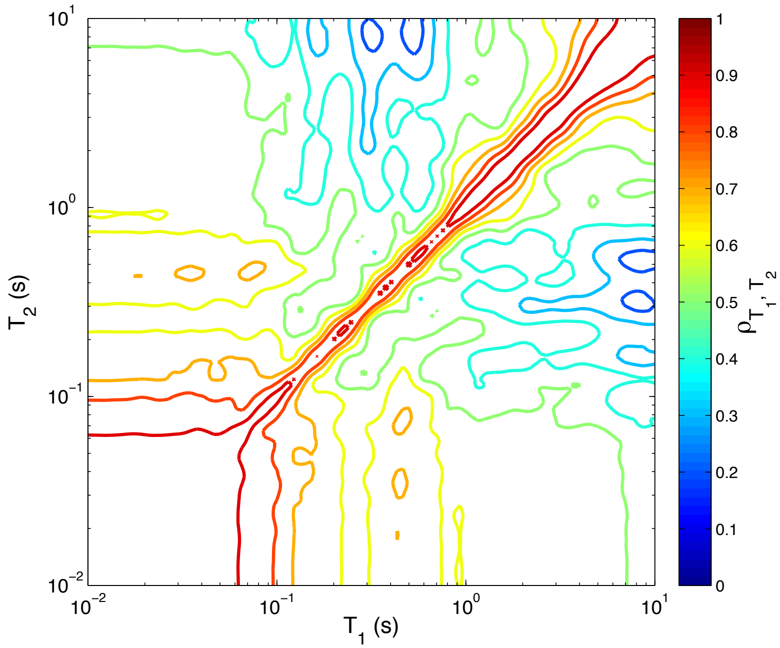
SDSU high-frequency module



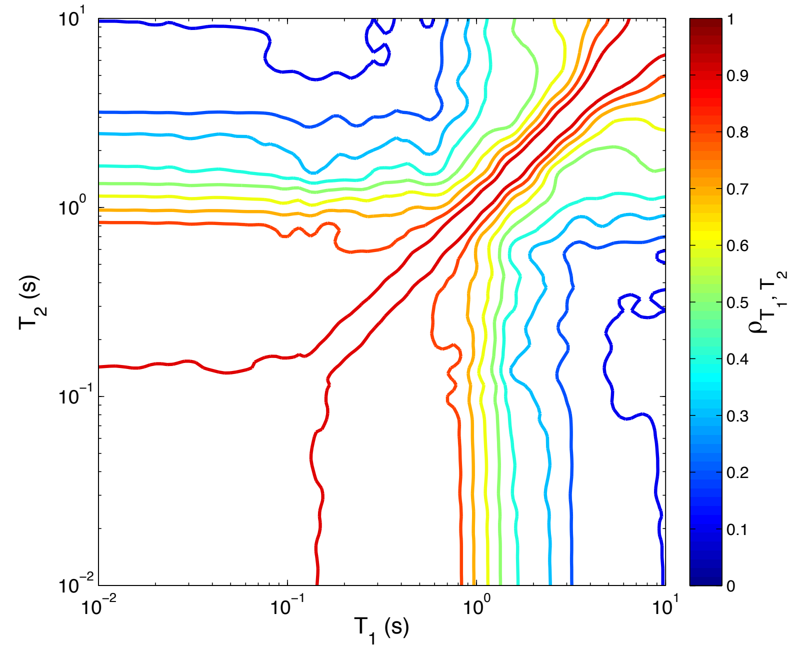

T_2 = 0.1s
T_2 = 0.8s
T_2 = 2s
T_2 = 5s
ρ_{T_1, T_2}
T_1 (s)
URS
SDSU
Baker Jayaram (2008)



Baker & Jayaram empirical model (independent of M, R, site conditions, etc.)



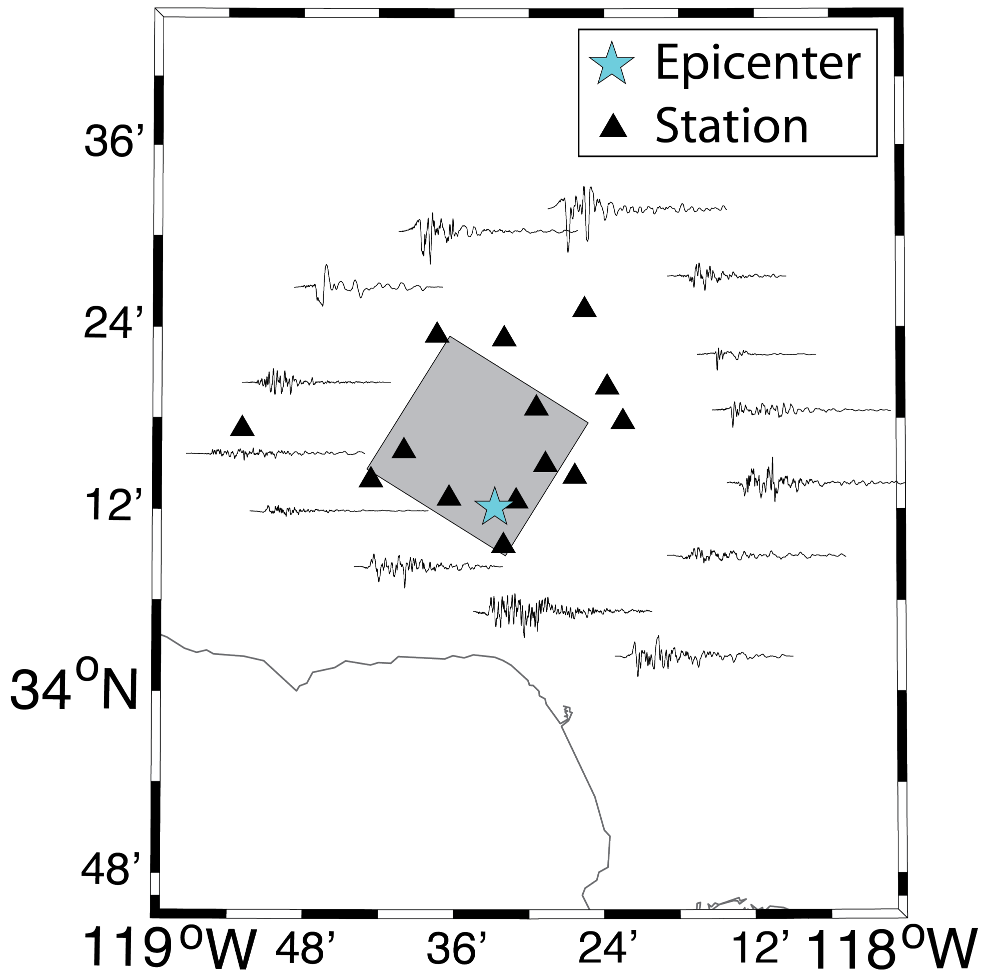
URS high-frequency module



SDSU high-frequency module

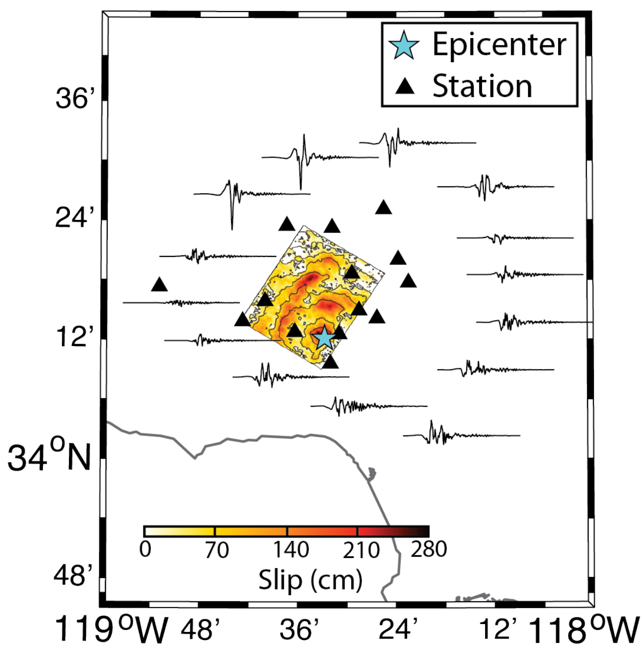
Velocity pulses in near-fault ground motions

Near-fault recordings from the 1994 Northridge earthquake

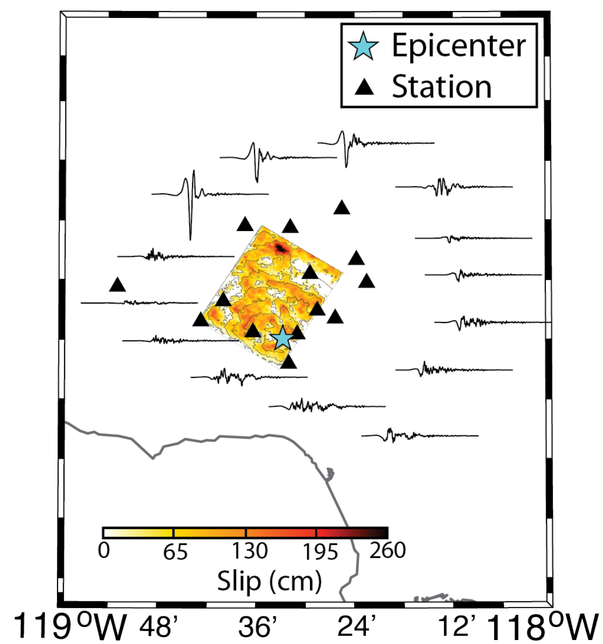


Comparable simulations and velocity time histories

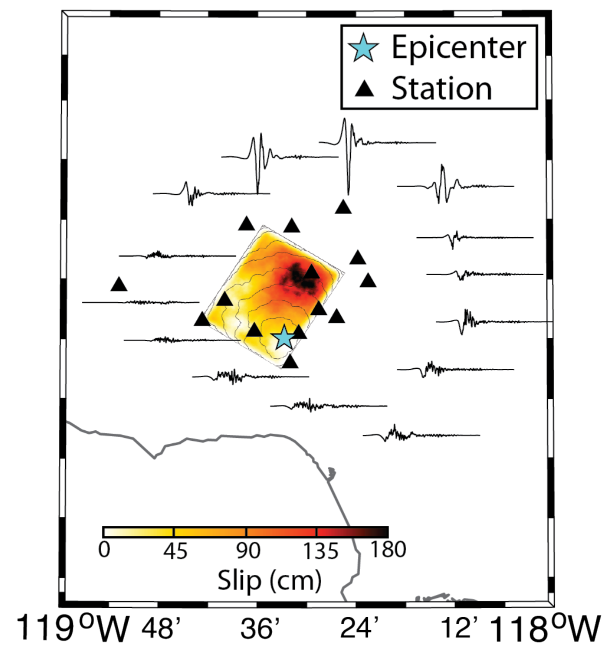
Validation source model



URS rupture generator



UCSB rupture generator

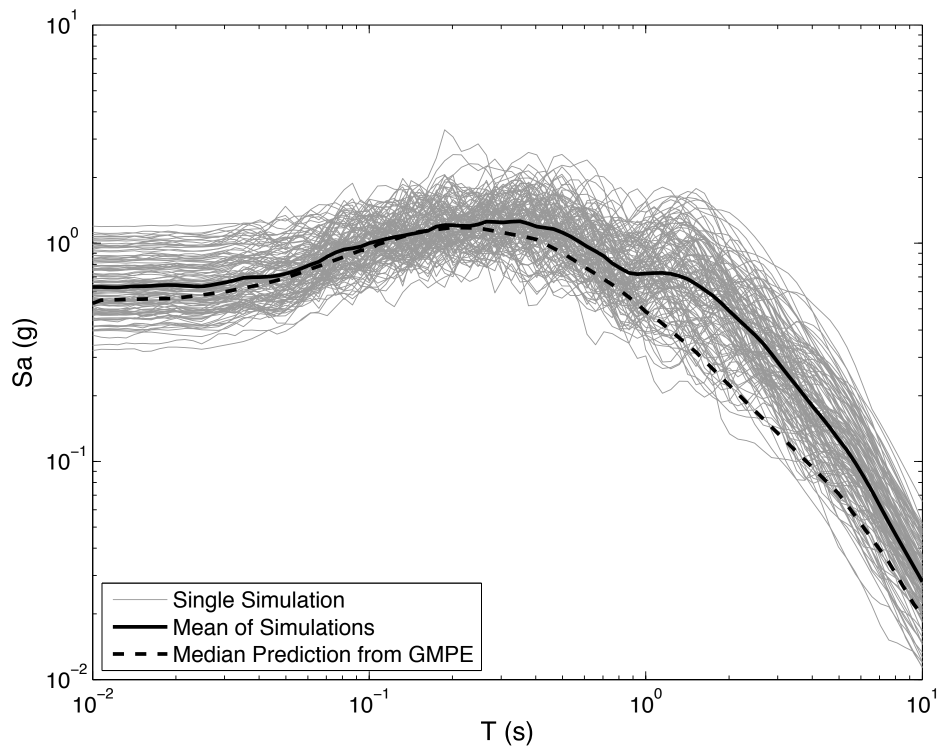


The "correct" answer for this property is not well constrained empirically, but it is of engineering interest.

