



Earthquake Response Records

DSO-99-04

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Purpose

This study was completed to examine typical acceleration responses at the top of concrete dams subjected to earthquake loadings. Comparisons were made between the input accelerations applied to finite element models and the accelerations generated at the dam crests during the dynamic analyses. This information will be instrumental in determining the number of cycles which would impact a spillway gate at the dam crest level during and immediately following an earthquake. The finite element analyses were continued for a long enough period of time after the ground motions had ceased for the response amplitude at the dam crest to decay to half its maximum response amplitude. Four arch and two gravity type dams were included in the study.

Conclusions

In all cases, the input accelerations were significantly amplified at the dam crest. For the dams included in this study, the acceleration amplification ranged from .002 g per foot of dam height at Hoover Dam, to .043 g per foot of dam height at Deadwood Dam. Greater amplification occurred in the three thin arch dams than for either the gravity dams or the thick arch dam (Hoover). The crest and input acceleration curves generated for the gravity and thick arch dams tended to remain in phase, which was not the case for the thin arch dams. The crest accelerations generated for the two gravity dams and the thick arch dam also tended to decay very rapidly after the input motion ended. The crest accelerations generated for these dams decreased by half within 2 to 3 cycles after the input motion ended. The crest accelerations generated for the three thin arch dams decayed more slowly, requiring 5 to 25 cycles to reach half amplitude after the input motion ended. Table C.1 in Appendix C contains a summary of these results and the dam characteristics. Figures C.1 to C.12 show the input versus crest acceleration curves from each analysis.

Description of the Six Dam Analyses

Deadwood Dam

Deadwood Dam is located approximately 55 miles northeast of Boise, Idaho. The dam has a 749-foot total crest length at elevation 5340 and a structural height of 157 feet. The arch section is 514 feet long with a 35-foot-long thrust block on the right abutment separating it from a 200-foot-long gravity tangent section. The dam has a 9-foot crest width and a vertical upstream face. The slope of the downstream face is a constant 0.2167 H : 1 V from the crest down to an elevation of 5280 feet and then varies along a circular curve to become 0.5745 H : 1 V at the base of the maximum section. [1] The dam thickness at the base is approximately 51 feet. The original specifications drawing showing the general plan, elevations, and sections is presented in figure A.1.

Finite Element Model

Deadwood Dam was modeled using 54 shell elements and 374 nodes in the dam model. The cut out for the spillway was modeled. Accelerations occurring at node No. 102 were plotted for this study. Node N. 102 is located on the dam crest to the left of the spillway. The location of node No. 102 is shown in figure A.2, which shows plan and elevation views of the finite element model. Sixteen boundary elements and 66 nodes were used to model the foundation. One hundred twenty six three-dimensional solid elements and 306 nodes were used to model the reservoir.

Material Properties

Concrete Properties

Young's Modulus	3,000,000 psi
Poisson's Ratio	.2
Density	150 pcf

Foundation Properties

Young's Modulus	1,500,000 psi
Poisson's Ratio	.22
Density	165 pcf

Note: This analysis was originally used as part of a sensitivity study concerning variations in material properties; therefore, these material properties are similar to but not exactly those existing at the dam site.

Input Motion

The Sterno earthquake record was used for the Deadwood Dam analysis. Sterno is a M6.5 scaled earthquake record. Upstream/downstream, vertical and cross-canyon directional components were applied to the model. Time history plots of this input ground motion and the corresponding acceleration response spectra are shown in figure B.1. The acceleration spectral intensity of the upstream/downstream record is 440 cm/sec.

Acceleration Spectral Intensity (ASI) is the area under the 5 percent acceleration response spectra curve between the periods of 0.1 and 0.5 seconds and indicates the energy content of the EQ, thus, the relative impact an earthquake might have on concrete dams.

Type of Analysis

The EACD3D96 linear-elastic finite element program was used for this analysis. The EACD3D96 program applies the input motion at nodes along the dam-foundation contact.

Monticello Dam

Monticello Dam is a 296-foot-high constant-center concrete arch dam located on Putah Creek, 30 miles west of Sacramento, California (see figures A.3 through A.5). Monticello Dam has a crest length of 1,203 feet, a crest thickness of 12 feet, and a maximum base width of 100 feet. The spillway is an uncontrolled morning-glory-type concrete intake structure that discharges through a 28-foot-diameter shaft and tunnel under the right abutment of the dam. [2]

Finite Element Model

Monticello Dam was modeled using 121 shell elements and 780 nodes in the dam model. Accelerations occurring at node No. 25 were plotted for this study. Node No. 25 is located on the dam crest between the two maximum cantilevers. The location of node No. 25 is shown in figure A.6, which shows plan and elevation views of the finite element model.

Material Properties

Concrete Properties

Young's Modulus	3,000,000 psi
Poisson's Ratio	.2
Density	150 pcf

Foundation Properties

Young's Modulus	1,500,000 psi
Poisson's Ratio	.22
Density	165 pcf

Note: This analysis was originally used as part of a sensitivity study concerning variations in material properties; therefore, these material properties are similar to but not exactly those existing at the dam site.

Input Motion

A Synthetic Earthquake was used for this analysis. Upstream/downstream, vertical, and cross-canyon directional components were applied to the model. Time history plots of this input motion and the corresponding acceleration response spectra are shown in figure B.2. The acceleration spectral intensity of the upstream/downstream record is 273 cm/sec.

Type of Analysis

The EACD3D96 finite element program was used for this analysis. The EACD3D96 program applies the input motion at nodes along the dam-foundation contact.

Morrow Point Dam

Morrow Point Dam is a major feature of the Colorado River Storage Project and is located on the Gunnison River in west-central Colorado, about 22 miles east of Montrose. The dam is a double-curvature, thin-arch concrete structure with a structural height of 465 feet and a crest length of 740 feet. The maximum section varies in thickness from 12 feet at the crest to 51 feet at bedrock. Four large openings near the top of the dam compose the spillway. Figure A.7 shows the plan view and section of Morrow Point Dam. [3]

Finite Element Model

Morrow Point Dam was modeled using 38 shell elements and 262 nodes for the dam model. Accelerations occurring at node No. 9 were plotted for this study. Node No. 9 is located near the center of the dam crest. The location of node No. 15 is shown in figure A.8, which shows plan and elevation views of the finite element model. The spillway openings, the added section and mass for the gate chambers, the gates, and the mechanical equipment were not included in the model.

Material Properties

Concrete Properties

Young's Modulus	3,000,000 psi
Poisson's Ratio	.2
Density	150 pcf

Foundation Properties

Young's Modulus	1,500,000 psi
Poisson's Ratio	.22
Density	165 pcf

Note: This analysis was originally used as part of a sensitivity study concerning variations in material properties; therefore, these material properties are similar to but not exactly those existing at the dam site.

Input Motion

The Convict Creek M6.5 earthquake record was used for this analysis. Upstream/downstream, vertical, and cross-canyon directional components were applied to the model. Time history plots of this input motion and the corresponding acceleration response spectra are shown in figure B.3. The acceleration spectral intensity of the upstream/downstream record is 284 cm/sec.

Type of Analysis

The EACD3D96 finite element program was used for this analysis. The EACD3D96 program applies the input motion at nodes along the dam-foundation contact.

Hoover Dam

Hoover Dam is a 727-foot-high concrete thick-arch dam located on the border between Arizona and Nevada, about 36 miles from Las Vegas, Nevada. The dam has a crest length of 1,244 feet, a crest thickness of 45 feet, and a maximum base width of 660 feet. [4] Figures A.9 and A.10 show the dam and plan and elevation drawings.

Finite Element Model

Hoover Dam was modeled using 210 three-dimensional solid elements and 1,167 nodes for the dam model. Accelerations occurring at node No. 675 were plotted for this study. Node No. 675 is located on the dam crest between the two maximum cantilevers. The dam, reservoir and foundation model are shown in figure A.11. The location of node No. 675 is shown in figure A.12, which shows a plan and elevation view of the dam finite element model. The reservoir model consists of 210 three-dimensional solid elements and 474 nodes, while the foundation model consists of 54 two-dimensional boundary elements and 205 nodes.

Material Properties

Concrete Properties

Young's Modulus	6,875,000 psi
Poisson's Ratio	.2
Density	156 pcf

Foundation Properties

Young's Modulus	1,000,000 psi
Poisson's Ratio	.2
Density	140 pcf

Note: This analysis was originally used as part of a sensitivity study concerning variations in material properties; therefore, these material properties are similar to but not exactly like those existing at the dam site.

Input Motion

A Convict Creek earthquake record was used for this analysis. Upstream/downstream, vertical, and cross-canyon directional components were applied to the model. Time history plots of this input motion and the corresponding acceleration response spectra are shown in figure B.4. The

acceleration spectral intensity of the upstream/downstream record is 516 cm/sec. This Convict Creek record differs from that used in the Morrow Point analysis.

Type of Analysis

The EACD3D96 finite element program was used for this analysis. The EACD3D96 program applies the input motion at nodes on the dam-foundation contact.

Carraizo Dam

Carraizo Dam is a concrete gravity dam with a maximum structural height of approximately 32 m (105 ft) and a total crest length of approximately 222.3 m (730 ft) (see figure A.13 and table 1). The dam is located on the Rio Grande de Loisa about 24 km (15 miles) south of San Juan, Puerto Rico. The spillway gates were modified in 1976 to raise the normal reservoir water surface to elevation 41.144 m (135 ft). Table 1 lists various dimensions of the dam.[5]

Table 1.—Carraizo Dam Dimensions

Description	Meters	Feet	Inches
Elevations			
Base of dam (approx)	12.0	39.37	472
Spillway crest	31.0	101.71	1,220
Top of spillway gates	43.0	141.08	1,693
Top of dam	44.0	144.36	1,732
Dimensions			
Height			
Maximum height of dam	32.0	105.0	1,260
Spillway gates	10.144	33.28	400
Cross-canyon widths			
Spillway gates	11.887	39.00	468
Concrete piers	2.438	8.00	96
Pier to pier	14.326	47.0	564
Maximum upstream length			
Base of dam	29.608	97.14	1,165
Crest lengths			
Total concrete	222.26	729.2	8,750
Non-overflow (left section)	60.0	196.8	2,362
Intake	22.6	74.1	890
Overflow section	120.046	393.9	4,726
Net spillway openings (8 gates)	95.096	312.0	3,744
Non-overflow (right section)	19.6	64.3	772

Finite Element Model

Carraizo Dam was modeled using 2,585 three-dimensional solid elements and 12,668 nodes for the dam and foundation model. Accelerations occurring at node No. 6038 were plotted for this study. Node No. 6038 is located on the dam crest. Figure A.14 shows the entire dam and foundation model. The figure A.15 shows upstream and downstream vies of the dam model. The location of node No. 6038 is shown in figure A.16.

Material Properties

Average values for the concrete and foundation properties assumed for these analyses are listed in Table 2. A massless foundation was assumed for this analysis. The four previously discussed EACD3D96 analyses included the effects of mass in the foundation. The assumption of a massless foundation is typically used during standard linear elastic analysis for dams, unless the EACD3D96 linear elastic finite element program is used.

Table 2.—Material Properties for Concrete and Rock Used in Carraizo Studies

Description	Assumed	Tested
Concrete		
Density (lb/ft)	—	149.9
Poisson's ratio		0.20 6
Modulus of Elasticity (lb/in ²)		
Laboratory static		
Sustained (2/3 x lab static)	—	
Dynamic (lab static)	2,700,000 4,000,000	4,002,000 — —
Foundation		
Density (lb/ft)		
Modulus of elasticity (lb/in ²)	zero 1,500,000	— —

Input Motions

Carraizo Dam was analyzed for four ground motion records: Gilroy, Sturno, Adak and Puget1. Statistics for each ground motion are presented in Table 3. Plots of the input motions and response spectrums for each of the four ground motions are shown in figure B.5 through B.8.

Table 3.—Summary of Input Motions Used in Analyses of Carraizo Dam

Seismic	Peak g	@time (sec)	ASI (cm/sec)
Sturno	-0.358	5.26	318
	0.251	4.67	263
EW	0.260	4.55	121
NS			
UP	-0.312	1.72	300
Gilroy	-0.237	1.6	21
	0.432	0.88	240
EW			
NS	0.250	30.27	200
UP	-0.200	31.56	200
Adak	0.120	24.58	86
197			
287	0.300	19.64	235
UP	-0.180	10.95	202
Puget	-0.110	0.16	78
086			
356			
Up			

Type of Analysis

The ABAQUS finite element program was used for the analyses of Carraizo Dam. These were linear-elastic analyses. The input motions were applied at nodes along the base of the foundation.

La Plata Dam

La Plata Dam is a concrete gravity dam with a maximum structural height of approximately 40 m (131 ft) and a total crest length of approximately 235.92 m (774.0 ft). The dam is located on the Rio de La Plata about 4.8 km (3 miles) south of Toa Alta, Puerto Rico. Table 4 lists various dimensions of the dam.

Table 4.—La Plata Dam Dimensions

Description	Meters	Feet	Inches
Elevations			
Base of dam (approx)	7.0	22.97	276
Spillway crest	47.12	154.59	1,855
Top of spillway gates	52.62	172.64	2,072
Top of dam (roadway crest)	57.0	187.0	2,244
Dimensions			
Height			
From base to roadway crest	50	164.0	1,968
From base to spillway crest	40.1	131.6	1,580
Spillway gates	5.5	18.0	217
Cross-canyon widths			
Spillway gates			
Concrete piers			
Pier to pier			
Maximum upstream length			
Base of dam	41.0	134.6	1,615
Crest lengths			
Total concrete	263.23	863.6	10,363
Piers (4 at 1.83m each)	7.32	24.0	288
Spillway bays (6 at 35.05m each)	210.3	690.0	8,280
Pumping station	18.3	60.0	720
Right abutment non-overflow section	13.97	45.8	550
Left abutment non-overflow section	13.34	43.8	525

Finite Element Model

La Plata Dam was modeled using 2,764 three-dimensional solid elements and 11,209 nodes for the dam and foundation model. Accelerations occurring at node No. 3770 were plotted for this study. Node No. 3770 is located at the top of the spillway pier. Figure A.17 shows the entire dam and foundation model. Figure A.18 shows the dam model and the location of node No. 3770.

Material Properties

Average values for the concrete and foundation properties assumed for these analyses are listed in table 5. A massless foundation was assumed.

Table 5.—Material Properties for Concrete and Rock
Used in La Plata Studies
(Tested values from Carraizo Dam)

Description	Assumed	Tested
Concrete		
Density (lb/ft)	—	149.9
Poisson's ratio	—	0.206
Modulus of elasticity (lb/in ²)	—	4,002,000
Laboratory static	2,700,000	—
Sustained (2/3 x lab static)	4,000,000	—
Dynamic (lab static)		
Foundation		
Density (lb/ft)	zero	—
Modulus of elasticity (lb/in ²)	1,500,000	—

Input Motions

La Plata Dam was analyzed using the same four ground motion records which were used in the Carraizo Dam analyses: Gilroy, Sturmo, Adak and Puget1. Statistics for each ground motion are presented in table 3. Plots of the input motions and response spectrums for each of the four ground motions are shown in figures B.5 through B.8.

Type of Analysis

The ABAQUS finite element program was used for the analyses of La Plata Dam. These were linear-elastic analyses. The input motion was applied at nodes along the base of the foundation.

