Hazard Assessment Methods for Large and Critical Infrastructure

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Menu du jour

- Natural hazards for large infrastructure
- Seismic hazard as a example
  - Hazard vs. Risk
  - Overview and key components
  - Deterministic and probabilistic assessment
  - State of knowledge and current challenges
- Assessing other hazards

Natural hazards

- Landslide/rockslide
- Fault rupture (permanent static displacement)
- Seismic ground motions (cyclic demand, acceleration, velocity, displacement)
- Liquefaction
- Tsunami
- Volcanic eruption
- Storm (wind, waves)

Low probability – large consequences.

One hazard can trigger another one.

All can lead to foundation, structural or component failures.

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Context: Hazard vs. Risk

Hazard

- Probability that a seismic event will affect a given area over a certain time period.
- « There is a 50% probability that a certain level of seismic ground motion will affect a site in the Los Angeles area in the next 5 years. »

Risk

- The risk combines the **hazard**, **exposure** and **vulnerability (fragility)** of human infrastructure**. Risk represents consequences** (e.g. in terms of dollars, deaths and downtime).

December 2003: M 6.6
California (San Simeon): very limited damage, 2 deaths
Iran (Bam): 80% of city destroyed, 31 000 deaths

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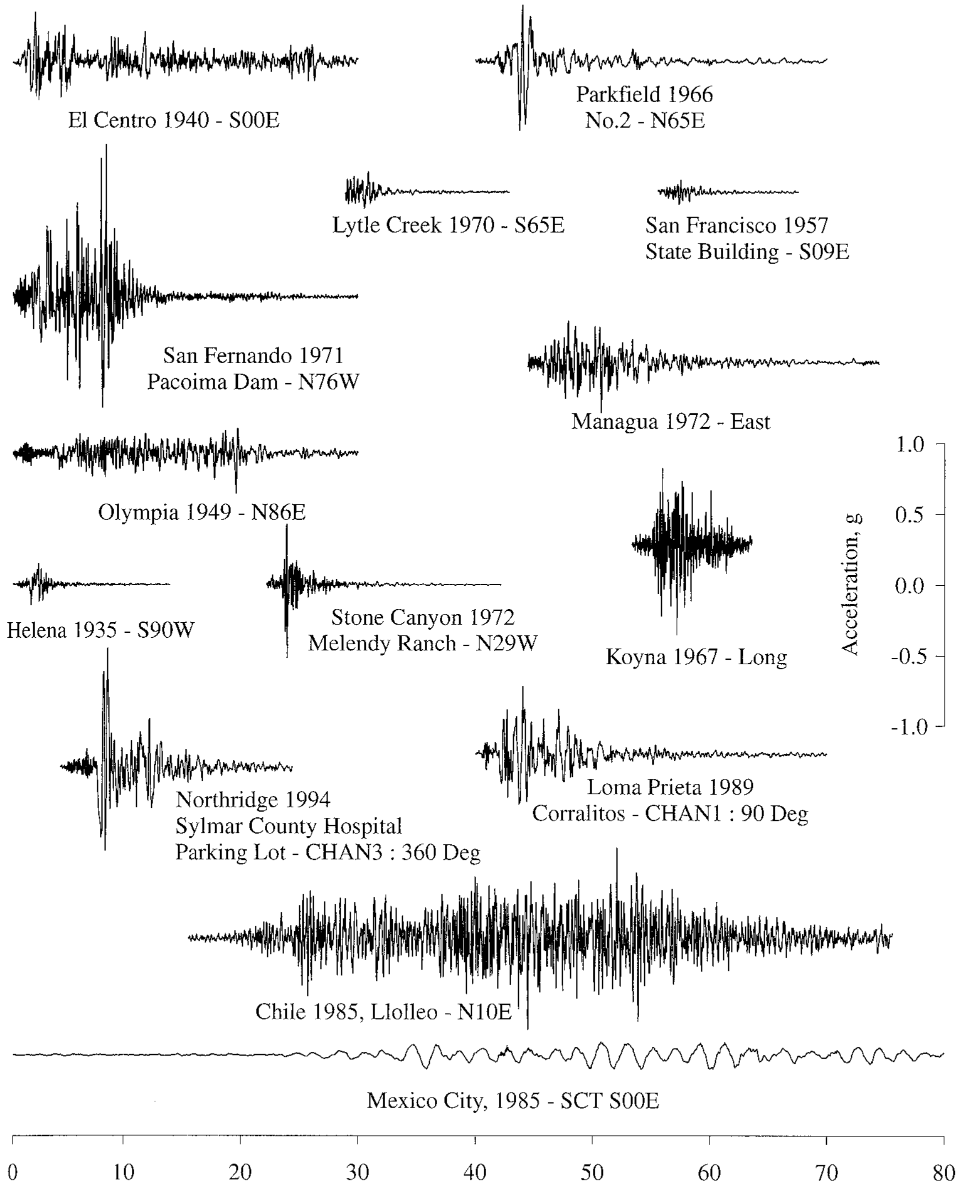
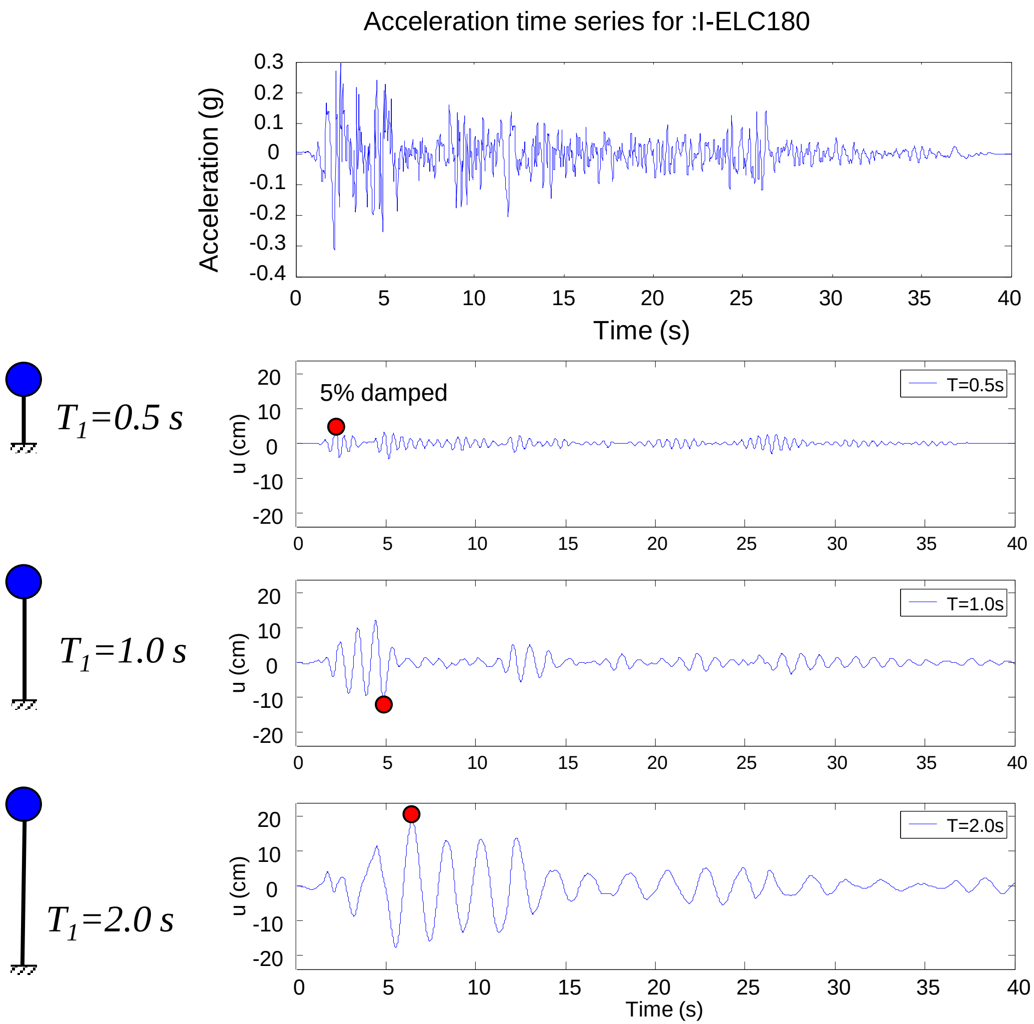
Seismic Ground Motions

