Guiding Ground-motion Selection for Infrastructure Assessment Using Suites of Region-Specific Earthquake Simulations

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Relevance of Ground-Motion Simulations to Earthquake Engineering Applications

Inform and Support PBEE

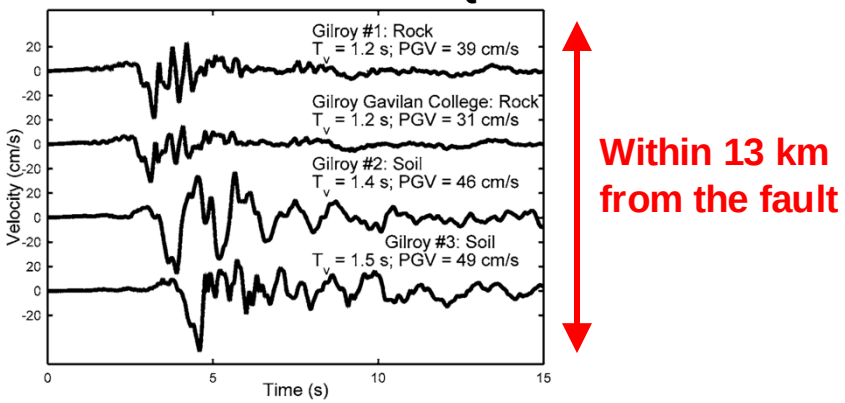
Seismic Hazard

- ❑ Constrain empirical models for scenarios lacking data based on several simulations from a wide range of seismic sources to obtain target spectra

Structural Fragility

- ❑ Map the variability of seismic demand in the near field where empirical data are limited, and **ground motions are shaped by the rupture details** and coupling with the local site conditions
- ❑ Inform the selection of ground motions to obtain realistic **infrastructure response distributions**
- ❑ Enable true site-specific seismic design and assessment procedures for a broad range of infrastructure

