Seismic Issues for California's Nuclear Power Plants

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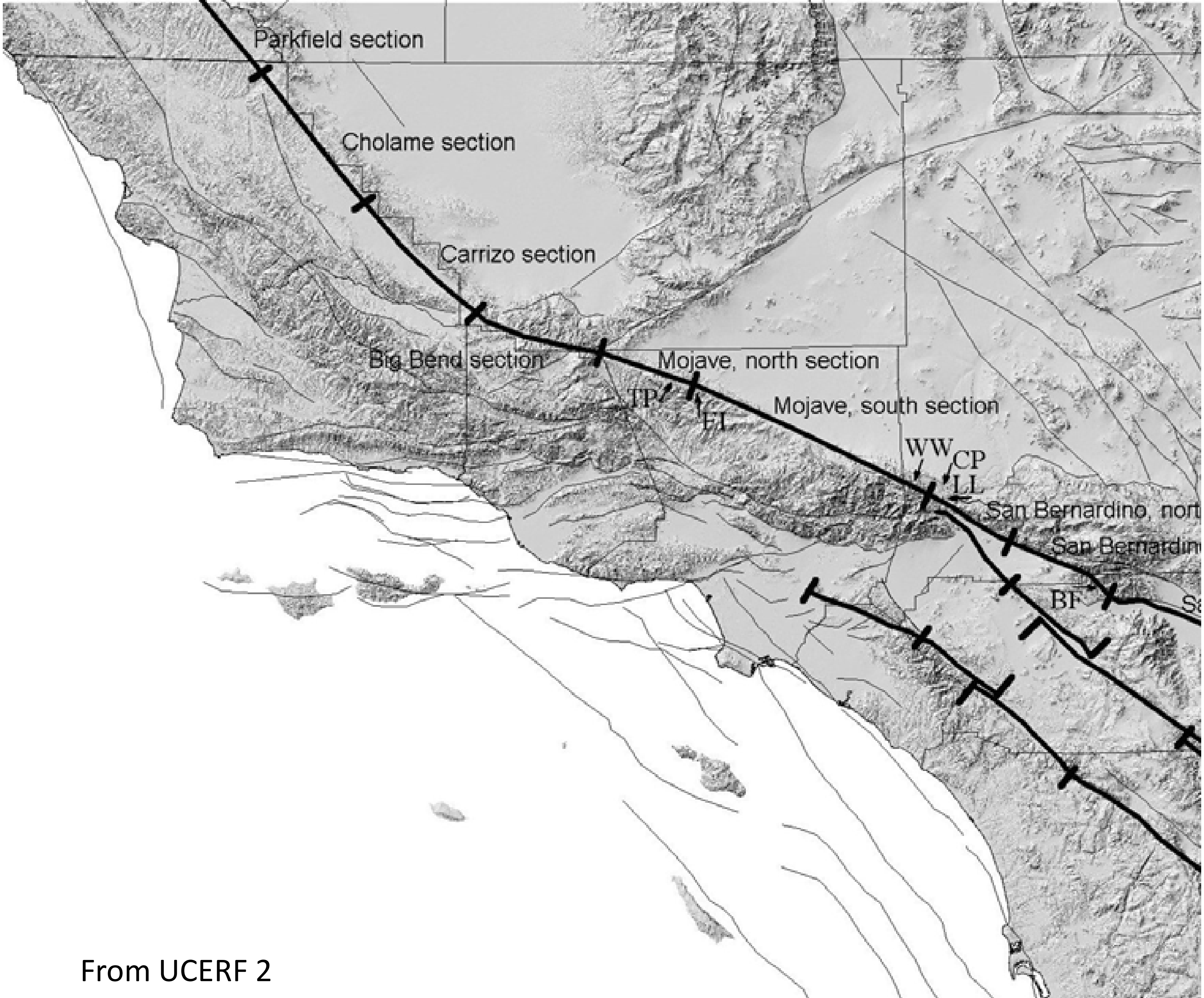

Parkfield section
Cholame section
Carrizo section
Big Bend section
Mojave, north section
Mojave, south section
TP
EL
WW
CP
LL
San Bernardino, nort
San Bernardin
BF

From UCERF 2

Seismic Setting for California's Nuclear Power Plants

- Major Offshore Strike-Slip Faults
  - Well defined geometry
    - 5-10 km offshore
    - Segmentation?
  - Slip-rates
    - 0.5 - 3 mm/yr
- Offshore / Onshore Thrust Faults
  - Not well constrained geometry
    - May extend under NPP (depending on dip and location)
  - Lower slip rates than SS
    - 0.2 – 2.0 mm/yr
- Smaller Offshore / Onshore faults
  - SS & RV
  - Low slip-rates
    - 0.01 – 0.5 mm/yr

Reaction to 2011 Tohoku Eqk

- For CA nuclear plants, focus has been on the large magnitude of the Tohoku Eqk
  - Are the DCPP and SONGS plants designed for M9 earthquake
  - If the Japanese can be surprised by a large magnitude earthquake, why do we think we won't be surprised too?
  - Can offshore SS rupture together in a large magnitude earthquake?
    - Linking multiple faults

