PSHA, Site Response, and Site Spectra

Technical Presentation
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TOPIC 1: PSHA

Robin K. McGuire
Gabriel R. Toro
Risk Engineering, Inc.
Boulder, Colorado

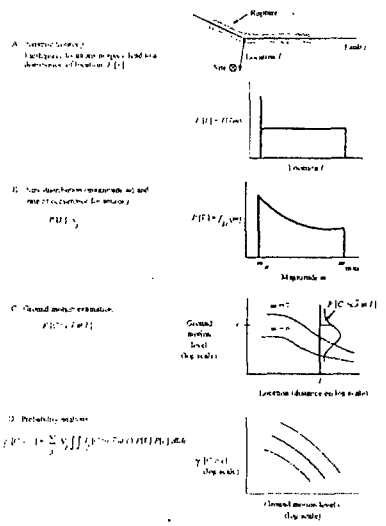
Topics of Discussion

- Topic 1 – Probabilistic seismic hazard analysis
- Topic 2 – Site response
- Topic 3 – Site hazard
- Topic 4 – Site spectra

Topic 1: PSHA

- PSHA methodology
- Seismic sources (EPRI, New Madrid, Charleston)
- Ground motion models
- Revised σ's
- CAV
- Calculations (rock, soil, deaggregation)

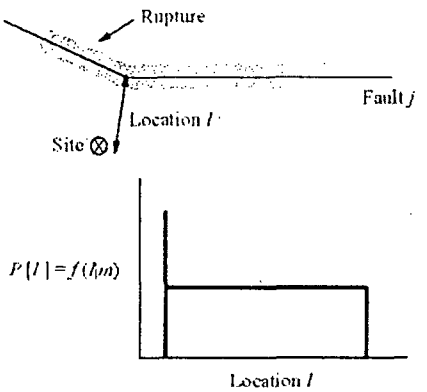
Steps in seismic hazard analysis



Source: McGuire (2004)

Step A ~ Distribution of location

A. Seismic Source *j*.
Earthquake locations in space lead to a distribution of location: $P[l]$



Source. McGuire (2004)

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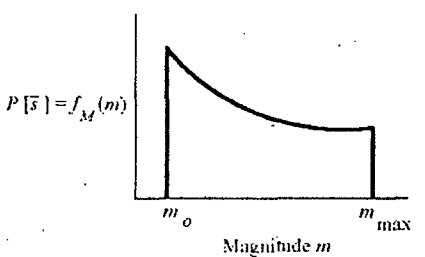
Step B ~ Distribution of magnitude

B. Size distribution (magnitude *m*) and rate of occurrence for source *j*:

$P[\bar{s}]$, ν_j



Source: McGuire (2004)

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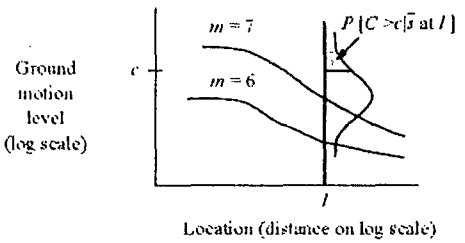
Step C ~ Distribution of ground motion

C. Ground motion estimation:

$P[C > c|\bar{s} \text{ at } l]$

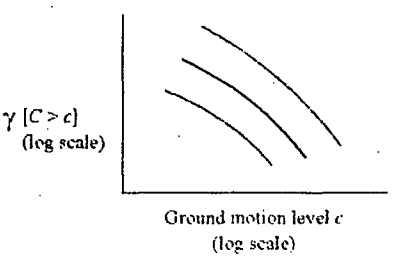


Source: McGuire (2004)

Step D ~ Integration of hazard

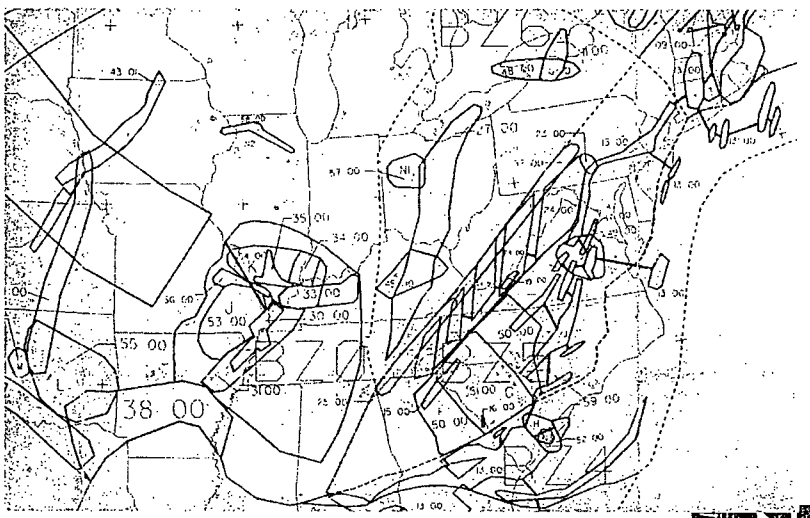
D. Probability analysis:

$$\gamma[C > c] = \sum_j \nu_j \int\int P_j[C > c|\bar{s} \text{ at } l]\, P[\bar{s}]\, P[l]\, d\bar{s}\, dl$$



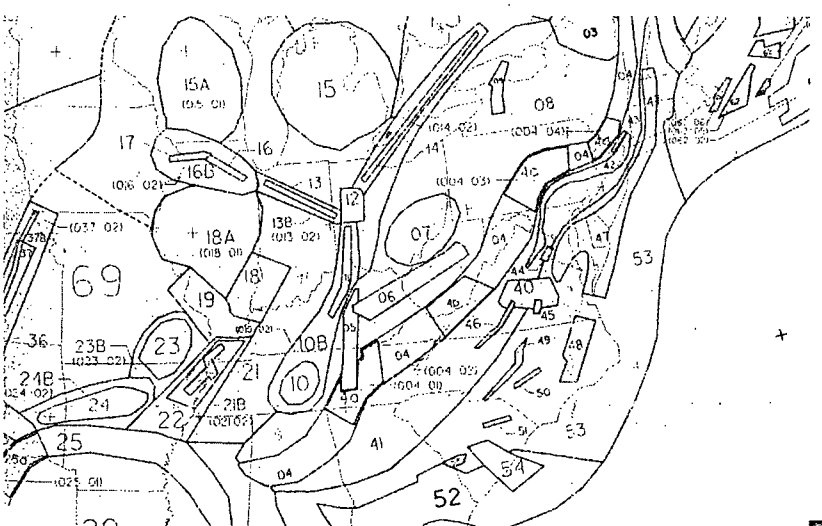
Source: McGuire (2004)

EPRI-SOG sources for Bechtel team



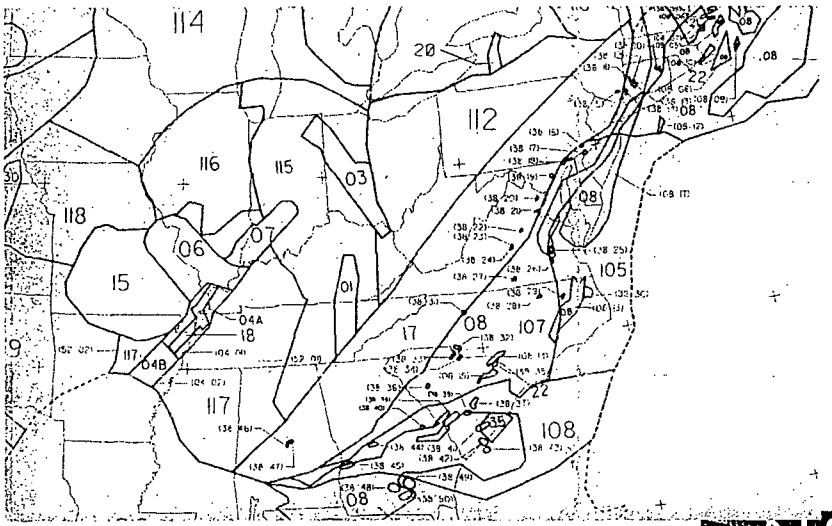
Source: EPRI-SOG (1989)