Results

Deadwood Dam

Natural Frequencies:

Mode	Frequency (Hz)	Period (sec)
1	5.7	.175
2	6.0	.167
3	7.8	.128

Accelerations

Figure C.1 contains four plots of the upstream/downstream input acceleration curve versus the acceleration curve generated at the dam crest. Each plot shows 5 seconds of a 20 second time history. The input record actually ends at 12 seconds. When the input motion ends, the accelerations at the dam crest quickly decay. Peak values decrease by one half in 4 to 5 cycles (see plot 3 on figure C.1). The scale used in this figure varies from frame to frame. The maximum upstream/downstream crest acceleration of 7.3 g occurs at 7.3 seconds (see frame 2). The maximum upstream/downstream input acceleration was .71 g, occurring at 7.2 seconds.

Monticello Dam

Natural Frequencies:

Mode	Frequency (Hz)	Period (sec)
1	3.0	.333
2	3.2	.313
3	4.2	.238

Accelerations

Figure C.2 contains four plots of the upstream/downstream input acceleration curve versus the upstream/downstream acceleration curve generated at the dam crest. Each plot shows a segment of the time history. The input acceleration amplitudes gradually decrease until they reach zero g at 11.4 seconds. The peak value of the response accelerations decrease by one half after 25 cycles. The maximum upstream/downstream crest acceleration of 5.8 g occurs at 2.11 seconds, while the maximum upstream/downstream input acceleration was .47 g occurring at 2.05 seconds.

Morrow Point Dam

Natural Frequencies:

Mode	Frequency (Hz)	Period (sec)
1	3.2	.313
2	3.6	.278
3	5.4	.185

Accelerations

Figure C.3 contains four plots of the upstream/downstream input acceleration curve versus the upstream/downstream acceleration curve generated at the dam crest. Each plot shows a segment of the time history. The input acceleration record ends at 15 seconds. The peak values of the response at the dam crest decreased by one half after 5 cycles. The maximum upstream/downstream crest acceleration of 2.7 g occurs at 7.7 seconds, while the maximum upstream/downstream input acceleration was .4 g occurring at 6.9 seconds.

Hoover Dam

Natural Frequencies:

Mode	Frequency (Hz)	Period (sec)
1	3.75	.267
2	4.39	.228
3	4.43	.226

Accelerations

Figure C.4 contains four plots of the upstream/downstream input acceleration curve versus the upstream/downstream acceleration curve generated at the dam crest. Each plot shows 5 seconds of a 20 second time history. The input record actually ends at 15.9 seconds. When the input motion ends the accelerations at the dam crest quickly decay. Peak values decrease to one third in 2 cycles. The maximum upstream/downstream crest acceleration of 4.7 g occurs at 4.4 seconds. The maximum upstream/downstream input acceleration was .74 g occurring at 4.36 seconds.

Carraizo Dam

Natural Frequencies:

Mode	Frequency (Hz)	Period (sec)
1	5.99	.167
2	7.76	.129
3	10.84	.092

Accelerations

Adak

Figure C.5 contains four plots of the upstream/downstream input acceleration curve versus the upstream/downstream acceleration curve generated at the top of the dam. Each plot shows a portion of the 70 second time history. The input record actually ends at 60 seconds. When the input motion ends, the accelerations at the dam crest quickly decay. Peak values decrease by one third in 3 cycles. The maximum upstream/downstream acceleration response of .78 g occurs at 30.5 seconds. The maximum upstream/downstream input acceleration was .25 g occurring at 30.3 seconds.

Gilroy

Figure C.6 contains four plots of the upstream/downstream input acceleration curve versus the upstream/downstream acceleration curve generated at the top of the dam. Each plot shows a portion of the 14 second time history. The input record actually ends at 12 seconds. When the input motion ends, the accelerations at the dam crest quickly decay. Peak values decrease by one

half in 3 cycles. The maximum upstream/downstream acceleration response of 1.2 g occurs at 2.0 seconds. The maximum upstream/downstream input acceleration was 0.31 g occurring at 1.72 seconds.

Puget

Figure C.7 contains four plots of the upstream/downstream input acceleration curve versus the upstream/downstream acceleration curve generated at the top of the dam. Each plot shows a portion of the 28 second time history. The input record actually ends at 25 seconds. When the input motion ends, the accelerations at the dam crest quickly decay. Peak values decrease by one half in 3 cycles. The maximum upstream/downstream acceleration response of 1.3 g occurs at 1.5 seconds. The maximum upstream/downstream input acceleration was .3 g occurring at 19.6 seconds.

Sturno

Figure C.8 contains four plots of the upstream/downstream input acceleration curve versus the upstream/downstream acceleration curve generated at the top of the dam. Each plot shows a portion of the 23 second time history. The input record actually ends at 20 seconds. When the input motion ends, the accelerations at the dam crest quickly decay. Peak values decrease by one half in 3 cycles. The maximum upstream/downstream acceleration response of 1.6 g occurs at 4.9 seconds. The maximum upstream/downstream input acceleration was .36 g occurring at 5.3 seconds.

La Plata Dam

Natural Frequencies:

Mode	Frequency (Hz)	Period (sec)
1	5.17	.193
2	5.54	.180
3	11.46	.087

Accelerations

Adak

Figure C.9 contains four plots of the upstream/downstream input acceleration curve versus the upstream/downstream acceleration curve generated at the top of the dam. Each plot shows a portion of the 70 second time history. The input record actually ends at 60 seconds. When the input motion ends, the accelerations at the dam crest quickly decay. Peak values decrease by one half in 3 cycles. The maximum upstream/downstream acceleration response of 1.26 g occurs at 25.8 seconds. The maximum upstream/downstream input acceleration was .25 g occurring at 30.3 seconds.

Gilroy

Figure C.10 contains four plots of the upstream/downstream input acceleration curve versus the upstream/downstream acceleration curve generated at the top of the dam. Each plot shows a portion of the 15 second time history. The input record actually ends at 12 seconds. When the input motion ends, the accelerations at the dam crest quickly decay. Peak values decrease by one half in 3 cycles. The maximum upstream/downstream acceleration response of 2.2 g occurs at 1.75 seconds. The maximum upstream/downstream input acceleration was 0.31 g occurring at 1.72 seconds.

Puget

Figure C.11 contains four plots of the upstream/downstream input acceleration curve versus the upstream/downstream acceleration curve generated at the top of the dam. Each plot shows a portion of the 28 second time history. The input record actually ends at 25 seconds. When the input motion ends, the accelerations at the dam crest quickly decay. Peak values decrease by one half in 3 cycles. The maximum upstream/downstream acceleration response of 1.3 g occurs at 8.5 seconds. The maximum upstream/downstream input acceleration was .3 g occurring at 19.6 seconds.

Sturno

Figure C.12 contains four plots of the upstream/downstream input acceleration curve versus the upstream/downstream acceleration curve generated at the top of the dam. Each plot shows a portion of the 24 second time history. The input record actually ends at 20 seconds. When the input motion ends, the accelerations at the dam crest quickly decay. Peak values decrease by one half in 3 cycles. The maximum upstream/downstream acceleration response of 3.0 g occurs at 5.4 seconds. The maximum upstream/downstream input acceleration was .36 g occurring at 5.3 seconds.

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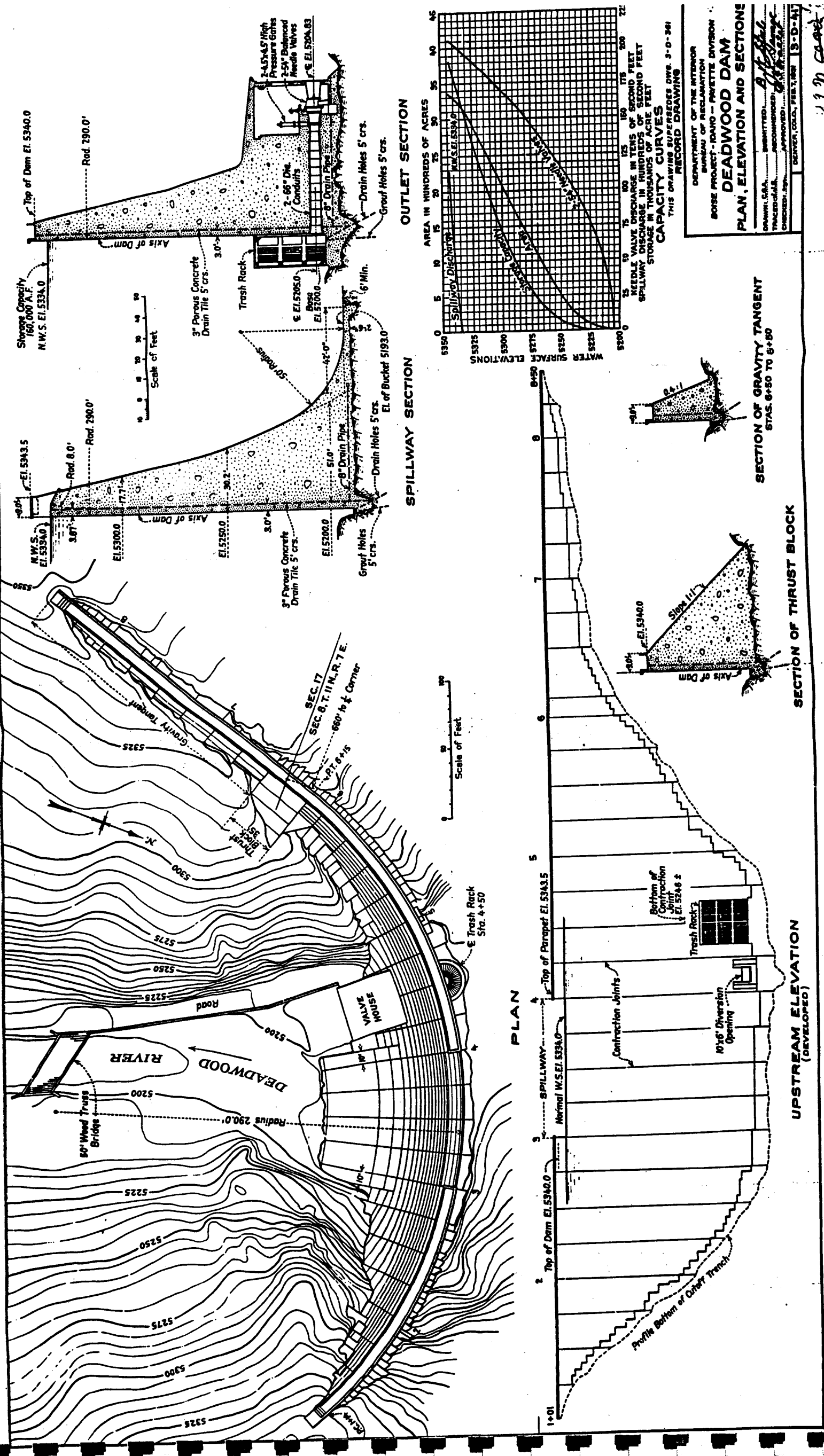
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Appendix A