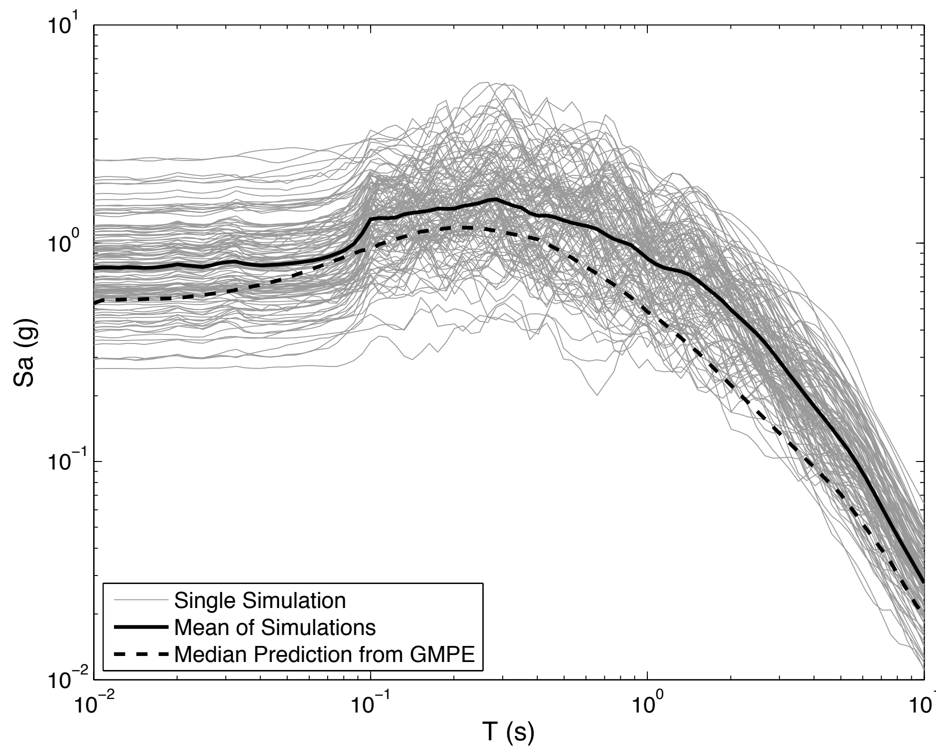
Response spectra (max direction orientation)

Broadband platform simulations of M=7 Hayward events at R_{rup} = 1km
URS rupture generator and low-frequency module

URS high-frequency module

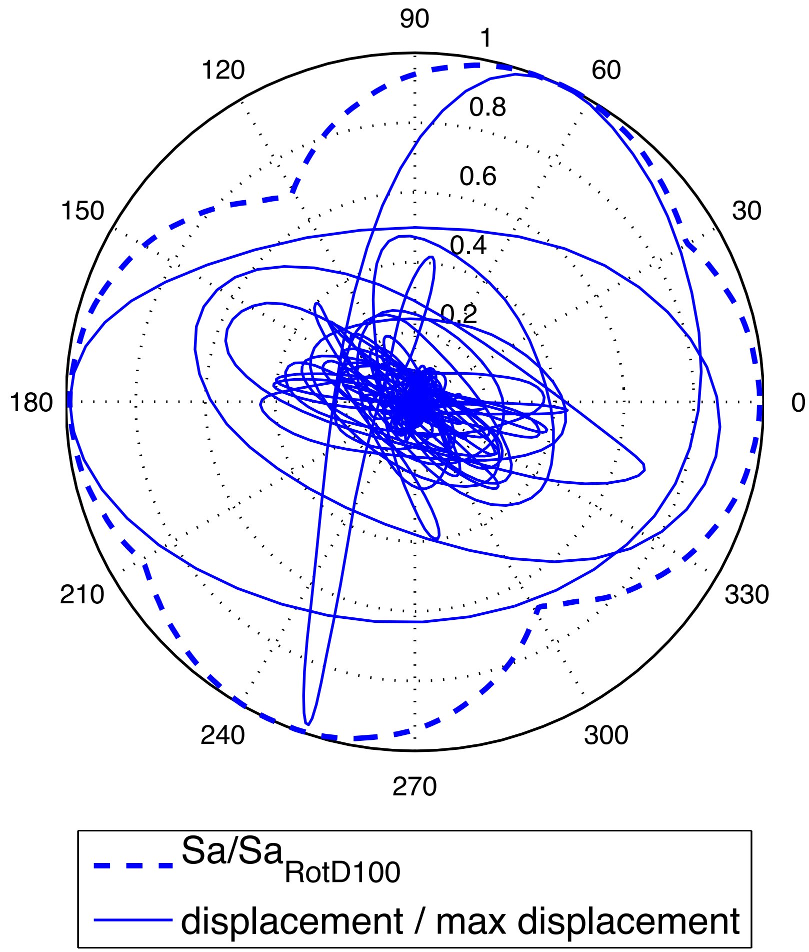


SDSU high-frequency module

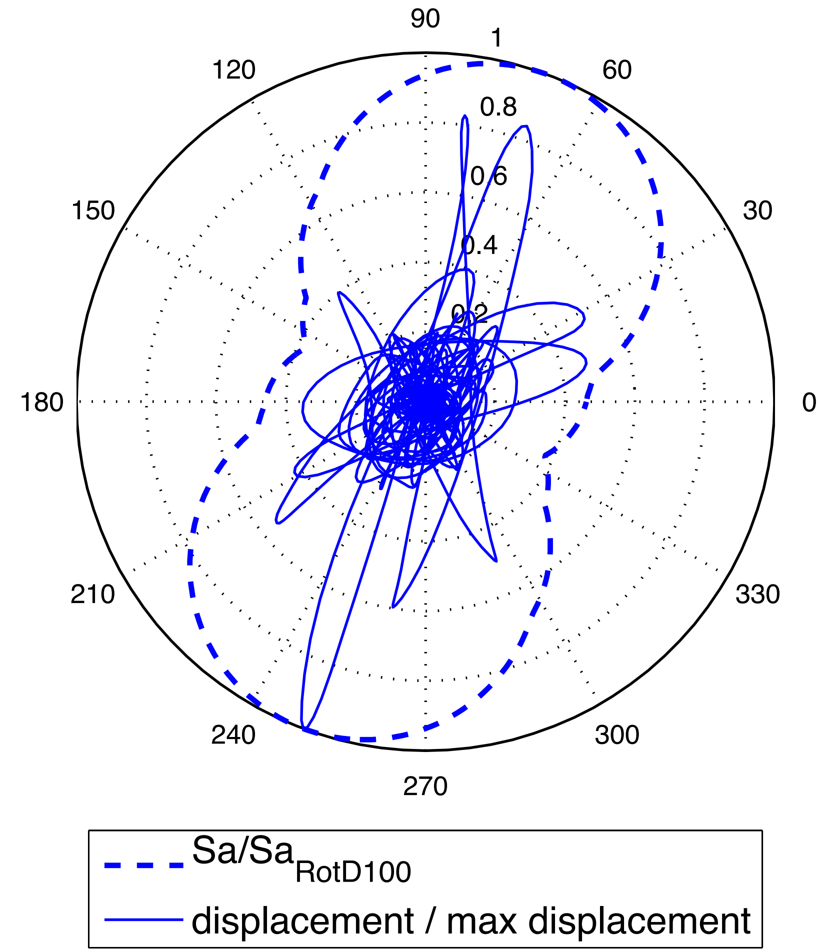


"Flagpole" oscillator responses

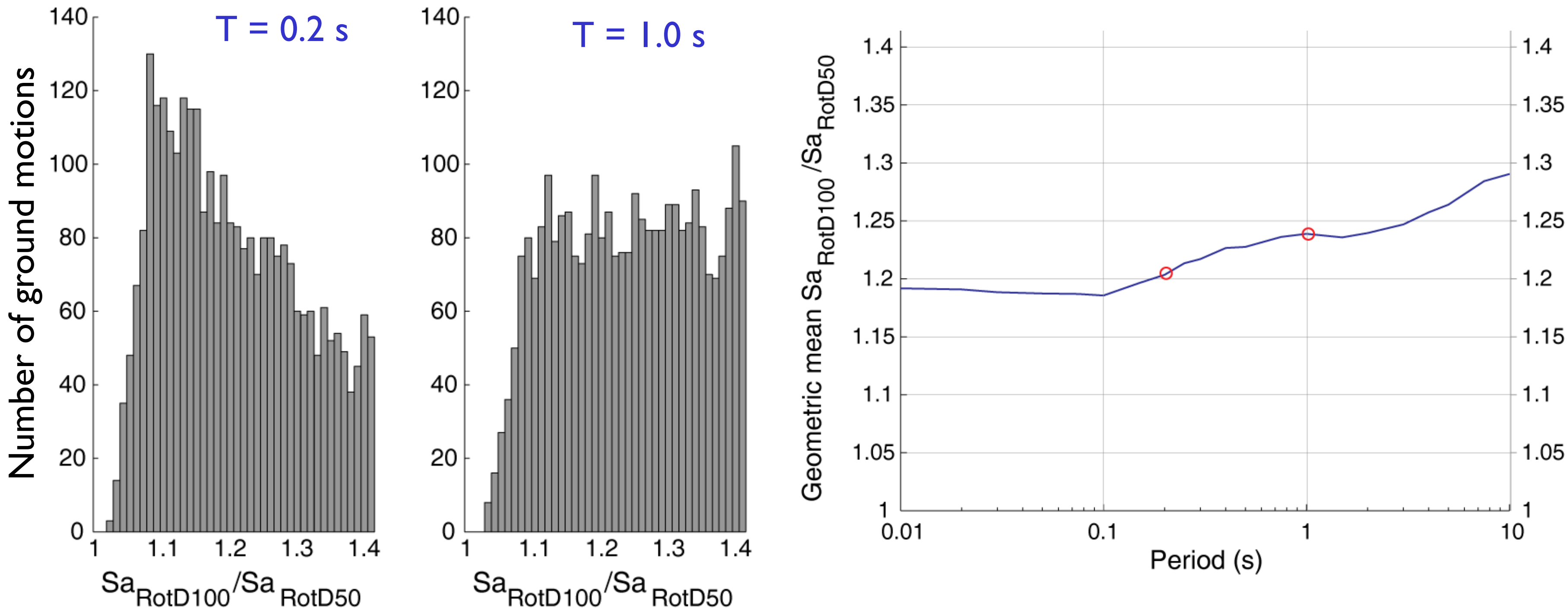
T = 1s, $Sa_{RotD100}/Sa_{RotD50} \approx 1$



T = 1s, $Sa_{RotD100}/Sa_{RotD50}$ = 1.41



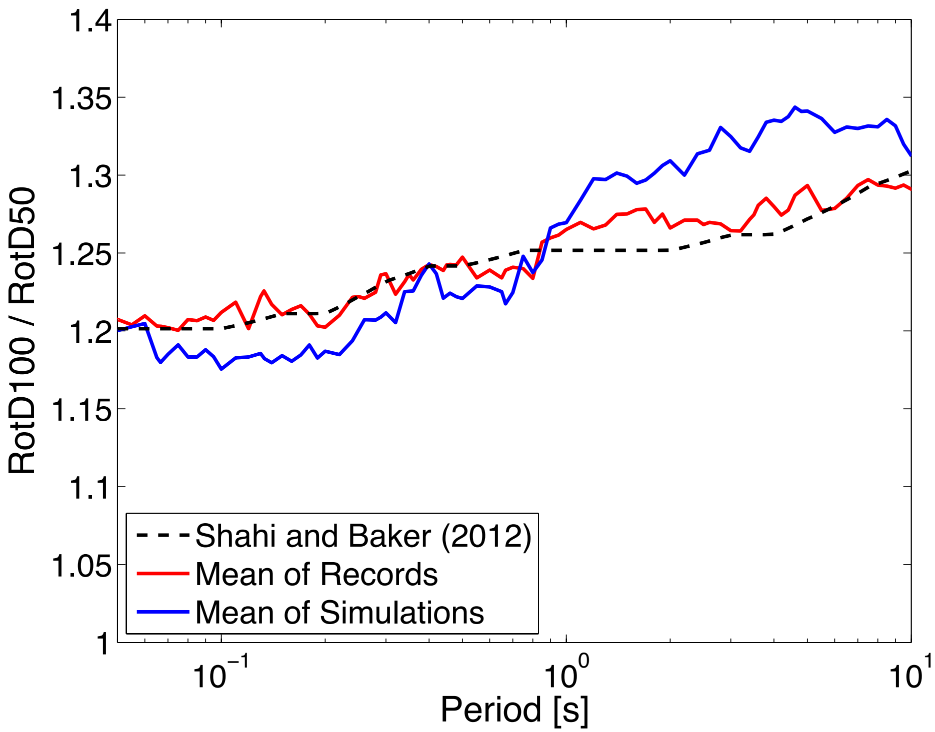
Histograms of $Sa_{RotD100}/Sa_{RotD50}$ from recordings



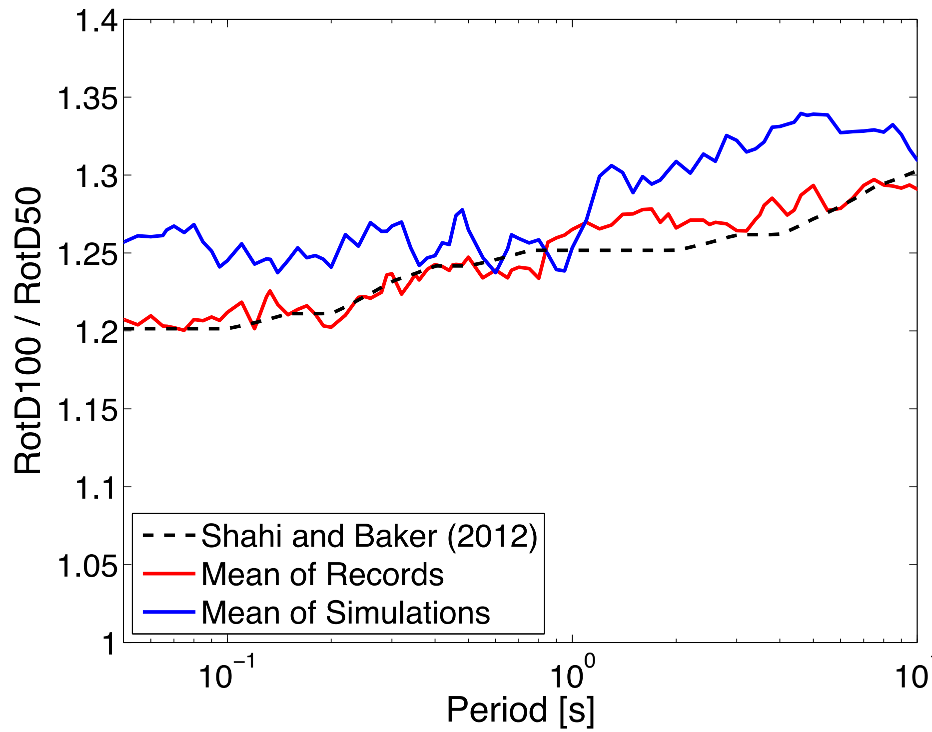
Results NGA -West2 data

Geometric mean $Sa_{RotD100}/Sa_{RotD50}$ ratios from simulations

With URS high-frequency module



With SDSU high-frequency module



Ground motion properties for validation

Properties we have studied:

- Spectral correlations
- Velocity pulses in near-fault motions
- Polarization of response spectra
- Inelastic response spectra
- Simple structural model collapse capacities

We have targeted properties with the following characteristics:

- Simple and general, but of engineering relevance
- Relatively stable in recorded ground motions (so that we know the "correct" answer even for large or unusual events)

  Stable:

  - Little variation in empirical models across a range of magnitude/distance/site conditions
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Ground motion properties for validation

Properties we studied this year:

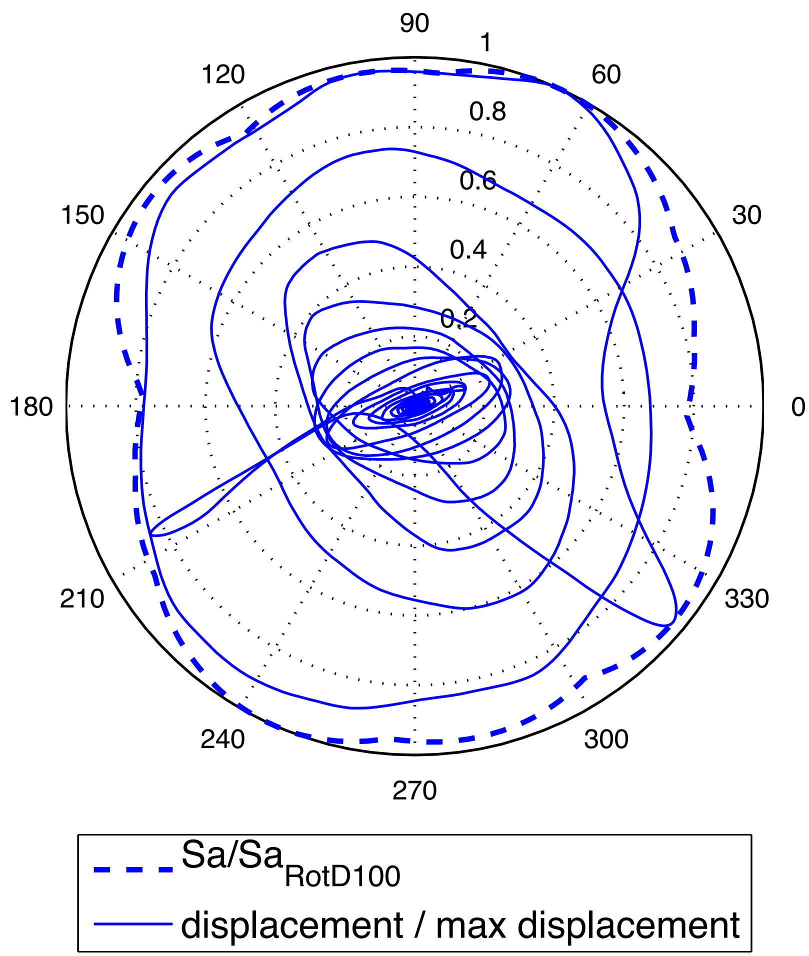
- Spectral correlations
- Velocity pulses in near-fault motions
- Polarization of response spectra
- Inelastic response spectra
- Simple structural model collapse capacities

Our target properties for validation ideally have the following characteristics:

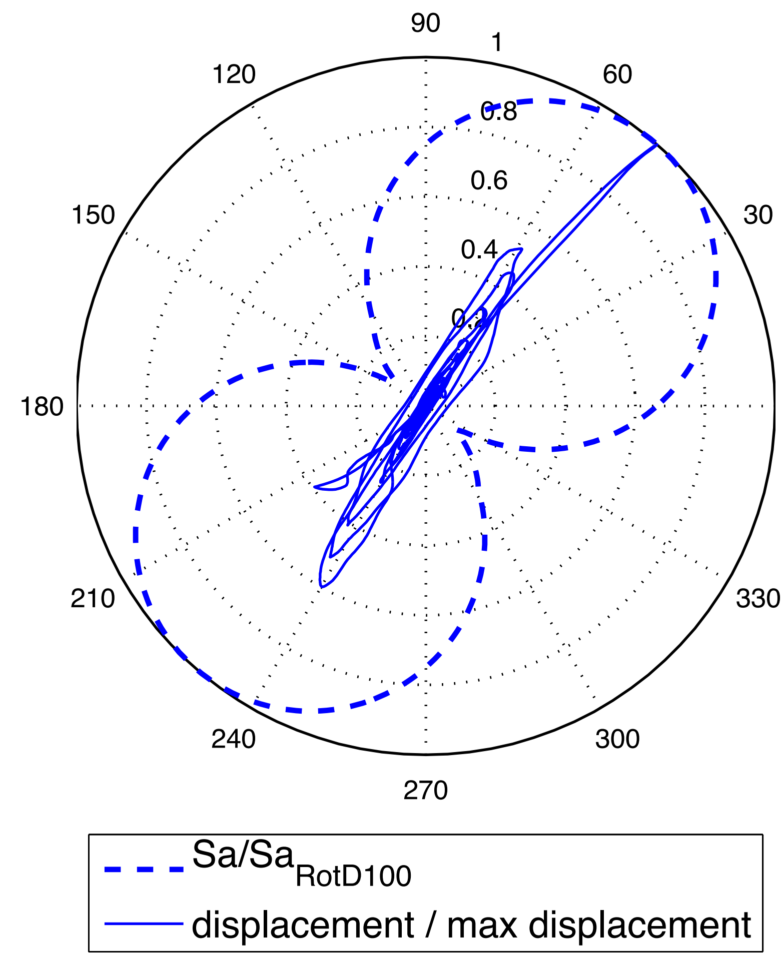
- Simple and general, but of engineering relevance
- Relatively stable in recorded ground motions (so that we know the "correct" answer even for large or unusual events)

SDOF Oscillator Response

T = 5s, RotD100/RotD50 = 1

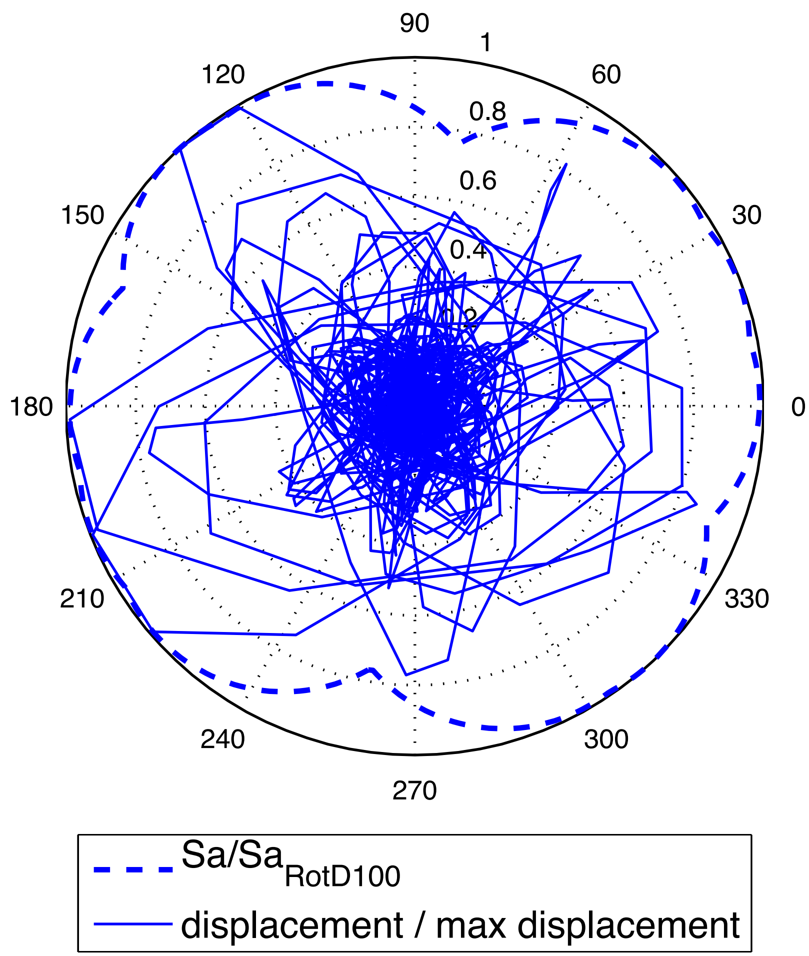


T = 5s, RotD100/RotD50 = 1.41

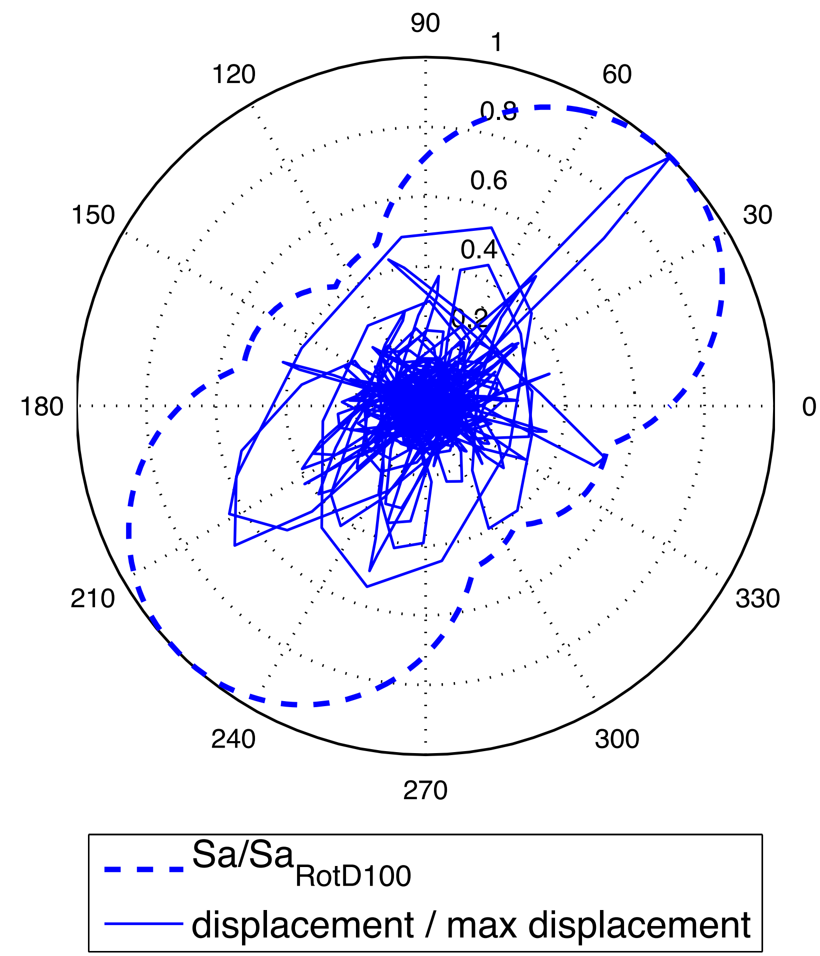


SDOF Oscillator Response

T = 0.2s, RotD100/RotD50 = 1



T = 0.2s, RotD100/RotD50 = 1.42



Conclusions

- In this case, the UCSB rupture generator produces relatively smoother slip time histories than the URS rupture generator and the inverted source used by the validation module
- Simulations tend to have more pulse-like ground motions than recordings
- The elastic response spectra computed from simulations match recordings at long periods in general, but tend to underestimate responses at periods shorter than 1s
- Structural collapse capacities are inconsistent between simulations and recordings, even when the elastic spectral shape is matched

Thank you!

Extra Slides

Simulation Validation Example

Northridge Ground Motion Data

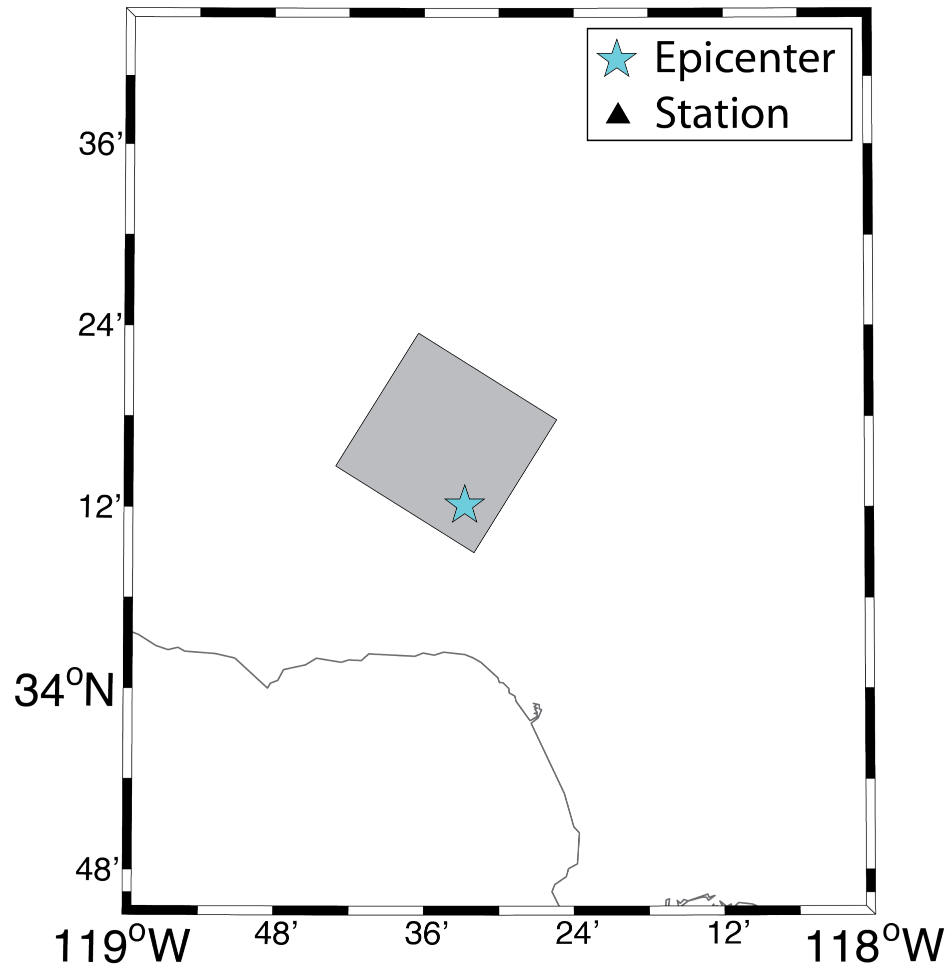
- Recordings from NGA database
- Simulations from SCEC Broadband Platform
  - Validation simulations
  - 6 realizations of simulations using the rupture generator

Ground Motion Set	Type	Rupture Generator*	Short Name
1	Recordings	N/A	NGA
2	Simulations	Validation	VAL
3	Simulations	URS	URS 1
4	Simulations	URS	URS 2
5	Simulations	URS	URS 3
6	Simulations	UCSB	UCSB 1
7	Simulations	UCSB	UCSB 2
8	Simulations	UCSB	UCSB 3

