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Scientific Notebook No. 224: Probabilistic Seismic Hazard Analyses Using EZ-FRISK V.3.0 (06/13/1997 through 05/03/2000)

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Rui Chen / John Stamatakos

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Risk Engineering, Inc. (303) 499-3000

1. Initial Entries:

Scientific Notebook: # 224

Issued to: Rui Chen
John Stamatakos

Issued Date: May 3, 1997

Project Title: Probabilistic Seismic Hazard Analyses using EZ-FRISK (3.0)

Project Number: 20-0750-471 (PI: John Stamatakos)

1.1 Objectives.

Generating seismic Hazard curves as input to the SEISMO module of the TPA code for dose-sensitivity studies. Also, generating input for FAULTO module of the TPA code for dose-sensitivity analyses, if applicable.

1.2 Technical Approaches

The technical approach is mainly Probabilistic Seismic Hazard Analyses (PSHA). The analyses will use a commercially available computer code, EZ-FRISK, versions and considering multiple expert's opinions (pseudo-experts)

1.3 Data Sources

- Existing Literature
- DOE documentations on Yucca Mountain site
- Previously calculated data by R. Hofmann
- CNWRA FIELD, LABORATORY, AND LITERATURE REVIEW ANALYSES of FAULTING DATA
- GPS DATA FROM CAL-TECH/NRC GPS SURVEYS

[signature] 6/3/97

1.4 Computer, Computer Codes, and Data Files

- IBM PC to Run the main software EZ-FRISK (3.0)
- Sun ULTRA to generate graphics and word processing
- Main analysis computer code in EZ-FRISK™ Version 3.0 produced by Risk Engineering, Inc. 4155 Darley Avenue, Suite A, Boulder, Colorado 80303 USA (1996)
- Data file are going to be reside on the PC : c:/EZF30/YM

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2. IN-PROGESS ENTRIES

2-1 Examination of Ground Motion Attenuation Functions (Area Source) existing in the Attenuation Database in EZ-FRISK (3.0)

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For Area Sources:

There are currently 6 attenuation functions that are good for area sources in EZ-FRISK database, namely:

① Abra.-Silva (1995) FW Rock (FW - Footwall Rock ; HW Hangwall)
② Abra.-Silva (1995) HW Rock
③ Boore-Joyner-Fumal (1993)
④ Campell (1993)
⑤ Idriss (1993)
⑥ Sadigh (1994)

Predicted ground motions (Peak ground acceleration, g) by this equations are illustrated in Fig on P. 4. The Figure shows that Functions by Abra-Silva (1995) FW Rock, Boor-Joyner-Fumal (1993), Idriss (1993) and Sadigh (1994) predict very similar ground motion:

Abra.-Silva (1995) HW Rock predicts the most PGA

Campell (1993) predicts the least PGA for distance > 10 km but it predicts the most PGA for distance < 0.5 km

Therefor Abra-Silva (1995) HW Rock, Idriss (1993), Campell (1993) } selected for initial YM Single zone analysis

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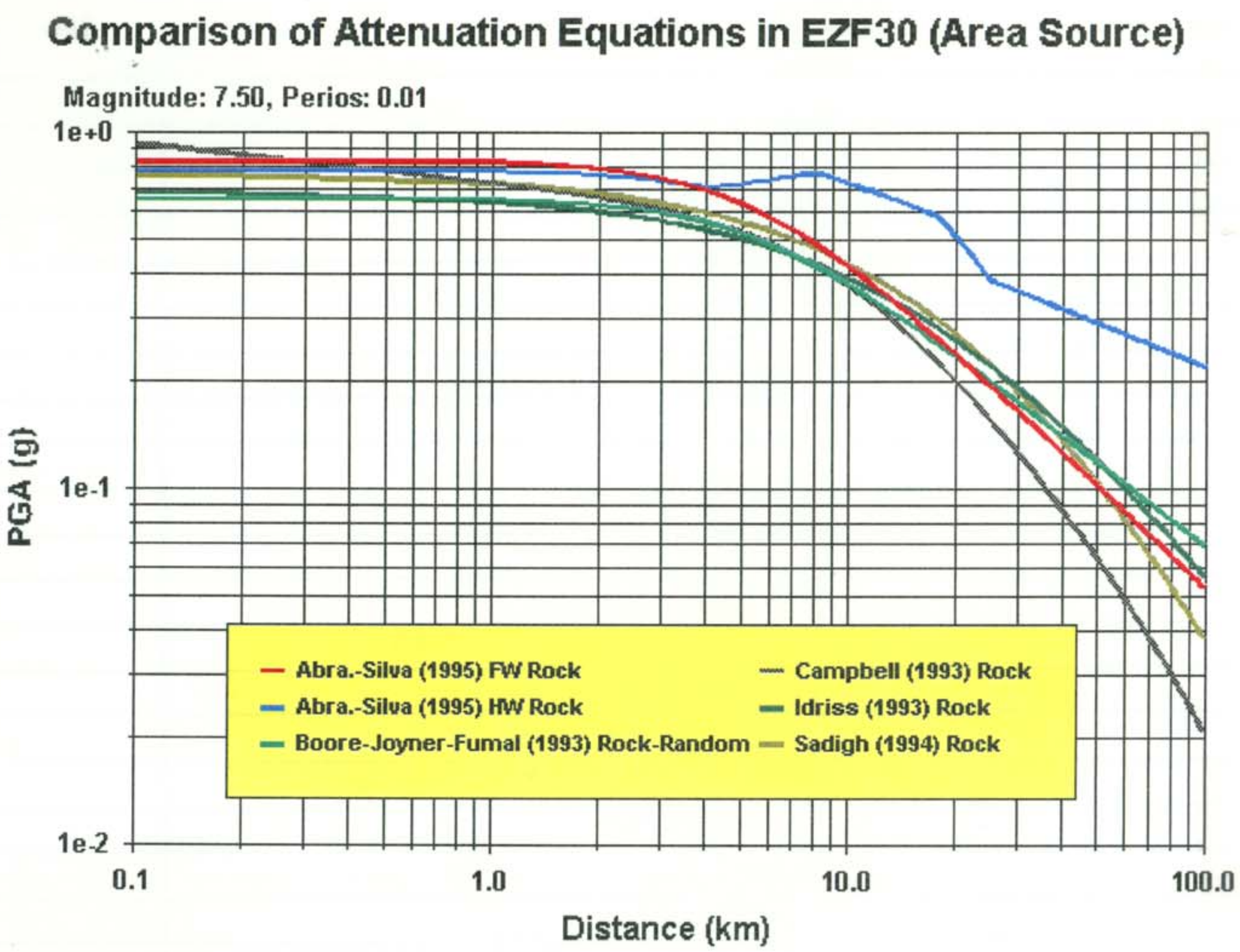


2-2 First Approximation Analyses for YM site
— single zone first approximation

Single zone covers:

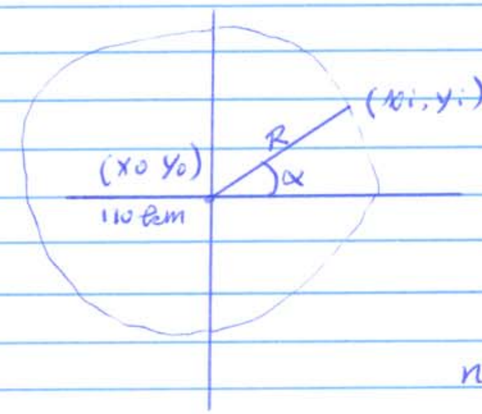
YM & 110 km radius around YM

YM coordinates were measured from fig. on p. 6 as:

(548000 4078000)

The circle with 110 km radius covers an area depicted by fig on p. 7.

Coordinates along the periphery are calculated as:



$x_i = R\cos\alpha_i + x_0$

$y_i = R\sin\alpha_i + y_0$

$\alpha_i = \frac{360}{n}$

n — using n side-polygon to approximate a circle

For n=12

$x_0 = 548$

$y_0 = 407.8$

$R = 110$

coordinates are listed →

calculated using Fortran file on page 8

alpha,	x,	y
0.0000	658.0000	407.8000
30.0000	643.2628	462.8000
60.0000	603.0000	503.0628
90.0000	548.0000	517.8000
120.0000	493.0000	503.0628
150.0000	452.7372	462.8000
180.0000	438.0000	407.8000
210.0000	452.7372	352.8000
240.0000	493.0000	312.5372
270.0000	548.0000	297.8000
300.0000	603.0000	312.5372
330.0000	643.2628	352.8000

Information potentially subject to copyright protection was redacted from this location. The redacted material is from the following reference:

Simonds, et al., 1995 and Frizzell and Shulters, 1990. Figure 1-2: Locations of faults at or near Yucca Mountain..... .No additional information is known.

Information potentially subject to copyright protection was redacted from this location. The redacted material is from the following reference:

Nakata, et al., 1982; Sawyer, et al., 1995; Piety, 1996. Figure 1-1: Regional map showing locations of faults beyond a 10 km radius... . No additional information is known.

```
      PROGRAM POROCITY
C ***************************************************
C This program calculates coordinate of a polygon
C that approximate a circle with radius R and
C certered at x0, y0
C ***************************************************
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      REAL*8 x(1000),y(1000),alpha(1000)
      REAL*8 x0,y0,R
      INTEGER n
C
C Open files for output coordinates
C
      OPEN(UNIT=3,FILE='cir_coord.out',STATUS='UNKNOWN',
     .      FORM='FORMATTED')
C
C Input Information
C
      n=12
      x0=548
      y0=407.8
      R=110
C
C Calculate Coordinates
C
      WRITE(3,2000)
      DO 77 i=1,12
       alpha(i)=(i-1)*30
       x(i)=R*cosd(alpha(i))+x0
       y(i)=R*sind(alpha(i))+y0
       WRITE(3,3000) alpha(i),x(i),y(i)
   77 CONTINUE

C
 2000 FORMAT('alpha, x, y')
 3000 FORMAT(3F12.4)
      END
```

These calculations are based on UTM map system. It was later found that EZ-FRISK (3.0) uses only Geometric system. i.e. Longitude and Latitude

Longitude & latitude at YM are measured from fig in P.10 as:

548564.5
4078096.7 } in UTM and transfer to

-116.4553
36.8694 } in Geo. coordinates along the periphery are:

calculated using Arcinfo per Ren Martin for a 36 sided polygon to approximat a circle centered at

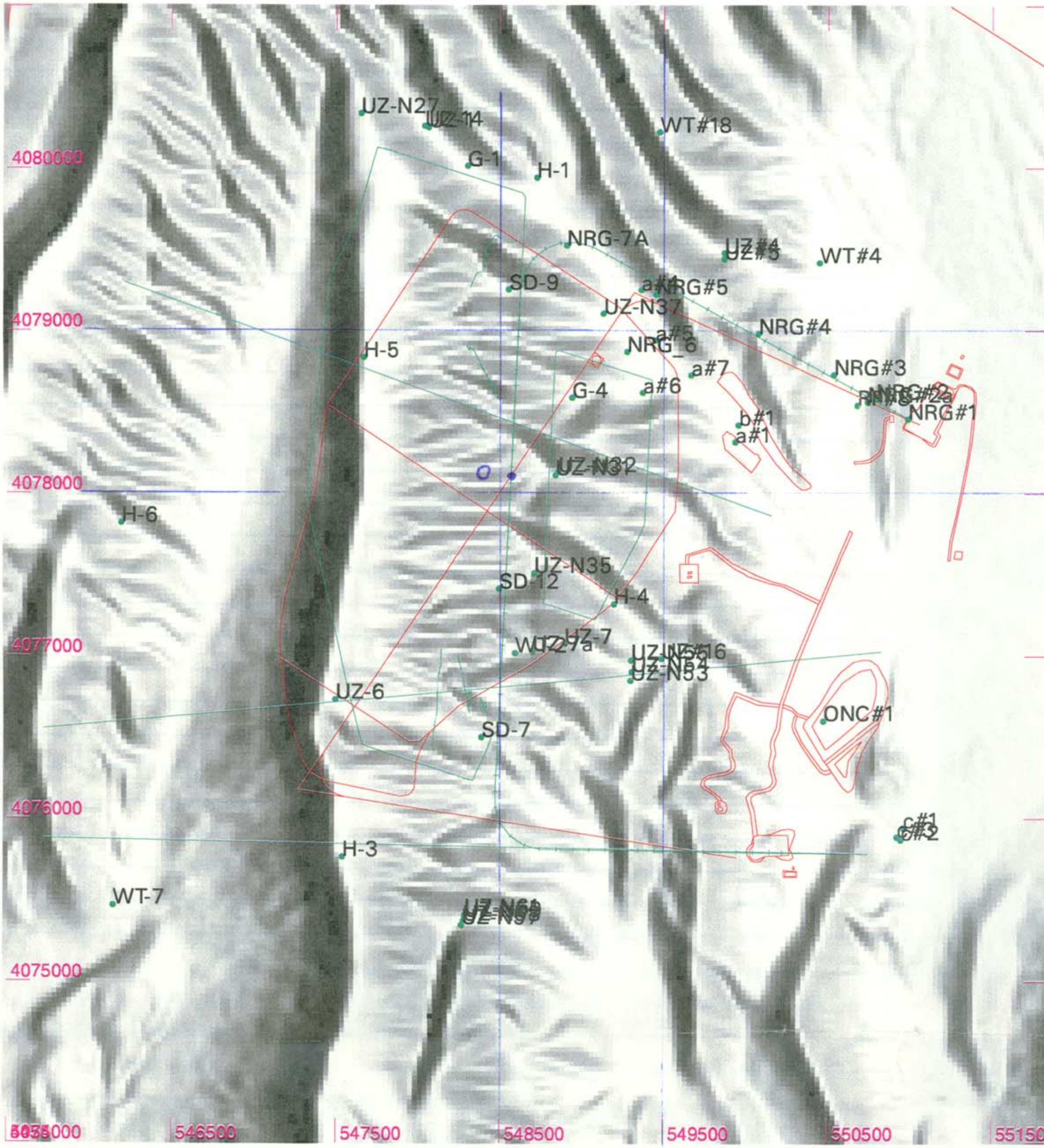
X₀ = -116.4553

Y₀ = 36.8694

R = 110 km

The calculation was in UTM to perserve true distance and translated to Geo coordinates.

-116.462135	35.857681
-116.673805	35.873516
-116.878815	35.918728
-117.071396	35.991764
-117.246086	36.090710
-117.397232	36.212585
-117.520546	36.353729
-117.612000	36.509983
-117.668839	36.676575
-117.689087	36.848606
-117.671844	37.021145
-117.617310	37.188423
-117.527061	37.345226
-117.403641	37.487499
-117.250633	37.610081
-117.072762	37.709373
-116.875465	37.782402
-116.664902	37.826607
-116.448067	37.840862
-116.230835	37.824574
-116.021095	37.778202
-115.825180	37.703346
-115.648582	37.602310
-115.497559	37.478241
-115.376381	37.335060
-115.288452	37.177170
-115.236588	37.009544
-115.221802	36.837303
-115.244476	36.665314
-115.303741	36.499195
-115.397446	36.344017
-115.522659	36.203926
-115.675415	36.083542
-115.851288	35.986187
-116.044937	35.914890
-116.250641	35.871624
-116.462135	35.857681



Yucca Mountain ESF Facilities -- A Comparison
Green: ESF, TBM Ramps, and PDB layout by May, Potter, Seetkind, Dickerson and San Juan, Jun96.
Red: DOE Jan94 ESF, TBM Ramps, and PDB layout. Authors Unknown.
Capture to ARC/Info, Danny Skelton and Ron Martin. 02/25/1997
MapScale: 32000. Map Projection: UTM zone 11.

2.2.1 Building a new area source in EZ-FRISK (3.0)

Region: Yucca Mountain

Name: circle-36

(seismic source) Representing a single zone centered at YM, has a radius of 110 km and uses a 36 sided polygon ~~to approximate the circle as documented on p.9~~.

Depth: 10 km

Min Magnitude: 4

Max Magnitude: 7.5

Activity Rate: (1/1500 = 6.7 e-004) Too small, need to be modified according to Wong et al (1995). See P.33

~~Beta (b in b of the GR recurrence curve): 2.0~~

[signature] 6/16

2.2.2 Building Input File

Calculation parameters:

Title: YM - Single Zone Approximation

Vertical Integration inc: 5 km (default)

Horizontal " ": 5 km (")

Number of Rupture length: 4 (")

Number of Integration steps: 25 (")

Magnitude Integration Inc: 0.1 M (")

Site parameters:

Location: -116.4553, 36.8494

Amplitudes: Amplitude of ground motion in g ranging 0.01 - 2.0

Spectral Frequency / period.
using default 100 Hz (indicating PGA) to 1 Hz.

Frequency / Period to plot PGA   33 Hz (default)

Annual Frequencies: 10^{-3} 10^{-4} 10^{-5}
corresponding to 1000, 10000 and 100000 yrs return periods

Deaggregation: Yes

Deterministic Fractiles: 0 .15 .85

Source & Atten Eqs.

Area Source & Region: Yucca Mountain as established on P.11

Select Atten Equation: (See P.3) Abra - Silva (1995) HW Rock
Idriss (1993)
Campbell (1993)

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2.2.3 Results: plots & text files are available

① Hazard Plot. Fig in pages 14 & 15 for frequencies of 100 and 1, respectively

- It shows hazard curves for all three selected attenuation eqs.
- For frequency of 1 (page 15), there are only two curves because function Abra - Silva (1995) HW Rock does not have parameter definition at frequency of 1 Hz for area source.
- The figs show the annual frequency of exceedance of ground accelleration indicated by the horizontal axis.
- The fig indicate comparison of total hazard by different atten eqs.
- At annual frequency of exceedance level 1e-4 (once every 10,000 yrs), the maximum PGA is about 0.08 g as predicted by Abra. - Silva (1995) HW Rock
- Hazard is very low for this very simplified single zone model.

② Probabilistic Spectra plot. Fig on page 16.

- It plots the uniform hazard spectra for the annual frequency of exceedence of 10^{-4} for each atten eq.
- It shows for annual frequency of exceedance of 10^{-4}, the PGA ranges from 0.01 to 0.1 for frequencies 1 to 12. Abra. - Silva (1995) HW Rock is not shown because only one frequency level (100 Hz) is calculated

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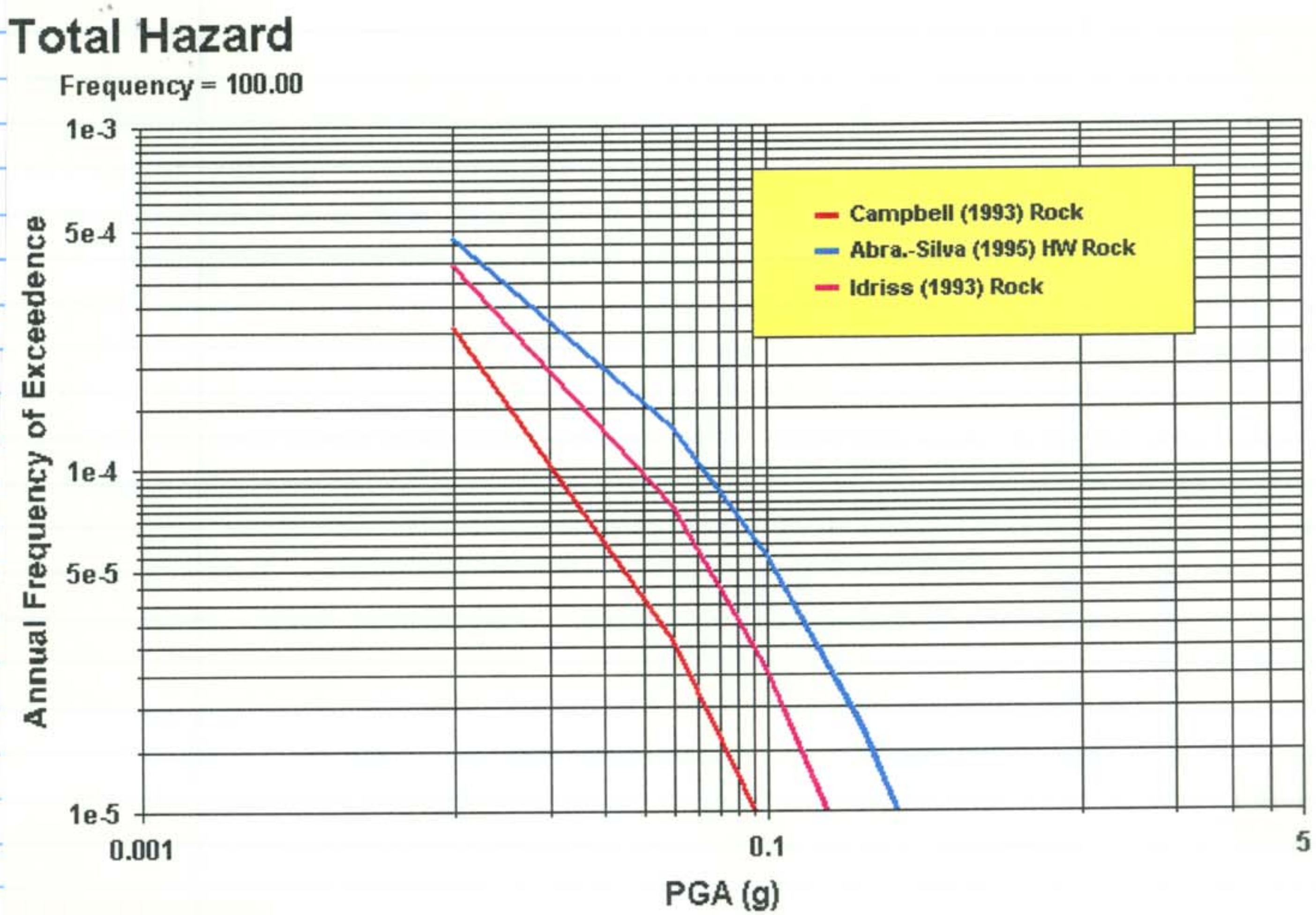

Very low hazard is due to inappropriate activation rate for the area source D

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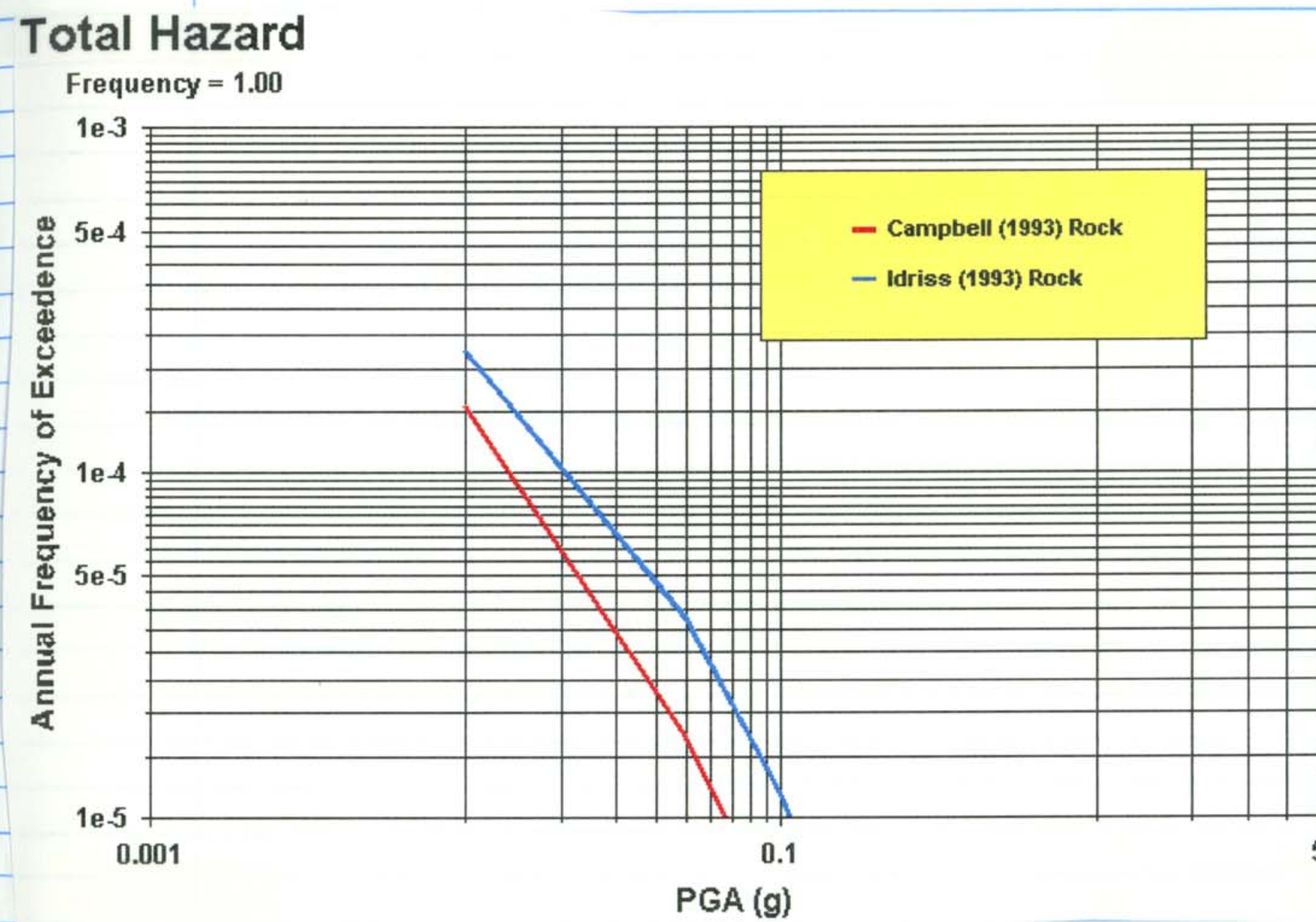
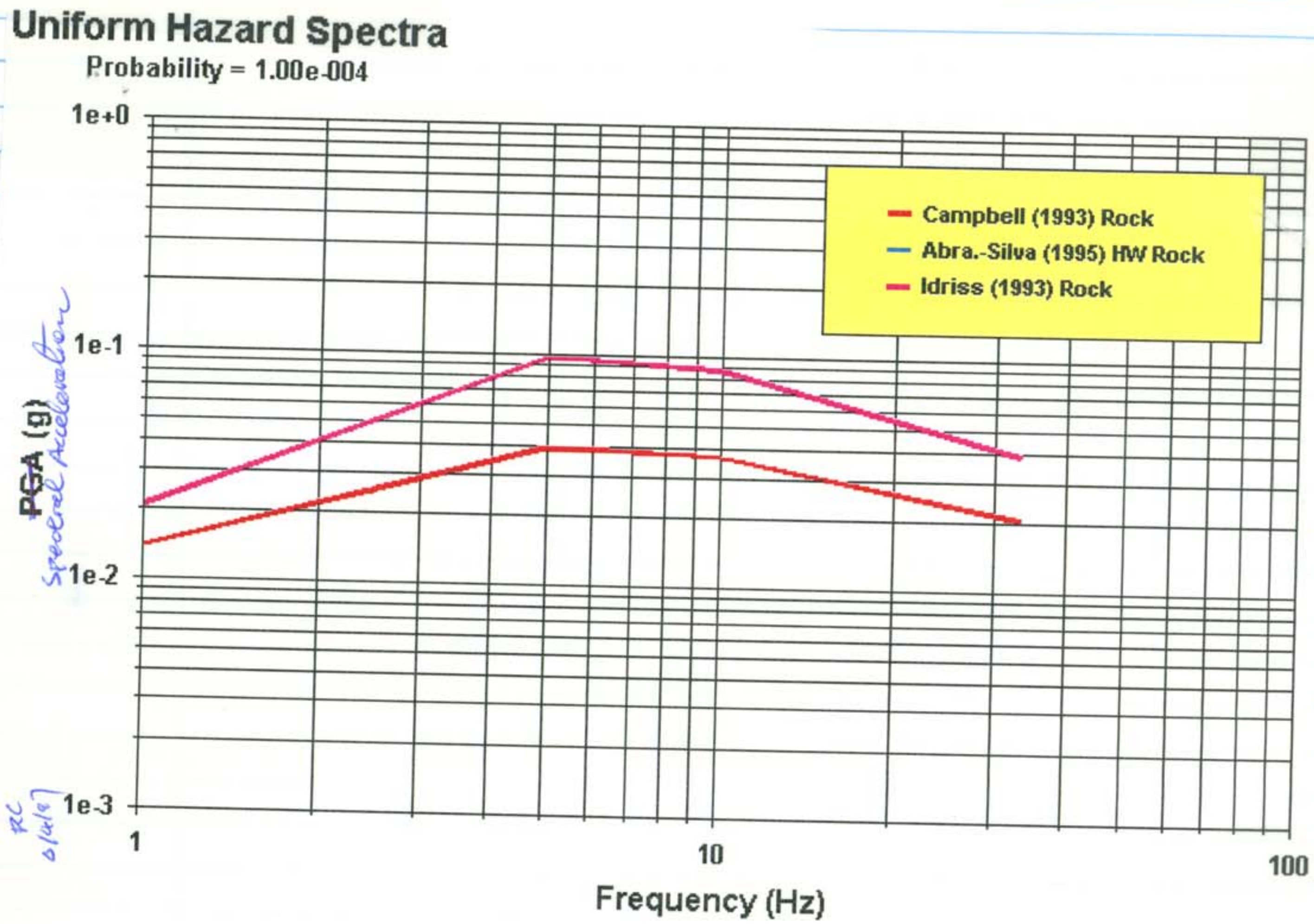




③ Deterministic Spetra Plot

- Figs on p.18, 19, & 20 plot the deterministic spectra for the deterministic fractiles of 0, 15%, and 85%, respectively

- ~~PGA~~ RC Ground acceleration is the highest (1g) at frequency of about 5 Hz and for fractile of 0.85.

