EQSIM San Francisco Bay Area Ground Motion Assessment and Acceptance

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Validation Methodologies

Historical events

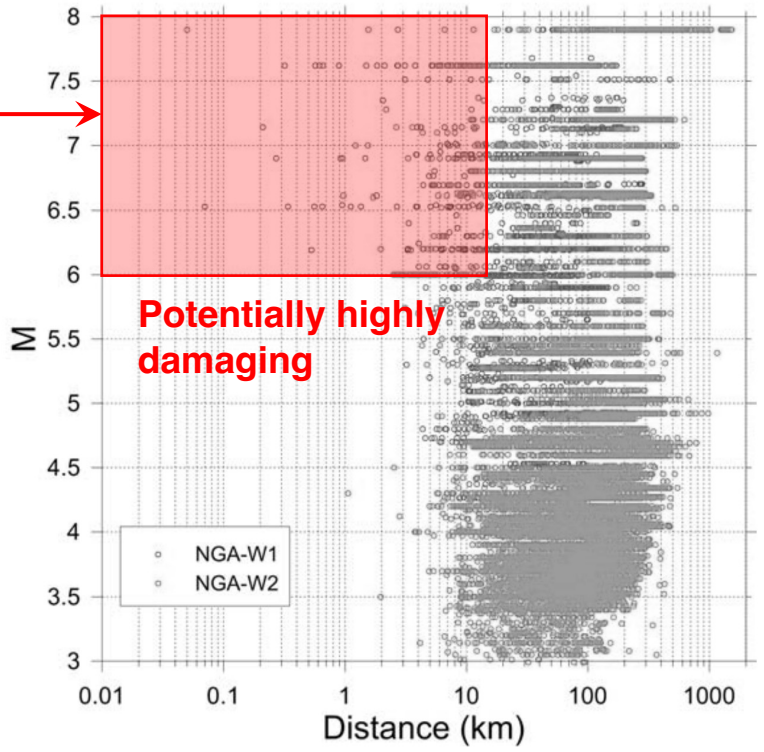
- ❑ Station-by-station inspection
- ❑ Seismogram waveforms comparison
- ❑ Use of well-constrained GMMs

VS

Not-historical Events

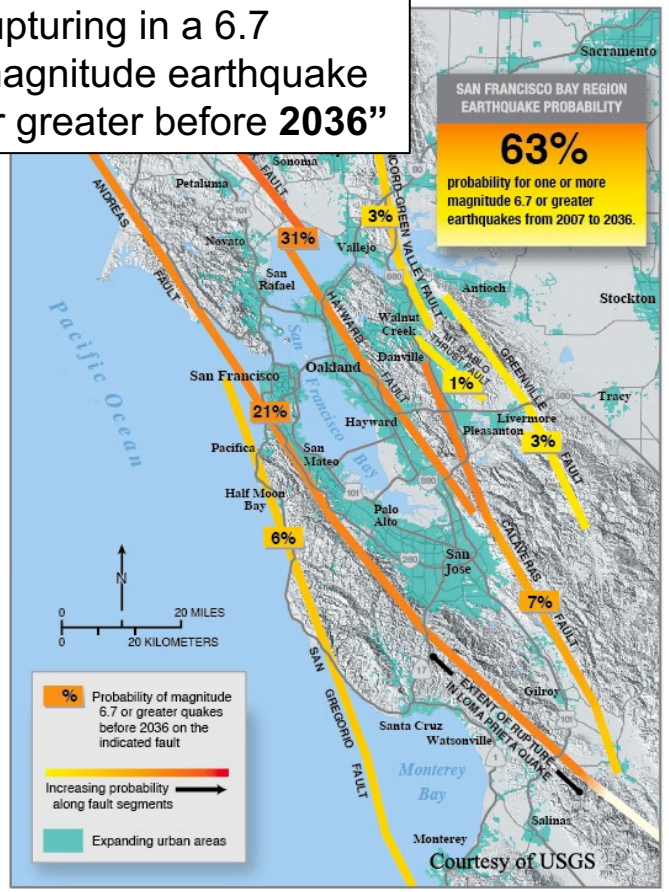
- ❑ Records from consistent events are scarce/not available
- ❑ GMMs are not well constrained
- ❑ The expected GMs characteristics need to be inferred from the knowledge of geology/rupture

Very sparse database for **large M-short distance** records



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

"The Hayward Fault has a 31.7% chance of rupturing in a 6.7 magnitude earthquake or greater before **2036"**



[Source: Berkeley Seismology Lab]

EQSIM/CESER Ground Motions Assessment and Acceptance

Four-step methodology

Application-oriented

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 GMMs

Step 3: Comparison of the distribution of simple proxies for infrastructure response

Step 4: Comparison of the distribution of engineering demand parameters for a realistic model of a structure.

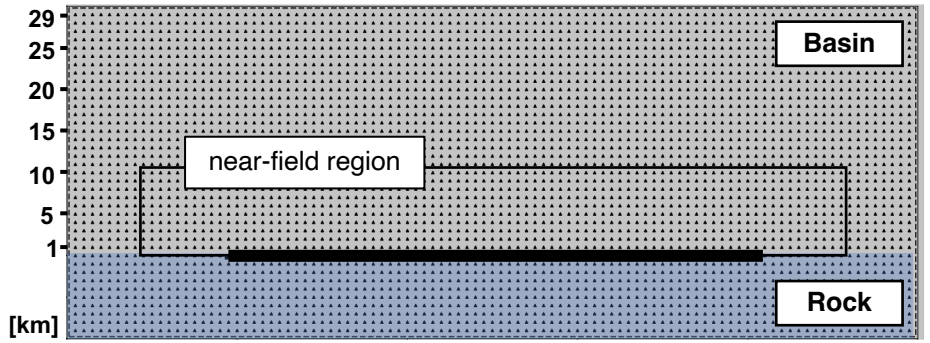
Acceptance criteria

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

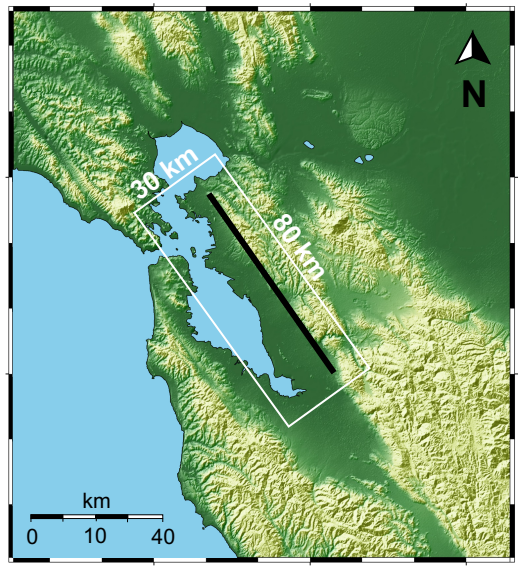
Petrone, F., Abrahamson, N., McCallen, D., Miah, M., (2021), Validation of (not-historical) large-event near-fault ground-motion simulations for use in civil engineering Applications, *Earthquake Engineering and Structural Dynamics*, 50(1), p. 116-134