EPRI-SOG sources for Dames & Moore team



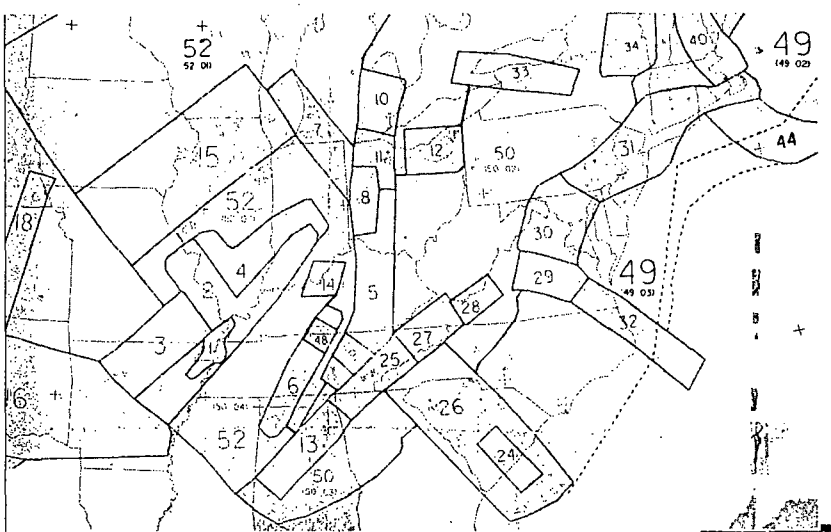
Source: EPRI-SOG (1989)

EPRI-SOG sources for Law Engineering team



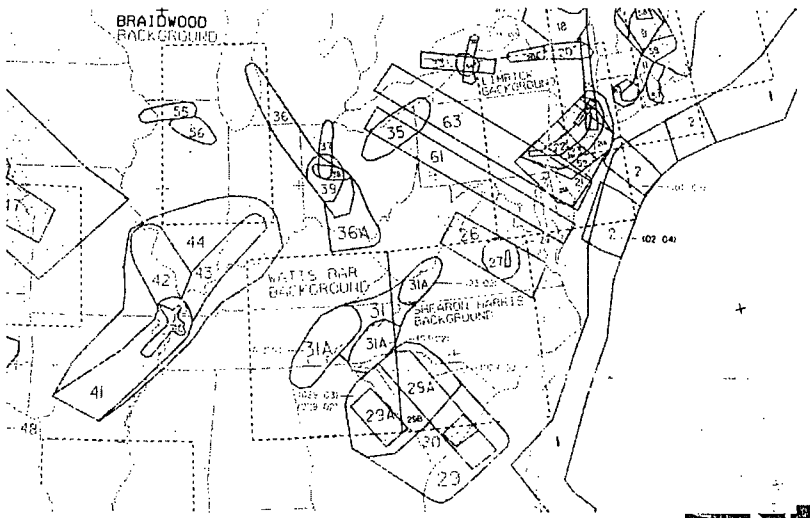
Source: EPRI-SOG (1989)

EPRI-SOG sources for Rondout team



Source: EPRI-SOG (1989)

EPRI-SOG sources for Woodward-Clyde team



Source: EPRI-SOG (1989)

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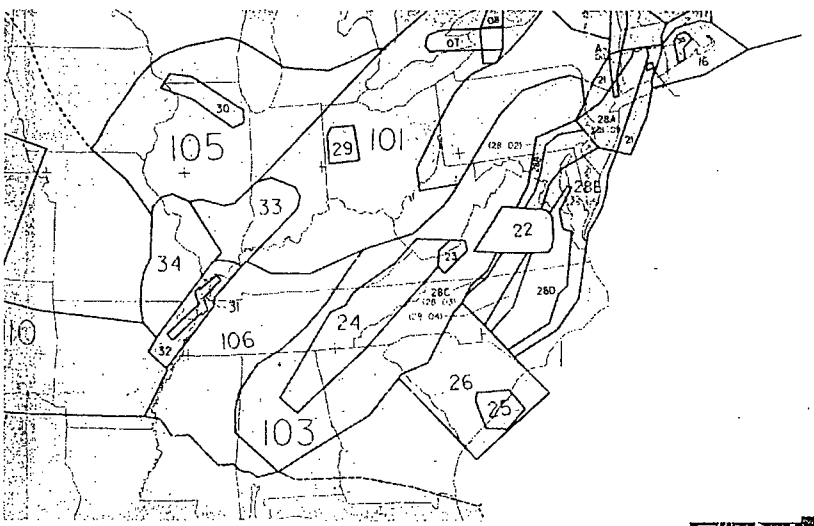
EPRI-SOG sources for Weston Geophysical team



Source: EPRI-SOG (1989)

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Seismicity parameters in EPRI-SOG project

- EPRI-SOG seismicity parameters determined by statistical analysis of historical seismicity
- Seismicity parameters calculated for each source per degree cell using smoothing options specified by each team for each source
- Alternative sets of seismicity parameters were weighted using weights specified by each team

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Seismicity parameters for Bechtel source BZ5, constant a and b

INITIAL HOMOGENEOUS SOLUTION : -1.45 0.91

A-ESTIMATES

	97.00	96.00	95.00	94.00	93.00	92.00	91.00	90.00	79.00	78.00	77.00	76.00	75.00	74.00	73.00
42.00												0-1.460	-1.450	-1.450	-1.450
41.00												0-1.460	-1.460	-1.450	-1.450
40.00									0-1.460	-1.460	-1.460	-1.460	-1.450	-1.460	-1.460
39.00								0-1.450	-1.460	-1.460	-1.460	-1.460	-1.450	-1.450	
38.00							0-1.450	-1.450	-1.450	-1.450	-1.450	-1.450	-1.450	-3.450	
37.00					0-1.440	-1.440	-1.450	-1.450	-1.450	-1.440	-1.440	-1.450	-1.450		
36.00			0-1.430	-1.430	-1.440	-1.440	-1.450	-1.450	-1.450	-1.450	-1.450				
35.00		0-1.440	-1.430	-1.420	-1.430	-1.440	-1.450	-1.450	-1.450	-1.450					
34.00	0-1.440	-1.440	-1.440	-1.430	-1.430	-1.430	-1.440	-1.450	-1.450	-1.460	-1.460				
33.00	0-1.450	-1.450	-1.450	-1.440	-1.440	-1.440	-1.440	-1.450	-1.450						
32.00	-1.430	-1.450	-1.450	-1.450	-1.450	-1.440	-1.440								
31.00	-1.430	-1.450													

B-ESTIMATES

	97.00	96.00	95.00	94.00	93.00	92.00	91.00	90.00	79.00	78.00	77.00	76.00	75.00	74.00	73.00
42.00												0 0.920	0.920	0.920	0.910
41.00												0 0.930	0.930	0.920	0.910	0.910
40.00									0 0.920	0.930	0.930	0.930	0.910	0.900	0.900
39.00								0 0.920	0.920	0.930	0.930	0.920	0.910	0.900	
38.00							0 0.910	0.920	0.920	0.920	0.920	0.920	0.920	0.910	
37.00						0 0.900	0.900	0.910	0.910	0.910	0.910	0.920	0.920		
36.00				0 0.900	0.890	0.890	0.900	0.910	0.910	0.920	0.920	0.920			
35.00			0 0.910	0.900	0.890	0.890	0.890	0.900	0.910	0.920	0.920				
34.00		0 0.910	0.910	0.900	0.900	0.900	0.900	0.900	0.910	0.920	0.920	0.920			
33.00		0 0.910	0.910	0.910	0.900	0.900	0.900	0.900	0.910	0.920					
32.00	0.920	0.920	0.920	0.910	0.910	0.900									
31.00	0.920	0.920													

