CENTER FOR NUCLEAR WASTE REGULATORY ANALYSES

CNWRA
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COPY 488

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Notebook #: 488
Authors: Ofoegbu, G.
Date Recorded: 09/06/2002
Operating System/Version: Windows, Sun OS, UNIX

Application Used/Version No.: ANSYS/LS-DYNA on SUN;
ProShake on Windows NT
File Type(s): Various
Files Description of Media: 1 CD: Data files for dynamic soil structure interaction analyses to evaluate sability of PFS cask storage pads when subjected to dynamic loading from the design-basis earthquake.

Table of Contents

October 31 2001

GWO GWO

Dynamic Soil-Structure Interaction Analysis of the PFS Cask Storage Pad

Objective

Conduct dynamic soil-structure interaction analyses to evaluate the stability of the PFS cask storage pads when subjected to dynamic loading from the design-basis earthquake. The analyses will be performed using explicit finite element modeling. A ground-motion time history equivalent to the design-basis ground motion will be applied at the bedrock level of a model that includes the soil stratigraphy from ground surface to bedrock, cask storage pads, and casks. Determine the effects of the ground motion on the stability of the casks.

Computer Codes

Finite element analyses will be performed using the computer code LS-DYNA (ANSYS Inc., *ANSYS/LS-DYNA User's Guide, Version 5.7*. Canonsburg, PA: ANSYS Inc.), which runs on the COYOTE computer platform (SUN workstation). Aspects of the finite element model will be verified by comparing the model calculations with calculations performed using the computer code ProShake, which runs on the CALIB computer platform (WINDOWS NT workstation). ProShake (EduPro Civil Systems Inc., *ProShake Ground Response Analysis Program Version 1.1*. Redmond, WA: EduPro Civil Systems Inc.) performs one-dimensional analysis of the vertical propagation of horizontally polarized shear waves through a soil profile.

Investigators

Names	Signatures	Initials
Goodluck I Ofoegbu	[signature]	GIO
G. Douglas Gute	[signature]	DG

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Verification of ProShake

Two verification examples were run

(1) ProShake tutorial
(2) Standard test example for SHAKE91.

The test examples and results are documented in the following files on computer CALIB

D:\PShakeVerify\Tutorial
D:\PShakeVerify\S91Cases

The verification tests are also documented in a QA file (hardcopy), "Software Release Notice".

~~JV~~ Guo 10/31/2001

Verification Test 1

Soil profile: Compare with p. 7-9 of ProShake manual.

Input Motion: Compare with p. 10 of ProShake manual.

Output: Compare with p. 45-46 of ProShake manual.

ProShake Report

Data File: D:\PShakeVerify\Tutorial\TUTORIAL.DAT

Soil Profile Compare with p. 7-9 of ProShake manual

Profile Name: Soil profile for ProShake Tutorial #1
Water Table: Not Applicable
Number of Layers: 16

Layer Number	Material Name	Thickness (ft)	Unit Weight (pcf)	Gmax (ksf)	Vs (ft/sec)	Modulus Curve	Damping Curve	Mod. Parameter	Damp. Parameter
1	Soft silty clay	5.00	100.00	752.74	492.13	Vucetic - Dobry	Vucetic - Dobry	10.00	10.00
2	Soft silty clay	5.00	100.00	752.74	492.13	Vucetic - Dobry	Vucetic - Dobry	10.00	10.00
3	Soft silty clay	5.00	100.00	752.74	492.13	Vucetic - Dobry	Vucetic - Dobry	10.00	10.00
4	Soft silty clay	5.00	100.00	752.74	492.13	Vucetic - Dobry	Vucetic - Dobry	10.00	10.00
5	Soft silty clay	5.00	100.00	752.74	492.13	Vucetic - Dobry	Vucetic - Dobry	10.00	10.00
6	Soft silty clay	5.00	100.00	752.74	492.13	Vucetic - Dobry	Vucetic - Dobry	10.00	10.00
7	Soft silty clay	5.00	100.00	752.74	492.13	Vucetic - Dobry	Vucetic - Dobry	10.00	10.00
8	Soft silty clay	5.00	100.00	752.74	492.13	Vucetic - Dobry	Vucetic - Dobry	10.00	10.00
9	Soft silty clay	5.00	100.00	752.74	492.13	Vucetic - Dobry	Vucetic - Dobry	10.00	10.00
10	Soft silty clay	5.00	100.00	752.74	492.13	Vucetic - Dobry	Vucetic - Dobry	10.00	10.00
11	Stiff clay	10.00	120.00	1,800.00	694.70	Vucetic - Dobry	Vucetic - Dobry	20.00	20.00
12	Stiff clay	10.00	120.00	1,800.00	694.70	Vucetic - Dobry	Vucetic - Dobry	20.00	20.00
13	Stiff clay	10.00	120.00	1,800.00	694.70	Vucetic - Dobry	Vucetic - Dobry	20.00	20.00
14	Stiff clay	10.00	120.00	1,800.00	694.70	Vucetic - Dobry	Vucetic - Dobry	20.00	20.00
15	Stiff clay	10.00	120.00	1,800.00	694.70	Vucetic - Dobry	Vucetic - Dobry	20.00	20.00
16	Bedrock	Infinite	150.00	29,138.43	2,500.00	Rock	Rock		

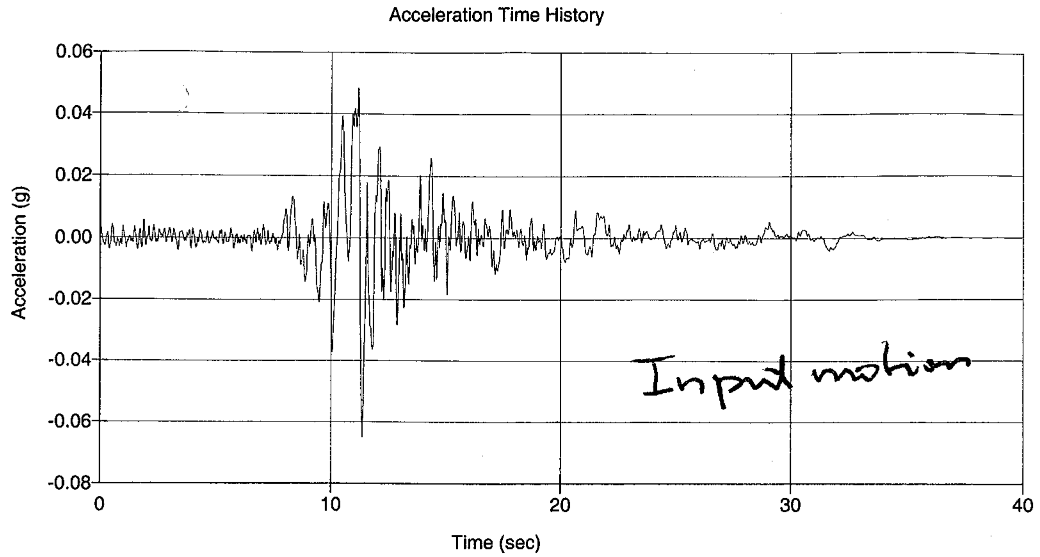
Input Motion Compare with p. 10 of ProShake manual.

Number of Motions: 1
Number of Iterations: 5
Strain Ratio: 0.65
Tolerance: 5.00%

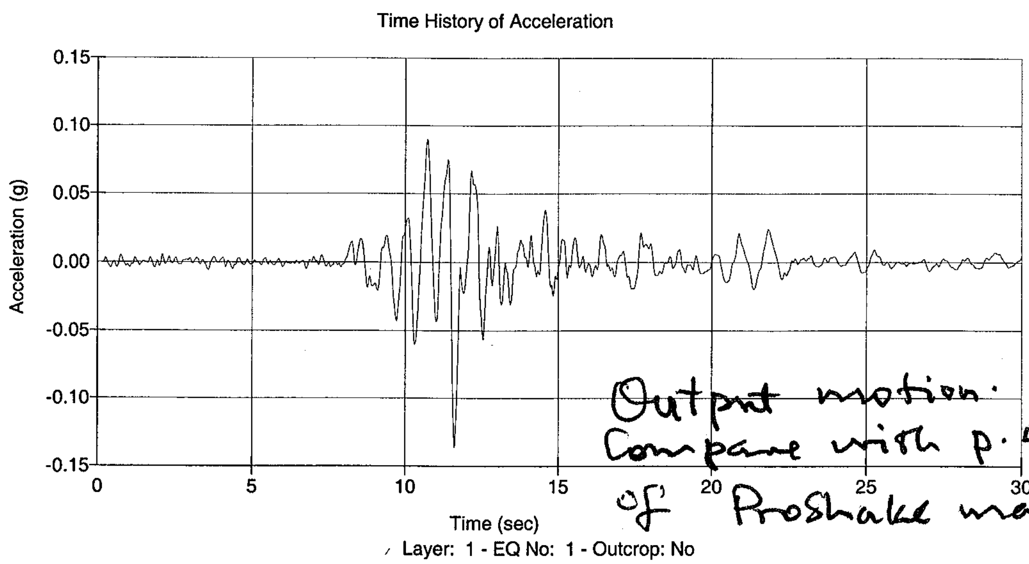
File Name	No of Acc. Values	Max. Acc. (g)	Time Step (sec)	Cuttoff Freq. (Hz)	No of Fourier Terms	Layer	Outcrop
C:\PROGRA~1\PROSHAKE\YERBA.EQ	2000	0.065	0.020	20.00	2048	16	Yes

Output Locations

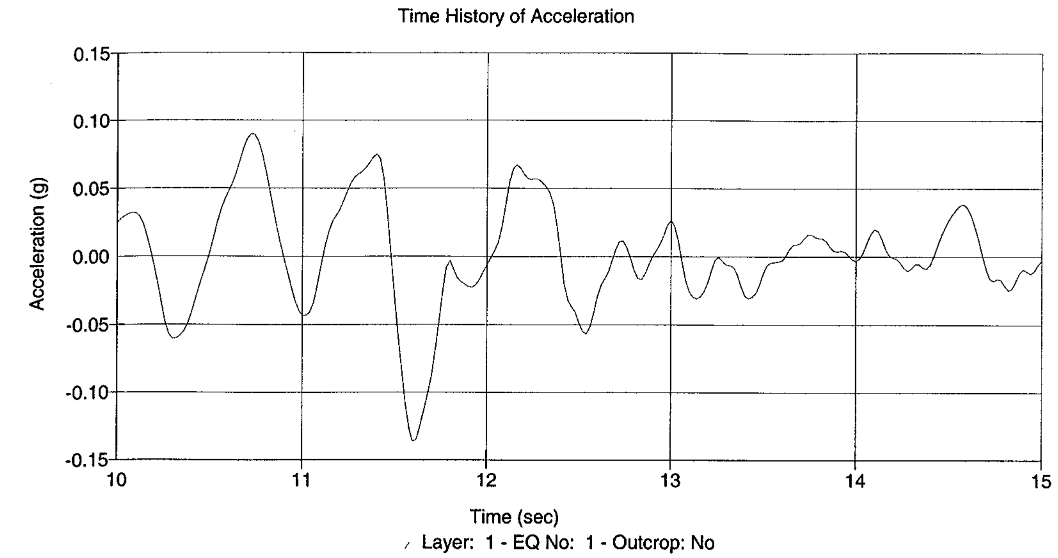
Layer No	Depth (ft)	Outcrop
1	0.00	No
2	5.00	No
11	50.00	No



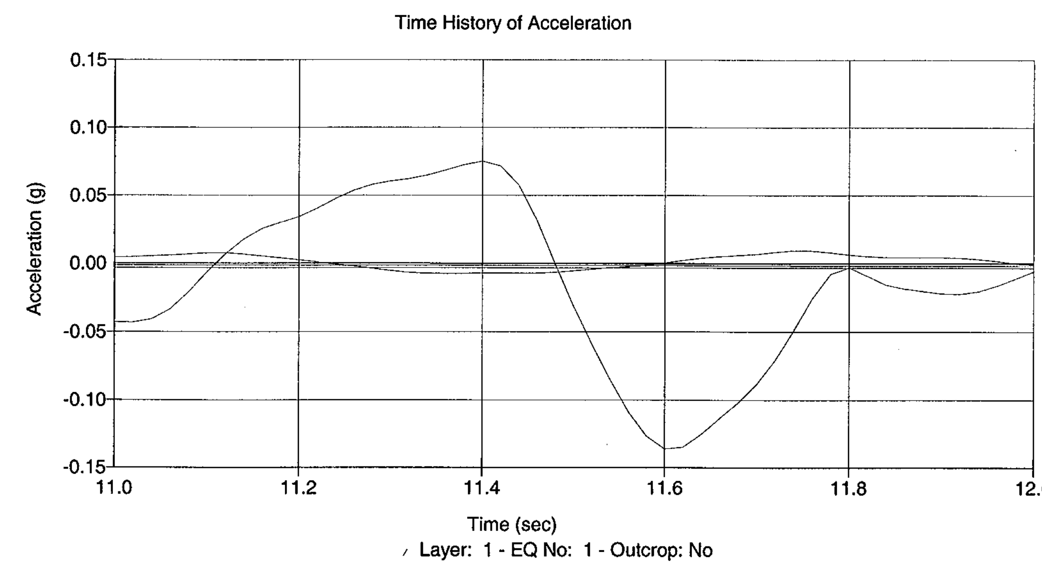
Input motion

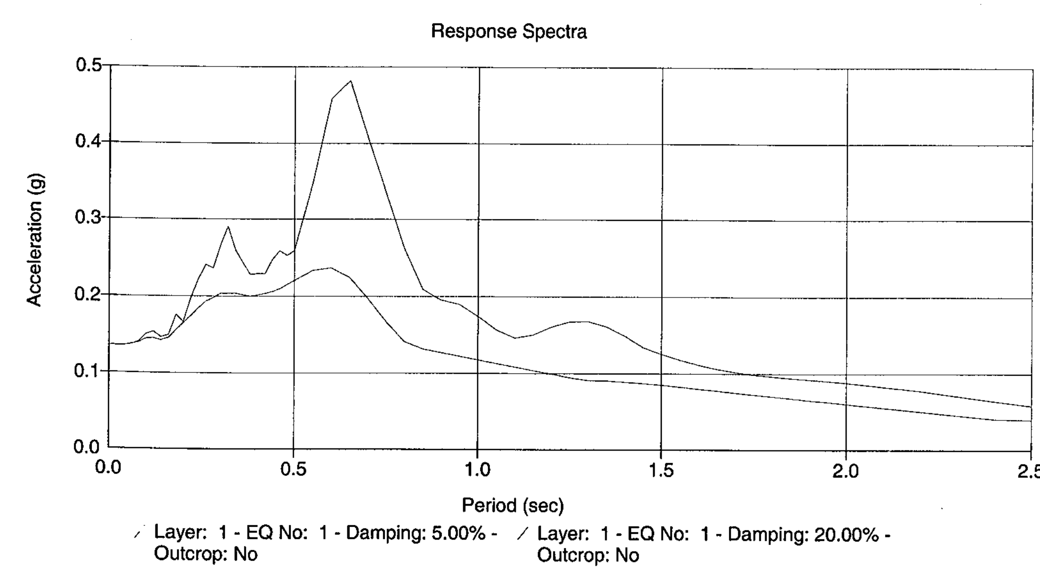


Output motion. Compare with p. 45 of ProShake manual.



Output motion. Compare with p. 45 of ProShake manual.





Output motion. Compare with p. 46 of ProShake manual.

Verification Test 2

The test problem is described on p.42-44 of the ProShake manual and in the SHAKE91 manual (see reference on the left side below).

USER·S MANUAL
FOR

SHAKE91

A Computer Program for Conducting Equivalent Linear
Seismic Response Analyses of Horizontally Layered Soil Deposits

Program Modified based on the Original *SHAKE* program published in
December 1972 by Schnabel, Lysmer & Seed

Modifications by

I. M IDRISS
JOSEPH I. SUN

Sponsored by

Structures Division
Building and Fire Research Laboratory
National Institute of Standards and Technology
Gaithersburg, Maryland

Center for Geotechnical Modeling
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University of California
Davis, California

November 1992

The input motion used for this example is the same as the input motion described in SHAKE91 manual (left side). The input motion used for the example described on p. 42-44 of ProShake manual is, however, different. Therefore, the results presented in the following pages should be compared with the corresponding results in SHAKE91 manual.

ProShake Report

Data File: D:\PShakeVerify\S91Case\STDTEST.DAT

Soil Profile

Profile Name: SHAKE91 Standard Test Example -- 150-ft layer
Water Table: 10.00 ft
Number of Layers: 17

Layer Number	Material Name	Thickness (ft)	Unit Weight (pcf)	Gmax (ksf)	Vs (ft/sec)	Modulus Curve	Damping Curve	Mod. Parameter	Damp. Parameter
1	Sand	5.00	125.00	3,881.99	1,000.00	Sand (Seed and Idriss 1970)	Sand (Idriss 1990)		
2	Sand	5.00	125.00	3,144.41	900.00	Sand (Seed and Idriss 1970)	Sand (Idriss 1990)		
3	Sand	10.00	125.00	3,144.41	900.00	Sand (Seed and Idriss 1970)	Sand (Idriss 1990)		
4	Sand	10.00	125.00	3,503.49	950.00	Sand (Seed and Idriss 1970)	Sand (Idriss 1990)		
5	Clay	10.00	125.00	3,881.99	1,000.00	Clay (Seed and Sun 1989)	Clay (Idriss 1990)		
6	Clay	10.00	125.00	3,881.99	1,000.00	Clay (Seed and Sun 1989)	Clay (Idriss 1990)		
7	Clay	10.00	125.00	4,697.20	1,100.00	Clay (Seed and Sun 1989)	Clay (Idriss 1990)		
8	Clay	10.00	125.00	4,697.20	1,100.00	Clay (Seed and Sun 1989)	Clay (Idriss 1990)		
9	Sand	10.00	130.00	6,822.98	1,300.00	Sand (Seed and Idriss 1970)	Sand (Idriss 1990)		
10	Sand	10.00	130.00	6,822.98	1,300.00	Sand (Seed and Idriss 1970)	Sand (Idriss 1990)		
11	Sand	10.00	130.00	7,913.04	1,400.00	Sand (Seed and Idriss 1970)	Sand (Idriss 1990)		
12	Sand	10.00	130.00	7,913.04	1,400.00	Sand (Seed and Idriss 1970)	Sand (Idriss 1990)		
13	Sand	10.00	130.00	9,083.85	1,500.00	Sand (Seed and Idriss 1970)	Sand (Idriss 1990)		
14	Sand	10.00	130.00	9,083.85	1,500.00	Sand (Seed and Idriss 1970)	Sand (Idriss 1990)		
15	Sand	10.00	130.00	10,335.40	1,600.00	Sand (Seed and Idriss 1970)	Sand (Idriss 1990)		
16	Sand	10.00	130.00	13,080.75	1,800.00	Sand (Seed and Idriss 1970)	Sand (Idriss 1990)		
17	Rock	Infinite	140.00	69,565.22	4,000.00	Linear	Linear		1.00

Input Motion

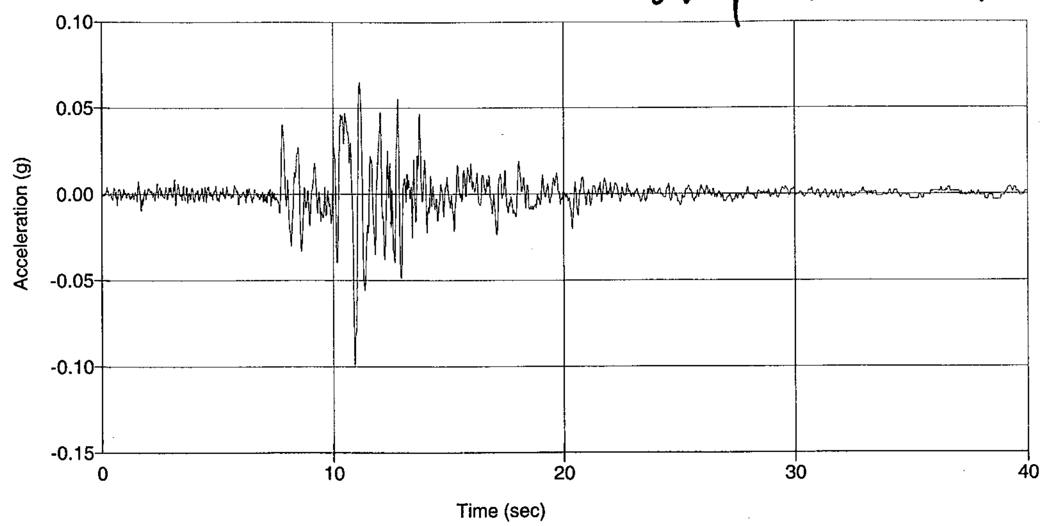
Number of Motions: 1
Number of Iterations: 8
Strain Ratio: 0.50
Tolerance: 5.00%

File Name	No of Acc. Values	Max. Acc. (g)	Time Step (sec)	Cuttoff Freq. (Hz)	No of Fourier Terms	Layer	Outcrop
D:\PSHAKE~1\S91CASE\LPDIAM.EQ	2000	0.100	0.020	25.00	2048	17	Yes

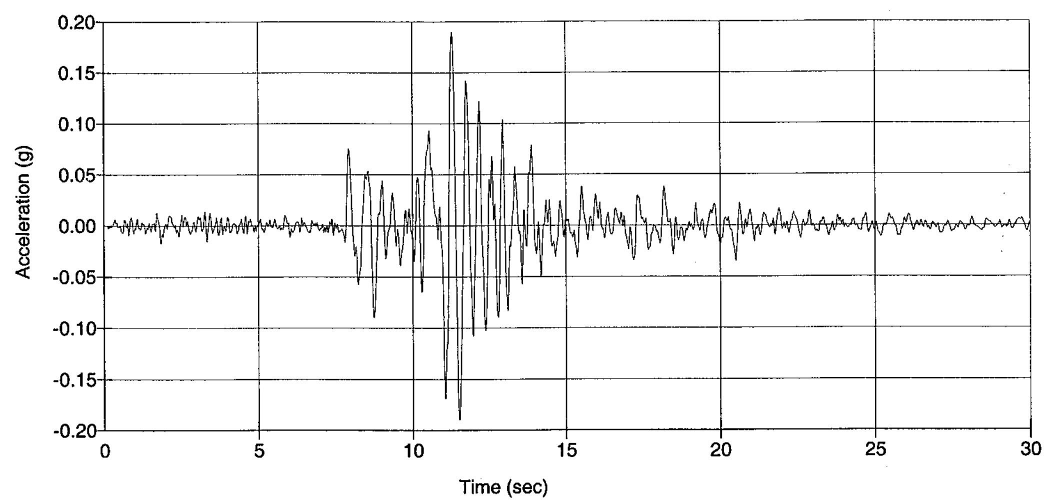
Output Locations

Layer No	Depth (ft)	Outcrop
1	0.00	Yes
2	5.00	No
3	10.00	No
4	20.00	No
5	30.00	No

Acceleration Time History Input motion.

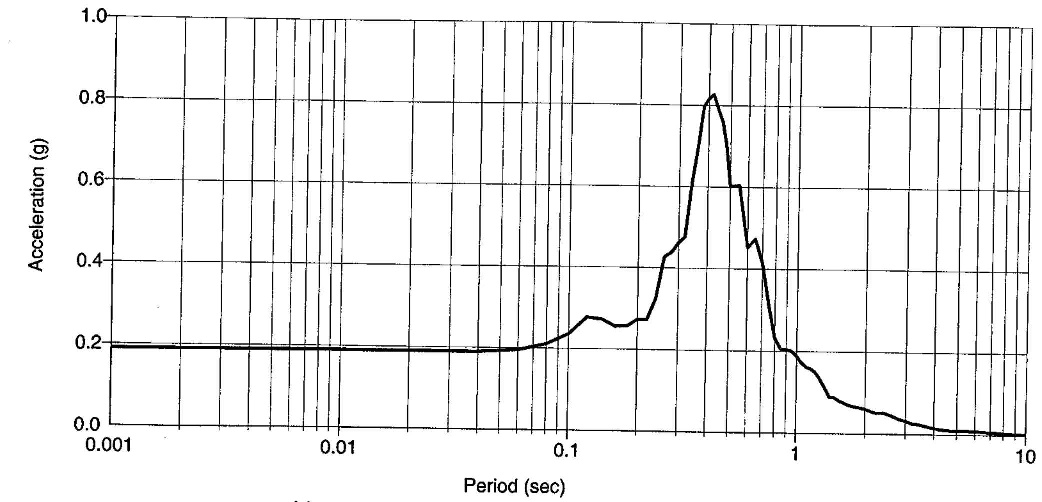


Time History of Acceleration



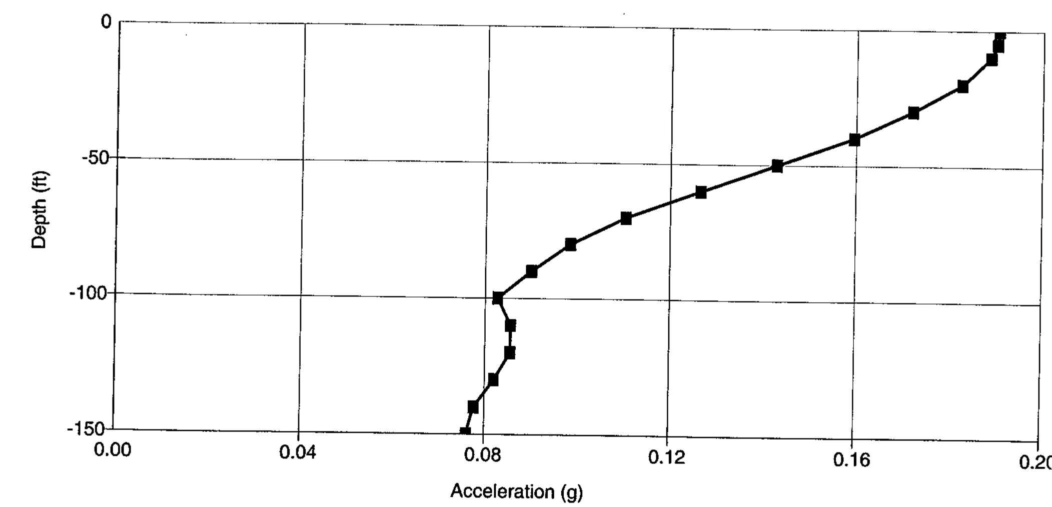
Layer: 1 - EQ No: 1 - Outcrop: Yes

Response Spectra



Layer: 1 - EQ No: 1 - Damping: 5.00% - Outcrop: Yes

Peak Acceleration



EQ No: 1

Soil Stratigraphy

The soil stratigraphy at the PFS site is described in Table F-3 of the following document (Appendix F, Rev. 1):

Geomatrix Consultants, Inc. 1999. Fault evaluation study and seismic hazard assessment, Private Fuel Storage facility, Skull Valley, Utah: Report prepared for Stone and Webster Engineering Corporation.

TABLE F-3

BEST ESTIMATE PROFILE FOR SKULL VALLEY PFSF SITE
CONSTANT TERTIARY SEDIMENT VELOCITY
Private Fuel Storage Facility
Skull Valley, Utah

Page 1 of 1

Layer	Depth to Base of Layer (ft)	Average Layer Shear Wave Velocity (fps)	Average Layer Compression Wave Velocity (fps)	Unit Weight (pcf)
Eolian silts (Soil cement) 1	5±2	560	1,117	100
Lacustrine silt 2	10±1	528	1,131	80
Lacustrine silt 3	12±1	727	1,260	80
Lacustrine sand 4	18±1	- 854	1,472	100
Lacustrine silt 5	26±1	871	1,440	94
Lacustrine sands 6	35±1	1,022	1,667	115
Lacustrine sands 7	50±5	1,190	2,085	115
Dense sands and silty sands capped by Promontory Soil 8 & 9	90±5	1,800	3,400	120
Tertiary Salt Lake group – unsaturated 10	125	2,900	5,023	135
Tertiary Salt Lake group – saturated 11	700±100	2,900	5,023	145
Shallow crustal rocks 12	4,593	6,398	11,155	165
Crustal rocks 13	15 km	11,122	19,357	170

Increasing Tertiary Sediment Velocity

Layer	Depth to Base of Layer (ft)	Average Layer Shear Wave Velocity (fps)	Average Layer Compression Wave Velocity (fps)	Unit Weight (pcf)
Eolian silts	5±2	560	1,117	
Lacustrine silt	10±1	528	1,131	80
Lacustrine silt	12±1	727	1,260	80
Lacustrine sand	18±1	854	1,472	100
Lacustrine silt	26±1	871	1,440	94
Lacustrine sands	35±1	1,022	1,667	115
Lacustrine sands	50±5	1,190	2,085	115
Dense sands and silty sands capped by Promontory Soil	90±5	1,800	3,400	120
Tertiary Salt Lake group – unsaturated, Layer 1	125	2,900	5,023	135
Tertiary Salt Lake group – saturated, Layer 1	300±33	2,900	5,023	145
Tertiary Salt Lake group – saturated, Layer 2	500±67	4,000	6,928	145
Tertiary Salt Lake group – saturated, Layer 4	700±100	5,000	8,660	145
Shallow crustal rocks	4,593	6,398	11,155	165
Crustal rocks	15 km	11,122	19,357	170

\SF3\DEPTDATA\DOC_SAFE 4000S 4790 4790-002 REPORT REVISIONS\APX-F-REV1 DOC F-21

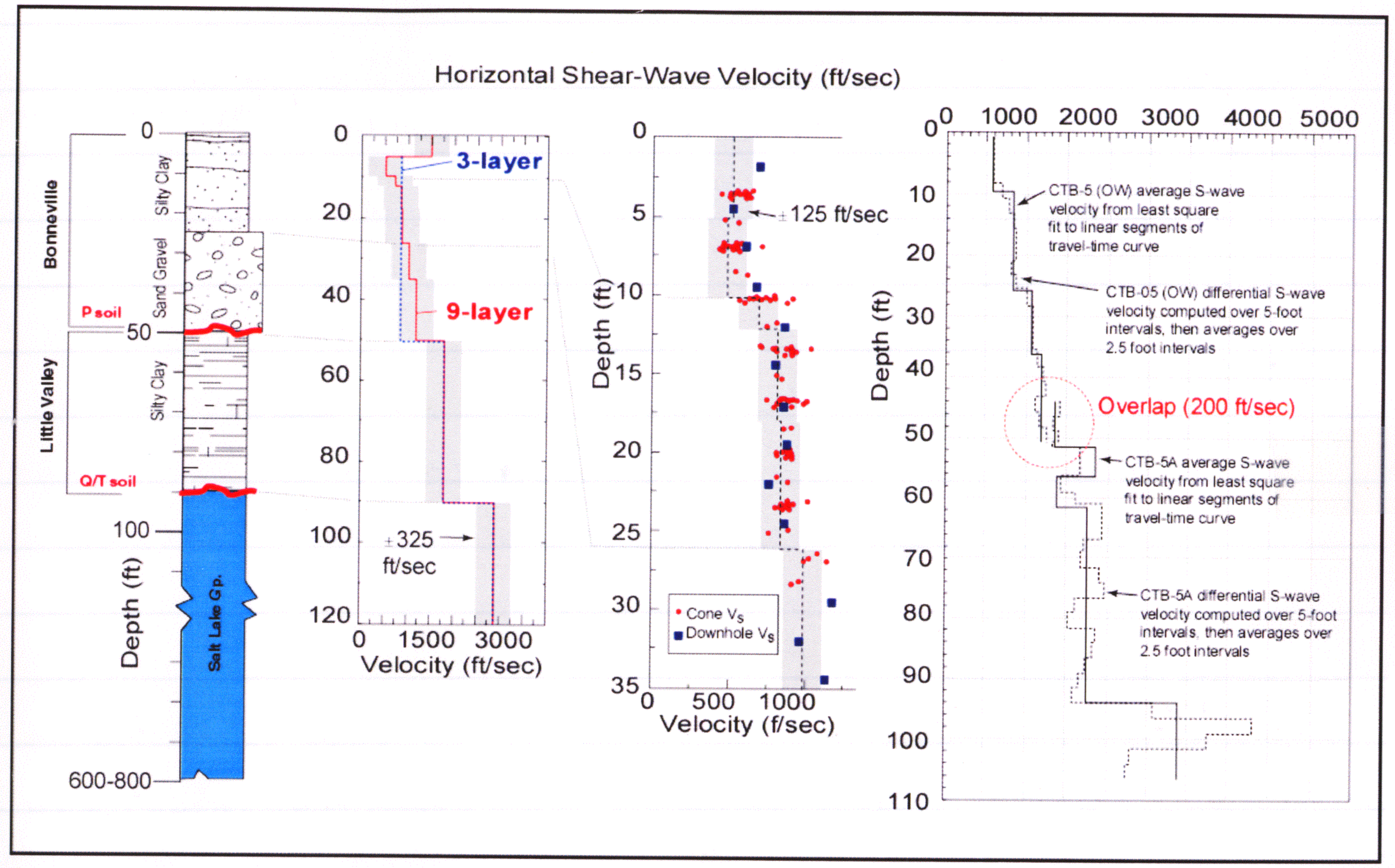
Summary

(1) 90 ft of soil underlain by bedrock (Tertiary Salt Lake Group).

(2) Top 5 ft will be replaced by soil cement.

The stratigraphy is also summarized in the following figure.

Skull Valley Site Stratigraphy (compiled by John Stamatakos — Presentation to NRC on October 15, 2001).



November 1 2001

Modeling Approach

(1) Analyze response of the Skull Valley soil profile to each of the ~~three~~ two horizontal (GWO 11/01/2001) components of the design ground motion.

(2) Compare results obtained using ProShake and LS-DYNA for the cases of (i) North-South motion and (ii) East-West motion.

(3) If the comparison in item (2) indicates that the finite element model is satisfactory, attempt a combined deconvolution of all three components of the design ground motion ~~to obtain~~ (GWO 11/01/2001) ~~the~~ (GWO 11/01/2001) using a finite element model, to obtain the equivalent ground motion at the top of Tertiary bedrock (see p. 12 and 13).

(4) Develop the finite element model for the soil-structure interaction analysis.

Note: ~~Models~~ (GWO 11/01/2001) Steps (1)–(3) deal with site response modeling, whereas Step (4) deals with soil-structure interaction. Therefore, the models used for Steps (1)–(3) do not include the cask storage pads.

Analysis of Site Response to North-South Ground Motion Component

ProShake Modeling

Directory: D:\PfsSSIAnal\PShakeModels

Files:

Ns01.dat	ProShake input
Ns01.lyr	ProShake output
Ns01out.eq	North-south ground motion time history at 90-ft depth (ProShake output)

(GWO 11/01/2001)

D:\PfsSSIAnal\InputMotion\Fp2000f.eq (Input motion at ground surface).

Input motion is applied at ground surface to obtain ground motion time history at 90-ft depth.

