REPUBLIC OF SLOVENIA

STABILITY PACT FOR
SE EUROPE
Disaster Preparedness and Prevention Initiative - DPPI

MINISTRY OF DEFENCE
Administration for Civil Protection and Disaster Relief

MINISTRY FOR ENVIRONMENT AND SPATIAL PLANNING
Environmental Agency of the Republic of Slovenia
Seismology and Geology Office

NATO North Atlantic Treaty Organization
SCIENCE FOR PEACE AND SECURITY PROGRAMME
Public Diplomacy Division

FIRST WORKSHOP

FOR THE NATO SCIENCE FOR PEACE PROJECT NO. 983054

"HARMONIZATION OF SEISMIC HAZARD MAPS FOR THE WESTERN BALKAN COUNTRIES"

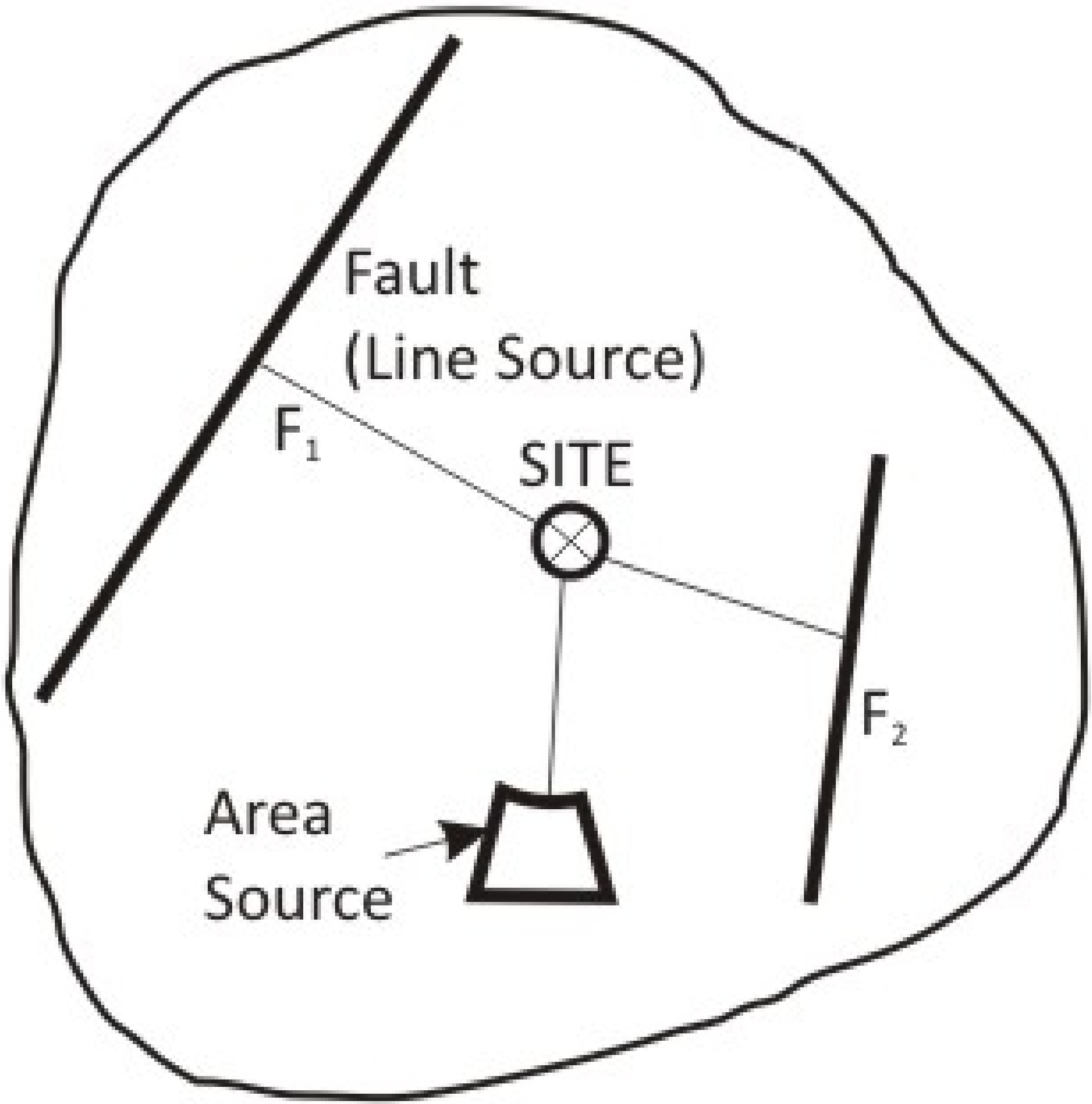
Ig near Ljubljana, Slovenia

7 – 9 November 2007

Basis of Cornell PSHA Approach

Zoran Milutinović, RDM/IZIIS

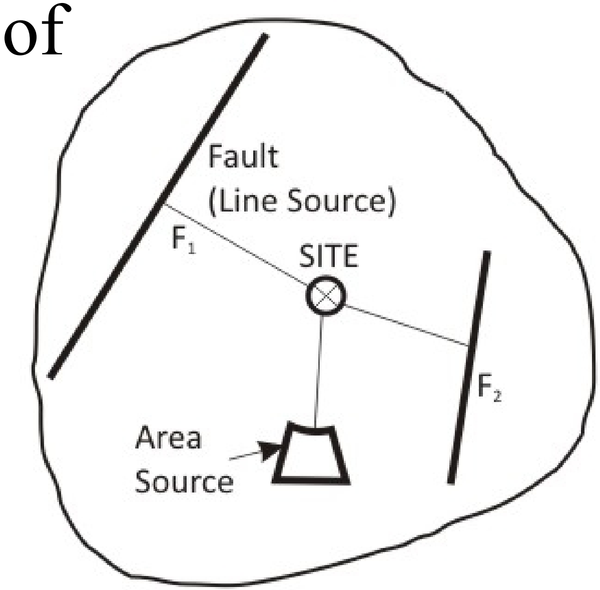
This project is supported by: The NATO Science for Peace and Security Programme


Fault
(Line Source)
F1
SITE
F2
Area
Source

$$p_E(z) = 1 - e^{(\nu_z \bullet t)}$$

ν_z = annual frequency of ground motion exceedance

$p_E(z)$ = probability of exceedance of a ground motion level z



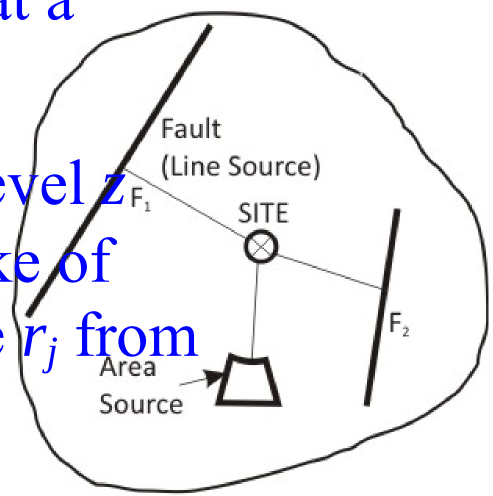
$$\nu_z = \sum_N \left[\sum_M \lambda(m_i) \bullet \sum_R P(R = r_j \mid m_i) \bullet P(Z > z \mid m_i r_j) \right]_n$$

