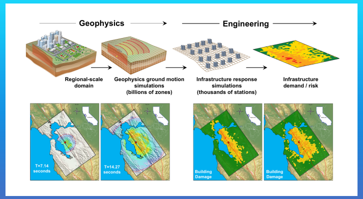

PEER International Pacific Rim Forum

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A 4-Step Methodology for the Validation of Not-Historical Large-Event Ground-Motion Simulations: the San Francisco Bay Area Case Study

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June 17, 2021

BERKELEY LAB

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Agenda

- Introduction
  - Relevance of simulated GMs to engineering domains
  - Historical vs not-historical events
- Proposed 4-step validation methodology and *acceptance criteria*
  - Rock-basin canonical domain
  - The San Francisco Bay Area region
    - Simulation-based site-specific analysis vs ASCE/SEI 7-16
- Concluding remarks

Relevance of simulated GMs to engineering domains

Inform and support PBEE

Understand what features relevant to the evaluation of the structural risk characterize near-field ground motions

Map the complex variability of structural risk in areas of high seismicity

Enable true site-specific evaluations of earthquake structural risk

Perform Nonlinear TH analyses

&

Evaluate seismic hazard based on a (very) large number of simulations from a range of seismic sources

Predict ground-motion amplitudes

Validation methodologies

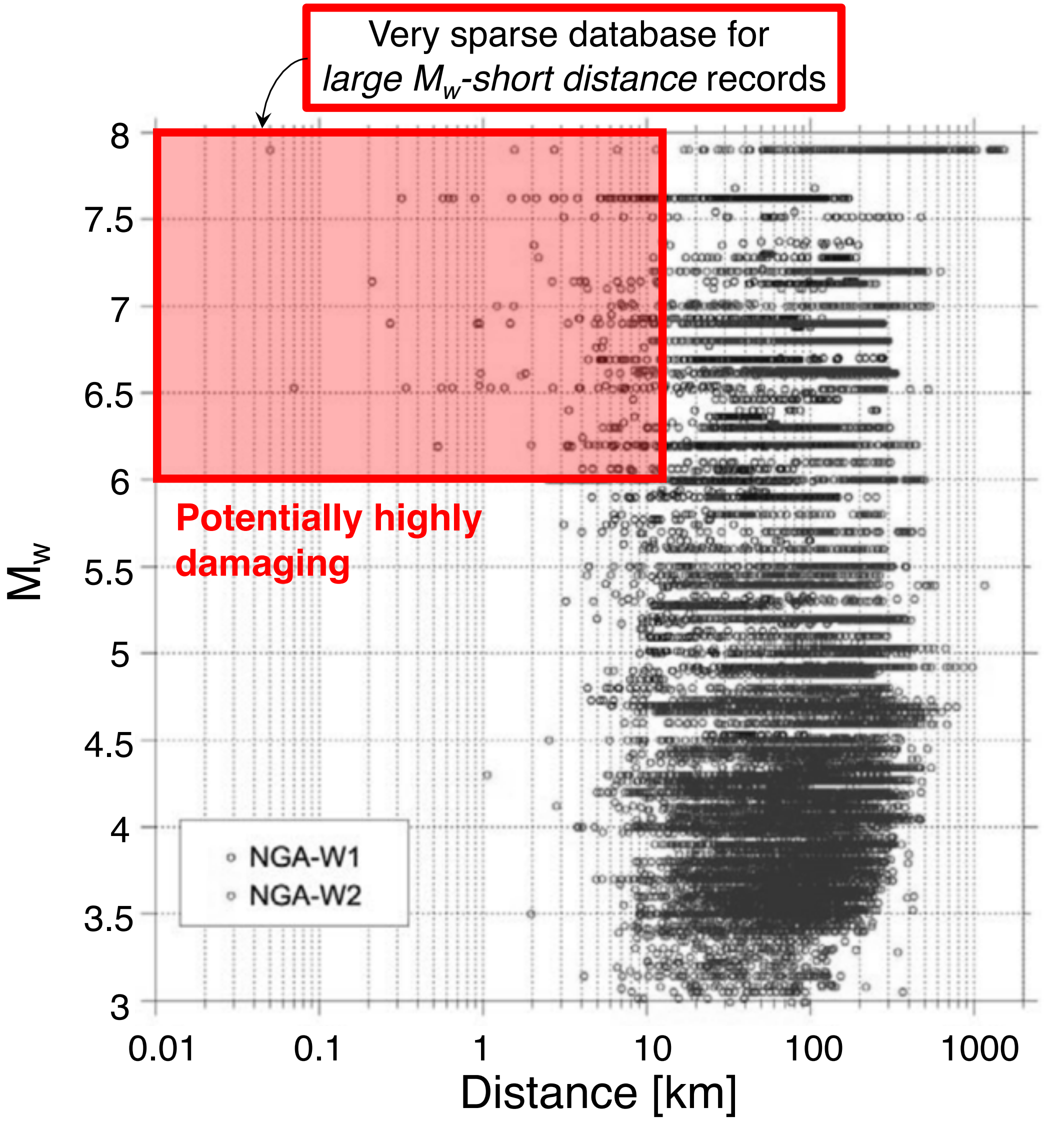
Historical events

- ❑ Station-by-station inspection
- ❑ Seismogram waveforms comparison
- ❑ Use of well-constrained GMMs

vs

Not-historical Events

- ❑ Records from consistent events are scarce/not available
- ❑ GMMs are not well constrained
- ❑ the expected GMs characteristics need to be inferred from the knowledge of geology/rupture



[Source: adapted from Ancheta et al. (2014)]

Proposed 4-step methodology

Four-step methodology and acceptance criteria

Step 1: Selection of a population of *real records* consistent with the simulated scenarios

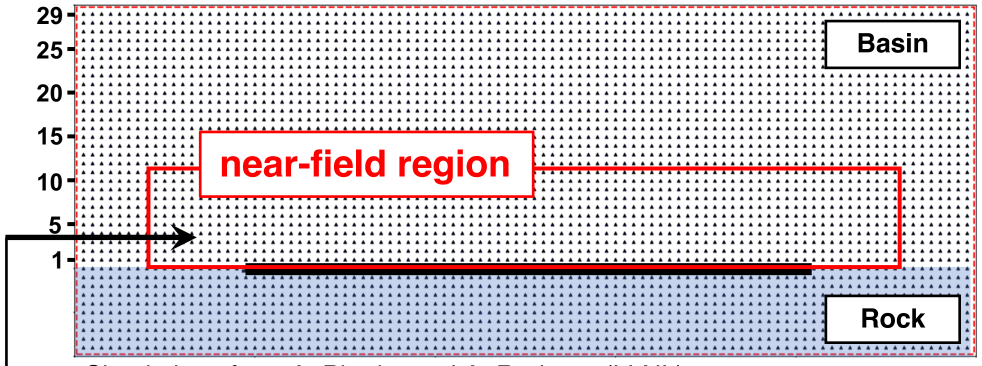
Step 2: Comparison of the *distribution of IMs* from the simulated records, real records, and GMPEs

Step 3: Comparison of the *distribution of simple proxies for building response*

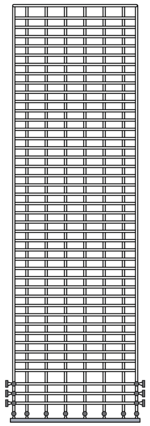
Step 4: Comparison of the *distribution of Engineering Demand Parameters (EDPs)* for a realistic model of a structure.