TOTAL AREA OF THIS ZONE: 43.74(111.1)**2 KM-SQ

Source: REI 1989 EPRI Report

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Seismicity parameters for Bechtel source BZ5, variable a, constant b

INITIAL HOMOGENEOUS SOLUTION : -1.45 0.91

A-ESTIMATES

B	87.00	86.00	85.00	84.00	83.00	82.00	81.00	80.00	79.00	78.00	77.00	76.00	75.00	74.00	73.00
42.00												0-1.950	-1.950	-1.900	-1.960
41.00											0-1.930	-1.920	-1.930	-1.590	-1.220
40.00										0-2.010	-2.030	-2.010	-1.820	-1.320	-1.340	-0.810
39.00									0-1.930	-1.970	-1.870	-1.820	-1.750	-1.650	-1.290	
38.00								0-1.690	-1.840	-1.640	-1.750	-1.800	-1.670	-1.520		
37.00							0-1.410	-1.490	-1.440	-1.660	-0.970	-1.120	-1.020	-1.700		
36.00						0-3.880	-1.040	-1.150	-1.760	-1.970	-1.570	-1.550	-1.440	-1.630		
35.00					0-1.130	-0.830	-0.760	-0.880	-1.480	-1.930	-1.930	-1.960	-1.770			
34.00				0-1.340	-1.340	-1.230	-1.290	-1.000	-1.350	-1.660	-1.870	-2.020	-1.970			
33.00				0-1.910	-1.830	-1.720	-1.500	-1.260	-1.340	-1.500	-1.930					
32.00	-2.290	-2.270	-2.110	-1.790	-1.450	-1.240										
31.00	-2.360	-2.360														

B-ESTIMATES

B	87.00	86.00	85.00	84.00	83.00	82.00	81.00	80.00	79.00	78.00	77.00	76.00	75.00	74.00	73.00
42.00												0.970	0.950	0.930	0.910
41.00											0.980	0.960	0.940	0.910	0.880
40.00										0.950	0.970	0.980	0.950	0.900	0.860	0.830
39.00									0.910	0.940	0.960	0.960	0.950	0.880	0.870	
38.00								0.860	0.880	0.900	0.920	0.940	0.950	0.930	0.900	
37.00							0.850	0.840	0.840	0.880	0.920	0.940	0.970	0.950		
36.00					0.940	0.610	0.880	0.820	0.870	0.900	0.910	0.940	0.960			
35.00			0.960	0.960	0.920	0.870	0.880	0.880	0.920	0.950	0.950					
34.00		0.930	0.950	0.960	0.950	0.930	0.900	0.910	0.930	0.950	0.950					
33.00		0.930	0.930	0.950	0.930	0.930	0.920	0.920	0.930							
32.00	0.950	0.960	0.920	0.940	0.940	0.930										
31.00	0.900	0.950														

TOTAL AREA OF THIS ZONE: 43.74(111.1)**2 KM-SQ

Source: REI 1989 EPRI Report

Seismicity parameters for Bechtel source BZ5, variable a and b

INITIAL HOMOGENEOUS SOLUTION : -1.45 0.91

A-ESTIMATES

B	87.00	86.00	85.00	84.00	83.00	82.00	81.00	80.00	79.00	78.00	77.00	76.00	75.00	74.00	73.00
42.00												0-1.920	-1.790	-1.340	
41.00											0-1.910	-1.880	-1.810	-1.570	-1.710
40.00										0-1.990	-2.010	-1.990	-1.810	-1.520	-1.260	-0.940
39.00									0-1.930	-1.960	-1.850	-1.810	-1.740	-1.410	-1.300	
38.00								0-1.710	-1.850	-1.700	-1.440	-1.680	-1.790	-1.670	-1.530	
37.00							0-1.430	-1.510	-1.470	-1.490	-0.970	-1.120	-1.810	-1.770		
36.00						0-0.870	-1.030	-1.160	-1.300	-1.880	-1.570	-1.570	-1.420	-1.610		
35.00					0-1.120	-0.820	-0.760	-0.900	-1.490	-1.540	-1.920	-1.960	-1.750			
34.00				0-1.550	-1.340	-1.240	-1.270	-0.990	-1.360	-1.650	-1.850	-2.010	-1.950			
33.00				0-1.920	-1.840	-1.720	-1.300	-1.230	-1.330	-1.590	-1.810					
32.00	-2.310	-2.290	-2.130	-1.790	-1.450	-1.240										
31.00	-2.390	-2.370														

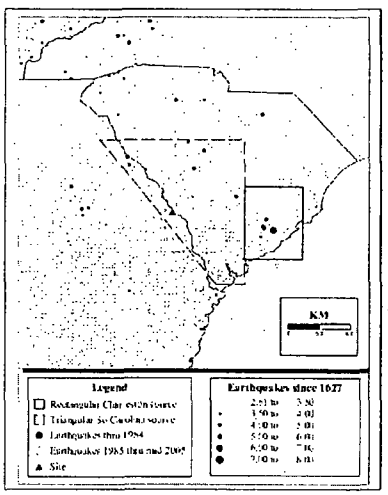
B-ESTIMATES

B	87.00	86.00	85.00	84.00	83.00	82.00	81.00	80.00	79.00	78.00	77.00	76.00	75.00	74.00	73.00
42.00												1.090	1.070	1.030	0.980
41.00											1.090	1.070	1.030	0.980	0.900
40.00										1.070	1.060	1.070	1.030	0.880	0.800	0.740
39.00									0.940	0.990	1.030	1.010	0.990	0.830	0.820	
38.00								0.850	0.900	0.900	0.910	1.020	1.010	0.970	0.900	
37.00							0.830	0.810	0.760	0.880	0.910	0.940	1.040	1.000		
36.00						0.990	0.920	0.840	0.720	0.880	0.890	0.980	1.010	1.000		
35.00				1.000	1.030	0.930	0.820	0.890	0.850	0.970	1.010	0.970				
34.00		0.900	0.950	1.010	1.000	0.980	0.890	0.910	0.980	1.010	1.000					
33.00		0.800	0.900	0.980	0.920	0.940	0.930	0.950	0.970							
32.00	0.800	0.830	0.880	0.940	0.960	0.930										
31.00	0.820	0.830														

TOTAL AREA OF THIS ZONE: 43.74(111.1)**2 KM-SQ

Source: REI 1989 EPRI Report

PSHA requires evaluation of whether seismicity from 1985-now would change seismicity parameters



