Familiar Interface for PEER Recorded Ground Motion Database (NGA) Users

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Development of the PEER-LBNL Simulated Ground Motion Database (SGMD)

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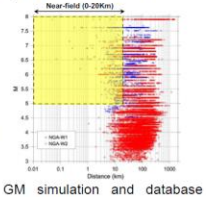
BACKGROUND AND MOTIVATION

- PEER recorded ground motion (GM) databases (NGA-West2 and NGA-East) are extensively used in the U.S. and around the world.
- A simulated ground motion database (SGMD) is needed because of:
  - Scarcity of recorded near-fault GMs from large magnitude earthquakes.
  - Insufficient recorded GMs to conduct regional scale simulations.
  - Inability of Ground Motion Models (GMMs) to capture all effects of rupture propagation, e.g., directivity.
  - Increased number of validated GM simulations from multiple regions.



- Combining expertise of physics-based GM simulation and database development & maintenance, PEER and the Lawrence Berkeley National Lab (LBNL) are developing the first open-access SGMD.

DATABASE HARDWARE

- Large storage server (> 90 TB SSD) with regular maintenance & backups (network interface of 10 GB/s) allowing scalability.
- Ability to accommodate compressed and uncompressed data from many regions and fault rupture realizations.

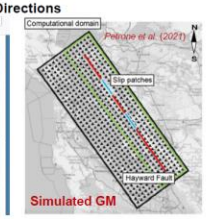
Item	Value
Compressed data per realization (**6.25 m** spacing)	291 GB
# of realizations	30
Total compressed data per region	8.7 TB
# of regions	6
Total compressed data	**52.4 TB**
Uncompressed data per realization (**2 km** spacing)	2.3 GB
# of realizations	100
Total uncompressed data per region	0.23 TB
# of regions	300
Total compressed data	**57.5 TB**

RECORDED vs SIMULATED GROUND MOTION DATABASES

Earthquake & Station Characteristics

Characteristic	Search Item	Recorded GM	Simulated GM
Source	Earthquake	Real Event (e.g., Loma Prieta)	Region/Realization (e.g., SF Bay Area, Realization 1)
	Fault Type	Strike-slip, Normal, Reverse, etc.	
Source to Site	Distance	R_{JB}, R_{rup}	R_{JB}, R_{rup} Latitude, Longitude, Depth
Site	Site Class	Vs30	Vs30
	Location	Depends on station	Grid defined by fault direction & spacing

GM Characteristics & Directions



- GM data at the **physical stations**
- **Recorded** 3 components of acceleration, velocity & displacement
- Horizontal GMs: Depend on **sensor orientation**

- GM data at the **grid stations**
- **Computed** 3 components of acc., velocity & displacement
- Horizontal GMs: **Fault Normal (FN) & Fault Parallel (FP)**

Acknowledgements: The development of SGMD is a joint effort of PEER and LBNL. Authors thank David McCallen, Floriana Petrone, Houjun Tang, Gabriel Vargas & Amarnath Kasalanati for their contributions to this collaborative effort.

RECORDED vs. SIMULATED GROUND MOTION DATABASES

GM Data File Names and Data Format

EQ — GM Direction — Realization 1 — GM Direction

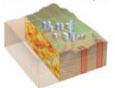
RSN750_LOMAP_BRK000.AT2

Record Seq. No. — Berkeley — Acc.

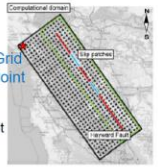
SFBA_Real1_1_1_1_FP.AT2

Region — Grid loc.* — Acc.

*Grid loc.: 1_1_1: Indices for FP, FN & depth

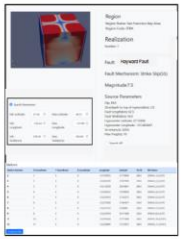


Simulated GM includes not only surface, but also **subsurface** motions.



Same format (e.g., 5 values/row with data advancing row by row, NPTS & DT locations) such that existing processing codes can be directly used.

SIMULATED GROUND MOTION DATABASE INTERFACE



Interface supports the two common uses of simulated motions:

1. Regional scale simulations
2. Simulations at a specific location for different realizations

Similar to PEER recorded GM database, in simulated GM database, fault rupture & simulation parameters (unique for each realization) are documented in a **Flatfile**.