Application-oriented

Rock-basin computational domain



Simulations from A. Pitarka and A. Rodgers (LLNL)



- Three M_w 7 strike-slip earthquake events which differ for the characteristics of the rupture only (Pitarka et al., 2019)
- 40-km x 100-km
- Frequency resolution 5-Hz
- Average V_{s30} = 382-m/sec
- Flat topography

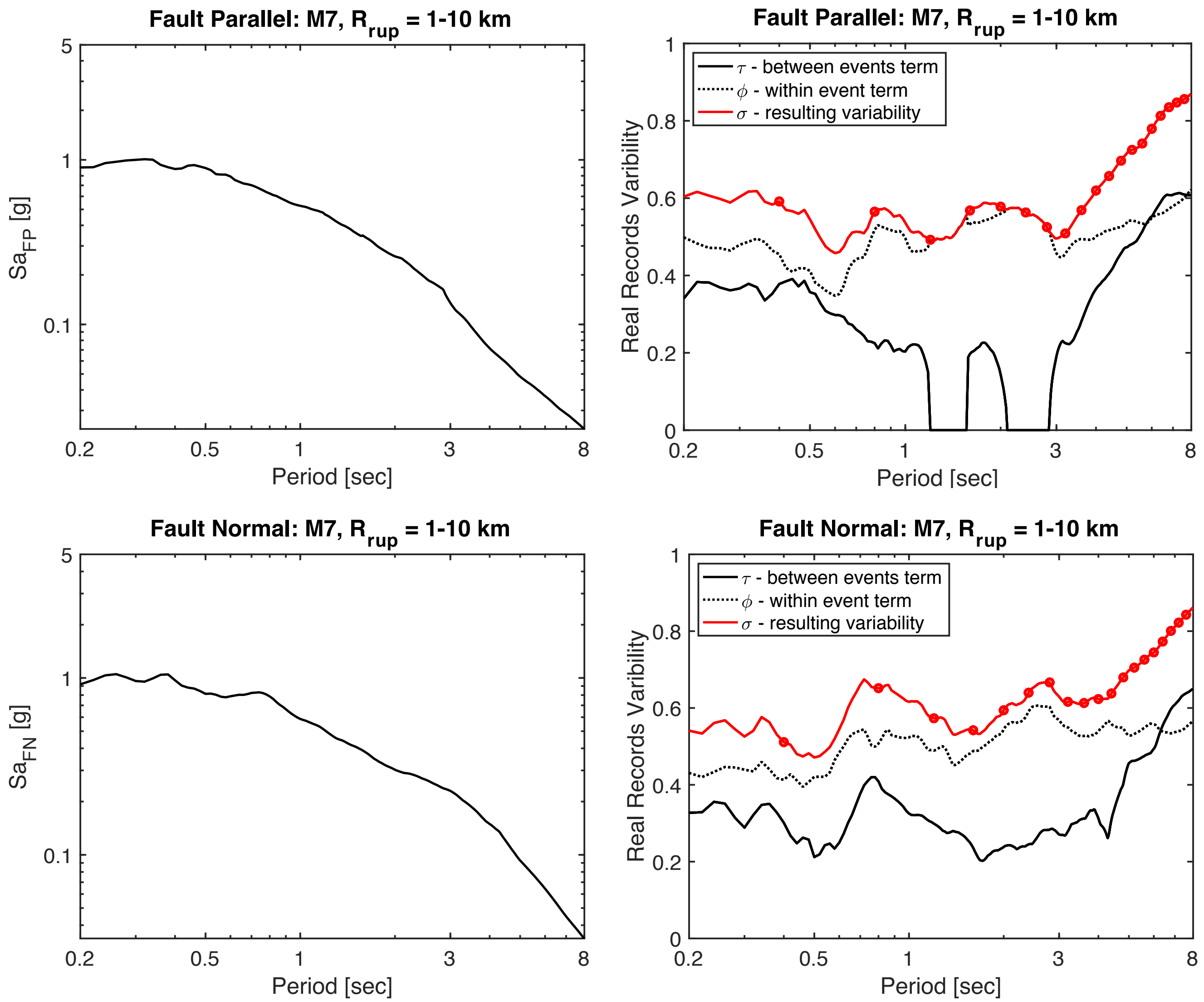
- 40-story Steel MRF (T_1 = 3.76-sec)
- 2,490 building runs for each component (FN and FP)

Petrone, F., Abrahamson, N., McCallen, D., Miah, M., (2020), Validation of (not-historical) large-event near-fault ground-motion simulations for use in civil engineering Applications, *Earthquake Engineering and Structural Dynamics*, 50(1), p. 116-134

