Seismic (Faulting and Seismicity) Hazard Overview for Sacramento, California

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Presentation Outline

- Introduce seismic hazards and seismicity information to mainly undergraduate and graduate engineering and geology students, with an emphasis in the Sacramento region
- Introduction of terms
- Setting of Sacramento and possible explanation why there is so little earthquake activity and seismicity within the study area.
- Explanation why some distant earthquakes are felt in Sacramento, especially in tall buildings or while sitting or laying down
- Discussion of faulting and seismicity with respect to Sacramento
- Introduction to the Uniform California Earthquake Rupture Forecast (UCERF) model and ground motion prediction equations
- Brief discussion between Probabilistic Seismic Hazards Assessment (PSHA) and Seismic Hazard Curves
- Brief overview of two example projects driven by seismic hazard near Sacramento
- Deaggregation discussion
- Questions

Key Terms

- **Active fault**- As used by the California Geological Survey, is a fault that has ruptured the surface of the earth within the last 11,700 years.
  - Note this term may have a different time range when used by the United States Bureau of Reclamation or by the US Army Corps of Engineers or the State of California’s Department of Water Resources for dam related projects.

- **Deaggregation**- Is a decomposition of earthquake hazards into individual components such as fault or area sources, spectral period or peak ground acceleration, location and distance from fault or area source to target, soil classification, uncertainty, source model and ground motion model(s) used to estimate the mean frequency of exceedance of any given spectral acceleration at the site. A product of a deaggregation run is a 3-D deaggregation chart.

- **Seismic Hazard**- A description of ground shaking, and related effects such as liquefaction, lateral spreading, dynamic compaction, differential settlement, earthquake induced landslides and ridge top shattering. This term should not be confused with **Seismic Hazards Analysis.**

- **Seismic Hazard Analysis**- May be defined as a procedure to determine the probability of an earthquake in a given geographic area, within a given window of time with a ground motion value exceeding a designated value.

Key Terms (Continued)

- **Probabilistic Seismic Hazard Analysis (PSHA)**- Is a procedure originally derived from flood zone analysis, it's goal is to quantify (or probability) of exceeding various ground-motion levels at a site (or a map of sites) given all possible earthquakes. The procedure accounts for both epistemic aleatory uncertainties. A product of a PSHA are **seismic hazard curves**.

  A PSHA has three main pieces, they are:
  - A.) The identification and use seismic-hazard source model(s),
  - B.) selection ground motion prediction equations taking into account the fault or area sources of seismicity of; and,
  - C.) a probabilistic calculation accounting for both epistemic and aleatory uncertainty. (See Baker, 2016 for an introduction to PSHA)

Key Terms (Continued-2)

- **Seismic Hazard Curves**- Are a product of a probabilistic seismic hazard analysis. The curves are seismic source specific. They may show the annual rate or probability at which a specific ground motion level will be exceeded at the site of interest. Hazard curves typically have “annual probability of exceedance” or its reciprocal, “return period”, on the vertical axis on a logarithmic scale, and peak ground acceleration on the horizontal axis on an arithmetic scale. Hazard curves may also depict another measure of seismic loading, such as the response spectra acceleration at a given period of vibration, on the horizontal axis. (Modified from: USBR)

- **Uniform California Earthquake Rupture Forecast**- Is an earthquake rupture forecast tool that is focused on most of California and a small contiguous swath outside of the State boundaries. It does not include parts of Northern California near the Cascadia Subduction Zone. Currently there are UCERF tools using a time independent approach and one using a time dependent approach. The models do not account for spatial temporal clustering.

Sacramento’s Setting

- Sacramento is located on an asymmetrical syncline in the southern part of the Sacramento Valley, which is on the Sierra Nevada microplate.

- Most of the strain at the latitude is accommodated to the west of Sacramento in the San Francisco Bay and an area of a smaller amount of strain is accommodated in the Lake Tahoe to Reno and Sparks area.

- Sacramento is also located near the beginning of the Sierra Nevada foothills. The first outcrops of “granite” aka quartz diorite are in Orangevale, Roseville and Folsom, but not in Sacramento.

