Fault Displacement Hazard Analysis, Hetch -Hetchy Aqueduct System, SF Bay Area:

Northern Calaveras, Southern Hayward, and San Andreas Faults

Surface Fault Displacement Hazard Workshop

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PEER, UC Berkeley, Berkeley, California

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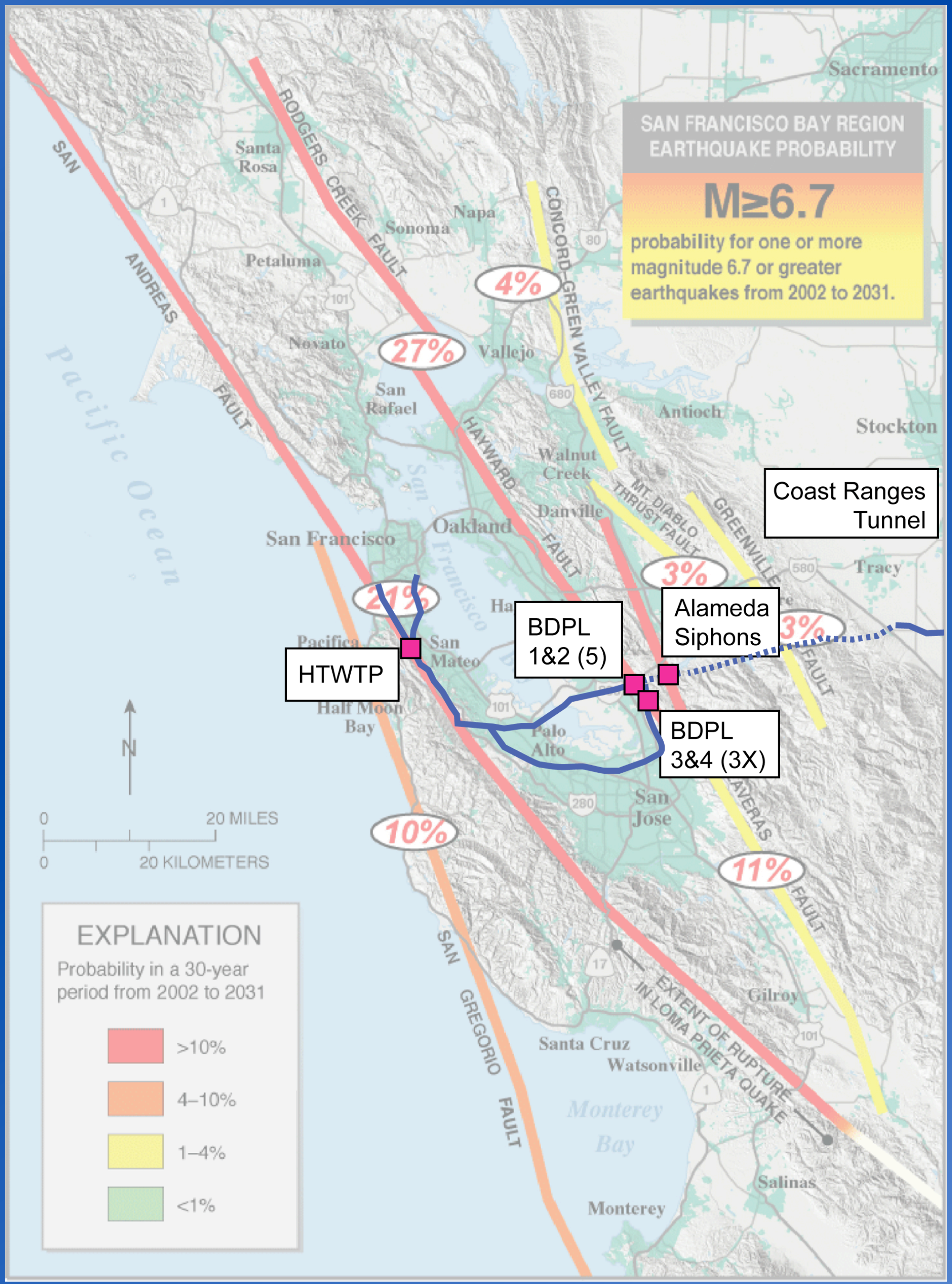
Purpose

- SFPUC General Seismic Design Requirements (2006; 2008)
- Achieve system-wide performance goals following major Bay Area earthquake
- Desire for uniform approach to determine design displacements for major pipeline fault crossings
- 475- and 975-year return period displacements



From 2002 WGCEP

Fault Displacement Hazard Analysis Methodology

$$\nu(d) = \sum_n \alpha_n(M^0) \int_{M_n^0}^{M_n^u} f_n(M) \left[\int_0^{0.5} f_n(r \mid M) \cdot P_n(D > d \mid M, r) \cdot P_n(D > 0 \mid M) \cdot \mathrm{d}r \right] \mathrm{d}M$$

Parameters:

- Fault rupture model: magnitude and rate distribution
- Probability of surface-fault rupture
- Displacement versus magnitude relation
- Variability in displacement along rupture *r = x/L*

- Separate treatment of fault creep, slip direction, secondary rupture, etc...

Rupture Model

(After 2002 WGCEP)

Southern Hayward:
HS only: 6.7
HS+HN: 6.9
H+RC: 7.25
Floating: 6.9

Northern Calaveras:
CN only: 6.8
Floating: 6.2
C_all: 6.9
CN+CC: 6.9

Peninsula San Andreas:
1906 repeat: 7.9
SAP+SAS: 7.4
Floating: 6.9
SAP only: 7.15

