

Assessing and Enhancing Seismic Resilience Using Site-Specific Simulated Ground Motions



Selim Günay and Khalid M. Mosalam

Pacific Earthquake Engineering Research Center (PEER)

University of California, Berkeley



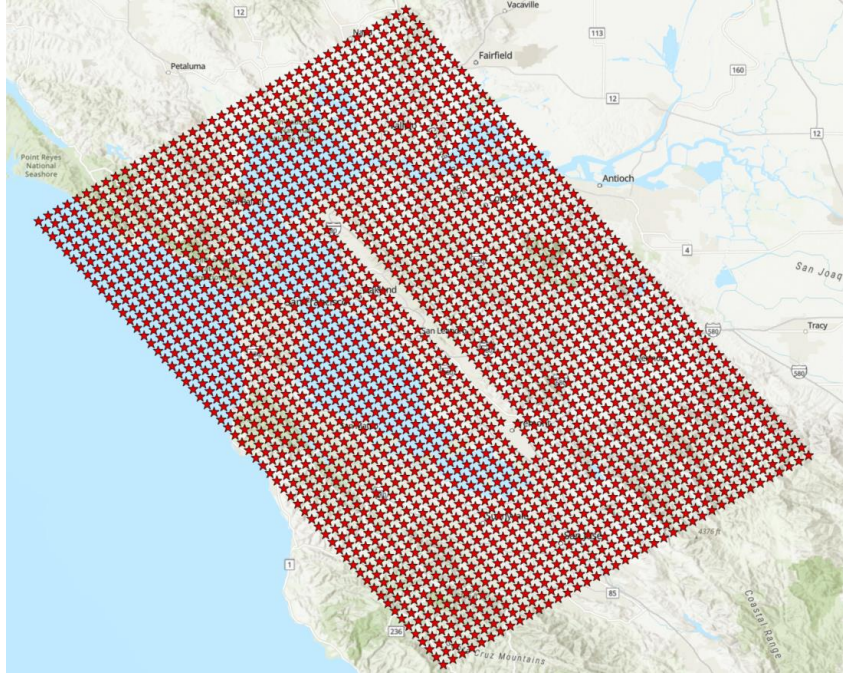
Thanks to SOM engineers & several PEER + CEE lab staff

Outline

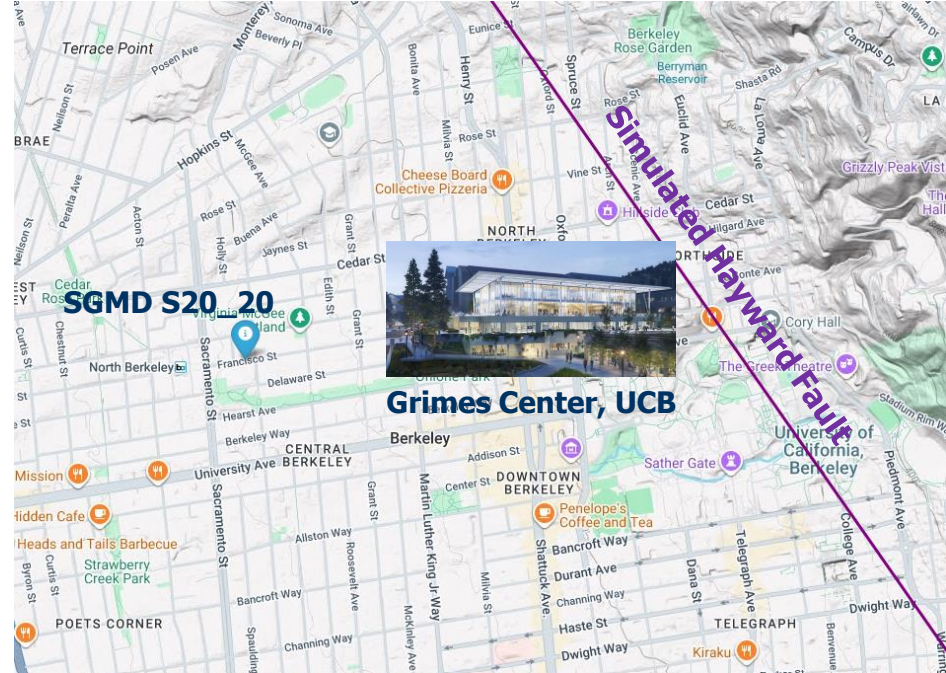
- SGMD: What it enables
- Grimes Engineering Center: Demonstration
- Regional implications

SGMD enables a fundamentally different way to design and assess resilient infrastructure, demonstrated through the Grimes Center

SGMD Bridges Two Scales



Regional-scale (millions of structures)



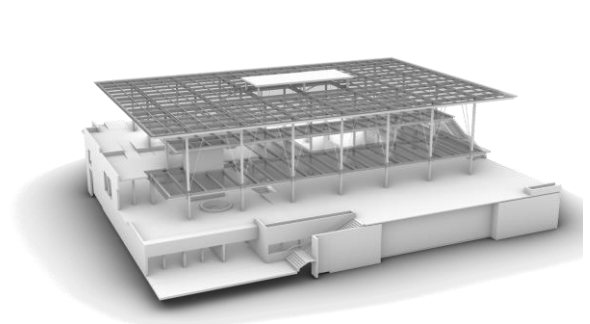
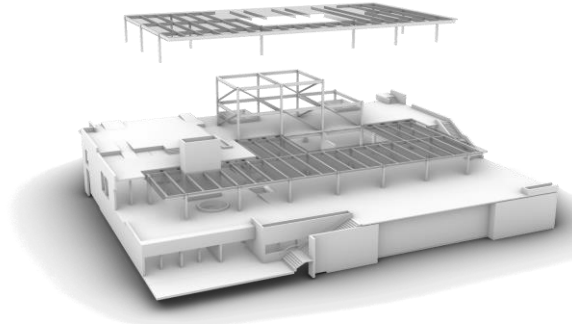
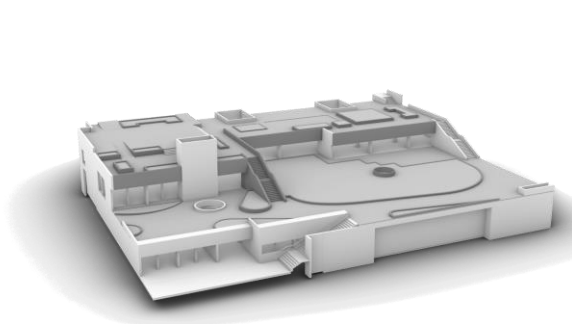
Building-specific assessment (site-specific hazard)