Geometry

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Figure A1



1928

Figure A2

Deadwood Dam

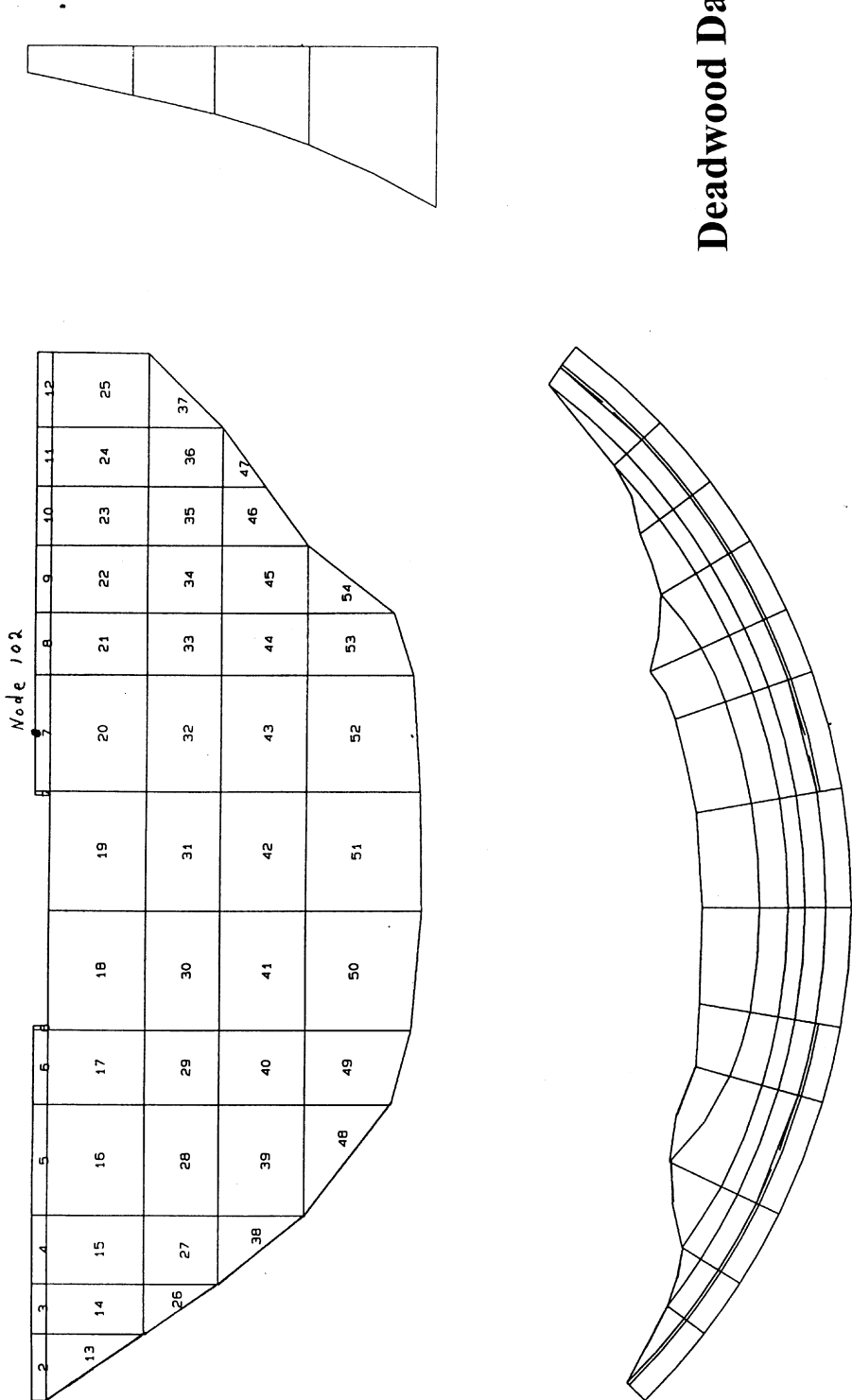


Figure A3
Monticello Dam



Figure A4

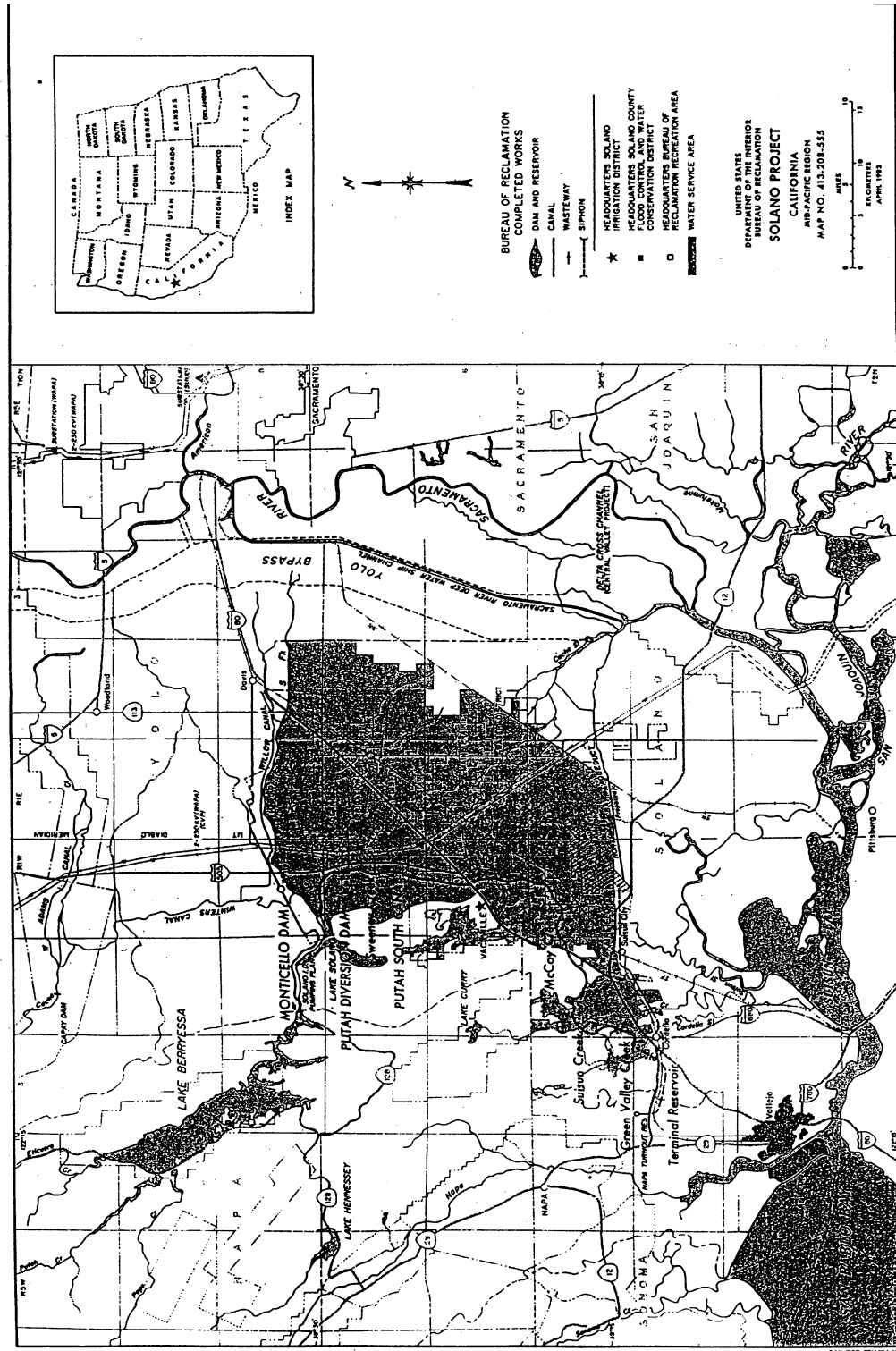


Figure A5

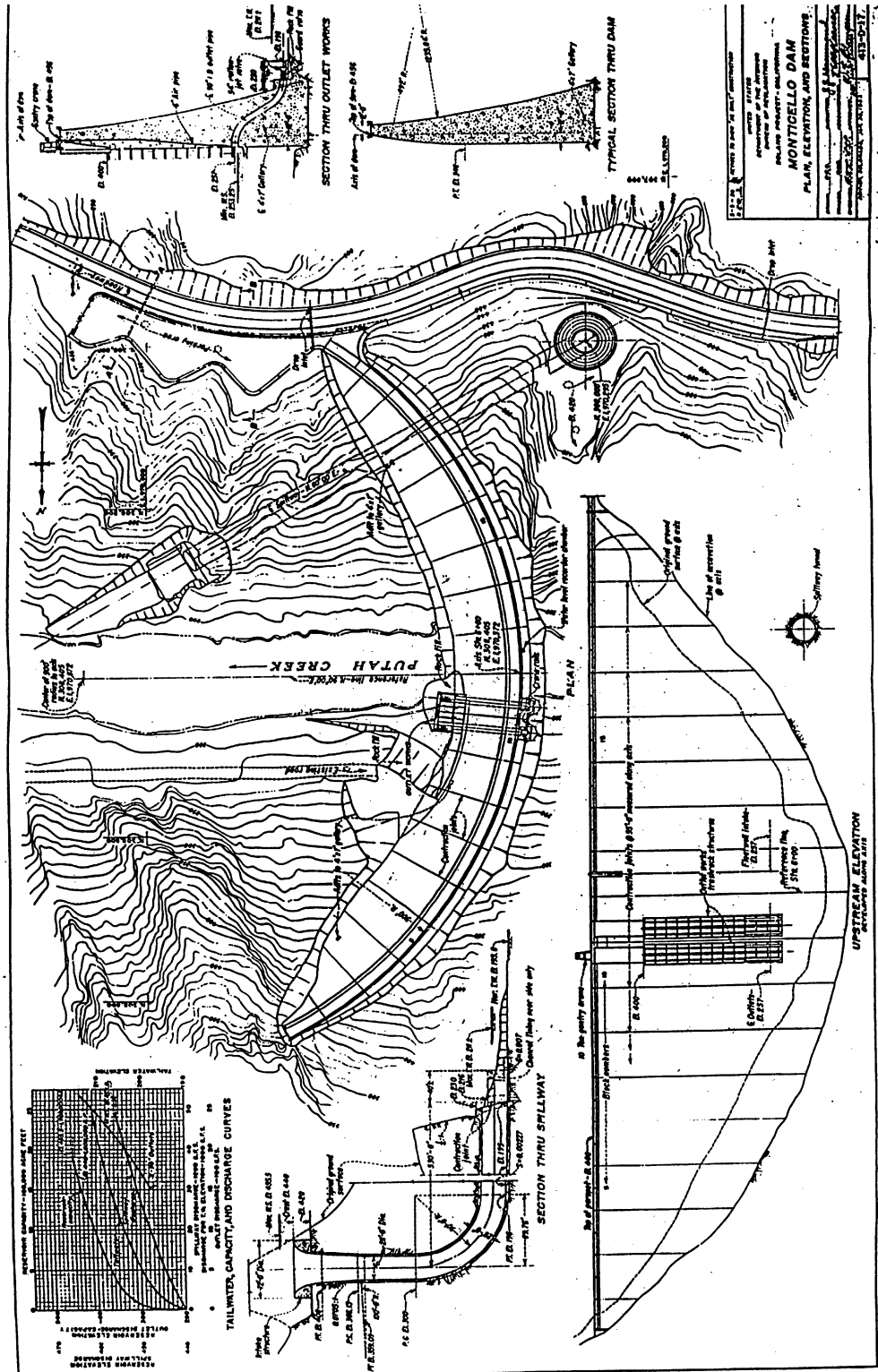


Figure A6

Monticello Dam

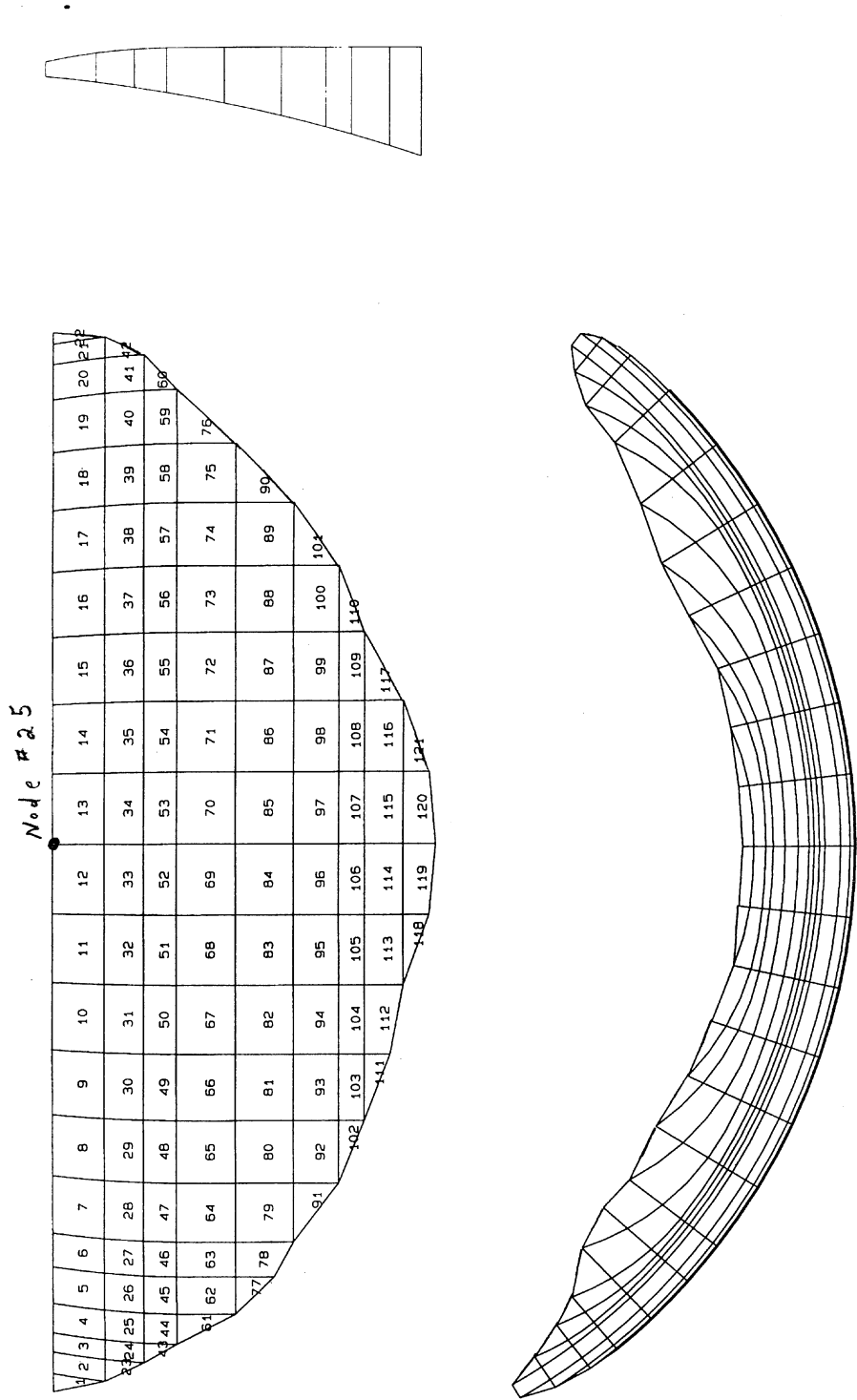


Figure A7

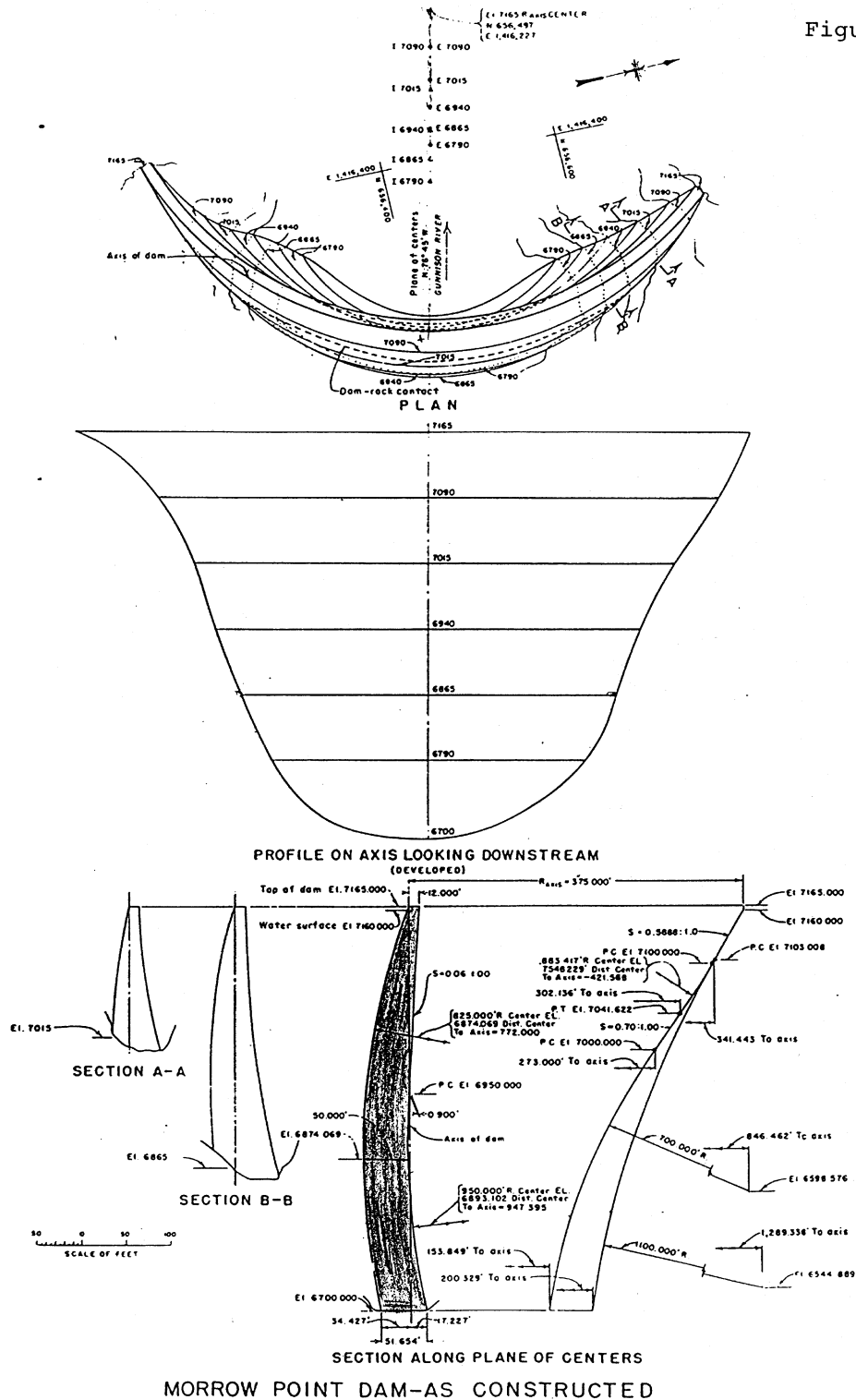
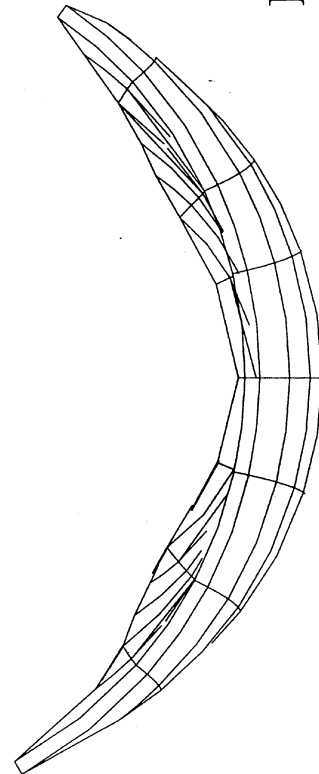
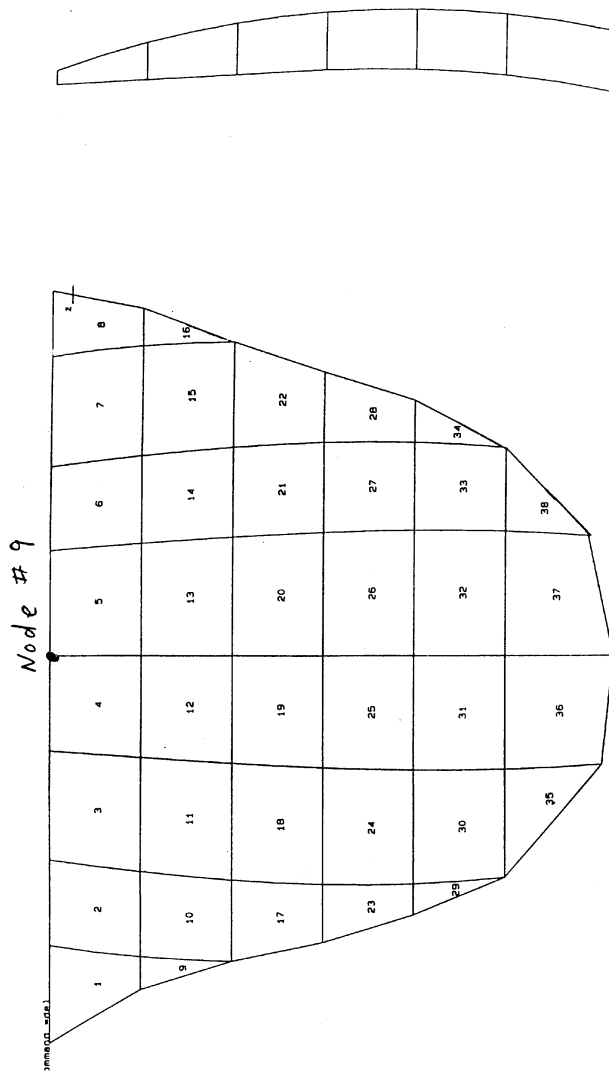