- There are for seismic hazards assessment, three soil/rock type in or adjacent to Sacramento (Class “D”, Class “B/C” and Class “A”) these soil classes may affect the seismic hazard deaggregation results.

Footprint Map of the Sierra Nevada Microplate

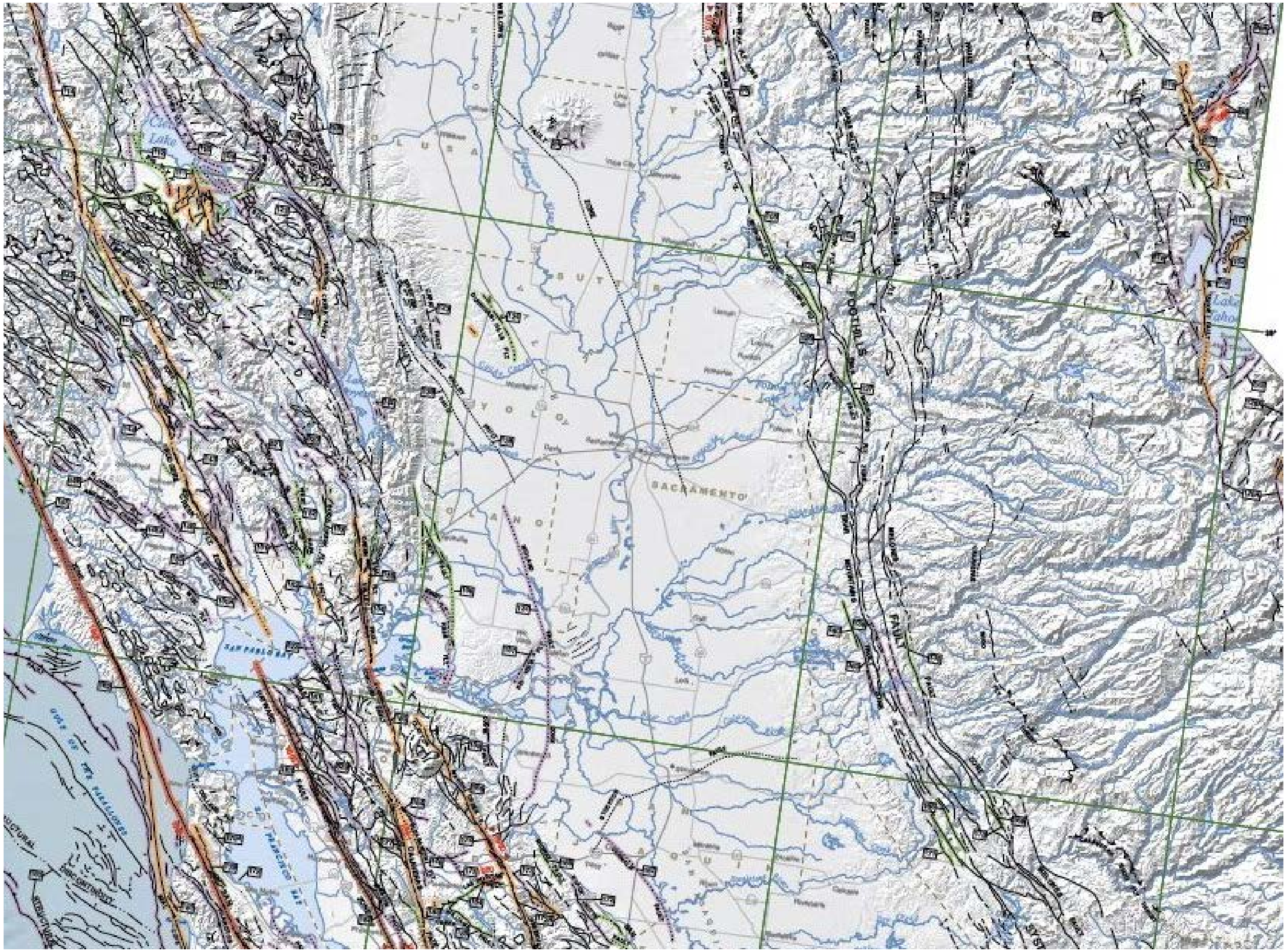
Faulting in Sacramento County

- There are no known “active faults” as defined by the California Geological Survey within the County of Sacramento.
- However, there are at least two faults in Sacramento County and maybe more:
- Mormon Island Fault Zone, along the eastern border of Sacramento County near Folsom and the Mormon Island Dam
- An fault was found by Kiersh runs under the right abutment of Folsom Dam.
- There may be a third fault, the Willows Fault, but its presence has not been confirmed in Sacramento County. It does not daylight in Sacramento County.
- Several joint sets and lineations have also been mapped and/or trenched, but did not show conclusive proof to be faults.