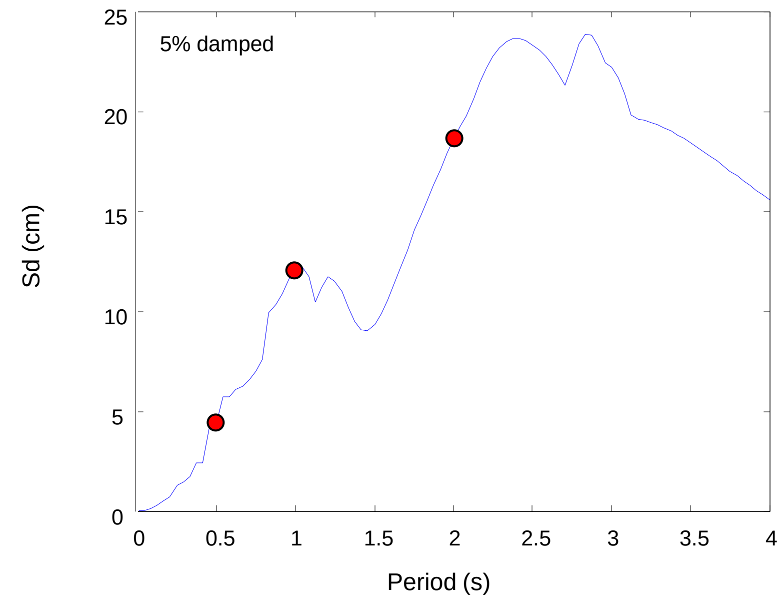


Source: Chopra (2000)

Ground Motion Intensity Measures (IMs)

Concept of response spectrum





Acceleration response spectrum (*Sa*) used in design in addition to Peak Ground Acceleration (PGA) and/or acceleration time series