④ Source contribution plot

P.21.

There is only one source (circle-36). Fig on p21 plots such plot for Equation = Abra. - Silva (1995) HW Rock
Frequency = 100.00

Since there is only on source, this curve is identical to Abra-Silva (1995) Rock curve in Fig on p.14.

⑤ Activity Rate curve.

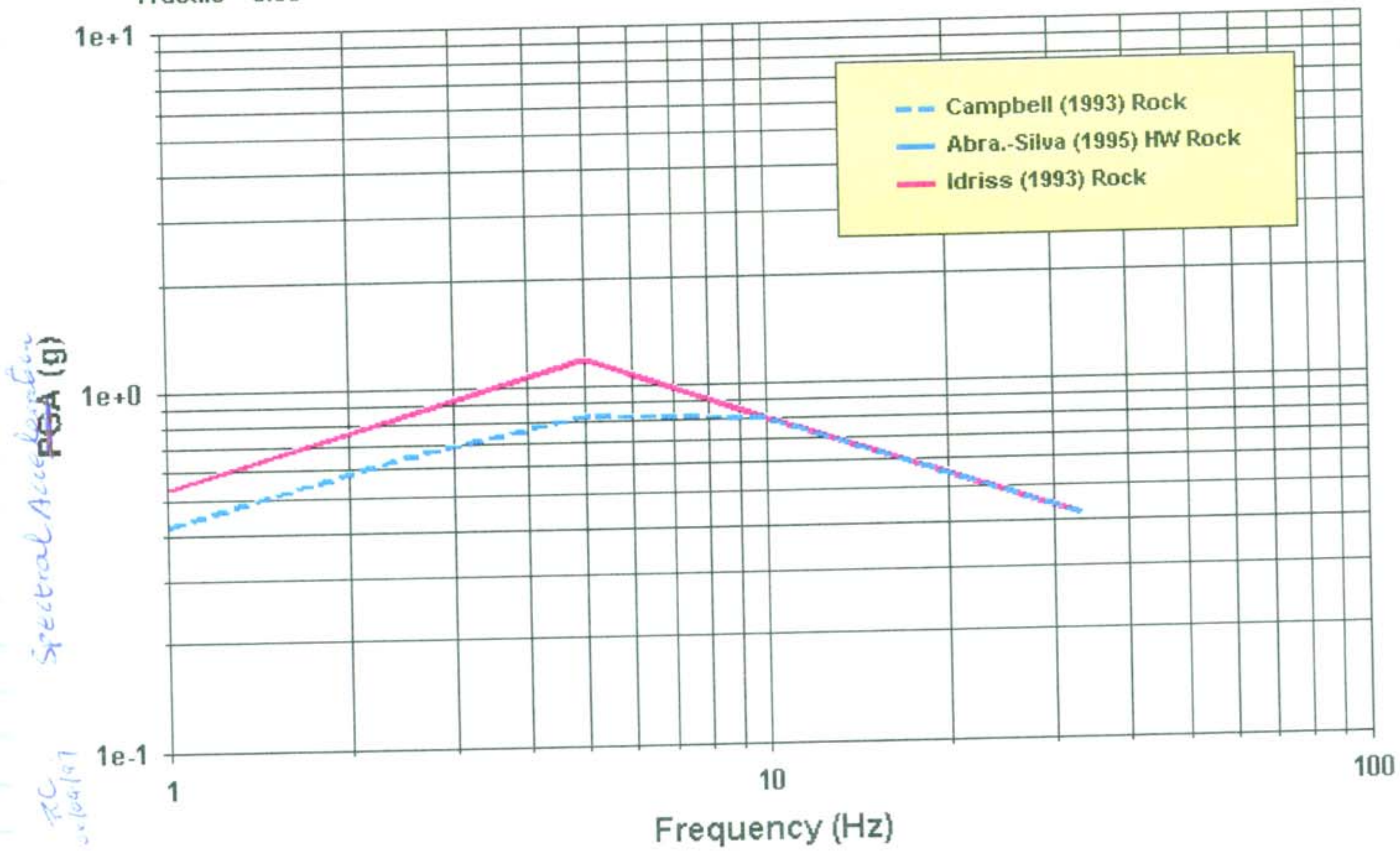
or sometimes called frequency curve

$\log N = a - bM$ (Gutenberg - Richter frequency-of-occurrence

It is the input, plotting it out is a good way to check whether the appropreate curve have been used.

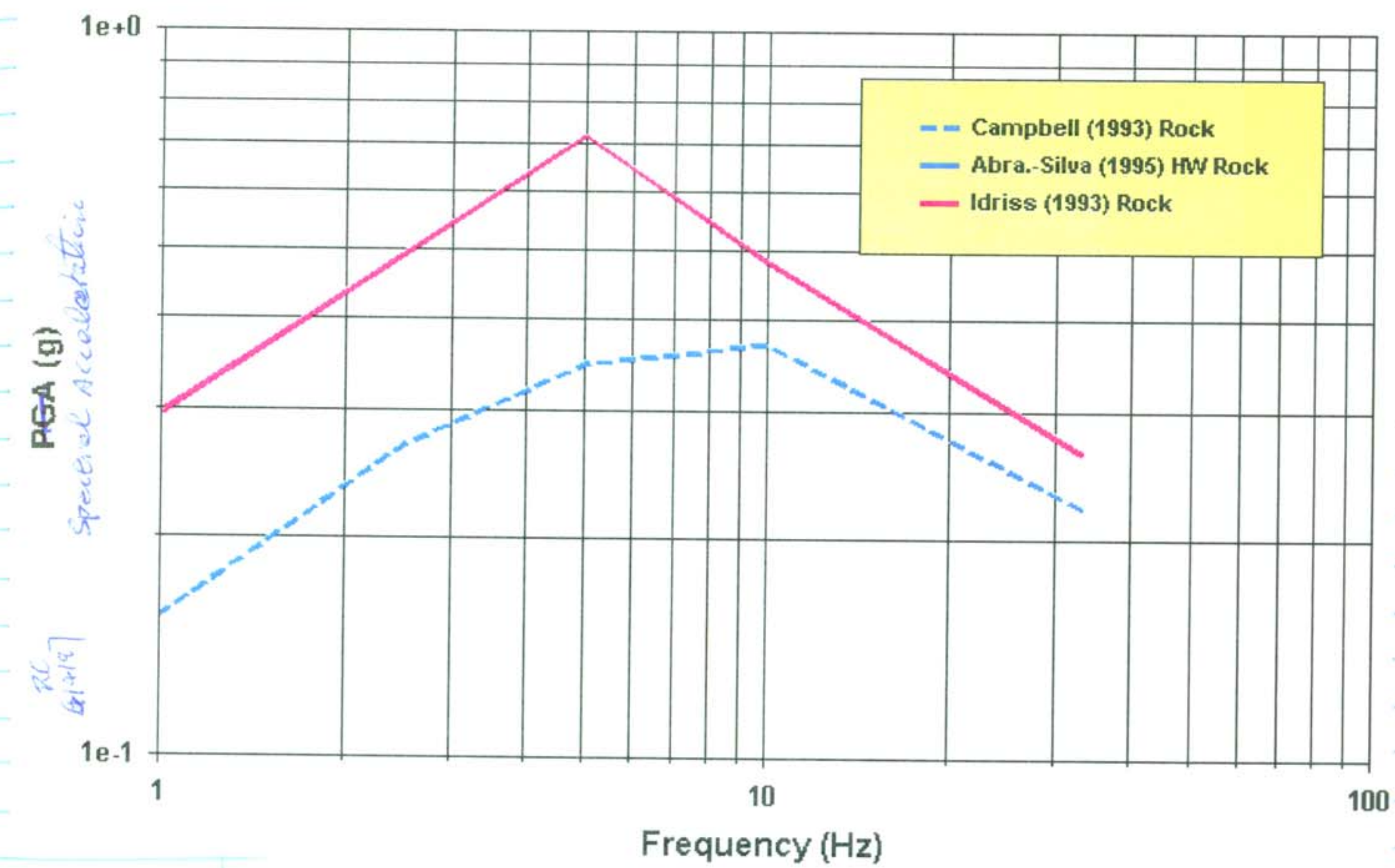
Deterministic Spectra

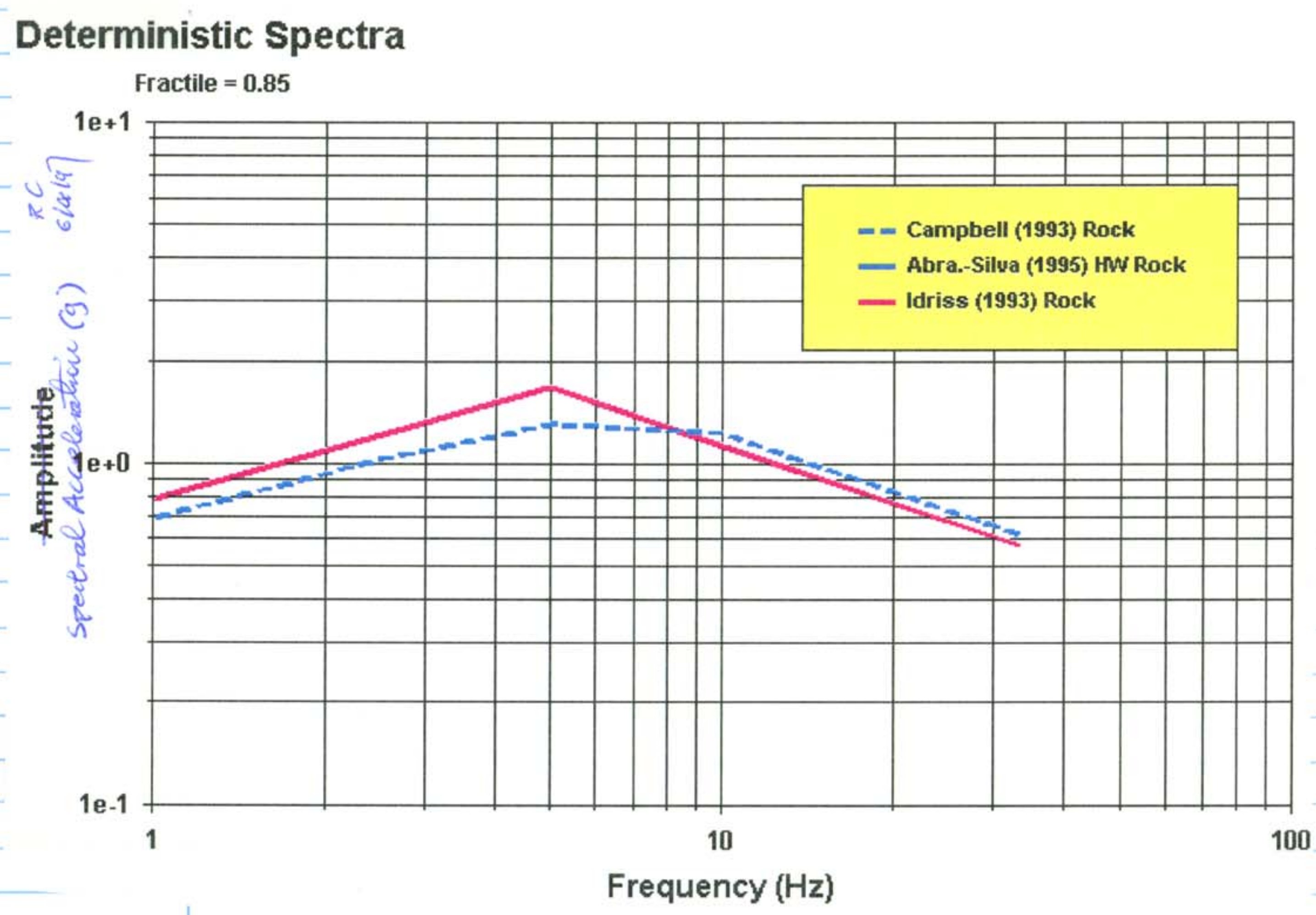
Fractile = 0.00

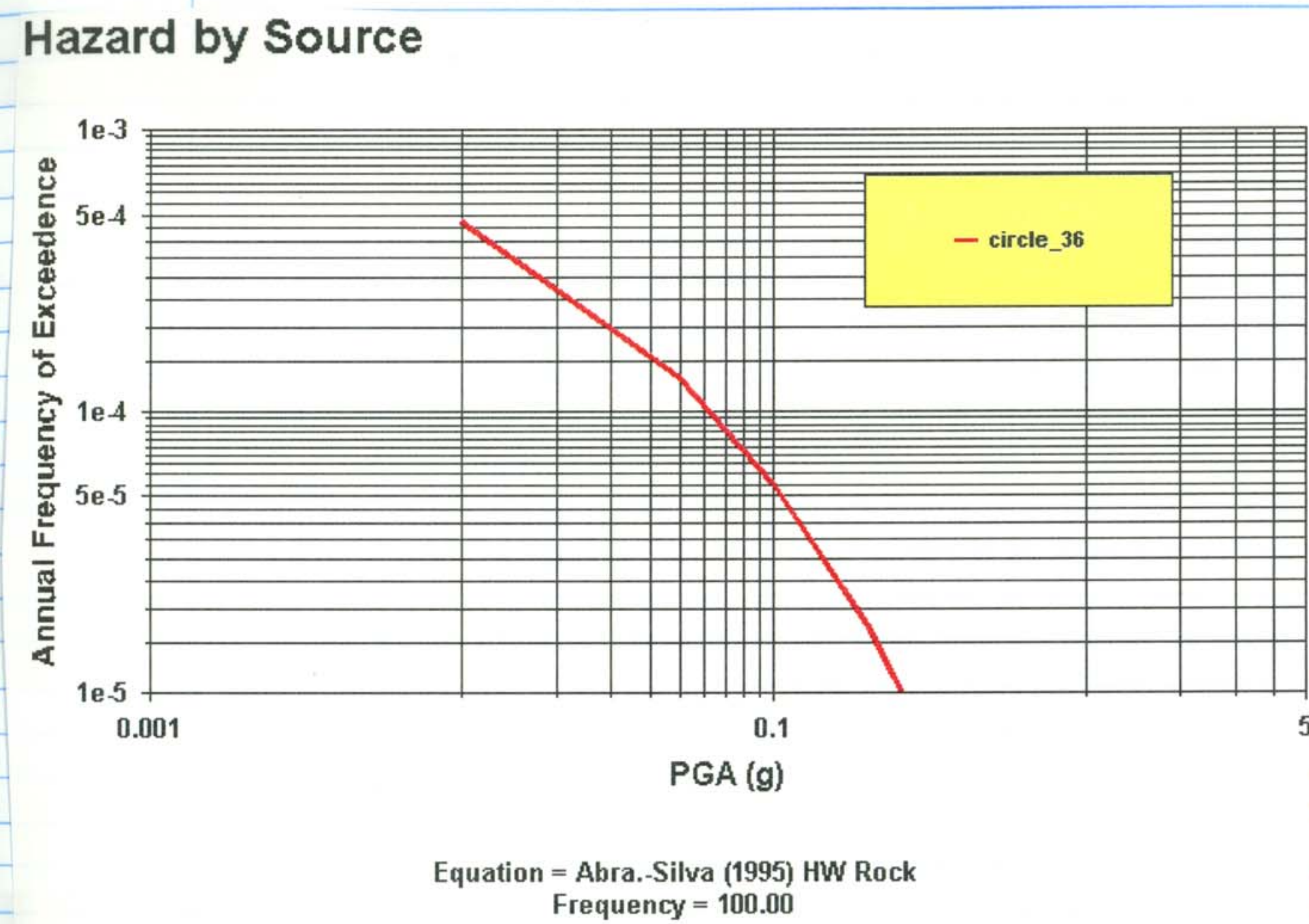


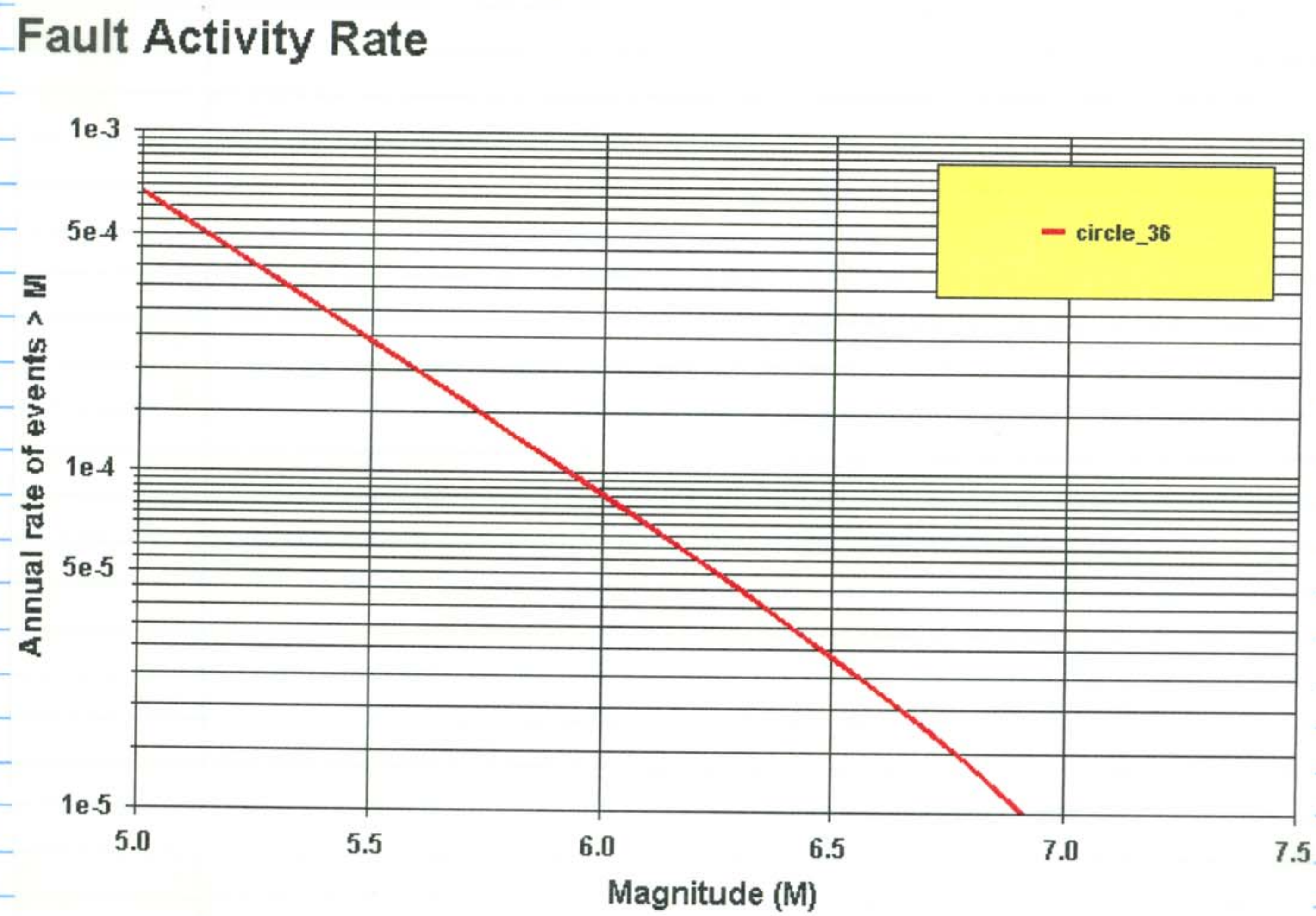
Deterministic Spectra

Fractile = 0.15



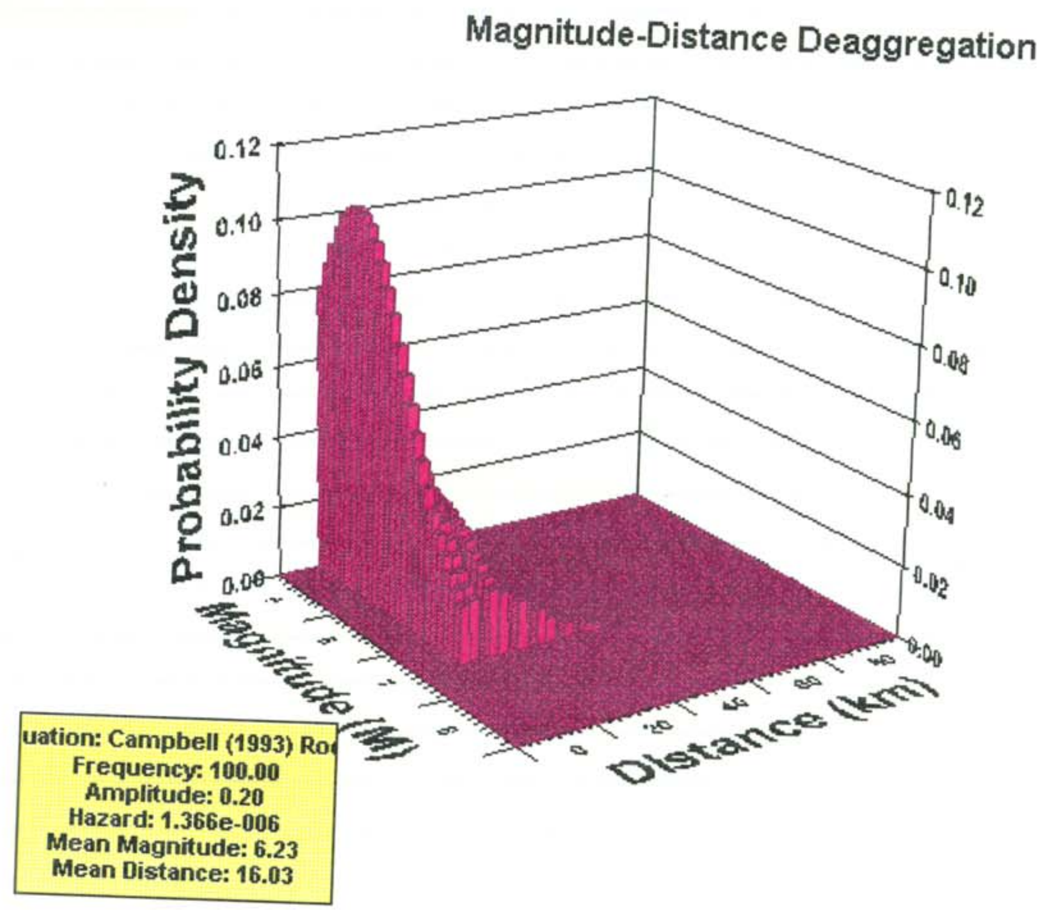

Deterministic Spectra
Fractile = 0.85
Campbell (1993) Rock
Abra.-Silva (1995) HW Rock
Idriss (1993) Rock
Amplitude
Spectral Acceleration (g)
1e+1
1e+0
1e-1
1
10
100
Frequency (Hz)


Hazard by Source
circle_36
Annual Frequency of Exceedence
1e-3
5e-4
1e-4
5e-5
1e-5
0.001
0.1
5
PGA (g)
Equation = Abra.-Silva (1995) HW Rock
Frequency = 100.00



⑥ Deaggregation Plot:

Plots the contribution to hazard by magnitude, distance, and attenuation epsilon. As an example, the following fig shows contribution by distance and Magnitude for Campbell (1993) Rock attenuation eq.



2-2 Examination of ground motion attenuation functions for dip-slip fault sources (normal faulting) ... EZ-FRISK (3.0)

Currently there is only one attenuation equation available for dip-slip

- Campbell (1993) Rock (Frequency 100 Hz)

and it is only for a single frequence for PGA.

For oblique faulting, the available atten eqs are.

- Abra.-Silva (1995) HW Rock (1 Hz)
- Campbell (1993) Rock (spectra)
- Idriss (1993) Rock (spectra)

Fig on p. 30 shows comparison of these attens eqs all for PGA

[i.e. freq. of 100 Hz, except Abra.-Silva (1995) HW Rock, which is for freq. of 1 Hz]

Test parameters include:

Magnitude: 7.5
Min Distance: 0.1 km
Max Distance: 100 km
Distance Inc.: 1 km

Observations:

Campbell (1993) for normal fault at frequency 100 Hz is identical to Campbell (1993) for oblique fault at the same frequency.

6/5/96
RC

2-3 Fundamentals (1)

Types of Seismic Hazard Analysis (SHA) (Panel on Seismic Hazard Analysis, 1988)

a. Deterministic (DSHA)
one or more earthquakes are selected with only implicit consideration of their probability of occurence

b. Semiprobabilistic Seismic Hazard Analyses
Similar to DSHA, except that the probability of occurence is an explicit consideration in the selection of the earthquake

* c. Single model PSHA

d. Multiple model PSHA

e. Hybrid Procedure

~~Imp~~ Basic Aspects of PSHA

1> Data collection
- Seismic source characteristics
- Earthquake reccurrence characteristics for each source
- Ground motion attenuation characteristics

* EZ-FRISK does
AHC
8/25/2000

2> Calculation of PSH (Cornell, 1968)
- using a single set of input parameters & result in a single seismic hazard curve

3> Addressing uncertainties (resulting in precentile curves)

4> Using and aggregate multiple opinions.

* 5> Disaggregation Analyses (closing the loop).

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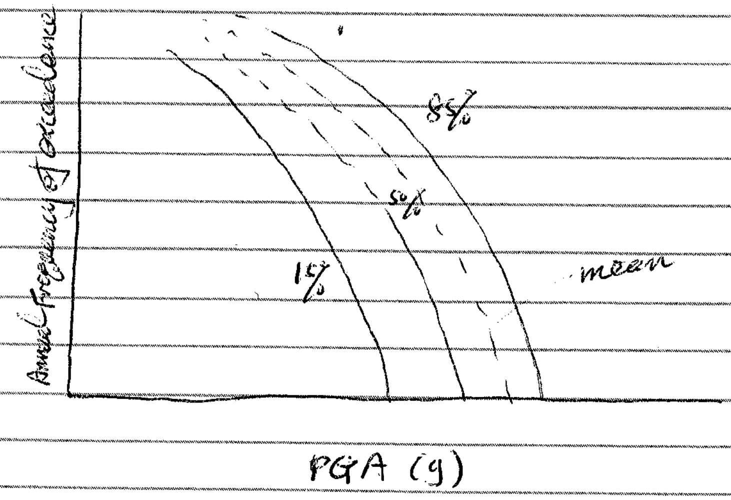
R.C.

Addressing uncertainties in PSHA

- Percentile seismic hazard curves



Methods used for generating percentile seismic hazard curves.