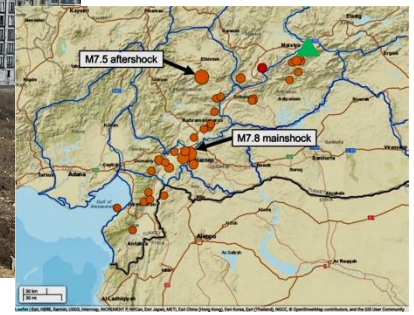
1989 LOMA PRIETA EARTHQUAKE



Source: Rodriguez-Marek and Bray, 2006

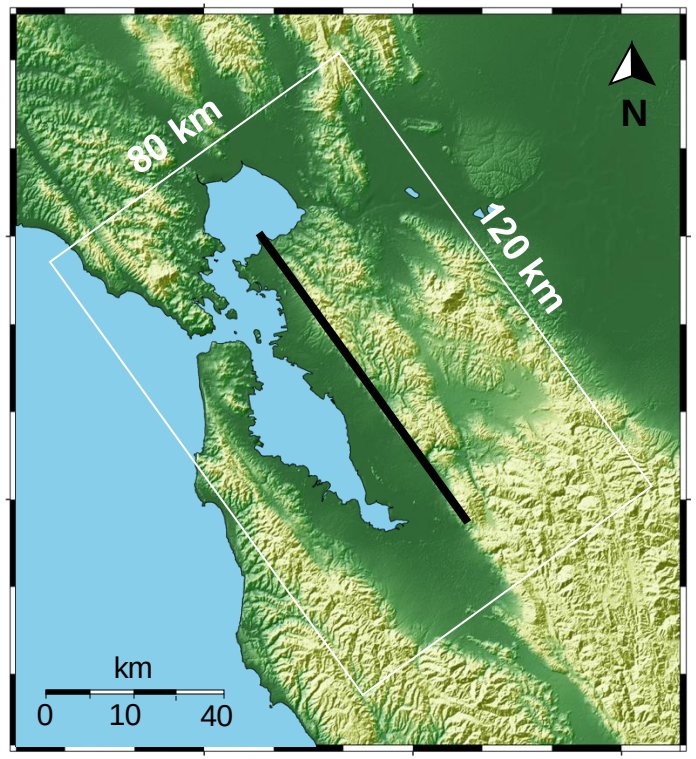
Feb 6, 2023, TURKEY-SYRIA EARTHQUAKES

Source: EERI Earthquakes Reconnaissance, 2023



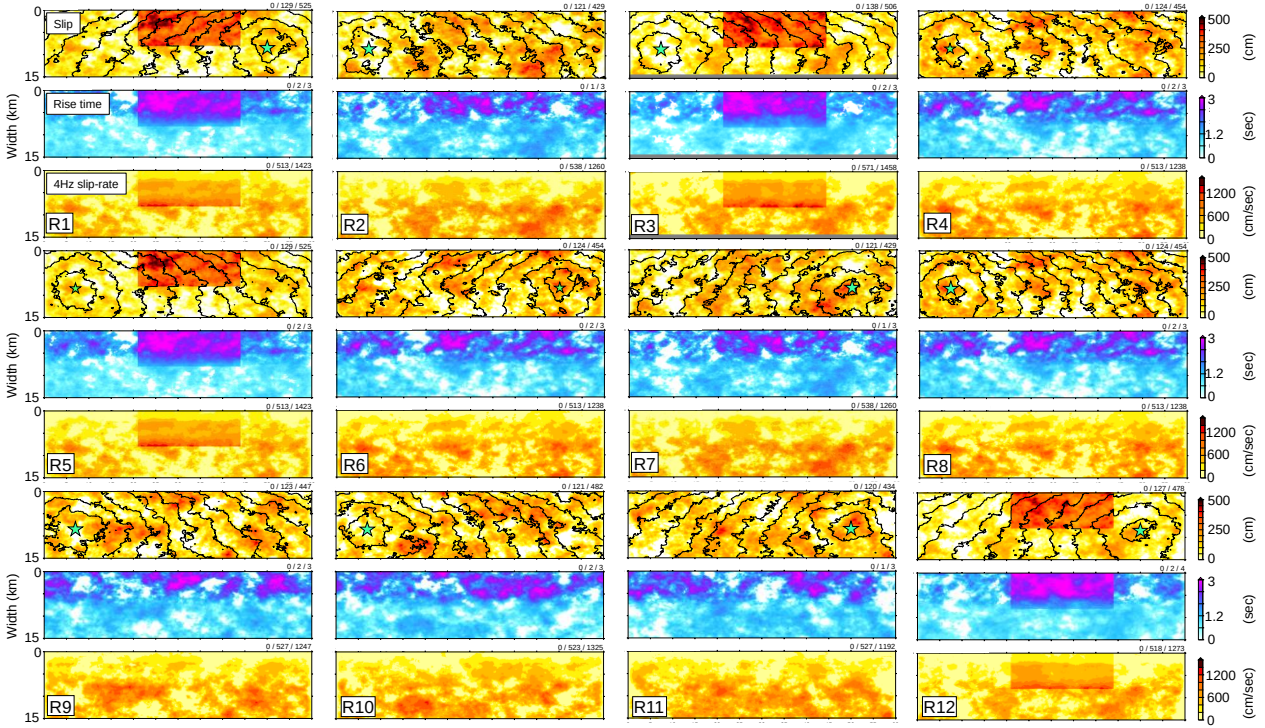
Suites of Region-Specific Earthquake Simulations

The data from such simulations are invaluable for the earthquake research community and engineers seeking to **build and retrofit earthquake-resilient homes and infrastructure**.



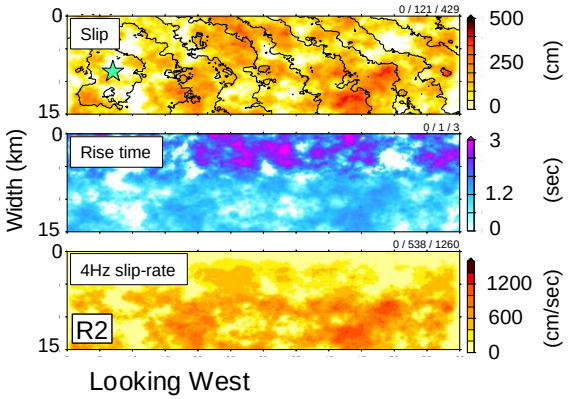
- ❑ assess the expected demand (**amplitude and variability**) on a site-specific basis and for target hazard levels
- ❑ understand the underlying causes for the observed GM intensities **to inform the next-generation of design methodologies**

Excerpt from a preliminary set of 25 realizations (M7 HF)

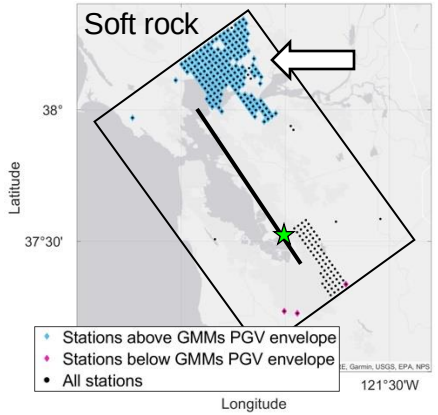


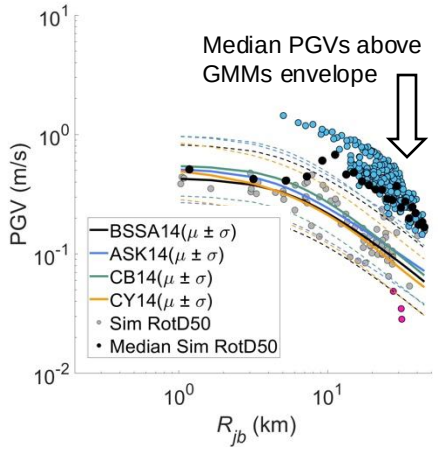
Graves and Pitarka (2016)