Applications

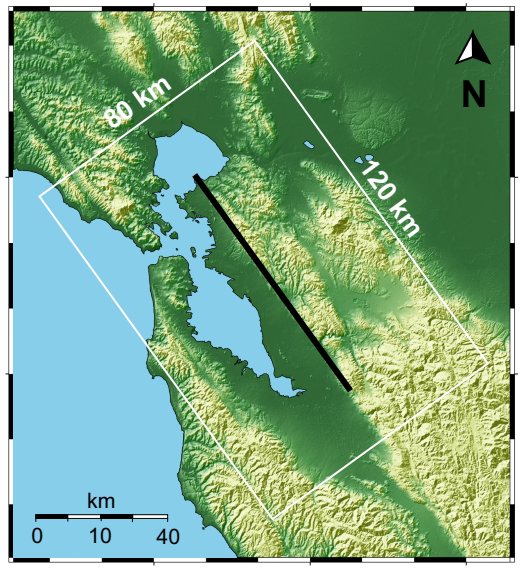
Rock-basin



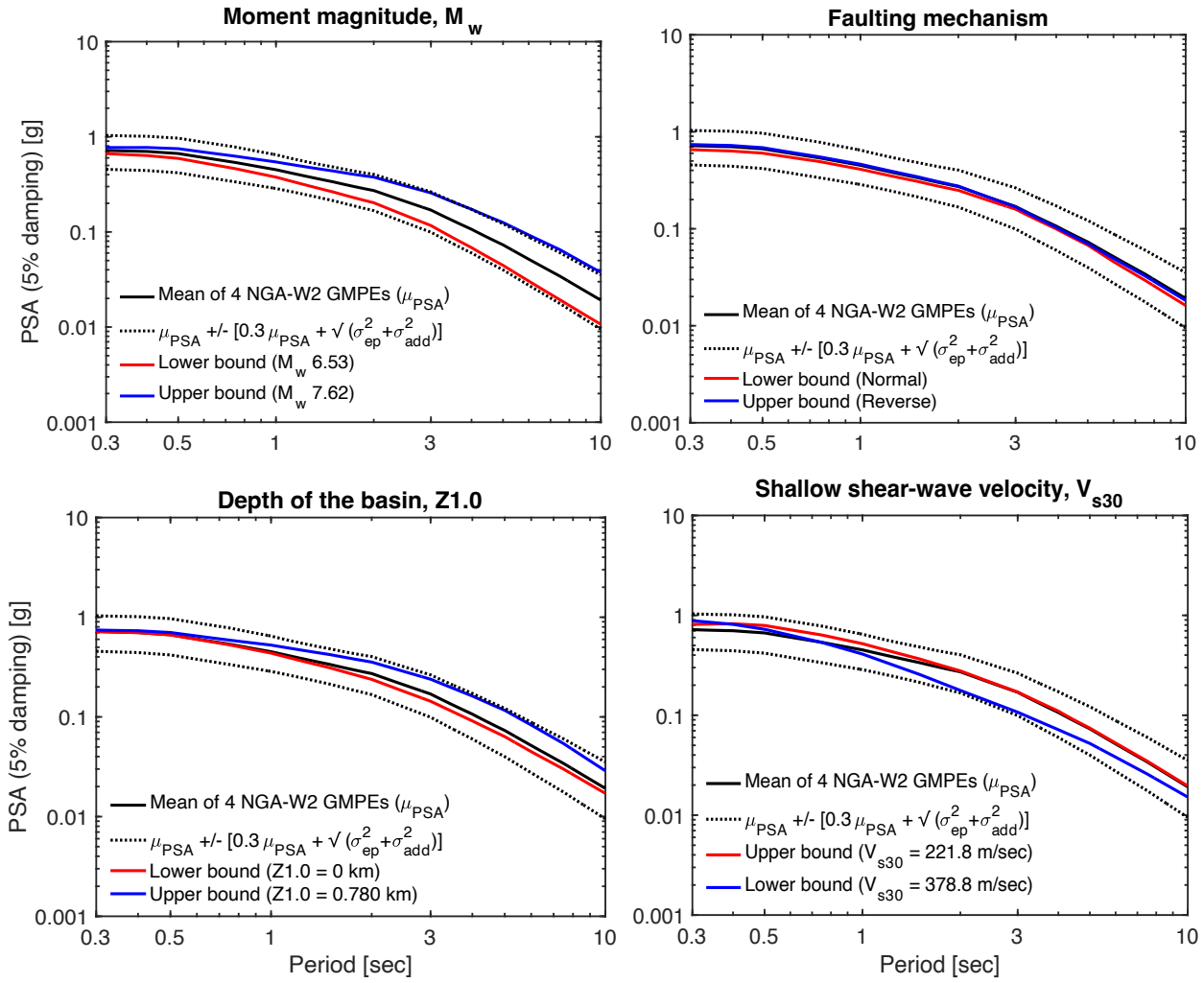
SFBA Gen #1



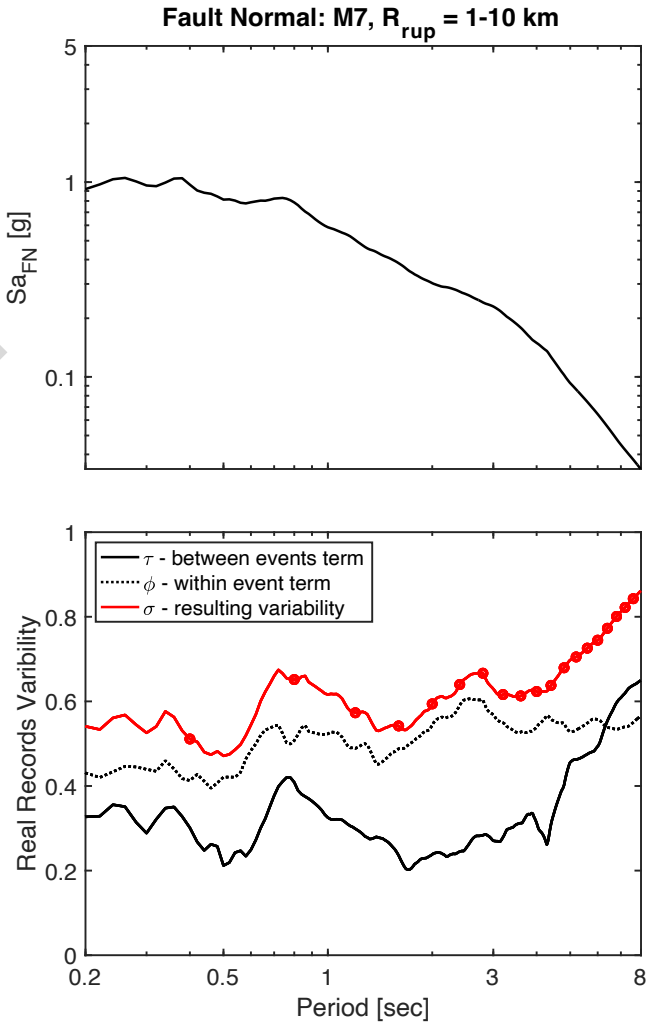
SFBA Gen #2



Methodology overview: Step 1

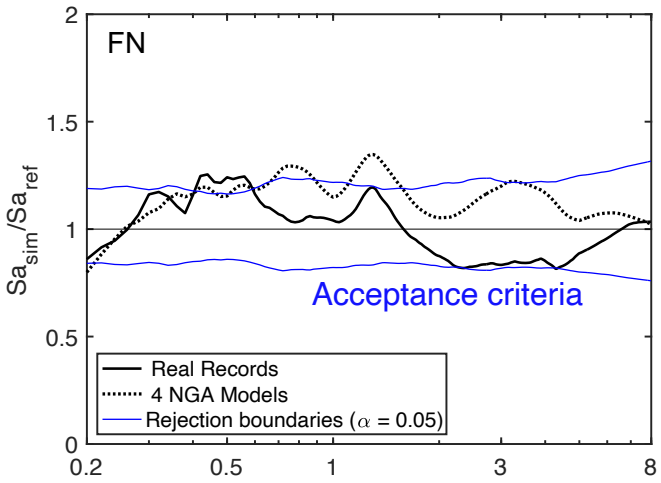


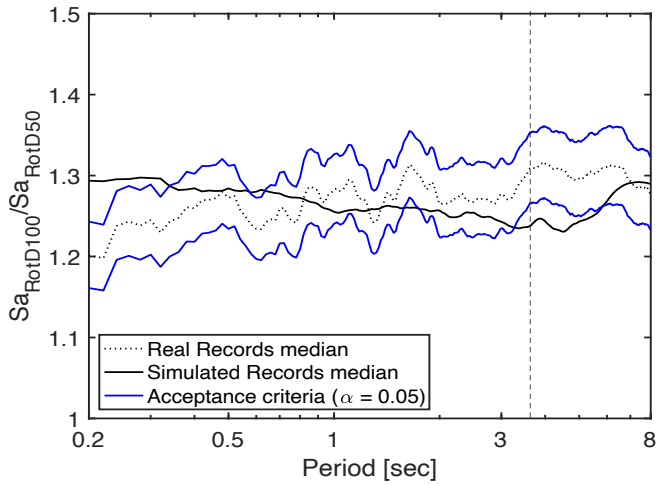
The variability resulting from the uneven sampling of earthquakes is evaluated with a linear mixed-effects model.

