Surface Fault Displacement Hazard Workshop

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Shaking Hazard Compatible Methodology for Probabilistic Assessment of Fault Displacement Hazard

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Credits

- USC Strong Motion Research Group (Earthquake Engineering and Engineering Seismology)
  - Misha Trifunac
  - Vincent Lee
- Work supported by METRANS - Metropolitan Transportation Research Center, a U.S. Department of Transportation designated university transportation center (Grant 03-27; PI-s: Trifunac and Todorovska).
- Numerous discussions on the application aspects of this project with Anoosh Shamsabadi – Caltrans.

Publications

- Todorovska MI, Trifunac MD, and Lee VW (**2007**). Shaking hazard compatible methodology for probabilistic assessment of permanent ground displacement across earthquake faults, ***Soil Dynam. and Earthqu. Eng***., 27(6), 586–597 .
- Todorovska MI, Trifunac MD (**2006**). A note on probabilistic assessment of fault displacement hazard, ***Proc. 8th National Conference on Earthquake Engineering*** (commemorating the 100th anniversary of the 1906 earthquake), April 18-22, 2006, San Francisco California, Paper Number: 8NCEE-001793, pp. 10.
- ***Proc. Earthquake Engineering in the 21st Century*** *(EE-21C)*, Skopje-Ohrid, Macedonia, August 27-September 1, **2005**, pp. 11.

Relation to previous published work on PFDH

- Previous published work on PFDH:
  - Youngs et al., *Earthquake Spectra*, 2003, 19(1): 191-219.
  - Stepp et al., *Earthquake Spectra* 2001; **17**(1): 113-151.

  Methodology and results aimed at application to the potential Yucca Mountain nuclear waste repository site in Nevada.
- Our work –scaling models **specific for California**, and **compatible** with our scaling models we use for the other modules of our EQRISK program for assessment of: ground shaking, liquefaction initiation, and peak ground strain hazard (Lee and Trifunac, 1987; Trifunac, 1991; Todorovska and Trifunac, 1996, 1999).

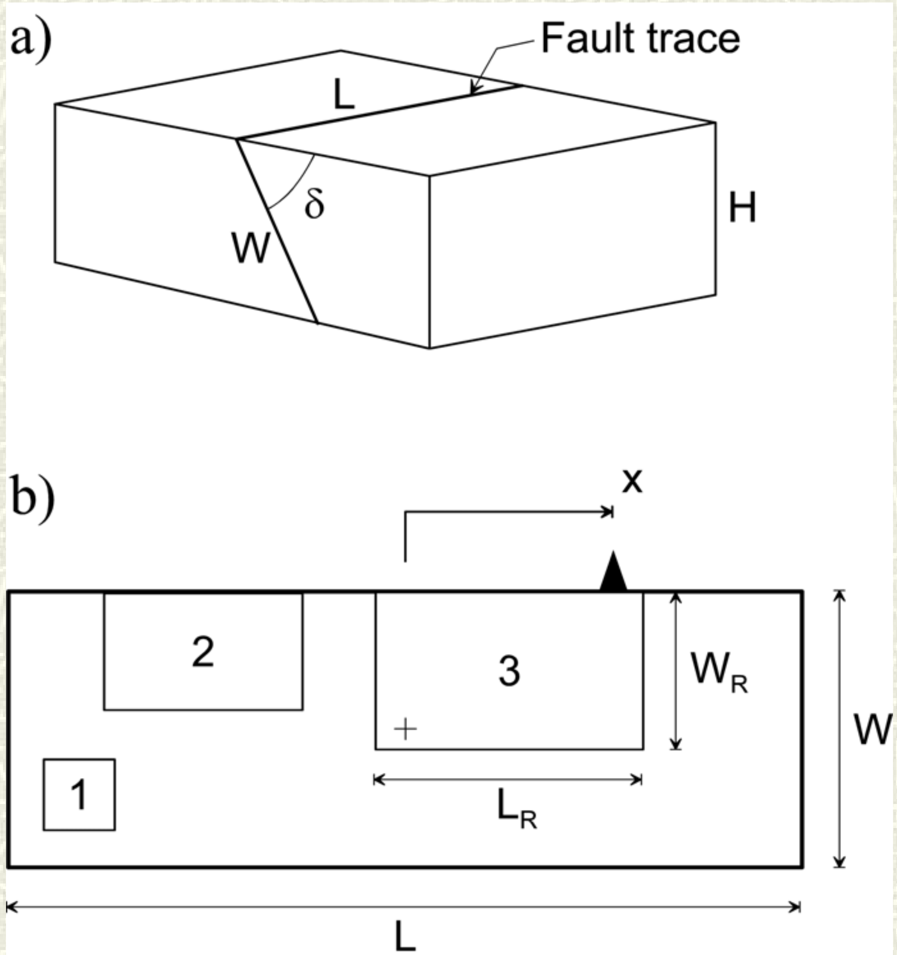
Outline

- General methodology.
  - Considers only earthquakes on the main fault, which are the main cause for the dislocation across the fault (principal faulting in Youngs et al.).
  - Simpler than PSHA for ground shaking – involves only one fault.
- Results for two hypothetical faults, Class A and B
  - Class A: the most active faults, with average slip rate > 5 mm/year (like the San Andreas Flt).
  - Class B: all other faults (like the Palos Verdes Flt crossed by the Vincent Thomas Bridge).

Motivation

- Vincent Thomas Bridge, crosses the Palos Verdes Fault in Los Angeles Area
- San Diego–Coronado Bay Bridge , Rose Canyon Fault Zone
- Bart Tunnel, and Clermont Water Tunnel, both crossing the Hayward Fault in northern California

Model



Methodology

- *D* - random variable representing, for an earthquake that *has ruptured* the ground surface, the absolute value of the displacement across the rupture at the ground surface
- D_{site} - displacement *at the site*, which may or may not have been affected by the earthquake

$$p(d,t) = P\left\{ D_{\text{site}} > d \,\middle|\, t \right\}$$

Methodology

- Assumption: Earthquakes occurrence is a Poissonian or a generalized Poissonian process.
- Then $\left\{ D_{\text{site}} > d \,\middle|\, t \right\}$ is Selective Poissonian process
- Expected number of exceedances

$$m(d,t) = \sum_{i=1}^{L} q_i(d) n_i(t)$$

$n_i(t) =$ expected number of earthquakes

of magnitude M_i during exposure t,

we get it from the adopted Gutenberg-Richter law

for the fault

$q_i(d)$ = prorating factor, a conditional probability.