A. Logic Tree
- Panel on Seismic Hazard Analysis (1988)
- Coppersmith and Youngs (1990)
- Coppersmith and Youngs (1986)
- Youngs and others (1985)
- Kulkarni and others (1984)

B. Developing a probability distribution of seismic Hazard for example using a Monte Carlo approach by sampling each of the uncertain parameters from its respective probability distribution describing the uncertainty in the parameter.

- Lawrence Livermore National Laboratory (1989)
- Hofmann (1994, 1995 etc.)

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Effort needed for PSHA outside of EZ-FRISK (3.0)

- Uncertainty Analyses i.e. Percentile curves
- Multiple Opinion Aggregation

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2-4 Building a new fault source (first fault source ~~for~~ YM)
BM – Bare Mountain

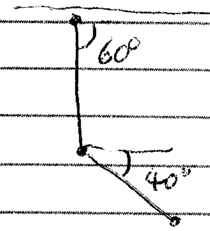
Region: Yucca Mountain

Name: Bare Mountain (BM)

Type: Normal

Coordinate:	Longitude	Latitude
	-116.613351 (5394~~00~~)	36.908600 (4084600)
	-116.578894 (537600)	36.752874 (4065120)

Profile:



depth1 = 0
depth2 = 9 km
depth3 = 15 km

Parameter:

Min Magnitude: 4.5
Max Magnitude: 6.6

Rupture length
Al: -2.57 ?
Bl: 0.61 ?
Sgl: 1.e-002

Recurrence type: characteristic

Slip Rate (mm/yr): 0.30 mm/yr
(or Activity Rate #/yr): 5e5

Rate: 12 ?
Beta: 2.0
Delta 1: 0.5 ?
Delta 2: 1.5 ?

2-5 Death Valley E&S.

Reverse

Depth 1: 4
" 2: 10
" 3: 20

Dip 1: 90
Dip 2: 90

Min M: 5
Max M: 7~~8~~

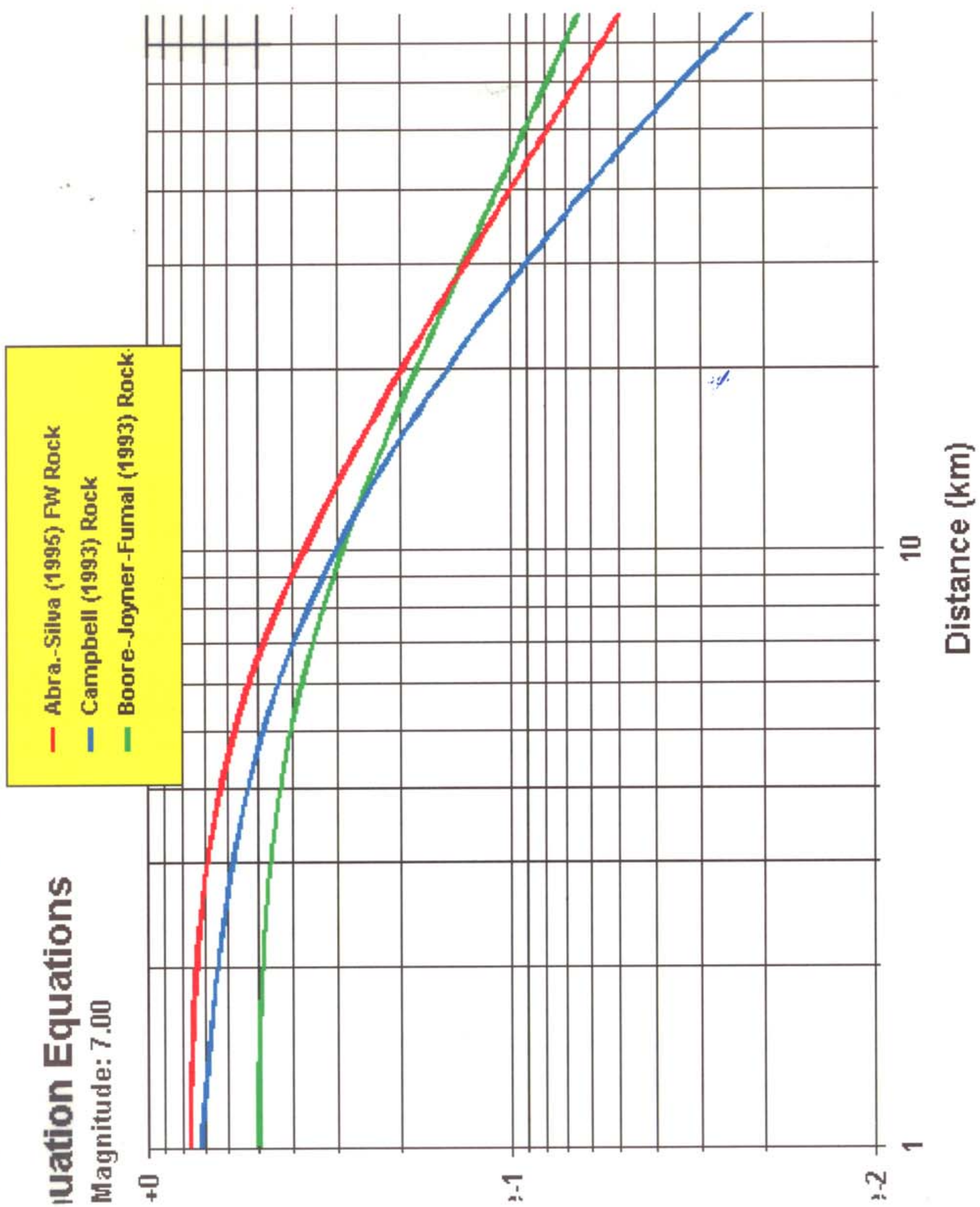
OK 8/25/00 [signature]

characteristic

Al: -2.~~67~~
Bl: 0.~~56~~
Sigl 1e-002

Slip Rate

Rate: ~~3~~
Beta 2.0725
Delta 1 .0.5
Delta 2 .1.5


uation Equations
Magnitude: 7.00
Abra.-Silva (1995) FW Rock
Campbell (1993) Rock
Boore-Joyner-Fumal (1993) Rock
Distance (km)
1
10

2-3 Second Approximation Analyses for YM site

Attempt to reproduce seismic hazard analyses carried out by the DOE for the ESF [Wong et al. 1995, or CRWMS 1994 (BABOOOOO-01717-5705-00001 Rev 00)

2.3.1 Selection of Attenuation Functions

- DOE selection:

  Tsai et al (1990)

  Campbell (1995)

  Joyner and Boore (1988)

  Idriss (1991)

- Available Attenuation Equations in EZ-FRISK 3.0.

  Campbell (1993)

  Idriss (1993)

  Boore, Joyner & Fumal (1993)

* Campbell (1993) is identical to DOE's selection

Idriss (1993) and Boore Joyner & Fumal (1993) are more updated version ~~fr~~ of those used by DOE [i.e. Idriss (1991)), Joyner and Boore (1988)

OK J Shmalk 8/25/00

* Tsai et al. (1990) may be incoperated in EZ-FRISK in the future if deemed necessary.

- Figs on Pages 34 & 35 depicts these equations for area source and fault source, respectively.

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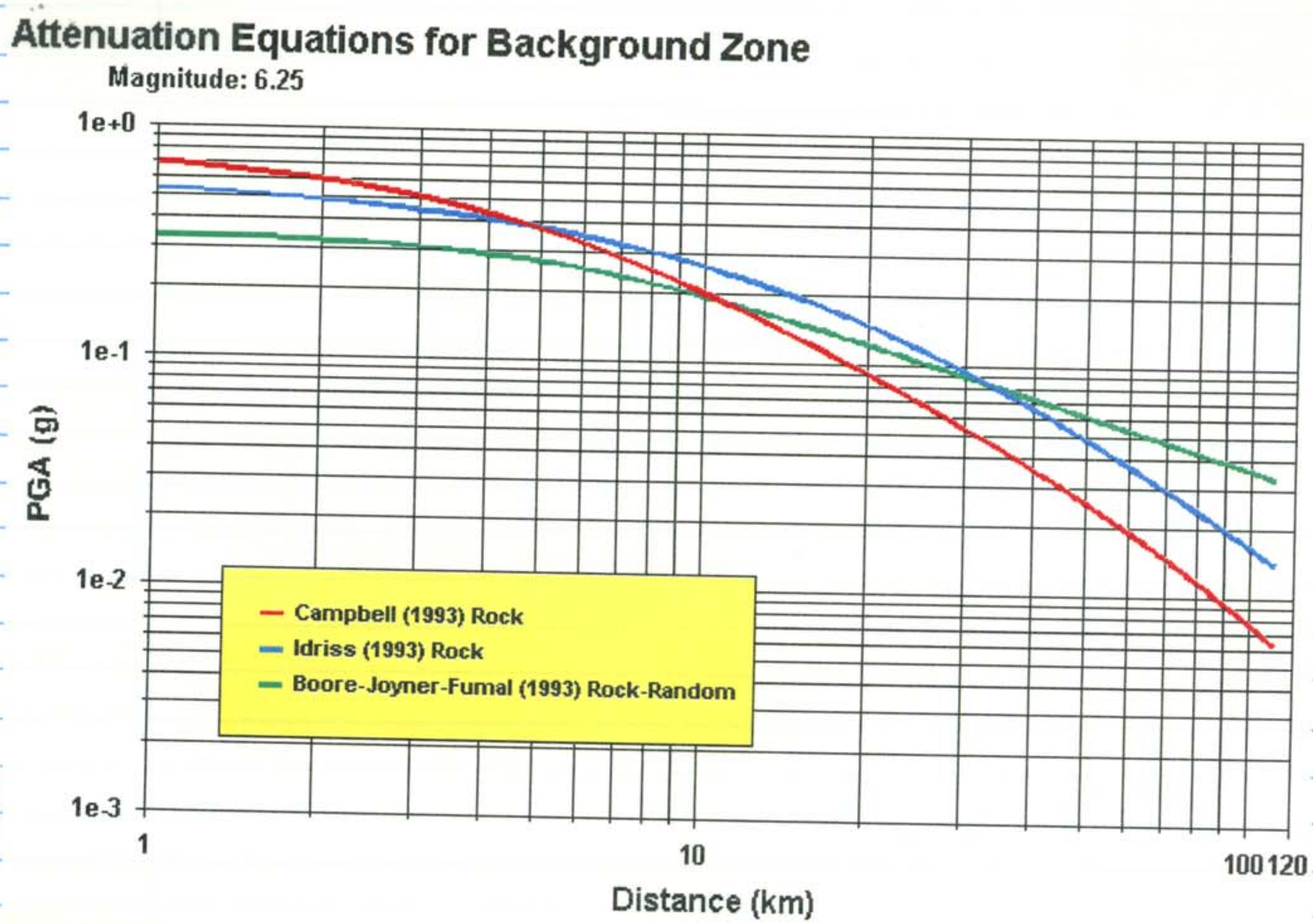
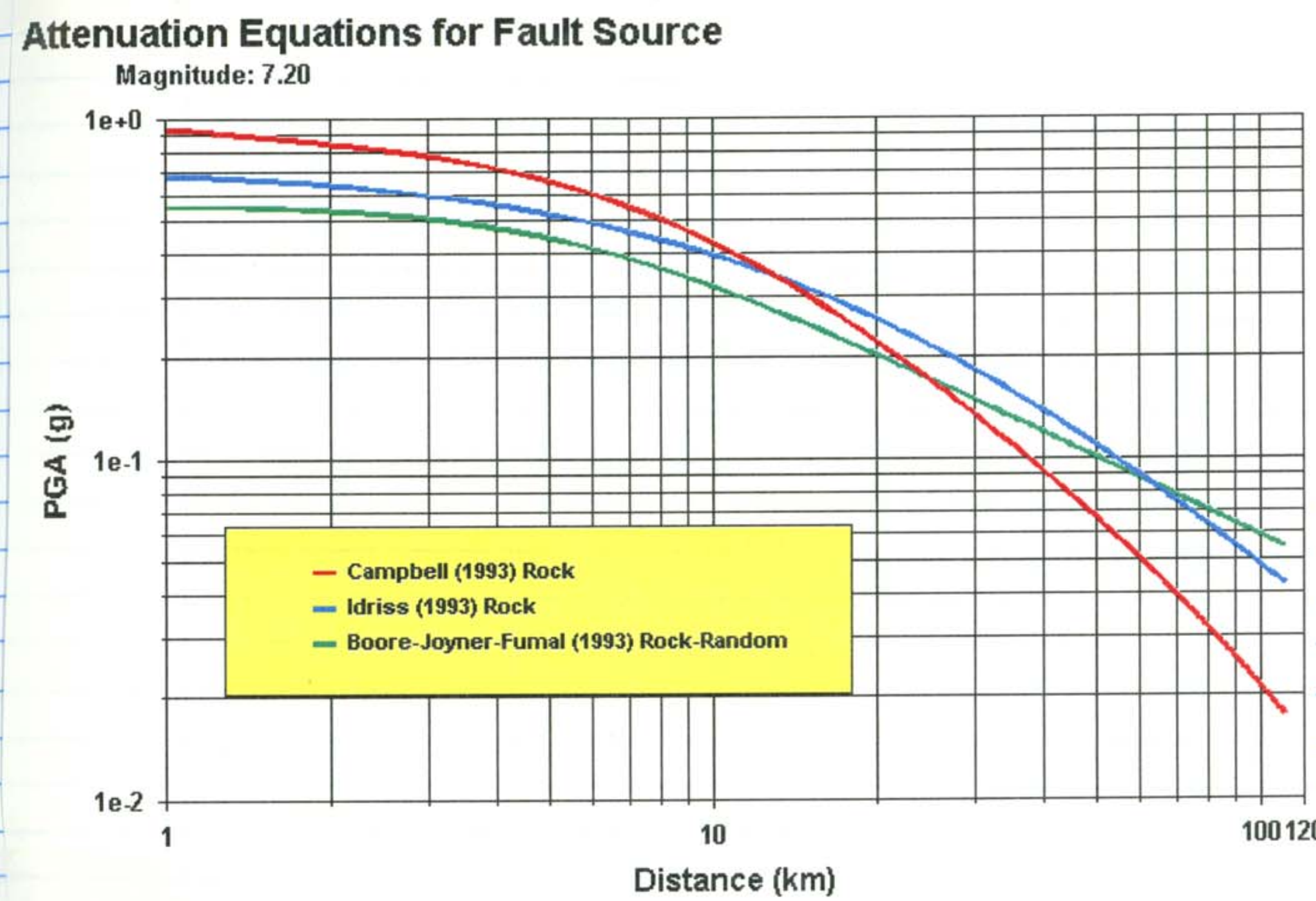

Attenuation Equations for Background Zone
Magnitude: 6.25
1e+0
1e-1
1e-2
1e-3
PGA (g)
1
10
100 120
Distance (km)
Campbell (1993) Rock
Idriss (1993) Rock
Boore-Joyner-Fumal (1993) Rock-Random


Attenuation Equations for Fault Source
Magnitude: 7.20
1e+0
1e-1
1e-2
PGA (g)
1
10
100 120
Distance (km)
Campbell (1993) Rock
Idriss (1993) Rock
Boore-Joyner-Fumal (1993) Rock-Random

2.3.2 Source characteristics for background zone:

Region: Yucca Mountain

Name: circle-36 (will replace the source zone built on p.11)

Depth: DOE: 0-15 km uniformly distributed
since EZ-FRISK takes only one fixed depth, the mean of DOE data [i.e), 7.5 km] is used.

Min Magnitude: 4 (DOE used 5, however this diff should not significantly affect results)

Max Magnitude: 6.25

Activity Rat (rate of earthquake per year occuring in the entire source above the minimum magnitude)

According to DOE is $\log N = a - bM$

$a = -1.37 \pm 0.05$

$b = 0.83 \pm 0.01$

Select the mean values:

$\log N = -1.37 - 0.83 M$

For $M_{min} = 4$

$\log N = -4.69$, $N = 2.0417 \times 10^{-5}$ (yr/km², see Fig A-3 of ~~DOE~~ CRWMS 1994)

In the entire area:

$N = \pi \cdot (110\ km)^2 \cdot 2.0417 \times 10^{-5} = 0.7757$

Beta:

$\beta = \ln(10) \cdot b$

$= \ln(10) \cdot 0.83$

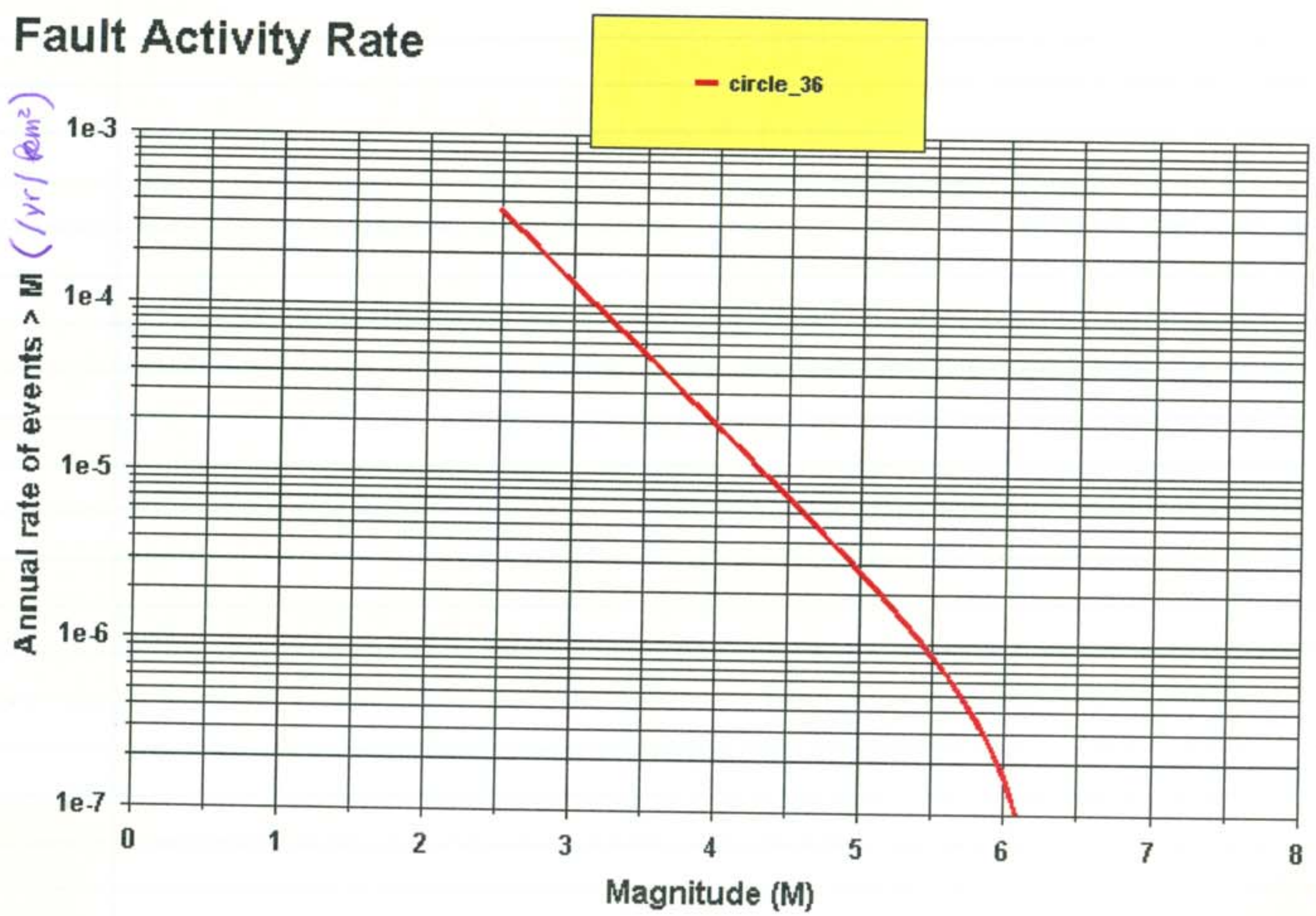
$= 1.91$

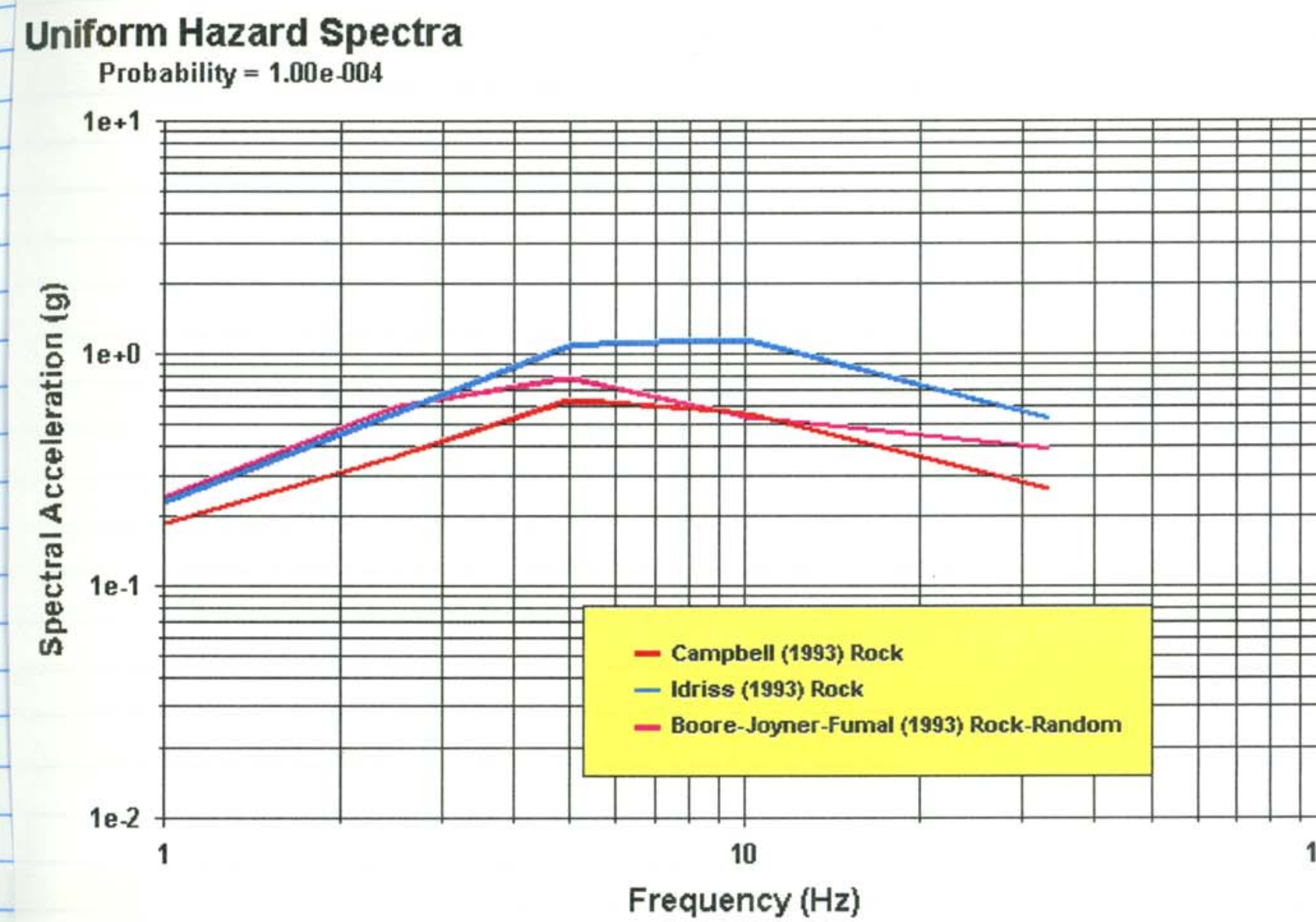
Fig. on P.38 show earthquake recurrence curve. The rat is ~~in~~ /yr/km². This curve ~~is~~ ~~com~~ duplicate that shown (the mean) on P A-17 of CRWMS (1994 report)

2.3.3 Analyses using only the background zone described on p.36

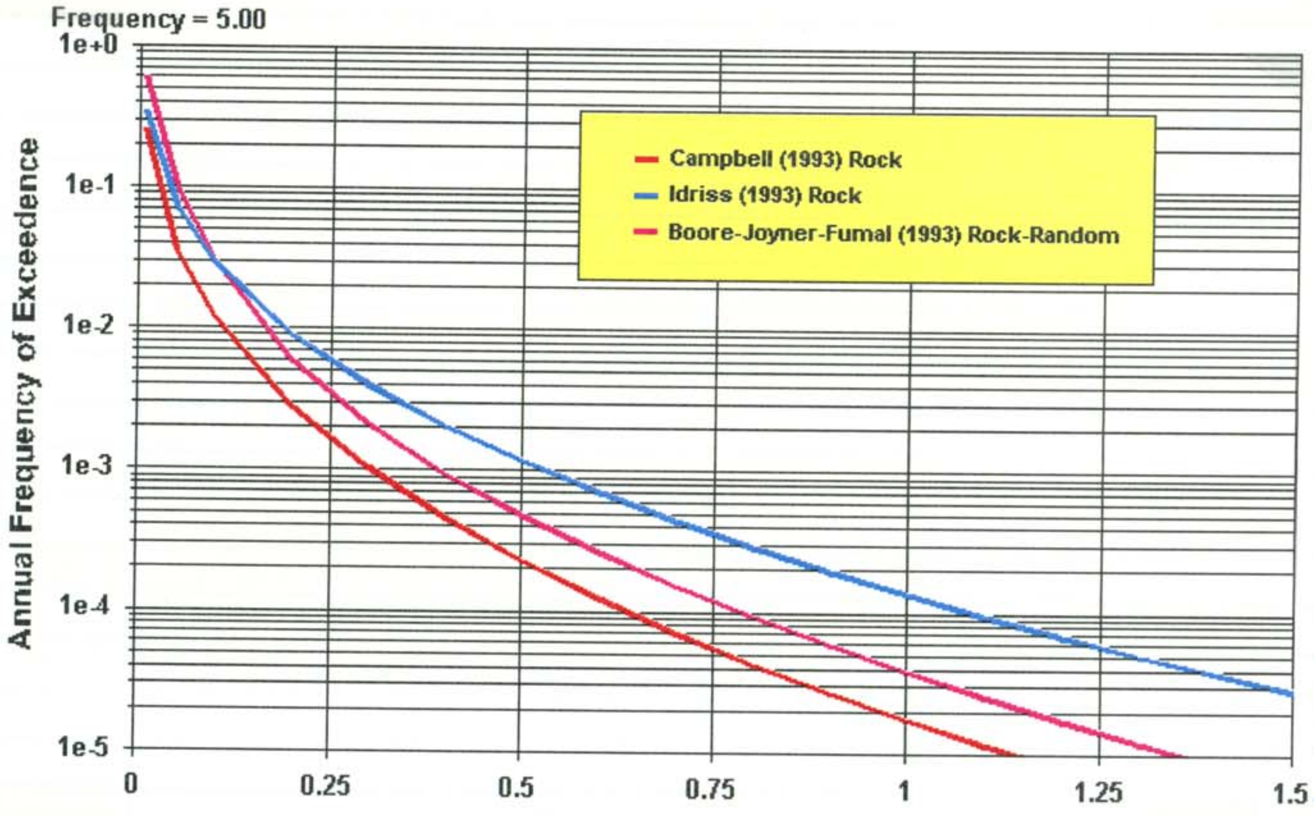
- Input file and calculation parameters are build in the same way as described on p.11. Input file name: YM1.INP
- Attenuation functions are selected according to description on p.33 and those shown on p.34 are selected
- Modified area source described on p.36 is used to attempt to re duplicate DOE analyses for ESF [Wong et al. 1995] ~~Fig on P38 shown~~
- Figs on p.39-42 show results.