BETA USERS

Law of diffusion of innovation (Rogers, 1962): How new ideas, technologies, or products spread through a population.

Rogers, E.M. (1962). How research can improve practice: A case study. Theory into Practice, 89-93

Potential Beta Users:

1. PEER research (promote use of simulated GMs through Request for Proposals)
2. SimCenter tools
3. Energy providers (PG&E, Southern California Edison, etc.)
4. Government agencies related to infrastructure networks (water, gas, transportation, etc.)
5. Structural engineering firms (using nonlinear dynamic analyses for design & assessment)
6. Simulated GM researchers in various regions in US & worldwide

DATA ROLL-OUT SCHEDULE

Task	Jan.–March	April–May	June–July	Aug.–Sep.
Complete Server Configuration (Setup & Test)				
Complete User Interface				
Include All Data & Metadata for SFBA Simulations				
Beta Version Roll-out				
Feedback from Beta Users				
Full Version Roll-out				

CONCLUDING REMARKS

- Simulated GM database is currently under development with a preliminary version in https://sgmd.peer.berkeley.edu/. The interface is to be finalized by June 2024.
- For seamless integration of the simulated GM database into current research & practice, the developed interface is similar to that of PEER recorded GM databases.
- The specifics & use cases of simulated GM are considered in the interface.
- Feedback from potential users is essential to develop the full version of the SGMD.
- The database development and the full version roll-out will be regularly communicated to the PEER community.

Outline

- Introduction
- Recorded Ground Motion Databases
- Simulated Ground Motion Database

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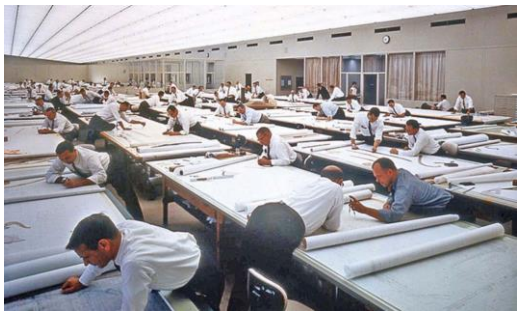
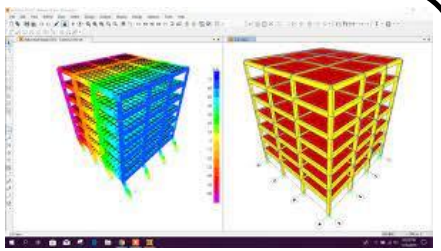
Earthquake Engineering Profession

Past (H)



Earthquake Engineering Fundamentals

Current (H-MC*)

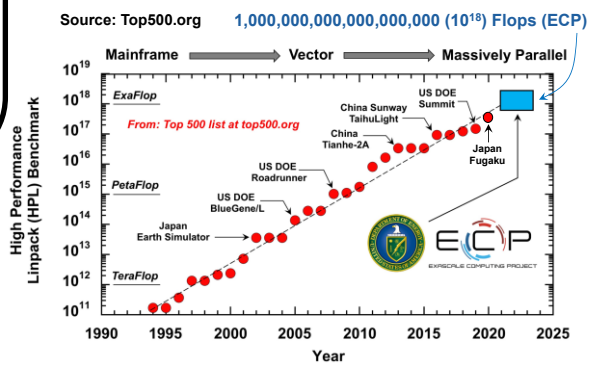


Ductile Response + Collapse Prevention + Saving Lives

*H-MC: Human-Machine Collaboration

Future (M)