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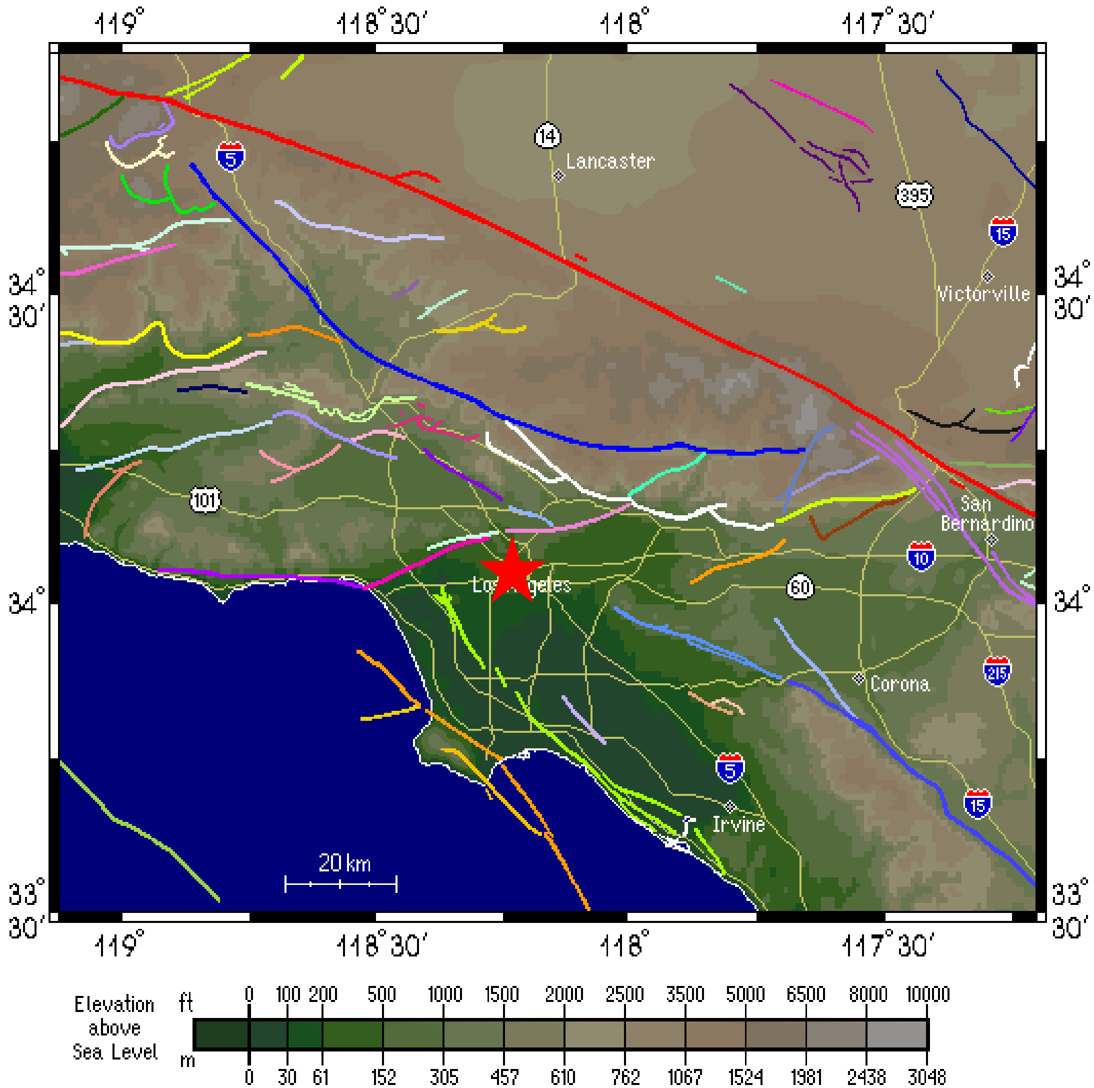
Seismic Hazard Analysis (SHA)



Schematic map of Los Angeles area and surrounding faults (USGS)

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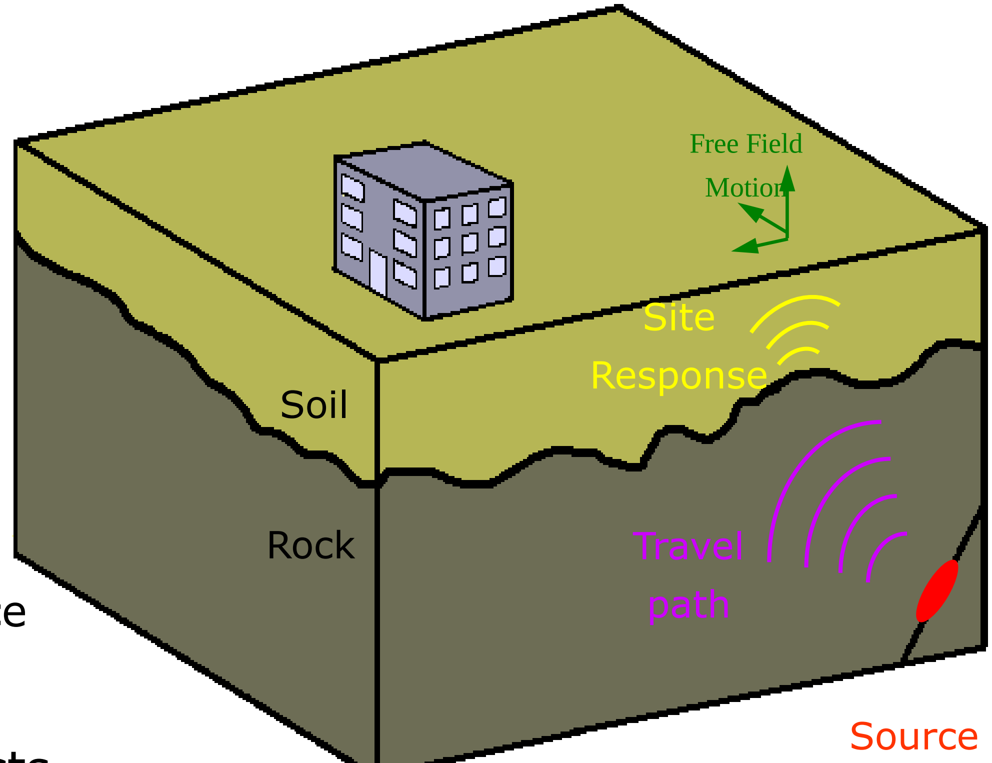
Contributions to Ground Motions