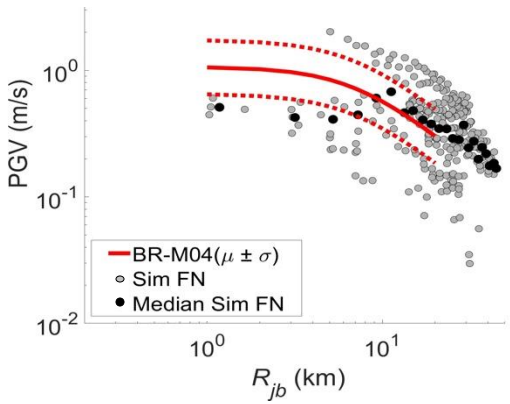
Strong Motions for Critical Infrastructure Analysis

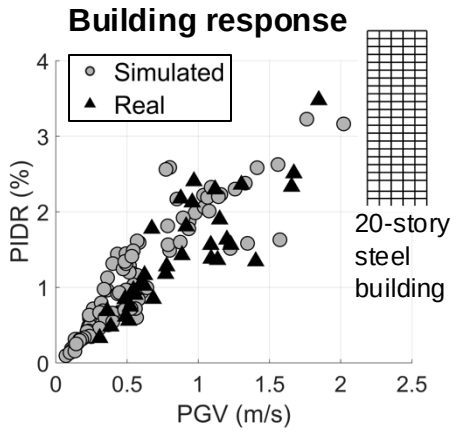


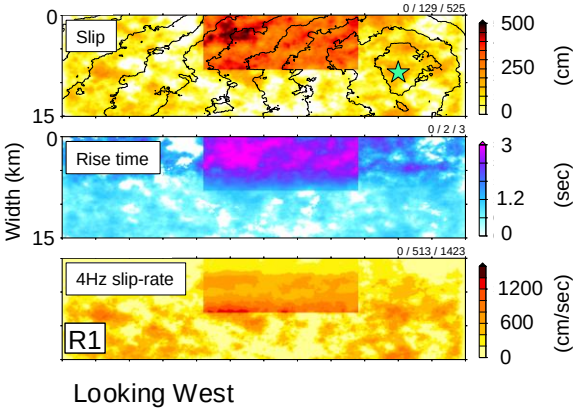
Forward directivity



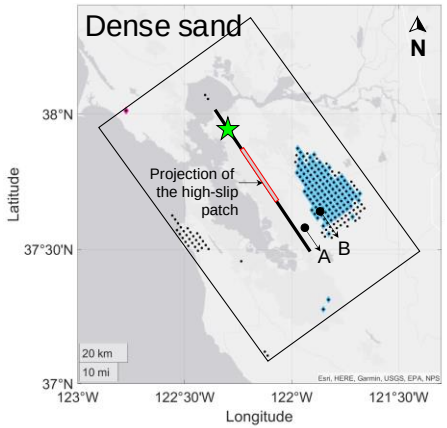


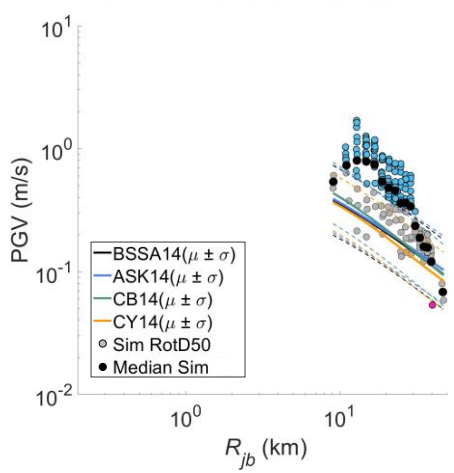


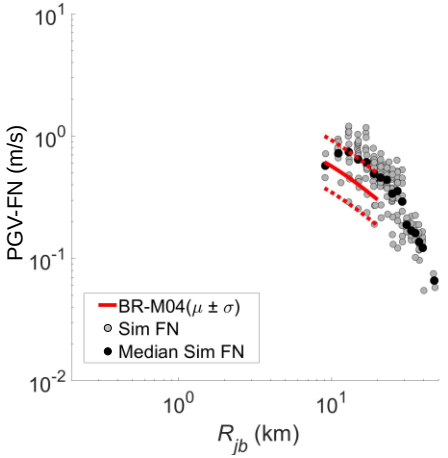


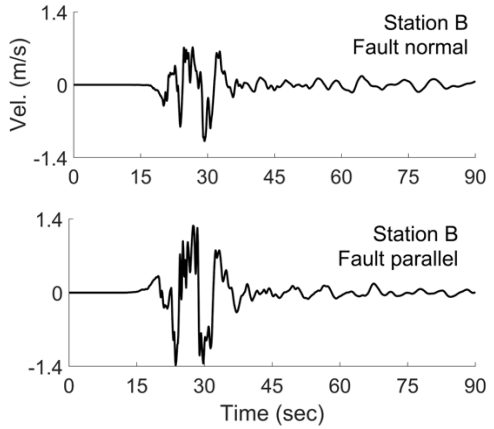


