PFDHA

Presented by
Robert Youngs
AMEC Geomatrix

Workshop on Surface Fault Displacement Hazard

UC Berkeley, May 21, 2009

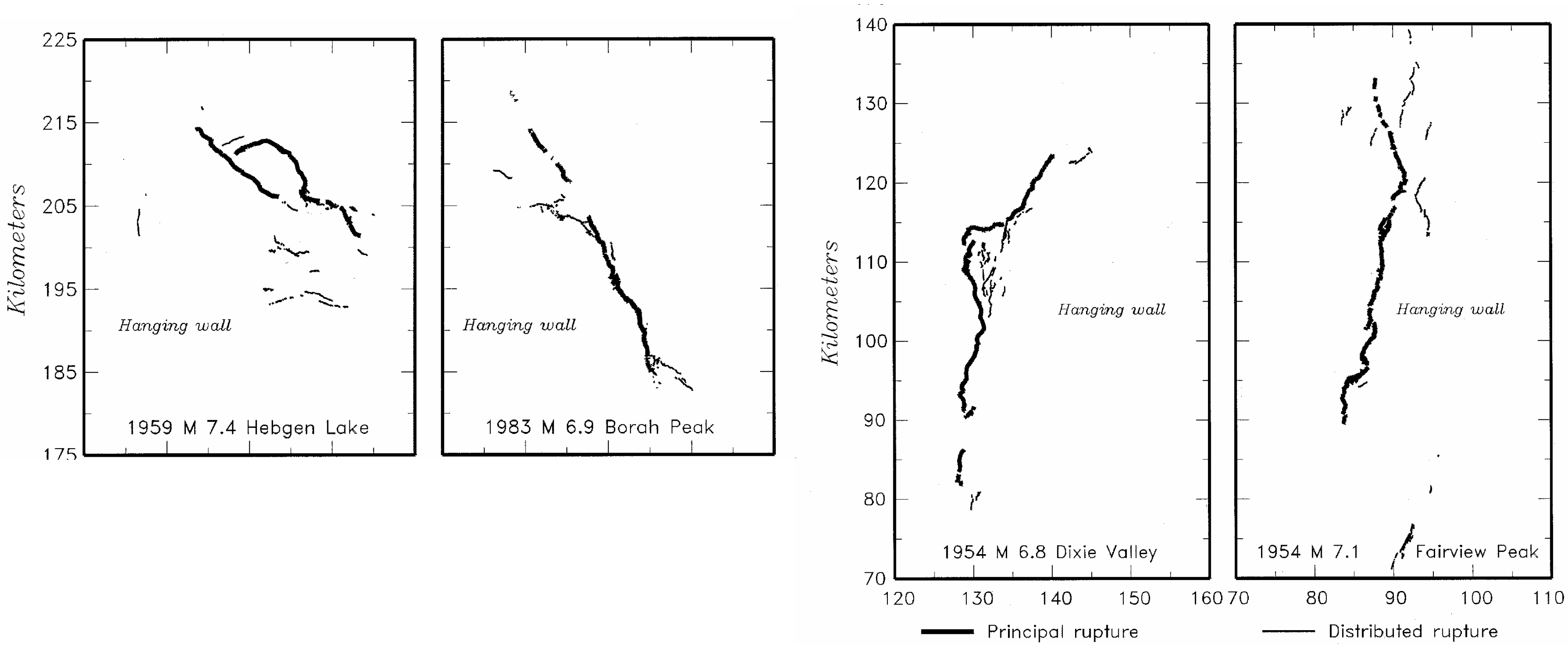
A Methodology for Probabilistic Fault Displacement Hazard Analysis

- Initially developed to assess fault rupture hazard for the proposed Yucca Mountain nuclear waste repository
- Refined in hazard study for Los Alamos
- Published in *Earthquake Spectra*, v. 19
- Methodology has general applicability
- Probability distributions developed for only normal faulting earthquakes

Two Approaches

- Earthquake Approach
  - Uses PSHA formulation
  - Considers two types of faulting
    - *Principal* faulting – slip on the main plane of weakness responsible for the release of seismic energy during earthquake
    - *Distributed* faulting – slip on other faults, fractures or shears in the vicinity of the principal rupture
- Displacement Approach
  - Uses the characteristics of fault displacement observed at the site of interest without invoking a specific mechanism for their cause

