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Implications of the inter-period correlation of simulated ground motions on structural risk

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Outline

1. Introduction
2. Evaluation of Existing Ground Motion Simulation Methods → What is the status of the simulations?
3. Correlation of ϵ: Incorporation into SMSIM → A partial fix!
4. Structural Fragility Example → Why does this matter?
5. Conclusions

1) Introduction

Definition:

Epsilon (ϵ) is the number of standard deviations difference between the observed/simulated IM (i.e. Sa or FAS, in ln units) and the median model prediction (ln units); a **normalized residual**.

Question:

Why does the **inter-period correlation of ϵ (ρ_ϵ)** matter?

Answer:

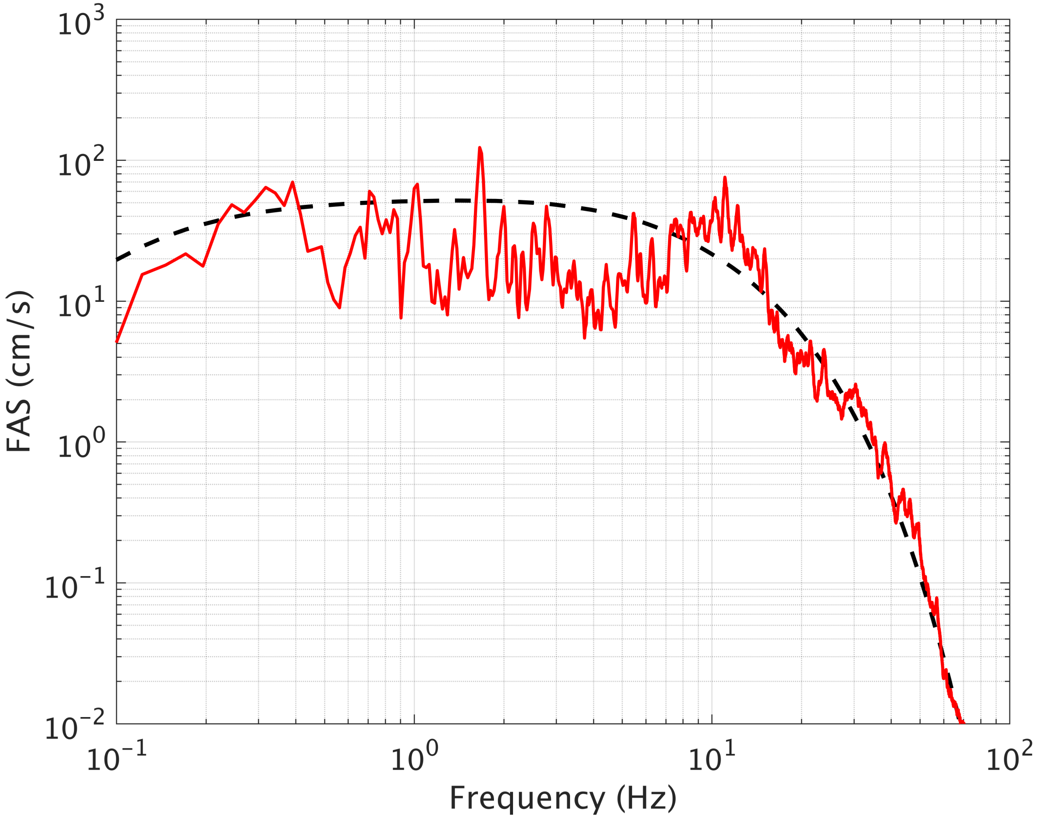
$\boldsymbol{\epsilon}$ is an indicator of the **peaks and troughs** at a given frequency in a spectrum.
$\boldsymbol{\rho_\epsilon}$ characterizes the **relative width** of these extrema.

We show that ρ_ϵ is an essential component of simulated ground motions for **capturing the variability** of structural response that is needed in seismic fragility and seismic risk studies.

