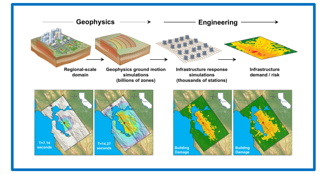
PEER International Pacific Rim Forum, June 16-17, 2021, online



Developing a Community Accessible Database of Synthetic Ground Motion Records

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Acknowledgements: Dr. S. Günay & Mr. E. Choi

Forum Context

Regional scale simulations are at the forefront of PEER current & future directions:

- Very relevant use of PBEE technologies
- Truly achieving community resilience
- Functional recovery on all infrastructure levels

Pacific Rim Forum is important for PEER:

- Earthquake engineering community engagement
- Bringing together multidisciplinary expertise from structural and geotechnical engineering together with earth science
- Sharing research results and state-of-the-art & state-of-practice advancements
- Highlighting 21st century technologies, particularly HPC & Data Science and their potential adoption in PEER activities

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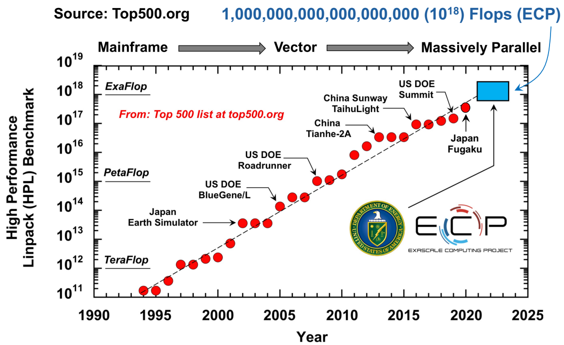
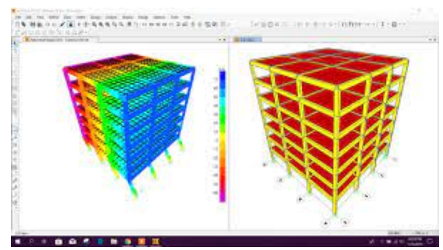
Earthquake Engineering Profession



Past (H)

Earthquake Engineering Fundamentals

Current (H-MC*)



Ductile Response + Collapse Prevention + Saving Lives + Loss estimation

*H-MC: Human-Machine Collaboration

Future (M)

Functional Recovery + Resilient Communities

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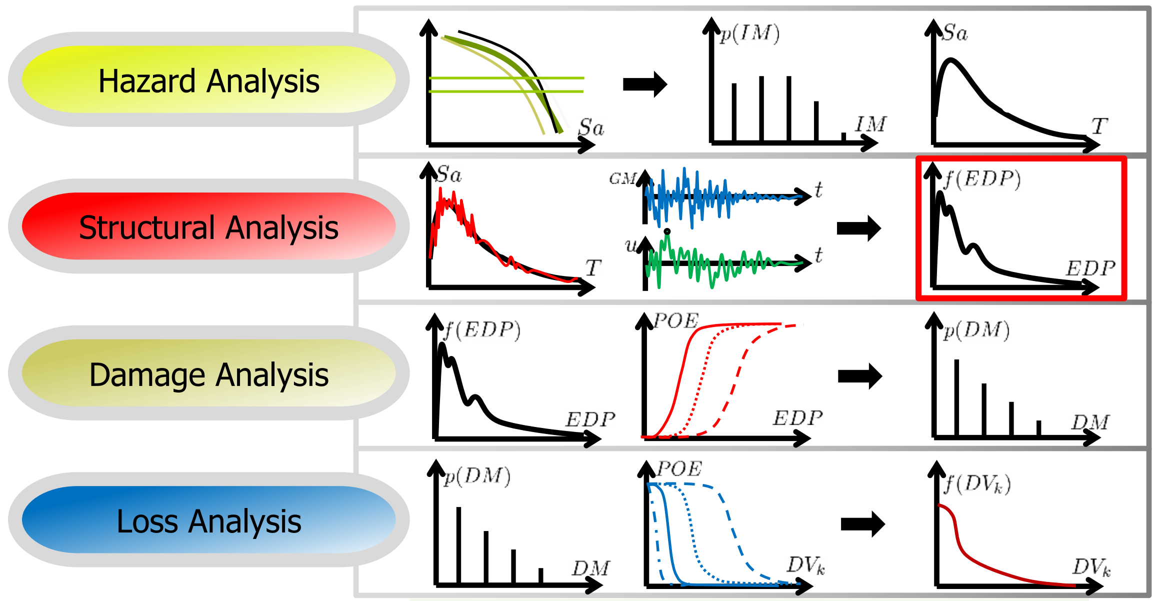
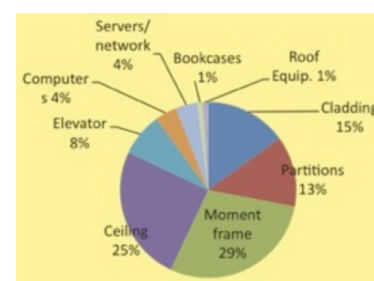
PEER PBEE Framework



Probabilistic PBEE Framework

$$\lambda(DV > dv) = \int_{im}\int_{dm}\int_{edp} G(dv \mid dm)\,dG(dm \mid edp)\,dG(edp \mid im)\left|d\lambda(im)\right|$$



Loss Assessment

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Why Did PEER Develop the Ground Motion (GM) Databases?

- Objective of PBEE: Realistic quantification of uncertainty & estimation of structural system performance
- First, proper definition of the hazard and the corresponding selection of ground motions (GMs) are needed.
- Historically, access to earthquake GM has been hampered by difficult access to “big data”, and by data gathering & storage inconsistencies.
- Late 1990s, PEER recognized the need to improve access to earthquake GM data and embarked on an effort to create a web-based searchable database of strong GM data.