- Source effects
  - Tectonic regime
  - Fault focal mechanism
  - Fault rupture max magnitude
  - Recurrence models (over time)
  - Depth of rupture effects
- Path effects (attenuation)
  - Distance effects, damping
- Site effects
  - Wave propagation to the surface
  - Basin effects
- Other relevant site-source effects
  - Hanging wall effects
  - Rupture directivity



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Seismic Source Characterization

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  - Distance effects, damping
- Site effects
  - Wave propagation to the surface
  - Basin effects
- Other relevant site-source effects
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  - Rupture directivity

Ground Motion Characterization

Both accounted for through
Ground Motion Prediction Equations (GMPEs)

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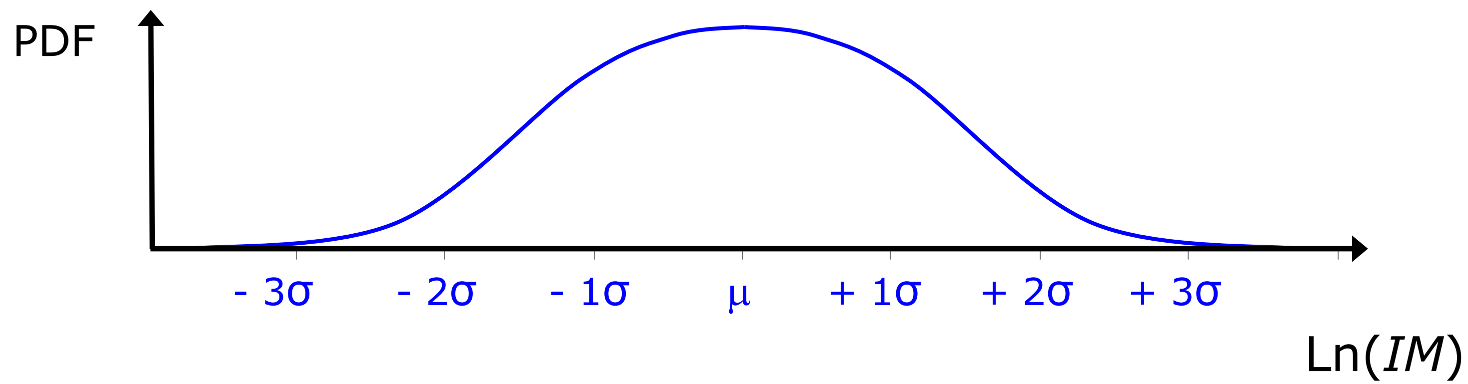
Ground Motion Prediction Equations (GMPEs)

- Empirical regression models constrained by known physical processes
- Contain multiple sub-equations to account for different effects

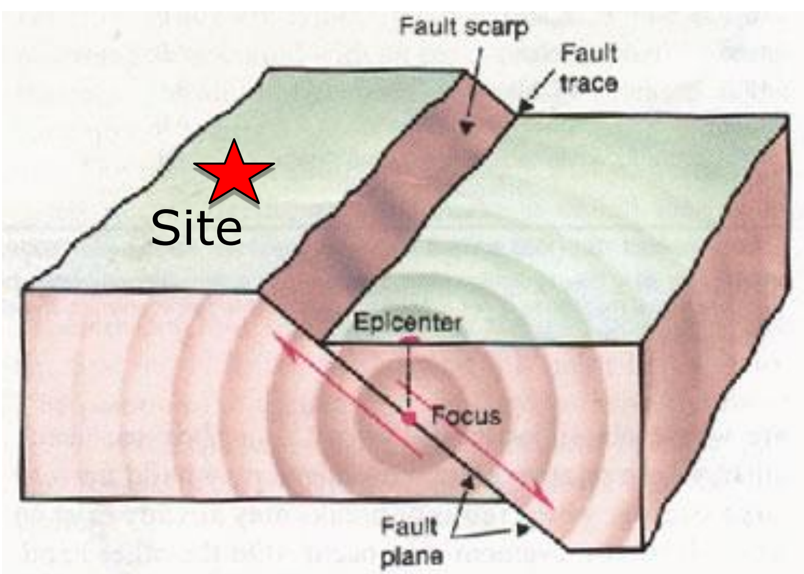
$$\ln(IM) = C_0 + f(\text{Magnitude}) + f(\text{Distance}) + f(\text{Source}) + f(\text{Site}) \ldots + \text{error}$$

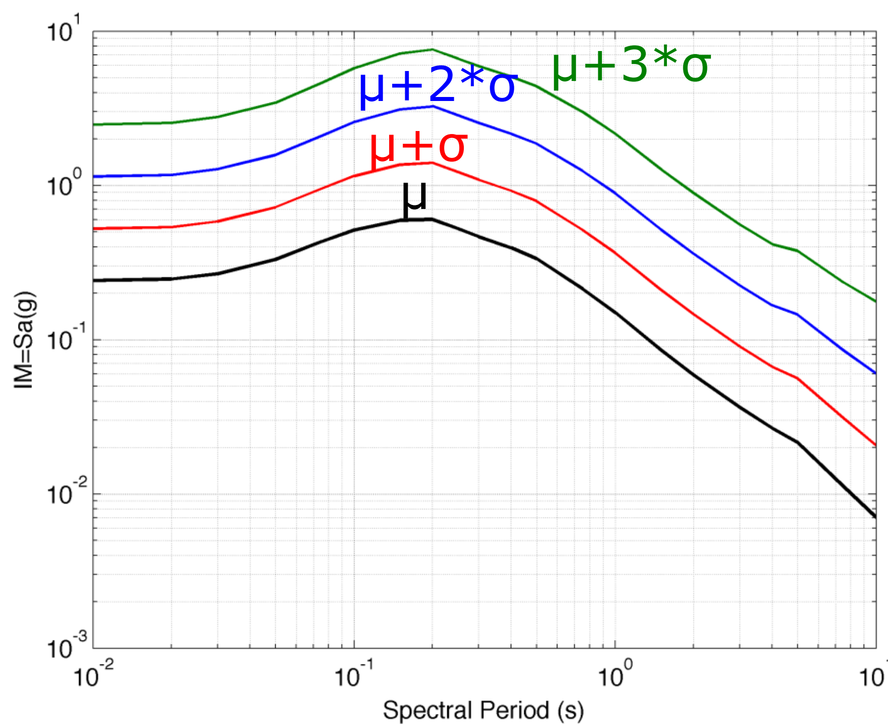
- ln(*IM*) is normally distributed with median μ and standard deviation σ