Figure A8

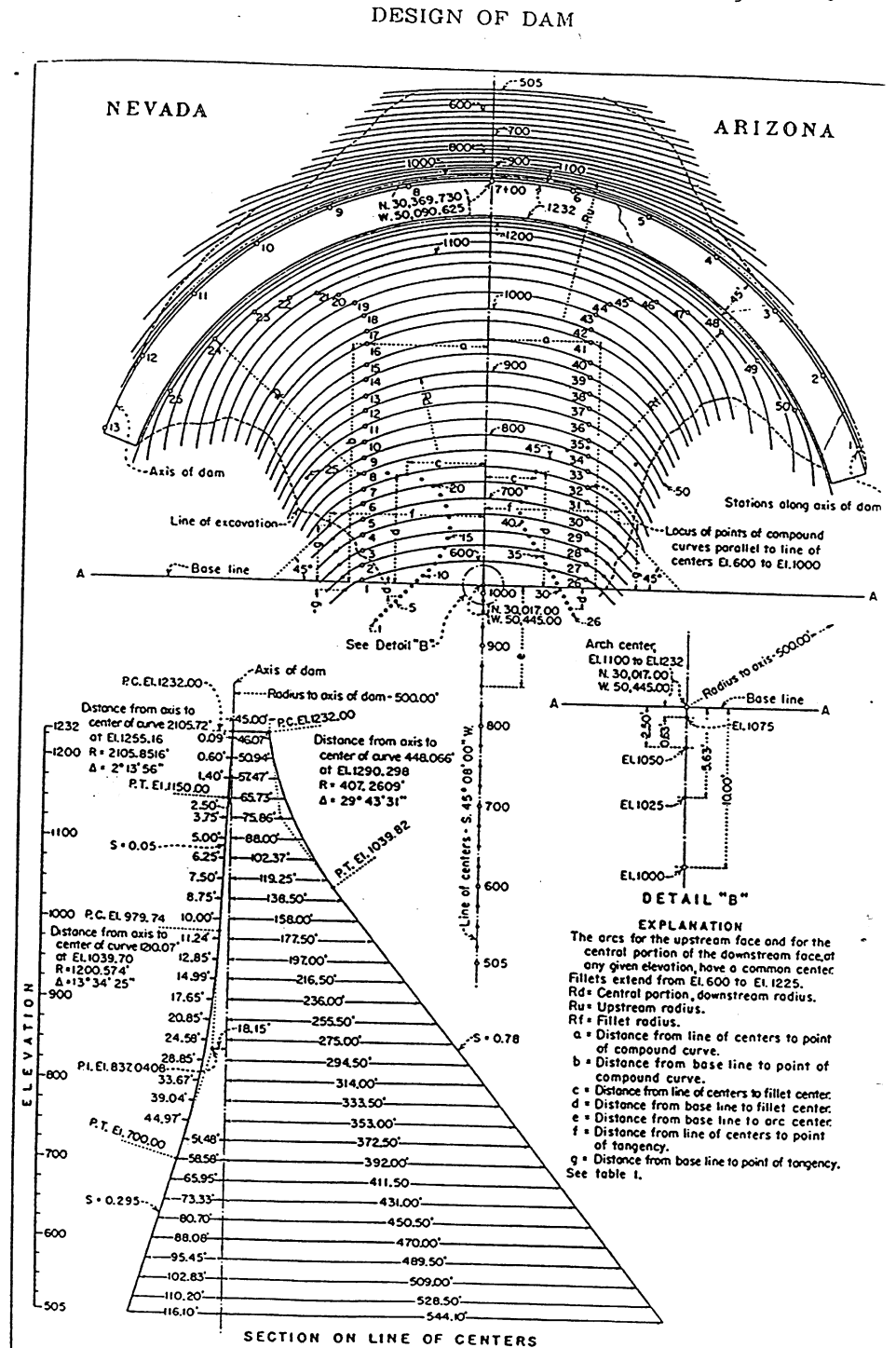


Morrow Point Dam

Figure A9
Hoover Dam



Figure A10



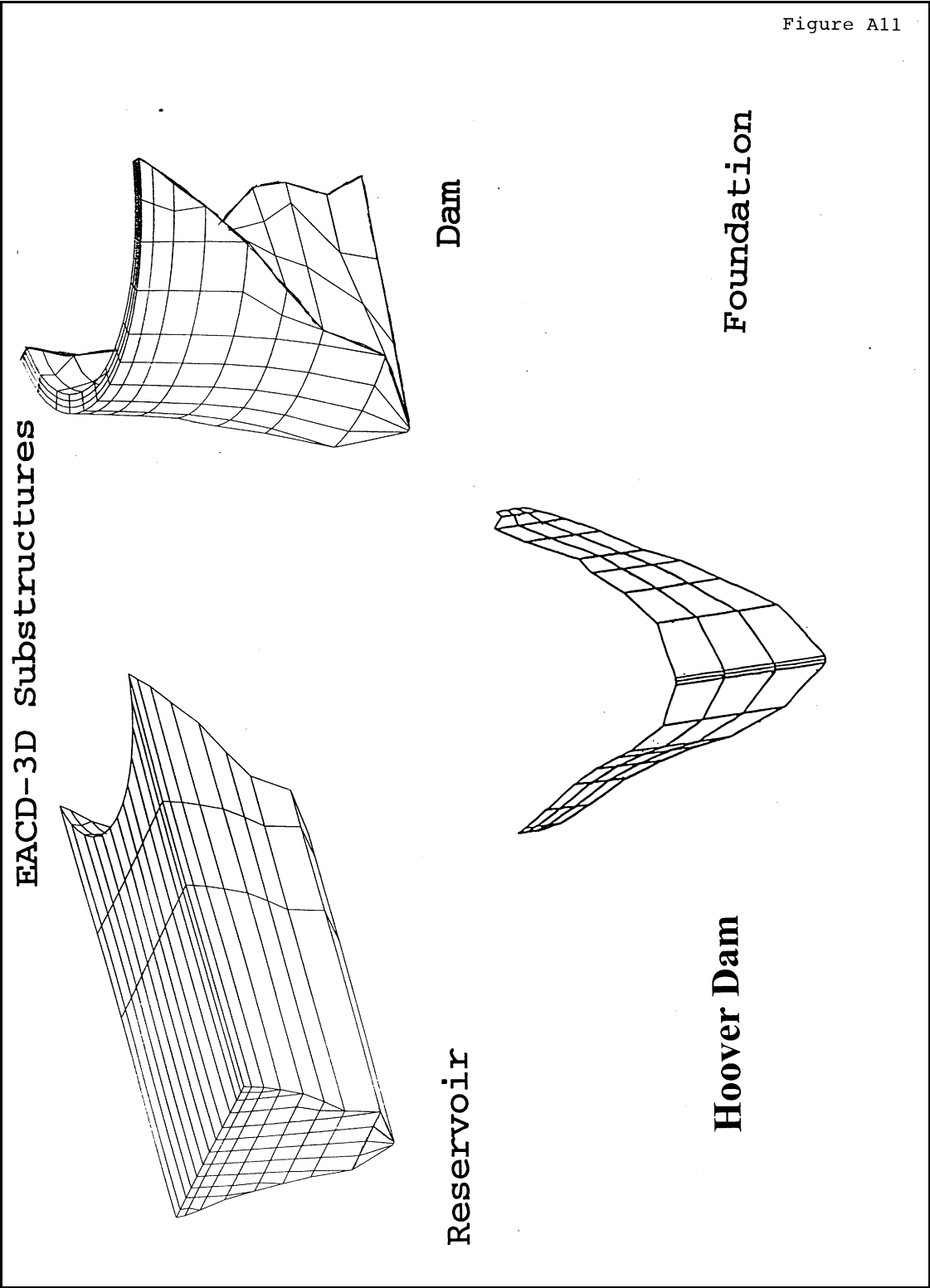
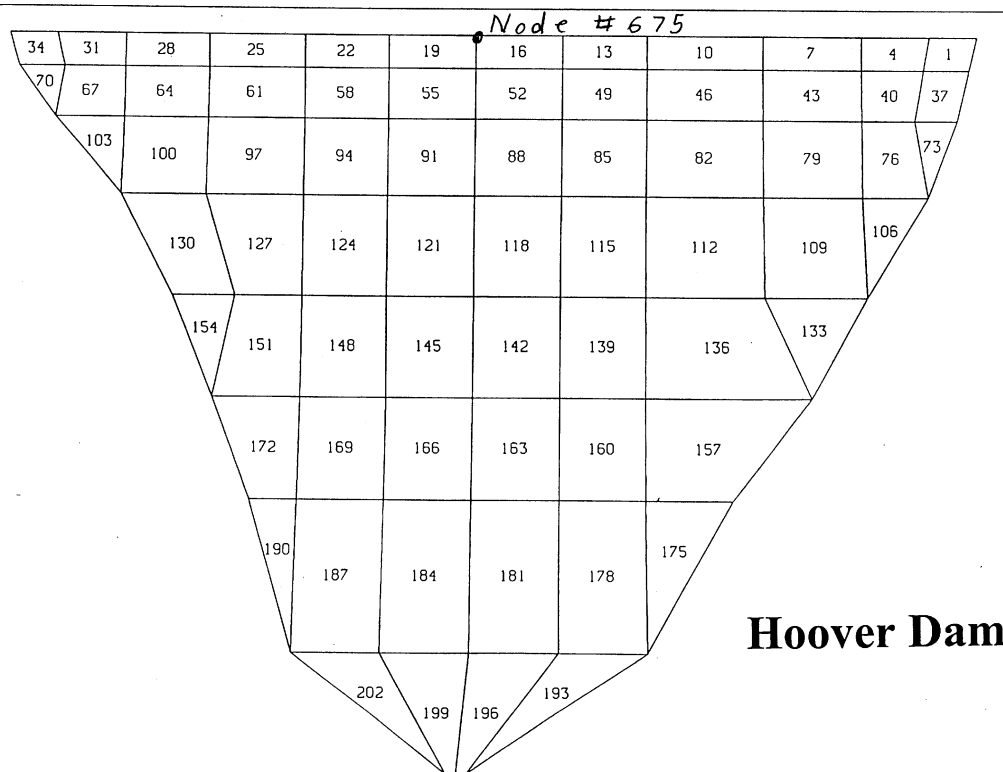
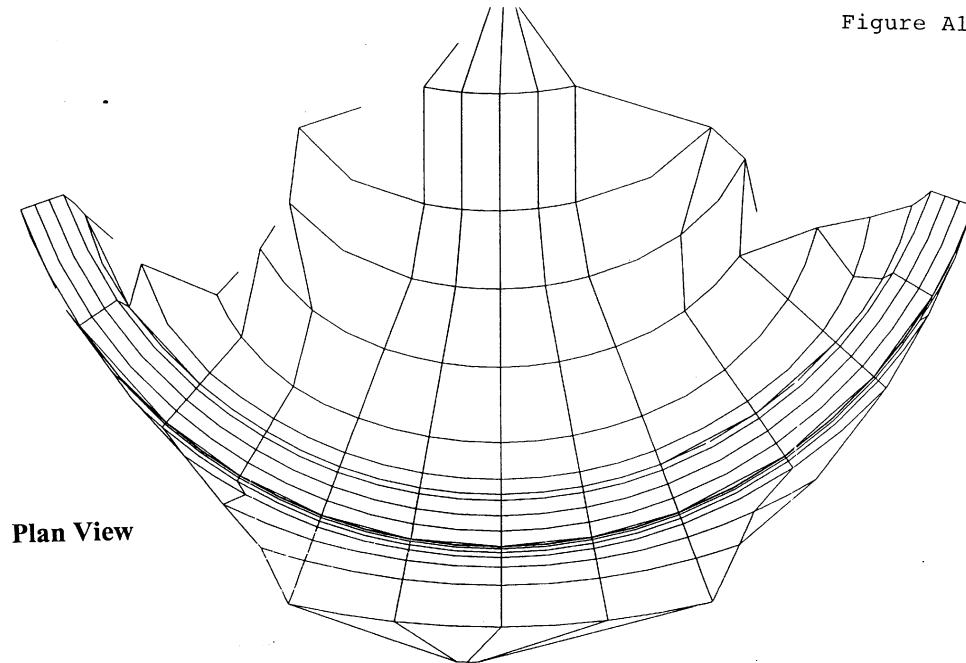