**URS method was used for low and high frequency and site response*

Ground Motion Set

- Rupture
  - $M_W = 6.67$
  - Dimensions = 20 km by 25 km
  - Dip = 40°



Ground Motion Set

- Rupture
  - M_W = 6.67
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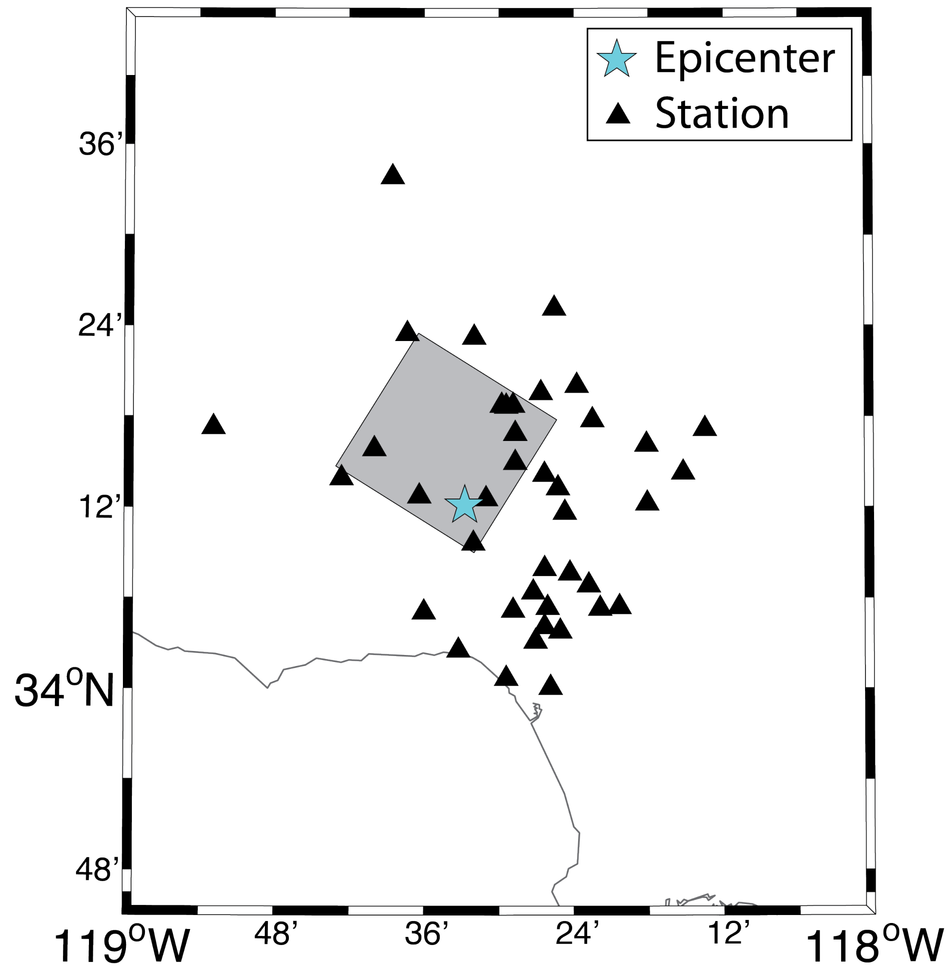
- Ground Motions
  - 40 stations
  - Within 20.5km of fault rupture



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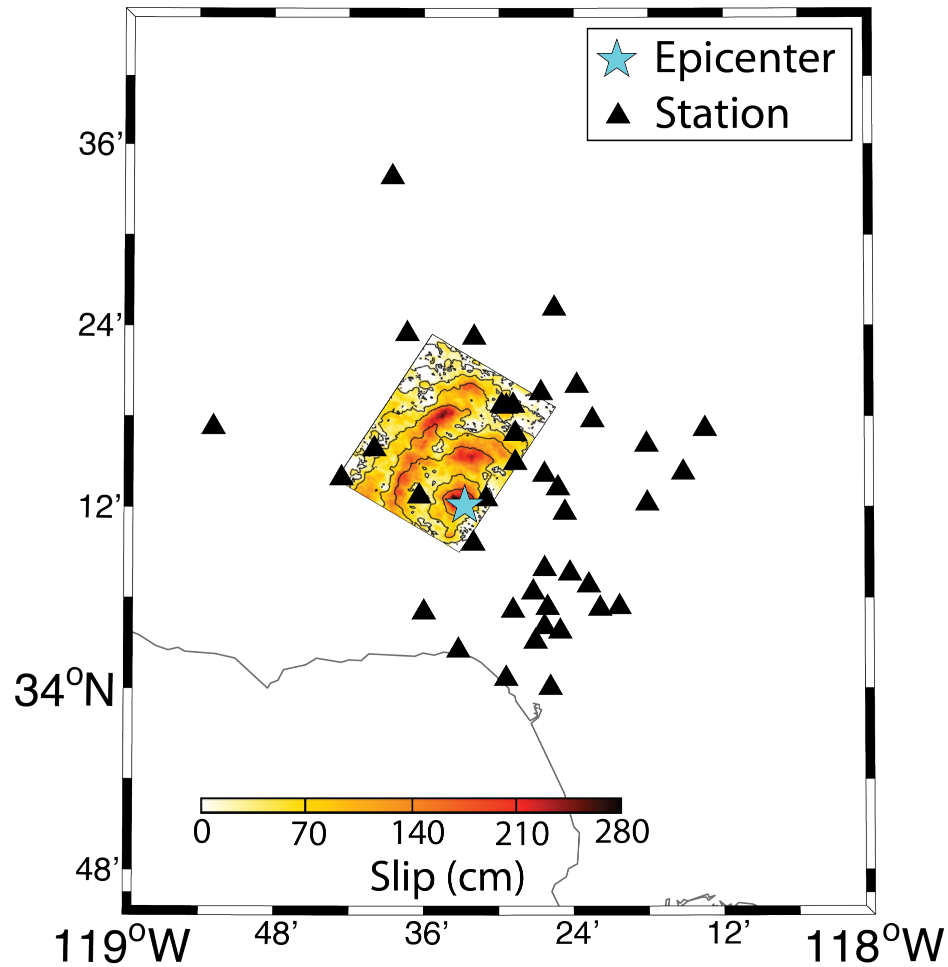
- Slip Time History
  - Validation simulations = source inversion



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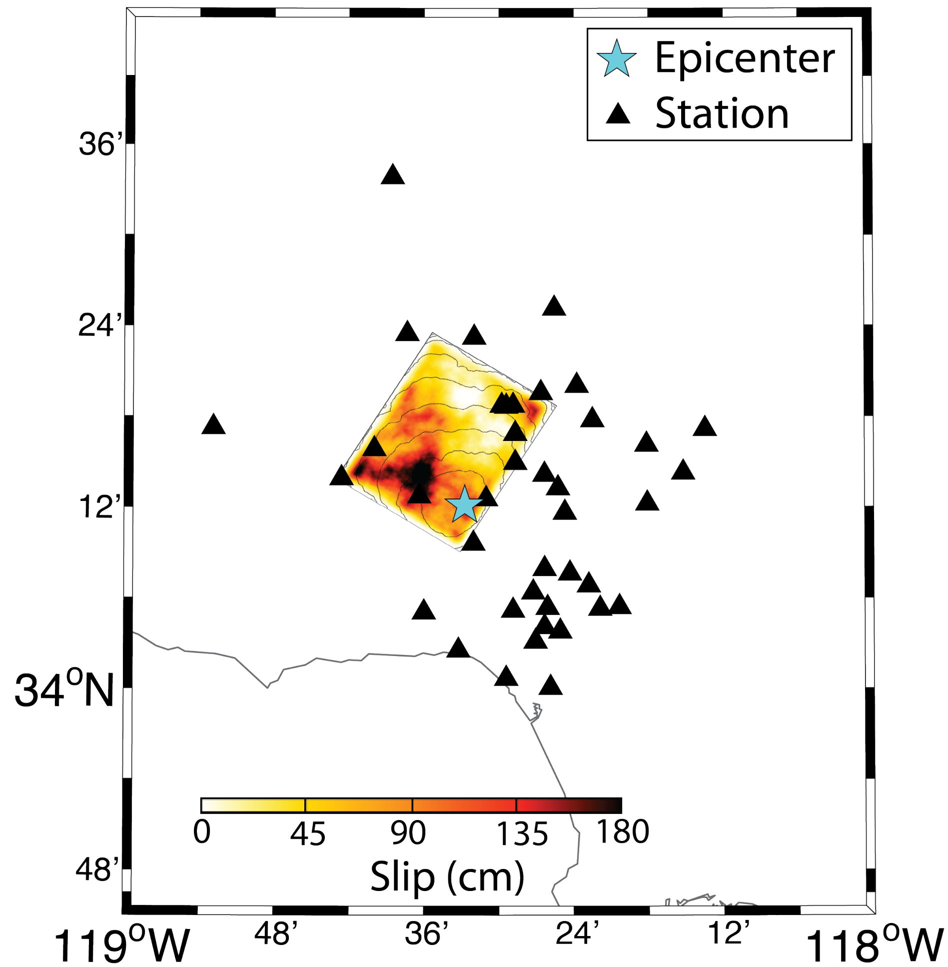
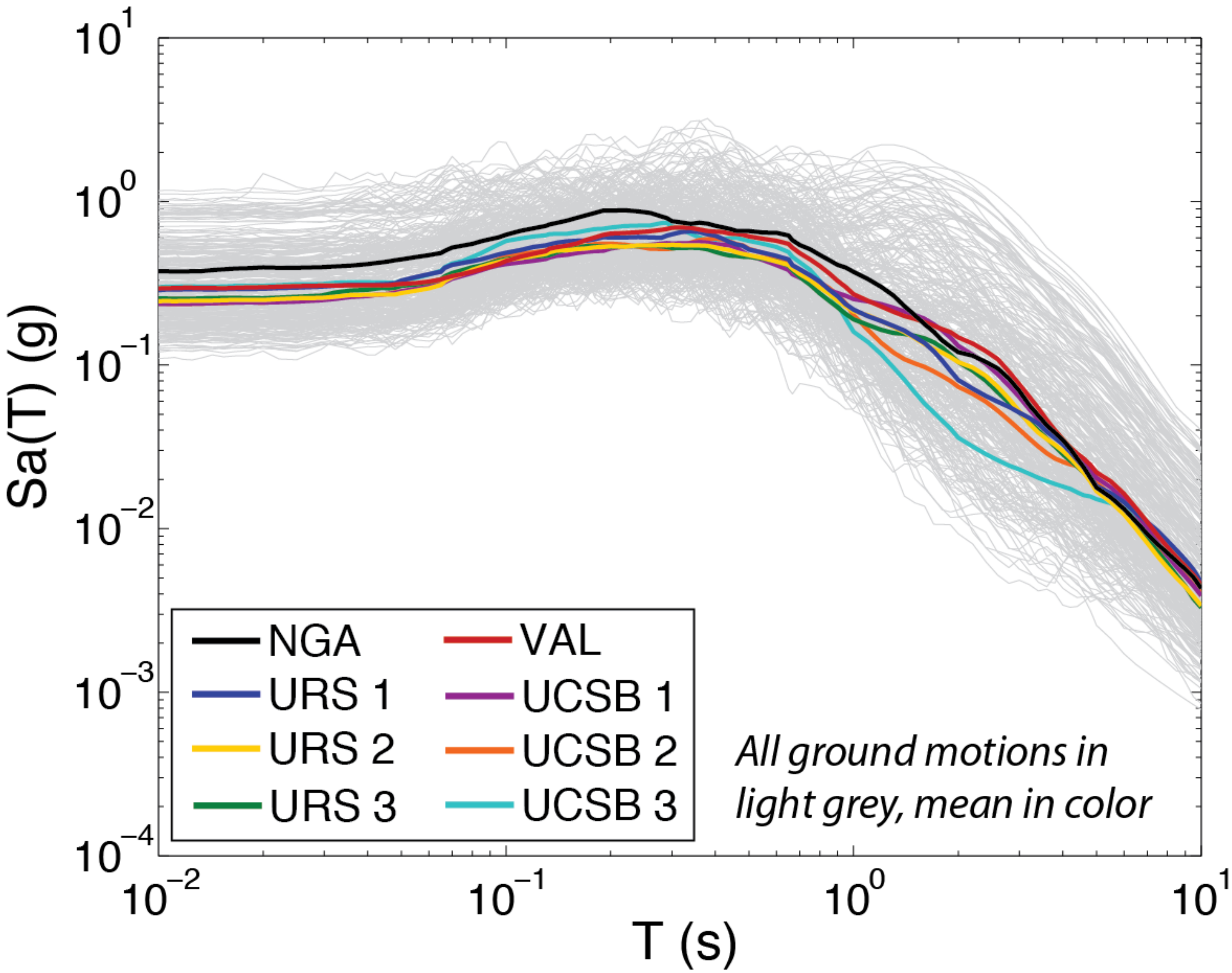
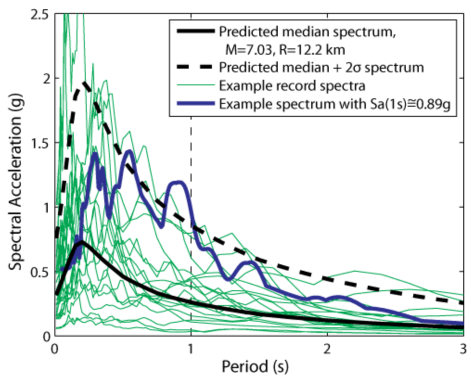
  - Rupture generator simulations



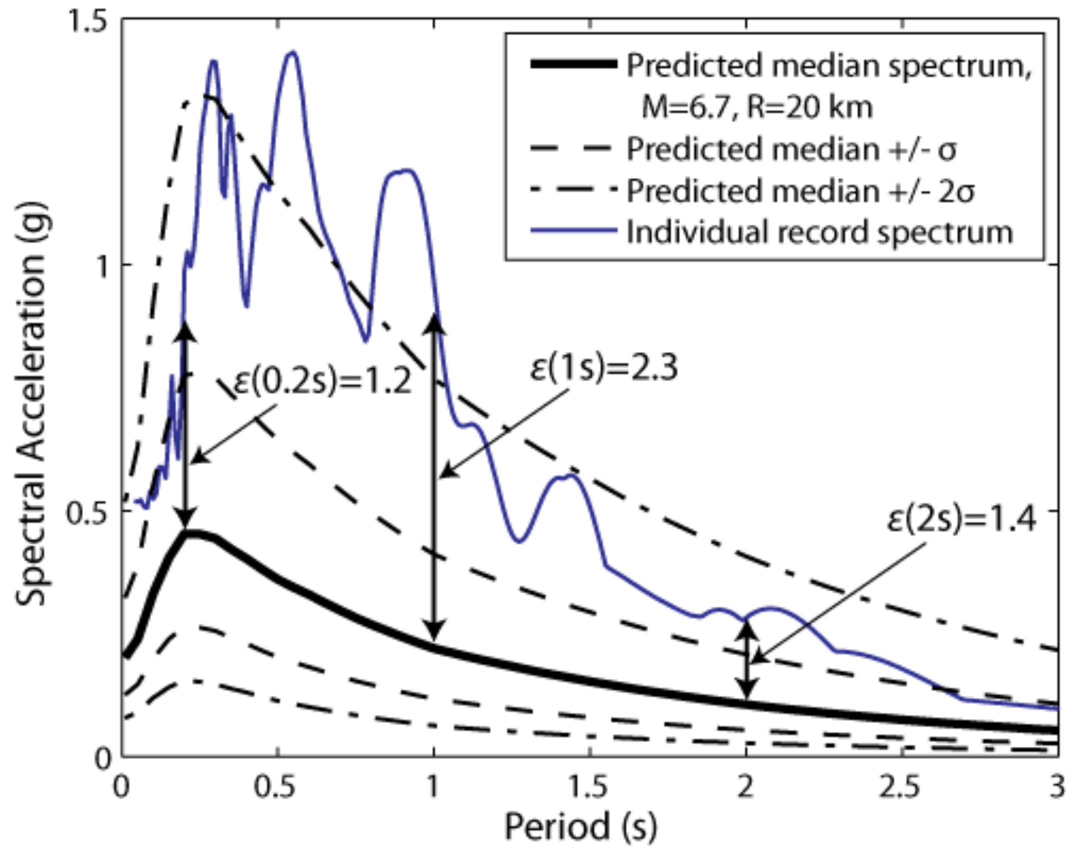
Elastic Response Spectra



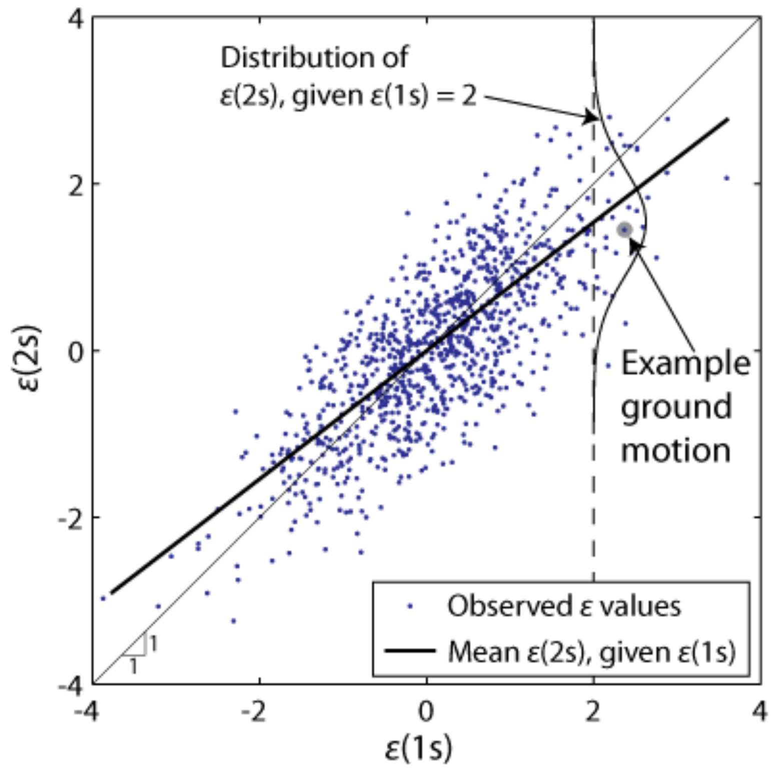
Calculation of ε values at three periods