Seismic Hazards in/near Sacramento

- Principal hazard is strong ground shaking
- No seismic hazards map has been produced by CGS for Sacramento yet.
- Fault rupture not known in the Holocene
- Liquefaction along drainages and uncontrolled saturated fill- maybe
  - May also be near areas of sand boils during times of peak flow
  - Mormon Island Dam liquefaction mitigation project
- Dynamic compaction or differential settlement possible, but not fully assessed
- Lateral spreading along drainages and on and along levees- maybe
- Earthquake induced landsliding possible (minimal in city limits), potentially somewhat higher to the east near Natomas and Folsom Lake

Map of Nearby Faults to Sacramento
(Excerpt from CGS Fault Activity Map, 2010)



Faults Near or That May Affect Seismic Hazard Assessment in Sacramento

Fault	Style	Status	Distance	Notes
Great Valley Thrust Fault	Thrust	TBD	70 km	Significant contributor seismic hazard assessment
Dunnigan Hills Fault	Thrust	To be determined	70 km	-----
Mormon Island Fault Zone	Oblique?	Not Active	32 km from CBD	Located along eastern county line near the city of Folsom
Bear Mountain Fault Zone, East Branch	Normal	Active as defined by USACOE	~45 km from CBD	Closest capable fault to Sacramento
Bear Mountain Fault Zone West Branch	Oblique	Not Active	~40 km from CBD	Between the Pine Hills Intrusive Complex and Folsom Lake
Foothills Fault System	Reverse/ Oblique	Not Active	~50 km	Cleveland Hills Fault not a part of System

Faults Near or That May Affect Seismic Hazard Assessment in Sacramento (Continued)

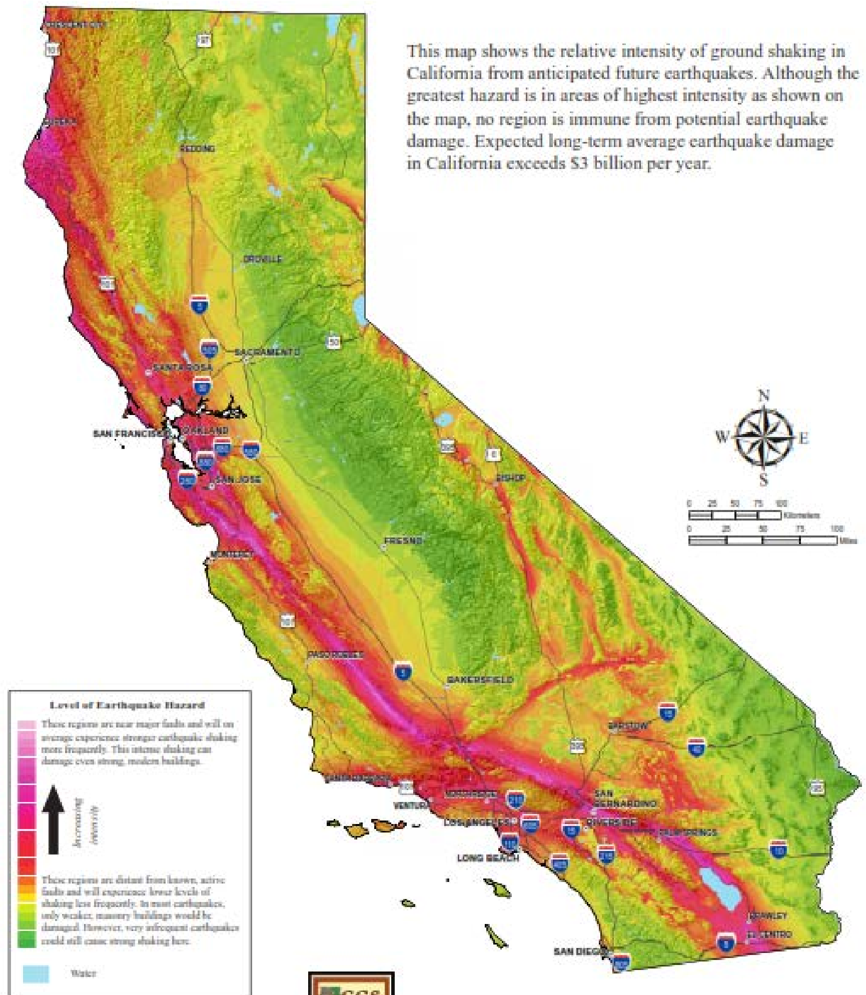
Fault	Style	Status	Distance	Notes
San Andreas Fault	Strike slip	Active	150 km	Loma Prieta earthquake felt in Sacramento
Hayward Fault	Strike slip	Active	~120 km	1868 earthquake
Willows Fault Zone	Reverse	To be determined	~15 km from CBD	Not considered active, but used in SHA by DWR
West Lake Tahoe Fault	Normal	Active	163 km	Newly A-P zoned fault
Geona Fault (Nevada)	Normal	--------	190 km	Along eastern side of the Sierra Nevada and highway 50
Cascadia Subduction Zone	Thrust	Offshore, plunges under part of state	~500 km	May contribute LPMG to Sacramento
(Southern) Midland Fault	Normal, then reactivated as Reverse-oblique	To be determined	40 km	Considered to be in two sections, south and north