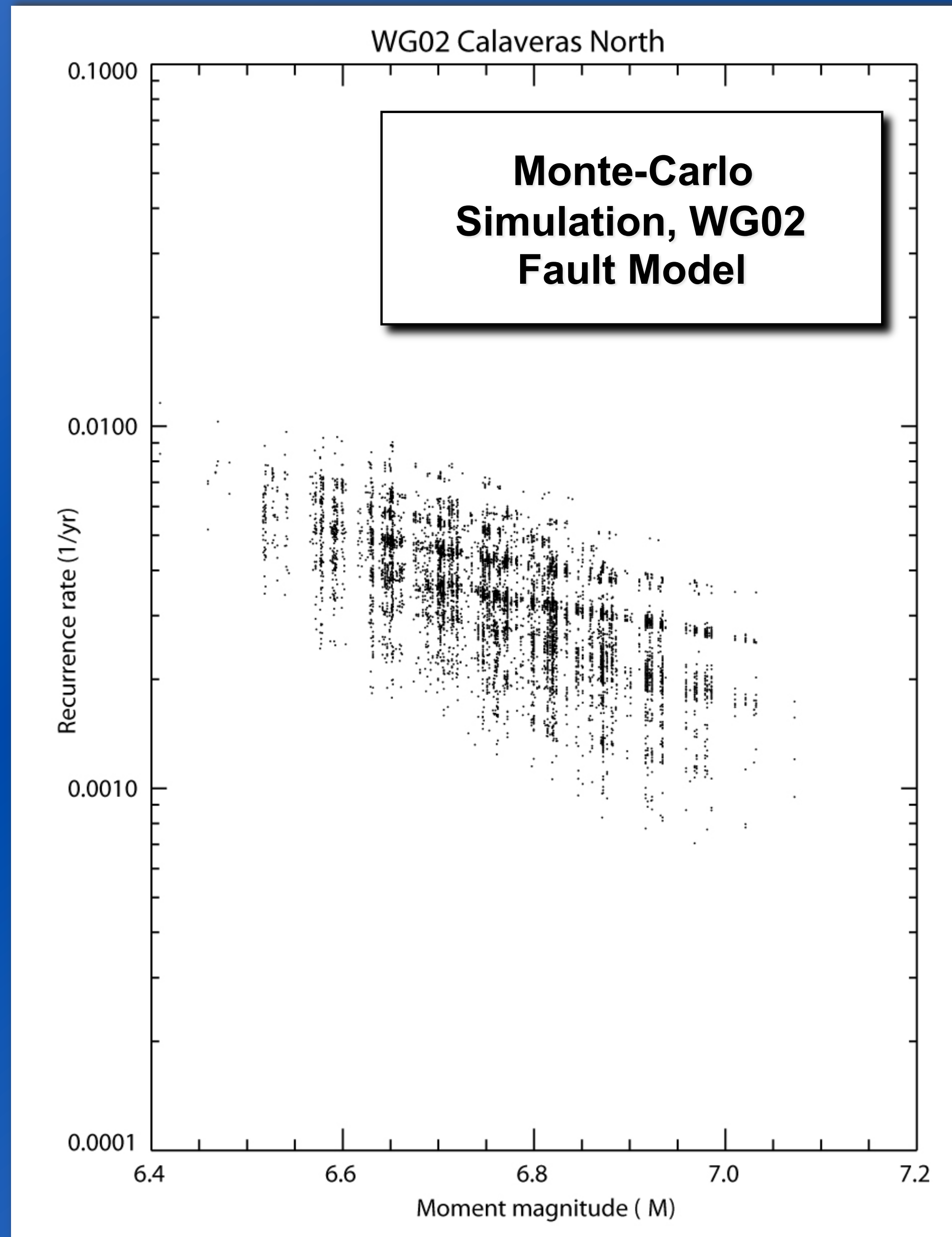
From 2002 WGCEP

Rupture Model (cont.)

- WG02 model simulations

WG02, Table 4.8. Long-term magnitudes and occurrence rates of rupture sources.

		Mean magnitude			Occurrence rate (/yr)			Recurrence interval (yr)		
Fault Name	Rupture Source	Mean	2.5%	97.5%	Mean	2.5%	97.5%	Mean	2.5%	97.5%
San Andreas	SAS	7.03	6.84	7.22	0.0007	0	0.0015	1402	646	∞
	SAP	7.15	6.95	7.32	0.0005	0	0.0010	2017	967	∞
	SAN	7.45	7.28	7.61	0.0001	0	0.0008	7180	1316	∞
	SAO	7.29	7.12	7.44	0.0002	0	0.0011	4540	897	∞
	SAS+SAP	7.42	7.26	7.56	0.0010	0.0002	0.0029	1037	343	4863
	SAP+SAN	7.65	7.48	7.79	0	0	0	∞	∞	∞
	SAN+SAO	7.70	7.53	7.86	0.0012	0.0004	0.0035	809	282	2772
	SAS+SAP+SAN	7.76	7.59	7.92	0.00002	0	0.0001	42489	8240	∞
	SAP+SAN+SAO	7.83	7.65	8.01	0.0001	0	0.0004	13046	2676	∞
	SAS+SAP+SAN+SAO	7.90	7.72	8.10	0.0026	0.0012	0.0042	378	239	808
	floating	6.90	6.90	6.90	0.0009	0.0001	0.0019	1104	536	7723
Hayward/RC	HS	6.67	6.36	6.93	0.0034	0.0012	0.0069	292	144	830
	HN	6.49	6.18	6.78	0.0032	0.0011	0.0069	312	146	907
	HS+HN	6.91	6.68	7.12	0.0024	0.0009	0.0047	413	211	1100
	RC	6.98	6.81	7.14	0.0040	0.0023	0.0063	250	159	438
	HN+RC	7.11	6.94	7.28	0.0005	0	0.0013	2086	766	∞
	HS+HN+RC	7.26	7.09	7.42	0.0003	0.0001	0.0007	3524	1511	19158
	floating	6.90	6.90	6.90	0.0003	0.0001	0.0006	3524	1706	7294
Calaveras	CS	5.79	0.00	6.14	0.0075	0	0.0158	134	63	∞
	CC	6.23	5.75	6.68	0.0054	0.0025	0.0097	184	103	397
	CS+CC	6.36	5.87	6.75	0.0018	0	0.0065	541	155	∞
	CN	6.78	6.58	6.97	0.0035	0.0015	0.0065	284	154	685
	CC+CN	6.90	6.68	7.11	0.0001	0	0.0011	10958	924	∞
	CS+CC+CN	6.93	6.72	7.14	0.0006	0	0.0018	1555	543	∞
	floating	6.20	6.20	6.20	0.0030	0.0009	0.0077	331	130	1158
	floating CS+CC	6.20	6.20	6.20	0.0120	0.0025	0.0285	83	35	405



Probability of Surface -Fault Rupture

Wells and Coppersmith (1993):

M6.8 = 81% probability

M7.0 = 87% probability

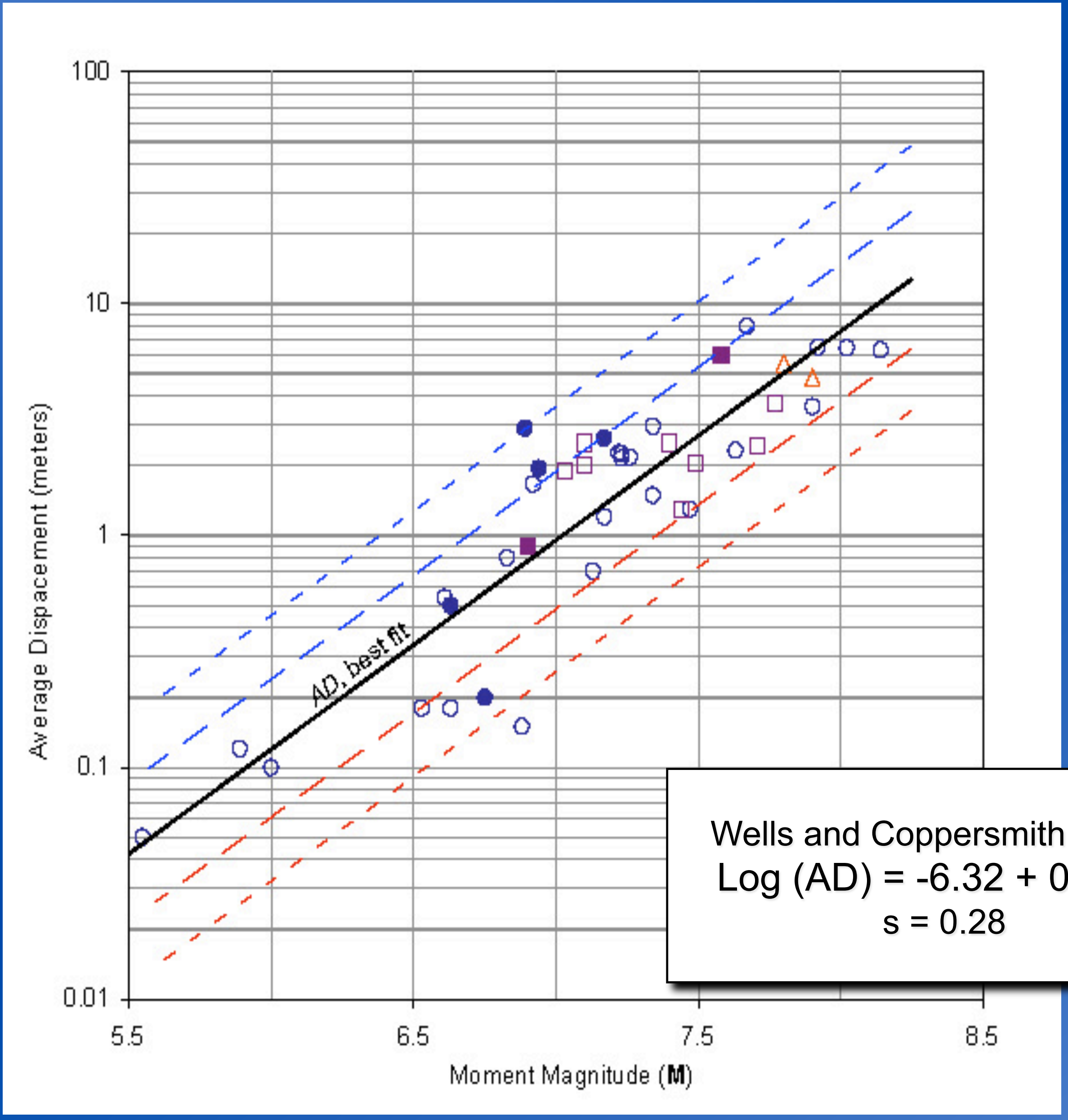
(Global dataset, 276 earthquakes)

