Deterministic Fault Displacement Hazard Methodologies for Gas Pipeline Crossings

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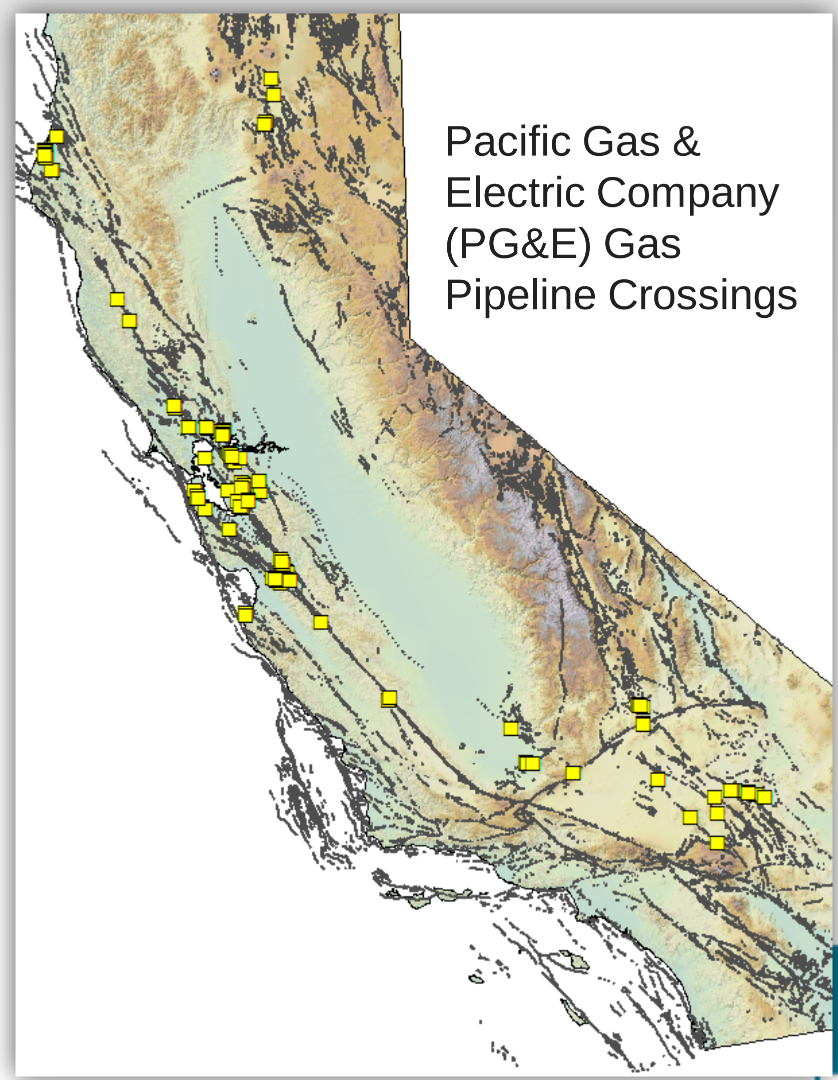
Introduction

=> Focus on Primary Displacement Amount (not location, etc.)

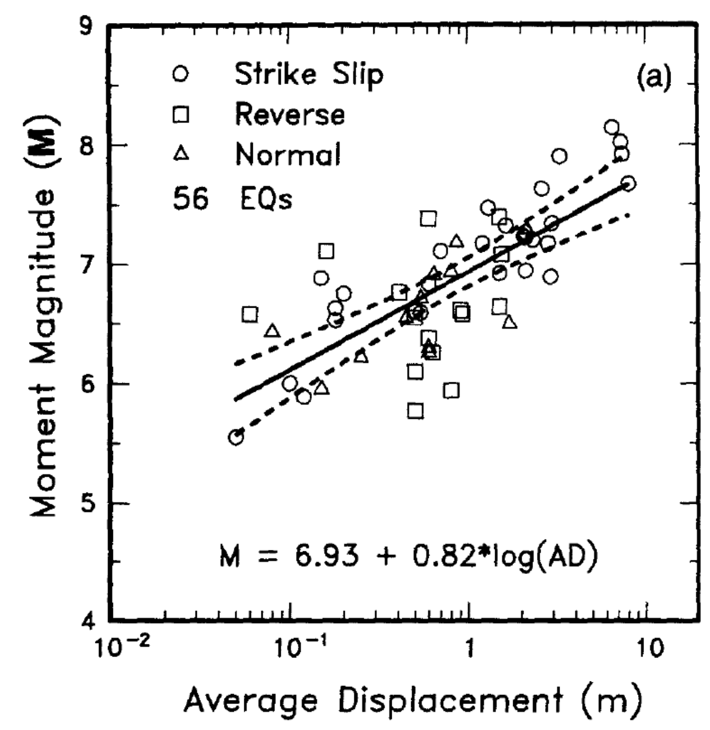
- Reluctance to Embrace PFDHA for Pipeline Analysis and Design
- Deterministic Approach for PG&E Pipelines
- Benefits of Site-Specific Displacement Data
- Data Needs