Grimes Center = Living Laboratory for a Resilient Design

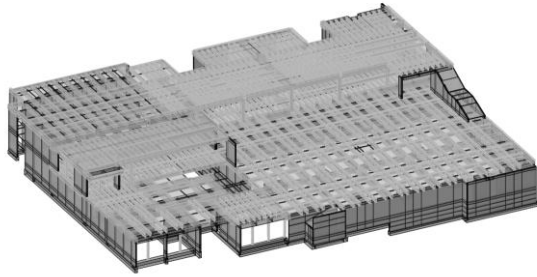
Not just design; Not just experiment

Closed loop: design → test → validate → improve

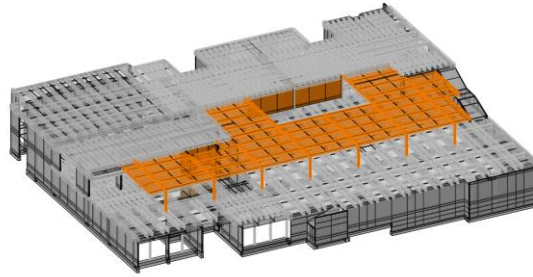
Grimes Center: Designed for Resilience and Rapid Post-Earthquake Immediate Occupancy



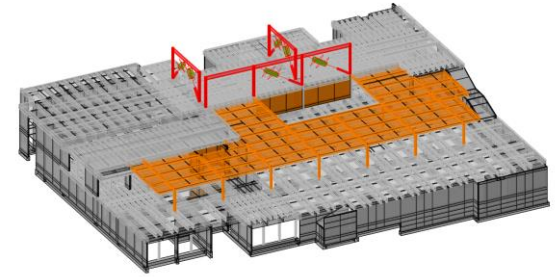
Grimes Engineering Center Structural System



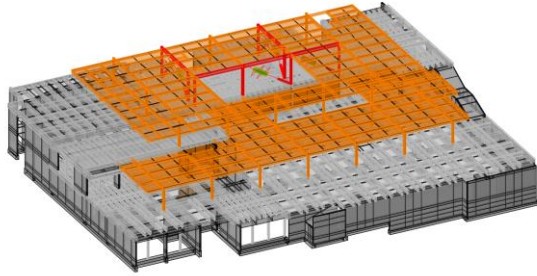
Step 1. Existing Condition



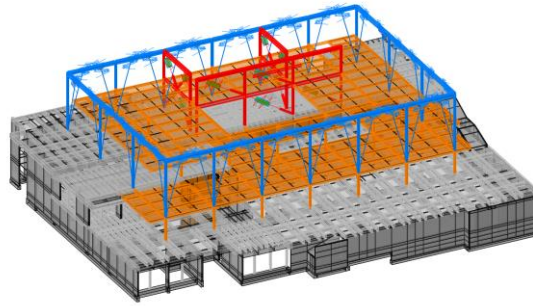
Step 2. Fill out Level 2



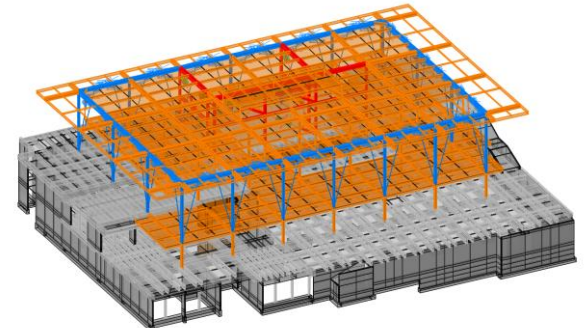
Step 3. **BRB** Interior Frames



Step 4. Add Level 3



Step 5. **SMA** Perimeter Frame



Step 6. Add Roof

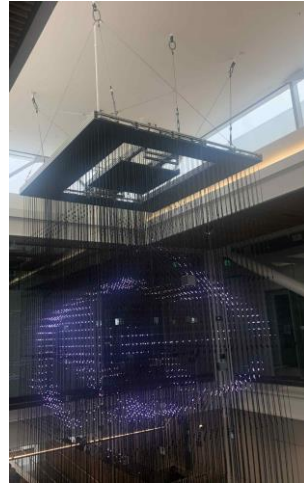
Buckling Restrained Braces (BRB) for ductility and energy dissipation.

Shape Memory Alloy (SMA) braces for recentering, residual drift reduction, and additional energy dissipation.