Functional Recovery + Resilient Communities



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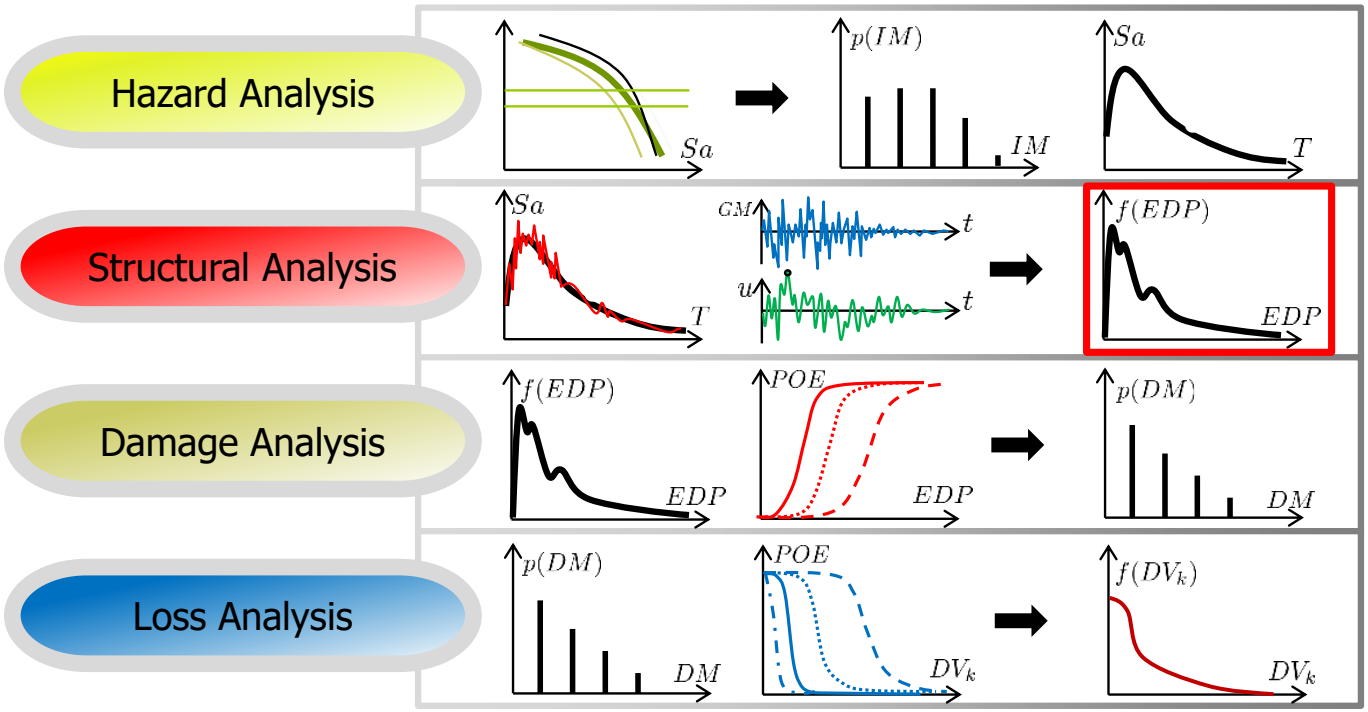
PEER DNA: Integrated PBEE Methodology



Probabilistic PBEE Framework

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

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

- Objective of PBEE: Estimate system performance accounting for uncertainties.
- Defining hazard & select corresponding GMs.
- Access to GMs has been hampered by collecting & manipulating “big data”.
- Late 1990s, PEER improved access to strong GM data by creating an accessible web-based searchable database (NGA).