Step 1 – Real records selection

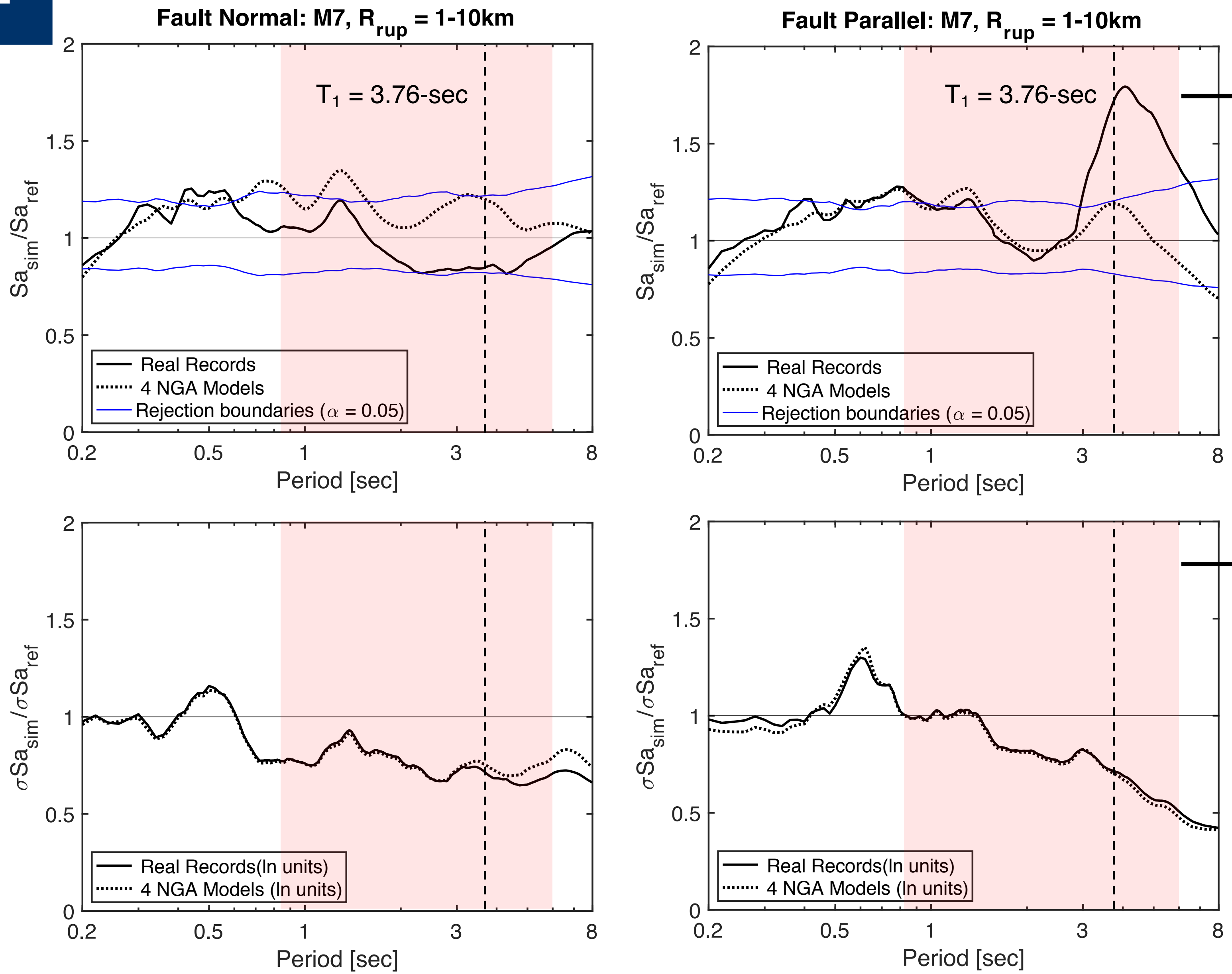
No.	Earthquake Name	Station Name	M_w	R_{rup} (km)	Vs30 (m/s)
1	Imperial Valley-06 (1979)	EC County Center FF	6.53	7.31	192.1
2		EC Meloland Overpass FF		0.07	186.2
3		El Centro Array #4		7.05	208.9
4		El Centro Array #5		3.95	205.6
5		El Centro Array #6		1.35	203.2
6		El Centro Array #7		0.56	210.5
7		El Centro Array #8		3.86	206.1
8		El Centro Differential Array		5.09	202.3
9*	Morgan Hill (1984)	Coyote Lake Dam (SW Abut)	6.19	0.53	597.1
10*	Loma Prieta (1989)	Gilroy - Gavilan Coll.	6.93	9.96	729.7
11		LGPC		3.88	477.7
12	Landers (1992)	Lucerne	7.28	2.19	684.9
13	Northridge-01 (1994)	Jensen Filter Plant	6.69	5.43	373.1
14		Jensen Filter Plant Generator		5.43	525.8
15		Newhall - Fire Sta		5.92	269.1
16		Newhall - W Pico Canyon Rd.		5.48	285.9
17		Rinaldi Receiving Sta		6.50	282.3
18		Sylmar - Converter Sta		5.35	251.2
19		Sylmar - Converter Sta East		5.19	370.5
20		Sylmar - Olive View Med FF		5.30	440.5
21	Kobe, Japan (1995)	KJMA	6.90	0.96	312.0
22		Takarazuka		0.27	312.0
…	…	…	…	…	…
38	Chi-Chi, Taiwan (1999)	WGK	7.62	9.96	258.9
		Median	7.07 (mean)	2.88	365.7
		StDev (ln units)	0.50 (linear)	1.16	0.42

- Total of 38 real records resolved in FN and FP component (*Baker and Shahi, 2011*)



- The variability resulting from the uneven sampling of earthquakes was evaluated with a linear mixed-effects model

Step 2 – Distribution of IMs for the two separate components



Overestimate of Sa amplitude with respect to real records

Acceptance criteria

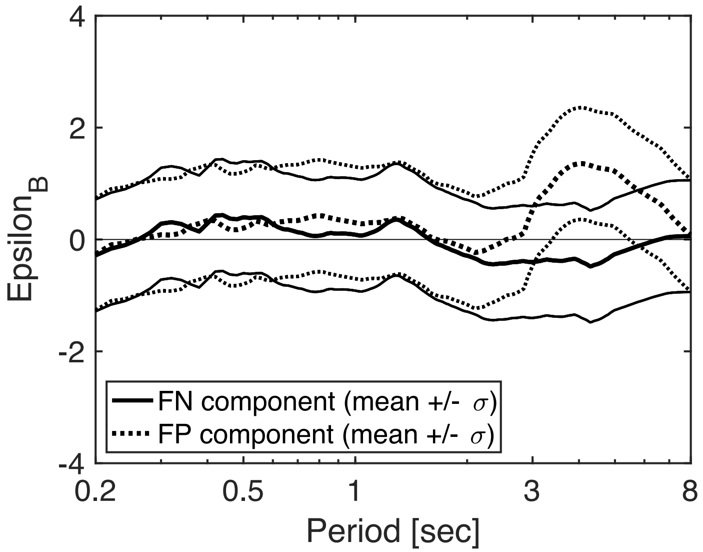
$$\mu_{lnSa,rec} \pm 1.96 \sqrt{\frac{\sigma^2_{lnSa,rec}}{n_{rec}} + \frac{\sigma^2_{lnSa,sim}}{n_{sim}}}$$