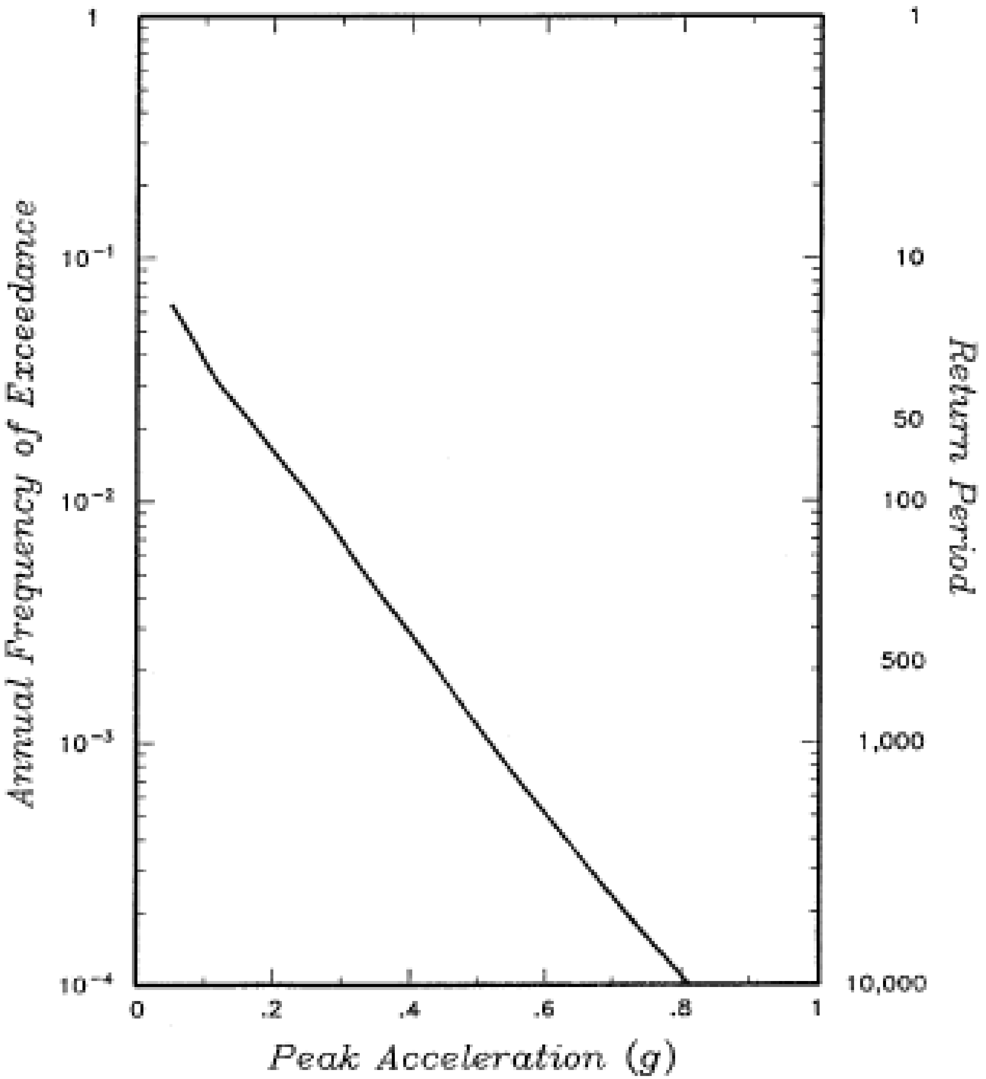
$\sum_N$ = summation over all (N) seismic sources

$\lambda(m_i)$ = the annual frequency of occurrence of earthquakes of magnitude m (above a certain minimum size of engineering significance) on seismic source n

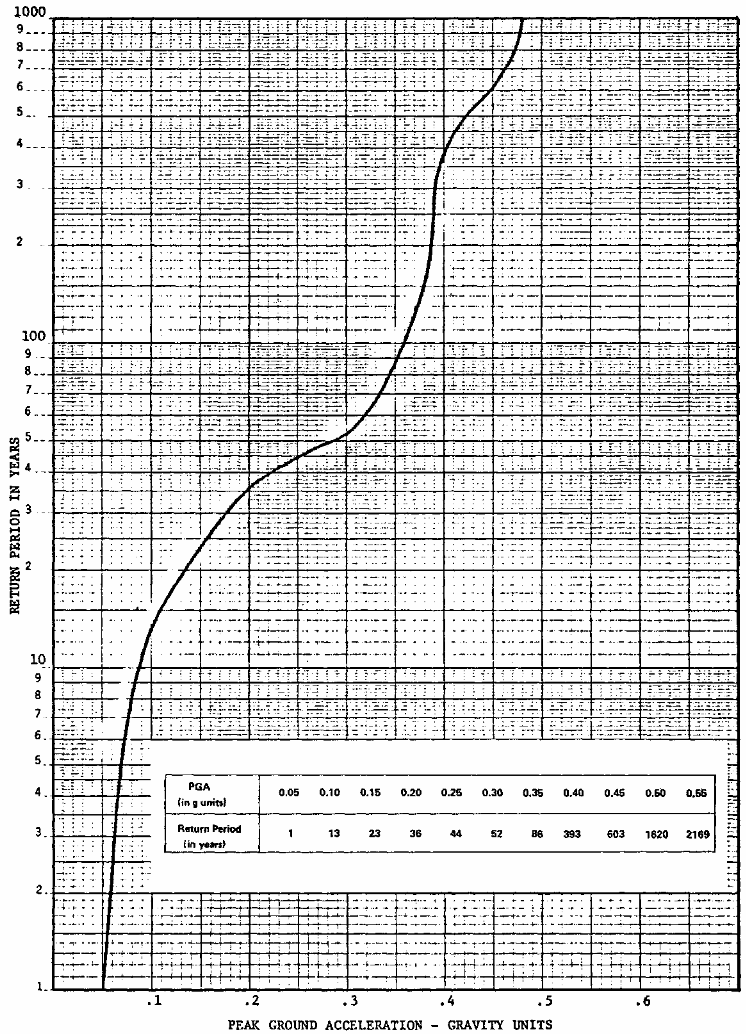
$P(R = r_j \mid m_i)$ = the probability of an earthquake of magnitude m on source n occurring at a certain distance r_j from the site

$P(Z > z \mid m_i, r_j)$ = the probability that ground motion level z will be exceeded, given an earthquake of magnitude m_i on source n at distance r_j from the site





Example seismic hazard curve showing relationship between peak ground acceleration and probability (annual frequency) of exceedance



PGA (in g units)	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55
Return Period (in years)	1	13	23	36	44	52	86	393	603	1620	2169

Acceleration Zone Graph

PSHA Flow

Source Characterization

- *Model of the source geometry*
  - Areal (Gridded seismicity)
  - Fault Sources

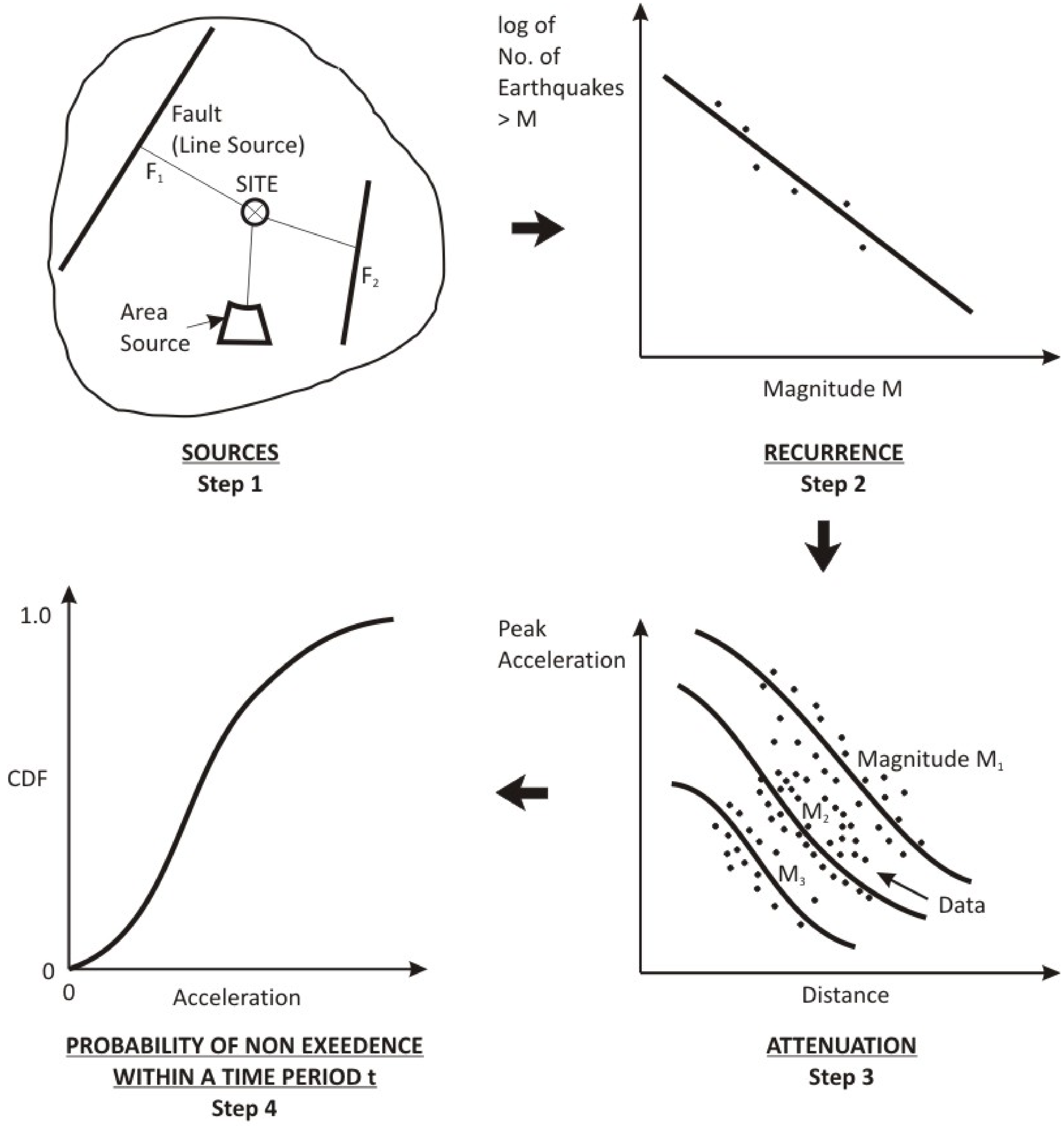
- *Model of the occurrence of earthquakes on the source*
  - the maximum magnitude
  - the distribution of earthquake magnitudes (Recurrence Relations)
  - the distribution of rupture dimensions for each earthquake magnitude
  - the distribution of locations of the earthquakes for each rupture dimension
  - the rate at which earthquakes occur on the source