Seismic Design Basis for Nuclear Power Plants

- **We design for ground motions and tsunami wave heights, not earthquake magnitudes**
- Deterministic Approach for Ground Motion
  - Select large rare earthquake scenario
  - Use 84th percentile ground motion level
    - not worst case
- Probabilistic Approach for Ground Motion
  - Select chance of ground motion level being exceeded at a site (e.g. 1/10,000 per year)
    - Accounts for rates of earthquakes and large variability of ground motion

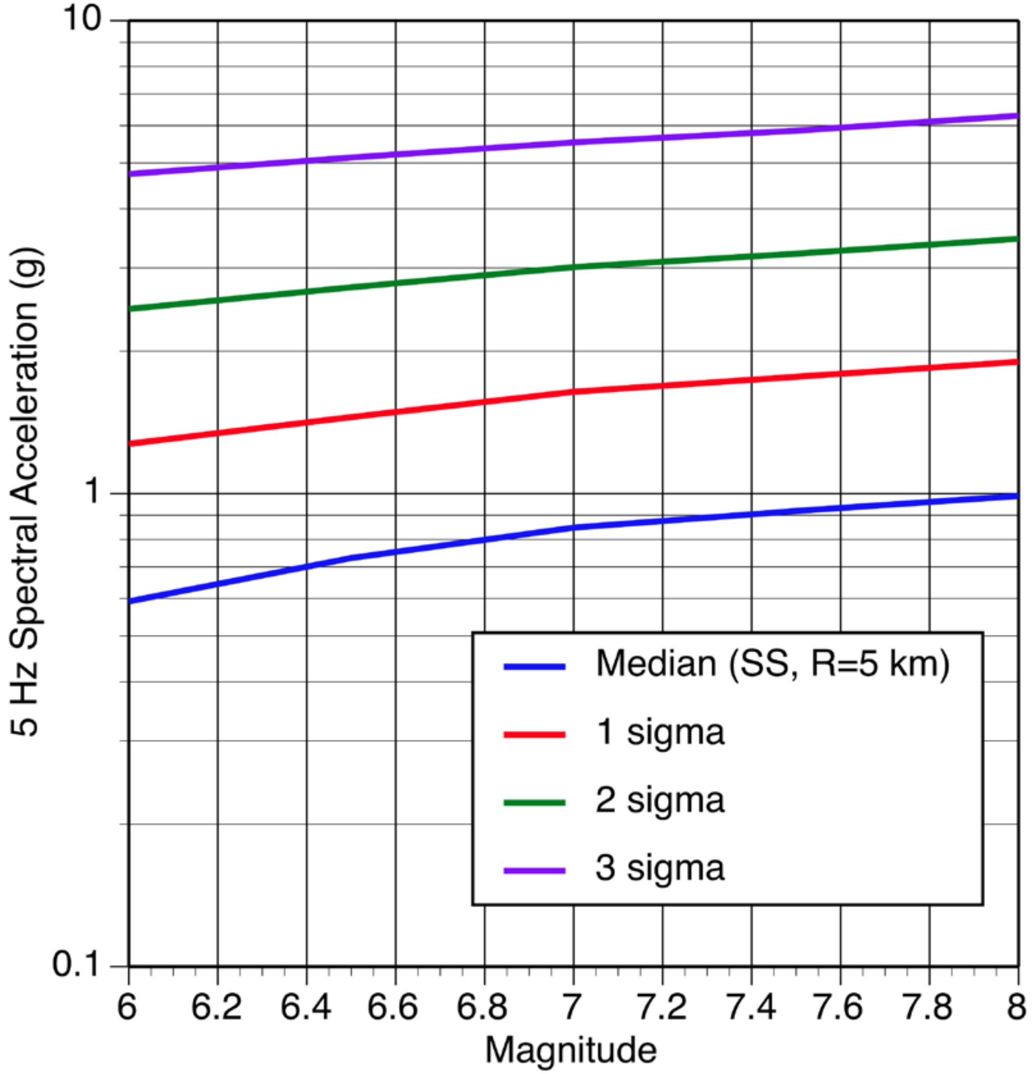
Residual Risk

- Not designed for worst-case
- “Safe” = very small residual risk
- NRC determines what is “very small”
  - Zero risk is not possible
- Beyond design basis events need to be considered at critical facilities
  - What do these “extreme events” look like?