1) Introduction

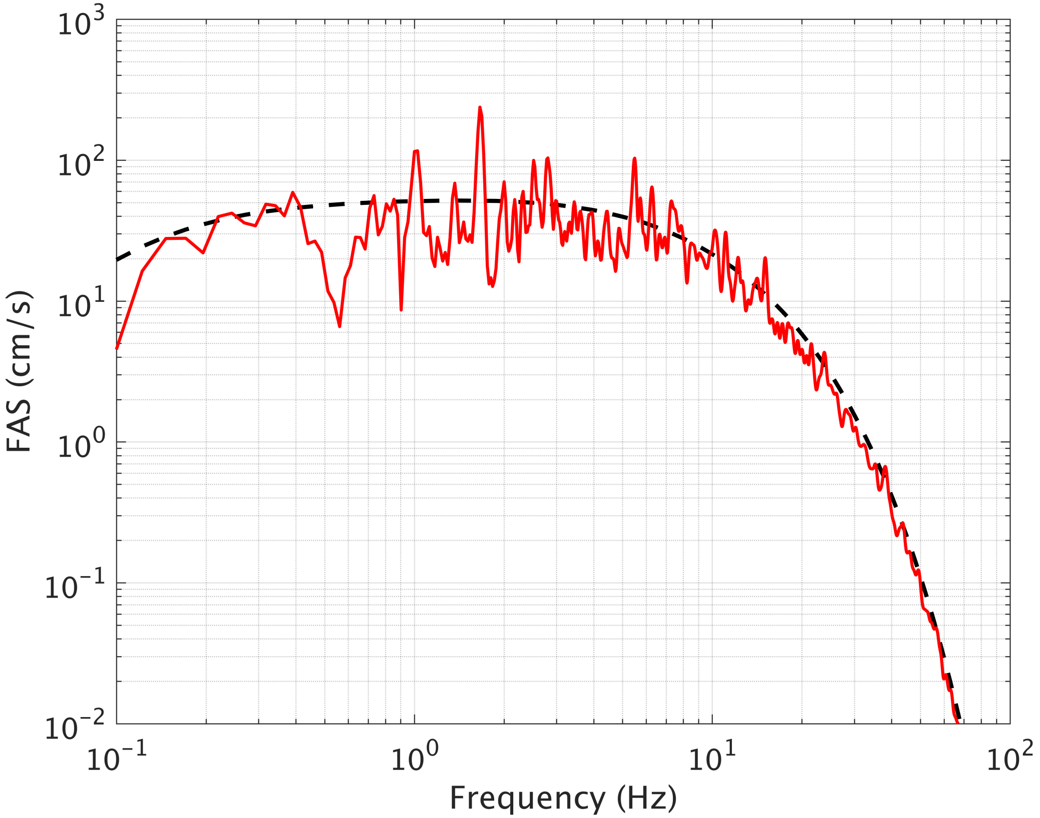
Example spectrum with high ρ_ϵ

(smoothed FAS)



Example spectrum with low ρ_ϵ

(smoothed FAS)



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2) Evaluation of Existing Ground Motion Simulation Methods

- Others (Burks and Baker, 2014; Tothong and Cornell, 2006) have studied the inter-period correlation of response spectra from simulated ground motions – mixed results.

- We focus in the Fourier Amplitude Spectra (FAS) domain to analyze the simulations and compare with the correlations in the data.
  - FAS provides the simulation developers better feedback to modify their methods that is not clear when using PSA

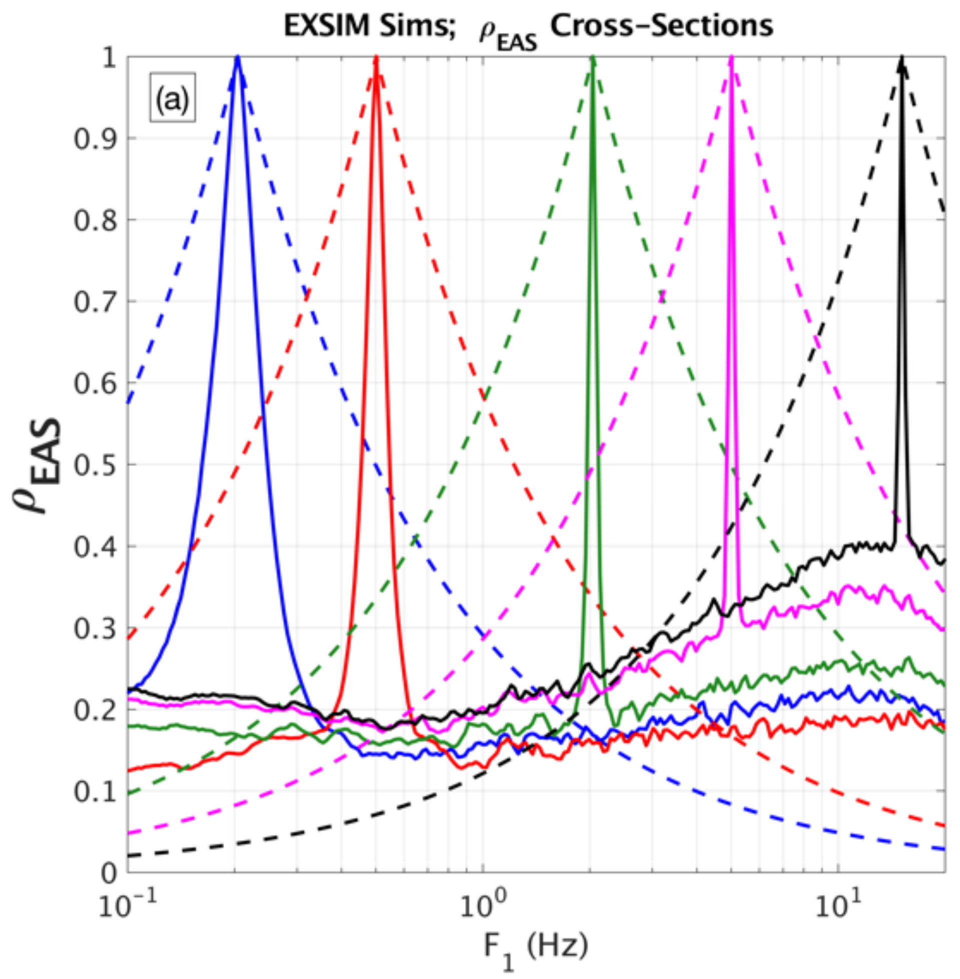
- Methods analyzed:

GP (Graves and Pitarka, 2015)
SDSU (Olsen and Takedatsu, 2015)
EXSIM (Atkinson and Assatourians, 2015)
UCSB (Crempien and Archuleta, 2015)
SONG (Song, 2016)
→ SCEC BBP (1d)

