FRAGILITY ANALYSIS OF MAMMOTH POOL DAM
STATUS REPORT

Dr. R. Craig Findlay, P.E., G.E.

SOUTHERN CALIFORNIA EDISON
An EDISON INTERNATIONAL Company

FEI
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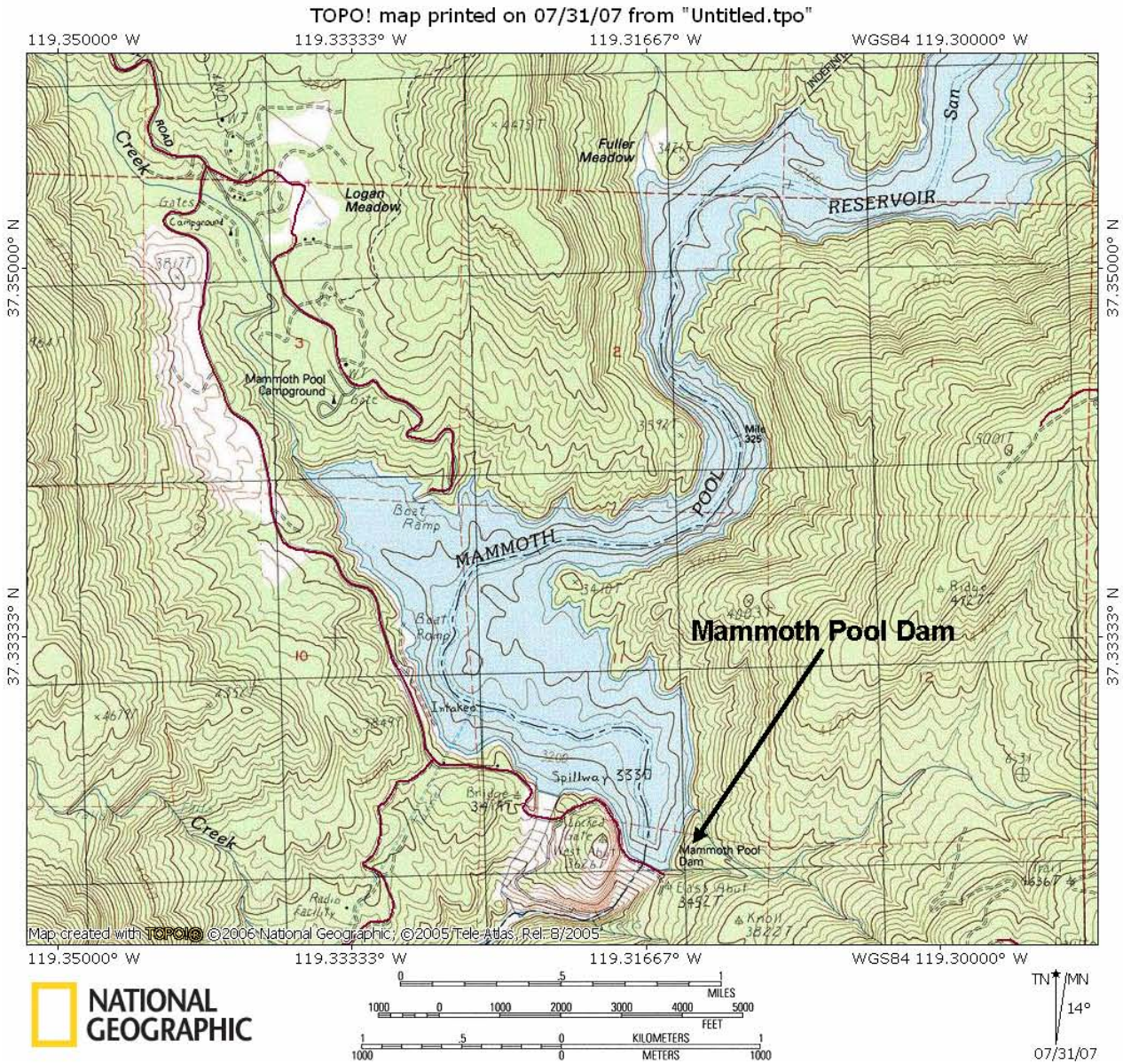
SCE PORTFOLIO RISK ASSESSMENT PROGRAM

- **Preliminary Stages of Portfolio Risk Assessment Program**

- **Fragility Analyses: assess the level of safety ("risk") at various return periods of natural events**

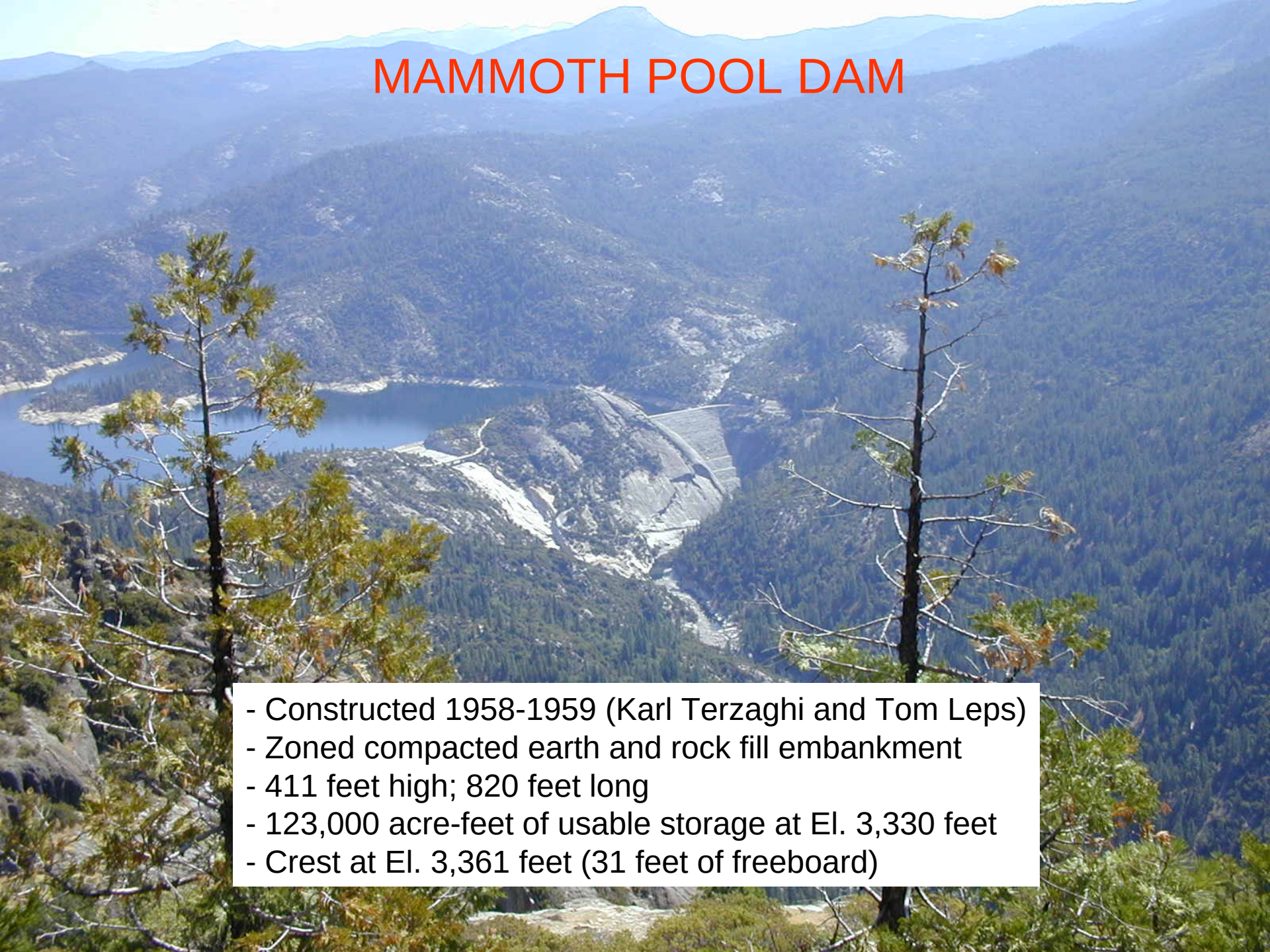
- **Analyses currently being performed at:**
  - **Dam 7 (concrete gravity), and**
  - **Mammoth Pool Dam (embankment)**

This presentation deals with Mammoth Pool Dam

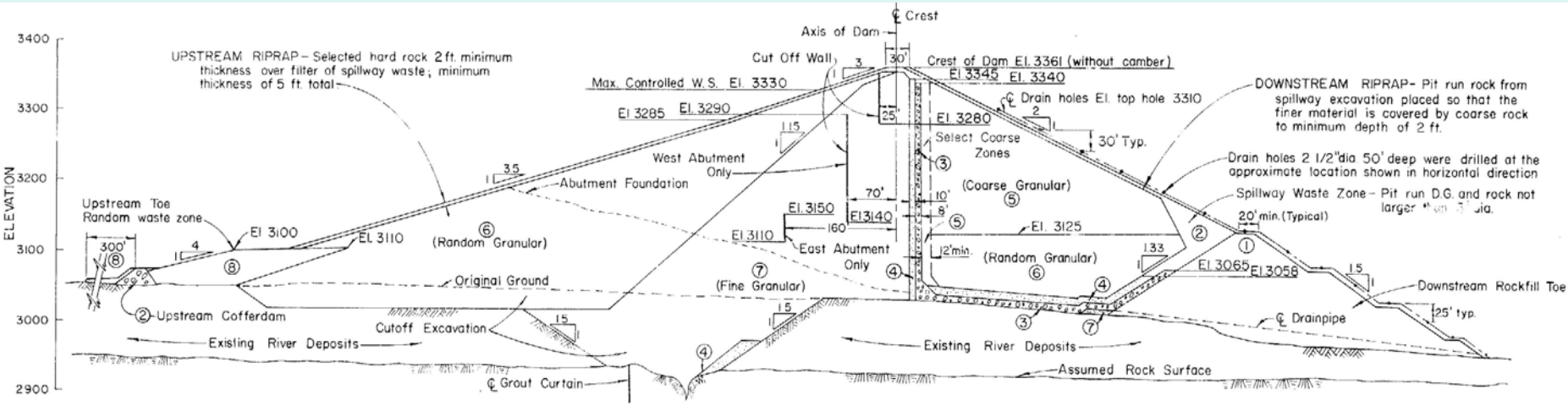

TOPO! map printed on 07/31/07 from "Untitled.tpo"
119.35000° W
119.33333° W
119.31667° W
WGS84 119.30000° W
37.35000° N
37.33333° N
Creek
Logan Meadow
Fuller Meadow
RESERVOIR
San
Mammoth Pool Campground
Mile 325
MAMMOTH
POOL
Boat Ramp
Intakes
Spillway 3330
Mammoth Pool Dam
Mammoth Pool Dam
Map created with TOPO!® ©2006 National Geographic; ©2005 Tele Atlas, Rel. 8/2005
NATIONAL GEOGRAPHIC
MILES
FEET
KILOMETERS
METERS
TN
MN
14°
07/31/07

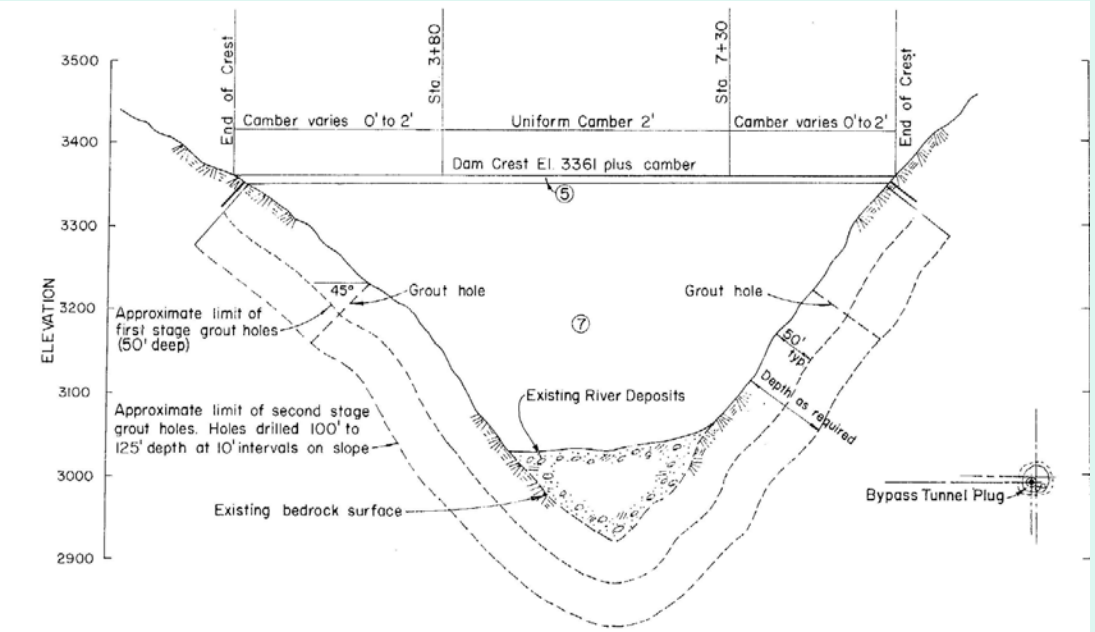
Project Location

MAMMOTH POOL DAM



- Constructed 1958-1959 (Karl Terzaghi and Tom Leps)
- Zoned compacted earth and rock fill embankment
- 411 feet high; 820 feet long
- 123,000 acre-feet of usable storage at El. 3,330 feet
- Crest at El. 3,361 feet (31 feet of freeboard)





RIVER SECTION ALONG AXIS OF DAM — LOOKING DOWNSTREAM

ASSESS THE SCOPE OF SEISMIC ANALYSIS

What needs to be assessed?

