U.S. Department of Energy
Office of Civilian Radioactive Waste Management

YUCCA MOUNTAIN PROJECT

Proposed Ground Motions for Postclosure Analysis

Presented to:

Nuclear Waste Technical Review Board
Joint Meeting of the Natural System and Engineered System Panels

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24 February 2003
Las Vegas, Nevada

Objectives

- **Develop postclosure ground motions for:**
  - **Annual exceedance probabilities < 10^{-4}**
  - **Waste emplacement level (Point B)**
  - **Analyses of rockfall, drip shield/waste package structural response, and seismic scenario abstraction**

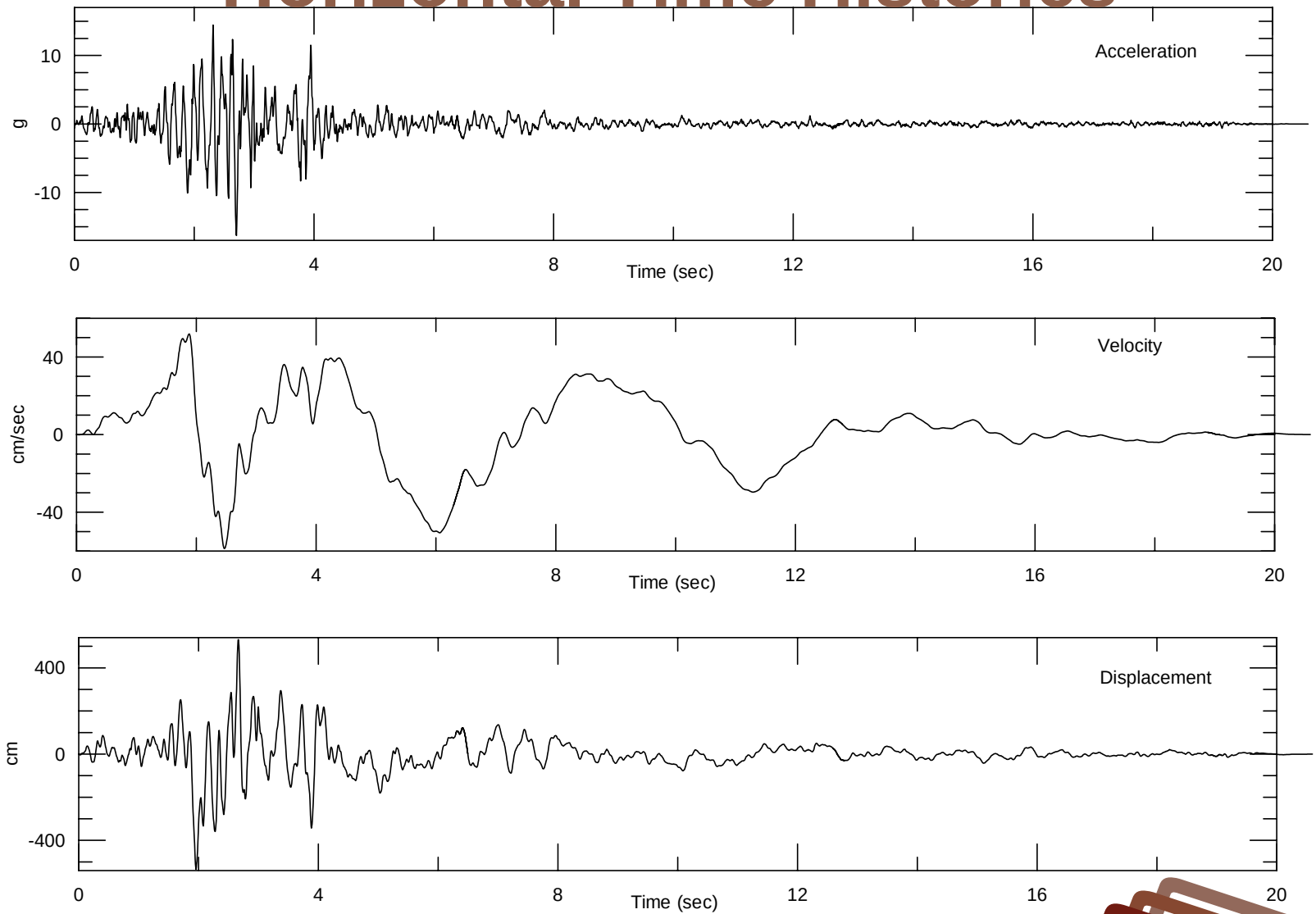
Approach

- **For each annual exceedance probability of interest (e.g., 10^{-6}, 10^{-7})**
  - **Use the same approach as for preclosure ground motions:**
    - **Determine the response spectrum at the waste emplacement level (Point B)**
    - **Determine the peak ground velocity at the waste emplacement level**
  - **Develop a suite of 15 time histories for postclosure analyses that represent the observed variability of ground motion**