ProShake Model

ProShake Report

Data File: D:\PFSSSI~1\PSHAKE~1\NS01.DAT

Soil Profile

Profile Name: PFS Skull Valley Soil Profile (Basecase Soil Properties)
Water Table: Not Applicable
Number of Layers: 10

Layer Number	Material Name	Thickness (ft)	Unit Weight (pcf)	Gmax (ksf)	Vs (ft/sec)	Modulus Curve	Damping Curve	Mod. Parameter	Damp. Parameter
1	Soil cement	5.00	100.00	6,993.22	1,500.00	PFS-1 Modulus Reduction	PFS-1 Damping		
2	Lacustrine silt	5.00	80.00	693.19	528.00	PFS-1 Modulus Reduction	PFS-1 Damping		
3	Lacustrine silt	2.00	80.00	1,314.18	727.00	PFS-1 Modulus Reduction	PFS-1 Damping		
4	Lacustrine sand	6.00	100.00	2,266.79	854.00	PFS-2 Modulus Reduction	PFS-2 Damping		
5	Lacustrine silt	8.00	94.00	2,216.46	871.00	PFS-2 Modulus Reduction	PFS-2 Damping		
6	Lacustrine sands	9.00	115.00	3,733.31	1,022.00	PFS-3 Modulus Reduction	PFS-3 Damping		
7	Lacustrine sands	15.00	115.00	5,061.59	1,190.00	PFS-3 Modulus Reduction	PFS-3 Damping		
8	Dense sands and silty sands	20.00	120.00	12,084.29	1,800.00	PFS-4 Modulus Reduction	PFS-4 Damping		
9	Dense sands and silty sands	20.00	120.00	12,084.29	1,800.00	PFS-4 Modulus Reduction	PFS-4 Damping		
10	Tertiary Salt Lake Group	Infinite	135.00	35,287.81	2,900.00	PFS-5 Modulus: Rock-Linear	PFS-5 Damping: Rock-Linear		

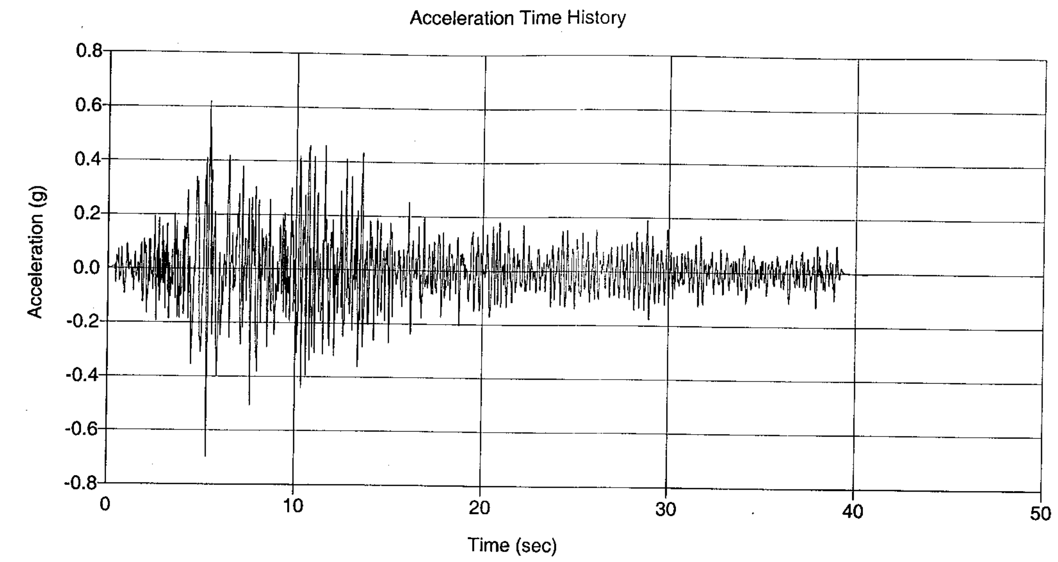
Input Motion

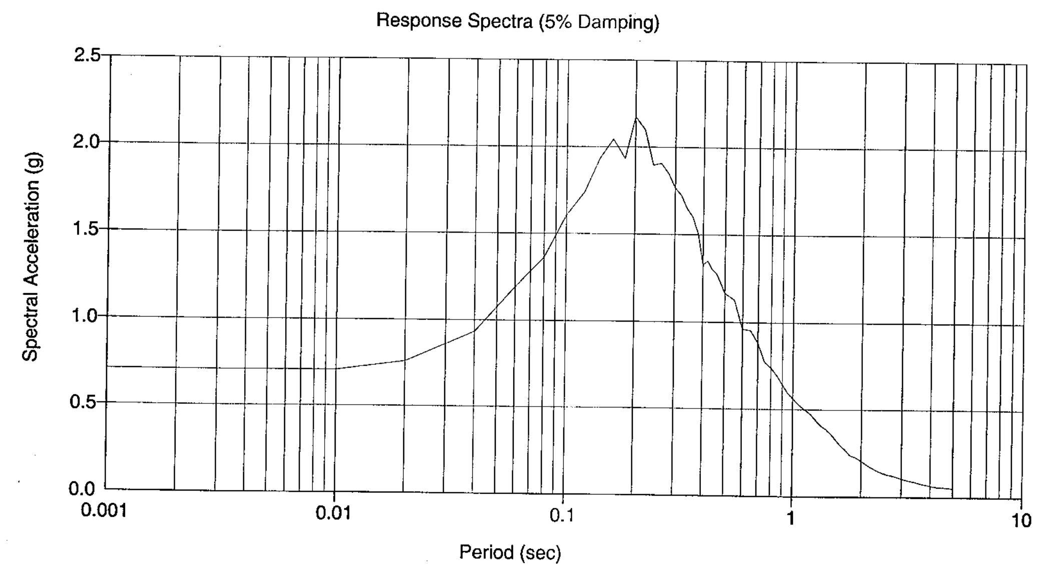
Number of Motions: 1
Number of Iterations: 8
Strain Ratio: 0.60
Tolerance: 5.00%

File Name	No of Acc. Values	Max. Acc. (g)	Time Step (sec)	Cuttoff Freq. (Hz)	No of Fourier Terms	Layer	Outcrop
D:\PFSSSI~1\INPUTM~1 \FP2000F.EQ	8192	0.707	0.005	33.00	16384	1	Yes

Output Locations

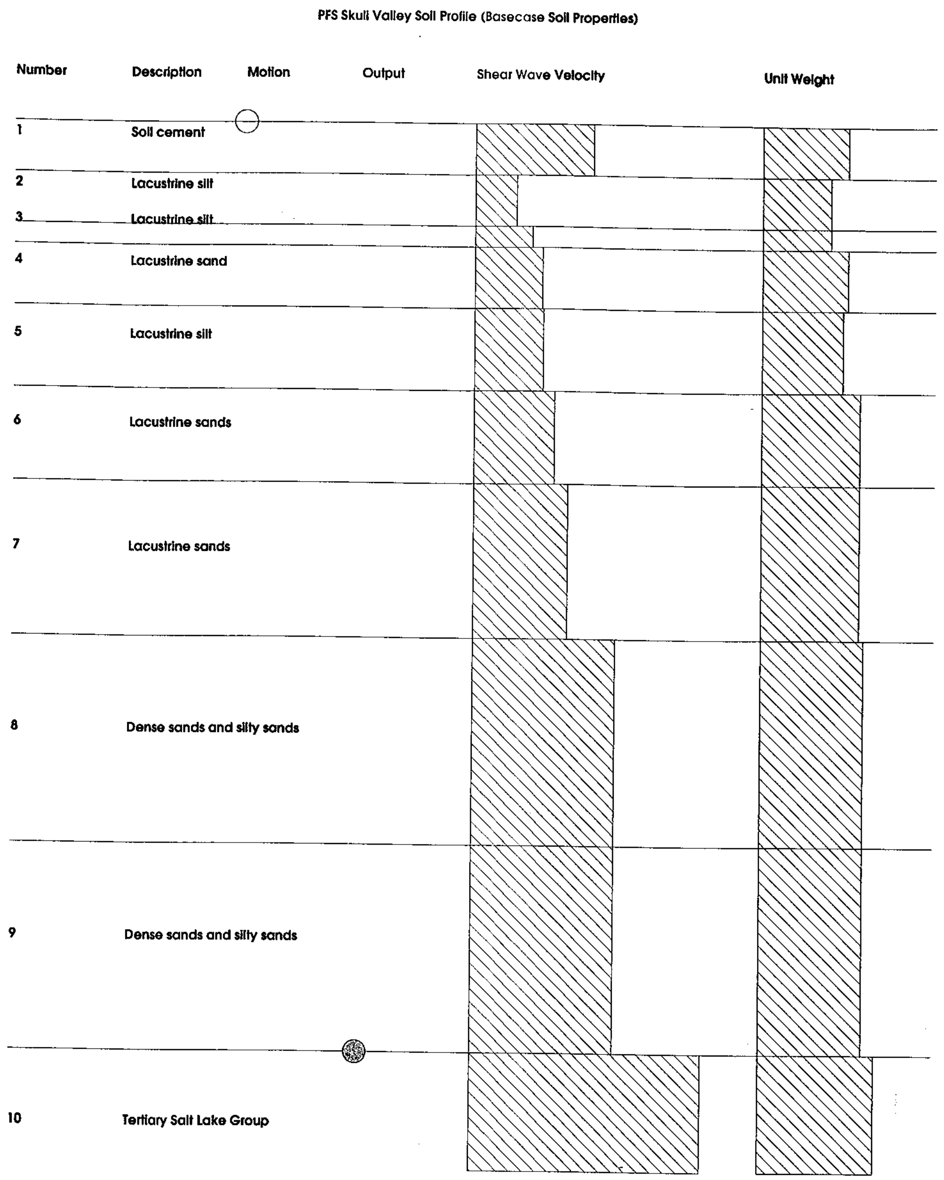
Layer No	Depth (ft)	Outcrop
10	90.00	No





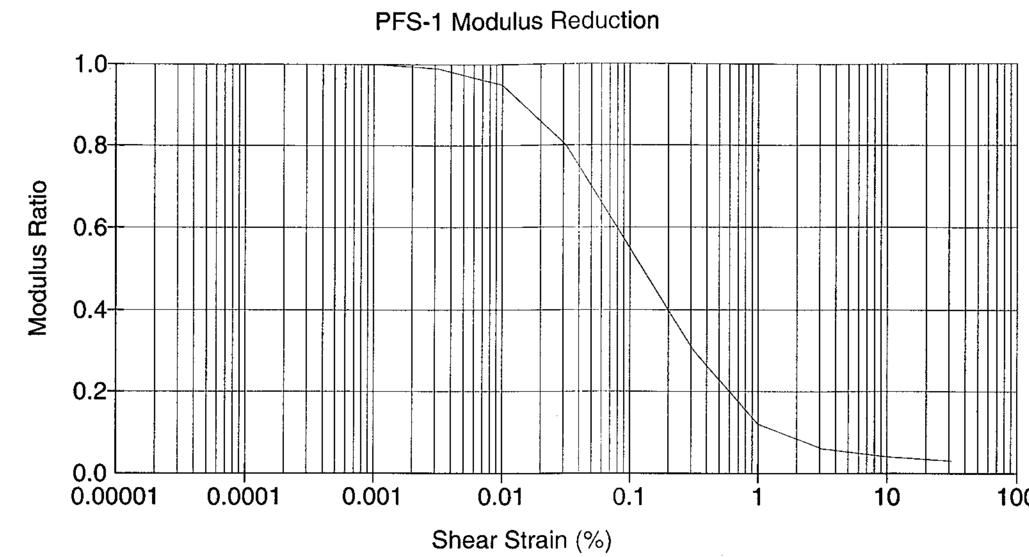
~~Ips~~ GAO 11/01/2001

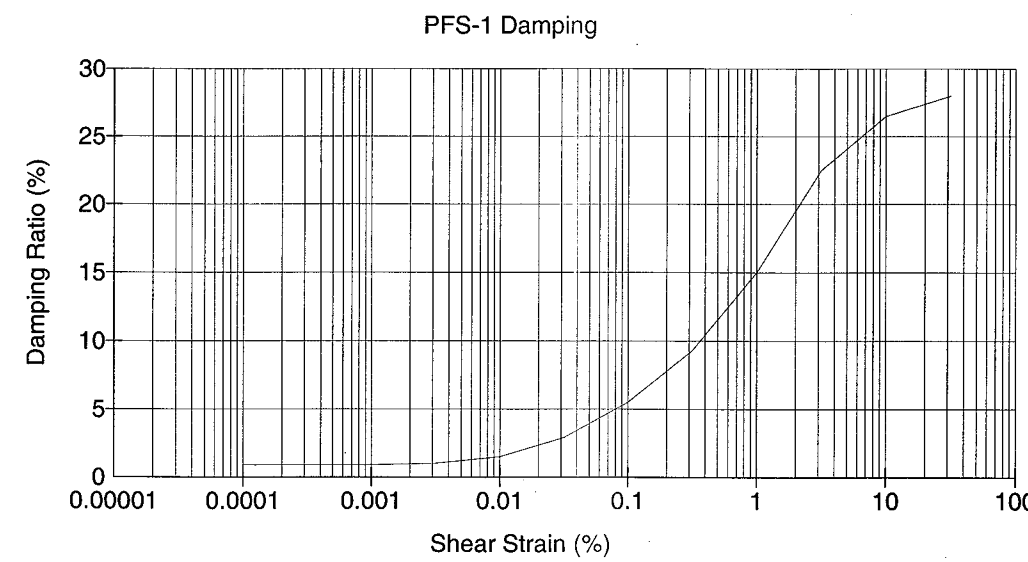
Input motion, applied at the top of Layer Number 1. (Both acceleration time history and response spectrum are shown, but only the time history was applied as input. ProShake calculated the response spectrum from the time history.



This is the soil profile as interpreted by ProShake. The point (elevation) of application of the input motion (open circle) and the location at which the output motion will be calculated (filled circle) are shown in the plot. The calculated output motion will be used as input in the finite element model.

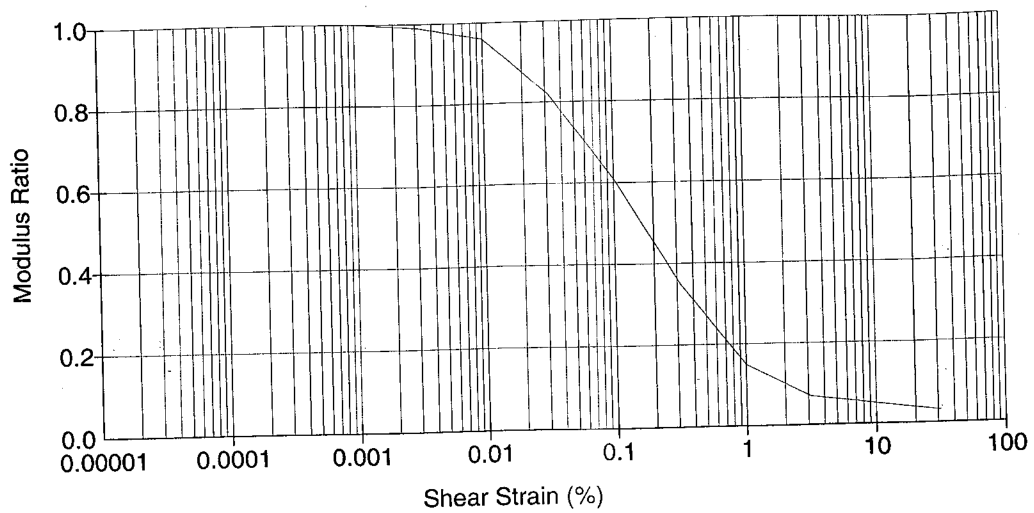
The modulus and damping curves named PFS-1 through PFS-5 (p. 16) were taken from information supplied by PFS and are shown in the following pages.





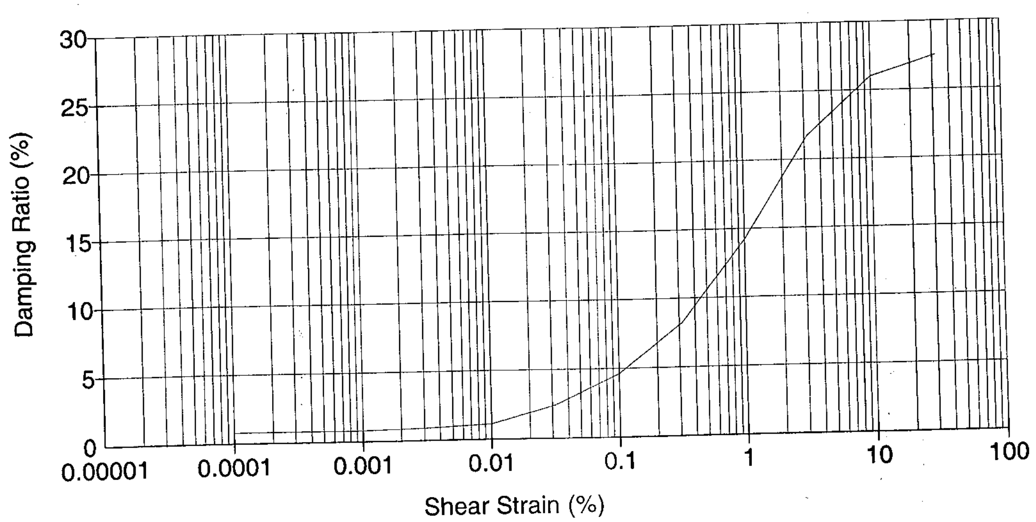
PFS-1 modulus reduction and damping curves as interpreted by ProShake.

PFS-2 Modulus Reduction

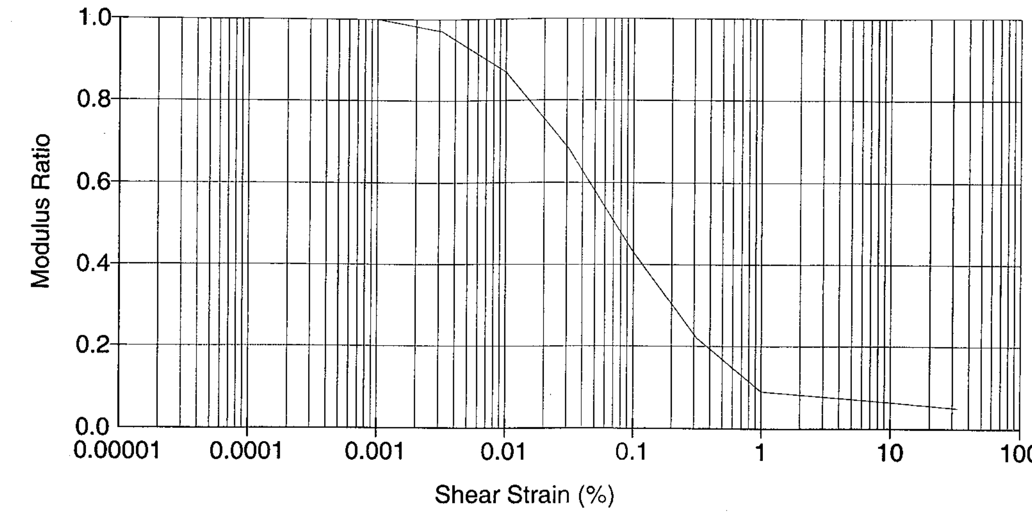


PFS-2 modulus reduction and damping curves as interpreted by ProShake.

PFS-2 Damping

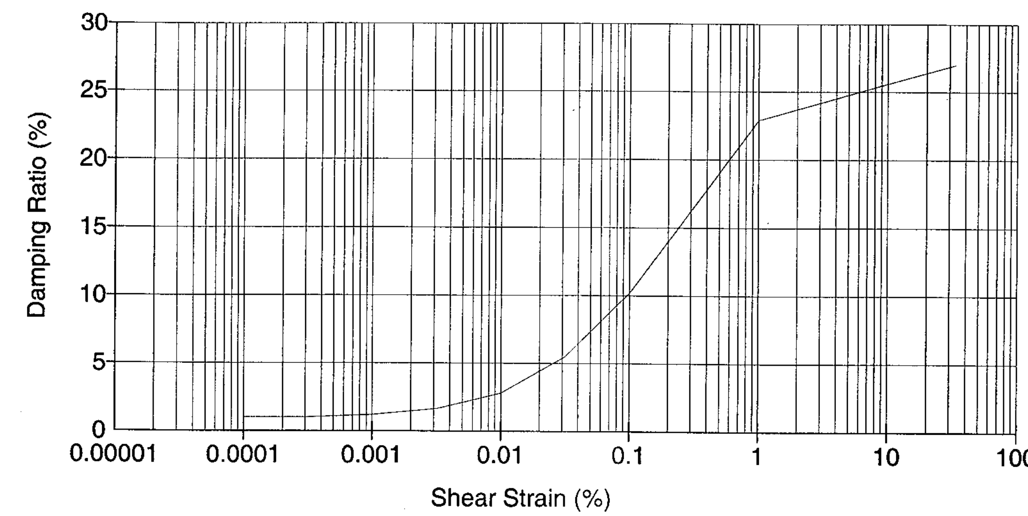


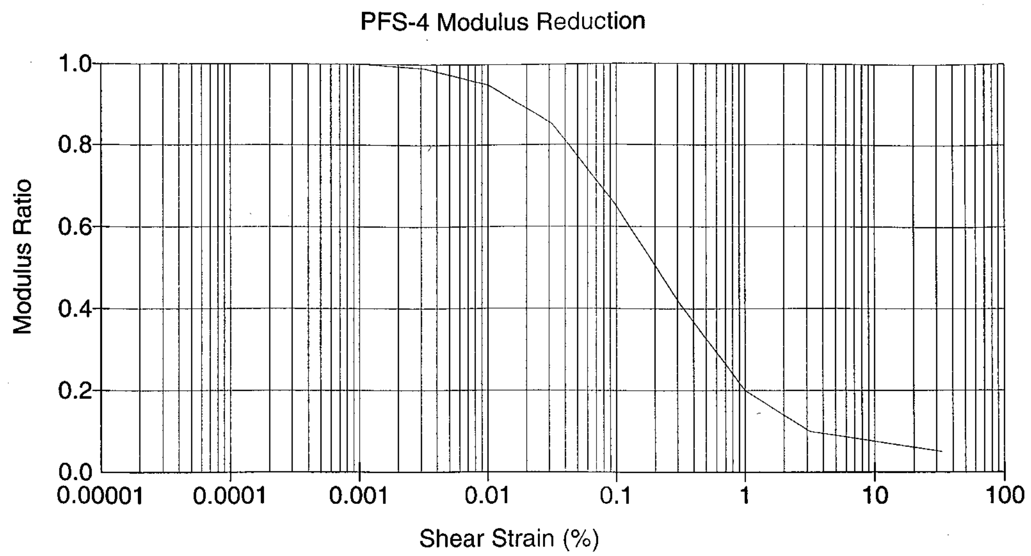
PFS-3 Modulus Reduction

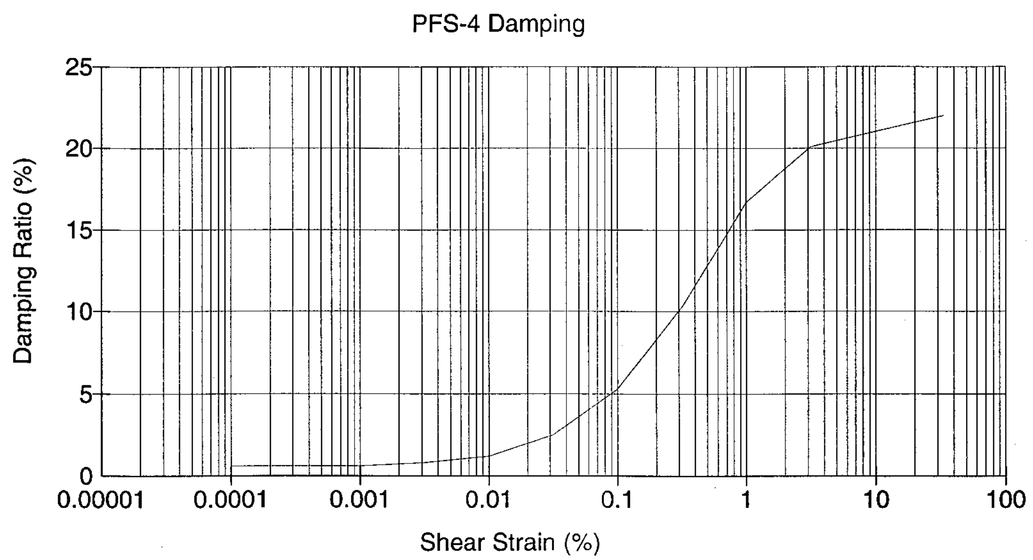


PFS-3 modulus reduction and damping curves as interpreted by ProShake.

PFS-3 Damping

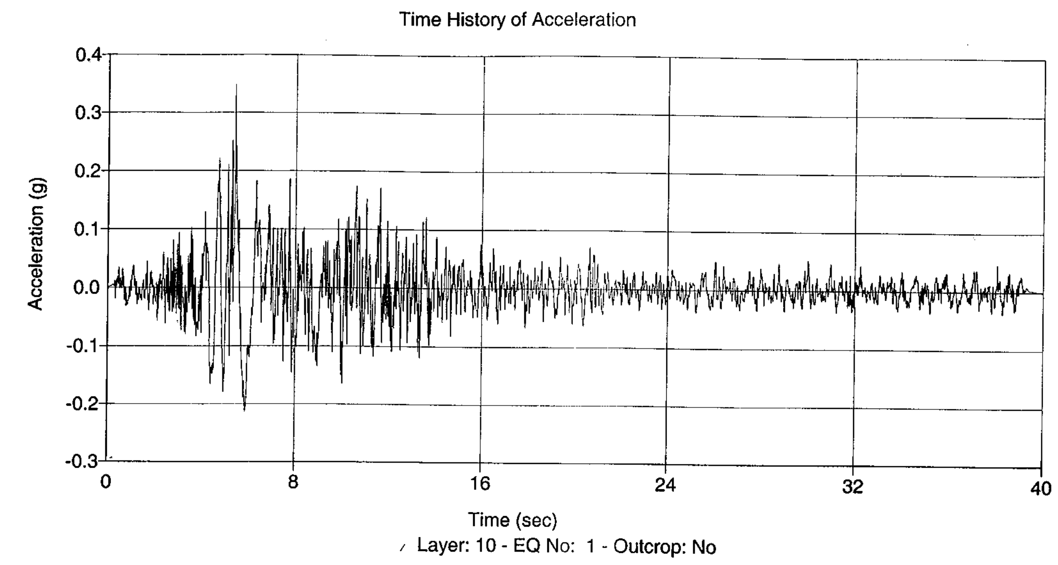




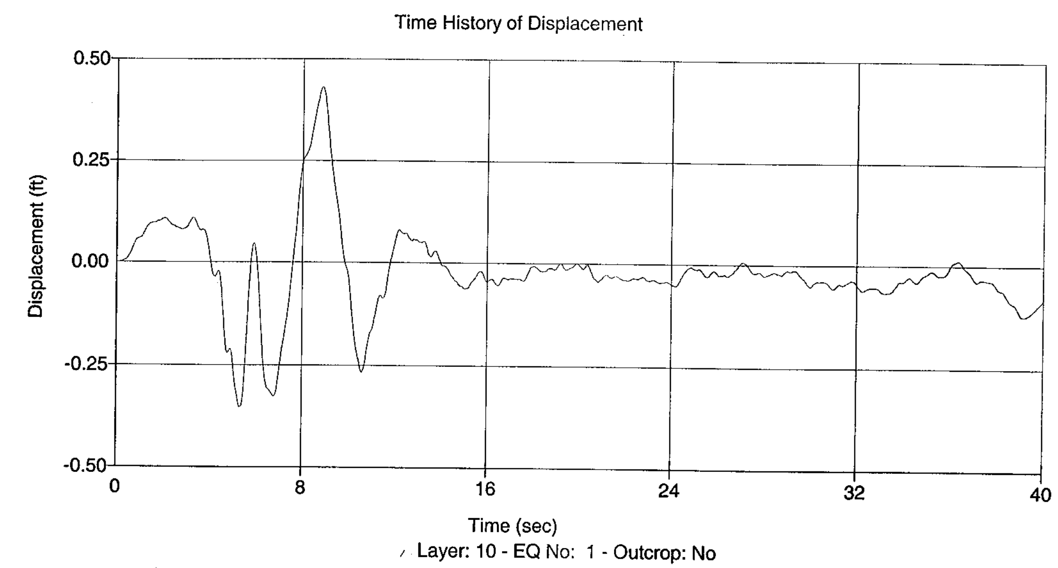


PFS-4 modulus reduction and damping curves as interpreted by ProShake.

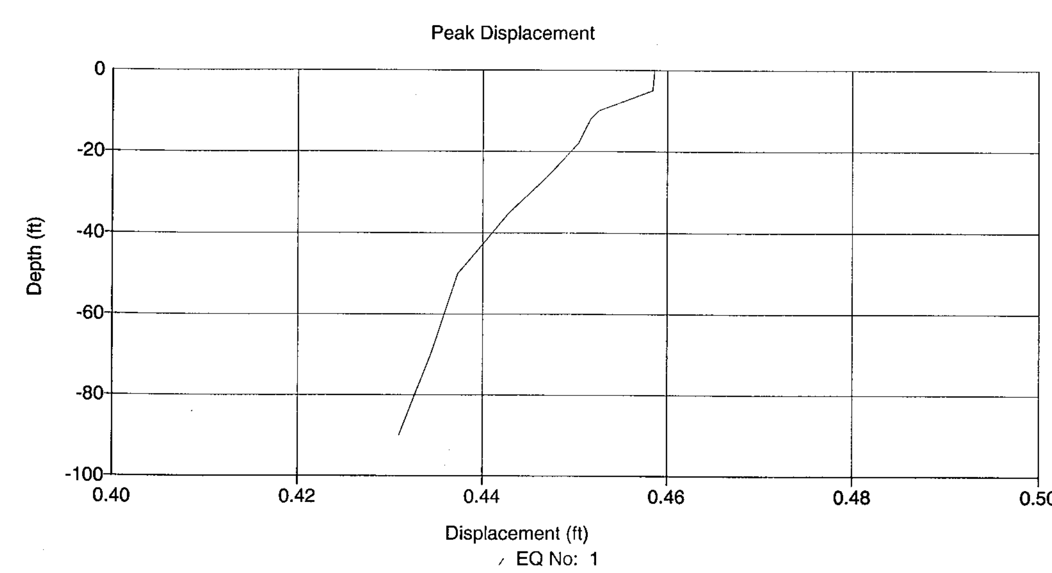
The curves PFS-5 consist of constant values of 1.0 for modulus reduction and 3.94% for damping at all strains. These curves are not plotted.



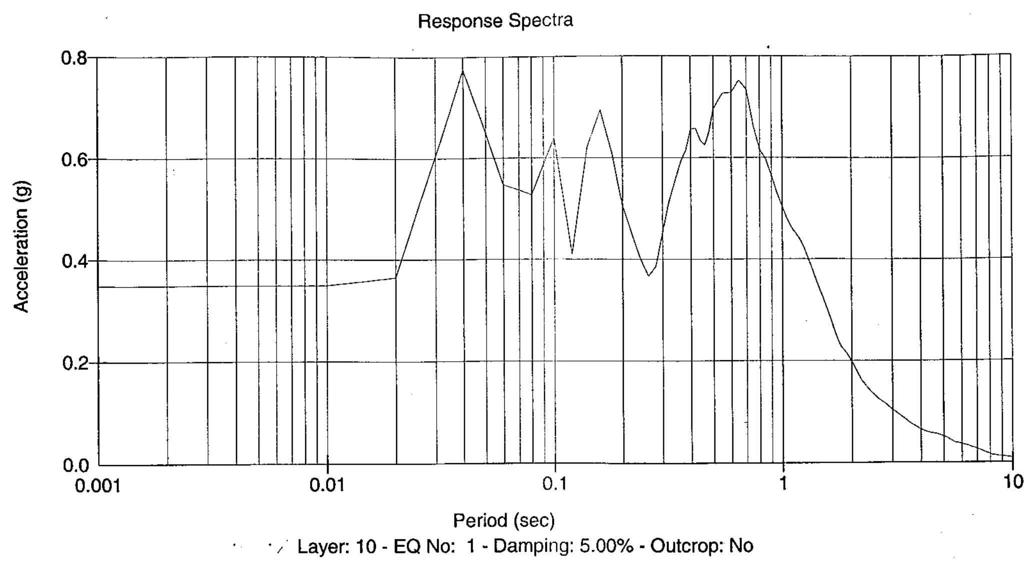
Acceleration history at base of layer 9 (top of Tertiary bedrock) from ProShake. Note that this represents the north-south motion.



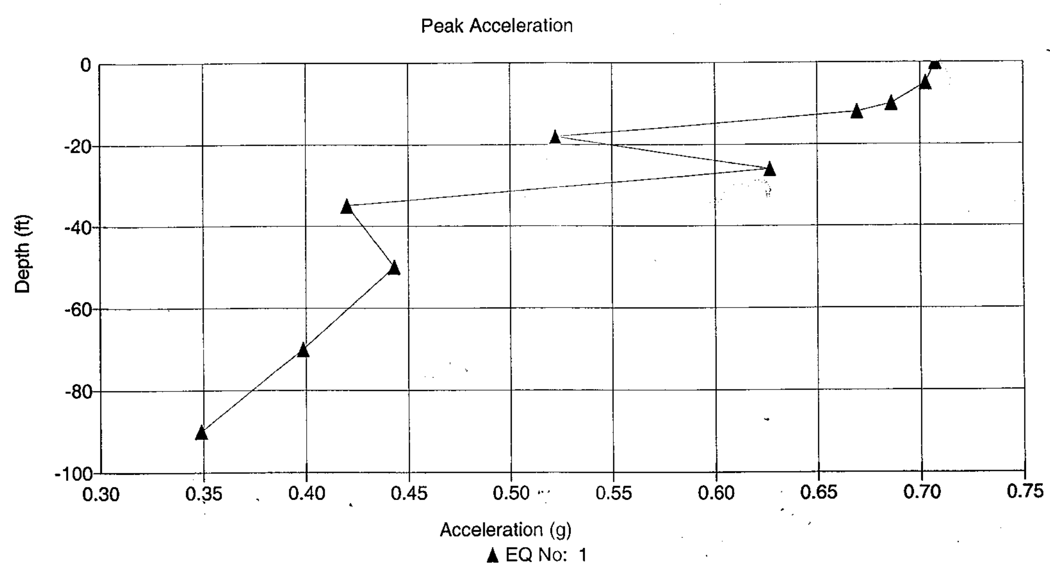
Displacement history at top of Tertiary from ProShake.



Profile of maximum displacement from ProShake.



Acceleration response spectrum at top of Tertiary from ProShake



Profile of peak acceleration from ProShake.

The acceleration history calculated for the top of the Tertiary bedrock (p. 23) will be used as input for the finite element model. The input will be applied at 90-ft depth to calculate a response at the ground surface. Such calculated response should be essentially the same as the North-South component of the design ground motion (p. 17).

NsSoilProp.xls

SoilLayer	Top (ft)	Base (ft)	ElemRows	ElemVol	UnitWt pcf	Density	MatDamp	ElemDamp	PRatio	sMod (ksf)	yMod (psf)	bMod (psf)
1.a	0.0	-3.0	1.0	75.0	100.0	3.1056	0.0094	4.036E-05	0.1770	6967.3	1.6401E+07	8.4629E+06
1.b	-3.0	-5.0	1.0	50.0	100.0	3.1056	0.0094	6.054E-05	0.1770	6967.3	1.6401E+07	8.4629E+06
2	-5.0	-10.0	1.0	125.0	80.0	2.4845	0.0459	1.478E-04	0.3607	441.9	1.2025E+06	1.4384E+06
3	-10.0	-12.0	1.0	50.0	80.0	2.4845	0.0342	2.753E-04	0.2505	985.8	2.4655E+06	1.6468E+06
4	-12.0	-18.0	2.0	75.0	100.0	3.1056	0.0223	9.574E-05	0.2463	1899.3	4.7344E+06	3.1104E+06
5	-18.0	-26.0	2.0	100.0	94.0	2.9193	0.0286	9.797E-05	0.2115	1719.7	4.1670E+06	2.4075E+06
6	-26.0	-35.0	2.0	112.5	115.0	3.5714	0.0552	1.374E-04	0.1989	2533.1	6.0738E+06	3.3619E+06
7	-35.0	-50.0	3.0	125.0	115.0	3.5714	0.0562	1.259E-04	0.2584	3406.6	8.5741E+06	5.9157E+06
8	-50.0	-70.0	4.0	125.0	120.0	3.7267	0.0146	3.134E-05	0.3053	11246.8	2.9361E+07	2.5132E+07
9	-70.0	-90.0	4.0	125.0	120.0	3.7267	0.0177	3.800E-05	0.3053	10958.7	2.8609E+07	2.4488E+07

Values of elastic parameters and damping ratio calculated from the strain-compatible damping and shear modulus output from ProShake. It was assumed that Poisson's ratio does not vary with strain, and values of Poisson's ratio were calculated using S-wave and P-wave velocities as shown in the table on the left.