Figure A12



HOOVER DAM - UPSTREAM ELEMENT NUMBERS

Figure A13



- Aerial View of Carraizo Dam

Figure A14

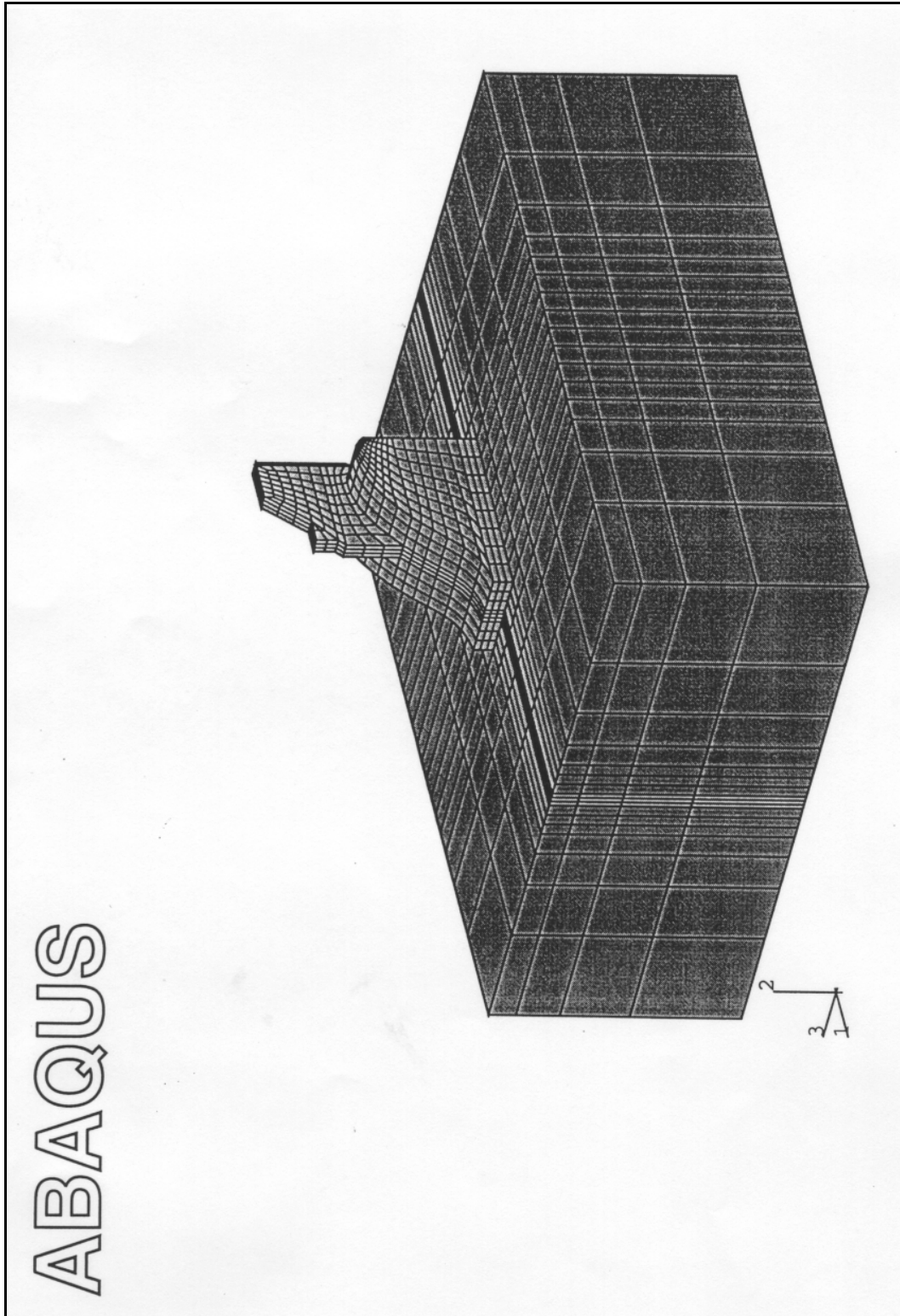


Figure 15A

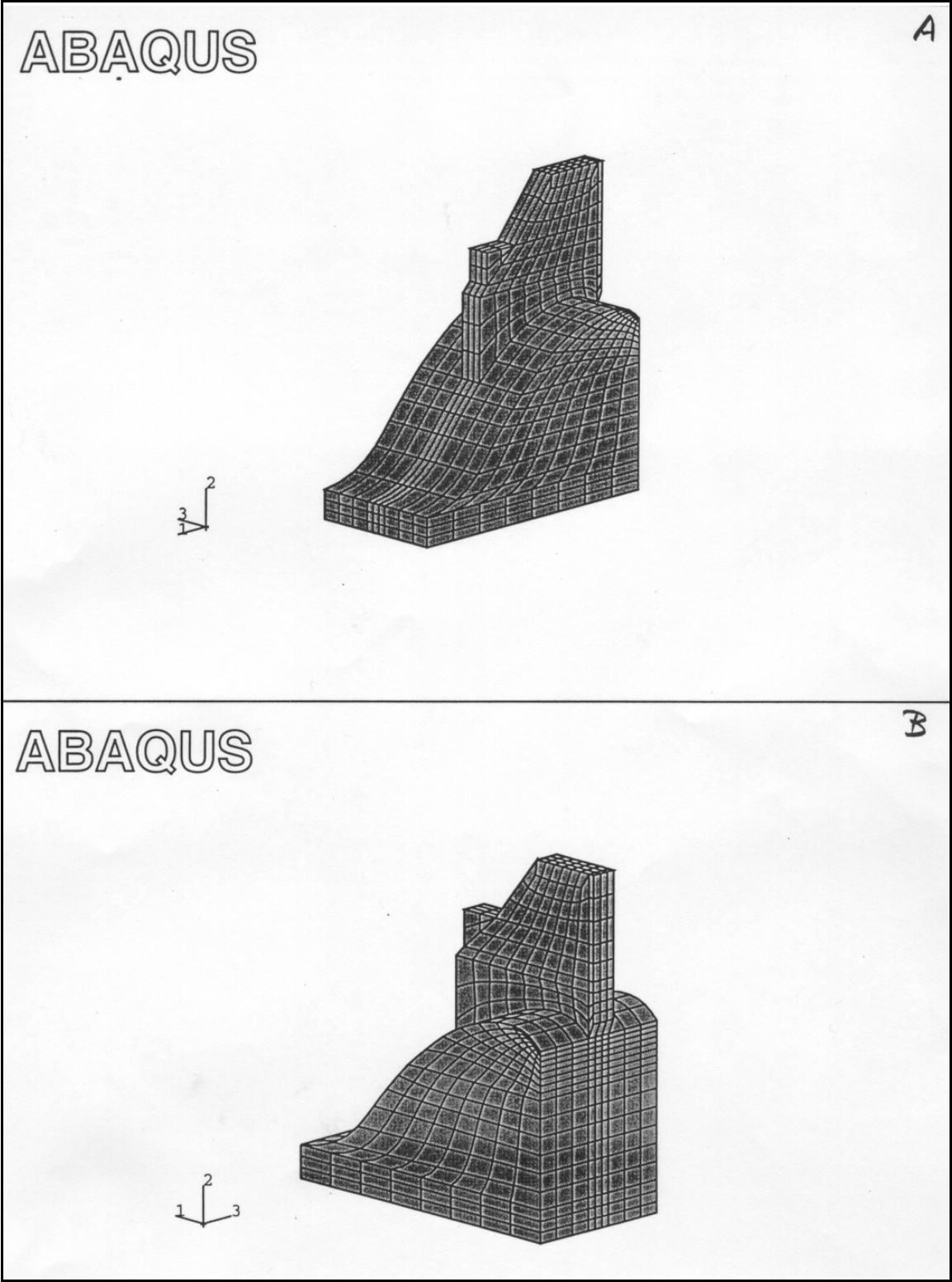


Figure A16

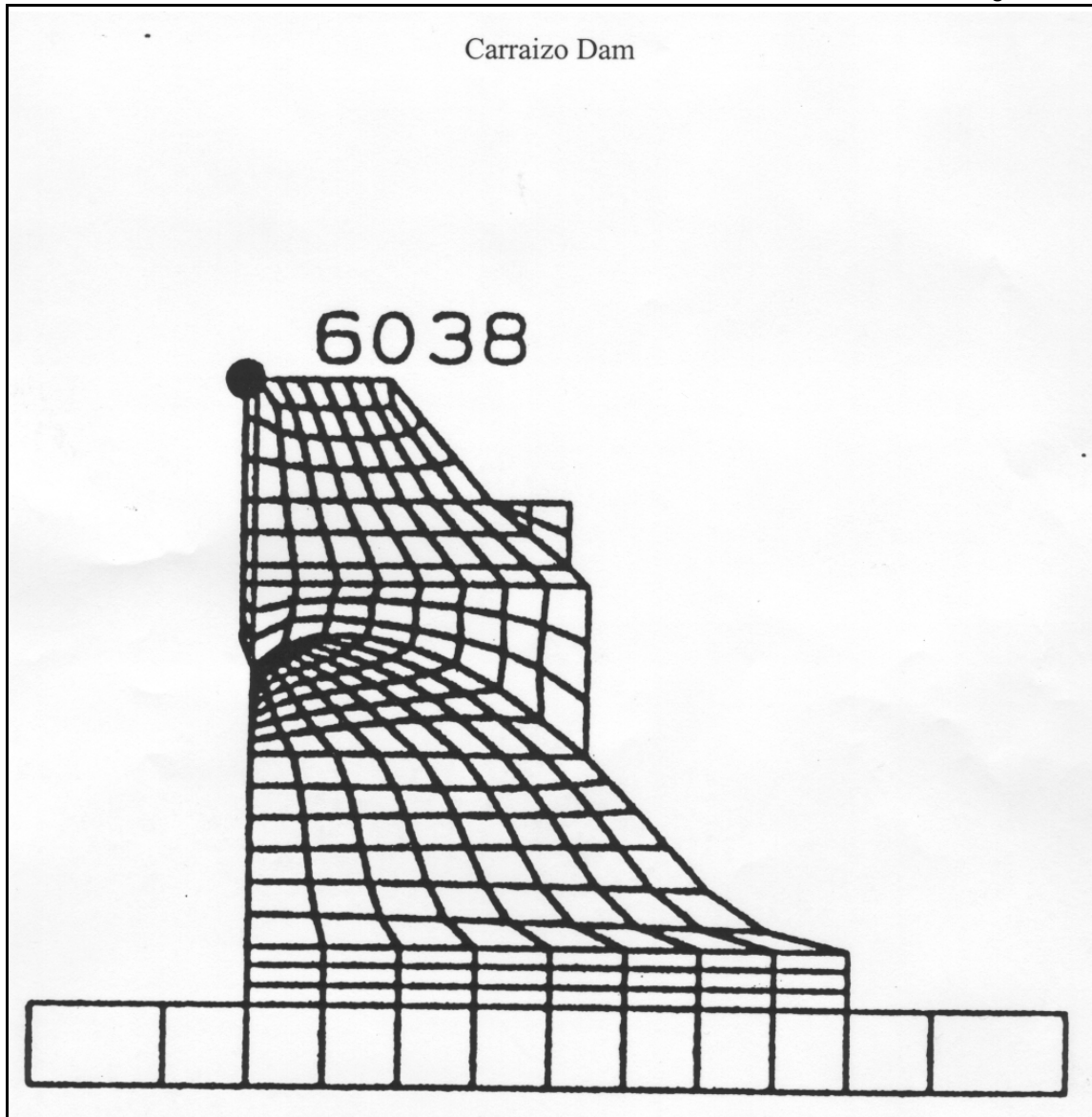


Figure A17

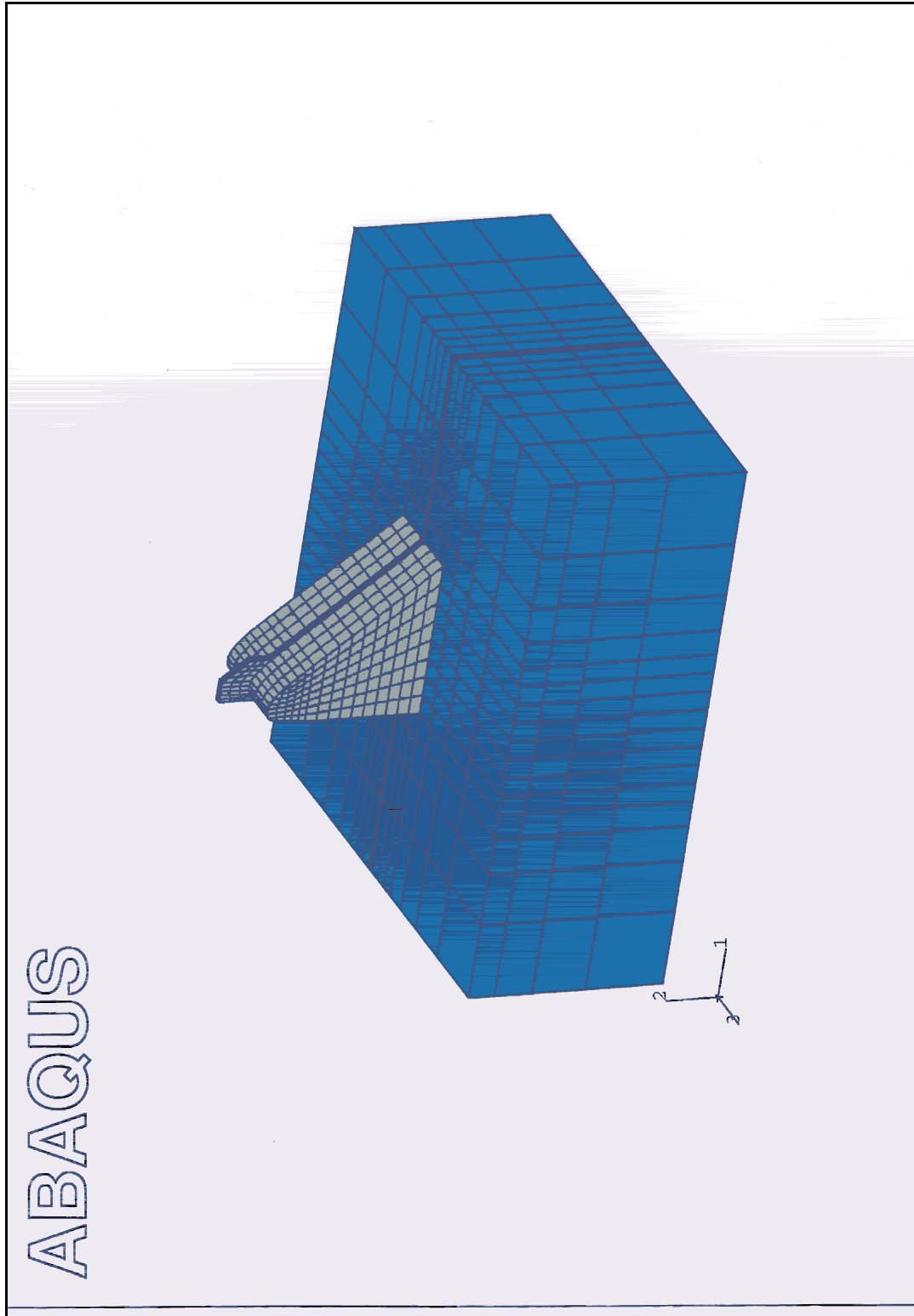
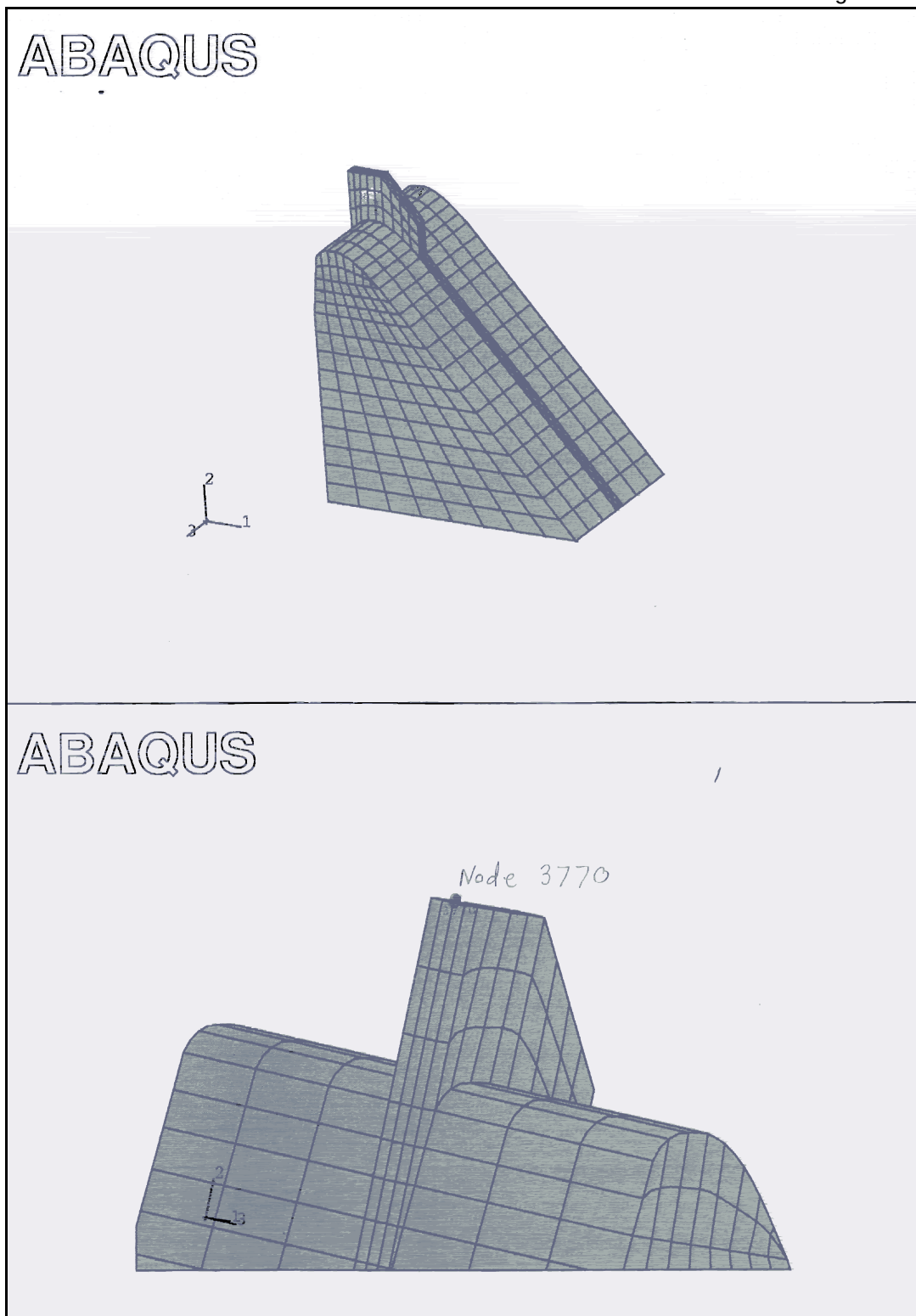