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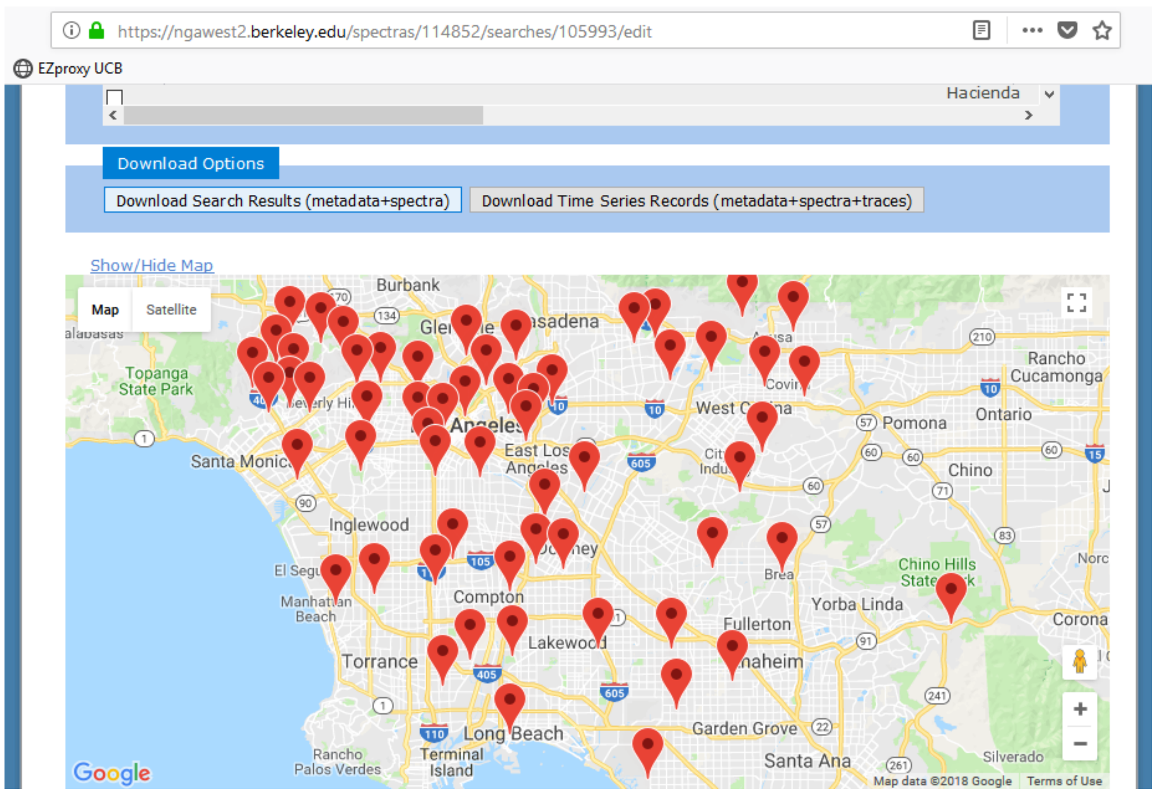
How Did PEER Develop the Ground Motion Databases?

1. Collect the most important GM records worldwide.
2. Ensure that all data had been processed consistently & reliably.



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How Did PEER Develop the Ground Motion Databases?

3. Collect related metadata: earthquake magnitude, various site-to-source distance measures, type of faulting, local site conditions at the recording stations, and other relevant engineering parameters.

	A	B	C	AV	AW	AX	AY	AZ
1	Record Sequence Number	EQID	Earthquake Name	EpiD (km)	HypD (km)	Joyner-Boore Dist. (km)	Campbell R Dist. (km)	RmsD (km)
737	736	0118	Loma Prieta	61.49	63.92	40.85	-999	59.53
738	737	0118	Loma Prieta	40.12	43.76	24.27	-999	39.18
739	738	0118	Loma Prieta	90.77	92.43	70.9	-999	89.24
740	739	0118	Loma Prieta	26.57	31.81	19.9	-999	28.64
741	740	0118	Loma Prieta	26.57	31.81	19.9	-999	28.64
742	741	0118	Loma Prieta	9.01	19.66	3.85	-999	17.46
743	742	0118	Loma Prieta	81.15	83.02	61.15	-999	79.97
744	743	0118	Loma Prieta	86.90	88.64	66.89	-999	85.82
745	744	0118	Loma Prieta	70.71	72.84	50.71	-999	69.24

Screenshot from the NGA-West Flatfile

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How Did PEER Develop the Ground Motion Databases?

4. PEER created the online database making all information publicly available.
5. Various enhancements to the database have been made over the years.

PEER Strong Ground Motion Databases

New NGA-East Ground Motion Database

The NGA-East database constitutes the largest database of processed recorded ground motions in Stable Continental Regions (SRCs). It was developed as part of a large multi-disciplinary research project coordinated by PEER. The NGA-East database includes the two- and three-component ground-motion recordings from numerous selected events (M > 2.5, distances up to 1500 km) recorded in the Central and Eastern North America (CENA) region since 1988. The database contains over 29,000 records from 81 earthquake events and 1379 recording stations. The database includes time series and pseudo-spectral acceleration (PSA) for the 5%-damped elastic oscillators with periods ranging from 0.01 to 10 sec. Additionally, the NGA-East database includes Fourier amplitude spectral (FAS) of the processed ground motions.

NGA-East was jointly sponsored by the U.S. Nuclear Regulatory Commission (NRC), the U.S. Department of Energy (DOE), the Electric Power Research Institute (EPRI) and the U.S. Geological Survey (USGS).

New NGA-West 2 Ground Motion Database

The new NGA-West 2 Database is larger than the old database by a factor of six, and also new features have been added to the new online tool.