Methodology

- Conditional probability

$$q_i(d) \triangleq P\left\{D_{\text{site}} > d \,\middle|\, \text{event } M = M_i \text{ has occurred}\right\}$$

$$= P\left\{D > d \,\middle|\, \text{event } M = M_i \text{ occurred}\right\} \times$$

$$P\left\{\begin{matrix}\text{rupture breaks} \\ \text{ground surface}\end{matrix}\right\} \times P\left\{\begin{matrix}\text{rupture extends} \\ \text{horizontally to the site}\end{matrix}\right\}$$

Methodology

- Finally:

$$p\left(d,t\right) = \text{Probab. of exceedance during exposure } t$$

$$= 1 - e^{-m(t)}$$

$$\frac{m(d,t)}{t} = \text{ average occurrence rate of the exceedance}$$

$$T(d) = \frac{t}{m(d,t)} = \text{ aver. return period of the exceedance}$$

Probability that rupture breaks the surface for a generic model

$$P\left\{\begin{matrix}\text{rupture breaks}\\\text{ground surface}\end{matrix}\right\} = \min\left(1, \frac{W_R(M)}{W}\right)$$

$$\equiv r_W(W, W_R)$$

W = fault width

W_R = rupture width

Probability that rupture extends to the site for a generic model

$$P\left\{\begin{array}{l}\text{rupture}\\ \text{extends}\\ \text{horizontally}\\ \text{to the site}\end{array}\right\} = \begin{cases} 1, & L_R(M) \geq L \\ \min\left(1, \dfrac{L_R(M)}{L - L_R(M)}\right), & L_R(M) < L, \quad |x| \leq \dfrac{L}{2} - L_R(M) \\ \min\left(1, \dfrac{\frac{L}{2} - |x|}{L - L_R(M)}\right), & L_R(M) < L, \quad |x| > \dfrac{L}{2} - L_R(M) \end{cases}$$

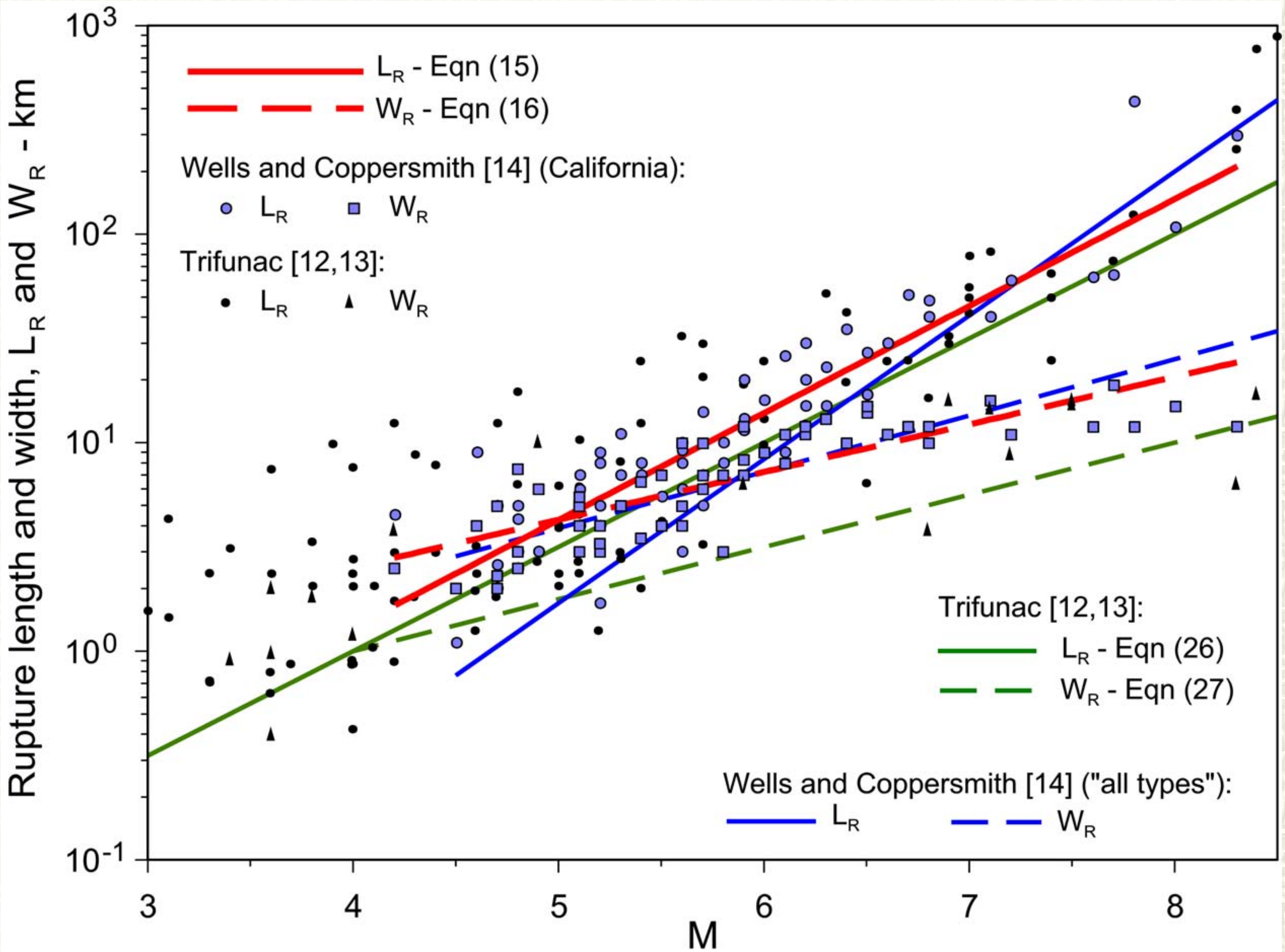
$$\equiv r_L(L, L_R, x)$$

$L =$ fault length

$L_R =$ rupture length

$x =$ distance of the site from the center of the fault

Rupture length and width, L_R and W_R



Rupture length and width

We use our fit through a subset of the data in Wells and Coppersmith, 1994, for California earthquakes:

$$\log_{10} L_R(M) = 0.5113\,M - 1.9341$$

$$\log_{10} W_R(M) = 0.2292\,M - 0.5128$$

If we want to consider the uncertainty in in rupture length and width estimates

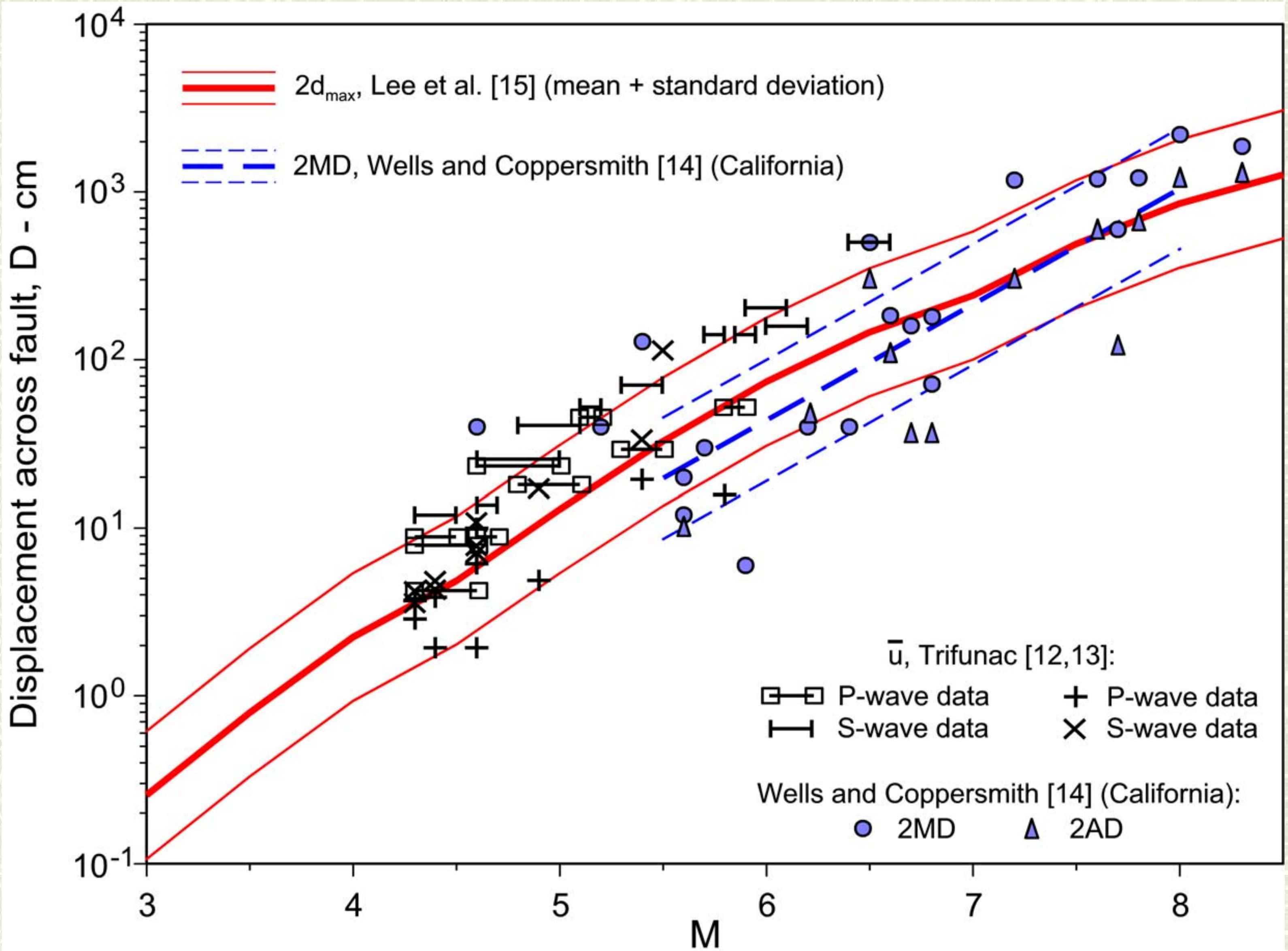
$$P\left\{\begin{matrix}\text{rupture breaks}\\ \text{ground surface}\end{matrix}\right\} = \int_0^\infty r_W\left(W, y\right) f_{W_R}\left(y\right) \mathrm{d}y$$

$$P\left\{\begin{matrix}\text{rupture extends}\\ \text{horizontally to the site}\end{matrix}\right\} = \int_0^\infty r_L\left(W, y\right) f_{L_R}\left(y\right) \mathrm{d}y$$

$f_{L_R}\left(y\right)$ = Prob. density function for L_R

$f_{W_R}\left(y\right)$ = Prob. density function for W_R

Displacement across fault, D



Displacement across fault at surface

- Lee et al. (1995) with $D = 2\,d_{\max}$
- Mag + site + soil + % rock path model

$$\log_{10} d_{\max} = M - 2.2470\log_{10}(\Delta/L_R) + 0.6489M$$
$$+0.0518s - 0.3407v - 2.9850$$
$$-0.1369M^2 + (-0.0306S_L^1 + 0.2302S_L^2 + 0.5792S_L^3)$$
$$+[-0.3898r - 0.2749(1-r)]R/100$$

$$\Delta = S\left(\ln\frac{R^2 + H_R{}^2 + S^2}{R^2 + H_R{}^2 + S_0^2}\right)^{-1/2}$$ =representative source to station distance