Liquefaction?

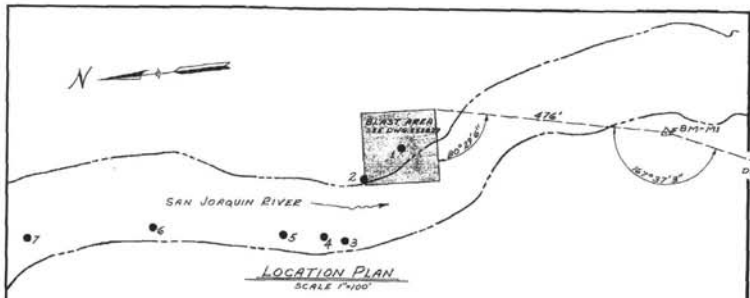
Deformation?

Liquefaction Potential

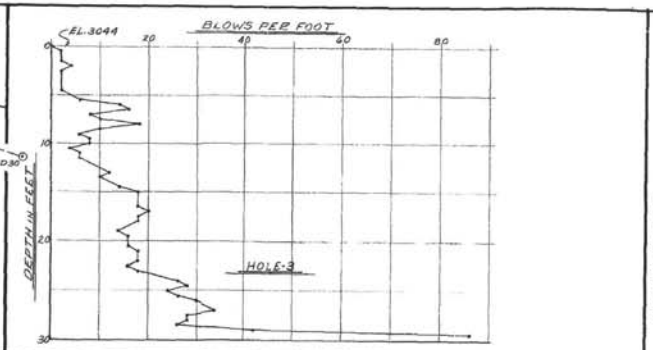
- Dam is of modern compacted lift construction

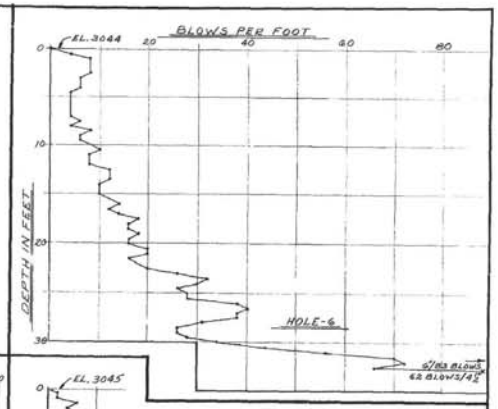
- Dam founded on up to ~100 feet of alluvial soils;

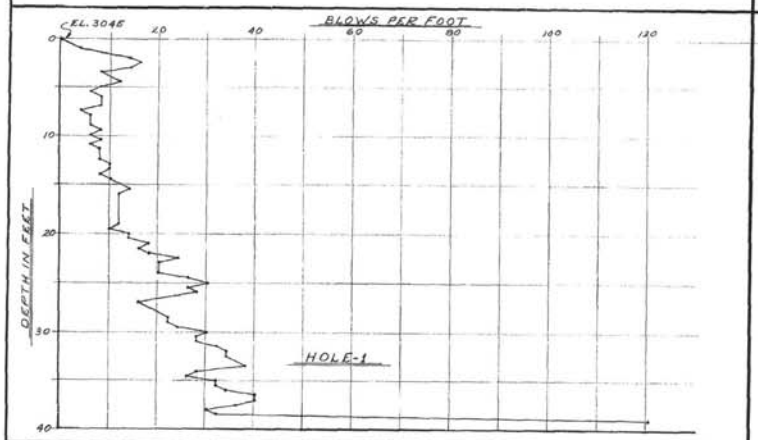
- Original explorations found:
    - Downstream very dense for full profile
    - Upstream upper 30 feet relatively looser

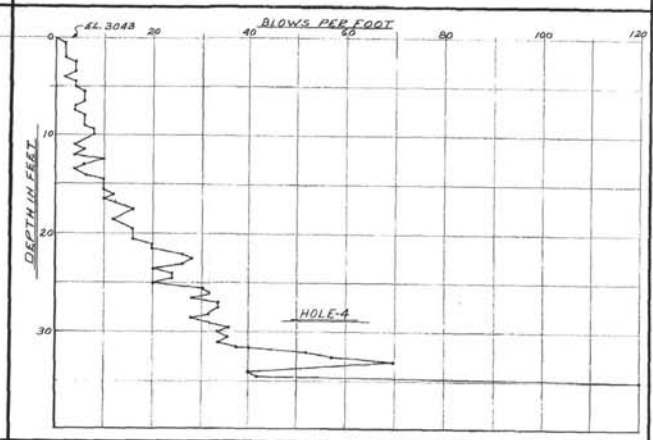


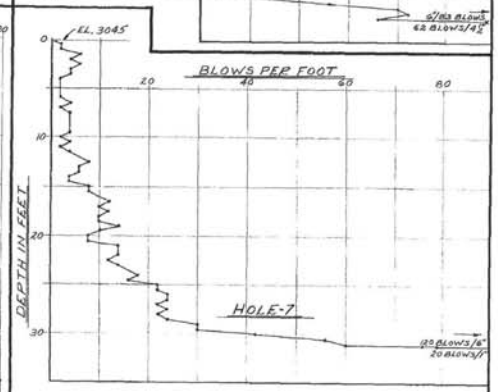
LOCATION PLAN
SCALE 1"=100'

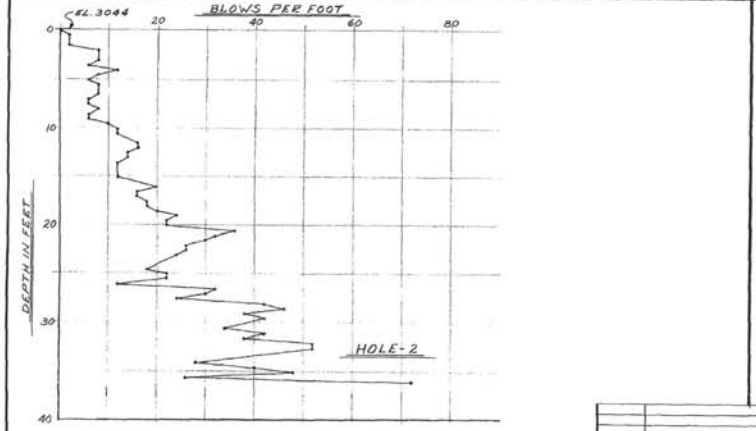


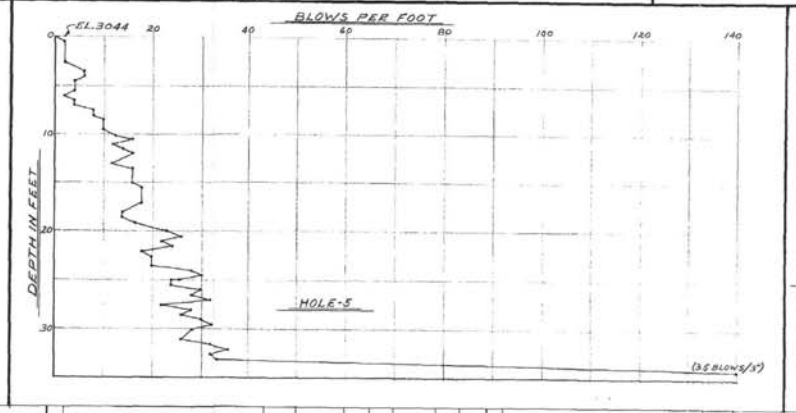












NOTE
PENETRATIONS WERE OBTAINED USING A 3" ø FLAT BOTTOMED STEEL DISK PENETROMETER, WITH A 200 LB. WEIGHT FALLING 30" IN AIR.

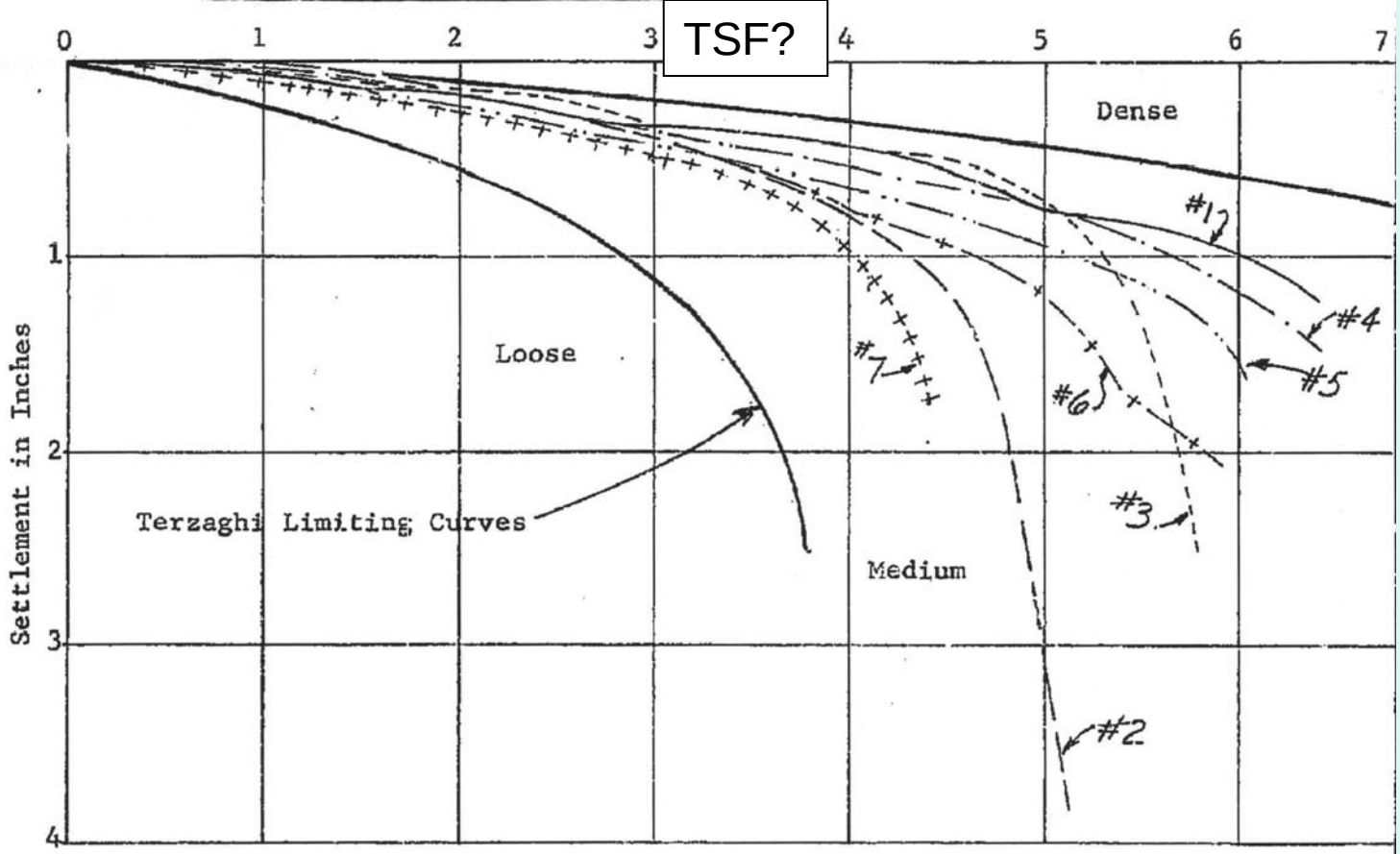
NO CASING WAS USED

THIS DWG. SUPERSEDES DWG. N-1206

N-1206	PENETRATION PLOTS																						
DRWG. NO.	CROSS REFERENCES	NO.	REVISIONS	DATE	APPROVED	O.K.	O.K.	CHECKED	MADE	J.O. NO.	NO.	REVISIONS	DRAWN	TRACED	COMPARED	3-24-59 DATE	APPROVED	O.K.	O.K.	CHECKED	R.H.G. 12-51 MADE	J.O. NO.	LOCATION MAMMOTH POOL