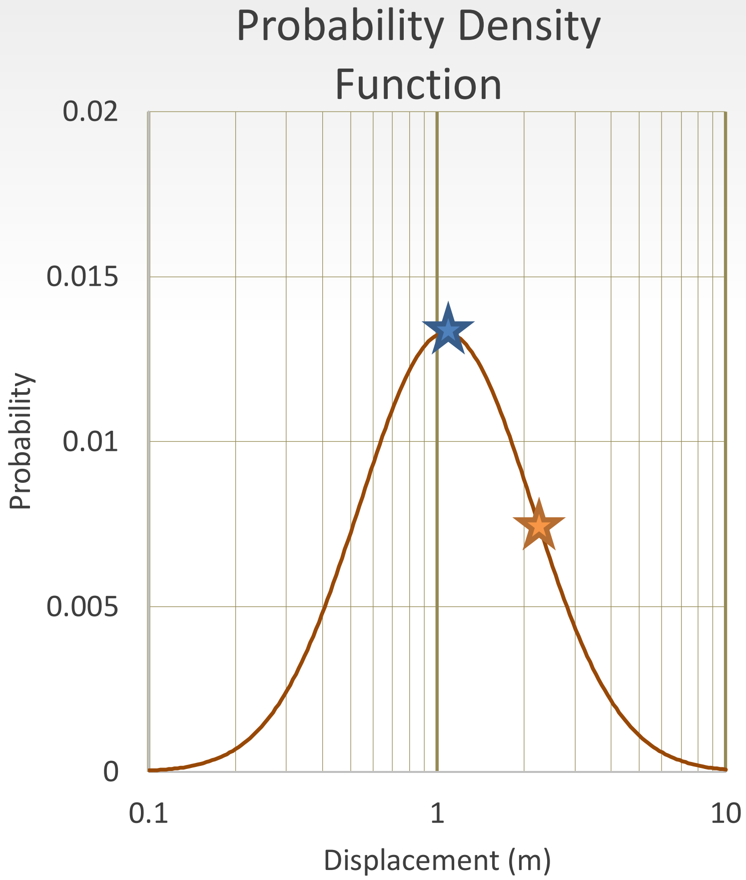


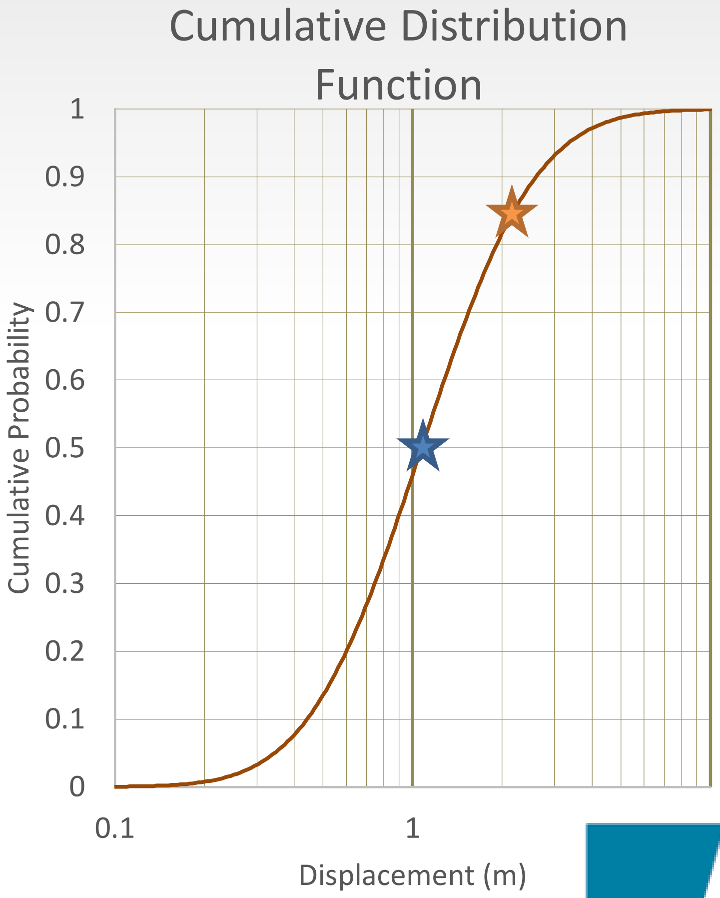
Pacific Gas & Electric Company (PG&E) Gas Pipeline Crossings

DFDHA and PFDHA – Five Easy Steps

- Scenario = **M** 7.0
- WC94 $\text{Log}_{10}(AD)$–**M**
- Log_{10} sigma = 0.3
- 1,000 yr RI