Deterministic Seismic Hazard Analysis (DSHA)

- Usually based on large plausible earthquake scenario on a near-by fault
- Use source info directly with ground motion prediction equation (specify percentile)





Probabilistic Seismic Hazard Analysis (PSHA)

Allin Cornell 1968

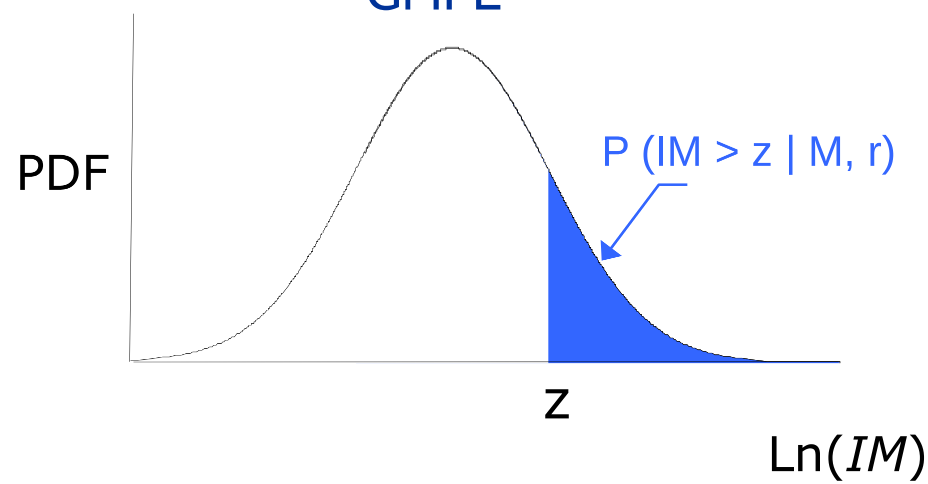
Source model

$$\nu(IM > z) = \sum_{i=1}^{N_{flt}} \lambda_i \times \int_M \int_R f(M) f(R) P(IM > z \mid M, R)\, dM\, dR$$

Rate that ground motion parameter is exceeded

Summation across all M and R

GMPE



Rate of earthquakes on fault *i*

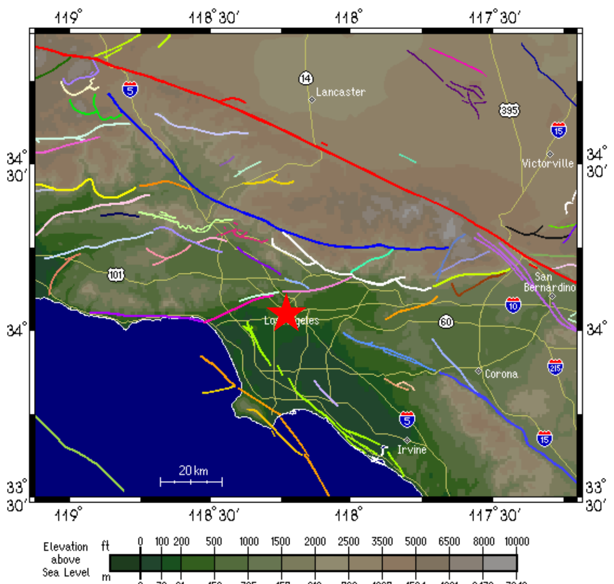
Summation across sources (faults)

PSHA Curve

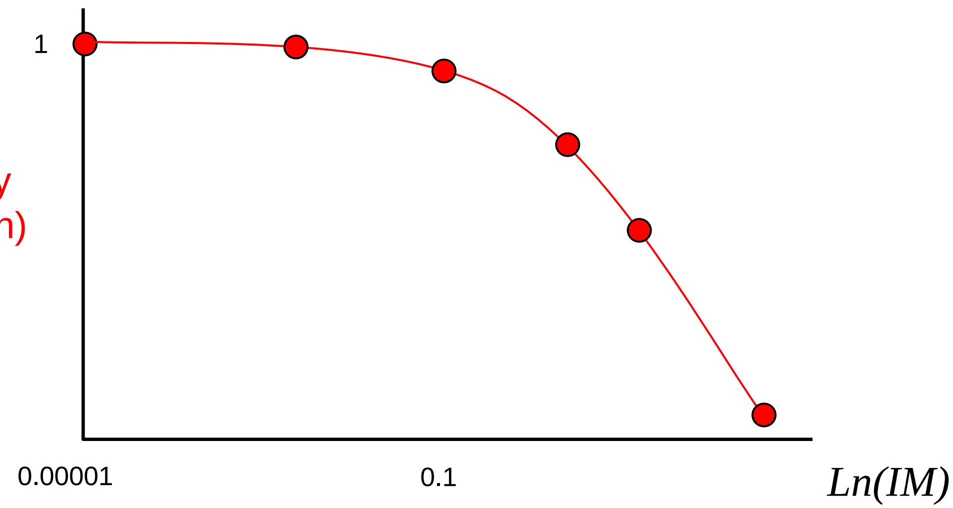
$$\upsilon(IM > z) = \sum_{i=1}^{N_{flt}} \lambda_i \times \int_M \int_R f(M) f(R) P(IM > z \mid M, R)\, dM\, dR$$

Rate that ground motion parameter is exceeded

Annual probability of exceedance (Ln)



Hazard Curve



Notes:

Each hazard curve is for a given site/location for a given IM.