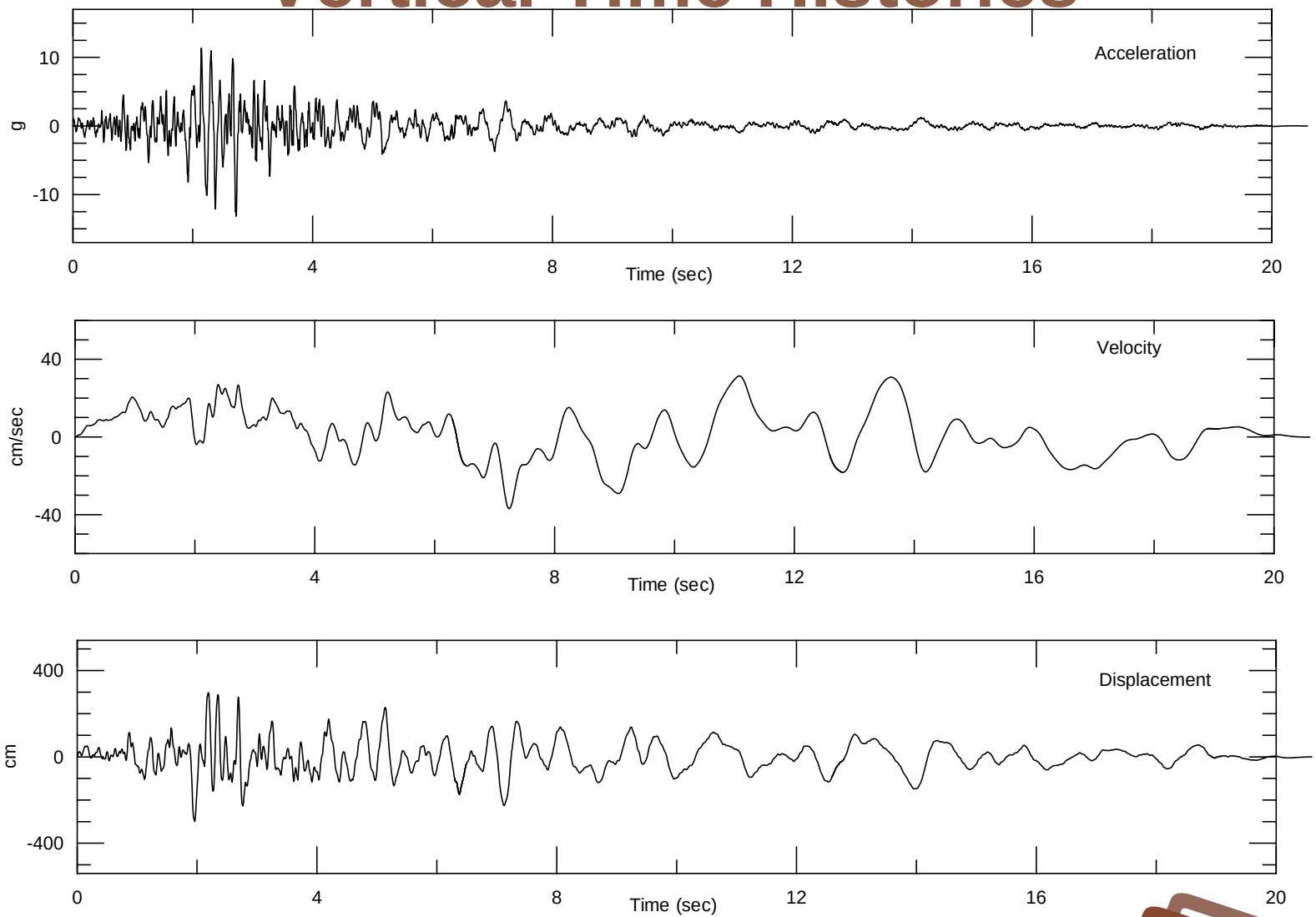
Development of Time Histories

- **Select appropriate strong ground motion records to represent magnitude and distance contributions to hazard at given annual exceedance probability**
- **Condition strong ground motion records to response spectral shape for Yucca Mountain**
- **Scale strong ground motion records to peak ground velocity (PGV) at waste emplacement level (Point B)**
  - **Scale horizontal component 1 to Point B PGV**
  - **Scale horizontal component 2 and vertical component to maintain inter-component variability as observed in the original record**

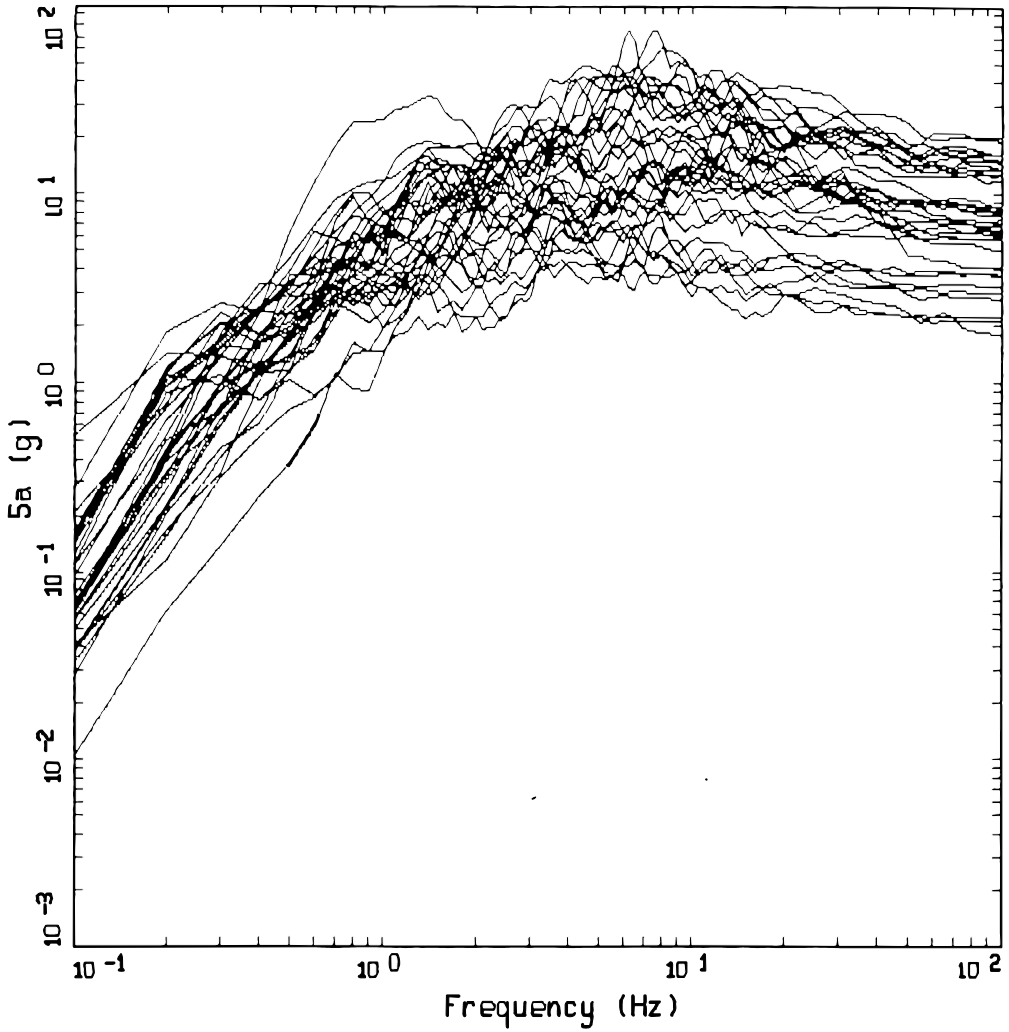
Annual Exceedance Probability 10^{-7} Horizontal Time Histories



Annual Exceedance Probability 10^{-7} Vertical Time Histories



Annual Exceedance Probability 10^{-7} Horizontal Spectra from Scaled Time Histories



Scaled to 535 cm/sec

Annual Exceedance Probability 10^{-7} Horizontal Spectra from Scaled Time Histories

