Probabilistic Fault Displacement Hazard Analysis

September 19, 2018

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What is PFDHA?

– PFDHA = Probabilistic fault displacement hazard analysis

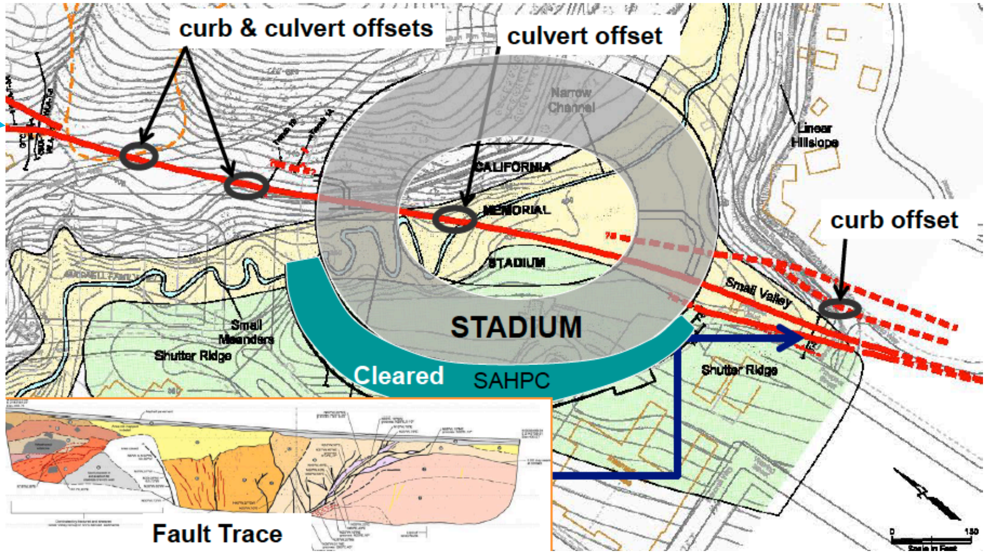
– The purpose is to provide design fault displacement values for structures that are at least partly located on or very close to an active fault.

– Is an alternative to the deterministic approach for displacement hazard,
  - Deterministic generally assumes that the probability of fault surface rupture = 1
  - may over-estimate the hazard.

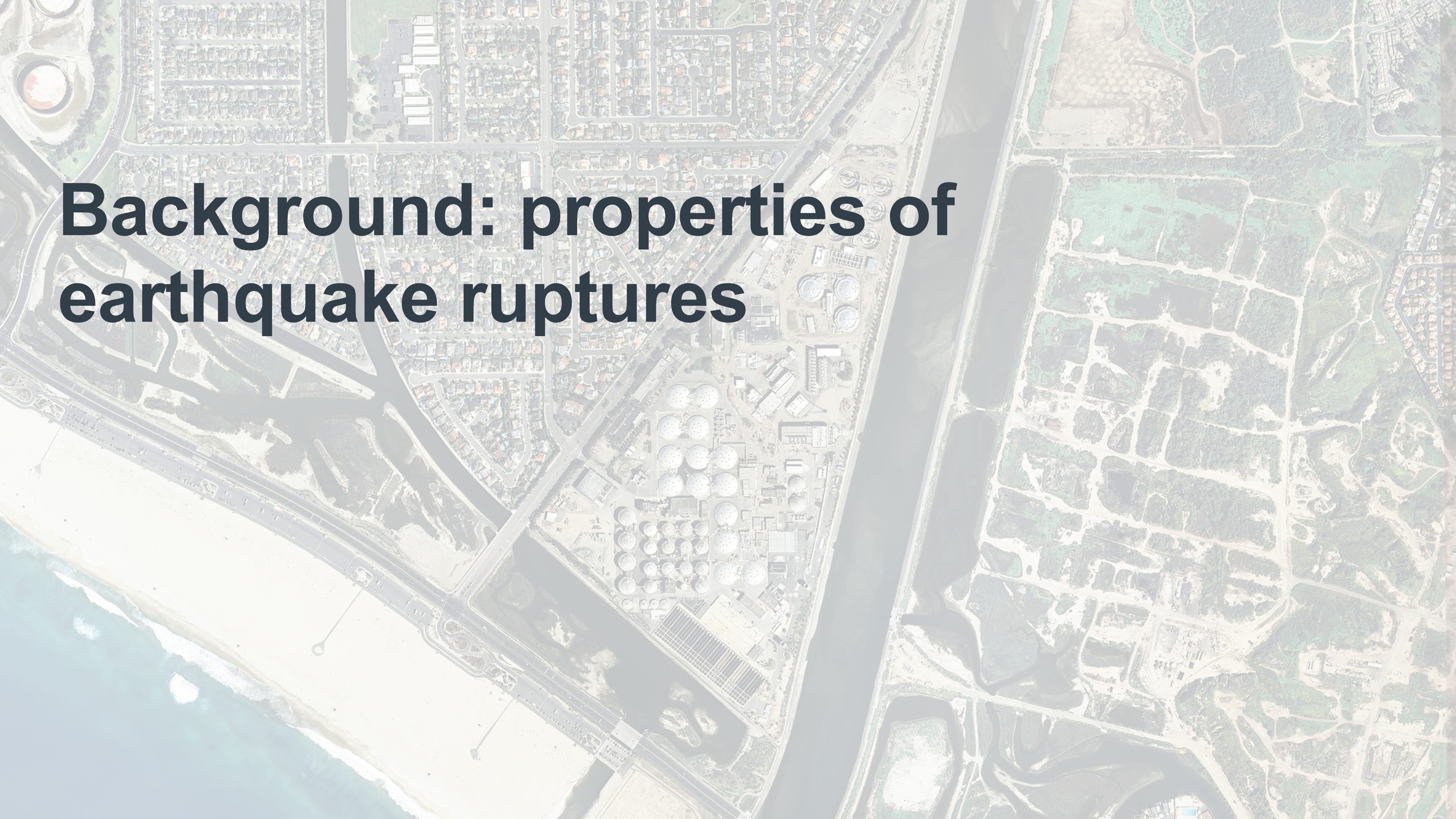
– Is a relatively new application in the field of probabilistic hazard assessment, with methodology formally proposed by Youngs et al. (2003)

Why PFDHA?

- Typically, avoidance is the preferred mitigation measure against fault displacement
- Fault Displacement Hazard is used:
  - When avoidance is not an option:
    - Roads, rails, bridges, tunnels
    - Pipelines (e.g. Alaska pipeline)
  - When active faulting is discovered at/near an existing site (e.g. UC Berkeley stadium, Bray 2018)
  - When engineering mitigation measures are feasible (Oettle and Bray, 2013)
- PFDHA is less conservative compared to deterministic estimates in most cases, and consistent with PBEE

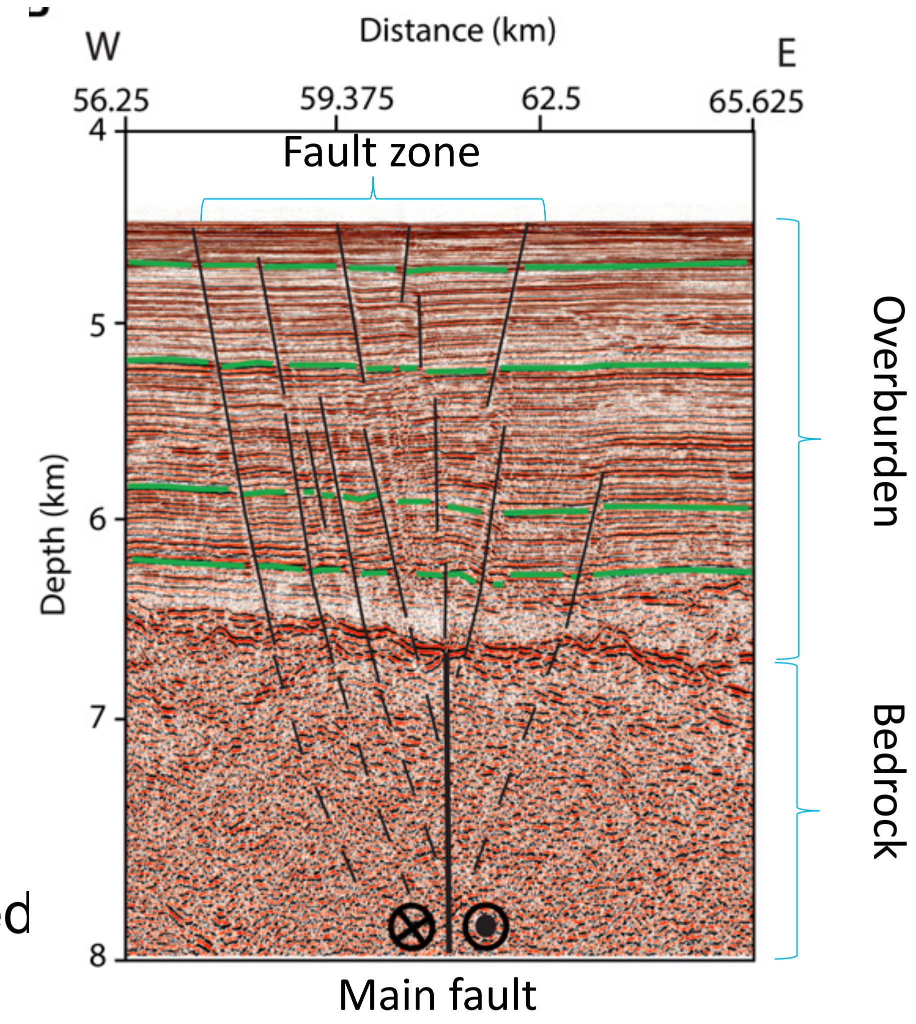


Background: properties of earthquake ruptures



EARTHQUAKE RUPTURES

– Surface vs. depth
  - Faults are locked where the rocks are sufficiently strong to resist stresses caused by movement of crustal blocks
  - In soft overburden, strength is not sufficient to resist movement
  - During an earthquake, the movement in the softer overburden is driven by movement from below
  - Deformation in the overburden is distributed throughout and leads to complex rupture patterns at the surface
  - New fault strands are created, old strands re-activated