For S. Hayward and N. Calaveras:

$$P(D > 0 \mid \mathbf{M}) = 1$$

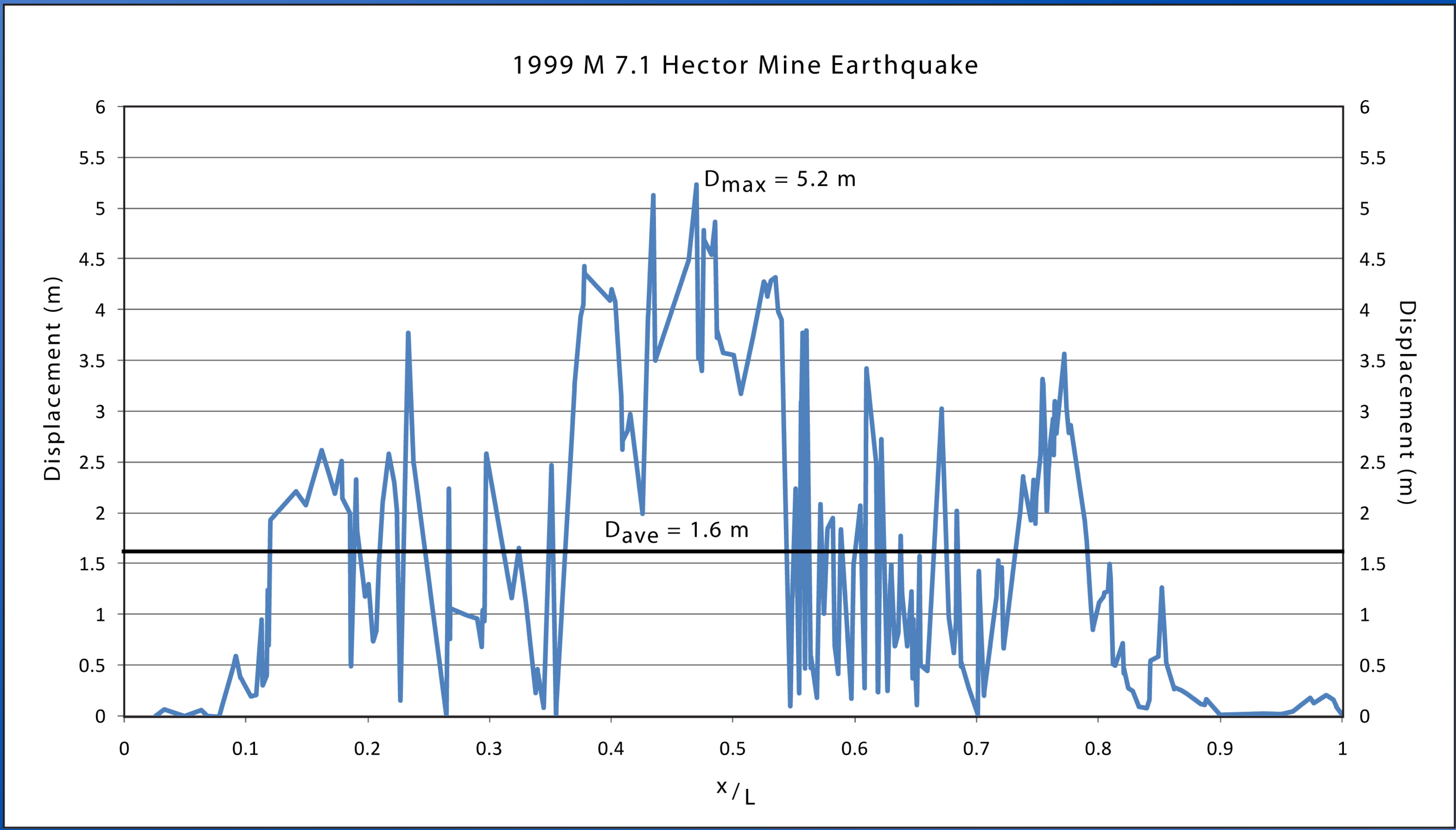
Northern Calaveras Fault, Valley Crest Nursury, Sunol Valley

Displacement – Magnitude Relation



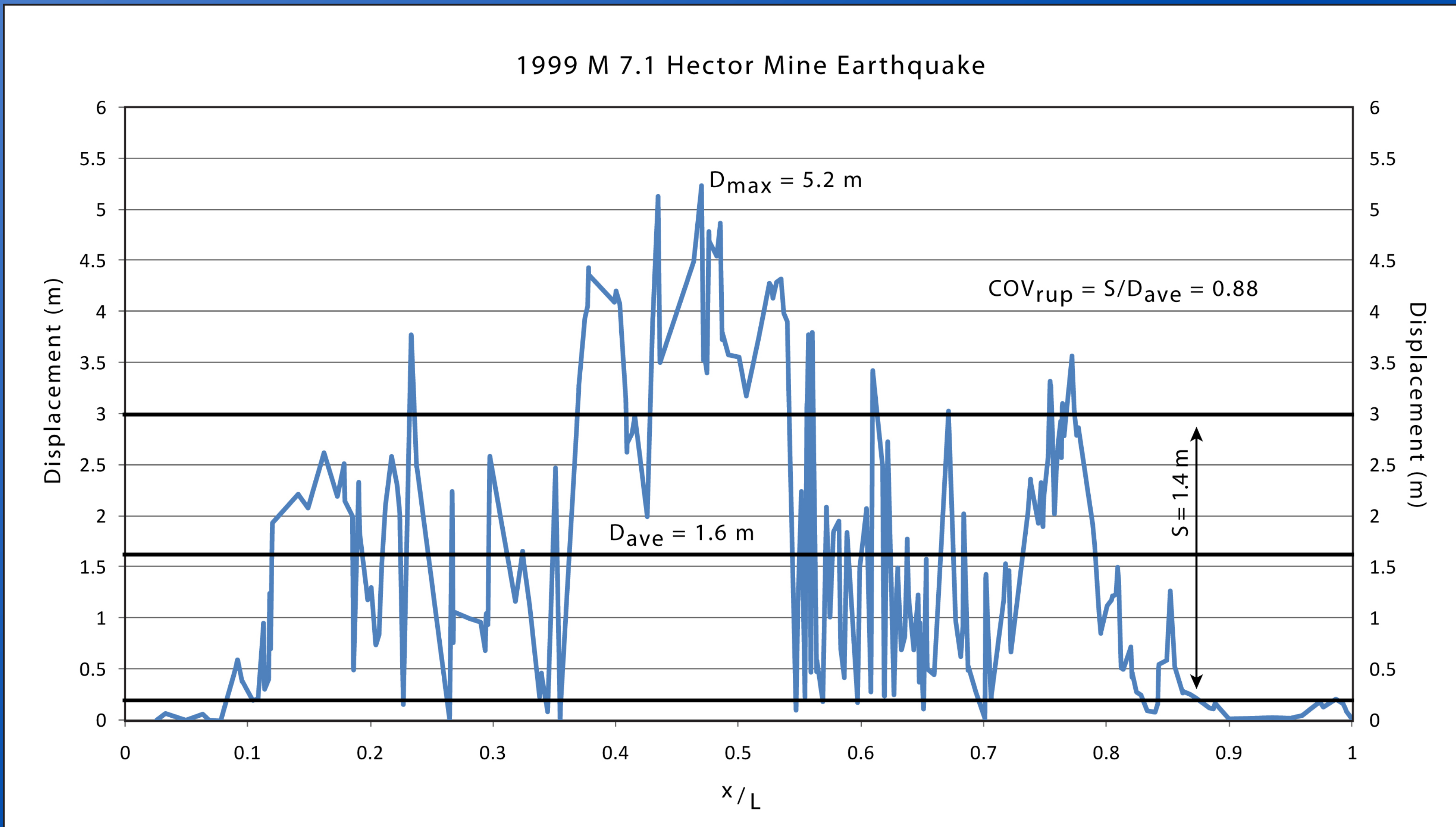
Wells and Coppersmith (1994)
Log (AD) = -6.32 + 0.9 * **M**
s = 0.28