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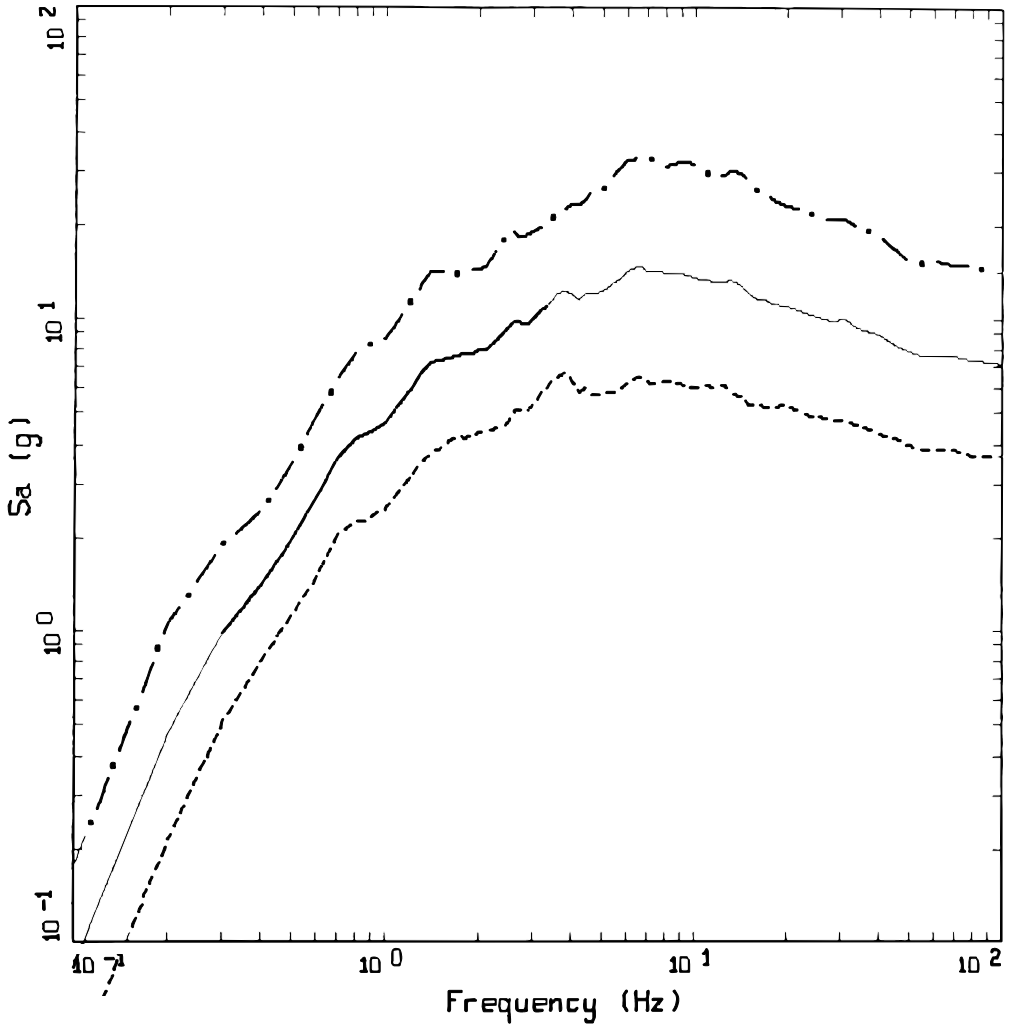
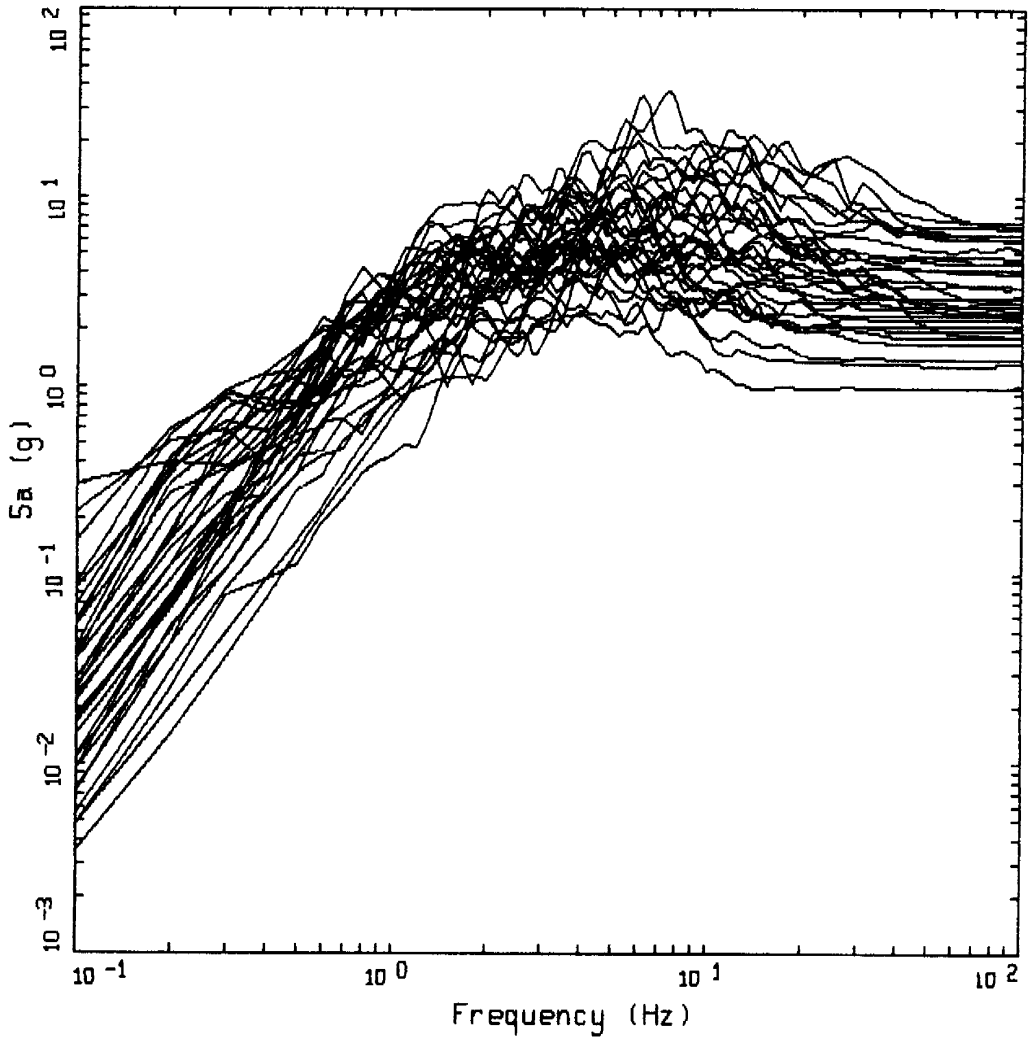


LEGEND
84TH PERCENTILE, PGA = 14.26 g
50TH PERCENTILE, PGA = 7.18 g
16TH PERCENTILE, PGA = 3.61 g

Scaled to 535 cm/sec

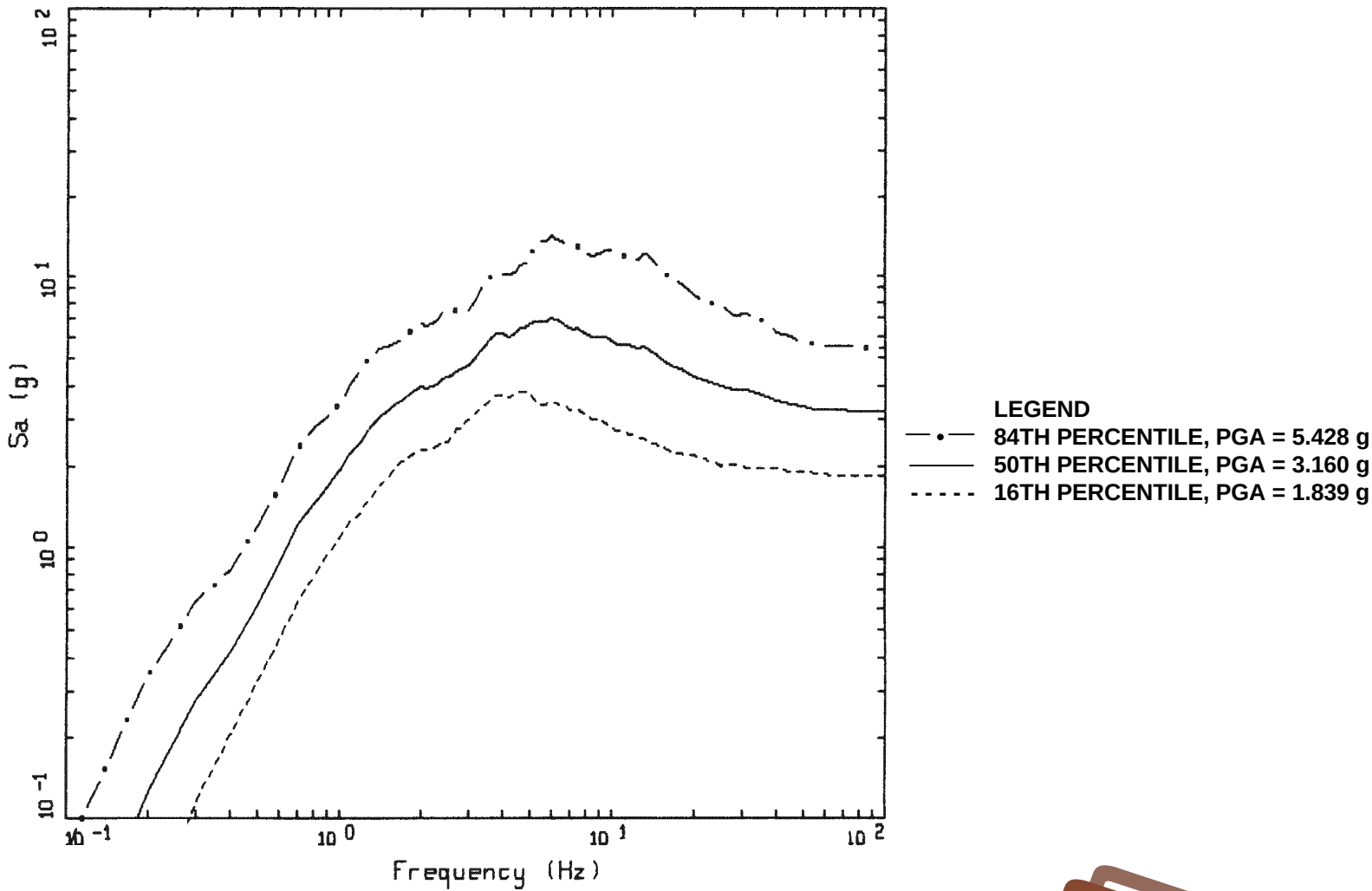
Annual Exceedance Probability 10^{-6} Horizontal Spectra from Scaled Time Histories