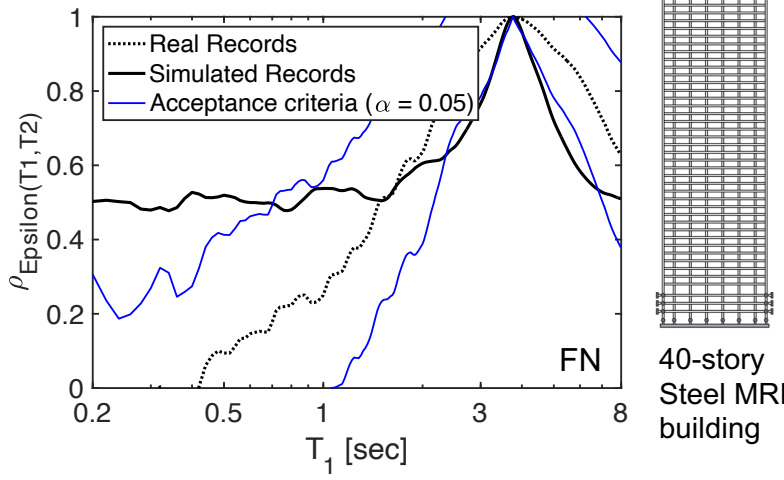


Petrone, F., Abrahamson, N., McCallen, D., Pitarka, A., Rodgers, A., 2021, "Engineering evaluation of the EQSIM simulated ground-motion database: The San Francisco Bay Area region". Earthquake Engineering and Structural Dynamics, 50(15).

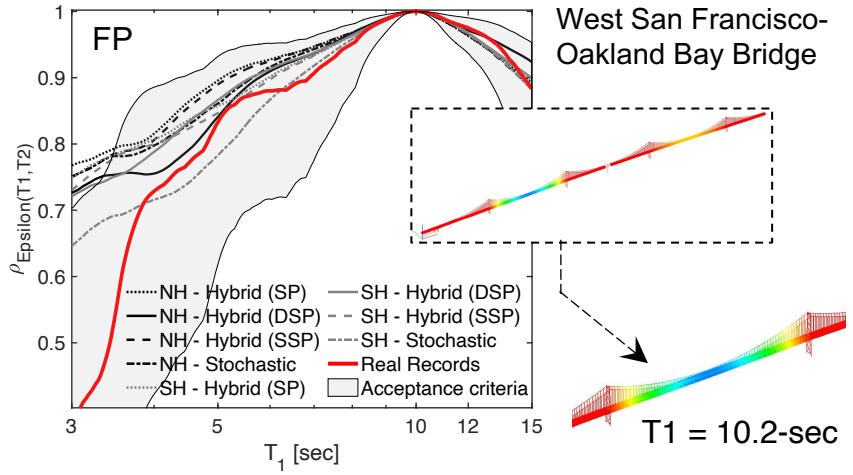
Methodology overview: Steps 2 & 3

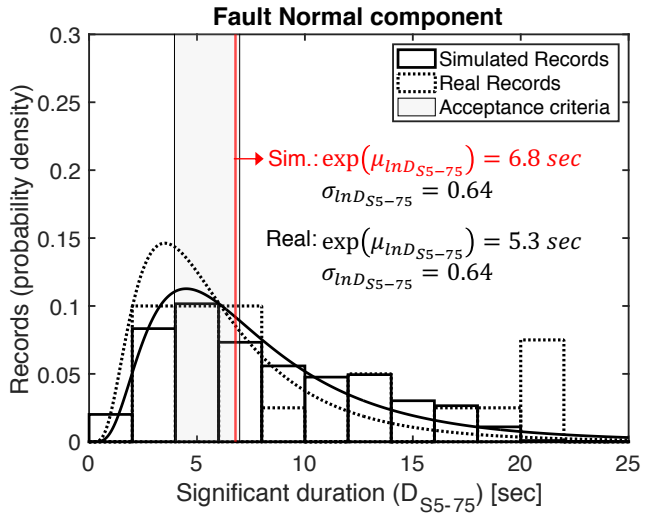






40-story Steel MRF building



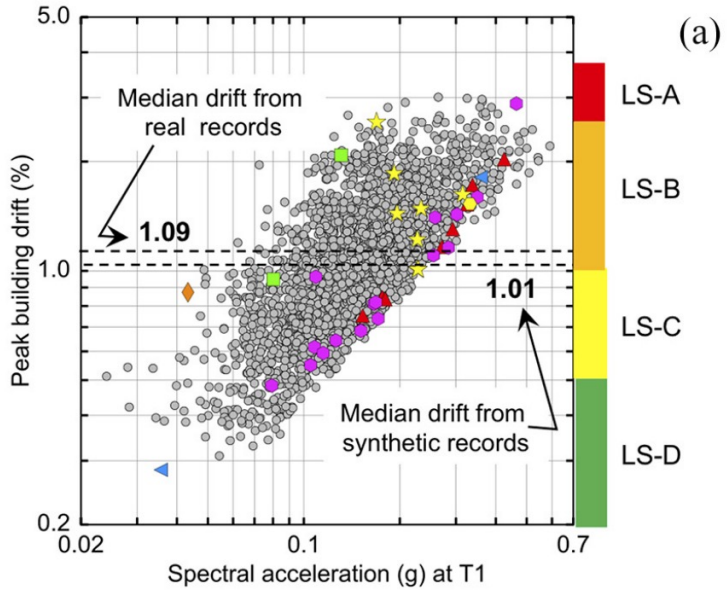


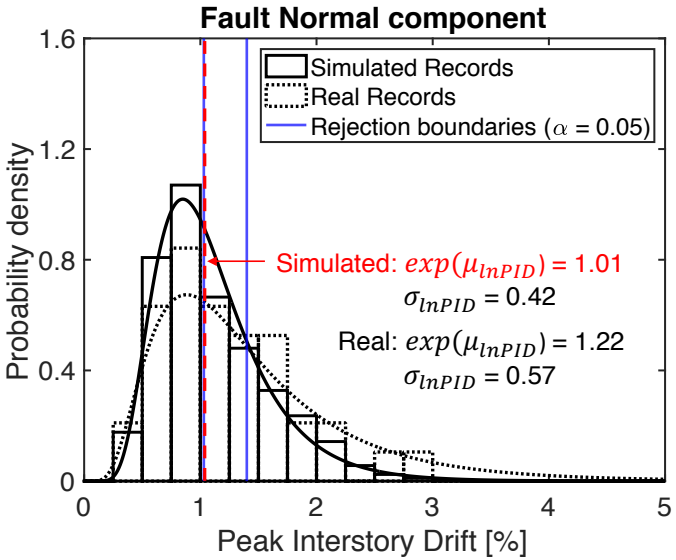
- Develop informed judgment on where the simulated motions exhibit limitations and where they can be used with confidence
- Application-specific selection of the metrics for validation

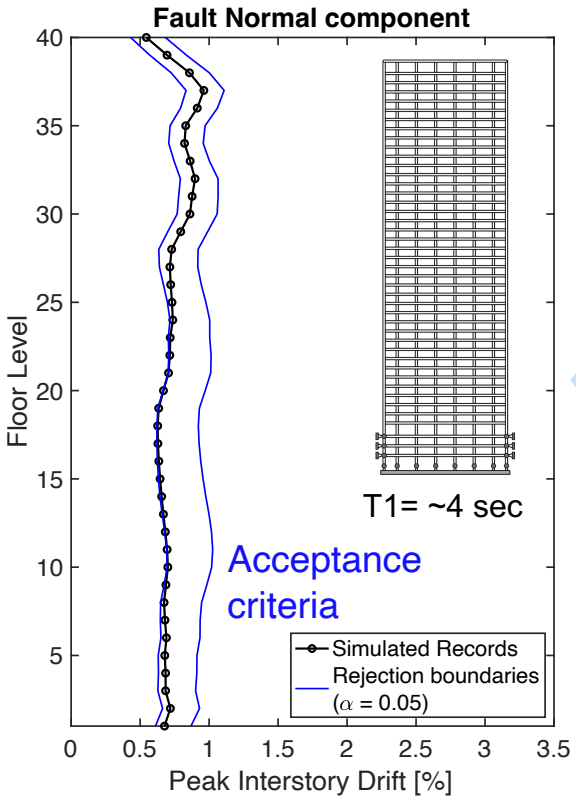
Taslimi A., **Petrone, F.**, 2024, "Assessment of the Seismic Demand Posed to Suspension Bridges in the Near-Field with Site-Specific Arrays of Simulated Ground Motions," ASCE J. Bridge Eng. DOI: 10.1061/JBENF2/BEENG-6353