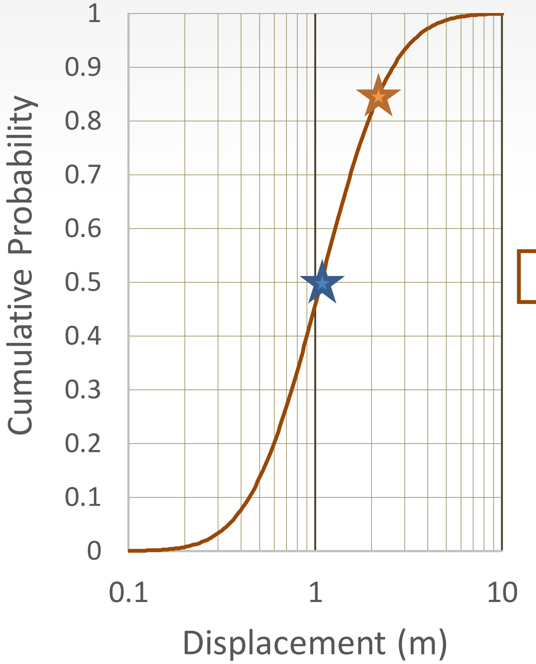


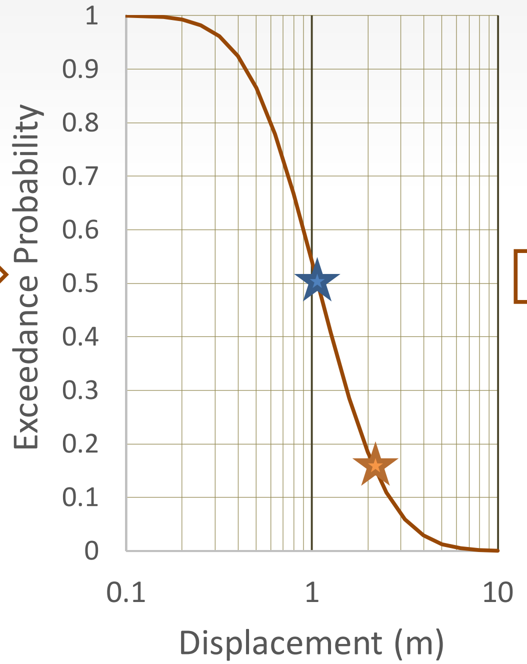


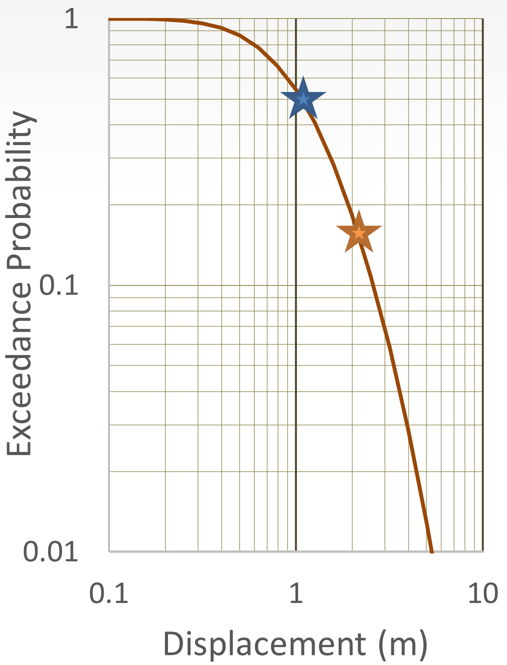


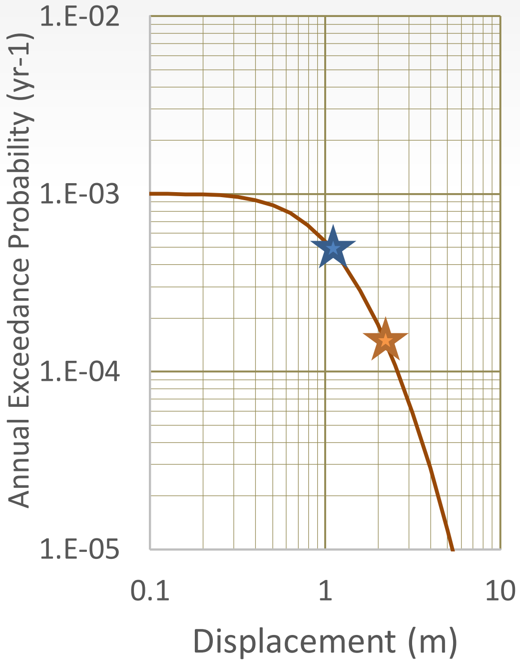
DFDHA and PFDHA – Five Easy Steps (cont.)

Mean Rate = 1/1000 yr^{-1} (1.E-03)


Cumulative Distribution Function


Complementary Cumulative Distribution (CCDF)


CCDF


Probabilistic Hazard Curve

- Semi-Log Plots
- Log-Log Plots

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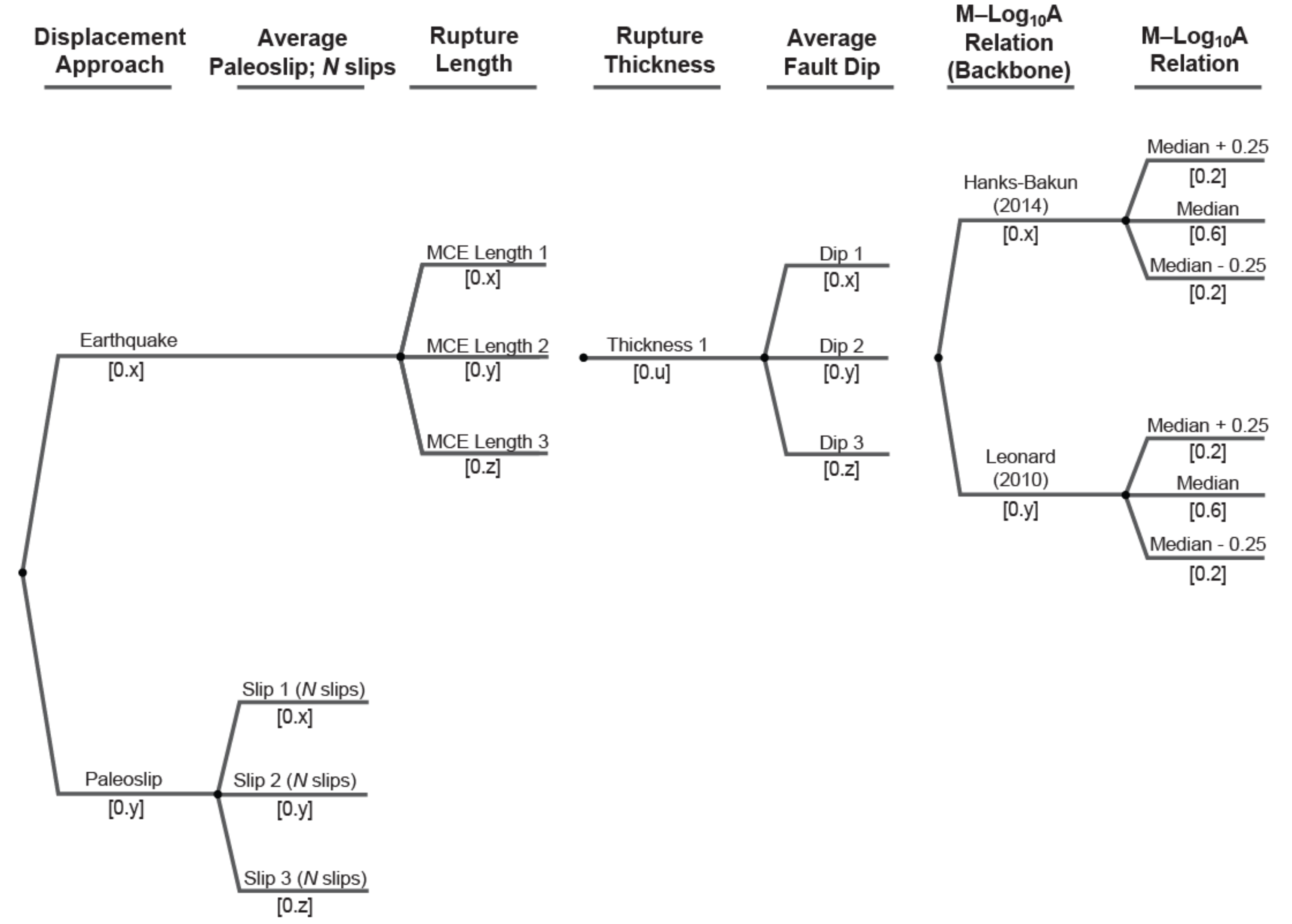
PG&E's Deterministic Fault Displacement Hazard Analysis (DFDHA) Approach

- Fault Source Characterization Logic Tree
- Captures Uncertainty in Rupture Behavior