Scaled to 244 cm/sec

Annual Exceedance Probability 10^{-6} Horizontal Spectra from Scaled Time Histories

(Continued)



Scaled to 244 cm/sec

Results

Annual Exceedance Probability	Peak Ground Velocity (cm/sec)	
	Horizontal	Vertical
10^{-6}	244	233
10^{-7}	535	625

Postclosure Ground Motion Issues

- **Large calculated strains**
  - **Direct application of site response ground motion model, with 10^{-6} inputs from Probabilistic Seismic Hazard Analysis (PSHA), leads to some cases in which calculated strains may be larger than the rock can sustain**
- **Extreme seismic source parameters**
  - **Point source modeling to obtain ground motions consistent with PSHA results for 10^{-6} require extreme source parameter values (e.g., stress drop > 1000 bars)**
- **Can calculated low probability ground motions be realized?**

Observed Extreme Ground Motion

- **Largest recorded peak ground accelerations range from about 1.5 to over 2 g**
- **Largest recorded peak ground velocities range from about 130 cm/sec to over 250 cm/sec**
- **Geologic evidence at Yucca Mountain**
  - **Precarious rocks**
  - **Slopes**
  - **Lithophysae**

Saturation of Extreme Ground Motion

- **Can we demonstrate that ground motion at Yucca Mountain will saturate at some level**
- **Approaches**
  - **Strain threshold - incorporate strain threshold for rock fracture into equivalent-linear analysis**
  - **Point-source or finite-source modeling - for ranges of seismic source parameters defined by the PSHA ground motion experts, evaluate the distribution of calculated ground motions**
- **Scoping studies underway**

Strain Threshold Approaches

- **Reduce Point A motions until calculated strains do not exceed fracture strain threshold**
  - **Motivation: Undeformed lithophysae may indicate that fracture strain threshold has not been exceeded at Yucca Mountain since the rocks were formed (13 m.y.)**
- **Modify shear modulus reduction and damping curves used in the equivalent-linear site response model to take into account rock fracture at some strain threshold**
  - **Apply equivalent-linear model below Point A to take nonlinear effects into account**
  - **Match PSHA results for linear behavior below Point A**

Summary of Point A Peak Values

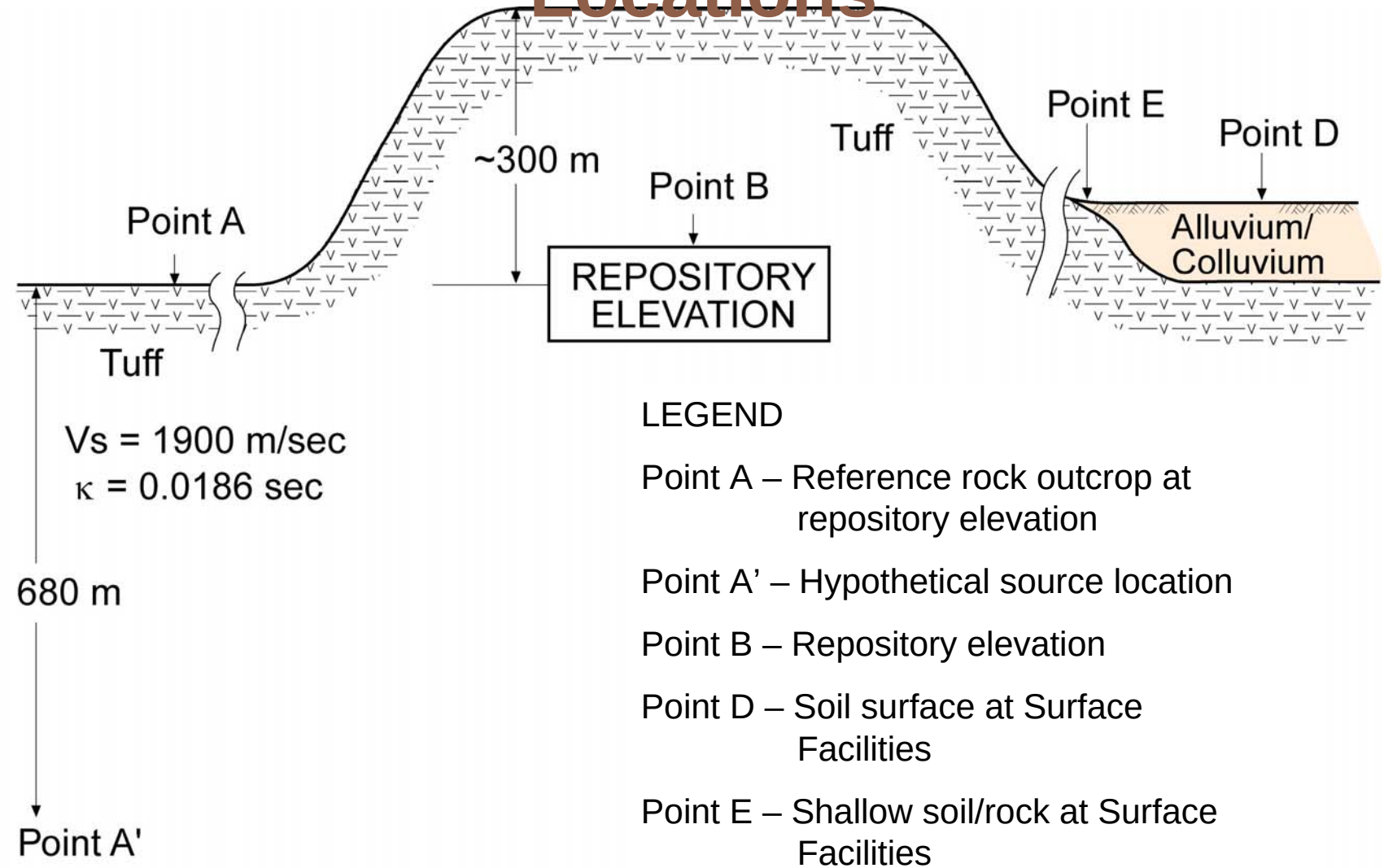
APE	Mean PGA (g)		Mean PGV (cm/sec)	
	Horizontal	Vertical	Horizontal	Vertical
10^{-7}	5.838	8.652	655	572
10^{-6}	2.860	4.124	301	224
10^{-4}	0.534	0.715		
5×10^{-4}	0.245	0.254		

PGA = Peak Ground Acceleration
PGV = Peak Ground Velocity

Strain Threshold Approaches

- **Apply fracture strain threshold within B-C (above repository only)**
  - **Scale Point A motions**
  - **Average B-C strains at fracture levels**
  - **Indirect limitation on Point A motions**
  - **107 years, no evidence of deformation**
- **Apply fracture strain threshold below A (A to A')**
  - **Model effects of fracture generation on dynamic material properties, response spectra**
  - **Direct limitation on motions at Point A**
  - **Saturation effects modeled**