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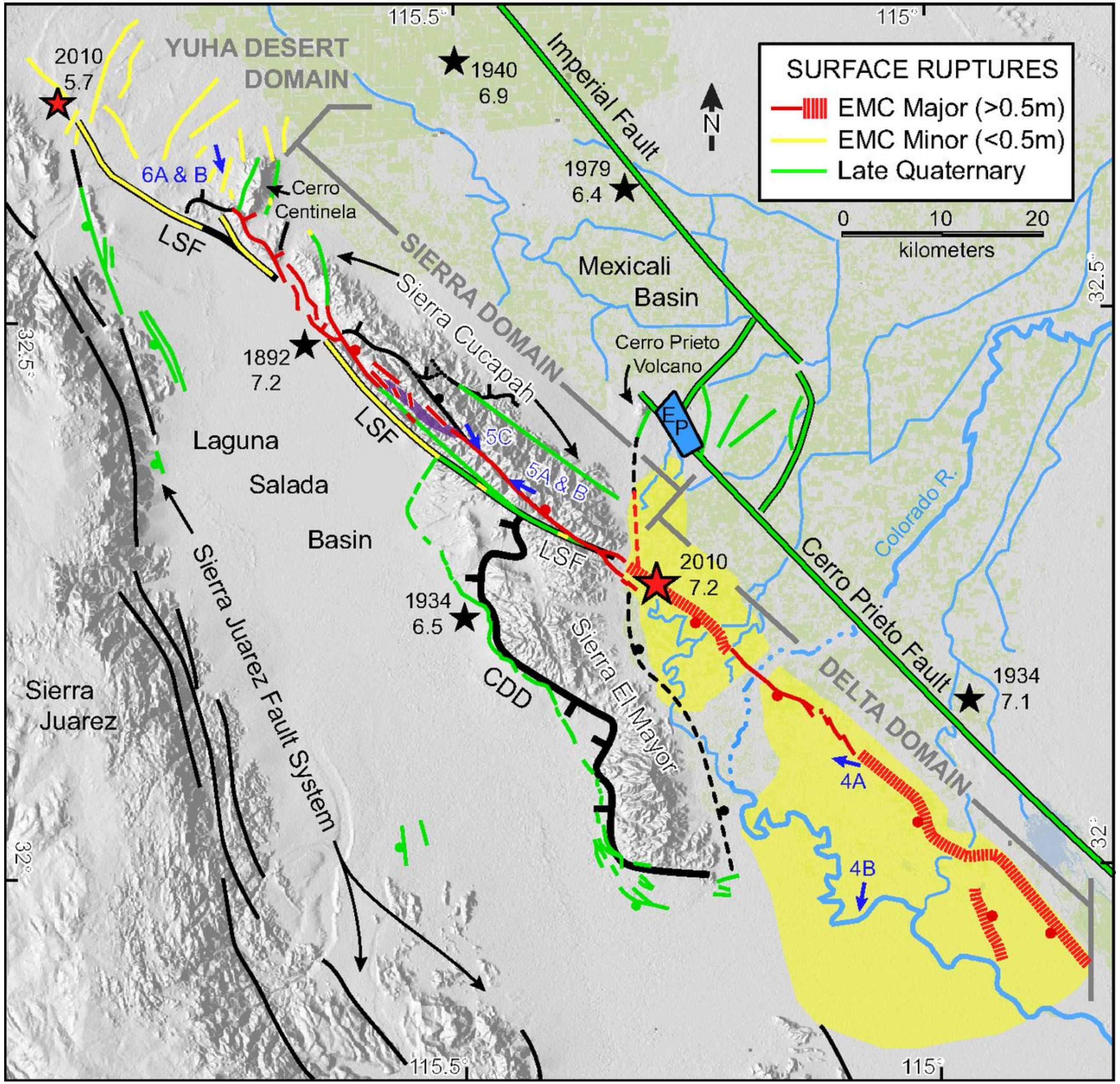
EARTHQUAKE RUPTURES

- Earthquakes do not necessarily break the same fault strands in subsequent earthquakes, they will also create new strands, especially in soft overburden
- Many examples:
  - El-Mayor
  - Nagano
  - Landers
  - Kaikoura
  - Etc…..



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PFDHA Methodology: Direct method

PFDHA: DIRECT METHOD

– If a long history of rupture events can be established at or near the site, it is possible to develop PFDHA with little external data

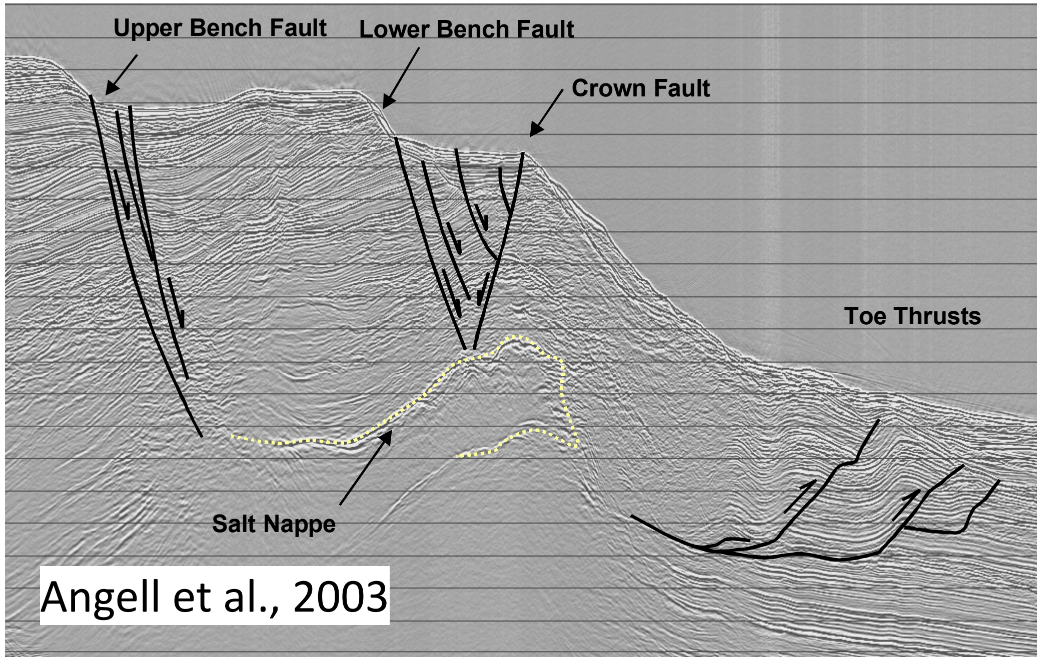
– The frequency of displacement exceedance $\nu(d)$ can be written as:

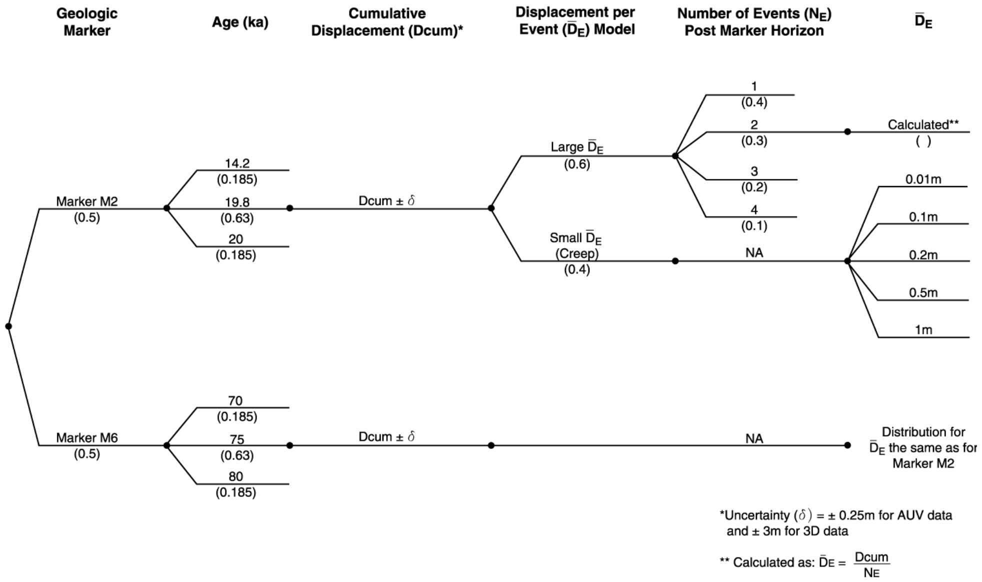
$$\nu(d) = \lambda_{DE} . P(D > d)$$

- d = displacement
- λ_{DE} = rate of displacement events on the fault
- $P(D > d)$ = conditional probability that displacement D in an event exceeds d.

– Straightforward approach

– Very rare that this kind of data is available





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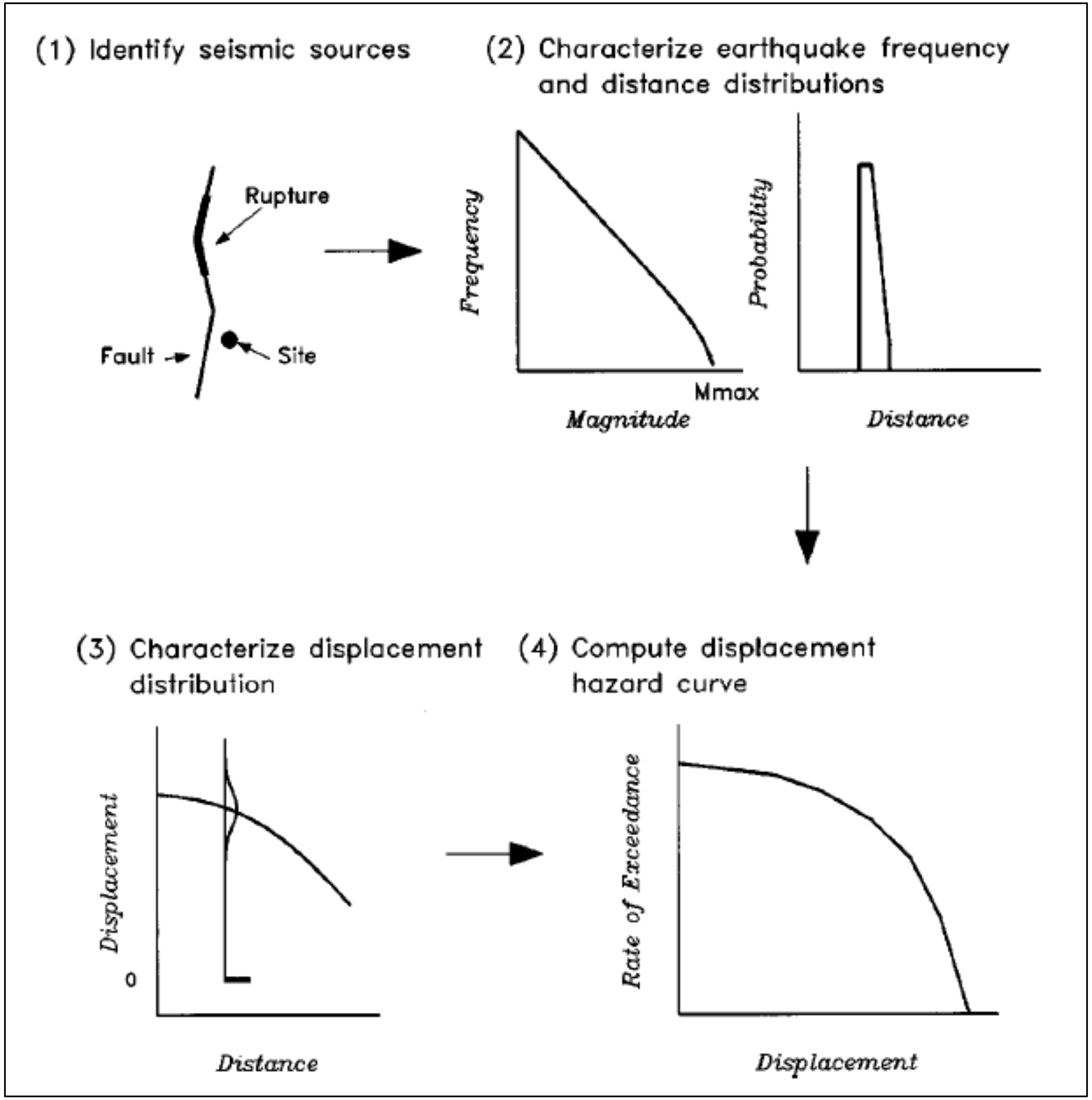
PFDHA Methodology: Earthquake method