Ground Motion Features Important for NPPs

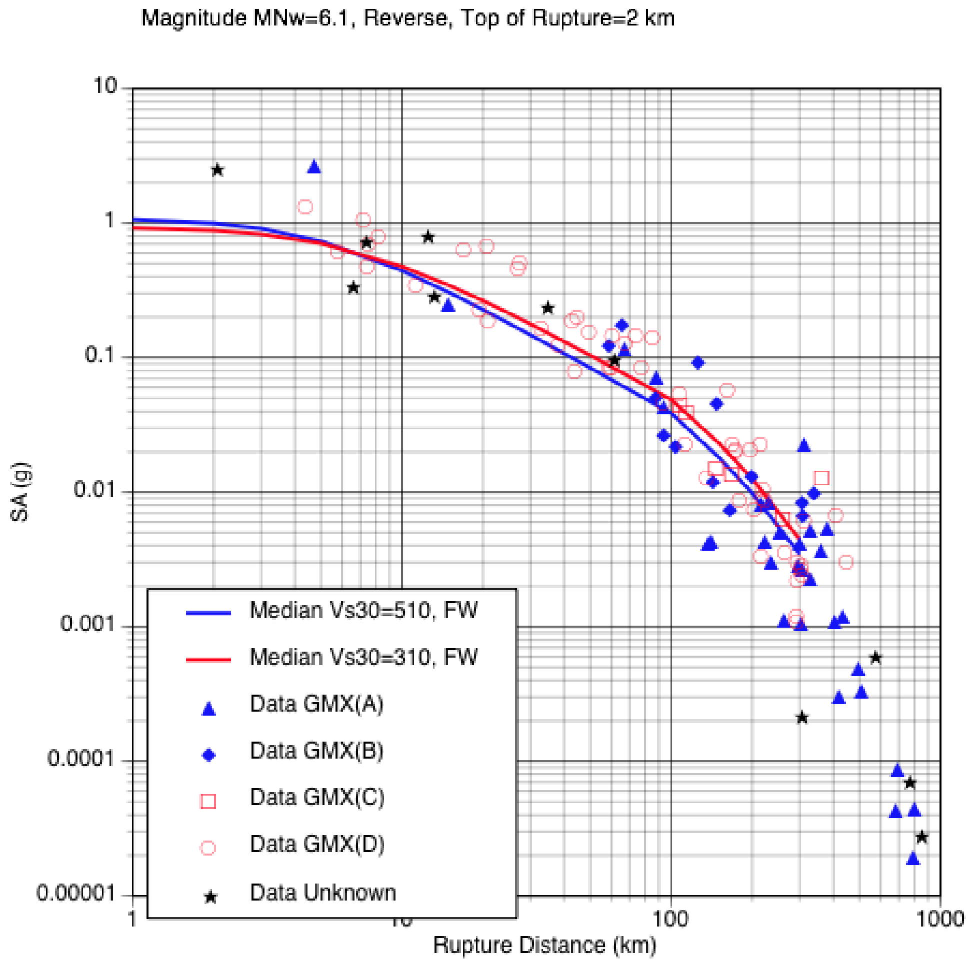
- Systems, Components, Structures (SSCs) important to safety
  - Main frequency band of interest: 3-30 Hz
- Few SSCs are sensitive to low frequency ground motions
  - Sloshing (spent fuel pool, reservoirs)
  - Sliding of spent fuel racks
  - Cranes

Magnitude Scaling of High Frequency Ground Motion at Short Distances (SS)