Application-specific

Methodology overview: Step 4

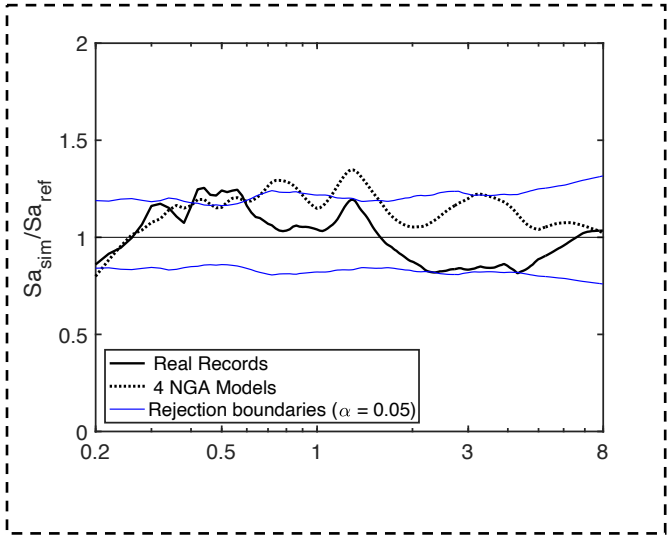






$$(\mu_{lnPID})_{rec,i} \pm 1.96\sqrt{\frac{\sigma^2_{lnPID,rec,i}}{n_{rec}} + \frac{\sigma^2_{lnPID,sim,i}}{n_{sim}}}$$

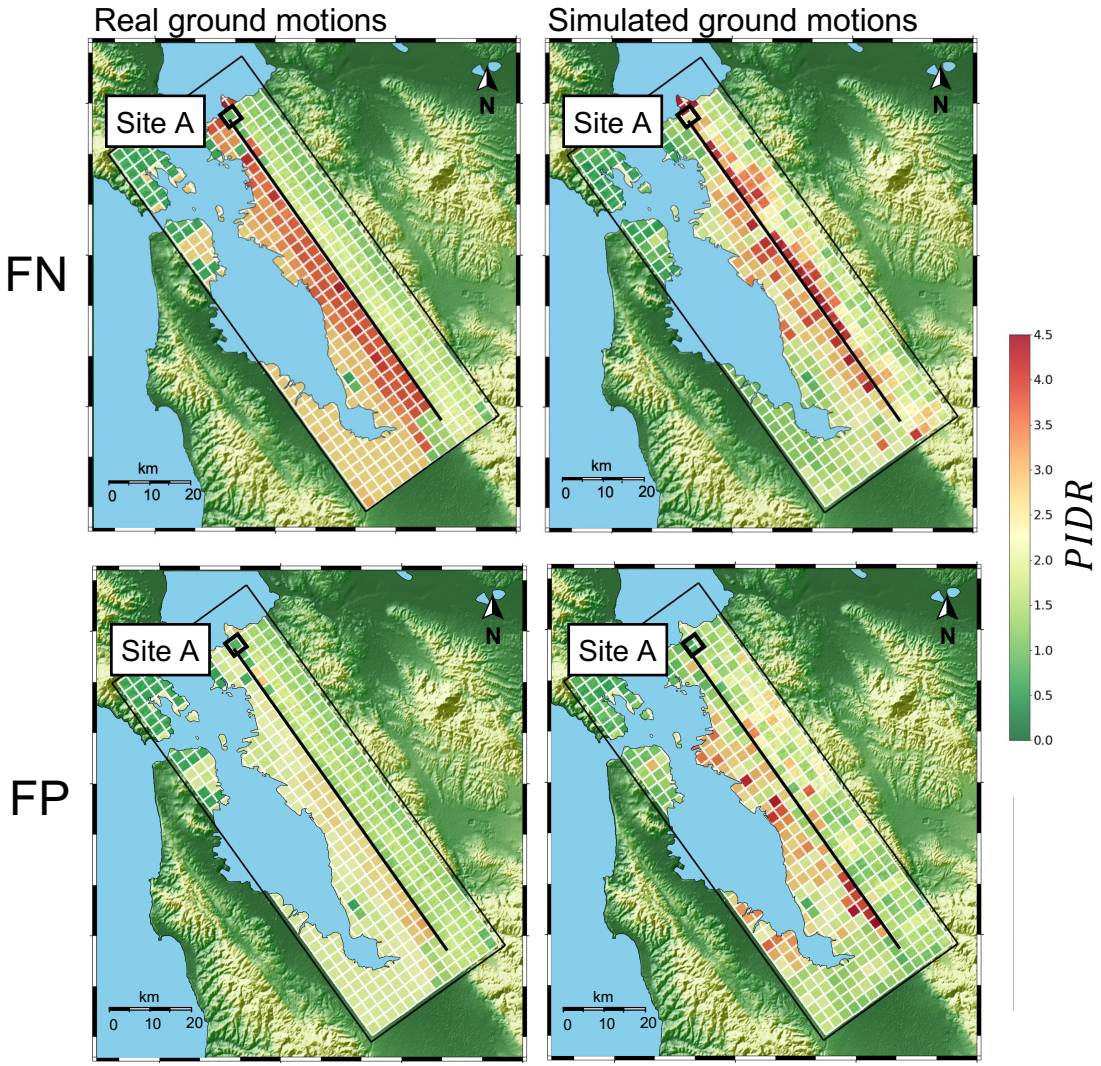
recall

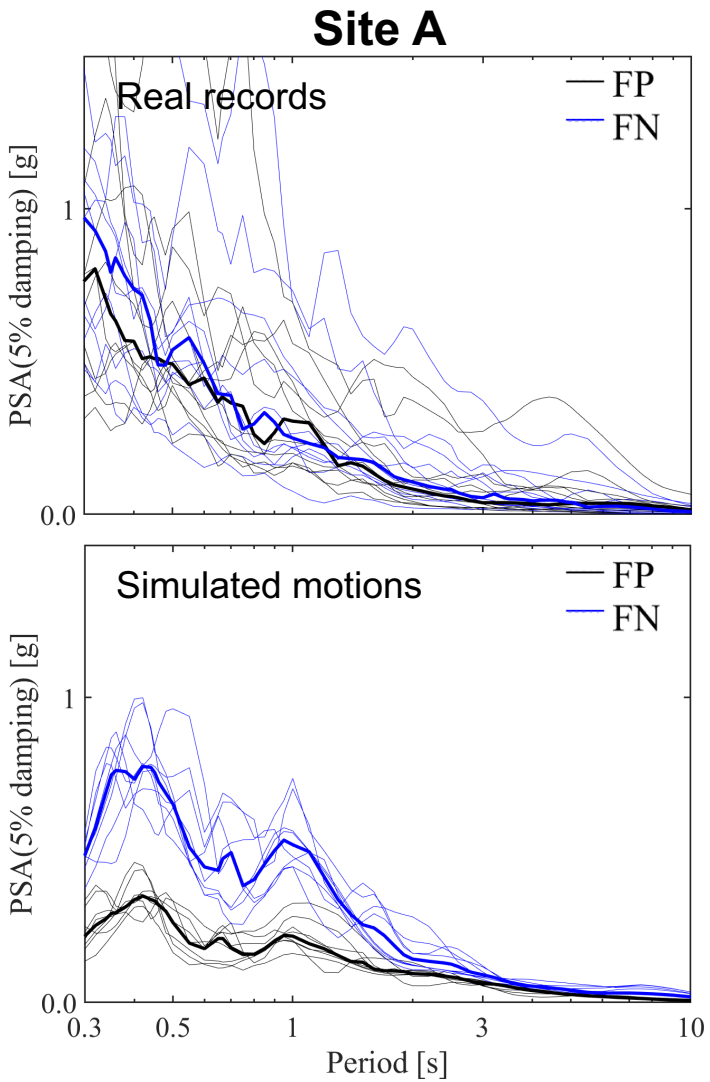


- Understand how the identified characteristics of the SGMs can reflect in the median predictions of structural response, for an informed application-specific utilization of the motions

San Francisco Bay Area Gen #1

Assess the implications introduced by the use of site-specific simulated motions as opposed to real records in ASCE-7 compliant approaches (3-story RC building).