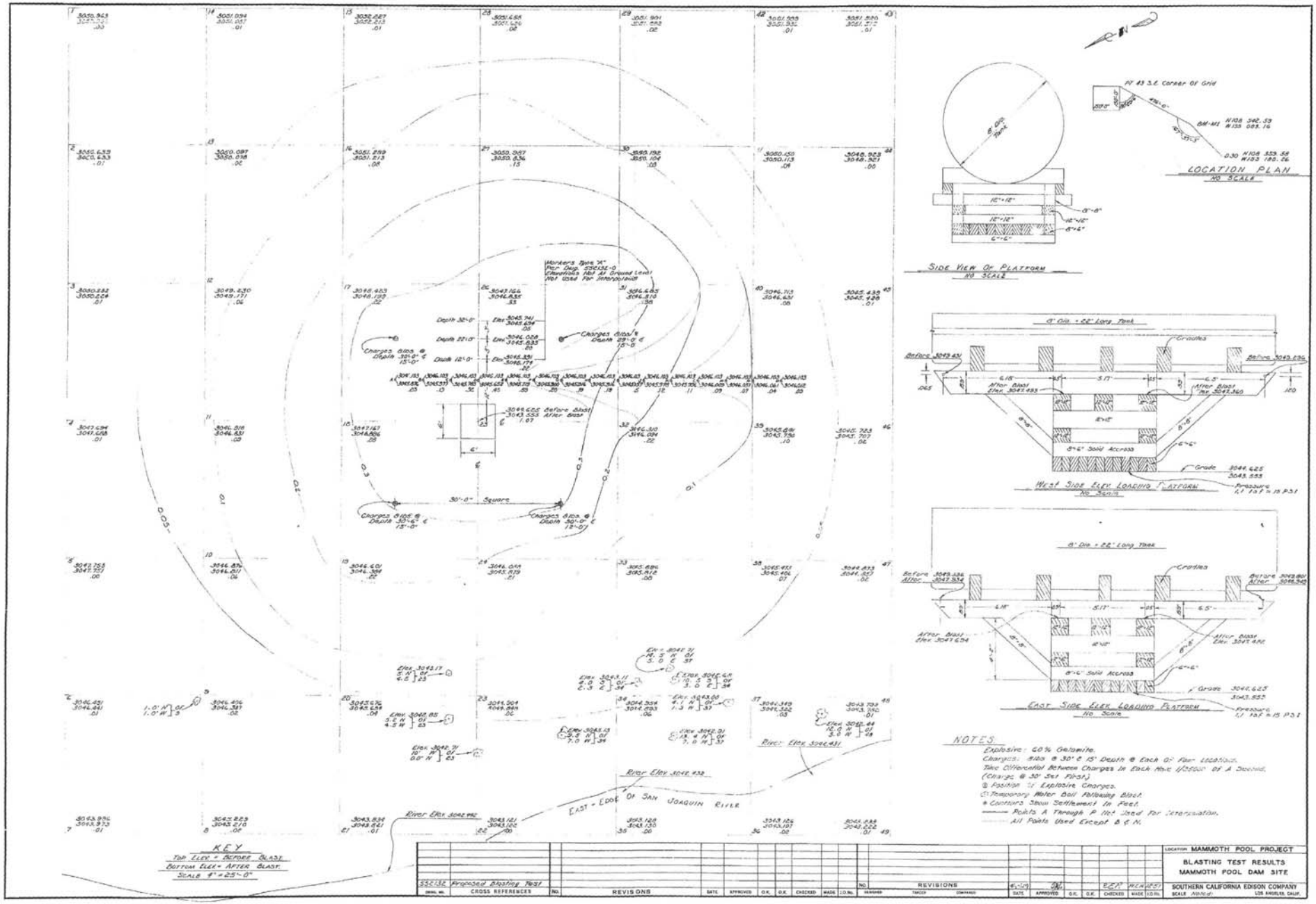
DAMSITE
PENETRATION TESTS
SOUTHERN CALIFORNIA EDISON COMPANY
SCALE LOS ANGELES, CALIF.

553872-1



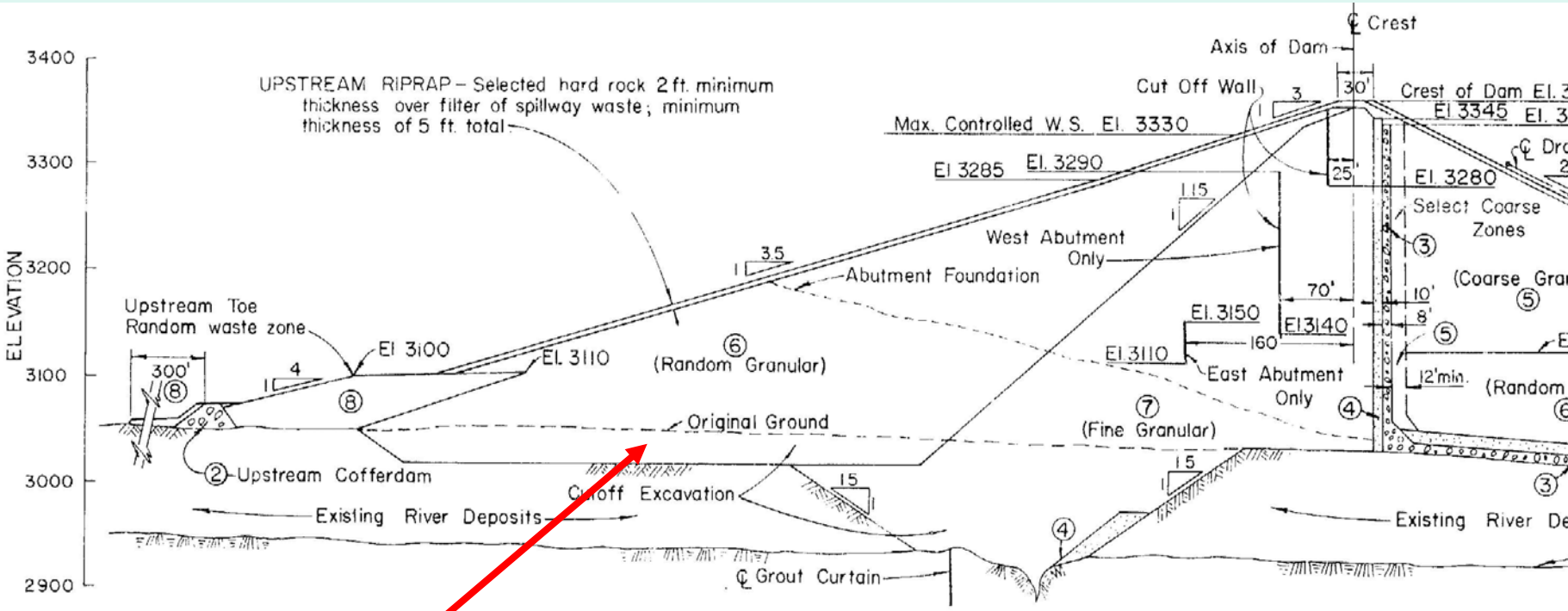
Zone No.	Elev. ft.	In-Place Dry Den. pcf	Laboratory Dry Density Max. pcf	Laboratory Dry Density Min. pcf	Relative Density Percent	Percent of Maximum Density	Sand Description	% Rock
1	3017.9	100.0	114.6	93.4	35	87	Coarse, clean	5
2	3019.6	109.4	117.9	101.6	52	93	Gravelly, coarse	33
3	3016.0	107.2	117.9	101.6	41	91	Coarse, clean	0
4	3027.8	88.3	94.0	81.0	61	94	Uniform, medium	0
5	3032.5	105.5	106.0	88.6	100	100	Coarse, clean	4
6	3028.1	101.3	103.8	88.8	87	98	Medium to coarse	5
7	3012	98.2	108.2	93.2	34	91		

Note: Plate 1 foot square, 3 feet minimum distance from edge of plate to bank. Plate set on level surface. Small load applied to seat plate.



LOCATION PLAN
NO SCALE
SIDE VIEW OF PLATFORM
NO SCALE
WEST SIDE ELEV. LOADING PLATFORM
NO SCALE
EAST SIDE ELEV. LOADING PLATFORM
NO SCALE
8' Dia. = 22' Long Tank
Cradles
8'-6" Solid Access
Grade
Pressure 1.1 tsf = 15 PSI
Workers Type "A" Per Dwg. 552132-0 Elevations Not At Ground Level Not Used For Interpolation
Charges Blds. @ Depth 30'-0" ℄ 15'-0"
Charges Blds. @ Depth 30'-0" ℄ 12'-0"
30'-0" Square
Charges Blds. @ Depth 30'-6" ℄ 15'-0"
Charges Blds. @ Depth 30'-0" ℄ 12'-0"
Depth 32'-0"
Depth 22'-0"
Depth 12'-0"
Elev. 3045.741 3045.694
Elev. 3046.028 3045.835
Elev. 3045.891 3045.174
3049.625 Before Blast 3043.555 After Blast
River Elev. 3042.432
River Elev. 3042.431
River Elev. 3042.442
EAST - EDGE OF SAN JOAQUIN RIVER
KEY
TOP ELEV. = BEFORE BLAST
BOTTOM ELEV. = AFTER BLAST
SCALE 4" = 25'-0"
NOTES
Explosive: 60% Gelamite.
Charges: Blds @ 30' & 15' Depth @ Each Of Four Locations.
Time Differential Between Charges In Each Hole 1/35000 Of A Second.
(Charge @ 30' Set First.)
Position Of Explosive Charges.
Temporary Water Ball Following Blast.
Contours Show Settlement In Feet.
Points A Through P Not Used For Interpolation.
All Points Used Except B & N.
552132 Proposed Blasting Test
DRWG. NO.
CROSS REFERENCES
NO.
REVISIONS
DATE
APPROVED
O.K.
CHECKED
MADE
I.O. No.
LOCATION MAMMOTH POOL PROJECT
BLASTING TEST RESULTS
MAMMOTH POOL DAM SITE
SOUTHERN CALIFORNIA EDISON COMPANY
SCALE Noted
LOS ANGELES, CALIF.

552827-



Removed 30’ Depth of Looser Alluvium

Therefore, chance of significant liquefaction appears remote;
>>>> Focus on deformation analysis

Deformation Analysis

- GeoStudio Analysis Suite – GeoSlope Intl., Calgary
    - SEEP/W for seepage analysis/seepage forces
    - SIGMA/W for Initial stress analysis
    - QUAKE/W for Seismic Response (Equivalent Linear Model, similar to QUAD4M)
    - SLOPE/W for Newmark Deformation Analysis

BENEFIT:
- CAD-like Problem Set up (Fast Problem Development)
- Integrated Models/Same FEM Mesh (Mitigates transposition errors)
- Streamline consideration of many time histories
- Newmark implementation allows consideration of many potential failure surfaces

SEEP/W, SLOPE/W and SIGMA/W have been around for a long time..

But, how does QUAKE/W compare to other methods?