PoissonRatio.xls

Soil Layer	Layer#	SwVel (fps) V_s	PwVel (fps) V_p	velRatioSqd R_v	PoissonRatio ν
Eolian silts	1	560	1117	3.978600128	0.3321
Lacustrine silt	2	528	1131	4.588358729	0.3607
Lacustrine silt	3	727	1260	3.003808684	0.2505
Lacustrine sand	4	854	1472	2.970981029	0.2463
Lacustrine silt	5	871	1440	2.73330864	0.2115
Lacustrine sands	6	1022	1667	2.660537643	0.1989
Lacustrine sands	7	1190	2085	3.069857355	0.2584
Dense sand/silt	8	1800	3400	3.567901235	0.3053
Dense sand/silt	9	1800	3400	3.567901235	0.3053
Tertiary	10	2900	5023	3.000062901	0.2500

$$\nu = \frac{R_v - 2}{2(R_v - 1)} \; ; \; R_v = \left(\frac{V_p}{V_s}\right)^2$$

Element damping (ElemDamp) is the mass-proportional damping coefficient used in the finite element model. ElemDamp is equal to the ratio MatDamp/(ElemVol × Density).

November 20 2001

Damping

The finite element code (LS-DYNA) implements material damping through the Rayleigh damping parameters defined as follows

$$\bar{C} = \alpha \bar{M} + \beta \bar{K} \quad (1)$$

where $\bar{C}$, $\bar{M}$, and $\bar{K}$ are the damping, mass, and stiffness matrices; and α and β are the mass-proportional and stiffness-proportional damping parameters. It can be shown that, for mode-superposition analysis, the parameters α and β ~~can be~~ (GIO) is related to the effective damping factor c at frequency f ~~through~~ through the equation

$$\alpha + (2\pi f)^2 \beta = 4\pi f c \quad (2)$$

[Reference: Bathe K.J., 1982. Finite Element Procedures in Engineering Analysis. Englewood Cliffs, NJ: Prentice-Hall, Inc., p.529]

The effective damping c (fraction of critical damping) varies with frequency f. If the values of c are known to be c_0 and c_1 at two frequencies

f_0 and f_1 respectively, then equation (2) can be solved for α and β, as follows:

$$\beta = \frac{f_0 c_0 - f_1 c_1}{\pi (f_0 - f_1)(f_0 + f_1)} \quad \text{--- (3)}$$

$$\alpha = 4\pi f_0 (c_0 - \pi f_0 \beta) \quad \text{--- (4)}$$

Equations (3) and (4) were used to evaluate α and β for the following sets of parameters

Set 1	Set 2
c_0 = MatDamp	c_0 = MatDamp
f_0 = 0.5 Hz	f_0 = 0.4 Hz
c_1 = 0.1	c_1 = 0.1
f_1 = 10 Hz	f_1 = 10 Hz

where MatDamp represents the column of damping values labeled "MatDamp" on p.25. The rationale for the parameter values in Set 1 and Set 2 is to obtain a value of effective damping ratio that is close to the specified material damping (p.25) at low frequencies but increases to 0.1 or more at higher frequencies. The resulting α, β, and c values are shown on the following pages.

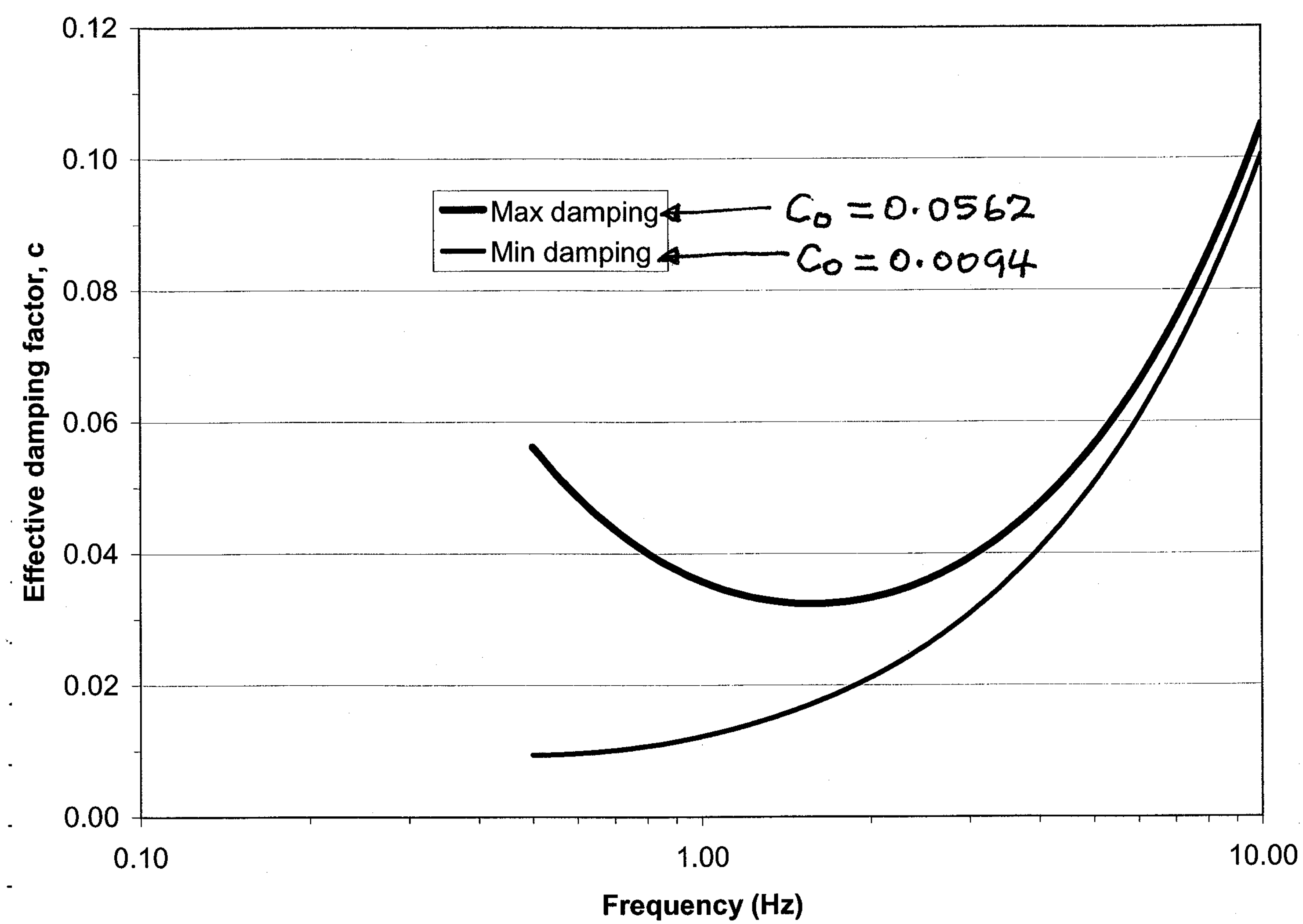
RDamp01NS.xls

f0=0.5 Hz
f1=10 Hz
c1=0.1

SoilLayer	MatDamp (c0)	AlphaDampParam	BetaDampParam
1.a	0.0094	0.02758	0.003190
1.b	0.0094	0.02758	0.003190
2	0.0459	0.25634	0.003248
3	0.0342	0.18301	0.003229
4	0.0223	0.10843	0.003211
5	0.0286	0.14791	0.003221
6	0.0552	0.31463	0.003263
7	0.0562	0.32090	0.003264
8	0.0146	0.06017	0.003198
9	0.0177	0.07960	0.003203

Soil layers 1a and 1b represent soil cement. The other soil layers are as described on p. 12-13. See also p. 25.

Parameter Set 1



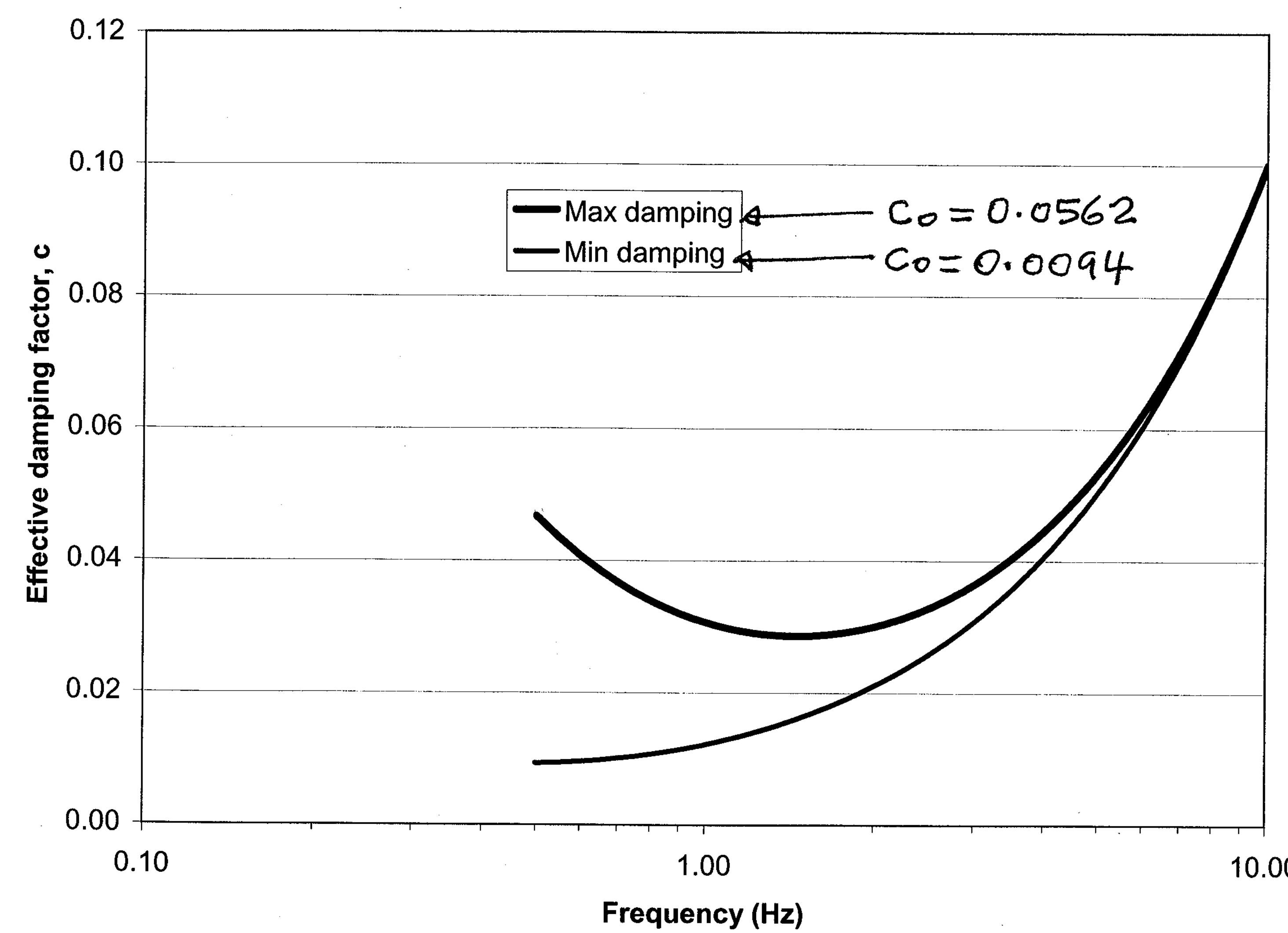
RDamp02NS.xls

f0=0.4 Hz
f1=10 Hz
c1=0.1

For Beta=0
and f=2 Hz

SoilLayer	MatDamp (c0)	AlphaDampParam	BetaDampParam	Alpha
1.a	0.0094	0.02719	0.003176	0.2362
1.b	0.0094	0.02719	0.003176	0.2362
2	0.0459	0.21095	0.003130	1.1536
3	0.0342	0.15205	0.003145	0.8595
4	0.0223	0.09213	0.003160	0.5605
5	0.0286	0.12385	0.003152	0.7188
6	0.0552	0.25777	0.003118	1.3873
7	0.0562	0.26281	0.003117	1.4125
8	0.0146	0.05337	0.003170	0.3669
9	0.0177	0.06897	0.003166	0.4448

Parameter Set 2



These two sets of α and β values will be used in the finite element models. An alternative set of α values obtained by setting β=0 and f = 2 Hz in equation (2) (p. 26) is also shown in the table on p. 29. This set will also be used but may not be successful, because it may lead to overdamping of low-frequency motions and underdamping of high frequencies.

November 23, 2001

Finite Element (LS-DYNA) Analyses of Site Response to the North-South Ground Motion Component

Input Motion: The same as the output from the ProShake analysis, which is plotted on p. 23 (time history) and on p. 24 (response spectrum). The time-history file is NsO1out.eq, which is located in the subdirectory D:\PfsSSIAnal\PShakeModels of computer CALIB.

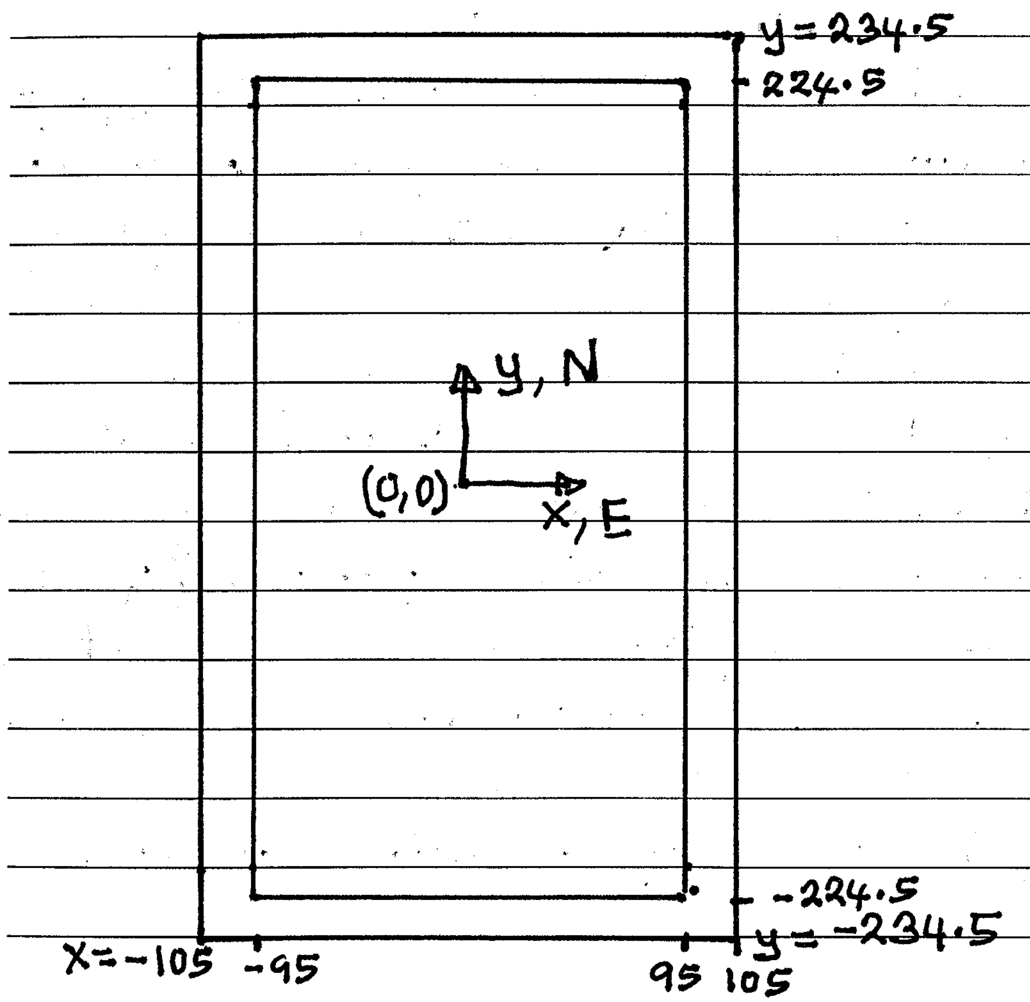
Subdirectory: The input and output files associated with the finite element analyses are located in the following subdirectory of

computer CALIB:

D:\PfsSSIAnal\1DMotionCases\PN3
D:\PfsSSIAnal\1DMotionCases\PN4.

Model Geometry

Horizontal Plane



Vertical Dimension

Axis: z, U
Varies from z=0 at ground surface to z=-90 ft at the base of the soil profile, as described on p. 25 (table).

The model extends laterally through: $-95 \le x \le 95$ ft and $-224.5 \le y \le 224.5$ ft, plus a 10-ft wide zone around the model perimeter assigned properties that promote the absorption of dynamic energy. The 10-ft wide boundary zone is referred to hereafter as the Absorbing Zone.

Boundary Conditions

The model boundary conditions need to satisfy two model states:

(1) the initial static equilibrium state, prior to the occurrence of earthquake loading; and

(2) the dissipation of dynamic energy during seismic loading.

That is, the specified boundary conditions need to provide the mechanical restraint necessary to simulate the initial static equilibrium state, and at the same time provide an appropriate combination of energy transmission and absorption to simulate the dissipation of dynamic energy.

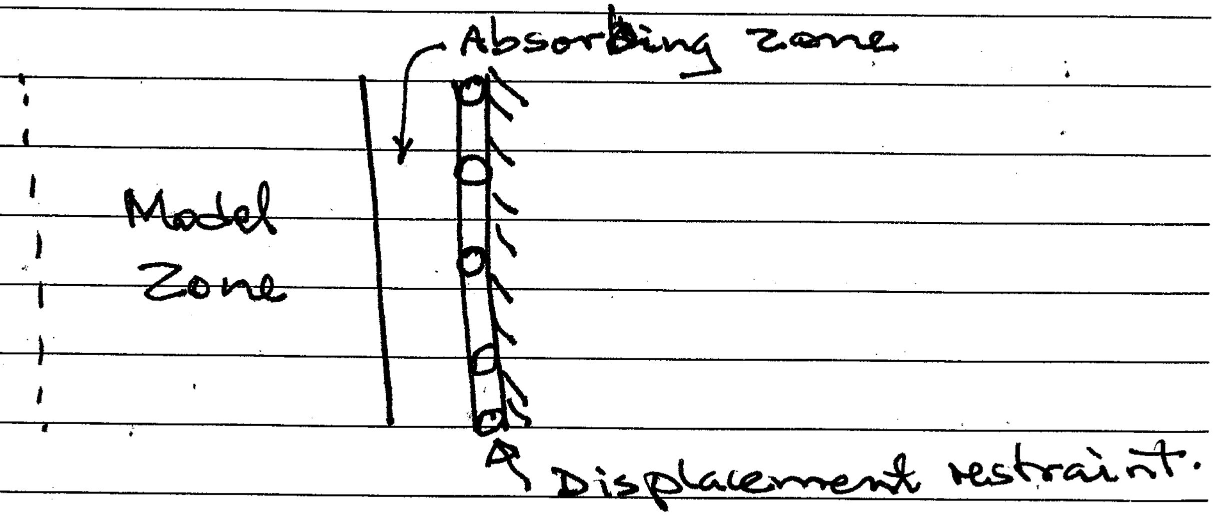
The following boundary conditions were tested.

A. Non-Reflecting Boundary. This approach was unsuccessful because it does not provide any mechanical restraint. LS-DYNA includes a formulation of this boundary

condition that consists of (i) displacement restraints during an initial (dynamic relaxation) analysis phase to establish static equilibrium; and (ii) non-reflecting conditions (applied through a system of dampers) during the transient analysis phase. The approach was successful during the initial phase, in the sense that an appropriate initial stress state was obtained. The approach was, however, unsuccessful during the transient phase. Because of the lack of boundary restraint and the fact that the seismic input was applied over the entire model base, the earthquake loading excited the natural frequency of the entire model causing it to ~~respond~~ respond like a rigid body.

B. Grounded Springs and Dampers were placed around the boundaries, except the ground surface. The springs were assigned stiffness consistent with the elastic stiffness of the surrounding ~~Disk~~ 11/23/2004 GTO infinite domain, the viscosity of the dampers was assigned ~~based~~ 11/23/2004 GTO to simulate the material damping of the infinite domain. This approach was not successful. The springs were too "noisy", generating transient boundary motions that did not decay fast enough. It is possible that a combination of spring stiffness and damper viscosity could be found to make this approach successful, but there wasn't enough time to investigate this possibility.

C. Boundary Zone With High Damping The use of a boundary zone assigned relatively high damping was attempted. All the boundaries (except ground surface) were surrounded by a zone (10-ft wide) assigned about 10 times the model damping values. Displacement restraints were applied around the periphery of the high-damping zone (absorbing zone).



This procedure was implemented with mass-proportional damping only, both in the model and absorbing zones. It was not successful

in preventing energy reflection back into the model. It is possible that the approach would be more successful with Rayleigh damping (i.e., combined mass-proportional and stiffness-proportional damping) but elevated β-damping values in the absorbing zone would probably slow the calculation down considerably. Therefore, this approach was abandoned.

D. Boundary Plastic Zone. Cyclic plastic deformation is an effective mechanism of absorbing dynamic energy. Therefore, a series of trial models were setup in which the high-damping zone in the previous case (Case C) was replaced with a plastic zone. The zone was assigned a yield strength small enough to permit plastic deformations within the absorbing zone during part of the initial "static" phase and all of the transient phase. Two plasticity-based constitutive models were attempted: one with both volumetric and shear yielding, and the other with shear yielding only. The model with shear yielding only was more successful. The other model generated much "noise". Therefore, a boundary absorbing zone based on shear yielding was used in subsequent models.

January 7 2002

The Modeling Approach described on p.14 is modified as follows:

The ProShake 1D wave-propagation code will be used for deconvolution analyses to obtain the equivalent motion components (of the PFS design ground motion) at 90-ft depth and at other desired depths between 90 ft and the ground surface.

Deconvolution Analyses with ProShake

Input motions:

ProShake input	PFS source file
Fn2000f.eq	~~Fn2000f.acc~~ GTO 1/07/2002 Fn2000f.acc
Fp2000f.eq	Fp2000f.acc
V2000f.eq	V2000f.acc

These files are located in D:\PfsSSIAnal\Input Motion

The .acc files are the PFS-supplied source files providing the acceleration time histories for the 2000 yr return period ~~acceleratio~~ earthquake. (GTO 1/07/2002) The .eq files were obtained using a ProShake utility to translate the .acc file format into the format required by ProShake. The Fn, Fp, and V prefixes represent the fault-normal, fault-parallel, and vertical components. The fault-normal and fault-parallel directions correspond to East and North, respectively [ref. Figures 11, 12, and 13 of PFS calculation # 05996.02.G(P018)-3, Revision 1 (March 21, 2001), "Development of Time Histories for 2000-Year Return Period Design Spectra"].

ProShake is based on the analysis of the vertical propagation of a horizontally polarized shear wave through a series of laterally (horizontally) infinite horizontal soil layers. Three analyses were performed as follows:

(1) East-west motion component using shear wave velocities.
(2) North-south motion component using shear wave velocities
(3) Vertical motion component using p-wave velocities.

Stratigraphic model used for horizontal motion

ProShake Report

Data File: D:\PFSSSI~1\PSHAKE~1\EW2.DAT

Soil Profile

Profile Name: PFS Skull Valley Soil Profile (Basecase Soil Properties)
Water Table: Not Applicable
Number of Layers: 23

Soil Layer #'s on p. 28-29

Layer Number	Material Name	Thickness (ft)	Unit Weight (pcf)	Gmax (ksf)	Vs (ft/sec)	Modulus Curve	Damping Curve	Mod. Parameter	Damp. Parameter
1	Soil cement	3.00	100.00	6,993.22	1,500.00	PFS-1 Modulus Reducti	PFS-1 Damping	1a	
2	Soil cement	2.00	100.00	6,993.22	1,500.00	PFS-1 Modulus Reducti	PFS-1 Damping	1b	
3	Lacustrine silt	2.50	80.00	693.19	528.00	PFS-1 Modulus Reducti	PFS-1 Damping	2	
4	Lacustrine silt	2.50	80.00	693.19	528.00	PFS-1 Modulus Reducti	PFS-1 Damping	2	
5	Lacustrine silt	2.00	80.00	1,314.18	727.00	PFS-1 Modulus Reducti	PFS-1 Damping	3	
6	Lacustrine sand	3.00	100.00	2,266.79	854.00	PFS-2 Modulus Reducti	PFS-2 Damping	4	
7	Lacustrine sand	3.00	100.00	2,266.79	854.00	PFS-2 Modulus Reducti	PFS-2 Damping	4	
8	Lacustrine silt	4.00	94.00	2,216.46	871.00	PFS-2 Modulus Reducti	PFS-2 Damping	5	
9	Lacustrine silt	4.00	94.00	2,216.46	871.00	PFS-2 Modulus Reducti	PFS-2 Damping	5	
10	Lacustrine sands	4.50	115.00	3,733.31	1,022.00	PFS-3 Modulus Reducti	PFS-3 Damping	6	
11	Lacustrine sands	4.50	115.00	3,733.31	1,022.00	PFS-3 Modulus Reducti	PFS-3 Damping	6	
12	Lacustrine sands	5.00	115.00	5,061.59	1,190.00	PFS-3 Modulus Reducti	PFS-3 Damping	7	
13	Lacustrine sands	5.00	115.00	5,061.59	1,190.00	PFS-3 Modulus Reducti	PFS-3 Damping	7	
14	Lacustrine sands	5.00	115.00	5,061.59	1,190.00	PFS-3 Modulus Reducti	PFS-3 Damping	7	
15	Dense sands and s	5.00	120.00	12,084.29	1,800.00	PFS-4 Modulus Reducti	PFS-4 Damping	8	
16	Dense sands and s	5.00	120.00	12,084.29	1,800.00	PFS-4 Modulus Reducti	PFS-4 Damping	8	
17	Dense sands and s	5.00	120.00	12,084.29	1,800.00	PFS-4 Modulus Reducti	PFS-4 Damping	8	
18	Dense sands and s	5.00	120.00	12,084.29	1,800.00	PFS-4 Modulus Reducti	PFS-4 Damping	8	
19	Dense sands and s	5.00	120.00	12,084.29	1,800.00	PFS-4 Modulus Reducti	PFS-4 Damping	9	
20	Dense sands and s	5.00	120.00	12,084.29	1,800.00	PFS-4 Modulus Reducti	PFS-4 Damping	9	
21	Dense sands and s	5.00	120.00	12,084.29	1,800.00	PFS-4 Modulus Reducti	PFS-4 Damping	9	
22	Dense sands and s	5.00	120.00	12,084.29	1,800.00	PFS-4 Modulus Reducti	PFS-4 Damping	9	
23	Tertiary Salt Lake G	Infinite	135.00	35,287.81	2,900.00	PFS-5 Modulus: Rock-L	PFS-5 Damping: Rock-Lin		

analyses. The relationship with the stratigraphic models on p. 28-29 (and hence, the stratigraphy on p. 12-13) is indicated (column 9).
The same stratigraphic model was used for the analysis of the vertical motion component, except that p-wave velocities were used instead of s-wave velocities as shown on p. 39 (column 6). The modulus calculated using the p-wave velocities is the so-called constrained modulus ($\lambda + 2G$ on p. 39).

Soil Profile

Profile Name: PFS Skull Valley Soil Profile (Basecase Soil Properties): Vp Approximation
Water Table: Not Applicable
Number of Layers: 23

Layer Number	Material Name	Thickness (ft)	Unit Weight (pcf)	(λ+2G)max (ksf)	Vp (ft/sec)	Modulus Curve	Damping Curve	Mod. Parameter	Damp. Parameter
1	Soil cement	3.00	100.00	17,752.60	2,389.92	PFS-1 Modulus Reduction	PFS-1 Damping		
2	Soil cement	2.00	100.00	17,752.60	2,389.92	PFS-1 Modulus Reduction	PFS-1 Damping		
3	Lacustrine silt	2.50	80.00	3,180.61	1,131.00	PFS-1 Modulus Reduction	PFS-1 Damping		
4	Lacustrine silt	2.50	80.00	3,180.61	1,131.00	PFS-1 Modulus Reduction	PFS-1 Damping		
5	Lacustrine silt	2.00	80.00	3,947.54	1,260.00	PFS-1 Modulus Reduction	PFS-1 Damping		
6	Lacustrine sand	3.00	100.00	6,734.58	1,472.00	PFS-2 Modulus Reduction	PFS-2 Damping		
7	Lacustrine sand	3.00	100.00	6,734.58	1,472.00	PFS-2 Modulus Reduction	PFS-2 Damping		
8	Lacustrine silt	4.00	94.00	6,058.26	1,440.00	PFS-2 Modulus Reduction	PFS-2 Damping		
9	Lacustrine silt	4.00	94.00	6,058.26	1,440.00	PFS-2 Modulus Reduction	PFS-2 Damping		
10	Lacustrine sands	4.50	115.00	9,932.62	1,667.00	PFS-3 Modulus Reduction	PFS-3 Damping		
11	Lacustrine sands	4.50	115.00	9,932.62	1,667.00	PFS-3 Modulus Reduction	PFS-3 Damping		
12	Lacustrine sands	5.00	115.00	15,538.35	2,085.00	PFS-3 Modulus Reduction	PFS-3 Damping		
13	Lacustrine sands	5.00	115.00	15,538.35	2,085.00	PFS-3 Modulus Reduction	PFS-3 Damping		
14	Lacustrine sands	5.00	115.00	15,538.35	2,085.00	PFS-3 Modulus Reduction	PFS-3 Damping		
15	Dense sands and silty sands	5.00	120.00	43,115.56	3,400.00	PFS-4 Modulus Reduction	PFS-4 Damping		
16	Dense sands and silty sands	5.00	120.00	43,115.56	3,400.00	PFS-4 Modulus Reduction	PFS-4 Damping		
17	Dense sands and silty sands	5.00	120.00	43,115.56	3,400.00	PFS-4 Modulus Reduction	PFS-4 Damping		
18	Dense sands and silty sands	5.00	120.00	43,115.56	3,400.00	PFS-4 Modulus Reduction	PFS-4 Damping		
19	Dense sands and silty sands	5.00	120.00	43,115.56	3,400.00	PFS-4 Modulus Reduction	PFS-4 Damping		
20	Dense sands and silty sands	5.00	120.00	43,115.56	3,400.00	PFS-4 Modulus Reduction	PFS-4 Damping		
21	Dense sands and silty sands	5.00	120.00	43,115.56	3,400.00	PFS-4 Modulus Reduction	PFS-4 Damping		
22	Dense sands and silty sands	5.00	120.00	43,115.56	3,400.00	PFS-4 Modulus Reduction	PFS-4 Damping		
23	Tertiary Salt Lake Group	Infinite	135.00	105,865.65	5,023.00	PFS-5 Modulus: Rock-Linear	PFS-5 Damping: Rock-Linear		

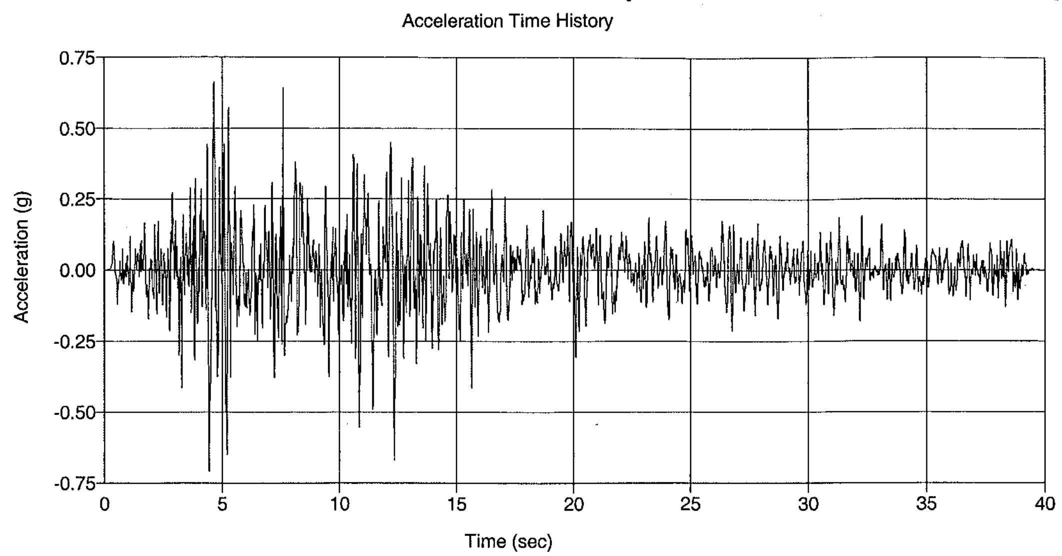
Stratigraphic model used for analysis of vertical motion component.

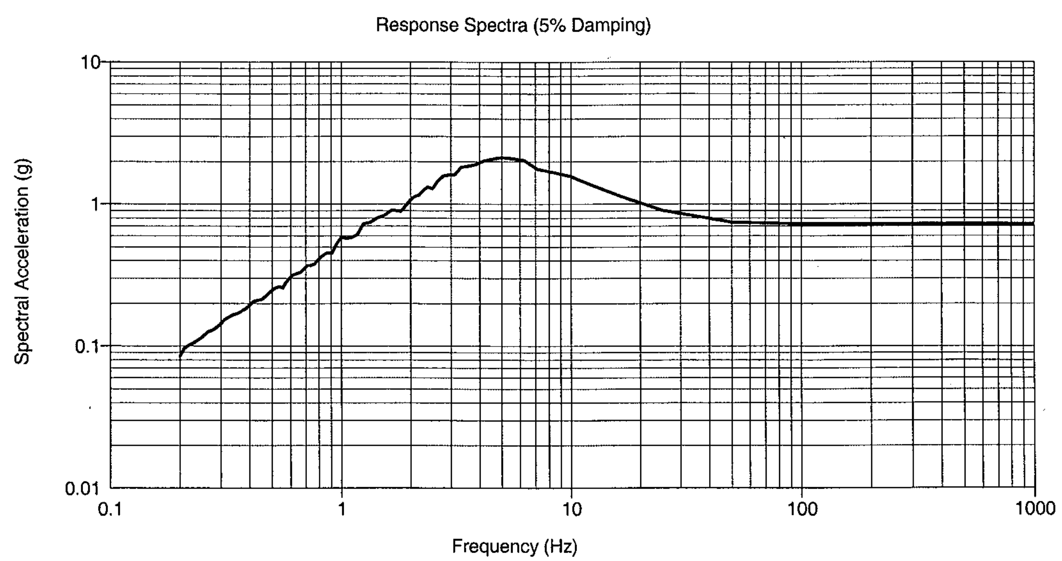
$$V_s = \sqrt{\frac{G}{\rho}} = \text{shear wave velocity}$$

$$V_p = \sqrt{\frac{\lambda + 2G}{\rho}} = \text{p-wave velocity}$$

ρ = mass density
G = shear modulus
λ = Lamé elastic parameter.