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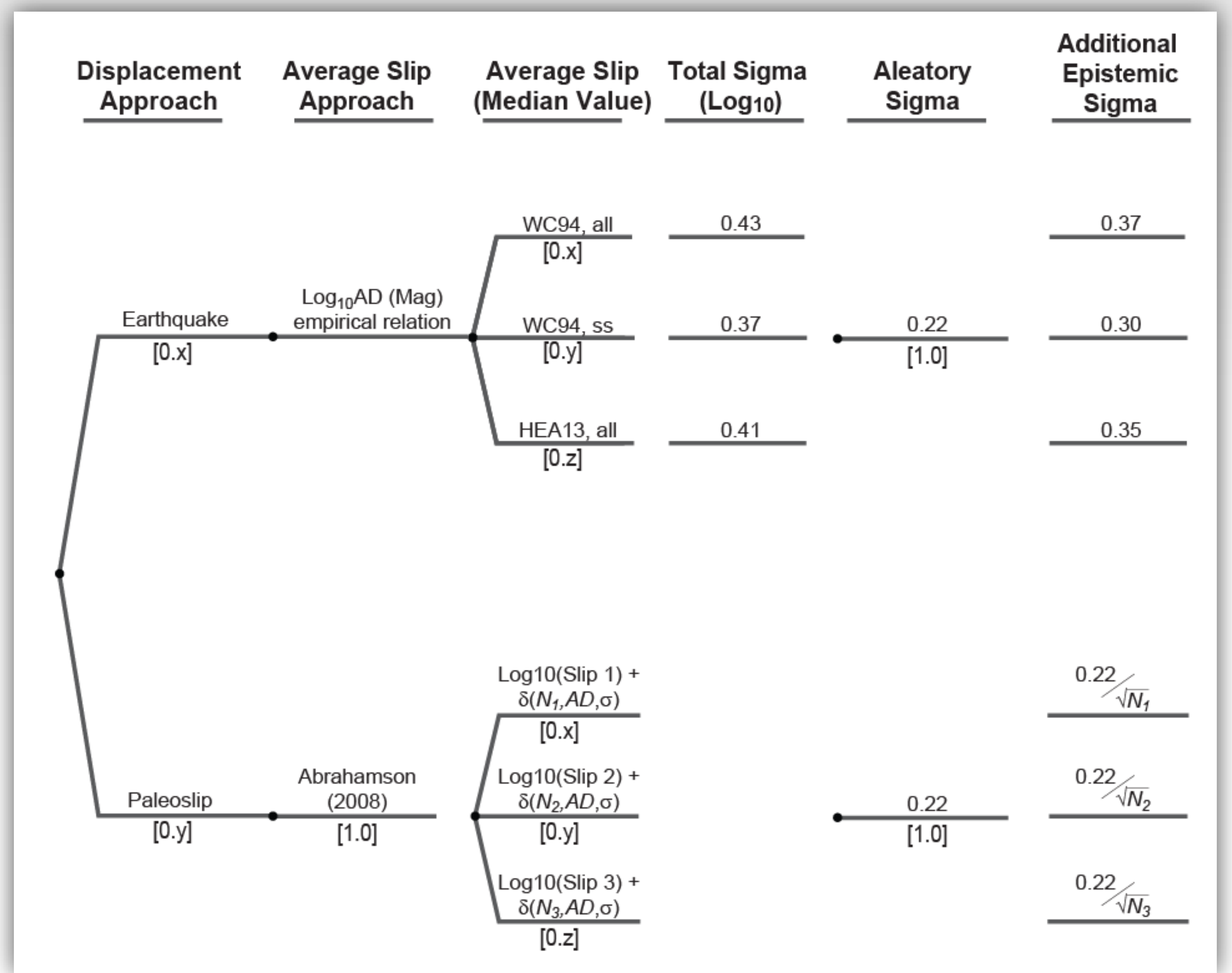
PG&E's Deterministic Fault Displacement Hazard Analysis (DFDHA) Approach

- Displacement Prediction Equation Logic Tree
- Uncertainty in Displacement Mean
- Uncertainty in Displacement Variability



Separating the “Sigmas”

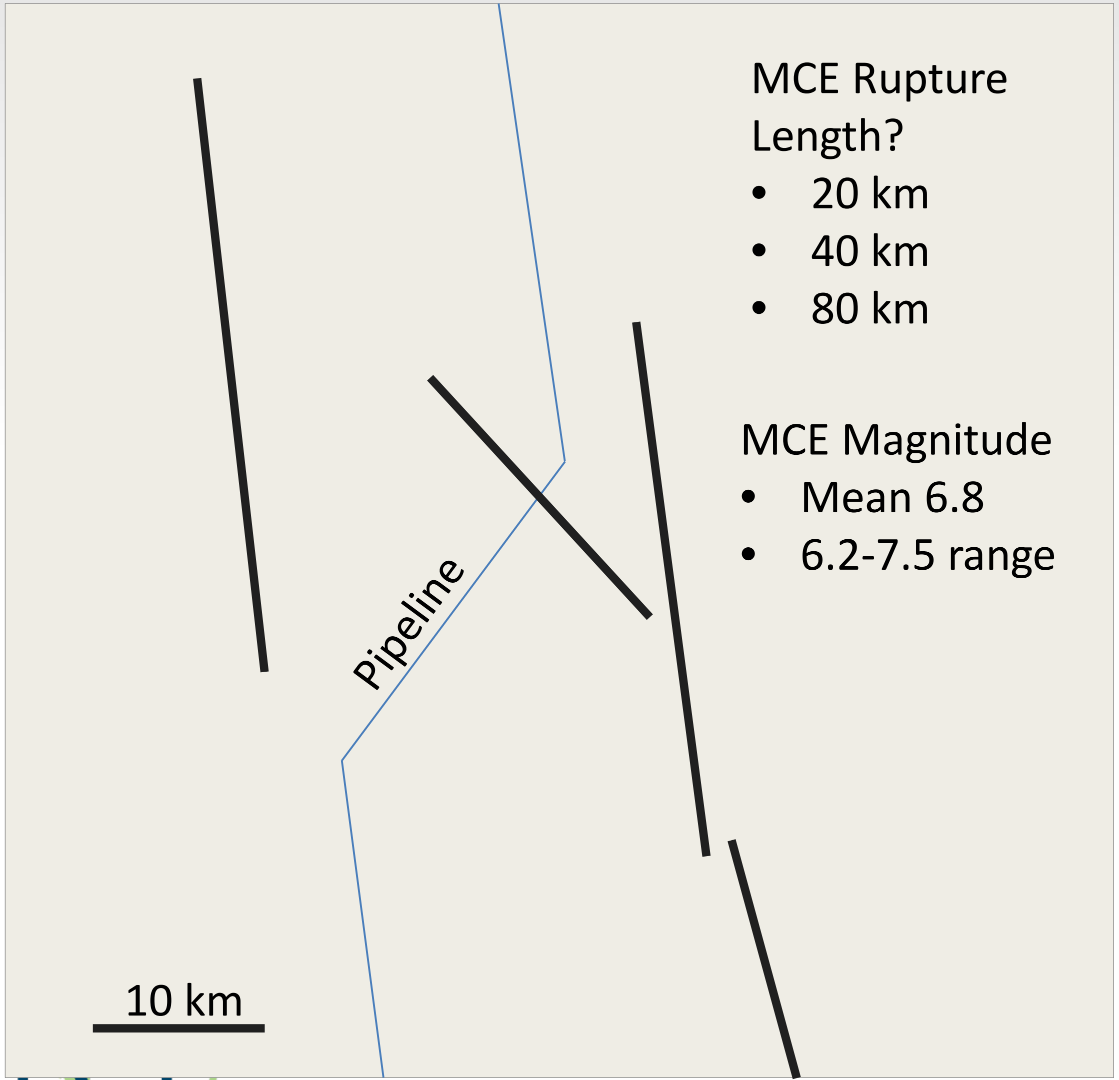
- Using the “Magnitude” approach, need to account for the total D(M) sigma ($\log_{10}$ in this case). Following Abrahamson (2008):