Locations



LEGEND

Point A – Reference rock outcrop at repository elevation

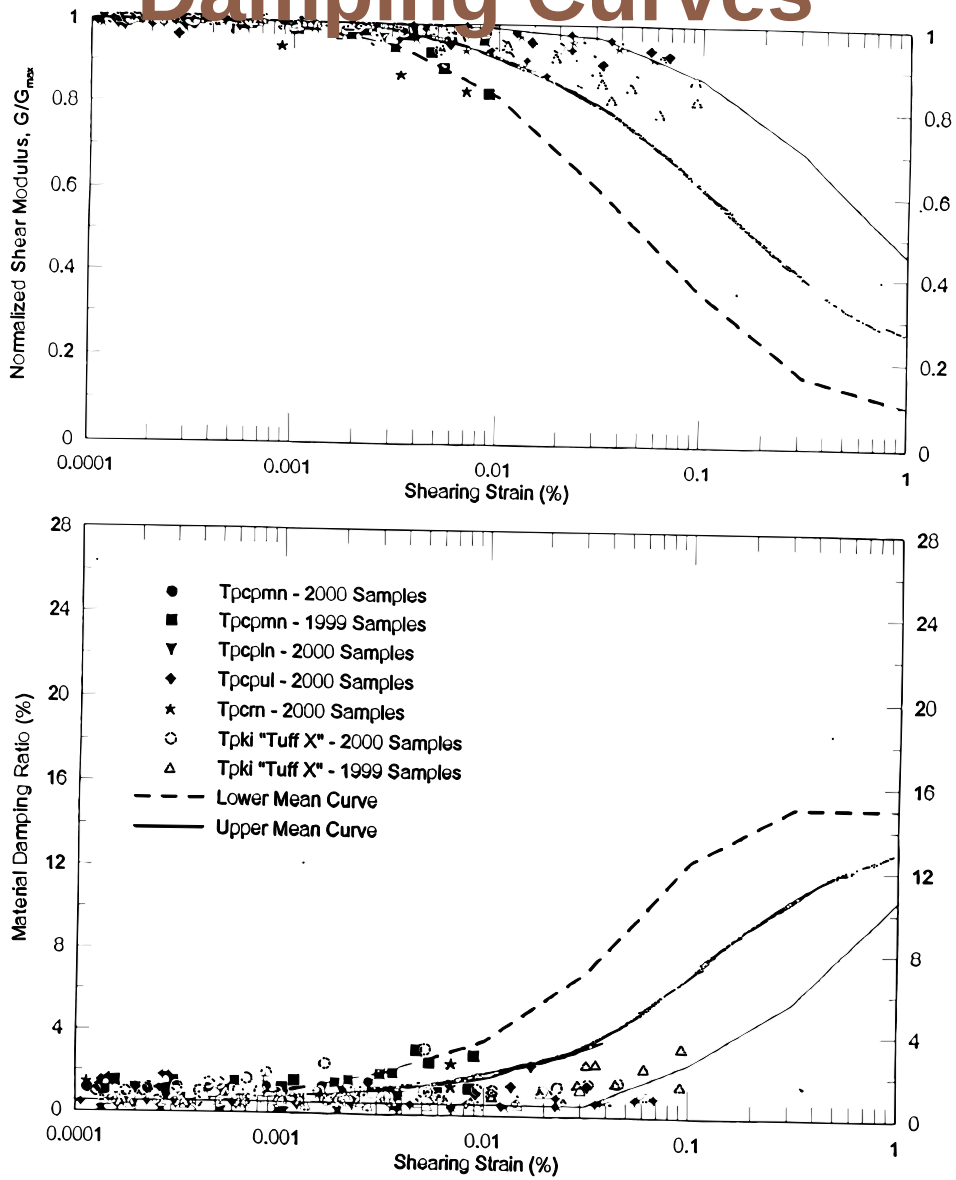
Point A' – Hypothetical source location

Point B – Repository elevation

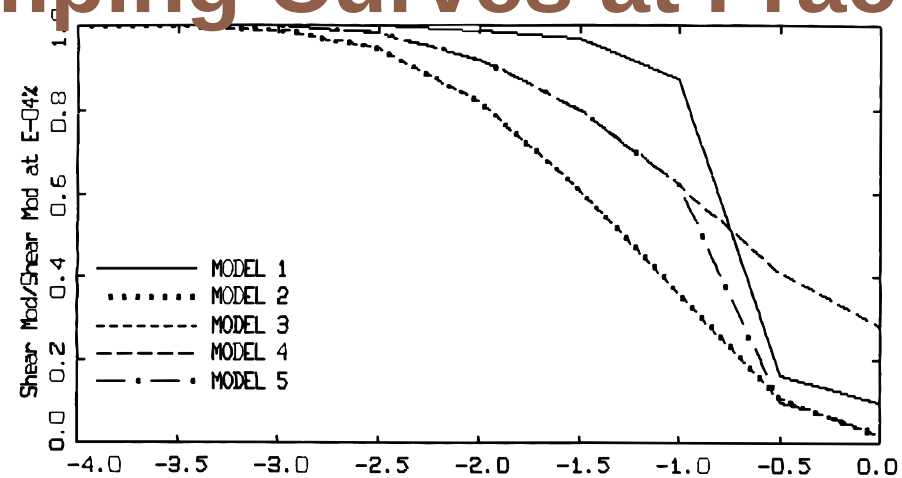
Point D – Soil surface at Surface Facilities

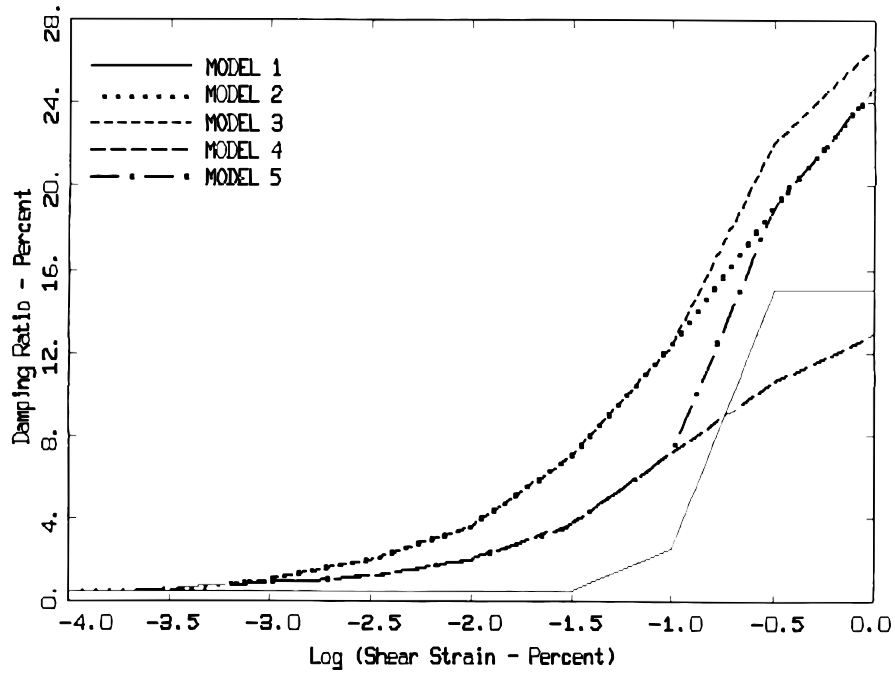
Point E – Shallow soil/rock at Surface Facilities