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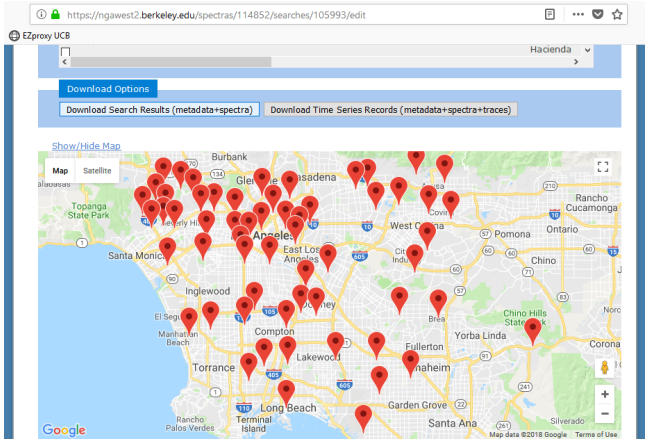
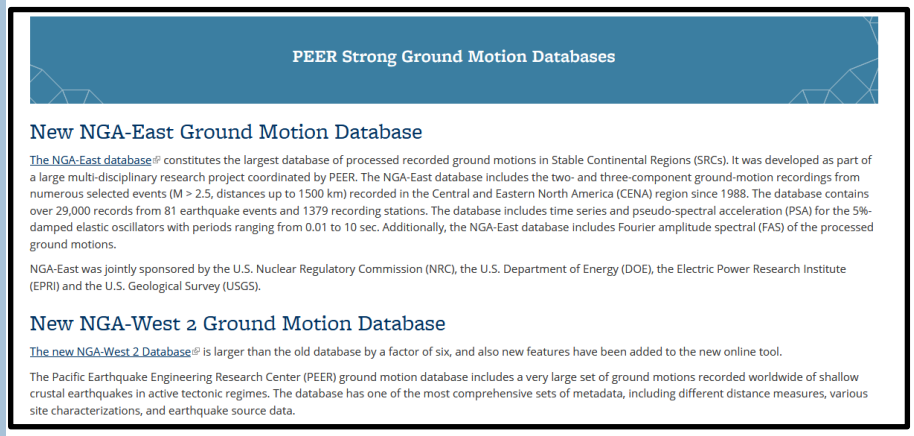
How Did PEER Develop Recorded GM Databases?

1. Collect GM records worldwide.
2. Process all data consistently & reliably.
3. Include metadata (source, site, magnitude, type of faulting, various source-to-site distance measures, local site conditions at recording stations, etc.).



NGA-West Flatfile

	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



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

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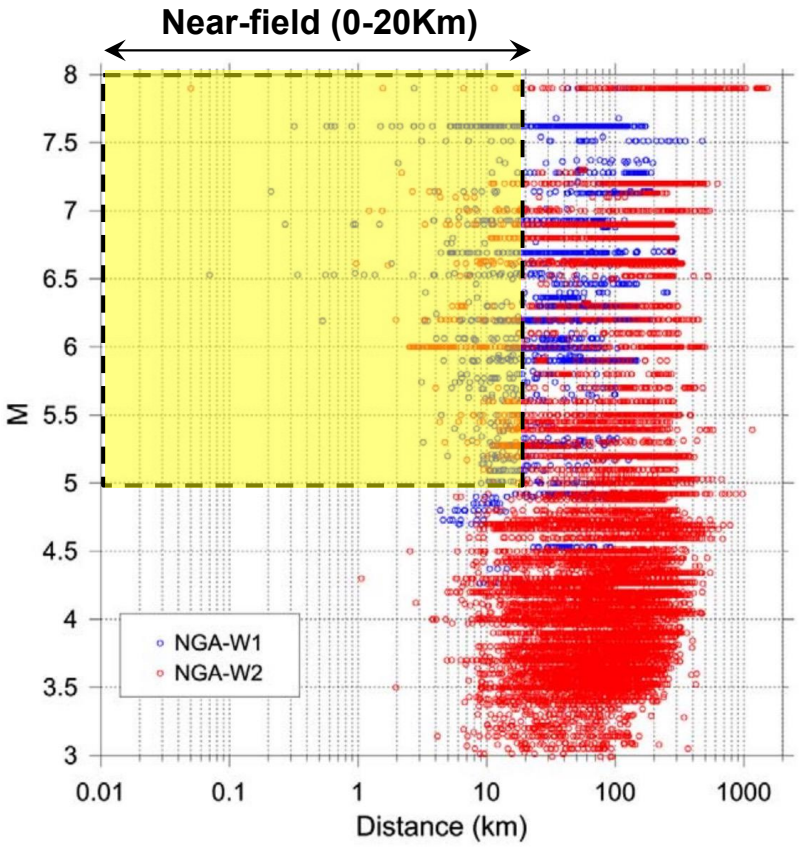
Need for Simulated GM Database



- ✓ Scarcity of recorded near-fault GMs from large magnitude earthquakes.
- ✓ Insufficient recorded GMs to conduct regional scale simulations.
- ✓ Lack of the ability of most GM Models (GMMs) to capture effects of rupture propagation, e.g., directivity.
- ✓ Increased number of validated GM simulations from multiple regions.