EARTHQUAKE METHOD

– Similar to traditional PSHA (Cornell, 1968)

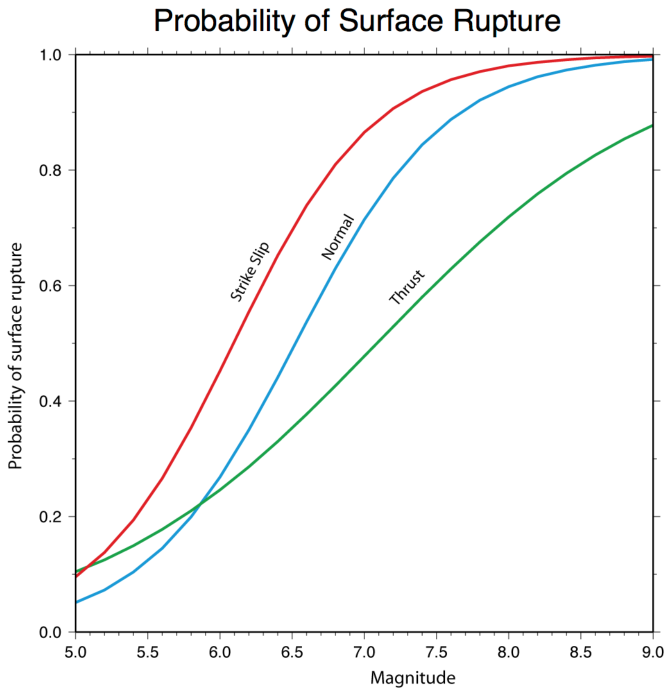
– Schematic at right illustrates the components of the earthquake approach to PFDHA (from Youngs et al., 2003)
  - For a single fault rupture

– Ergodic (applies models developed from other regions to the site)

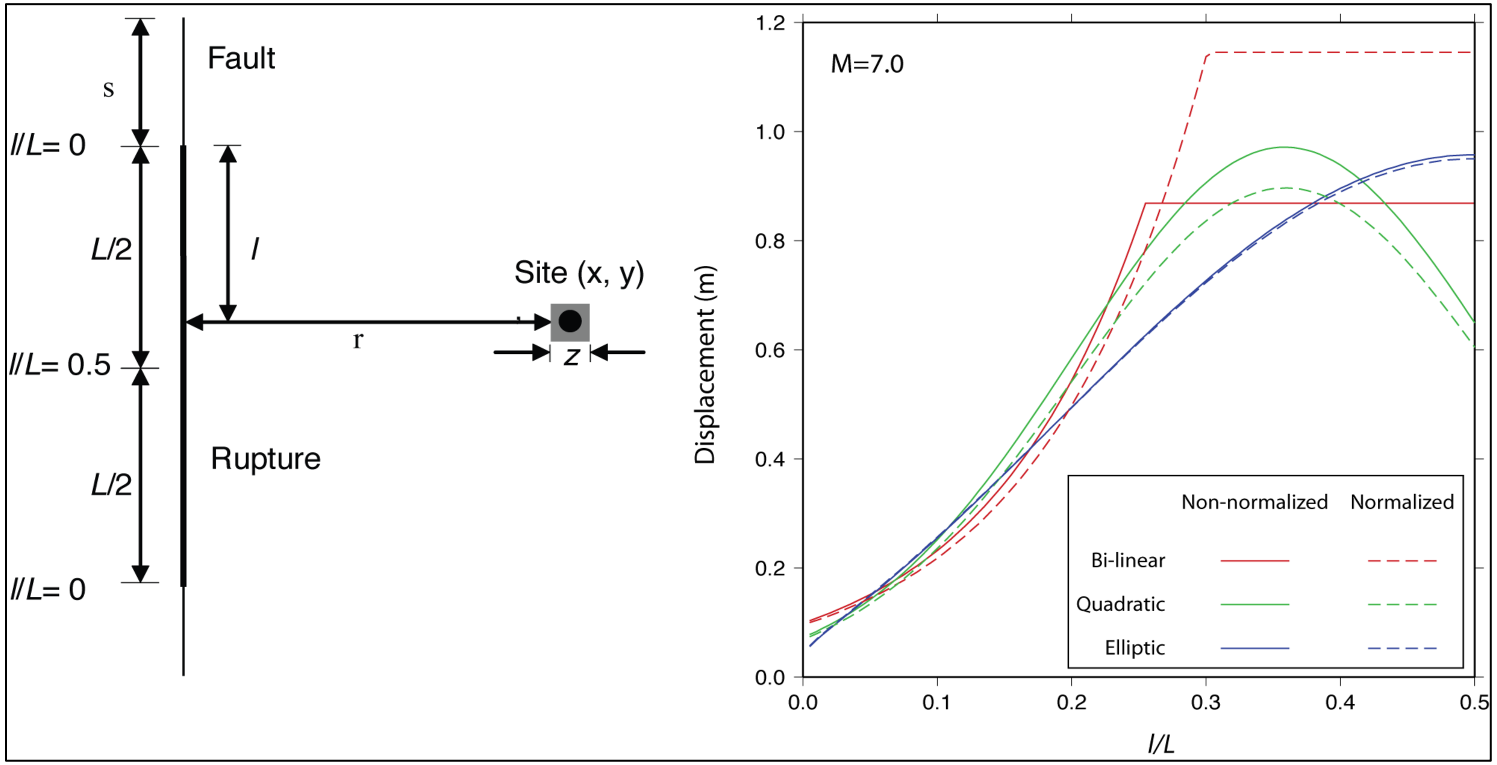


EARTHQUAKE METHOD

- Ground Displacement Models: quantify the surface slip distribution and probability of surface rupture
- Models for different types of faulting
  - Thrust (Moss and Ross 2011)
  - Normal (Youngs et al. 2003)
  - Strike-slip (Petersen et al. 2011)



Slip distribution functions for a strike slip earthquake (Petersen et al., 2010)



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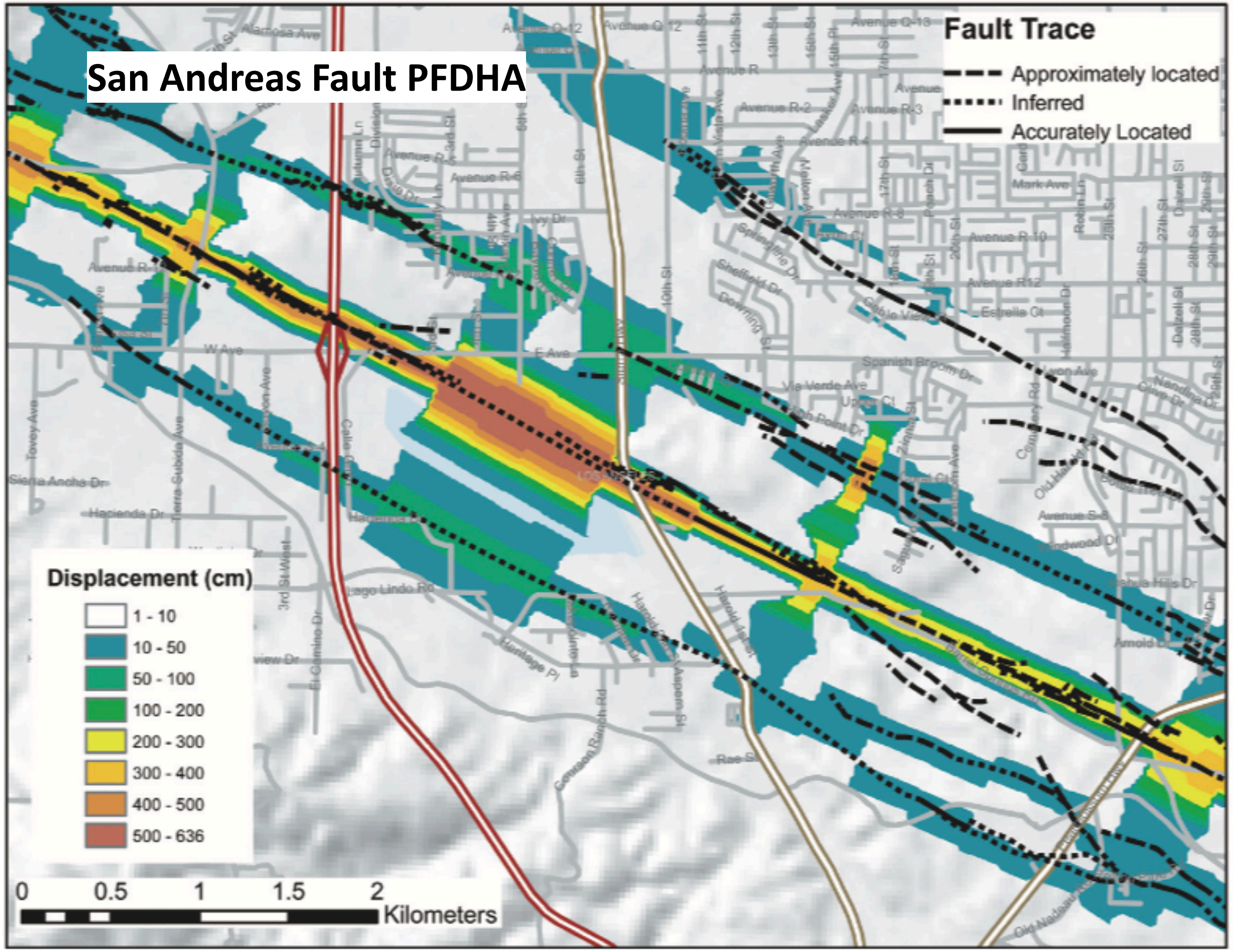
PFDHA ADVANCES