Tuff Shear Modulus Reduction and Damping Curves



Tuff Shear Modulus Reduction and Damping Curves at Fracture





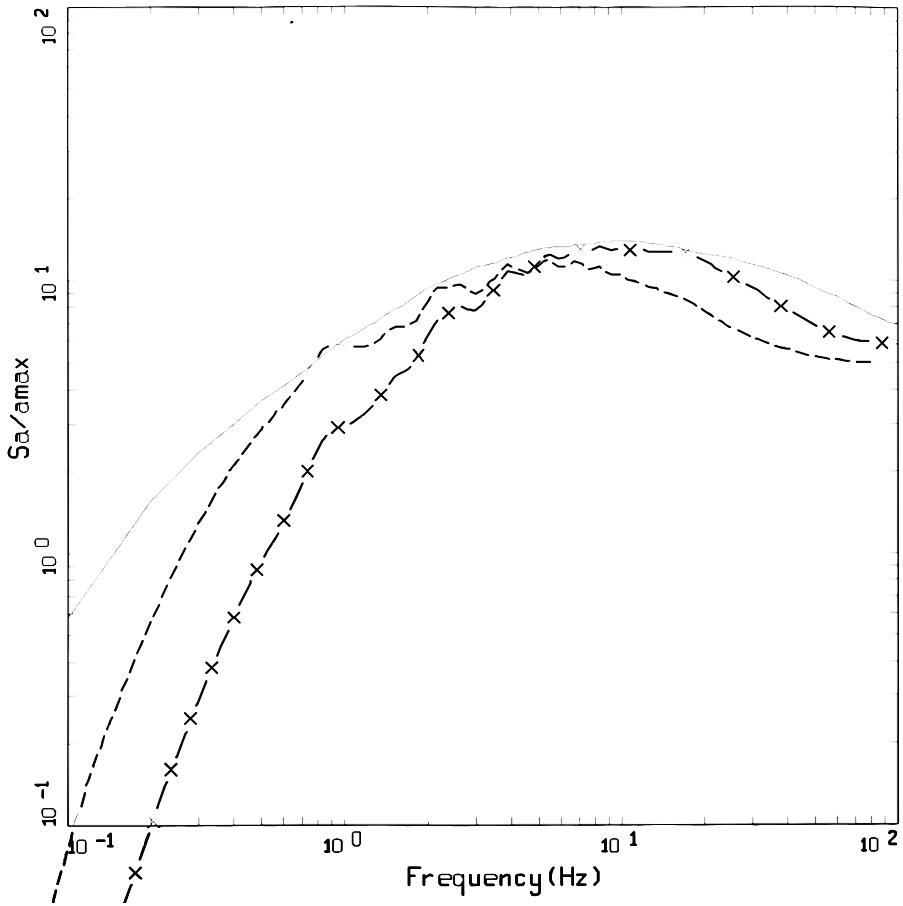
Fracture Strain Scaling
Point A

AEP 10^{-7} (yr^{-1})					
Hz	**UHS (g)**	**M**	**D (km)**	**H (km)**	**Stress Drop (bars)**
1	**5.47**	**7.7**	**51**	**8**	**15,000**
10	**13.76**	**6.5**	**1**	**8**	**2,500**

Average Western U.S. Stress Drop = 60 bars
Average Central/Eastern U.S. Stress Drop = 120 bars

M = Magnitude of earthquake
D = Distance
H = Depth of earthquake
UHS = Uniform Hazard Spectrum

Annual Exceedance Probability 10^{-7} Average Horizontal Spectra Compared with Uniform Hazard Spectrum