Underestimate of Sa variability with respect to both real records and GMPEs

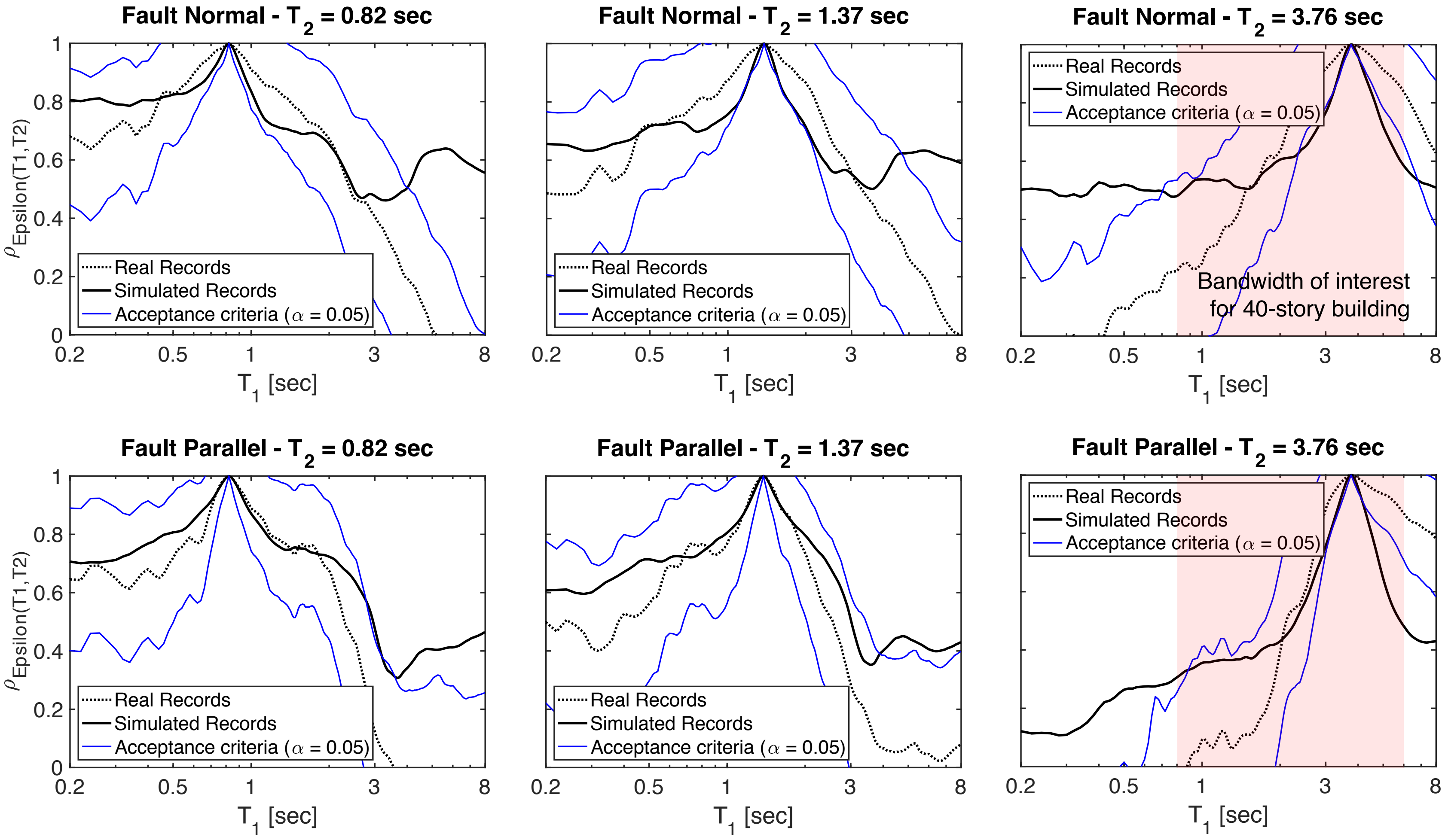
Step 3 – Distribution of Building Response Proxies

- ❑ Inter-period correlation
- ❑ Ground-motion polarization
- ❑ Ground-motion significant duration

Inter-period correlation



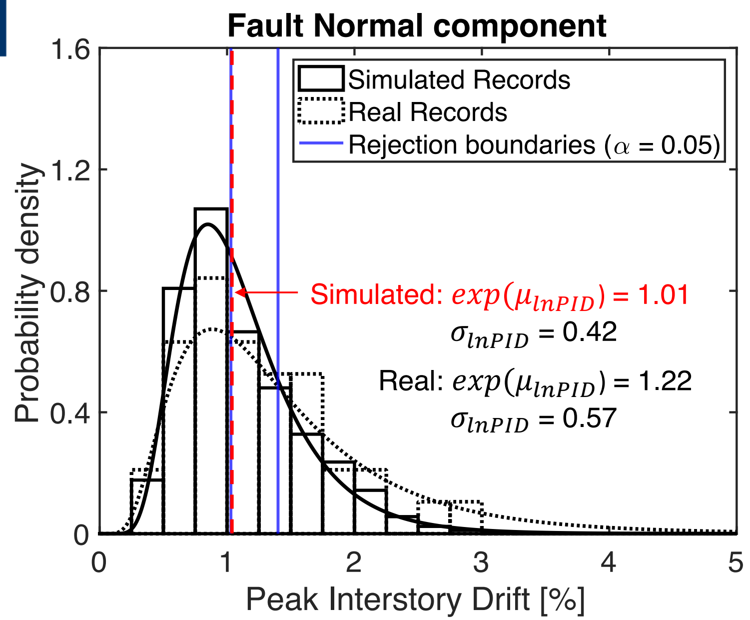
$$\varepsilon_{Bi} = \frac{ln[Sa_i(T)_{sim}] - \mu_{lnSa(T)_{rec}}}{\sigma_{lnSa(T)_{sim}}}$$