Forward directivity + high-slip patches + local geological conditions





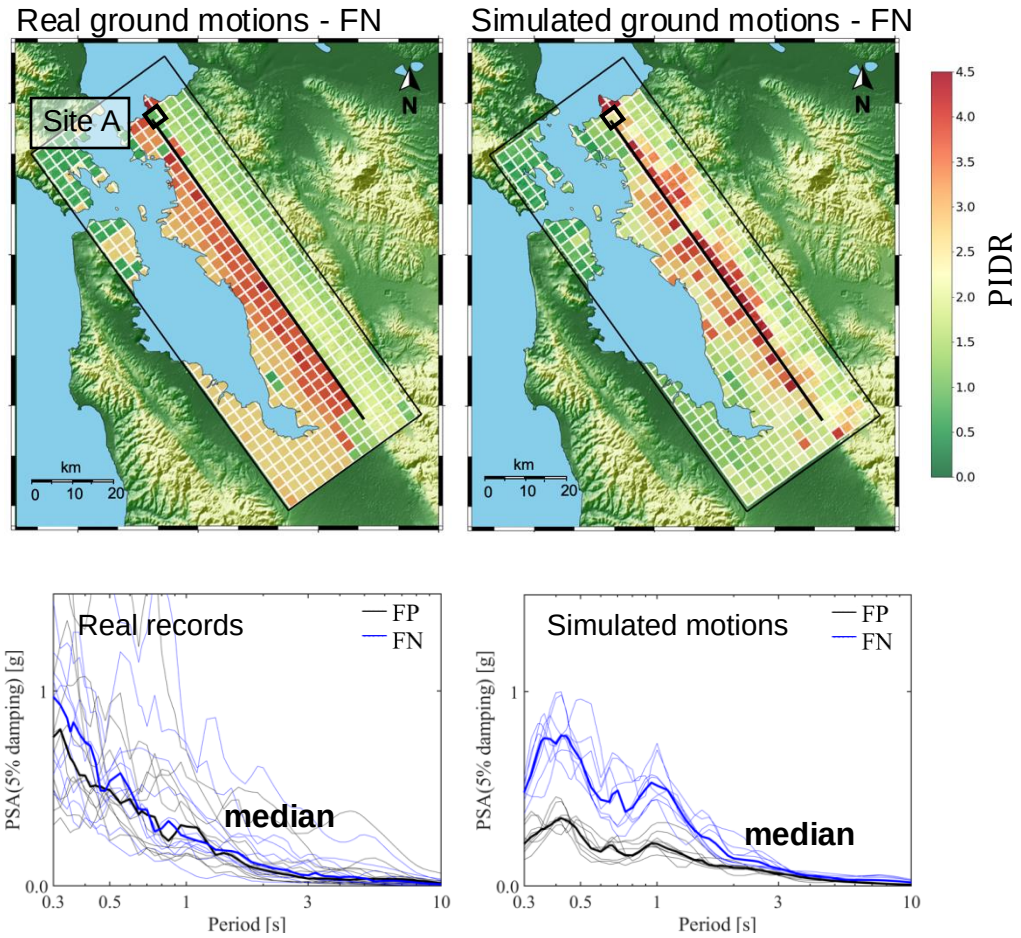


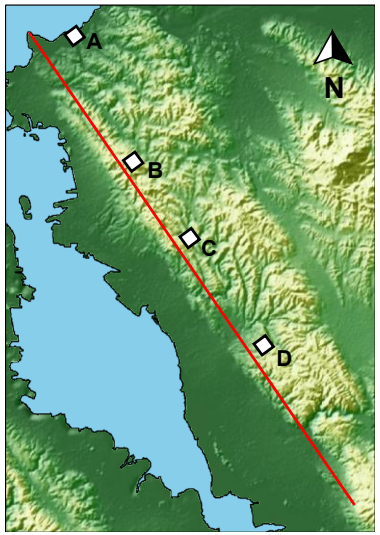


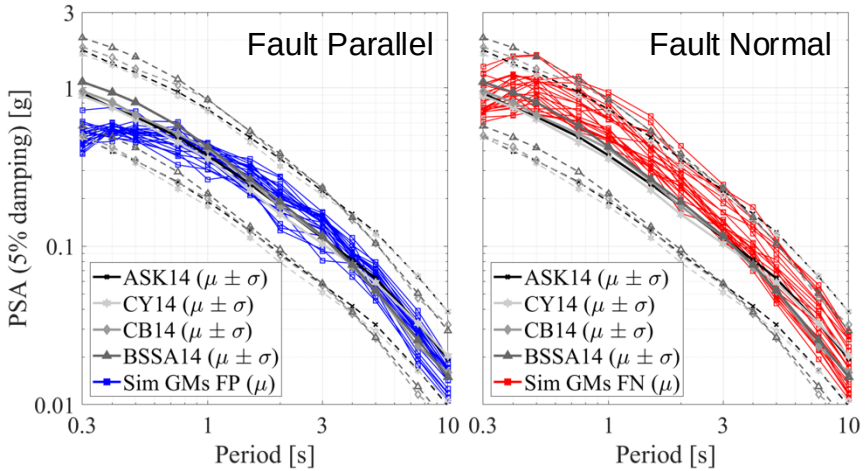
Petrone F., Taslimi A., Mohammadi Nia M., McCallen D., Pitarka A. 2024. Ground Motions Site and Event Specificity: Insights from Assessing a Suite of Simulated Ground Motions in The San Francisco Bay Area. *Earthquake Spectra*. 40(4)