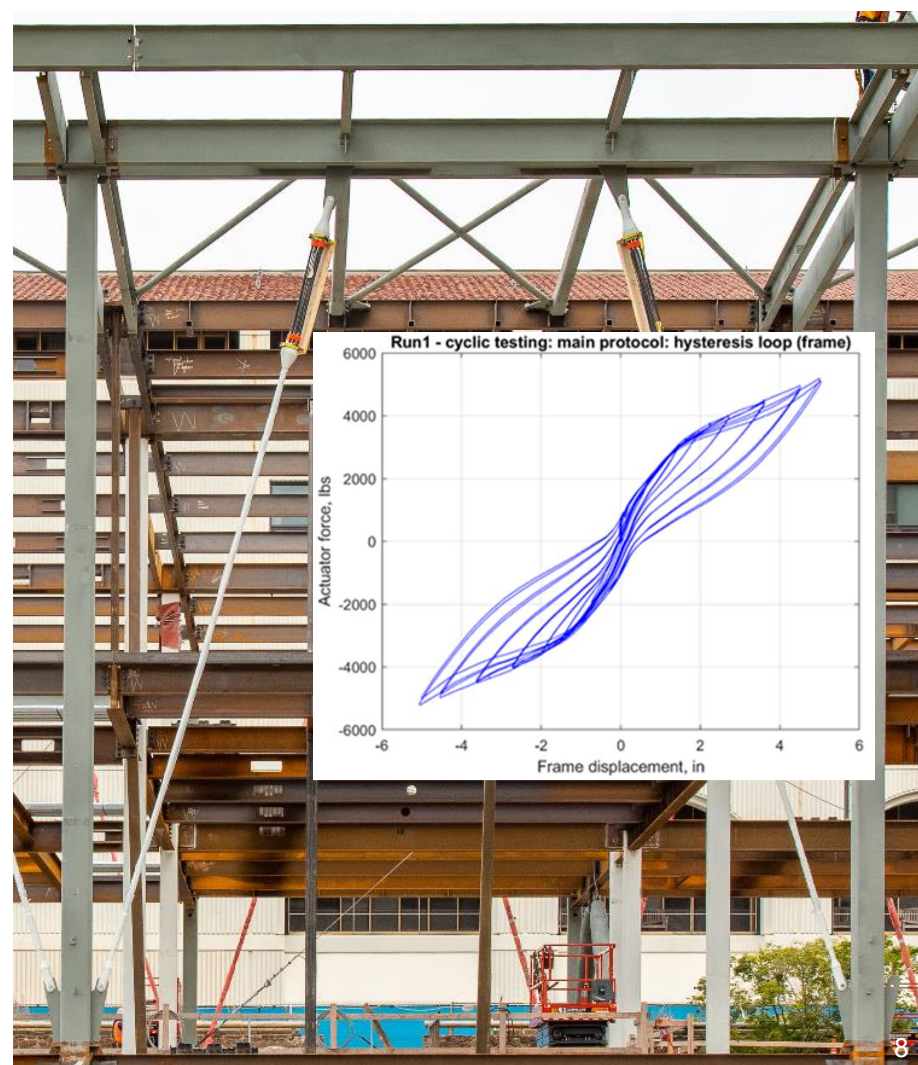
SMA Benefits

Compared to a conventional tension rod system,
SMA reduced:

- ✓ Peak drift by **20%**
- ✓ Residual drift **50%** (up to **75%**)
- ✓ Torsion by **35%**
- ✓ Floor acceleration by **10%** (*Safety of occupants, content & functional recovery*)



This directly impacts functional recovery.

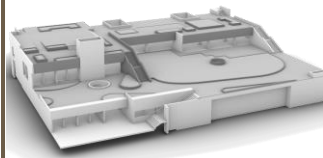


Grimes Center: Design, Experiments, and Condition Assessment

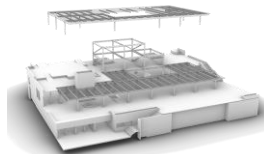
Preliminary Design (SOM)



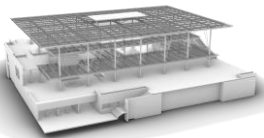
Challenging Location



Reduced Weight



Additional Floor



Lightweight Pavilion

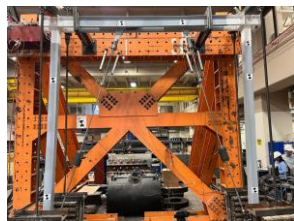
Experiments (PEER/CEE)



Shaking table tests

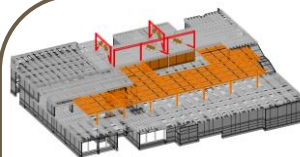


SMA tests

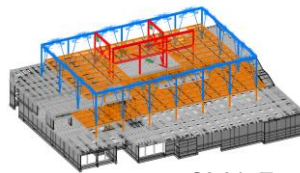


Frame tests

Final Design (SOM)



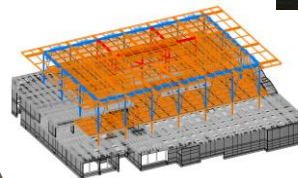
BRB Frames



SMA Frames

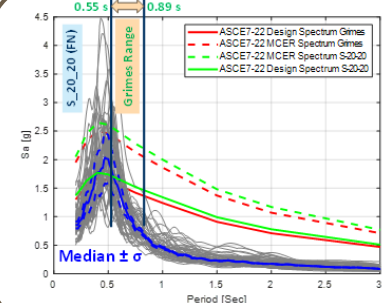
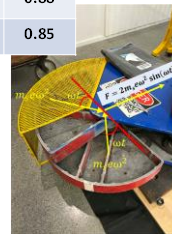


Add Roof



Field Tests & Validation (PEER)

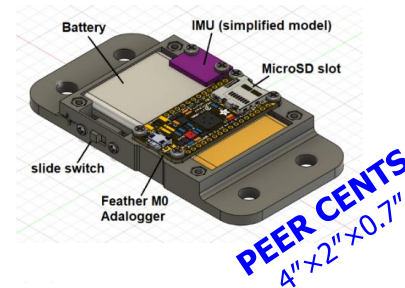
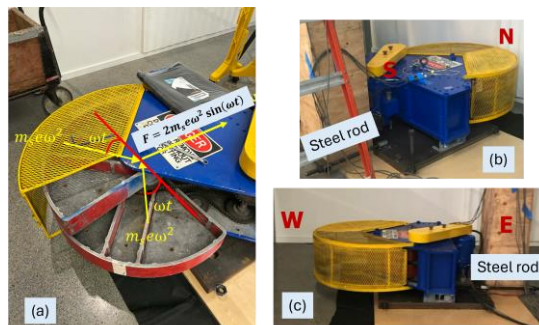
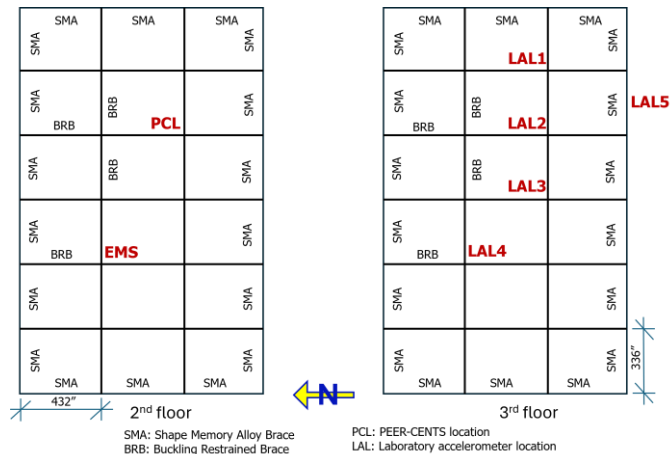
	Period T_n [s]		
	N-S	E-W	Torsion
Analytical	0.55	0.67	0.88
EMS tests	0.65	0.78	0.85