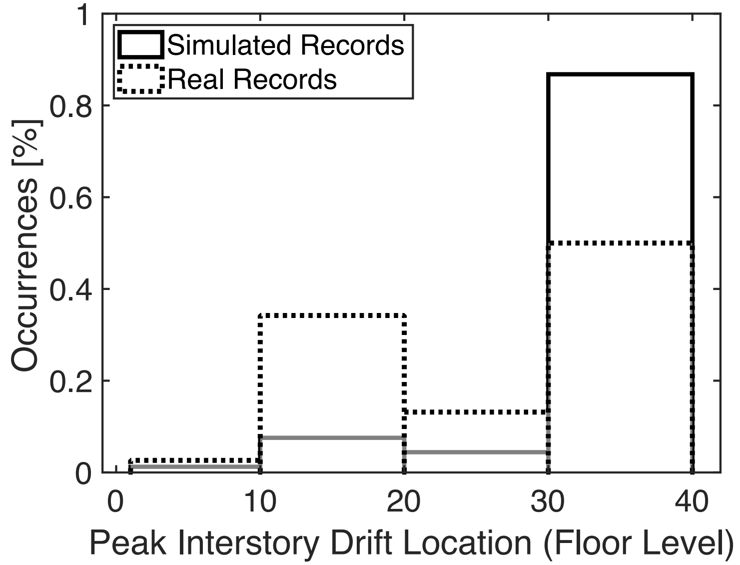


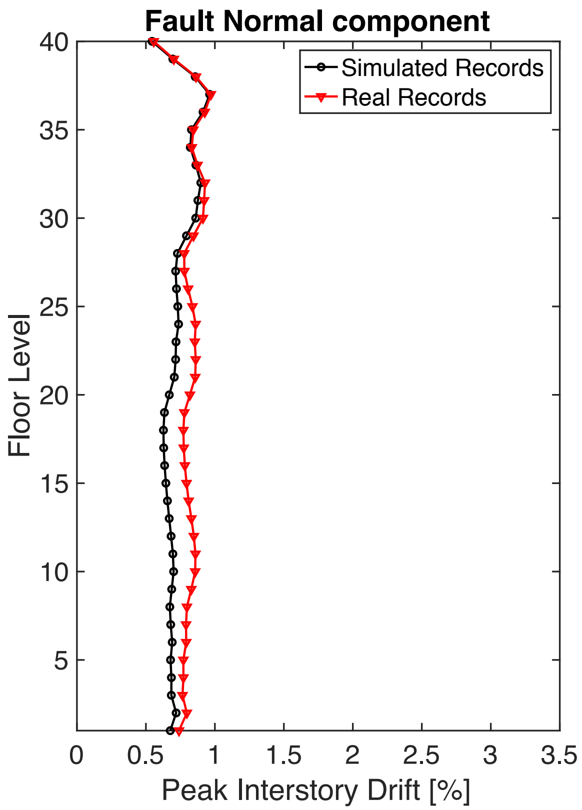
Acceptance criteria

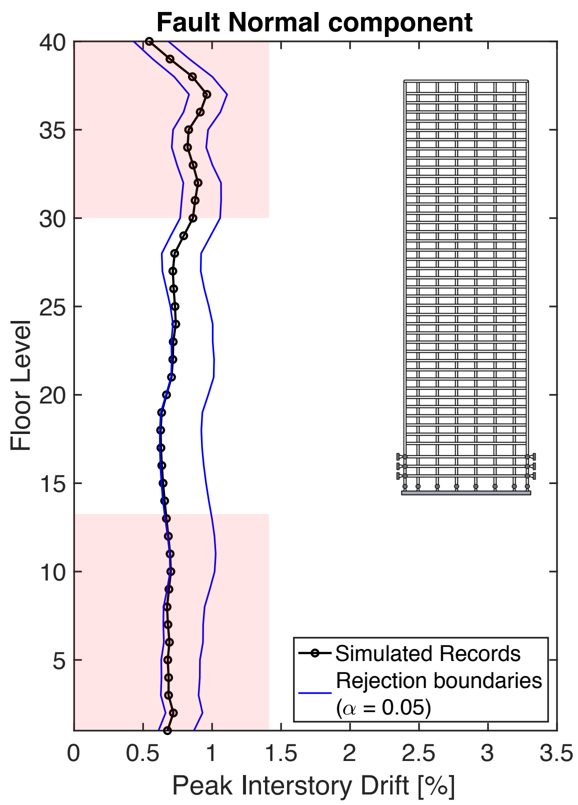
$$\rho_{rec_{(T_1,T_2)}} \pm 1.96\ \sigma_{\rho(T_1,T_2)}$$

Step 4 – Distribution of building response from FEMs







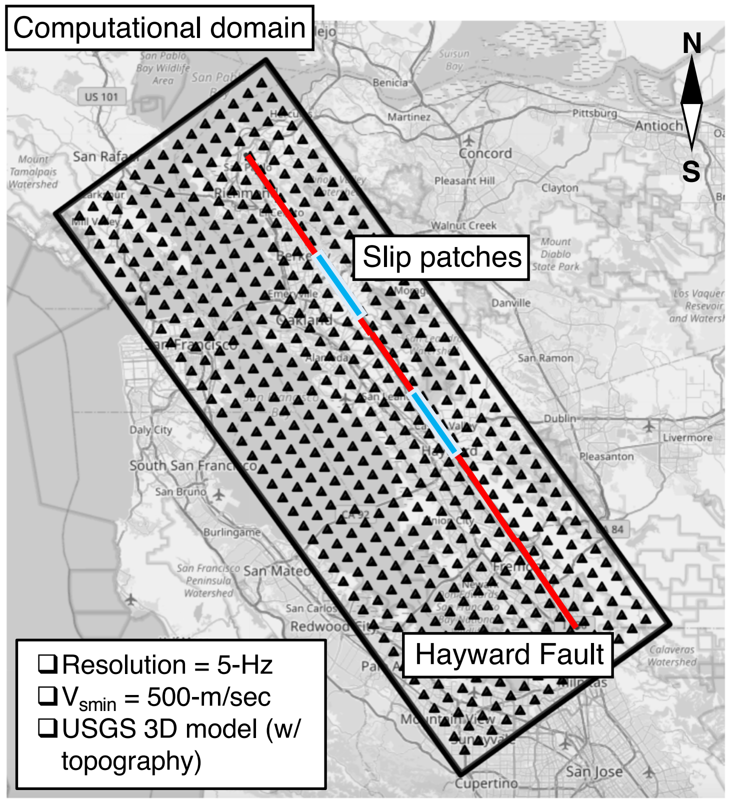


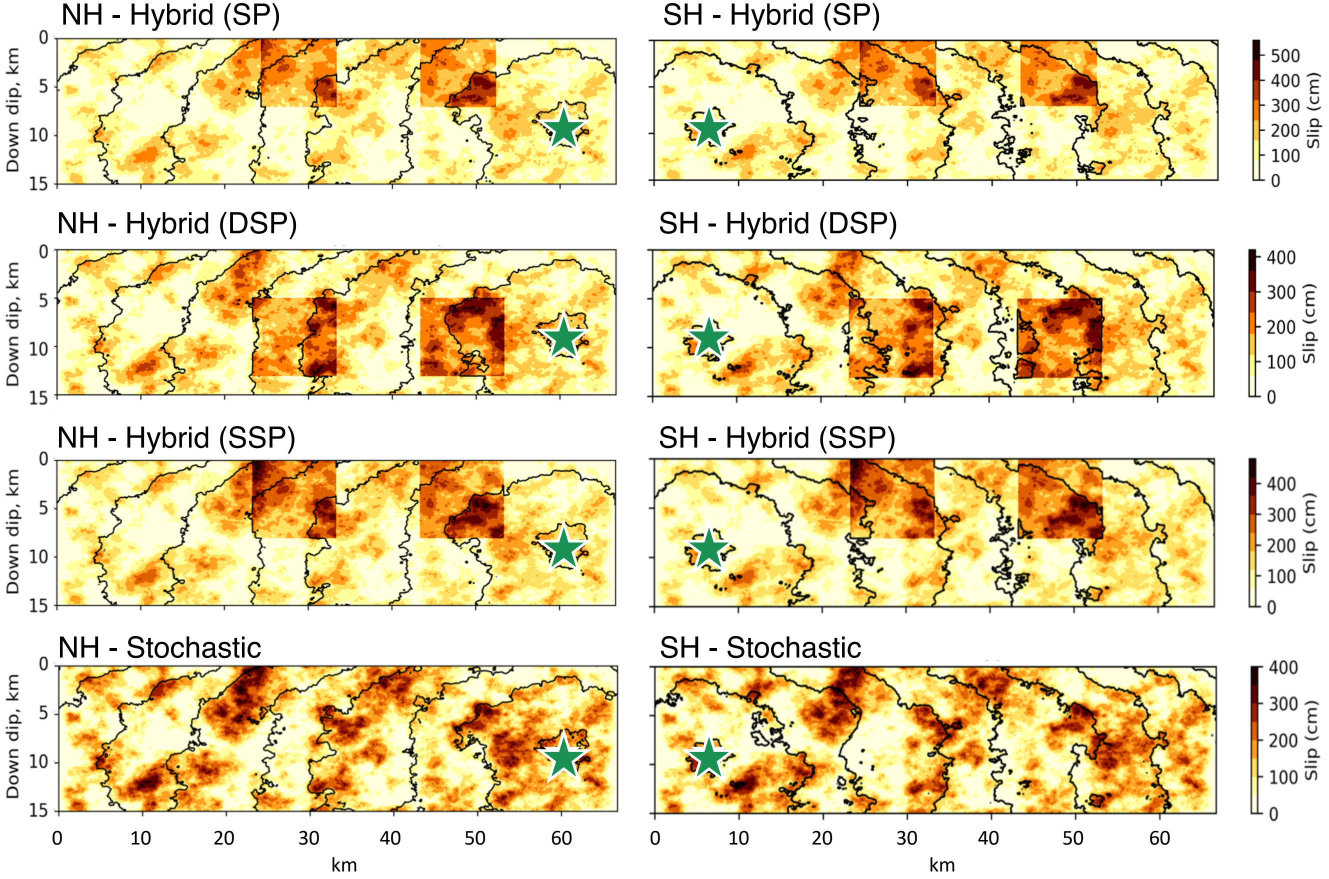
Acceptance criteria

$$(\mu_{lnPID})_{rec,i} \pm 1.96\sqrt{\frac{\sigma^2_{lnPID,rec,i}}{n_{rec}} + \frac{\sigma^2_{lnPID,sim,i}}{n_{sim}}}$$