- Site-specific analyses allowed identifying features of the SGMs that are specific to the simulated event and site location (e.g., in the proximity of the e fault)

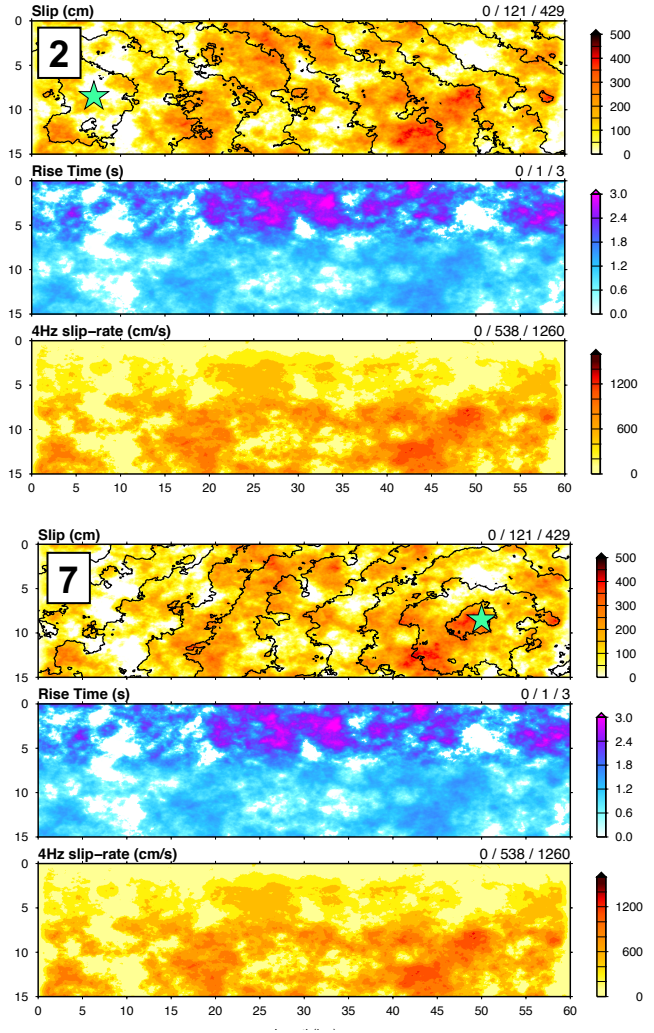
Matinrad, P., & **Petrone, F.** (2023). "ASCE/SEI 7-compliant site-specific evaluation of the seismic demand posed to reinforced concrete buildings with real and simulated ground motions." *Earthquake Engineering and Structural Dynamics*. https://doi.org/10.1002/eqe.3995

San Francisco Bay Area Gen #2 (20 realizations)

No.	Tag	Hypocenter location	High slip patch (Y/N)	Rupture Velocity factor	Slip min/avg/max (cm)	Rise Time min/avg/max (sec)	4-Hz slip rate min/avg/max (cm/sec)
1	R1	North	Y	0.82	0/129/525	0/2/3	0/513/1423
2	R2	South	N	0.82	0/121/429	0/1/3	0/538/1260
3	R3	South	Y	0.72	0/138/506	0/2/3	0/571/1458
4	R5	South	N	0.82	0/124/454	0/2/3	0/513/1238
5	R6	South	Y	0.82	0/129/525	0/2/3	0/513/1423
6	R9	North	N	0.82	0/124/454	0/2/3	0/513/1238
7	R10	North	N	0.82	0/121/429	0/1/3	0/538/1260
8	R11	South	N	0.65	0/124/454	0/2/3	0/513/1238
9	R12	South	N	0.75	0/123/447	0/2/3	0/527/1247
10	R13	South	N	0.75	0/121/482	0/2/3	0/523/1325
11	R14	North	N	0.75	0/120/434	0/1/3	0/527/1192
12	R15	North	Y	0.82	0/127/478	0/2/4	0/518/1273
13	R16	South	Y	0.65	0/129/525	0/2/3	0/513/1423
14	R17	South	Y	0.72	0/129/525	0/2/3	0/564/1576
15	R19	South	Y	0.82	0/129/525	0/2/3	0/563/1564
16	R20	South	Y	0.72	0/140/557	0/2/3	0/558/1445
17	R21	South	Y	0.72	0/129/525	0/2/3	0/562/1539
18	R22	South	N	0.82	0/120/449	0/1/3	0/526/1288
19	R23	North	N	0.82	0/123/447	0/2/3	0/527/1247
20	R24	North	N	0.72	0/123/447	0/2/3	0/527/1247

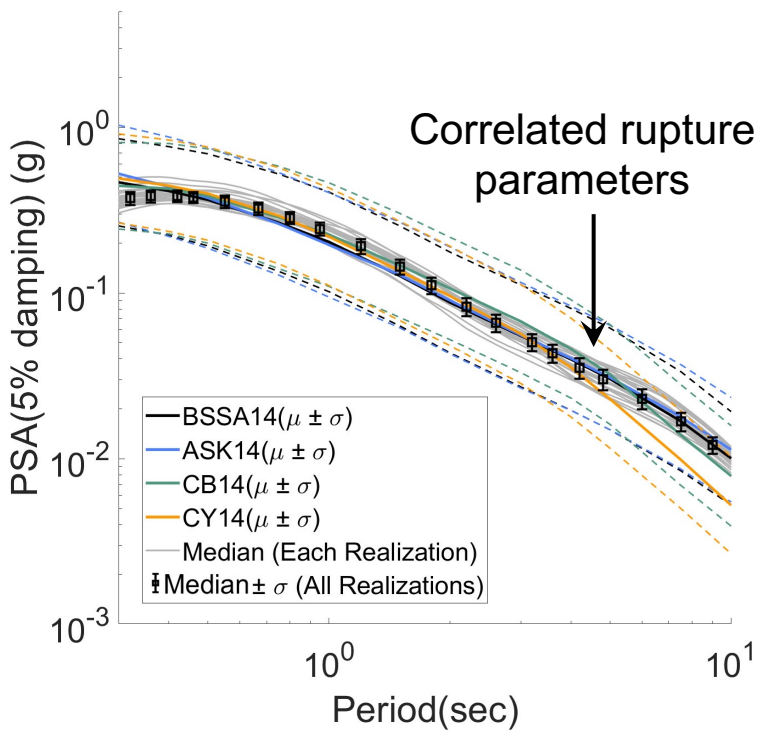
- Small-scale stochastic rupture variability + high-slip patches
- Min Vs = 250 m/sec
- Max f = 5 Hz
- Mw7