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Requirements of a Successful Database

- ✓ Scalability, i.e., large storage server (**up to 95 TB SSD**) with regular maintenance & backups (**network interface of 10 GB/s**).
- ✓ Procedure to expand the database with new data including an effective web interface with well-defined search options.

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Compressed data per realization (**6.25 m** spacing)	291 GB
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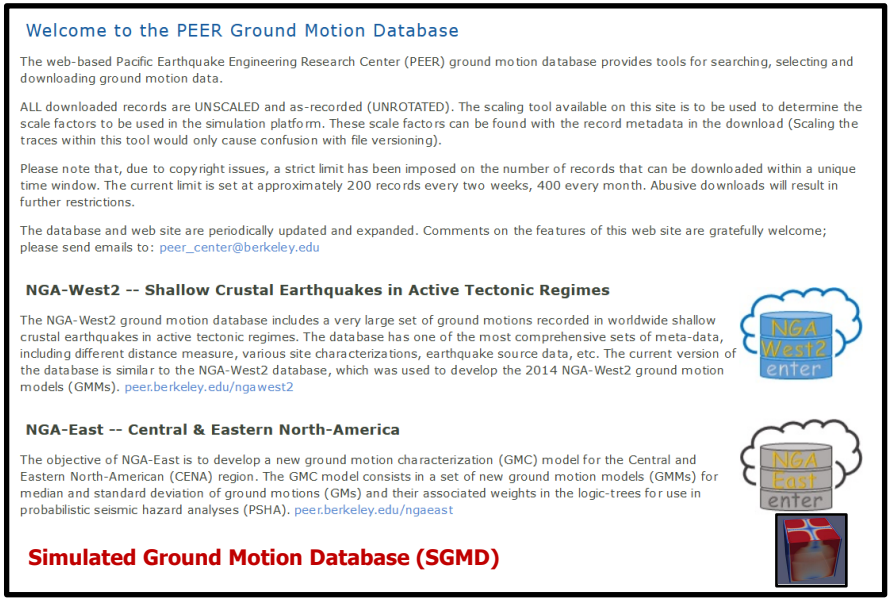

Use the well-known NGA interface with added specifics & use cases of the simulated GMs.

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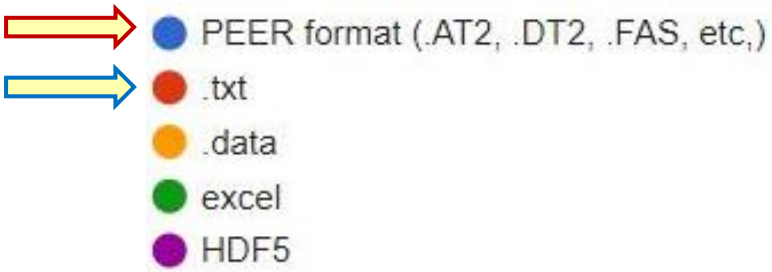
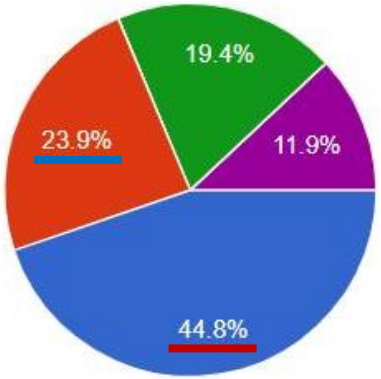
Survey About Simulated GM Database Interface (March 2022)

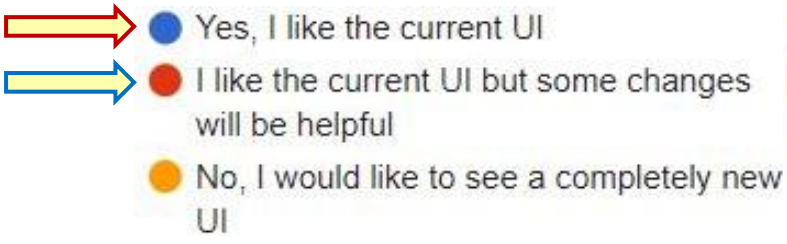
What simulated GM data products would you like to have readily available? (**71 responses**)