The San Francisco Bay Area Case Study

The same validation approach was extended to a real domain representing the San Francisco Bay Area to simulate 8 M_w 7 Hayward Fault earthquakes.





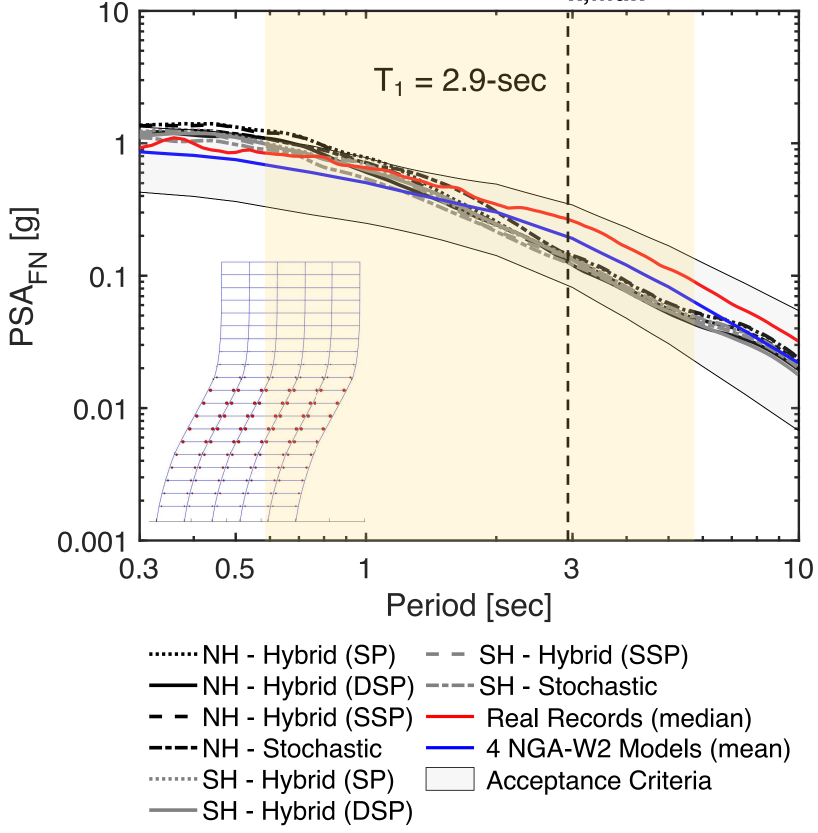
Simulations by Arthur Rodgers and Arben Pitarka

Petrone, F., Abrahamson, N., McCallen, D., Pitarka,A., Rodgers, A., Engineering Evaluation of the EQSIM Simulated Ground-Motion Database: The San Francisco Bay Area Region*, Earthquake Engineering and Structural Dynamics* (under review)

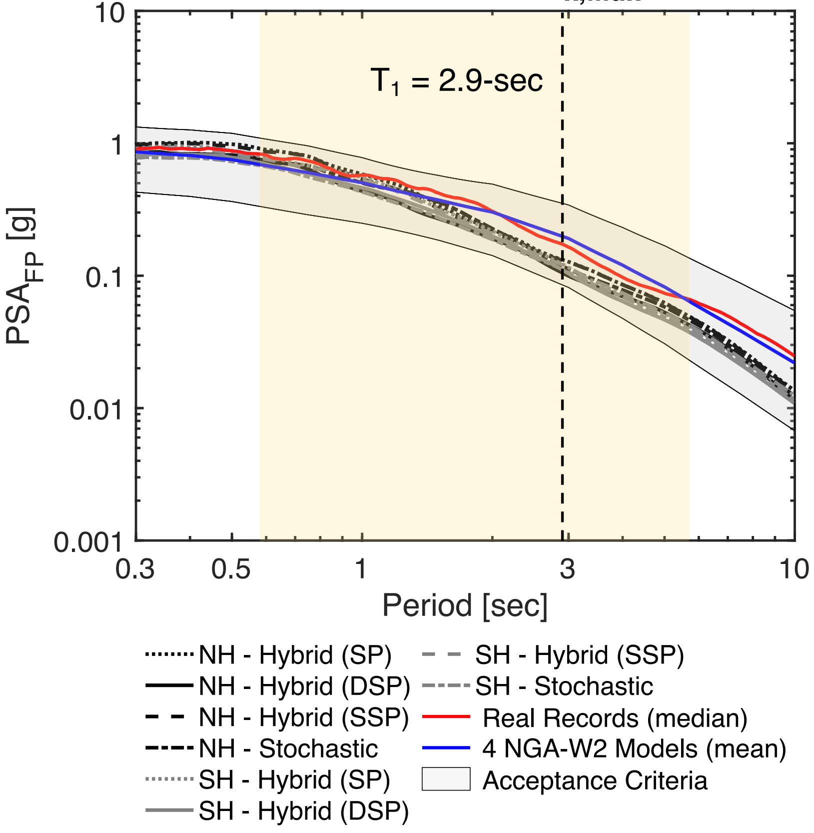
SFBA ground-motion validation (snapshot)

PSA and ground-motion significant duration

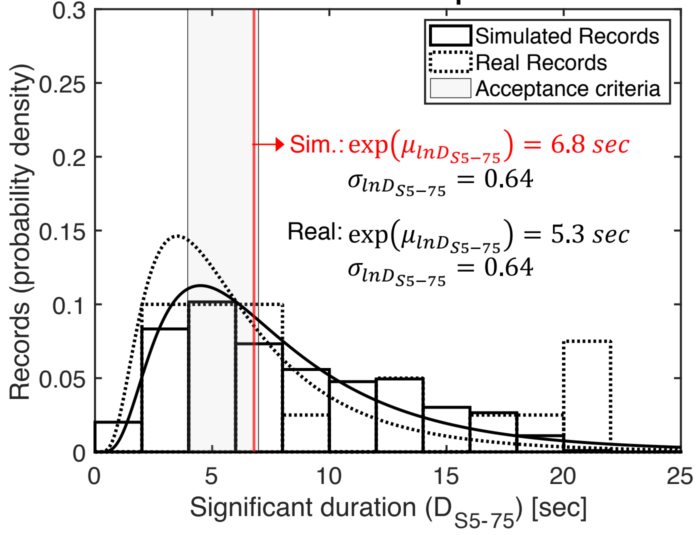
FN component: near-field ($R_{x,max}$ = 6-7 km)