Variability in Displacement Along Rupture



From Treiman et al. (2002) as
provided by Wesnousky (2008)

Variability in Displacement Along Rupture



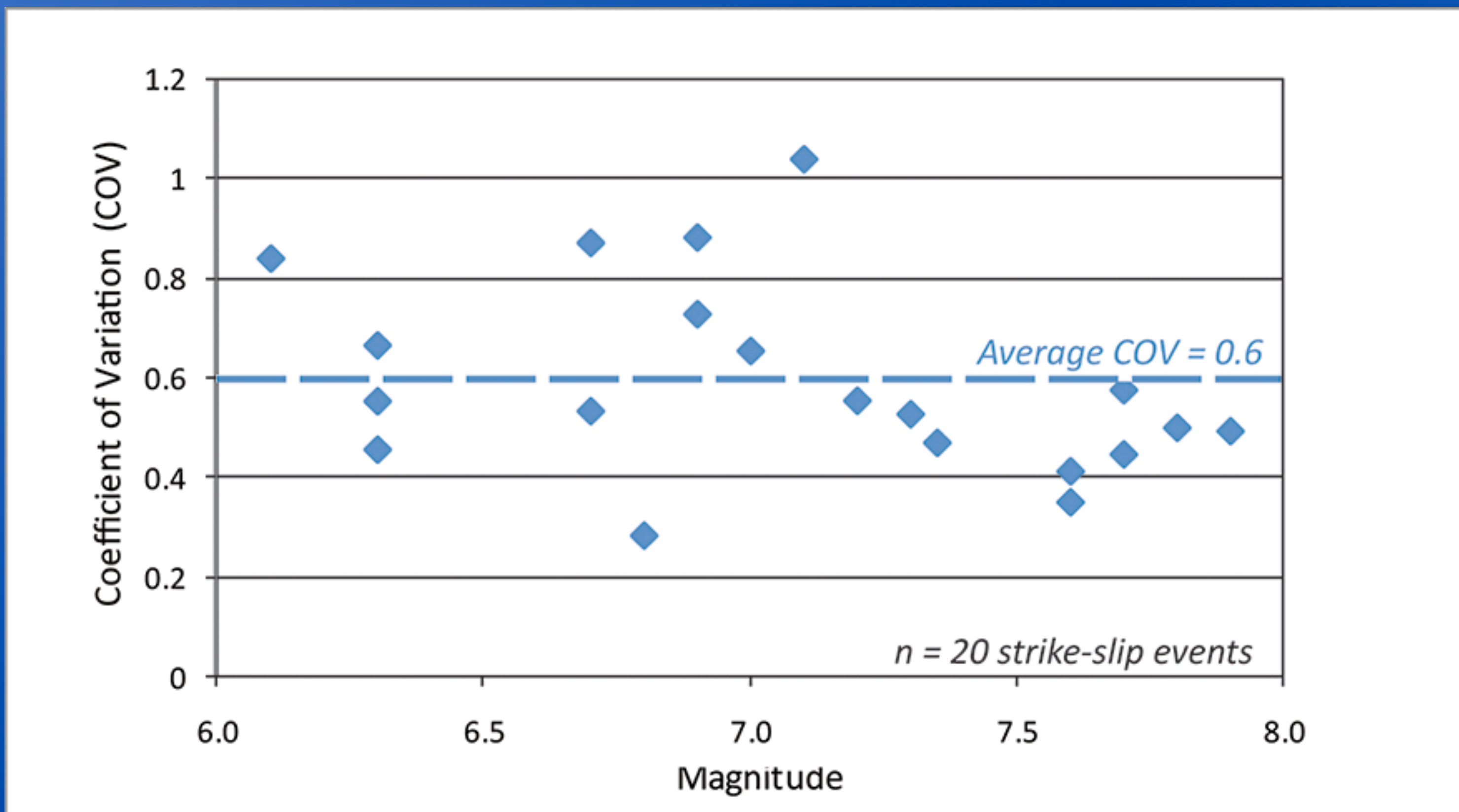
From Treiman et al. (2002) as provided by Wesnousky (2008)

Variability in Displacement Along Rupture

Along-strike COV (SFPUC, 2006)