Figure A18



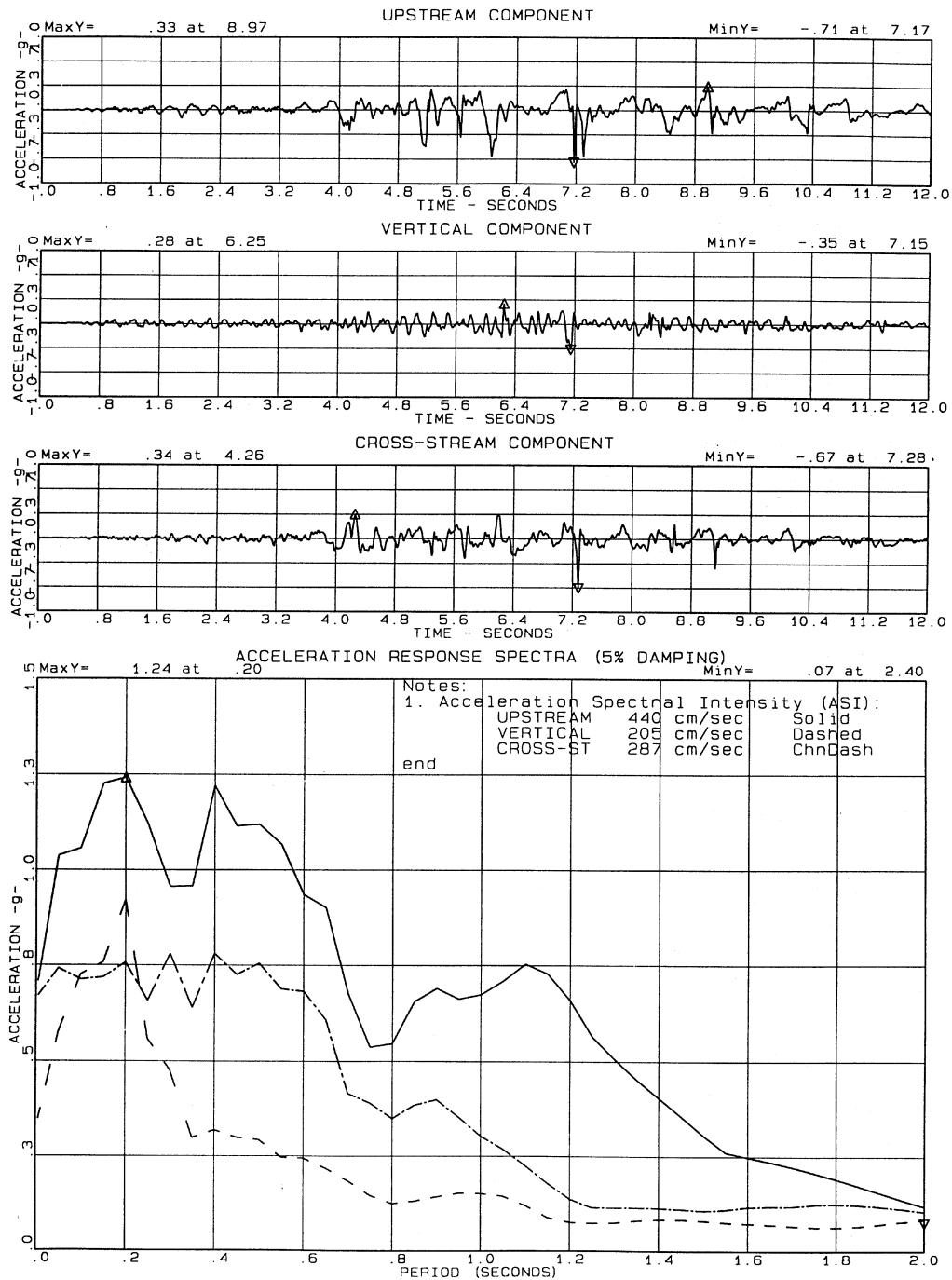
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Appendix B