Seismicity Near Sacramento

- There have been no known damaging earthquakes in historic times within 50 km of Sacramento.
- There is however a limited amount of low level seismicity, usually below magnitude 3 in and around Sacramento County.
- The closest known damaging earthquakes were the Winters-Vacaville earthquakes in1892. They are estimated to have had magnitudes of 6.2 and 6.4. The exact locations of the epicenters and zone of rupture are unknown.

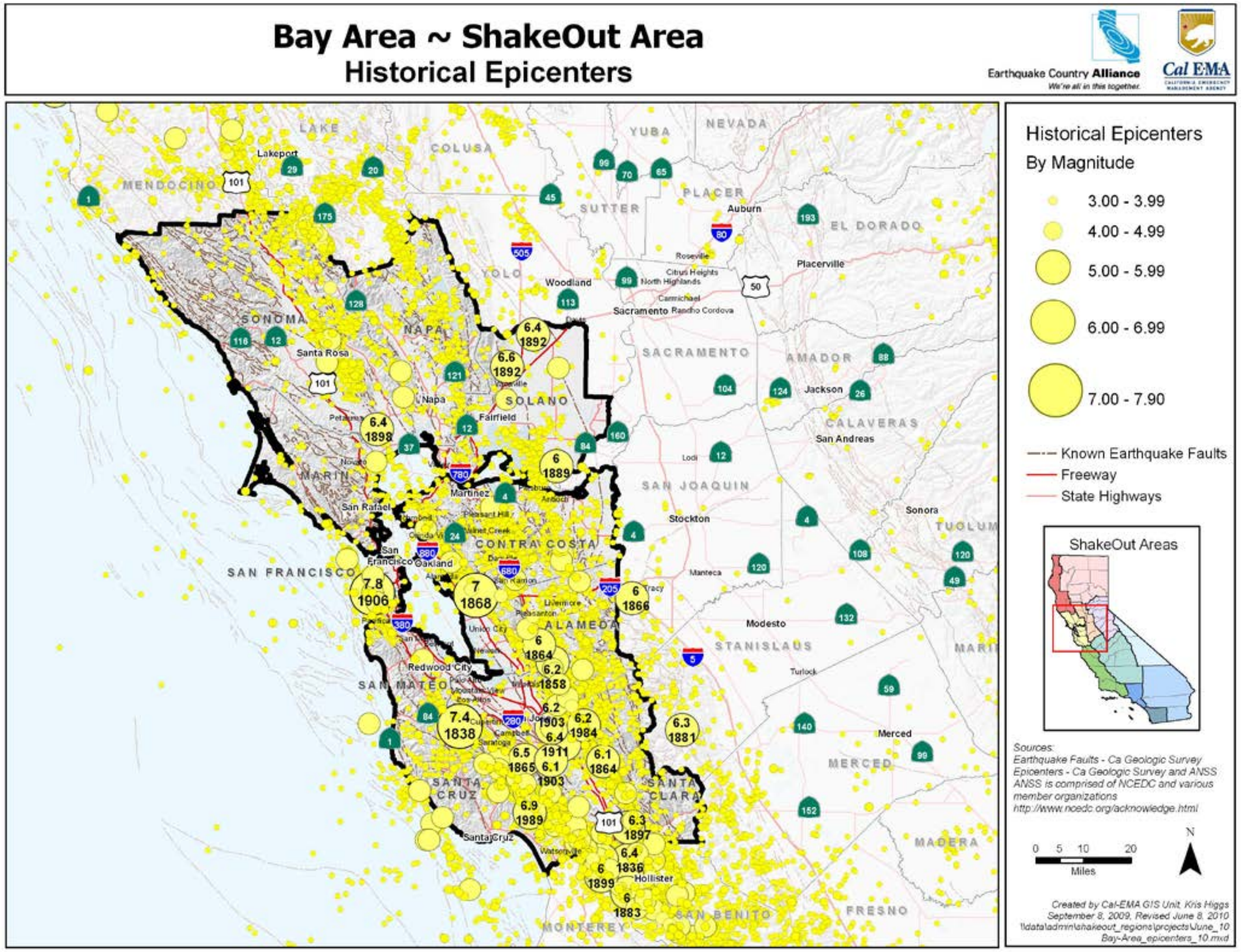
Earthquake Shaking Potential for California