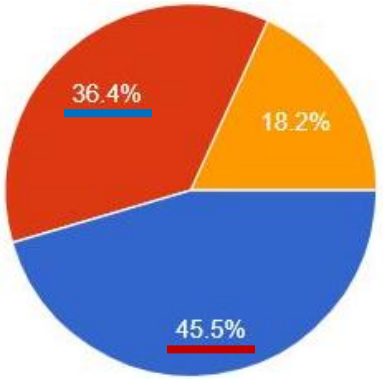
What would be the most convenient simulated GM data & metadata format? (**67 responses**)





Would you want the user interface (UI) same as NGA? (**66 responses**)





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PEER Recorded GM Database Interface

New Search

https://ngawest2.berkeley.edu

Load Sample Input Values | Clear Input Values

NGA West2

Search

These characteristics are defined in the NGA-West2 Flatfile.
You need to re-run Search when any of these parameters are updated.

Record Characteristics:

RSN(s)	:	750	*RSN1,..RSNn*
Event Name	:	Loma Prieta	
Station Name	:	Berkeley LBL	

Search Parameters:

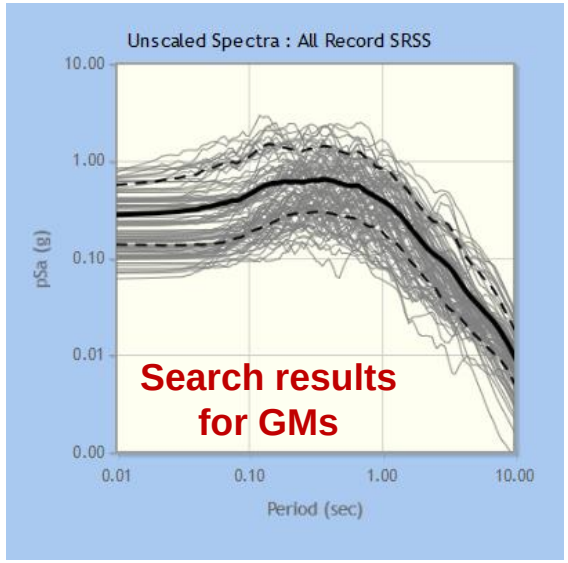
Fault Type	:	Strike Slip (SS)	
Magnitude	:	6.5, 7.2	*min,max*
R_JB(km)	:	1, 20	*min,max*
R_rup(km)	:	1, 15	*min,max*
Vs30(m/s)	:	320, 760	*min,max*
D5-95(sec)	:	30, 50	*min,max*
Pulse	:	ONLY Pulse-like Records	

Additional Characteristics:

Max No. Records	:		*(<=100)*

Suite

Spectral Ordinate	:	SRSS
Damping Ratio	:	5%
Suite Average	:	Arithmetic



Controls

Search Records

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Recorded vs. Simulated GM Databases (1/3)

Earthquake & Station Characteristics

Characteristic	Search Item	Recorded GM Dataset	Simulated GM Dataset
Source	Earthquake	Real Event (e.g., Loma Prieta)	Region/Realization (e.g., SF Bay Area, Realization 1)
	Fault Type	Strike-slip, Normal, Reverse, etc.	
Source to Site	Distance	R_{JB}*, R_{rup}**	R_{JB}, R_{rup}
			Latitude, Longitude, Depth
Site	Site Class	Vs30	Vs30
	Location	Depends on station	Grid defined by fault direction & spacing

*R_{JB}: Joyner-Boore Distance; shortest horizontal distance from recording site to vertical projection of rupture