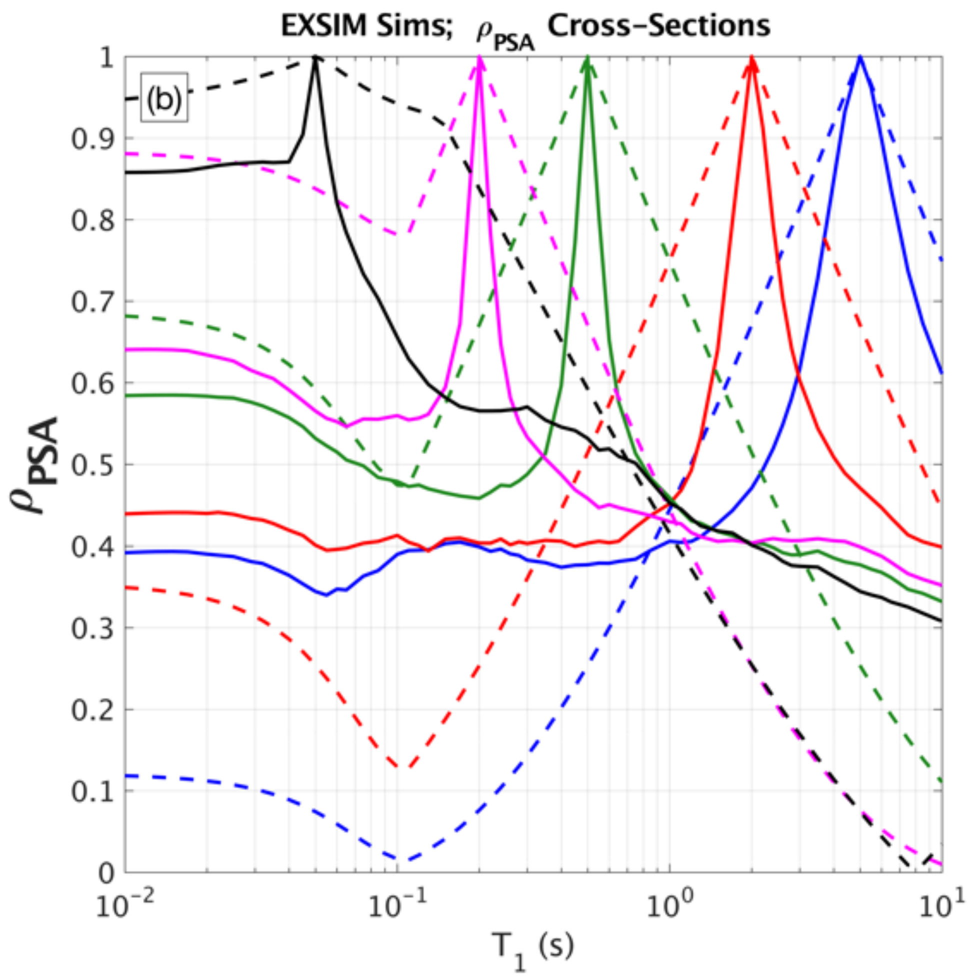
LLNL (Rodgers et al., 2018) → 3d finite difference

Pitarka (Pitarka et al., 2017) → GP wave propagation (1d)