Principal and Distributed Faulting



Earthquake Approach Formulation

- PSHA

$$\nu_k(z) = \sum_n \alpha_n(m^0) \int_{m^0}^{m_n^u} f_n(m) \left[\int_0^{\infty} f_n(r \mid m, \text{Site } k) \cdot P(Z > z \mid m, r) \cdot \mathrm{d}r \right] \cdot \mathrm{d}m$$

- PFDHA

$$\nu_k(d) = \sum_n \alpha_n(m^0) \int_{m^0}^{m_n^u} f_n(m) \left[\int_0^{\infty} f_n(r \mid m, \text{Site } k) \cdot P^*(D > d \mid m, r, \text{Site } k) \cdot \mathrm{d}r \right] \cdot \mathrm{d}m$$

Fault Displacement "Attenuation" Function

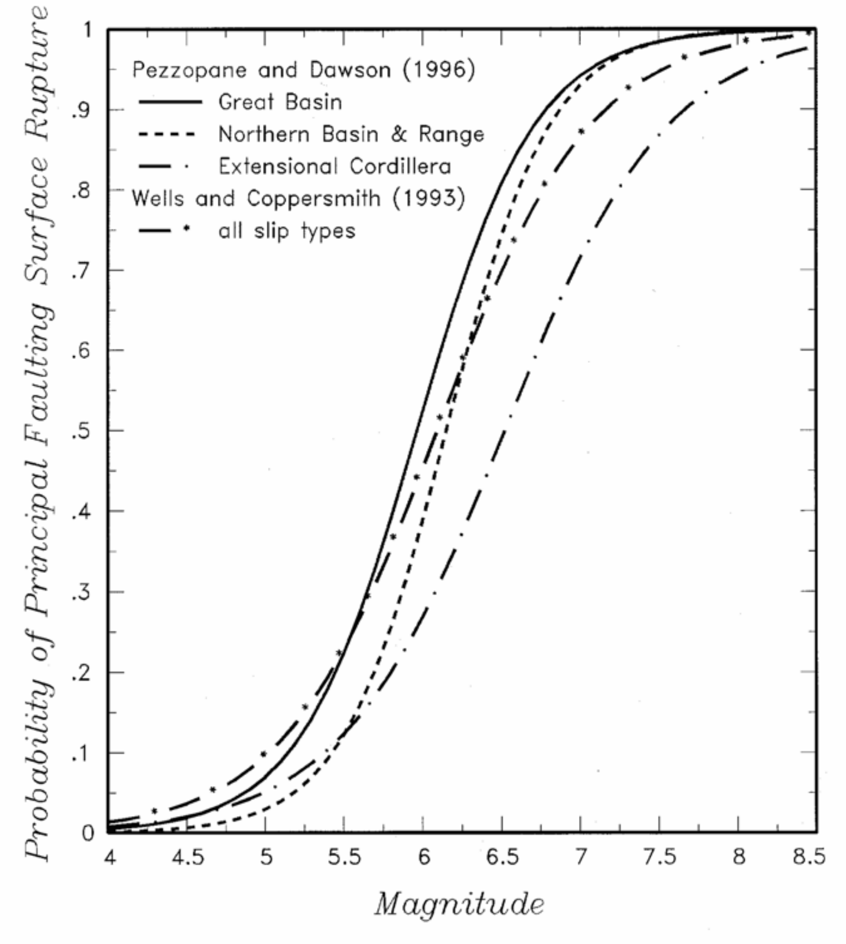
$$P_n^{*}(D > d \mid m, r, \text{Site } k) = P_n(\text{Slip} \mid m, r) \cdot P_{kn}(D > d \mid m, r, \text{Site } k, \text{Slip})$$

- P_n(Slip|m,r) probability that (surface) slip occurs given the event

- P_n(D>d|$m,r,$Site $k,$ Slip) probability distribution for the amount of slip give some slip occurs