Seismicity, Local Source, & Charleston Source

Source: Vogtle 2006 ESP Application

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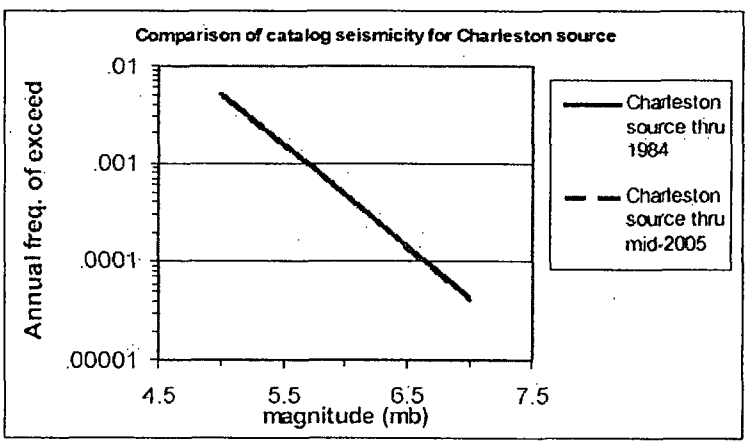
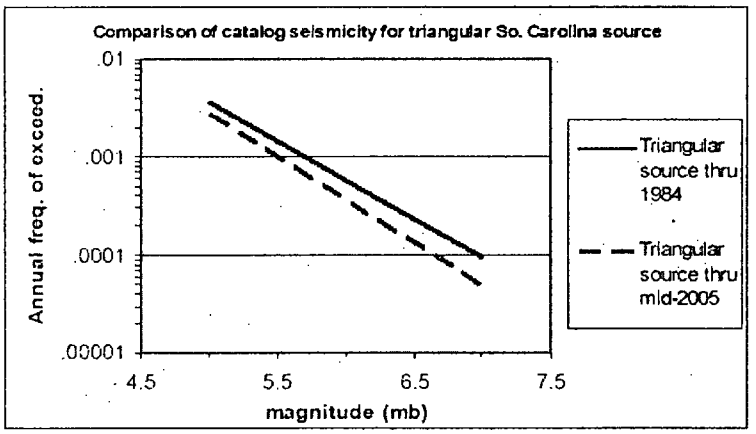
PSHA requires evaluation of whether seismicity from 1985-now would change seismicity parameters



Source: Vogtle 2006 ESP Application

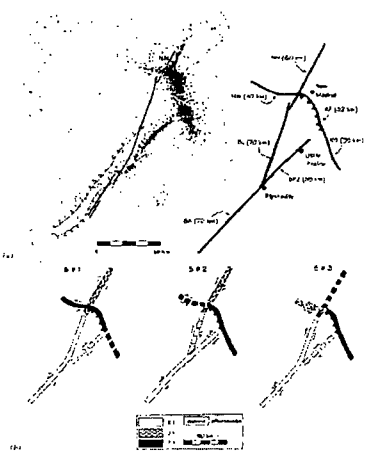
RISK ENGINEERING

PSHA requires evaluation of whether seismicity from 1985-now would change seismicity parameters



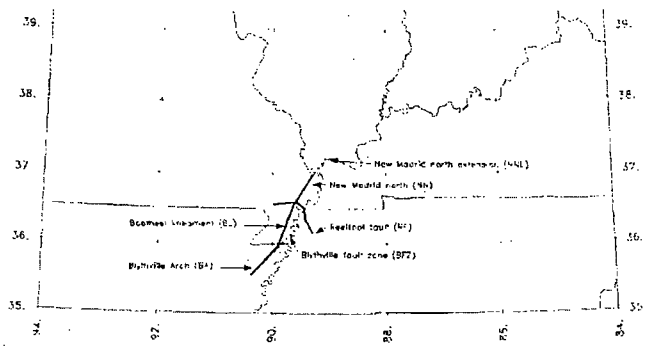
Source: Vogtle 2006 ESP Application

Geometries of postulated faults and 1811-1812 rupture sequences in New Madrid seismic zone



Source: Exelon (2003) Clinton ESP application

Geometries of faults in New Madrid seismic zone as modeled for PSHA



Source: Exelon (2003) Clinton Report

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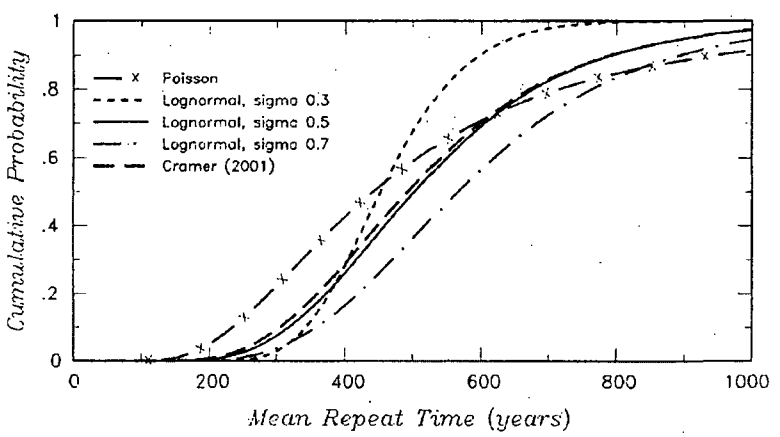
Distribution of mean repeat times for New Madrid earthquakes



Source: Exelon (2003) Clinton Report

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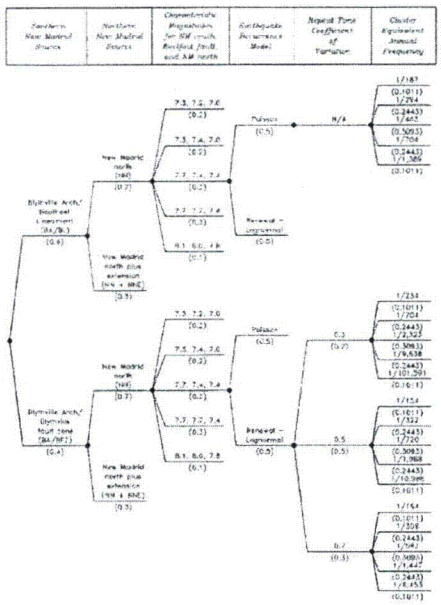

Source: Exelon (2003) Clinton Report

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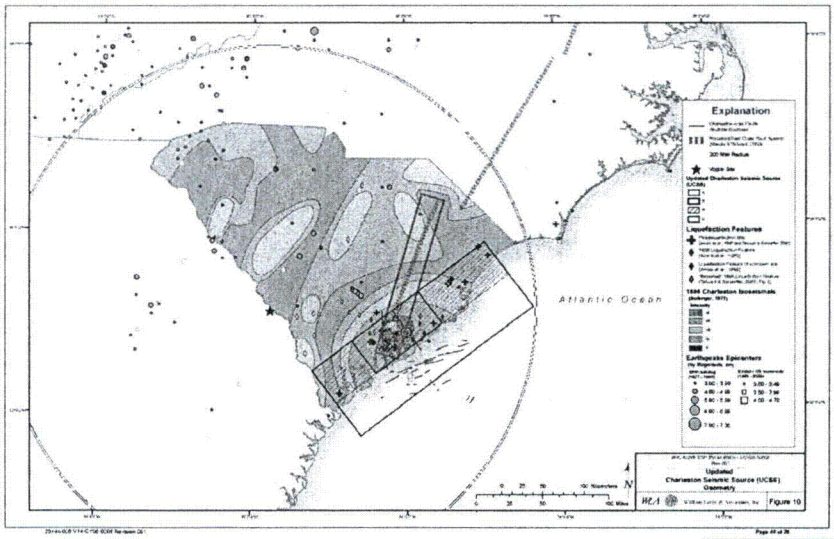
Updated Charleston seismic source geometries



Source: Southern Nuclear Co (2006) Vogtle ESP application

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Maximum magnitude and recurrence interval distributions for Charleston source

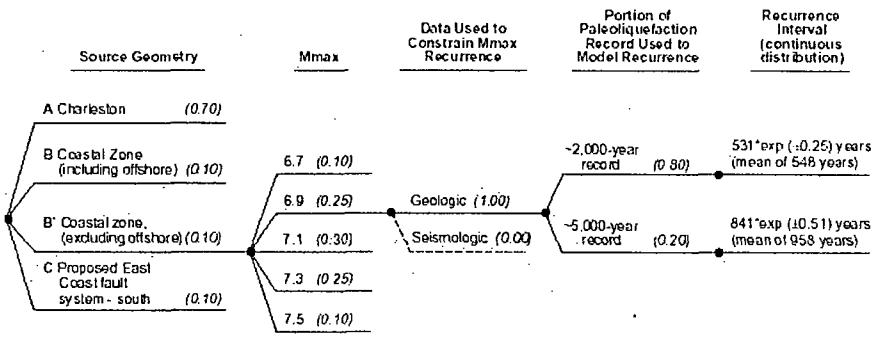
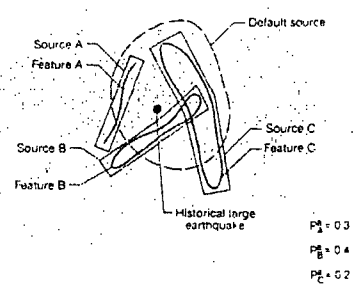
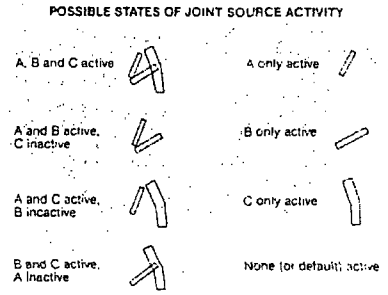