$$\sigma_T = \sqrt{\sigma_{AD}^2 + \sigma_{AS}^2} \approx 0.4$$

- For a particular point along an active fault, this total consists of a true natural variability sigma, σ_{SS} , which is about 0.22 based on Hecker et al. (2013). The rest is additional model uncertainty…

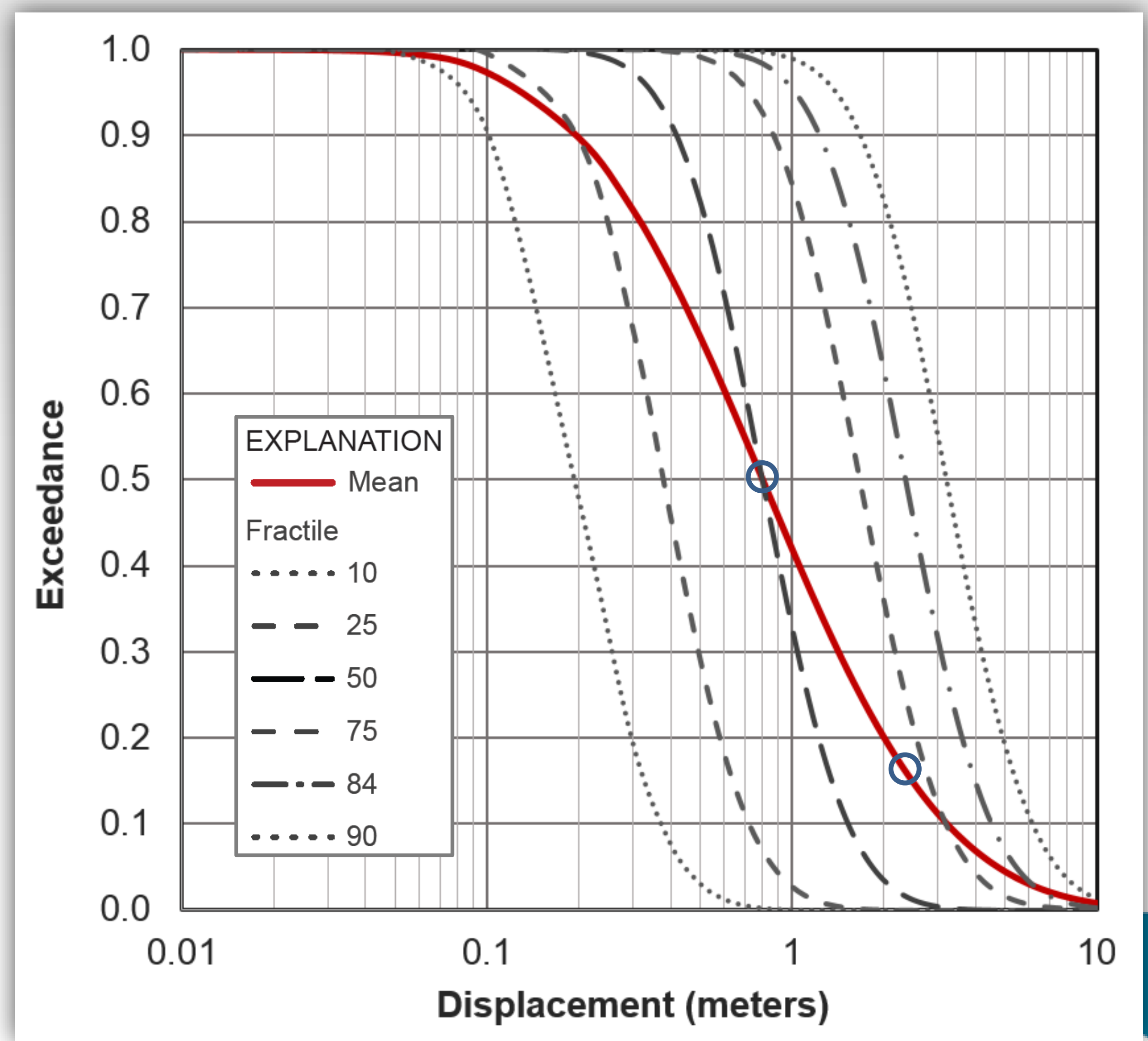
$$\sigma_{AE} = \sqrt{\sigma_T^2 - \sigma_{SS}^2} \approx 0.35$$

Example – Hypothetical Fault Crossing



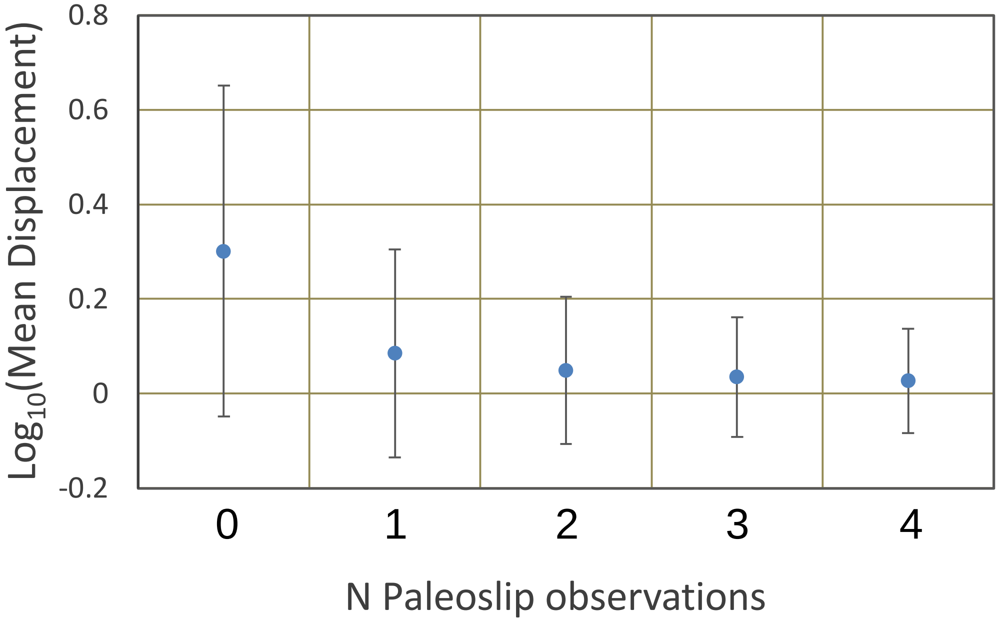
MCE Rupture Length?
- 20 km
- 40 km
- 80 km