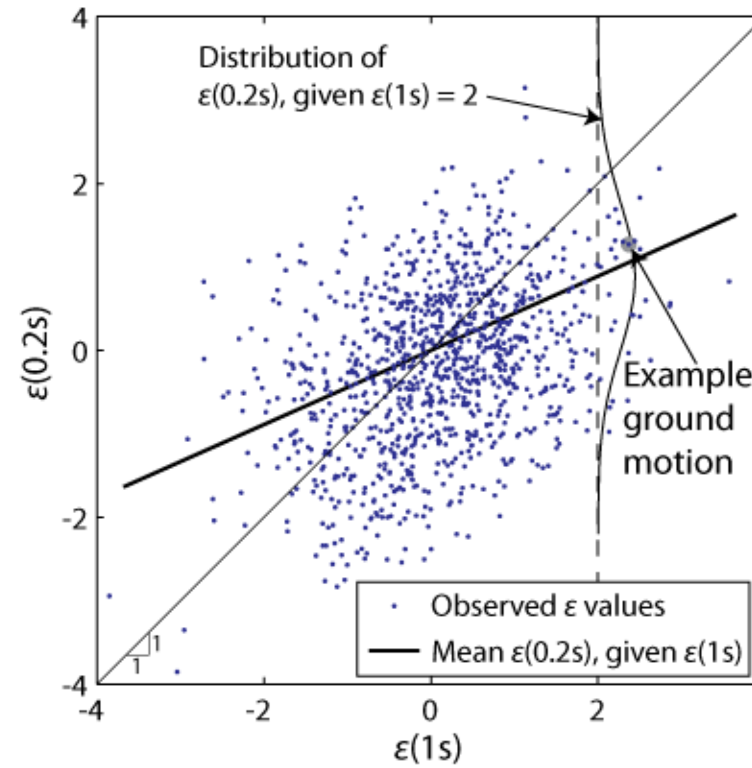


$$\varepsilon(T) = \frac{\ln Sa(T) - \mu_{\ln Sa(T)}}{\sigma_{\ln Sa(T)}}$$

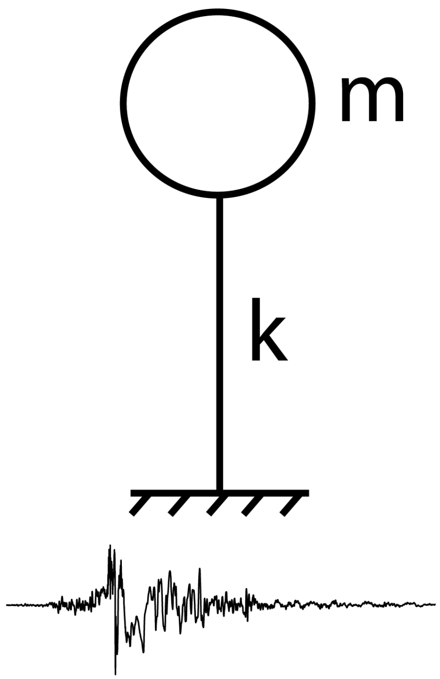


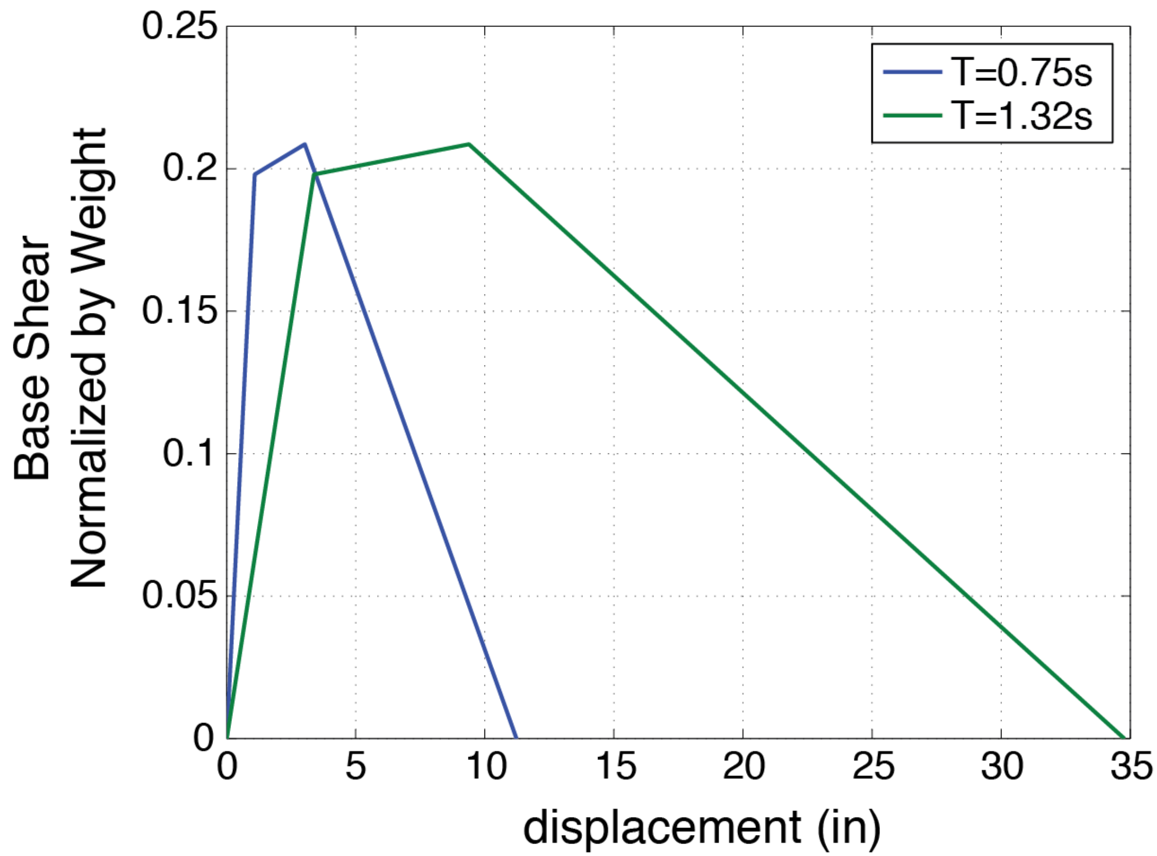
ε values at varying periods, from many ground motions



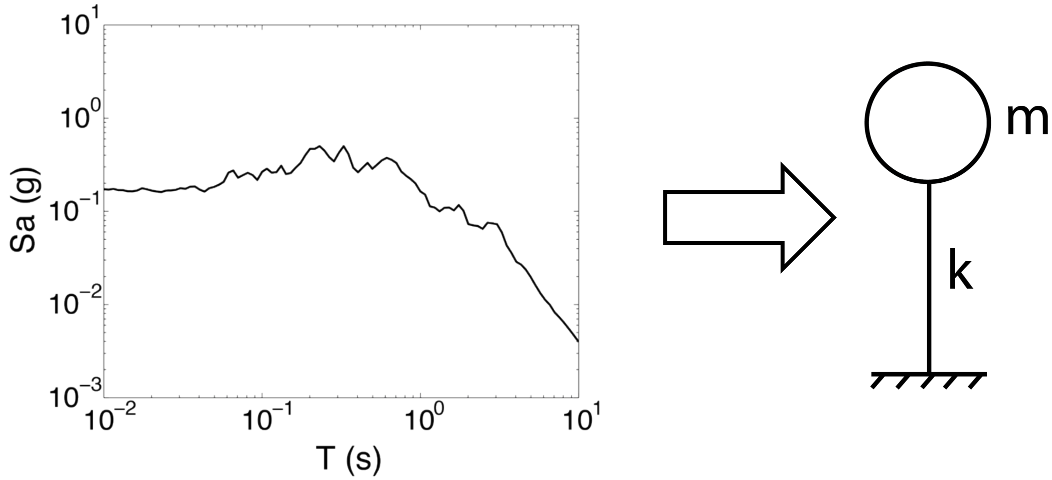


Example Building Collapse Capacities





Incremental Dynamic Analysis



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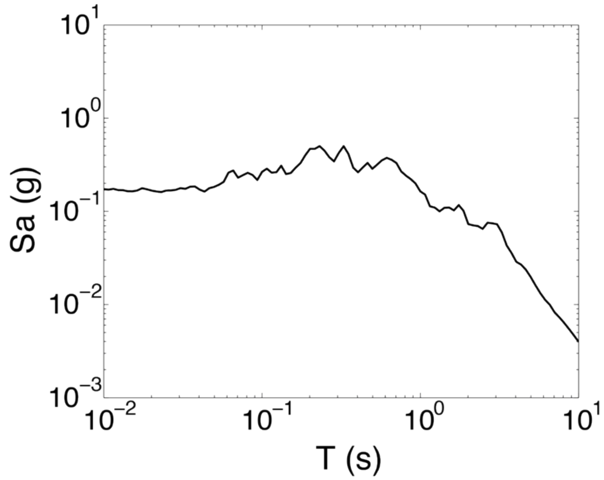

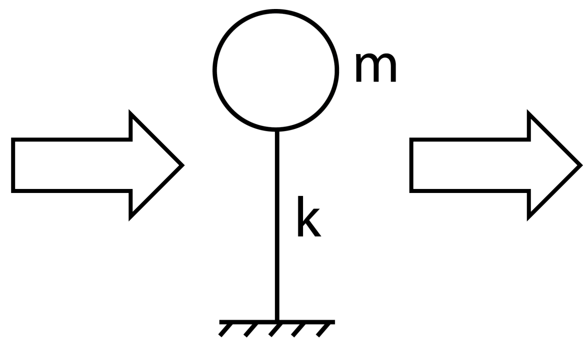

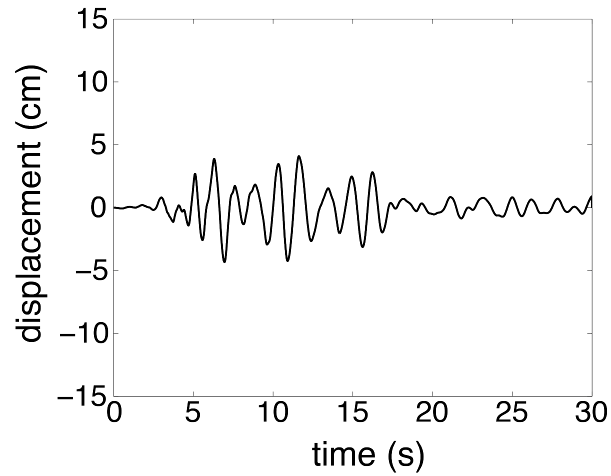

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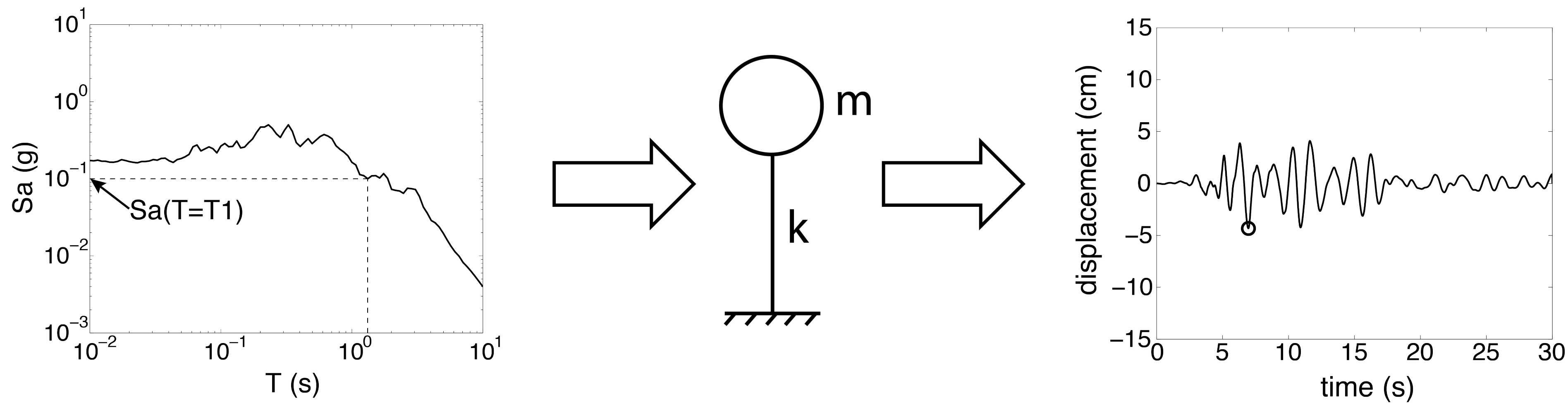