2) Evaluation of Existing Ground Motion Simulation Methods

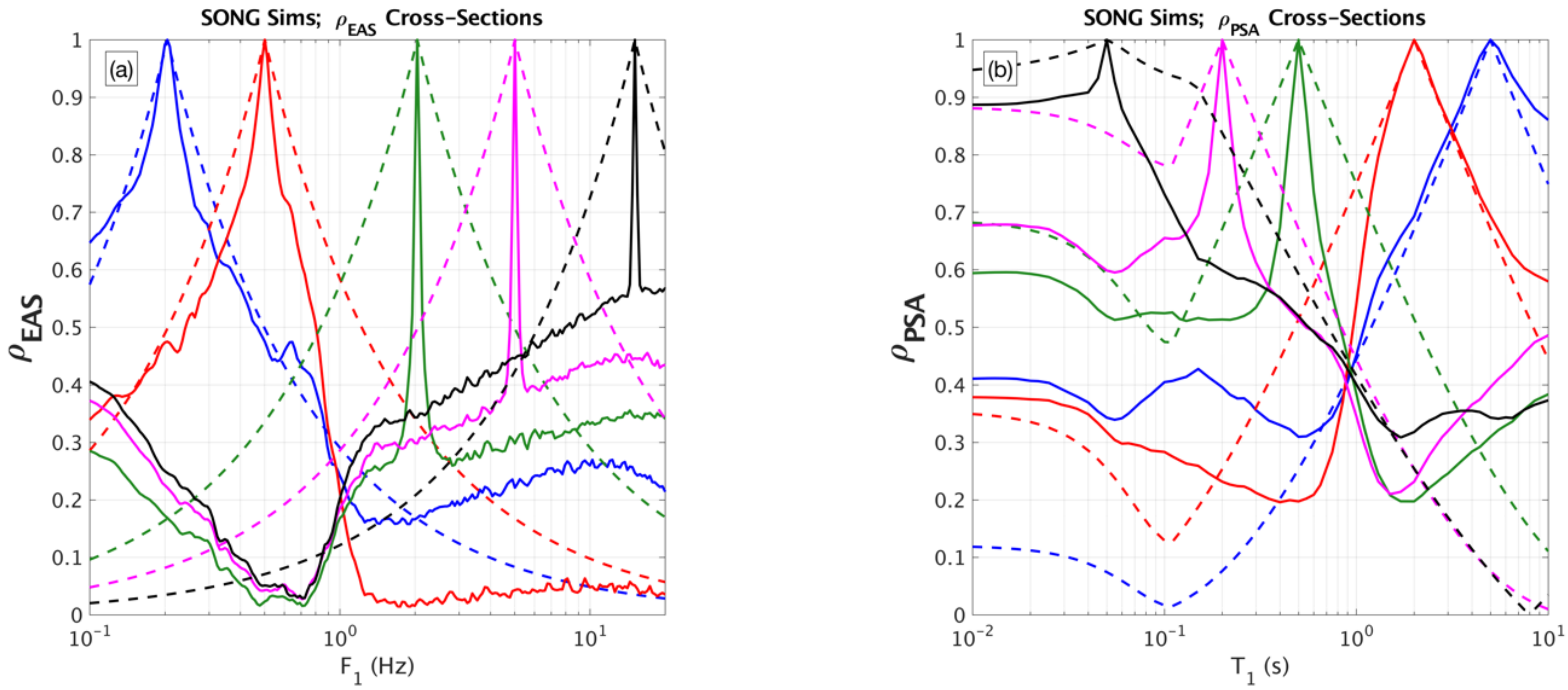


Dashed: empirical FAS correlation model



Dashed: empirical PSA correlation model

2) Evaluation of Existing Ground Motion Simulation Methods



Dashed: empirical FAS correlation model

Dashed: empirical PSA correlation model

2) Evaluation of Existing Ground Motion Simulation Methods

Conclusions regarding correlation in simulations:

- None of the finite-fault simulation methods tested capture the total inter-period correlations over the entire frequency range evaluated, although several of the methods show promise at low frequencies.
  - By using a 1d velocity model, the BBP correlations are unable to capture the between-site component, which strongly contributes to the total correlation

Implementation:

- Stochastic part: should be straight-forward (shown next)
- Deterministic part: more difficult – likely requires modifying the rupture generator or the wave propagation
  - changes to the rupture generator may be the most promising approach to modifying the long period inter-period correlations.

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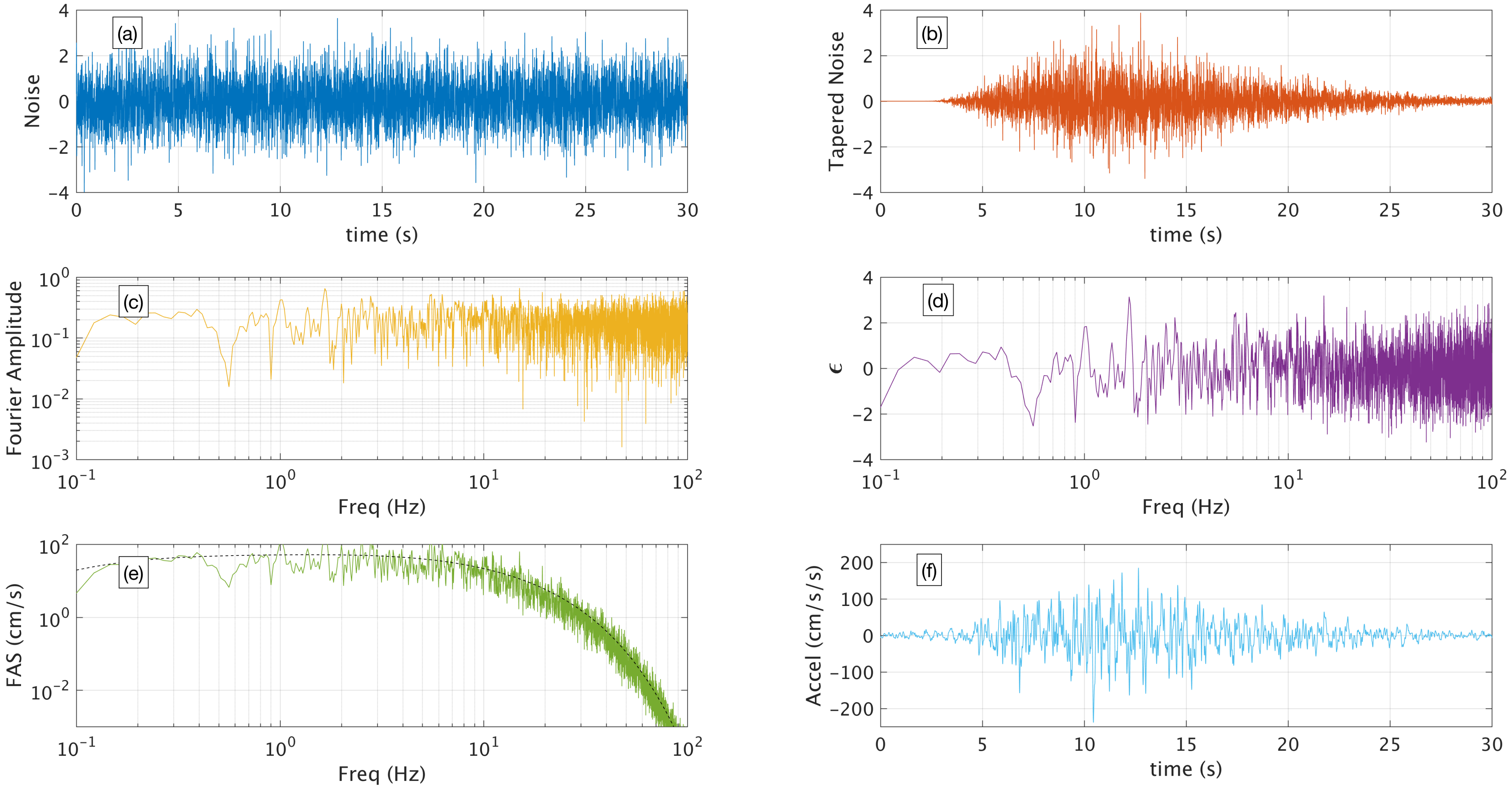
3) Correlation of ϵ: Incorporation into SMSIM