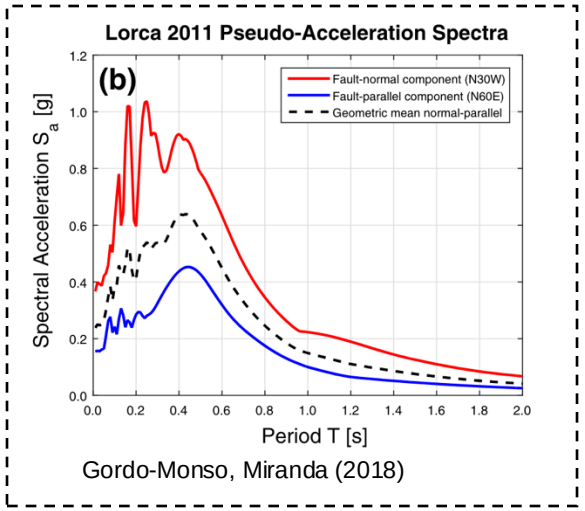
Ground-Motion Polarization at Near-Field Sites

Understand how these characteristics can affect structural responses when following code compliant approaches – ASCE 7 - RotD100 amplitude scaling (3-story RC building).









Can we leverage suites of simulated ground motions to inform the selection of records that **target site-specific amplitude and variability in each component?**

Matinrad, P., & Petrone, F. (2023). "ASCE/SEI 7-compliant site-specific evaluation of the seismic demand posed to reinforced concrete buildings with real and simulated ground motions." *Earthquake Engineering and Structural Dynamics*. https://doi.org/10.1002/eqe.3995

Selecting Ground Motions for Component-Specific Target Spectral Amplitude and Variability: **Proposed Methodology**

Determine the **site-specific target spectrum** for the location and hazard level of interest for the RotD50

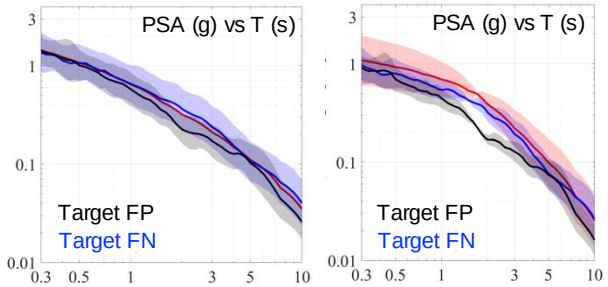
Compute the **component variability ratio** (CVR) based on the simulated GMs

$$CVR_{i,k}^{j} = \frac{Sa_{i,k}^{j,sim}}{Sa_{i,k}^{RotD50,sim}}$$ (Zengin and Abrahamson, 2021)

Derive **median and standard deviation** of the component specific target spectrum **based on the set of simulated motions**

$$Sa_{i,k}^{j,sim,T} = CVR_{i,k}^{j} \times Sa_{k}^{D}$$

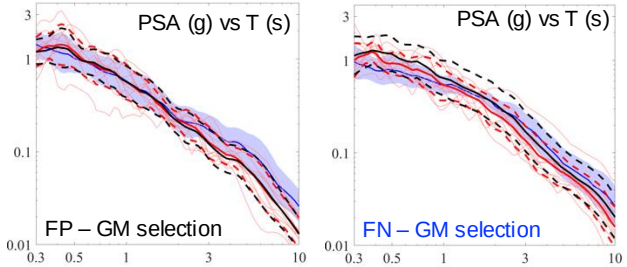
$$\sigma_{Sa^{j,T},k} = stdev\left[\ln\left(Sa_{i,k}^{j,sim}\right)\right]$$



$$CMS_{i,k}^{j,sim,T} = \exp\left(\ln(Sa_{GMM}) * CVR_{i,k}^{j} + \epsilon \cdot \rho \cdot \sigma_{k}^{j,sim}\right)$$

$$\sigma_{CMS^{j,T},k} = \sigma_{k}^{j,sim}\sqrt{1-\rho^2}$$

Randomly select *m* sets of simulated ground motions; compute the **resultant normalized error** (RNE). Sort the ground motion sets based on min(RNE).