Figure 11. Updated Charleston seismic source (USGS) logic tree with weights for each branch shown in italics

Source: WLA UCSS

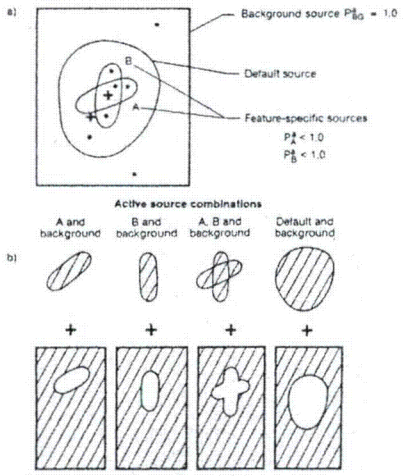
Example of treatment of alternative source geometries





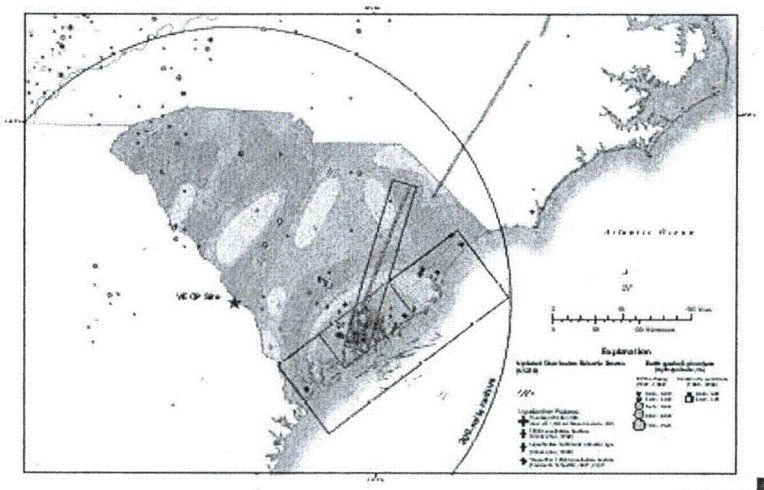
Source: REI (1989) EPRI Report

Example of "donut" sources representing regions surrounding alternative source geometries