Hemphill-Haley and Weldon (1999) = 14 events; COV ~ 0.85

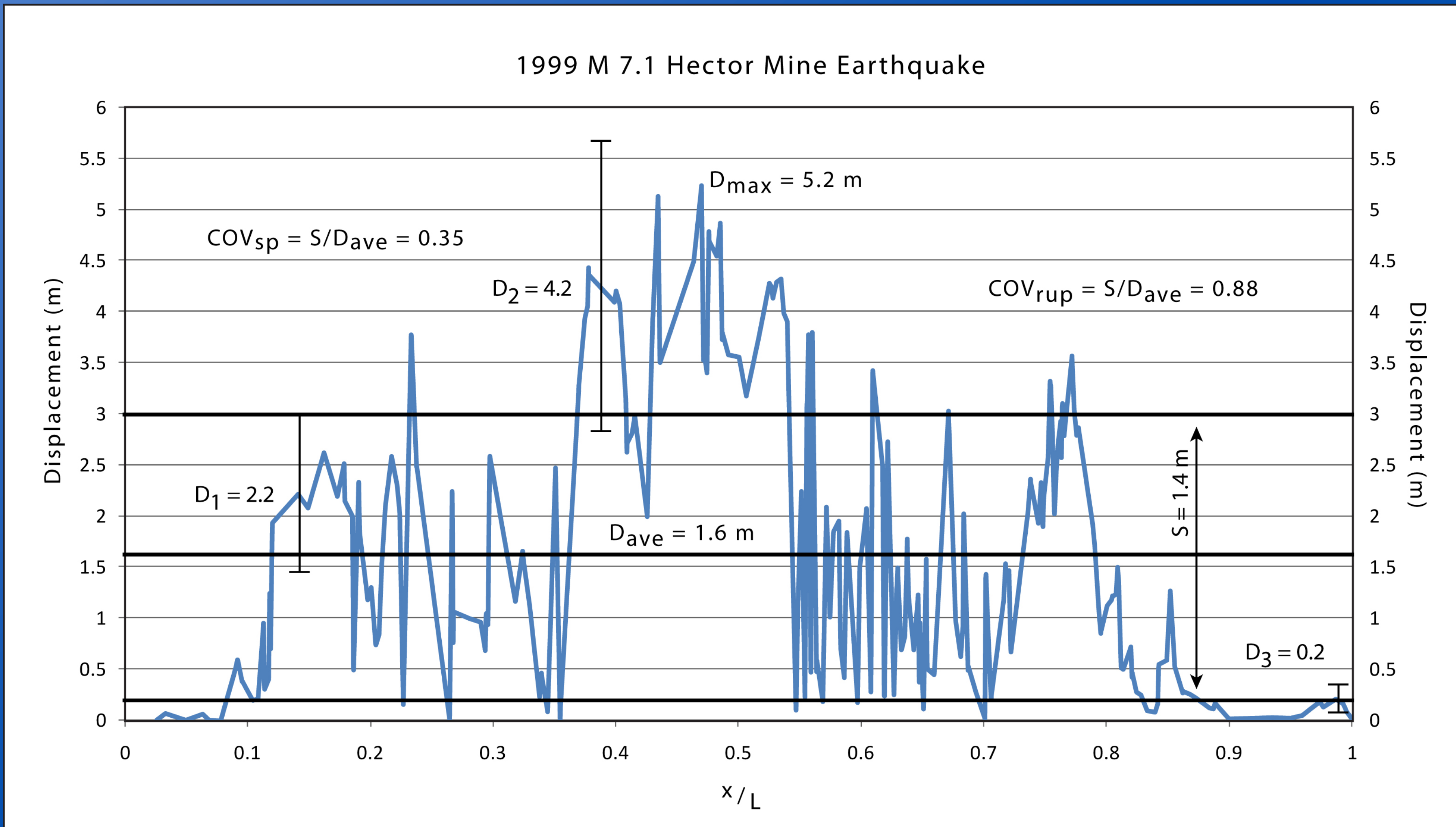
Wesnousky (2008) = 20 strike-slip events; COV = 0.6 ± 0.2



Combined $\sigma_{\log(AD)} = 0.39$

Data from Wesnousky (2008)

Alternative: Variability in Displacement at a Point



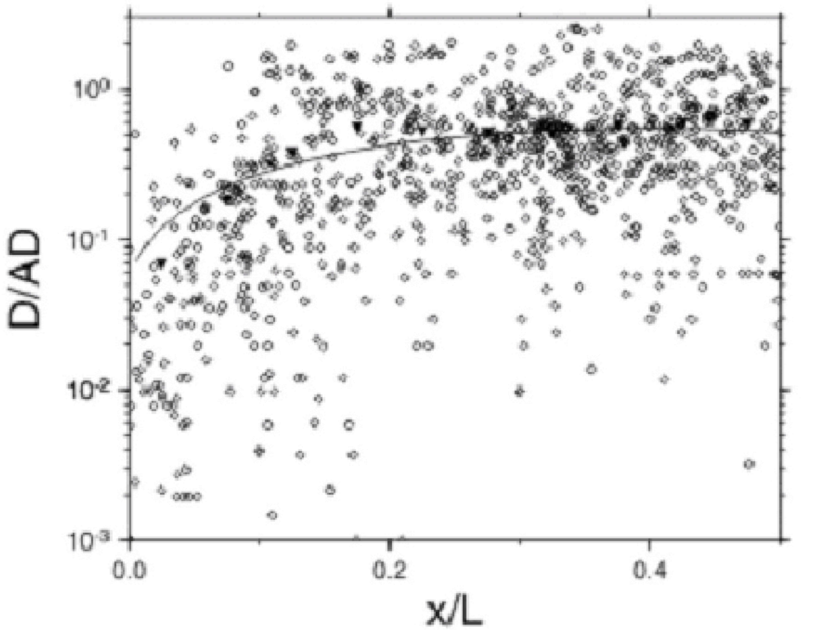
From Treiman et al. (2002) as provided by Wesnousky (2008)

Slip-at-a point COV (Hecker and Abrahamson, 2004) ~ 0.35

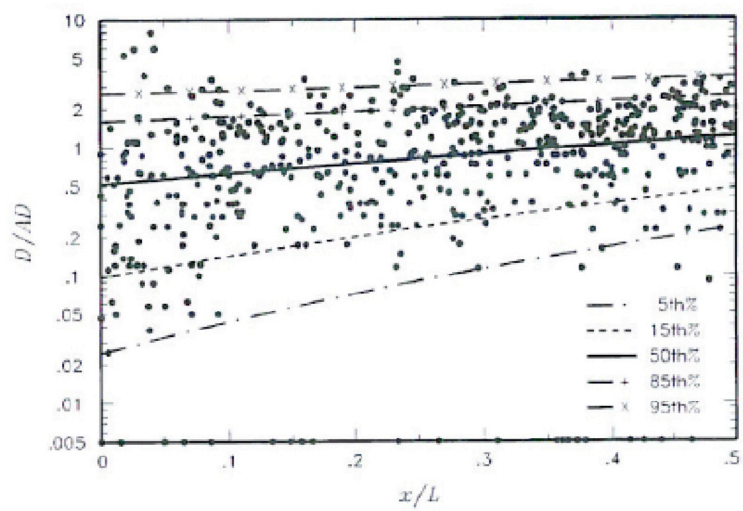
Variability in Displacement Along Rupture

D/AD versus x/L (Youngs et al., 2003; Petersen et al., 2005)

From Petersen et al. (2005), strike-slip faulting events



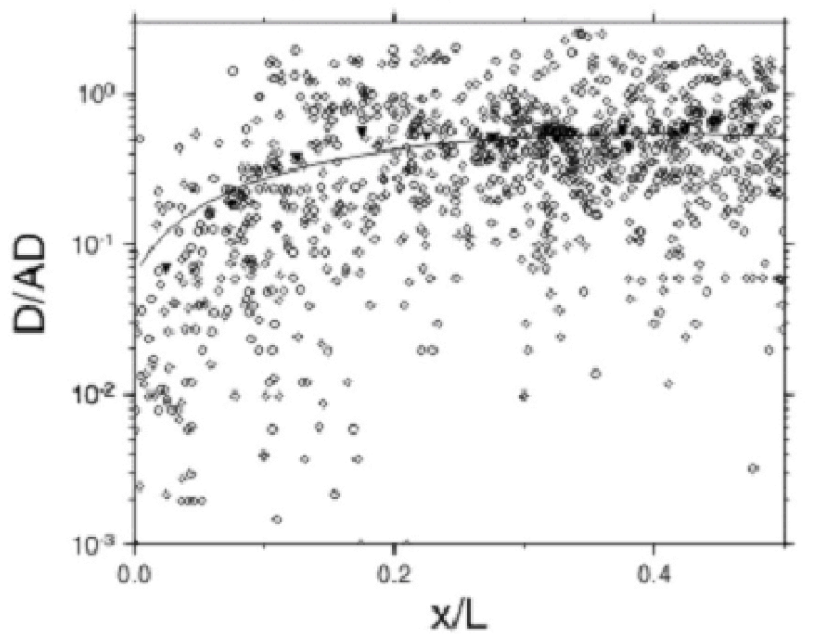
From Youngs et al. (2003), normal faulting events