- GeoSlope Intl. compared with flat ground, one dimensional conditions

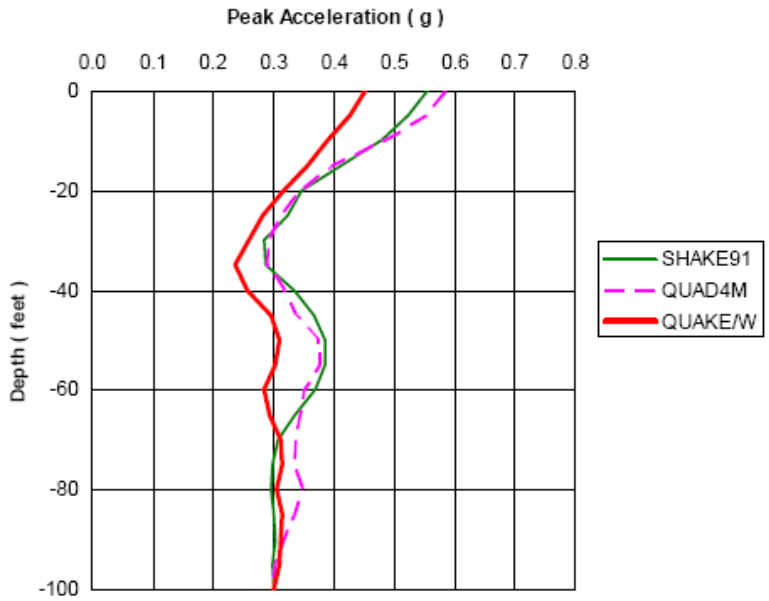


Figure 6 Peak acceleration with input motion scaled to 0.3g

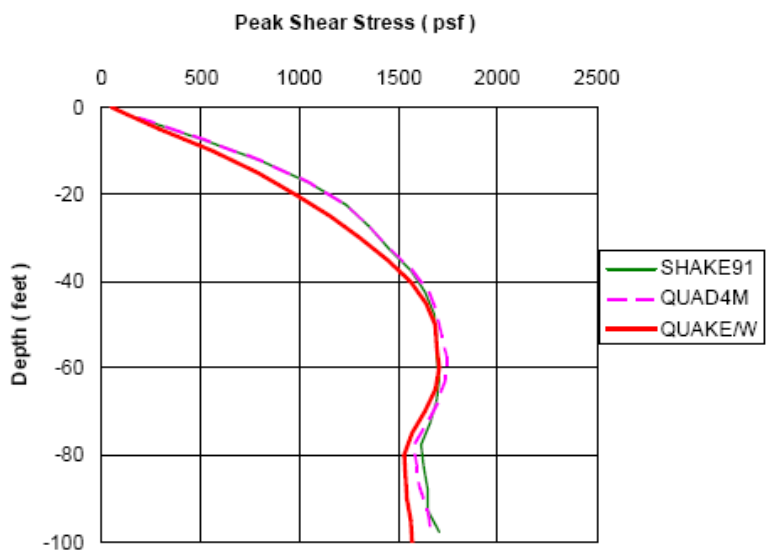


Figure 7 Peak shear stress with input motion scaled to 0.3g

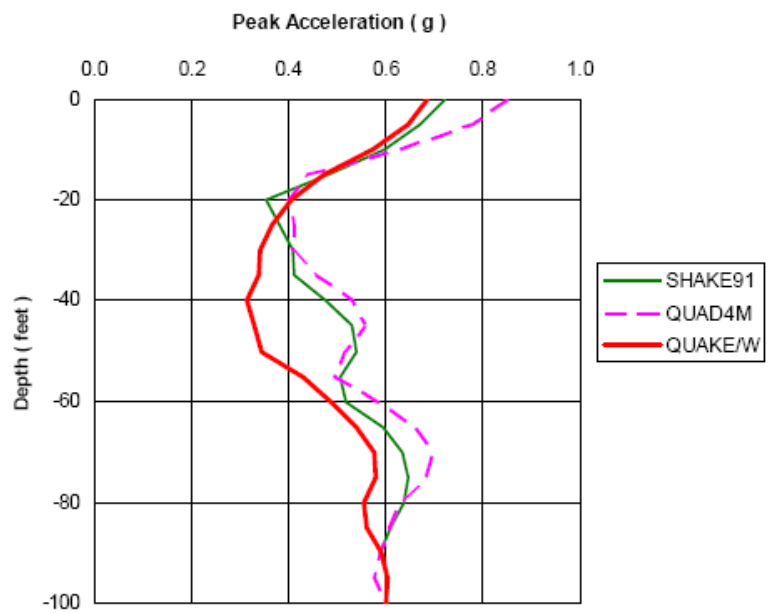


Figure 8 Peak acceleration with input motion scaled to 0.6g

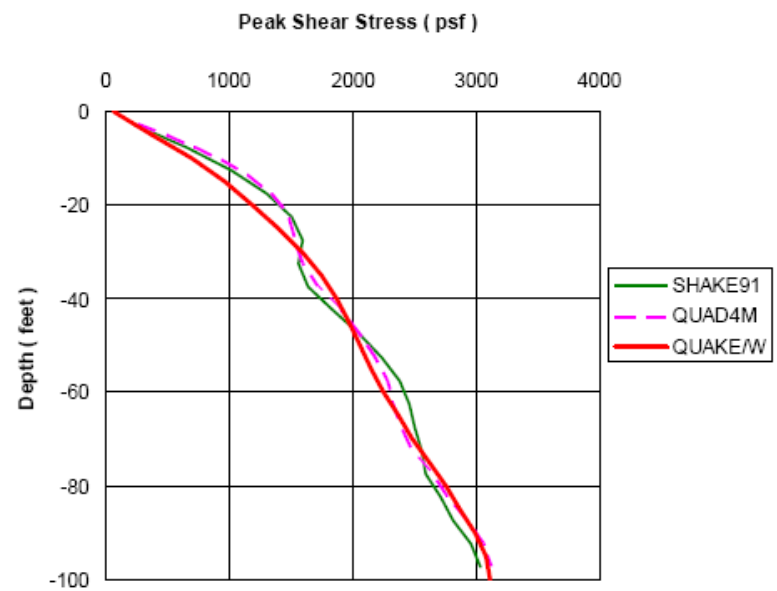
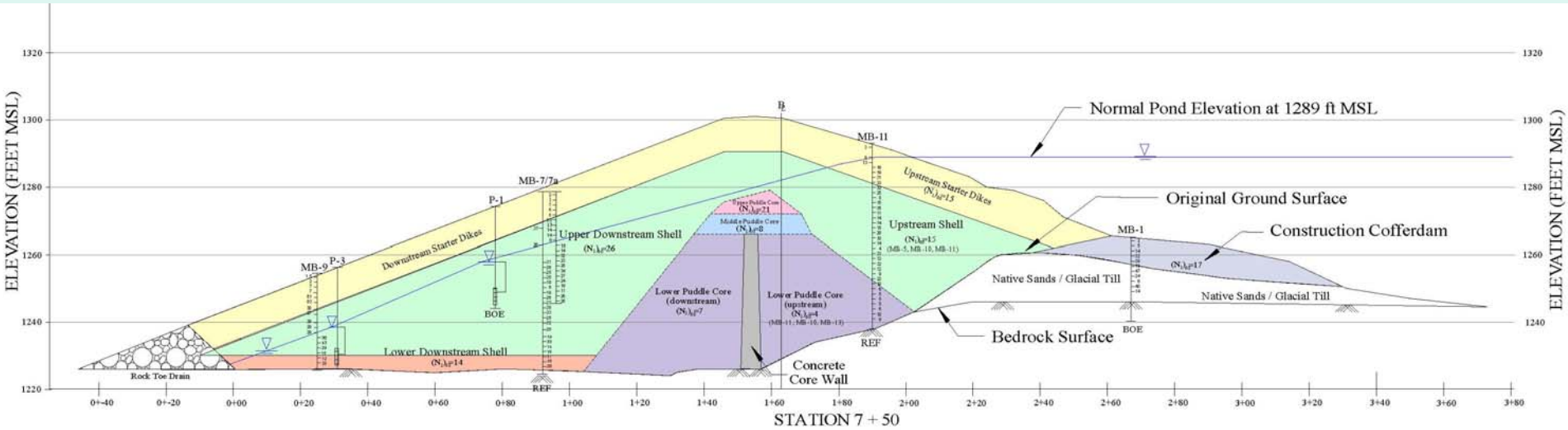


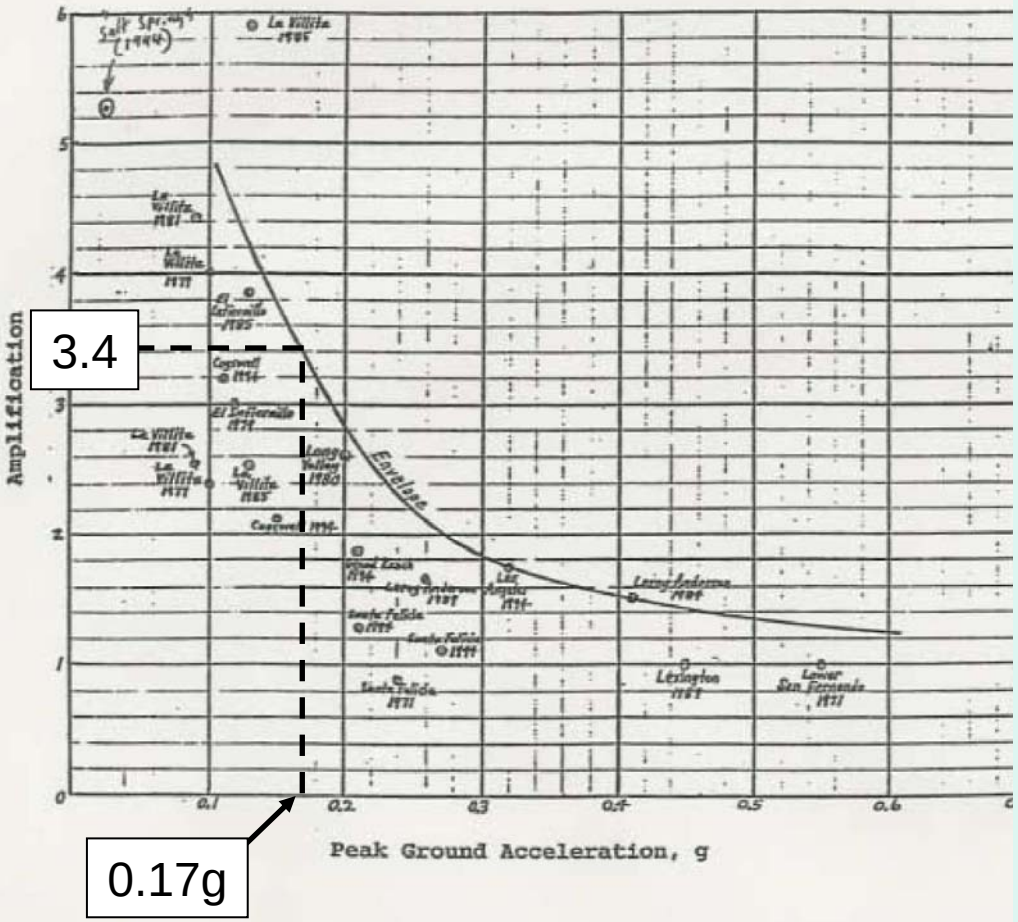
Figure 9 Peak shear stress with input motion scaled to 0.6g



Diversion Dam
Crogan, New York
Brookfield Power
Hydraulic Fill (Sand)
<u>QUAD4M Analysis</u>

Morgan Territory Park Record
1980 Livermore Earthquake, Scaled to 0.17g

MEASURED RATIOS (AMPLIFICATION) OF CREST AND BASE ACCELERATIONS AT EMBANKMENT DAMS IN RESPONSE TO EARTHQUAKES



Notes: This graph represents measured accelerations at embankment dams ranging widely in size, geometry, materials, and foundation conditions.

The two plotted values for La Villita Dam for each indicated year are based on the positive and negative amplitudes from asymmetric accelerograms of crest motion.

The envelope is drawn as an upper limit of amplifications, reflecting the average of La Villita peak crest accelerations in the 1985 earthquake.

LEPS AND JANSEN PLOT

FIGURE 12

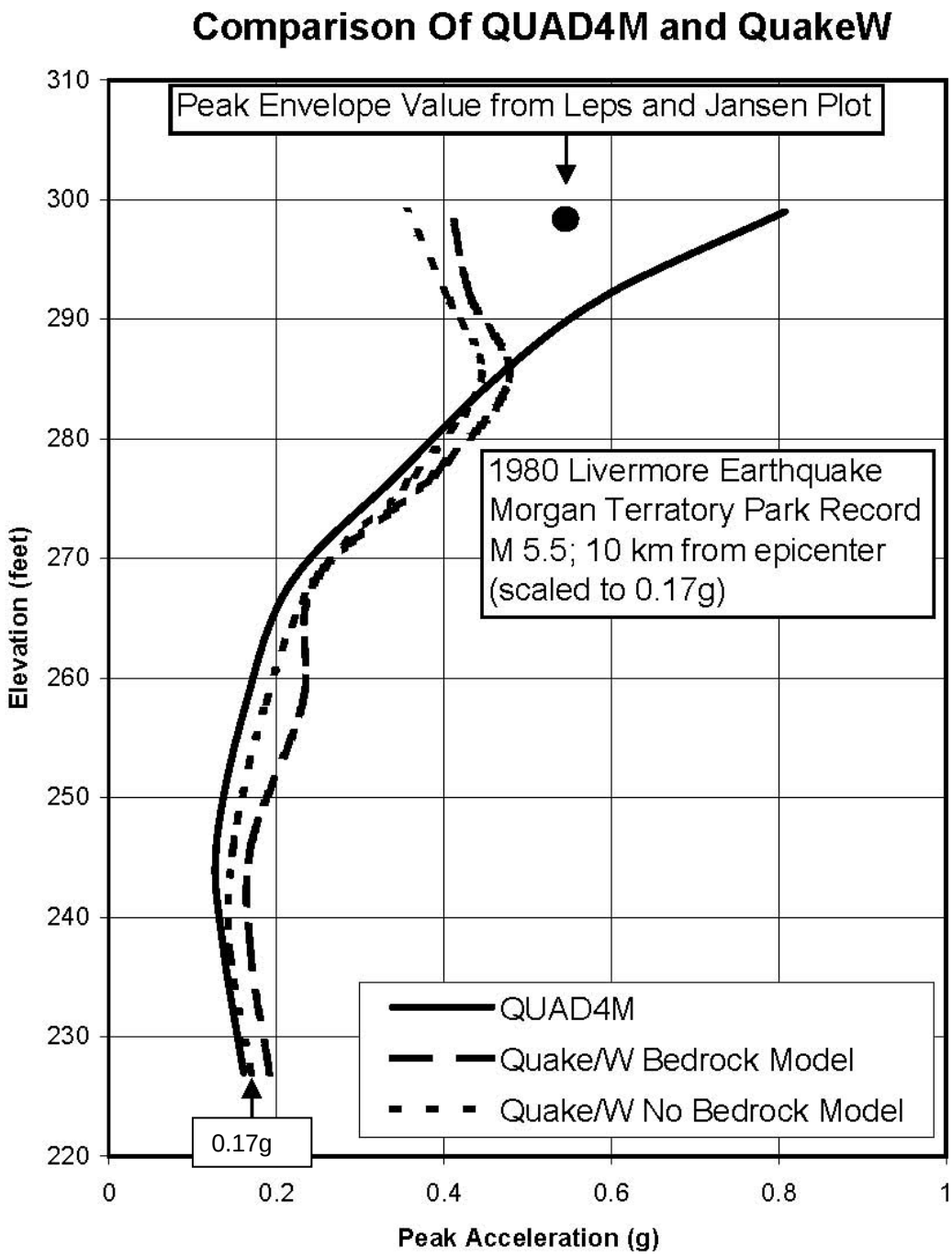
1980 Livermore Earthquake
Morgan Territory Park Record
Scaled to 0.17g