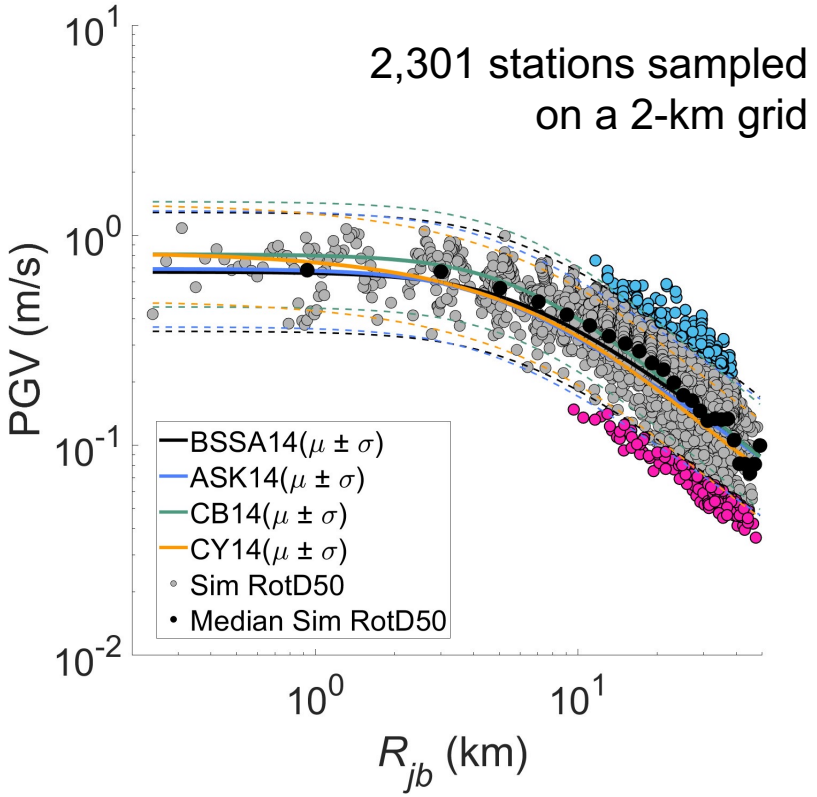
Example of mirrored realizations

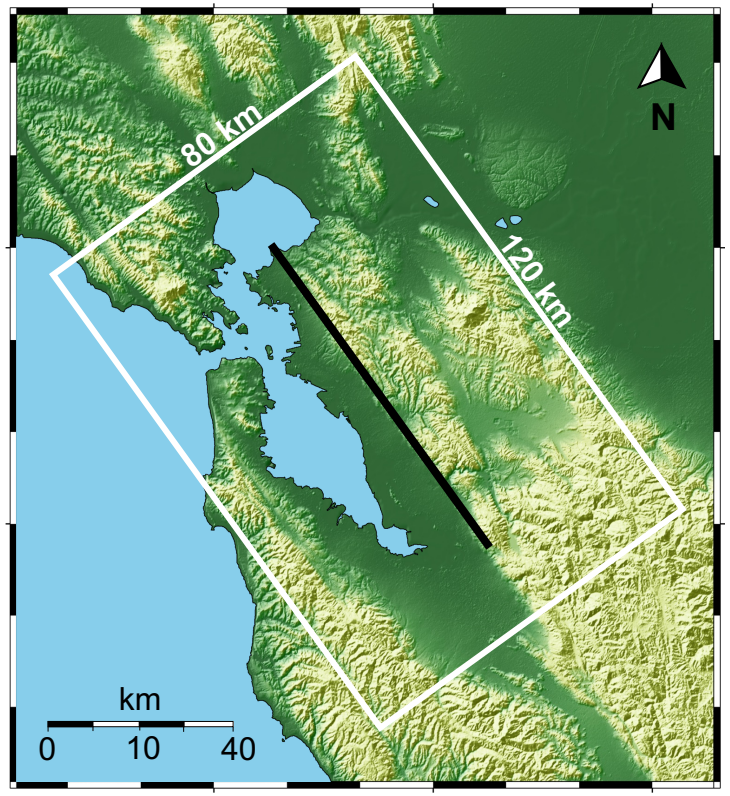


Aggregated GMs for the Full Domain across all Realizations

Selected IMs: PSA and PGV

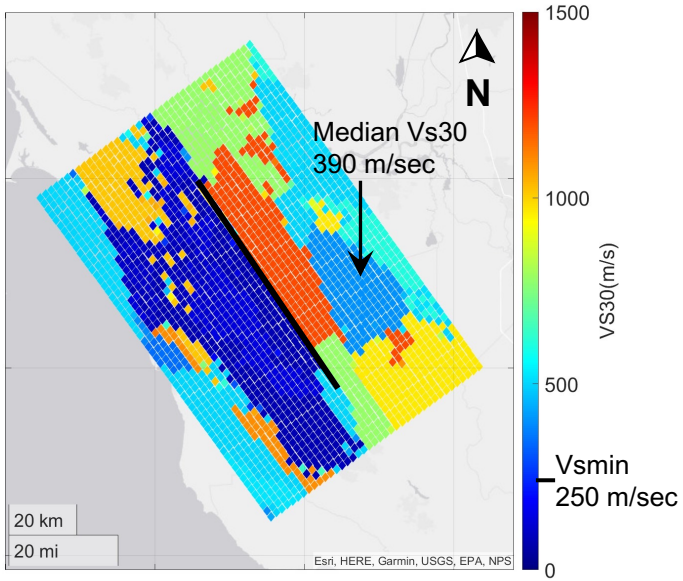




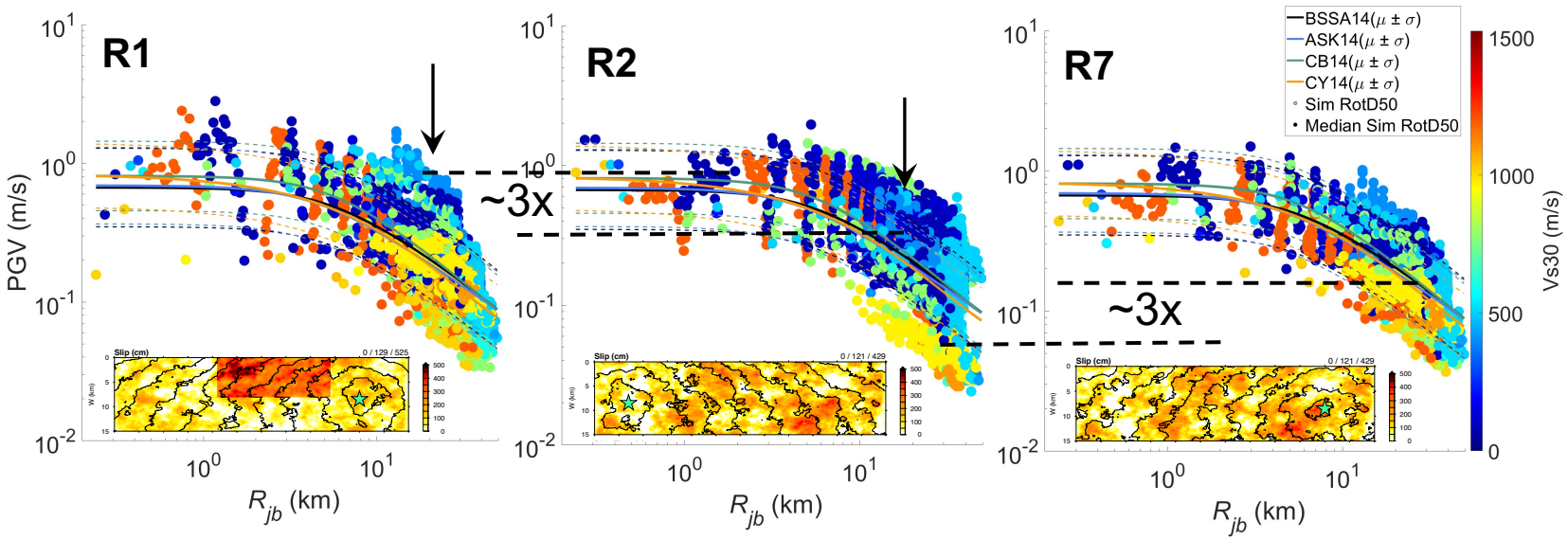


San Francisco Bay Area Gen #2

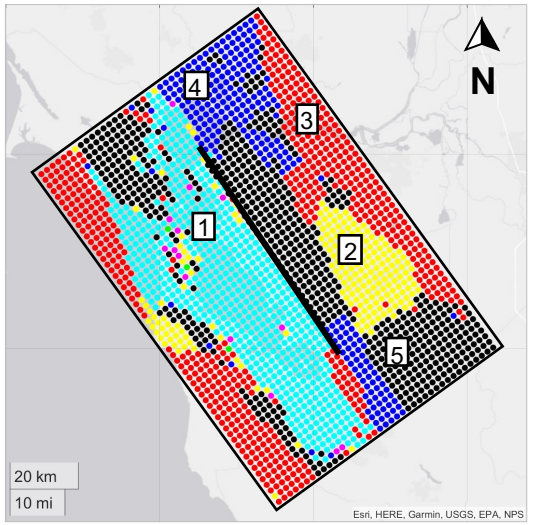
Full domain



USGS velocity model (v21.1)



Subdomains



Isolate and help interpret the influence of

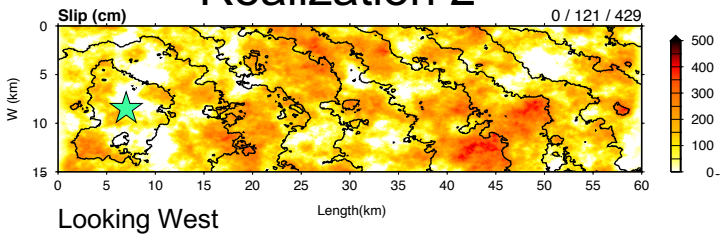
1. site conditions
2. rupture directivity effects,
3. rupture model parameters

on **key IMs**.