Key issue - constraining the distributions (shape and extent)

- Affects all the distributions in PSHA
- Main issue is lack of data. Knowledge can be improved incrementally over time.
  - Some data is static/permanent and could be retrieved with large resource investment
- Trenching/drilling (slip rate, earthquake recurrence, site characterization)
- Remote sensing and geophysical methods as "X-rays" through the Earth (fault geometry, crust properties)

Key issue - constraining the distributions (shape and extent)

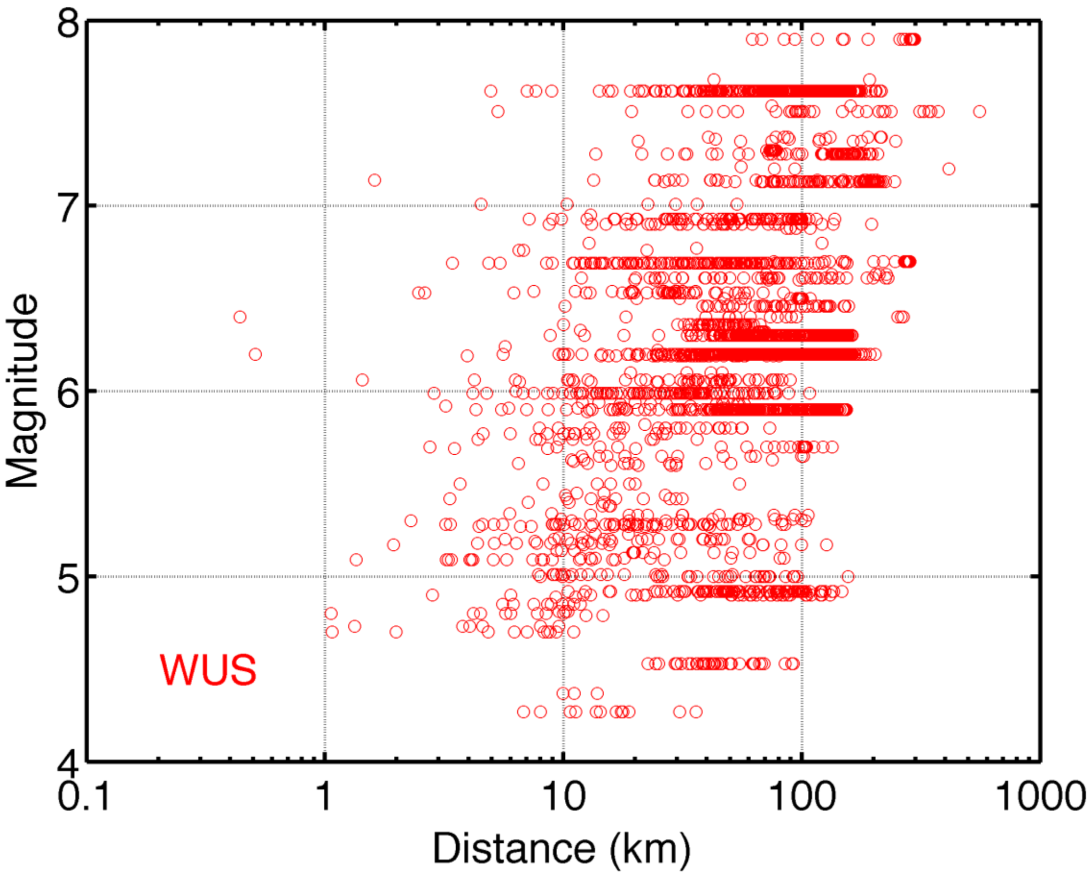
- Other data may require waiting for earthquakes… Instrumentation history is recent!
  - Local instrumentation, GPS technology (long term slip rate), etc.
  - Strong motion instrumentation, especially for sites near large magnitude events (critical for design)