MCE Magnitude
- Mean 6.8
- 6.2-7.5 range



Let's Go Paleoseismic!

- Collecting site-specific data of past per-event slip is the best means of reducing displacement hazard uncertainty
- Approach by Abrahamson (2008) relies on Hecker et al. (2013) analysis



Example: Earthquake approach slip = 2.0 m; Paleoslips = 1 m

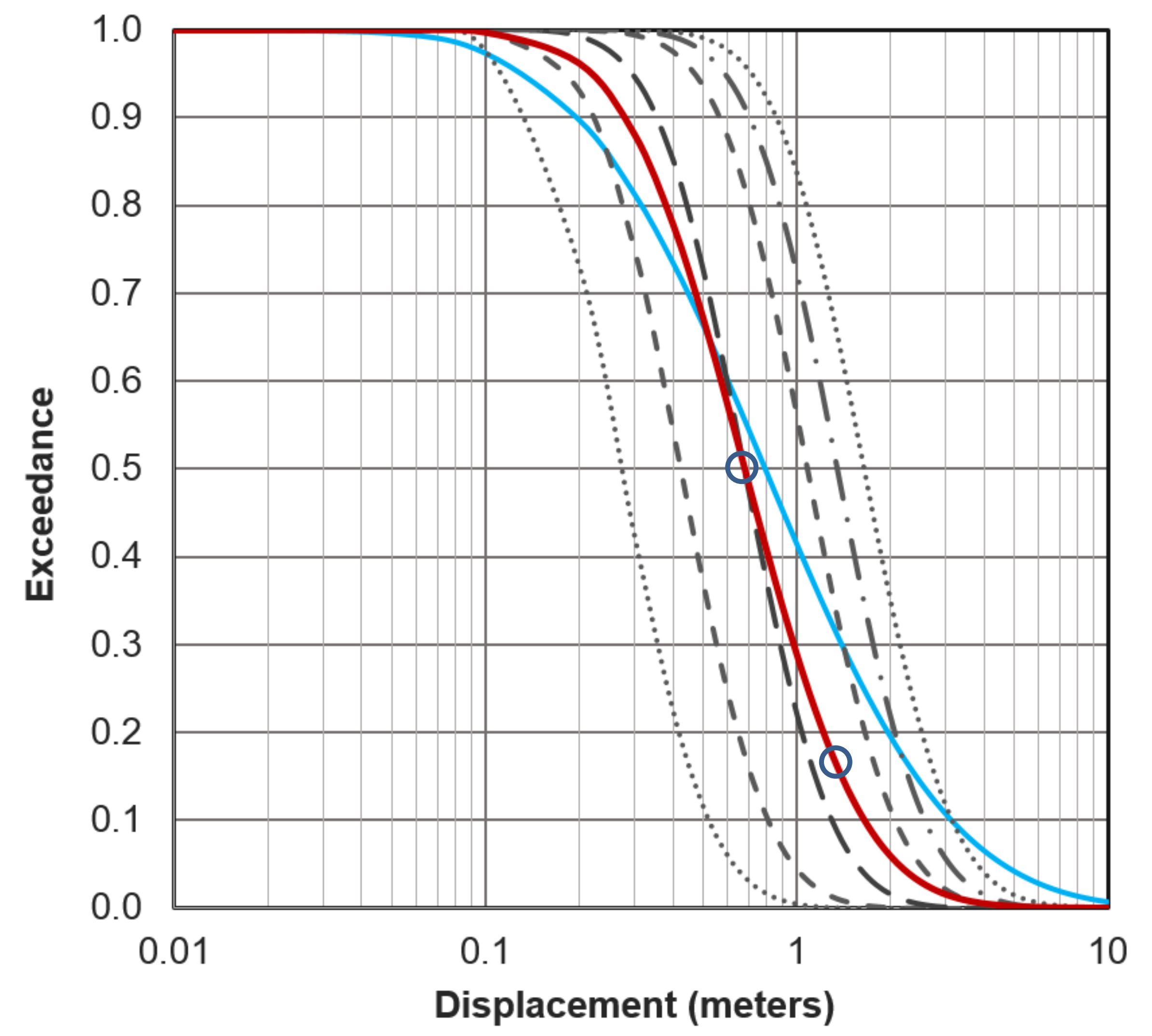
1 σ_{AE} error bars shown

Example – Hypothetical Trench Data at Crossing

- Example of a single MRE Slip = 0.65 ±0.15 m

- 50th percentile hazard reduced from 0.8 to 0.7 m
- 84th percentile hazard reduced from 2.2 to 1.3 m