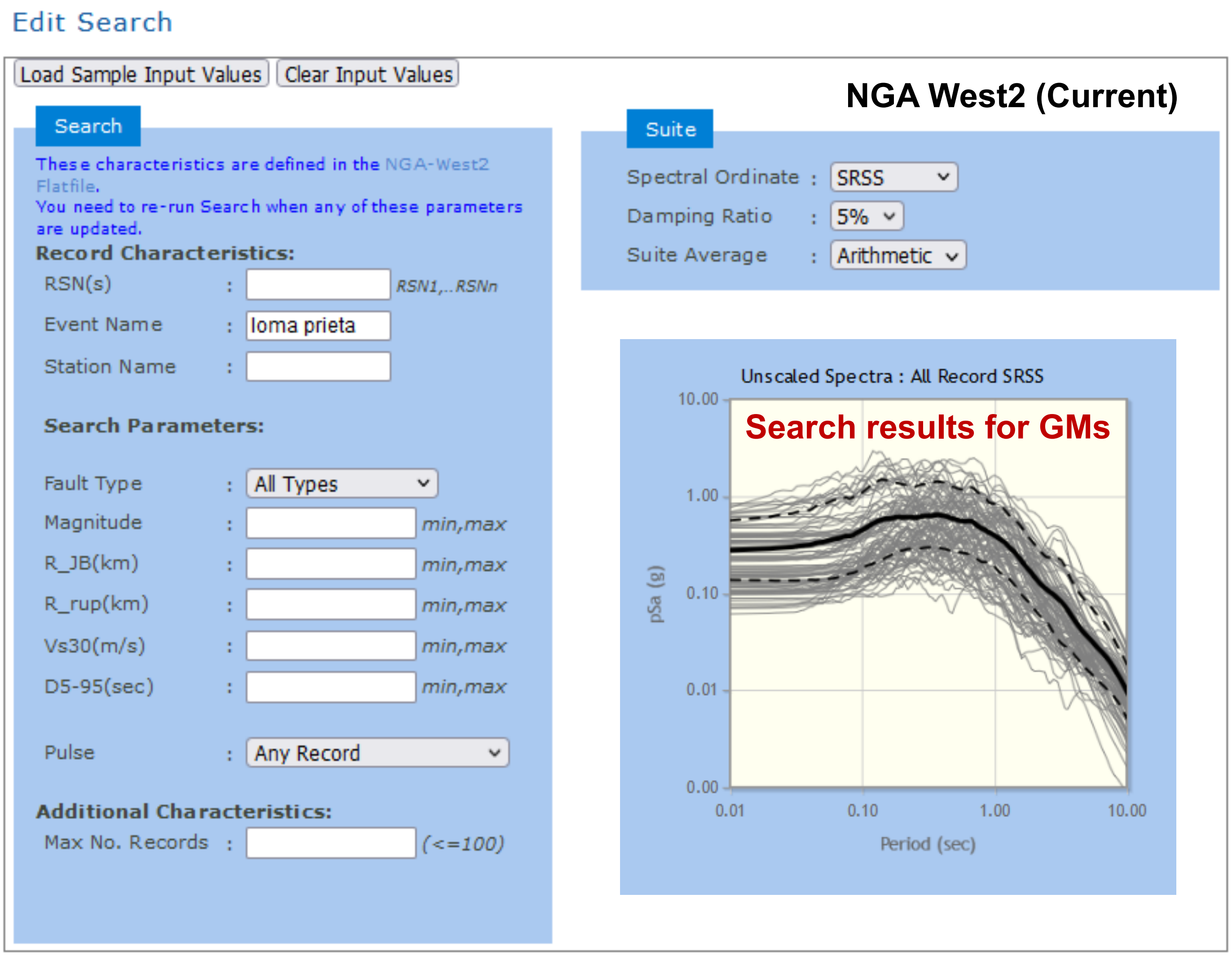
The Pacific Earthquake Engineering Research Center (PEER) ground motion database includes a very large set of ground motions recorded worldwide of shallow crustal earthquakes in active tectonic regimes. The database has one of the most comprehensive sets of metadata, including different distance measures, various site characterizations, and earthquake source data.

https://peer.berkeley.edu/peer-strong-ground-motion-databases

Key Requirements of a Successful Database

- ✓ Proper maintenance
- ✓ *Effective web interface with well-defined search options*
- ✓ Procedure to expand the database with new data
- ✓ Scalability, e.g., server with sufficient storage, etc.

PEER Ground Motion Databases



Synthetic Ground Motion Database

New NGA-East Ground Motion Database

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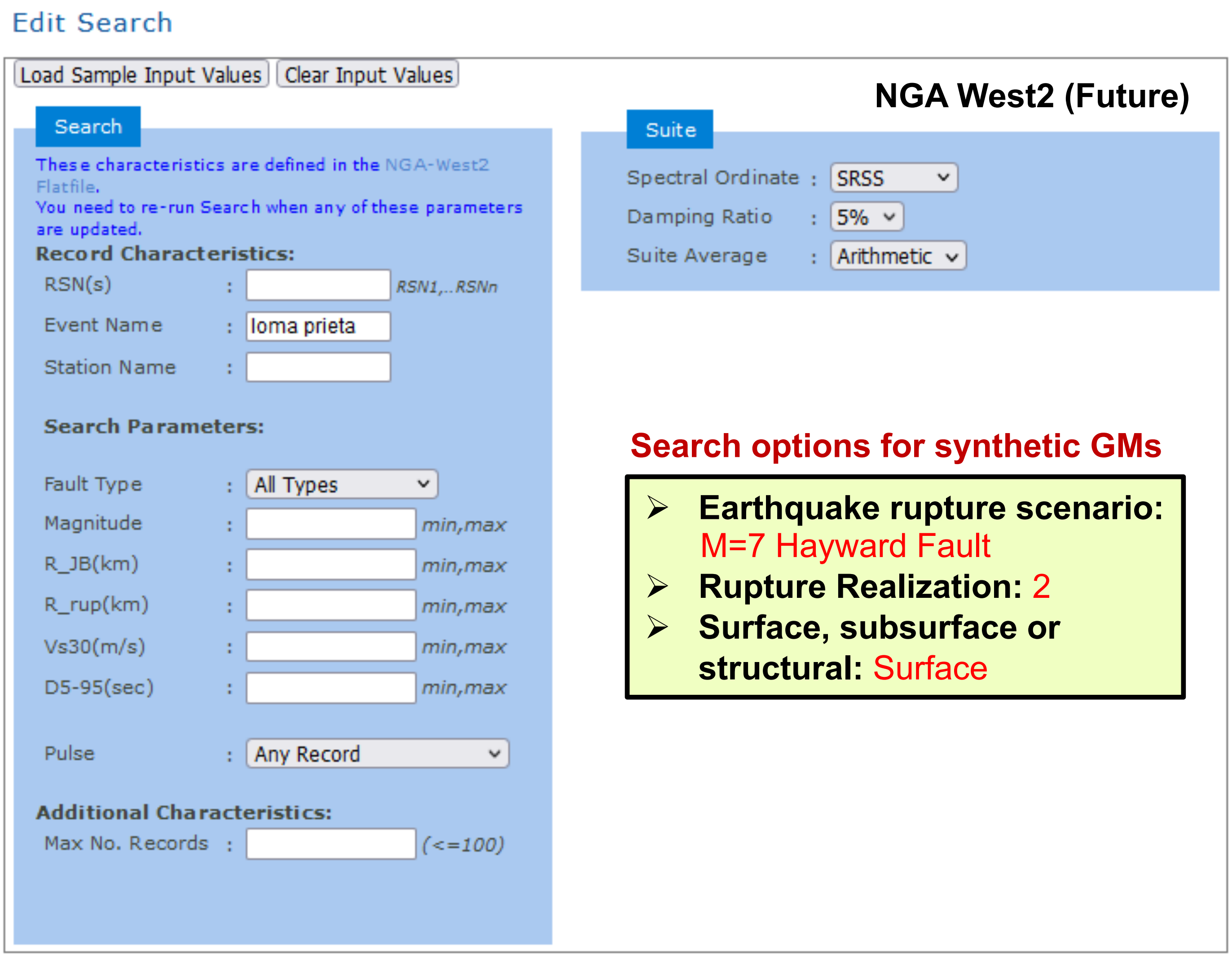
New Synthetic Motion Database