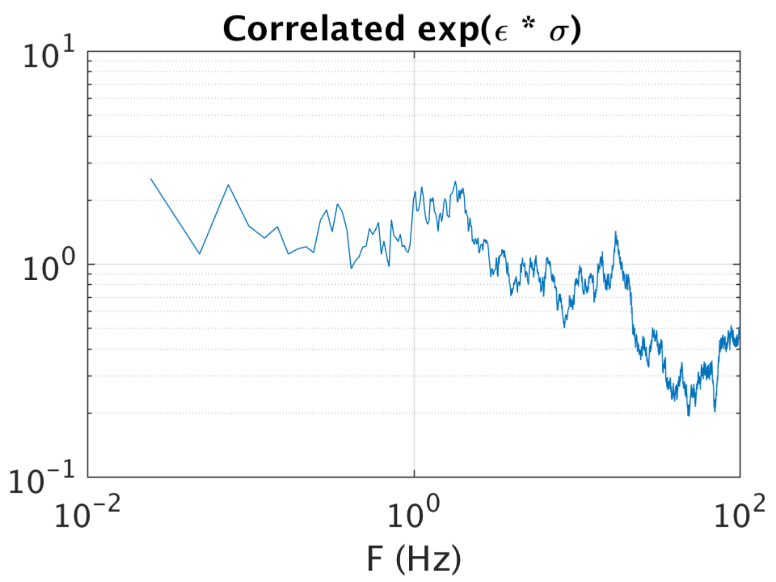
SMSIM (Boore, 2003)

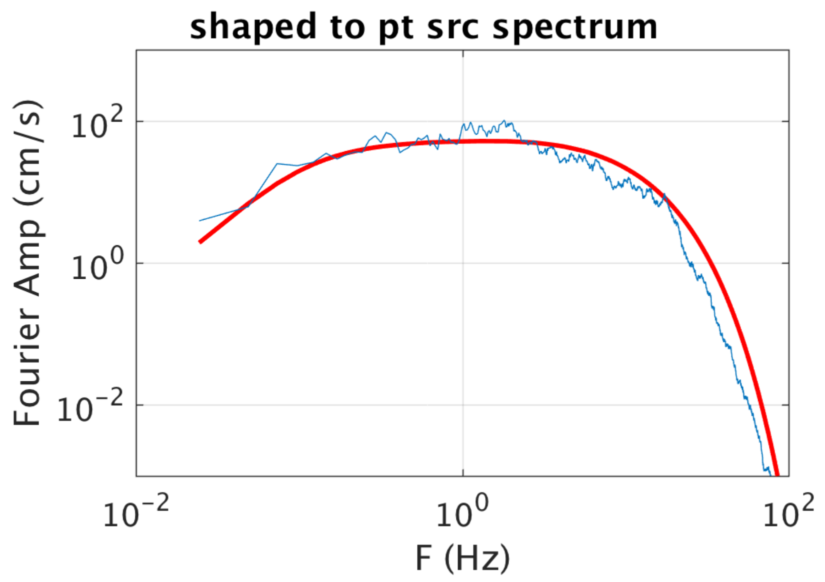


3) Correlation of ϵ: Incorporation into SMSIM

Steps to incorporate correlated ϵ into SMSIM:

- Generate zero-mean correlated random variables using a total correlation model for FAS (e.g. Bayless and Abrahamson, 2018 in prep)
- scale the ϵ by the desired standard deviation
- Insert the correlated ϵ into step d of the SMSIM procedure and proceed as usual (shape to spectrum then inverse transform)





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4) Structural Fragility Example

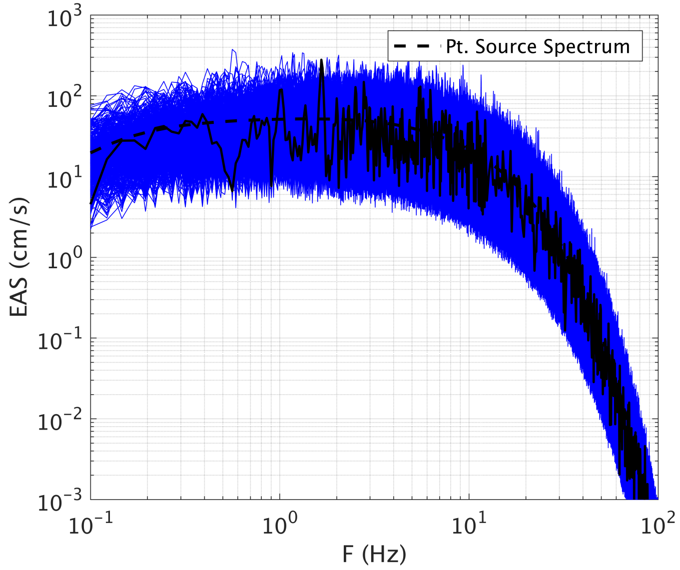
We develop example structural fragilities using an IDA with two sets of ground motions created using the correlated and uncorrelated versions of SMSIM

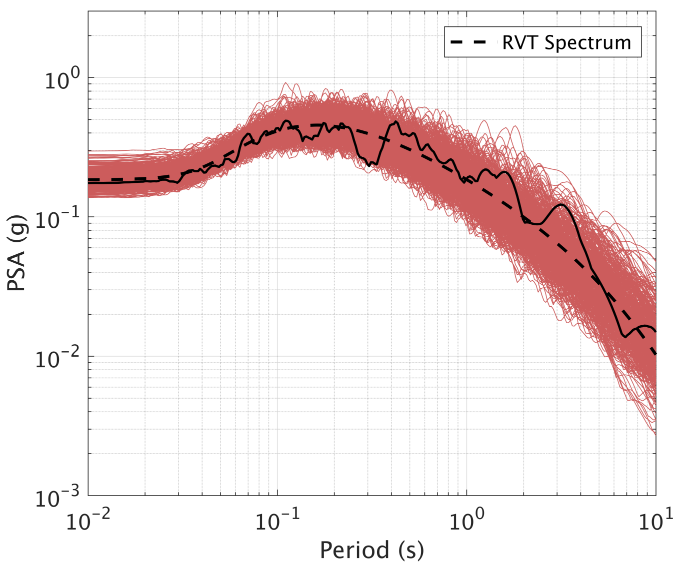
Procedure:

1. Suites of 500 uncorrelated and correlated ground motions with the same median spectra
2. Perform incremental dynamic analysis (IDA) to get structural fragility functions: the probability of a structural consequence (EDP) as a function of the ground motion intensity
   - Structural models and dynamic nonlinear structural analyses using OpenSees (McKenna et al., 2010)
3. Combine structural fragilities with seismic hazard to calculate the EDP hazard
4. Compare results between suites of ground motions

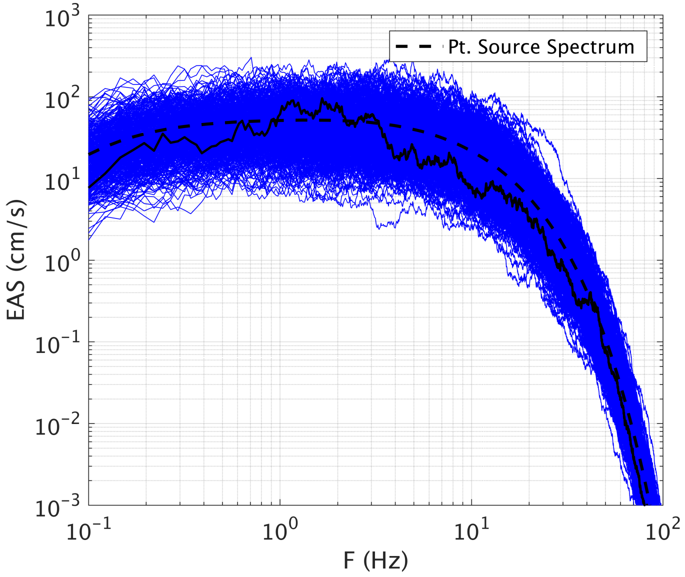
4) Structural Fragility Example

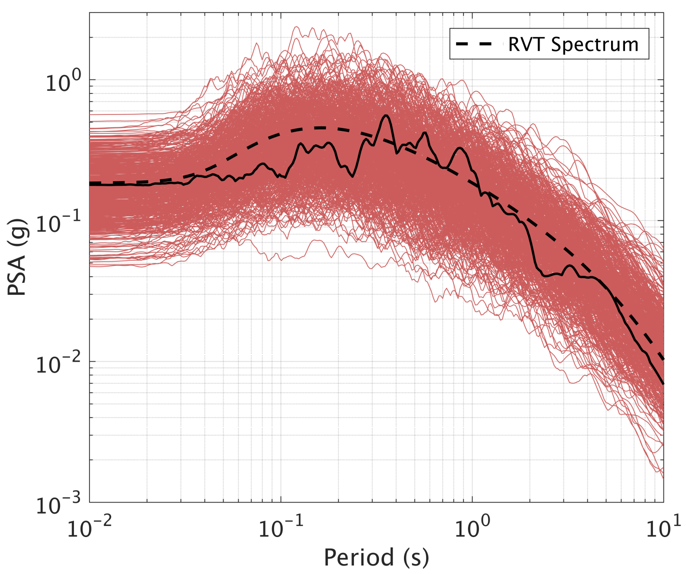
Uncorrelated
(standard SMSIM)