- Petersen et al. (2011) developed a comprehensive method not only for single fault rupture but also:
  - uncertainties in fault location
  - secondary faulting
  - unpredictability of rupture location
- Analysis necessary over the whole fault zone



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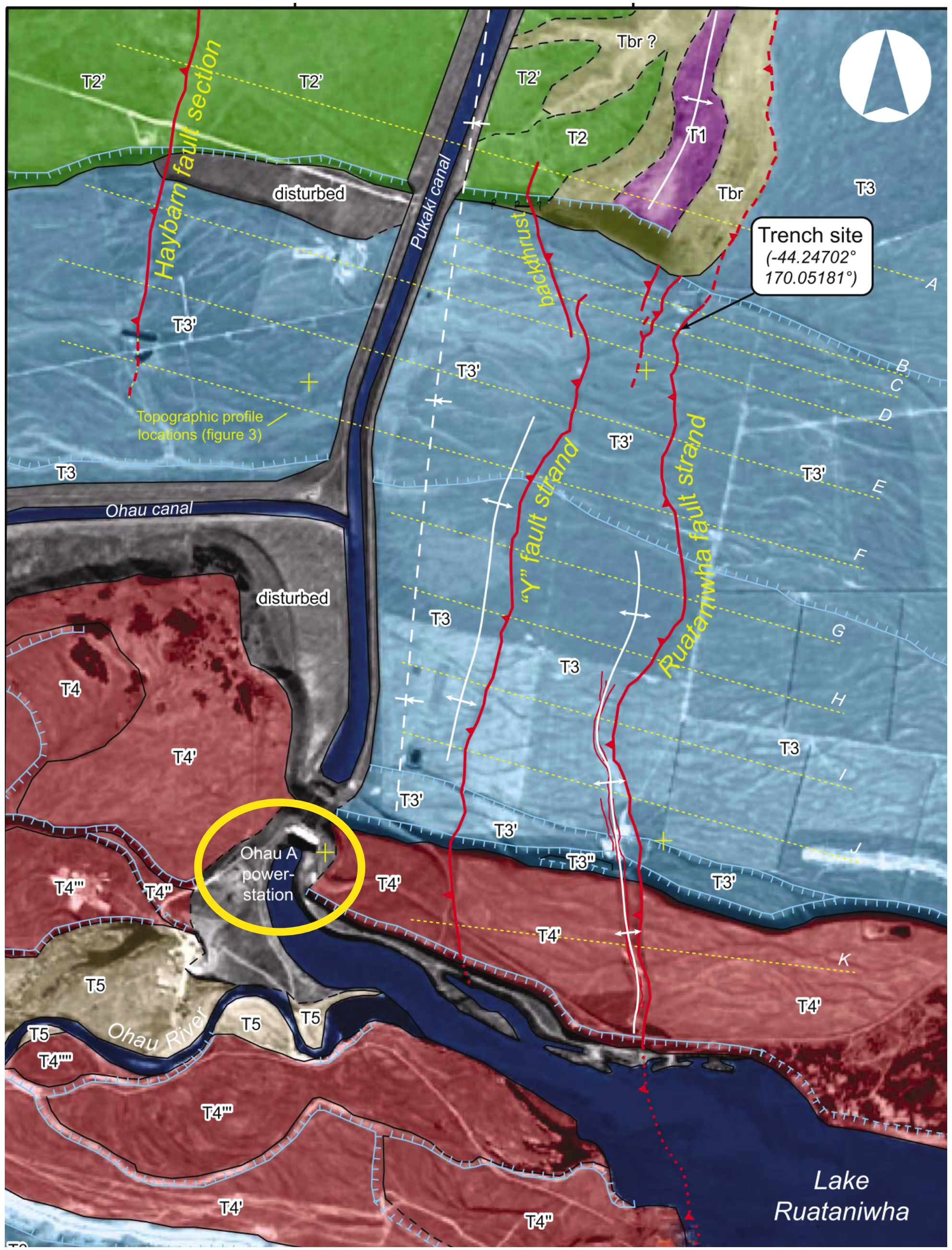
Examples of PFDHA

1) OHAU POWER SYSTEM, NZ

Headwater for the Ohau A power station (yellow circle) is transferred to the penstock intakes via canals from Lakes Ohau and Pukaki

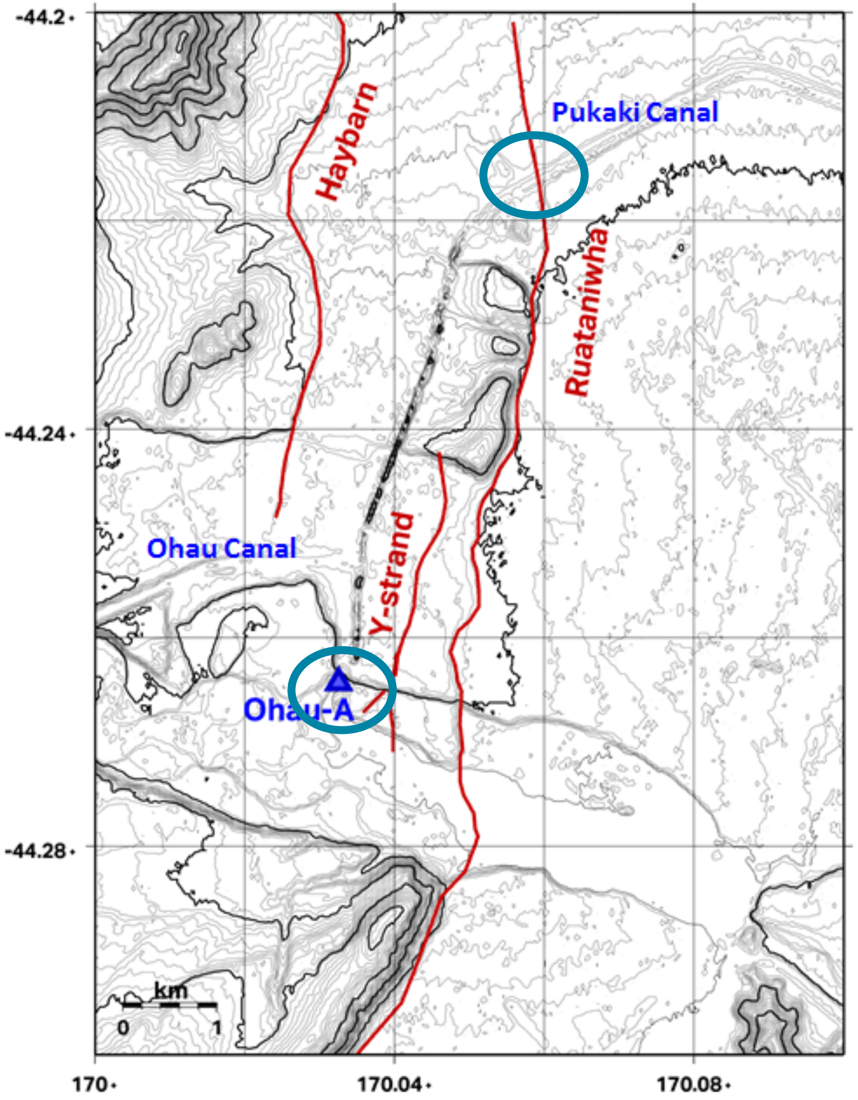
- the canals cross into the Ostler Fault Zone (OFZ) and the powerhouse is located within the broad zone of deformation associated with the OFZ.
- movement on the Ostler fault, and in particular on the Y-strand, which is only 500 m away from the powerhouse site, may cause secondary movement as well as tilting at the powerhouse and penstocks



1) OHAU POWER SYSTEM, NEW ZEALAND

Fault characterization

- Deformation is partitioned over several parallel fault strands
- Not all strands are equal: Ruataniwha is the longest strand and corresponds to the most pronounced uplift and therefore carries a larger weight
- Ostler fault system with recurrence times of 2,000-4,000 years, distributed over several strands