**R_{rup}: Closest distance from recording site to rupture surface

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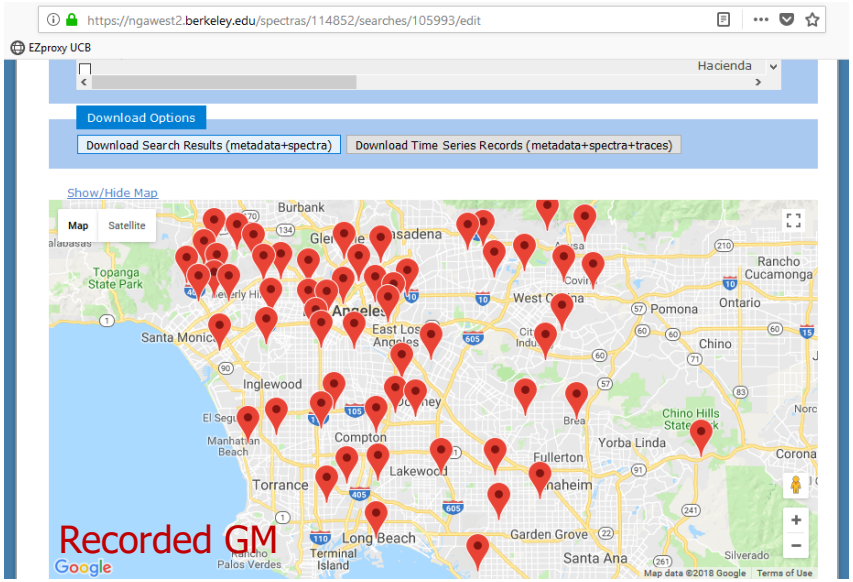
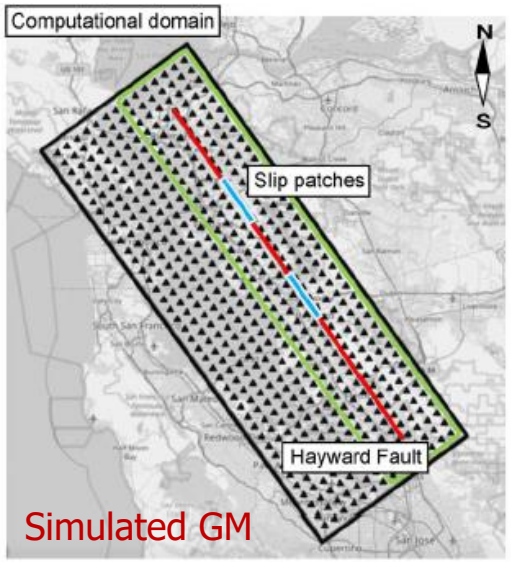
Recorded vs. Simulated GM Databases (2/3)

GM Characteristics & Directions





Petrone et al. (2021)

- GM data at the **physical stations**
- **Recorded** 3 components of acceleration, velocity & displacement
- Horizontal motions depend on **sensor orientation**

- GM data at the **grid stations**
- **Computed** 3 components of acceleration, velocity & displacement
- Horizontal motions are **Fault Normal & Fault Parallel**

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Recorded vs. Simulated GM Databases (3/3)

Same format (e.g., 5 values/row with data advancing row by row) such that existing processing codes can be directly used.

Recorded GM

```
PEER NGA STRONG MOTION DATABASE RECORD
Loma Prieta, 10/18/1989, Berkeley LBL, 0
ACCELERATION TIME SERIES IN UNITS OF G
NPTS=   7998, DT=   .0050 SEC,
  -.6271696E-03  -.6274197E-03  -.6277088E-03  -.6280397E-03  -.6284100E-03
  -.6288214E-03  -.6292747E-03  -.6297698E-03  -.6303135E-03  -.6308978E-03
  -.6315279E-03  -.6321932E-03  -.6328917E-03  -.6336054E-03  -.6343217E-03
  -.6350266E-03  -.6357286E-03  -.6364476E-03  -.6372324E-03  -.6381052E-03
  -.6390824E-03  -.6401759E-03  -.6414179E-03  -.6428192E-03  -.6443712E-03
  -.6460331E-03  -.6477755E-03  -.6496338E-03  -.6516370E-03  -.6537130E-03
  -.6557786E-03  -.6577601E-03  -.6596905E-03  -.6618403E-03  -.6646145E-03
  -.6682676E-03  -.6727977E-03  -.6779552E-03  -.6833546E-03  -.6886214E-03
```