This map shows the relative intensity of ground shaking in California from anticipated future earthquakes. Although the greatest hazard is in areas of highest intensity as shown on the map, no region is immune from potential earthquake damage. Expected long-term average earthquake damage in California exceeds $3 billion per year.

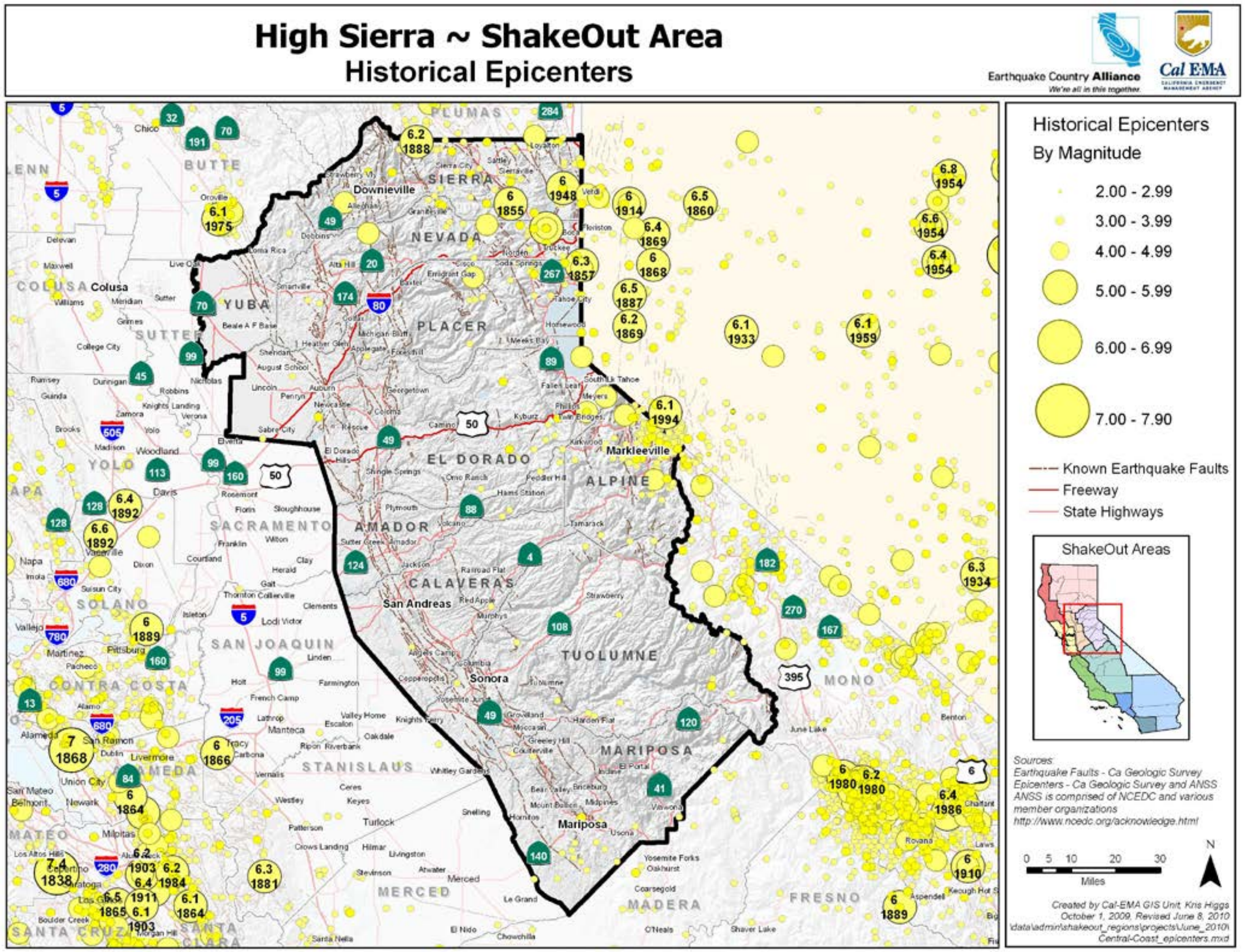


Source: California Geological Survey *Map Sheet 48 (Revised 2016)*

Map Showing Bay Area Earthquakes Epicenters and Sacramento



Location Map of Earthquake Epicenters Near Sacramento



Uniform California Earthquake Rupture Forecast Model (UCERF) and Seismic Hazard Analysis

- UCERF provides earth rupture forecasts over a given time period for a target region. The results may be determined with respect to a range of values, with the mean value usually the one presented.
  - Example: The probability of a magnitude 6.7 earthquake occurring in Northern California in a 30 year time frame is ~95%

- UCERF fault models are used in output files in the USGS deaggregation model (more later).

- When a rupture forecast is developed, it is then combined with a ground motion prediction equation to derive an estimate of intensity of shaking.