From Leps and Jansen Plot:

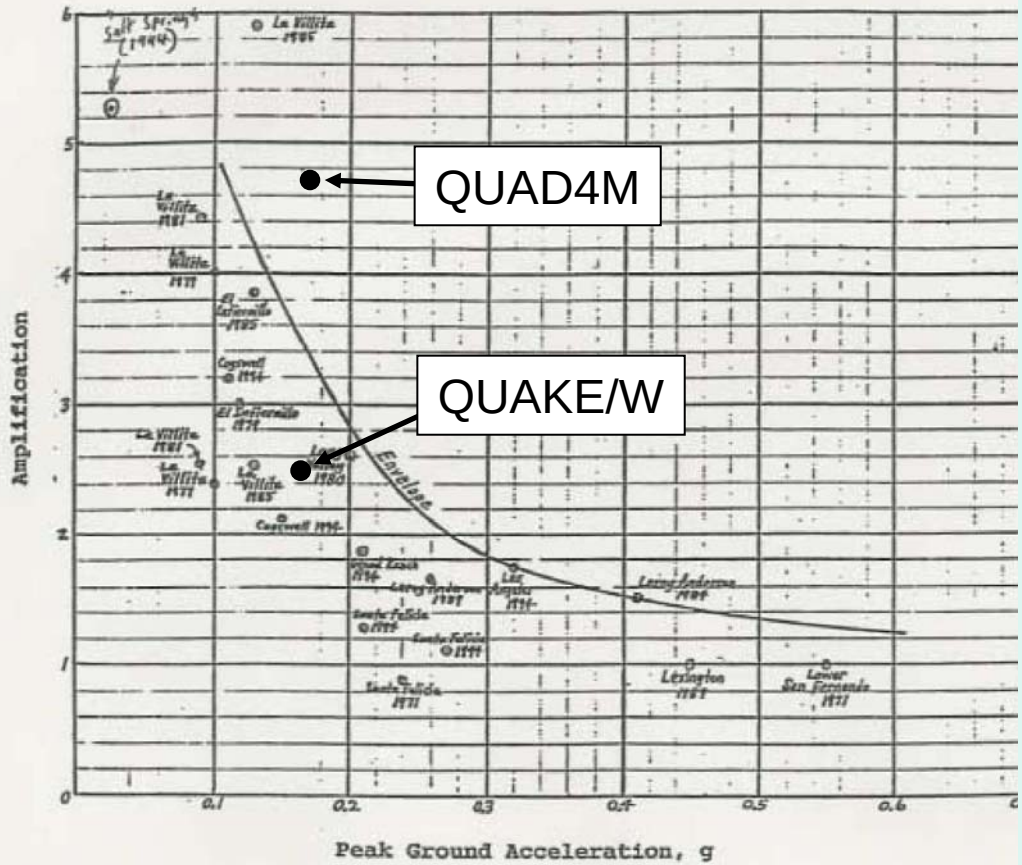
For 0.17g, Amplification = 3.4

Therefore:
Max. Envelope Crest Acceleration:

0.17g x 3.4 = <u>0.58g</u>


Comparison Of QUAD4M and QuakeW
Peak Envelope Value from Leps and Jansen Plot
1980 Livermore Earthquake
Morgan Terratory Park Record
M 5.5; 10 km from epicenter
(scaled to 0.17g)
QUAD4M
Quake/W Bedrock Model
Quake/W No Bedrock Model
0.17g
Elevation (feet)
Peak Acceleration (g)
310
300
290
280
270
260
250
240
230
220
0
0.2
0.4
0.6
0.8
1

MEASURED RATIOS (AMPLIFICATION) OF CREST AND BASE ACCELERATIONS AT EMBANKMENT DAMS IN RESPONSE TO EARTHQUAKES



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LEPS AND JANSEN PLOT

FIGURE 12

Time Histories: Developed by Geomatrix (Robert Youngs)

Probabilistic Seismic Hazard Assessment; Deaggregation of 1.0 Sec Hazard (estimated 0.08 to 1.7 second period for Mammoth Pool Dam)

Four Scenarios found as major contributors for Mammoth Pool Dam Site:

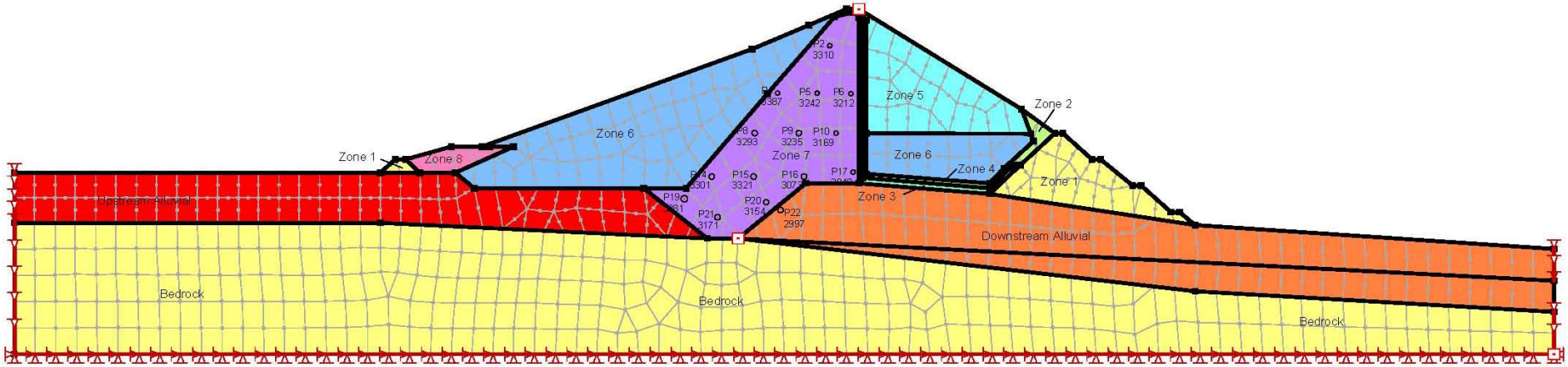
Event 1 – M6.6 at 58 km
Event 2 – M7.5 at 100 km
Event 3 – M7.9 at 200 km
Event 4 – M6.2 at 7 km

3 sets of time histories for each event; each time history scaled for return periods of 1000, 2500, 5000 and 10000 years

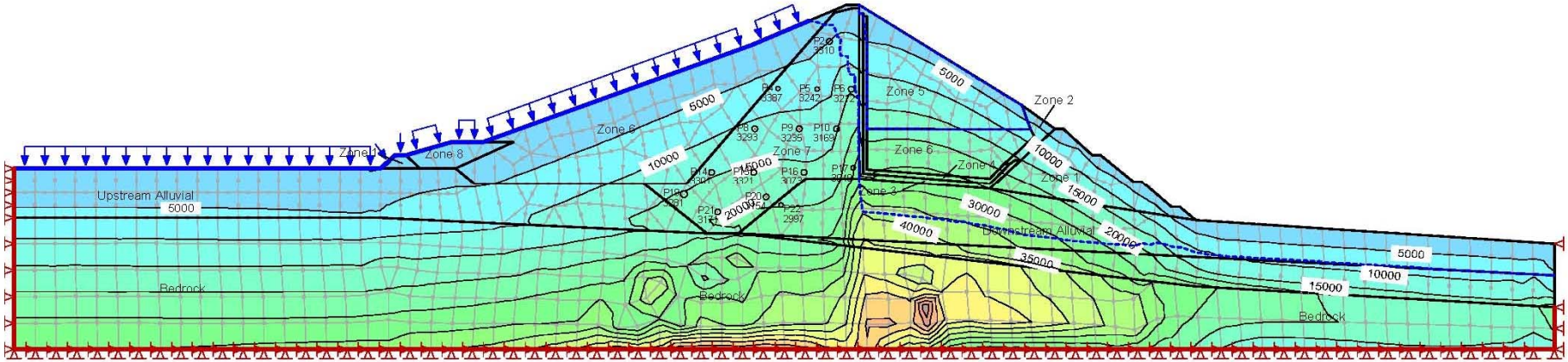
Time history set includes fault normal, fault parallel and vertical time histories.

- Since 2-D model, both fault normal and fault parallel analyses will be considered, each analysis also including the vertical time history.

-Total of 78 time history analysis runs



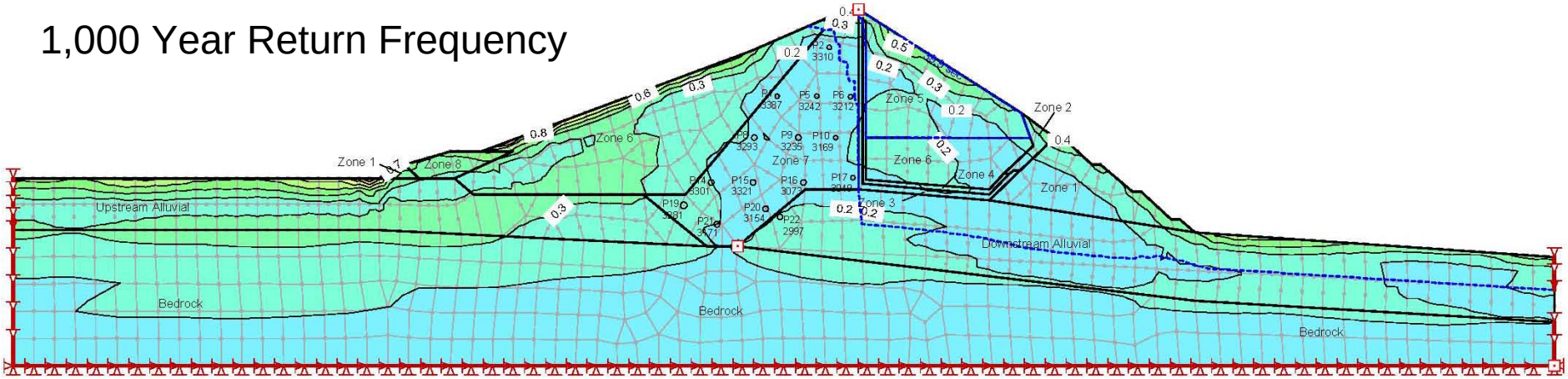
FINITE ELEMENT MESH
- Seep/W
- Slope/W
- Quake/W
- Slope/W