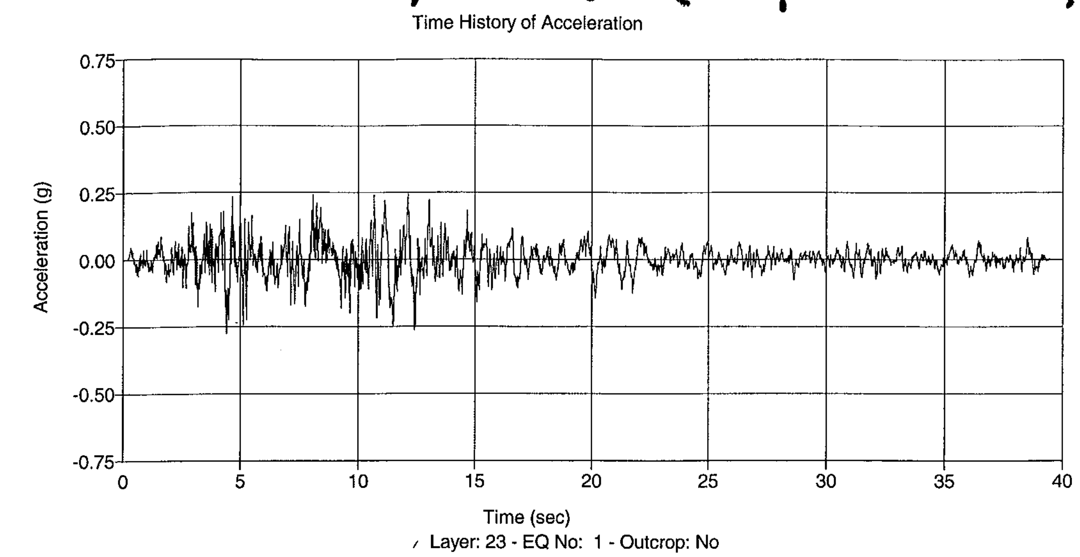
East Component (Input)

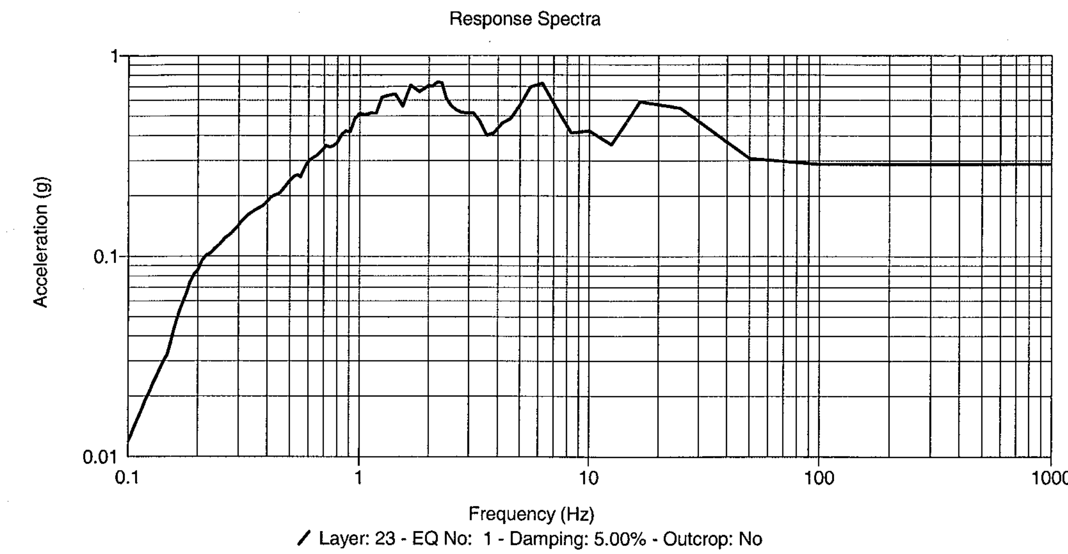


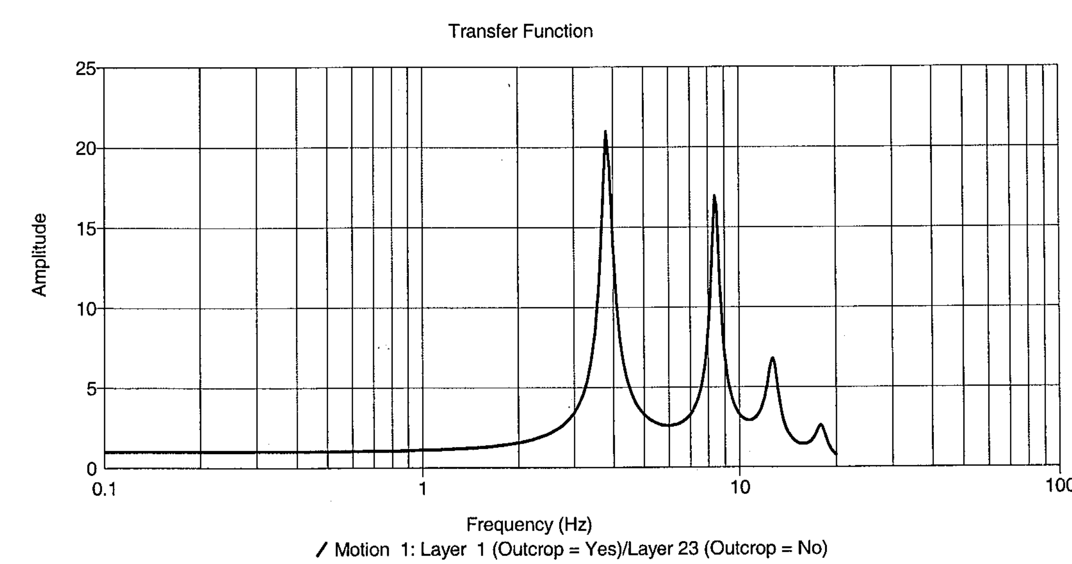


The above figure shows the input acceleration time history and response spectra applied at the ground surface in the ProShake analysis of the East motion component. The output acceleration time history and response spectra at 90-ft depth are shown on p. 41. The bottom figure on p. 41 gives the magnification factors for spectral acceleration from the model base (90-ft depth) to the ground surface.

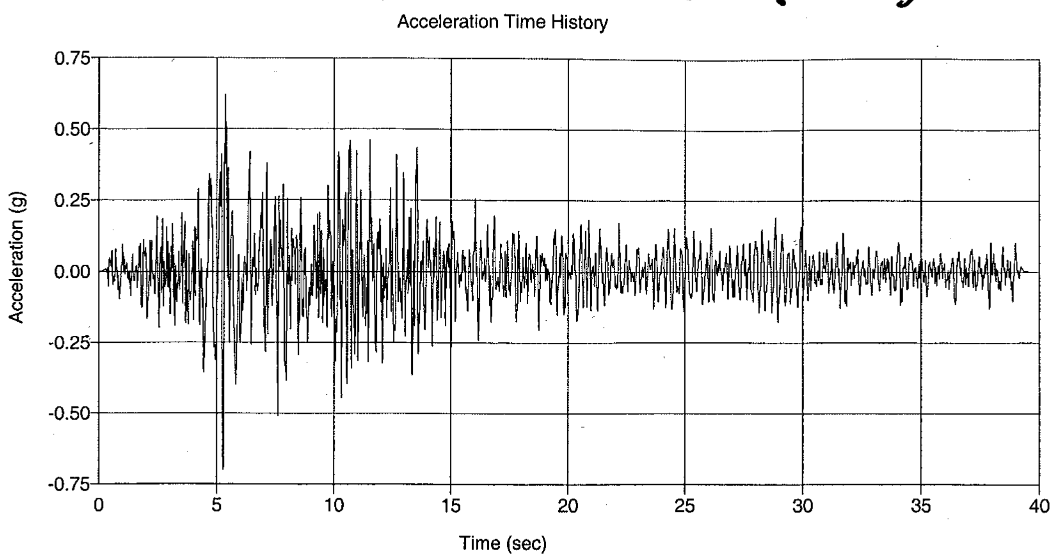
East Component (Output at 90-ft depth)

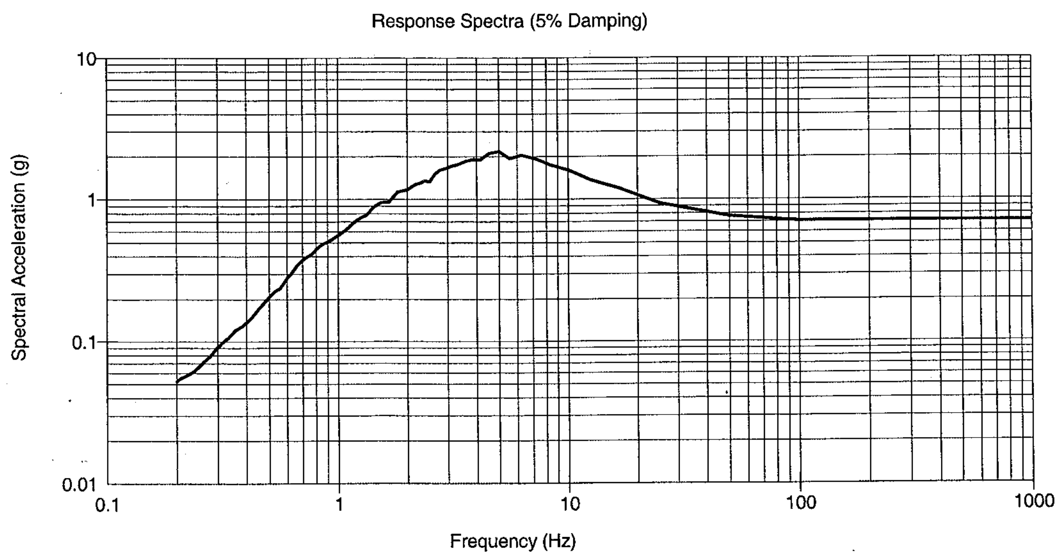






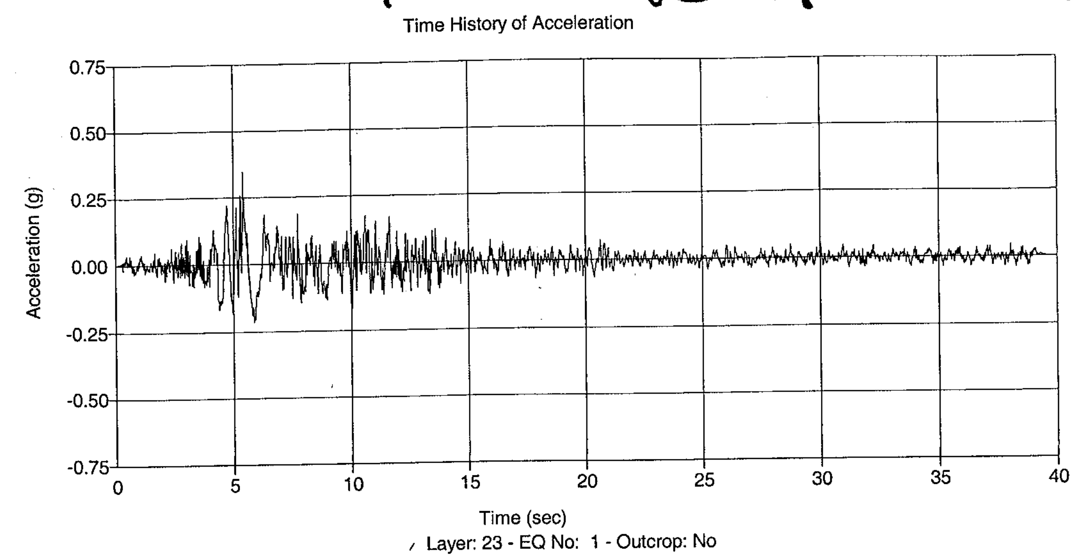
North Component (Input)

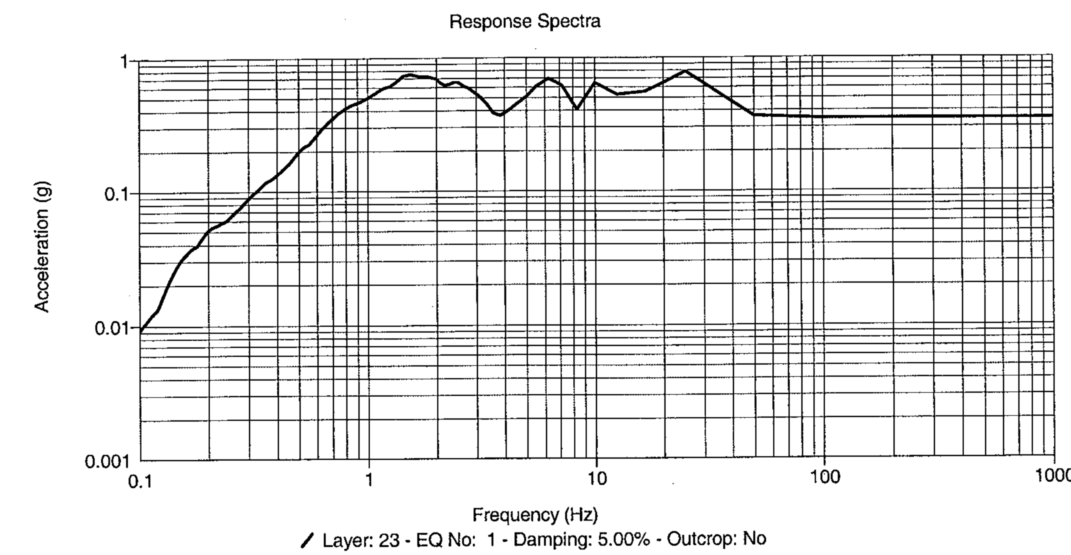


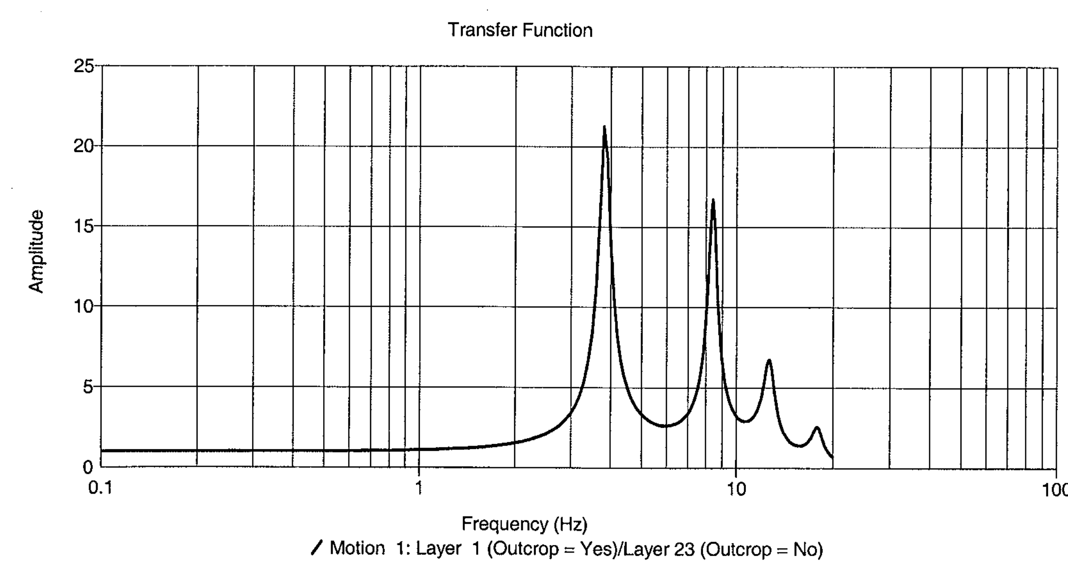


The above figures show the input time history and response spectra applied at the ground surface in the ProShake analysis of the North ground motion component. The output time history and response spectra are shown on p. 43. The bottom figure on p. 43 shows the spectral acceleration magnification factors for base (90-ft depth) to ground surface propagation of the North acceleration component.

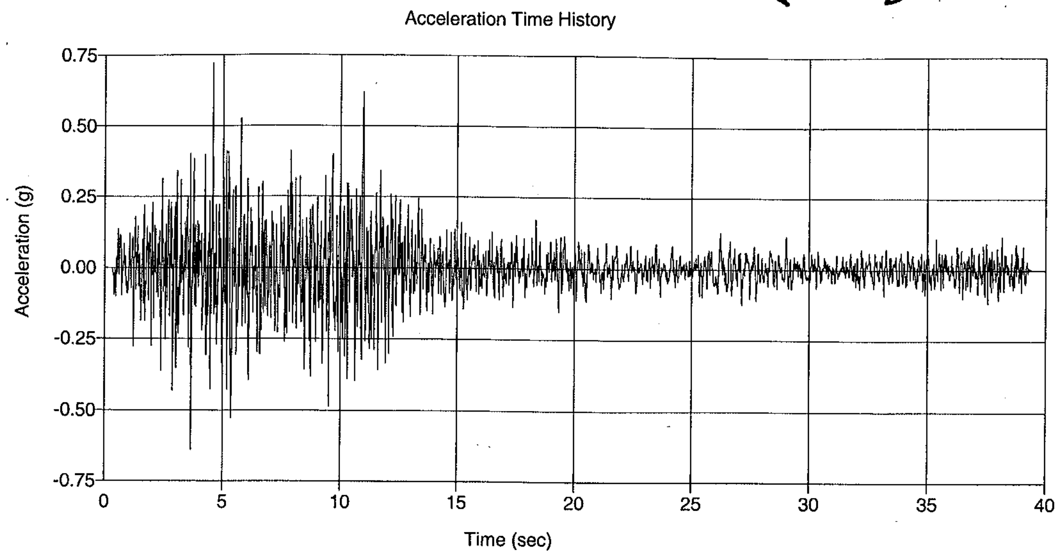
North Component (Output at 90-ft depth)

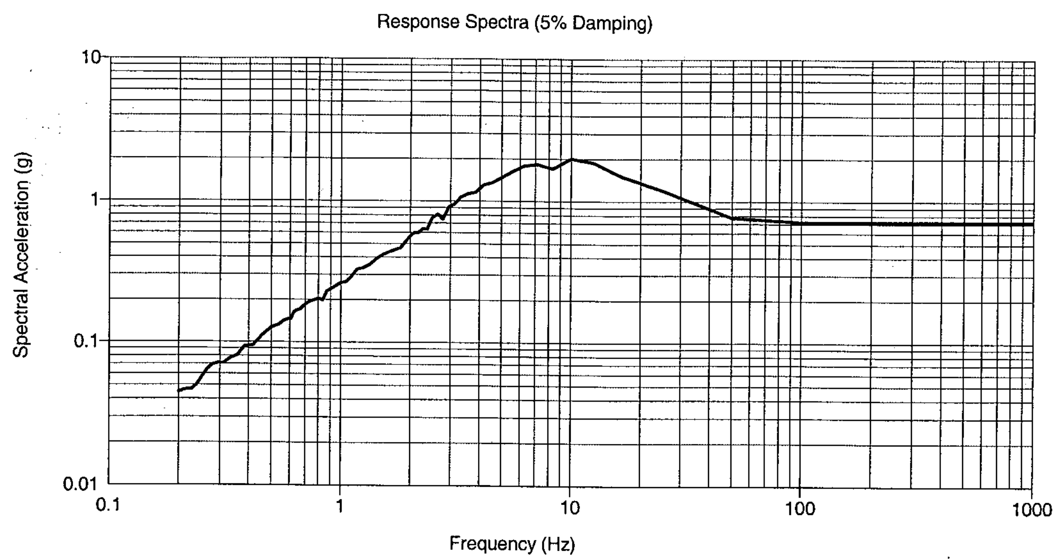






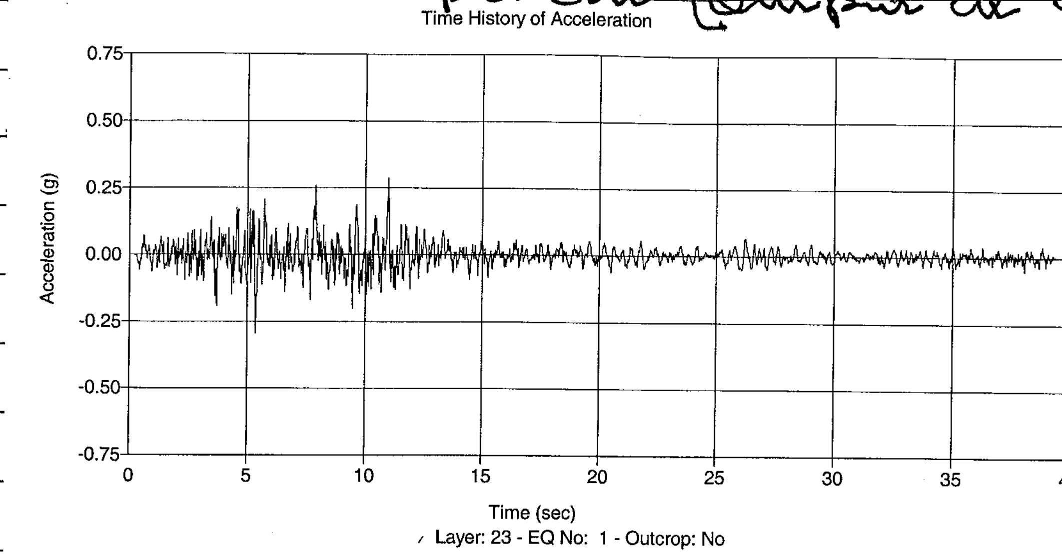
Vertical Component (Input)

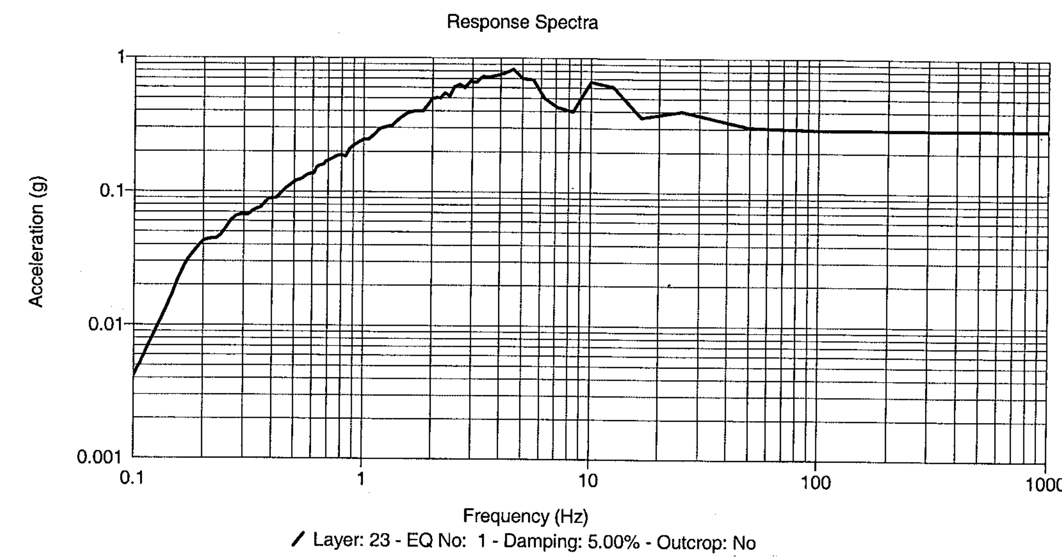


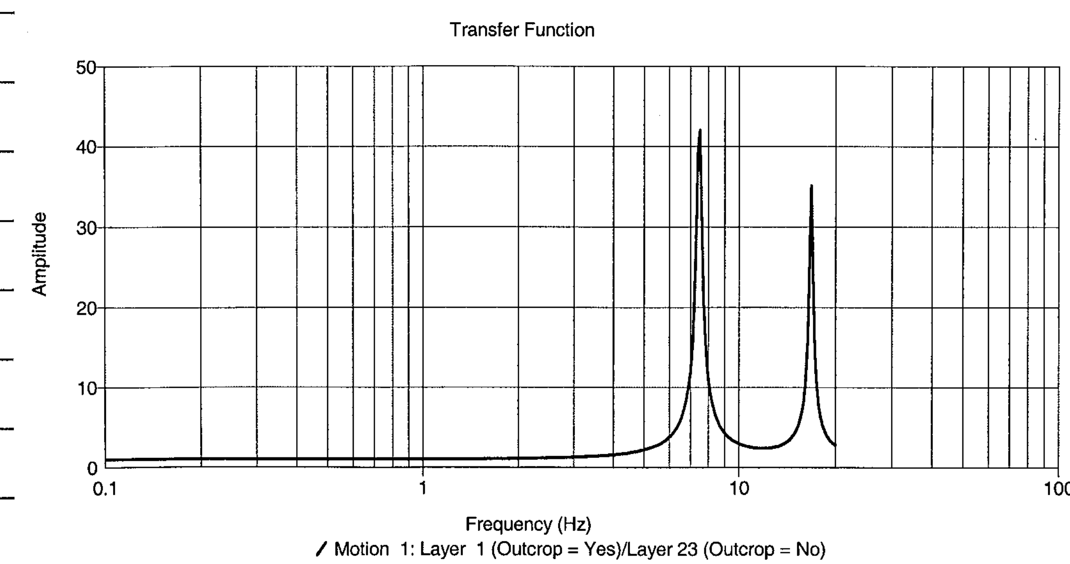


The above figures give the acceleration time history and response spectra applied at the ground surface in the ProShake analysis of the vertical ground motion component. The output time history and response spectra at 90-ft depth are given on p. 45. The bottom figure on p. 45 gives the magnification factors for spectral acceleration between 90-ft depth and the ground surface.

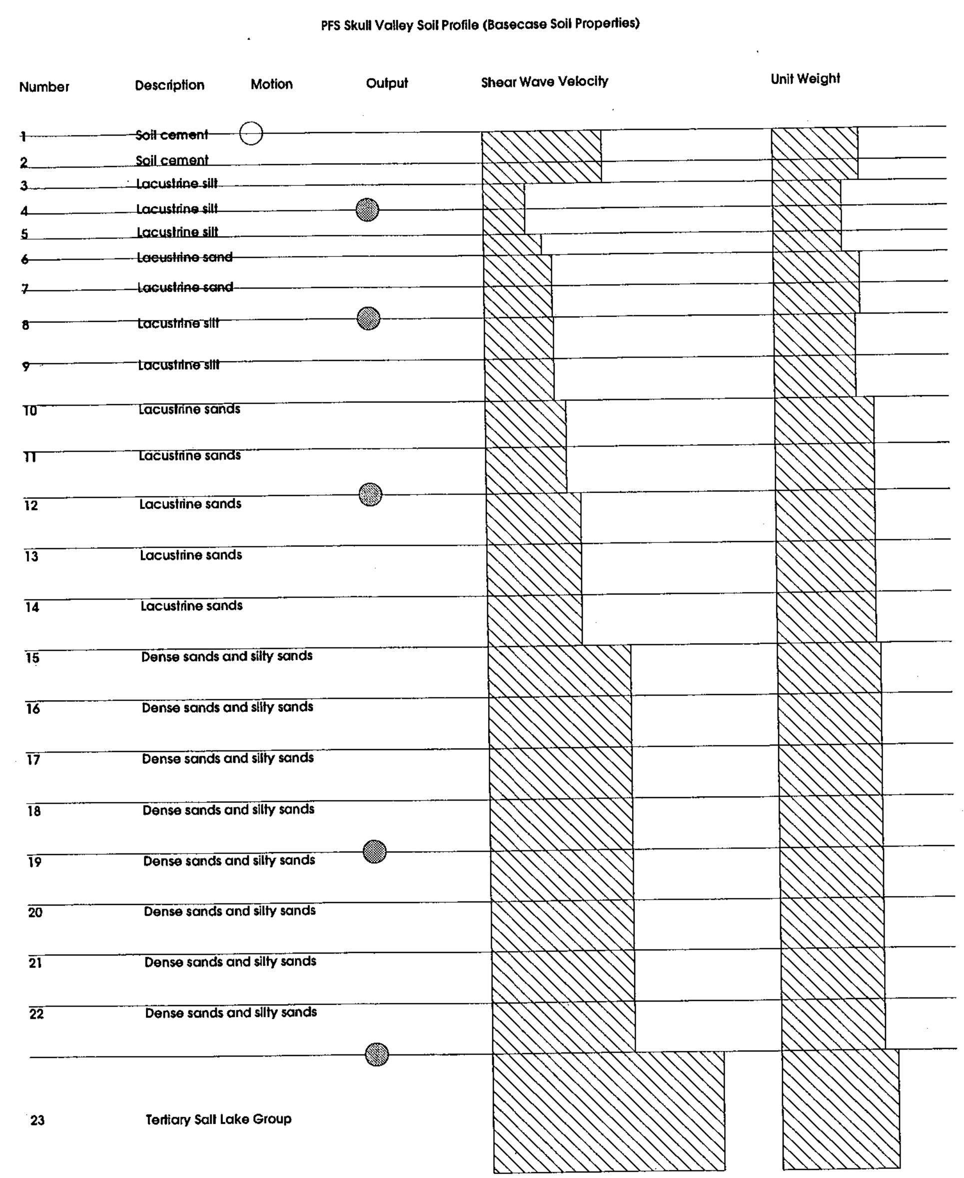
Vertical Component (Output at 90-ft depth)







The output time histories at 90-ft depth (top plot on p. 41, 43, and 45) will be applied as input at 90-ft depth in the finite element models.



Output time histories of the East and North motion components were also calculated at the locations shown in the above figure. These time histories will be used as specified lateral-boundary motions

in the finite element model. The application of the lateral-boundary motions is described below. The output file names are also given below.

Depth at which motion is calculated (from ProShake), ft	Depth range over which lateral-boundary motion is applied (FE model), ft
0.0 (input motion)	0 – 5 (soil cement)
7.5	>5 – 12 (Lacustrine silt)
18.0	>12 – 26 (Lacustrine sand/silt)
35.0	>26 – 50 (Lacustrine sands)
70.0	>50 – 90 (Dense sands/silty sands)
90.0	>90 – 200 (Tertiary Salt Lake Grp)

File Name	Description with depth
Ew2Out.eq	East ground motion at 90.ft
Ns2Out.eq	North ground motion at 90ft
Ud2Out.eq	Up (vertical) ground motion at 90ft.
bE1D00.eq	East ground motion at ground surface
bE2D08.eq	East ground motion at 7.5ft
bE3D18.eq	East ground motion at 18ft
bE4D35.eq	✓ ✓ ✓ ✓ 35ft
bE5D70.eq	✓ ✓ ✓ ✓ 70ft
bE6D90.eq	✓ ✓ ✓ ✓ 90ft
bN1D00.eq	North ✓ ✓ ✓ 0.0ft
bN2D08.eq	✓ ✓ ✓ ✓ 7.5ft
bN3D18.eq	✓ ✓ ✓ ✓ 18ft
bN4D35.eq	✓ ✓ ✓ ✓ 35ft
bN5D70.eq	✓ ✓ ✓ ✓ 70ft
bN6D90.eq	✓ ✓ ✓ ✓ 90ft

January 11 2002

Finite Element Modeling of Soil-Structure Interaction

Implements analysis step #4 of p. 14, modified to use the output from ProShake analyses (p. 36-47) as input motion.

Apply the motion components described on pages 41, 43, and 45 ~~at the~~ GWO 1/11/2002 at 90-ft depth in a finite element model and monitor the effects at the ground surface. The analysis will be implemented in two steps, as follows:

1. Verification Analyses

Perform analyses with models that do not include storage pads (soil-only models) to ensure that the calculated motion at the ground surface matches the ~~free~~ field GWO 1/11/2002 free-field motion (PFS design motion given on pages 40, 42, and 44).

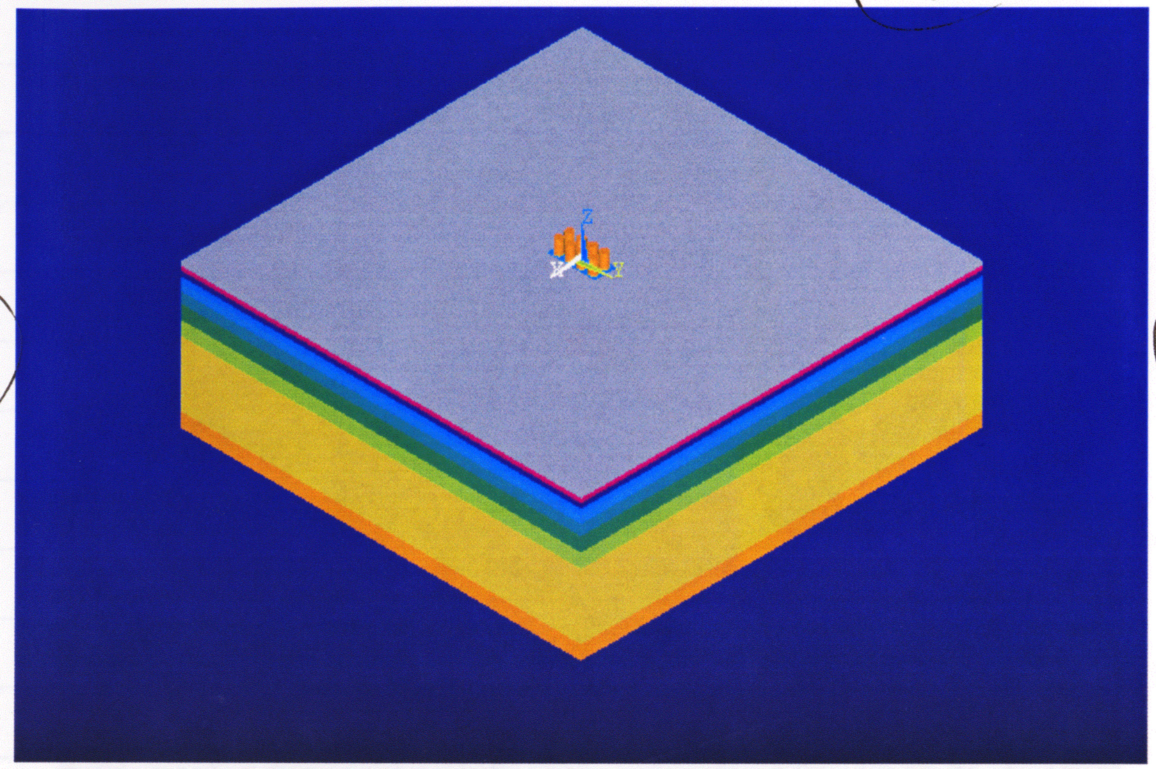
2. Soil-Structure Interaction Analysis

Perform analyses with models that include a

fully-loaded storage pad.