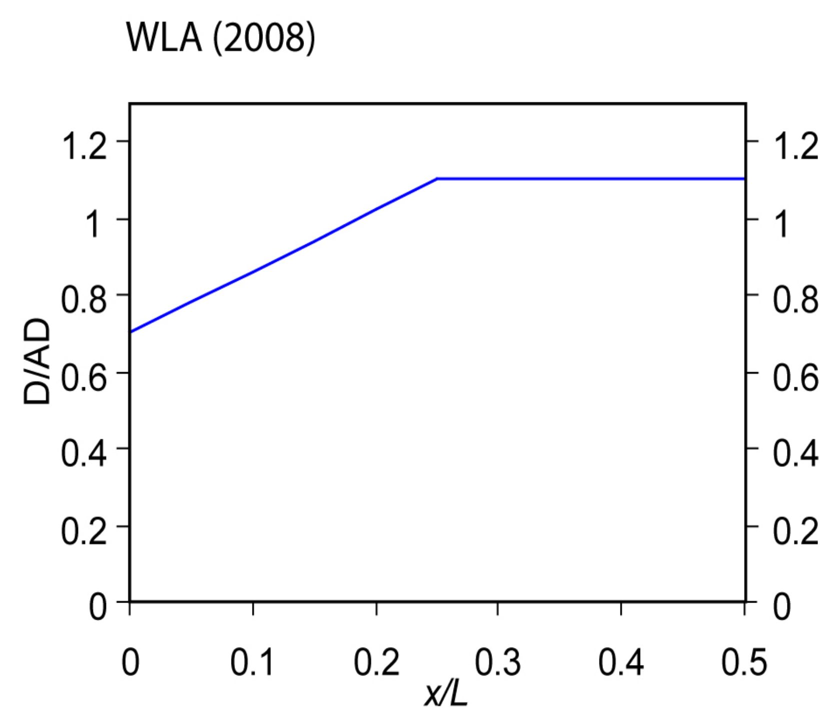


Variability in Displacement Along Rupture

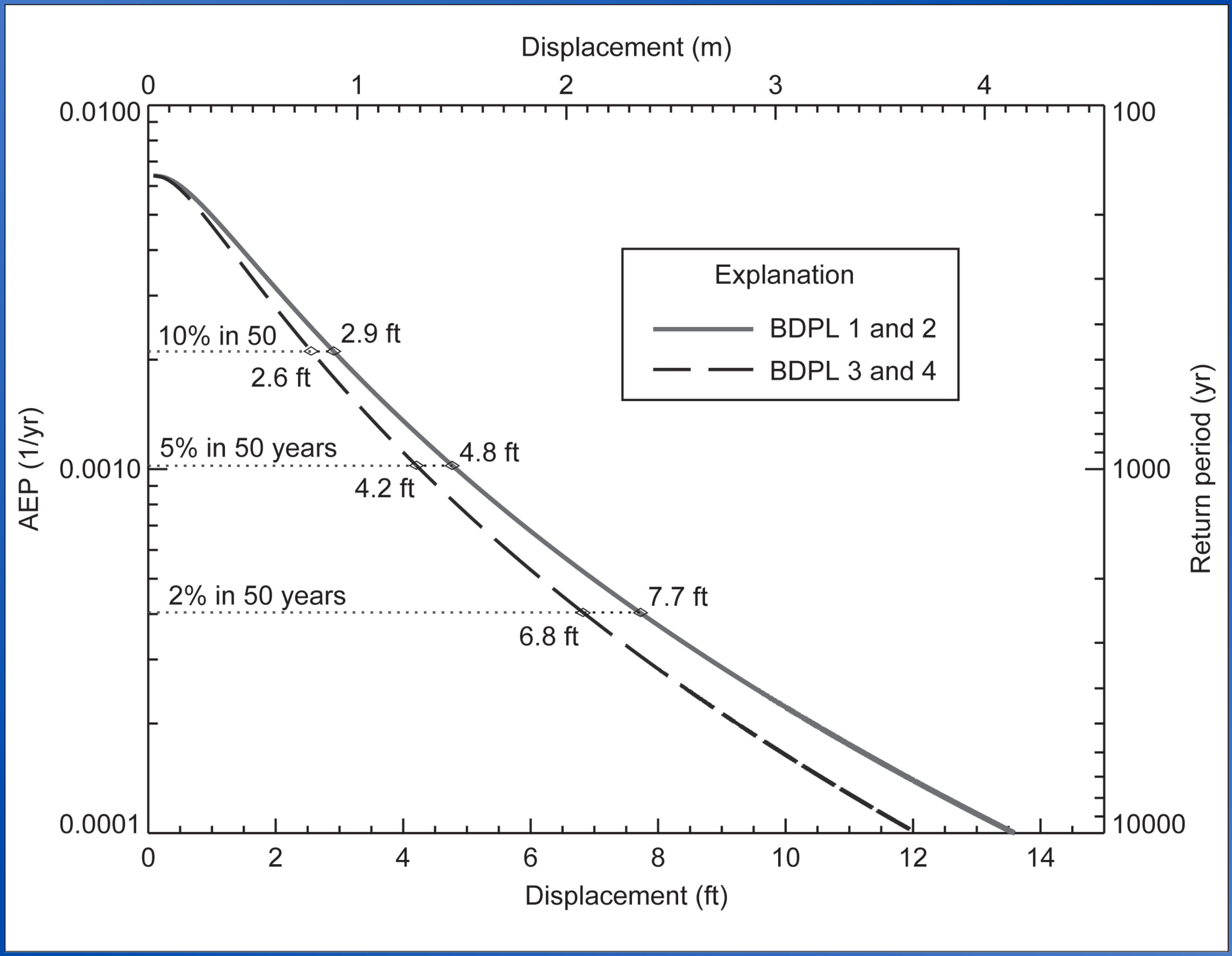
D/AD versus x/L - Scale factor that averages to D/AD = 1