Propagation Path Characterization

Model Earthquakes Occurrence

- (*Poisson process)*

Flowchart of Current Approaches to Assessment of Seismic Hazard



Earthquake potential of a fault of a given length

Wells and Coppersmith (1994), BSSA Vol. 84, No. 4 (pp 974-1002)

$$M_W = a + b\log(SRL)$$

SRL = surface rupture length (km)

Fault type	*a*	*b*
Strike slip (SS)	5.16	1.12
Normal (N)	4.86	1.32
Reverse (R)	5.00	1.22
All	5.08	1.16

Wells and Coppersmith developed also the following equations:

Mw = f(a, b, MD);	MD = f(a, b, Mw)
Mw = f(a, b, AD);	AD = f(a, b, Mw)
Mw = f(a, b, RLD);	RLD = f(a, b, Mw)
Mw = f(a, b, RW);	RW = f(a, b, Mw)
Mw = f(a, b, RA);	RA = f(a, b, Mw)

MD = maximum displacement (m)
AD = average displacement (m)
RLD = subsurface rupture length (km)
RW = downdip rupture width (km)
RA = rupture area (km^2)

Linear Magnitude-Frequency Relationship

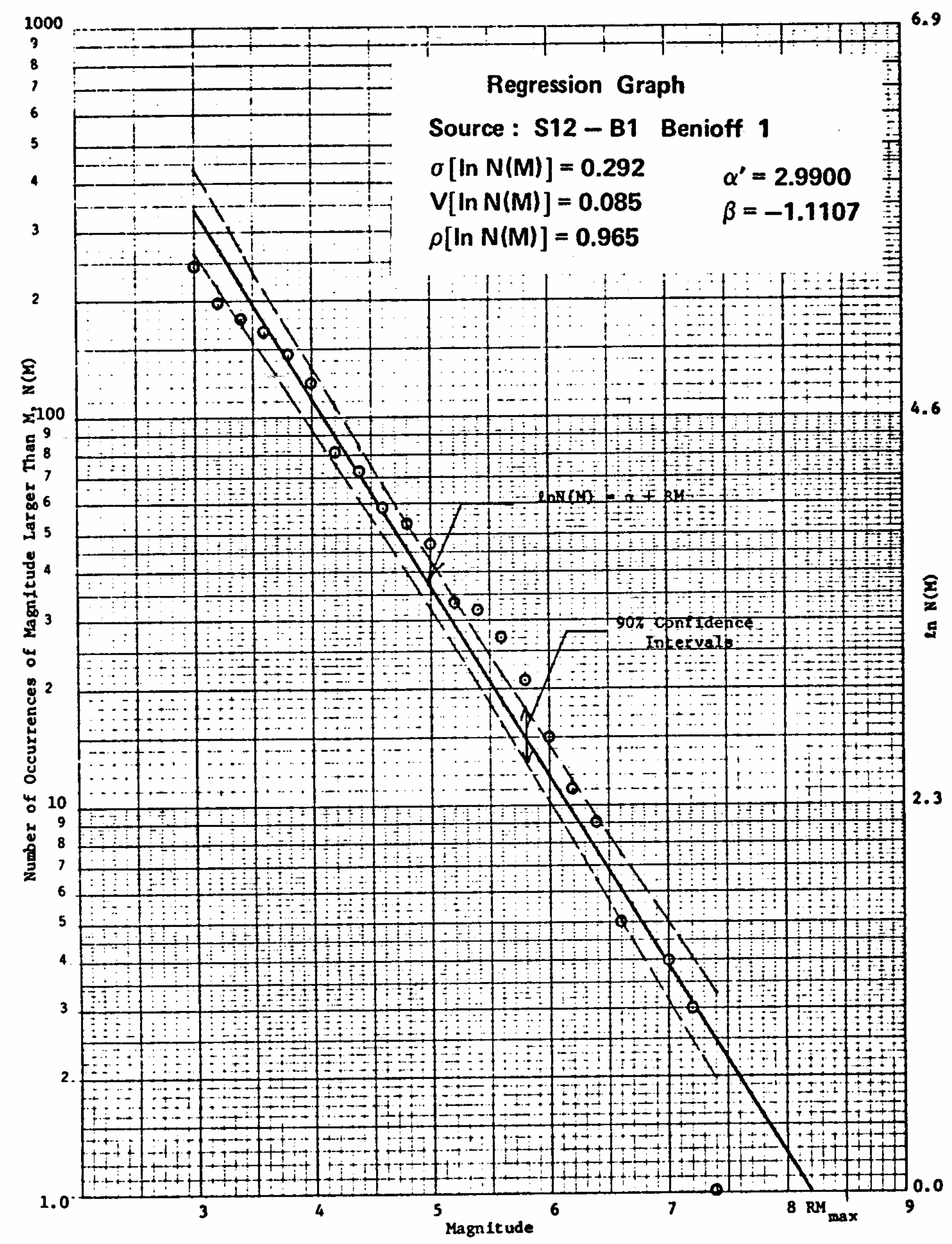
$$\ln N(M) = \begin{cases} \alpha & M < m_0 \\ \alpha - \beta(M - m_0) & m_0 \le M \le m_1 \\ 0 & M > m_1 \end{cases}$$

$$\ln N(M) = \alpha + \beta M$$

Disdvantages:

- Influence of large number of small magnitude events
- Overestimation of occurrence of large-magnitude events

Linear Magnitude-Frequency Relationship



Bi-linear Magnitude-Frequency Relationship

Shah et al., 1975; Rundle and Jackson, 1977; Kiremidjian et al., 1977

$$
\ln N(M) = \begin{cases} \alpha_1 & M < m_0 \\ \alpha_1 - \beta_1 (M - m_0) & m_0 \le M \le m_1 \\ \alpha_2 - \beta_2 (M - m_1) & m_1 \le M \le m_2 \\ 0 & M > m_1 \end{cases}
$$