PEER Ground Motion Databases



Search options for synthetic GMs

- **Earthquake rupture scenario:** M=7 Hayward Fault
- **Rupture Realization:** 2
- **Surface, subsurface or structural:** Surface

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Engaging the Earthquake Engineering Community

- <u>Value Proposition of PEER</u>:
  - Earthquake Engineering Center with 11 core institutions, 9 educational affiliates and 150+ faculty and many researcher/students
  - Developing and advancing PBEE **Framework**; Culture of developing and maintaining enabling technology tools (e.g., OpenSees & NGA databases)
  - Active connections to the Earthquake Engineering profession (**BIP**) in CA, other states, and internationally
- PEER hosting & maintaining the database add an important value to the broader use and impact of the synthetic motions.
- PEER can facilitate use of synthetic motions in transportation & other systems research and provide links to OpenSees and other tools (SimCenter, SoilQuake, etc.) & databases (NGA, NGL, Ø-Net, etc.).
- Addition of the synthetic GM database is a <u>timely opportunity</u> to engage the Earthquake Engineering community.
- Leveraging DOE resources will benefit the PEER community at large.

Engaging the Earthquake Engineering Community

- Database interface is planned to include a feedback feature.
- Engineers & researchers are to provide feedback on the database & its uses and to suggest improvements.
- Feedback publicly posted & monthly considered in website updates.
- The Earthquake Engineering community input will facilitate design standard guidance for synthetic motions & realize their benefits.

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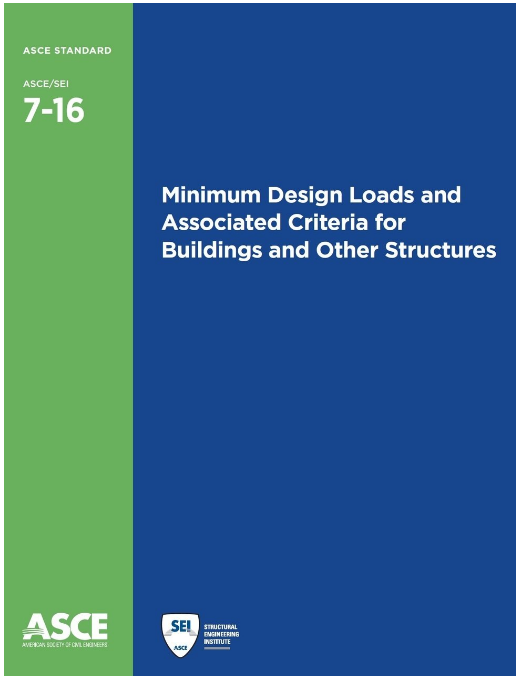
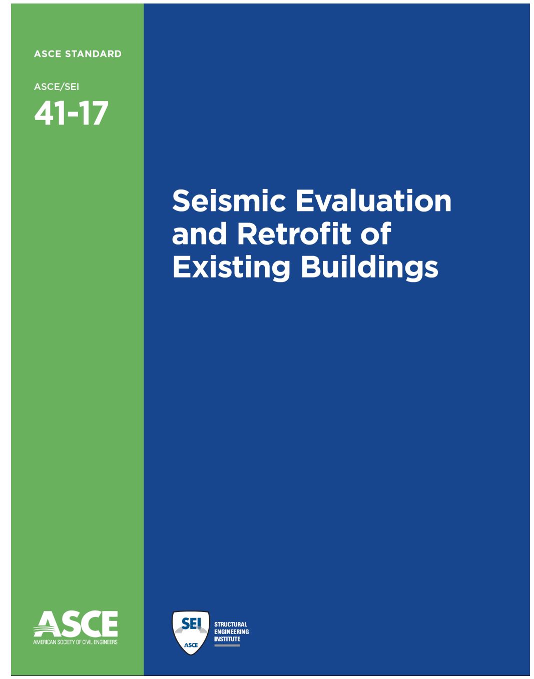
Transition to Practice



ASCE 7-16

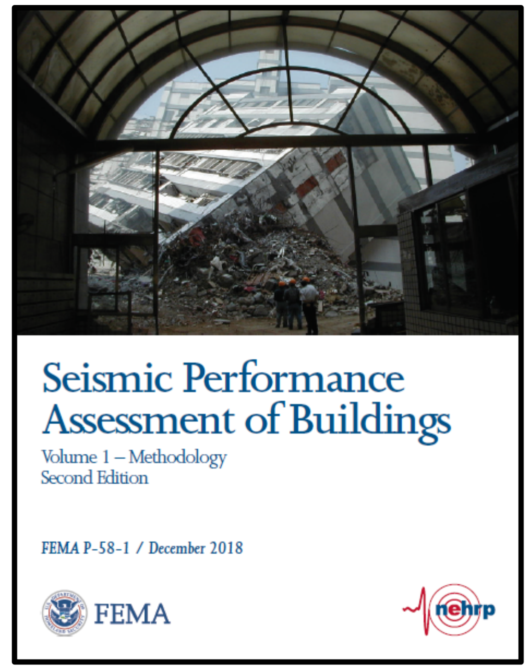


ASCE 41-17

- ASCE 7-16 requires a minimum of 11 ground motion time histories for each target spectrum.
- ASCE 7-16 Section 16.2.2: “Where the required number of recorded ground motions is not available, it shall be permitted to supplement the available records with simulated ground motions.”