ok
[signature] 8/25/00

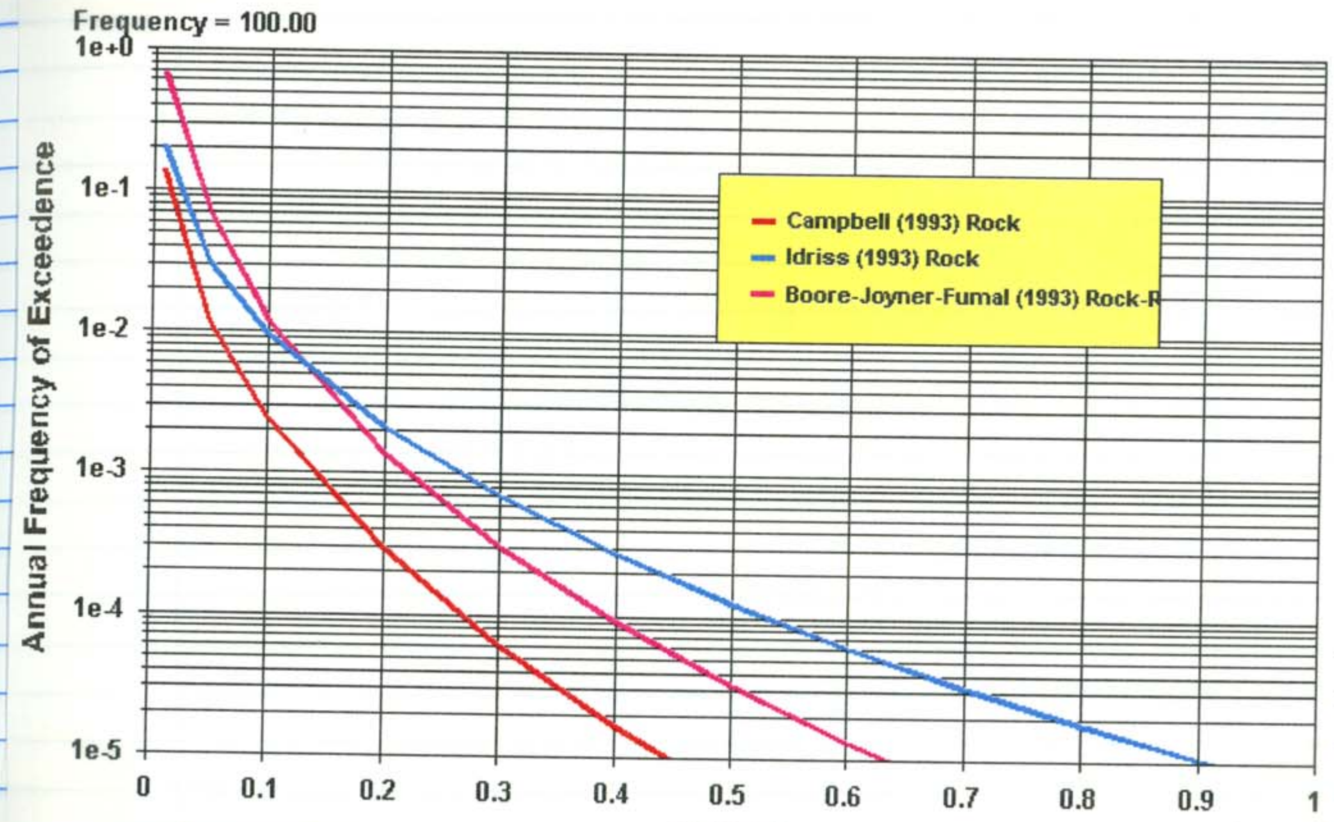

Fault Activity Rate
circle_36
Annual rate of events > M (/yr/km²)
1e-3
1e-4
1e-5
1e-6
1e-7
0
1
2
3
4
5
6
7
8
Magnitude (M)

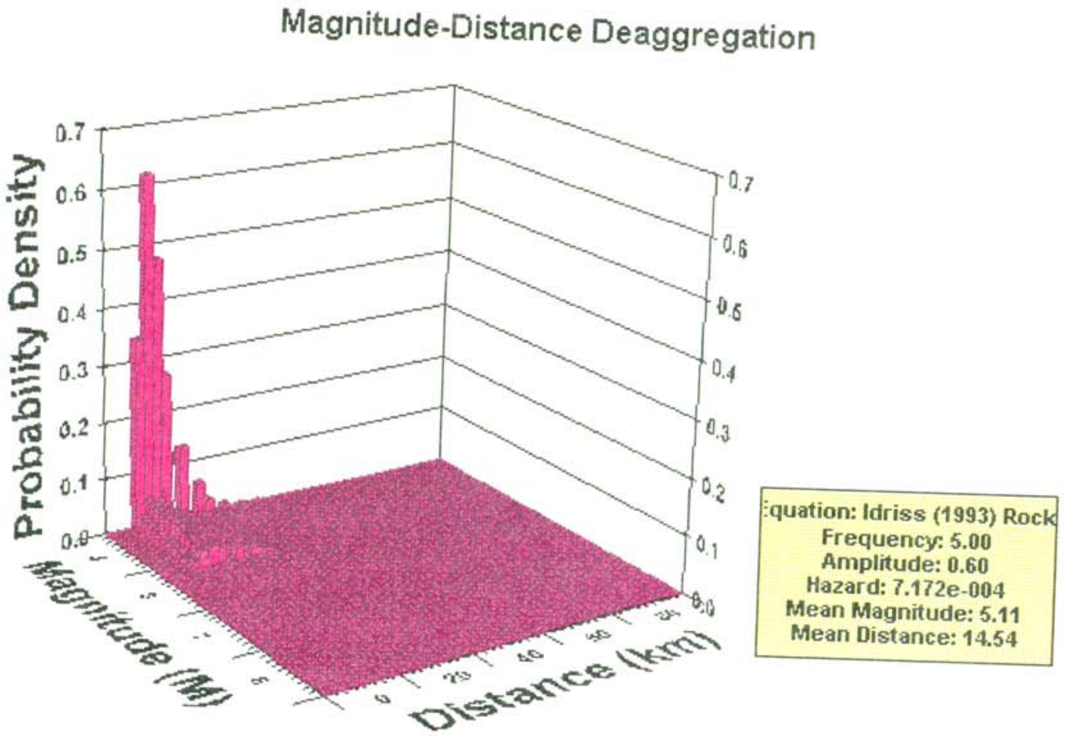

Uniform Hazard Spectra
Probability = 1.00e-004
Spectral Acceleration (g)
1e+1
1e+0
1e-1
1e-2
1
10
100
Frequency (Hz)
Campbell (1993) Rock
Idriss (1993) Rock
Boore-Joyner-Fumal (1993) Rock-Random

Total Hazard from the Background zone



Total Hazard from the background zone





Z-34 YM Fault Source ①: South Death Valley E&S

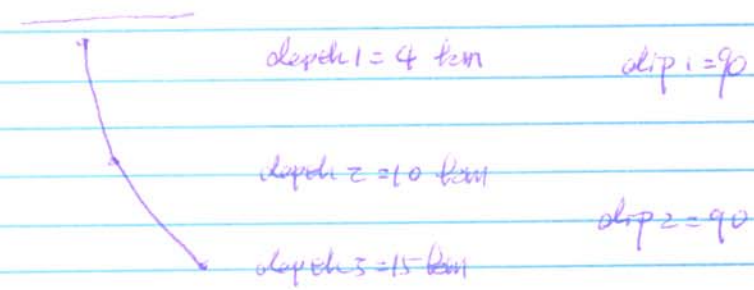
- using property information included in EZ-FRISK Fault source database for demonstration purpose only. These parameters, including geometry may be modified according to DOE & CNWRA data.

- Region: California

Name: S Death Valley E&S

Type: Reverse ?

Geometry:



Parameters:

Min magnitude: 5.

Max magnitude: 7.1

Rupture Length { Al = -2.42, Bl = 0.58, Sigl = 1. e-00 }

Recurrence: characteristic (instead of Exponential)

Rate type: Slip Rate (instead of Activity Rate a/yr)

Rate: 3 mm/yr

Beta: 2.0723

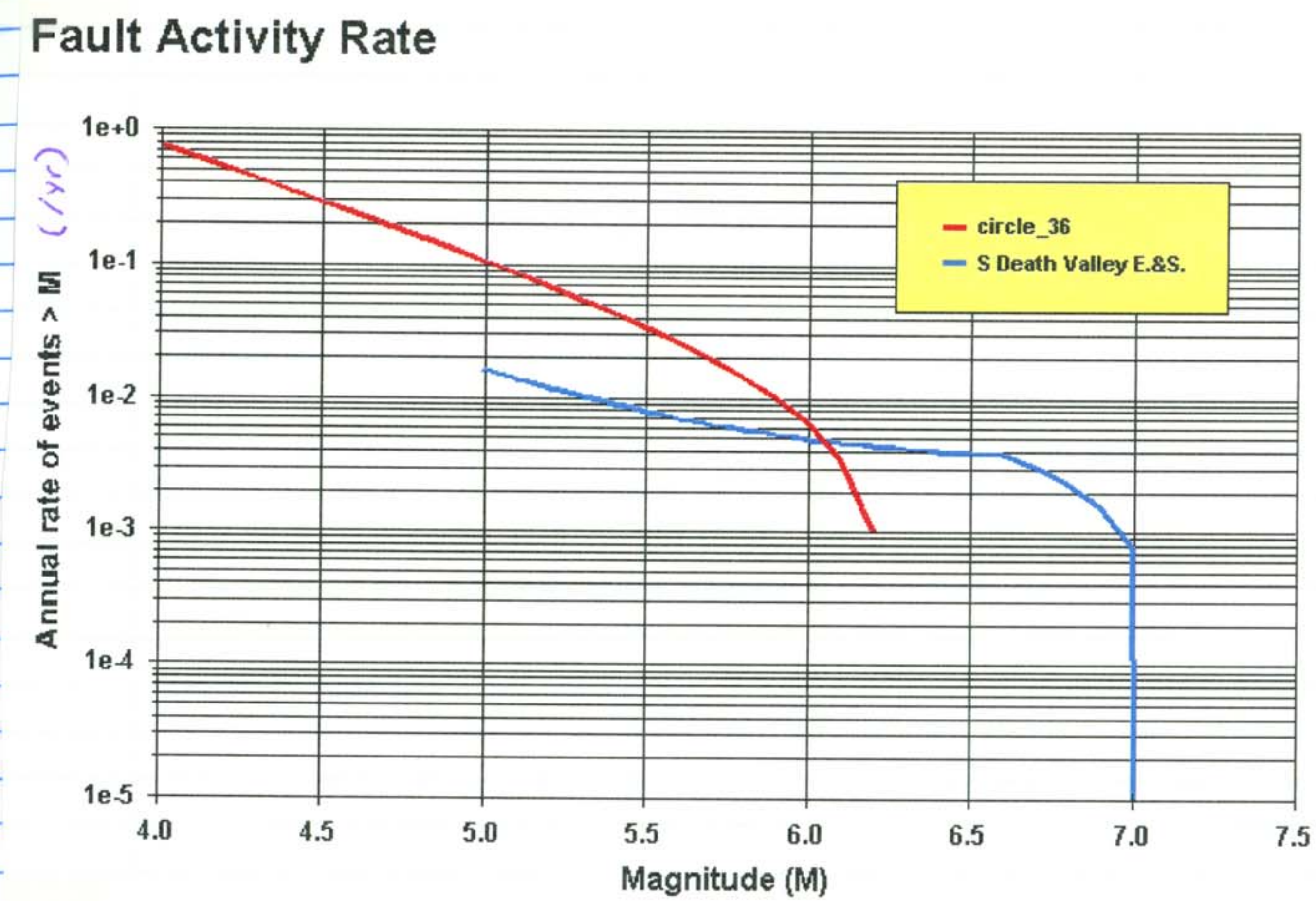
Delta1: 0.5

Delta2: 1.5

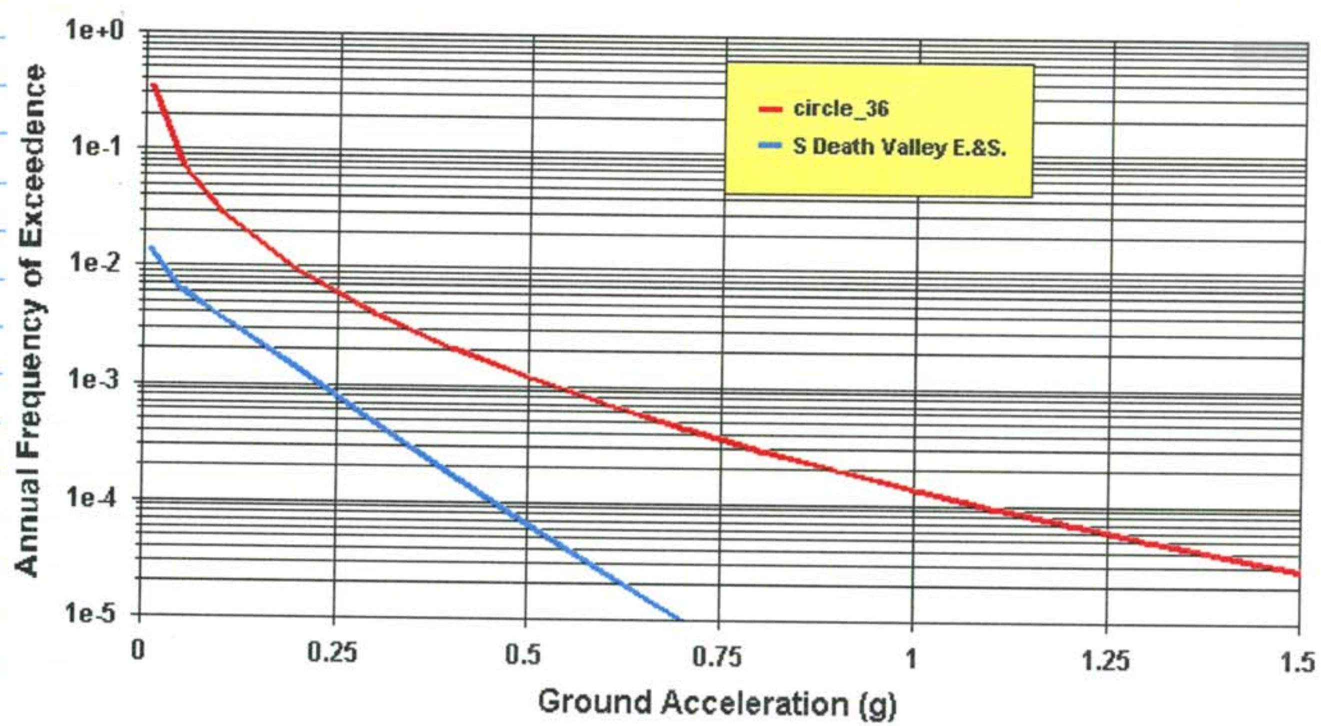
R.C. 6/18/97

2-3.5 Analyses including the background source zone described on p. 36 and South Death Valley fault zone described on p. 43

- Input: YMZ.INP
- Results: See Figs on p. 45 through



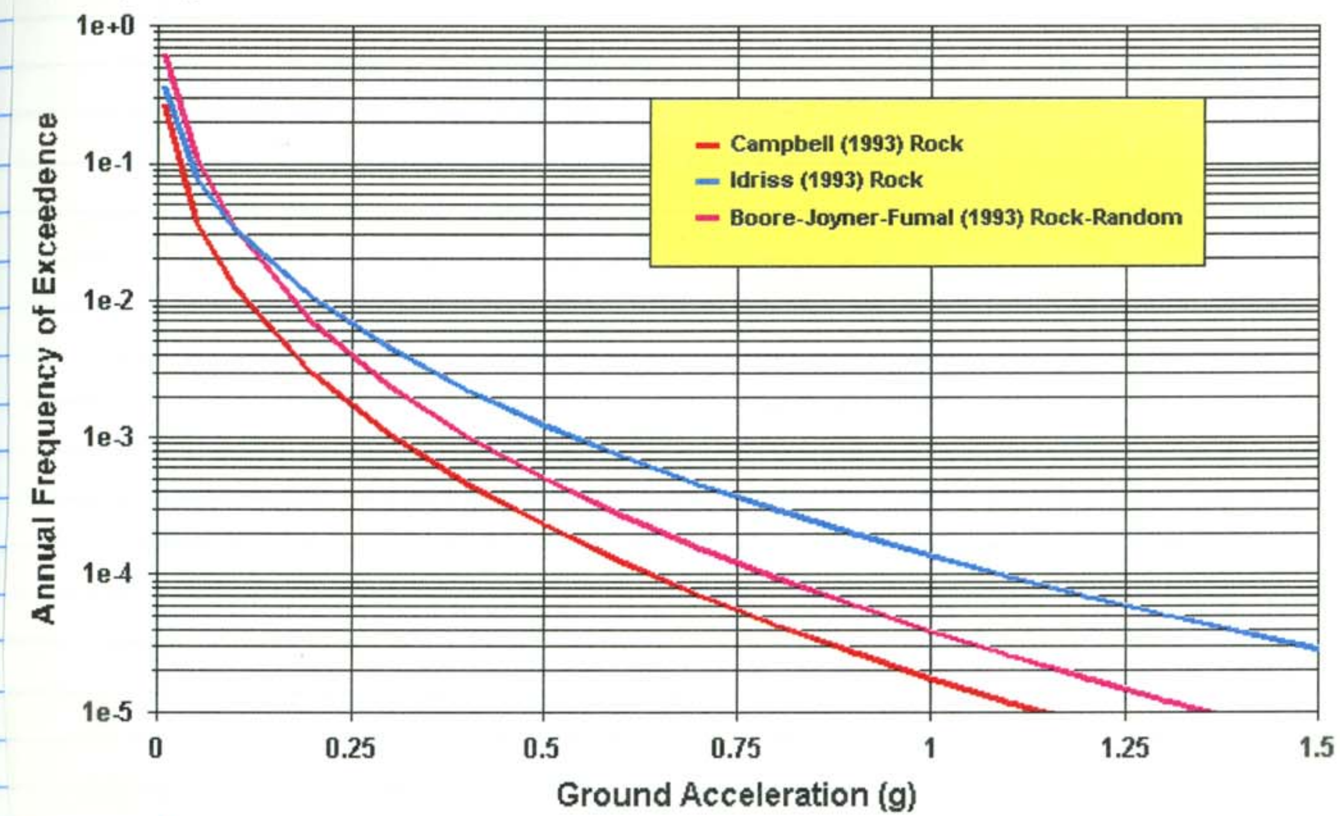
Hazard by Source from YM2.INP

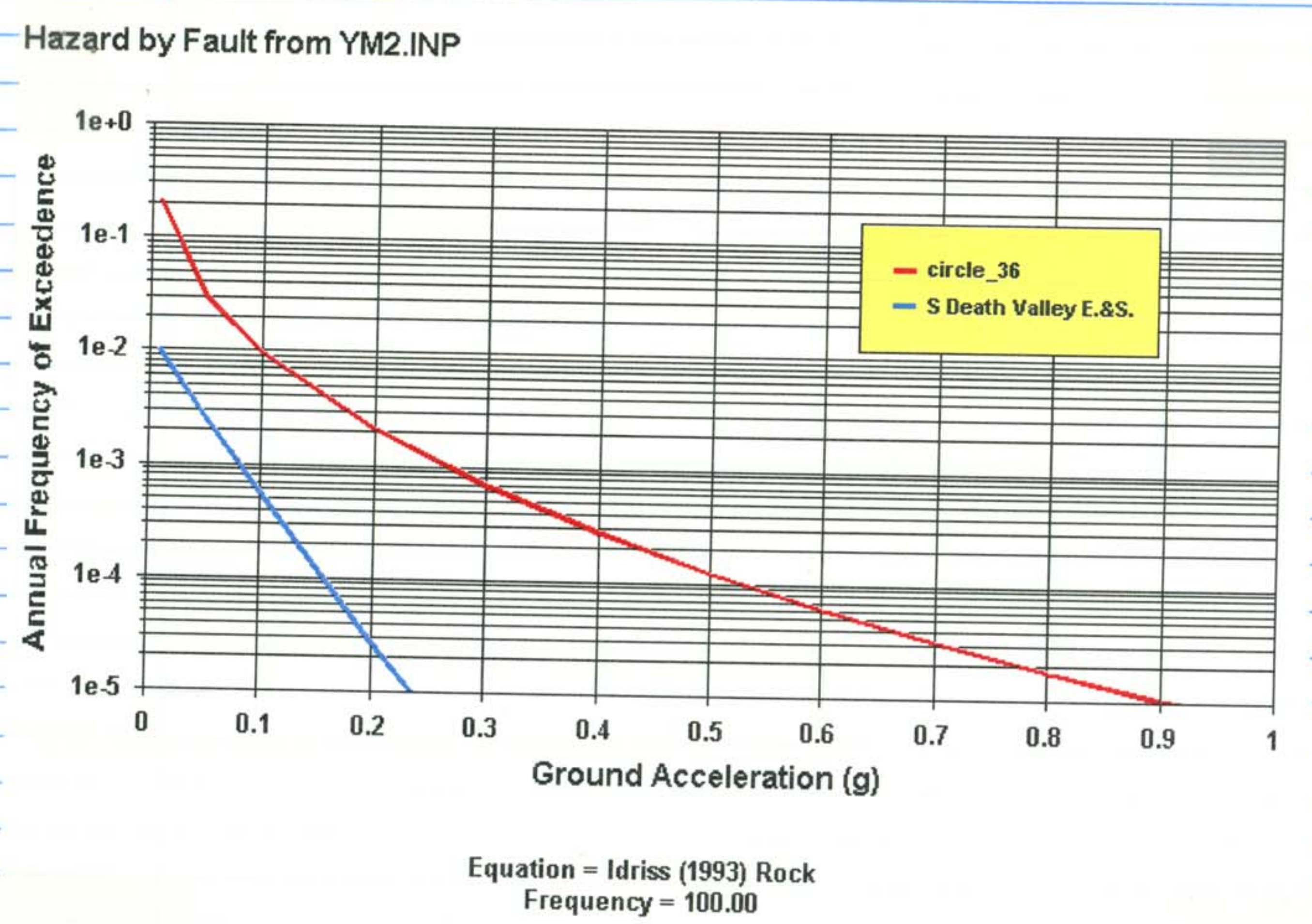


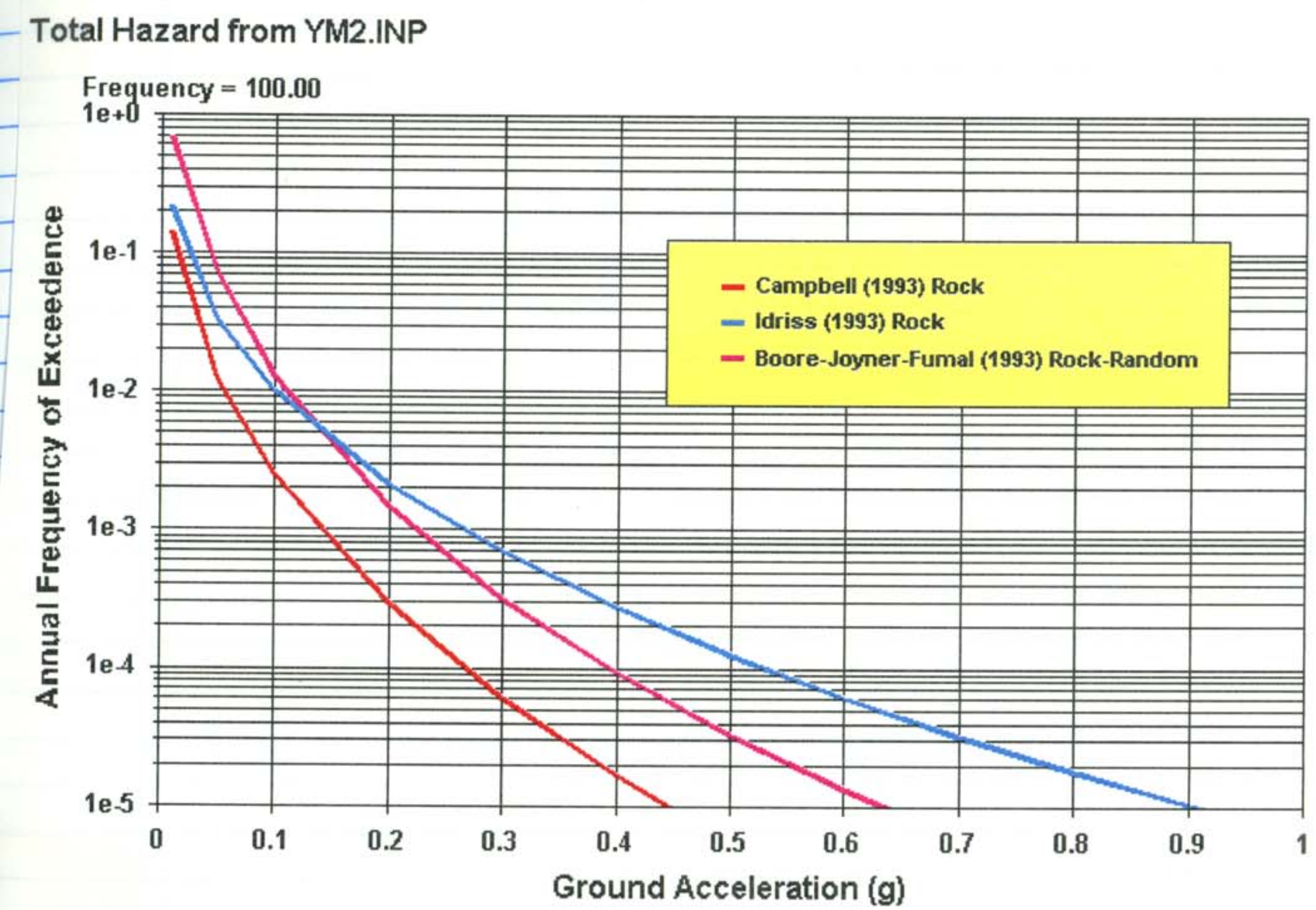
Equation = Idriss (1993) Rock
Frequency = 5.00