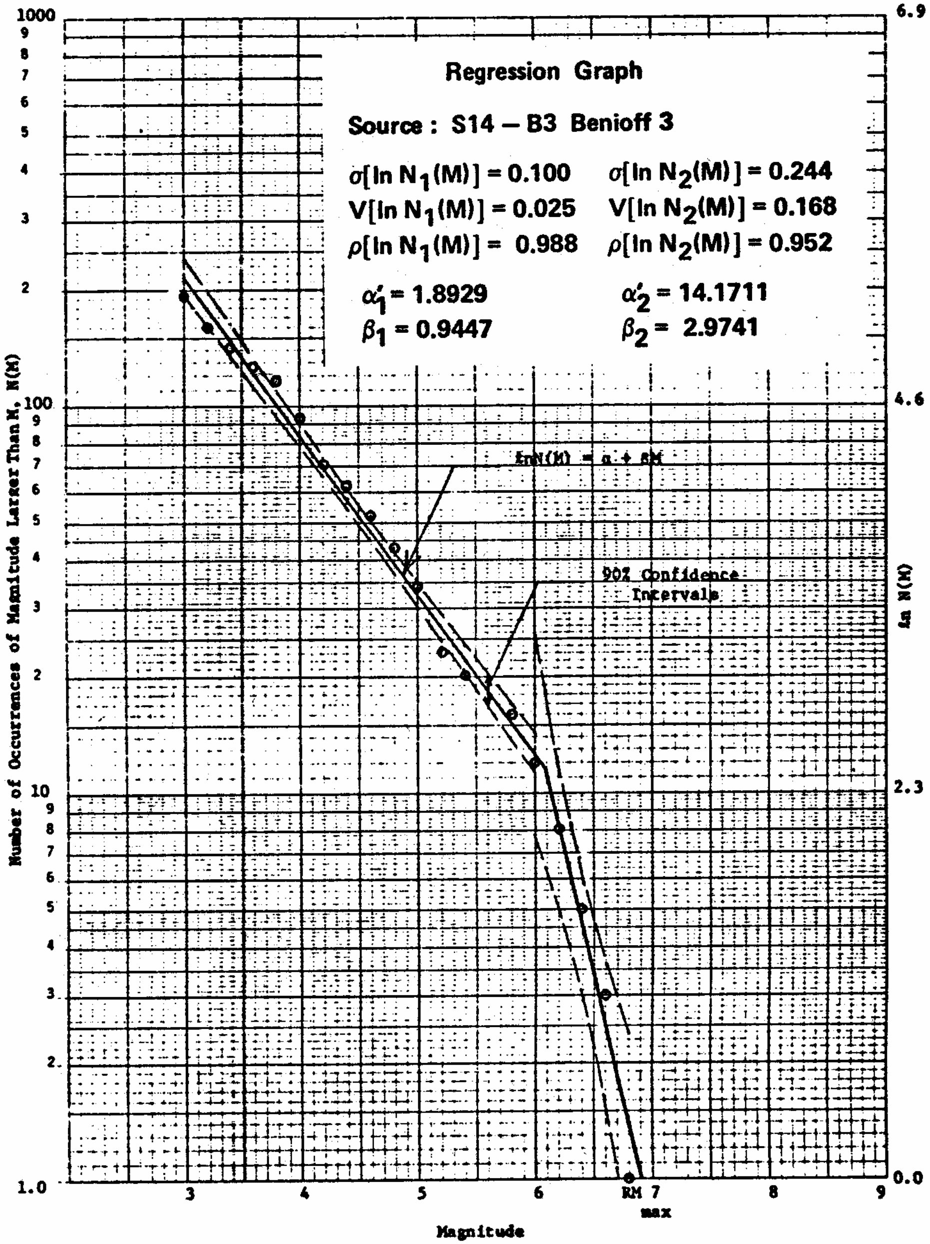
Advantages:

- Diminish the effect of large number of small magnitude events
- Decrease overestimation of occurrence of large-magnitude events

Disadvantage:

- Discontinuity at knee point m_1

Bi-inear Magnitude-Frequency Relationship



Quadratic Magnitude-Frequency Relationship

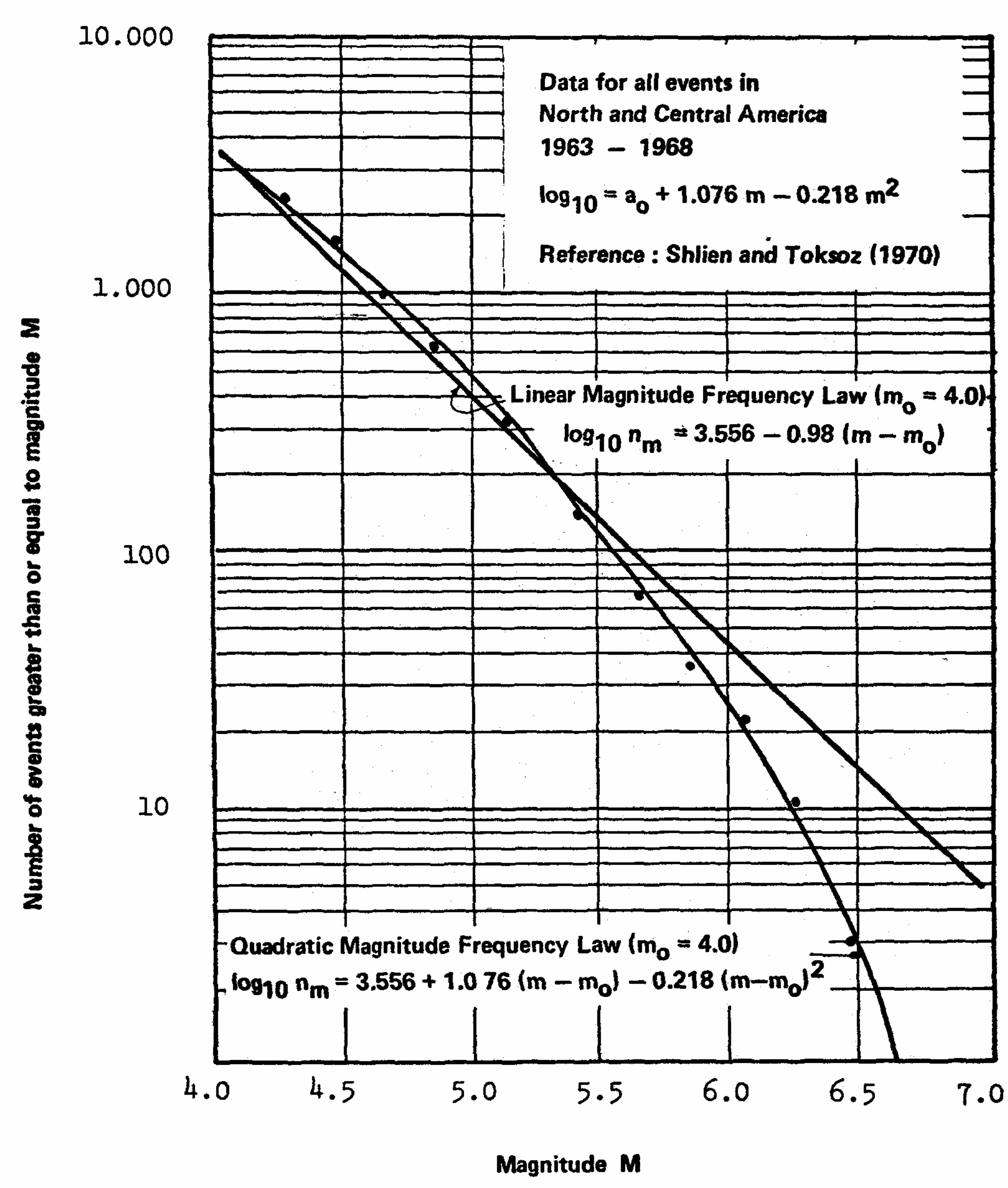
Merz & Cornell, 1973

$$\log_{10} N(M) = \begin{cases} \alpha & M < m_0 \\ \alpha + \beta_1 (M - m_0) + \beta_2 (M - m_0)^2 & m_0 \le M \le m_1 \\ 0 & M > m_1 \end{cases}$$

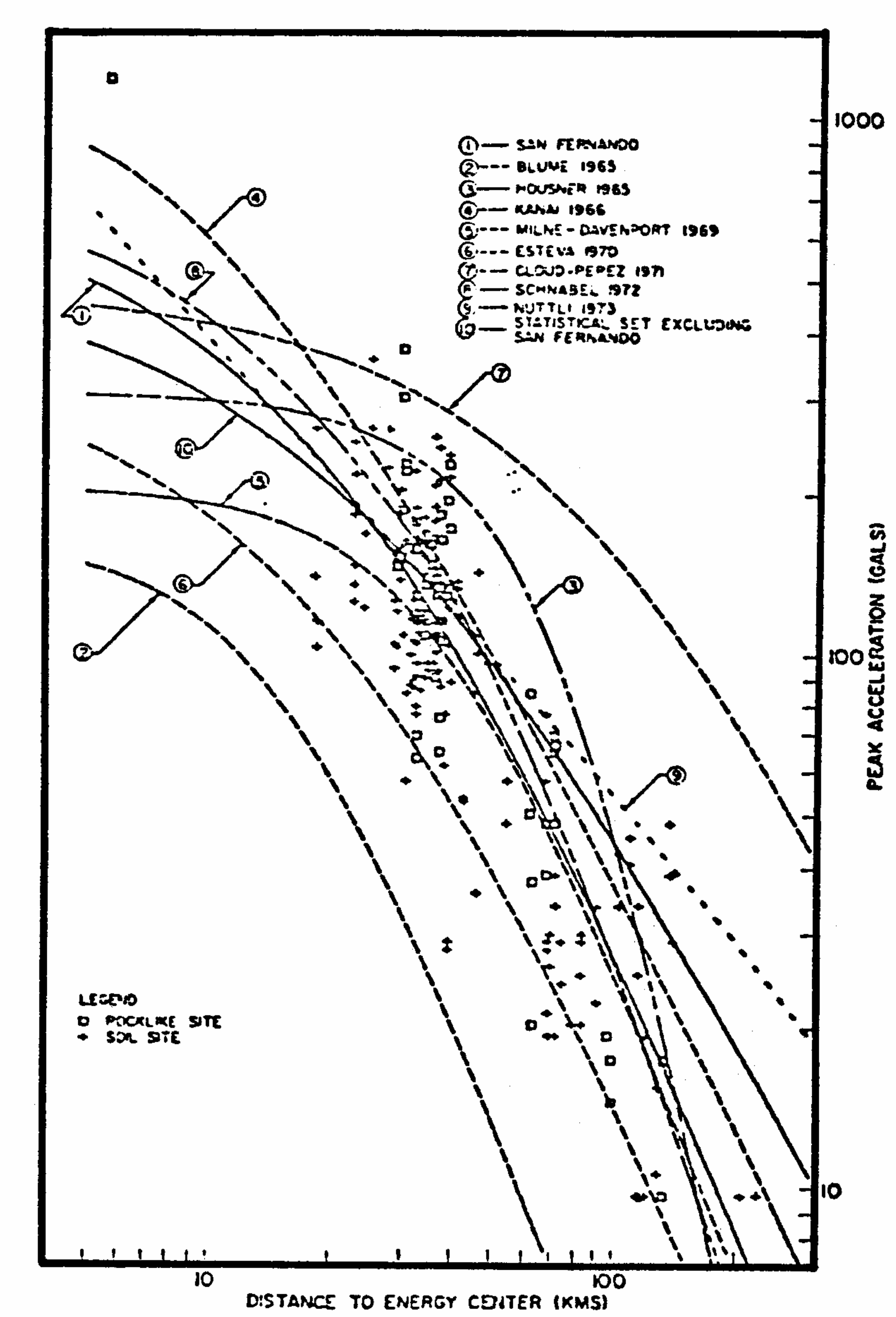
Advantages:

- Avoids overestimation of occurance of large-magnitude events (Linear & Bi-linear MFLs)
- Smooth the discontinuity at knee point m_1 (Bi-linear MFL)
- Avoids sharp discontinuities associated with truncation of upper bounds m_1 and m_2 for Linear and Bi-linear MFLs

Quadratic Magnitude-Frequency Relationship



Attenuation Relationship



NGA Ground Motion Relations (2007) for the Geometric Mean Horizontal Component of Peak and Spectral Ground Motion Parameters

- Abrahamson & Silva (July 9, 2007)
- Boore & Atkinson (May 2007)
- ***Campbell & Bozorgnia (May 2007)***
- Chiou & Youngs (June 14, 2006)
- Idriss (January 19, 2007)

EMPIRICAL GROUND MOTION MODEL (EGMM)
Kenneth W. CAMPBELL &Yousef BOZORGNIA

The general functional form

$$\ln Y = f_1(\mathrm{M}) + f_2(\mathrm{R}) + f_3(\mathrm{F}) + f_4(\mathrm{HW}) + f_5(\mathrm{S}) + f_6(\mathrm{D}) + \varepsilon_T$$

f1 - The dependence on magnitude
f2 - The dependence on source-to-site distance
f3 - The dependence on style of faulting
f4 - The dependence on hanging-wall effects
f5 - The dependence on shallow site conditions (both linear and nonlinear)
f6 - The dependence on sediment depth (both shallow and 3-D basin effects)

Ambraseys at al. EGMM (2005)

$$\log Y = a_1 + a_2 M_W + (a_3 + a_4 M_W)\log\left(\sqrt{d^2 + a_5^2}\right) +$$

$$+ a_6 S_S + a_7 S_A + a_8 F_N + a_9 F_T + a_{10} F_O$$

M_W = Moment magnitude

d = Joyner-Boore distance (km)

S_S = 1 for soft soil sites and 0 otherwise

S_A = 1 for stiff soil sites and 0 otherwise

F_N = 1 for normal-faulting earthquakes and 0 otherwise

F_T = 1 for thrust-faulting (i.e., reverse-faulting) earthquakes and 0 otherwise

F_O = 1 for odd-faulting earthquakes and 0 otherwise

Ambraseys, N.N., Douglas, J., Sarma, S.K. and Smit, P.M. (2005), Equations for the Estimation of Strong Ground Motions from Shallow Crustal Earthquakes Using Data from Europe and the Middle East: Horizontal Peak Ground Acceleration and Spectral Acceleration, Bulletin of Earthquake Engineering, 3, 1–53.

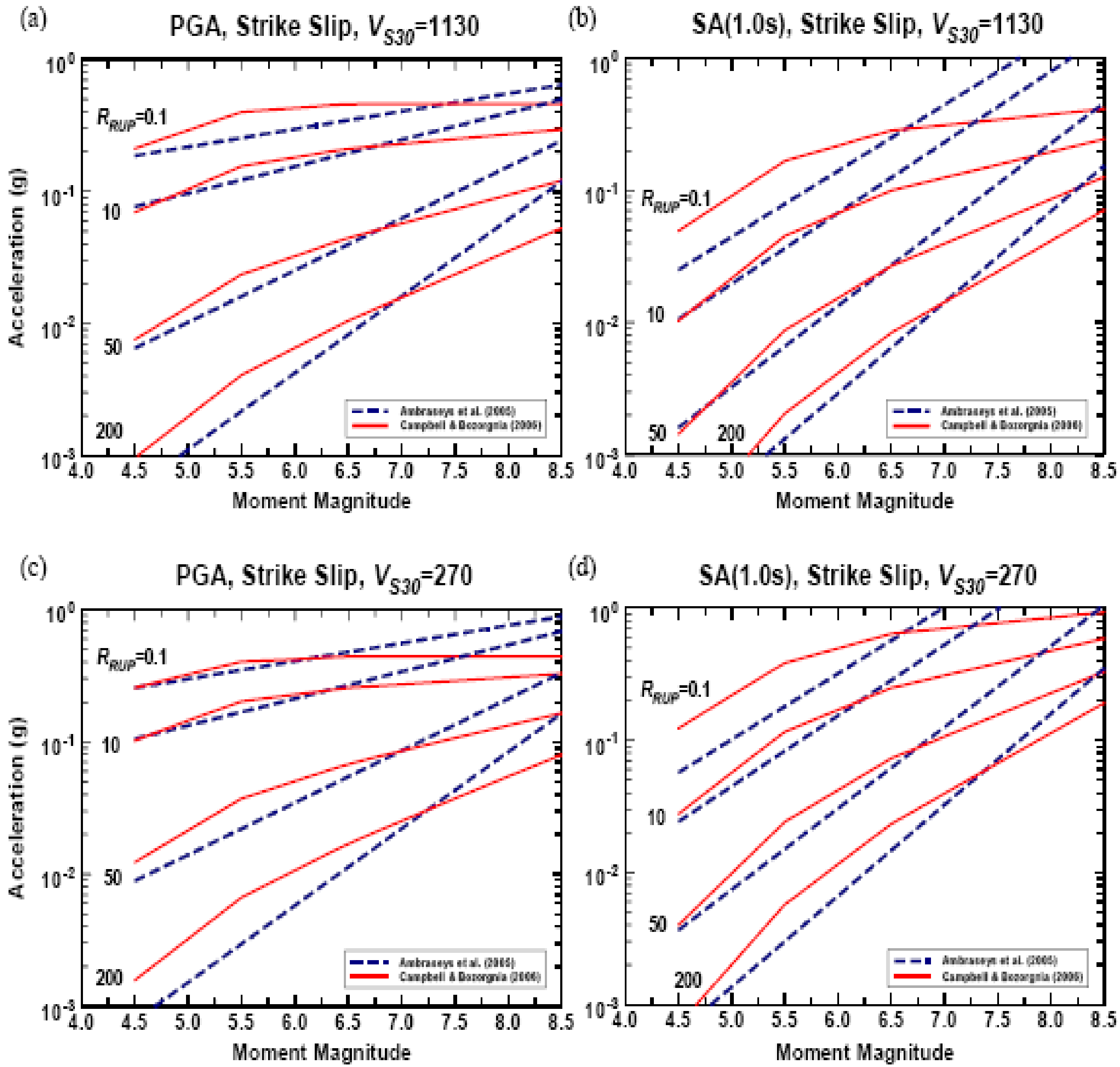


Figure 2: Comparison of magnitude-scaling characteristics predicted by the NGA and Ambraseys et al. (2005) empirical ground motion models: (a) PGA and NEHRP B site conditions, (b) SA(1.0s) and NEHRP B site conditions, (c) PGA and NEHRP D site conditions, (d) SA(1.0s) and NEHRP D site conditions.