- Clear potential benefit to the project



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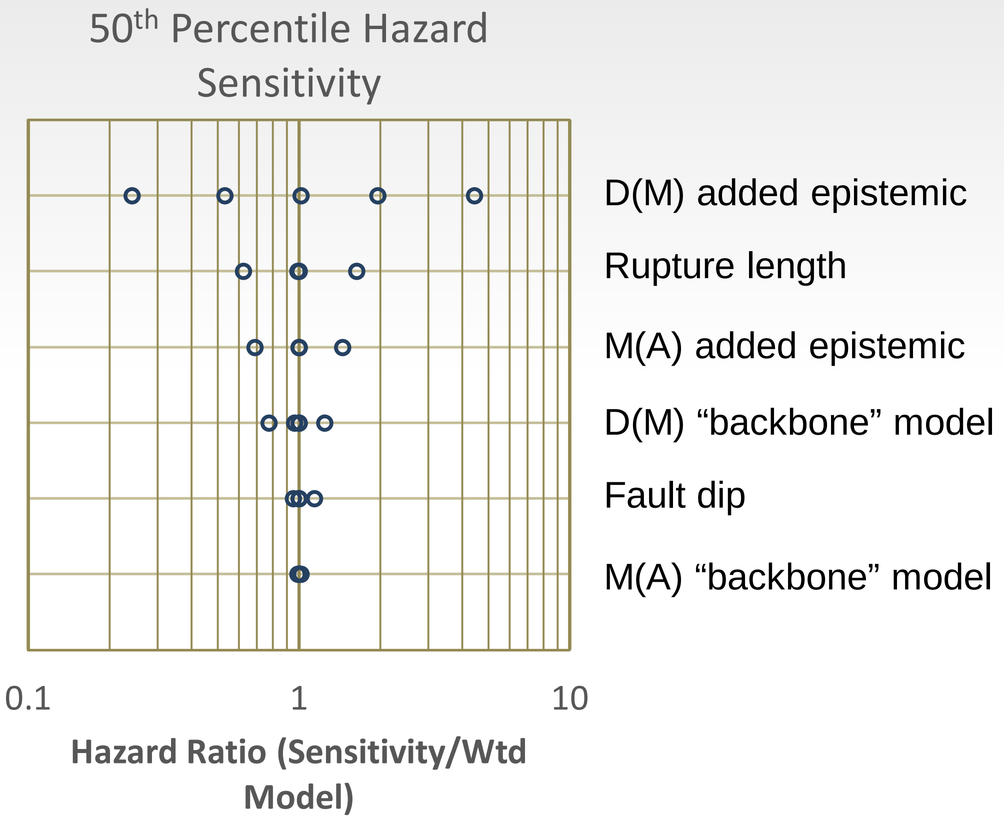
Contributions to Hazard Uncertainty - Tornado

- 50th, 84th percentile tornado plots
- Show ratio of displacement, sensitivity case to weighted mean
- Wider spread = greater contribution = potential area of need



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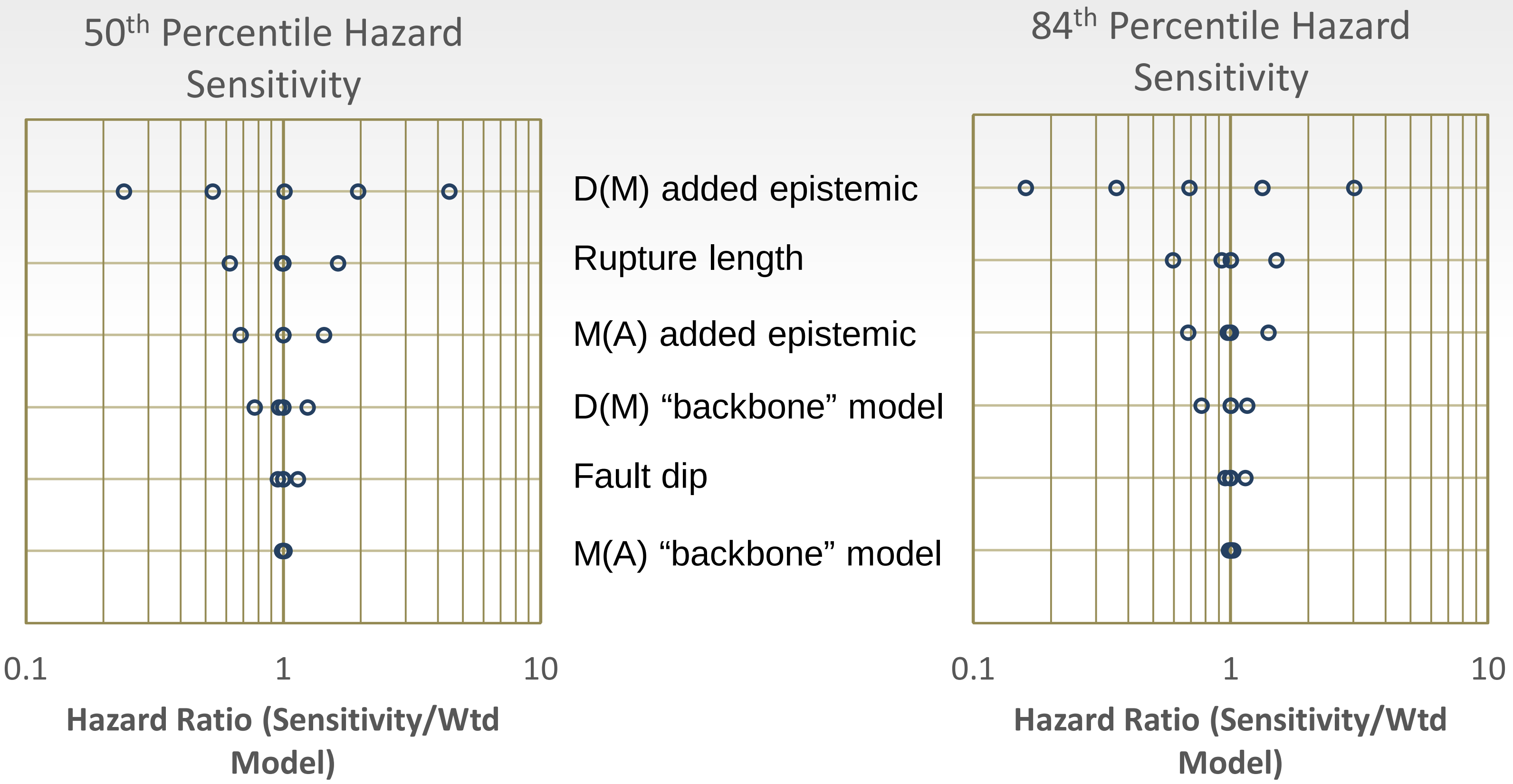
Contributions to Hazard Uncertainty - Tornado