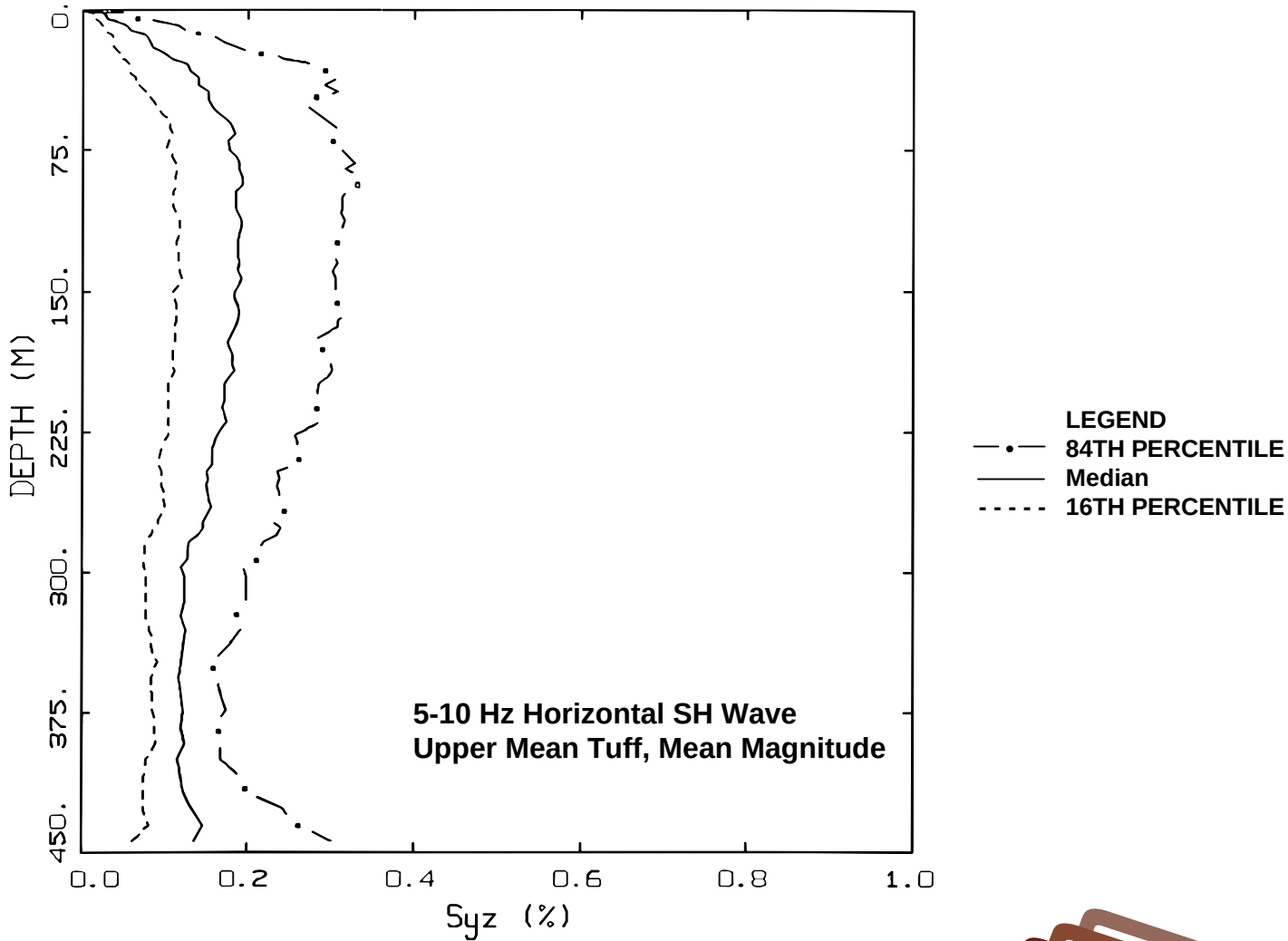
LEGEND

5%, LINEAR M=6.5, D=01 KM, SD=2,500 BARS, PGA = 5.712 g, PGV = 296.4 CM/SEC

5%, LINEAR M=7.7, D=51 KM, SD=15,000 BARS, PGA = 4.939 g, PGV = 506.9 CM/SEC

5%, 10-7 UHS, PGA = 6.919 g, PGV = 654.8

Repository Annual Exceedance Probability 10^{-6} Strains Versus Depth



Repository Annual Exceedance Probability 10^{-6} Strains Versus Depth

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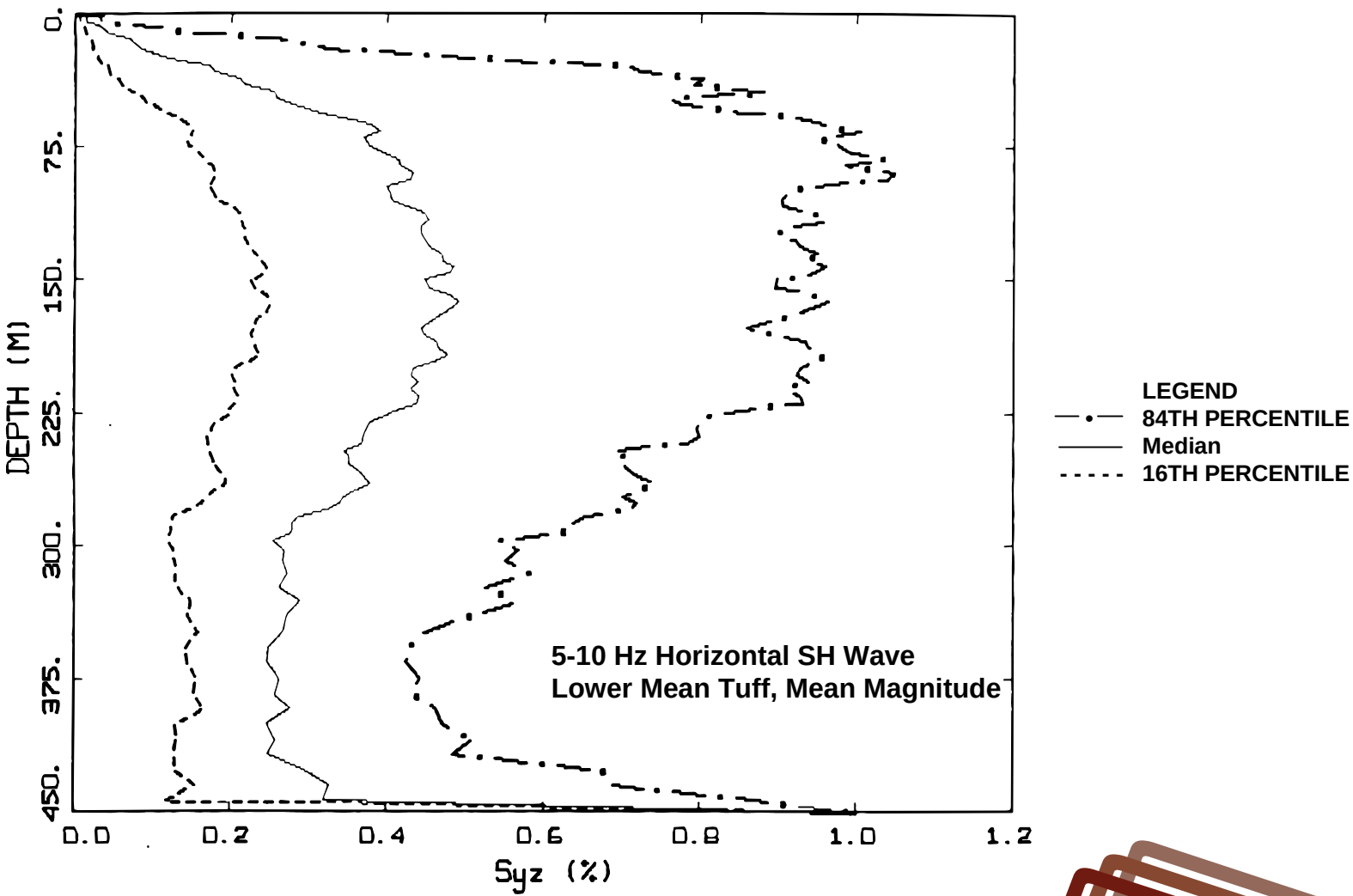
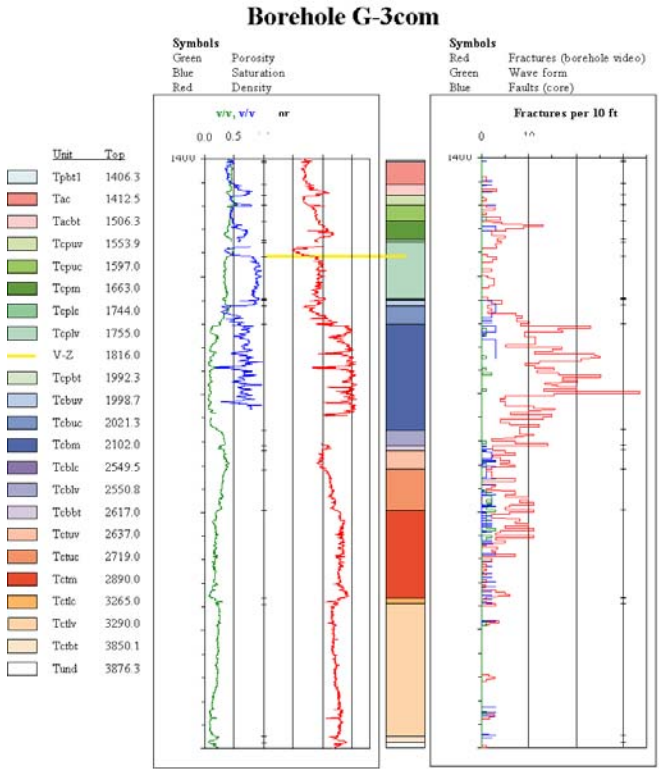


Geotechnical Approach

- **Estimate intact mechanical properties of tuff units below the repository horizon to depth of 1 km using existing data base**
- **Use UDEC discontinuum model to conduct numerical shearing tests on explicitly-fractured rock masses**
- **Develop estimated shear modulus reduction curves for deep tuffs for input to ground motion model**

Lithology/Rock Properties and Fracture Density of Deep Units



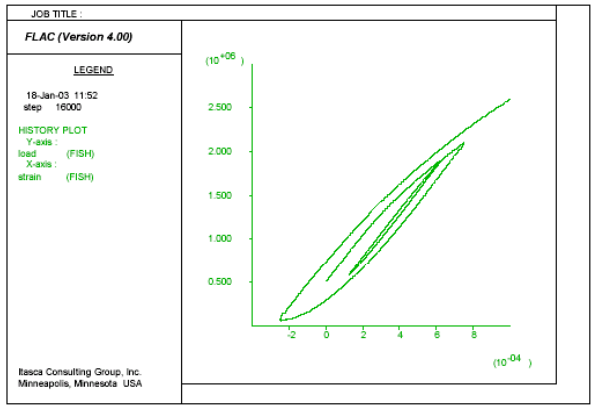
Calico Hills

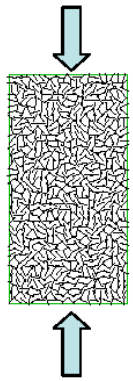
Prow Pass

Bullfrog

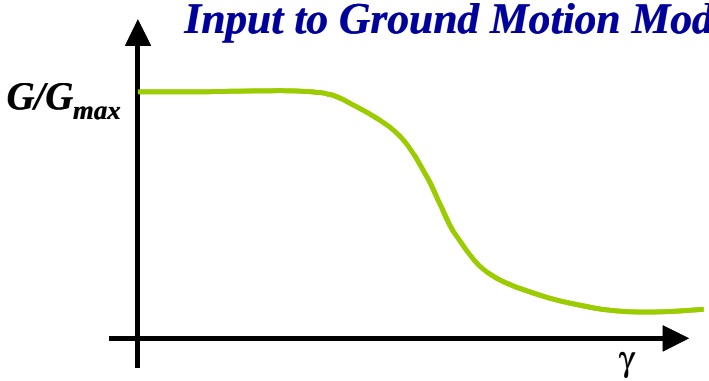
Tram

For Each Major Lithologic Unit, Numerical Cyclic Shear Testing





Input to Ground Motion Model



Status of Saturation Studies

- **Still running calculations at Point A’**
- **Characterize rock properties between Points A to A’**
  - **In situ strain measurements**
  - **Dynamic laboratory testing**
- **2D/3D numerical modeling of the jointed rock matrix**
- **Precarious rock observations**

Backup

Listing of Earthquakes Recorded on Rock Used for Time History Development

(Peak parameters are largest horizontal components recorded)