Transition to Practice

Tall Buildings Initiative

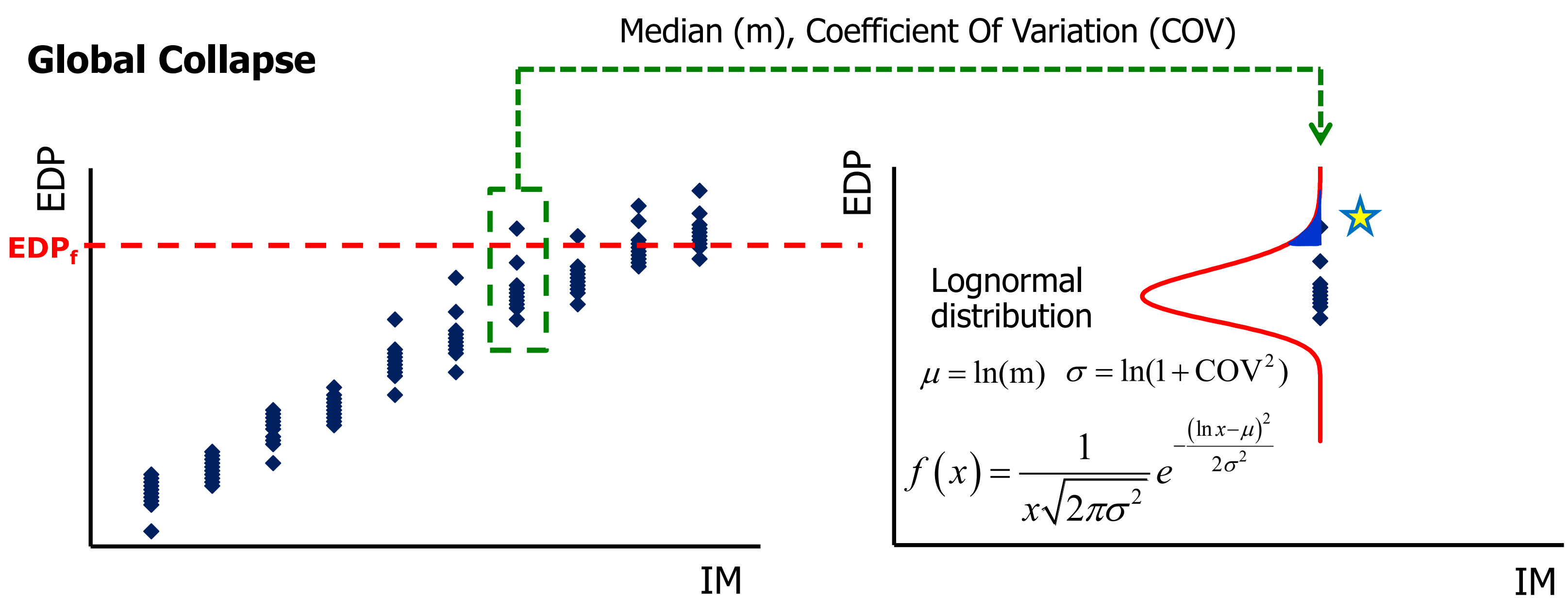


FEMA P-58

- ➢ A minimum of 11 ground motions are required for dynamic analysis.
- ➢ In PBEE, large number of GMs are needed to:
  - Quantify the uncertainty in structural/foundation response
  - Estimate probability of collapse

Transition to Practice

Global Collapse



p(C|IM) = # of GMs causing collapse/total # of GMs or shaded area

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Transition to Practice

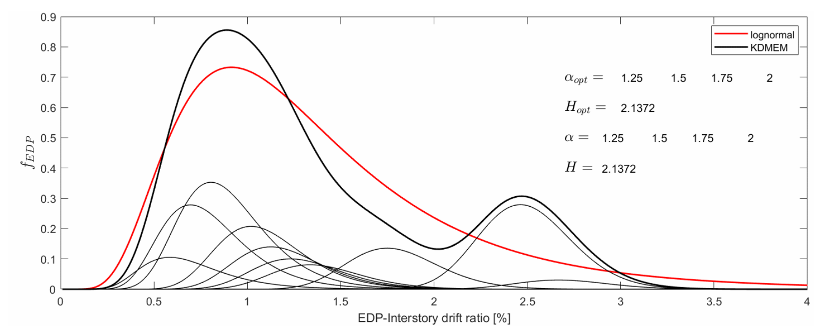
Kernel Density Maximum Entropy Method in PBEE

In probabilistic PBEE method, good estimation of distribution is required

- Kernel Density Maximum Entropy Method

$$f_{KD}(x,\boldsymbol{p}) = \sum_{i=1}^{N} p_i f_X^{(i)}(x)$$

- Obtain $\boldsymbol{p}^*$ by solving maximum entropy problem



$$\max_{\boldsymbol{p},\boldsymbol{\alpha}} H(\boldsymbol{p},\boldsymbol{\alpha})$$

$$s.t. \sum_{i=1}^{N} p_i = 1$$

$$\sum_{i=1}^{N} p_i \int_X x^{\alpha_k} f_X^{(i)}(x)dx = \frac{1}{N}\sum_{i=1}^{N} x_i^{\alpha_k} \quad for\ k = 1,2,\dots,M$$

$$where\ \boldsymbol{\alpha} \in \mathbb{R}^M\ is\ a\ set\ of\ fractional\ powers$$

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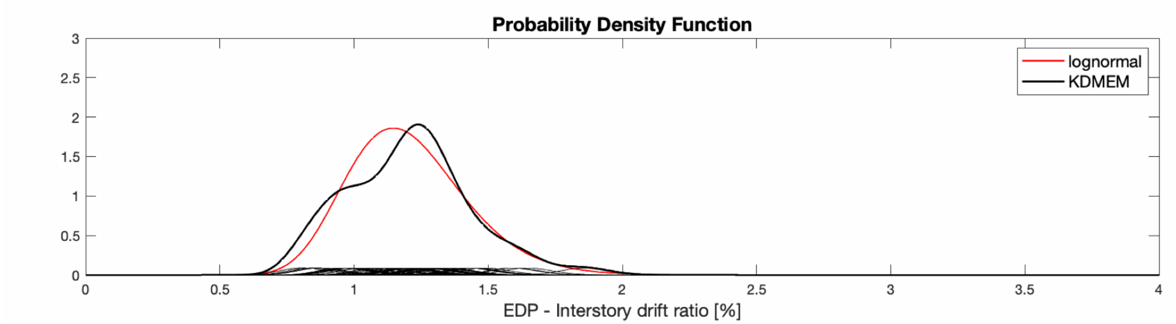
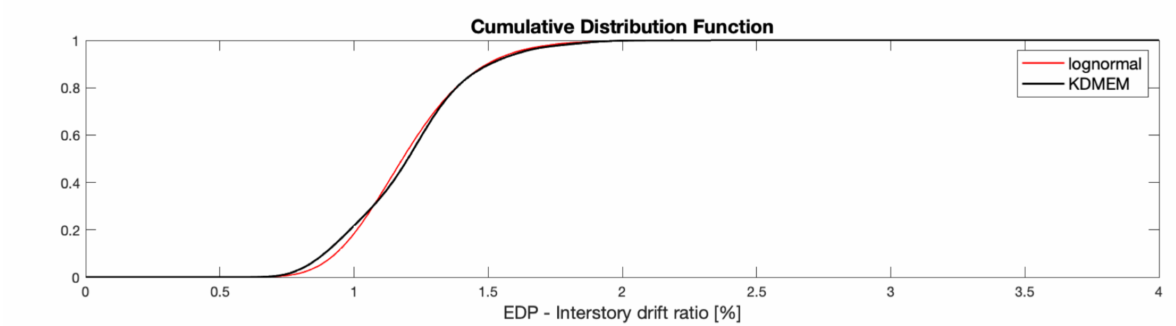
Transition to Practice