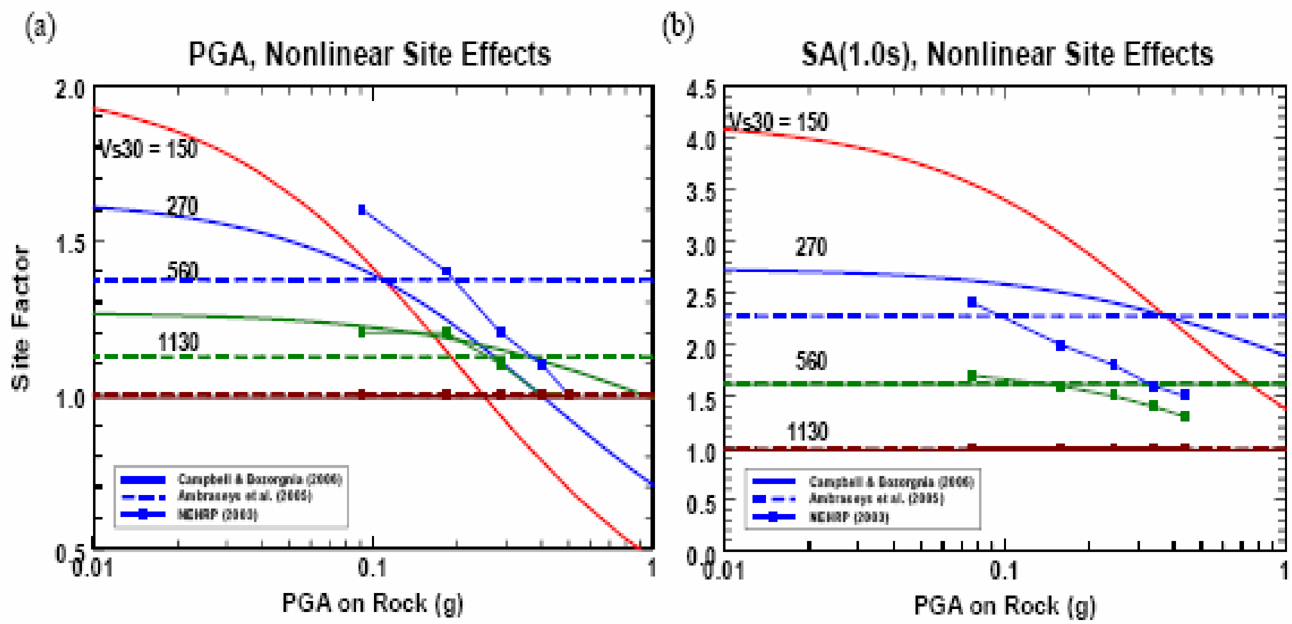


Figure 3: Comparison of site factors predicted by the NGA and Ambraseys et al. (2005) empirical ground motion models and by the NEHRP provisions: (a) PGA, (b) SA(1.0s).

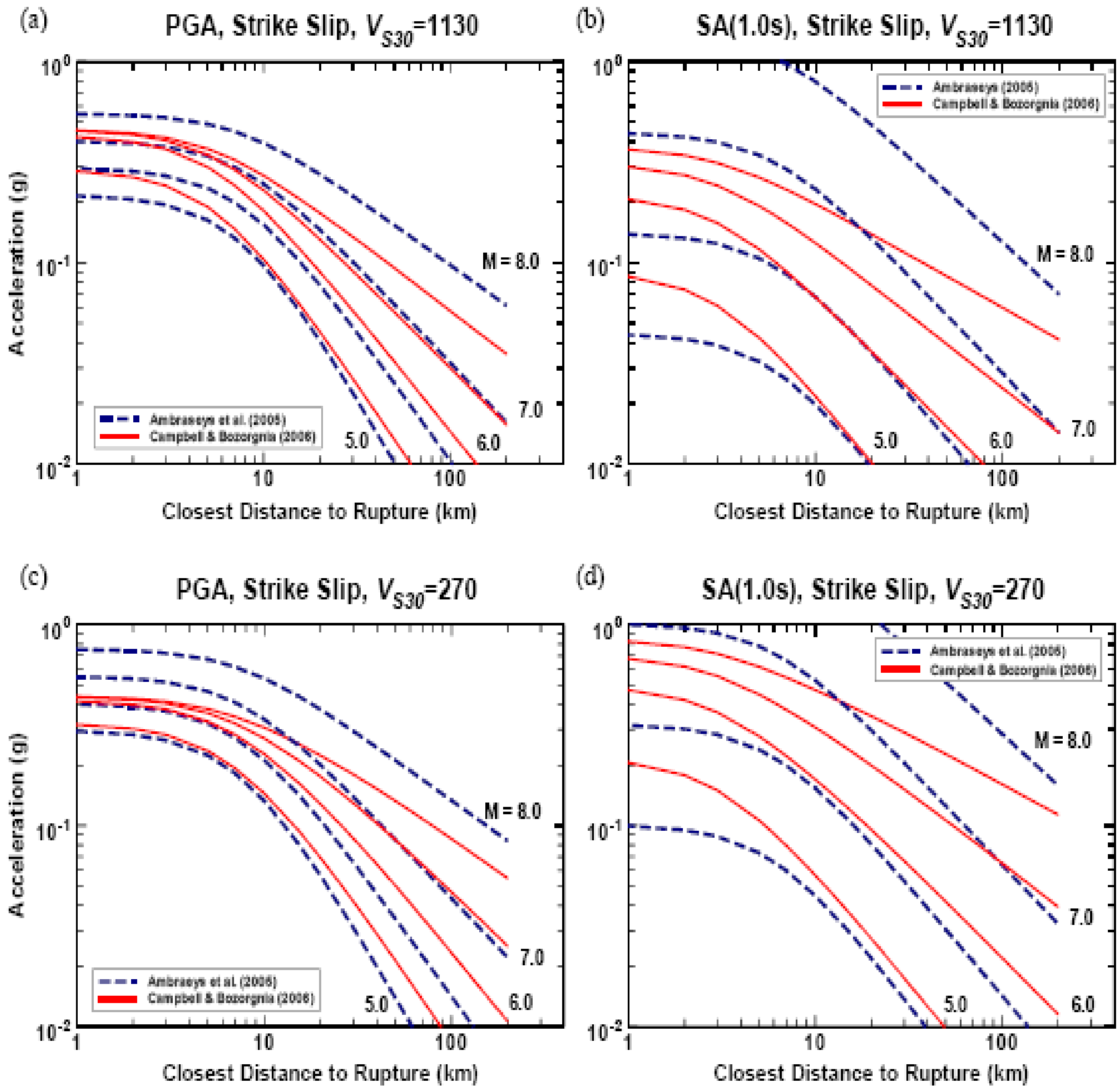


Figure 4: Comparison of distance-scaling characteristics predicted by the NGA and Ambraseys et al. (2005) empirical ground motion models: (a) PGA and NEHRP B site conditions, (b) SA(1.0s) and NEHRP B site conditions, (c) PGA and NEHRP D site conditions, (d) SA(1.0s) and NEHRP D site conditions.

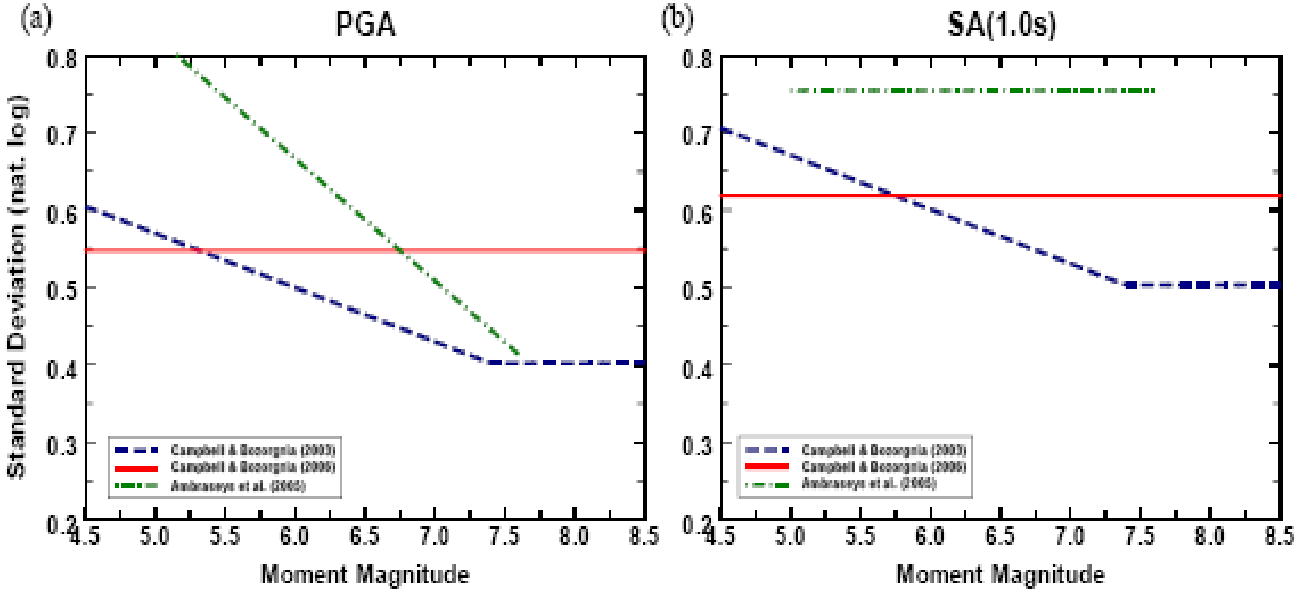


Figure 5: Comparison of aleatory standard deviations (natural log) predicted by the Campbell and Bozorgnia (NGA), Campbell and Bozorgnia (2003), and Ambraseys et al. (2005) empirical ground motion models.