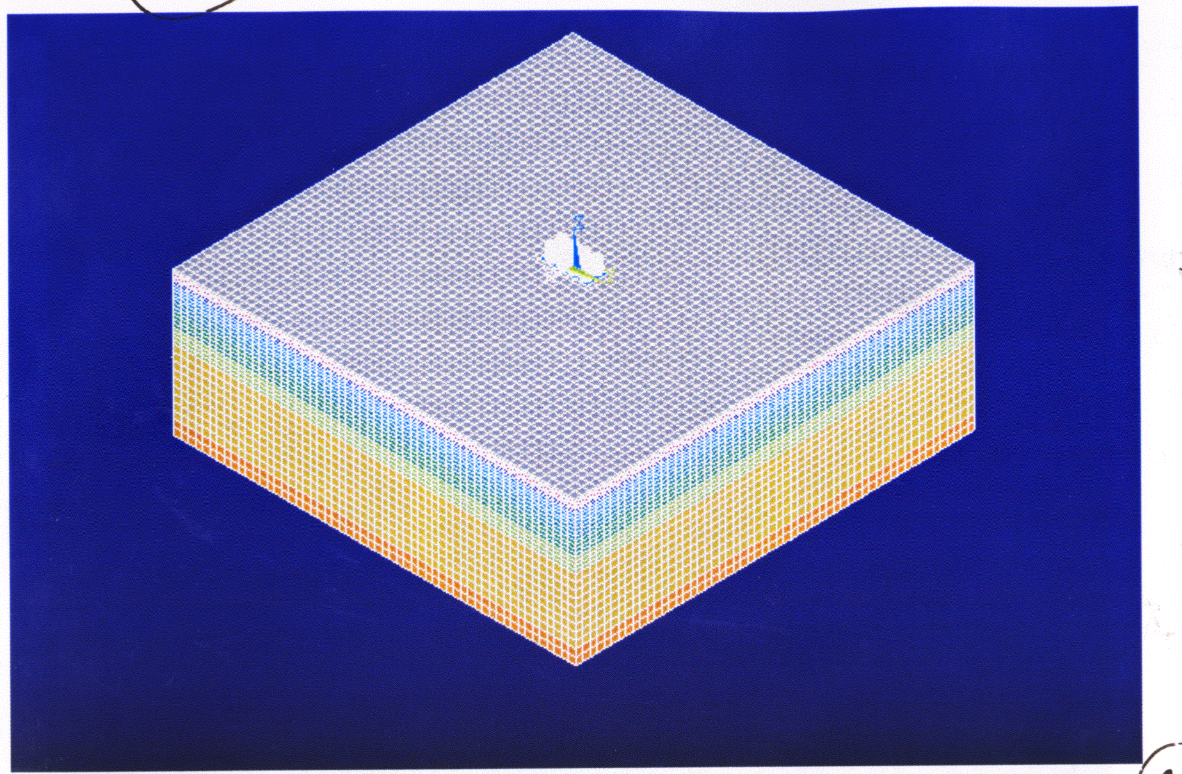
Model Description

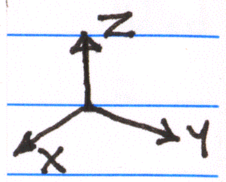
GWO



GWO GWO GWO

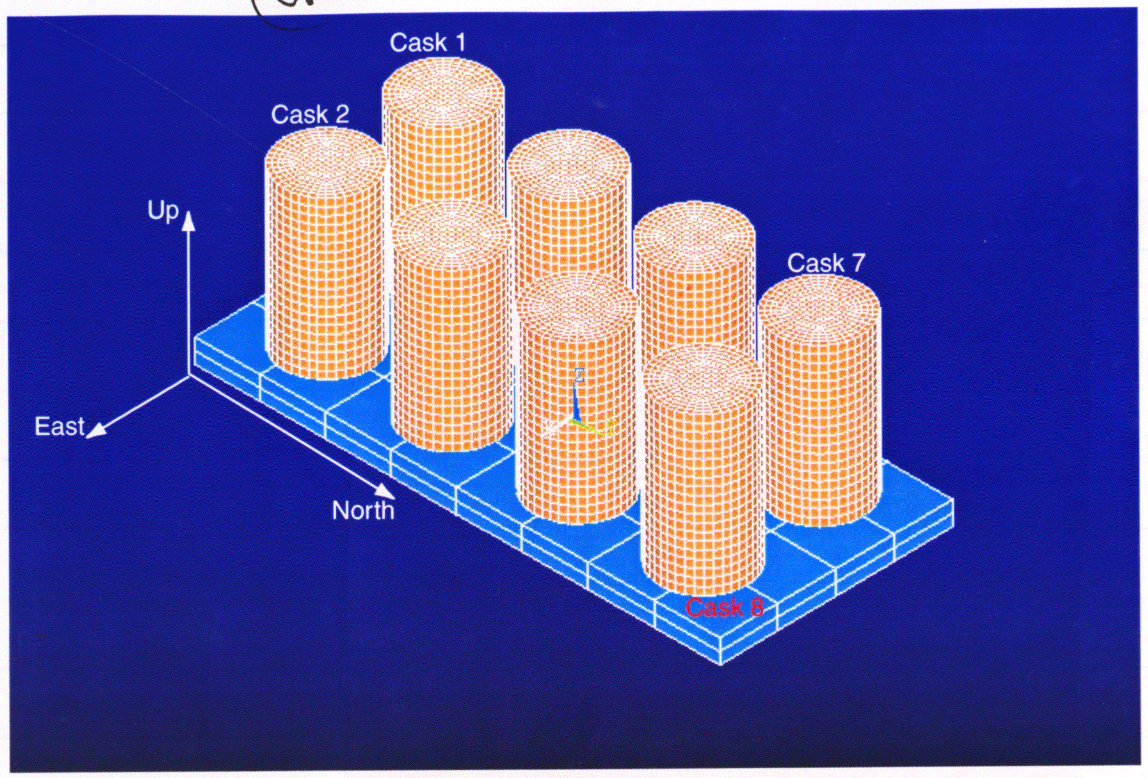
Geometry of finite element model. Coordinate axis are X = East, Y = North, and Z = Up. Model dimensions are 560 ft East-West, 560 ft North-South, and 200 ft vertically. The top of the model, i.e., Z = 0, corresponds to the groundsurface. GWO 1/11/2002 The ~~center~~ origin of the model (X = 0, Y = 0, Z = 0) is at the center of the top surface, i.e., at the ground surface. The fully loaded storage pad is shown in this model, but the model used for Verification Analysis does not include the pad.





Finite element mesh. Each element has a lateral dimension of 10 ft (in both East and North directions). The maximum vertical dimension of elements is 5 ft for elements above 90-ft depth. Vertical element dimensions increase from 5 ft at 90-ft depth to about 10 ft near the model base (at 200-ft depth). Above 90-ft depth, the minimum ~~element of vertical~~ vertical dimension of elements is controlled by the soil-layer thickness (given on p. 25). This model includes the fully loaded pad (white blub at the top center; see p. 51 for details), but the model used for Verification Analysis does not include the pad. The vertical discretization above 90 ft is the same as was used in the ProShake model and described on p. 38.

GRO 1/11/2002



Finite element model of the storage pad and casks showing the coordinate reference and the cask numbering used in the model. Casks are numbered first in the east direction and then in the north direction (Casks 1, 2, 7, and 8 are labeled).

The pad is 67 ft long (North-South), 30 ft wide (East-West), and 3 ft thick. Each cask has a cross-sectional diameter of 11.04 ft (132.5 inches) and height of 19.96 ft (239.5 inches).

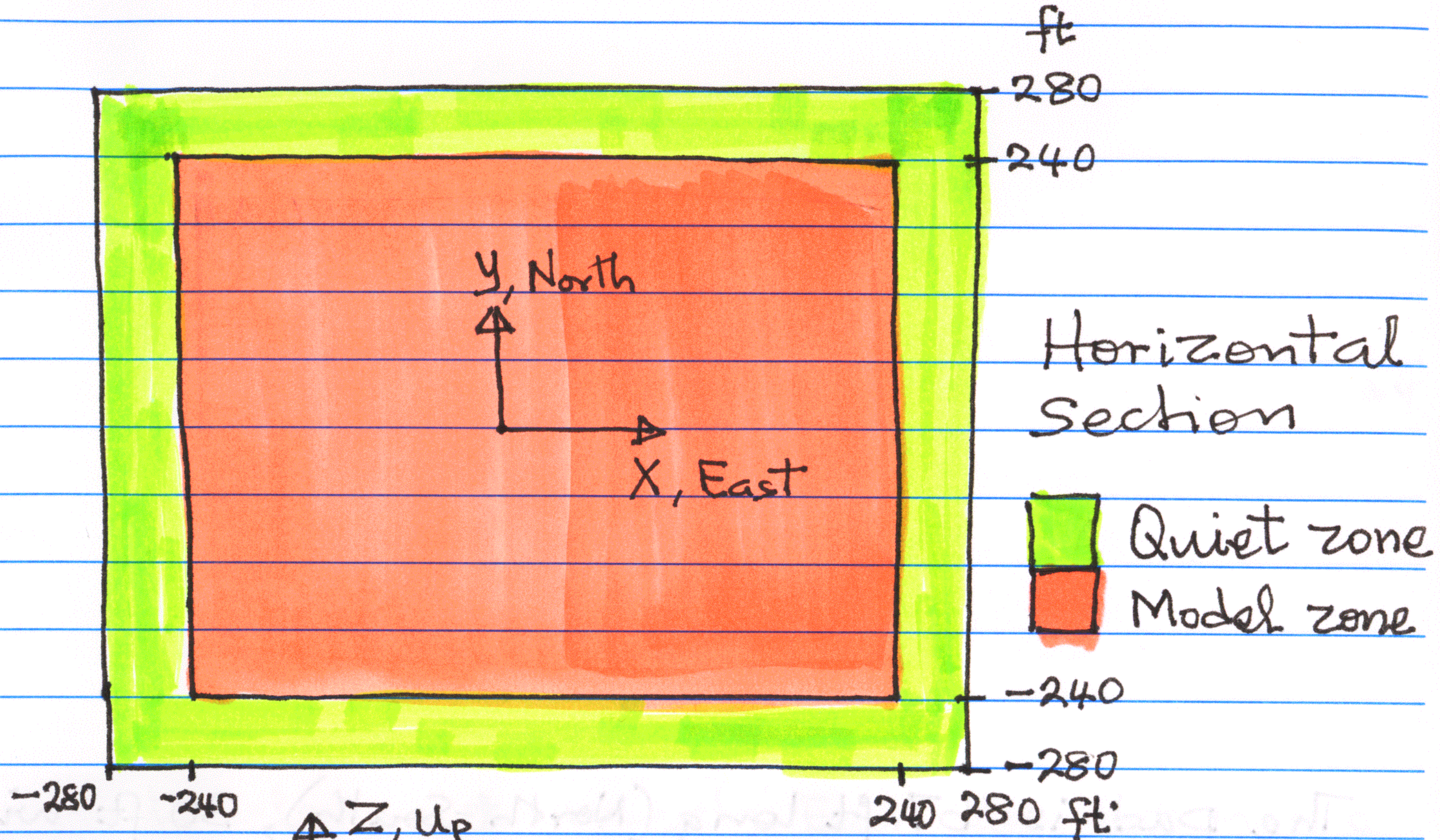
Weights:

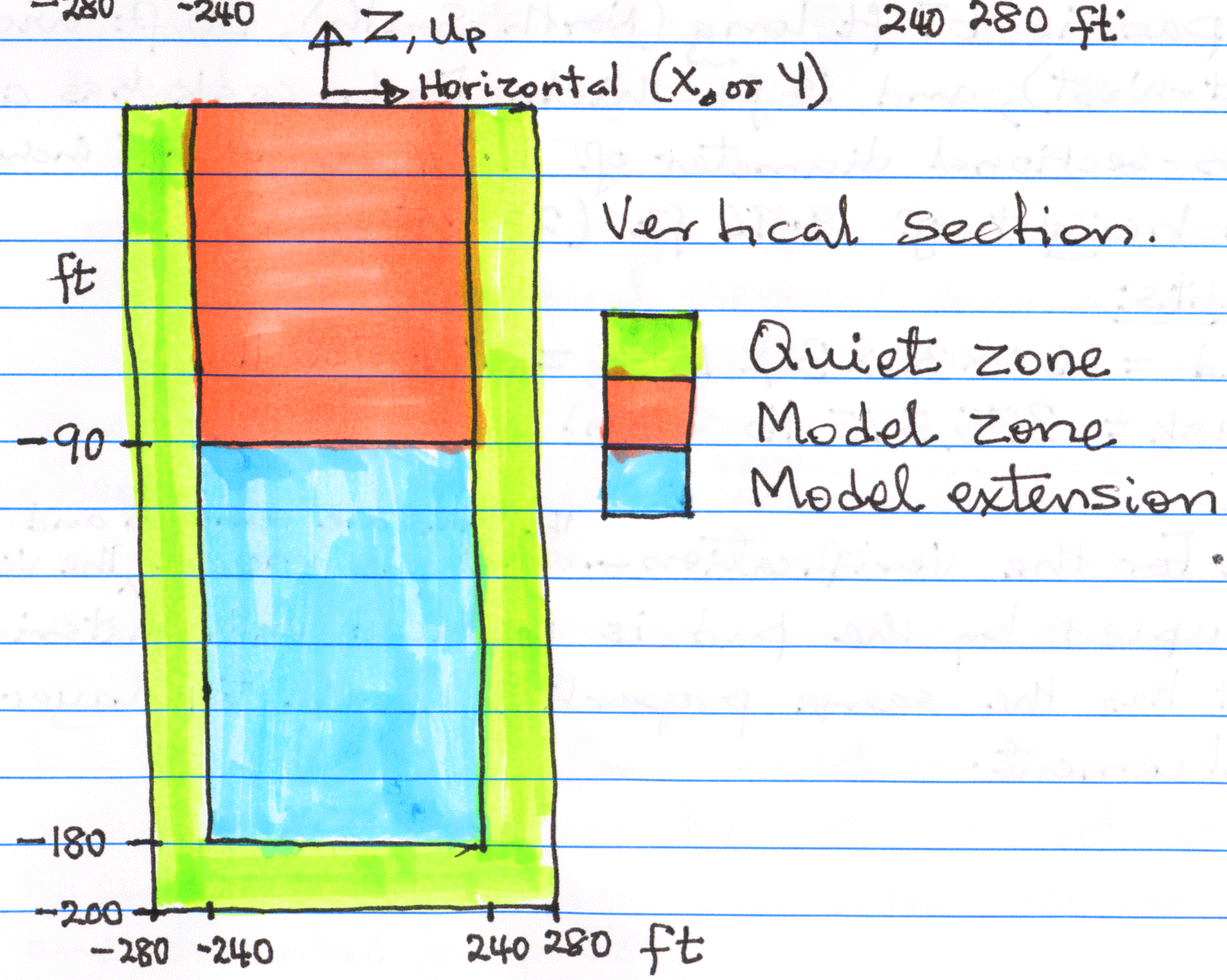
Pad = 67 x 30 x 3 x 150 = 904,500 lb.

Cask = 355,575 lb each.

~~Du~~ For the Verification-analysis model, the casks are removed and the volume occupied by the pad is replaced with material that has the same properties as the top layer of soil cement.

Boundary Conditions





The boundary conditions and applied loading are as follows:

(1) The model base (200-ft depth) is held at zero vertical displacement.

(2) The model vertical boundaries, at $x = \pm 280$ ft and at $y = \pm 280$ are ~~held at~~ (GYO 1/11/02) subjected to

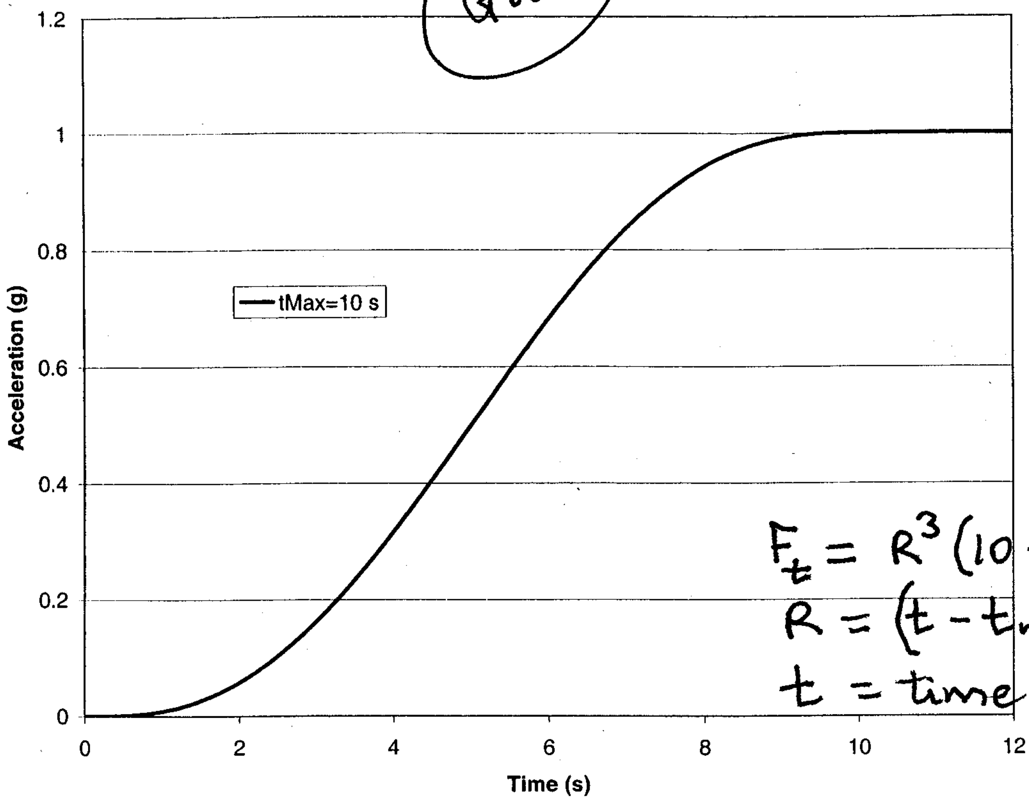
(i) zero acceleration normal to the boundary for the first 10 s, and

(ii) boundary normal acceleration from 10–50 s, using the depth-dependent ground motion time histories described on p. 47. The time histories approximately represent the free-field design-basis ground motion.

(3) The entire model is subjected to gravitational loading that is increased slowly from zero at zerotime to $m_E g$ at 10 s using the curve on p. 54, where M_E is the mass of ~~each~~ an (GYO 1/11/02) element and g is the gravitational acceleration (32.2 ft/s^2).

(4) The base of the model zone (orange color on p. 52), i.e., at depth of 90 ft, is subjected to an acceleration history at time of 10–50 s, using the ground motion components described

GIO



Gravity ramp curve. Was developed using C code shown below, which implements the equation

$$f = f_{min} + (f_{max} - f_{min}) F_t.$$

$$F_t = R^3 (10 - 15R + 6R^2)$$

$$R = (t - t_{min})/(t_{max} - t_{min})$$

t = time in s, $t_{min} = f_{min} = 0.0$, $t_{max} = 10$ s, $f_{max} = 1.0$

```
/*********************************************************************
Program Name: gravRamp

Generate data to describe gravitational acceleration as a function of
time. The function has zero value at zero time and increases to a
maximum value at a selected time

Author:              G.I. Ofoegbu
Date:                September 5 2001
System:              ANSI C Compiler
*********************************************************************/

#include <stdio.h>
#include <stdlib.h>
#include <string.h>

main()
{
  char* plotfile = {"gravCurve.plt"};
  char* timefile = {"timeMesh.out"};
  char* accfile = {"gravMesh.out"};
  char* curvfile = {"curvMesh.out"};
  float time;
  float fVal;
  float ratio,r2,r3;
  float tInc = 0.02;
  float fMin = 0.0;
  float fMax = 1.0;
  float tMin = 0.0;
  float tMax = 10.0;
  float realTime = 82.0;
  float gravity = 32.2;
  int onThisLine;
  FILE* Fp;
  FILE* Ftime;
  FILE* Facc;
  FILE* Fcurv;

  Fp = fopen(plotfile,"w");
  if (!Fp)
    DumpAndQuit(strcat("Unable to open plot file ",plotfile));
  fprintf(Fp,"%12s%12s\n","Time (s)","Acc (g)");

  Ftime = fopen(timefile,"w");
  if (!Ftime)
    DumpAndQuit(strcat("Unable to open plot file ",timefile));

  Facc = fopen(accfile,"w");
  if (!Facc)
    DumpAndQuit(strcat("Unable to open plot file ",accfile));

  Fcurv = fopen(curvfile,"w");
  if (!Fcurv)
    DumpAndQuit(strcat("Unable to open plot file ",curvfile));

  time = 0.0;
  onThisLine = 0;

  do{
    ratio = (time-tMin)/(tMax-tMin);
    r2 = ratio*ratio;
    r3 = ratio*ratio*ratio;
    fVal = fMin + (fMax-fMin)*r3*(10.0 - 15.0*ratio + 6.0*r2);
    fprintf(Fp,"%12.2f%12.8f\n",time,fVal);

    if (onThisLine < 7){
      fprintf(Facc,"%12.6f",gravity*fVal);
      fprintf(Fcurv,"%12.8f",fVal);
      fprintf(Ftime,"%12.2f",time);
      onThisLine++;
    }
    else{
      fprintf(Facc,"%12.6f\n",gravity*fVal);
      fprintf(Fcurv,"%12.8f\n",fVal);
      fprintf(Ftime,"%12.2f\n",time);
      onThisLine = 0;
    }

    time += tInc;
  } while (time < (tMax + 0.5*tInc));

  fprintf(Fp,"%12.2f%12.8f\n",tMax+realTime,fMax);
  fprintf(Facc,"%12.6f\n",gravity*fMax);
  fprintf(Fcurv,"%12.8f\n",fMax);
  fprintf(Ftime,"%12.2f\n",tMax+realTime);

}

DumpAndQuit(char* s)
{
  printf("\n%s\n",s);
  exit(1);
}
```

Plot output (→ gravCurve.plt)

GIO

on p. 41, 43, and 45 simultaneously. These input ground motion components were later modified as described subsequently.

(5) The quiet zone (green color on page. 52) was assigned relatively high damping to simulate energy loss into an infinite domain.

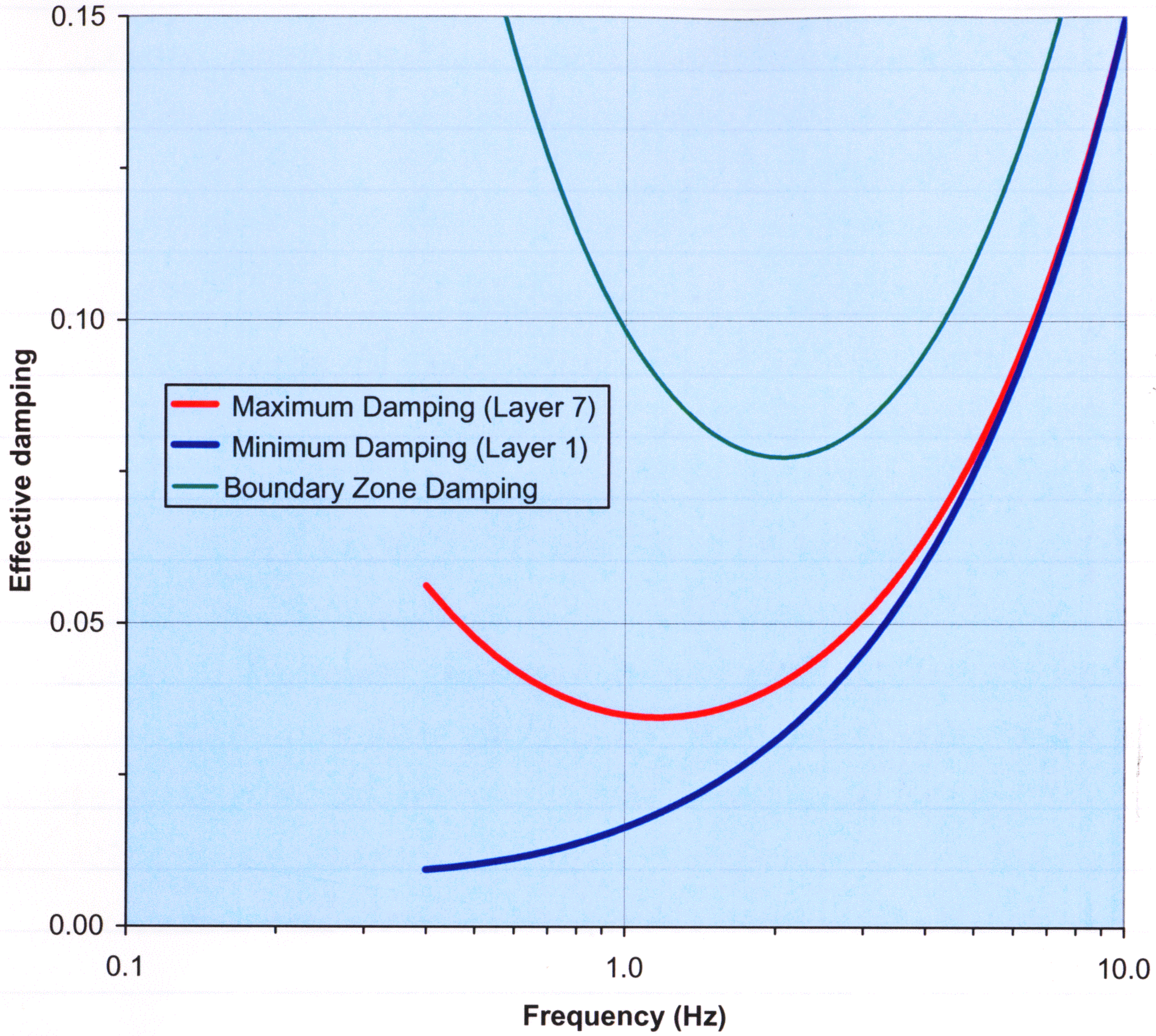
Material Properties and Models

The soil layers (including soil cement) are modeled as linear elastic, using the density and strain-compatible moduli given on p. 25. The model-extension zone (blue on p. 52) is assigned the properties of soil layer 9.

The concrete pad was modeled as linear elastic with ~~properties~~ density = 4.66 (=150 pcf), Young's modulus = ~~6.048 × 10^5~~ 5.32 × 10^8 psf (GIO 7/03/2002), and Poisson's ratio = 0.22. The Young's modulus was calculated from $5700\sqrt{f_c}$ psi where f_c = compressive strength = 4200 psi.

Casks are modeled as rigid bodies.

The damping values for the soil domain are shown on p. 56. Damping ~~was~~ is implemented using



SoilLayer	AlphaDampParam	BetaDampParam
1.a	0.01712	0.004770
1.b	0.01712	0.004770
2	0.20088	0.004724
3	0.14198	0.004739
4	0.08206	0.004754
5	0.11378	0.004746
6	0.24770	0.004712
7	0.25274	0.004711
8	0.04330	0.004764
9	0.05890	0.004760

Raleigh damping parameters α and β, the values of which are shown on the left. The α and β values were calculated using $f_0 = 0.4$, $f_1 = 10$, and $c_1 = 0.15$ in the equations on p. 27.

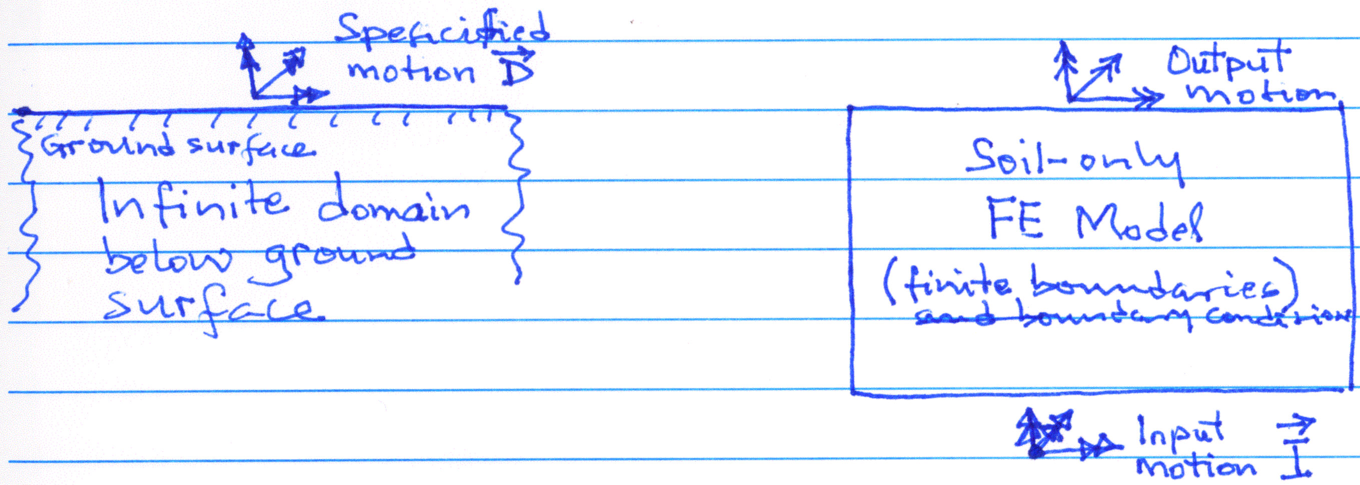
The Raleigh damping factors used for the boundary zone are $\alpha = 1.0$ and $\beta = 0.006$. Concrete pad is

assigned the same damping as Soil layer 1. The casks are assigned damping equivalent to $\alpha = 0.037$ and $\beta = 0.0016$.

January 16 2002

Verification Analysis

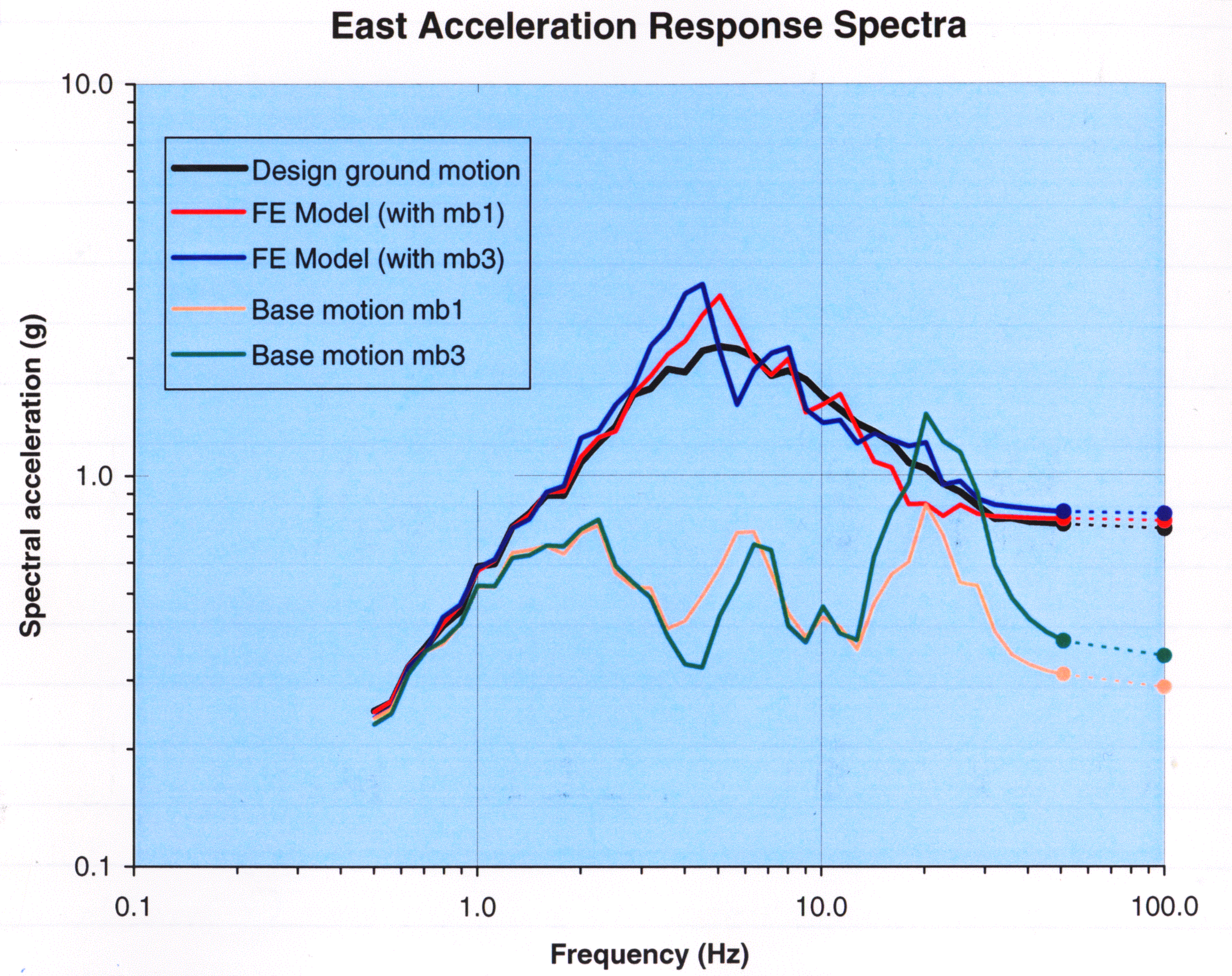
Purpose: To determine if the ground motion response at the ground surface from the soil-only finite element model matches the design ground motion.