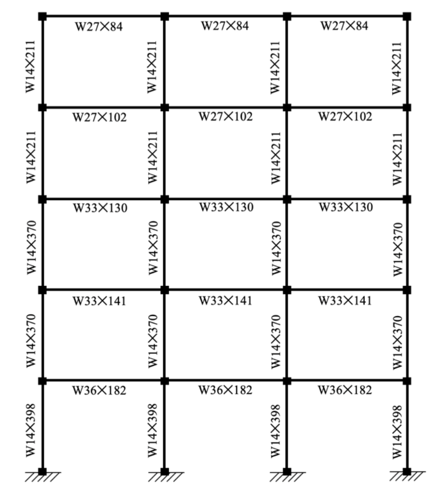
Kernel Density Maximum Entropy Method in PBEE

<u>Example</u>: Steel Moment-Resisting Frame Buildings Design Optimization

- Solve the maximum entropy problem with EDP data for each set of fractional powers, α.
- Find the distribution maximizing entropy among the solutions.







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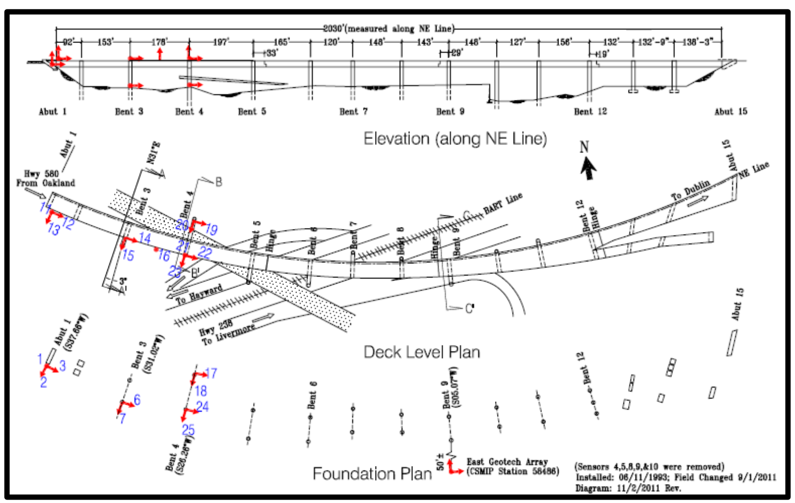
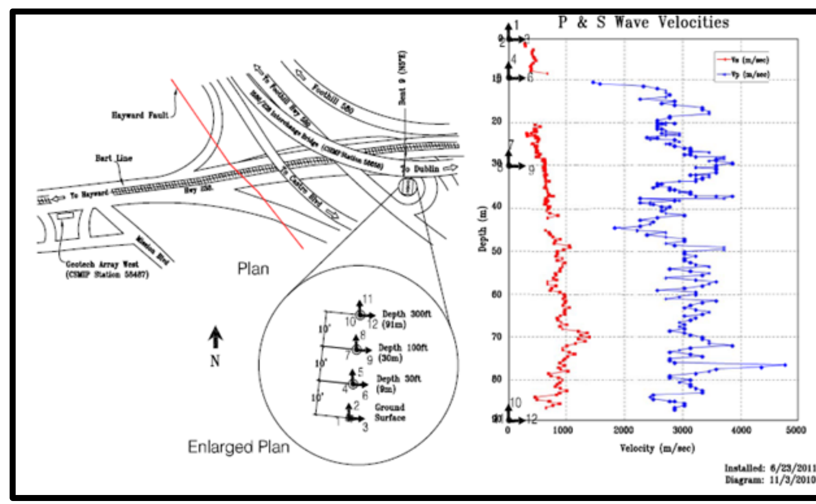
Transition to Practice: Advantages of the Synthetic Motion Database

- Availability of subsurface motions: Recorded GMs are generally at the surface with limited number of geotechnical arrays (**typically hard to maintain**);
- Realistic GM input to **long span structures** having insufficient number of recorded motions for multi-support excitation inputs;
- Suitable for scenario-based **regional-scale simulations**;





Bridge Sensors: **20**

Geotech Array Sensors: **12**

Hayward Hwy 580/238 Interchange
(Bridge Rapid Assessment Center for Extreme Events (**BRACE2**) Testbed)

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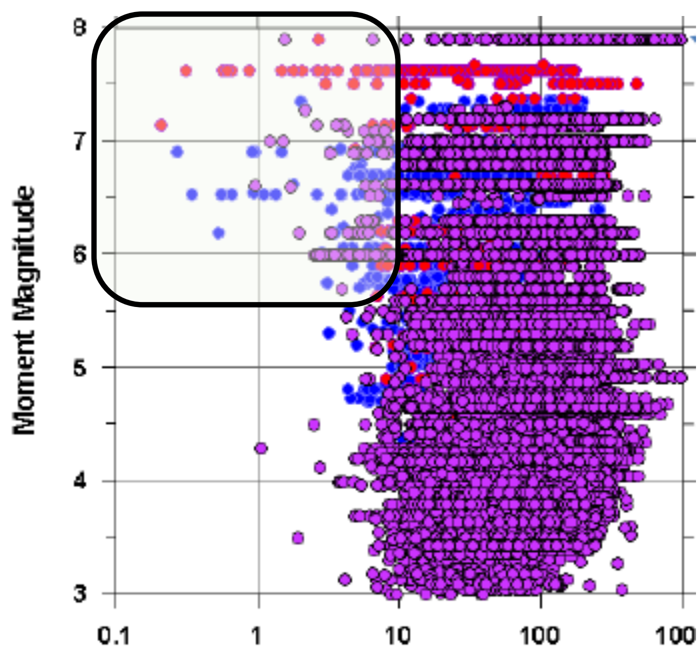
Transition to Practice: Advantages of the Synthetic Motion Database