$$\mathbf{P_n(t) = \frac{e^{-\lambda t}(\lambda t)^n}{n!}}$$

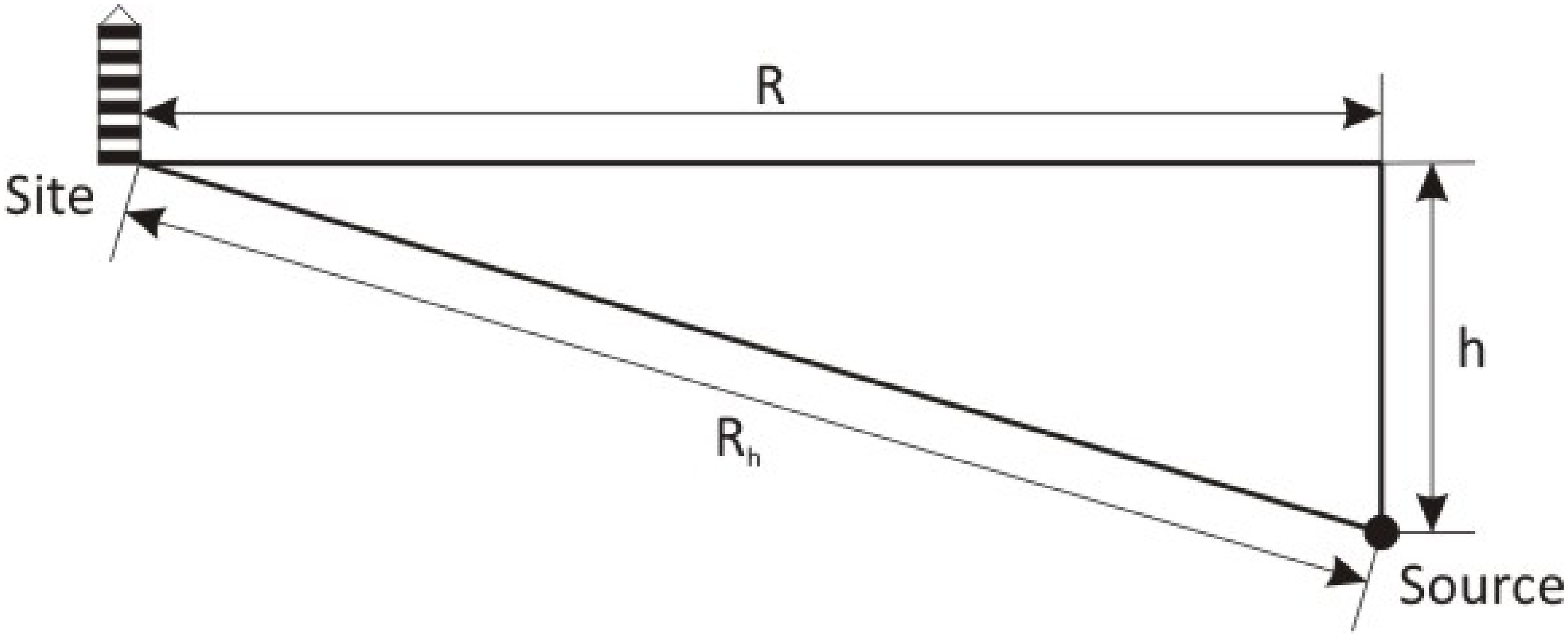
Pn(t) = Probability of having n events in time period t;

n = Number of events; and,

λ **= Mean rate of occurrence per unit of time t.**

$$P_0(t) = e^{-\lambda t}$$

$$P(t) = 1 - e^{-\lambda t}$$



Point Source, top view

$$N'(m) = \lambda = \frac{N(m)}{T} = \exp\left[\alpha_i' + \beta_i M\right]$$

$$\alpha_i' = \alpha_i - \ln(T)$$

$$\alpha_i' = \alpha_i - \ln(LT)$$

$$\alpha_i' = \alpha_i - \ln(AT)$$

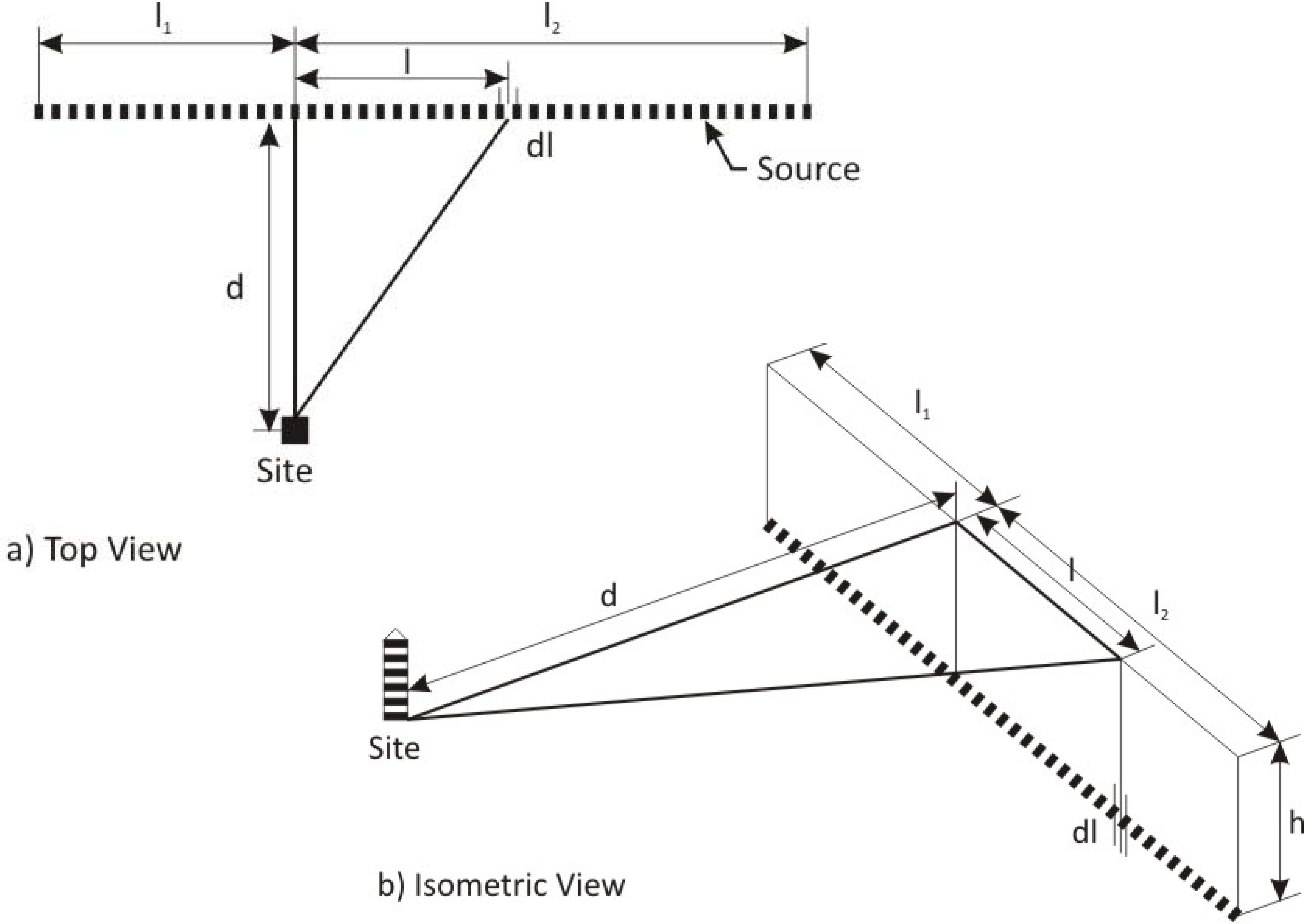
$$P_n\left[M > m, t\right] = \frac{\exp\left[-N'(m)t\right]\left[N'(m)t\right]^n}{n!}$$

$$P\left[\begin{matrix} at\,least\,one\,event \\ of\ magnitude\,M \end{matrix} > m \quad in \quad time \quad t\right] = P\left[M > m, t\right] = 1 - \exp\left[-N'(m)t\right]$$