$P_n(\text{Slip}|m,r)$ for Principal Rupture

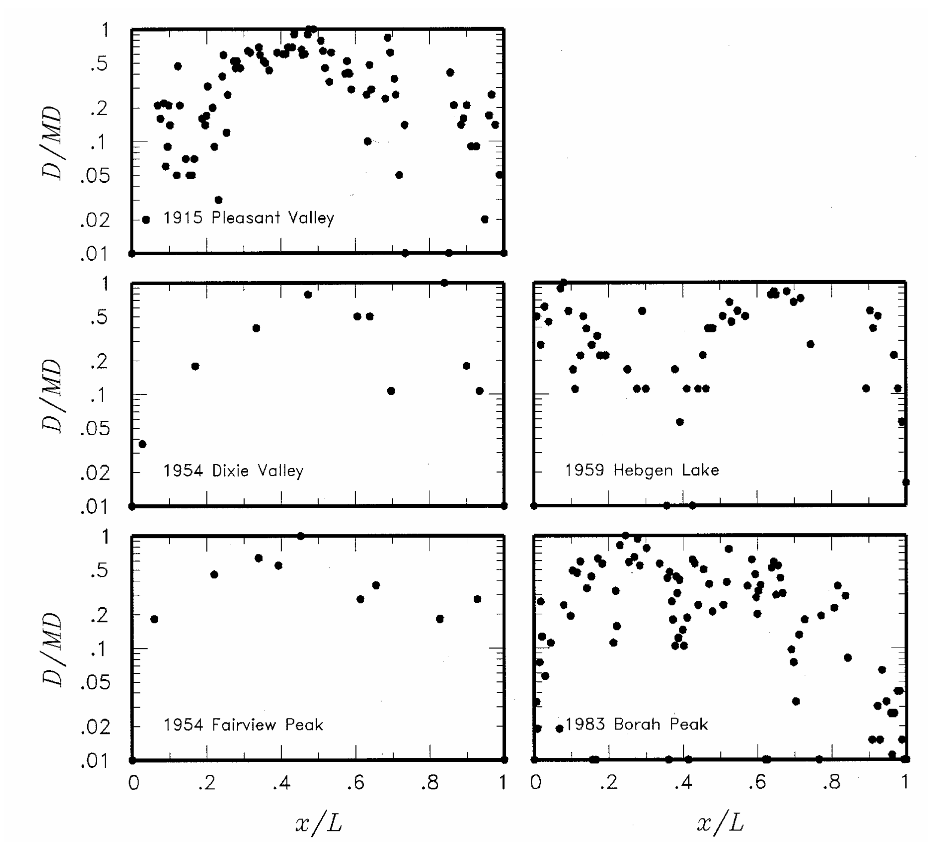
- Can be developed by randomly locating ruptures on fault plane as in standard PSHA calculation
- Alternatively, use empirical models for probability of surface rupture as a function of magnitude
  - Data needed is yes/no for occurrence of surface rupture in event of magnitude **M**



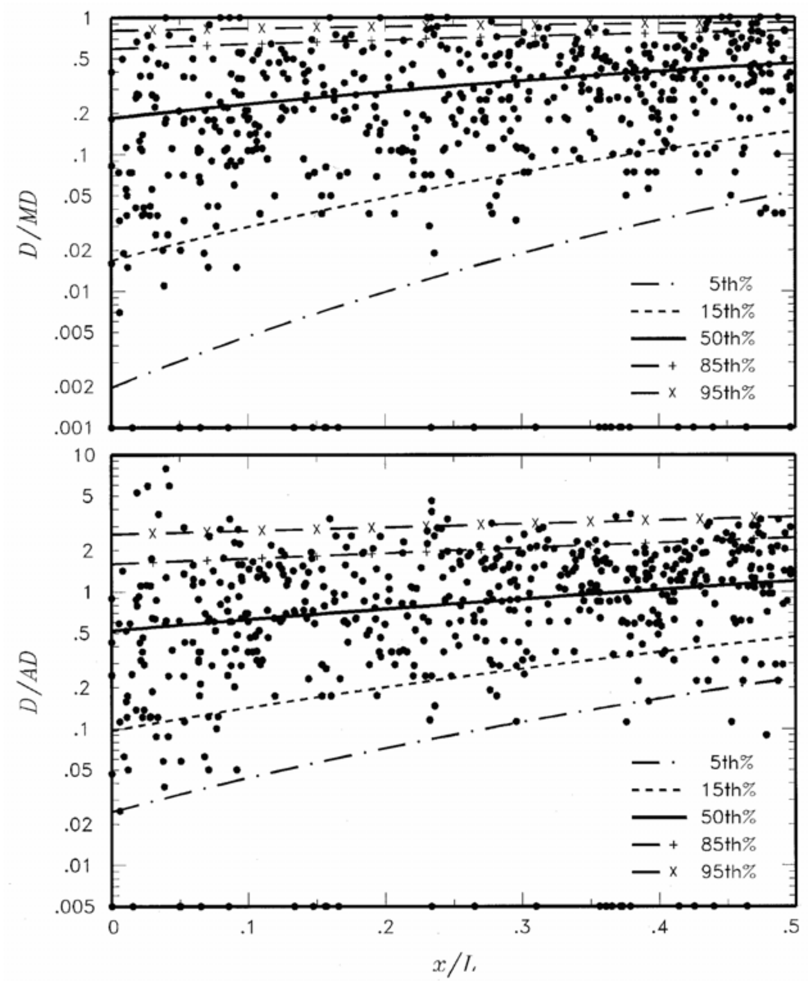
$P_n(D>d|m,r,\text{Site } k, \text{Slip})$ for Principal Rupture