- Used in the development of the California portion of the National Seismic Hazards Map and the Building Code. Also used by the insurance industry to estimate seismic hazard/risk exposure and help set earthquake insurance premiums.

Select Earthquakes and Sacramento

Earthquake(s)	Magnitude	Fault(s)	Distance In Kilometers	Damage	Secondary Effects	Notes: LPGM SPGM
Vacaville-Winters 1892	6.4 and 6.2	Unknown	~65 km?	Minor	Not in Sacramento	Possibly LPGM and SPGM
San Francisco 1906	7.8	San Andreas	~160 km	Minor	Not in Sacramento	LPGM
Kern County 1952	7.3	White Wolf Fault	~480	None	Not in Sacramento	LPGM
Fairview Peak and Dixie Valley, Nevada 1954	7.2 and 6.8	Fairview and Dixie Valley Faults	~400 km-424 km	Minor	Not in Sacramento	LPGM
Dog Valley (Truckee) 1948 and 1966	6.0 and 6.0	Dog Valley Fault	175 km-160 km	Minor	Not in Sacramento	LPGM
Oroville 1975	5.7	Cleveland Hill Fault	118 km	Minor	Not in Sacramento	LPGM
Coalinga 1983	6.2	Blind Fault near Anticline Ridge	314 km	Minor	Not in Sacramento	LPGM
Loma Prieta 1989	6.9	Sergeant Fault	~240 km	Minor	Not in Sacramento	LPGM

Select Earthquakes and Sacramento (Continued)