$H_R =$ focal depth

$S =$ source dimension

$S_0 =$ source coherence radius

Displacement across fault at surface

- D is lognormal:

$$\mu = M - 2.2470\log_{10}\left[\Delta\left(M, R=0, H_R = 0.5\, W_R \sin\delta, S, S_0\right)/L_R\right]$$

$$+0.6489M + 0.0518*2 - 0.3407v - 2.9850 - 0.1369M^2$$

$$-0.0306 + \log_{10} 2 - 0.0090$$

$$\sigma = 0.3975$$

$$P\left\{D > d \,\middle|\, \begin{array}{l}\text{event } M = M_l \text{ occurred} \\ \text{and ruptured the surface}\end{array}\right\}$$

$$= \frac{1}{\sqrt{2\pi}\sigma}\int_{-\infty}^{\log d} \exp\left\{-\frac{1}{2}\left[\frac{(\log x - \mu)}{\sigma}\right]^2\right\} \mathrm{d}x$$

Results for two hypothetical faults (vertical)

- Fault I (Class B)
- 2/3 and 1/3 partitioning of seismic moment between characteristic and Gutenberg-Richter events

$L = 100$ km; $W = 13$ km

$\dot{M}_0 = 38 \times 10^{22}$ dyn × cm/yr

b=0.8

- Fault II (Class A)
- three variants of distribution of seismic moment

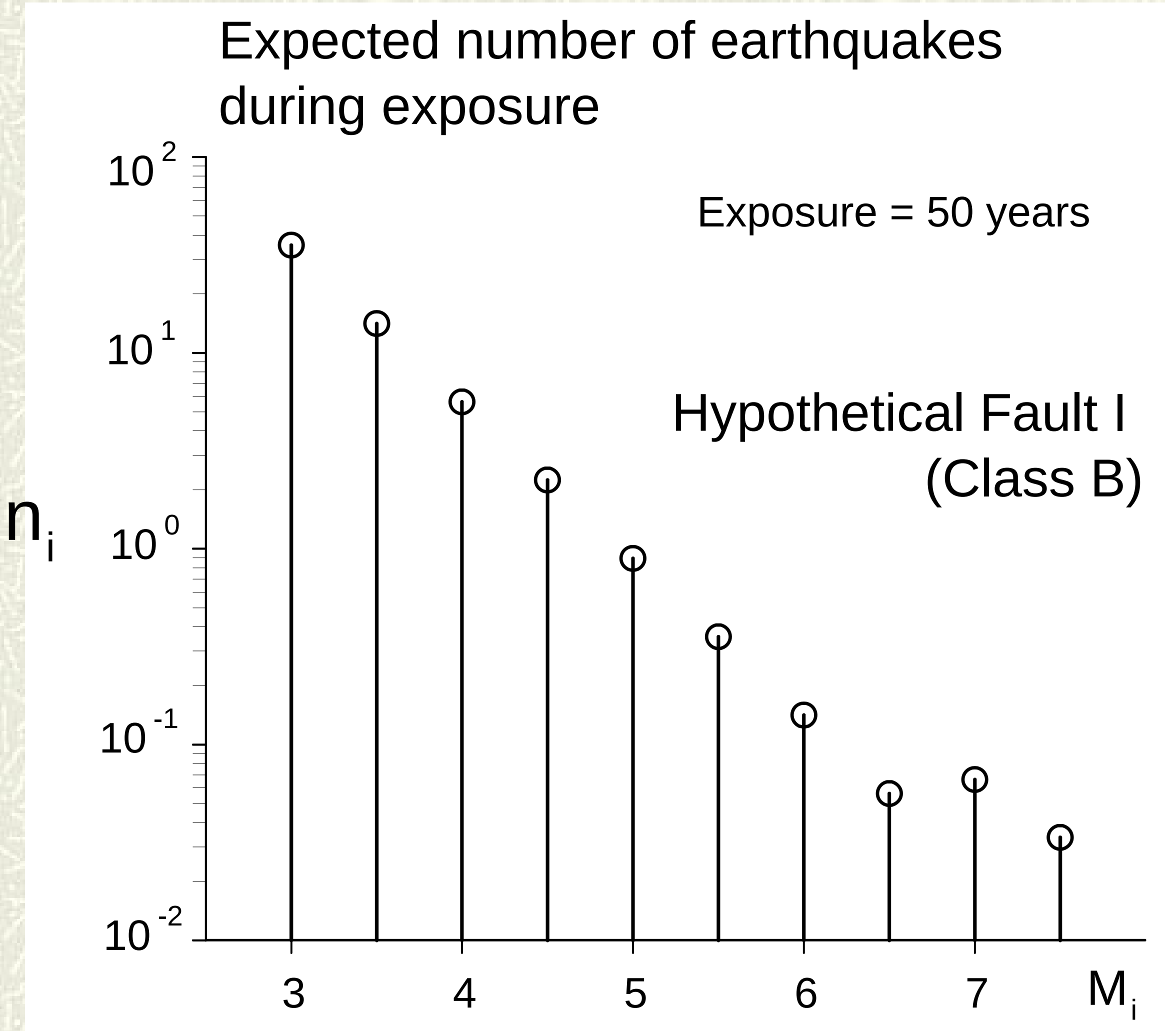
$L = 100$ km; $W = 18$ km

$\dot{M}_0(GR) = 4.45 \times 10^{24}$ dyn × cm/yr

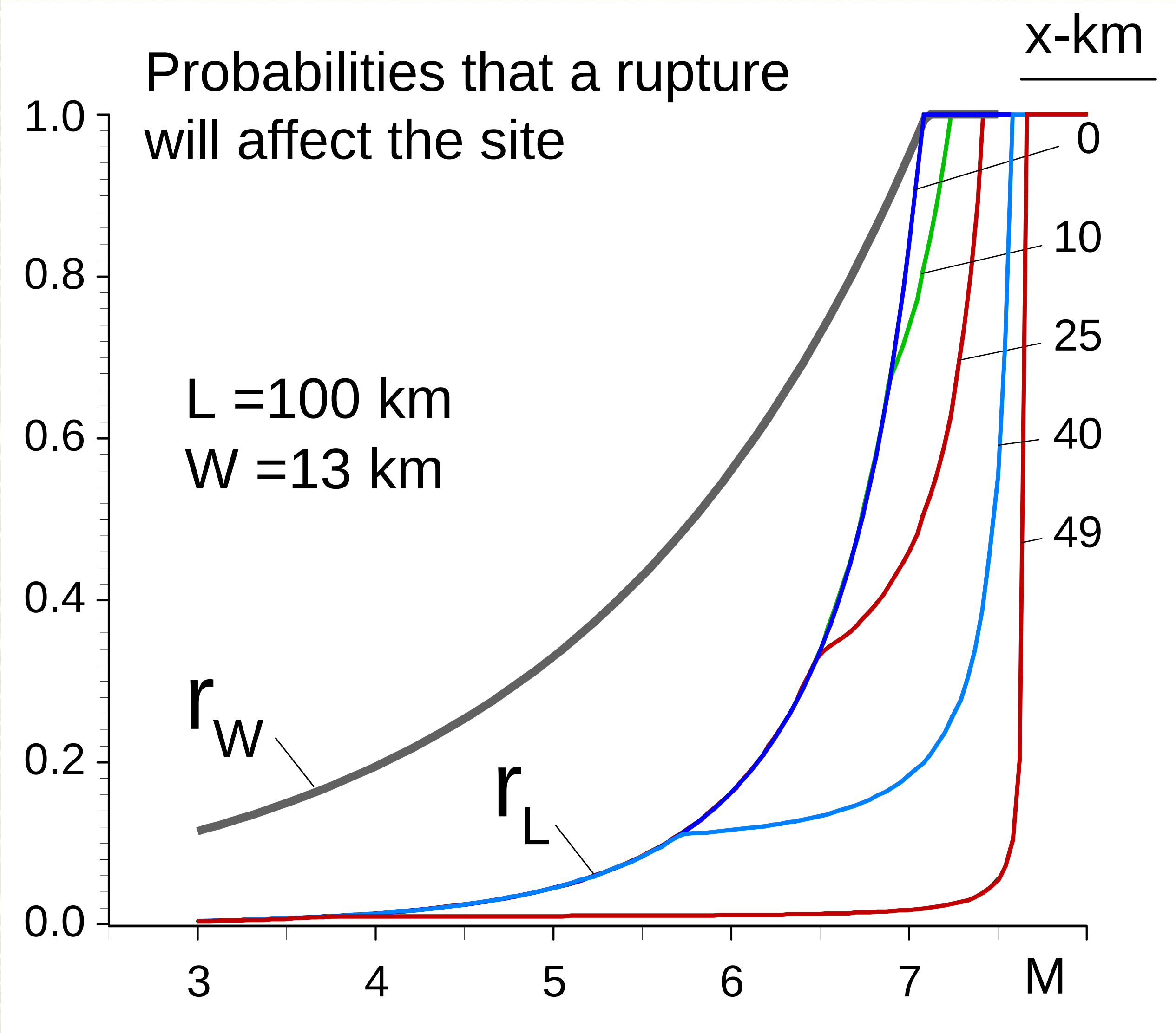
$\dot{M}_0(Char) = 8.9 \times 10^{24}$ dyn × cm/yr