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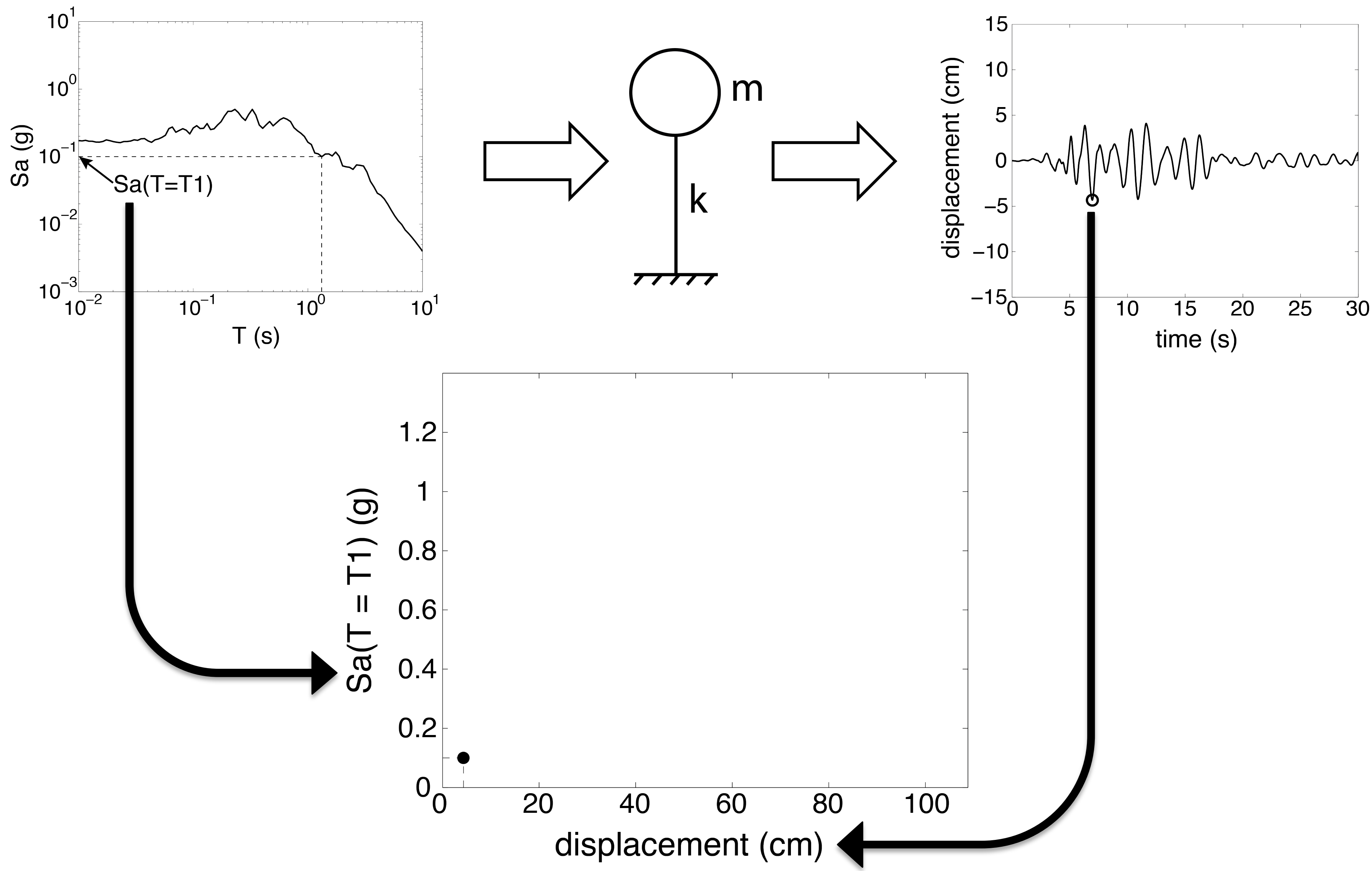

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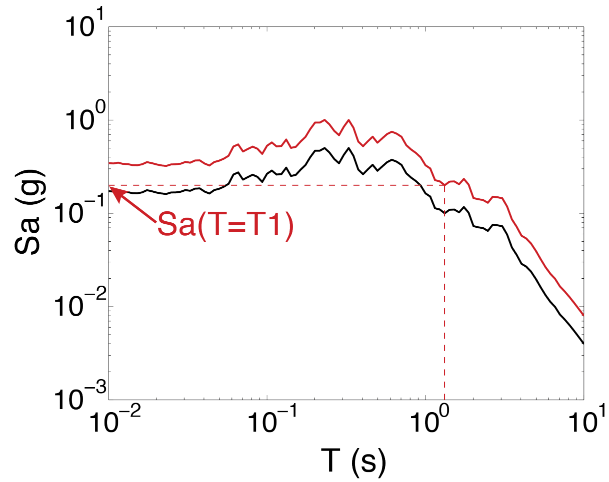

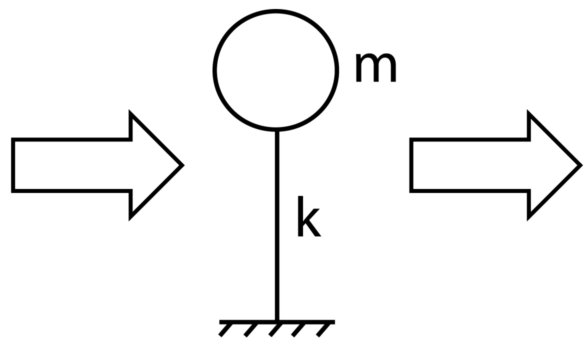

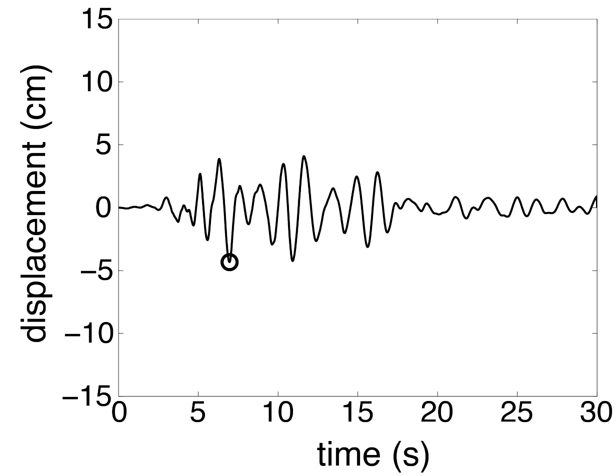

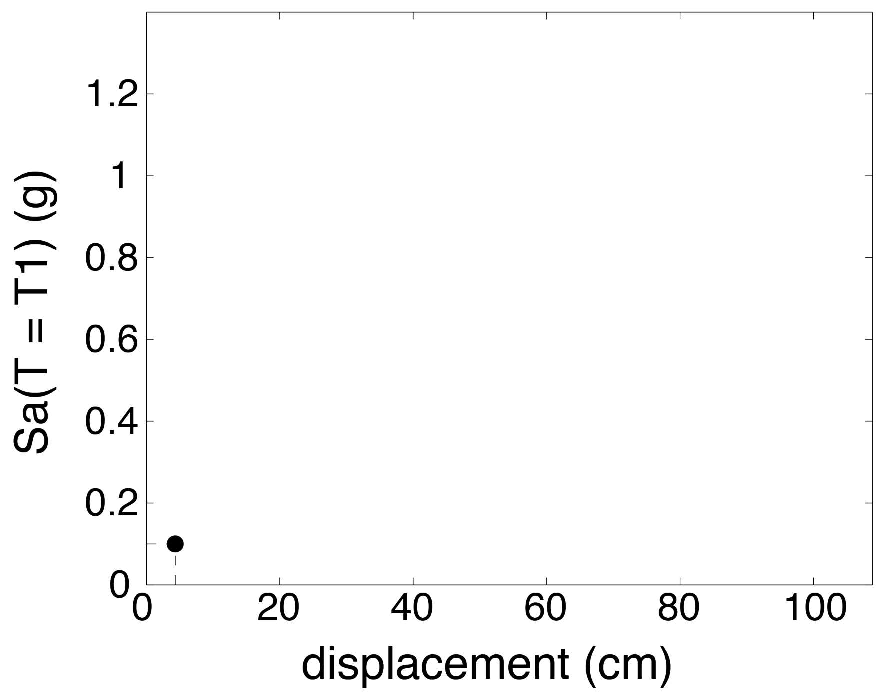

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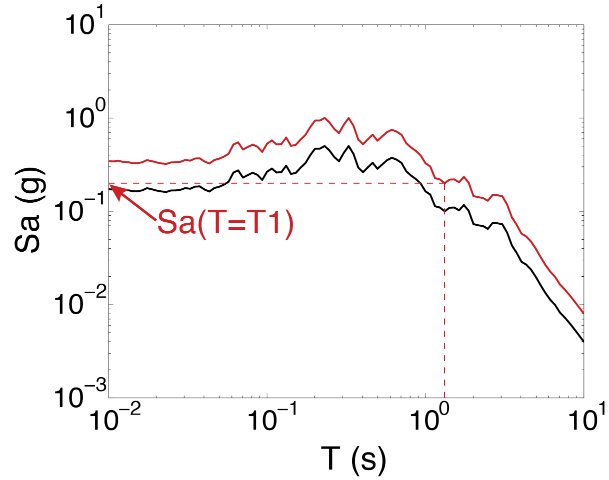

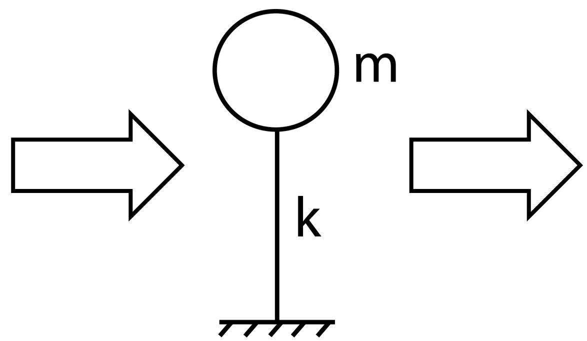

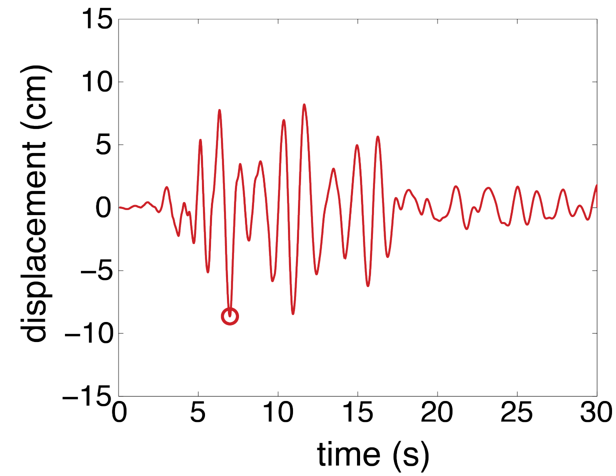

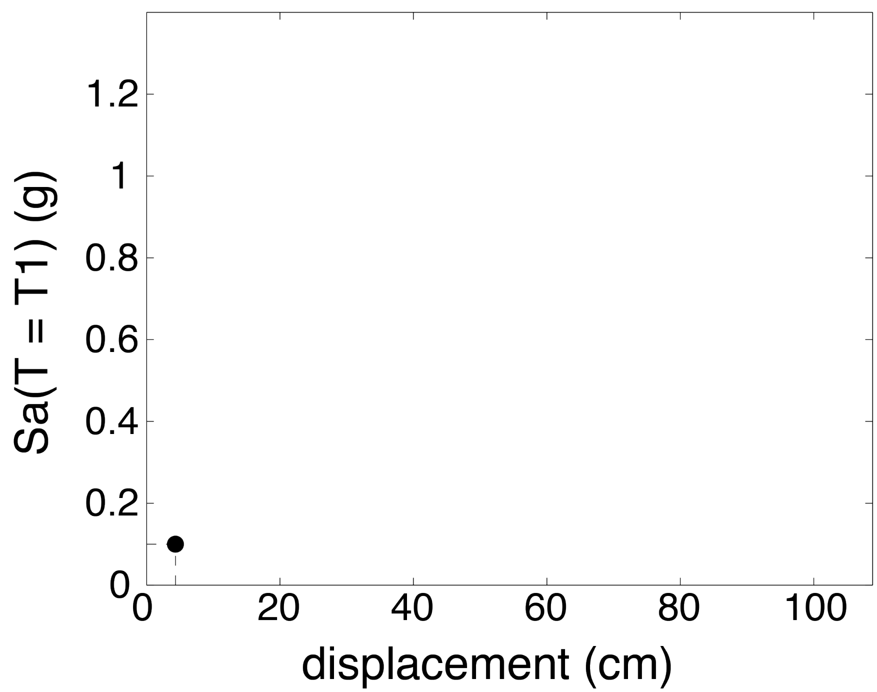

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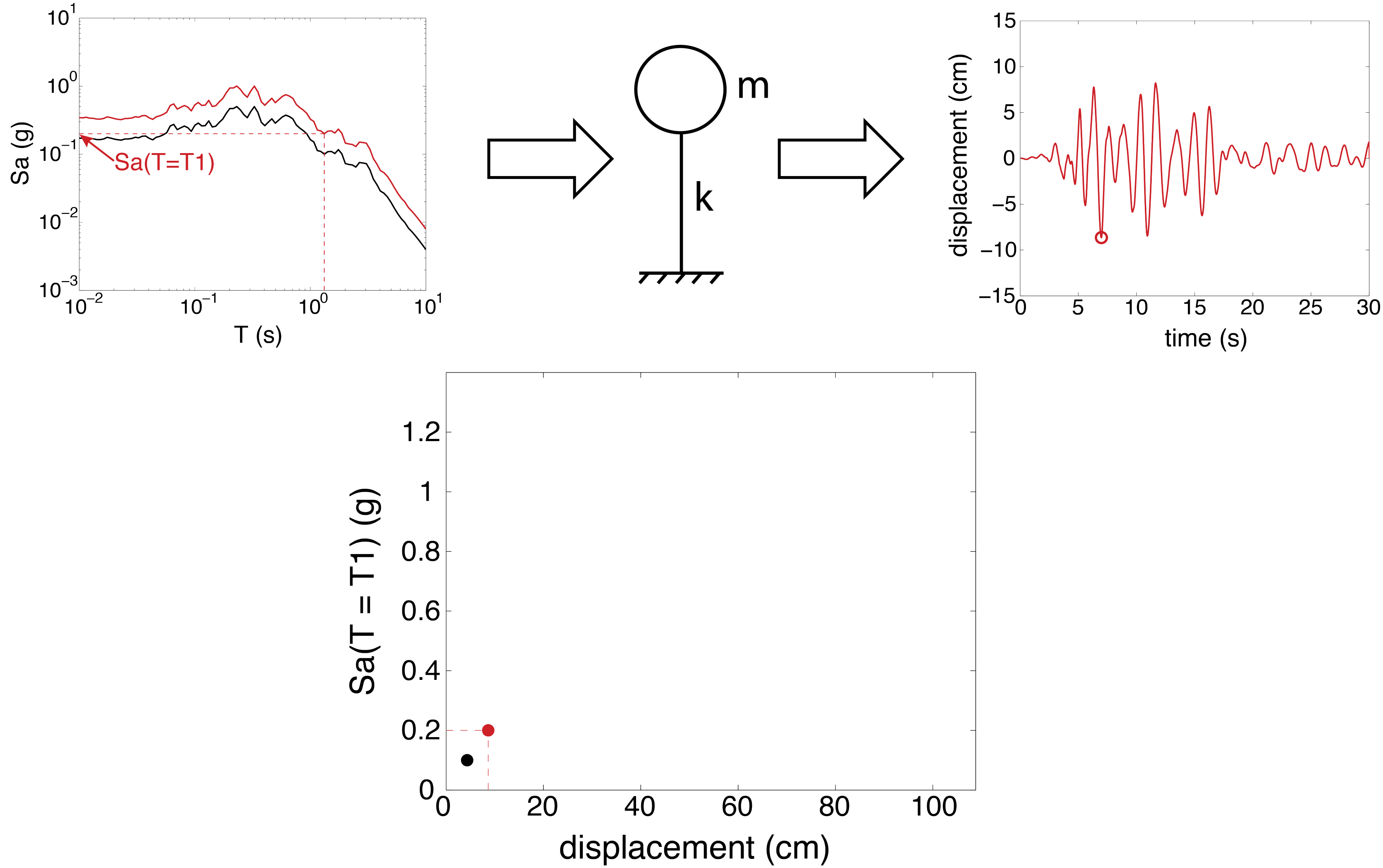