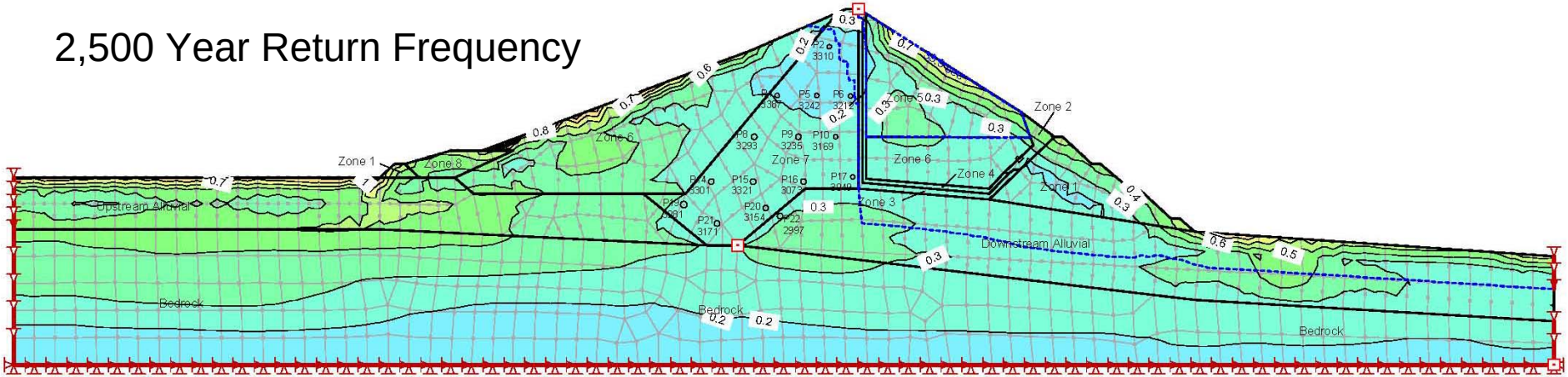
SIGMA/W FEM STRESS ANALYSIS – EFFECTIVE VERTICAL STRESSES

EVENT 1 – M 6.6 AT 58 KM
1989 LOMA PRIETA – PRESIDO STATION (M 6.9)
QUAKE/W RESULTS – PEAK ACCELERATION

1,000 Year Return Frequency

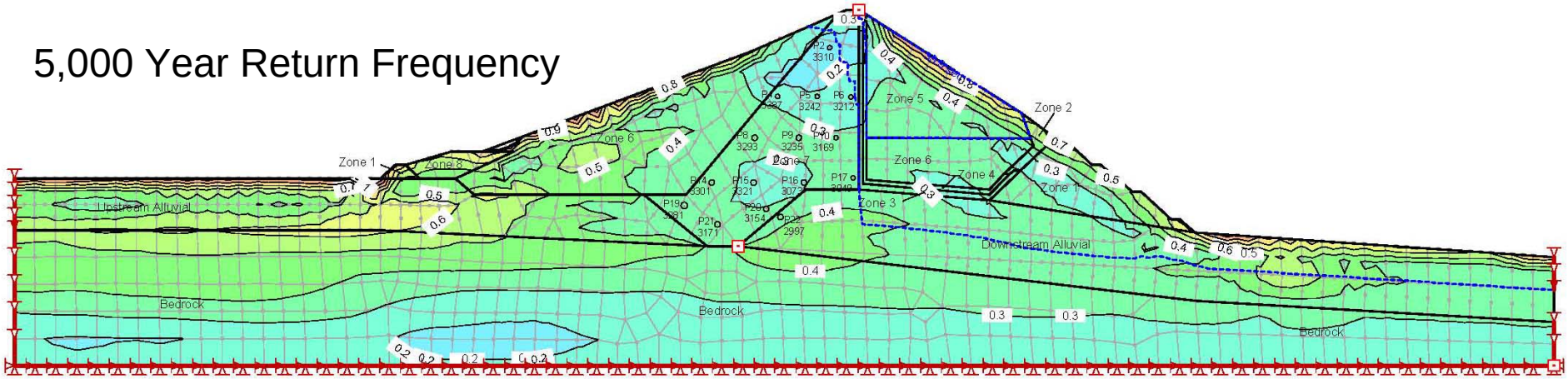


2,500 Year Return Frequency

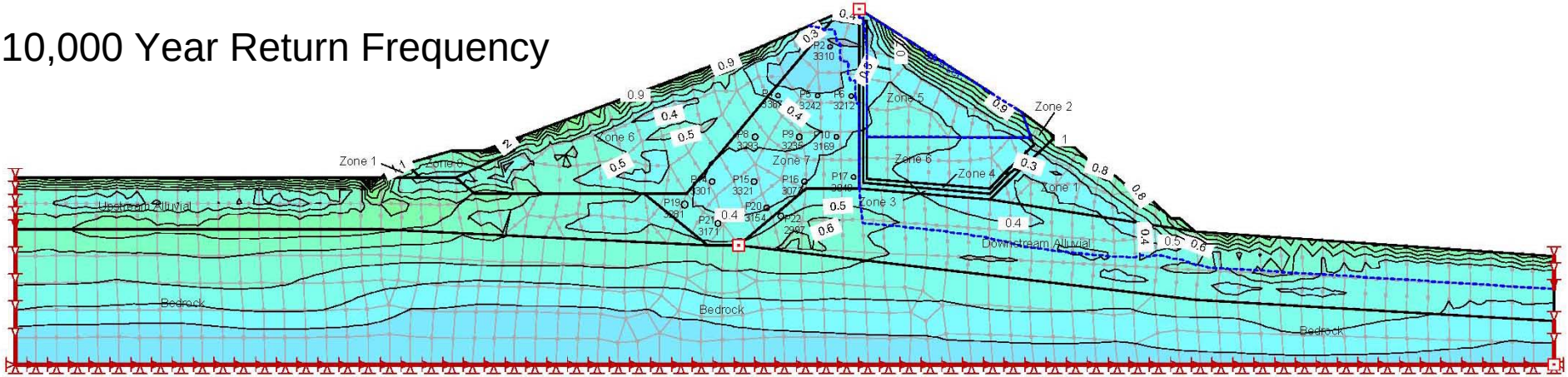


EVENT 1 – M 6.6 AT 58 KM
1989 LOMA PRIETA – PRESIDO STATION (M 6.9)
QUAKE/W RESULTS – PEAK ACCELERATION

5,000 Year Return Frequency



10,000 Year Return Frequency



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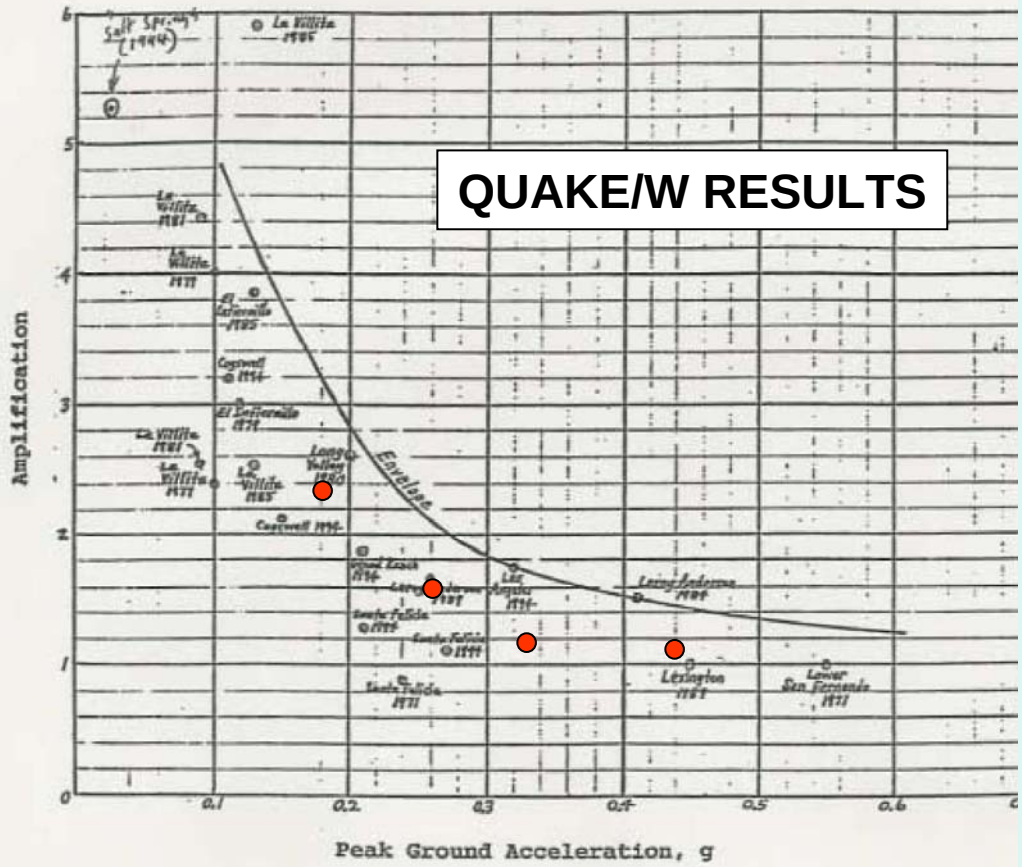

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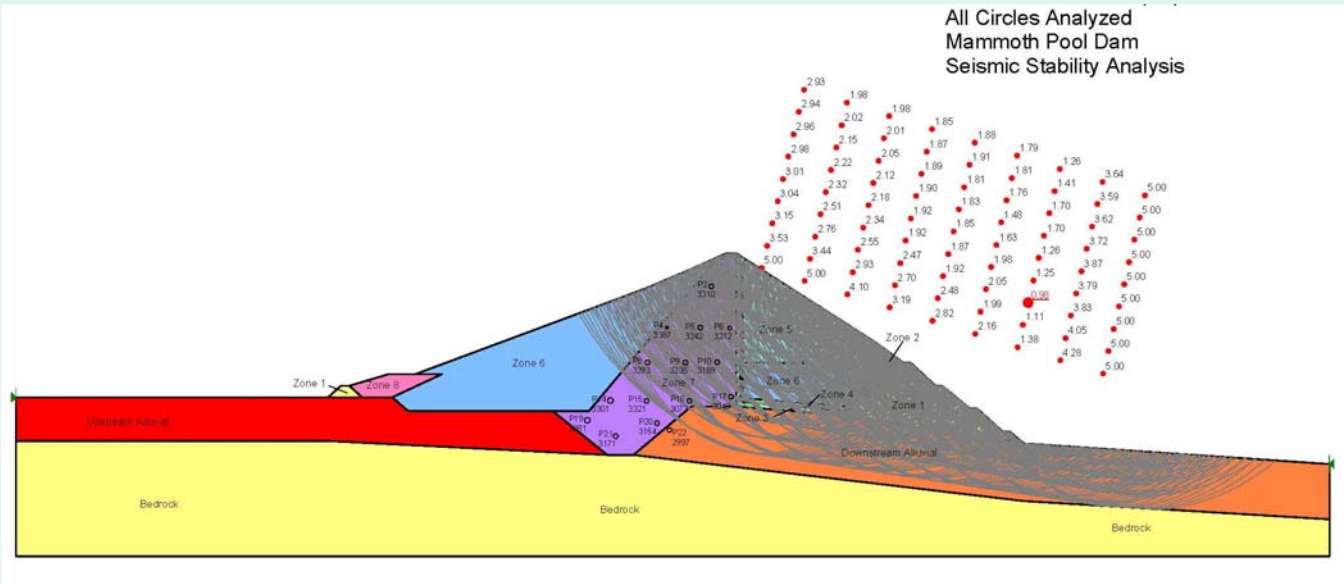
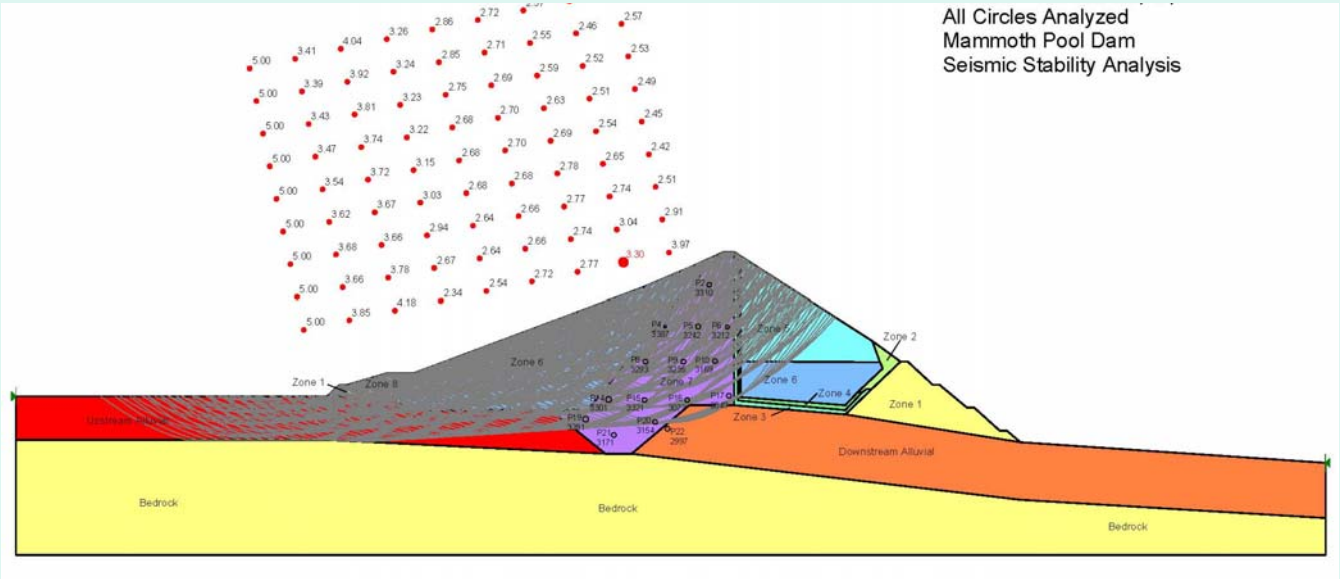
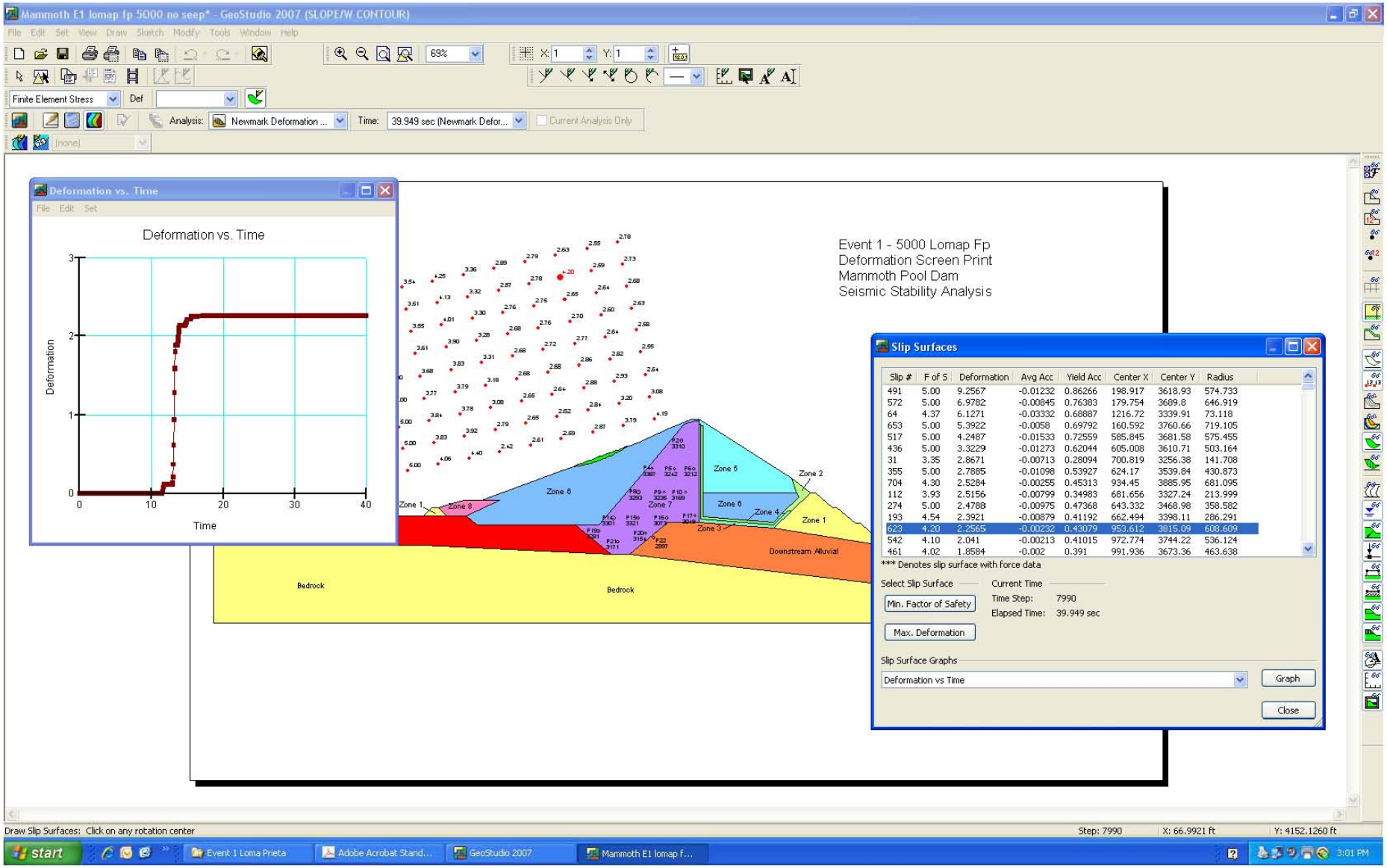
LEPS AND JANSEN PLOT