t = Exposure = 50 yrs

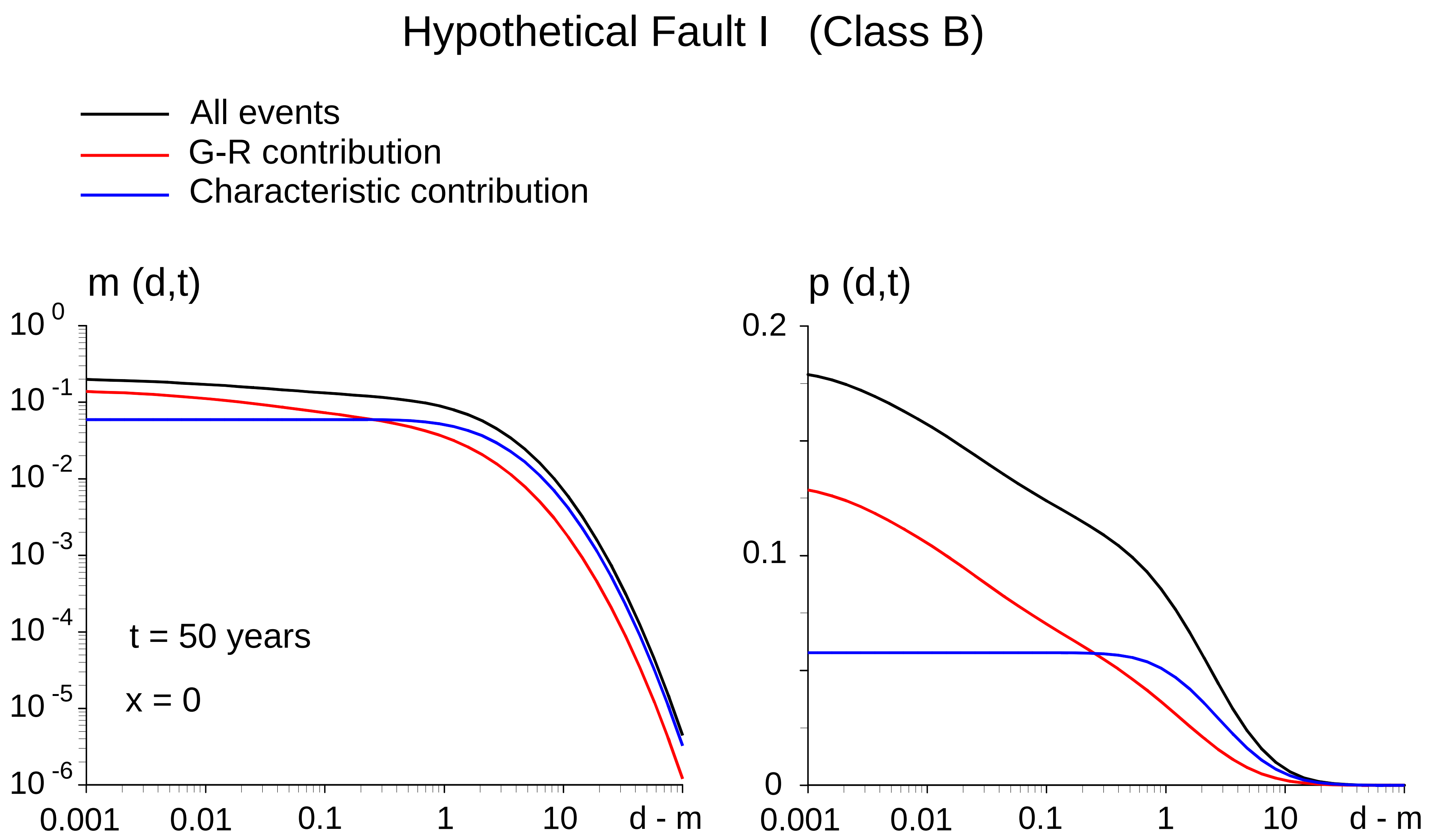
Fault I (Class B): earthquake rates



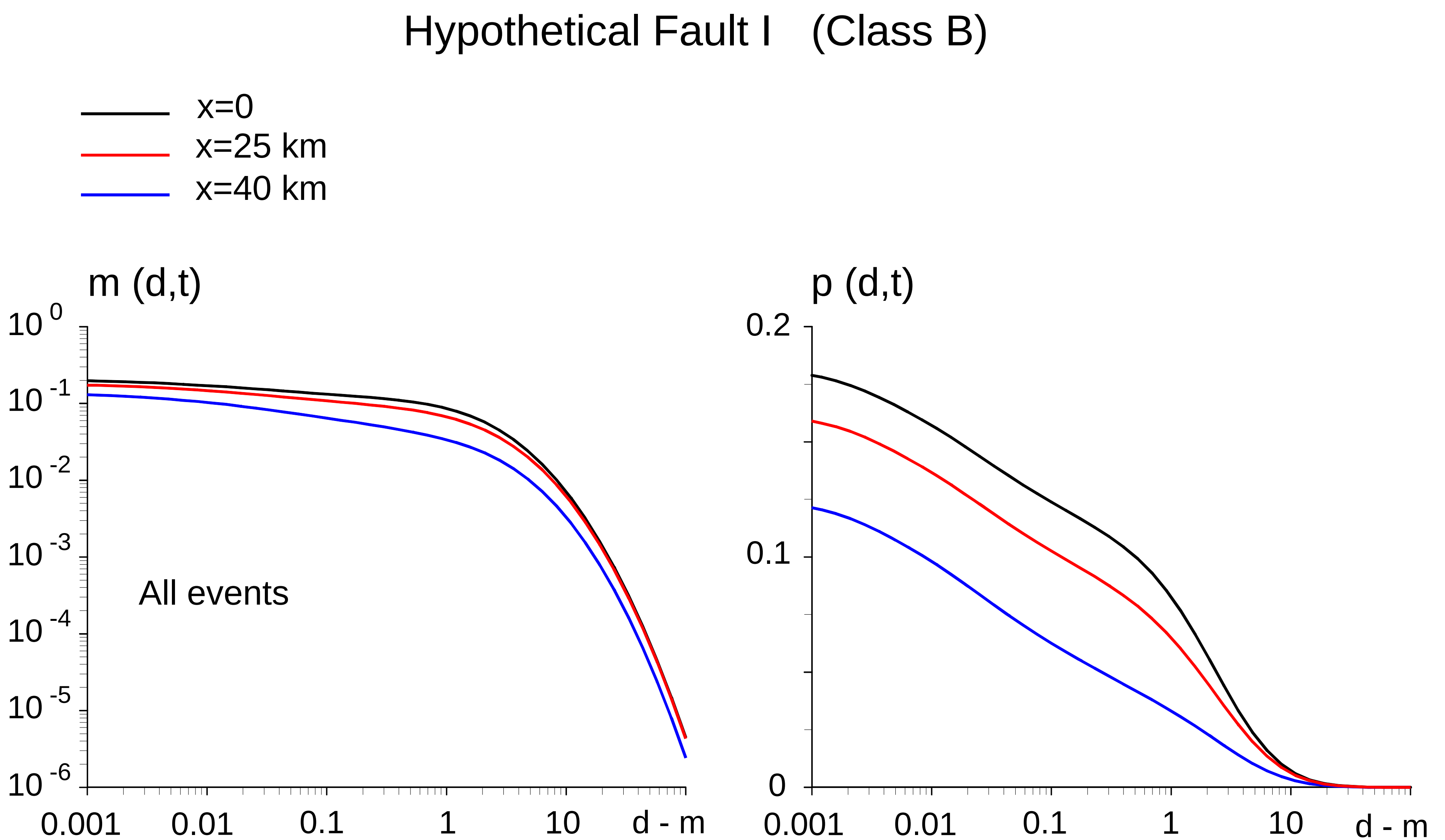
Fault I (Class B): *P*(site will be affected)