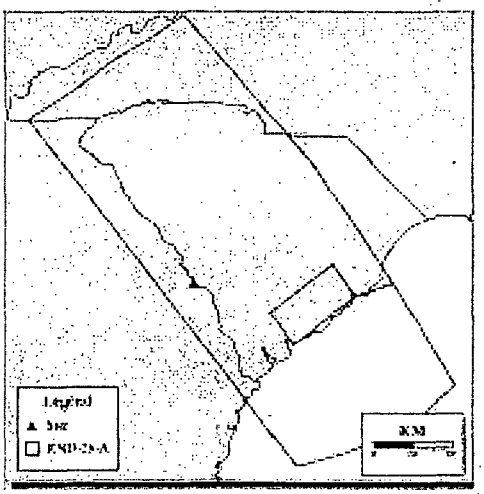
Source: REI 1989 EPRI Report

Four alternative geometries for Charleston source



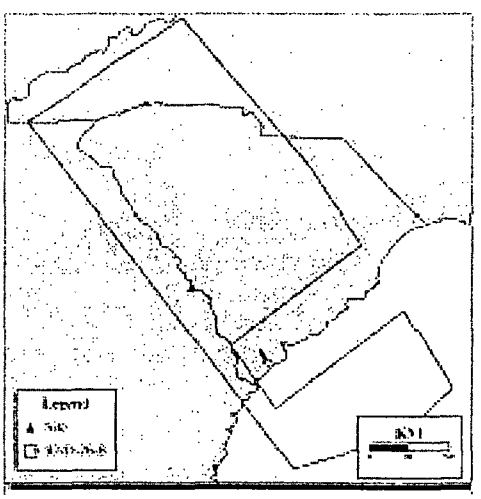
Source: Southern ESP Application Rev 0

Example: Rondout source 26-A



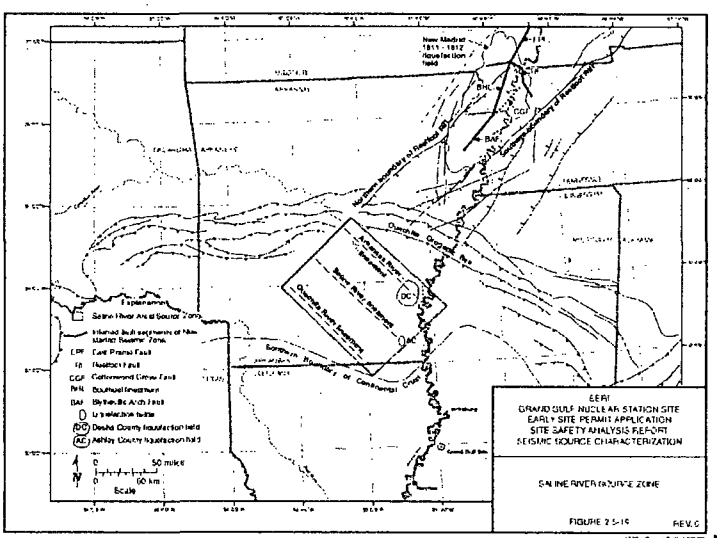
Source: Southern ESP Application Rev 0

Example: Rondout source 26-B

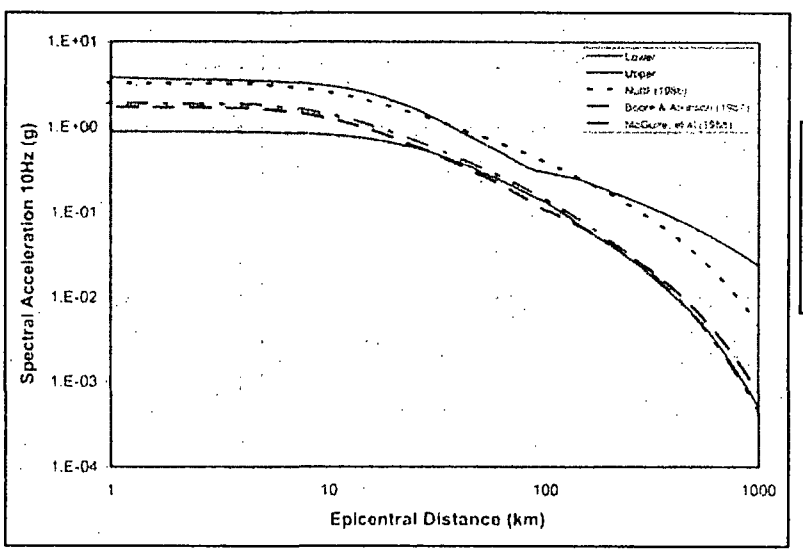


Source: Southern ESP Application Rev 0

Saline River source

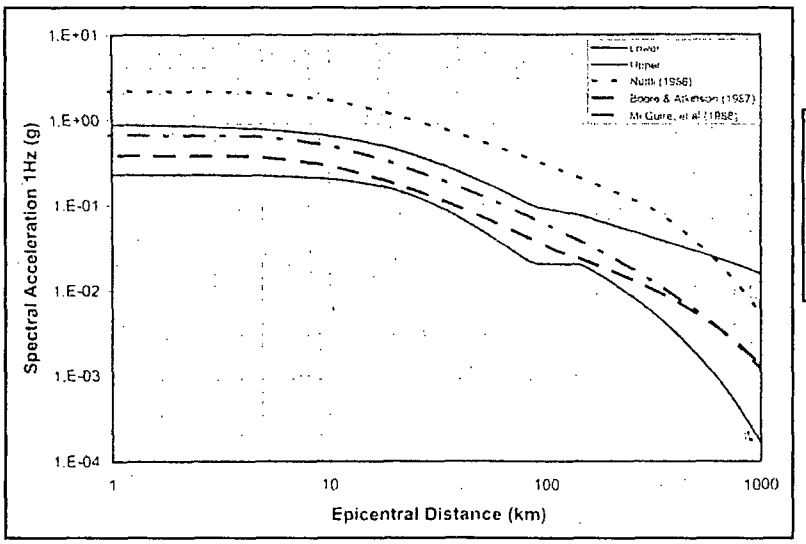


Source: Entergy (2003) Grand Gulf ESP application



EPRI 2004 10 Hz SA for m_b 7, compared to EPRI-SOG equations

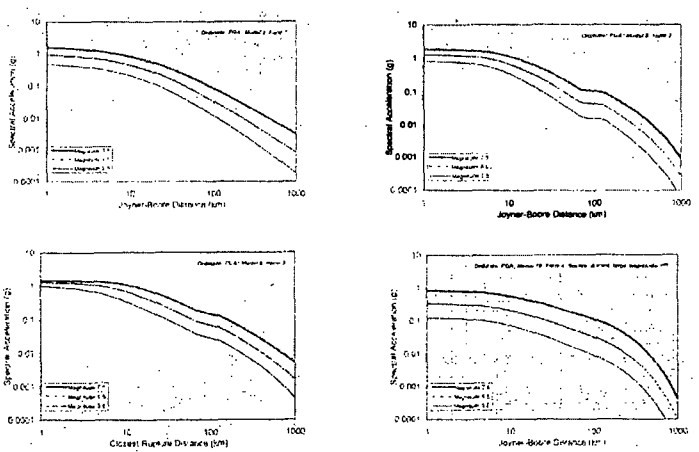
Source: EPRI, 2004



EPRI 2004 1 Hz SA for m_b 7, compared to EPRI-SOG equations

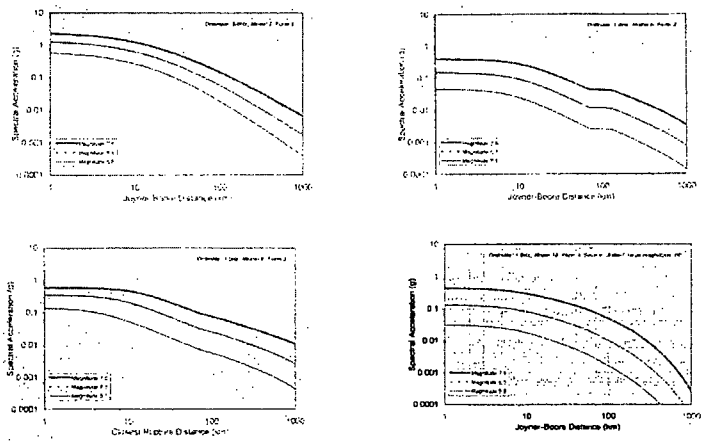
Source: EPRI, 2004

EPRI (2004): Four PGA models (**M**=5.5, 6.5, 7.5)



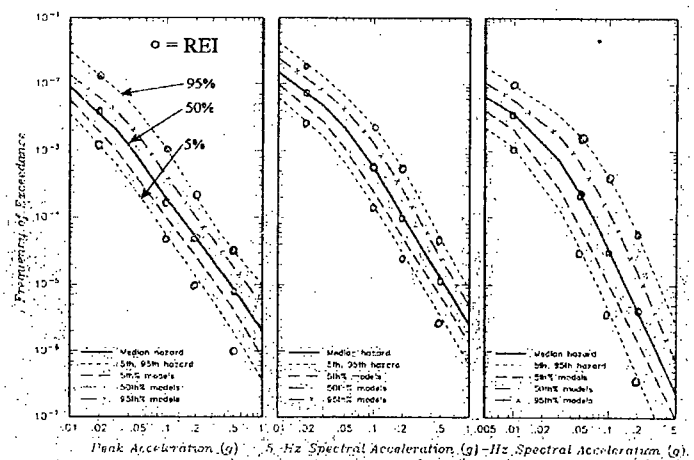
Source: EPRI (2004) Ground Motion Report

EPRI (2004): Four 1 Hz models (**M**=5.5, 6.5, 7.5)



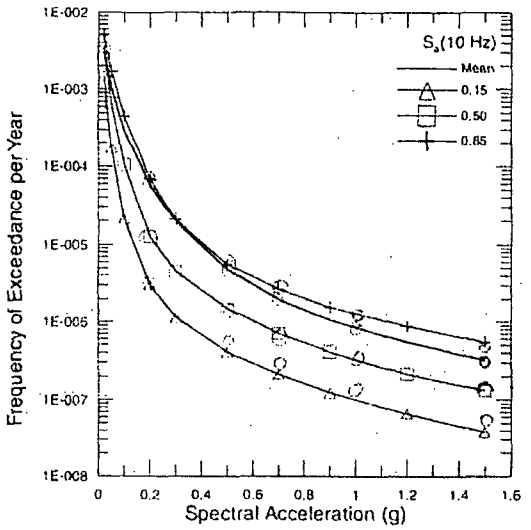
Source: CEUS Ground Motion Project 2003

Comparison of rock hazard curves for Clinton



Source: 2005 EPRI Report

Comparison of rock hazard curves for Grand Gulf

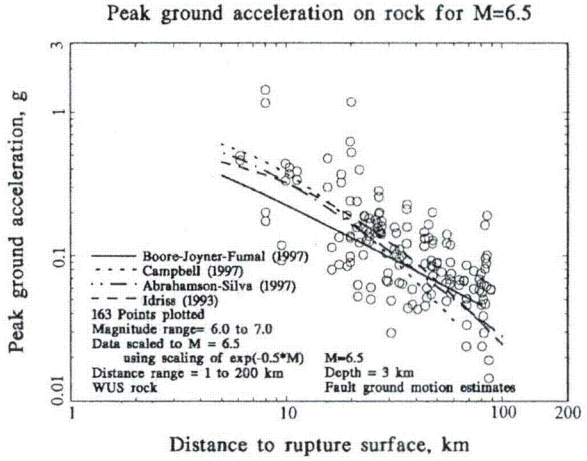


Source: 2005 EPRI Report

EPRI revised σ's

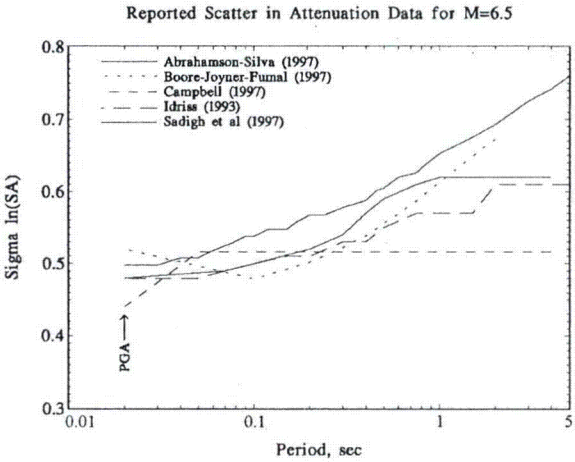
- σ is standard deviation of ln (ground motion amplitude)
- σ represents aleatory uncertainty
- Multiple σ's represent epistemic uncertainty
- In California we get σ's from data