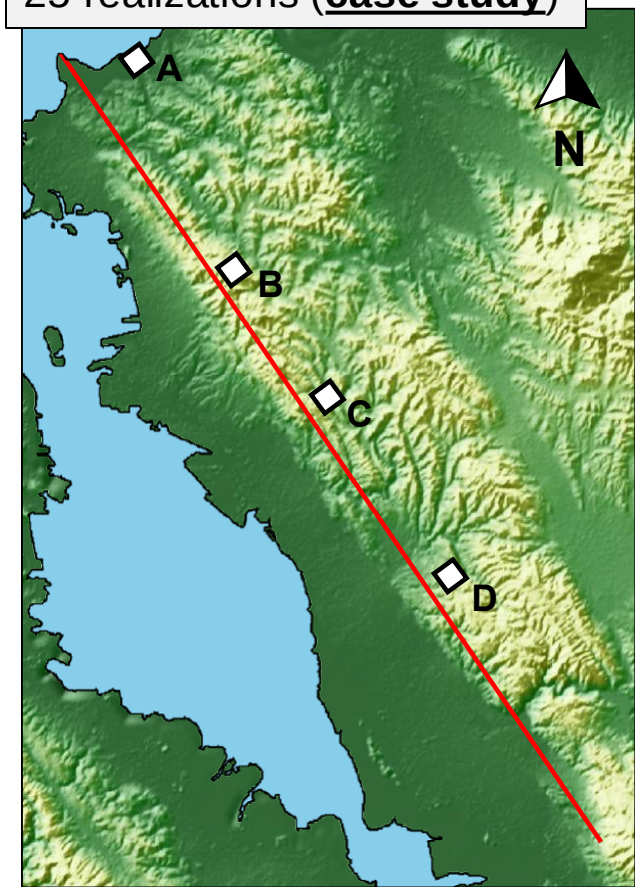


$$NE_{q}^{j} = \sum_{k=1}^{p}\left[\left(\frac{m_{q,k}{}^{j} - \mu_{Sa^{j,T},k}}{\mu_{Sa^{j,T},k}}\right)^2 + \left(\frac{s_{q,k}{}^{j} - \sigma_{k}{}^{j}}{\sigma_{Sa^{j,T},k}}\right)^2\right]; RNE_{q} = \sqrt{\left(NE_{q}^{j=1}\right)^2 + \left(NE_{q}^{j=2}\right)^2}$$

Matinrad, P., & Petrone, F. “Selection of Simulated Ground Motions for Component-Specific Target Spectral Amplitude and Variability”.

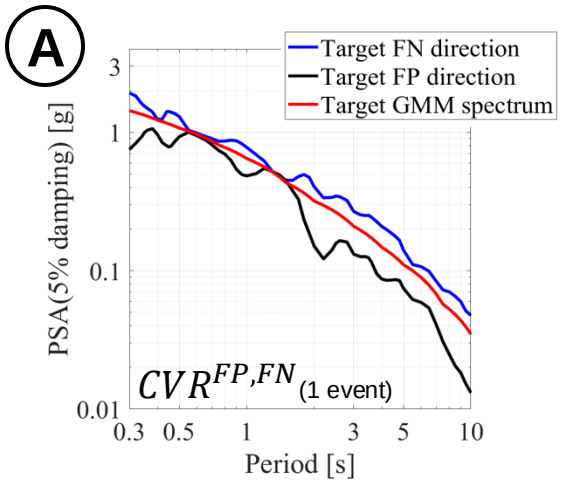
Demonstration 1: 10-story 3D RC Building

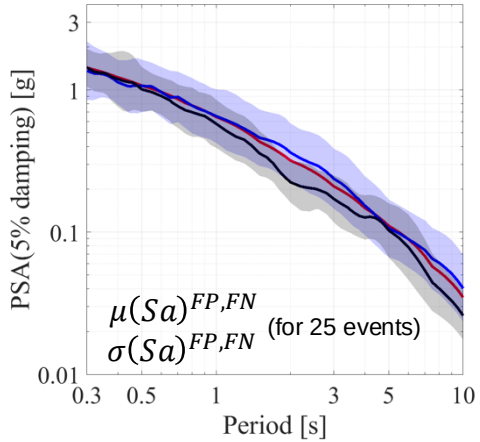
25 realizations (**case study**)

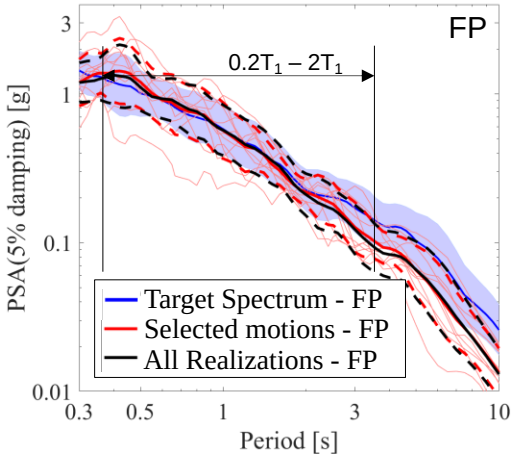


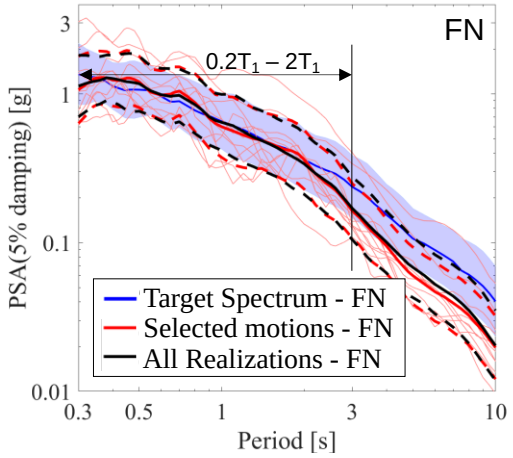
Hazard disaggregation (USGS 2018):