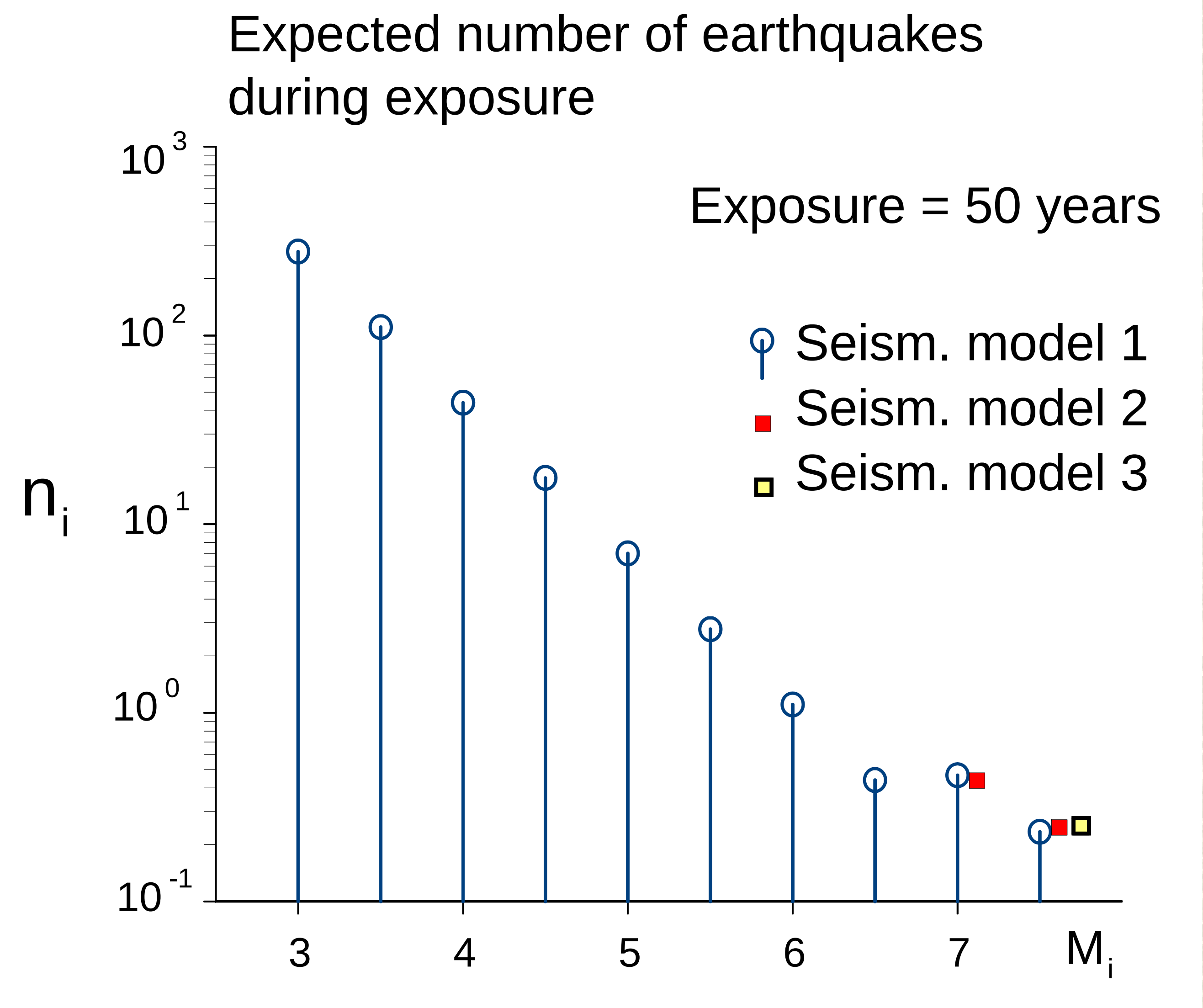
Fault I (Class B): Results



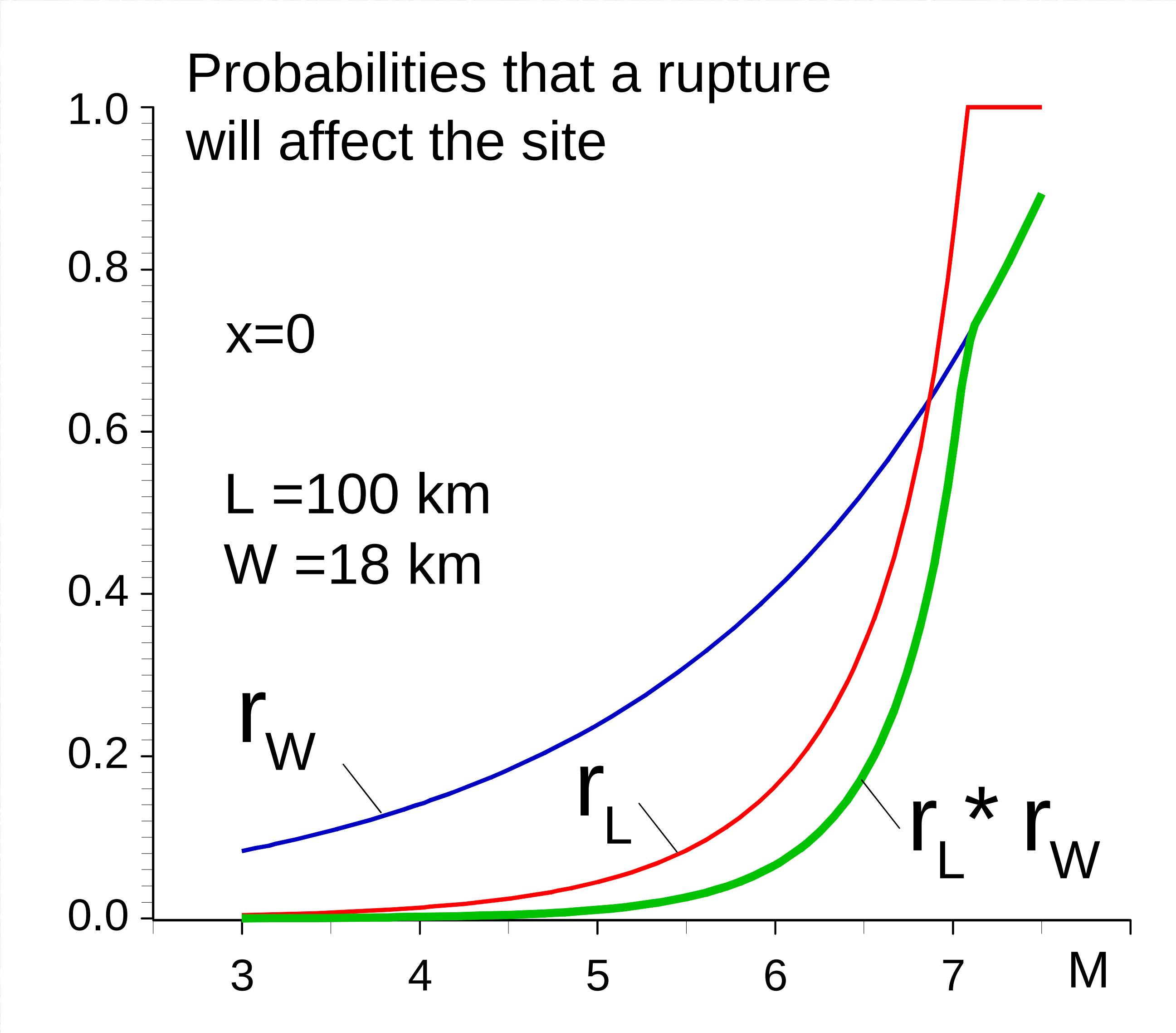
Fault I (Class B): Results (cont.)