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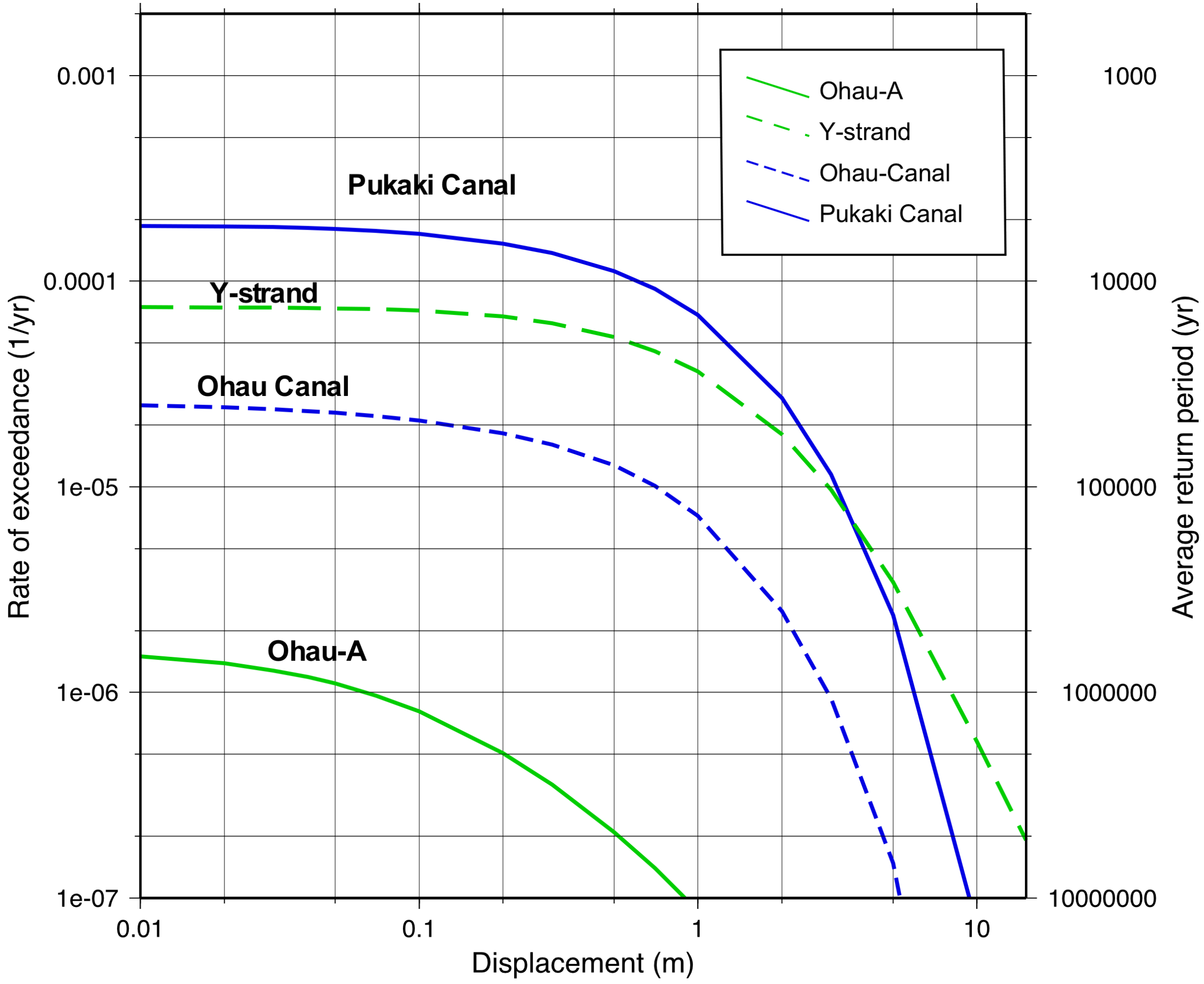
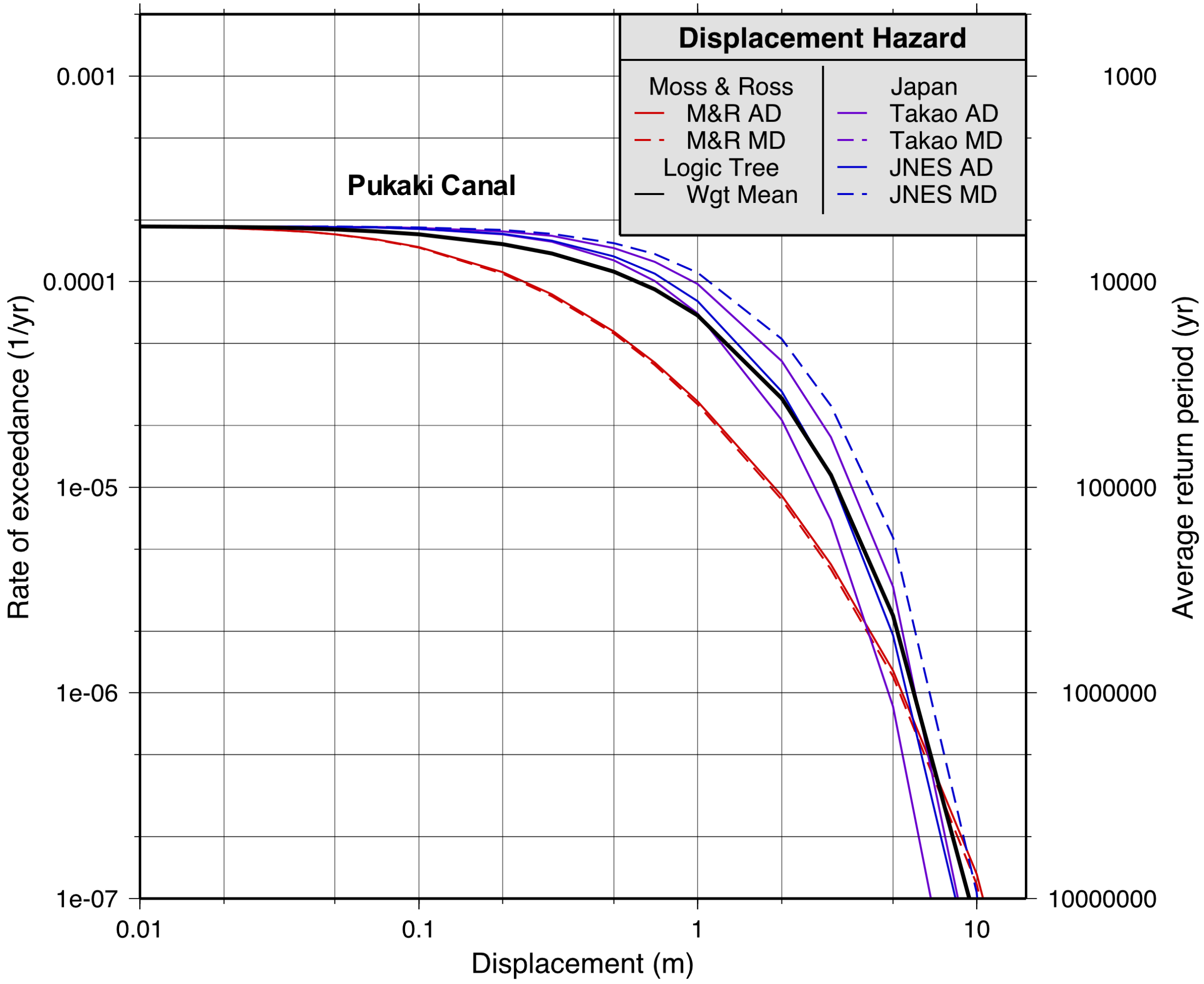
1) OHAU POWER SYSTEM, NEW ZEALAND





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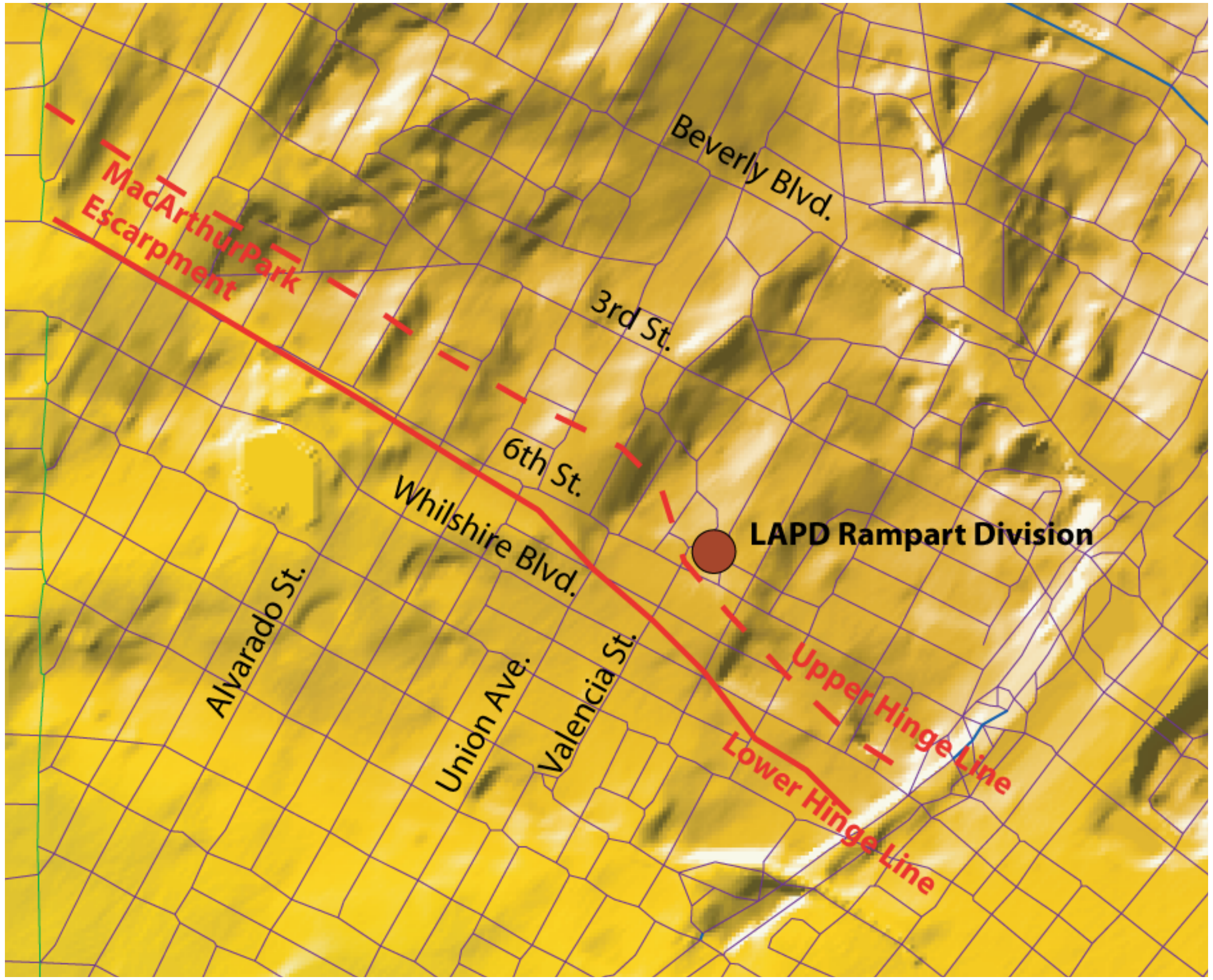
2) LAPD RAMPART

New LAPD Rampart station, located on the hanging wall of the MacArthur Park Escarpment

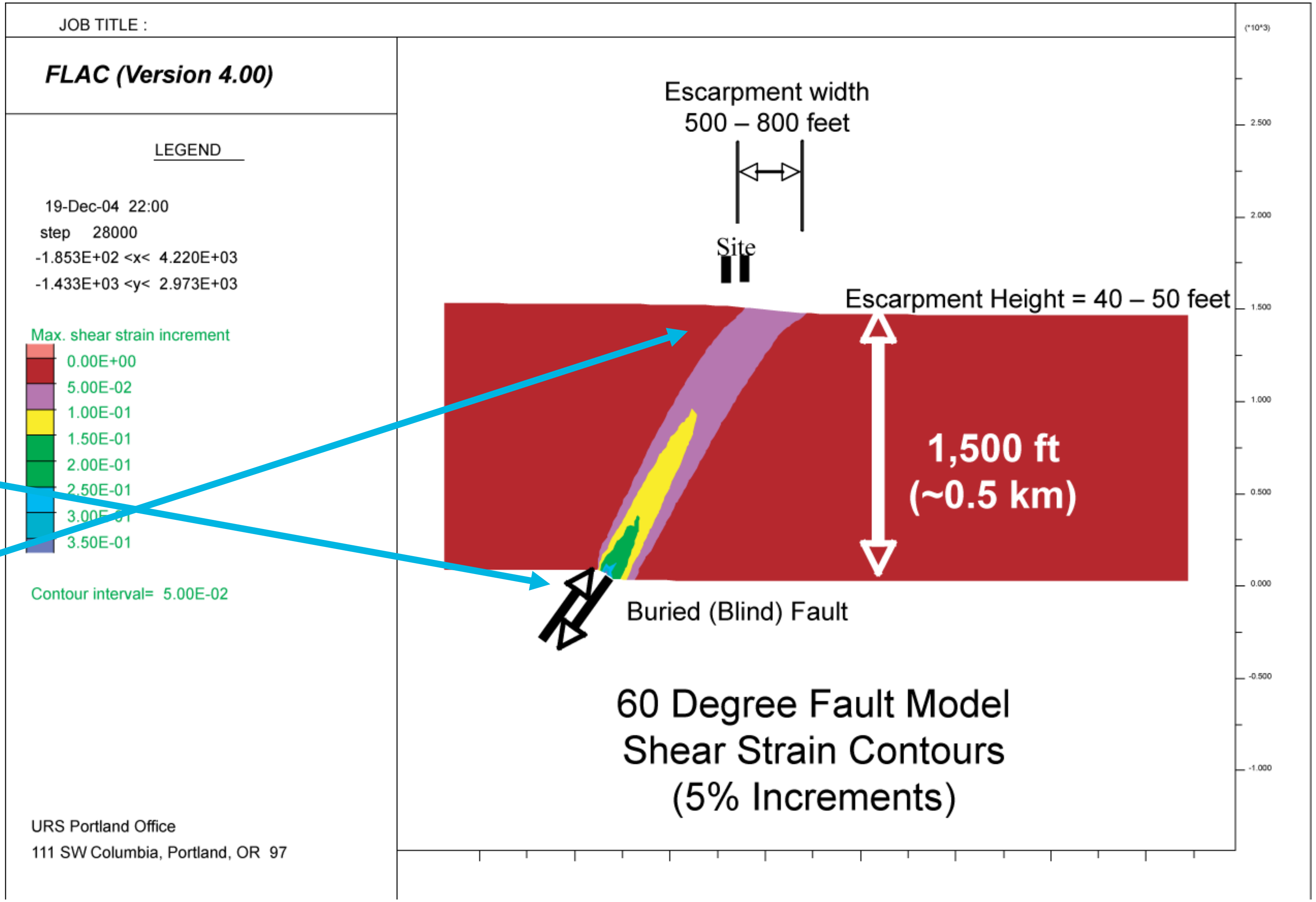
- Observed extension cracks at the site
- Likely related to uplift of the escarpment
- Secondary blind thrust structure of the Elysian Park Thrust
- How much extension to mitigate for?