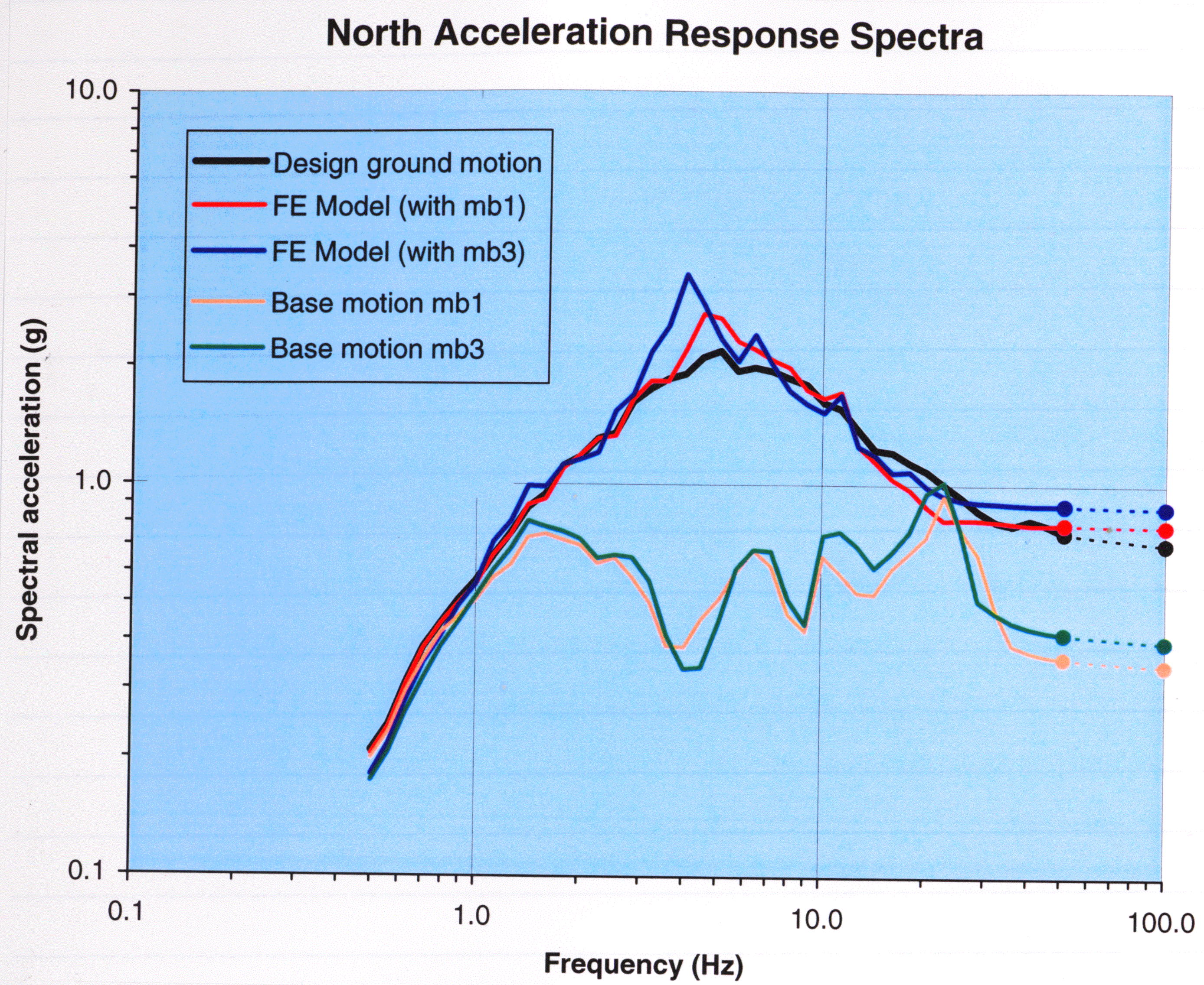
Determine if the output motion $\vec{O}$ matches the ~~desing~~ design motion $\vec{D}$. If necessary, modify the input motio $\vec{I}$ to obtain an $\vec{O}$ that matches $\vec{D}$. The first estimate of $\vec{I}$ was determined through the Deconvolution Analysis (p. 36) and is described on p. 41, 43, and 45. This version of $\vec{I}$ is referred to subsequently as Input motion mb1. The input motion mb1 was modified by frequency-domain scaling (described subsequently) to obtain another

1/16/2002 CRW

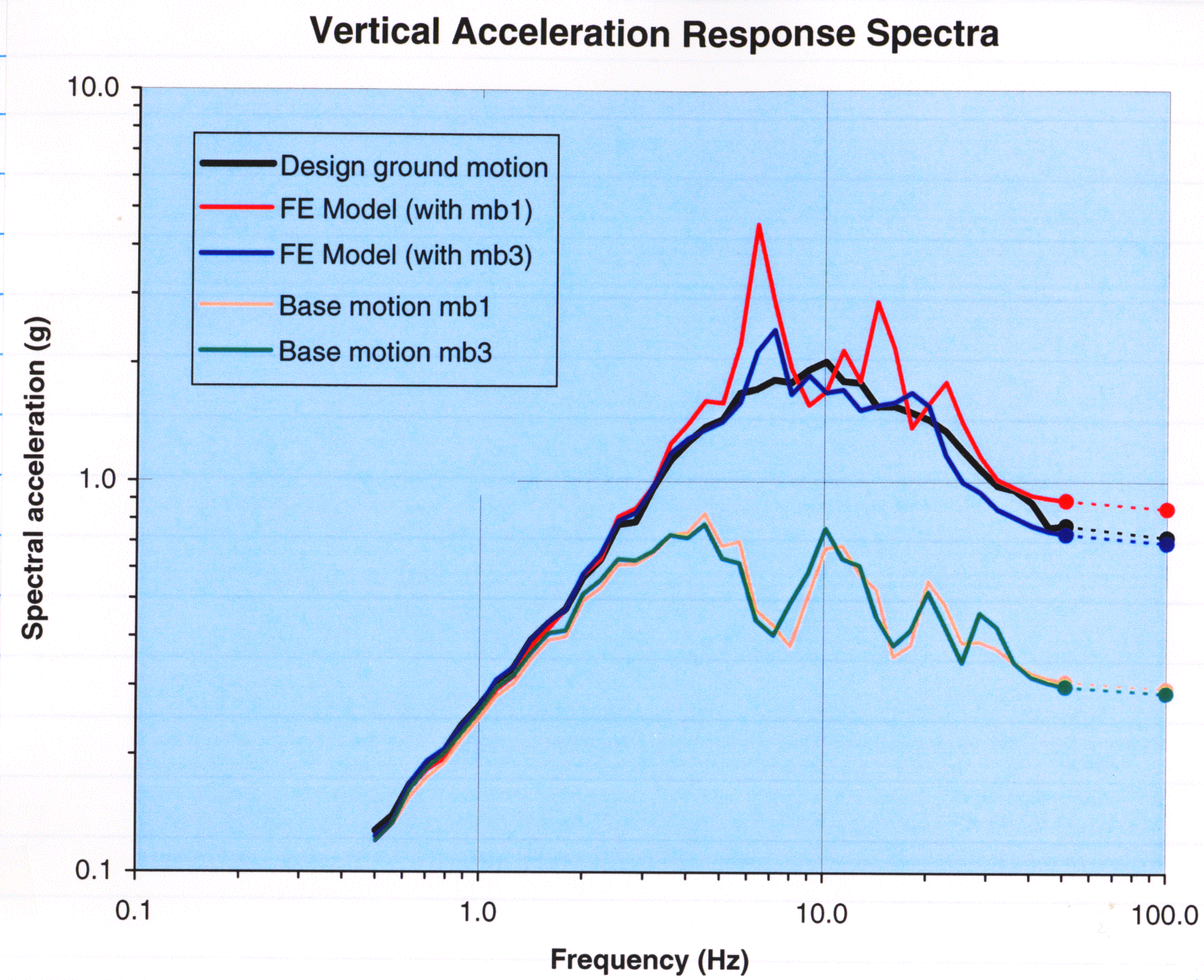
input motion, mb3. The results of the verification analyses performed using the two sets of input motion are described on the following figures:



This figure shows two sets of East acceleration response spectra calculated from the soil-only FE model. The two input base motions mb1 (from Deconvolution Analysis) and mb3 (from mb1 scaling), and the output motions at the ground surface calculated using each input, are shown. The output motions are compared with the design ground motion.



This figure shows the North acceleration response spectra.
mb1 = input base motion from Deconvolution Analysis
mb3 = input base motion from a modification of mb1.
The other curves represent output motions calculated at the ground surface using each of the two input base motions. The output motions are compared with the design ground motion.



This figure shows the vertical acceleration response spectra from the analyses described on p 58-59.

The results shown on p. 58-59:

(1) were calculated using a soil-only finite element model (no storage pad or casks) following the procedure described on p. 48-57;

(2) were calculated from a full 3D model, in which all three components of a given input motion are

applied simultaneously;

(3) indicate that the three components of motion are coupled, which explains why the two sets of vertical output motion components are so different notwithstanding the close similarity between the vertical components of mb1 and mb3.

The base motion mb3 was used as input in the subsequent soil-structure interaction analyses. The method used to scale mb1 to obtain mb3 is described starting on p. 62. The scaling calculations were performed by Dr. James F. Unruh of Southwest Research Institute Division 18, and ~~were~~ described through ~~two~~ inter-office memos. Two scaling (ie. iterations of the scaling) analysis were performed

Iteration 1: Input motion mb1 was scaled to obtain three ~~x~~ motion sets: Sorc6.asc, Sorc7d4.asc, and Sorc7d7.asc.
1/28/02 GW

Iteration 2: Input motion Sorc7d4.asc was ~~s~~ scaled to obtain SOURC7D.asc, which is the same motion named mb3.
GW 1/28/02

MEMORANDUM

TO: Goodluck Ofoegbu, Div 20, Ext. 6641

Jan 25, 2002

FROM: James F. Unruh, Div 18, Ext. 2344

SUBJECT: Source Modification to Meet Design Spectra

Problem: A set of source time histories are supplied as input to a Finite Element Model of a soil structure and a response spectrum is generated at the surface that does not meet a target design spectra. Modification of the source spectra is desired to closer meet the target design spectra.

Approach: Since the FEM of the soil structure is not readily available, the input base source vectors, B, (components X_B, Y_B, Z_B) and resulting FEM response vectors, F, (components X_F, Y_F, Z_F) are used to estimate the Frequency Response Function (FRF) of the FEM model, H_{DB}. With the target design response vector, D, (components X_D, Y_D, Z_D) known the problem is cast into an inverse problem. We compute the desired source, S, (components X_S, Y_S, Z_S) by multiplying the FEM FRF by the desired output D.

Solution: A couple of approaches were used to compute the FEM frequency response function. The first approach was to look at the distribution of energy with time in the base and FEM time histories. Typical time histories are shown in Figure 1 for the Z component of these signals. In addition to the time history the moving rms (red) and accumulated rms (green) levels are given to indicate at what time a majority of the signal energy has passed. It appears that a majority of the signal energy is contained within the first 20 seconds of the event. Thus, sample averaged spectral analysis of the events could be concluded within the first 20 seconds with little loss of response information. To this end, data blocks of 1024 points, sampled at 200 s/s, were used to generate sample averaged cross spectra and auto spectra of the three components of the system. Only the diagonal components of the FRF were computed from these sample averaged spectra due to the low number of statistical degrees of freedom generated by the time limited signal. The typical spectral record consisted of a 5.12 second segment of the time history. FRF estimates were computed for 3, 4, and 6 sample averages. Figure 2 gives the magnitude of the FRF estimates for the various sample averages and a comparison of the three axis FRFs for the nominal 4 sample averaged case. Here we see that the FRFs are well converged at 4 sample averages as indicated by the time histories having a majority of their energy expended with in the initial 20 seconds. A second approach was to consider the full time histories with no sample averaging, thus a single record of 8192 points was used to develop the diagonal FRFs as given in Figure 3. While the FRF looks quite smooth in the frequency range of interest (say .2 Hz to 33 Hz) it is only one sample and thus is statistically a poor estimate. Figure 3 shows the energy cutoff at around 33 Hz and tracking of the input and output in the low frequency range up to approximately 1.5 Hz. There after the are distinct anti-resonant behavior at selected frequencies, such as at near 4 and 8 Hz in the X and Y directions and near 7 and 15 Hz in the Z direction. Note since we are looking at the inverse FRF these would be resonant amplifications of the soil.

The required design spectra (the source in this inverse problem) exhibit energy in a very broad frequency range as is shown by the amplitude spectra given in Figure 4. Signal amplitude level is rather uniform in the frequency range is from 0.2 Hz to above 15 Hz. When passing this amplitude spectrum through the FRFs one should expect response reduction at the above mentioned selected frequencies, which correspond to amplifications by the soil mass of the desired source.

****

Note: The soil exhibits a very high level of amplified response, more than a single order of magnitude at selected frequencies and as such, small changes in the base source spectrum can produce large changes in the surface motion. Thus, we should expect a source that looks much like the one supplied with only small modifications near the noted amplified regions.

****

To this end I have computed three sets sources using FRFs calculated in different ways.

Sorc6.asc – Generated from a single record estimate of the FRF. Comparisons of source response spectra are given in Figure 5.

Sorc7D4.asc – Generated from a 4 sample average estimate of the FRF. Comparisons of source response spectra are given in Figure 6.

Sorc7D7.asc – Generated from a 7 sample average estimate of the FRF. Comparisons of source response spectra are given in Figure 7.

The above source spectra are in four columns of data: Time, Xacc, Yacc, and Zacc and consist of 8192 points sampled at 200 s/s. The files are forwarded under separate cover.

This memo documents the scaling analysis and gives the results of the first iteration of the analysis. The figures referred to in the memo are on the following pages.

Figure Number	Page
1	63
2	64
3	65
4	65
5	66
6	~~68~~ 67
7	~~69~~ 68

GAO

1/28/2002

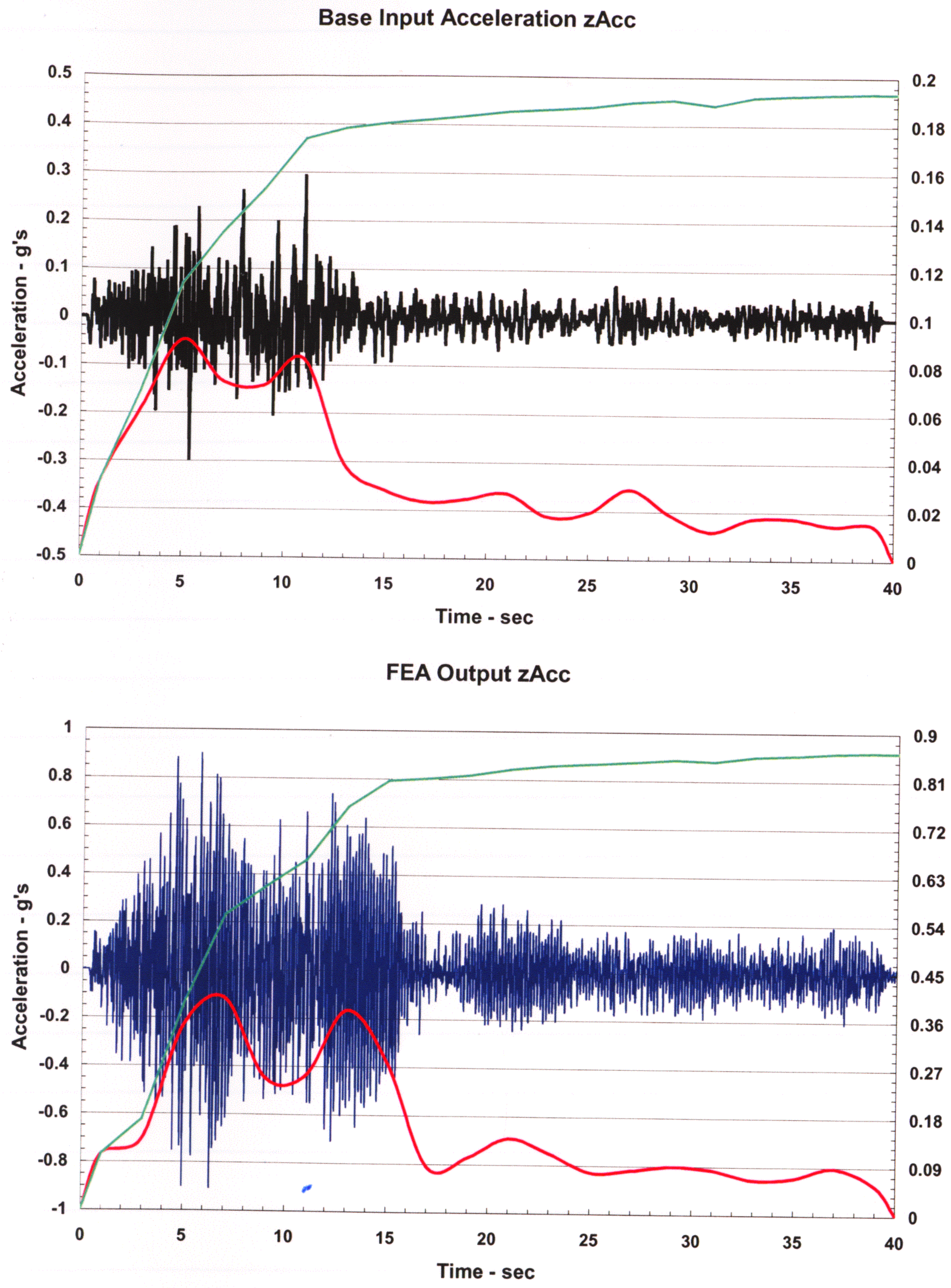


Figure 1 Typical Time History Distribution of RMS Energy

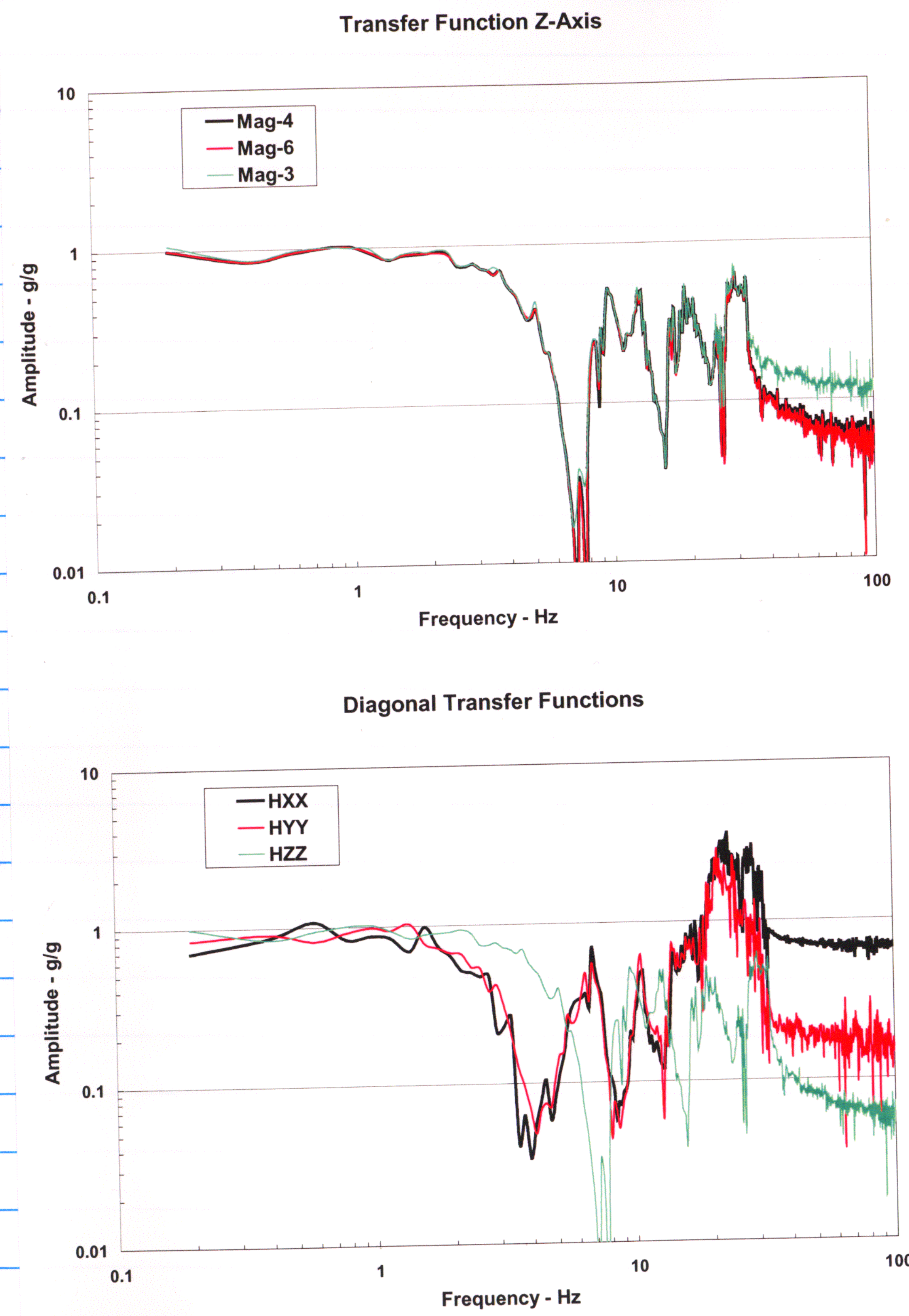


Figure 2 Typical System FRFs

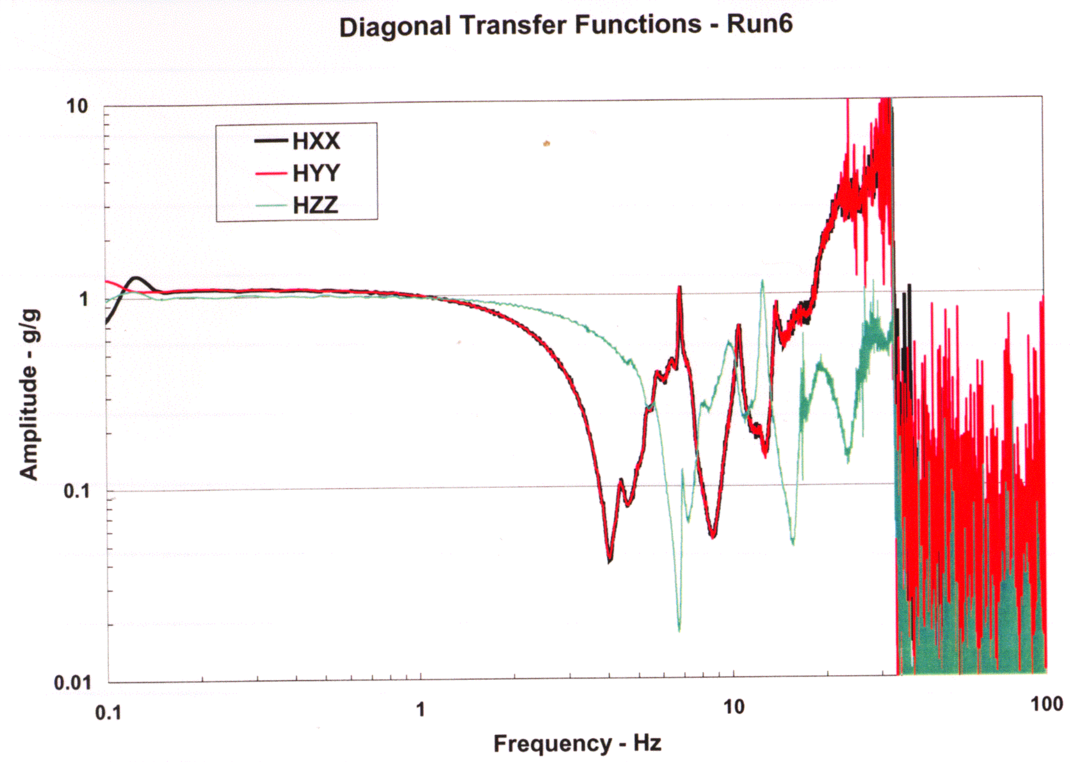


Figure 3 Single Record FRFs

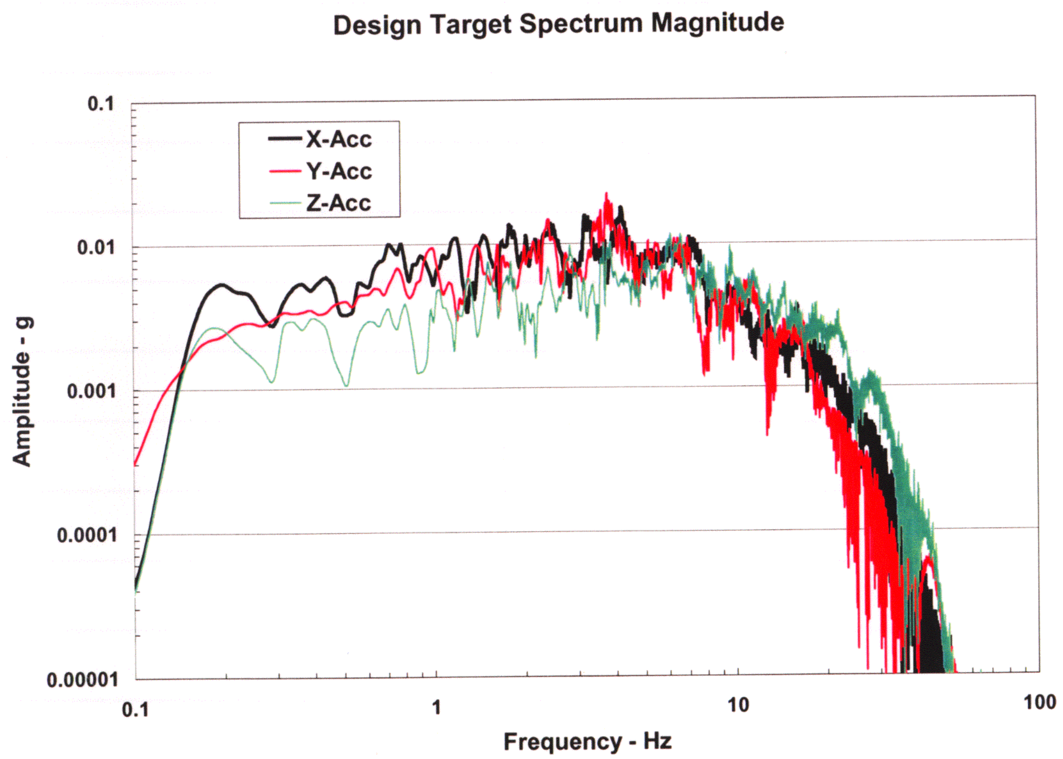
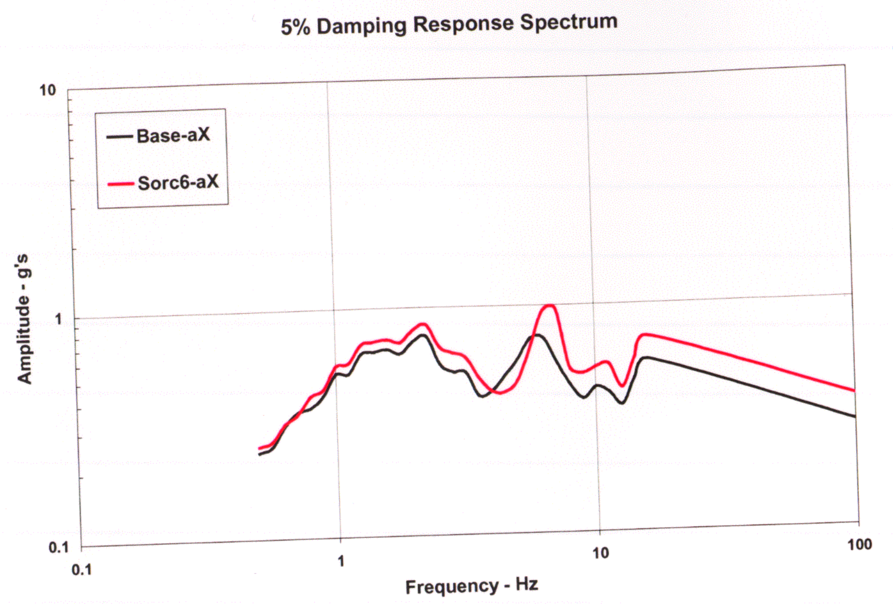
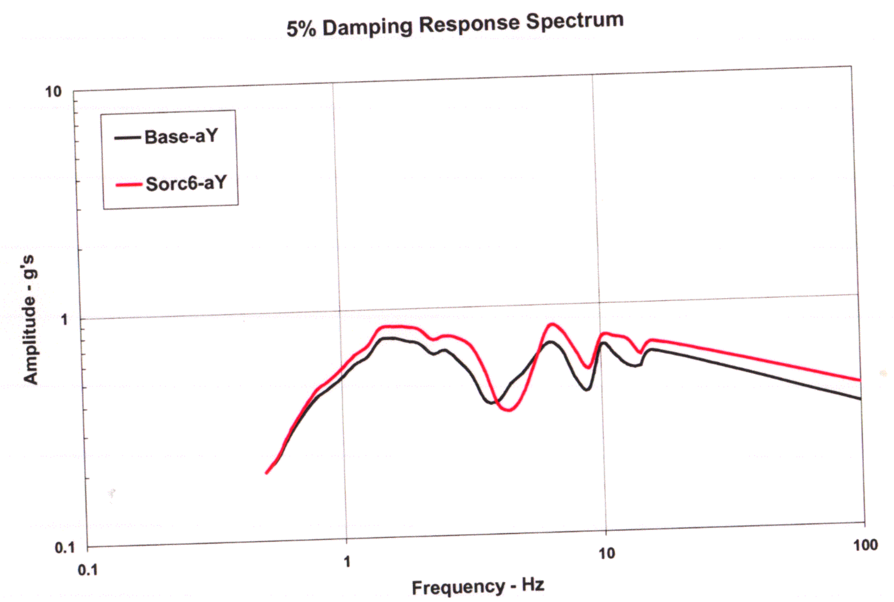


Figure 4 Target Design Spectra Energy Range

Figure 5 Sorc6.asc





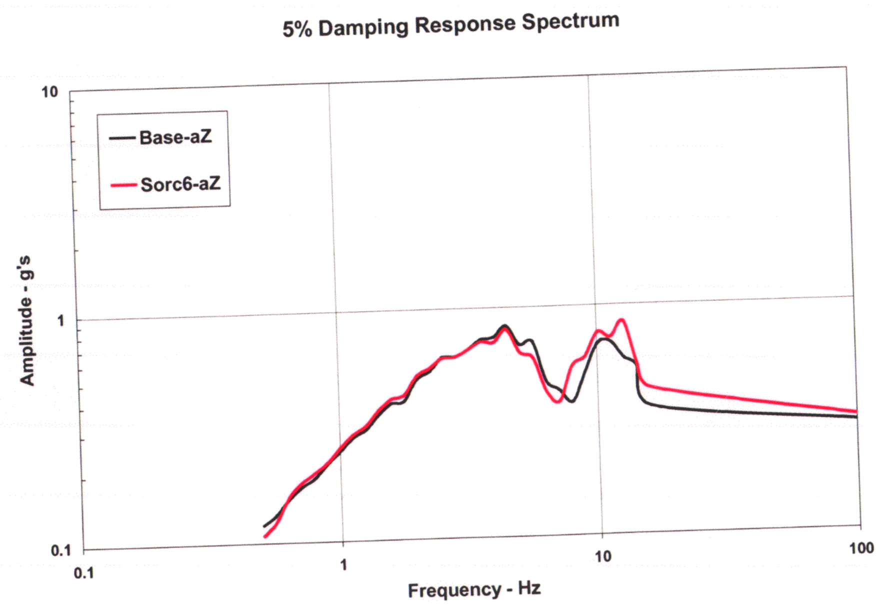
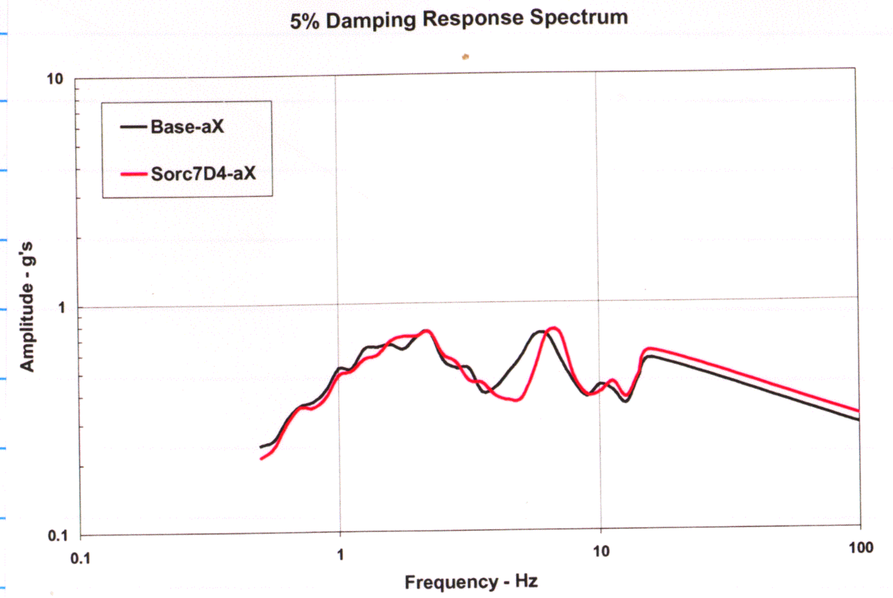
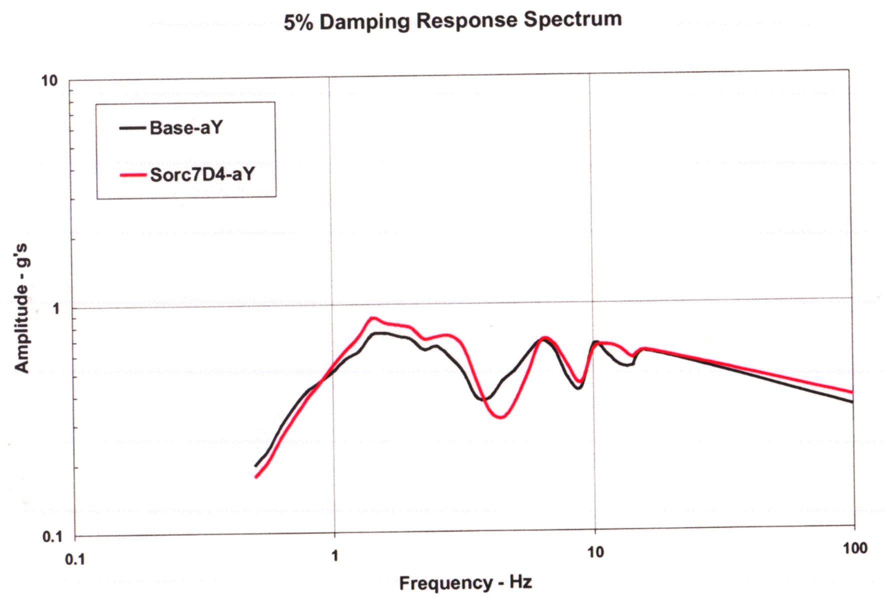


Figure 6 Sorc7D4.asc





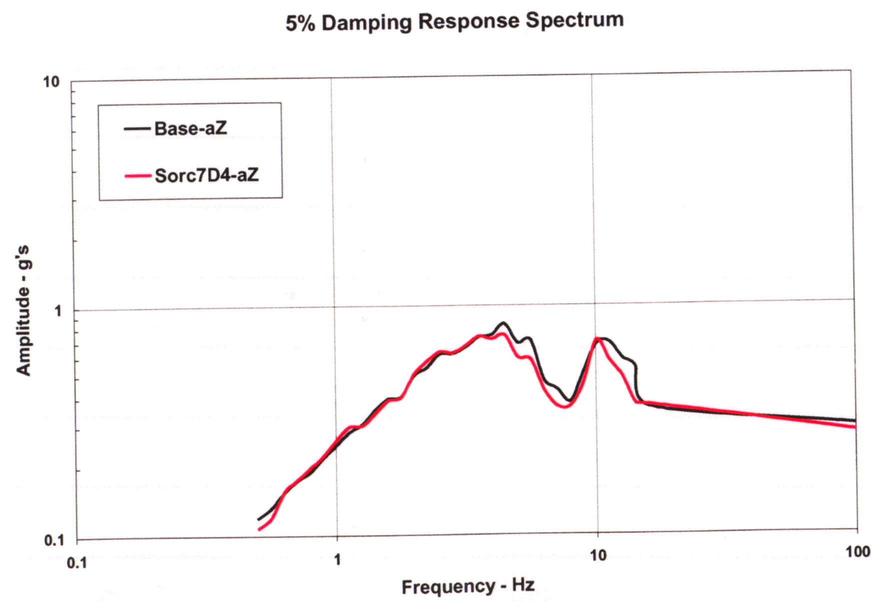
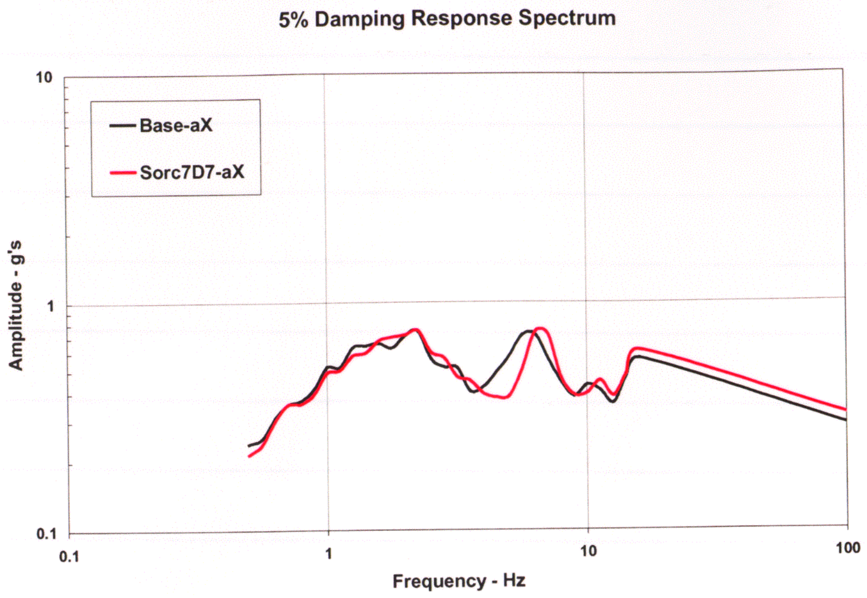
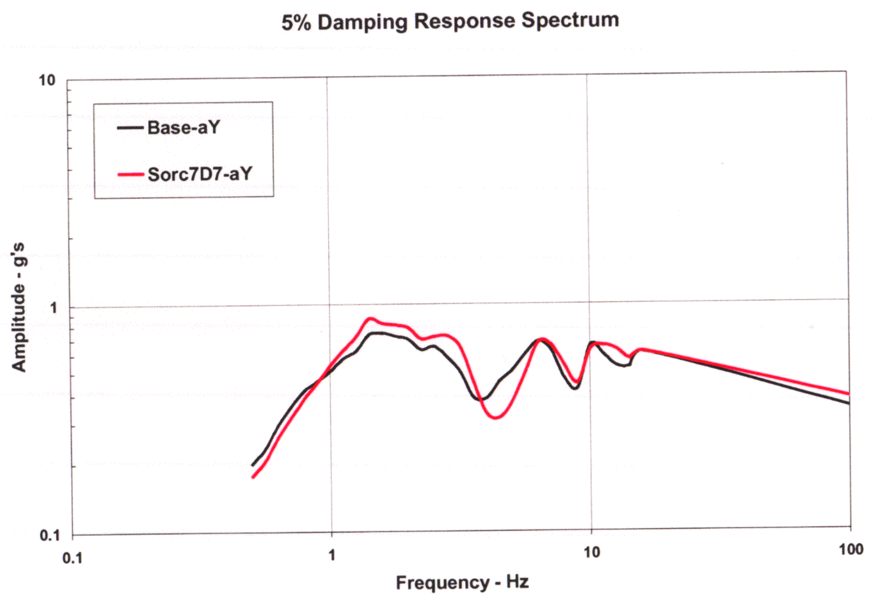
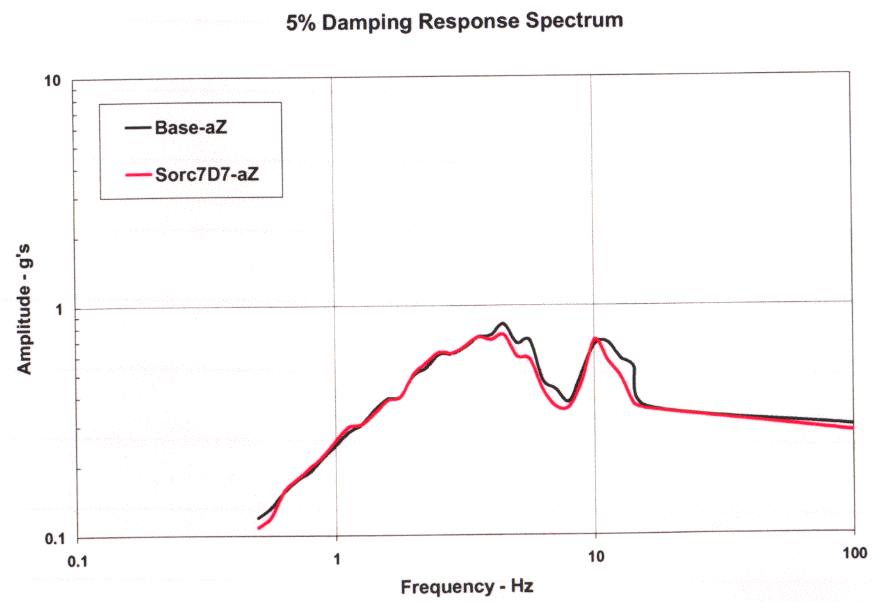


Figure 7 Sorc7D7.asc







February 12, 2002.