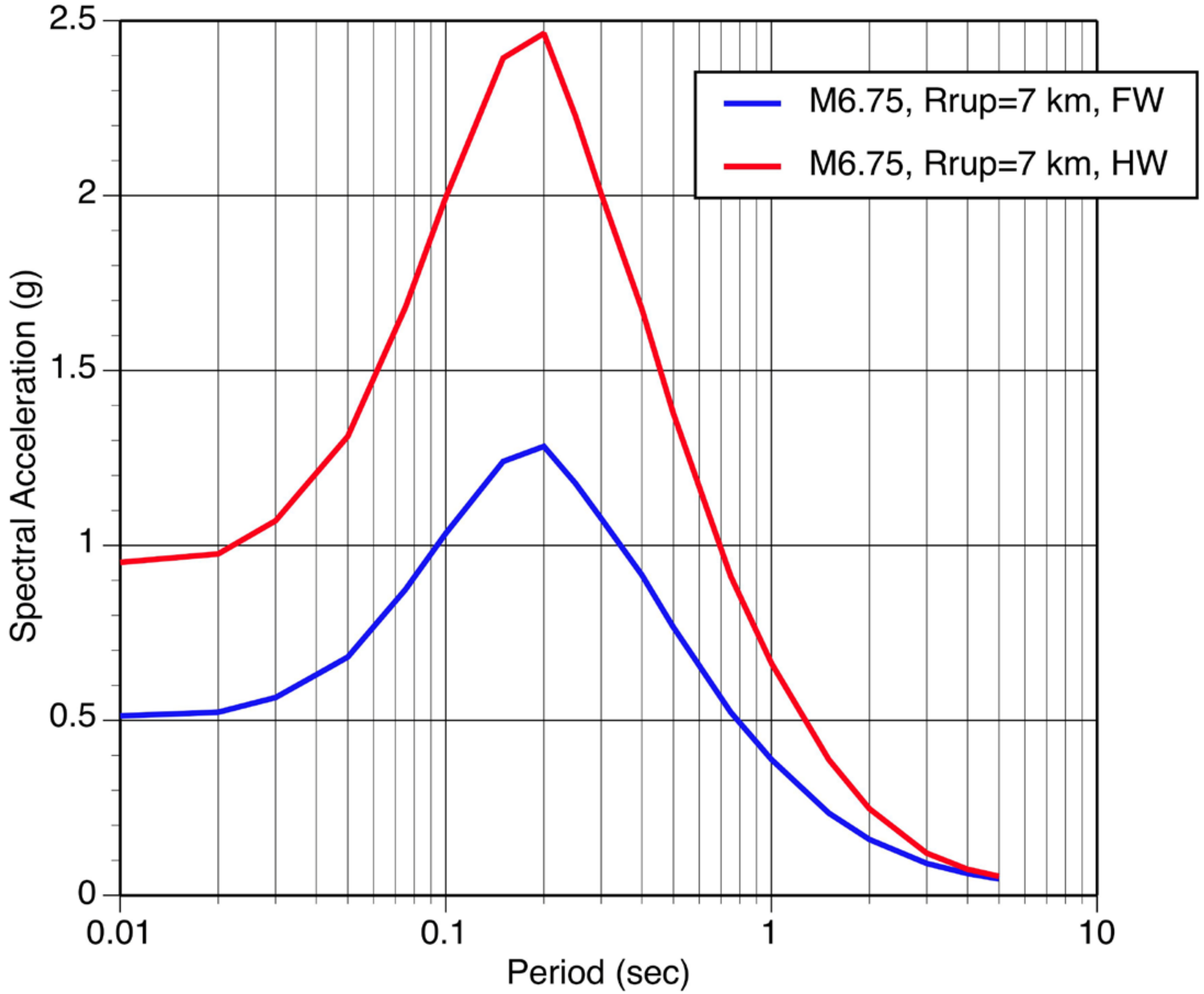


What Can Cause Beyond Design Basis Ground Motion?

Unusually Large Ground Motion
2011 Christchurch Eqk (5 Hz)



Example: HW Effects (84th percentile)