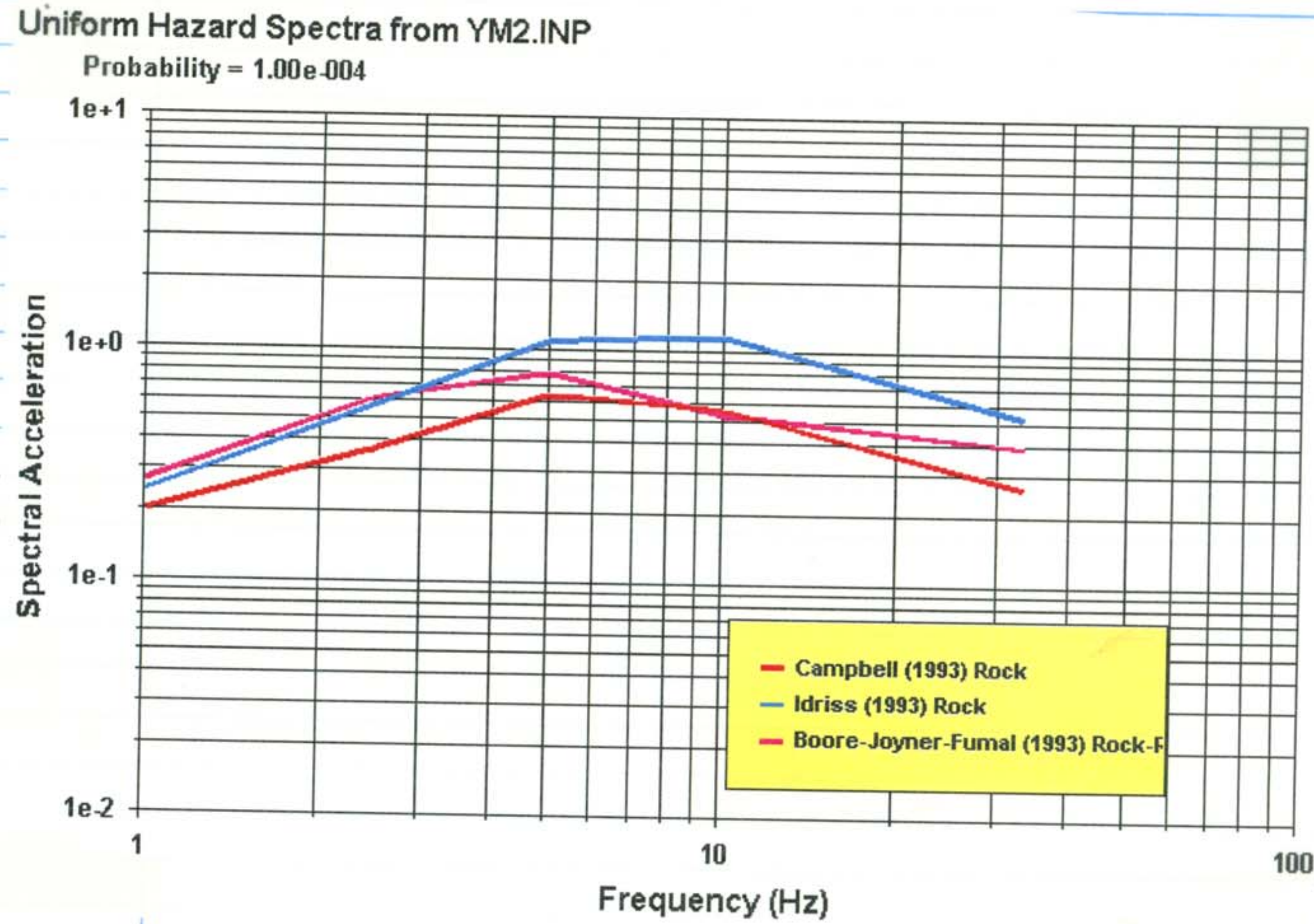
Total Hazard

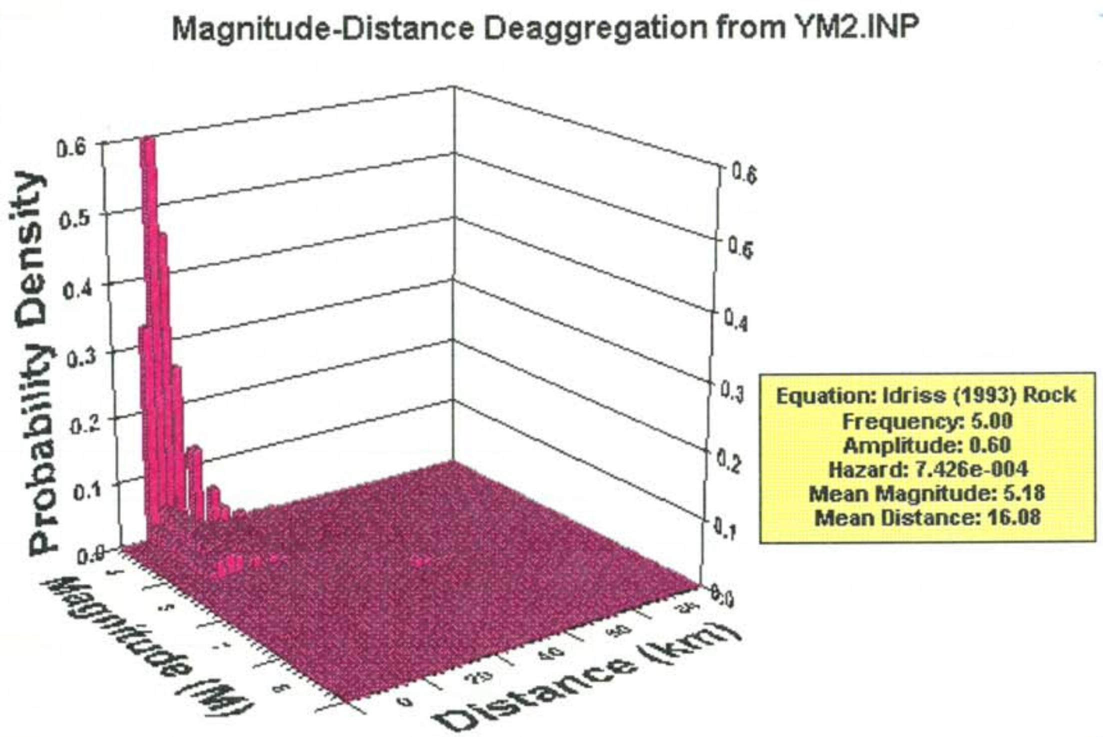
Frequency = 5.00




Hazard by Fault from YM2.INP
Annual Frequency of Exceedence
1e+0
1e-1
1e-2
1e-3
1e-4
1e-5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Ground Acceleration (g)
circle_36
S Death Valley E.&S.
Equation = Idriss (1993) Rock
Frequency = 100.00


Total Hazard from YM2.INP
Frequency = 100.00
Annual Frequency of Exceedence
1e+0
1e-1
1e-2
1e-3
1e-4
1e-5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Ground Acceleration (g)
Campbell (1993) Rock
Idriss (1993) Rock
Boore-Joyner-Fumal (1993) Rock-Random


Uniform Hazard Spectra from YM2.INP
Probability = 1.00e-004
1e+1
1e+0
1e-1
1e-2
Spectral Acceleration
1
10
100
Frequency (Hz)
Campbell (1993) Rock
Idriss (1993) Rock
Boore-Joyner-Fumal (1993) Rock-F


Magnitude-Distance Deaggregation from YM2.INP
Probability Density
Magnitude (M)
Distance (km)
Equation: Idriss (1993) Rock
Frequency: 5.00
Amplitude: 0.60
Hazard: 7.426e-004
Mean Magnitude: 5.18
Mean Distance: 16.08

2-3.6 Implementation of Additional Attenuation Functions ①

PGA

I. Boore, Joyner, and Fumal (1997)

1) Original Boore, Joyner, and Fumal (1997) equation:

$$\ln y = b_1' + b_2'(M-6) + b_3'(M-6)^2 + b_5' \ln r + b_V \ln \frac{V_S}{V_A} \quad \text{---- ①}$$

where: $r = \sqrt{r_{jb}^2 + h^2}$

$$b_1' = \begin{cases} b_{1SS} & \text{Strike slip} \\ b_{1RS} & \text{Reverse slip} \\ b_{1ALL} & \text{All Fault} \end{cases}$$

Y — Peak horizontal acceleration or pseudoacceleration response in g

Predictor variables:

M — Moment magnitude

r_{jb} — horizontal distance

V_S — Average shear wave velocity over 30m (in m/s)

Coefficients: b_{1SS}, b_{1RS}, b_{1ALL}, b_2, b_3, b_5, h, b_V, V_A

2) Equation form available in EZ-FRISK 3.0 (1996)

$$\log y = b_1 + b_2(M-6) + b_3(M-6)^2 + b_4 r + b_5 \log(r) + b_6 G_B + b_7 G_C$$

$$r = (d^2 + h^2)^{1/2} \quad \text{---- ②}$$

$$\sigma_{\log(y)} = \sigma$$

3) In order to input equation ① in the form of equation ②, equation needs to be modified

3.1 Change the base of log function from e to 10:

since: $\log_a b = \frac{\log_c b}{\log_c a}$

$$\log_e y = \ln y = \frac{\log y}{\log e}$$

Equation ① can, therefore, be rewritten as:

$$\log y = \log e \cdot [\, b_1' + b_2'(M-6) + b_3'(M-6)^2 + b_5(\log r / \log e) + b_V \ln \frac{V_S}{V_A} \,] \quad \text{—— ③}$$

Comparing Eqs. ② and ③, we obtain:

GPA

$h = h' = 5.57$

$$b_1 = \log e \cdot b_1' = \begin{cases} -0.1359 & \text{(strike slip)} \\ -0.0508 & \text{(reverse slip)} \\ -0.1051 & \text{(all)} \end{cases}$$

$b_2 = \log e \cdot b_2' = 0.2289$

$b_3 = \log e \cdot b_3' = 0$

$b_4 = 0 \quad = 0$

$b_5 = b_5' = -0.778$

$$b_6 = b_V \cdot \ln \frac{V_S}{V_A} \cdot \log e = \log e \cdot b_V \ln \frac{600}{V_A}$$

[for Rock site: $V_S = 600$ m/s] $= 0.1308$

$G_B = 1$

$G_C = 0$

$b_7 = 0$

A fortran program needs to be written for spectra accelerations.

Table 1 on page 54 lists conditions & coefficients.

Page 55 gives the source code for converting the coefficients.

Information potentially subject to copyright protection was redacted from this location. The redacted material is from the following reference:

Boore, Joyner, and Fumeel. Table 8: Smoothed coefficients for us in equation... . Seismological Research Letters. Vol. 68, No. 1. p. 146. January/February 1997. No additional information is known.

This Fortran file is calculate ground motion (g) according to Boore et al. (1997) and print out a Table for input in EZF30:


```
      PROGRAM Boore
C
C ============================================================
C  This program calculates ground motion due to earthquakes
C  according to attenuation function proposed by Boore, Joyner,
C  and Fumal (1997, Seismological Research Letters 68:128-153.
C  The coefficients for the attenuation function are read from
C  file "Boore.97". The results are written in the formate
C  required by EZF30 for input as tables in calculating
C  seismic hazard. These tabular results are written to
C  file "Boore_97.tbl"
C ============================================================
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      CHARACTER LINE*180, FNAME*80
      REAL*8 VAR(100,15)
      REAL*8 period(100), B1ss(100),B1rv(100),B1all(100),B2(100),B3(100)
      REAL*8 B5(100),Bv(100),Va(100),H(100),Sig1(100),Sigc(100)
      REAL*8 Sigr(100),Sige(100),Sigy(100)
      REAL*8 DIST(20),MAG(20)
      REAL*8 Y(20,20),sigma(20,20)
      INTEGER nperiod,ndist,nmag
C
C Open files
      FNAME='Boore.97'
      OPEN(UNIT=1,FILE=FNAME,STATUS='OLD',FORM='FORMATTED')
C
C Read the coefficient file
C
      READ(1,'(A)') LINE
      READ(1,'(A)') LINE
      READ(1,'(A)') LINE
      nperiod=0
      DO 88 i=1,1000
        READ(1,'(A)',END=99) LINE
        nperiod=i
        READ(LINE,*)  (VAR(i,j),j=1,15)
        period(i)=VAR(i,1)
        B1ss(i)=VAR(i,2)
        B1rv(i)=VAR(i,3)
        B1all(i)=VAR(i,4)
        B2(i)=VAR(i,5)
        B3(i)=VAR(i,6)
        B5(i)=VAR(i,7)
        BV(i)=VAR(i,8)
        VA(i)=VAR(i,9)
        H(i)=VAR(i,10)
        Sig1(i)=VAR(i,11)
        Sigc(i)=VAR(i,12)
        Sigr(i)=VAR(i,13)
        Sige(i)=VAR(i,14)
        Sigy(i)=VAR(i,15)
   88 CONTINUE
   99 CONTINUE
C
C Calculate ground motion
C
      FNAME='Boore_97.tbl'
      OPEN(UNIT=3,FILE=FNAME, STATUS='UNKNOWN',FORM='FORMATTED')
C
```

This Fortran file is calculate ground motion (g) according to Boore et al (1997) and print out a Table for input in EZFRC:


```
C       do 22 i=1,nperiod
C        write(3,7000) period(i),b1ss(i),b1rv(i),b1all(i),b2(i),b3(i),
C     .                b5(i),bv(i),va(i),h(i),
C     .                sig1(i),sigc(i),sigr(i),sige(i),sigy(i)
C    22 continue
C
        write(3,*) 'Boore et al. (1997) - Rock, Strick Slip'
        write(3,1000) nperiod
        ndist=20
        nmag=20
        DO 77 i=1,nperiod
          Write(3,2000) period(i),nmag,ndist
          DO 66 j=1,ndist
C             dist(j)=1.0+(j-1)*((100.0-1.0)/19.0)
            dist(j)=10.0**((j-1)*2.0/19.0)
            DO 55 k=1,nmag
             mag(k)=4.0+(k-1)*((8.0-4.0)/19.0)
             Y(j,k)=exp(b1ss(i)+b2(i)*(mag(k)-6)+b3(i)*(mag(k)-6)**2
     .               +b5(i)*log(sqrt(dist(j)**2+h(i)**2))
     .               +bv(i)*log(620/va(i)))
             sigma(j,k)=sigy(i)
   55       continue
   66     continue
          write(3,3000) (dist(j),j=1,ndist)
          do 33 k=1,nmag
           write(3,3500) mag(k)
           write(3,4000) (Y(j,k),j=1,ndist)
           write(3,4000) (sigma(j,k),j=1,ndist)
   33     continue
   77 continue
C
 1000 FORMAT(i5)
 2000 FORMAT(f4.2,2i4)
 3000 FORMAT(f4.2,f5.2,17f6.2,f7.2)
 3500 FORMAT(f4.2)
 4000 FORMAT(20f6.3)
 7000 FORMAT(8f7.3,f6.0,6f7.3)
      END
```

The table file for EZF30 for strike-slip fault and rock site is:

Boore-97.tbl in C:/EZF30/ATTEN/

Comparison of peak-ground motion calculated from EZF30 according to procedure on p.53 is identical to the results also calculated by EZF30 using the table, showing that table calculation is correct!

* For other type of slip and other site rather than rock site, a different table will have to be generated.

* Program "Boore.f" could also be used for other purposes in analyzing the attenuation function proposed by Boore et. al. (1997). For example, one could used it to print out files for using other graphic package for plotting purpose.

II. Spudich et al. (1997) [Seismological Research Letter, V 68: p190-198]

(A) Range of moment magnitude : 5.0 - 7.7
Range of distance : 0 - 70 km
Tend to overpredict for R > 70 km

$$\log_{10} Y = b_1' + b_2'(M-6) + b_3'(M-6)^2 + b_4' R + b_5' \log_{10} R + b_6' \Gamma \quad (4)$$

$$\sigma_{\log Y} = \sqrt{\sigma_1 + \sigma_2}$$

$$R = \sqrt{r_{jb}^2 + h^2}$$

$$\Gamma = \begin{cases} 0 & \text{Rock} \\ 1 & \text{soil} \end{cases}$$

$\sigma_{\log Y}$ = the standard deviation of $\log_{10} Y$

Y = peak horizontal acceleration (g) or pseudovelocity response (cm/s) at 5% damping for the geometric mean horizontal component of motion;

(B) Compare equation (4) with equation (3) we have:

PGA

$h = h$ = 5.57
$b_1 = b_1'$ = 0.156
$b_2 = b_2'$ = 0.229
$b_3 = b_3'$ = 0
$b_4 = b_4'$ = 0
$b_5 = b_5'$ = -0.945
$b_6 = b_6'$ = 0.077
$G_B = \Gamma = \begin{cases} 0 & \text{Rock} ✓ \\ 1 & \text{soil} \end{cases}$
$\sigma = \sigma' = \sqrt{\sigma_1 + \sigma_2}$ = 0.216

Table 2 on page 58 lists coefficients for equation (4)

For 5% damping motion, the pseudovelocity needs to be convert to pseudo acceleration. This is discussed on page 59 & 60.

A Fortran program is written for this purpose & attached to page 60.

Information potentially subject to copyright protection was redacted from this location. The redacted material is from the following reference:

Spudish, et al. Table 3: Smoothed coefficients for regression relation... Seismological Research Letter. Vol. 68. pp. 190-198. 1997.

(c) Table Input for Spectral Ground Acceleration:

Since coefficients in table are given as 5% damped spectral velocity, calculated velocity needs to be converted to acceleration.

According to EZF30.

$$\ln(V) = x + \ln\left(\frac{981}{2\pi f}\right) \qquad f \text{ - frequency}$$

$$\ln(a) = \ln(y)$$

$$\ln(V) = \ln(y) + \ln\frac{980}{2\pi f}$$

$$= \ln\left(y \cdot \frac{980}{2\pi f}\right) = \ln\left(\frac{y \cdot 980}{2\pi f}\right)$$

$$y = V \cdot \frac{2\pi f}{980} = V \cdot \frac{2\pi}{s \cdot 980}$$

Source code on page 60 calculates a table for input to EZF30 for calculating spectral acceleration.

```
      PROGRAM Spudich
C
C ==============================================================
C  This program calculates ground motion due to earthquakes
C  according to attenuation function proposed by Spudich et al.
C  (1997, Seismological Research Letters 68:190-198).
C  The coefficients for the attenuation function are read from
C  file "Spudich.97". The results are written in the formate
C  required by EZF30 for input as tables in calculating
C  seismic hazard. These tabular results are written to
C  file "Spudich_97.tbl"
C ==============================================================
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      CHARACTER LINE*180, FNAME*80
      REAL*8 VAR(100,15)
      REAL*8 period(100), NR(100),NQ(100),B1(100),B2(100),B3(100)
      REAL*8 B4(100),B5(100),B6(100),H(100),Sig1(100),Sig2(100)
      REAL*8 Sig3(100)
      REAL*8 DIST(20),MAG(20)
      REAL*8 Y(20,20),sigma(20,20)
      INTEGER nperiod,ndist,nmag
C
C Open files
      FNAME='Spudich.97'
      OPEN(UNIT=1,FILE=FNAME,STATUS='OLD',FORM='FORMATTED')
C
C Read the coefficient file
C
      READ(1,'(A)') LINE
      READ(1,'(A)') LINE
      nperiod=0
      DO 88 i=1,1000
        READ(1,'(A)',END=99) LINE
        nperiod=i
        READ(LINE,*) (VAR(i,j),j=1,13)
        period(i)=VAR(i,1)
        NR(i)=VAR(i,2)
        NQ(i)=VAR(i,3)
        B1(i)=VAR(i,4)
        B2(i)=VAR(i,5)
        B3(i)=VAR(i,6)
        B4(i)=VAR(i,7)
        B5(i)=VAR(i,8)
        B6(i)=VAR(i,9)
        H(i)=VAR(i,10)
        Sig1(i)=VAR(i,11)
        Sig2(i)=VAR(i,12)
        Sig3(i)=VAR(i,13)
   88 CONTINUE
   99 CONTINUE
C
C Calculate ground motion
C
      FNAME='Spudi_97.tbl'
      OPEN(UNIT=3,FILE=FNAME, STATUS='UNKNOWN',FORM='FORMATTED')
C
C      do 22 i=1,nperiod
C       write(3,7000) period(i),NR(i),NQ(i),b1(i),b2(i),b3(i),
C     .               b4(i),b5(i),b6(i),h(i),
```

```
C     .                  sig1(i),sig2(i),sig3(i)
C   22 continue
C
      write(3,*) 'Spudich et al. (1997) - Rock, Normal'
      write(3,1000) nperiod
      ndist=20
      nmag=20
      DO 77 i=1,nperiod
        Write(3,2000) period(i),nmag,ndist
        DO 66 j=1,ndist
          dist(j)=10.0**((j-1)*2.0/19.0)
          DO 55 k=1,nmag
           mag(k)=4.0+(k-1)*((8.0-4.0)/19.0)
           if(period(i).eq.0.01) then
             Y(j,k)=10**(b1(i)+b2(i)*(mag(k)-6)+b3(i)*(mag(k)-6)**2
     .             +b4(i)*sqrt(dist(j)**2+h(i)**2)
     .             +b5(i)*log10(sqrt(dist(j)**2+h(i)**2)))
           else
             Y(j,k)=2*3.14/(period(i)*981)
     .             *10**(b1(i)+b2(i)*(mag(k)-6)+b3(i)*(mag(k)-6)**2
     .             +b4(i)*sqrt(dist(j)**2+h(i)**2)
     .             +b5(i)*log10(sqrt(dist(j)**2+h(i)**2)))
           endif
           sigma(j,k)=10**(sqrt(sig1(i)**2+sig2(i)**2))
   55     continue
   66   continue
        write(3,3000) (dist(j),j=1,ndist)
        do 33 k=1,nmag
         write(3,3500) mag(k)
         write(3,4000) (Y(j,k),j=1,ndist)
         write(3,4000) (sigma(j,k),j=1,ndist)
   33   continue
   77 continue
C
 1000 FORMAT(i5)
 2000 FORMAT(f4.2,2i4)
 3000 FORMAT(f4.2,f5.2,17f6.2,f7.2)
 3500 FORMAT(f4.2)
 4000 FORMAT(20f6.3)
 7000 FORMAT(8f7.3,f6.0,6f7.3)
      END
```

III. Campbell (1997)

The expression for horizontal peak ground acceleration is identical to Campbell and Bozorgnia (1994) in EZ-FRISK (2.)

Equation:

$$\ln(A_H) = -3.512 + 0.904M - 1.328\ln\left(\sqrt{R_{seis}^2 + [0.149\exp(0.647M)]^2}\right) \cdots$$
$$+ [1.125 - 0.112\ln(R_{seis}) - 0.0957M]F$$
$$+ [0.440 - 0.171\ln(R_{seis})]S_{SR}$$
$$+ [0.405 - 0.222\ln(R_{seis})]S_{HR} + \varepsilon \quad \text{------ (5)}$$

A_H = PGA in g in the horizontal direction ($g = 981\ cm/s^2$)

ε = standard deviation of $\ln(A_H)$

M = Moment magnitude

R_{seis} = source-to-site distance (the closest distance to the rupture surface).

F = style of faulting { 1 reverse, thrust, reverse oblique; 0 strike slip.

$S_{SR}=0$ $S_{HR}=0$ for alluvium or firm soil

$S_{SR}=1$ $S_{HR}=0$ soft rock

$S_{SR}=0$ $S_{HR}=1$ hard rock.

[signature] 8/25/00

- However, in the database for atten. equations in EZ-FRISK (3.0), F, S_{SR} and S_{HR} are not given correctly.

  Therefor, a corrected version for use at YM (hard rock) is included and named Campbell (1997) A_H H rock.

- There is not a functional form in EZ-FRISK that can be used to input Campbell (1997) Spectral Acceleration (horizontal).

* Therefore, table input may have to be explored. This applies

The Campbell (1997) attenuation for SAH:

$$\ln(SA_H) = \ln(A_H) + C_1 + C_2 \tanh[C_3(M-4.7)] + (C_4 + C_5 M) R_{SEIS} + 0.5 C_6 S_{SR} + C_6 S_{HR} + C_7 \tanh(C_8 D)(1-S_{HR}) + f_{SA}(D) + \varepsilon \quad (6)$$

where: $D \geq 1$ km

$f_{SA}(D) = 0 \qquad D < 1$ km

$= C_6(1-S_{HR})(1-D) + 0.5 C_6 (1-D S_{SR}) \qquad D > 1$ km

The follow table lists coefficients (table 3)

Information potentially subject to copyright protection was redacted from this location. The redacted material is from the following reference:

Campbell. Table 3: Regression coefficients... 1997. No additional information is known.

For A_H:

$$\sigma = \begin{cases} 0.55 & A_H < 0.068\,g \\ 0.173 - 0.140 \ln(A_H) & 0.068\,g \leq A_H \leq 0.21\,g \\ 0.39 & A_H > 0.21\,g \end{cases}$$

$$\sigma = \begin{cases} 0.889 - 0.0691M & M < 7.4 \\ 0.38 & M \geq 7.4 \end{cases}$$

For SA_H: $\sigma_H = \sqrt{\sigma^2 + 0.27^2}$

For vertical components:

1) $$\ln(A_V) = \ln(A_H) - 1.58 - 0.10M - 1.5\ln[R_{SEIS} + 0.079\exp(0.661M)] + 1.89\ln[R_{SEIS} + 0.361\exp(0.576M)] - 0.11F + \varepsilon \quad (7)$$

$$\ln(SA_V) = \ln(SA_H) + C_1 - 0.10M + C_2\tanh[0.71(M-4.7)] + C_3\tanh[0.66(M-4.7)] + 1.50\ln[R_{SEIS} + 0.071\exp(0.661M)] + 1.89\ln[R_{SEIS} + 0.361\exp(0.576M)] - 0.11F + C_4\tanh(0.51D) + C_5\tanh(0.57D) + \varepsilon$$

Table 4 lists coefficients

~~For SAH: σH~~ = R.C.

For A_V: $\sigma_V = \sqrt{\sigma^2 + 0.36^2}$

For SA_V: $\sigma_V = \sqrt{\sigma_H^2 + 0.39^2}$

Information potentially subject to copyright protection was redacted from this location. The redacted material is from the following reference:

Campbell. Table 6: Regression coefficients... 1997. No additional information is known.

```
      PROGRAM Spudich
C
C ==========================================================
C  This program calculates ground motion due to earthquakes
C  according to attenuation function proposed by Campbell
C  (1997, Seismological Research Letters 68:154-179).
C  The coefficients for the attenuation function are read from
C  file "Campbell.97". The results are written in the formate
C  required by EZF30 for input as tables in calculating
C  seismic hazard. These tabular results are written to
C  file "Campb_97.tbl"
C ==========================================================
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      CHARACTER LINE*180, FNAME*80
      REAL*8 VAR(100,9)
      REAL*8 period(100), C1(100),C2(100),C3(100)
      REAL*8 C4(100),C5(100),C6(100),C7(100),C8(100)
      REAL*8 DIST(20),MAG(20)
      REAL*8 Y(20,20),sigma(20,20)
      REAL*8 AH(20,20),sigma1(20,20),f1(20,20)
      REAL*8 AH1(20,20),AH2(20,20),AH3(20,20),AH4(20,20)
      REAL*8 Y1(20,20),Y2(20,20),Y3(20,20),Y4(20,20)
      REAL*8 Y5(20,20)
      REAL*8 f,d,Shr,Ssr
      INTEGER nperiod,ndist,nmag
C
C Open files
      FNAME='Campbell_h.97'
      OPEN(UNIT=1,FILE=FNAME,STATUS='OLD',FORM='FORMATTED')
C
C Read the coefficient file
C
      READ(1,'(A)') LINE
      READ(1,'(A)') LINE
      READ(1,'(A)') LINE
      READ(1,'(A)') LINE
      READ(1,'(A)') LINE
      nperiod=0
C
C For peak ground acceleration
C
      period(1)=0.01
      C1(1)=0.0
      C2(1)=0.0
      C3(1)=0.0
      C4(1)=0.0
      C5(1)=0.0
      C6(1)=0.0
      C7(1)=0.0
      C8(i)=0.0
C
C For spectral acceleration
C
      DO 88 i=2,14
        READ(1,'(A)',END=99) LINE
        nperiod=i
        READ(LINE,*) (VAR(i,j),j=1,9)
        period(i)=VAR(i,1)
        C1(i)=VAR(i,2)
```

```
          C2(i)=VAR(i,3)
          C3(i)=VAR(i,4)
          C4(i)=VAR(i,5)
          C5(i)=VAR(i,6)
          C6(i)=VAR(i,7)
          C7(i)=VAR(i,8)
          C8(i)=VAR(i,9)
   88 CONTINUE
   99 CONTINUE
C
C Calculate ground motion
C
        FNAME='Campb_97.tbl'
        OPEN(UNIT=3,FILE=FNAME, STATUS='UNKNOWN',FORM='FORMATTED')

C         do 22 i=1,nperiod
C          write(3,7000) period(i),C1(i),C2(i),C3(i),
C                        C4(i),C5(i),C6(i),C7(i),C8(i)
C     22 continue
C
        write(3,*) 'Campbell (1997) - Hard Rock,SS,H'
        write(3,1000) nperiod
        ndist=20
        nmag=20
        F=0.0
        Ssr=0.0
        Shr=1.0
        D=0.1
        DO 77 i=1,nperiod
          Write(3,2000) period(i),nmag,ndist
          DO 66 j=1,ndist
            dist(j)=10.0**((j-1)*2.0/19.0)
            DO 55 k=1,nmag
             mag(k)=4.0+(k-1)*((8.0-4.0)/19.0)
             if(period(i).eq.0.01) then
              AH1(j,k)=-1.328*log(sqrt(dist(j)**2
                     +(0.149*exp(0.647*mag(k)))**2))
              AH2(j,k)=(1.125-0.112*log(dist(j))
                       -0.0957*mag(k))*F
              AH3(j,k)=(0.440-0.171*log(dist(j)))*Ssr
              AH4(j,k)=(0.405-0.222*log(dist(j)))*Shr
               AH(j,k)=exp(-3.512+0.904*mag(k)+AH1(j,k)
                       +AH2(j,k)+AH3(j,k)+AH4(j,k))
               Y(j,k)=AH(j,k)
               if(AH(j,k).LT.0.068) then
                 sigma1(j,k)=exp(0.55)
               elseif(AH(j,k).GT.0.21) then
                 sigma1(j,k)=exp(0.39)
               else
                 sigma1(j,k)=exp(0.173-0.140*log(AH(j,k)))
               endif
              sigma(j,k)=sigma1(j,k)
             else
              if(D.ge.1.0)then
                f1(j,k)=0.0
              else
                f1(j,k)=C6(i)*(1-Shr)*(1-D)+0.5*C6(i)*(1-D)*Ssr
              endif
              Y1(j,k)=log(AH(j,k))+C1(i)
              Y2(j,k)=C2(i)*tanh(c3(i)*(mag(k)-4.7))
```

```
            Y3(j,k)=(c4(i)+c5(i)*mag(k))*dist(j)
            Y4(j,k)=0.5*c6(i)*Ssr+c6(i)*Shr
            Y5(j,k)=c7(i)*tanh(c8(i)*D)*(1-Shr)+F1(j,k)
            Y(j,k)=exp(Y1(j,k)+Y2(j,k)+Y3(j,k)+Y4(j,k)+Y5(j,k))
            sigma(j,k)=exp(sqrt((log(sigma1(j,k)))**2+0.27**2))
           endif
   55     continue
   66   continue
        write(3,3000) (dist(j),j=1,ndist)
        do 33 k=1,nmag
         write(3,3500) mag(k)
         write(3,4000) (Y(j,k),j=1,ndist)
         write(3,4000) (sigma(j,k),j=1,ndist)
   33   continue
   77 continue
C
 1000 FORMAT(i5)
 2000 FORMAT(f4.2,2i4)
 3000 FORMAT(f4.2,f5.2,17f6.2,f7.2)
 3500 FORMAT(f4.2)
 4000 FORMAT(20(1P e9.2))
 7000 FORMAT(4f8.3,2f15.6,3f7.3)
      END
```

IV Sadigh et al. (1997)

Attenuation Relationship of Horizontal Response Spectral Accelerations (5% damping) for rock sites.

$$\ln(y) = c_1 + c_2 M + c_3 (8.5 - M)^{2.5} + c_4 \ln(r_{rup} + \exp(c_5 + c_6 M)) + c_7 \ln(r_{rup} + 2)$$ (8)

- This equation is identical to Sadigh (1993) in EZ-FRISK.