- Assess $D_{average}$ or D_{max} as a function of magnitude from empirical models (e.g. Wells and Coppersmith, 1994)
- Develop probability distribution for a normalized displacement $D/D_{average}$ or D/D_{max}
  - Account for location of site along the length of the rupture
  - Data needed is detailed mapping of amount of displacement along the length of the rupture

Displacement Variability Along Rupture Length

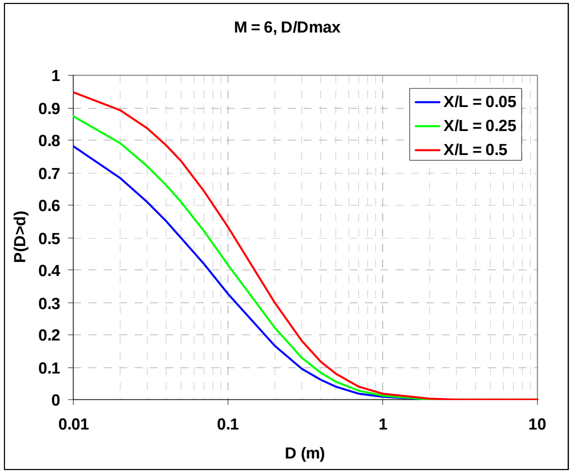


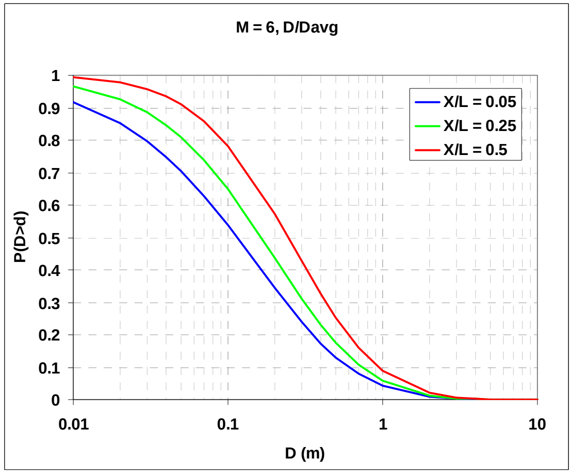
Wheeler (1989)