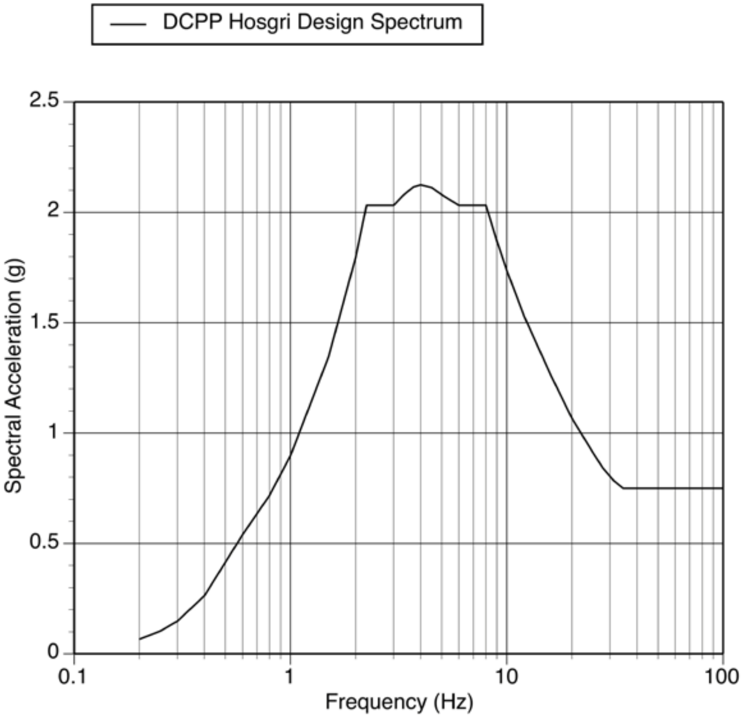


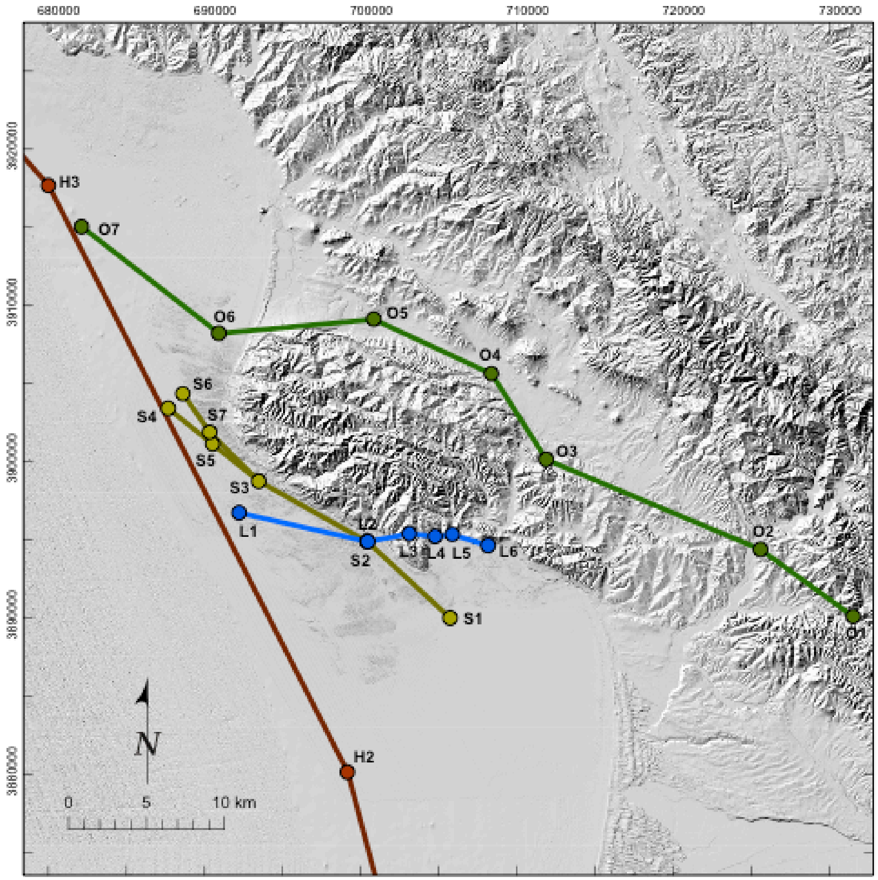
Design Ground Motions

- Development of design ground motions are based on source characterization (e.g. magnitude, distance, mechanism), ground motion model, and site condition
- Once design level is set, it does not change with new science, unless it is found to be inadequate
- Improved science leads to changes in source characterization, ground motion model, and site condition
  - Using new science, can check on the what events are within the design basis
  - Determine if there is acceptably low residual risk

Example – Diablo Canyon

- Design Ground Motion 1977
  - Based on
    - M7.5 earthquake on Hosgri fault at 5 km distance
    - Using 1970s ground motion models
    - 84th percentile ground motion





Note: Coordinates of fault sources are in Table 5-1

Legend

Seismic Sources

S1 — S2 Shoreline

L1 — L2 San Luis Bay

O1 — O2 Los Osos

H2 — H3 Hosgri

Seismic source model map traces of Hosgri, Los Osos, San Luis Bay, and Shoreline fault sources