Input Motions
Response Spectra

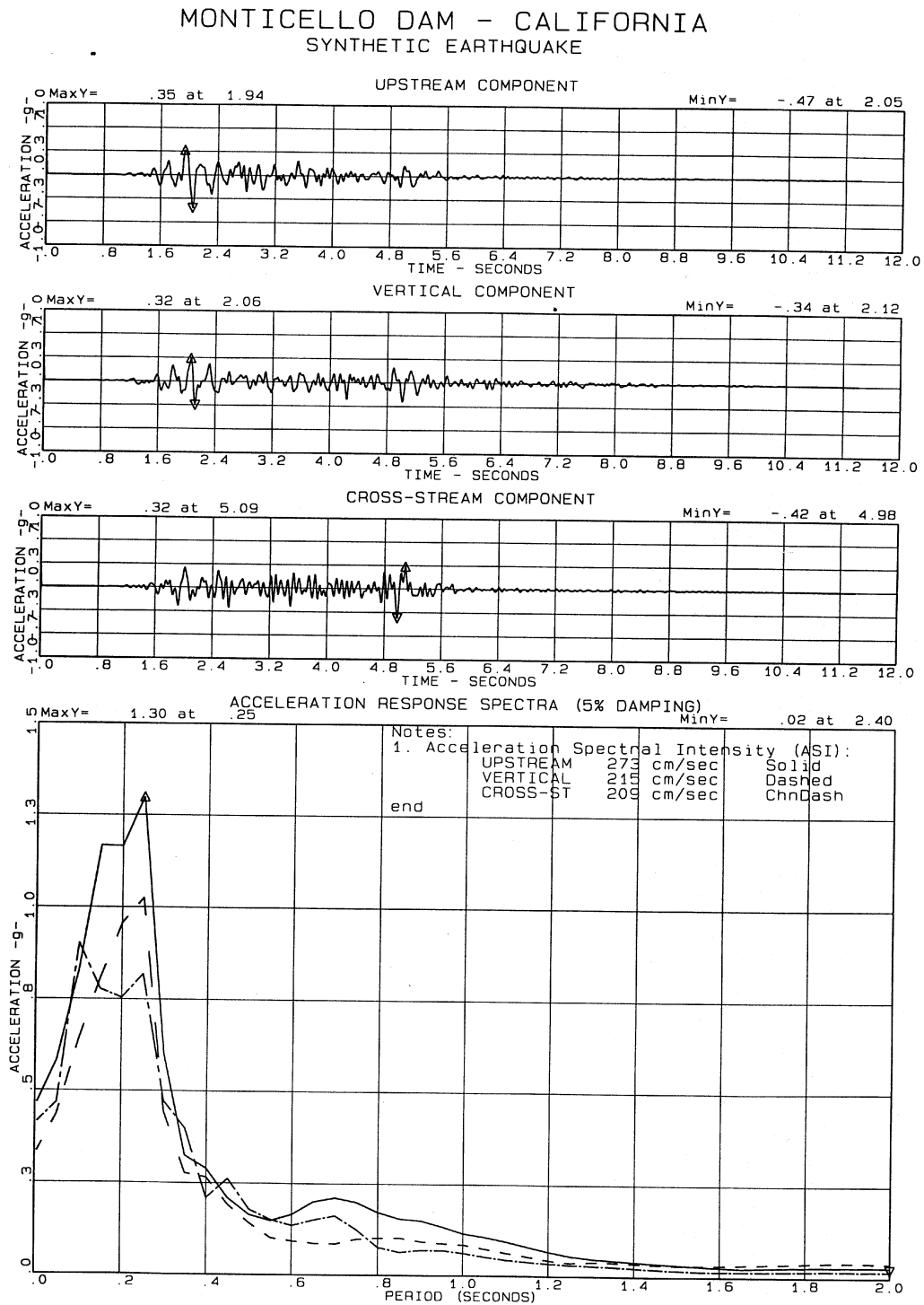
Figure B1

DEADWOOD DAM - IDAHO M6.5 STERNO SCALED EARTHQUAKE



Input=dwd.p2p. Created 20-Apr-99 10:15:03

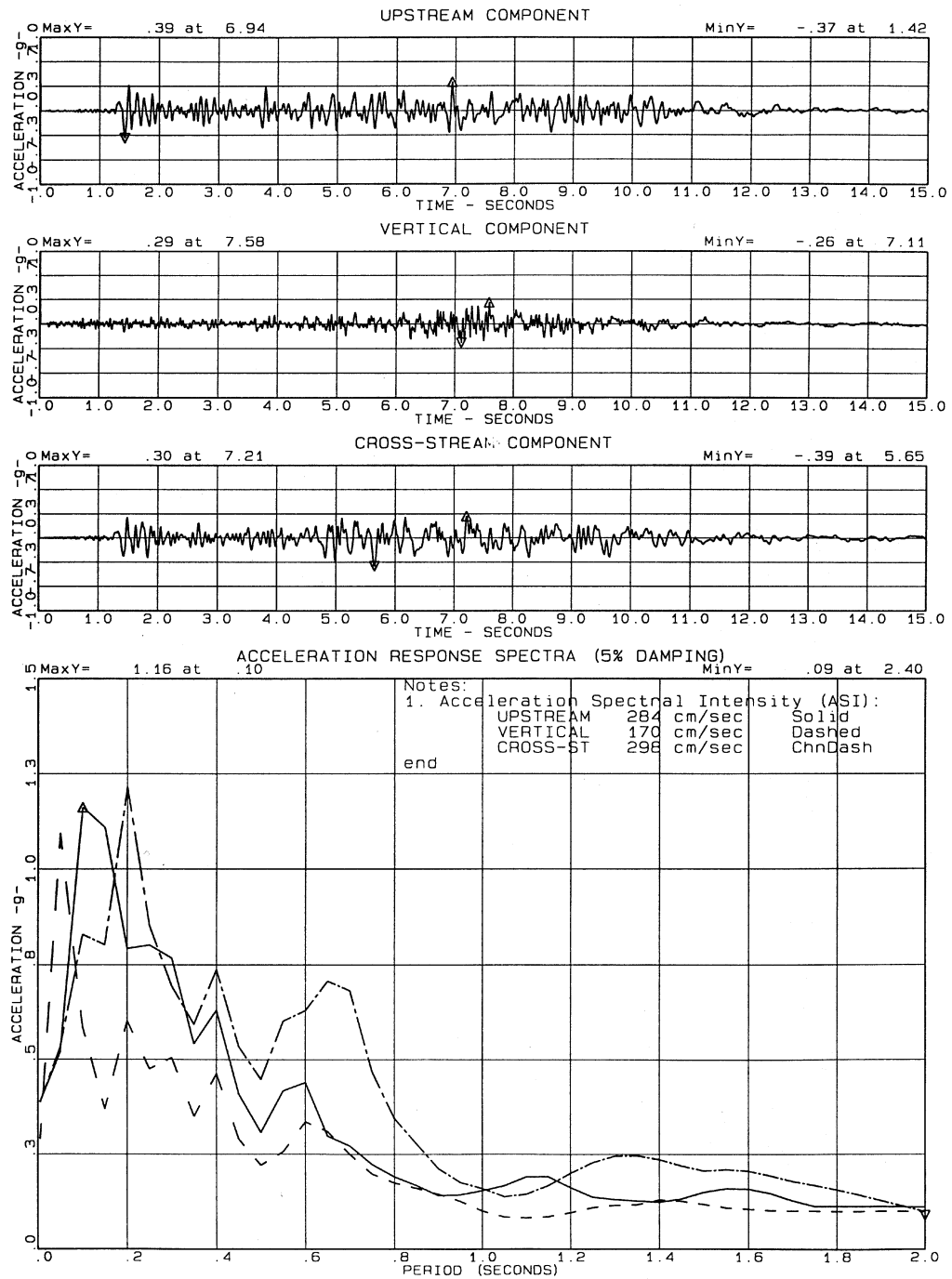
Figure B2



Input=mont.p2p, Created 20-Apr-99 10:15:19

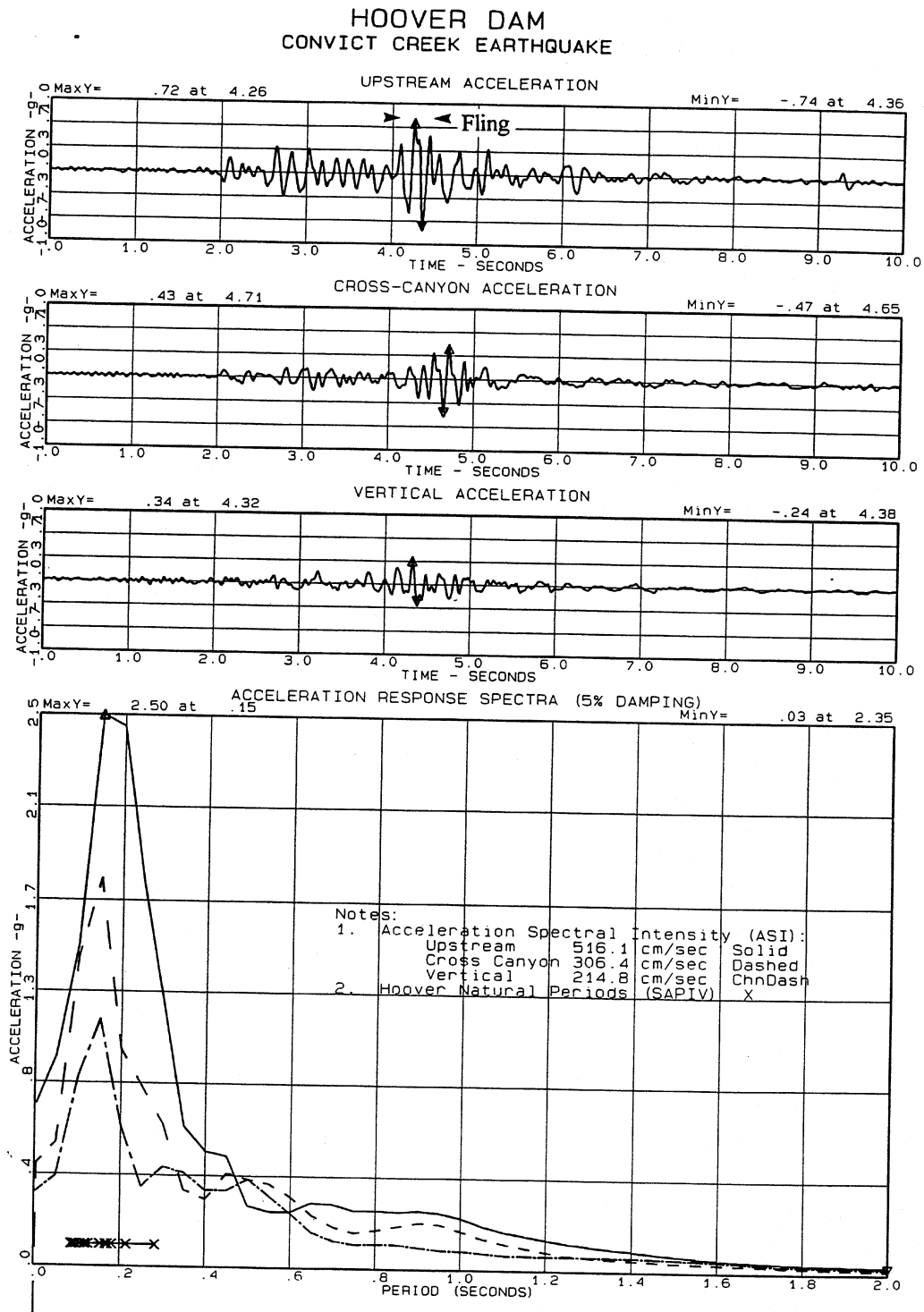
Figure B3

MORROW POINT DAM - COLORADO
M6.5 CONVICT CREEK EARTHQUAKE



Input=mpt.p2p. Created 20-Apr-99 10:29:54

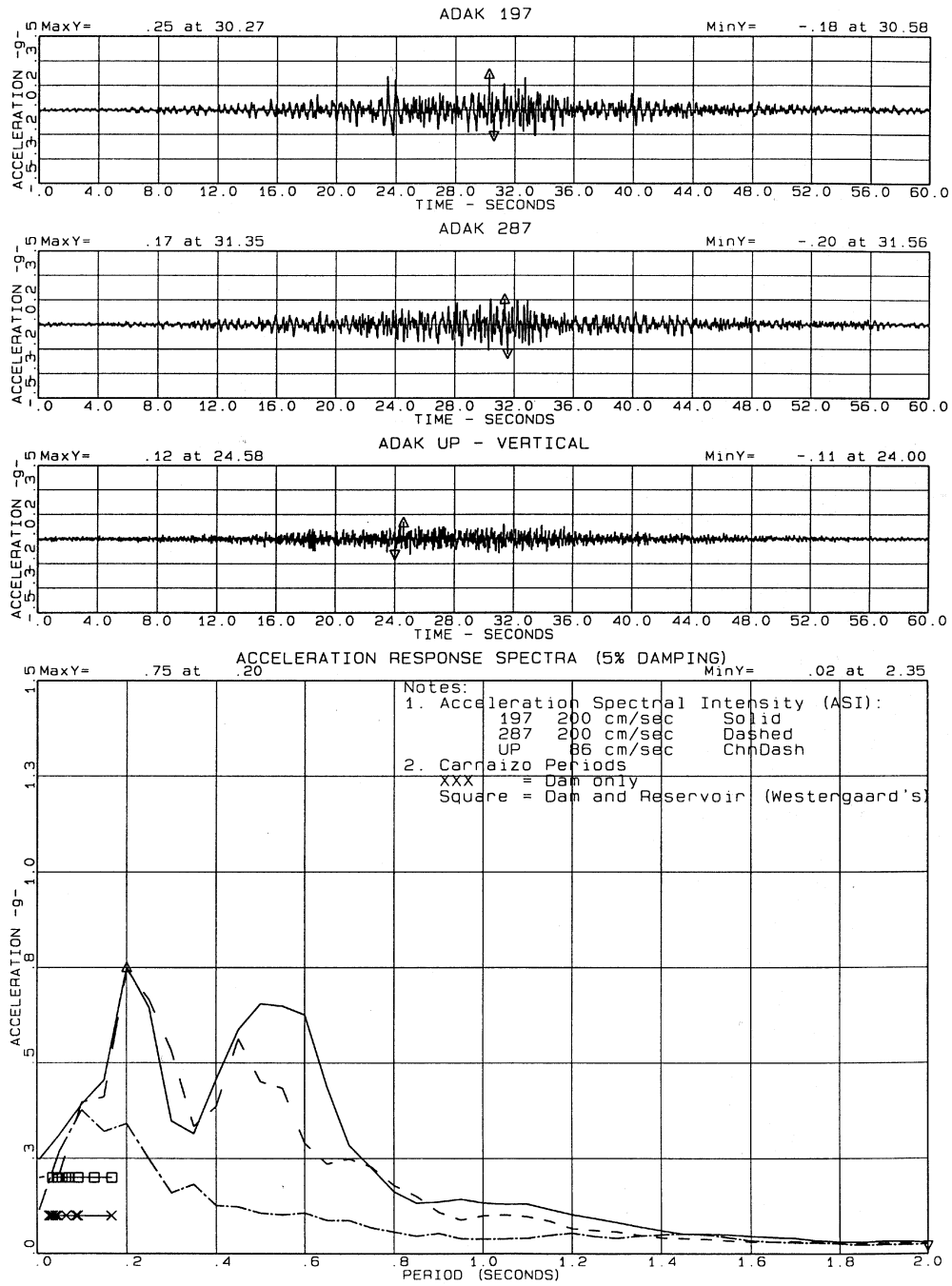
Figure B4



Input=cc.p2p Created 20-May-98 14:52:11

Figure B5

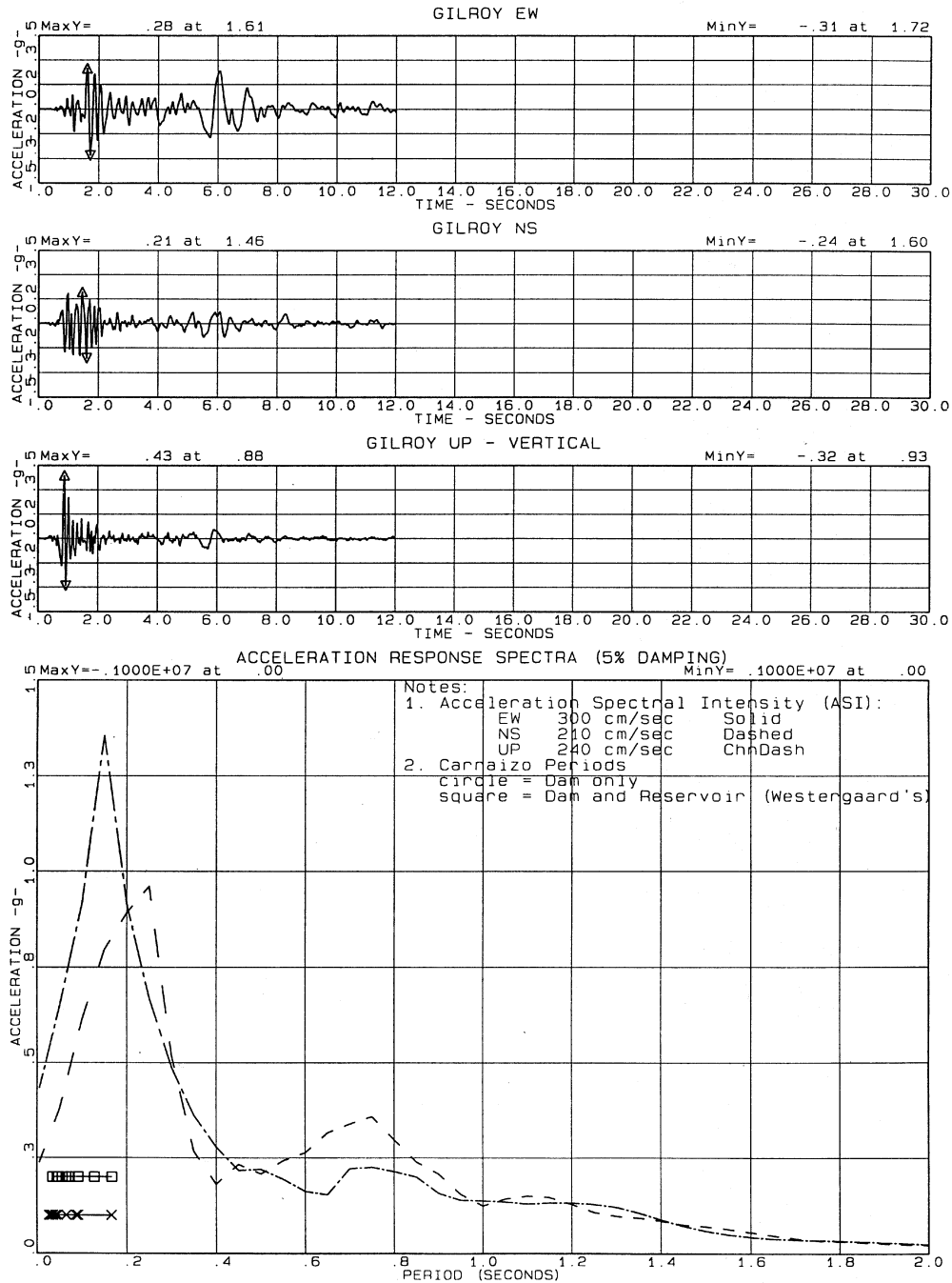
CARRAIZO DAM - PUERTO RICO M8.0 SCALED ADAK EQ, SUBDUCTION



Input=adak.p2p. Created 8-Mar-99 19:20:27

Figure B6

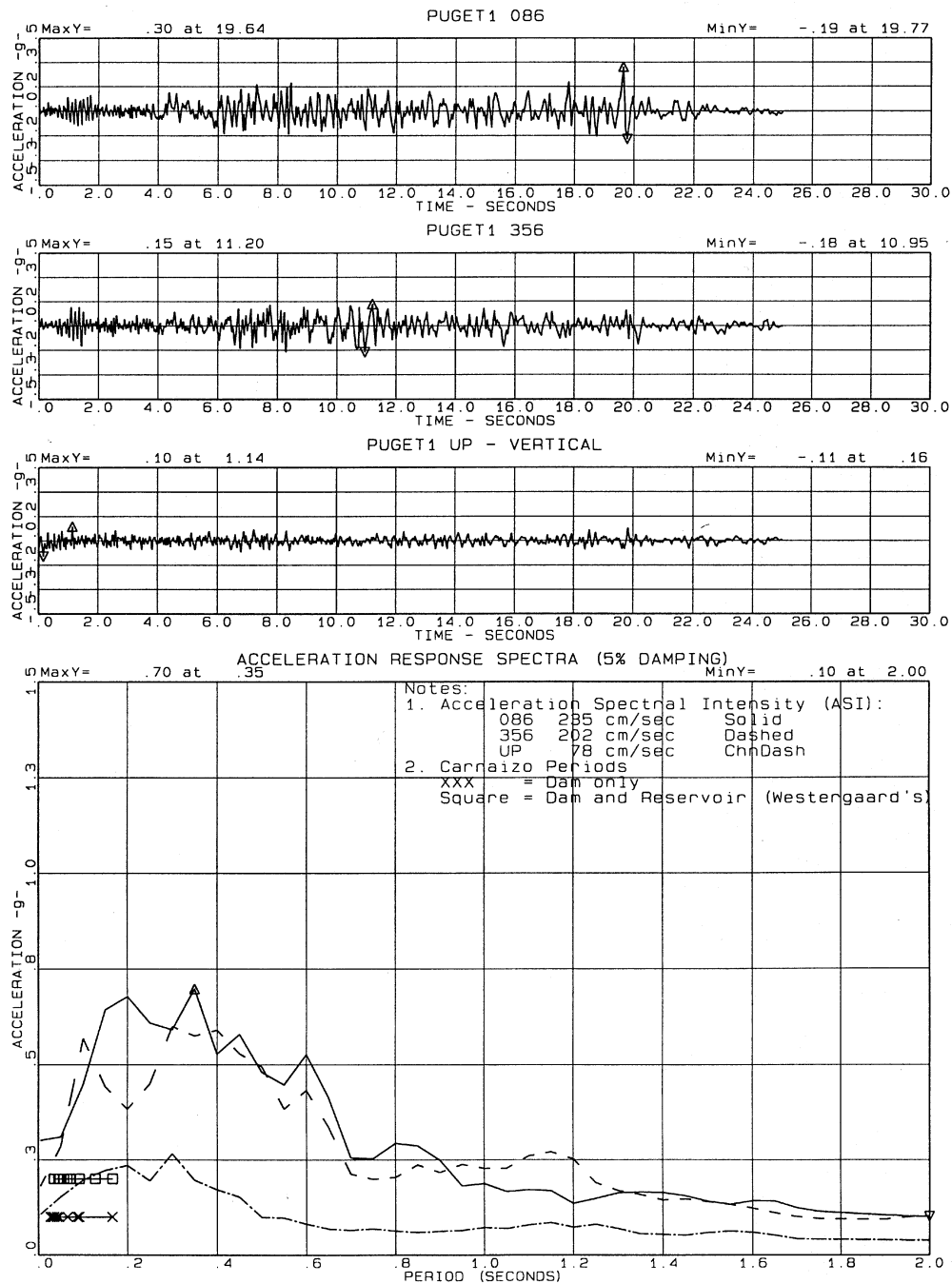
CARRAIZO DAM - PUERTO RICO
M6.2 SCALED GILROY EARTHQUAKE, RANDOM



Input=gilroy.p2p, Created 8-Mar-99 19:20:17

Figure B7

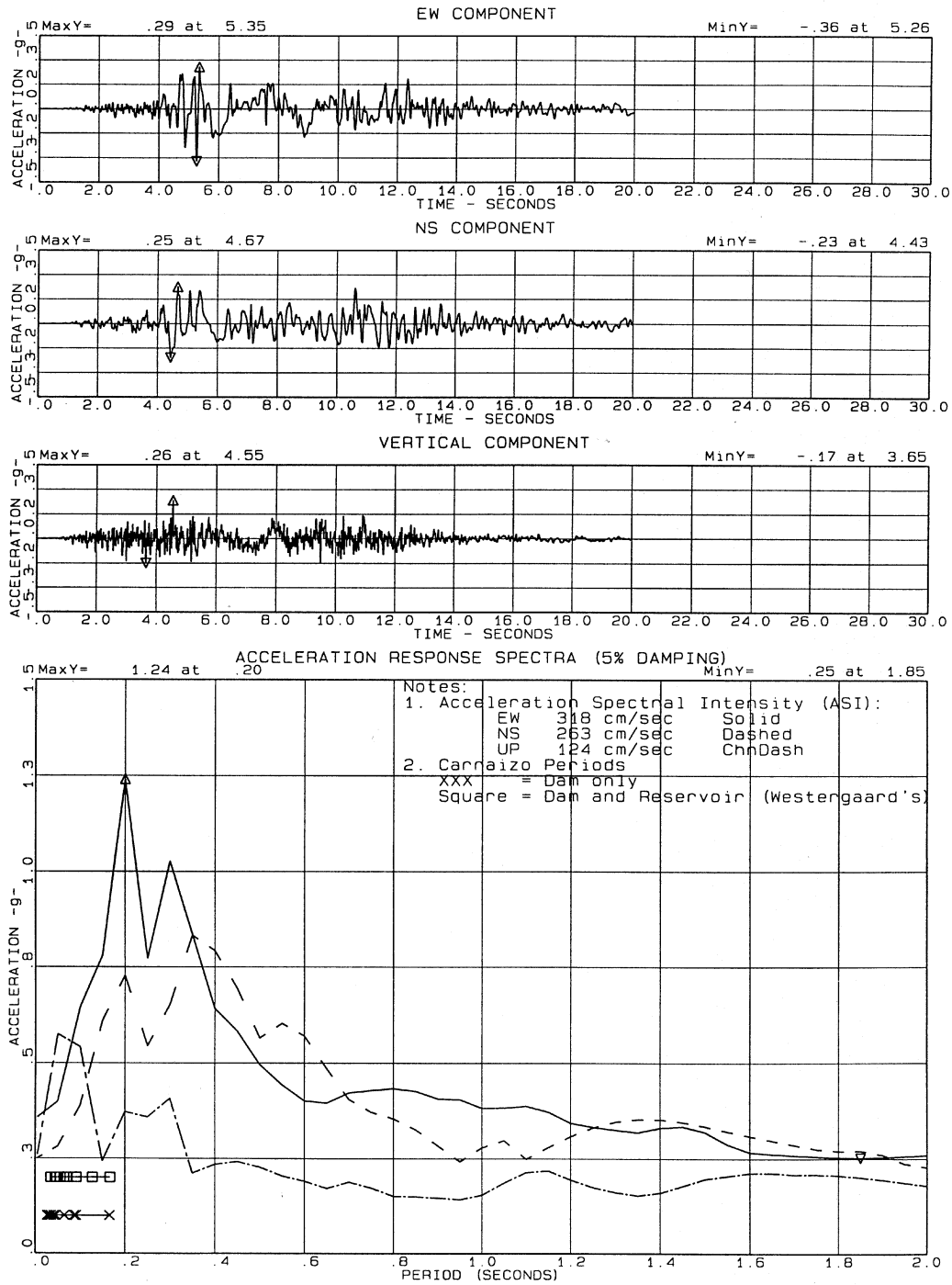
CARRAIZO DAM - PUERTO RICO M8.0 PUGET1 EQ, SUBDUCTION