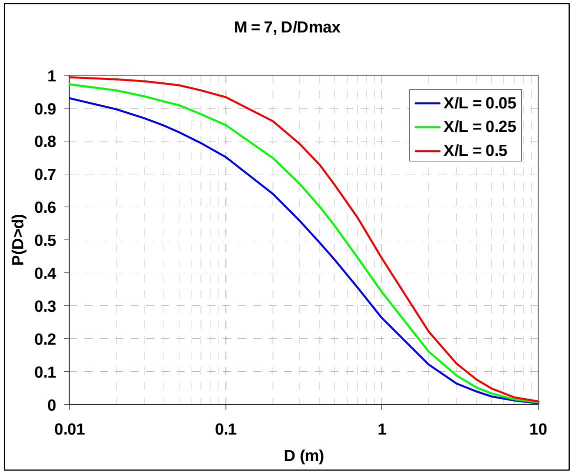


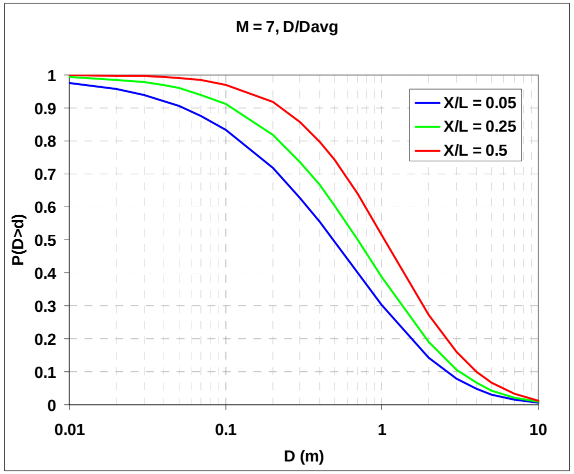
McCalpin (1998)