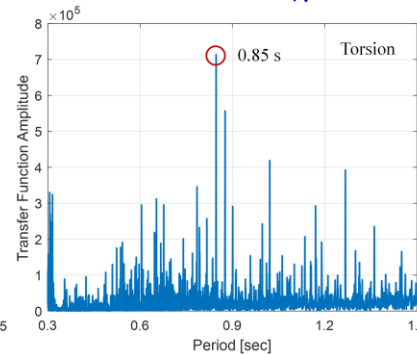
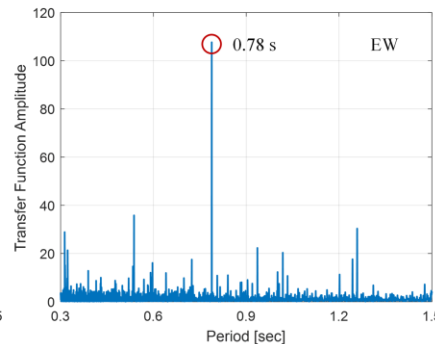
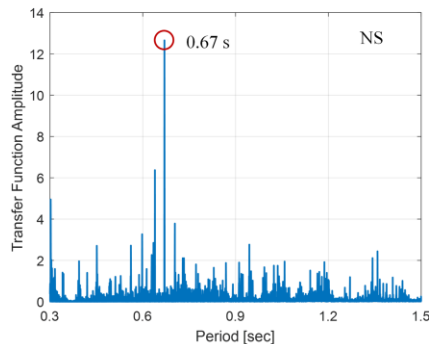
Integration of experiments, field monitoring & physics-based simulation into a unified framework for resilient design.

Field Testing

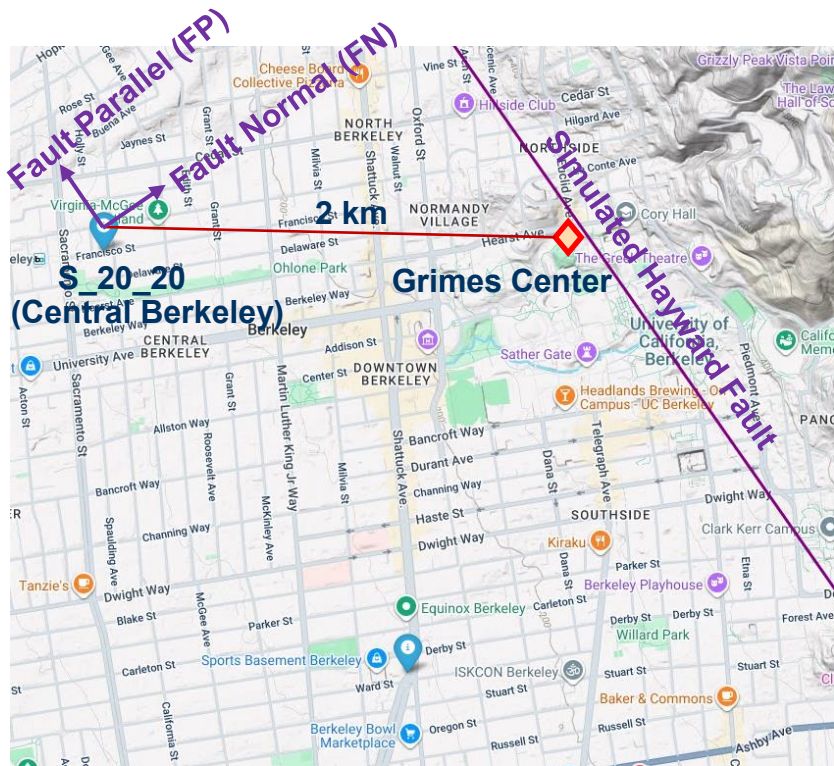
Forced vibration tests using Eccentric Mass Shaker (EMS) → Good agreement with analytical model



	Period T_n [s]		
	N-S	E-W	Torsion
Analytical	0.55	0.67	0.88
EMS tests	0.65	0.78	0.85