- HF - M7.19





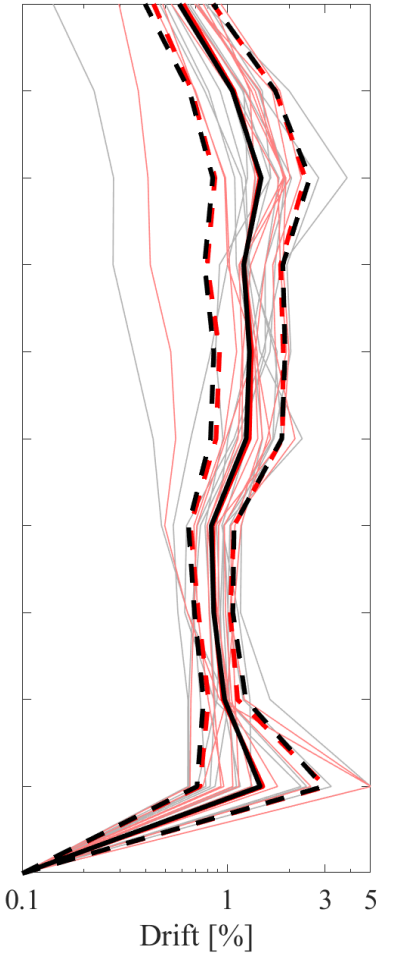




$$\mu\left(Sa_{i,k}^{j,sim,T}\right) = \mu_{Sa^{j,T},k} = \exp\left(\frac{\sum_{i=1}^{n} \ln\left(Sa_{i,k}^{j,sim,T}\right)}{n}\right)$$

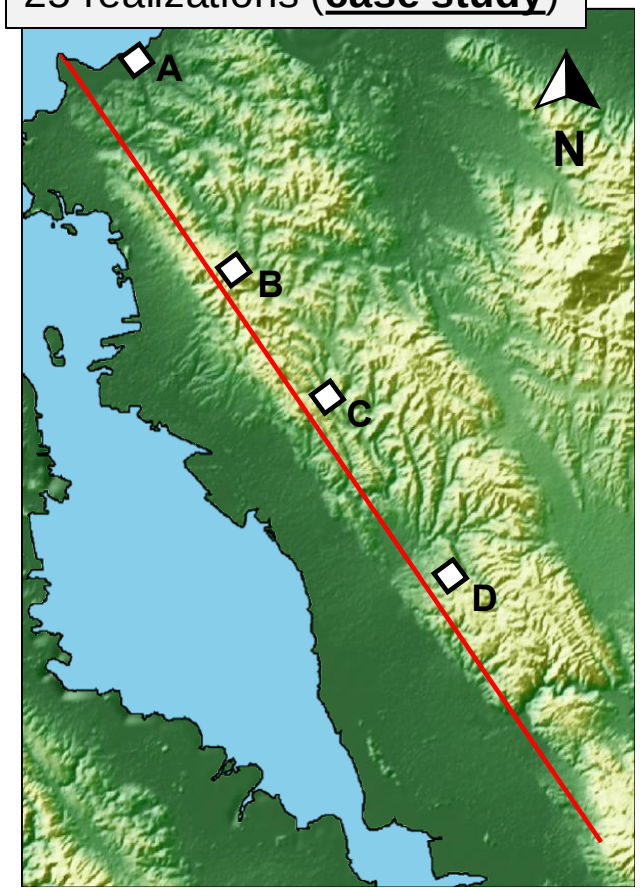
$$\sigma_{Sa^{j,T},k} = stdev\left[\ln\left(Sa_{i,k}^{j,sim}\right)\right]$$

Building response



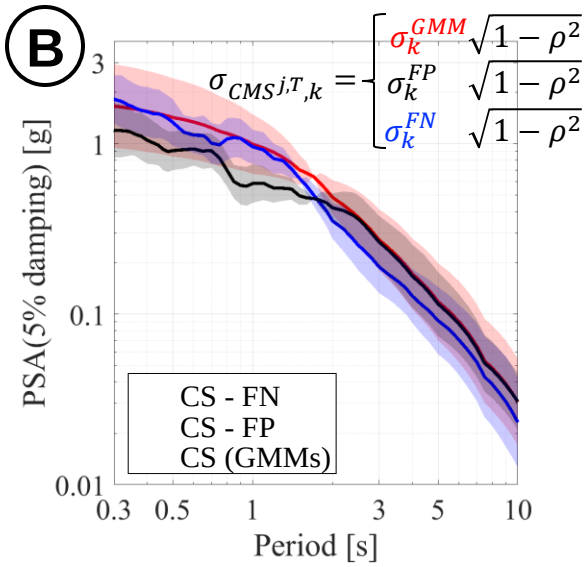
Demonstration 2: 10-story 3D RC Building