- coefficients for equation (8) are listed in the Tables on Page 64 for rock sites Tables 5 & 6

JLS 8/5/00

- However, in EZ-FRISK, there is no place to input Cz. However, Cz does not vary for different period(s). Assume same Cz is used for all periods in Z

- comparison for PGA for rocks sites reveals the following differences:

  $M_0 = 7.21$

  b for $M < M_0$ = .014

However, the resultant curves using Sadigh et al. (1997) coefficients & Sadigh (1993) in EZ-FRISK 3.0 are identical for PGA.

- PGA for other fault and SA could also be input in a straight forward manner.

Information potentially subject to copyright protection was redacted from this location. The redacted material is from the following reference:

Sadigh, et al. Table 2: Attenuation relationships of horizontal response spectral accelerations... 1997.. No additional information is known.

Information potentially subject to copyright protection was redacted from this location. The redacted material is from the following reference:

Sadigh, et al. Table 3: Dispersion relationships.. 1997.. No additional information is known.

The following fortran program shows implementation of Sadigh et al. [illegible] [illegible] format for EZF30.


```
      PROGRAM Sadigh
 C
 C ==============================================================
 C  This program calculates ground motion due to earthquakes
 C  according to attenuation function proposed by Sadigh et al.
 C  (1997, Seismological Research Letters 68:180-189)
 C  The coefficients for the attenuation function are read from
 C  file "Sadigh.97". The results are written in the formate
 C  required by EZF30 for input as tables in calculating
 C  seismic hazard. These tabular results are written to
 C  file "Sadig_97.tbl"
 C ==============================================================
 C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      CHARACTER LINE*180, FNAME*80
      REAL*8 VAR(100,15)
      REAL*8 period(100), C1(100),C2(100),C3(100),C4(100)
      REAL*8 C5(100),C6(100),C7(100)
      REAL*8 A1(100),A2(100),A3(100)
      REAL*8 period2(100), C12(100),C22(100),C32(100),C42(100)
      REAL*8 C52(100),C62(100),C72(100)
      REAL*8 DIST(20),MAG(20)
      REAL*8 Y(20,20),sigma(20,20)
      INTEGER nperiod,ndist,nmag
C
C Open files
      FNAME='Sadigh.97'
      OPEN(UNIT=1,FILE=FNAME,STATUS='OLD',FORM='FORMATTED')
C
C Read the coefficient file
C
      READ(1,'(A)') LINE
      READ(1,'(A)') LINE
      READ(1,'(A)') LINE
      READ(1,'(A)') LINE
      READ(1,'(A)') LINE
      nperiod=0
      DO 88 i=1,13
        READ(1,'(A)',END=99) LINE
        nperiod=i
        READ(LINE,*) (VAR(i,j),j=1,11)
        period(i)=VAR(i,1)
        C1(i)=VAR(i,2)
        C2(i)=VAR(i,3)
        C3(i)=VAR(i,4)
        C4(i)=VAR(i,5)
        C5(i)=VAR(i,6)
        C6(i)=VAR(i,7)
        C7(i)=VAR(i,8)
        A1(i)=VAR(i,9)
        A2(i)=VAR(i,10)
        A3(i)=VAR(i,11)
   88 CONTINUE
   99 CONTINUE
      READ(1,'(A)') LINE
      nperiod2=0
      DO 81 i=1,13
        READ(1,'(A)',END=91) LINE
        nperiod2=i
        READ(LINE,*) (VAR(i,j),j=1,8)
```

```
        period2(i)=VAR(i,1)
        C12(i)=VAR(i,2)
        C22(i)=VAR(i,3)
        C32(i)=VAR(i,4)
        C42(i)=VAR(i,5)
        C52(i)=VAR(i,6)
        C62(i)=VAR(i,7)
        C72(i)=VAR(i,8)
   81 CONTINUE
   91 CONTINUE
C
C Calculate ground motion
C
      FNAME='Sadig_97.tbl'
      OPEN(UNIT=3,FILE=FNAME, STATUS='UNKNOWN',FORM='FORMATTED')
C
C      do 22 i=1,nperiod
C       write(3,7000) period(i),C1(i),C2(i),C3(i),C4(i),
C     .               C5(i),C6(i),C7(i)
C   22 continue
C      do 21 i=1,nperiod2
C       write(3,7000) period2(i),C12(i),C22(i),C32(i),C42(i),
C     .               C52(i),C62(i),C72(i)
C   21 continue
C
      write(3,*) 'Sadigh et al. (1997) - Rock, Strick Slip'
      write(3,1000) nperiod
      ndist=20
      nmag=20
      DO 77 i=1,nperiod
        Write(3,2000) period(i),nmag,ndist
        DO 66 j=1,ndist
          dist(j)=10.0**((j-1)*2.0/19.0)
          DO 55 k=1,nmag
           mag(k)=4.0+(k-1)*((8.0-4.0)/19.0)
           if(mag(k).le.6.5)then
             Y(j,k)=exp(C1(i)+C2(i)*mag(k)+C3(i)*(8.5-mag(k))**2.5
     .             +C4(i)*log(dist(j)+exp(C5(i)+C6(i)*mag(k)))
     .             +C7(i)*log(dist(j)+2))
           else
             Y(j,k)=exp(C12(i)+C22(i)*mag(k)+C32(i)*(8.5-mag(k))**2.5
     .             +C42(i)*log(dist(j)+exp(C52(i)+C62(i)*mag(k)))
     .             +C72(i)*log(dist(j)+2))
           endif
           if(mag(k).lt.7.21)then
             sigma(j,k)=exp(a1(i)-a2(i)*mag(k))
           else
             sigma(j,k)=exp(a3(i))
           endif
   55     continue
   66   continue
        write(3,3000) (dist(j),j=1,ndist)
        do 33 k=1,nmag
         write(3,3500) mag(k)
         write(3,4000) (Y(j,k),j=1,ndist)
         write(3,4000) (sigma(j,k),j=1,ndist)
   33   continue
   77 continue
C
```

```
1000 FORMAT(i5)
2000 FORMAT(f4.2,2i4)
3000 FORMAT(f4.2,f5.2,17f6.2,f7.2)
3500 FORMAT(f4.2)
4500 FORMAT(20f6.3)
4000 FORMAT(20(1P e9.2))
7000 FORMAT(8f7.3,f6.0,6f7.2)
     END
```

V. Abrahamson and Silva (1997)

- This attenuation function is identical to the one used in EZ-FRISK 3.0. No modifications are necessary.
- However, if this model is to be selected for the PSHA for Yucca Mountain, the database coefficients will be checked. Tables 7&8 and 9&10 list coefficients for horizontal & vertical components

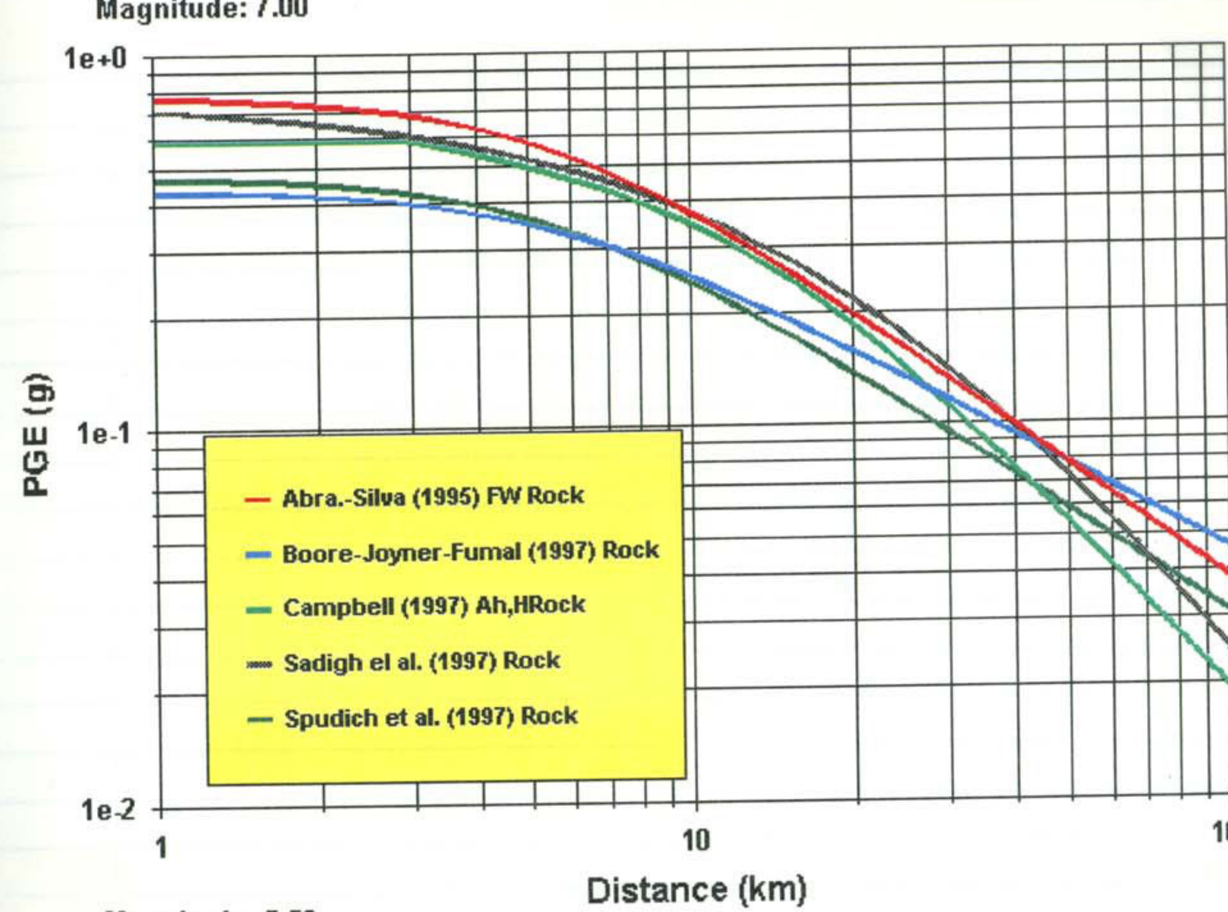
VI Summary of the Five Most updated Attenuation functions in Seismological Research Letters V68 N1.

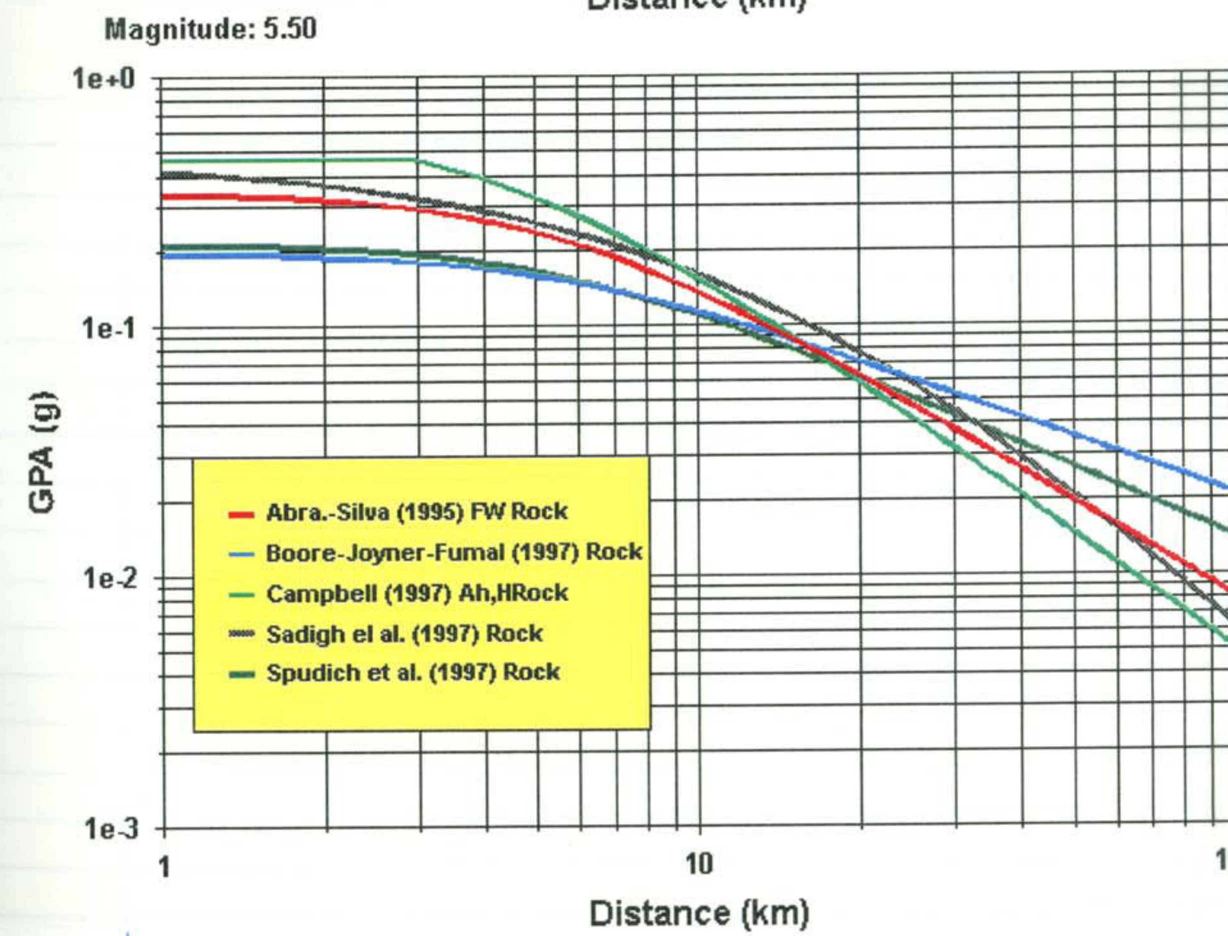
① The following fig shows comparison of the 5 most up-to-date atten. functions conducted by Abrahamson & Shedlock for strike-slip faults. Figs on page 69 ~~& 70~~ show same results from EZ-FRISK. Overall, Figs 69 ~~& 70~~ are comparable with the following fig.

RL [signature] 8/25/00

Information potentially subject to copyright protection was redacted from this location. The redacted material is from the following reference:

Abrahamson and Shedlock. Figure: strike-slip faults... No additional information is known.





PGA Comparison

(a) Comparison of Newer Versions with older versions.

(A) Abrahamson and Silva (1997) & Abrahamson and Silva (1995)

Identical

(B) Boore - Joyner - Fumal (1997) & Boore - Joyner - Fumal (1993)

1997 version predicts slightly lower PGA, as shown in Fig 1 on page 71 as well as SA

(C) Campbell (1997) & Campbell (1993)

See Fig 2 on page 71. The newer version predicts lower ~~PGA~~ & SA at near field but higher PGA & SA at far distan

8/25/10

(d) Sadigh et. al. (1997) & Sadigh (1994)

Identical

(e) Spudich et al (1997)

Branch need for YM or extensional areds.

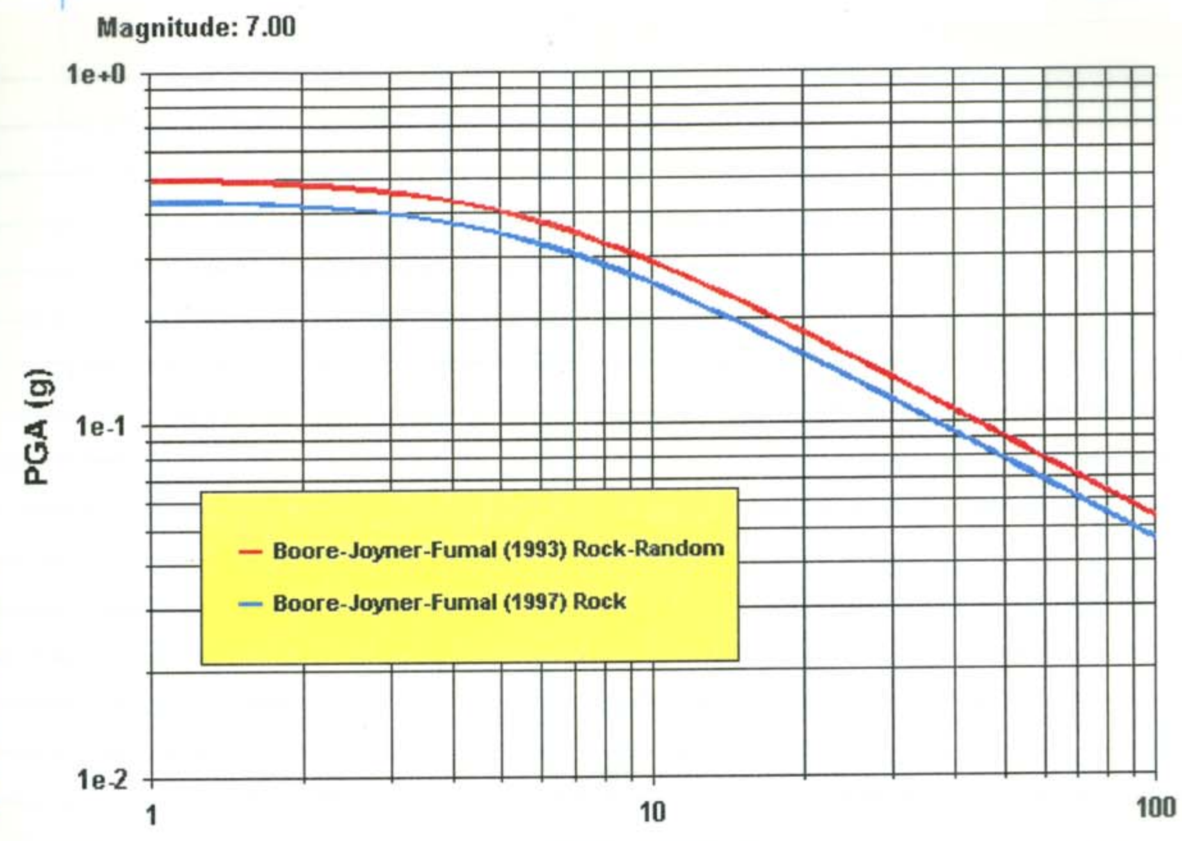


Fig 1

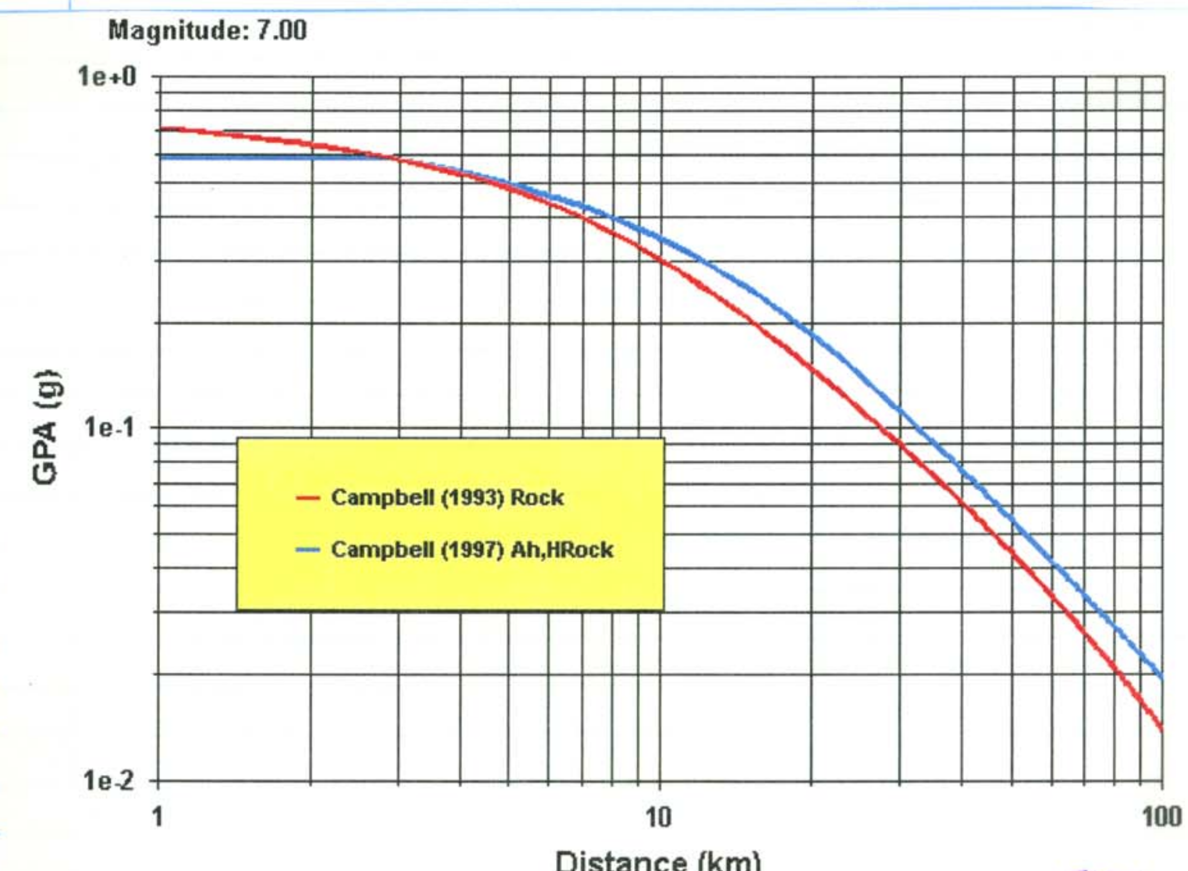


Fig 2

Table 4. Abrahamson & Silva (1997)
items in EZF30

Information potentially subject to copyright protection was redacted from this location. The redacted material is from the following reference:

Abahamson and Silva. Table: coefficients for the average horizontal component. 1997. No additional information is known.

Checking Abra-Silva (1995) database in EZF30 & calls the checked version Abra-Silva (1997)

$$F = \begin{cases} 1 & \text{reverse} \\ 0.5 & \text{reverse/oblique} \\ 0 & \text{otherwise} \end{cases} \qquad HW = \begin{cases} 1 & \text{hanging wall} \\ 0 & \text{otherwise} \end{cases}$$

only F=0 is included into EZF30

$$S = \begin{cases} 0 & \text{rock/shallow soil} \\ 1 & \text{deep soil} \end{cases}$$

Information potentially subject to copyright protection was redacted from this location. The redacted material is from the following reference:

Abrahamson and Silva. Table 4: Coefficients for standard errors... 1997. No additional information is known.

~~Note: $f_3(M)$ in Abrahamson & Silva is:~~

$$f_3(M) = \begin{cases} a_5 & \text{for } M \le 5.8 \\ a_5 + \frac{a_6 - a_5}{c_1 - 5.8} & \text{for } 5.8 < M < c_1 \\ a_6 & \text{for } M \ge c_1 \end{cases}$$

However, in EZF30, $f_3(M)$ is:

$$f_3(M) = \begin{cases} a_5 & \text{for } M \le 5.8 \\ a_5 + \frac{a_6 - a_5}{m_1 - 5.8}(M - 5.8) & \text{for } 5.8 < M < m_1 \\ a_6 & M \ge m_1 \end{cases}$$

Need to check which one is correct. May need to use "table" input.

Table 9. Abrahamson and Silva (1997)

Table 10. Abrahamson and Silva (1997)

Information potentially subject to copyright protection was redacted from this location. The redacted material is from the following reference:

Abrahamson and Silva. Table 9: Coefficients for the vertical component; Table 6: coefficients for standard errors for verticla component. 1997 No additional information is known.