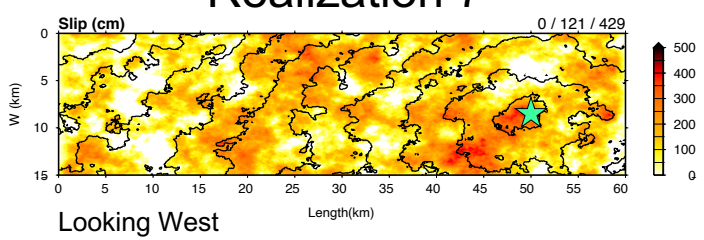
Subdomain ID	Site class (ASCE 7)		Vs30 [m/sec]	Z1.0 [km]	Z2.5 [km]
Full domain	-	Median [sigma (ln)]	409 [0.94]	0.26 [1.14]	1.58 [0.65]
1	Very loose sand	Median [sigma (ln)]	100 [0.25]	0.21 [0.85]	0.94 [0.25]
2	Dense sand	Median [sigma (ln)]	393 [0.05]	0.8 [0.91]	2.39 [0.74]
3	Very dense sand	Median [sigma (ln)]	519 [0.07]	0.42 [0.58]	2.35 [0.53]
4	Soft rock	Median [sigma (ln)]	782 [0.03]	0.34 [0.73]	2.30 [0.50]
5	Medium/hard rock	Median [sigma (ln)]	1072 [0.09]	-	1.41 [0.63]

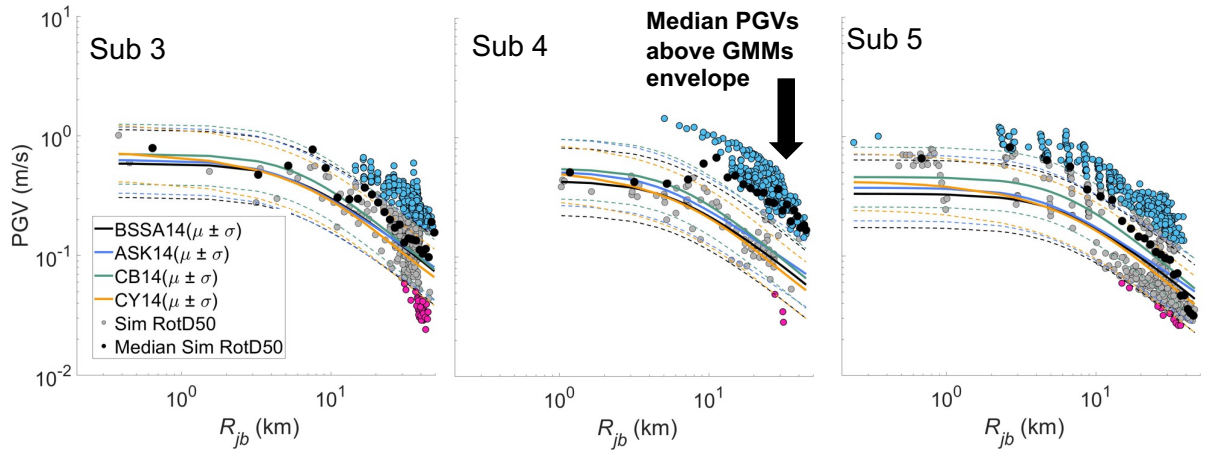
Subdomains analysis: case of ‘mirrored’ realizations