From Petersen et al. (2005),
strike-slip faulting events





Results – PFDHA, S. Hayward Fault



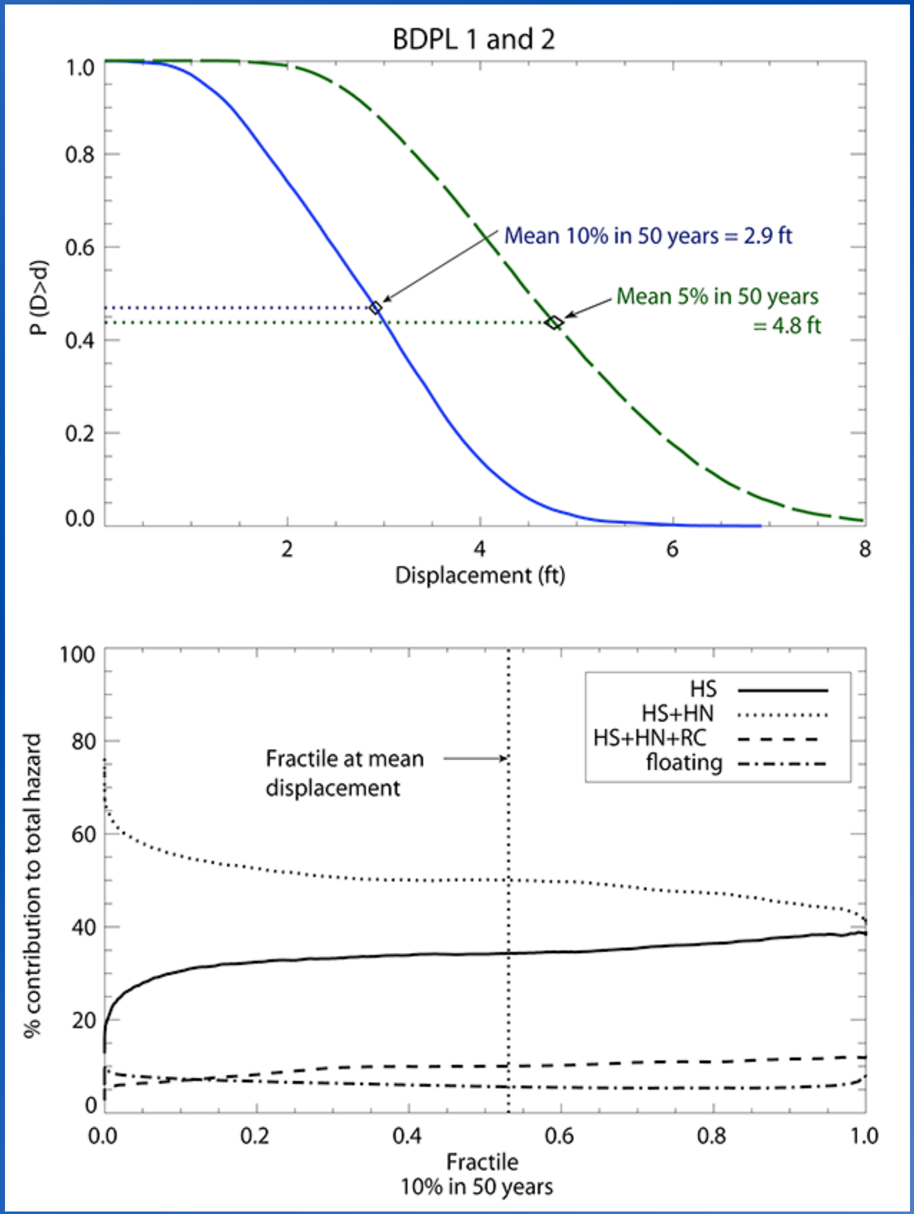
Results – PFDHA, S. Hayward Fault

475-year (10% in 50 yr)

- Mean = 2.9 ft (0.9 m)
- ± 1 standard deviation = 1.7 to 3.9 ft (0.5 to 1.2 m)

975-year (5% in 50 yr)

- Mean = 4.8 ft (1.5 m)
- ± 1 standard deviation = 3.2 to 6.1 ft (1.0 to 1.9 m)



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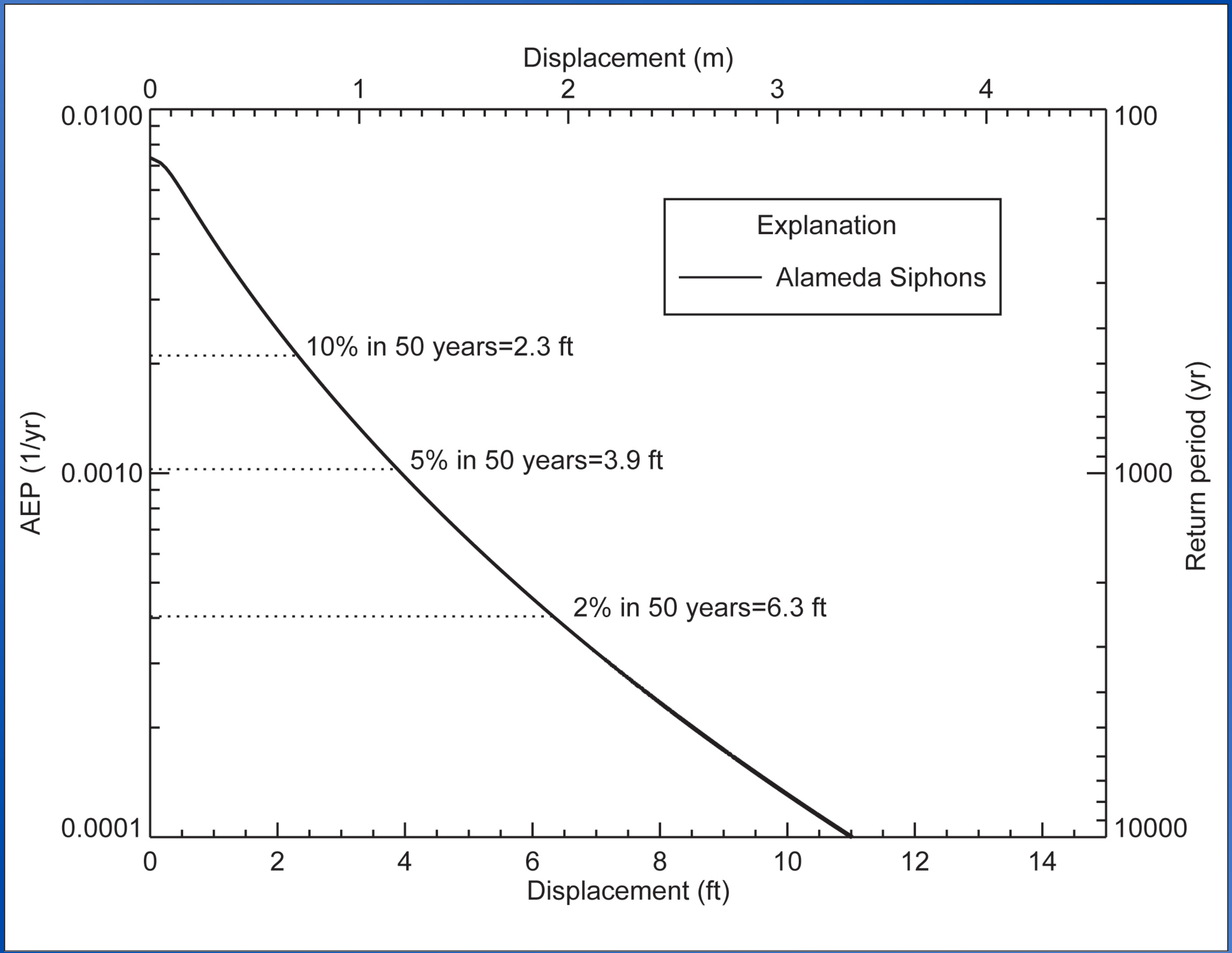
Results – PFDHA, N. Calaveras Fault