2) LAPD RAMPART

Solution:

- Use hybrid approach combining PFDHA/FEM for probabilistic surface strain
- PFDHA for underlying fault displacement
- FEM to model response at the surface to the buried fault displacement



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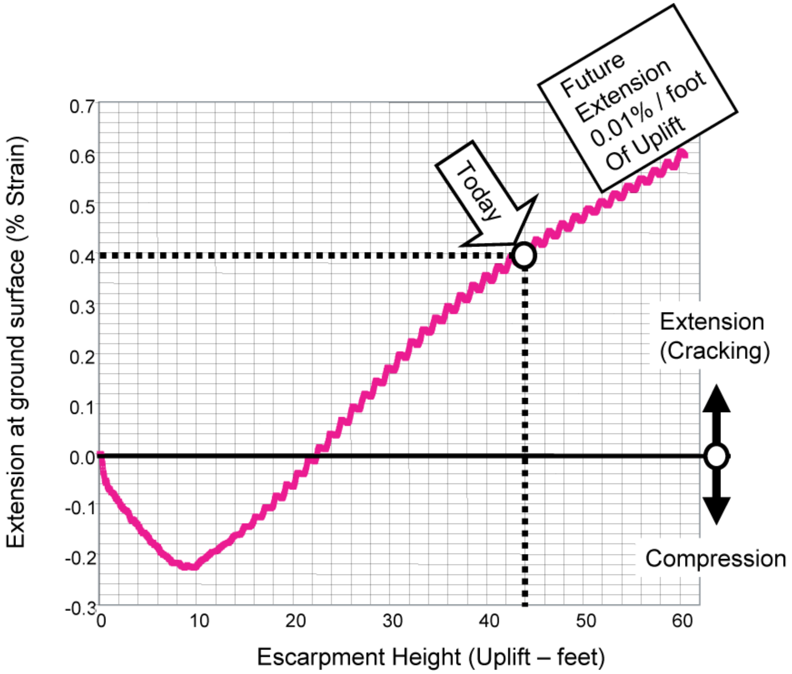
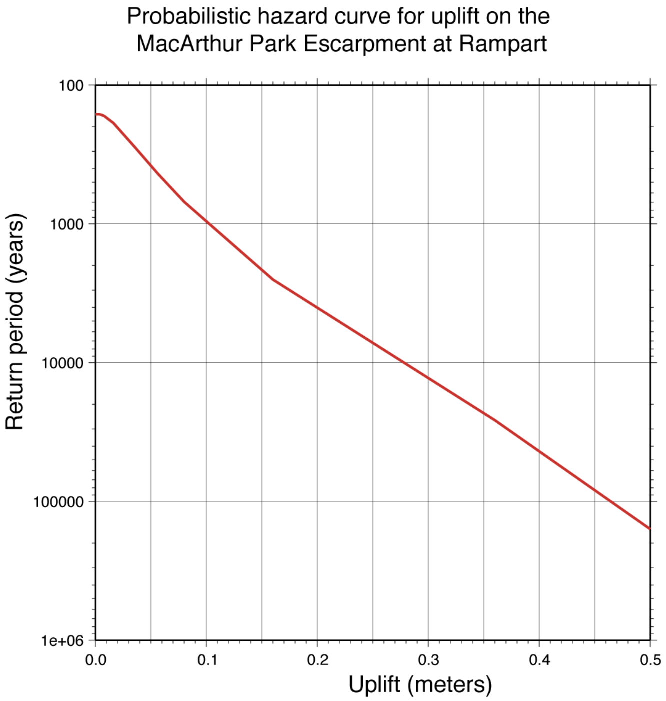
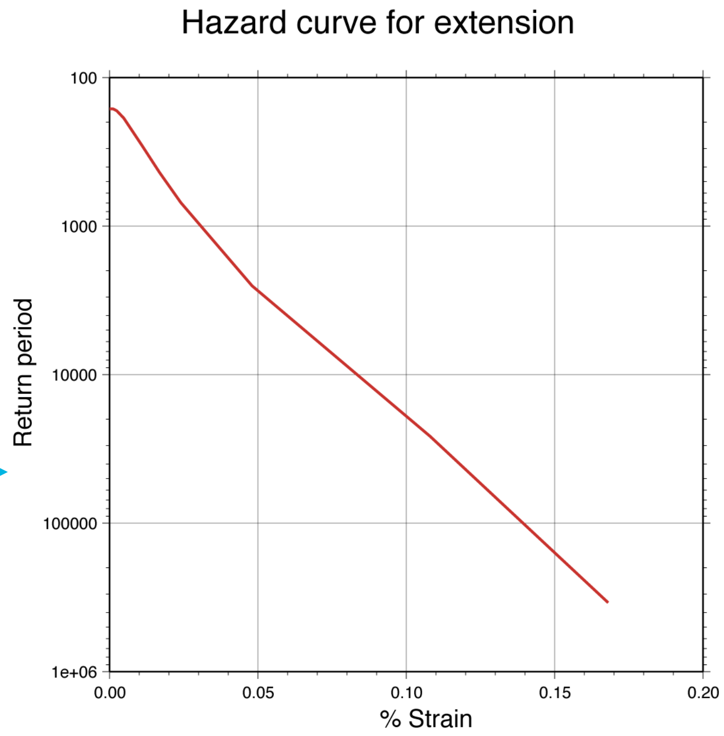
2) LAPD RAMPART

- Combining strain vs. uplift and uplift hazard curve
- Probabilistic strain for foundation design



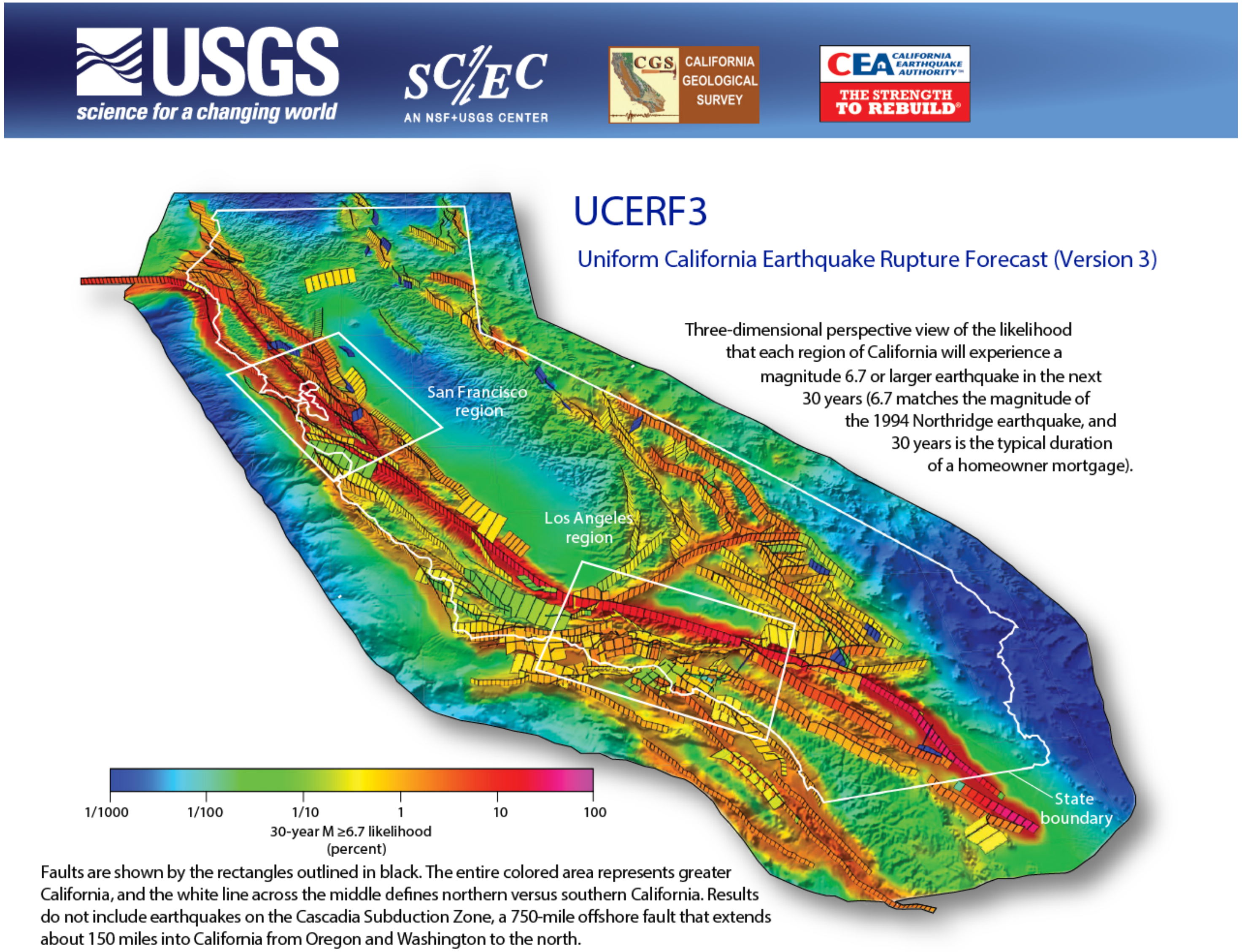




3) SOCAL SITE USING UCERF3

UCERF3 is the standard earthquake source model for California Seismic Hazard

- Consensus model with > 1000 logic tree branches that express the epistemic uncertainty (alternative models)
- Strong inter-relation between slip rates on different faults
- Many multi-segment and multi-fault earthquakes
- Complex to update with local data, but we can!