State of knowledge – earthquake recordings and GMPEs

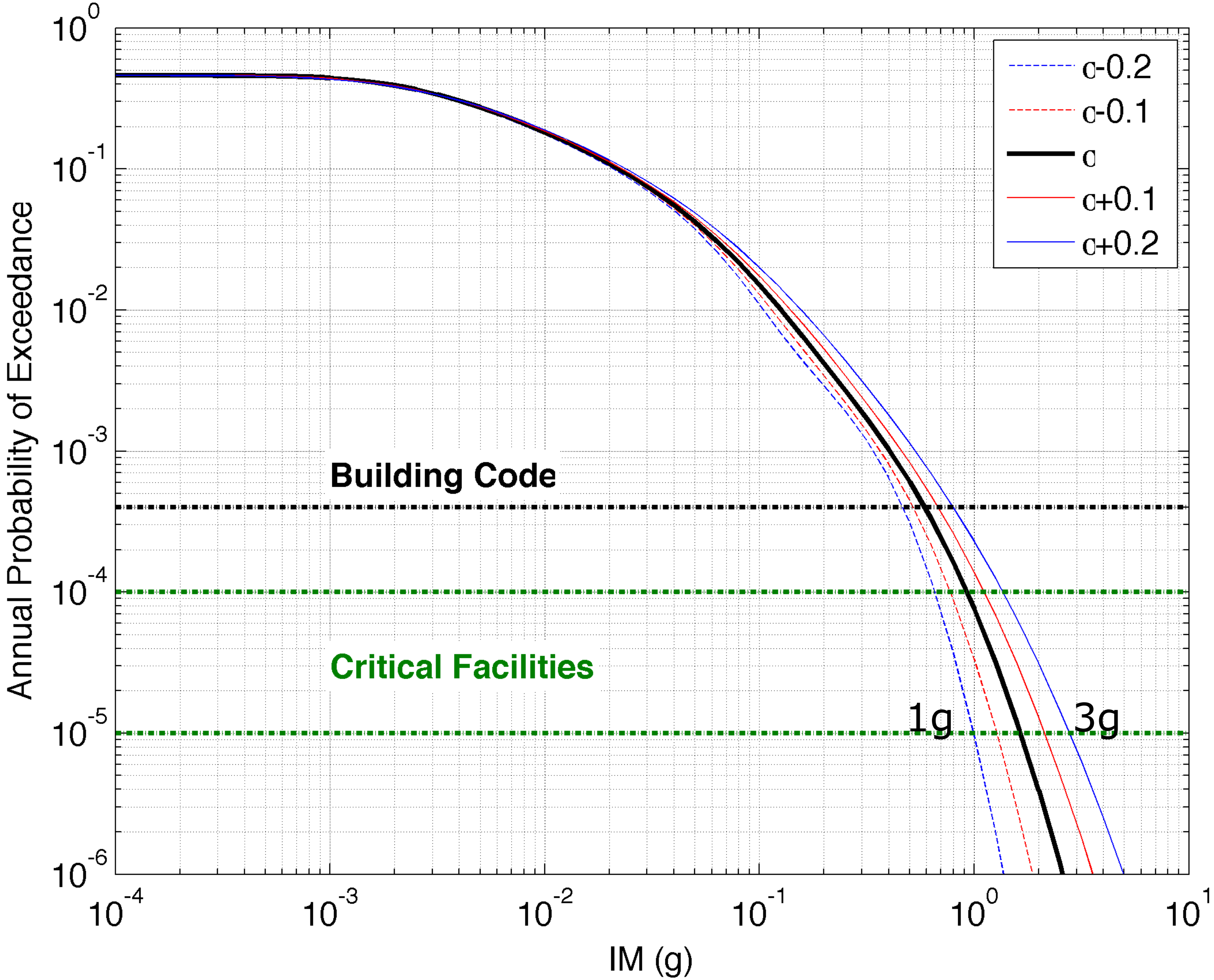
- "Well recorded" regions still lack in M7+ within 10km. Database dominated by a few events.

Active regions dataset (California and similar regions)

Stable continental region (Central and Eastern US and similar regions)

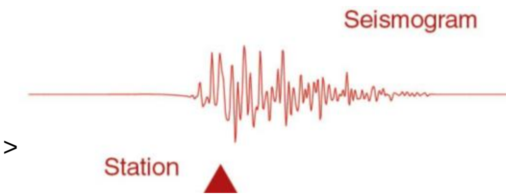


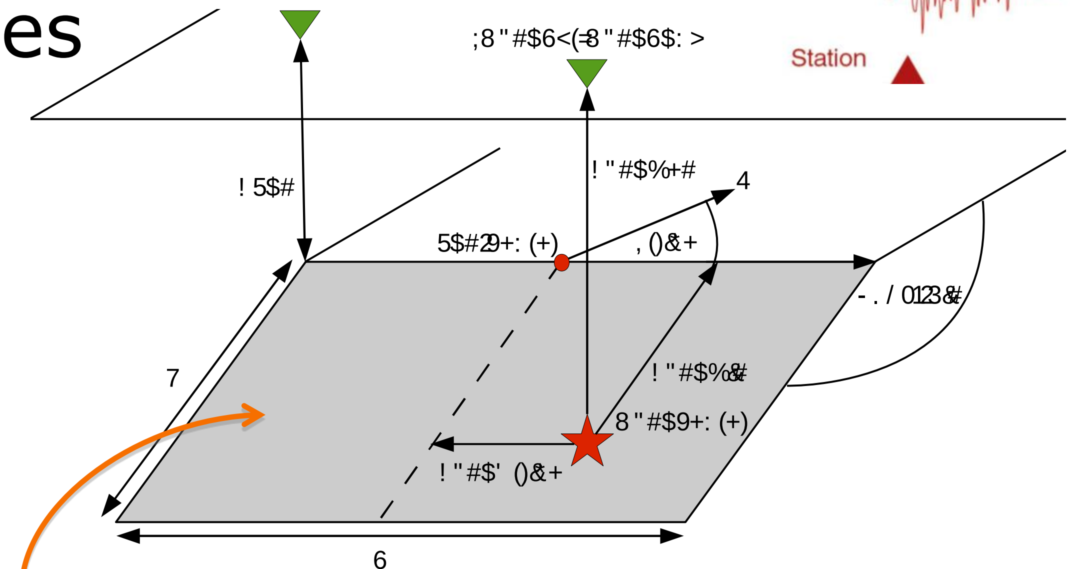
Does it matter?