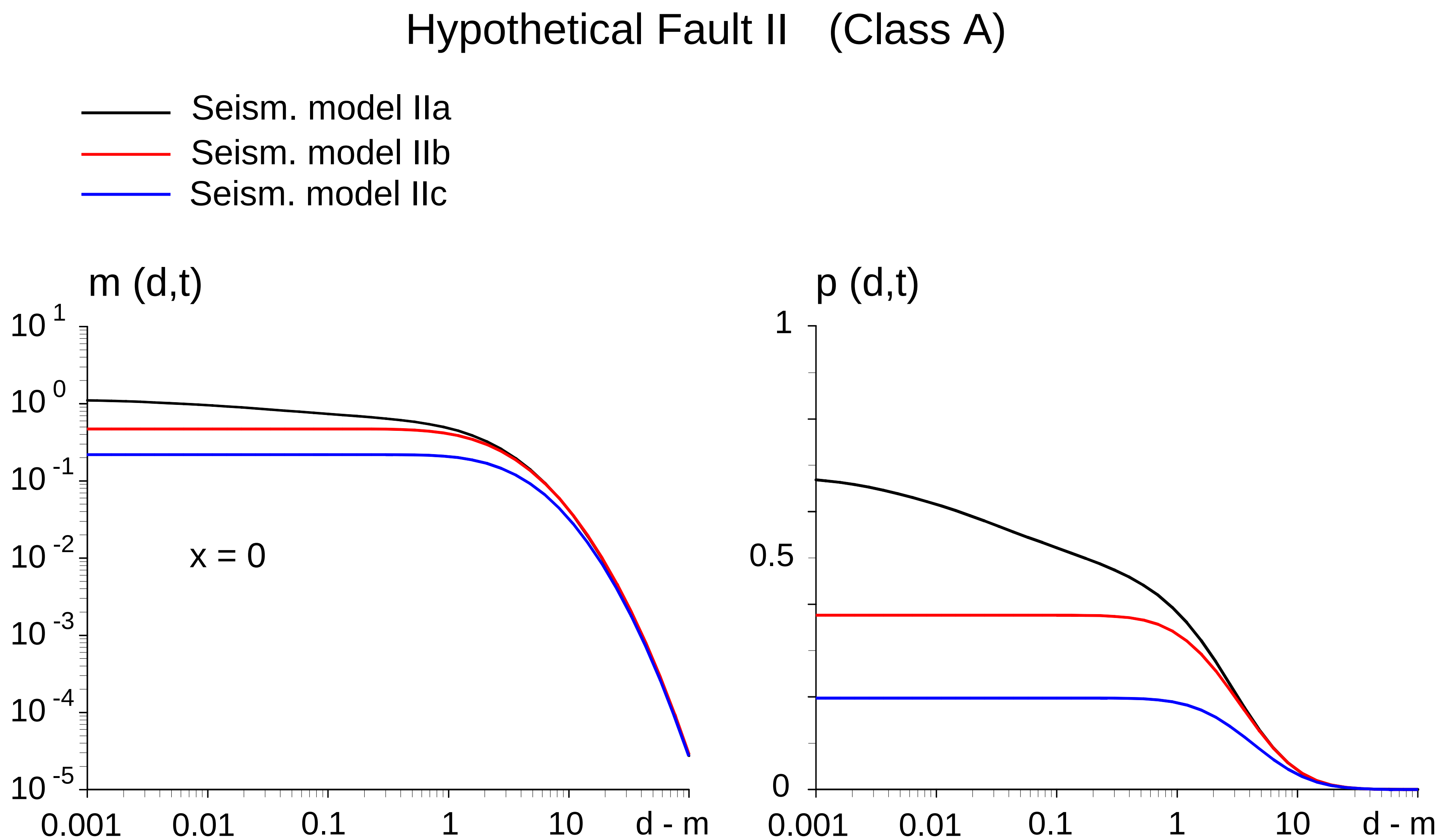
Fault II (Class A): earthquake rates



Fault II (Class A): *P*(site will be affected)



Fault II (Class A): Results



Conclusions

- Fault displacement hazard is generally small as *only one* fault contributes to the hazard, and *not every* earthquake affects the site.
- The results are quite sensitive to how the seismic moment is distributed over earthquake magnitudes.
- The hazard is the largest near the center of the fault.

Conclusions

- For a specific application, fault specific information should be used, to the extent possible, e.g. to define probabilities that rupture will break the ground surface and will affect the site, and for distribution of rupture along the fault.

References (principal)

- Todorovska M.I., M.D. Trifunac M.D., and V.W. Lee, 2006. Shaking hazard compatible methodology for probabilistic assessment of permanent ground displacement across earthquake faults, *Soil Dynam. and Earthqu. Eng*., accepted for publication.
- Lee V.W., M.D. Trifunac, M.I. Todorovska, and E.I. Novikova, 1995. Empirical equations describing attenuation of the peaks of strong ground motion, in terms of magnitude, distance, path effects and site conditions, Dept. Civil Eng. Report No. 95-02, Univ. Southern California, Los Angeles, California.
- Wells D.L., and K.J. Coppersmith, 1994. New empirical relationships among magnitude, rupture length, rupture width, rupture area, and surface displacement, *Bull. Seism. Soc. Am*. 84(4), 974-1002.