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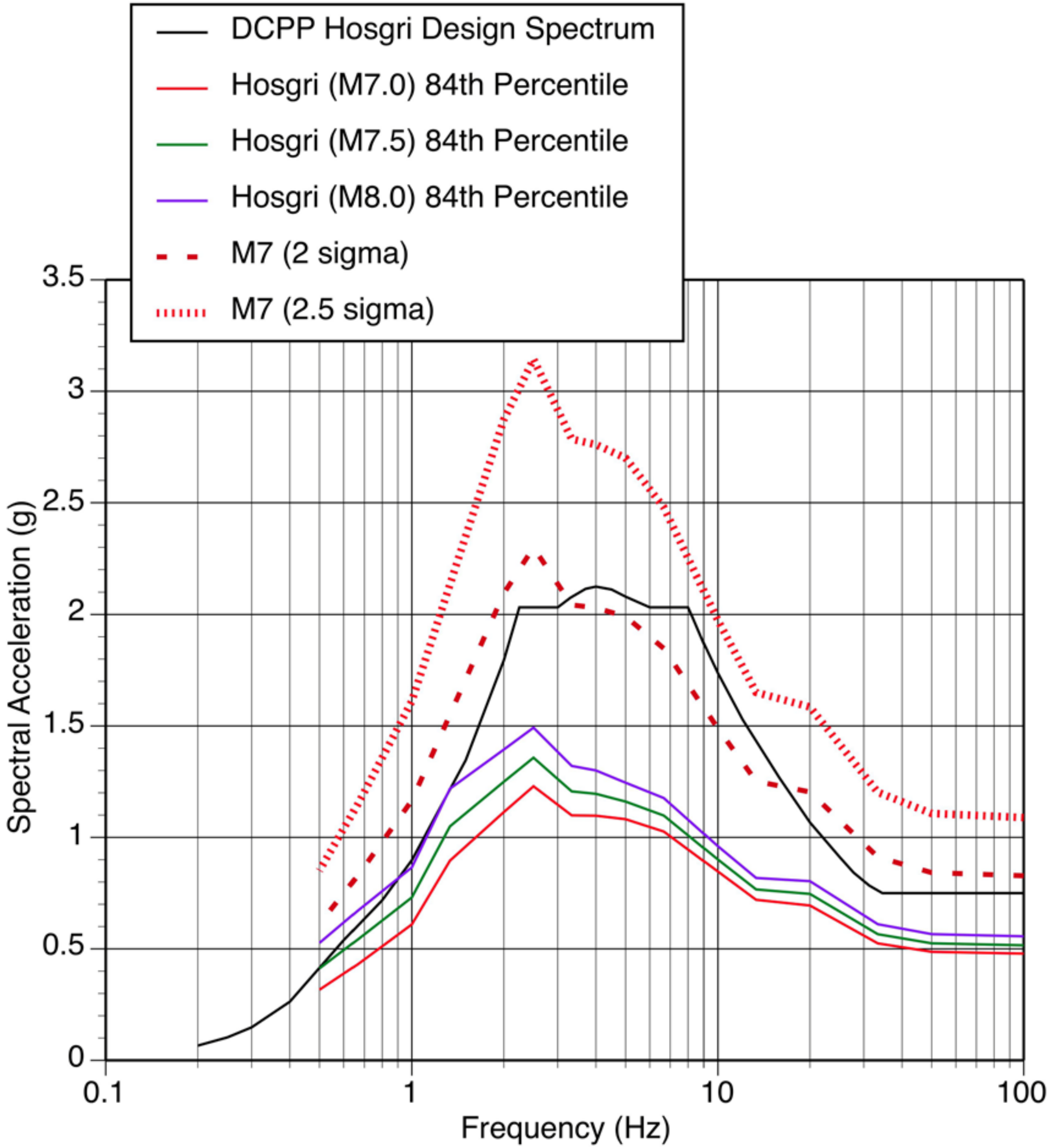
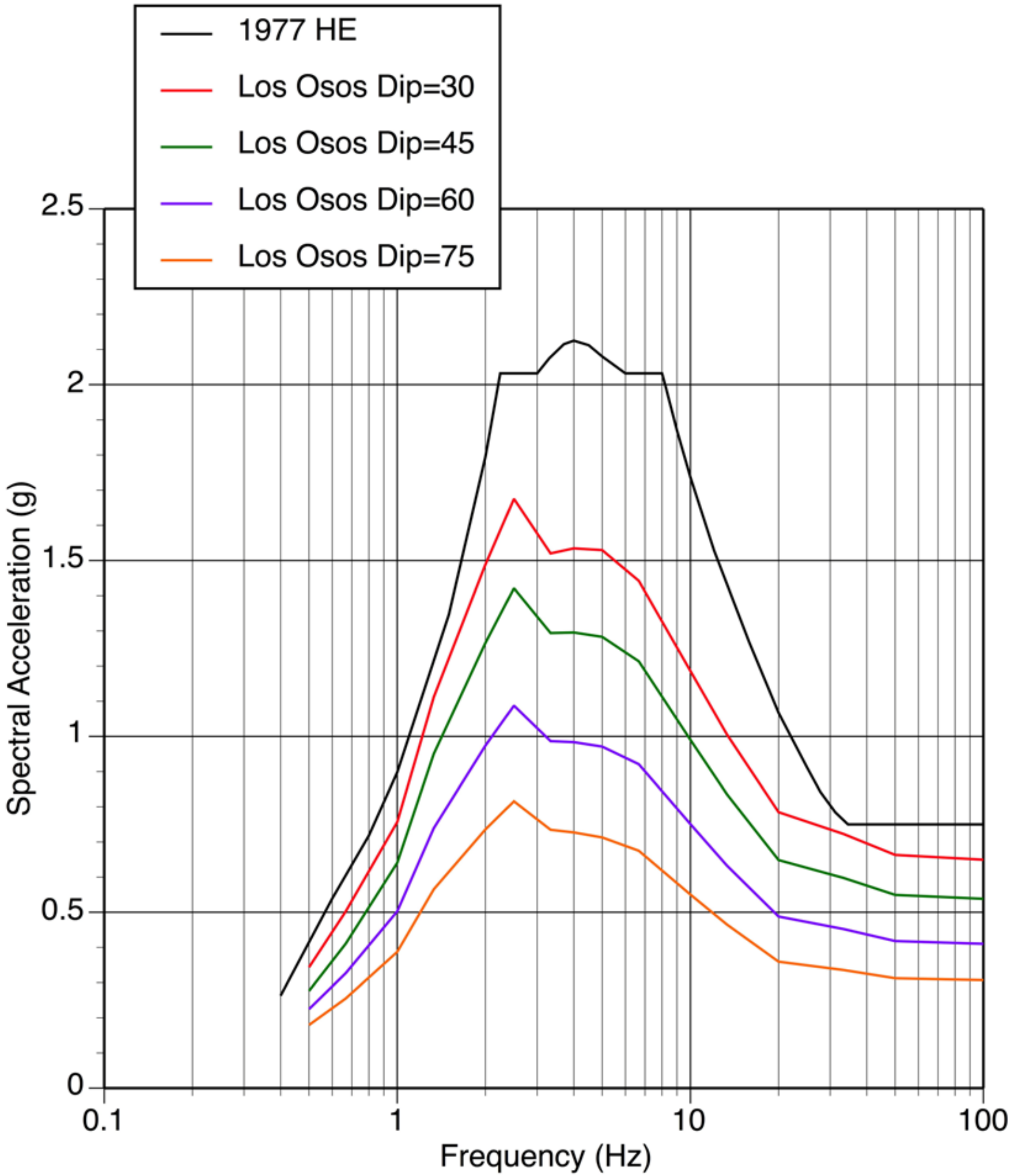
Pacific Gas and Electric Company