California data vs distance



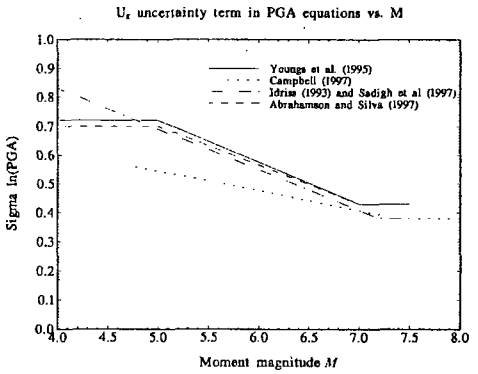
Source: McGuire (2004)

California σ's vs period



Source: McGuire (2004)

California σ's vs magnitude



Source: McGuire (2004)

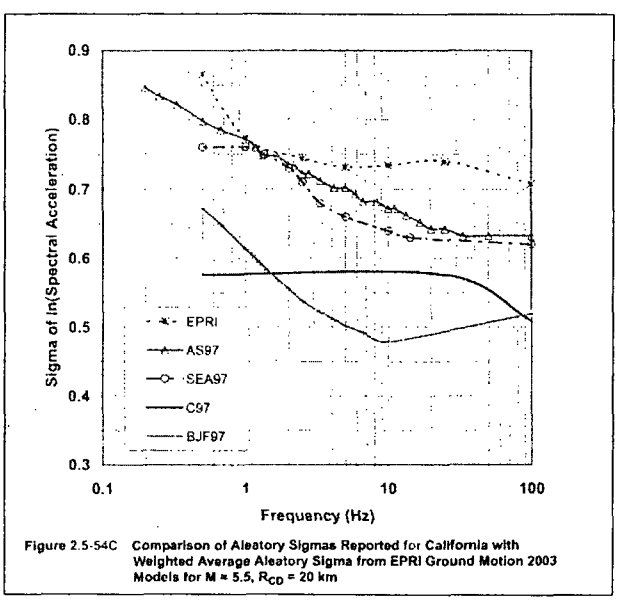


Figure 2.5-54C Comparison of Aleatory Sigmas Reported for California with Weighted Average Aleatory Sigma from EPRI Ground Motion 2003 Models for M = 5.5, R_{CD} = 20 km

Source: North Anna 2003 ESP Application

EPRI revised σ's *(continued)*

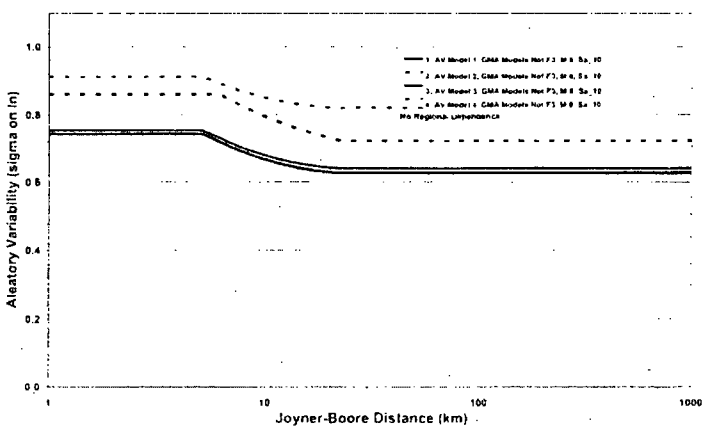
- In Central and Eastern US we have to estimate σ from models

Why would σ (CEUS) > σ (WUS)?

→Earthquake energy release more variable (stress drop)

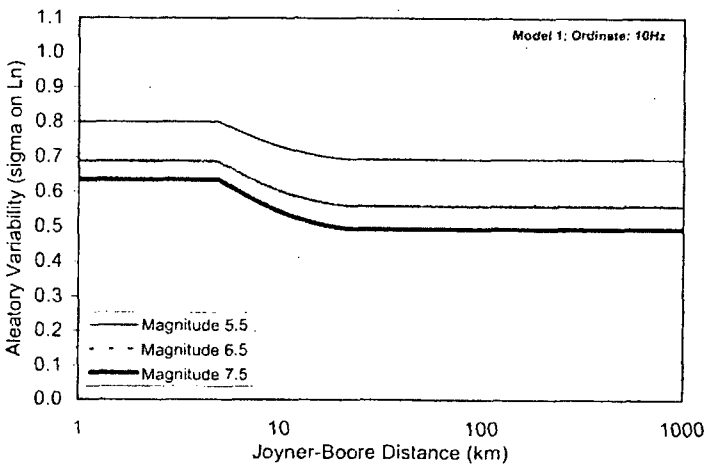
→Crustal path conditions more variable

σ's for 10 Hz SA, **M** = 6



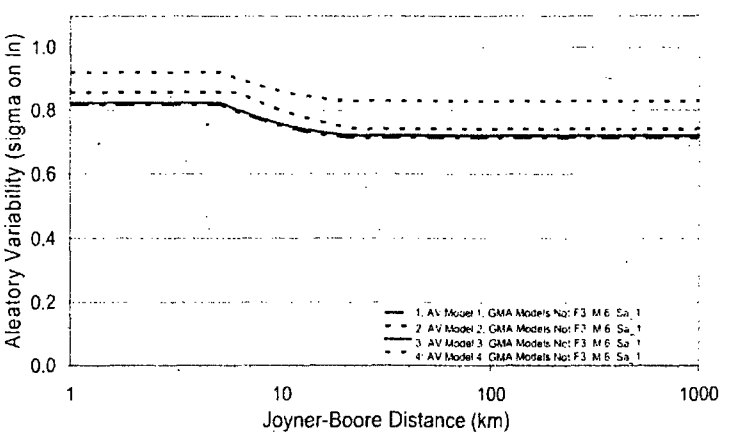
Source: EPRI (2004)

EPRI (2004) sigmas, model 1, 10 Hz



Source. EPRI (2004)

σ's for 1 Hz SA, **M** = 6



Source. EPRI (2004)

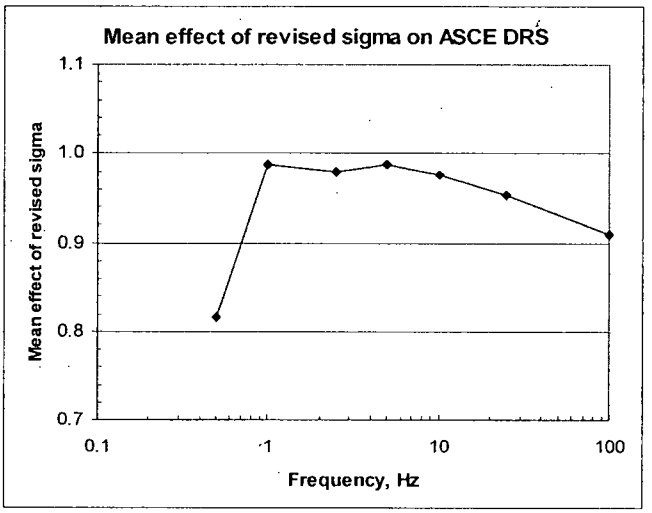
EPRI revised σ's

Recommended Standard Deviation, σ_t, for the CEUS. Values are in Ln units

	Model 1A WUS Inter-event WUS Intra-event wt = 0.7			Model 1B WUS Inter-event WUS Intra-event Reduced for homogeneous crustal structure wt = 0.3		
Frequency (Hz)	Intra-event	Inter-Event	Total	Intra-event	Inter-event	Total
PGA	0.51	0.37	0.63	0.48	0.37	0.61
25	0.56	0.43	0.71	0.53	0.43	0.68
10	0.56	0.43	0.71	0.53	0.43	0.68
5	0.56	0.43	0.71	0.53	0.43	0.68
2	0.56	0.43	0.71	0.53	0.43	0.68
1	0.60	0.43	0.74	0.57	0.43	0.71
0.5	0.62	0.43	0.75	0.59	0.43	0.73