- Recorded motions not available for **significantly large earthquakes** (NGA West2 database has records for $M_w \leq 7.9$) and in **near-fault region** (David McCallen, opening presentation).
- Synthetic motions can prevent problems with **unrealistically scaled motions** in GM selection (Roberto Paolucci, Day 1)



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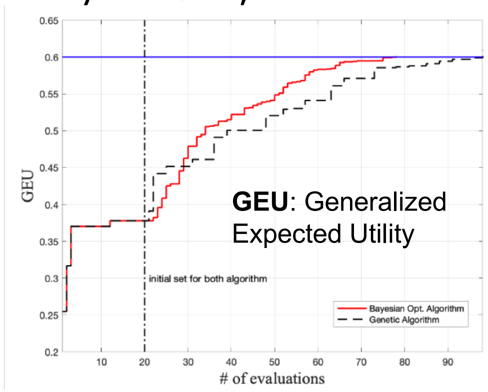
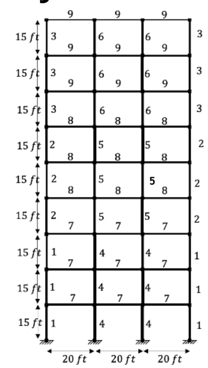
Potential Uses for Engineering Research & Practice: **Structural**

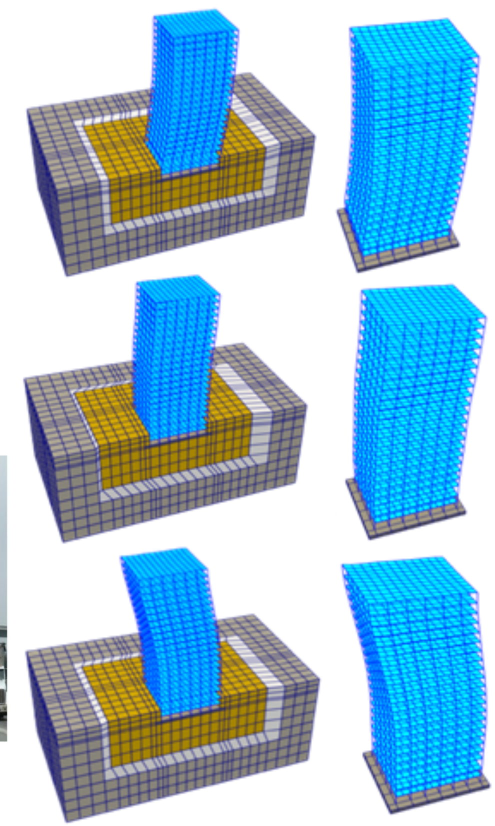
- Probabilistic Performance-Based Design Optimization: Minimize lifecycle costs; Achieve resiliency objectives



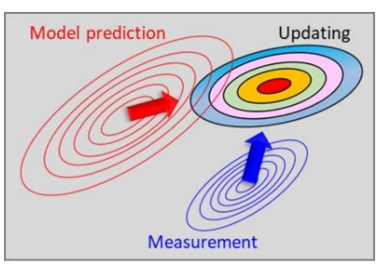


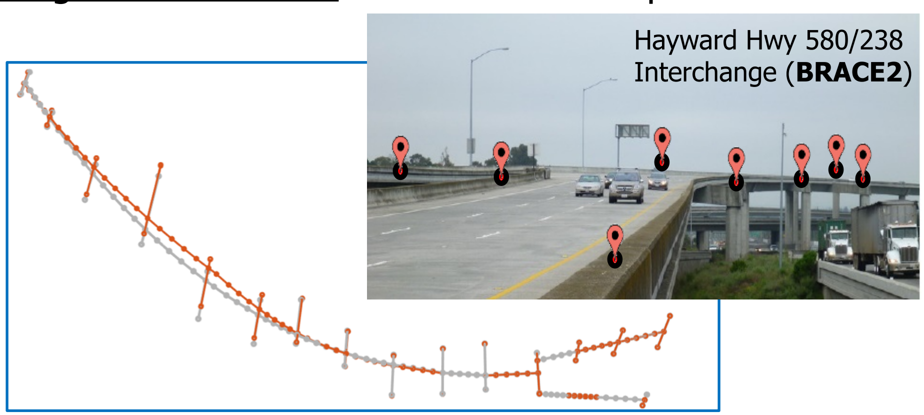
$d_9^{(i)}$: 7th, 8th, 9th floor beam section
$d_8^{(i)}$: 4th, 5th, 6th floor beam section
$d_7^{(i)}$: 1st, 2nd, 3rd floor beam section
$d_6^{(i)}$: 7th, 8th, 9th floor inner column section
$d_5^{(i)}$: 4th, 5th, 6th floor inner column section
$d_4^{(i)}$: 1st, 2nd, 3rd floor inner column section
$d_3^{(i)}$: 7th, 8th, 9th floor outer column section
$d_2^{(i)}$: 4th, 5th, 6th floor outer column section
$d_1^{(i)}$: 1st, 2nd, 3rd floor outer column section

Design set: $(\mathbf{283})^{9} \approx \mathbf{1.2{\times}10^{22}}$



- Instrumented Buildings for Verification: Validation & acceptance of synthetic motions





Courtesy of David McCallen

- Floor Motions: Nonstructural components
- Comparisons: Structural response with recorded & synthetic motions