Figure **5-8**

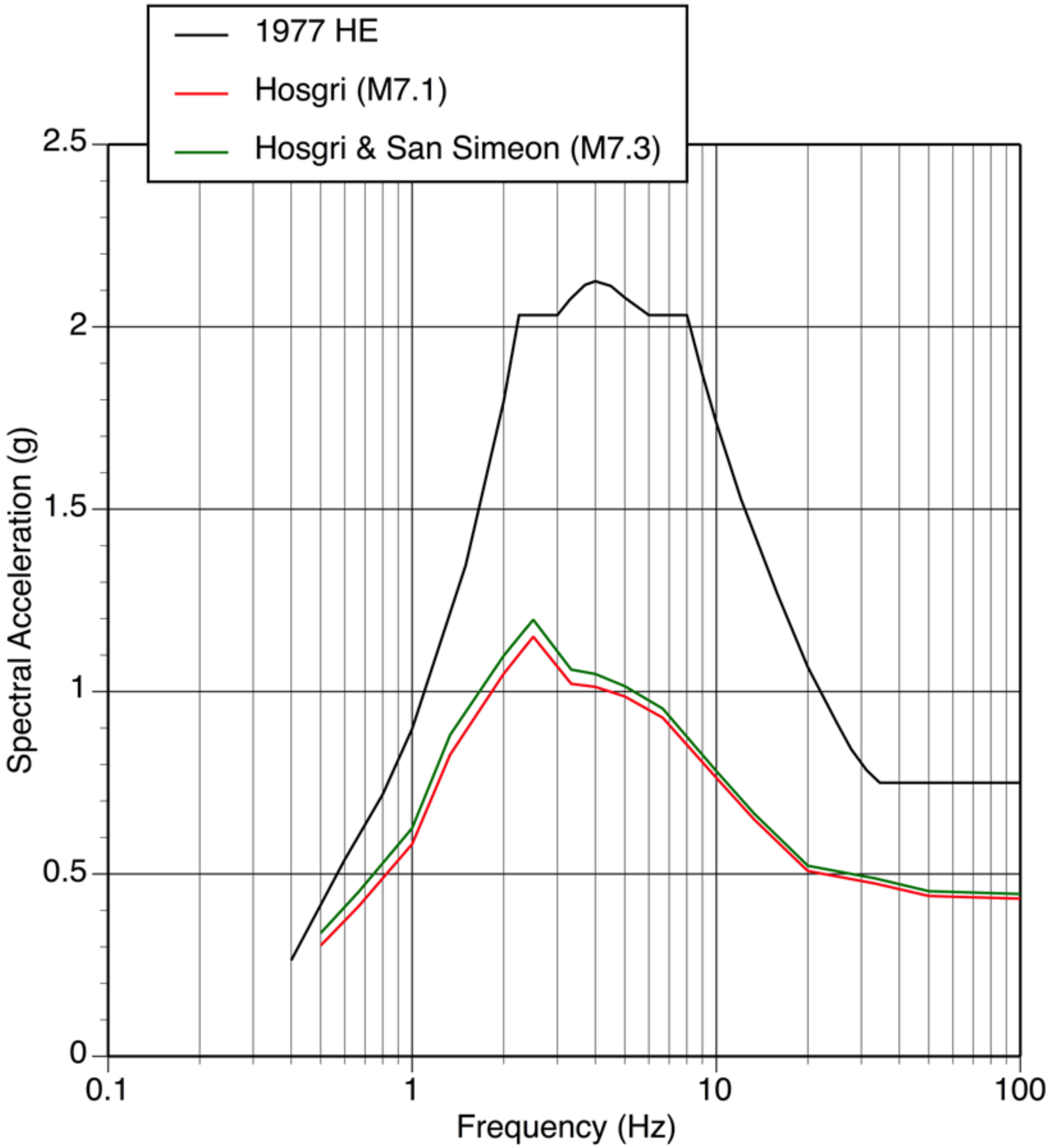
Mag Scaling vs Aleatory Varibility



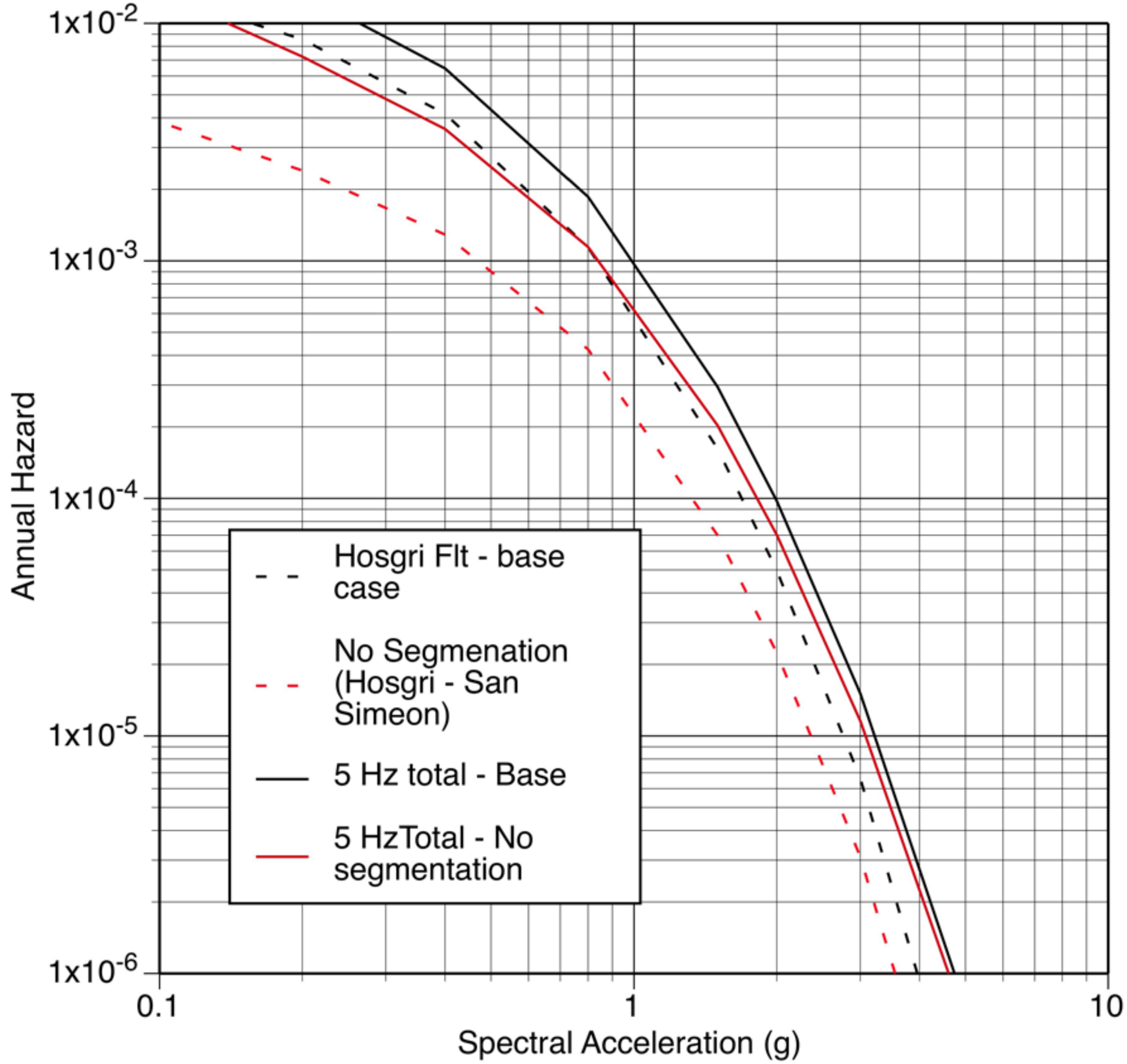
Example: Sensitivity to Dip (84th)



Example: Sensitivity to Segmentation



Example: Sensitivity to Segmentation (5 Hz)



Linking faults leads to larger magnitude earthquakes, but lower rates

NPPs: Residual Risk

- Probabilistic Risk Analysis (PRA)
  - Identifies potential vulnerabilities if beyond design basis ground motions occur
    - If possible, make modifications to strengthen weak link
  - Estimate the chance that this happens (hazard) and the chance of failure if large GM happens (fragility)
    - Typically use UHS
    - Does not address issue of what extreme events will look like
    - Use Conditional spectra?

Fragilities

- DCPP
  - Intensity measure (IM) for fragility is Sa averaged over 3-8.5 Hz
- SONGS
  - IM for fragility is the weighed average of the Sa at four frequencies:
    - 1 Hz (wt = 1/6)
    - 2.5 Hz (wt = 1/3)
    - 5 Hz (wt = 1/3)
    - 10 Hz (wt = 1/6)

Fragilities

- Structural models
  - Simple lumped mass models used to estimate floor spectra
  - Note: Core damage frequency dominated by failure of equipment, not structural collapse
- Improving structural models?
  - Need to get high frequencies (up to 30 Hz)
  - Can finite-element models improve floor spectra over lumped mass models?

Fragilities

- Improving the input ground motion description
  - Currently based on scaling of UHS at a reference level (such as 1E-4)