Source: Abrahamson and Bommer (2005)

Mean effect of revised σ for 28 sites



Source: Risk Engineering, Inc. (2006)

Observations about revised σ

- Affects 10^{-5} ground motion more than 10^{-4} ground motion
- Little effect for sites dominated by Charleston & New Madrid sources

EPRI CAV Model

CAV = Cumulative Absolute Velocity

Really: Cumulative Absolute Acceleration x Time

Units are g-sec (velocity)

$$CAV = \sum_{i=1}^{N} H\left(pga_i - 0.025\right) \int_{t=t_i}^{t_{i+1}} \left|a(t)\right| dt$$

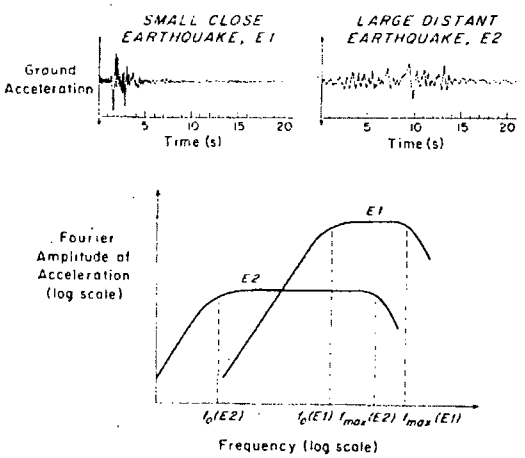
EPRI CAV model *(continued)*

- Fraction of ground motions with CAV ≤ 0.16 g-sec are eliminated from hazard calculations
- Estimate of CAV = f(M, amplitude, duration, V_{S30})
- CAV for spectral acceleration is linked to PGA through correlation
- CAV depends on amplitude, M, duration, and V_{S30} (site conditions!)

Ground motion correlation with PGA (of logarithmic deviation above & below logarithmic mean)

PGA	25 Hz	10Hz	5 Hz	2.5 Hz	1 Hz	0.5 Hz
1	0.91	0.88	0.75	0.60	0.55	0.50

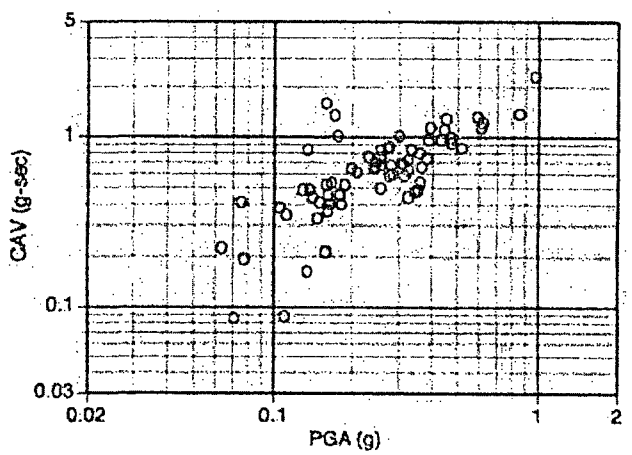
Spectra from small and large earthquakes



Source. McGuire and Arabasz, (1990)

RISK ENGINEERING

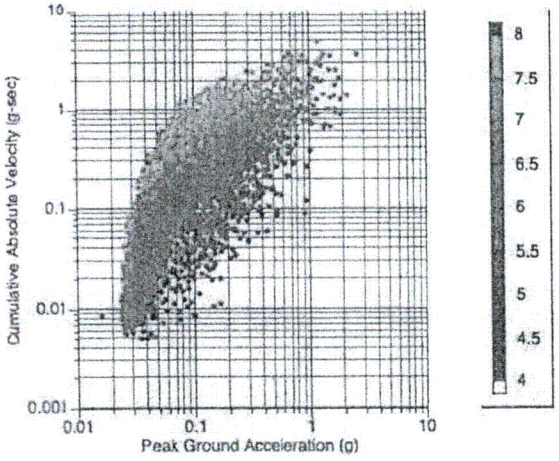
Dependence of CAV on PGA amplitude



Source: Abrahamson and Watson-Lamprey (2005) EPRI report

RISK ENGINEERING

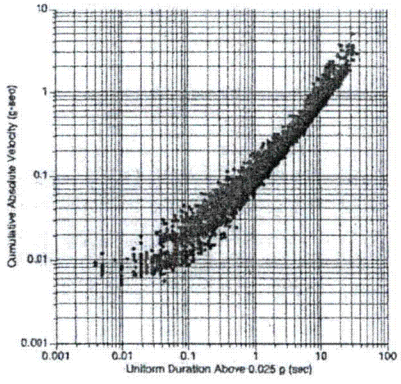
Dependence of CAV on PGA amplitude and magnitude



Source: Abrahamson and Watson-Lamprey (2005) EPRI report

RISK ENGINEERING

Dependence of CAV on strong motion duration



Source: Abrahamson and Watson-Lamprey (2005) EPRI report

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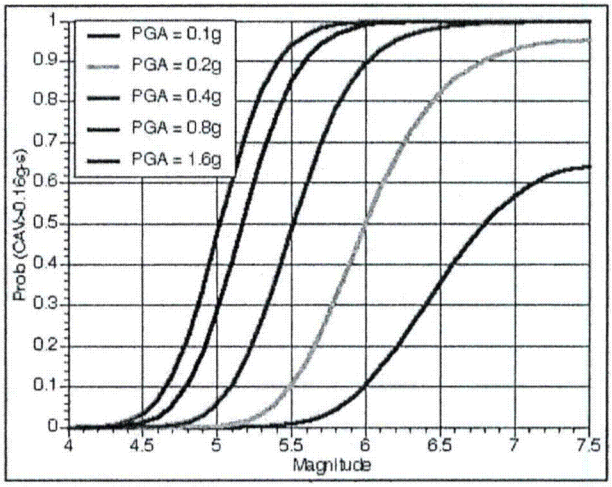
Probability of CAV > 0.16g-sec



Source: Abrahamson and Watson-Lamprey (2005) EPRI report

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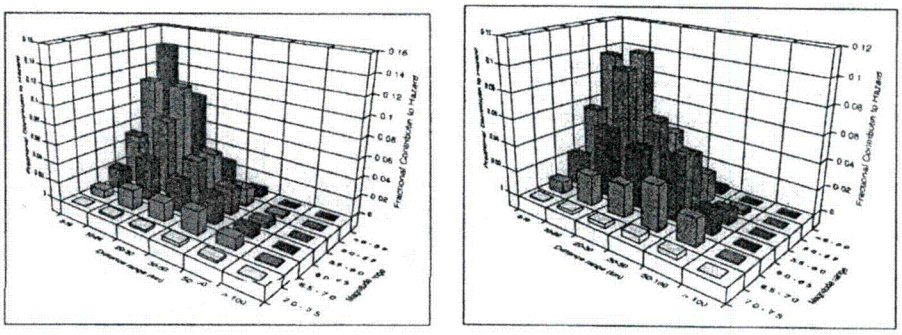
Effect of CAV on contribution to hazard

20 Hz 10^{-4} deaggregation, no CAV (left) and CAV (right)



Source: Abrahamson and Watson-Lamprey (2005) EPRI report

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Summary of PSHA applications

- Hazard based on EPRI-SOG updated by New Madrid and Charleston models (+ others)
- EPRI (2004) ground motions with revised σ
- CAV filter applied to account for damageability of small-magnitude earthquakes

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