SGMD Grimes Center Site Comparison



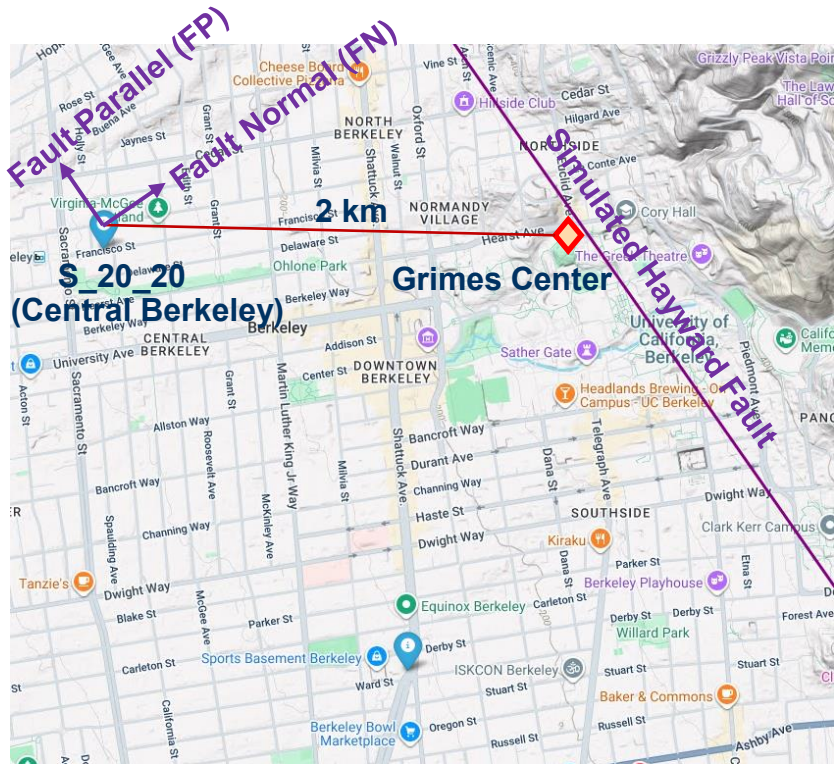
Closest SGMD site to the Grimes Center



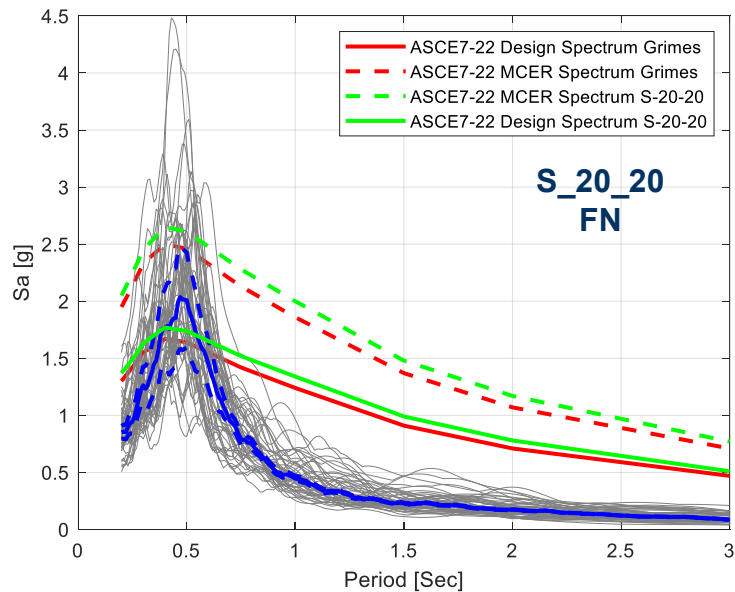
Grimes Center

SGMD provides site-specific, non-ergodic ground motions for condition assessment

SGMD Grimes Center Site Comparison

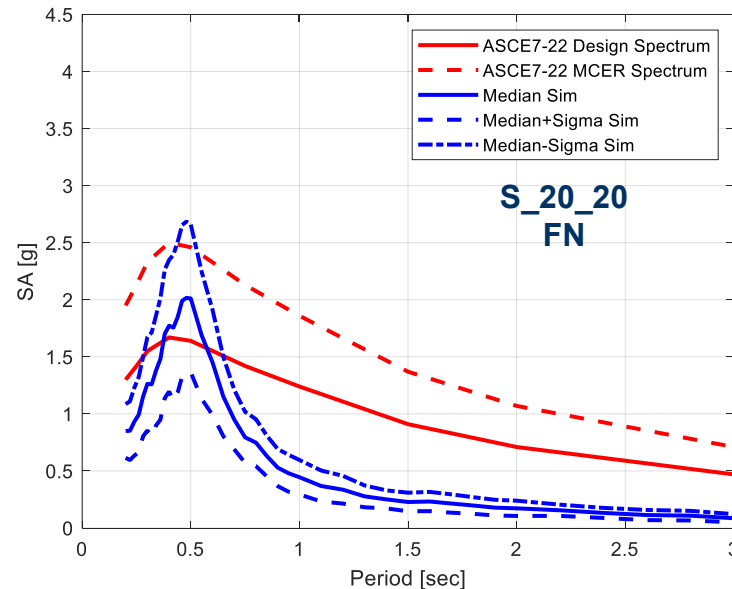
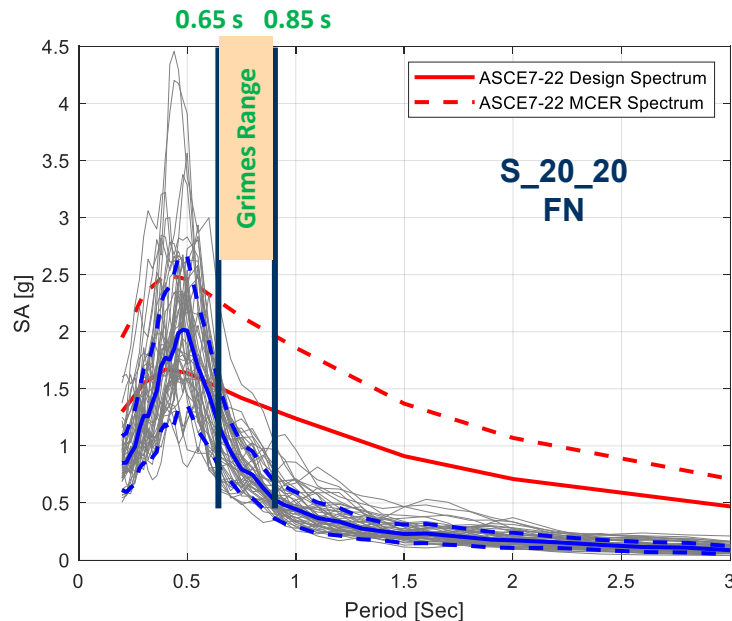


Closest SGMD site to the Grimes Center



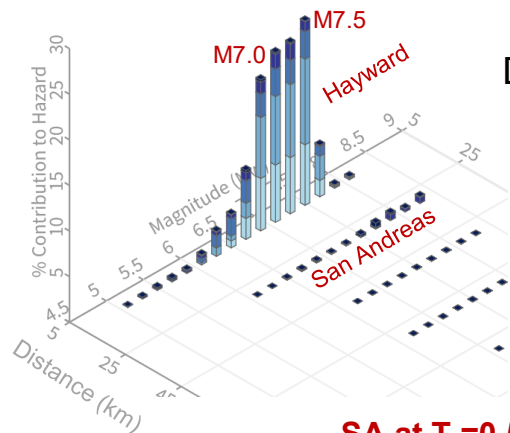
- SGMD sites are available in a 2 km × 2 km spacing.
- Design & MCER spectra at the building & S_20_20 sites are close.
- SGMD spacing (2 km) is sufficient for building-level assessment.