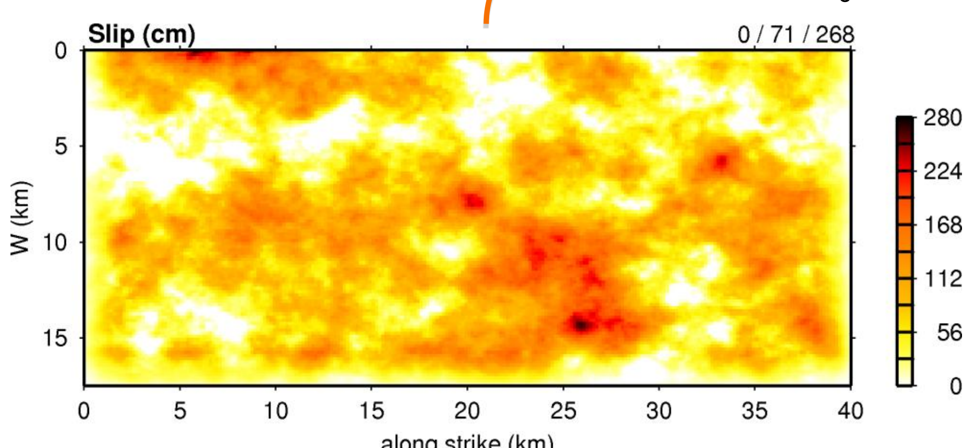


State of the art solution

- Use ground motion simulations
- FEM or FD codes

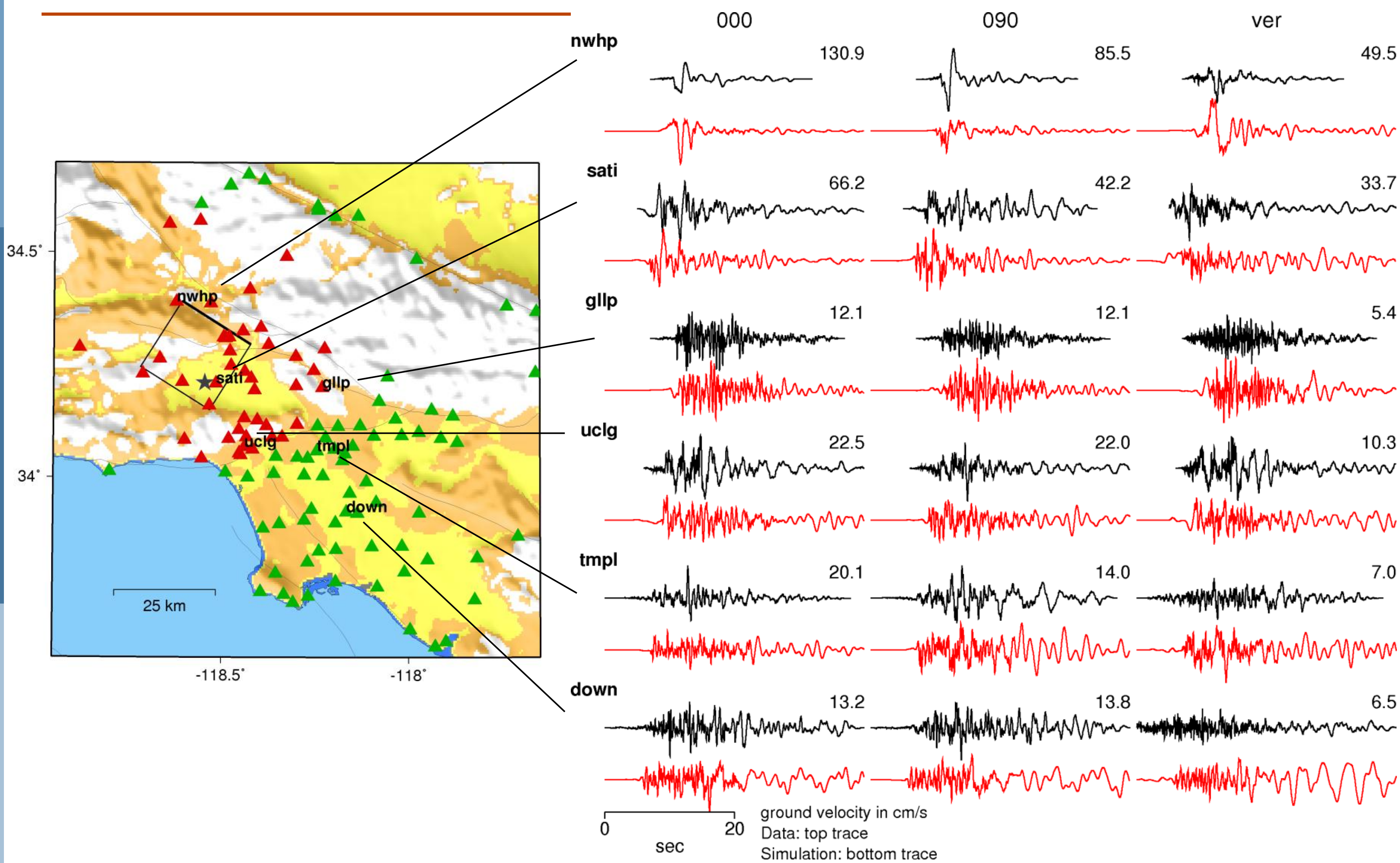






Source: R. Graves and R. Archuleta

Validation example: Northridge 1994



Source: R. Graves

From validation to forward simulations

- Can only validate for past events (limited number)
- If starting from small M events, what does the extrapolation look like to larger M?
- How to properly select the forward simulation parameters and their correlation?

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Other hazards

$$\upsilon(IM > z) = \sum_{i=1}^{N_{flt}} \lambda_i \times \int_M \int_r p(M)\, p(r)\, P(IM > z \mid M, r)$$

- Different hazards use tools similar to PSHA…
  - Fault rupture (permanent static displacement)
  - Liquefaction
  - Tsunami
  - Storm (wind, waves)
  - Landslide/rockslide
  - Volcanic eruption

Insight into solutions?

- How can we better constrain distributions in probabilistic framework?
- What to do with processes for which we are lacking data?

Thank you!

Adapted from USGS picture following the Loma Prieta 1989 earthquake

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