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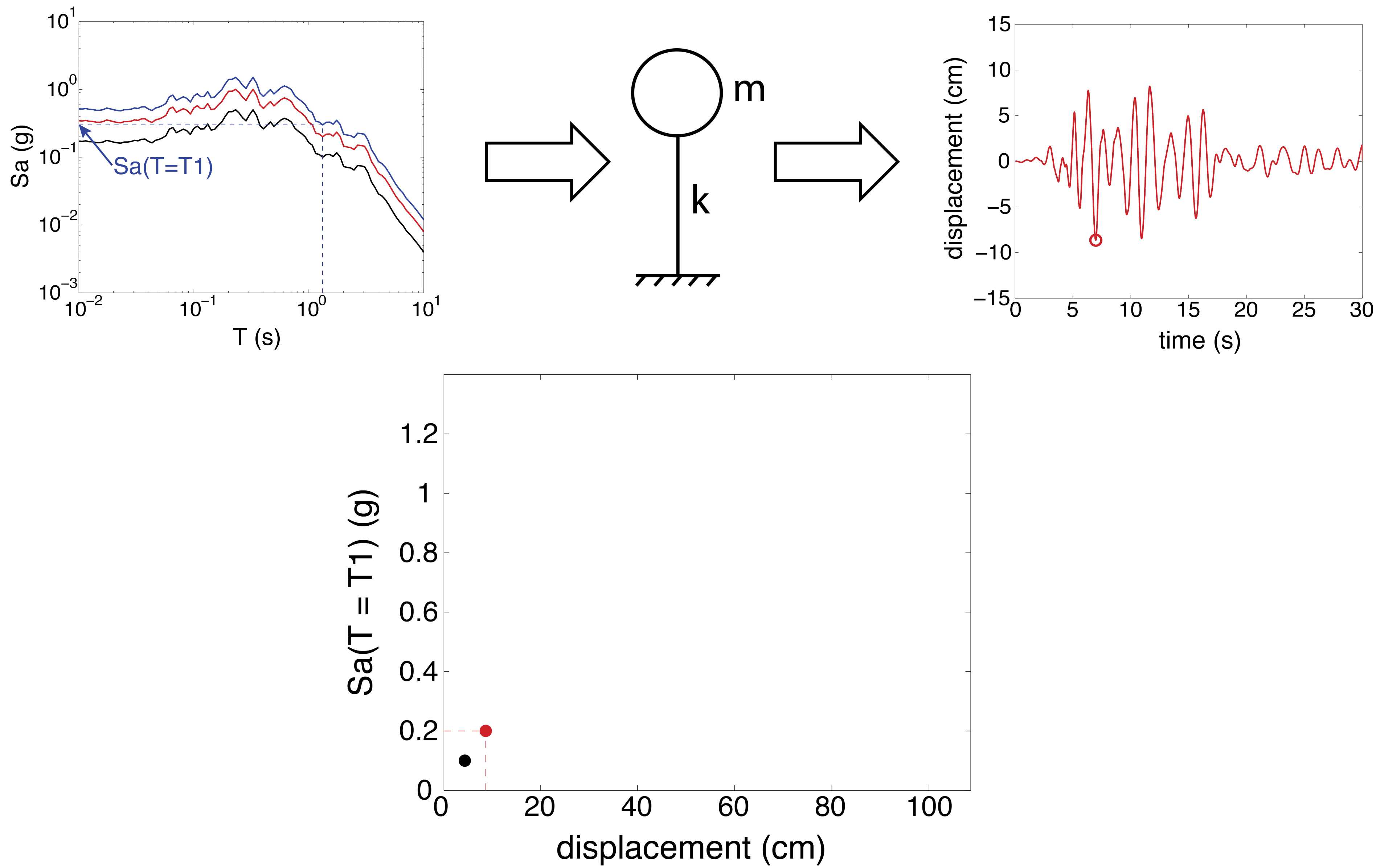

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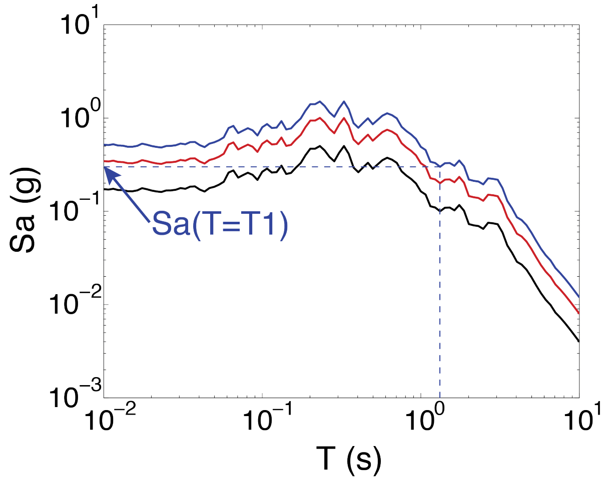

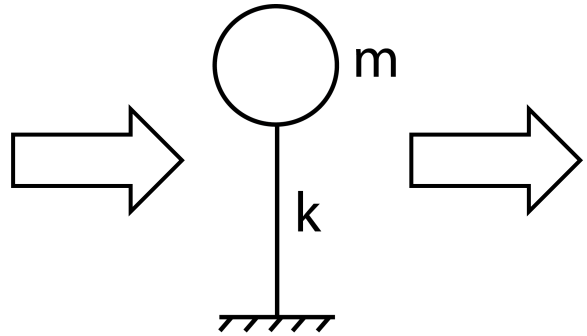

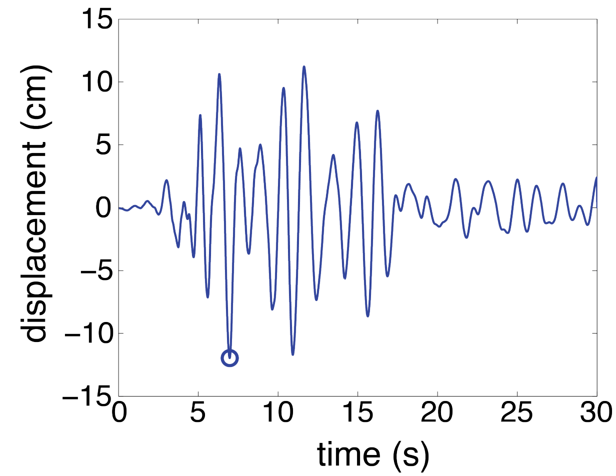

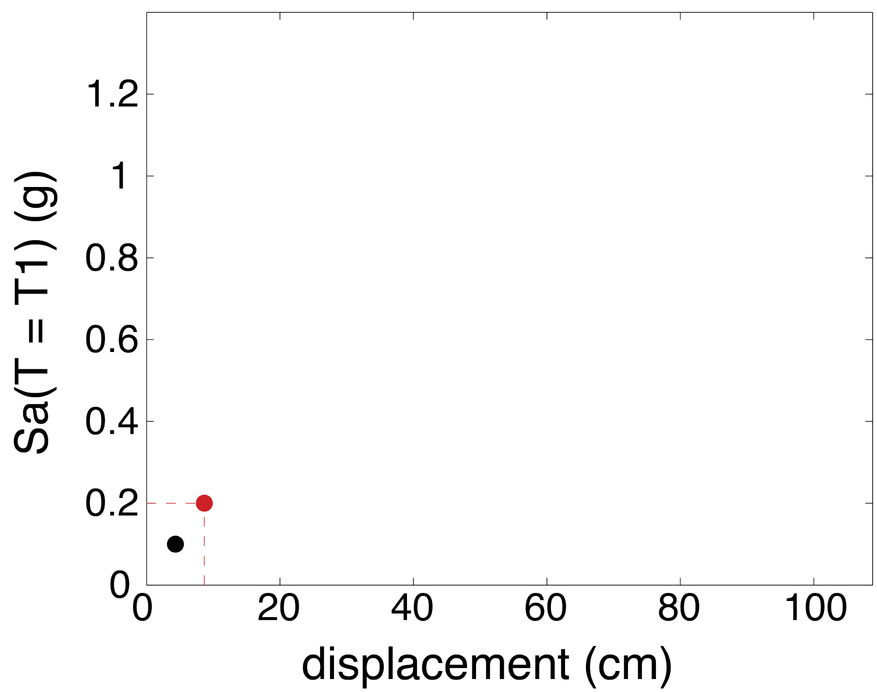

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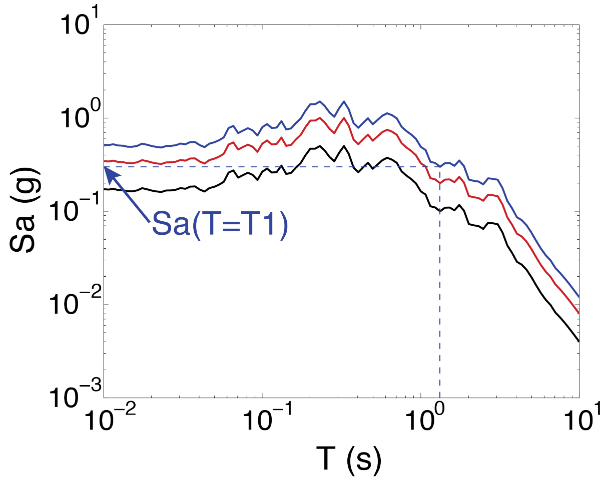