Example $P_n(D>d|m,r,\text{Site }k,\text{ Slip})$



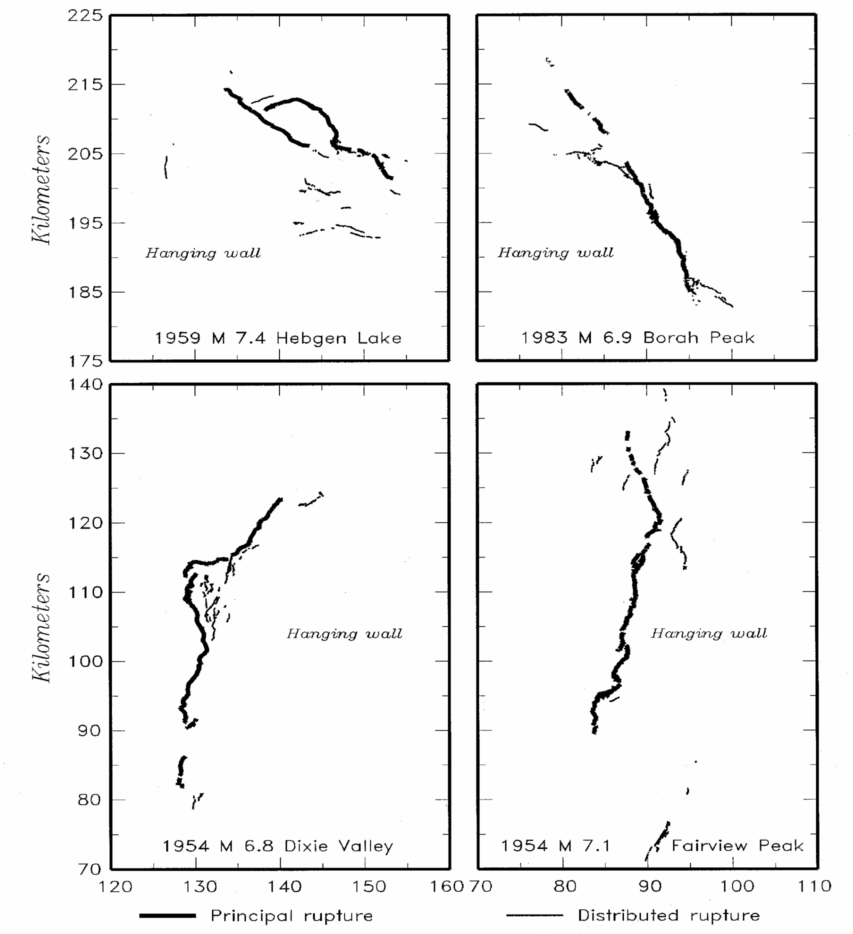






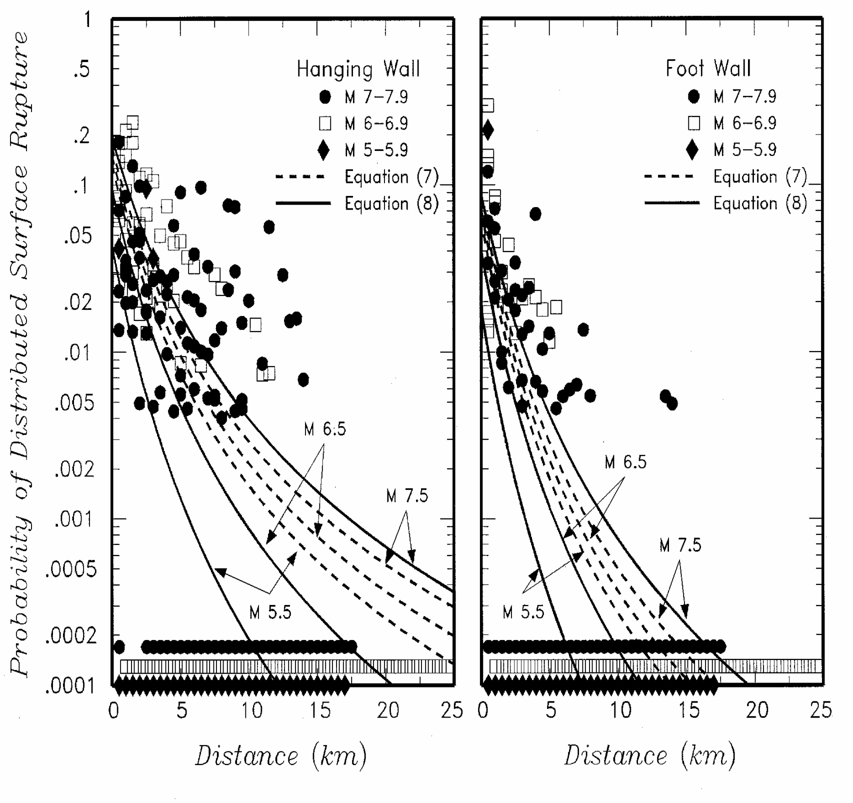
P_n(Slip|m,r) for Distributed Rupture

- Data needed is detailed mapping of distributed ruptures around the feature of main interest to geologists
- Map density of distributed ruptures for historical events
- Subdivide area into pixels (0.5 km x 0.5 km)
- Probability (frequency) of distributed rupture is equal to number of pixels with distributed rupture divided by total number of pixels
- Tradeoff between pixel size and completeness of mapping



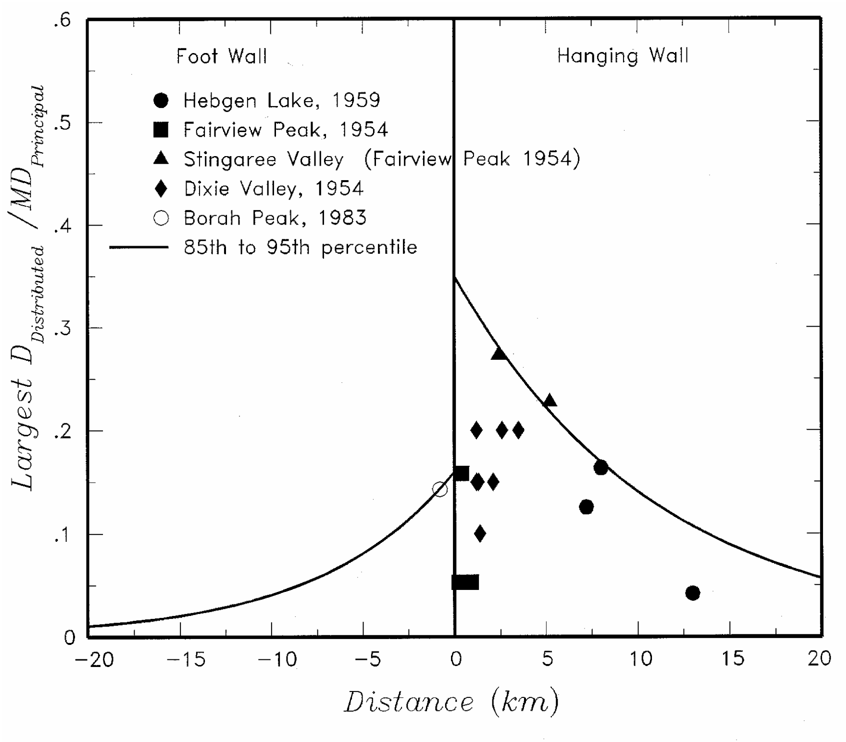
P_n(Slip|m,r) for Distributed Rupture

- Model probability of rupture a as function of distance from principal rupture, hanging wall versus foot wall, and magnitude