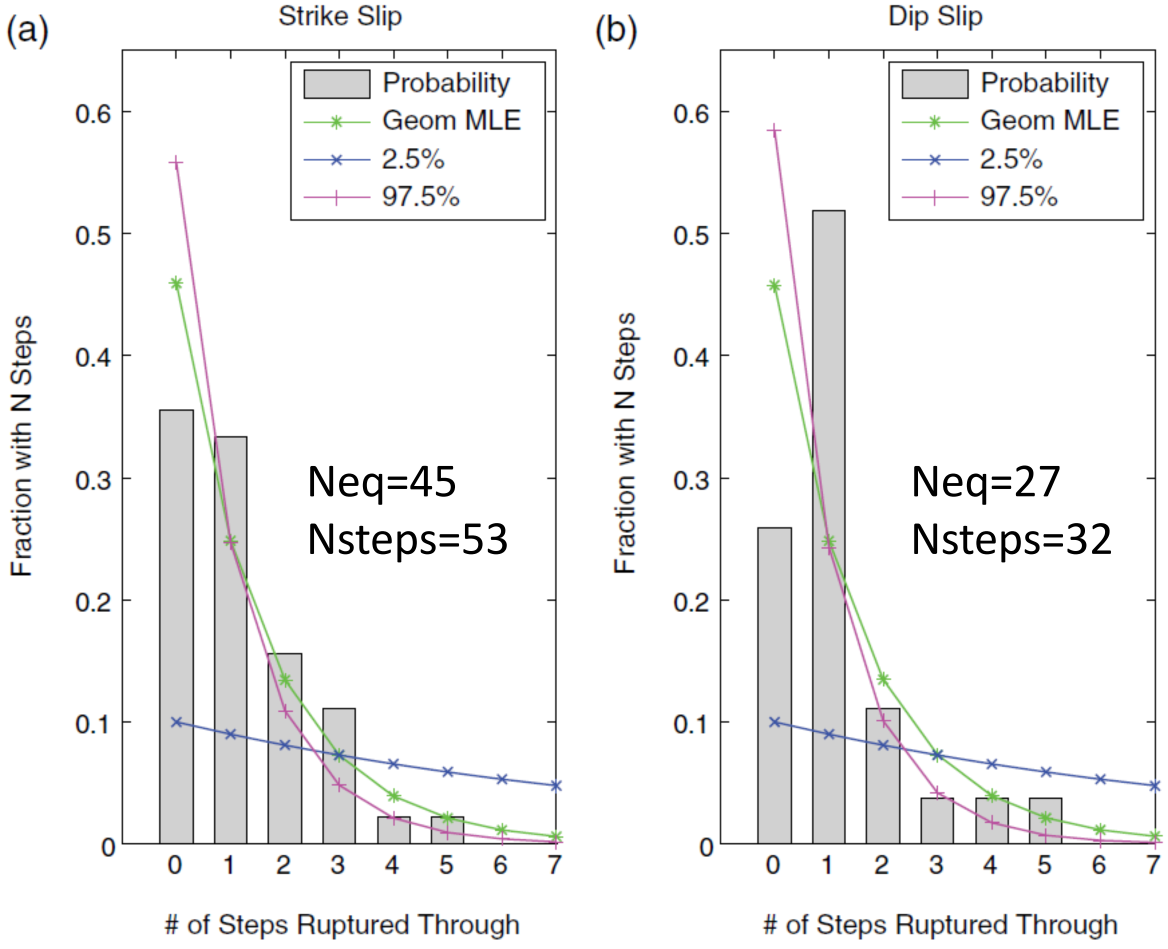
Data Needs – Primary Fault Displacement

- **Site-specific slip-at-a point information (trenching studies)**
  - **Expand Hecker et al. (2013) database and analysis**
- Refine empirical scaling relations such as D(M), M(A), M(L)
  - Continue updating: Wells and Coppersmith (1994); Leonard (2010); Manighetti et al. (2007); Wesnousky (2008); Shaw (2013), etc., but for additional parameters (geology, slip rate, fault maturity,…)
  - Focus on understanding along-strike displacement variability and off-fault deformation
  - Make progress on reverse faults (esp. off-fault deformation)
- Methodologies to characterize MCE rupture length, magnitude
  - Wesnousky and Biasi (2011); Biasi and Wesnousky (2016)

Future direction:

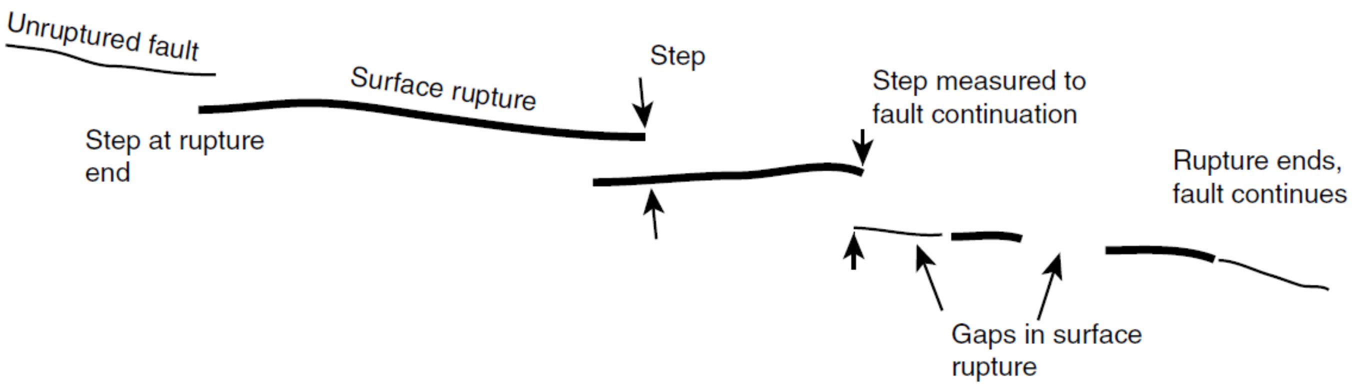
- Physics-based rupture models that can help incorporate effects of local conditions

Data Need Example: Rupturing Through Steps



Neq=45
Nsteps=53

Neq=27
Nsteps=32



Distribution of the number of steps ruptured through of 1 km or greater

Biasi and Wesnousky (2016)

Conclusions

- For gas pipelines, deterministic approaches still in favor
  - Resistance to evaluation & design for displacements < median
- PG&E DFDHA methodology focuses on MCE uncertainty through logic trees; separating epistemic and aleatory uncertainties following Abrahamson (2008)
  - Communicates uncertainty to engineers
- Site-specific data on past per-event slips are useful
  - Engineering projects can weight benefits of reducing uncertainties through additional data collection
  - Promotes consideration of site-specific study
- Data needs –
  - High-quality empirical information to reduce additional epistemic uncertainties
  - Improved methods for estimating rupture length, magnitude

Contributions to Hazard Uncertainty - Tornado

d/AD Secondary Displacement Hazard Uncertainty

(N. Lewandowski's "flash" talk)