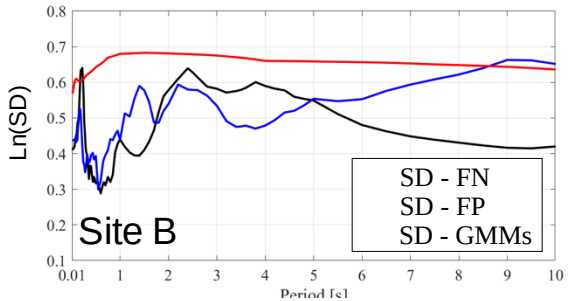
25 realizations (**case study**)

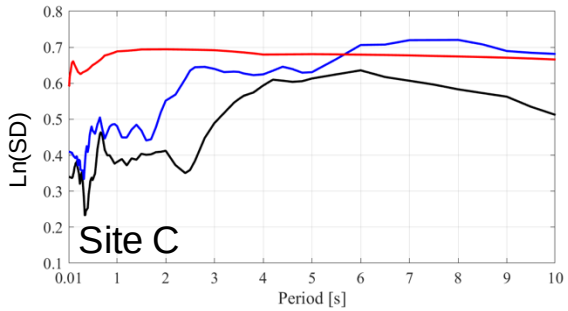


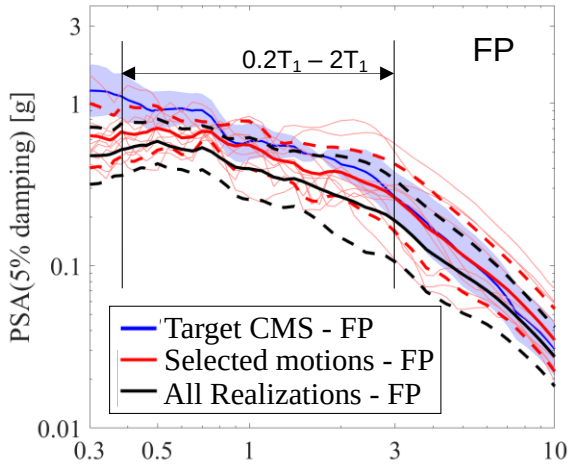
Hazard disaggregation (USGS 2018):

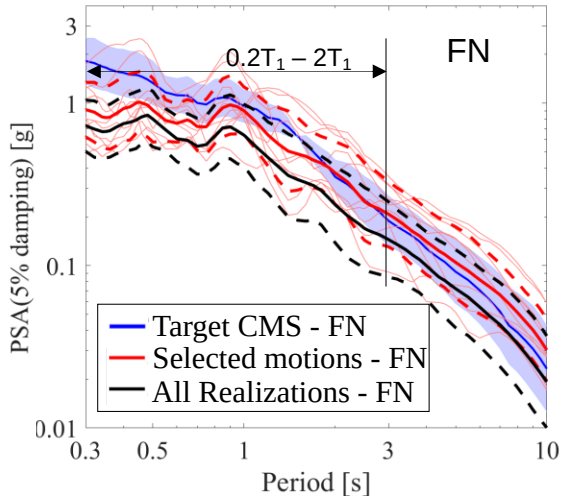
- ❑ HF - M7.17



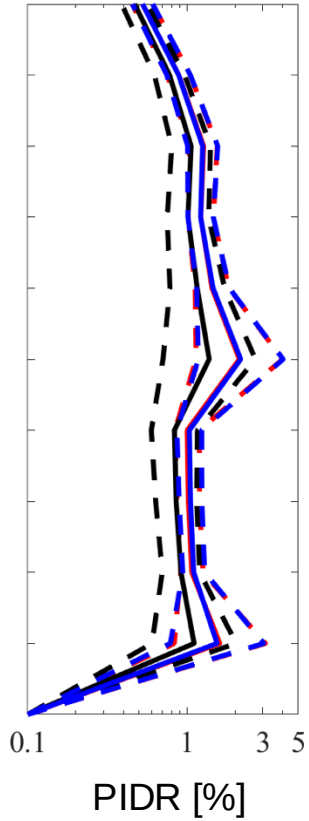








Building response - B



- Deterministic (median +/-1SD)
- CMS (median +/-1SD)
- All Realizations (median +/-1SD)

Concluding Remarks

- Physics-based simulations can inform the selection of scenarios - rupture details and initiation - that lead to low probability yet realistic strong motions for design and assessment of critical infrastructure.

- Suites of validated site-specific simulated motions provide invaluable data to update current ground-motion selection methods, allowing to target both median and variability for the separate ground-motion components.

- Future simulation efforts should 1. **be informed by hazard studies** in the region of interest to target the most relevant earthquake(s) to avoid amplitude scaling and matching and 2. **introduce uncorrelated rupture realizations**.