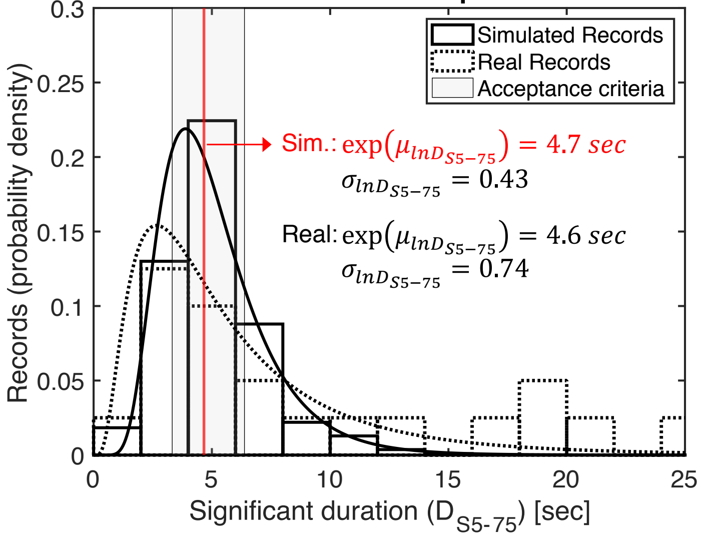
FP component: near-field ($R_{x,max}$ = 6-7 km)



Fault Normal component

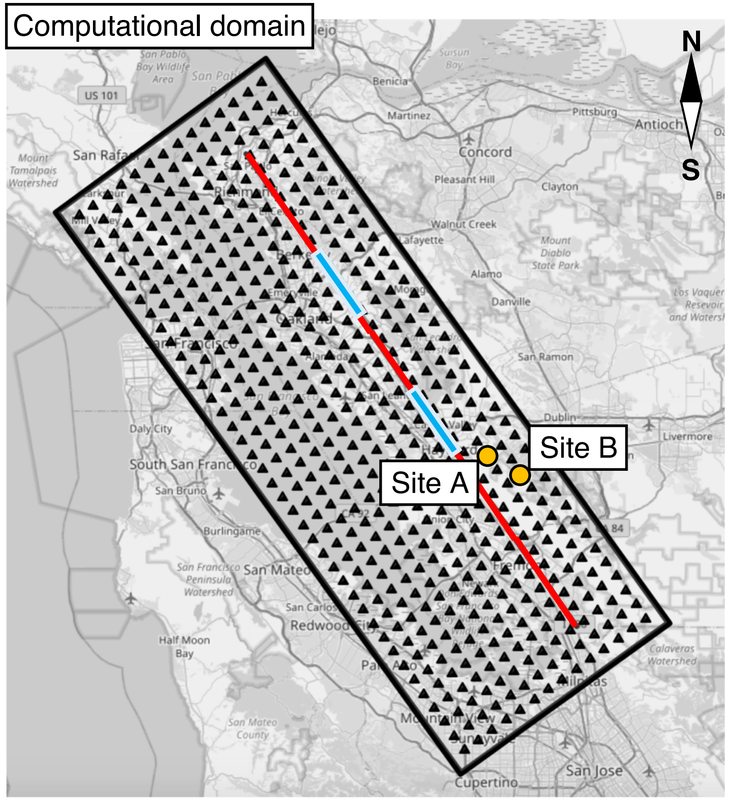


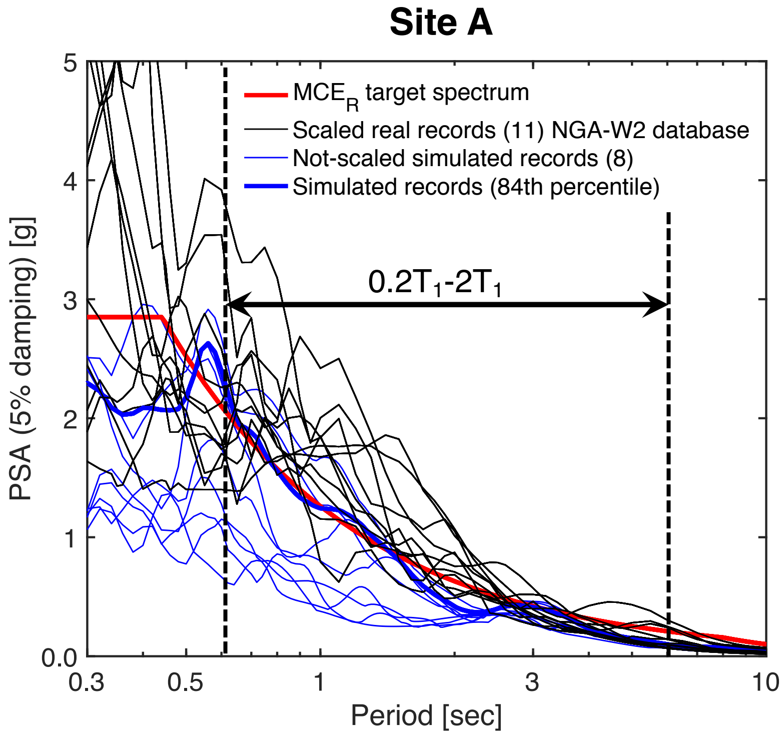
Fault Parallel component

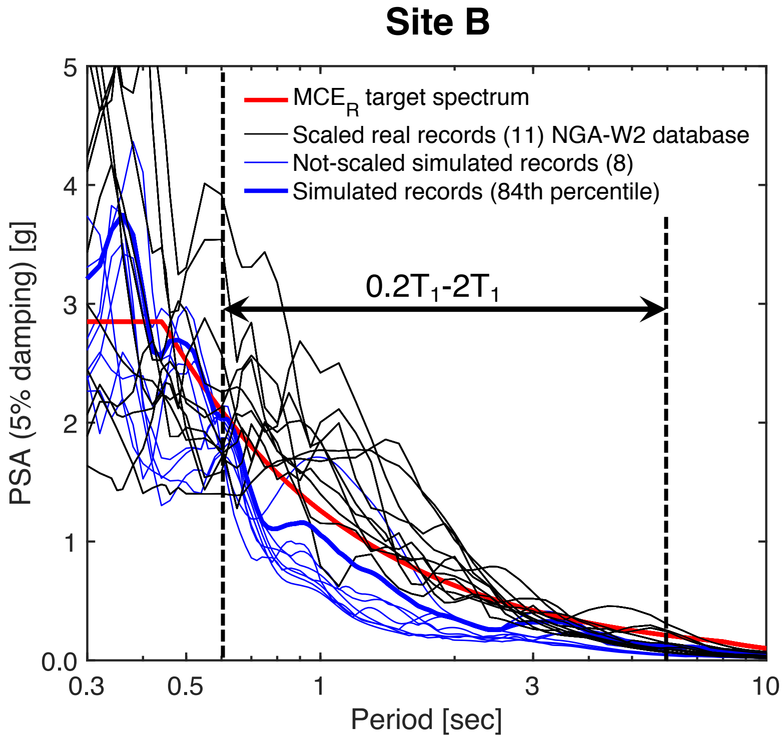


Simulation-Based Site-Specific Analysis

Can simulated ground motions enable true site-specific analyses?