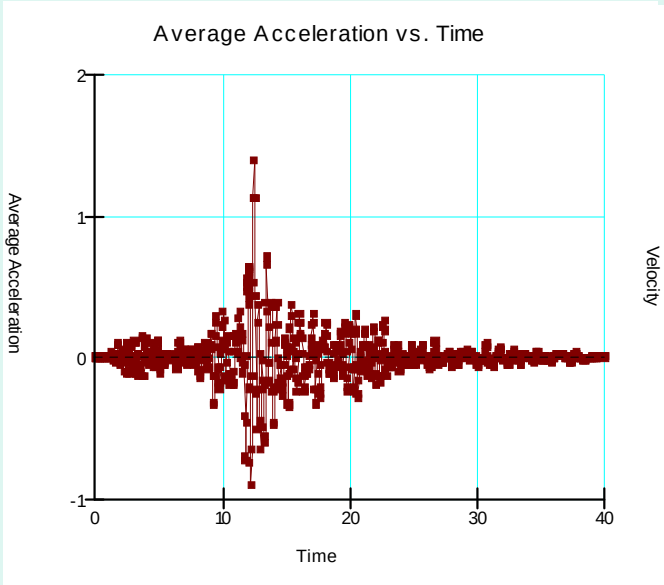
FIGURE 12

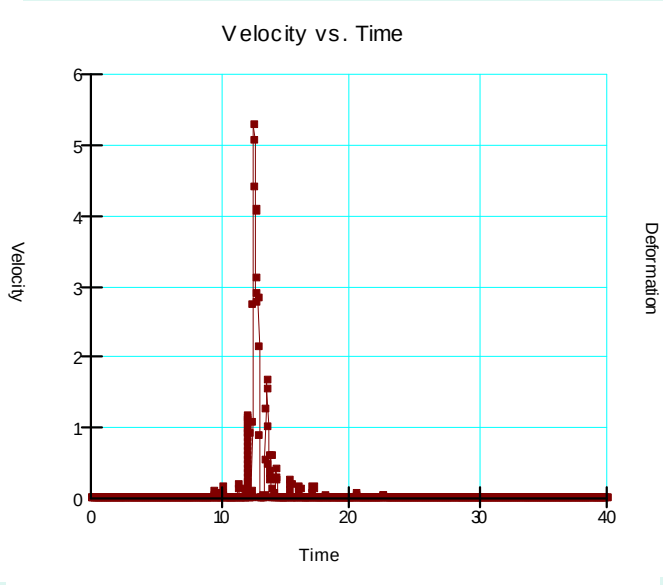
SLOPE/W DEFORMATION ANALYSIS
ALL CIRCLES ANALYZED

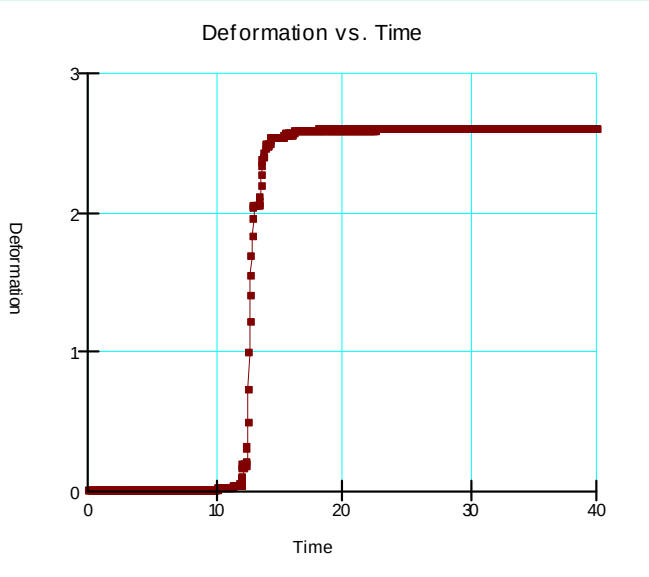





Mammoth E1 lomap fp 5000 no seep* - GeoStudio 2007 (SLOPE/W CONTOUR)
File Edit Set View Draw Sketch Modify Tools Window Help
Finite Element Stress
Def
Analysis: Newmark Deformation ...
Time: 39.949 sec (Newmark Defor...
Current Analysis Only
Deformation vs. Time
File Edit Set
Deformation vs. Time
Deformation
Time
0
1
2
3
0
10
20
30
40
Event 1 - 5000 Lomap Fp
Deformation Screen Print
Mammoth Pool Dam
Seismic Stability Analysis
Zone 1
Zone 2
Zone 3
Zone 4
Zone 5
Zone 6
Zone 7
Zone 8
Downstream Alluvial
Bedrock
Bedrock
Slip Surfaces
Slip # | F of S | Deformation | Avg Acc | Yield Acc | Center X | Center Y | Radius
491 | 5.00 | 9.2567 | -0.01232 | 0.86266 | 198.917 | 3618.93 | 574.733
572 | 5.00 | 6.9782 | -0.00845 | 0.76383 | 179.754 | 3689.8 | 646.919
64 | 4.37 | 6.1271 | -0.03332 | 0.68887 | 1216.72 | 3339.91 | 73.118
653 | 5.00 | 5.3922 | -0.0058 | 0.69792 | 160.592 | 3760.66 | 719.105
517 | 5.00 | 4.2487 | -0.01533 | 0.72559 | 585.845 | 3681.58 | 575.455
436 | 5.00 | 3.3229 | -0.01273 | 0.62044 | 605.008 | 3610.71 | 503.164
31 | 3.35 | 2.8671 | -0.00713 | 0.28094 | 700.819 | 3256.38 | 141.708
355 | 5.00 | 2.7885 | -0.01098 | 0.53927 | 624.17 | 3539.84 | 430.873
704 | 4.30 | 2.5284 | -0.00255 | 0.45313 | 934.45 | 3885.95 | 681.095
112 | 3.93 | 2.5156 | -0.00799 | 0.34983 | 681.656 | 3327.24 | 213.999
274 | 5.00 | 2.4788 | -0.00975 | 0.47368 | 643.332 | 3468.98 | 358.582
193 | 4.54 | 2.3921 | -0.00879 | 0.41192 | 662.494 | 3398.11 | 286.291
623 | 4.20 | 2.2565 | -0.00232 | 0.43079 | 953.612 | 3815.09 | 608.609
542 | 4.10 | 2.041 | -0.00213 | 0.41015 | 972.774 | 3744.22 | 536.124
461 | 4.02 | 1.8584 | -0.002 | 0.391 | 991.936 | 3673.36 | 463.638
*** Denotes slip surface with force data
Select Slip Surface
Min. Factor of Safety
Max. Deformation
Current Time
Time Step: 7990
Elapsed Time: 39.949 sec
Slip Surface Graphs
Deformation vs Time
Graph
Close
Draw Slip Surfaces: Click on any rotation center
Step: 7990
X: 66.9921 ft
Y: 4152.1260 ft
start
Event 1 Loma Prieta
Adobe Acrobat Stand...
GeoStudio 2007
Mammoth E1 lomap f...
3:01 PM