  - UHS is an envelope of different earthquakes
    - Disadvantage: Generally, not realistic ground motion
    - Advantage: limits the number of cases to run
  - Alternative: use conditional spectra (includes variability about CMS)
    - Disadvantage: requires many more runs (100s of time histories)
    - Advantage: properly tracks correlations of spectral values at different frequencies.
      - Should remove some conservatism in the core damage frequency based on UHS method

Summary

- Ground Motion Hazard (high frequency)
  - Dominated by nearby faults (< 15 km)
- Key Issues
  - Main offshore strike-slip faults
    - Slip-rate
    - Linking SS faults is not critical
  - Thrust faults
    - Geometry (location, dip)
    - Slip-rate
    - Hanging wall effects in GMPEs

Summary

- Beyond design basis events need to be considered
  - Ground motion
  - Aleatory variability is key factor leading to beyond design basis events
- Residual Risk
  - Seismic hazard should be mean centered with uncertainty
  - Need improved characterization of extreme events (large high frequency ground motions)
    - Not just scaling up typical events
    - Conditional spectra

Summary

- Improvements to PRA
  - Fragilities could be improved using modern engineering methods
    - Consider the required frequency band (up to 30 Hz)
  - Change from UHS to conditional spectra would provide more realistic input ground motions, accounting for variability in spectral shape
    - Improved characterization of extreme events (large high frequency ground motions)