SGMD vs Code Spectra



- At the dominant frequency, some individual motions exceed the MCER spectrum.
- The **median** and **median + 1 σ** responses align well with **Design** & **MCER** spectra.
- For $T > 0.75$ s, all motions are below the Design spectrum. Why?
 - ✓ Code spectra reflect contribution from multiple earthquake scenarios (different magnitudes & faults), particularly at longer periods.
 - ✓ Near- & supershear rupture ($V_r \geq V_s$) amplifies long-period response (*see David McCallen's presentation, morning session*).

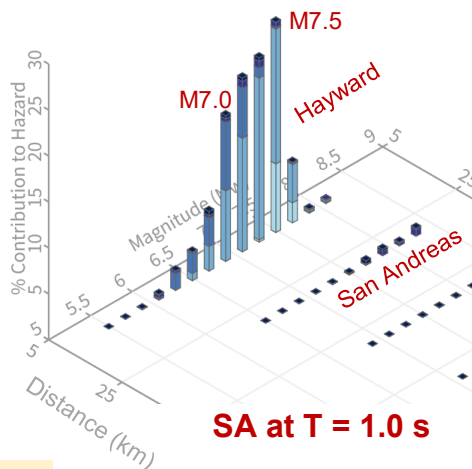
SGMD vs Code Spectra



SA at T = 0.5 s

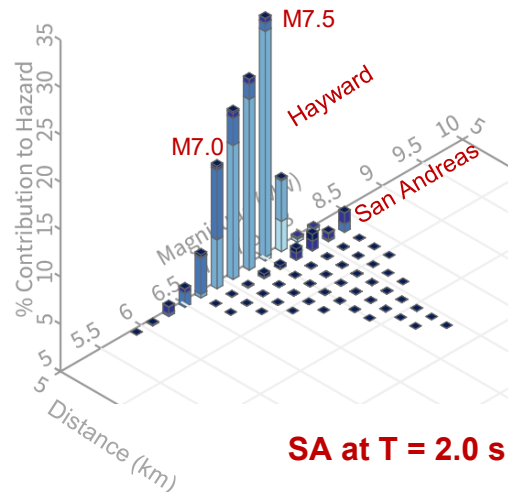
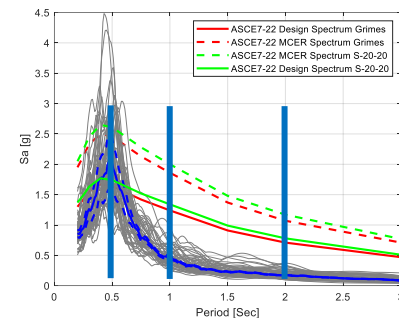
M7.0-7.5 on Hayward Fault contribute to the hazard almost equally → *Some GMs of M7.0 SGMD event are above code level & some are below*

Deaggregation of Hazard using USGS Unified Hazard Tool



SA at T = 1.0 s

**S_20_20
FN**



SA at T = 2.0 s

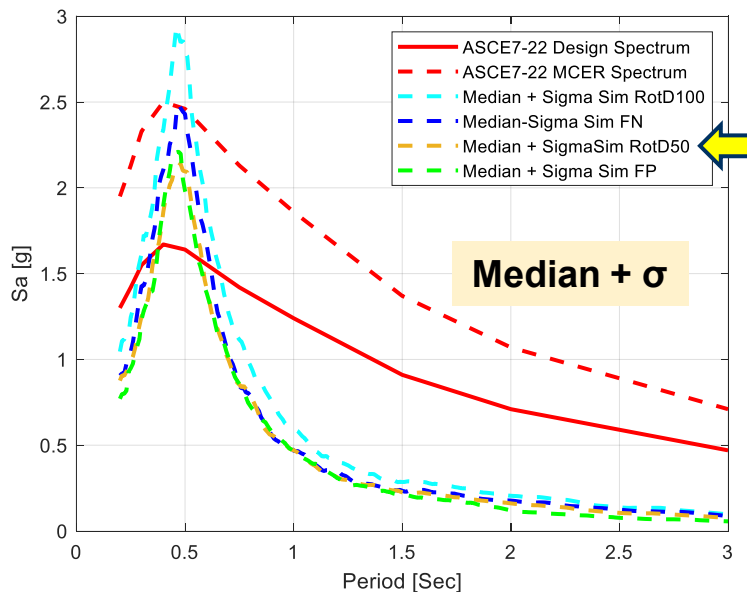
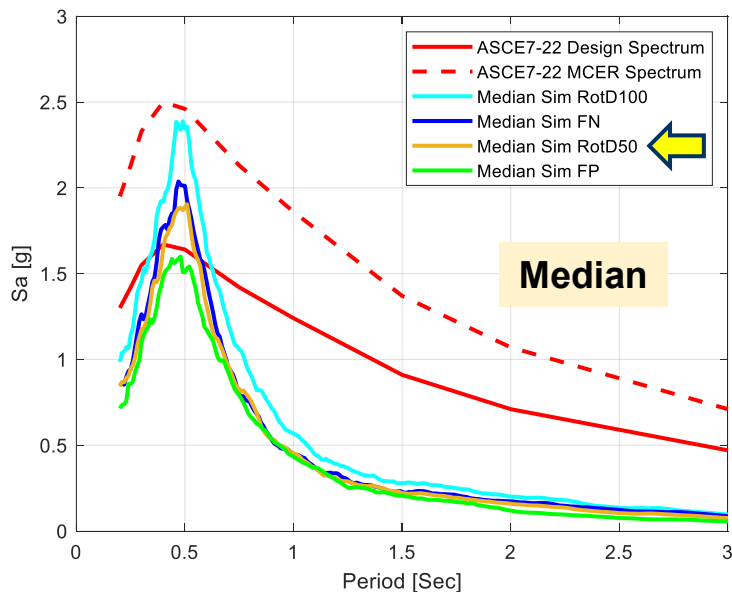
Do we still need to modify ground motions to match code spectra? (discussion)

SGMD provides:

1. Scenario-consistent motions
2. Not an artificial envelope

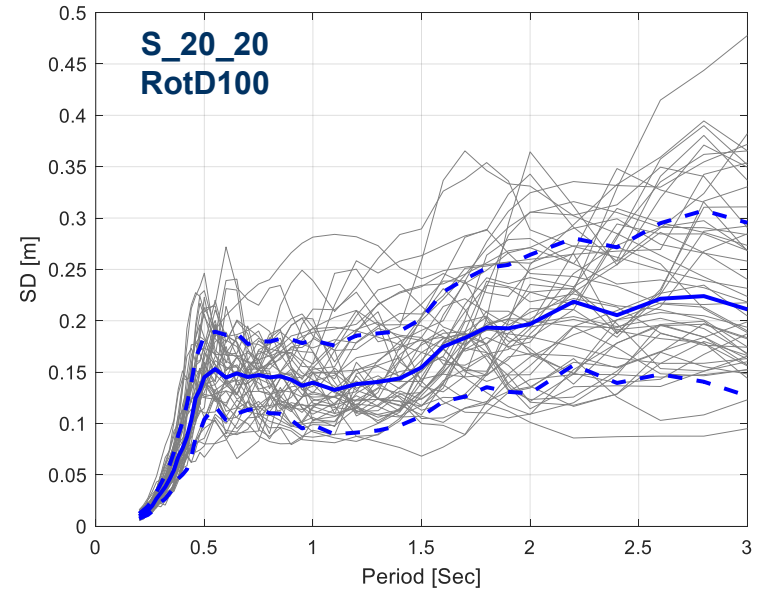
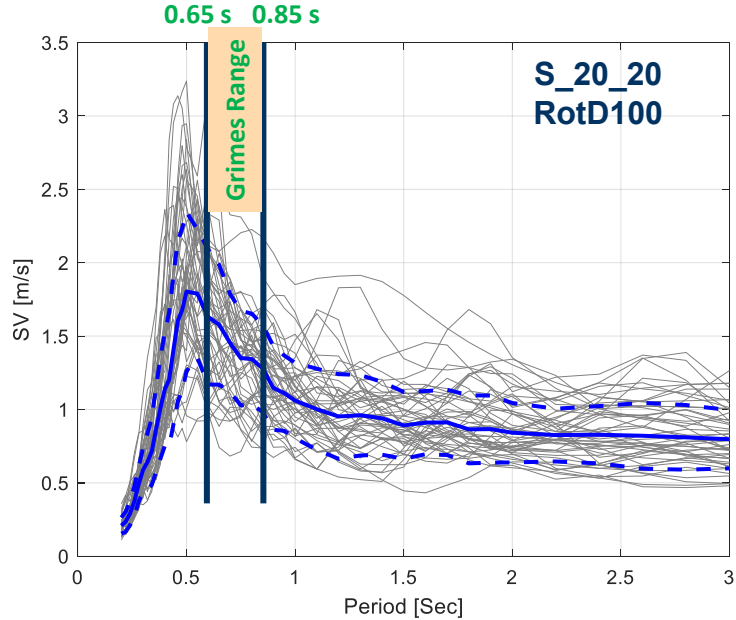
Contribution of M7.0 to hazard is lower than those of larger magnitudes (M7.5 dominates the hazard) → *All GMs of M7.0 SGMD event are below code level*

SGMD Motions and Directionality



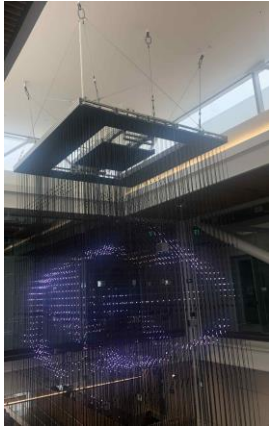
- **SGMD near-fault realism:** RotD100 > FN > RotD50 > FP, as expected from near-fault effects.
- **RotD50 & RotD100** are comparable to **Design & MCER** Spectra, respectively, at dominant frequency.
- **σ across 50 motions** is smallest for RotD50 as it uses median of 180 rotated motions → a smoothed response.

SGMD Motions: Other Spectra



- Velocity peak is at 0.55 s & pulse period is calculated as 0.67 s using wavelets, within natural period range of Grimes Center.
- These ground motions can result in high demands (**pulse period $\approx$ structural period $\rightarrow$ demand amplification**).
- Dispersion increases as the period increases.

SGMD Motions: Nonstructural Components



SGMD enables probabilistic assessment of nonstructural damage. This is where resilience is won or lost, not in collapse, but in functionality.

- Hypercube: 46,000-point LED art installation.
- Suspended from the ceiling.
- SGMD motions used to calculate probability of damage.

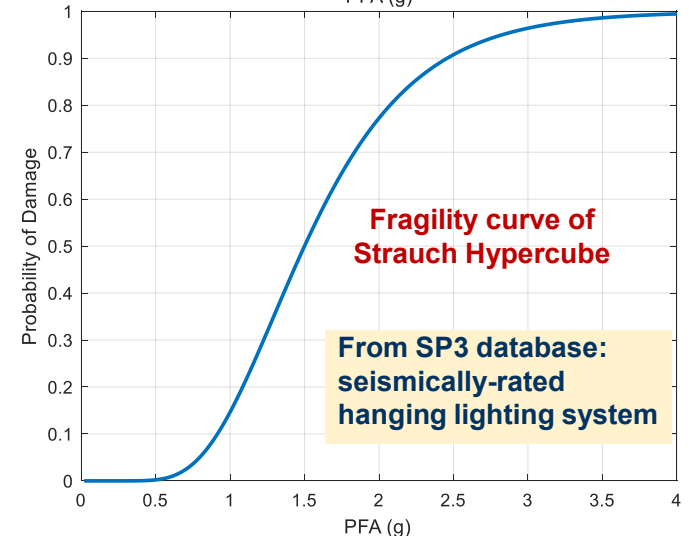
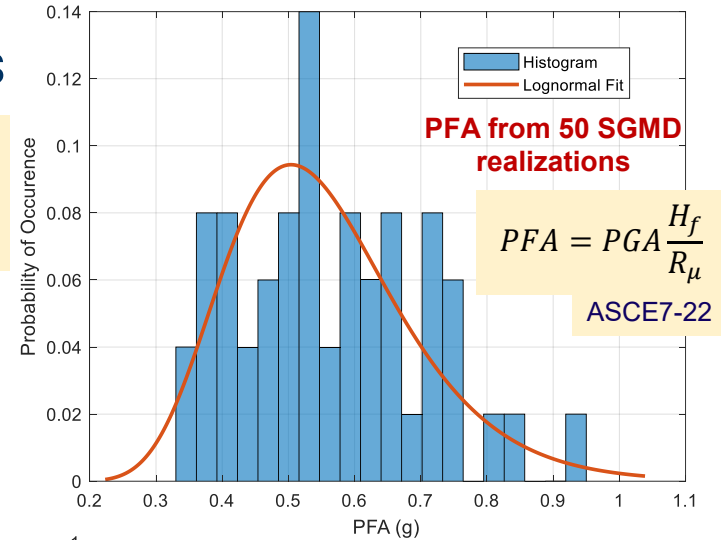
PFA: Peak floor acceleration