* Since vertical component tends to be smaller than horizontal components. Only horizontal attenuation eqs. are ~~included~~ built in GGF-30

[signature] 8/25/00

```
      PROGRAM Abrahamson
C
C ==============================================================
C  This program calculates ground motion due to earthquakes
C  according to attenuation function proposed by Abrahamson &
C  Silva (1997, Seismological Research Letters 68:94-127)
C  The coefficients for the attenuation function are read from
C  file "Abrahamson.97". The results are written in the formate
C  required by EZF30 for input as tables in calculating
C  seismic hazard. These tabular results are written to
C  file "Abrah_97.tbl"
C ==============================================================
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      CHARACTER LINE*180, FNAME*80
      REAL*8 VAR(100,18)
      REAL*8 period(100), C4(100),A1(100),A2(100),A3(100),A4(100)
      REAL*8 A5(100),A6(100),A9(100),A10(100),A11(100),A12(100),A13(100)
      REAL*8 C1(100),C5(100),CN(100),B5(100),B6(100)
      REAL*8 DIST(20),MAG(20)
      REAL*8 Y1(20,20),Y3(20,20),Y4(20,20),Ypa(20,20),Y5(20,20)
      REAL*8 Yhw1(20,20),Yhw2(20,20)
      REAL*8 Y(20,20),sigma(20,20)
      REAL*8 F,HW,S
      INTEGER nperiod,ndist,nmag
C
C Open files
      FNAME='Abrahamson.97'
      OPEN(UNIT=1,FILE=FNAME,STATUS='OLD',FORM='FORMATTED')
C
C Read the coefficient file
C
      READ(1,'(A)') LINE
      READ(1,'(A)') LINE
      READ(1,'(A)') LINE
      nperiod=0
      DO 88 i=1,28
        READ(1,'(A)',END=99) LINE
        nperiod=i
        READ(LINE,*) (VAR(i,j),j=1,18)
        period(i)=VAR(i,1)
        C4(i)=VAR(i,2)
        A1(i)=VAR(i,3)
        A2(i)=VAR(i,4)
        A3(i)=VAR(i,5)
        A4(i)=VAR(i,6)
        A5(i)=VAR(i,7)
        A6(i)=VAR(i,8)
        A9(i)=VAR(i,9)
        A10(i)=VAR(i,10)
        A11(i)=VAR(i,11)
        A12(i)=VAR(i,12)
        A13(i)=VAR(i,13)
        C1(i)=VAR(i,14)
        C5(i)=VAR(i,15)
        CN(i)=VAR(i,16)
        B5(i)=VAR(i,17)
        B6(i)=VAR(i,18)
   88 CONTINUE
   99 CONTINUE
```

```
C
C Calculate ground motion
C
      FNAME='Abrah_97.tbl'
      OPEN(UNIT=3,FILE=FNAME, STATUS='UNKNOWN',FORM='FORMATTED')
C
C      do 22 i=1,nperiod
C       write(3,7000) period(i),c4(i),a1(i),a2(i),a3(i),a4(i),
C     .                  a5(i),a6(i),a9(i),a10(i),a11(i),a12(i),
C     .                  a13(i),c1(i),c5(i),cn(i),b5(i),b6(i)
C  22 continue
C
      write(3,*) 'Abrahamson & Silva (1997) - Rock, Strick Slip'
      write(3,1000) nperiod
      ndist=20
      nmag=20
      F=0.0
      HW=1.0
      S=0.0
      DO 77 i=1,nperiod
        Write(3,2000) period(i),nmag,ndist
        DO 66 j=1,ndist
          dist(j)=10.0**((j-1)*2.0/19.0)
          DO 55 k=1,nmag
           mag(k)=4.0+(k-1)*((8.0-4.0)/19.0)
           if(mag(k).le.C1(i))then
            Y1(j,k)=a1(i)+a2(i)*(mag(k)-C1(i))+a12(i)
     .             *(8.5-mag(k))**cn(i)
     .             +(a3(i)+a13(i)*(mag(k)-c1(i)))
     .             *log(sqrt(dist(j)**2+c4(i)**2))
           else
            Y1(j,k)=a1(i)+a4(i)*(mag(k)-C1(i))+a12(i)
     .             *(8.5-mag(k))**cn(i)
     .             +(a3(i)+a13(i)*(mag(k)-c1(i)))
     .             *log(sqrt(dist(j)**2+c4(i)**2))
           endif
           if(mag(k).le.5.8)then
             Y3(j,k)=a5(i)
           elseif(mag(k).ge.c1(i))then
             Y3(j,k)=a6(i)
           else
C              Y3(j,k)=a5(i)+(a6(i)-a5(i))/(c1(i)-5.8)
             Y3(j,k)=a5(i)+(a6(i)-a5(i))/(c1(i)-5.8)
     .               *(mag(k)-5.8)
           endif
           if(mag(k).le.5.5)then
            Yhw1(j,k)=0
           elseif(mag(k).ge.6.5)then
            Yhw1(j,k)=1.0
           else
            Yhw1(j,k)=mag(k)-5.5
           endif
C
           if(dist(j).lt.4.0)then
            Yhw2(j,k)=0.0
           else if(dist(j).lt.8.0)then
            Yhw2(j,k)=a9(i)*(dist(j)-4.0)/4.0
           else if(dist(j).lt.18.0)then
            Yhw2(j,k)=a9(i)
           else if(dist(j).lt.24.0)then
```

```
          Yhw2(j,k)=a9(i)*(1-(dist(j)-18.0)/7.0)
         else
          Yhw2(j,k)=0.0
         endif
C
         Y4(j,k)=Yhw1(j,k)*Yhw2(j,k)
C         Ypa(j,k)=Y1(j,k)+F*Y3(j,k)+HW*Y4(j,k)
C         Y5(j,k)=a10(i)+a11(i)*log(Ypa(j,k)+c5(i))
         Y(j,k)=exp(Y1(j,k)+F*Y3(j,k)+HW*Y4(j,k))
C
         if(mag(k).lt.5.0)then
           sigma(j,k)=exp(b5(i))
         elseif(mag(k).ge.7.0)then
           sigma(j,k)=exp(b5(i)-2*b6(i))
         else
           sigma(j,k)=exp(b5(i)-b6(i)*(mag(k)-5.0))
         endif
   55    continue
   66   continue
        write(3,3000) (dist(j),j=1,ndist)
        do 33 k=1,nmag
         write(3,3500) mag(k)
         write(3,4000) (Y(j,k),j=1,ndist)
         write(3,4000) (sigma(j,k),j=1,ndist)
   33   continue
   77 continue
C
 1000 FORMAT(i5)
 2000 FORMAT(f4.2,2i4)
 3000 FORMAT(f4.2,f5.2,17f6.2,f7.2)
 3500 FORMAT(f4.2)
 4500 FORMAT(20f6.3)
 4000 FORMAT(20(1P e9.2))
 7000 FORMAT(2f5.2,2f7.3,f8.4,f7.3,3f7.3,
     .       2f7.3,f8.4,f5.2,f4.1,f5.2,f4.0,f5.2,f6.3)
      END
```

Testing of single zone YM model with new attenuation equations.

1. Attenuation equations.

Abra-Silva (1997) Rock.tbl

Boore et al (1997) Rock.tbl

Campbell (1997) Rock H. tbl

Idriss (1993) Rock

Sadigh et al (1997) Rock-tbl

Spudich et al. (1997) Rock.tbl

Note. A problem encountered at Frequency of 20 (or period of 0.25) EZF calculates zero hazard and stops. Don't know the reason. After eliminating this frequency from the input file. EZF run OK.

Trial Runs of EZ-FRISK to reproduce results of Ivan Wong for ESF.

About source-to-site distances

In EZ-FRISK:

① R_0 the shortest distance to the rupture

② Square root of closest horizontal distance squared + RZEROF

③ Square root of distance to fault trace squared + RZEROF squared

④ distance to hypocenter.

See Figure on p.81 for R_0, $R_{horizontal}$, RZEROF and R_{to} surf. expression.

$$R_0 = \overline{OA}$$

$$R_1 = \sqrt{R_{horizontal}^2 + RZEROF^2}$$

$$= \sqrt{\overline{OB}^2 + RZEROF^2}$$

$$R_2 = \sqrt{\overline{OC}^2 + RZEROF^2}$$

RZEROF fixed depth term.

Information potentially subject to copyright protection was redacted from this location. The redacted material is from the following reference:

A Figure 3: Alternative definitions of distance for fault sources. It is not known from the references listed below, where this figure came from.

In EZ-FRISK:

			(67) Abrahamson & Shedlock
Abrahamson and Silva 1997:	RZERO=0	R_0	r_{rup}
Boore et al., 1997	RZERO=0	R_1 *	r_{jb} *
Campbell, 1997	~~RZERO=0~~	~~R_0~~	~~r_{seis}~~
Idriss, 1993	RZERO=0	R_0	r_{rup}
Sadigh et al. 1997	RZERO=0	R_0	r_{rup}
Spudich et al. 1997	~~RZERO=0~~	~~R_1~~ *	r_{jb} *
Youngs, 1993	RZERO=0	R_0	See Fig. on P82.

Information potentially subject to copyright protection was redacted from this location. The redacted material is from the following reference:

Campbell. A Figure 1: source-to-site distance measures for ground motion atteodels.... 1997. No additional information is known.

Comparison of attenuation equations:

- rupture from surface to depth of 15 km in both cases

Case I: Vertical strike slip faults for rock

See figure (a) on page 82

$r_{rup} = r_{jb}$

$r_{seis} = r_{rup} - 3$ km according to Campbell (1997)

Figs on page 84, 85, and 86 show comparison, where Abrahamson and Silva (1997) use Hanging wall equations

Figs on page 87, 88, and 89 show comparison, where Abrahamson and Silva (1997) using Footwall equations is also included.

Case II: A fault with dip angle of $\alpha°$ and rupture from surface to a depth of h km:

$$\sin\alpha° = \frac{r_{rup}}{d} \qquad r_{rup} = r_{seis}$$

$$\tan\alpha° = \frac{h}{d - r_{jb}}$$

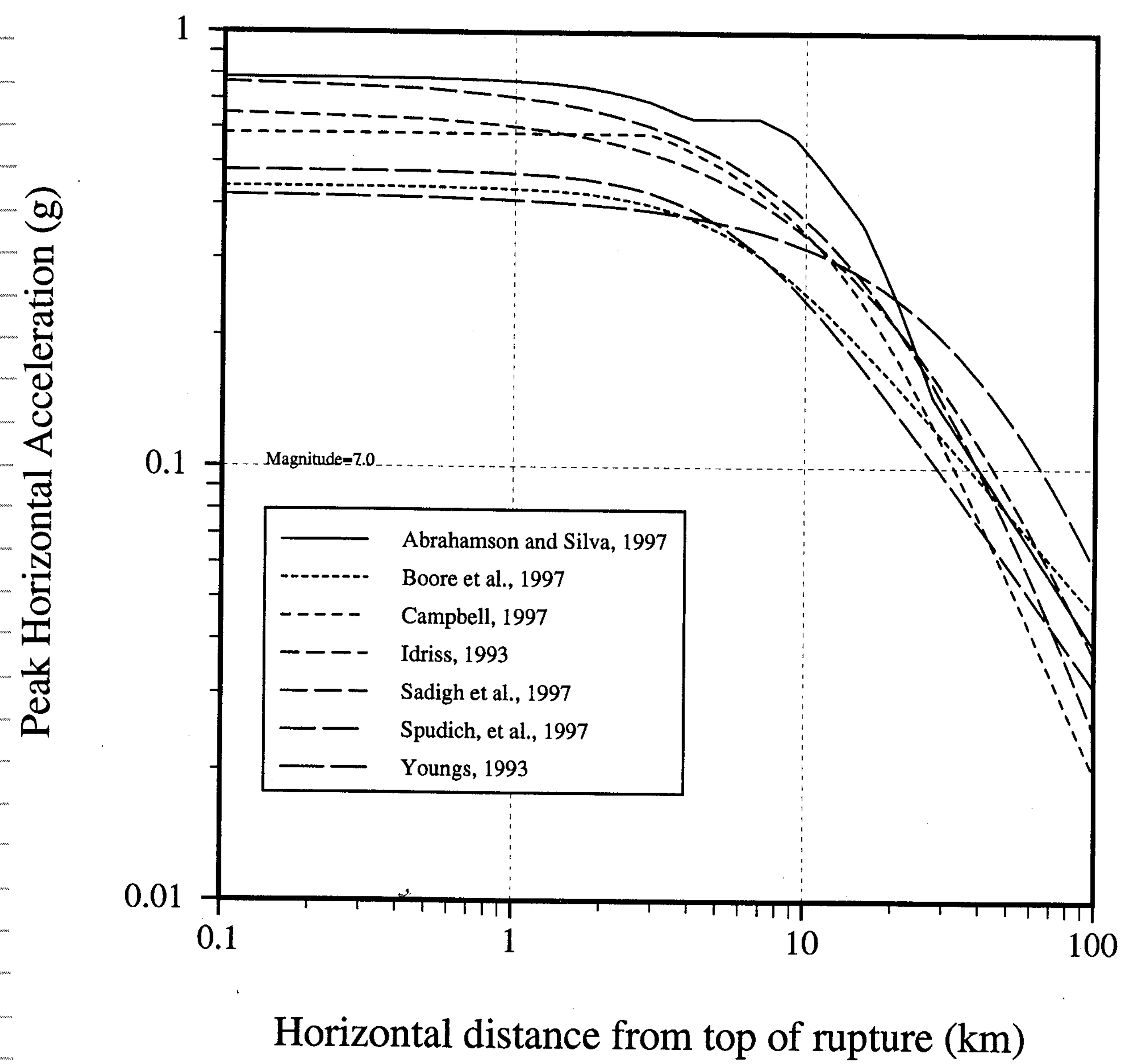
$$d = \frac{r_{rup}}{\sin\alpha°}$$

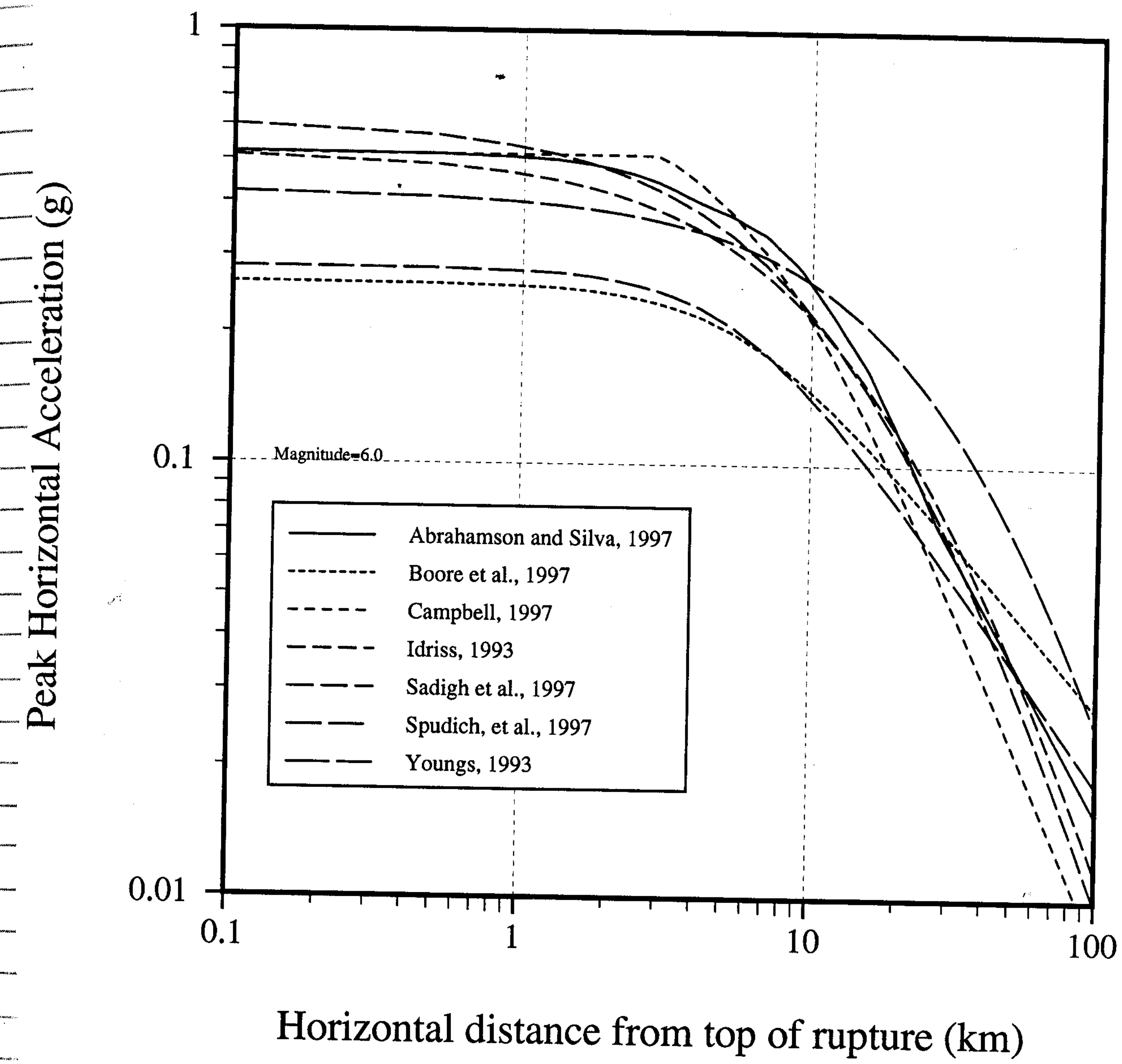
$$d = r_{jb} + \frac{h}{\tan\alpha°}$$

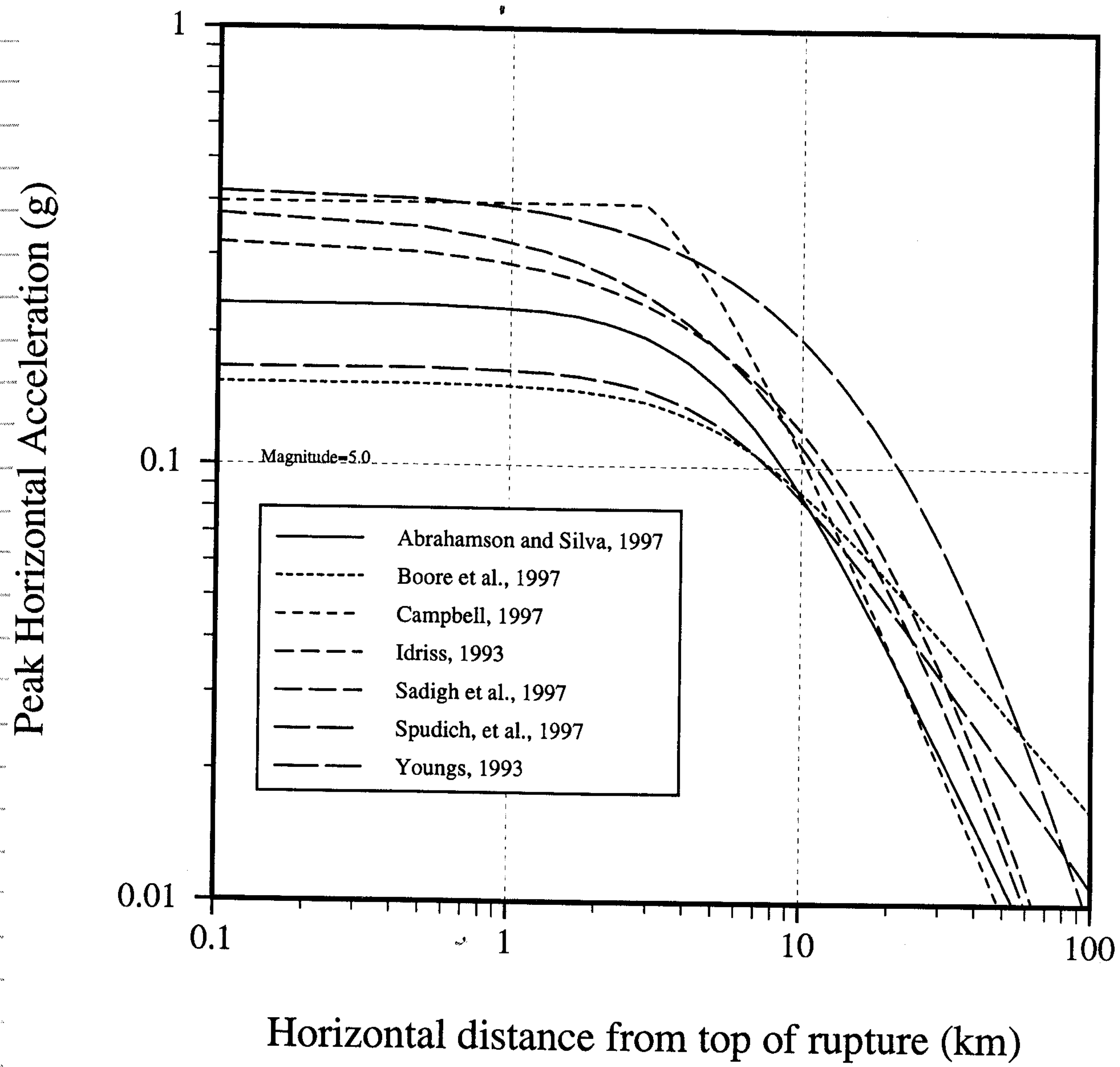
r_{seis} cut off should be:

r_{seis} should be less than:

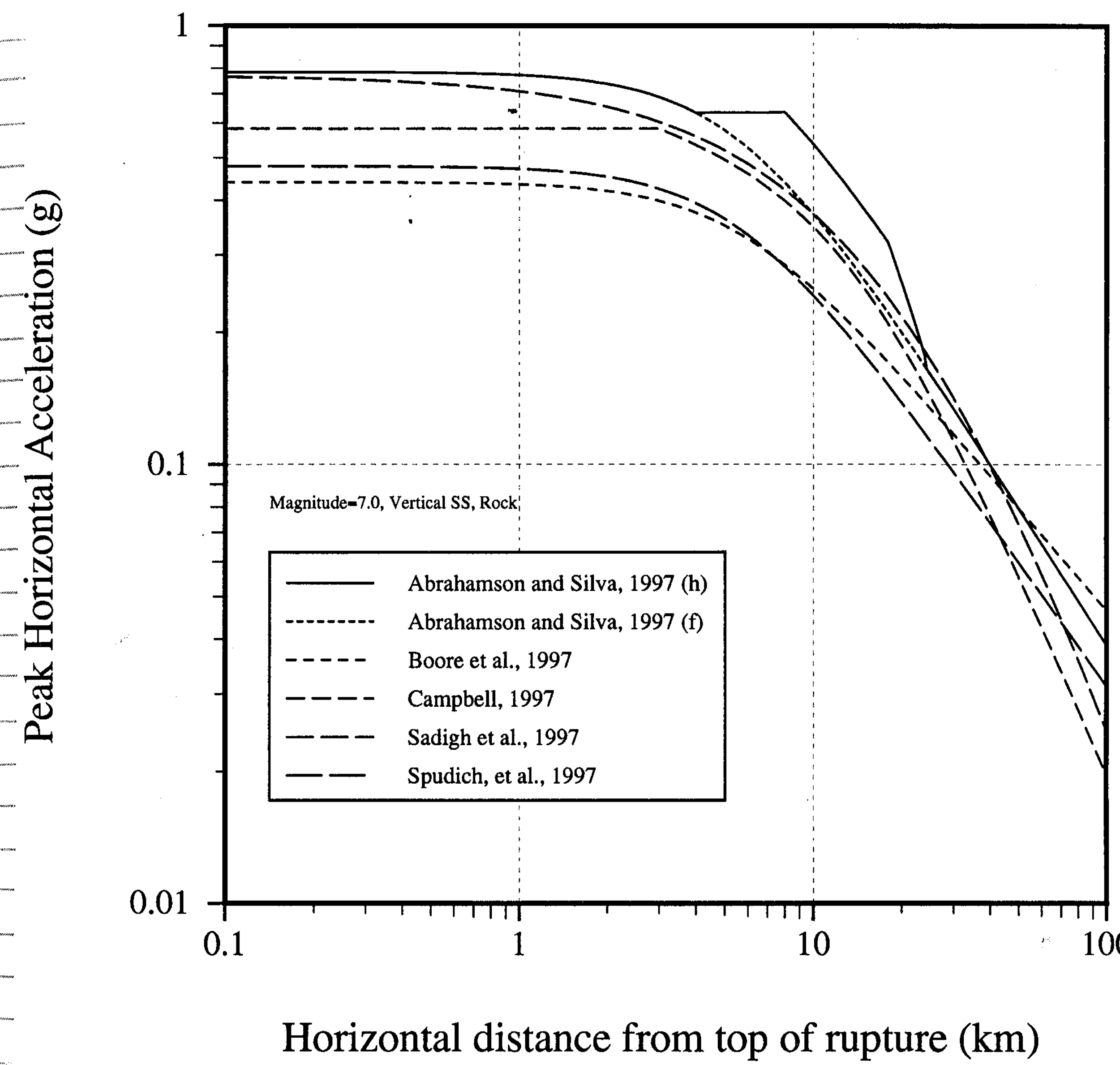
See Continuation on p. 90.


Peak Horizontal Acceleration (g)
1
0.1
0.01
Magnitude=7.0
Abrahamson and Silva, 1997
Boore et al., 1997
Campbell, 1997
Idriss, 1993
Sadigh et al., 1997
Spudich, et al., 1997
Youngs, 1993
0.1
1
10
100
Horizontal distance from top of rupture (km)

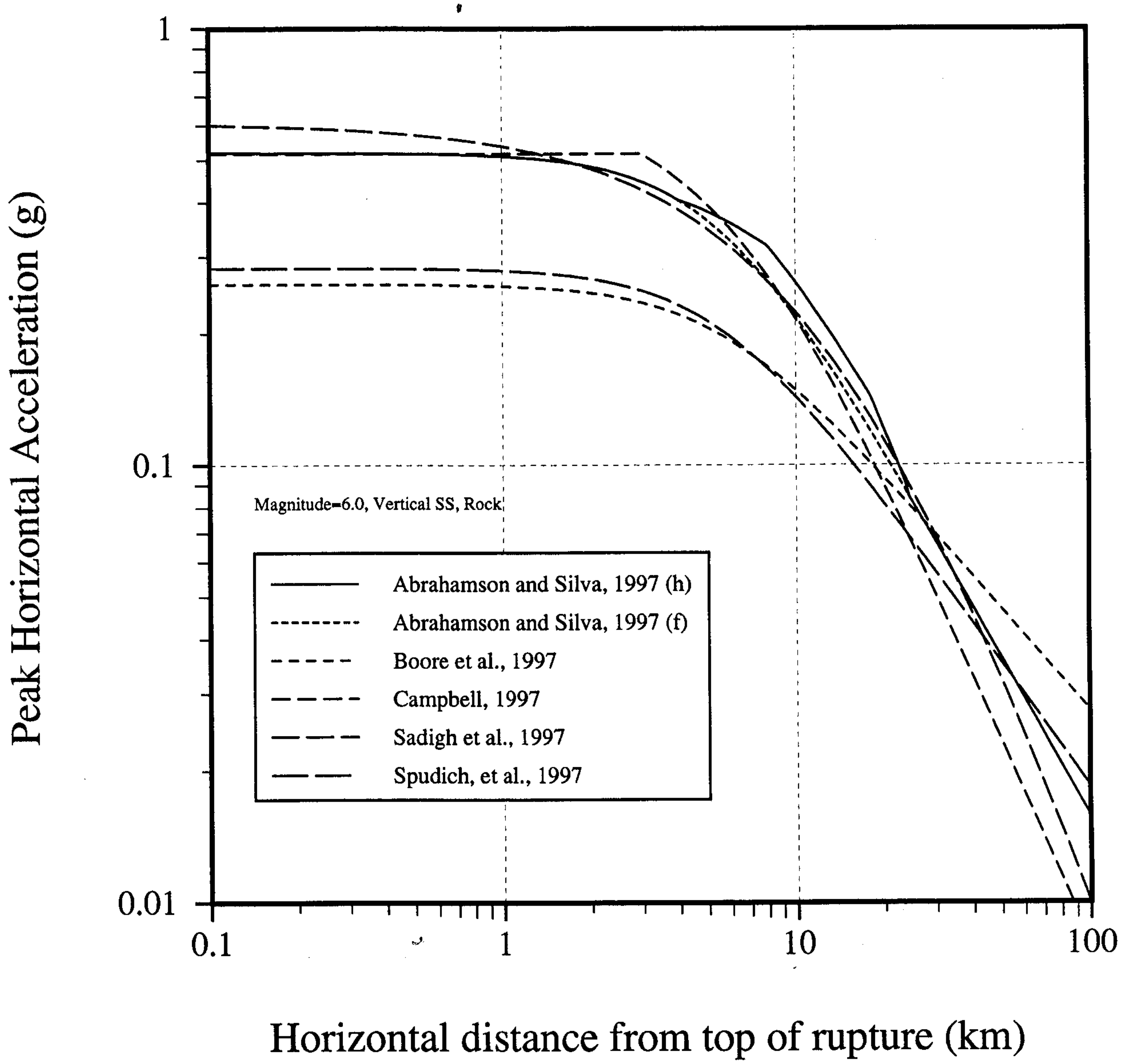

Peak Horizontal Acceleration (g)
1
0.1
0.01
Magnitude=6.0
Abrahamson and Silva, 1997
Boore et al., 1997
Campbell, 1997
Idriss, 1993
Sadigh et al., 1997
Spudich, et al., 1997
Youngs, 1993
0.1
1
10
100
Horizontal distance from top of rupture (km)