Earthquake(s)	Magnitude	Fault	Distance	Damage	Secondary Effects	LPGM SPGM
Cape Mendocino 1992	7.2, 6.5 and 6.2	Unknown thrust fault near Petrolia	~430 km	None swaying of tall buildings noticed	None	LPGM
Double Springs Flat, Nevada 1994	5.8 to 6.0	Step over fault Between the Genoa and Antelope Valley Faults	~221 km	Minor shaking of homes on rock1-2	None	LPGM
Off Shore California, 2005	7.2	Unknown	~730 km	None	None	LPGM
West Napa 2014	6.0	West Napa Fault	98 km	Minor	None	LPGM?

Examples of Projects Near Sacramento Where Seismic Hazards Assessment Played a Role

- Auburn Dam Project (USBR)
  - Foothills Fault System, including the Deadman and Spenceville faults
  - Fault traces seen in walls of bedrock above foundation site
  - Question about reservoir induced seismicity
  - Maximum Magnitude ~M_w6.5, PGA ~0.65g
  - Potential major treat to Sacramento if breached, causing an overtopping of Folsom Dam(s)
  - Project terminated

Examples of Projects Near Sacramento Where Seismic Hazards Assessment Played a Role (Continued)

- Mormon Island Dam (Folsom) liquefaction mitigation project
  - East Branch of Bear Mountains Fault Zone and Mormon Island Fault near dam
  - Maximum Capable Earthquake 6.5 on East Branch of Bear Mountains Fault Zone
  - Proximity Mormon Island Fault alignment towards Mormon Island Dam
  - Ancestral course of the American River runs underneath the dam.
  - The area near the foundation had been dredged for gold.
  - Mitigation done to dam foundation by compacting a rock matt as well as installing stone columns to relieve any excessive water pressure due cyclic shaking from earthquake

Deaggregation of Seismic Sources

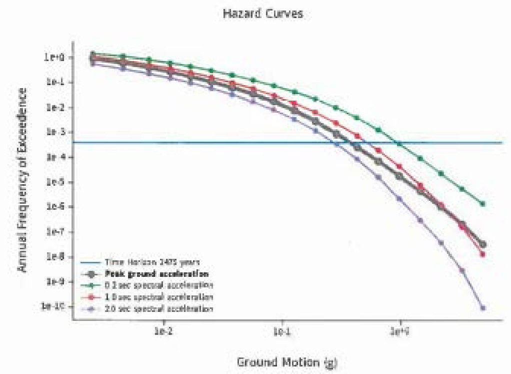
- **Deaggregation**- Once again, is a decomposition of earthquake hazards into individual components such as fault or area sources, spectral period or peak ground acceleration, location and distance from fault or area source to target, soil classification, uncertainty, source model and ground motion model(s) used to estimate the mean frequency of exceedance of any given spectral acceleration at the site. A product of a deaggregation run is a 3-D deaggregation chart.

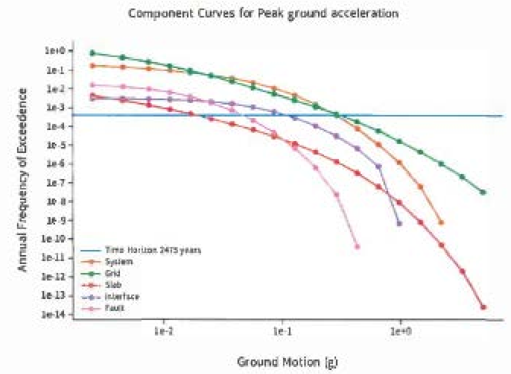
- The USGS has a deaggregation tool that is easy to use, it's url is: https://earthquake.usgs.gov/hazards/interactive This makes handling numerous faults and magnitudes easier to handle and to see which seismic sources contribute the most hazard at a subject site.

- Is important to consider what type site class that subject site is located on as well as the spectral period you are interested in, since your selection may change the fault that is the principal deaggregation contributor, possibly other than gridded seismicity.