3) UPDATING THE NEWPORT-INGLEWOOD FZ MODEL

- Update NI Fault Model
  - Synthesis of CPT and Seismic data
  - New interpretations of the NIFZ that post-date UCERF3 can be incorporated, e.g:
    - Sahakian et al. (2017)
    - Legg (2018)

- Will use complete UCERF3 (not the mean) and evaluate model uncertainties

L.A. NOW LOCAL

Notorious L.A. earthquake fault more dangerous than experts believed, new research shows

By RONG-GONG LIN II MAR 21, 2017 | 6:40 PM

A new study suggests that Southern California's Newport-Inglewood fault has a greater earthquake risk than previously believed. (March 21, 2017) (Sign up for our free video newsletter here http://bit.ly/2n6VKPR)

The Newport-Inglewood fault has long been considered one of Southern California's top seismic danger zones because it runs under some of the region's most densely populated areas, from the Westside of Los Angeles to the Orange County coast.

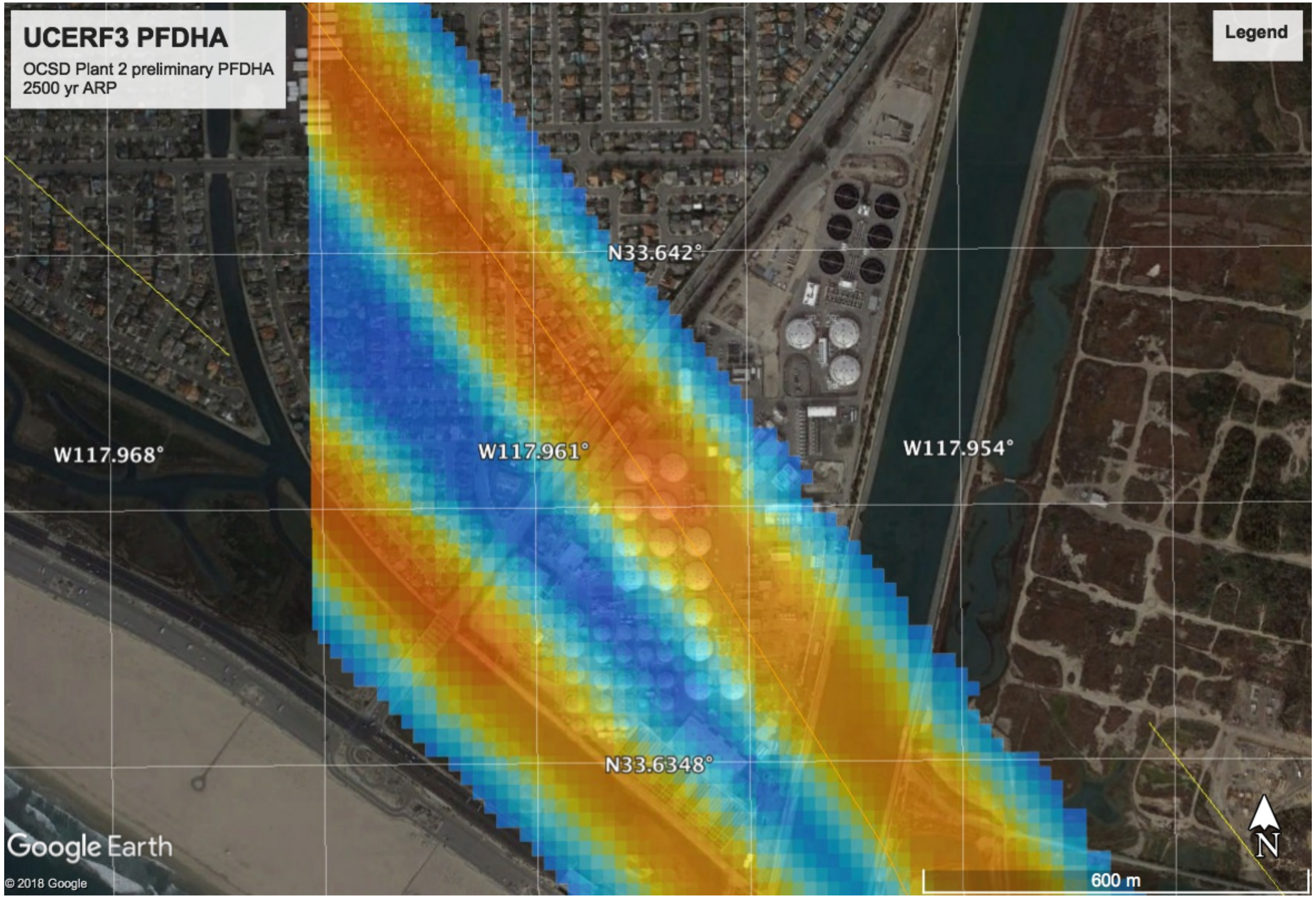
But new research shows that the fault may be even more dangerous than experts had believed, capable of producing more frequent destructive temblors than previously suggested by scientists.

A new study has uncovered evidence that major earthquakes on the fault centuries

LA Times, March 21, 2017

3) SOCAL SITE USING UCERF3

Map of 2500 year probabilistic fault displacement across the treatment plant



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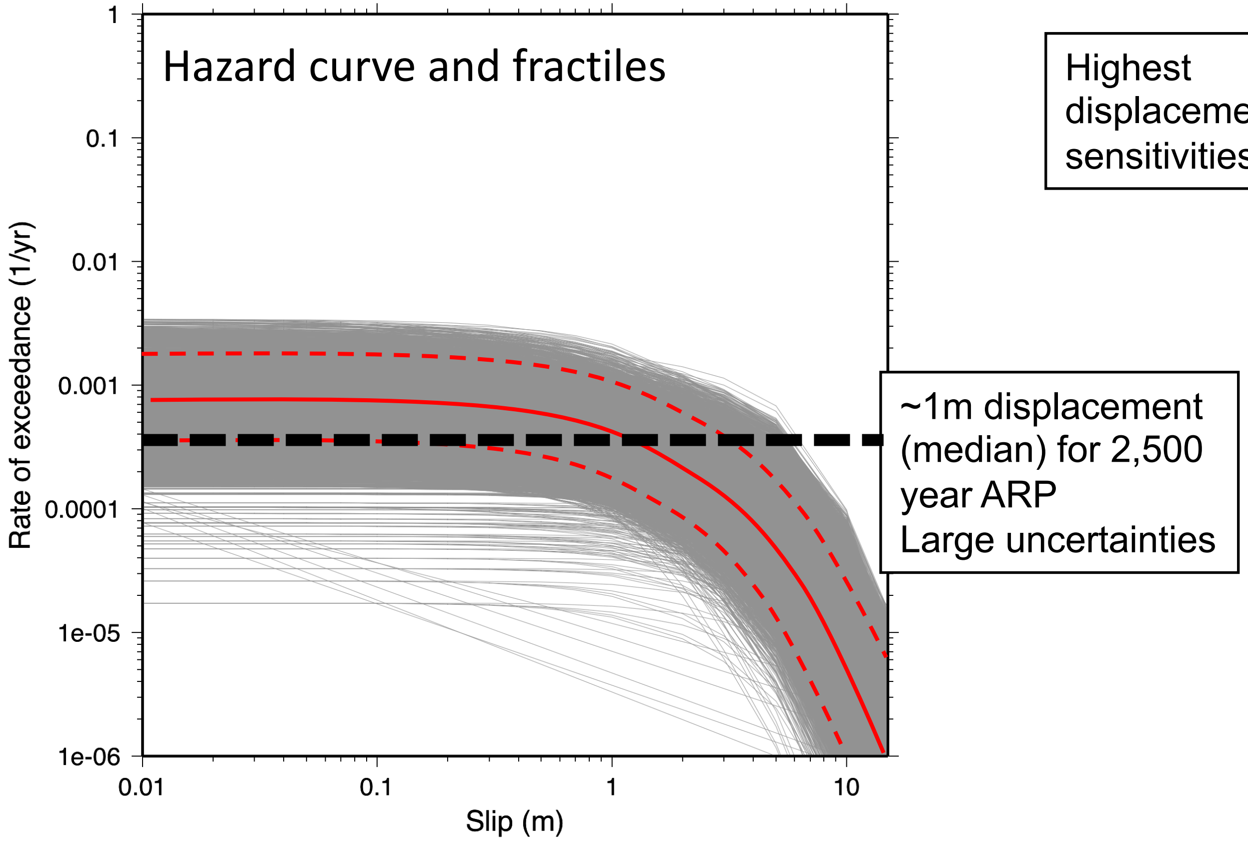
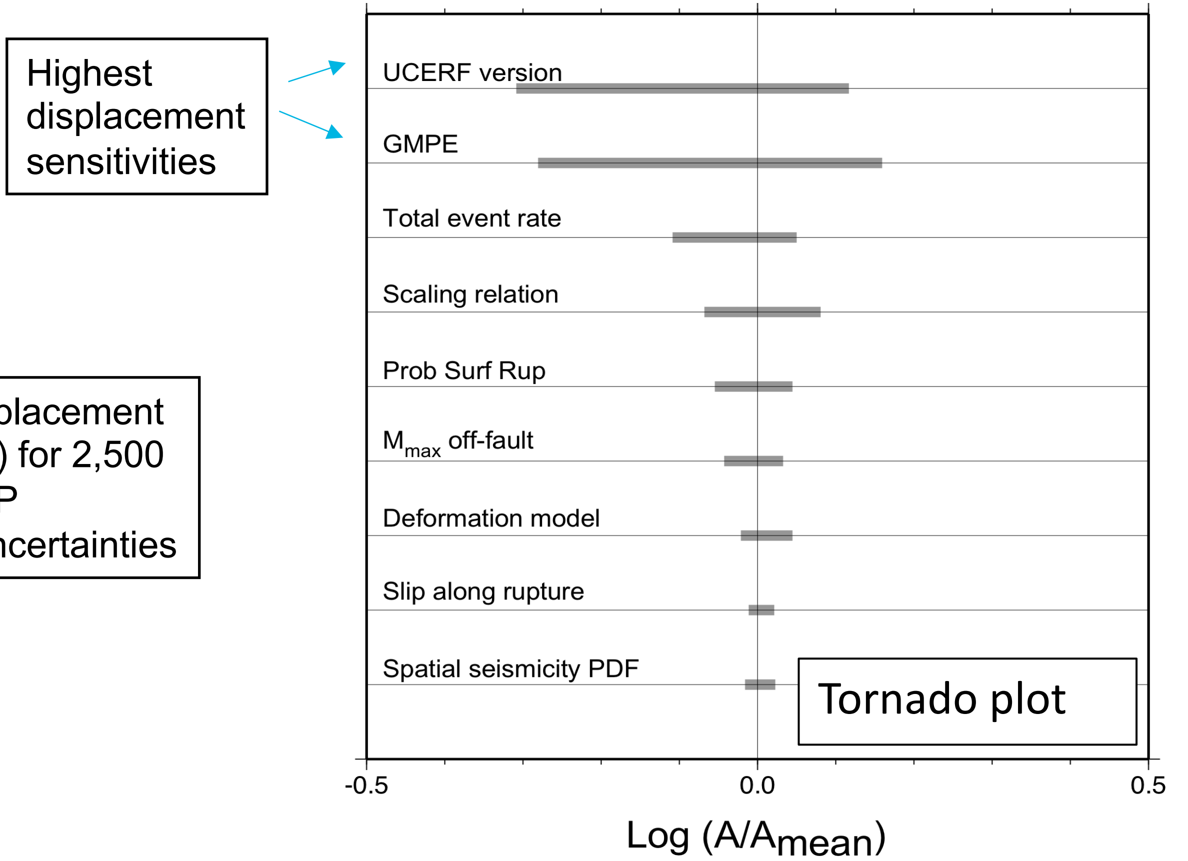
3) SOCAL SITE USING UCERF3