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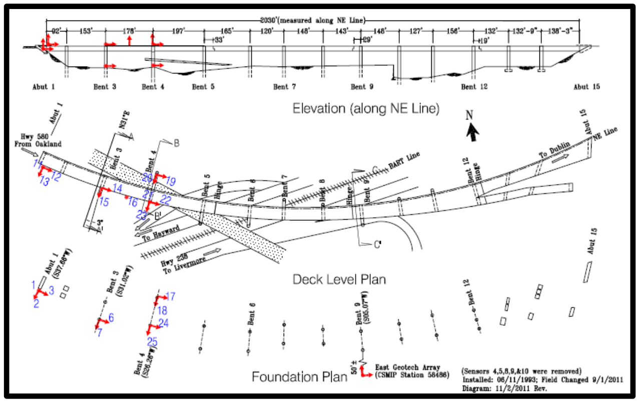
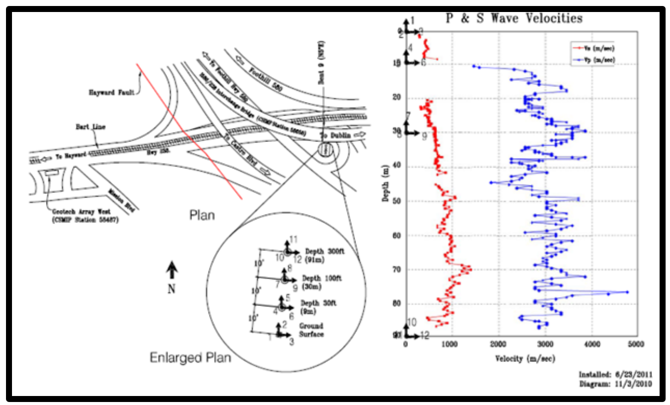
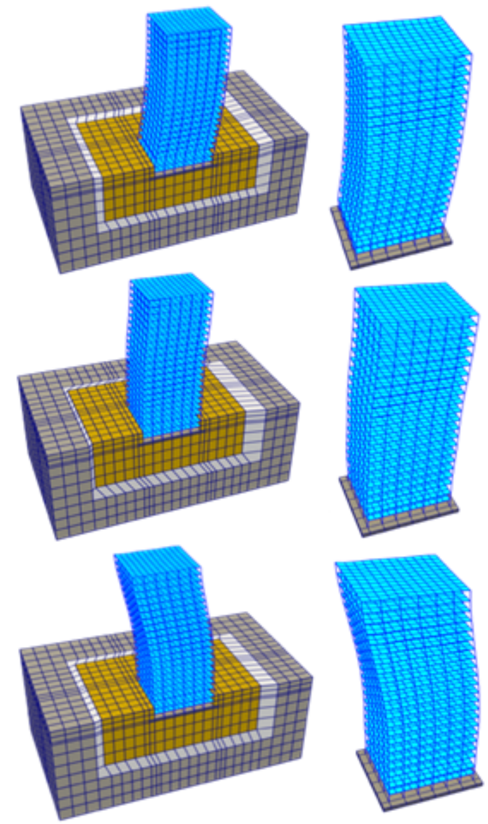
Potential Uses for Engineering Research & Practice: **Geotechnical**

- Free Field vs Motions at the Base of the Structure: Identify needs for SFSI (Soil-Foundation-Structure Interaction) modeling



Hayward Hwy 580/238 Interchange (**BRACE2**)





Courtesy of David McCallen

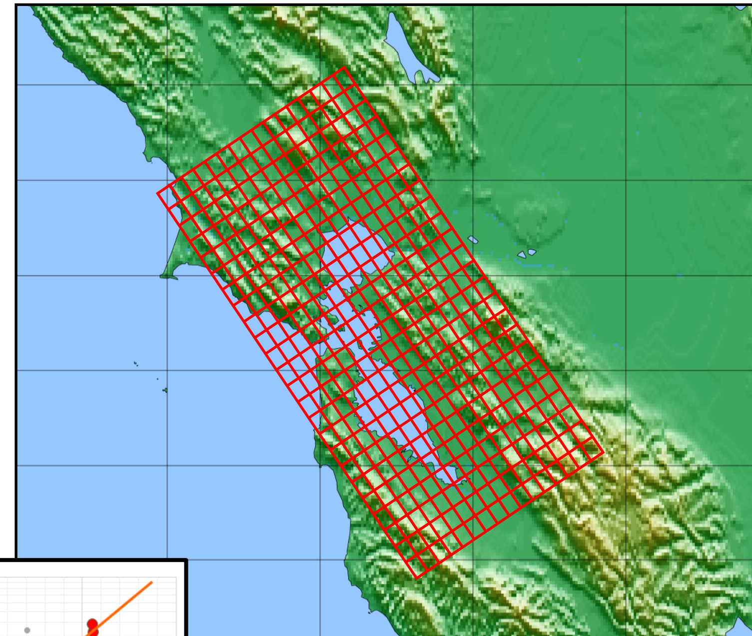
- Bedrock Motions: Use in complete SFSI modeling
- Subsurface Synthetic Motions vs Geotechnical Arrays: Characterize soil layers
- Synthetic Motions Coupling: With liquefaction (e.g., NGL), landslide analysis, etc.

Potential Uses for Engineering Research & Practice: **Regional Sim.**

- <u>Coupling Synthetic Motions with Generic Fragilities</u>: Scenario-based loss & consequence simulations

- <u>Identification of Weakest Links of a System</u>: Infrastructure networks to be retrofitted or need for further detailed analysis

- <u>Machine Learning Using Results of Many Simulations</u>: Potential updating of ShakeAlert location & magnitude estimations for Earthquake Early Warning (EEW)



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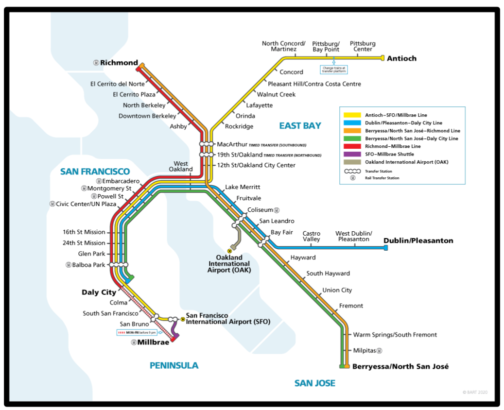

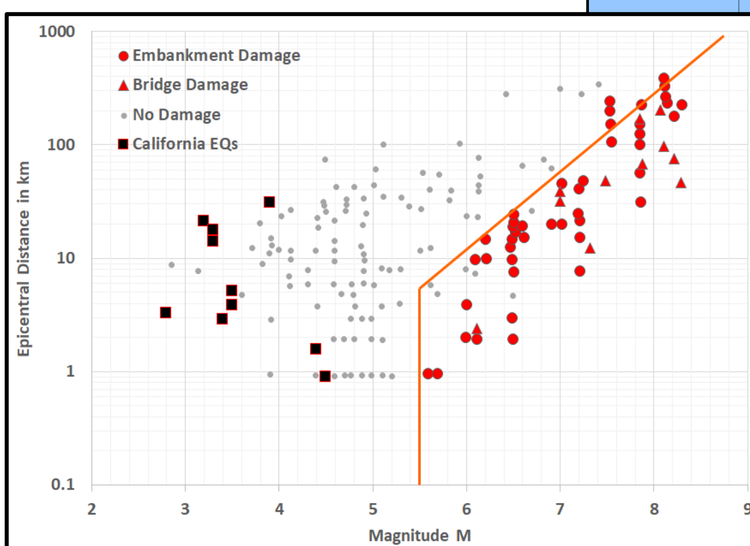

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Thank you!
Questions?