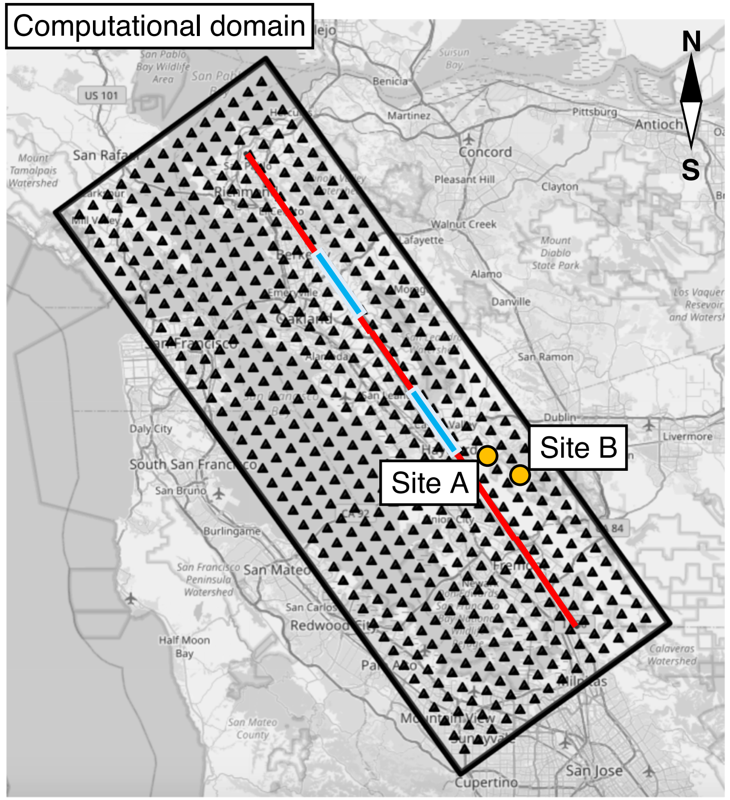


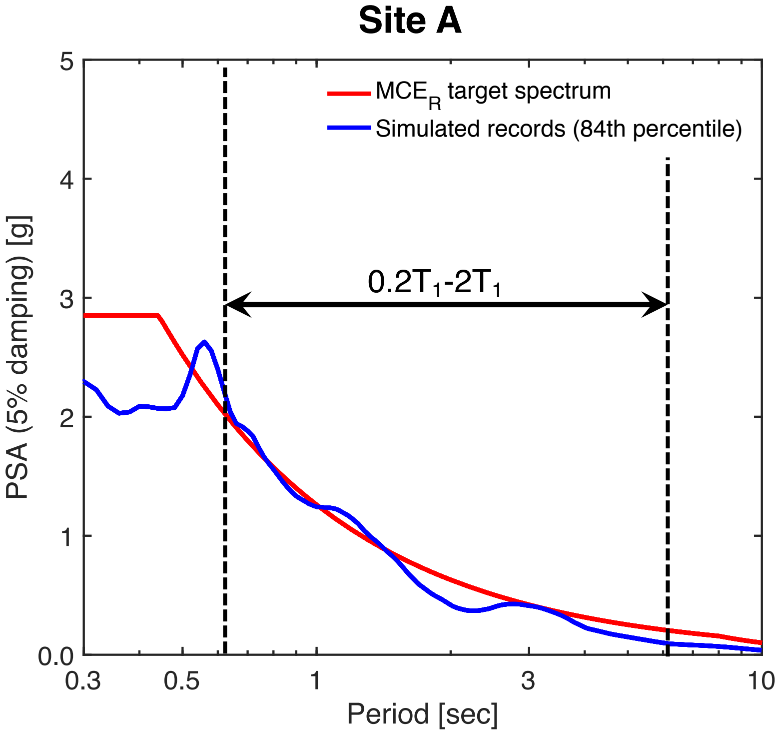


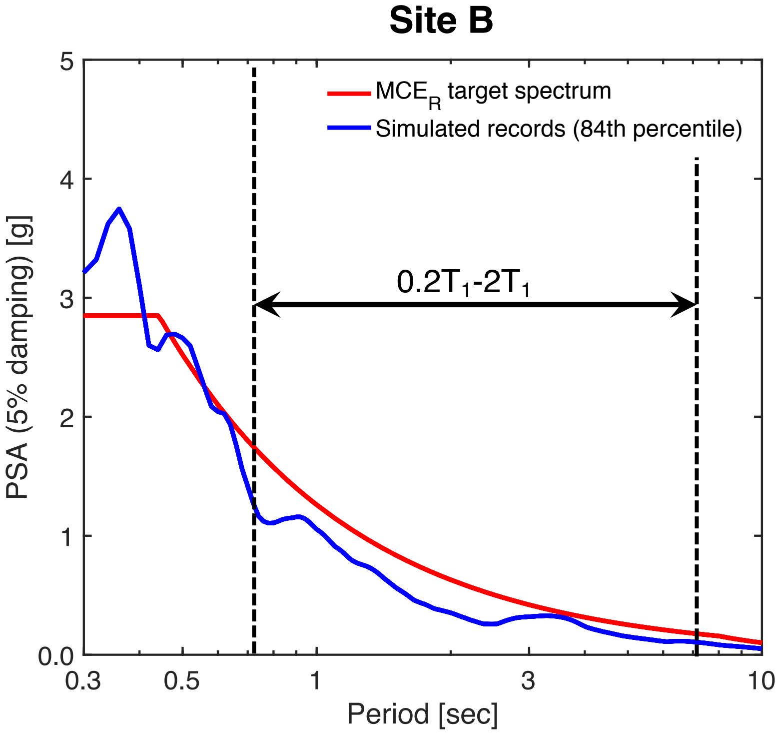
Soil class C: Vs_{30} = 637-m/sec
Scale factor: <5
M_w ~7.2, R_{rup} = 4 to 5-km
20-story RC-MRF: T_1 = 2.9-sec

Simulated Ground-Motion Selection

How do we select simulated ground motions?







Concluding remarks

- Current research is **expanding the proposed 4-step methodology** to explicitly incorporate ground-motion features affecting the response of long-period structures (e.g., pulse-like components).

- Current efforts are extending the site-specific analyses to the entire San Francisco Bay Area region to **investigate the effect of the site-specificity** enabled by physics-based ground-motion simulations **on structural design and assessment** at the regional scale for multiple building typologies.

- Future work will **further investigate the ground-motion variability** deriving from purely uncorrelated ruptures where multiple parameters are made to vary (e.g., randomization of the slip distribution seed, hypocenter, rupture speed, risetime, etc.).

Thank you!