H_f : Floor acc. amplification relative to GM as a function of period & height of floor (= 2.1)

R_μ : Structure ductility reduction factor as a function of response modification factor, overstrength factor obtained from R- μ -T relationships (= 1.9)

$$POE(DM) = \sum_{PFA} POE(DM|PFA)p(PFA)$$

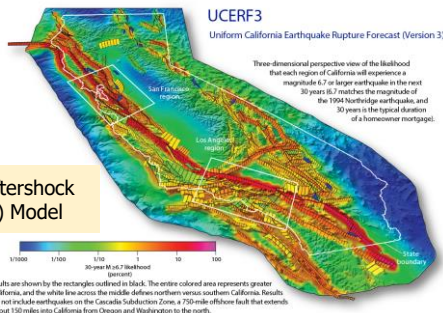
- If M7.0 Hayward scenario in SGMD occurs, **cube probability of damage is 1.3%.**
- According to USGS, Hayward fault has a **51% probability** of producing a M7.0 within the next 30 years.
- This is a promising result for achieving functional recovery.



Potential Use of SGMD for Regional Scale Simulations



Natural Hazards Engineering Research Infrastructure (NHERI) DesignSafe Cyberinfrastructure

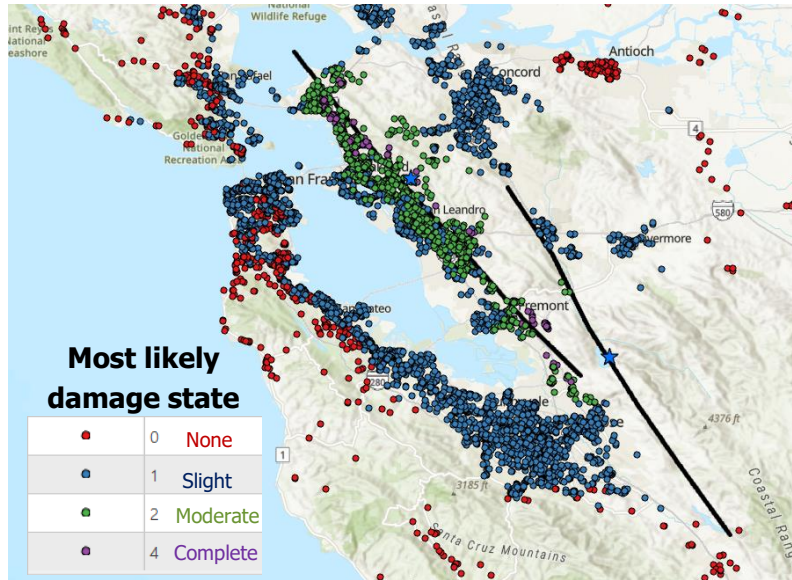


USGS Northern California Scenario

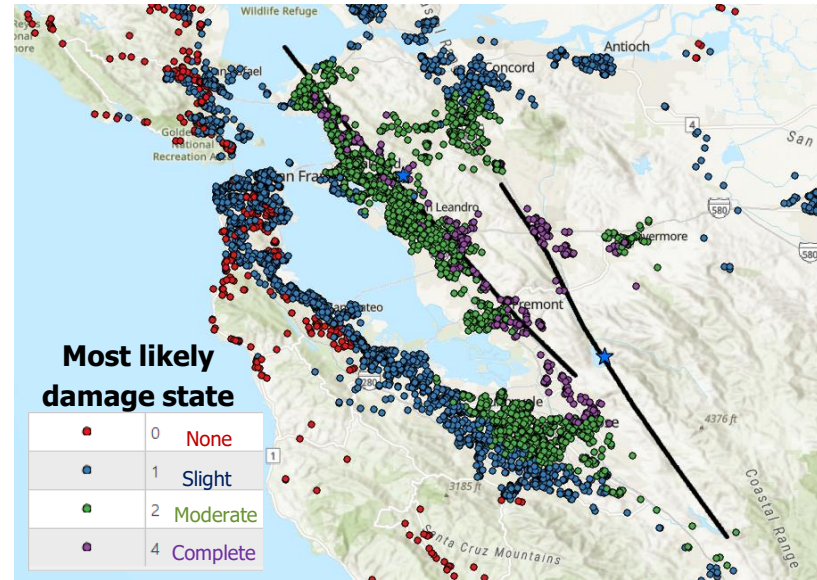
- Mainshock 1: Mw 7.2 on the Hayward fault
- Mainshock 2: Mw 7.2 on the Calaveras fault
- UCERF3-ETAS: 0.6% chance of 2nd event given the 1st

Regional Scale Assessment of Earthquake Sequences in SFBA

Potential Use of SGMD for Regional Scale Simulations



After 1st mainshock: Magnitude 7.2 on Hayward fault



After 2nd mainshock: Magnitude 7.2 on Calaveras fault



Future SGMD to enable (discussion):

1. Multi-event scenarios (ETAS)
2. Regional risk (millions of buildings)

- Regional scale assessment includes approximately 4 million buildings in SFBA
- Results from RC buildings with moment resisting frames shown

SGMD can be expanded to include earthquake sequence scenarios in the future

Conclusion

- SGMD provides site-specific, scenario-consistent ground motions
- SGMD enables direct use without artificial spectral matching or amplitude scaling
- SGMD supports both structural and nonstructural assessment
- SGMD allows scales from single building to regional simulations
- SGMD is a key enabler for resilient and performance-based design

SGMD is not just a dataset, it is a new paradigm for seismic design and assessment.