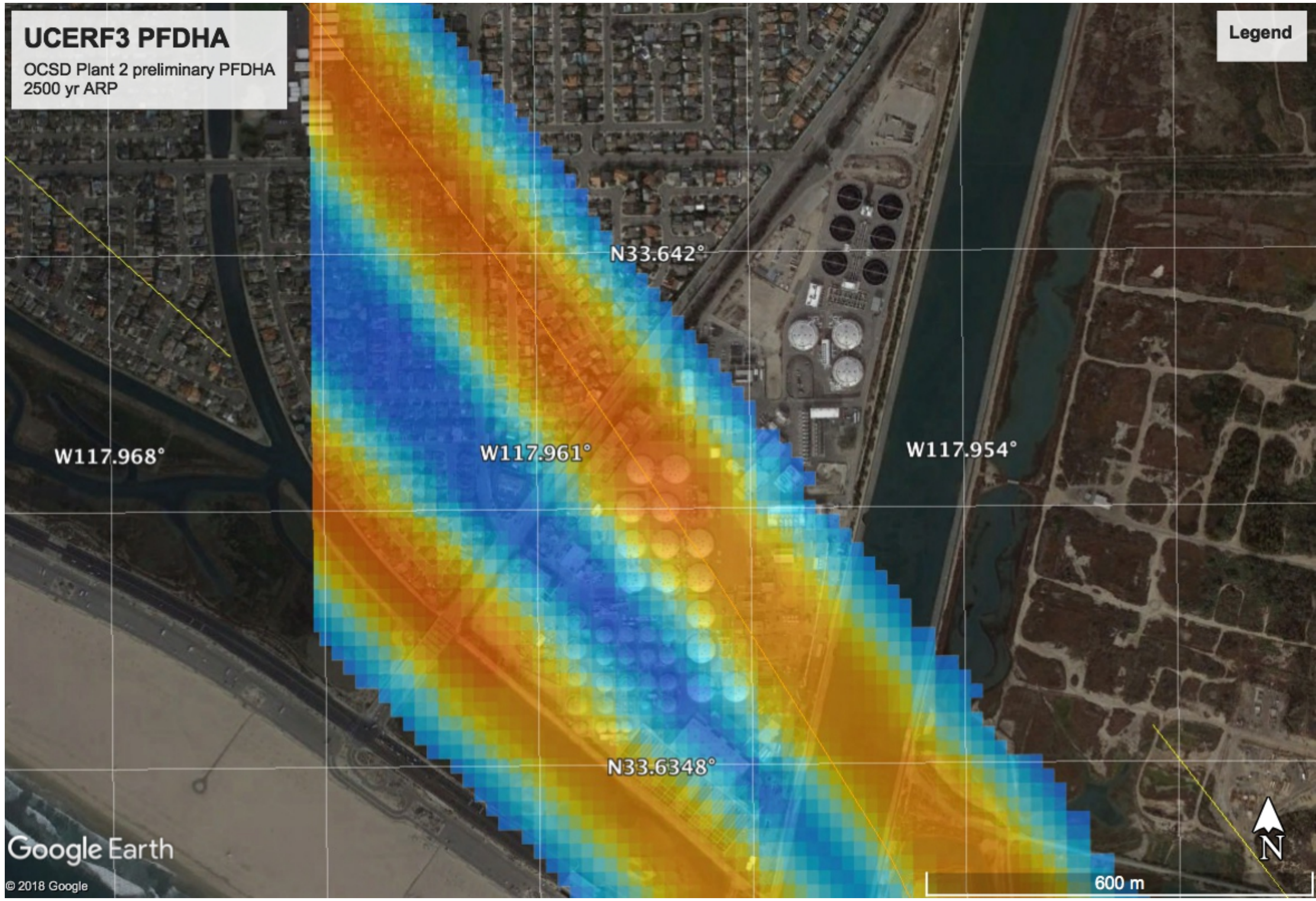
- Comprehensive analysis of epistemic uncertainty in the final results through fractiles
- Complete sensitivity analysis using tornado plots





3) APPLICATION OF THE DESIGN DISPLACEMENT MAPS

- Building/Facility setback based on engineering criteria
  - Use displacement contour to define setbacks based on maximum permissible displacement
- Future design
  - Use displacement maps to direct engineering mitigation measures
- Different return periods used for different criticality levels



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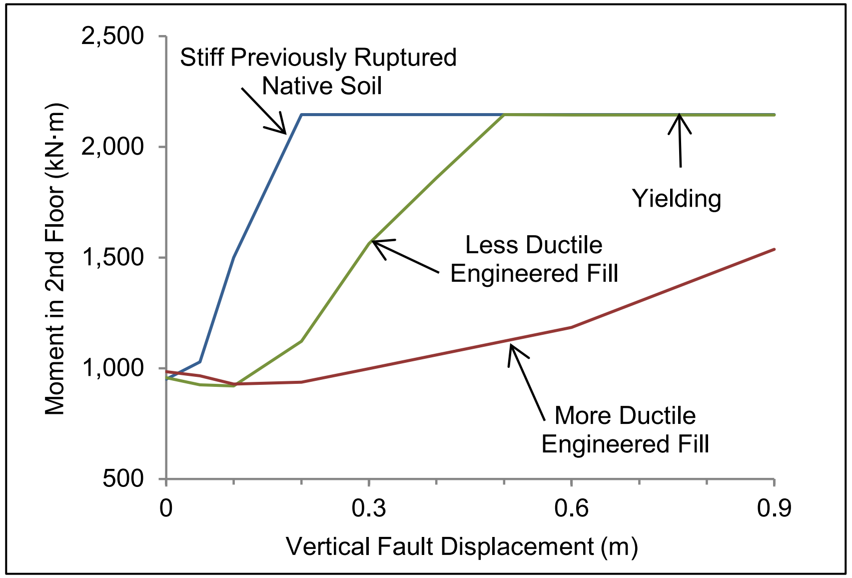
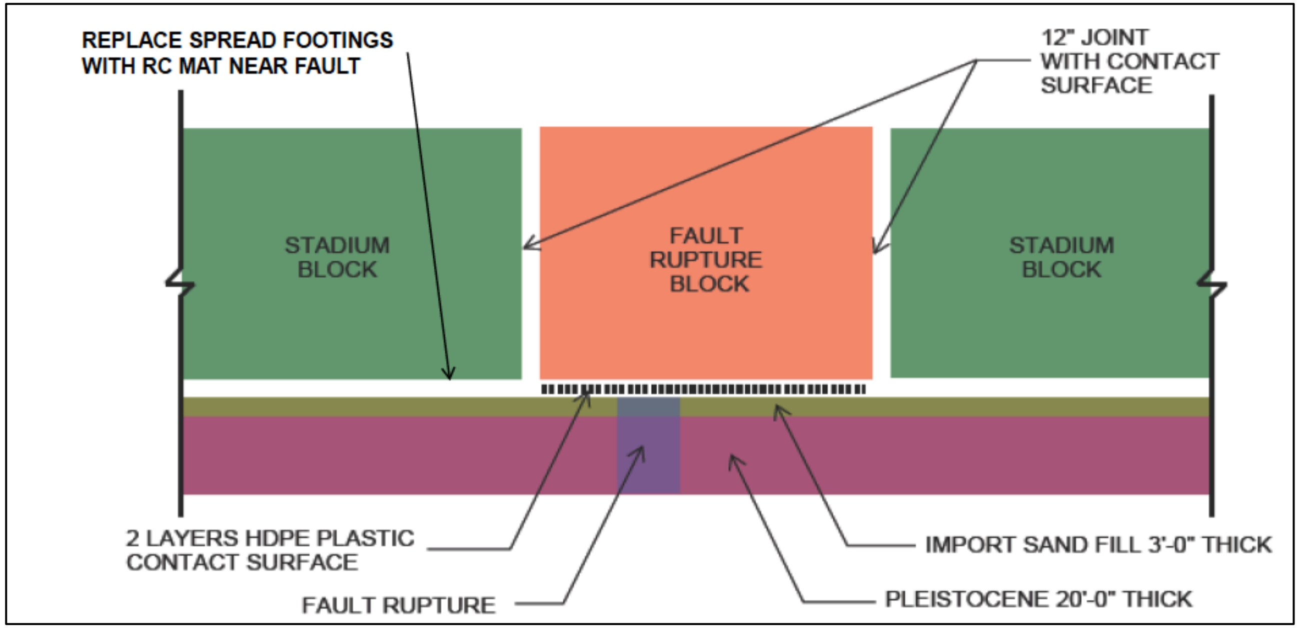
MITIGATION STRATEGIES

Engineering design: “Decouple, Diffuse, Divert” (Bray, 2018)

- Foundation
  - Choice of earth fill (engineered)
  - Slip layers to isolate foundation displacements
- Structural
  - Decoupling of elements
  - Strong+ductile foundations
- Engineering informed setbacks



(Bray, 2018)



CONCLUSION

- PFDHA can yield a complete analysis of primary and secondary surface rupture in simple and complex fault zones
- Models allow for local constraints to reduce uncertainties and variability terms
- For most faults, the results from a PFDHA are less conservative than scenario models
- Fully consistent with seismic practice and principles of Performance Based Earthquake Engineering
- Guidelines for performing PFDHA are available for certain applications (e.g. Caltrans, US Nuclear Regulatory Commission, IAEA, New Zealand)

Thank you