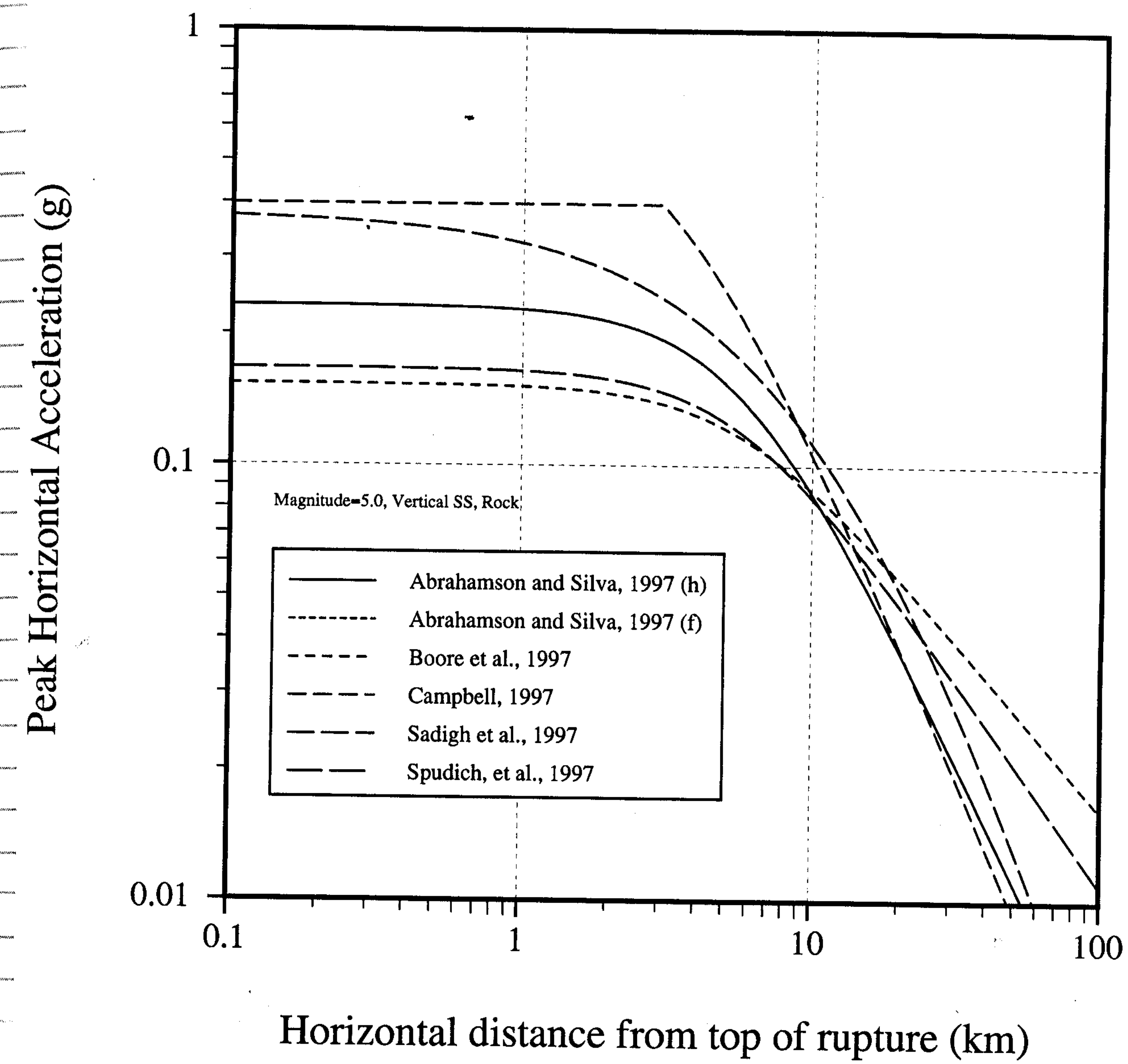
Peak Horizontal Acceleration (g)
1
0.1
0.01
0.1
1
10
100
Magnitude=5.0
Abrahamson and Silva, 1997
Boore et al., 1997
Campbell, 1997
Idriss, 1993
Sadigh et al., 1997
Spudich, et al., 1997
Youngs, 1993
Horizontal distance from top of rupture (km)



Peak Horizontal Acceleration (g)
1
0.1
0.01
0.1
1
10
100
Magnitude=7.0, Vertical SS, Rock
Abrahamson and Silva, 1997 (h)
Abrahamson and Silva, 1997 (f)
Boore et al., 1997
Campbell, 1997
Sadigh et al., 1997
Spudich, et al., 1997
Horizontal distance from top of rupture (km)



1
0.1
0.01
0.1
1
10
100
Peak Horizontal Acceleration (g)
Horizontal distance from top of rupture (km)
Magnitude=6.0, Vertical SS, Rock
Abrahamson and Silva, 1997 (h)
Abrahamson and Silva, 1997 (f)
Boore et al., 1997
Campbell, 1997
Sadigh et al., 1997
Spudich, et al., 1997



1
0.1
0.01
0.1
1
10
100
Peak Horizontal Acceleration (g)
Horizontal distance from top of rupture (km)
Magnitude=5.0, Vertical SS, Rock
Abrahamson and Silva, 1997 (h)
Abrahamson and Silva, 1997 (f)
Boore et al., 1997
Campbell, 1997
Sadigh et al., 1997
Spudich, et al., 1997

Case II: A normal fault with a dip angle α rupture from the ground surface to a depth of h: (see figure 6 on page 82)

A: For Campbell (R_{seis})

A-1 Hangingwall:

$$d_2 = AB + BD_2 = \frac{h}{tg\alpha} + \frac{h}{tg(90-\alpha)}$$

$$d_1 = \frac{3}{tg\alpha} + \frac{3}{tg(90-\alpha)}$$

$d_2 \le d \le d_1$:

$$\because \sin\alpha = \frac{R_{seis}}{d}$$

$$R_{seis} = d \cdot \sin\alpha \quad (1)$$

$d > d_2$:

$$\because tg\alpha = \frac{h}{AB} \rightarrow AB = \frac{h}{tg\alpha}$$

$$R_{seis}^2 = BC^2 + h^2$$

$$BC + AB = d$$

$$\therefore R_{seis}^2 = \left(d - \frac{h}{tg\alpha}\right)^2 + h^2 \quad (2)$$

$d \le AF$: $AF = \frac{3km}{tg\alpha}$

$$\frac{3km}{AE} = \sin\alpha \qquad AE = \frac{3km}{\sin\alpha} \qquad tg60^\circ = \frac{3km}{AF}$$

Same.

$$d = AF - \sqrt{R_{seis}^2 - 3km^2}$$

$$R_{seis}^2 = \left(\frac{3km}{tg\alpha} - d\right)^2 + 3km^2 \quad (3)$$

$AF < d \le d_2$: $AF = \frac{3km}{tg\alpha}$

$$d = AF + \sqrt{R_{seis}^2 - 3km^2}$$

$$R_{seis}^2 = \left(d - \frac{3km}{tg\alpha}\right)^2 + 3km^2 \quad (4)$$

A-2 Footwall:

$$R_{seis}^2 = 3km^2 + \left(d + \frac{3km}{tg\alpha}\right)^2 \quad (5)$$

B. For Abrahamson & Silva and Sadigh et al.

R_{rup}.

Hanging wall:

$$d_2 = \frac{h}{tg\alpha} + \frac{h}{tg(90-\alpha)}$$

$0 \le d \le d_2$:

$$R_{rup} = d \cdot \sin\alpha \quad (6)$$

$d > d_2$:

$$R_{rup}^2 = \left(d - \frac{h}{tg\alpha}\right)^2 + h^2 \quad (7)$$

Footwall:

$$R_{rup} = d \quad (8)$$

C. For Boore et al. and Spudich et al.

R_{jb}

Hanging wall:

$$d \le AB = \frac{h}{tg\alpha}:$$

$$R_{jb} = AB - d = \frac{h}{tg\alpha} - d \quad (9)$$

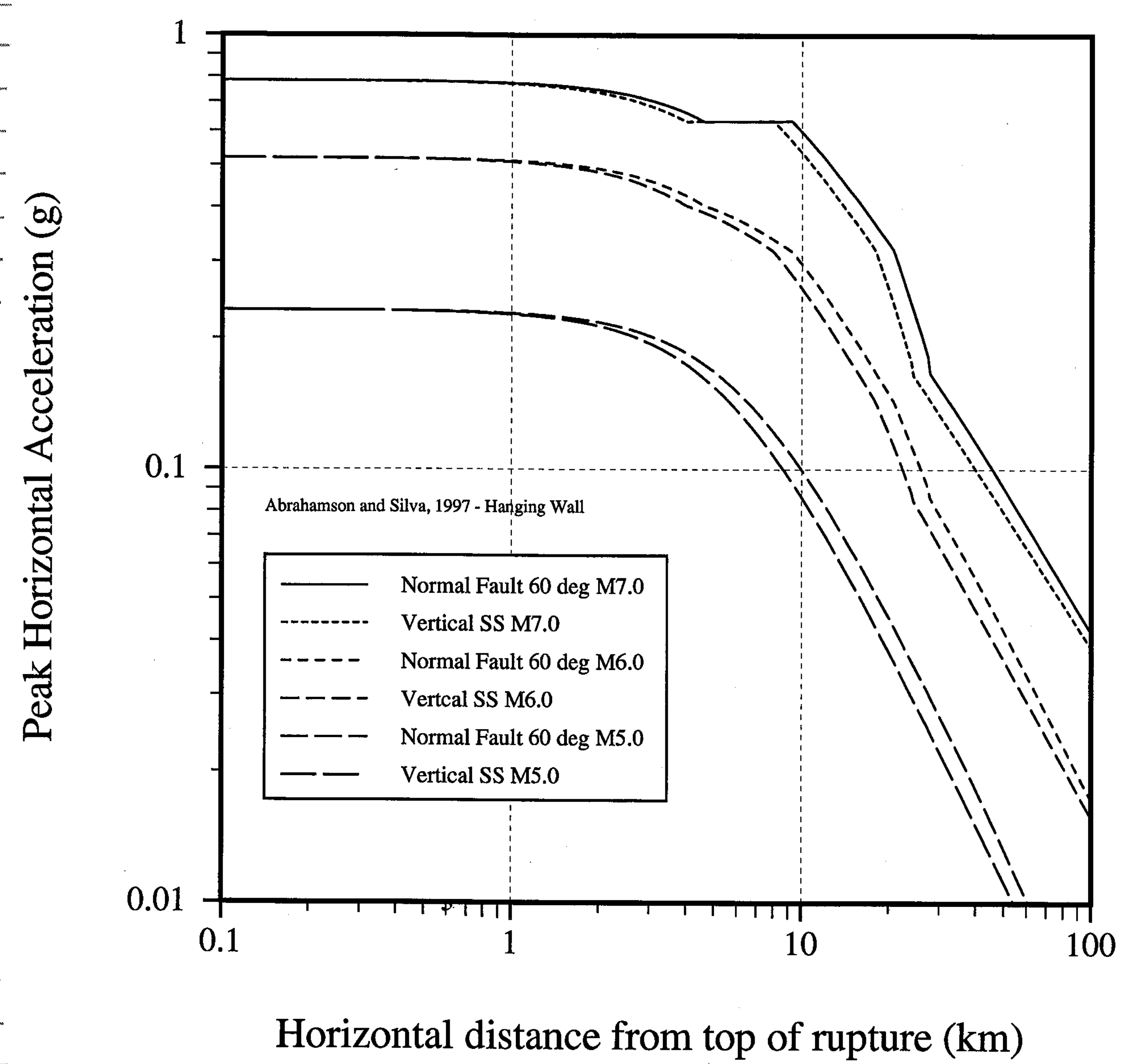
$d > AB$:

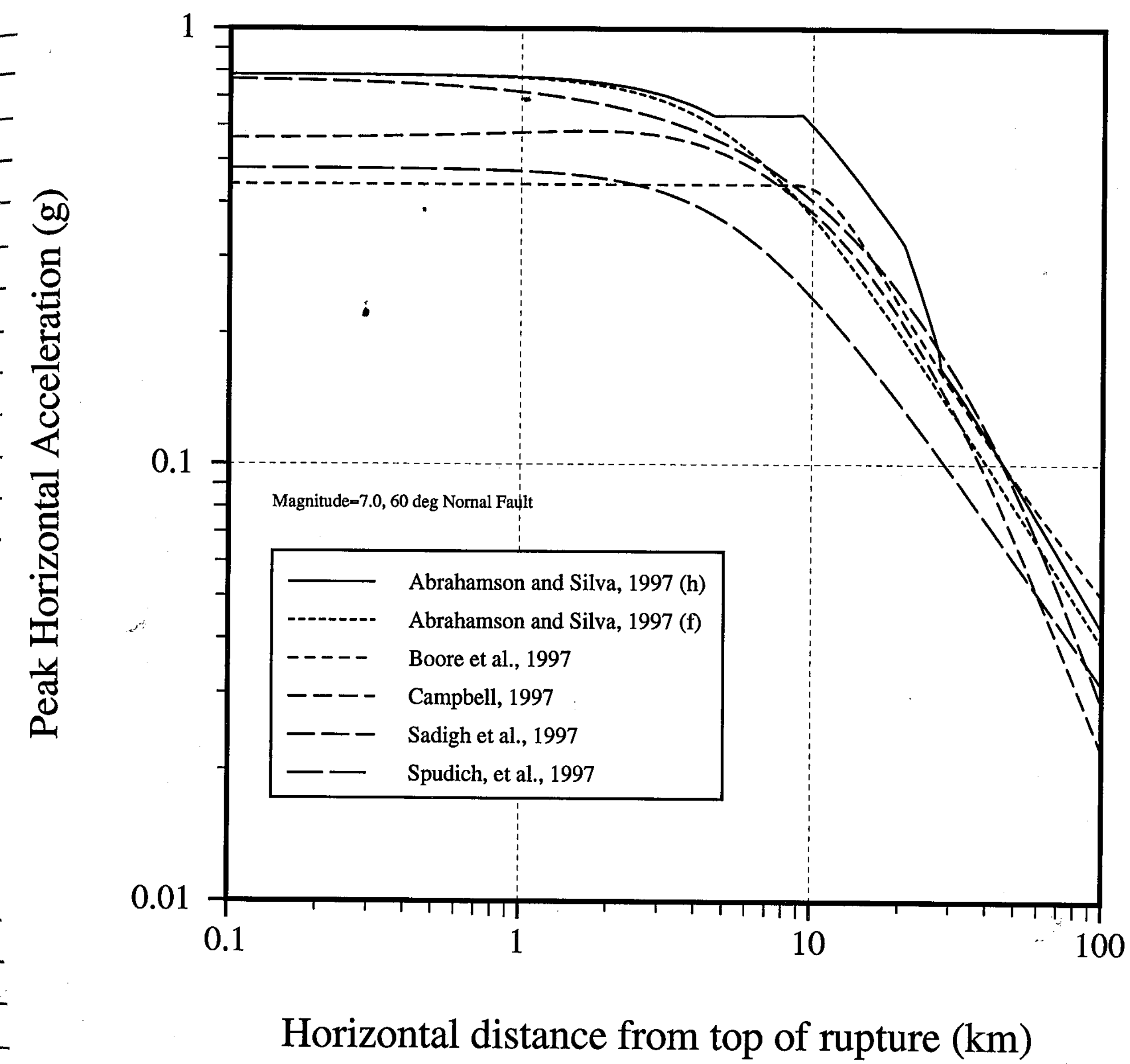
$$R_{jb} = d - AB = d - \frac{h}{tg\alpha} \quad (10)$$

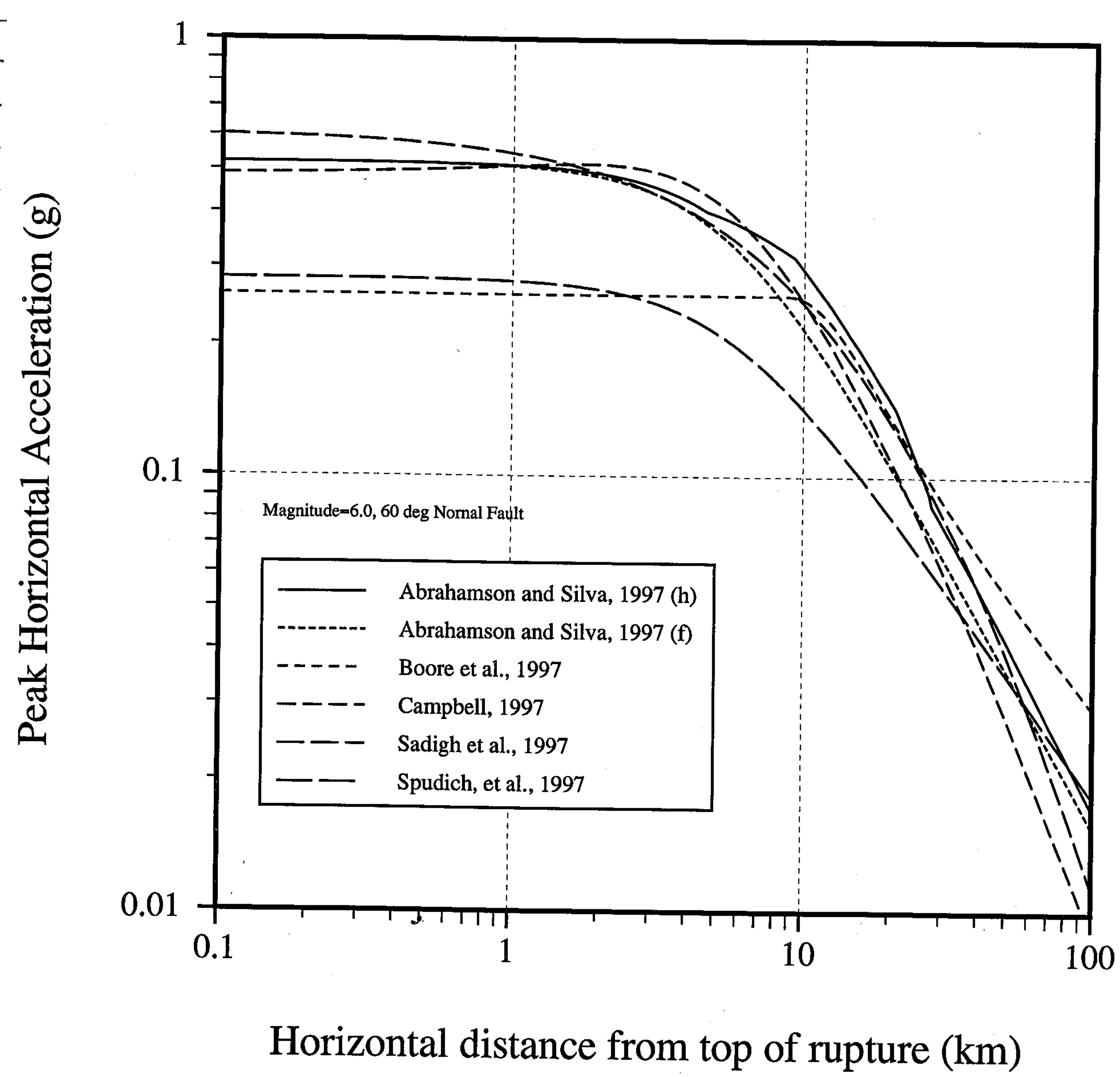
Footwall:

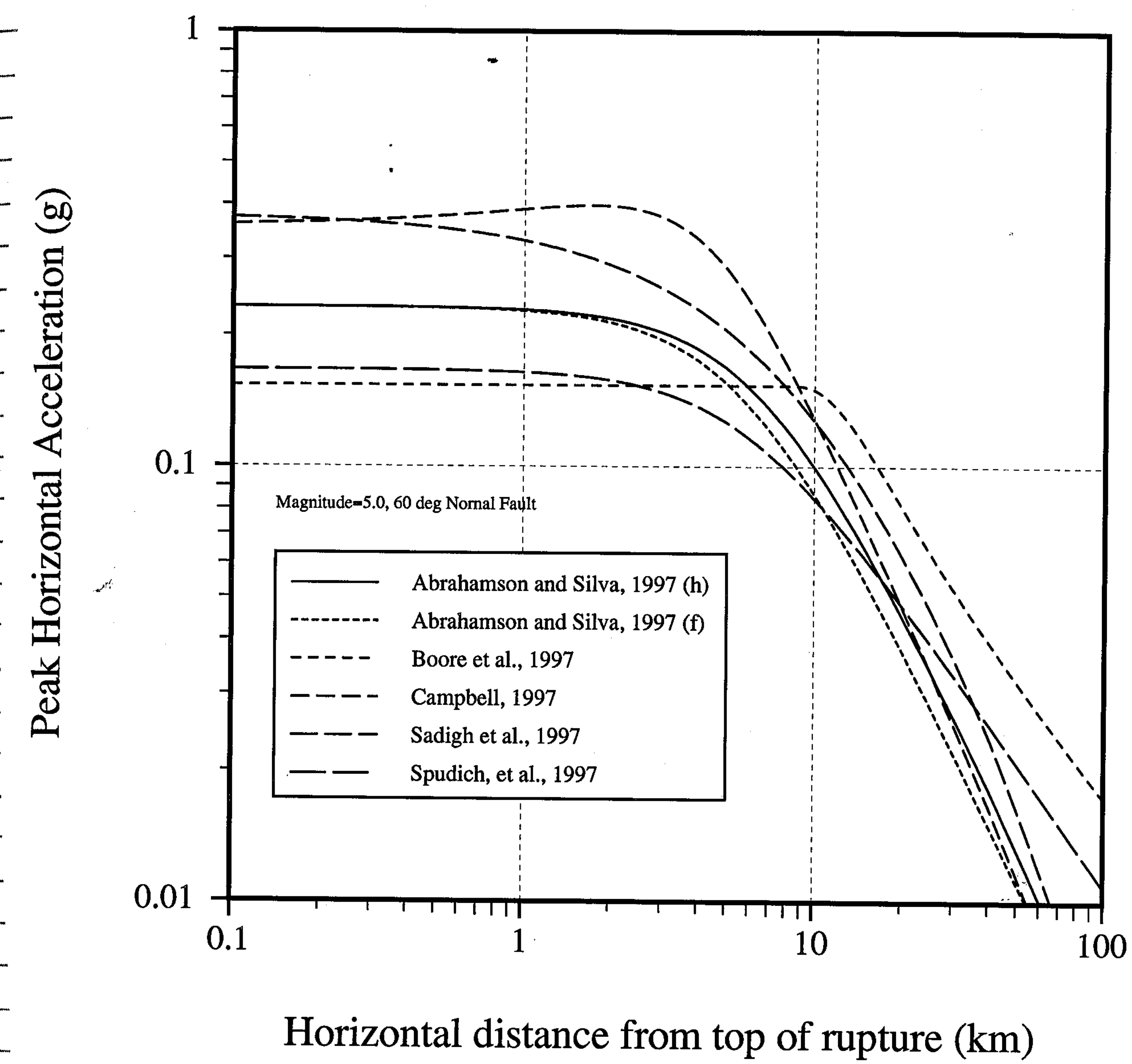
$$R_{jb} = d + AB = d + \frac{h}{tg\alpha} \quad (11)$$

Figures on p. 92, 93, 94 & 95 show comparison


1
0.1
0.01
0.1
1
10
100
Peak Horizontal Acceleration (g)
Horizontal distance from top of rupture (km)
Abrahamson and Silva, 1997 - Hanging Wall
Normal Fault 60 deg M7.0
Vertical SS M7.0
Normal Fault 60 deg M6.0
Vertcal SS M6.0
Normal Fault 60 deg M5.0
Vertical SS M5.0


1
0.1
0.01
0.1
1
10
100
Peak Horizontal Acceleration (g)
Horizontal distance from top of rupture (km)
Magnitude=7.0, 60 deg Nomal Fault
Abrahamson and Silva, 1997 (h)
Abrahamson and Silva, 1997 (f)
Boore et al., 1997
Campbell, 1997
Sadigh et al., 1997
Spudich, et al., 1997


Peak Horizontal Acceleration (g)
1
0.1
0.01
0.1
1
10
100
Horizontal distance from top of rupture (km)
Magnitude=6.0, 60 deg Nomal Fault
Abrahamson and Silva, 1997 (h)
Abrahamson and Silva, 1997 (f)
Boore et al., 1997
Campbell, 1997
Sadigh et al., 1997
Spudich, et al., 1997


Peak Horizontal Acceleration (g)
1
0.1
0.01
0.1
1
10
100
Horizontal distance from top of rupture (km)
Magnitude=5.0, 60 deg Nomal Fault
Abrahamson and Silva, 1997 (h)
Abrahamson and Silva, 1997 (f)
Boore et al., 1997
Campbell, 1997
Sadigh et al., 1997
Spudich, et al., 1997

Implications of Bare Mountain Fault Activity to Seismic Hazard at YM

Input to " Three Dimensional Geometry of the Bare Mountain Fault: Implications for Seismic Hazard at Yucca Mountain, Nevada"

by John A. Stamatakos, David A. Ferrill, Alan P. Morris, and Rui Chen

I Input:

1. Surface trace

1.	533 300	4084 174	
2.	533 427	4081 443	
3.	532 220	4077 633	
4.	533 490	4073 823	SHORT
5.	533 046	4070 521	
6.	534 252	4066 585	
7.	534 443	4063 918	Extension
8.	534 888	4060 616	
9.	534 824	4057 822	
10.	535 459	4050 773	
11.	535 396	4047 534	

See Page 99 for Long/Lat coordinates

Copied from Pencil Entry to Pen 08/25/09

Trace length and Maximum Magnitude. According to Wells & Coppersmith (1994)*:

ⓐ Long (Extension): 40 km

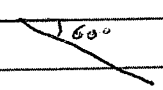
$M = 5.08 + 1.16 \log (SRL)$
$= 5.08 + 1.16 \log 40$
$= 6.94$

ⓑ Short: 20 km

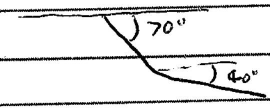
$M = 5.08 + 1.16 \log (SRL)$
$= 5.08 + 1.16 \log 20$
$= 6.59$

2. Slip Rate:
ⓐ 0.01 mm/yr
ⓑ ~~0.1 mm/yr~~
ⓒ 1.0 mm/yr

3. Dip Angle
ⓐ ~~60°~~



ⓑ 70° - 40°



4. Other paramters:
~~$\beta = \ln(10) \cdot b = \ln(10) \times 0.82 = 1.89$~~

Recurrence model: characteristic model
Al, Bl, and Sgl: -4.3793, 0.862, 0.28
D_1, D_2: 0.5 1.0
Seismogenica depth: 15 km
Style of Faulting: Dip slip to oblique

* Wells, D.L. and K.J. Coppersmith 1994. "New Empirical Relationships Among Magnitude, Rupture Length, Rupture Width, Rupture Area and Surface Displacement." Bull. Soc. Am., 84, no 4: 974-1002.

5. Attenuation Functions.

Abrahamson and Silva 1997

Sadigh et. al. (1997)

\# -- utm to long/lat (decimal degrees output [DD]) ---

1.	533300	4084174	-116.626217	36.904801	
2.	533427	4081443	-116.624912	36.880177	
3.	532220	4077633	-116.638618	36.845874	
4.	533490	4073823	-116.624541	36.811483	short
5.	533046	4070521	-116.629662	36.781732	
6.	534252	4066585	-116.616324	36.746207	
7.	534443	4063918	-116.614305	36.722158	
8.	534888	4060616	-116.609473	36.692374	
9.	534824	4057822	-116.610316	36.667189	extension
10.	535459	4050773	-116.603536	36.603619	
11.	535396	4047534	-116.604390	36.574421	

BML: Extension, Mmax = 6.94

~~BML-1 slip rate = 0.01~~ dip angle = 60°
BML-1a slip Rate = 0.01 mm/yr
BML-1b slip Rate = 0.1 mm/yr
BML-1c slip Rate = 1.0 mm/yr

BML-2 dip 70°-40°
BML-2a 0.01 mm/yr
BML-2b 0.1 mm/yr
BML-2c 1.0 mm/yr

[signature] 8/25/00

BMS: Short, Mmax = 6.59

BMS-1 60°
BMS-1a slip Rate = 0.01 mm/yr
BMS-1b slip Rate = 0.1 mm/yr
BMS-1c slip Rate = 1.0 mm/yr

BMS-2 70°-40°
BMS-2a 0.01 mm/yr
BMS-2b 0.1 "
BMS-2c 1.0 "

I have reviewed This scientific notebook and find it in compliance with QAP-001. There is sufficient information regarding procedures used for conducting tests, acquiring and analyzing data so that another qualified individual could repeat the activity

5/3/2000

Manager—MGFE