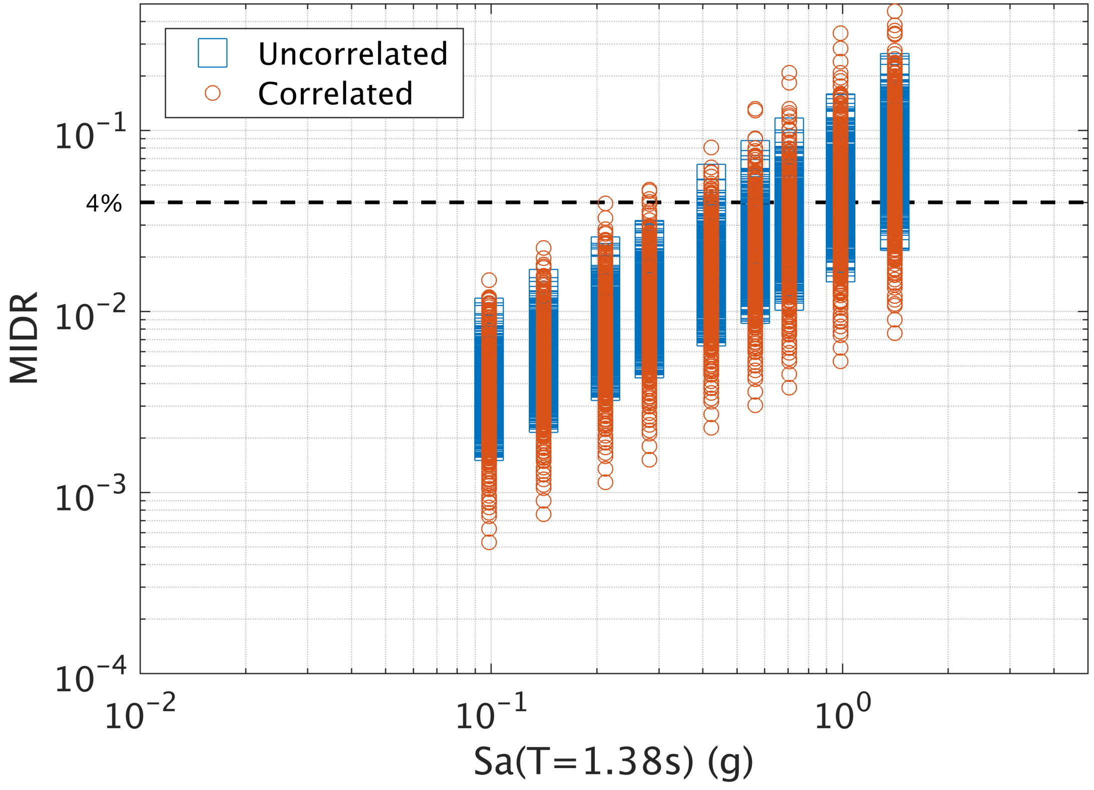
SMSIM with correlation



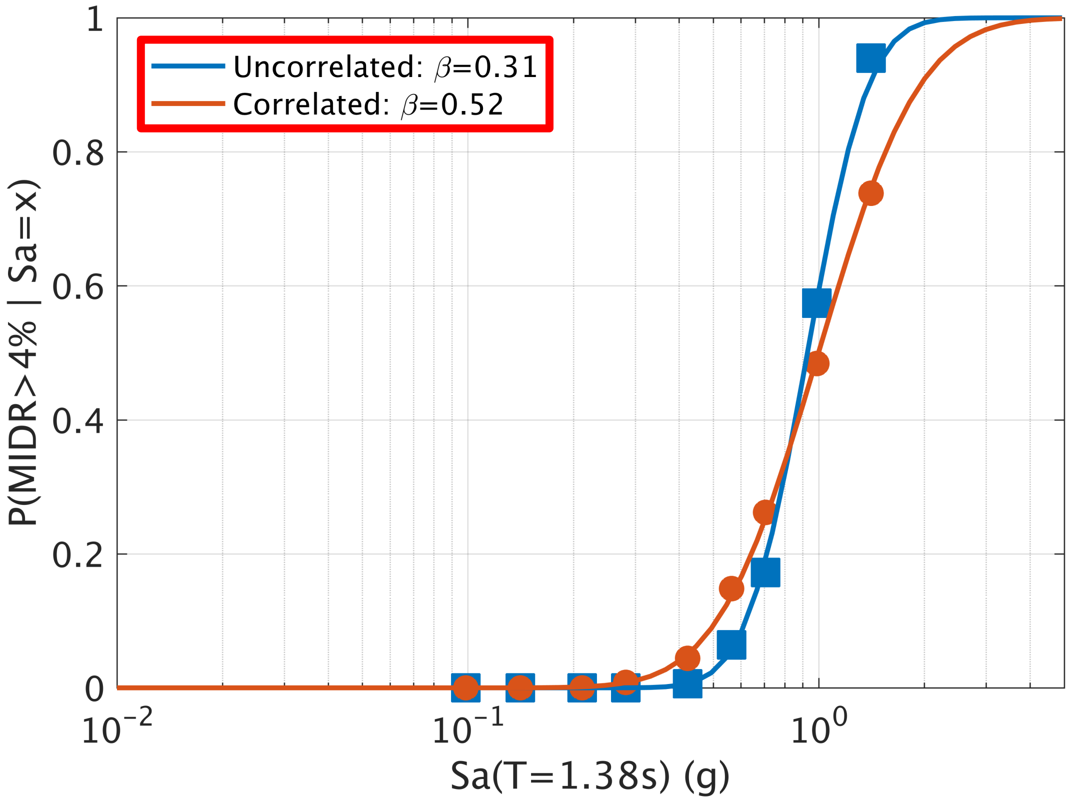


4) Structural Fragility Example

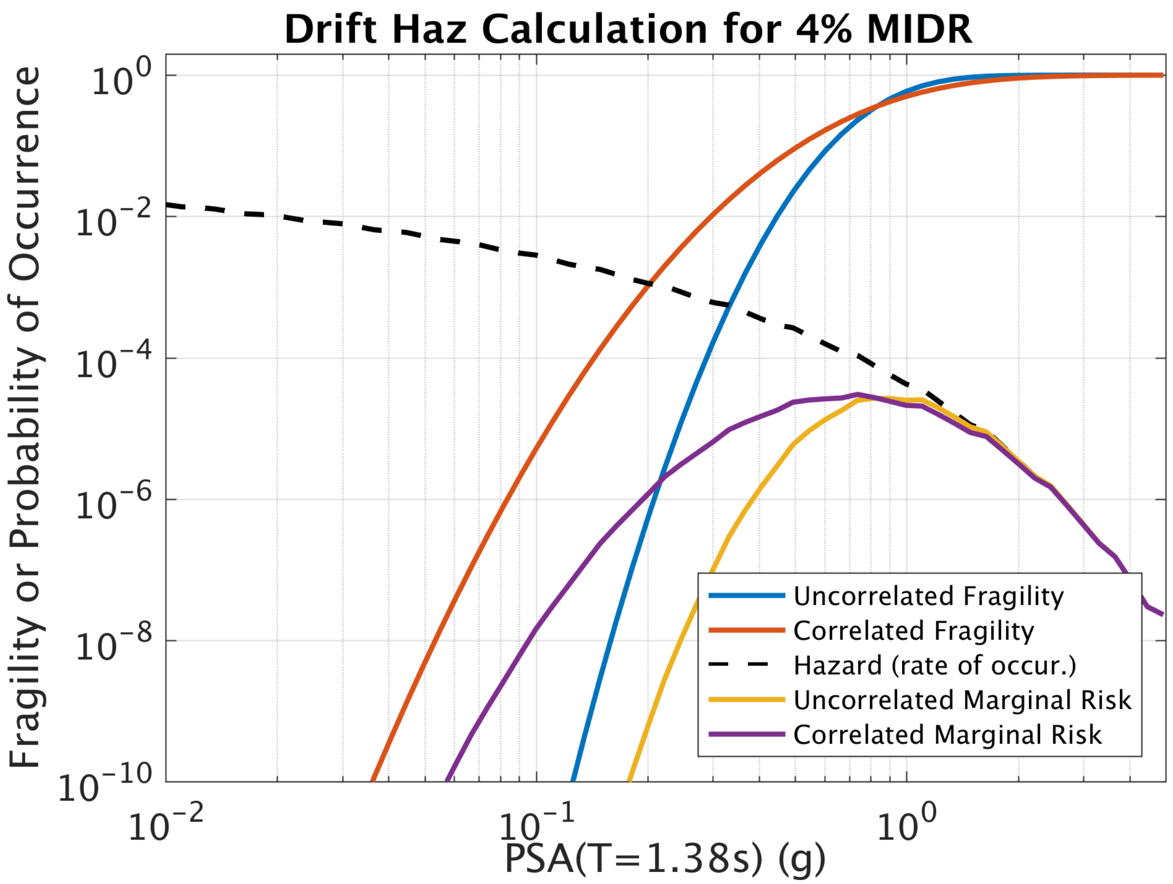
Structural analysis results for both sets