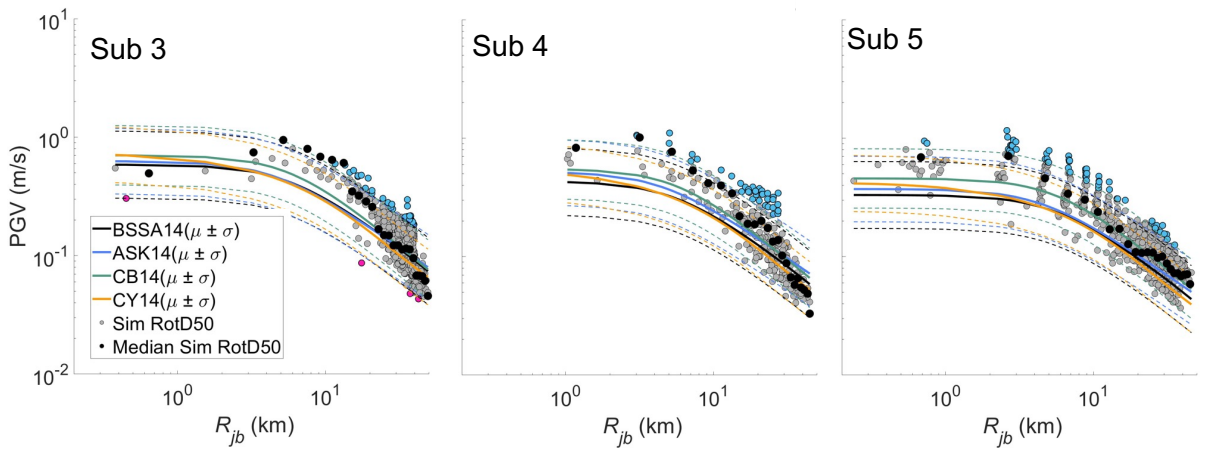
Realization 2

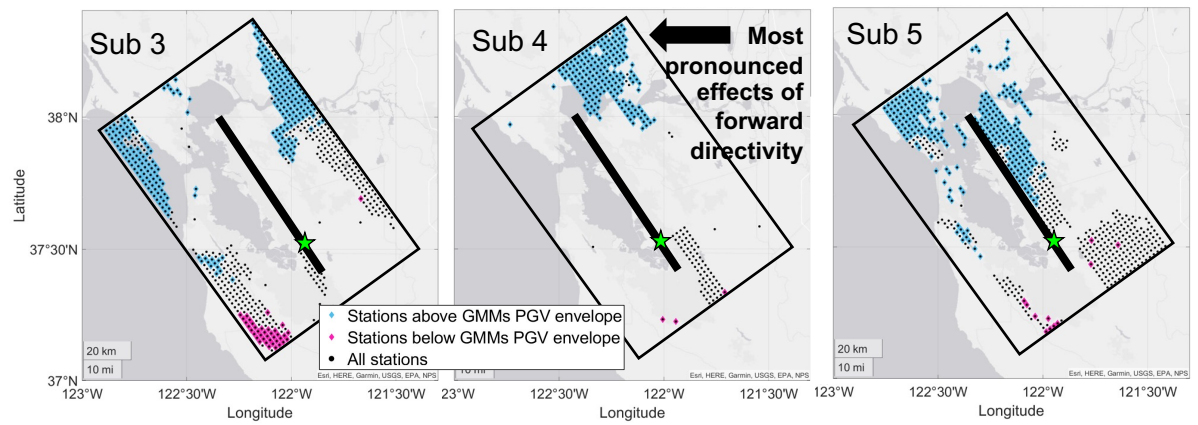


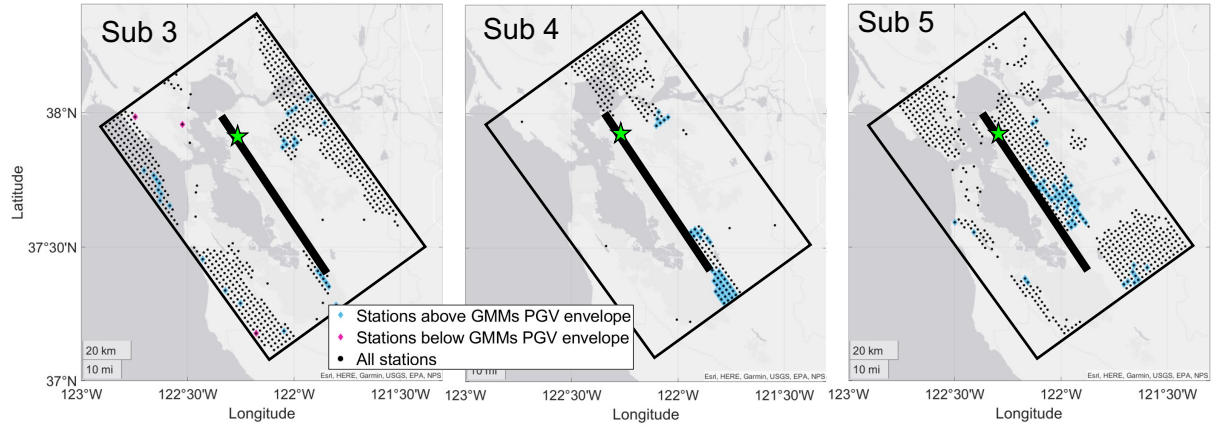
Realization 7



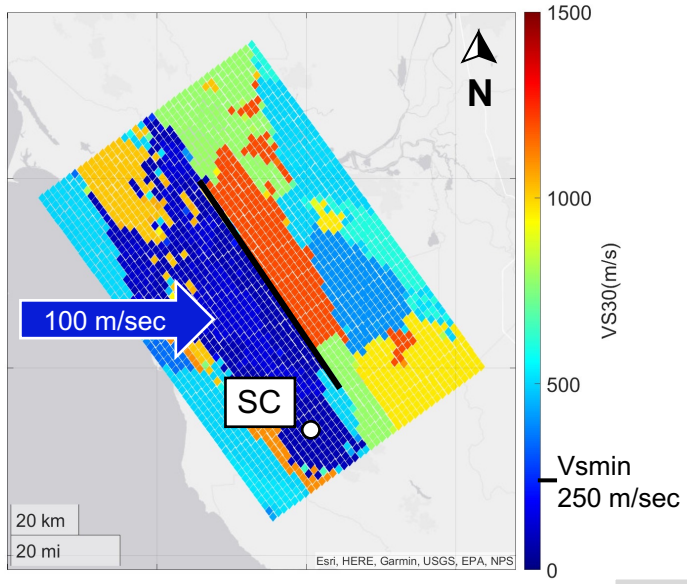




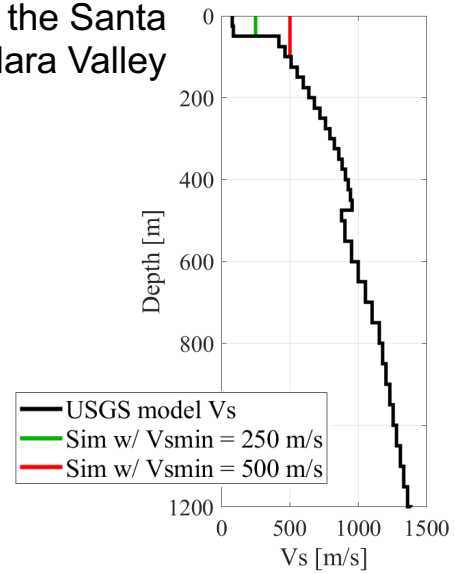




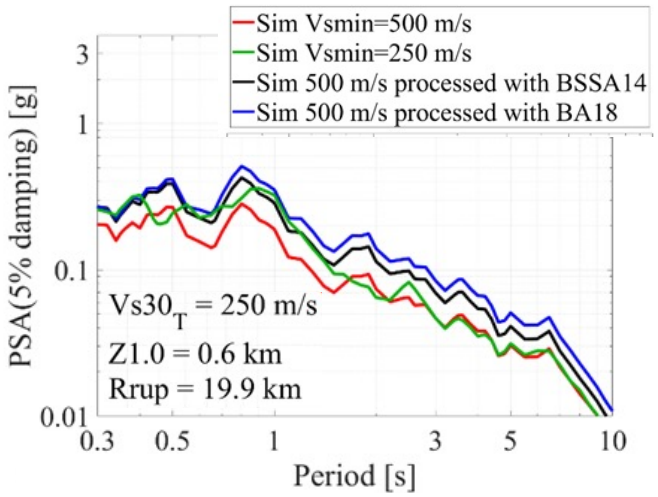
V_{smin} in SFBA simulations

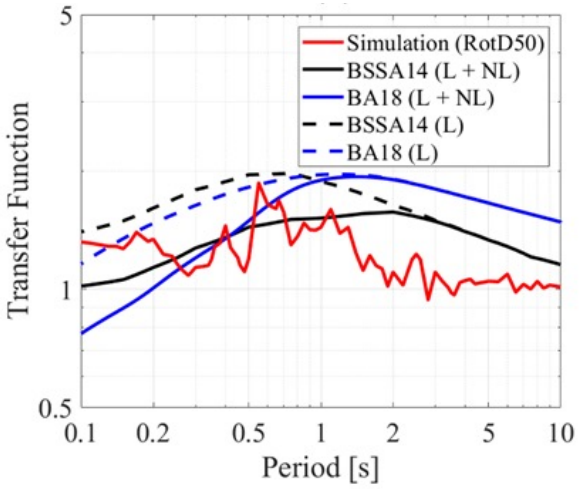


Site in the Santa Clara Valley

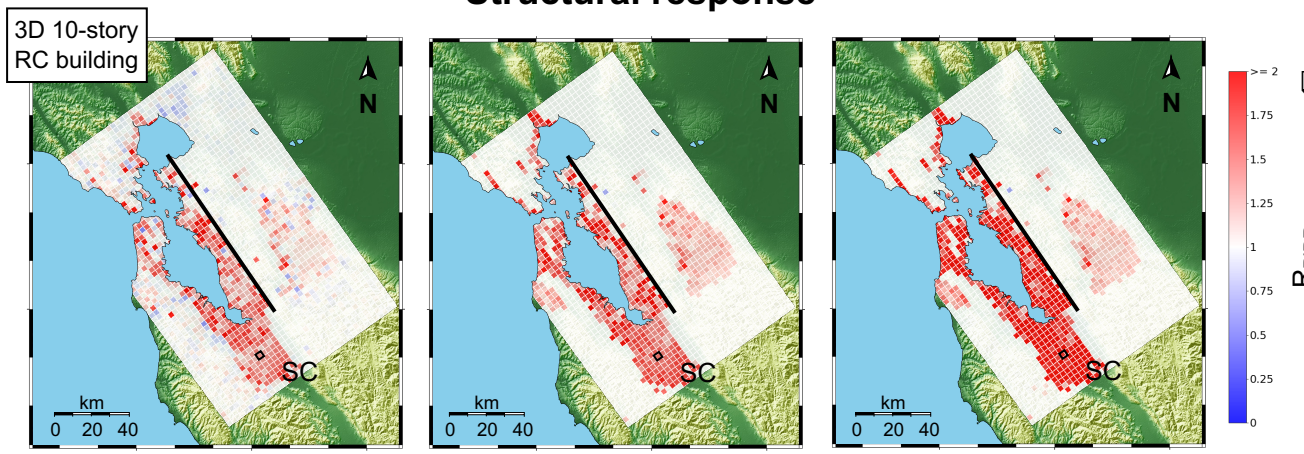


Spectral acceleration: 250 m/sec vs 500 m/sec + empirical factors





Structural response



- Cautious use of empirical factors for regions with geological structures not well represented in the databases of historical records.

Matinrad, P., **Petrone, F.**, Effect of Soft Sediments Modeling on the Seismic Response of a 3D Mid-Rise RC Building: High-Resolution Physics- Based Ground-Motion Simulations versus Empirical Factors (submitted)

Lessons Learned and Ongoing Work…

- Establish a feedback loop with seismologists to inform potential updates of simulation models/methods, based validation studies that look at **(1) multiple metrics and (2) implications on infrastructure response assessments.**

Metadata

- Provide clear guidance on the appropriate utilization of simulated ground motions in engineering domains
  - Max resolved frequency
  - Min shear wave velocity
  - Incorporation of nonlinearities (modeling approach)
  - Evidence from validation across multiple metrics (e.g., bandwidths for GM utilization)

- Current work is extending the application of the proposed validation methodology to **a larger set of empirical models** (non ergodic) and the incorporation of **uncorrelated rupture models.**