Simulated GM

```
PEER NGA SIMULATED GROUND MOTION DATABASE RECORD
SFBA, Realization 1, Lat: 37.643 Long: -122.697 Depth:0, FP
ACCELERATION TIME SERIES IN UNITS OF G
NPTS=  39877 , DT=  0.0022569400907791457  sec
0.0000000e+00 0.0000000e+00 0.0000000e+00 0.0000000e+00 0.0000000e+00
0.0000000e+00 0.0000000e+00 0.0000000e+00 0.0000000e+00 0.0000000e+00
0.0000000e+00 0.0000000e+00 0.0000000e+00 0.0000000e+00 0.0000000e+00
0.0000000e+00 0.0000000e+00 0.0000000e+00 0.0000000e+00 0.0000000e+00
0.0000000e+00 0.0000000e+00 0.0000000e+00 0.0000000e+00 0.0000000e+00
0.0000000e+00 0.0000000e+00 0.0000000e+00 0.0000000e+00 2.4614500e-299
1.2456181e-283 3.3732994e-278 4.5950762e-274 5.7944915e-271 -1.8427990e-268
3.6903480e-268 1.2971291e-264 -9.8762989e-263 2.3031557e-261 1.1810689e-259
```

Loma Prieta EQ — GM Direction

RSN750_LOMAP_BRK000.AT2

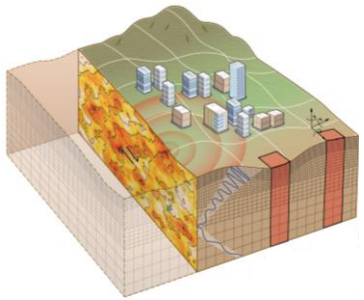
Record Sequence No. — Berkeley — Acceleration

Realization 1 — GM Direction

SFBA_Real1_1_1_1_FP.AT2

Region — Grid location* — Acceleration

*Grid location: 1_1_1 indices for Parallel to fault_Normal to fault_Depth



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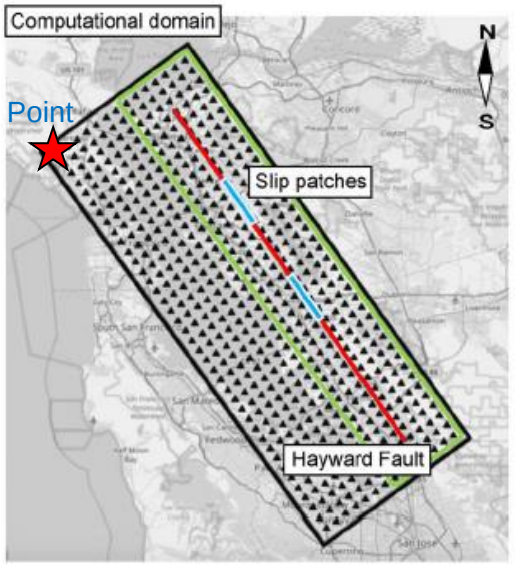

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Simulated GM Database Interface

1. Regional scale simulations
2. Simulations at a specific location (different realizations)

Similar to PEER recorded GM, in simulated GM, fault rupture & simulation parameters (unique for each realization) are documented in a **Flatfile**.

Region

Realization

Region Name	Region Code	Realization #	Fault Name	Magnitude	Fault Mechanis	Dip (°)	Strike (°)	ztor (Depth to top of rupture) (km)	Fault Length	Fault Width	Hyp_lon	Hyp_lat	Vs_min (m/s)	Max freq (Hz)	Grid spacing (km)
San Francisco Bay Area	SFBA	1	Hayward	7.0	Strike slip	90	30	0.2	62.5	16	-121.86	37.7301	320	10	2
San Francisco Bay Area	SFBA	2	Hayward	7.2	Strike slip	90	30	0.1	100	20	-121.86	37.7301	320	10	2
San Francisco Bay Area	SFBA	3	Hayward	7.1	Strike slip	90	30	0.5	60	16	-121.86	37.7301	320	10	2
San Francisco Bay Area	SFBA	4	Calaveras	7.2	Strike slip	90	35	0.2	62.5	16	-124.91	37.7301	320	10	2
San Francisco Bay Area	SFBA	5	Calaveras	7.0	Strike slip	90	35	0.2	62.5	16	-125.93	37.7301	320	10	2
San Francisco Bay Area	SFBA	6	Calaveras	6.8	Strike slip	90	35	0.2	62.5	16	-126.95	37.7301	320	10	2

Fault rupture parameters

Simulation parameters

PEER

Concluding Remarks

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- The specifics & use cases of simulated GM are considered in the interface as search options.

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