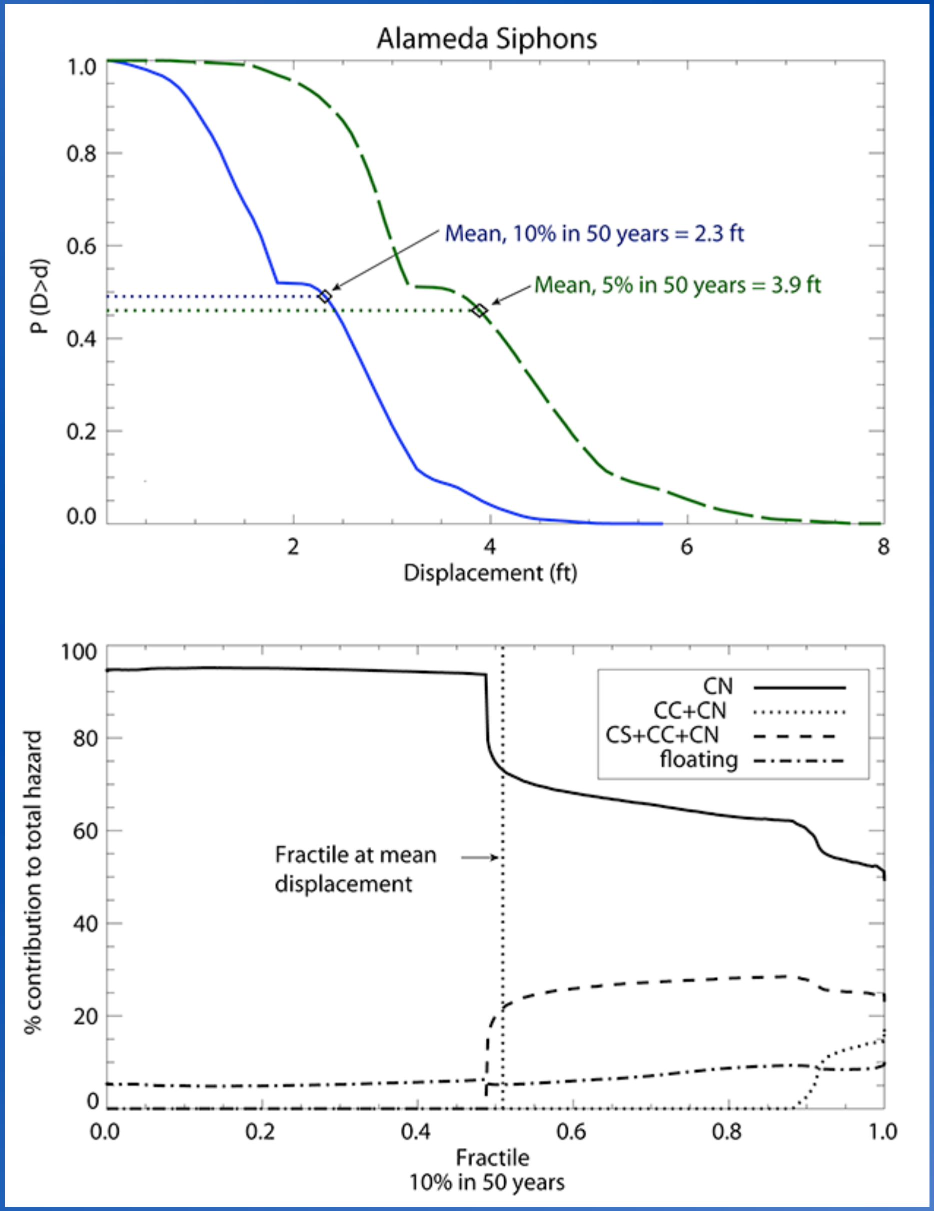
Results – PFDHA, N. Calaveras Fault

475-year (10% in 50 yr)

- Mean = 2.3 ft (0.7 m)
- ± 1 standard deviation = 1.2 to 3.2 ft (0.4 to 1.0 m)

975-year (5% in 50 yr)

- Mean = 3.9 ft (1.2 m)
- ± 1 standard deviation = 2.6 to 5.0 ft (0.8 to 1.5 m)



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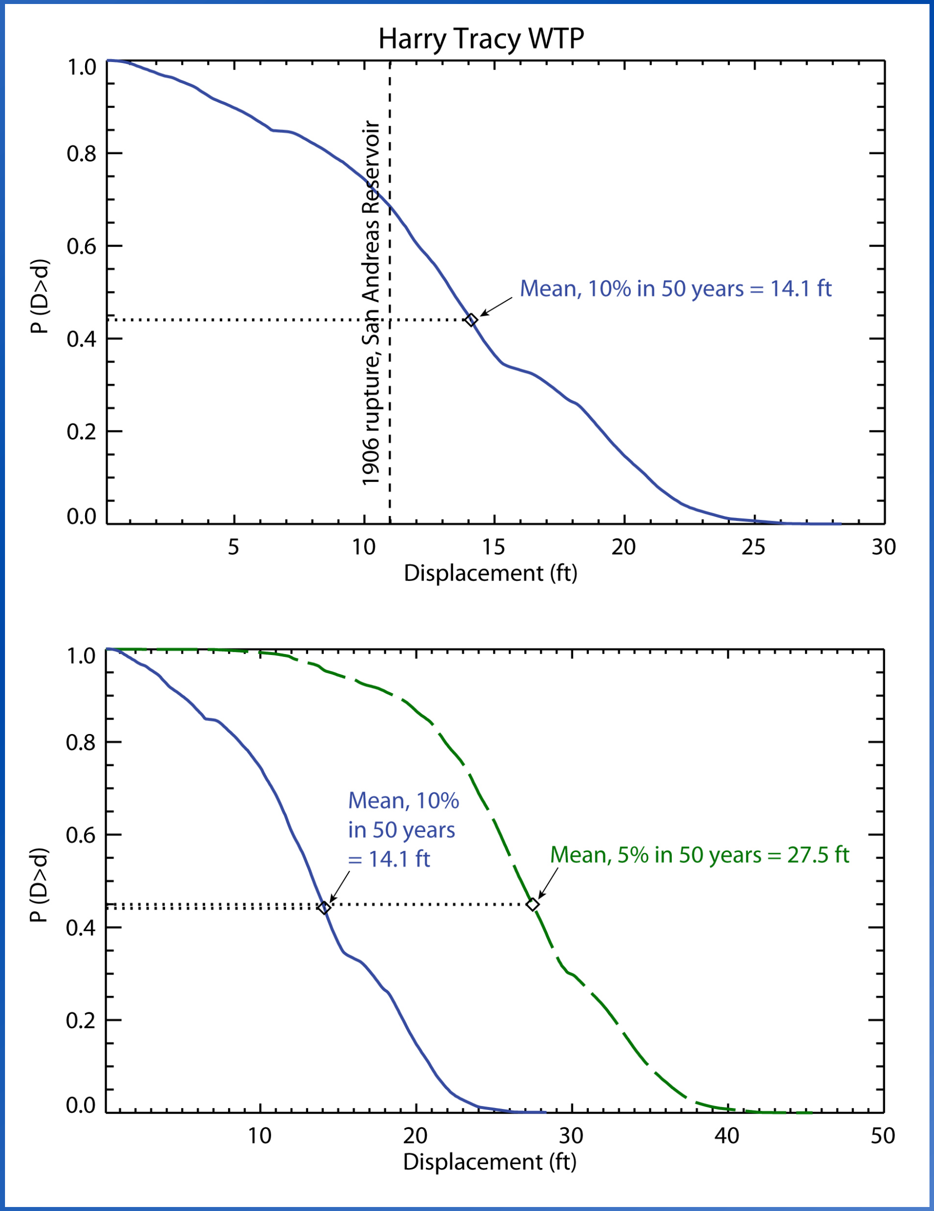
Results – PFDHA, San Andreas fault

475-year (10% in 50 yr)

- Mean = 14.1 ft (4.3 m)
- ± 1 standard deviation = 7.4 to 19.8 ft (2.3 to 6.0 m)

975-year (5% in 50 yr)

- Mean = 27.5 ft (8.4 m)
- ± 1 standard deviation = 21 to 33.5 ft (6.4 to 10 m)
- Hecker and Abrahamson (2004) approach yields ~16.5 to 20.5 ft (5 to 6 m)



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Discussion Points

- Variability/uncertainty in expected displacement from empirical approach is large, but less than for ground motions
- Values get ridiculous at upper end; need to truncate log -normal distribution?
- Uncertainty intended to guide engineering judgment and factor of safety
- These values are starting points for displacement characterization: distribution of slip, slip direction, creep, expected afterslip, secondary fault-rupture hazard...
- Slip-at-a point approach promising, but has limits.

FUGRO WLA