Earthquake	Date	Mag (M)	Station	Distance (km)	PGA (g)	PGV (cm/sec)	PGD (cm)	Avg Dur (5-75%) (sec)	Expected Dur (5-75%)
Coalinga	1983	5.8	Oil City	8.2	.568	12.5	1.2	1.7	4
Whitter Narrows	1987	6.0	Garvey Res.	12.1	.457	19.0	4.31	2.3	3
Whitter Narrows	1987	6.0	San Gabriel	9.0	.304	23.0	3.34	2.6	3
Helena, MT	1935	6.2	Carroll Coll.	8.0	.173	16.5	2.37	1.2	3
Parkfield	1966	6.1	Cholame #8	9.2	.273	11.3	3.6	5.0	3
Parkfield	1966	6.1	Temblor	9.9	.357	21.5	3.87	1.3	3
San Fernando	1971	6.6	Pacoima Dam	2.8	1.23	112.0	35.5	5.6	4
Gazli, USSR	1976	6.8	Karakyr	3.0	.718	71.6	25.3	5.0	5
Morgan Hill	1984	6.2	Coyote Lake	0.1	1.30	80.8	12.0	2.4	3
Morgan Hill	1984	6.2	Gilroy Arr #6	11.8	.292	36.7	6.12	3.8	3
Loma Prieta	1989	6.9	Corralitos	5.1	.644	55.2	11.37	4.1	6
Loma Prieta	1989	6.9	Gilroy Arr #6	19.9	.170	14.2	4.74	4.5	7
Northridge	1994	6.7	Pacoima Kag	8.2	.433	51.5	10.87	5.7	5
Landers	1992	7.3	Lucerne	1.1	.785	97.6	70.31	8.4	8
Chi-Chi, Taiwan	1999	7.6	TCU025	54	.075	19.0	22.0	12.2	14
Kobe	1995	6.9	Kobe Univ.	0.2	0.31	54.8	13.61	3.5	5
Koaceli	1999	7.4	Izmit	7.7	0.22	17.2	8.2	7.2	9

Scaling

APE (yr^{-1})	TARGET PGV (cm/sec)	
	H	V
10^{-6}	244	233
10^{-7}	535	625

$$\mathrm{H1S} = H1 \cdot \frac{PGV\,(HT)}{PGV\,(H1)}$$

$$\mathrm{H2S} = H2 \cdot \frac{PGV\,(HT)}{PGV\,(H1)}$$

$$\mathrm{VS} = V \cdot \frac{PGV\,(VT)}{PGV\,(V)} \cdot \frac{\dfrac{PGV(V)}{PGV(H1)}}{E\left\{\dfrac{PGV(V)}{PGV(H1)}\right\}}$$

10^{-6} Scaling Factors

Horizontal Target PGV = 244

		PGV	Horizontal Component Ratio	Scale Factor	SCALED PGV	
1	H1	9.1357	0.8004	26.7084	244.000	0.8004
	H2	7.3123		26.7084	195.299	
2	H1	10.6689	1.1002	22.8703	244.000	1.1002
	H2	11.7376		22.8703	268.442	
3	H1	3.9736	2.6329	61.4058	244.000	2.6329
	H2	10.4621		61.4058	642.431	
4	H1	6.4085	1.0631	38.0745	244.000	1.0631
	H2	6.8129		38.0745	259.399	
5	H1	11.0485	0.9765	22.0845	244.000	0.9765
	H2	10.7890		22.0845	238.271	
6	H1	56.8119	0.5418	4.2949	244.000	0.5418
	H2	30.7798		4.2949	132.195	
7	H1	45.4370	0.9920	5.3701	244.000	0.9920
	H2	45.0731		5.3701	242.045	
8	H1	29.7974	1.6460	8.1886	244.000	1.6460
	H2	49.0451		8.1886	401.613	
9	H1	7.2008	3.3462	33.8852	244.000	3.3462
	H2	24.0952		33.8852	816.471	
10	H1	17.0319	0.3206	14.3261	244.000	0.3206
	H2	5.4612		14.3261	78.237	
11	H1	33.9442	1.0486	7.1883	244.000	1.0486
	H2	35.5941		7.1883	255.860	
12	H1	25.0758	1.1122	9.7305	244.000	1.1122
	H2	27.8896		9.7305	271.379	
13	H1	7.2297	1.2432	33.7495	244.000	1.2432
	H2	8.9880		33.7495	303.340	
14	H1	59.4318	0.5144	4.1055	244.000	0.5144
	H2	30.5729		4.1055	125.518	
15	H1	11.0452	0.6277	22.0910	244.000	0.6277
	H2	6.9335		22.0910	153.169	
16	H1	35.5522	0.6489	6.8631	244.000	0.6489
	H2	23.0695		6.8631	158.329	
17	H1	26.1999	0.6537	9.3130	244.000	0.6537
	H2	17.1271		9.3130	159.505	
Median=		17.0794	0.9920	14.3261	244.000	
Std Dev=		2.1599	1.7904	2.2769	1.5011	
84th=						
16th=						

Largest Recorded Peak Accelerations

EARTHQUAKE LOCATION	M	STATION NAME	CLOS. DIST (km)	SITE CODES	COMP.	PGA (g)	PGV (cm/s)	PGD (cm)
Imperial Valley	6.5	El Centro Array #6	1.0	C	UP 140 230	1.655 0.410 0.439	57.5 64.9 109.8	26.41 27.69 65.89
Cape Mendocino	7.1	Cape Mendocino	8.5	A	UP 000 090	0.754 1.497 1.039	63.0 127.4 42.0	109.48 41.01 12.39
Nahanni, Canada	6.8	Site 1	6.0	-	UP 010 280	2.086 0.978 1.096	40.5 46.0 46.1	12.12 9.67 14.58
Northridge	6.7	Tarzana-Cedar Hill	4.1	C	UP 090 360	1.048 1.779 0.990	75.4 113.6 77.6	20.05 33.22 30.45
		Pacoima Dam (upper left abut)	8.0	A	UP 104 194	1.229 1.585 1.285	49.6 55.7 103.0	11.75 6.06 23.80

Largest Recorded Peak Velocities

EARTHQUAKE LOCATION	M	STATION NAME	CLOS. DIST (km)	SITE CODES	COMP.	PGA (g)	PGV (cm/s)	PGD (cm)
Cape Mendocino	7.1	Cape Mendocino	8.5	A	UP 000 090	0.754 1.497 1.039	63.0 127.4 42.0	109.48 41.01 12.39
Northridge	6.7	Rinaldi Receiving Station	0.0	C	UP 228 318	0.852 0.838 0.472	50.7 166.1 73.0	11.65 28.78 19.76
		Sylmar-Olive View Med FF	3.6	C	UP 090 360	0.535 0.604 0.843	19.1 78.2 129.6	8.54 16.05 32.68
Chi-Chi	7.6	TCU052	0.06	C	V N W	0.241 0.419 0.348	110.5 118.4 159.0	163.51 246.15 184.42
		TC068	0.50	C	V N W	0.486 0.462 0.566	187.3 263.1 176.6	266.55 430.00 324.11

Fracture Strain G/G_{max} and Hysteretic Damping Models

All models assume fracturing begins at a cyclic shear-strain of 0.1% with intense fracturing near 0.3% for both welded and nonwelded tuffs.

<u>Model 1</u>: Based on upper mean tuff (UMT) curves to a shear-strain of 0.1% where they drop (raise, hysteretic damping) to the lower mean tuff (LMT) curves (originally developed to model large scale fracture controlled nonlinearity).

<u>Model 2</u>: Based on LMT curves to a strain of 0.1% where the modulus drops one EPRI step (about a factor of 2 in reference strain) between 0.1% and 0.3% shear-strains. For damping the only change is not implementing the NRC damping cap of 15%.

<u>Model 3</u>: Same as Model 2 for G/G_{max} but damping increased one EPRI step between 0.1% and 0.3% shear-strains.

<u>Model 4</u>: Accommodation of the effects of the effects of confining pressure from Point A (300 m outcropping) and Point A' (≈ 1 km, 680 m below A) outcropping. These curves are an eyeball average of the original UMT and LMT curves.

<u>Model 5</u>: Same as Model 4 but dropping (raising) to Model 2 curves from 0.1% to 0.3% shear-strains.