Second and Final Iteration of Input Motion Scaling

MEMORANDUM

TO: Goodluck Ofoegbu, Div 20, Ext. 6641

FROM: James F. Unruh, Div 18, Ext. 2344

2/12/2002

SUBJECT: Source Modification to Meet Design Spectra

The previous input source file "src7d4.asc" was used with the corresponding output from the FEA model "mb2aU0.asc" to obtain a second iteration on the source required to meet the design spectra of "Design.asc".

The updated diagonal transfer functions of the FEA model as seen by the supplied input and response time histories, using 4 sample averages, are shown in Figure 1. There appears to be more emphasis on the 4 Hz response than on the 7 Hz response.

The corresponding time histories of the new source are attached along with their corresponding response spectra compared to the original source response spectra.

The new source spectra are in four columns of data: Time, Xacc, Yacc, and Zacc and consist of 8192 points sampled at 200 s/s. The new source file "SOURC7D.asc" is forwarded under separate cover.

This memo documents the second and final iteration of the scaling analysis. The figures referred to in the memo are on this and the next two pages.

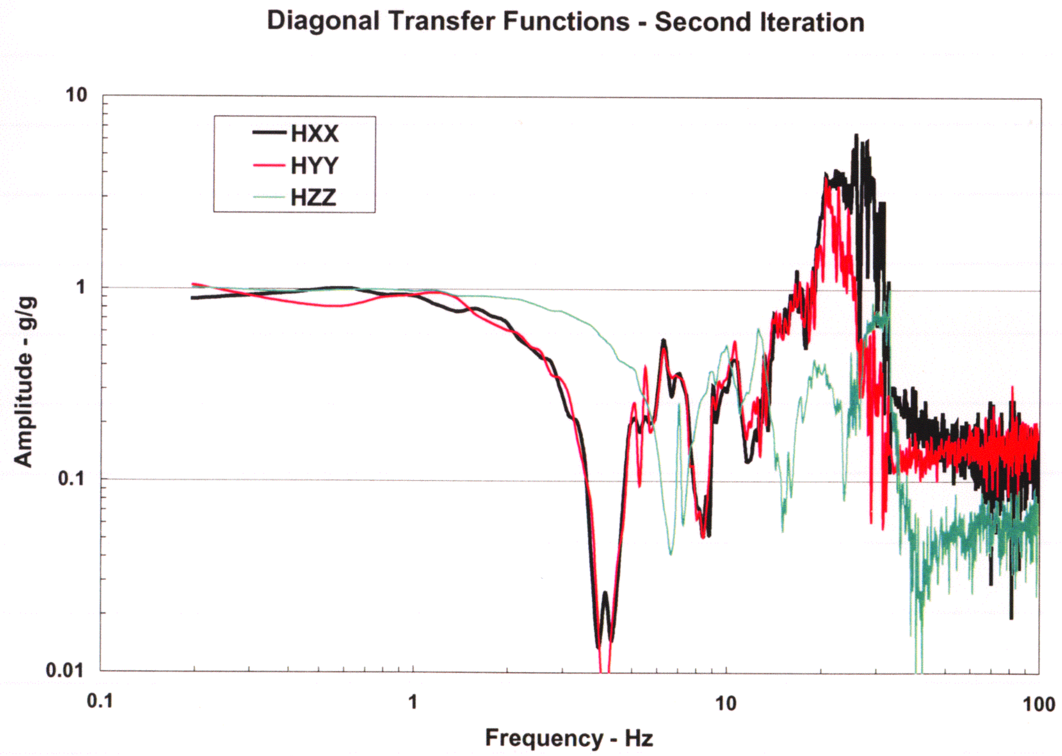
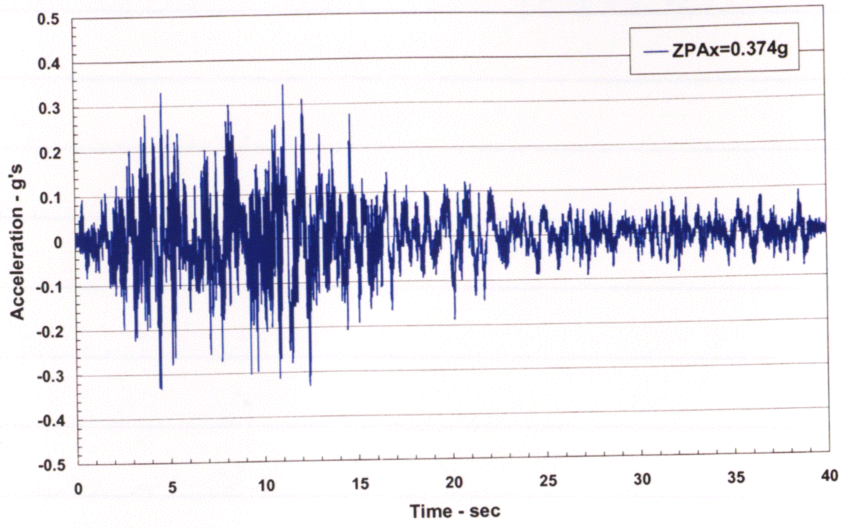
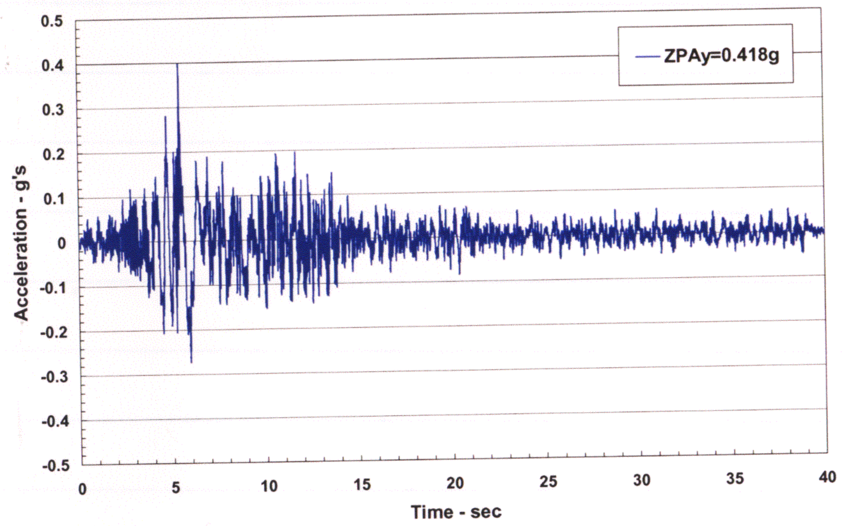


Figure 1 Typical System FRFs

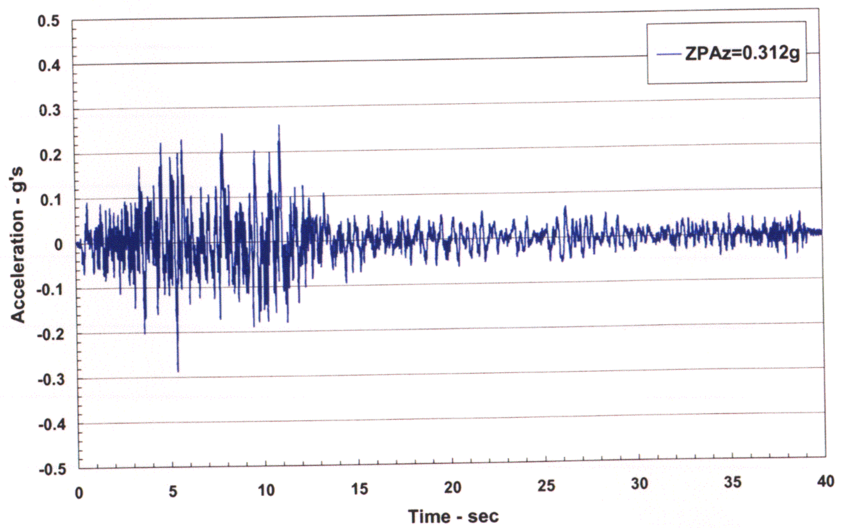
X-Acceleration Source Time History - Diagonal HYX -2nd Iteration



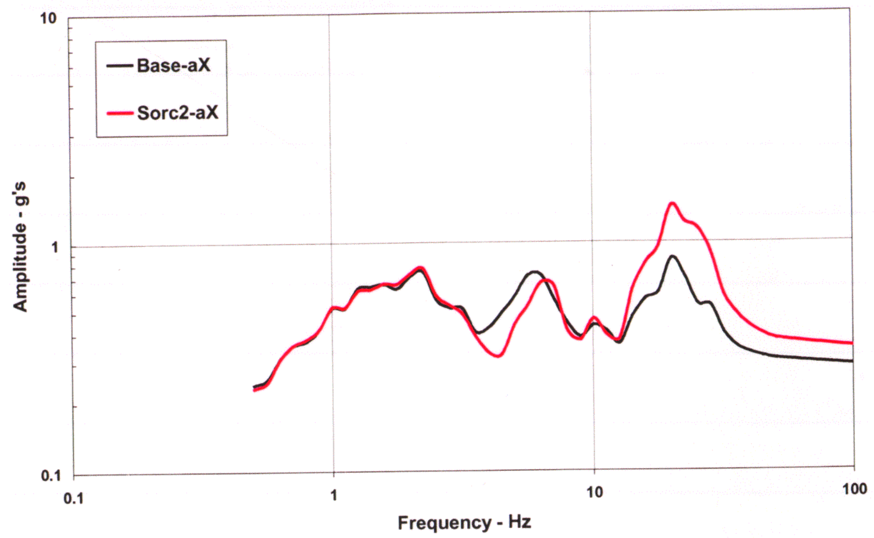
Y-Acceleration Source Time History - Diagonal HYX -2nd Iteration



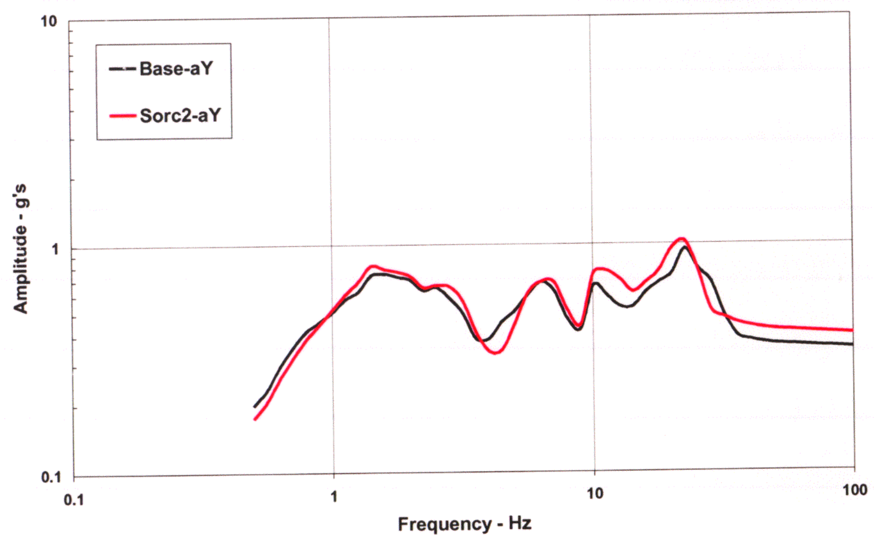
Z-Acceleration Source Time History - Diagonal HYX -2nd Iteration



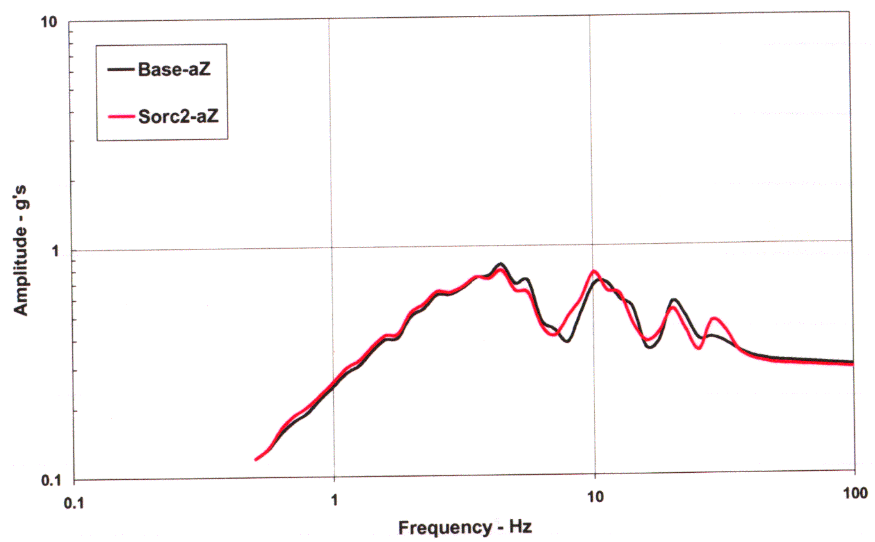
5% Damping Response Spectrum



5% Damping Response Spectrum



5% Damping Response Spectrum



The finite element model results presented on p. 58-60 show that when the scaled motion mb3 (referred to as SOURC7D.asc on p. 69) is applied as input base motion in the soil-only finite element model as described on page 53, Item (4), the output motion calculated at the ground surface closely matches the design ground motion. Therefore, using mb3 as the base input motion in a soil-structure interaction model (i.e., one that includes the pad and casks) ~~should~~ (GWO 2/12/2002) is equivalent to applying the design ground motion at the ground surface over a semi-infinite region that includes the structure. The free-field motion calculated from the model, i.e., at locations that are far enough away from the pad and from the finite boundaries, should match the design ground motion.

February 18 2002

Soil-Structure Interaction Modeling

Finite element model: pages 48-57.
Base motion: page 53, Item (4); page 72.

The following model cases will be analyzed by varying the cask base friction coefficient and the contact condition at the pad/soil interfaces

Case b21
Cask base friction coefficient = 0.8
Pad-to-soil contact condition: Frictional with $\mu = 0.31$
(μ = friction coefficient at pad/soil interfaces).

Case b22
Cask base friction coefficient = 0.2
Pad-to-soil contact condition: Frictional with $\mu = 0.31$

Case m31
Cask base friction coefficient = 0.8
Pad-to-soil contact condition: Bonded

Case m32
Cask base friction coefficient = 0.2
Pad-to-soil contact condition: Bonded.

Monitored Response: Histories of displacement, velocity, and acceleration at selected nodes.

The monitored response will be used to calculate the following:

(1) History of rocking angle for each cask.
(2) History of sliding displacement for each cask
(3) Acceleration history at selected points
(4) Profiles of peak East, peak North, and peak vertical accelerations along the X, Y, and -Z axes (see p. 52 for axis definition)
(5) Acceleration response spectra (from the acceleration history) at selected points.

The first (at time = 0.0) and last (at time = 50s) blocks of a nodal-history output file are shown on page 75. Such blocks were output at every 0.005 s time increment.

Calculation of Rocking Angle

The rocking angle, θ (see figure on page 76), is calculated using the displacement at the ~~mid~~ top GW 2/8/02 and base of the cask-cylinder axis, as follows (page 76)

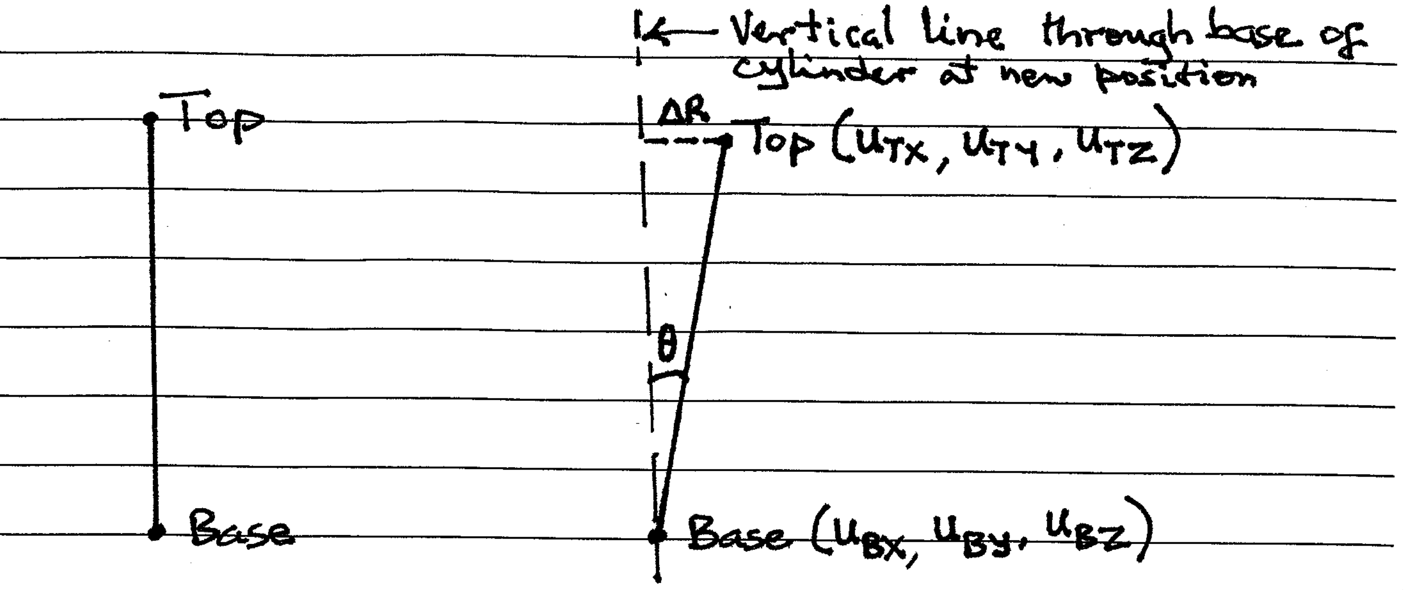
1LS-DYNA user input
ls-dyna/mpp dumpbdb utility (version 940.2a) date 01/18/2000

n o d a l p r i n t o u t f o r t i m e s t e p (at time 0.0000e+00)

nodal point	x-disp	y-disp	z-disp	x-vel	y-vel	z-vel	x-accl	y-accl	z-accl			
3304	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	-3.0000e+00
3319	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	2.0000e+01	0.0000e+00	0.0000e+00
3324	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	4.0000e+01	0.0000e+00
3598	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	4.0000e+01	-2.2204e-15	0.0000e+00
3612	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	6.0000e+01	0.0000e+00	0.0000e+00
3626	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	8.0000e+01	0.0000e+00	0.0000e+00
3640	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	1.0000e+02	0.0000e+00	0.0000e+00
3654	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	1.2000e+02	0.0000e+00	0.0000e+00
3668	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	1.4000e+02	1.7764e-15	0.0000e+00
3682	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	1.6000e+02	0.0000e+00	0.0000e+00
3696	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	1.8000e+02	0.0000e+00	0.0000e+00
3710	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	2.0000e+02	0.0000e+00	0.0000e+00
3724	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	2.2000e+02	0.0000e+00	0.0000e+00
3738	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	2.4000e+02	0.0000e+00	0.0000e+00
3752	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	2.6000e+02	7.1054e-15	0.0000e+00
5206	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	6.0000e+01	0.0000e+00
5208	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	8.0000e+01	0.0000e+00
5210	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	1.0000e+02	0.0000e+00
5212	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	1.2000e+02	0.0000e+00
5214	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	1.4000e+02	0.0000e+00
5216	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	1.6000e+02	0.0000e+00
5218	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	1.8000e+02	0.0000e+00
5220	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	2.0000e+02	0.0000e+00
5222	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	2.2000e+02	0.0000e+00
5224	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	2.4000e+02	0.0000e+00
5226	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	2.6000e+02	0.0000e+00
8235	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	-1.4211e-14	0.0000e+00	-5.0000e+00
11484	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	-1.4211e-14	0.0000e+00	-1.0000e+01
14733	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	-7.5000e+00
17982	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	-1.4211e-14	0.0000e+00	-1.2000e+01
21231	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	-1.4211e-14	0.0000e+00	-1.8000e+01
24480	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	-1.5000e+01
27729	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	-1.4211e-14	0.0000e+00	-2.6000e+01
30978	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	-2.2000e+01
34227	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	-1.4211e-14	0.0000e+00	-3.5000e+01
37476	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	-3.0500e+01
40725	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	-1.4211e-14	0.0000e+00	-5.0000e+01
45710	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	7.1054e-15	0.0000e+00	-4.5000e+01
45711	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	3.5527e-14	-2.8422e-14	-4.0000e+01
50472	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	-1.4211e-14	0.0000e+00	-7.0000e+01
57193	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	-7.1054e-15	0.0000e+00	-6.5000e+01
57194	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	-6.0000e+01
57195	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	-7.1054e-15	-2.8422e-14	-5.5000e+01
63468	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	-1.4211e-14	0.0000e+00	-9.0000e+01
70189	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	-7.1054e-15	0.0000e+00	-8.5000e+01
70190	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	-8.0000e+01
70191	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	-7.1054e-15	-2.8422e-14	-7.5000e+01
110701	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	-7.5000e+00	-2.4000e+01	0.0000e+00
110803	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	-7.5000e+00	-2.4000e+01	1.9960e+01
118345	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	7.5000e+00	-2.4000e+01	0.0000e+00
118447	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	7.5000e+00	-2.4000e+01	1.9960e+01
125086	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	-7.5000e+00	-8.0000e+00	0.0000e+00
125188	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	-7.5000e+00	-8.0000e+00	1.9960e+01
131827	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	7.5000e+00	-8.0000e+00	0.0000e+00
131929	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	7.5000e+00	-8.0000e+00	1.9960e+01
138568	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	-7.5000e+00	8.0000e+00	0.0000e+00
138670	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	-7.5000e+00	8.0000e+00	1.9960e+01
145309	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	7.5000e+00	8.0000e+00	0.0000e+00
145411	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	7.5000e+00	8.0000e+00	1.9960e+01
152050	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	-7.5000e+00	2.4000e+01	0.0000e+00
152152	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	-7.5000e+00	2.4000e+01	1.9960e+01
158791	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	7.5000e+00	2.4000e+01	0.0000e+00
158893	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	7.5000e+00	2.4000e+01	1.9960e+01
165566	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	-3.0000e+00
165586	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	1.5000e+01	0.0000e+00	0.0000e+00
165592	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	3.3500e+01	0.0000e+00
165611	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00
165612	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	8.3750e+00	0.0000e+00
165613	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	1.6750e+01	0.0000e+00
165614	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	2.5125e+01	0.0000e+00
165618	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	7.5000e+00	0.0000e+00	0.0000e+00

n o d a l p r i n t o u t f o r t i m e s t e p (at time 4.9996e+01)

nodal point	x-disp	y-disp	z-disp	x-vel	y-vel	z-vel	x-accl	y-accl	z-accl			
3304	-1.0624e+00	1.0104e+00	-5.4756e-01	2.0260e-02	-2.0275e-02	1.3378e-01	8.5255e-01	3.0192e+00	-4.8826e-01	-1.0624e+00	1.0104e+00	-3.5476e+00
3319	-1.0596e+00	1.0045e+00	-5.4481e-01	2.4955e-02	-1.6470e-02	8.6018e-02	7.7663e-01	2.7472e+00	-1.2860e-01	1.8940e+01	1.0045e+00	-5.4481e-01
3324	-1.0582e+00	9.8082e-01	-5.2886e-01	1.5859e-02	-8.1831e-03	6.7814e-02	2.5477e-01	2.3902e+00	-2.6886e+00	-1.0582e+00	4.0981e+01	-5.2886e-01
3598	-1.0489e+00	1.0018e+00	-5.4321e-01	1.4492e-02	-7.3716e-03	4.5830e-02	6.9338e-01	2.1262e+00	-5.8042e-01	3.8951e+01	1.0018e+00	-5.4321e-01
3612	-1.0300e+00	9.9868e-01	-5.4665e-01	1.0153e-02	1.9124e-04	4.0924e-02	3.1428e-01	1.7896e+00	-1.0219e+00	5.8970e+01	9.9868e-01	-5.4665e-01
3626	-1.0015e+00	9.9406e-01	-5.5194e-01	5.5304e-03	6.6251e-03	4.3804e-02	1.0269e-01	1.5654e+00	-1.8396e+00	7.8998e+01	9.9406e-01	-5.5194e-01
3640	-9.6158e-01	9.8693e-01	-5.6028e-01	4.8902e-03	1.1222e-02	5.7664e-02	-4.0816e-01	1.4332e+00	-2.1917e+00	9.9038e+01	9.8693e-01	-5.6028e-01
3654	-9.0889e-01	9.7620e-01	-5.7286e-01	6.4262e-03	1.3466e-02	5.9961e-02	-6.6760e-01	1.3368e+00	-2.1732e+00	1.1909e+02	9.7620e-01	-5.7286e-01
3668	-8.4201e-01	9.5984e-01	-5.9163e-01	6.6642e-03	1.3012e-02	5.5858e-02	-9.3710e-01	1.2496e+00	-2.2970e+00	1.3916e+02	9.5984e-01	-5.9163e-01
3682	-7.6010e-01	9.3584e-01	-6.1909e-01	5.9083e-03	9.6899e-03	4.8945e-02	-1.1407e+00	1.2008e+00	-2.3084e+00	1.5924e+02	9.3584e-01	-6.1909e-01
3696	-6.6382e-01	9.0237e-01	-6.5627e-01	5.0822e-03	3.7310e-03	4.4575e-02	-1.3617e+00	1.2018e+00	-2.0435e+00	1.7934e+02	9.0237e-01	-6.5627e-01
3710	-5.5557e-01	8.5910e-01	-6.9782e-01	4.1958e-03	-4.0495e-03	4.0490e-02	-1.4175e+00	1.2183e+00	-1.5445e+00	1.9944e+02	8.5910e-01	-6.9782e-01
3724	-4.3617e-01	8.0906e-01	-7.3086e-01	2.1715e-03	-1.2819e-02	3.8273e-02	-1.3073e+00	1.2387e+00	-1.0914e+00	2.1956e+02	8.0906e-01	-7.3086e-01
3738	-3.0341e-01	7.6069e-01	-7.4515e-01	-4.1558e-04	-2.1325e-02	4.0706e-02	-1.0190e+00	1.2273e+00	-7.5341e-01	2.3970e+02	7.6069e-01	-7.4515e-01
3752	-1.5564e-01	7.2520e-01	-7.4407e-01	-2.4201e-03	-2.7437e-02	4.5342e-02	-5.7784e-01	1.2307e+00	-5.3570e-01	2.5984e+02	7.2520e-01	-7.4407e-01
5206	-1.0561e+00	9.5908e-01	-5.2361e-01	1.1693e-02	-8.4213e-03	5.2209e-02	-1.7586e-01	2.2108e+00	-1.5504e+00	-1.0561e+00	6.0959e+01	-5.2361e-01
5208	-1.0536e+00	9.2558e-01	-5.1732e-01	1.0783e-02	-3.6986e-03	5.3237e-02	-4.7649e-01	1.6385e+00	-1.3323e+00	-1.0536e+00	8.0926e+01	-5.1732e-01
5210	-1.0496e+00	8.7898e-01	-5.0838e-01	1.1173e-02	9.4277e-04	5.1160e-02	-6.2430e-01	1.3322e+00	-1.3797e+00	-1.0496e+00	1.0088e+02	-5.0838e-01
5212	-1.0429e+00	8.1738e-01	-4.9481e-01	1.2084e-02	5.9510e-03	5.2608e-02	-7.1088e-01	8.4660e-01	-1.6295e+00	-1.0429e+00	1.2082e+02	-4.9481e-01
5214	-1.0326e+00	7.3882e-01	-4.7348e-01	1.3554e-02	1.2023e-02	5.1093e-02	-7.6089e-01	4.6798e-01	-1.7732e+00	-1.0326e+00	1.4074e+02	-4.7348e-01
5216	-1.0170e+00	6.4230e-01	-4.3843e-01	1.5243e-02	1.9150e-02	4.8187e-02	-7.3118e-01	6.0423e-02	-1.7710e+00	-1.0170e+00	1.6064e+02	-4.3843e-01
5218	-9.9473e-01	5.2965e-01	-3.8111e-01	1.6639e-02	2.6080e-02	4.2179e-02	-5.6203e-01	-2.6058e-01	-1.6972e+00	-9.9473e-01	1.8053e+02	-3.8111e-01
5220	-9.6522e-01	4.0738e-01	-2.9377e-01	1.7600e-02	3.2846e-02	3.7922e-02	-2.7465e-01	-5.3041e-01	-1.4774e+00	-9.6522e-01	2.0041e+02	-2.9377e-01
5222	-9.2969e-01	2.8700e-01	-1.7970e-01	1.8524e-02	3.8370e-02	3.4619e-02	6.4275e-02	-5.7851e-01	-1.2828e+00	-9.2969e-01	2.2029e+02	-1.7970e-01
5224	-8.9377e-01	1.7938e-01	-6.0738e-02	1.9234e-02	4.2644e-02	3.5223e-02	3.3729e-01	-5.1085e-01	-1.2182e+00	-8.9377e-01	2.4018e+02	-6.0738e-02
5226	-8.6614e-01	8.8623e-02	2.7791e-02	2.0221e-02	4.7395e-02	3.7352e-02	5.1899e-01	-2.9997e-01	-1.1569e+00	-8.6614e-01	2.6009e+02	2.7791e-02
8235	-1.0624e+00	1.0105e+00	-5.4789e-01	1.9269e-02	-1.9822e-02	1.3234e-01	6.6870e-01	2.8967e+00	-3.0771e-01	-1.0624e+00	1.0105e+00	-5.5479e+00
11484	-1.0817e+00	1.0290e+00	-5.4330e-01	-5.4106e-03	-1.1941e-02	1.0388e-01	3.1570e-01	2.2574e+00	-4.7946e-02	-1.0817e+00	1.0290e+00	-1.0543e+01
14733	-1.0712e+00	1.0196e+00	-5.4585e-01	7.0537e-03	-1.6316e-02	1.1760e-01	5.5523e-01	2.5856e+00	-1.8334e-01	-1.0712e+00	1.0196e+00	-8.0459e+00
17982	-1.0856e+00	1.0326e+00	-5.4177e-01	-9.7520e-03	-1.0040e-02	9.6906e-02	2.1614e-01	2.1119e+00	4.3578e-02	-1.0856e+00	1.0326e+00	-1.2542e+01
21231	-1.0927e+00	1.0395e+00	-5.3917e-01	-1.5977e-02	-6.1724e-03	8.6070e-02	2.6524e-02	1.7904e+00	1.3234e-01	-1.0927e+00	1.0395e+00	-1.8539e+01
24480	-1.0890e+00	1.0357e+00	-5.4050e-01	-1.2964e-02	-8.1367e-03	9.1326e-02	1.3365e-01	1.9582e+00	9.8929e-02	-1.0890e+00	1.0357e+00	-1.5541e+01
27729	-1.1057e+00	1.0524e+00	-5.3381e-01	-2.3105e-02	3.1892e-05	7.2566e-02	-1.4179e-01	1.2905e+00	2.0407e-01	-1.1057e+00	1.0524e+00	-2.6534e+01
30978	-1.0989e+00	1.0456e+00	-5.3662e-01	-1.9840e-02	-3.1613e-03	7.8944e-02	-9.4302e-02	1.5400e+00	1.6127e-01	-1.0989e+00	1.0456e+00	-2.2537e+01
34227	-1.1179e+00	1.0646e+00	-5.2868e-01	-2.6098e-02	6.5549e-03	6.4287e-02	1.1822e-02	8.8871e-01	1.7480e-01	-1.1179e+00	1.0646e+00	-3.5529e+01
37476	-1.1115e+00	1.0581e+00	-5.3142e-01	-2.5000e-02	3.0574e-03	6.8239e-02	-7.4974e-02	1.0853e+00	1.9628e-01	-1.1115e+00	1.0581e+00	-3.1031e+01
40725	-1.1374e+00	1.0840e+00	-5.2147e-01	-2.6160e-02	1.7509e-02	5.6953e-02	-1.1634e-01	3.5388e-01	1.1521e-01	-1.1374e+00	1.0840e+00	-5.0521e+01
45710	-1.1303e+00	1.0768e+00	-5.2422e-01	-2.6125e-02	1.3608e-02	5.9149e-02	1.4890e-02	5.4684e-01	1.2770e-01	-1.1303e+00	1.0768e+00	-4.5524e+01
45711	-1.1237e+00	1.0704e+00	-5.2662e-01	-2.6290e-02	9.8975e-03	6.1615e-02	6.4111e-02	7.2215e-01	1.4668e-01	-1.1237e+00	1.0704e+00	-4.0527e+01
50472	-1.1497e+00	1.0962e+00	-5.1814e-01	-2.7624e-02	2.2190e-02	5.4883e-02	-2.3944e-02	9.5099e-02	1.2440e-01	-1.1497e+00	1.0962e+00	-7.0518e+01
57193	-1.1458e+00	1.0926e+00	-5.1920e-01	-2.7259e-02	2.1056e-02	5.5353e-02	-1.0207e-01	1.5674e-01	1.2195e-01	-1.1458e+00	1.0926e+00	-6.5519e+01
57194	-1.1428e+00	1.0894e+00	-5.2001e-01	-2.6797e-02	1.9901e-02	5.5864e-02	-1.3885e-01	2.2102e-01	1.1292e-01	-1.1428e+00	1.0894e+00	-6.0520e+01
57195	-1.1399e+00	1.0866e+00	-5.2089e-01	-2.6401e-02	1.8718e-02	5.6380e-02	-1.4051e-01	2.8744e-01	1.1290e-01	-1.1399e+00	1.0866e+00	-5.5521e+01
63468	-1.1677e+00	1.1140e+00	-5.1211e-01	-2.5320e-02	2.7038e-02	5.3011e-02	5.0484e-01	-8.0390e-02	1.8515e-01	-1.1677e+00	1.1140e+00	-9.0512e+01
70189	-1.1625e+00	1.1092e+00	-5.1374e-01	-2.6628e-02	2.5749e-02	5.3461e-02	3.9798e-01	-5.1089e-02	1.6858e-01	-1.1625e+00	1.1092e+00	-8.5514e+01
70190	-1.1580e+00	1.1048e+00	-5.1548e-01	-2.7436e-02	2.4532e-02	5.3924e-02	2.4760e-01	-1.3103e-02	1.4702e-01	-1.1580e+00	1.1048e+00	-8.0515e+01
70191	-1.1537e+00	1.1002e+00	-5.1682e-01	-2.7737e-02	2.3351e-02	5.4396e-02	9.8894e-02	3.8438e-02	1.4104e-01	-1.1537e+00	1.1002e+00	-7.5517e+01
110701	-1.2310e+00	1.0727e+00	-5.4845e-01	2.0230e-02	-2.6787e-02	8.7654e-02	8.1130e-01	2.6388e+00	-1.4731e+00	-8.7310e+00	-2.2927e+01	-5.4845e-01
110803	-1.2231e+00	1.0470e+00	-5.4852e-01	-3.6665e-03	-9.2663e-02	8.7579e-02	2.8864e+00	2.9223e+00	-1.4736e+00	-8.7231e+00	-2.2953e+01	1.9411e+01
118345	-1.0491e+00	1.2037e+00	-5.4918e-01	2.5802e-02	-2.8019e-02	8.3454e-02	1.0918e+00	2.8957e+00	-1.6807e+00	6.4509e+00	-2.2796e+01	-5.4918e-01
118447	-1.0511e+00	1.1743e+00	-5.4921e-01	8.2367e-02	-9.3523e-02	8.3363e-02	1.0546e+00	1.9129e+00	-1.6824e+00	6.4489e+00	-2.2826e+01	1.9411e+01
125086	-1.1578e+00	1.1125e+00	-5.4991e-01	1.9647e-02	-2.4932e-02	1.2327e-01	1.1542e+00	2.7355e+00	-7.0877e-01	-8.6578e+00	-6.8875e+00	-5.4991e-01
125188	-1.1522e+00	1.1017e+00	-5.4991e-01	-2.1715e-02	-6.0516e-02	1.2326e-01	2.6170e+00	2.1802e+00	-7.0974e-01	-8.6522e+00	-6.8983e+00	1.9410e+01
131827	-1.0313e+00	7.8247e-01	-5.5032e-01	2.6376e-02	-2.6320e-02	1.1973e-01	1.0772e+00	2.6113e+00	-6.5150e-01	6.4687e+00	-7.2175e+00	-5.5032e-01
131929	-1.0345e+00	7.7836e-01	-5.5034e-01	8.7533e-02	-7.1798e-02	1.1973e-01	4.0429e-01	2.2324e+00	-6.5174e-01	6.4655e+00	-7.2216e+00	1.9410e+01
138568	-1.0588e+00	1.0481e+00	-5.4836e-01	1.9896e-02	-2.1032e-02	1.2599e-01	9.6837e-01	3.4189e+00	-6.9887e-01	-8.5588e+00	9.0481e+00	-5.4836e-01
138670	-1.0555e+00	1.0506e+00	-5.4837e-01	-1.7727e-02	-8.3687e-03	1.2599e-01	2.6239e+00	5.0009e+00	-6.9983e-01	-8.5555e+00	9.0506e+00	1.9412e+01
145309	-1.0275e+00	1.2682e+00	-5.4852e-01	2.5725e-02	-2.0094e-02	1.2406e-01	7.6043e-01	2.95[illegible]3e+00	-1.0437e+00	6.4725e+00	9.2682e+00	-5.4852e-01
145411	-1.0310e+00	1.2660e+00	-5.4852e-01	7.9475e-02	4.0292e-04	1.2407e-01	5.9302e-01	5.611[illegible]e+00	-1.0437e+00	6.4690e+00	9.2660e+00	1.9411e+01
152050	-1.2291e+00	9.8635e-01	-5.4302e-01	1.9136e-02	-1.8704e-02	1.0171e-01	9.0047e-01	3.2275e+00	-2.3419e+00	-8.7291e+00	2.4986e+01	-5.4302e-01
152152	-1.2223e+00	1.0032e+00	-5.4304e-01	-5.4454e-03	2.0227e-02	1.0168e-01	2.8926e+00	6.3033e+00	-2.3450e+00	-8.7223e+00	2.5003e+01	1.9417e+01
158791	-1.0237e+00	1.2079e+00	-5.4368e-01	2.4362e-02	-1.7256e-02	9.7341e-02	8.0374e-01	3.3122e+00	-[illegible]0277e+00	6.4763e+00	2.5208e+01	-5.4368e-01
158893	-1.0266e+00	1.2211e+00	-5.4369e-01	7.4898e-02	3.0699e-02	9.7317e-02	1.1711e+00	6.9557e+00	-3.[illegible]301e+00	6.4734e+00	2.5221e+01	1.9416e+01
165566	-1.0555e+00	9.8993e-01	-5.4873e-01	2.2702e-02	-1.9934e-02	1.4126e-01	9.1332e-01	3.0080e+00	-1.1[illegible]03e+00	-1.0555e+00	9.8993e-01	-3.5487e+00
165586	-1.0594e+00	9.9822e-01	-4.9699e-01	2.6962e-02	-2.1515e-02	1.0805e-01	8.3471e-01	3.0408e+00	-6.95[illegible]e-01	1.3941e+01	9.9822e-01	-4.9699e-01
165592	-1.0589e+00	9.8993e-01	-4.4165e-01	1.9239e-02	-1.7861e-02	8.6641e-02	6.2894e-01	3.1980e+00	-4.0206e+00	-1.0589e+00	3.4490e+01	-4.4165e-01
165611	-1.0582e+00	9.9892e-01	-4.9922e-01	2.2216e-02	-2.0582e-02	1.4246e-01	9.1524e-01	3.1323e+00	-9.5725e[illegible]	-1.0582e+00	9.9892e-01	-4.9922e-01
165612	-1.0534e+00	9.7530e-01	-5.7241e-01	2.2599e-02	-1.8936e-02	1.3916e-01	7.9751e-01	3.3185e+00	-1.5095e+[illegible]	-1.0534e+00	9.3503e+00	-5.7241e-01
165613	-1.0583e+00	9.9247e-01	-4.9295e-01	2.1918e-02	-1.7043e-02	1.2376e-01	7.4737e-01	3.3524e+00	-2.3457e+00	-1.0583e+00	1.7742e+01	-4.9295e-01
165614	-1.0544e+00	9.7932e-01	-5.8101e-01	2.1448e-02	-1.5985e-02	1.0741e-01	7.0573e-01	3.3042e+00	-3.2816e+00	-1.0544e+00	2.6104e+01	-5.8101e-01
165618	-1.0506e+00	9.8691e-01	-5.5937e-01	2.6641e-02	-2.2960e-02	1.3055e-01	9.3369e-01	3.0543e+00	-1.0066e+00	5.4494e+00	9.8691e-01	-5.5937e-01