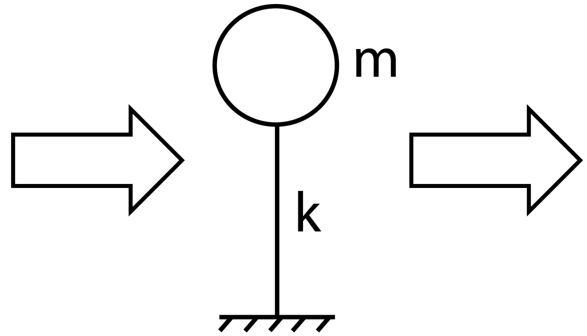

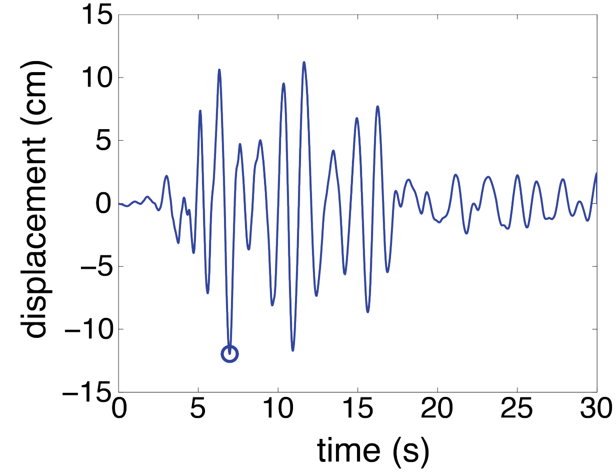

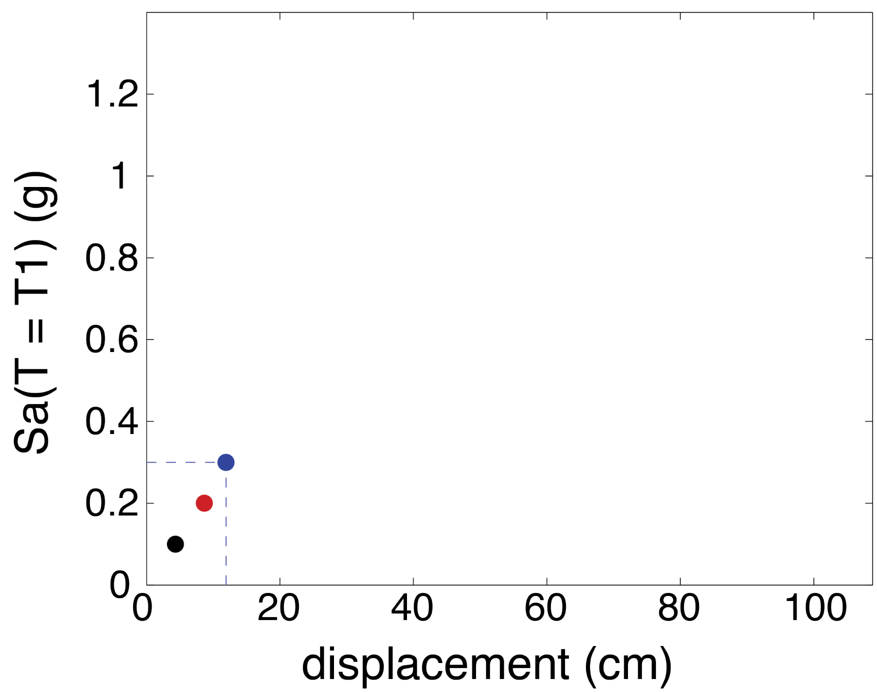

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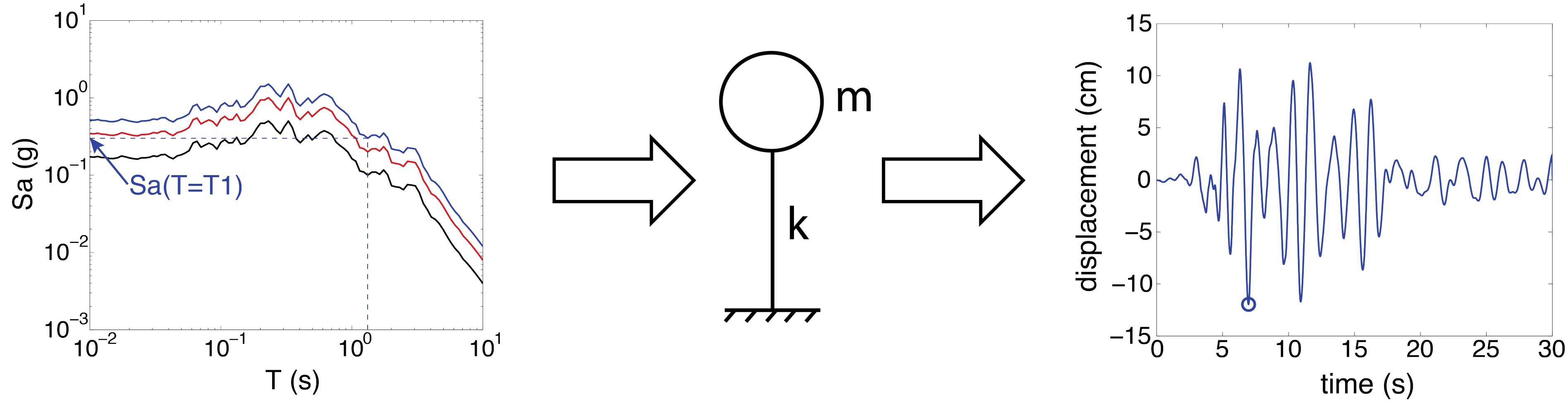
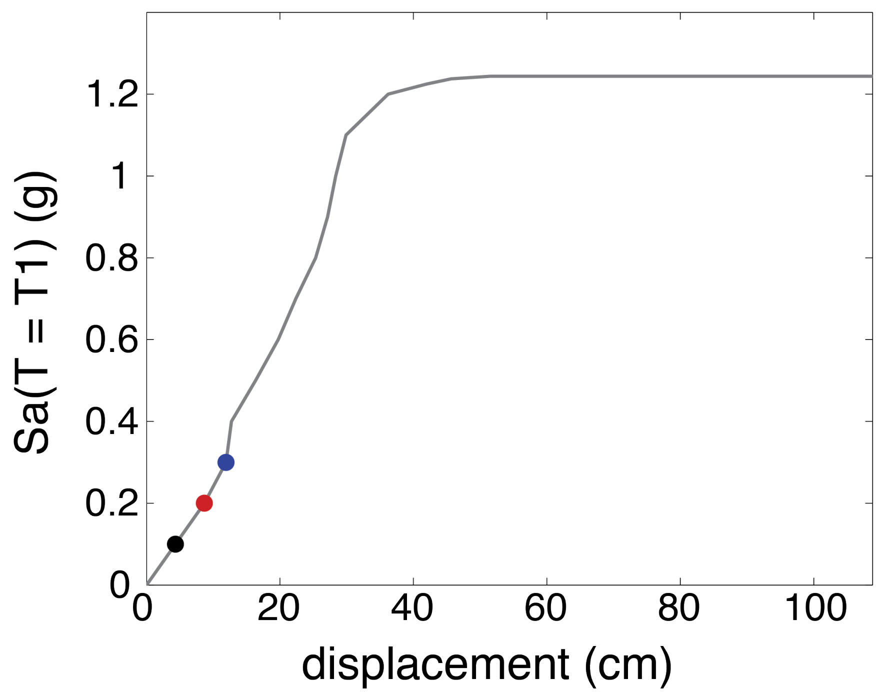
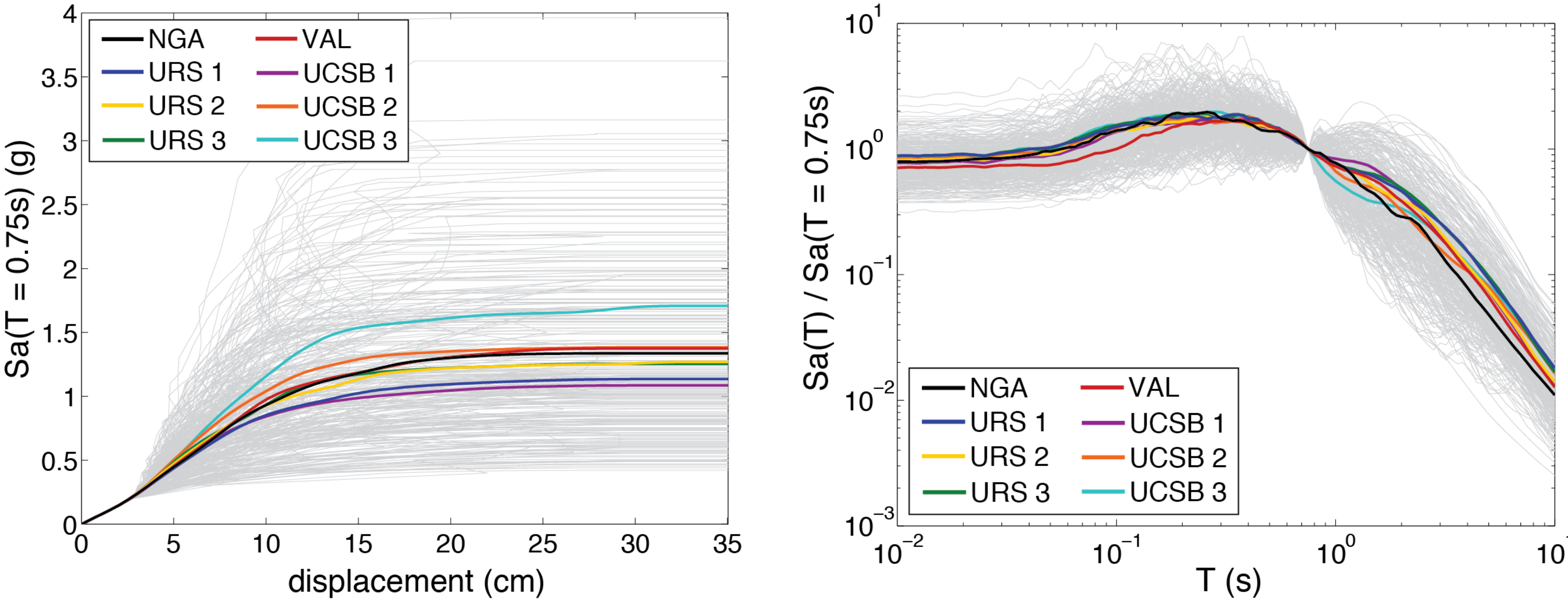




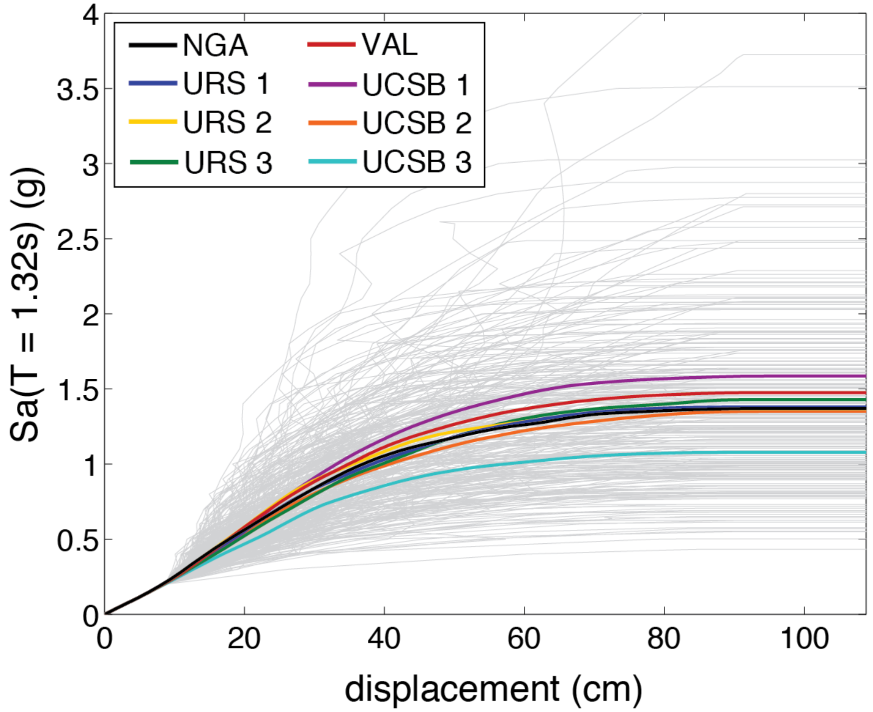
Example Building Collapse Capacities

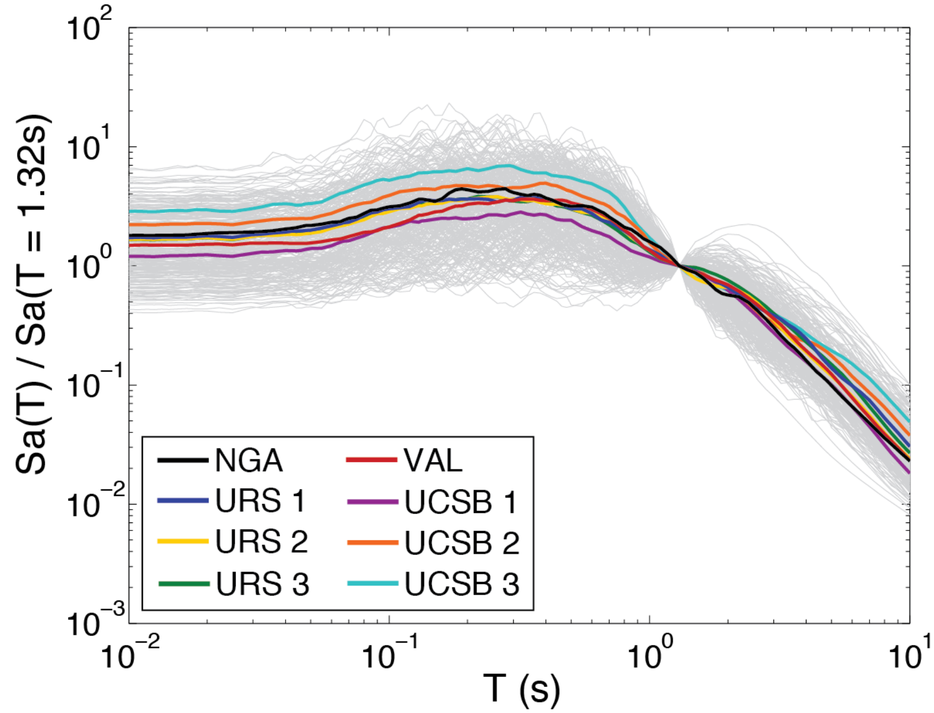
T = 0.75s



Example Building Collapse Capacities

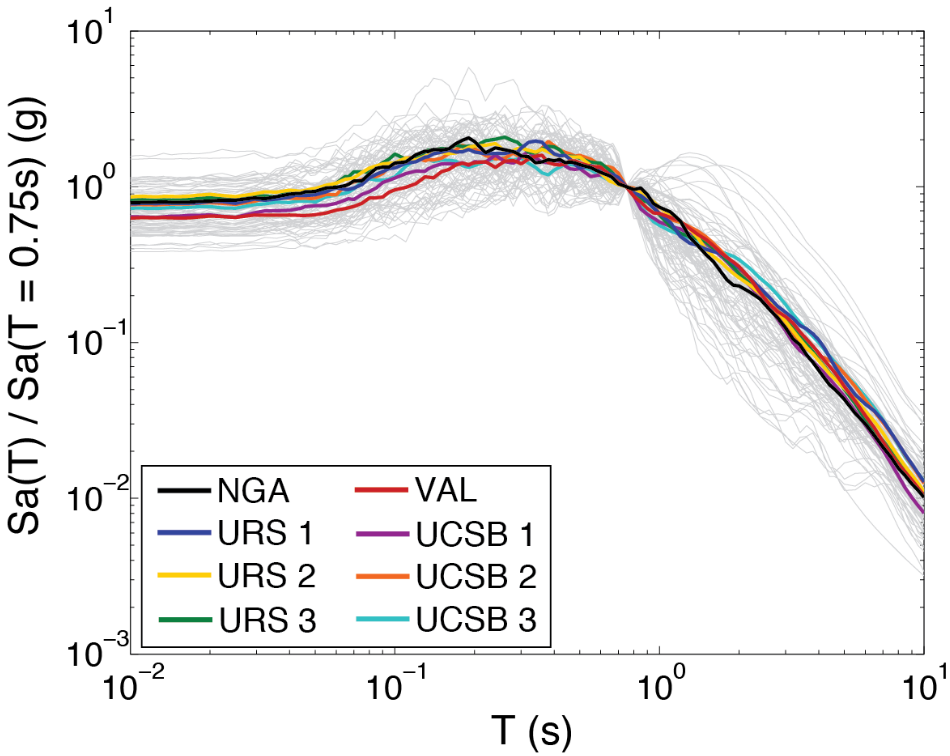
T = 1.32s

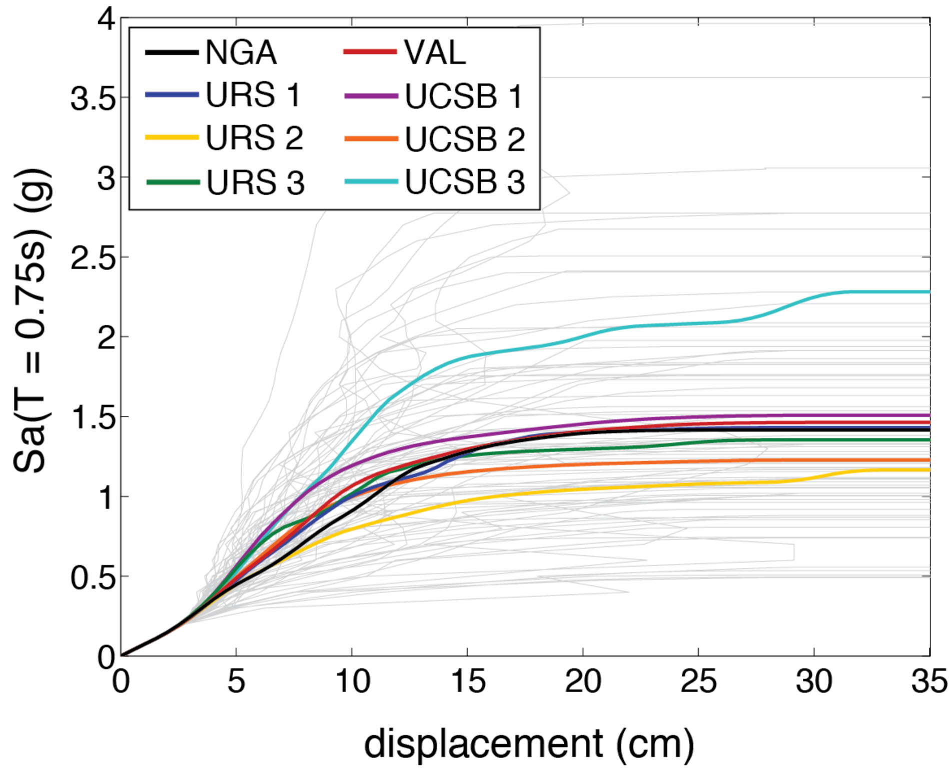




Effect of Matching Response Spectra on Collapse Capacity

T = 0.75s





Effect of Matching Response Spectra on Collapse Capacity

T = 1.32s