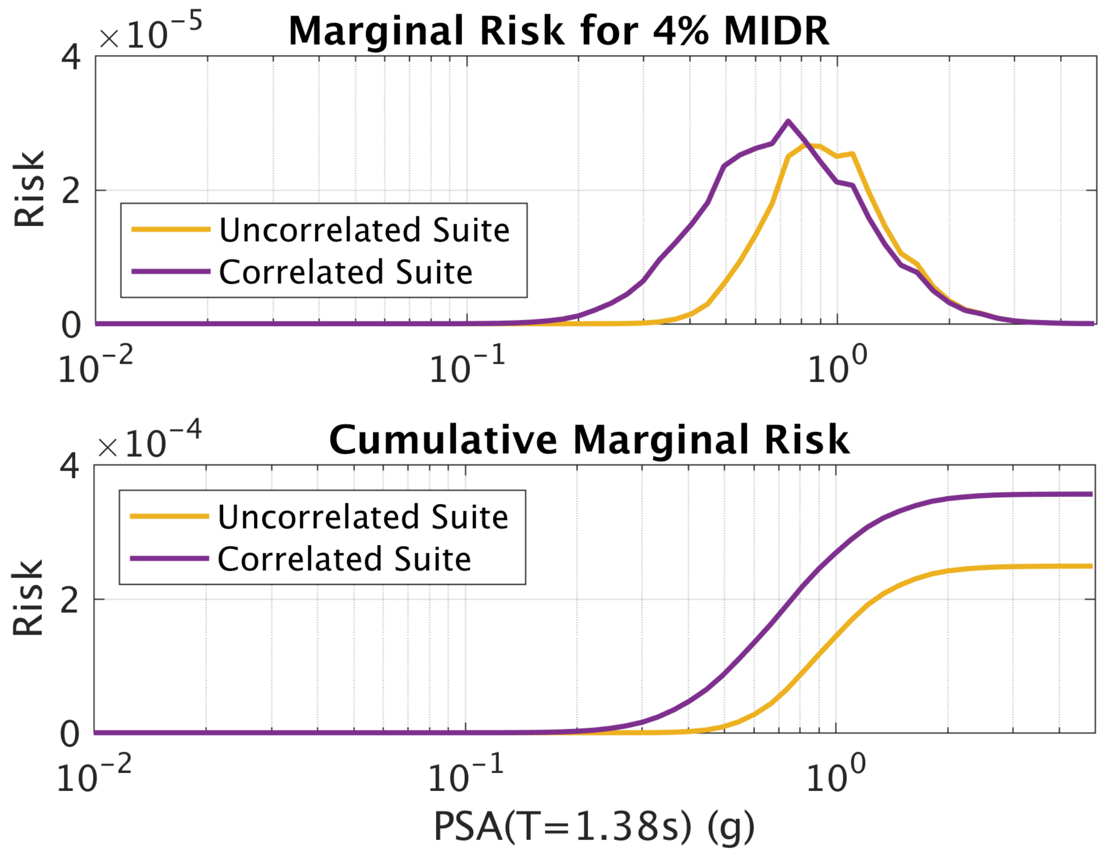


MIDR>4% probabilities (symbols)
CDF fragility functions (lines)



4) Structural Fragility Example





In this example, a 43% increase in structural risk using the correlated version of SMSIM

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5) Conclusions

- Without the adequate inter-period correlation in simulated ground motions, **variability in the structural response may be under-estimated**.

- This leads to **structural fragilities which are too steep** (under-estimated dispersion parameter β) and propagates through to non-conservative estimates of seismic risk.

Simulations:

- Using the correlation of the FAS provides the developers of the simulation methods better feedback in terms of how they can modify their methods that is not clear when using PSA comparisons.

- None of the six finite-fault simulation methods tested adequately capture the inter-period correlations over the entire frequency range evaluated, although several of the methods show promise at low frequencies.

- Changes to the rupture generator may be the most promising approach to modifying the long period inter-period correlations, if needed

Thank you!

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