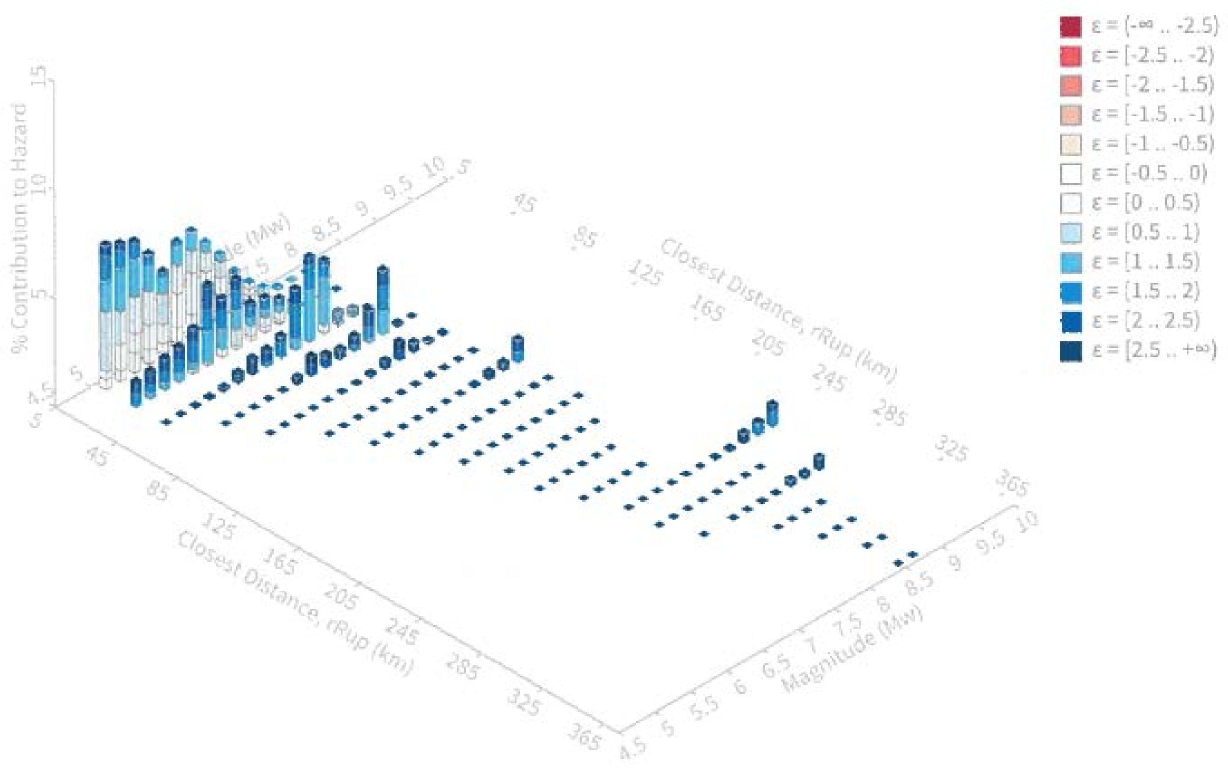
- Several deaggregation runs with changes in period with for different sites in the Sacramento area. Results showed that the seismic source which contributed the most varied from gridded seismicity to the San Andreas Fault.

Example of Seismic Hazard Curve





Example of 3-D Deaggregation Chart



Example of Earthquake Sources for a Site Seismic Hazard Assessment for Sacramento

- Deaggregated seismic hazard contribution using the USGS Unified Hazard Tool
- 2% in 50 years reoccurrence interval using the UCERF 3 model
- PGA designated
- Site class D soil used at State Capital

✓ Main contributor: Gridded seismicity

✓ Great Valley (Blind) Faults

✓ Cascadia Subduction Zone a minor contributor

Deaggregation of Seismic Sources and Ground Motion Prediction Equations

- Different buildings and structures can have different periods that they are most sensitive to.
  - A generic example would be that one and two story homes may have a shorter that a period that a 20 story office building in an area where the site soil classification are the same. A structure such as a bridge may have yet a different period than either homes or a tall building.
- Deaggregation for ground motion prediction equations follows a similar process as deaggregation for seismic hazard sources with the exception of using ground motion prediction equations instead of seismic hazard sources.