Initial Position of Cylinder Axis — Displaced Position of Cylinder Axis

U_{TX}, U_{TY}, U_{TZ} : Displacements at top of axis

U_{BX}, U_{BY}, U_{BZ} : Displacements at base of axis

$$\Delta R = \sqrt{(U_{TX} - U_{BX})^2 + (U_{TY} - U_{BY})^2}$$

$$\theta = \arcsin(\Delta R / L)$$

L = height of cylinder

The maximum rocking angle before tipover is given by

θ_{max} = ~~arcsin~~ arctan (D/L) ; D = diameter of cylinder

= ~~arcsin~~ arctan (132.5/239.5)

= ~~~33.6°~~ ~28.9°

GW 9/20/2002

Calculation of Cask Sliding Displacement

Cask sliding, S_c, is evaluated using the relative displacement between the base of a cask and the midpoint of the top of the pad. This ignores any contributions from the elastic deformation of the pad and from cask rocking to the relative displacement.

$$S_c = \sqrt{(U_{BX} - U_{PX})^2 + (U_{BY} - U_{PY})^2}$$

U_B = cask-base displacement

U_P = displacement of midpoint of pad top surface.

The calculation of cask rocking angle and sliding displacement (pages 74–77) is implemented through the C code documented on page 78.

The extraction of acceleration history (at selected points) from the finite element nodal history output file is ~~to~~ GW 2/18/2002 implemented through the C code documented on page 79.

The calculation of ~~profil~~ GW 2/18/02 profiles of peak acceleration from the finite element nodal output file is implemented through the C code documented on page 80.

Calculation of Cask Rocking and Sliding History

```c
/***********************************************************************
Program Name: CaskDHist
File Name: CaskDHist.c

Calculate cask rocking and sliding history using nodal displacement
history from LS-DYNA output file

Author:             G.I. Ofoegbu
Date:               January 29 2002
System:             ANSI C Compiler
***********************************************************************/

#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <conio.h>
#include <math.h>

char* ResultFile = "M32\\m32Nodout"; // Update for each model case
float tStart = 10.0;
float zeroTime = 10.0;
int ERROREND = 1;
int NORMALEND = 0;
int NumHistNodes = 71;
// for m02: int NumHistNodes = 70;

int GetHist(FILE* Fout, int theBase, int theTop, int padCenter);
void DumpAndQuit(char* s);
double CaskRock(double uBase, double vBase, double uTop, double vTop);
double CaskSlide(double uBase, double vBase, double uPad, double vPad);

main()
{
  char mess[120];
  char* jobname = {"m32"};          // Update for each model case
  int base[] = {110701,118345,125086,131827,138568,145309,152050,158791};
  int  top[] = {110803,118447,125188,131929,138670,145411,152152,158893};
  int i,theTop,theBase,theCask;
  int padCenter = 165611;
// for m02:  int padCenter = 110654;
/*
  float xpos[] = {-7.5,7.5,-7.5,7.5,-7.5,7.5,-7.5,7.5};
  float ypos[] = {-24.0,-24.0,-8.0,-8.0,8.0,8.0,24.0,24.0};
*/
  char* outfile = {"jjjCiHis.txt"};
  FILE* Fout;

  for (i=0; i<8; i++){
    theBase = base[i];
    theTop = top[i];
    theCask = i+1;
    sprintf(outfile,"%3sC%1dHis.txt",jobname,theCask);
    Fout = fopen(outfile,"w");
    if (!Fout)
      DumpAndQuit(strcat("Unable to open output file ",outfile));
    fprintf(Fout,
        "Rocking and sliding displacement history for cask %d\n",theCask);
    if (GetHist(Fout,theBase,theTop,padCenter) == ERROREND){
        sprintf(mess,
          "Error encountered while reading history for cask %d",theCask);
        DumpAndQuit(mess);
    }
    fclose(Fout);
    printf("Working ... finished cask %d\n",theCask);
  }

  printf("\nDone ... Press any key to end: ");
  getch();
  return(0);
}

int GetHist(FILE* Fout, int theBase, int theTop, int padCenter)
{
  char inpLine[160];
  char* marker = {" n o d a l   p r i n t   o u t   f o r   t i m e"};
  int i,node;
  int topFound,baseFound,padFound;
  float vx,vy,vz;
  float ax,ay,az;
  double time;
  double ux,uy,uz;
  double uTop[3];
  double uBase[3];
  double uPad[3];
  double sDisp;
  double rAngle;
  FILE* Fin;

/* Open results file */

  Fin = fopen(ResultFile,"r");
  if (!Fin)
    DumpAndQuit(strcat("Unable to open input file ",ResultFile));

/* Print heading information */

  fprintf(Fout,"%12s%15s%15s%15s%15s%15s\n",
            "Time (s)",
            "Rock (deg)"
            "Slide (in)"
            "ESlide (in)",
            "NSlide (in)",
            "URDisp (in)"     );

/* Read and print nodal-history results */

  while (fgets(inpLine,160,Fin))
    if (!strncmp(inpLine,marker,strlen(marker))){
      if (sscanf(&inpLine[106],"%lf",&time) != 1){
        printf("Unable to extract current time from input line\n");
        return(ERROREND);
      }

/*  Read and discard NumHistNodes+2 lines if time<zeroTime */

      if (time < zeroTime){
        for (i=0; i < NumHistNodes+2; i++)
          fgets(inpLine,160,Fin);
        continue;
      }

/*    Read and discard two lines, then read NumHistNodes input lines */

      fgets(inpLine,160,Fin);
      fgets(inpLine,160,Fin);
      topFound = baseFound = padFound = 0;
      for (i=0; i<NumHistNodes; i++){
        if (!fgets(inpLine,160,Fin)){
          printf("Unexpected end of file. time=%.4f\n",time);
          return(ERROREND);
        }
        if (sscanf(inpLine,"%d%lf%lf%lf%f%f%f%f%f%*f%*f%*f",
          &node,&ux,&uy,&uz,&vx,&vy,&vz,&ax,&ay,&az) != 10){
           printf("Invalid input line. time=%.4f\n",time);
           return(ERROREND);
        }
        if (node == theBase){
          baseFound = 1;
          uBase[0] = ux;
          uBase[1] = uy;
          uBase[2] = uz;
        }
        else if (node == theTop){
          topFound = 1;
          uTop[0] = ux;
          uTop[1] = uy;
          uTop[2] = uz;
        }
        else if (node == padCenter){
          padFound = 1;
          uPad[0] = ux;
          uPad[1] = uy;
          uPad[2] = uz;
        }
      }
      if (!baseFound){
        printf("No data found. Node=%d, time=%.4f\n",
            theBase,time);
        return(ERROREND);
      }
      else if (!topFound){
        printf("No data found. Node=%d, time=%.4f\n",
            theTop,time);
        return(ERROREND);
      }
      else if (!padFound){
        printf("No data found. Node=%d, time=%.4f\n",
            padCenter,time);
        return(ERROREND);
      }
      sDisp = CaskSlide(uBase[0],uBase[1],uPad[0],uPad[1]);
      rAngle = CaskRock(uBase[0],uBase[1],uTop[0],uTop[1]);
      fprintf(Fout,"%12.4f%15.2f%15.4E%15.4E%15.4E%15.4E\n",
            time-tStart,
            rAngle,
            sDisp*12.0,
            (uBase[0]-uPad[0])*12.0,
            (uBase[1]-uPad[1])*12.0,
            (uBase[2]-uPad[2])*12.0
      );
    }

  fclose(Fin);
  return(NORMALEND);
}

double CaskSlide(double ubase, double vbase, double upad, double vpad)
{
  return(
    sqrt((ubase-upad)*(ubase-upad) + (vbase-vpad)*(vbase-vpad))
  );
}

double CaskRock(double ubase, double vbase, double utop, double vtop)
{
  double pi;
  double rad;
  double cL = 19.96;
  double dr;

  pi = 4.0*atan(1.0);
  dr = CaskSlide(ubase,vbase,utop,vtop);
  rad = asin(dr/cL);
  return(rad*180.0/pi);
}

void DumpAndQuit(char* s)
{
  printf("\n%s\n",s);
  printf("Press any key to end: ");
  getch();
  exit(1);
}
```

Extraction of Acceleration History at Selected Points

```c
/***********************************************************************
Program Name: NodeAHist
File Name: NodeAHist.c

Extract the acceleration history for a set of nodes
from history data in an LS-DYNA output file

Author:             G.I. Ofoegbu
Date:               February 2002
System:             ANSI C Compiler
***********************************************************************/

#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <math.h>

#pragma hdrstop
#include <conio.h>

char* ResultFile[] = {"B22\\b22Nodout"}; // Update for each model case
int NumResultFile = 1;
double gAcc = 32.2;
float tStart = 10.0;
float zeroTime = 10.0;
int ERROREND = 1;
int NORMALEND = 0;
int NumHistNodes = 71;
// for m01: int NumHistNodes = 70;

int GetAccHist(int theNode, FILE* FpOut);
void DumpAndQuit(char* );

main()
{
  char* jobname = {"b22"};        // Update for each model case
  char* nodeFile = {"outNodes.txt"};
  char* outfile = {"jjja123456.his"};
  char inpLine[100];
  int node;
  float x,y,z;
  FILE* Fin;
  FILE* Fout;

  Fin = fopen(nodeFile,"r");
  if (!Fin)
    DumpAndQuit(strcat("Unable to open node file ",nodeFile));
  else
    printf("Opened node file named %s\n",nodeFile);

  while (fgets(inpLine,100,Fin))
    if (sscanf(inpLine,"%d %f %f %f",&node,&x,&y,&z) == 4){

      sprintf(outfile,"%3sa%d.his",jobname,node);
      Fout = fopen(outfile,"w");
      if (!Fout)
        DumpAndQuit(strcat("Unable to open output file ",outfile));

      fprintf(Fout,"%15s%15s%15s%15s\n",
        "Time (s)","xAcc (g)","yAcc (g)","zAcc (g)");

      if (GetAccHist(node,Fout) == ERROREND){
        sprintf(inpLine,
          "Error encountered while reading history for node %d",
          node);
        DumpAndQuit(inpLine);
      }

      fclose(Fout);
      printf("Working ... processed node %d\n",node);
    }

  printf("\nDone ... Press any key to end: ");
  getch();
  return 0;
}

int GetAccHist(int theNode, FILE* Fout)
{
  char inpLine[160];
  char* marker = {" n o d a l   p r i n t   o u t   f o r   t i m e"};
  int i,node,foundNode;
  int k;
  float time;
  float ux,uy,uz;
  float vx,vy,vz;
  float ax,ay,az;
  FILE* Fin;

/* Open results file */

for (k=0; k < NumResultFile; k++)
{
  Fin = fopen(ResultFile[k],"r");
  if (!Fin)
    DumpAndQuit(strcat("Unable to open input file ",ResultFile[k]));

/* Read and print nodal-history results */

  while (fgets(inpLine,160,Fin))
    if (!strncmp(inpLine,marker,strlen(marker))){
      if (sscanf(&inpLine[106],"%f",&time) != 1){
        printf("Unable to extract current time from input line\n");
        return(ERROREND);
      }

/*  Read and discard NumHistNodes+2 lines if time<zeroTime */

      if (time < zeroTime){
        for (i=0; i < NumHistNodes+2; i++)
          fgets(inpLine,160,Fin);
        continue;
      }

/*    Read and discard two lines, then read NumHistNodes input lines */

      fgets(inpLine,160,Fin);
      fgets(inpLine,160,Fin);
      foundNode = 0;
      for (i=0; i<NumHistNodes; i++){
        if (!fgets(inpLine,160,Fin)){
          printf("Unexpected end of file. Node=%d, time=%.4f\n",
            theNode,time);
          return(ERROREND);
        }
        if (sscanf(inpLine,"%d%f%f%f%f%f%f%f%f%f%*f%*f%*f",
          &node,&ux,&uy,&uz,&vx,&vy,&vz,&ax,&ay,&az) != 10){
           printf("Invalid input line. Node=%d, time=%.4f\n",
             theNode,time);
           return(ERROREND);
        }
        if (node == theNode){
          ax /= gAcc;
          ay /= gAcc;
          az /= gAcc;
          fprintf(Fout,"%15.4E%15.4E%15.4E%15.4E\n",
            time-tStart,ax,ay,az);
          foundNode = 1;
        }
      }
      if (!foundNode){
        printf("No data found. Node=%d, time=%.4f\n",theNode,time);
        return(ERROREND);
      }
    }

  fclose(Fin);
}
  return(NORMALEND);
}

void DumpAndQuit(char* s)
{
  printf("\n%s\n",s);
  printf("Press any key to end: ");
  getch();
  exit(1);
}
```

See inset on this page

File outNodes.txt

```
Acceleration history plotted for the following nodes

   NODE          X                    Y                    Z
Top of pad at model center
  165611         0.                   0.                   0.
Base of pad at model center
  165566         0.                   0.       -3.00000000000
Soil surface below pad at model center
    3304         0.                   0.       -3.00000000000
Midpoint of East edge of pad
  165586    15.0000000000             0.                   0.
Midpoint of north edge of pad
  165592         0.         33.5000000000                  0.
Free-field point along east axis
    3654    120.000000000             0.                   0.
Free-field point along north axis
    5214         0.         140.000000000                  0.
Point within SSI zone along east axis beyond east edge of pad
    3598    40.0000000000   -0.222044604925E-14            0.
Point within SSI zone along north axis beyond north edge of pad
    5206         0.         60.0000000000                  0.
```

Calculation of Profiles of Peak Acceleration

```
/**********************************************************************
Program Name: AMaxProfile
File Name: AMaxProfile.c

Develop the profile of maximum acceleration along a line defined by
a list of nodes using acceleration histories from LS-DYNA output file

Author:              G.I. Ofoegbu
Date:                January 2002
System:              ANSI C Compiler
**********************************************************************/

#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <conio.h>
#include <math.h>

char* ResultFile[] = {"M31\\m31Nodout"}; // Update for each model case
int NumResultFile = 1;
double gAcc = 32.2;
float zeroTime = 10.0;
int ERROREND = 1;
int NORMALEND = 0;
int NumHistNodes = 71;
// for m01: int NumHistNodes = 70;

int MaxAcc(int theNode, double* xamax, double* yamax, double* zamax);
void DumpAndQuit(char* );

main()
{
  char* jobname = {"m31"};                // Update for each model case
  int axis;
  char* axisName = {"xENU"};
  char* nodeFile[] = {"xx",
                      "M31\\EastLine.txt",
                      "M31\\NorthLine.txt",
                      "M31\\UpLine.txt"};
// for m01:  char* nodeFile[] = {"xx","EAxisNd.txt","NAxisNd.txt","UAxisNd.txt"};
  char* outfile = {"jjjKAmax.prfl"};
  char inpLine[100];
  int node;
  float distance;
  float x,y,z;
  double xamax,yamax,zamax;
  FILE* Fin;
  FILE* Fout;

  printf("Enter axis number 1,2, or 3 for E,N, or U axis: ");
  scanf("%d",&axis);
  if (axis<1 || axis>3)
    DumpAndQuit("Value of axis must be 1, 2, or 3");

  Fin = fopen(nodeFile[axis],"r");
  if (!Fin)
    DumpAndQuit(strcat("Unable to open node file ",nodeFile[axis]));

  sprintf(outfile,"%3s%1cAmax.prfl",jobname,axisName[axis]);
  Fout = fopen(outfile,"w");
  if (!Fout)
    DumpAndQuit(strcat("Unable to open output file ",outfile));

  fprintf(Fout,
    "Maximum acceleration profile: Model=%s, Line=%c\n",
    jobname,axisName[axis]);
  fprintf(Fout,"%15s%15s%15s%15s\n",
    "Distance (ft)","E-Amax (g)","N-Amax (g)","U-Amax (g)");

  while (fgets(inpLine,100,Fin))
    if (sscanf(inpLine,"%d %f %f %f",&node,&x,&y,&z) == 4){

      if (axis == 1)
        distance = x;
      else if (axis == 2)
        distance = y;
      else
        distance = z;

      if (MaxAcc(node,&xamax,&yamax,&zamax) == ERROREND){
        sprintf(inpLine,
          "Error encountered while reading history for node %d",
          node);
        DumpAndQuit(inpLine);
      }
      fprintf(Fout,"%15.2f%15.5f%15.5f%15.5f\n",
        distance,xamax,yamax,zamax);
      printf("Working ... processed node %d\n",node);
    }

  fclose(Fout);
  printf("\nDone ... Press any key to end: ");
  getch();
  return 0;
}

int MaxAcc(int theNode, double* xamax, double* yamax, double* zamax)
{
  char inpLine[160];
  char* marker = {" n o d a l   p r i n t   o u t   f o r   t i m e"};
  int i,node,foundNode;
  int k;
  float time;
  float ux,uy,uz;
  float vx,vy,vz;
  float ax,ay,az;
  double dax,day,daz;
  double amx = 0.0;
  double amy = 0.0;
  double amz = 0.0;
  FILE* Fin;

/* Open results file */

for (k=0; k < NumResultFile; k++)
{
  Fin = fopen(ResultFile[k],"r");
  if (!Fin)
    DumpAndQuit(strcat("Unable to open input file ",ResultFile[k]));

/* Read and print nodal-history results */

  while (fgets(inpLine,160,Fin))
    if (!strncmp(inpLine,marker,strlen(marker))){
      if (sscanf(&inpLine[106],"%f",&time) != 1){
        printf("Unable to extract current time from input line\n");
        return(ERROREND);
      }

/*  Read and discard NumHistNodes+2 lines if time<zeroTime */

      if (time < zeroTime){
        for (i=0; i < NumHistNodes+2; i++)
          fgets(inpLine,160,Fin);
        continue;
      }

/*    Read and discard two lines, then read NumHistNodes input lines */

      fgets(inpLine,160,Fin);
      fgets(inpLine,160,Fin);
      foundNode = 0;
      for (i=0; i<NumHistNodes; i++){
        if (!fgets(inpLine,160,Fin)){
          printf("Unexpected end of file. Node=%d, time=%.4f\n",
            theNode,time);
          return(ERROREND);
        }
        if (sscanf(inpLine,"%d%f%f%f%f%f%f%f%f%f%*f%*f%*f",
            &node,&ux,&uy,&uz,&vx,&vy,&vz,&ax,&ay,&az) != 10){
          printf("Invalid input line. Node=%d, time=%.4f\n",
            theNode,time);
          return(ERROREND);
        }
        if (node == theNode){
          foundNode = 1;
          dax = sqrt(ax*ax);
          day = sqrt(ay*ay);
          daz = sqrt(az*az);
          if (amx < dax) amx = dax;
          if (amy < day) amy = day;
          if (amz < daz) amz = daz;
        }
      }
      if (!foundNode){
        printf("No data found. Node=%d, time=%.4f\n",theNode,time);
        return(ERROREND);
      }
    }

  fclose(Fin);
}
  *xamax = amx/gAcc;
  *yamax = amy/gAcc;
  *zamax = amz/gAcc;
  return(NORMALEND);
}

void DumpAndQuit(char* s)
{
  printf("\n%s\n",s);
  printf("Press any key to end: ");
  getch();
  exit(1);
}
```

See page 81

File EastLine.txt

LIST ALL SELECTED NODES. DSYS= 0
SORT TABLE ON X NODE NODE

NODE	X	Y	Z
165611	0.	0.	0.
165618	7.50000000000	0.	0.
165586	15.0000000000	0.	0.
3319	20.0000000000	0.	0.
3598	40.0000000000	-0.222044604925E-14	0.
3612	60.0000000000	0.	0.
3626	80.0000000000	0.	0.
3640	100.000000000	0.	0.
3654	120.000000000	0.	0.
3668	140.000000000	0.177635683940E-14	0.
3682	160.000000000	0.	0.
3696	180.000000000	0.	0.
3710	200.000000000	0.	0.
3724	220.000000000	0.	0.
3738	240.000000000	0.	0.
3752	260.000000000	0.710542735760E-14	0.

File NorthLine.txt

LIST ALL SELECTED NODES. DSYS= 0
SORT TABLE ON Y NODE NODE

NODE	X	Y	Z
165611	0.	0.	0.
165612	0.	8.37500000000	0.
165613	0.	16.7500000000	0.
165614	0.	25.1250000000	0.
165592	0.	33.5000000000	0.
3324	0.	40.0000000000	0.
5206	0.	60.0000000000	0.
5208	0.	80.0000000000	0.
5210	0.	100.000000000	0.
5212	0.	120.000000000	0.
5214	0.	140.000000000	0.
5216	0.	160.000000000	0.
5218	0.	180.000000000	0.
5220	0.	200.000000000	0.
5222	0.	220.000000000	0.
5224	0.	240.000000000	0.
5226	0.	260.000000000	0.

File UpLine.txt

LIST ALL SELECTED NODES. DSYS= 0
SORT TABLE ON Z NODE NODE

NODE	X	Y	Z
63468	-0.142108547152E-13	0.	-90.0000000000
70189	-0.710542735760E-14	0.	-85.0000000000
70190	0.	0.	-80.0000000000
70191	-0.710542735760E-14	-0.284217094304E-13	-75.0000000000
50472	-0.142108547152E-13	0.	-70.0000000000
57193	-0.710542735760E-14	0.	-65.0000000000
57194	0.	0.	-60.0000000000
57195	-0.710542735760E-14	-0.284217094304E-13	-55.0000000000
40725	-0.142108547152E-13	0.	-50.0000000000
45710	0.710542735760E-14	0.	-45.0000000000
45711	0.355271367880E-13	-0.284217094304E-13	-40.0000000000
34227	-0.142108547152E-13	0.	-35.0000000000
37476	0.	0.	-30.5000000000
27729	-0.142108547152E-13	0.	-26.0000000000
30978	0.	0.	-22.0000000000
21231	-0.142108547152E-13	0.	-18.0000000000
24480	0.	0.	-15.0000000000
17982	-0.142108547152E-13	0.	-12.0000000000
11484	-0.142108547152E-13	0.	-10.0000000000
14733	0.	0.	-7.50000000000
NODE	X	Y	Z
8235	-0.142108547152E-13	0.	-5.00000000000
3304	0.	0.	-3.00000000000
165566	0.	0.	-3.00000000000
165611	0.	0.	0.

The three text files referred to on page 80 that are used to define profile lines for peak acceleration are documented on this page (left column).

Acceleration response spectra were calculated from the acceleration time histories. The calculation was performed by Dr. James F. Unruh of Southwest Research Institute Division 18. The calculation procedure is described briefly in ~~the~~ e memo (GO 9/09/2002) from J.F. Unruh reproduced below. 9/09/2002

GO

From: James F. Unruh [mailto:James.Unruh@SwRI.org]
Sent: Monday, September 09, 2002 8:06 AM
To: ofoegbu@cnwra.swri.edu
Subject: RE: Documentation Response Spectra Calculation

See the attached paragraph. This routine has been used here at SwRI since 1982 in our bi-axial earthquake simulatior laboratory.

> ACTSKW.for is a numerical method for computing response spectra from strong-motion earthquake records. The method is based on the numerical solution to the governing differential equation, as presented by Navin C. Nigam and Paul C. Jennings, "Digital Calculation of Response Spectra from Strong-Motion Earthquake Records", California Institute of Technology, June 1968. Prior to processing, the acceleration time history is enveloped to insure zero initial and final conditions by a ramp up to 1.0 at 0.03T, hold to 0.97T, and ramp down to zero and 1.0T. The rectangular, half-sine, terminal-peak, triangle, and initial peak sawtooth classical shock pulses are used to verify the accuracy of the shock calculation routine.

-----Original Message-----
From: Goodluck Ofoegbu [mailto:ofoegbu@cnwra.swri.edu]
Sent: Friday, September 06, 2002 3:35 PM
To: 'James F Unruh'
Subject: Documentation Response Spectra Calculation

Hi Jim,

Is there a short description of the response spectra calculation procedure that I can insert into my scientific notebook? Thanks.

Goodluck I Ofoegbu, Ph.D.
Principal Engineer

GO 9/09/02

September 09, 2002

Analysis Files (See the attached CD).

The analysis files associated with the project are located in the attached CD. All files and subdirectories are contained in a directory named

PfsSSIAnal

Subdirectory \InputMotion contains the acceleration history data described on page 36.

Subdirectory \FrFld contains files associated with the Verification Analysis (p. 57). The lateral-boundary motion time histories listed on page 47 are located in \FrFld\LBndMotion.

Subdirectories \FrFld\Mb1 and \FrFld\Mb3 contain files associated with the Verification analyses performed with the base-input motions mb1 and mb3, respectively, which are discussed on pages 57-72.

Subdirectory \CPModel contains files associated

with the model cases described on pages 73-74 and the post-processing calculations described on pages 74-81. The subdirectory names correspond to the model-case names, e.g., \CPModel\M31 contains the files associated with model case m31 (see p. 73 for a description of the model cases).

The finite element (LS-DYNA) input file is named

jobName.k

and the nodal-history output file (described on p. 74-75) is named

jobNameNodout

where "jobName" is a variable representing the model name, e.g., ~~"mb3"~~ (GW 9/9/02) jobName=mb3 for the analysis in \FrFld\Mb3 and jobName=m32 for the analysis in the subdirectory \CPModel\M32.

The subdirectory \FullReport contains various subdirectories in which the plots and sketches developed in the project are collated. The collated plots are summarized further in the subdirectory \FullReport\Figures, in which the file names correspond with the actual figure numbers in the project report.

9/9/2002

Element Managers are requested to put the following statement at the conclusion of "manual" Scientific Notebooks:

"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.

9-30-04

(Element Manager signature and date above line, Name of Element beneath line)"

ADDITIONAL INFORMATION FOR SCIENTIFIC NOTEBOOK NO. 488

Document Date:	10/31/2001
Availability:	Southwest Research Institute® Center for Nuclear Waste Regulatory Analyses 6220 Culebra Road San Antonio, Texas 78228
Contact:	Southwest Research Institute® Center for Nuclear Waste Regulatory Analyses 6220 Culebra Road San Antonio, TX 78228-5166 Attn.: Director of Administration 210.522.5054
Data Sensitivity:	■"Non-Sensitive" ☐ Sensitive ☐"Non-Sensitive - Copyright" ☐ Sensitive - Copyright
Date Generated:	09/06/2001
Operating System: (including version number)	Windows NT, Sun
Application Used: (including version number)	ANSYS/LS-DYNA, Version 5.7 on SUN workstation; ProShake on Windows NT workstation.
Media Type: (CDs, 3 1/2, 5 1/4 disks, etc.)	1 - CDs
File Types: (.exe, .bat, .zip, etc.)	various
Remarks: (computer runs, etc.)	Media contains: data files for dynamic soil structure interaction analyses to evaluate stability of PFS cask storage pads when subjected to dynamic loading from the design-basis earthquake using explicit finite element modeling.