Average Acceleration vs. Time
Average Acceleration
Time
2
1
0
-1
0
10
20
30
40

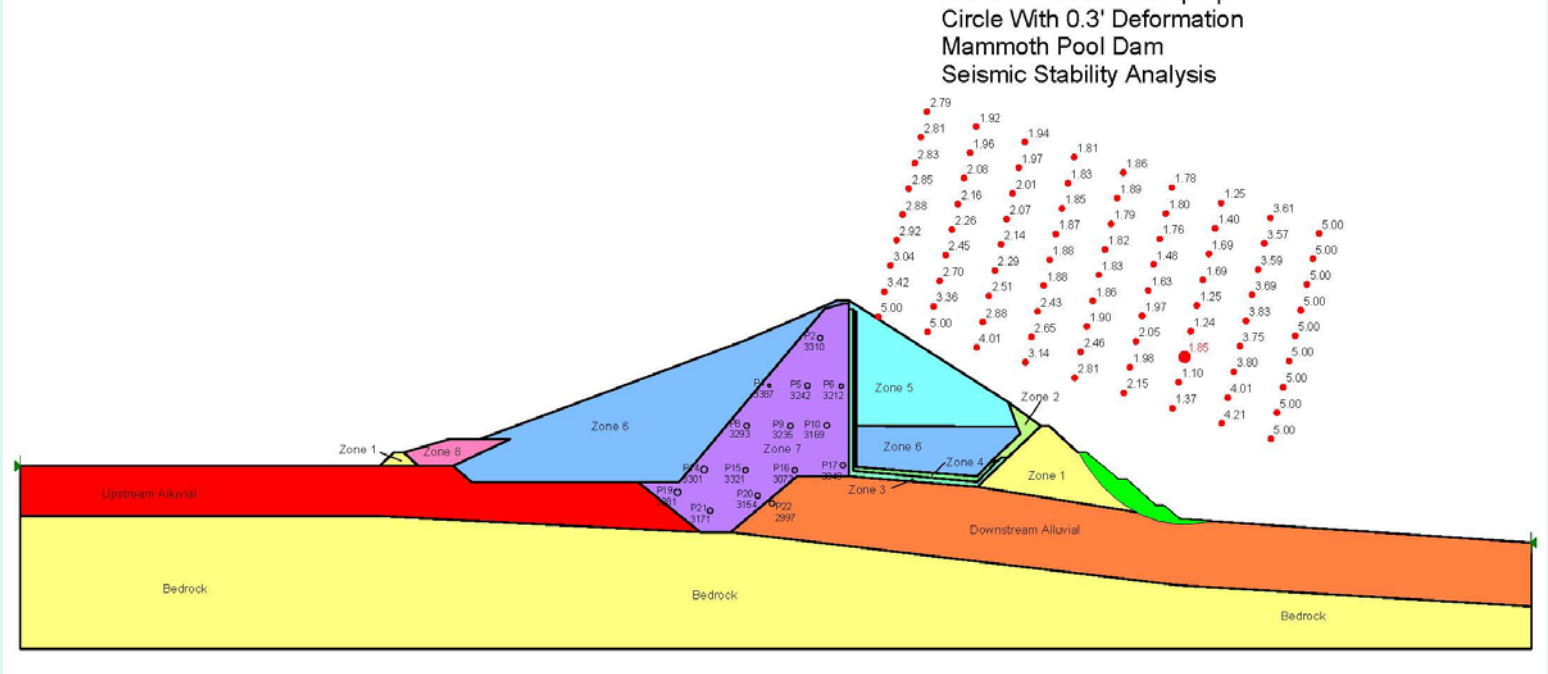

Velocity vs. Time
Velocity
Time
6
5
4
3
2
1
0
0
10
20
30
40

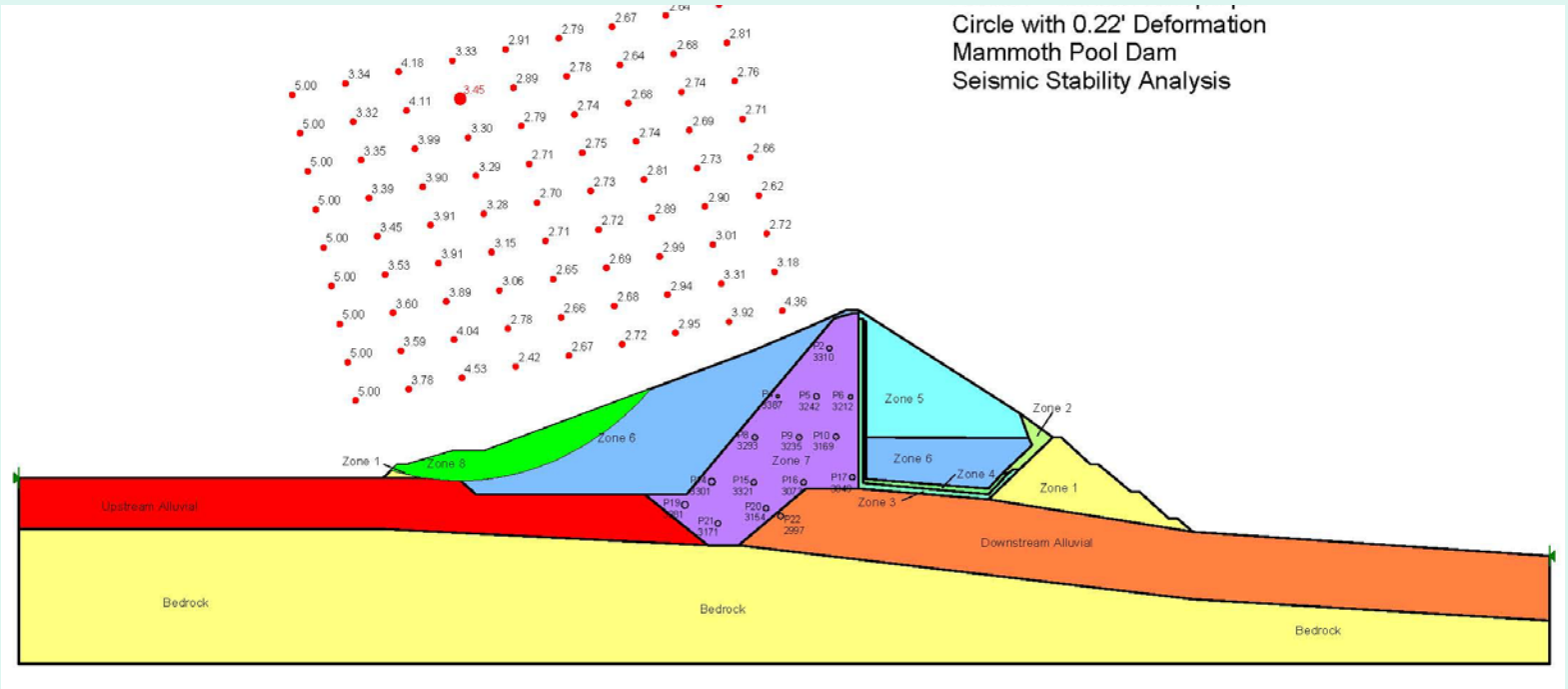

Deformation vs. Time
Deformation
Time
3
2
1
0
0
10
20
30
40

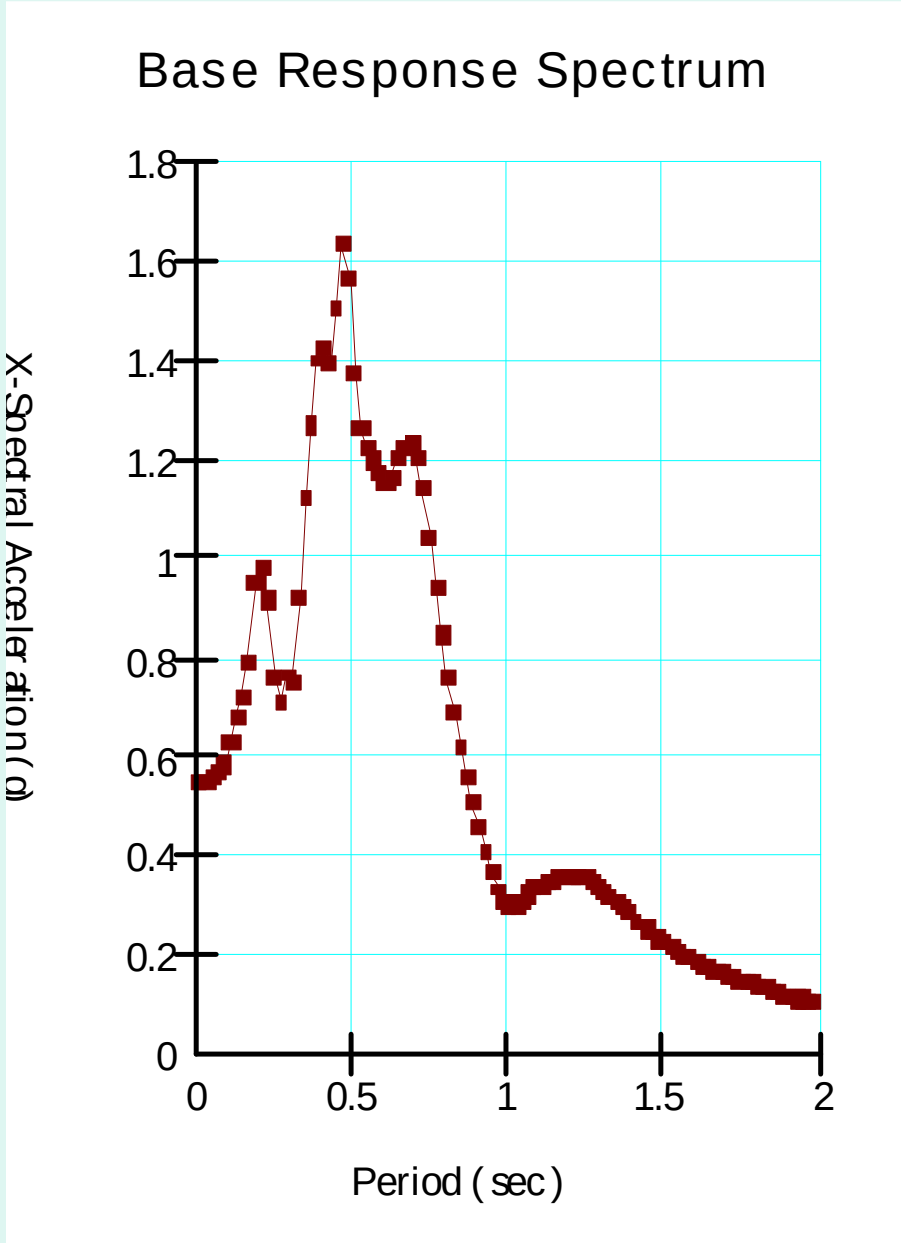
Mammoth Pool Dam - Deformation Analysis

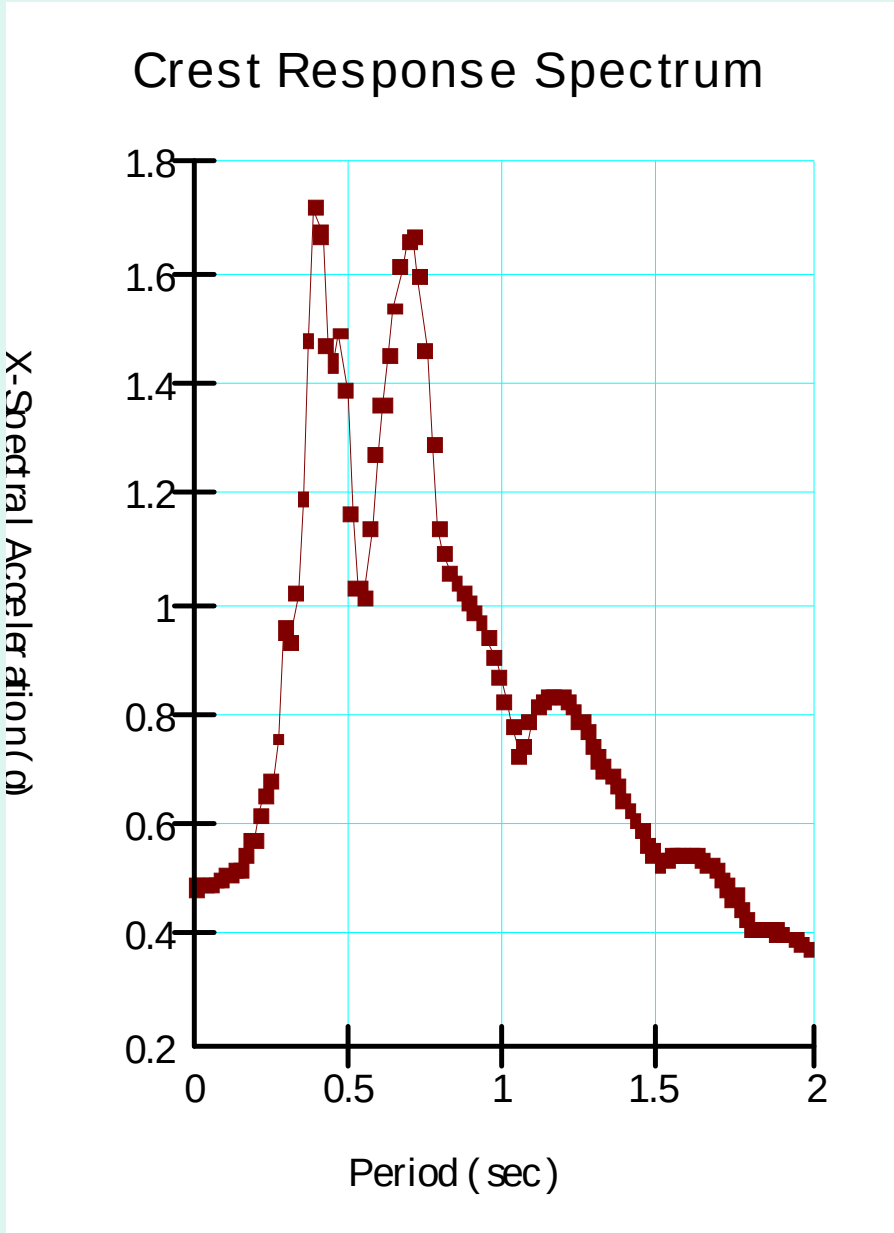
1989 Loma Prieta - San Francisco Presido - Fault Parallel + Vertical Time Histories

					Downstream Slope Deformation						Upstream Slope Deformation					
Scaled Horizontal PGA (g)	Scaled Vertical PGA (g)	Peak Horz Crest* Acceleration (g)	Peak Horz Base** Acceleration (g)	Amplification	Number of Circles Analyzed	Maximum Deformation (feet)	Maximum Deformation Location	Number of Circles Greater Than 2' Deformation	Maximum >2' Deformation Slope Penetration (feet)	Description of Maximum 2' Penetration	Number of Circles Analyzed	Maximum Deformation (feet)	Maximum Deformation Location	Number of Circles Greater Than 2' Deformation	Maximum >2' Deformation Slope Penetration (feet)	Description of Maximum 2' Penetration
0.13	0.04	0.43	0.18	2.38	810	2.5	Shallow	1	10	Shallow	729	2.6	Shallow	1	5.0	Shallow
0.17	0.06	0.41	0.26	1.59	810	3.8	Shallow	1	11	Shallow	729	3.2	Shallow	5	11.0	Shallow
0.21	0.07	0.37	0.33	1.12	801	9.3	Shallow	4	14	Shallow	729	5.2	Shallow	14	13.0	Shallow
0.26	0.09	0.49	0.44	1.10	801	7.7	Shallow	6	15	Shallow	729	12.8	Shallow	20	18.0	Shallow


Circle With 0.3' Deformation
Mammoth Pool Dam
Seismic Stability Analysis
Zone 1
Zone 2
Zone 3
Zone 4
Zone 5
Zone 6
Zone 7
Zone 8
Upstream Alluvial
Downstream Alluvial
Bedrock
Bedrock
Bedrock


Circle with 0.22' Deformation
Mammoth Pool Dam
Seismic Stability Analysis
Zone 1
Zone 2
Zone 3
Zone 4
Zone 5
Zone 6
Zone 7
Zone 8
Upstream Alluvial
Downstream Alluvial
Bedrock
Bedrock
Bedrock


Base Response Spectrum
X-Spectral Acceleration (g)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
0.5
1
1.5
2
Period (sec)


Crest Response Spectrum
X-Spectral Acceleration (g)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0.5
1
1.5
2
Period (sec)

END
Dr. R. Craig Findlay, P.E., G.E.
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