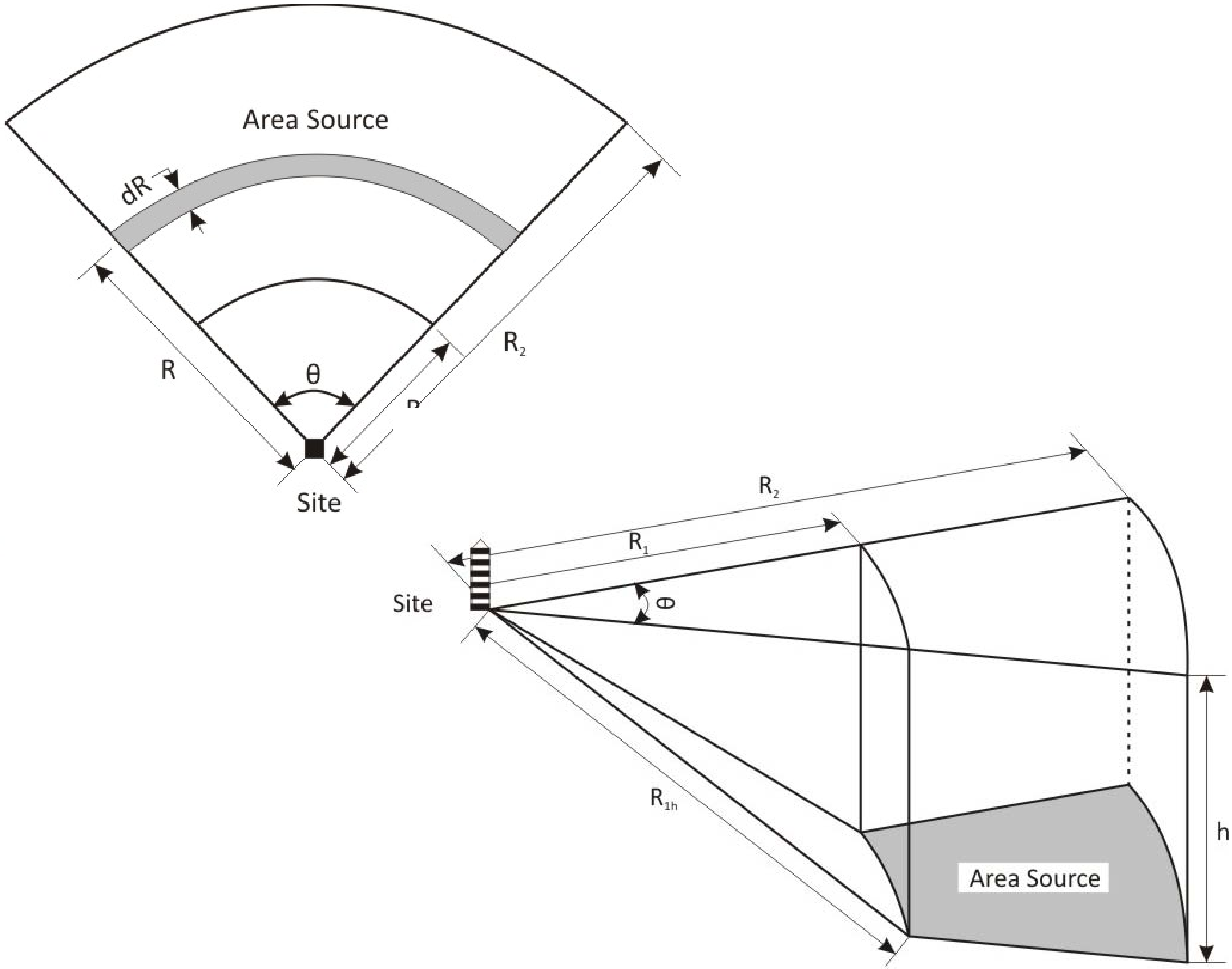
$$A = \frac{b_1 \exp(b_2 M)}{(R_h + b_4)^{b_3}}$$

$$P\left|A > a, t\right| = P\left[\frac{b_1 \exp(b_2 M)}{(R_h + b_4)^{b_3}} > a, t\right] = P\left[M > \ln\left[\frac{a}{b_1}(R_h + b_4)^{b_3}\right]^{\frac{1}{b_2}}, t\right]$$

$$P\left[a > a, t\right] = 1 - \exp\left[-e^{\alpha'}\left(\frac{a}{b_1}\right)^{\frac{\beta}{b_2}}(R_h + b_4)^{\frac{\beta b_3}{b_2}}\, t\right]$$

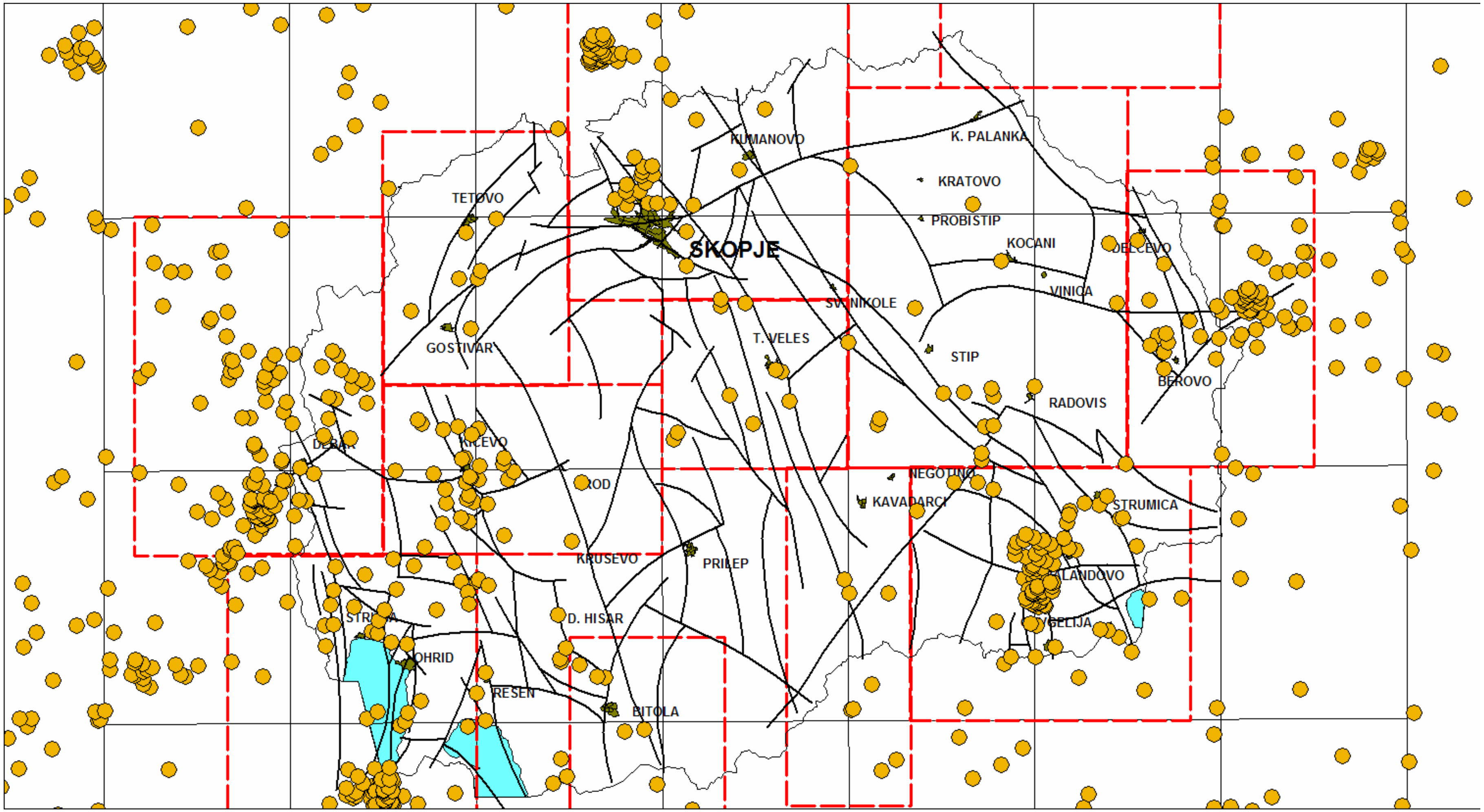


l1
l2
l
dl
Source
d
Site
a) Top View
l1
l
l2
d
Site
dl
h
b) Isometric View



a) Top View

b) Isometric View



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RP 500 SH Map of Macedonia