$P_n(D>d|m,r,$Site k, Slip) for Distributed Rupture

- Data needed is the amplitude of displacement on the secondary ruptures
- Very limited amount of data reported
- Modeled as displacement normalized by principal fault displacement



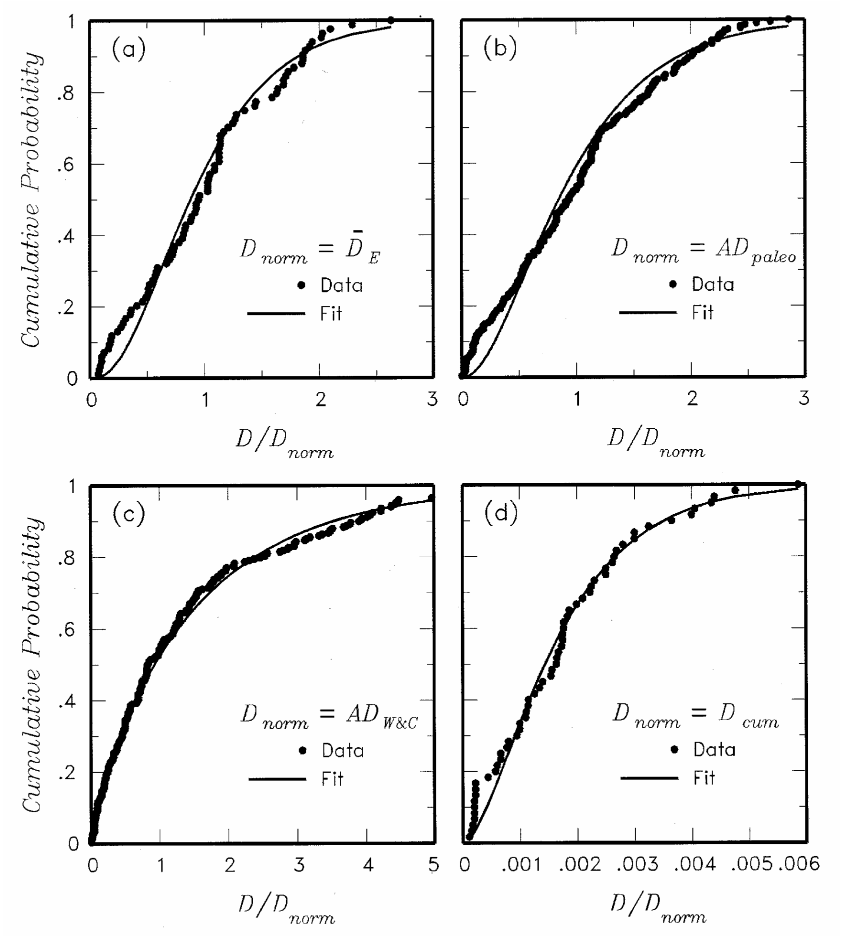
Displacement Approach

$$\nu(d) = \lambda_{DE} \cdot P(D > d \mid \text{Slip})$$

- λ_{DE} is frequency of displacement events
  - Number of events in time period T
  - Slip rate divided by average displacement per event
  - Average displacement computed from observations at site or from relationships between scale (e.g. length) of feature and displacement $\overline{D}_E = \alpha' L_{Total}$
  - Data needed is characterization of specific feature at site of interest

$P(D>d|\text{Slip})$

- Developed from data for normalized distributions of displacement in individual slip events



Displacement Hazard Curves

- Different shape than ground motion hazard curves due to effect of probability of slip (smaller earthquakes unlikely to produce surface rupture
- Integral of hazard curve provides an estimate of fault slip rate that provides a check on consistency of modeling