Input-puget1.p2p. Created 8-Mar-99 19:20:39

Figure B8

CARRAIZO DAM - PUERTO RICO
M6.5 SCALED STURNO EARTHQUAKE, RANDOM



Input=sturno.p2p, Created 8-Mar-99 19:20:07

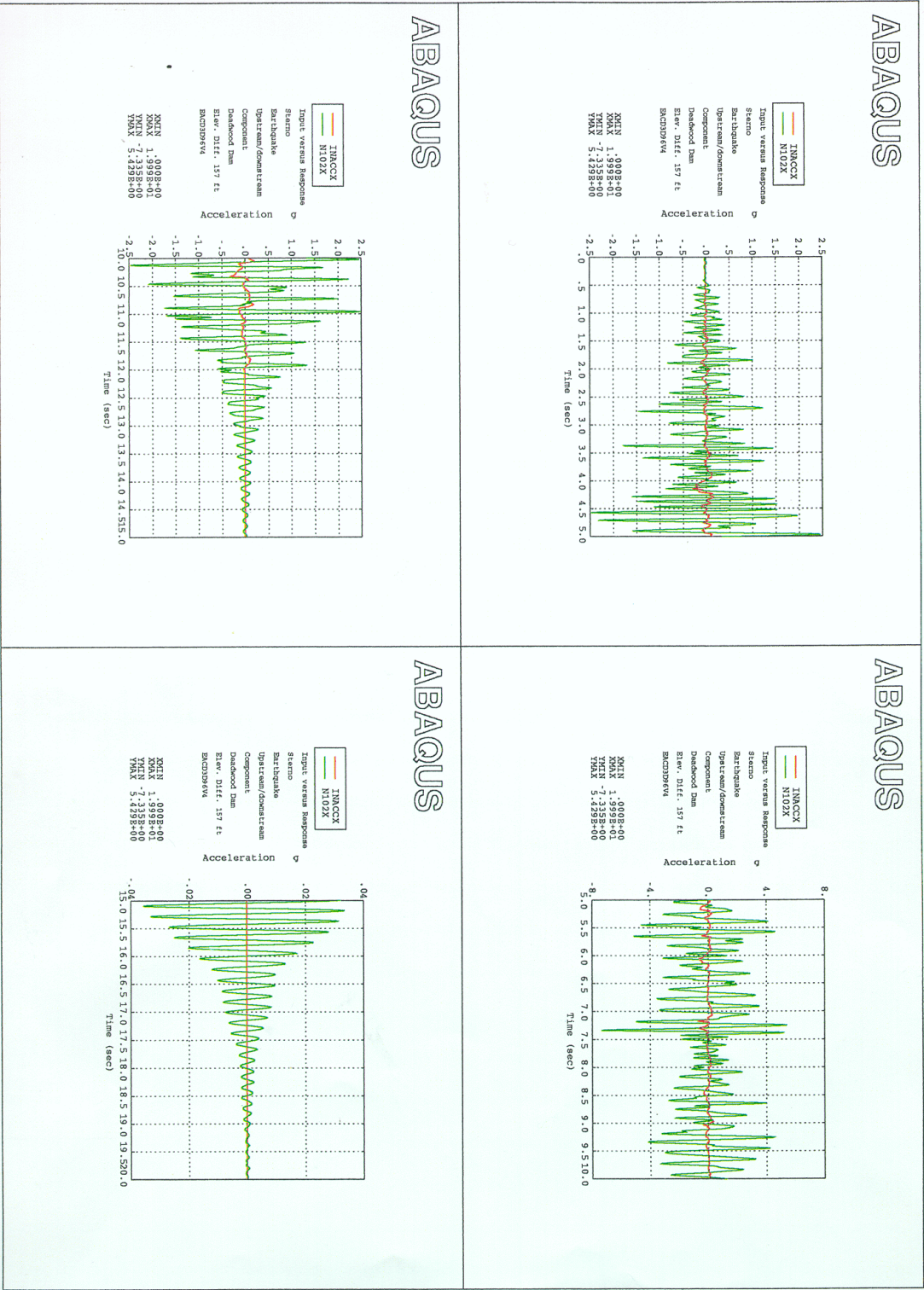
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Appendix C

Input and Response
Acceleration Time Histories

Table C1 : Analysis of Earthquake Responses at Dam Crests Number of Cycles Required for Accelerations at Dam Crests To Decay by One-half after the Input Motion Ends											
Dam	Type	Number of Cycles Required for Response Decay to One-half Peak Magnitude	First Natural Frequency (Hz)	First Natural Period (sec)	Crest Thickness (ft)	Base Thickness (ft)	Height (ft)	Peak Response Acceleration (g)	Peak Input Acceleration (g)	Accel. Amplification per foot of Dam Height (g)	Program Used
Deadwood	Arch	5	5.7	0.18	9	51	157	7.4	0.71	0.043	EACD3D96
Monticello	Arch	25	3	0.33	12	100	296	5.8	0.4	0.018	EACD3D96
Morrow Point	Arch	8	3.2	0.31	12	51	465	2.7	0.4	0.005	EACD3D96
Hoover	Arch	2	3.8	0.15	45	660	727	1.9	0.37	0.002	EACD3D96
Carraizo	Gravity	Adak : 3 Gillroy : 3 Puget : 3 Sturno : 3	6	0.17	---	97	105 105 105 105	0.78 1.2 1.3 1.6	0.25 0.31 0.3 0.36	0.005 0.008 0.010 0.012	ABAQUS
LaPlata	Gravity	Adak : 3 Gillroy : 3 Puget : 3 Sturno : 3	5.2	0.19	---	41	150 150 150 150	1.26 1.8 1.3 3	0.25 0.31 0.3 0.36	0.007 0.010 0.007 0.018	ABAQUS

Figure C1



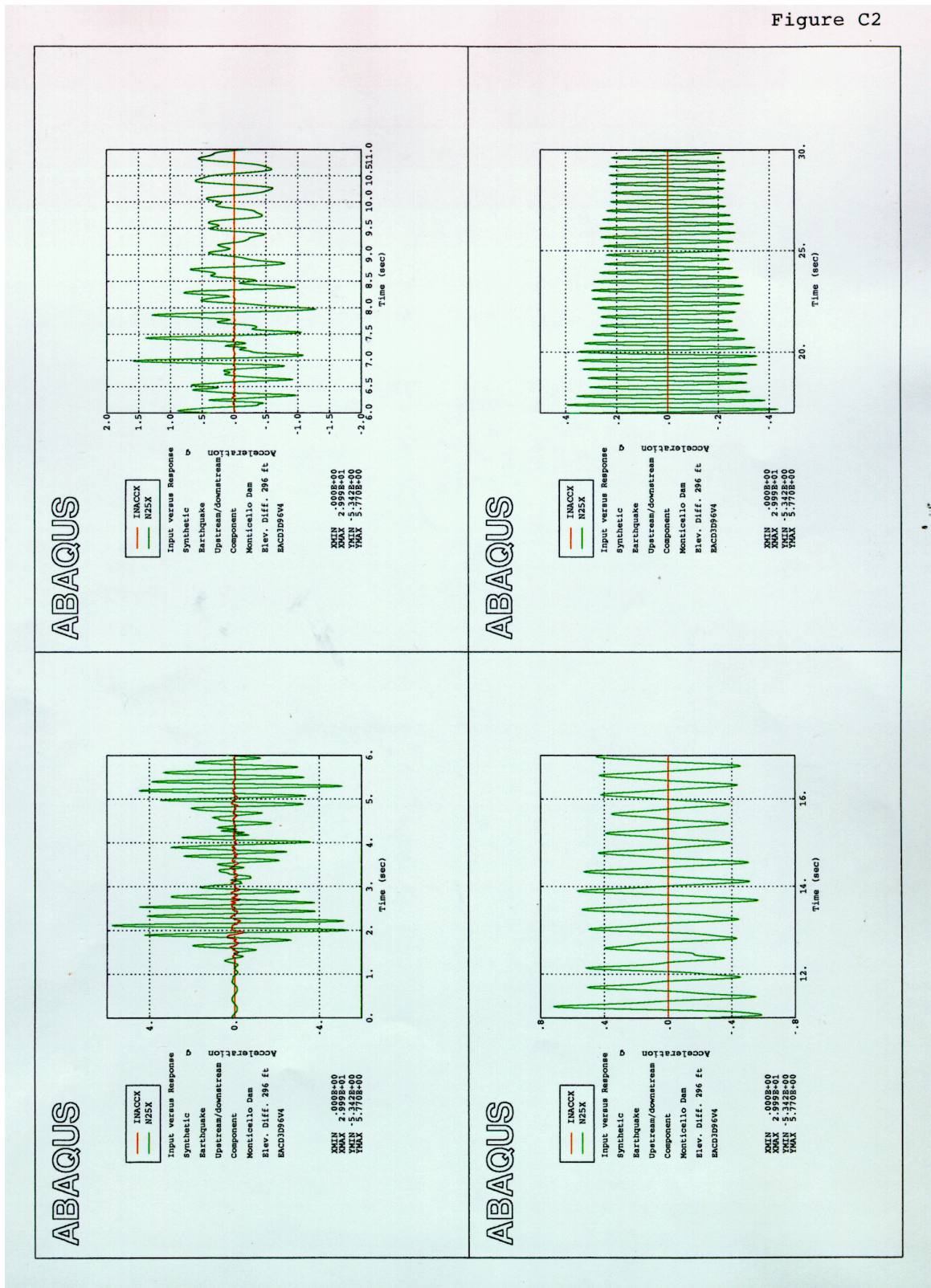


Figure C2

Figure C3

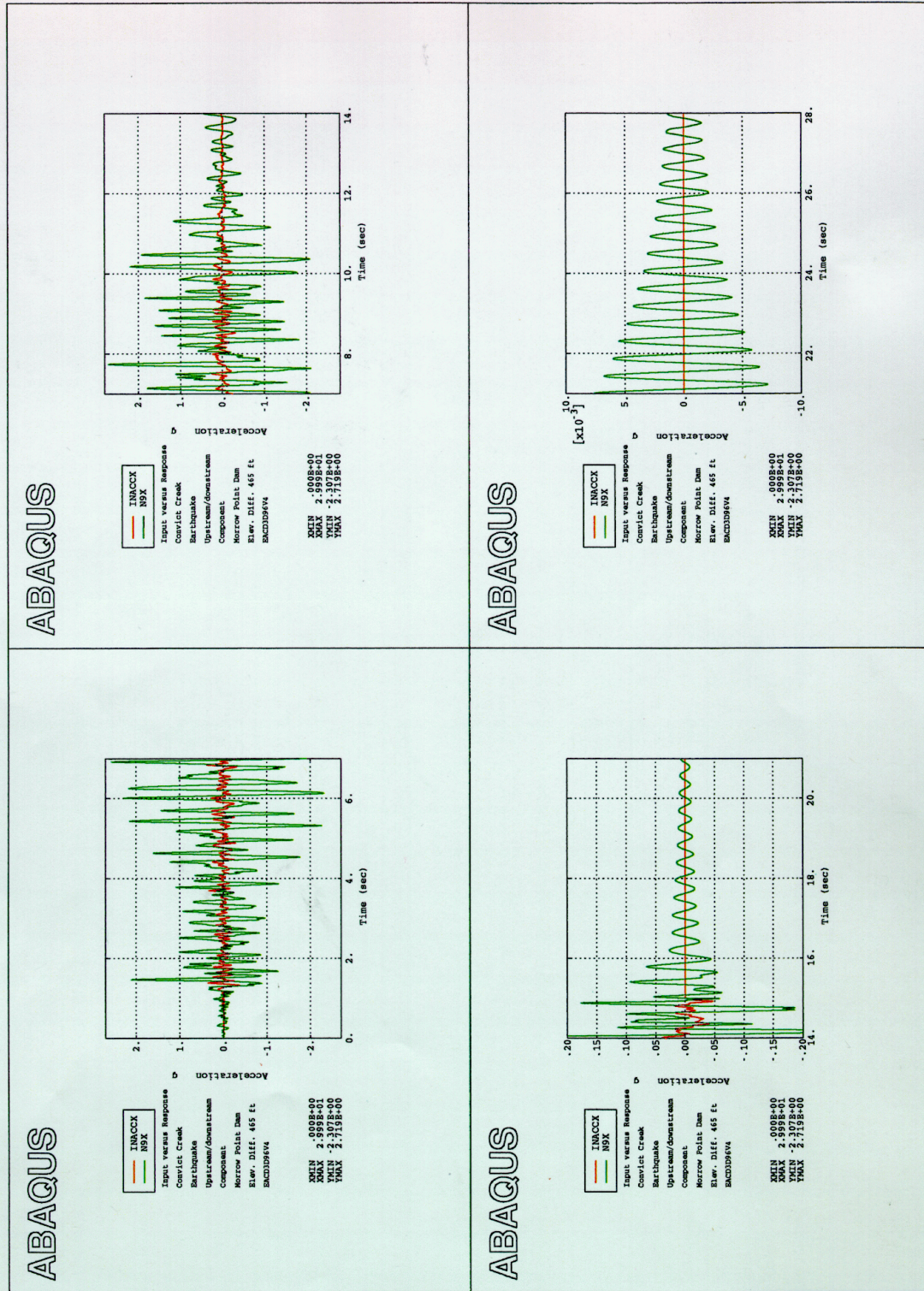


Figure C4

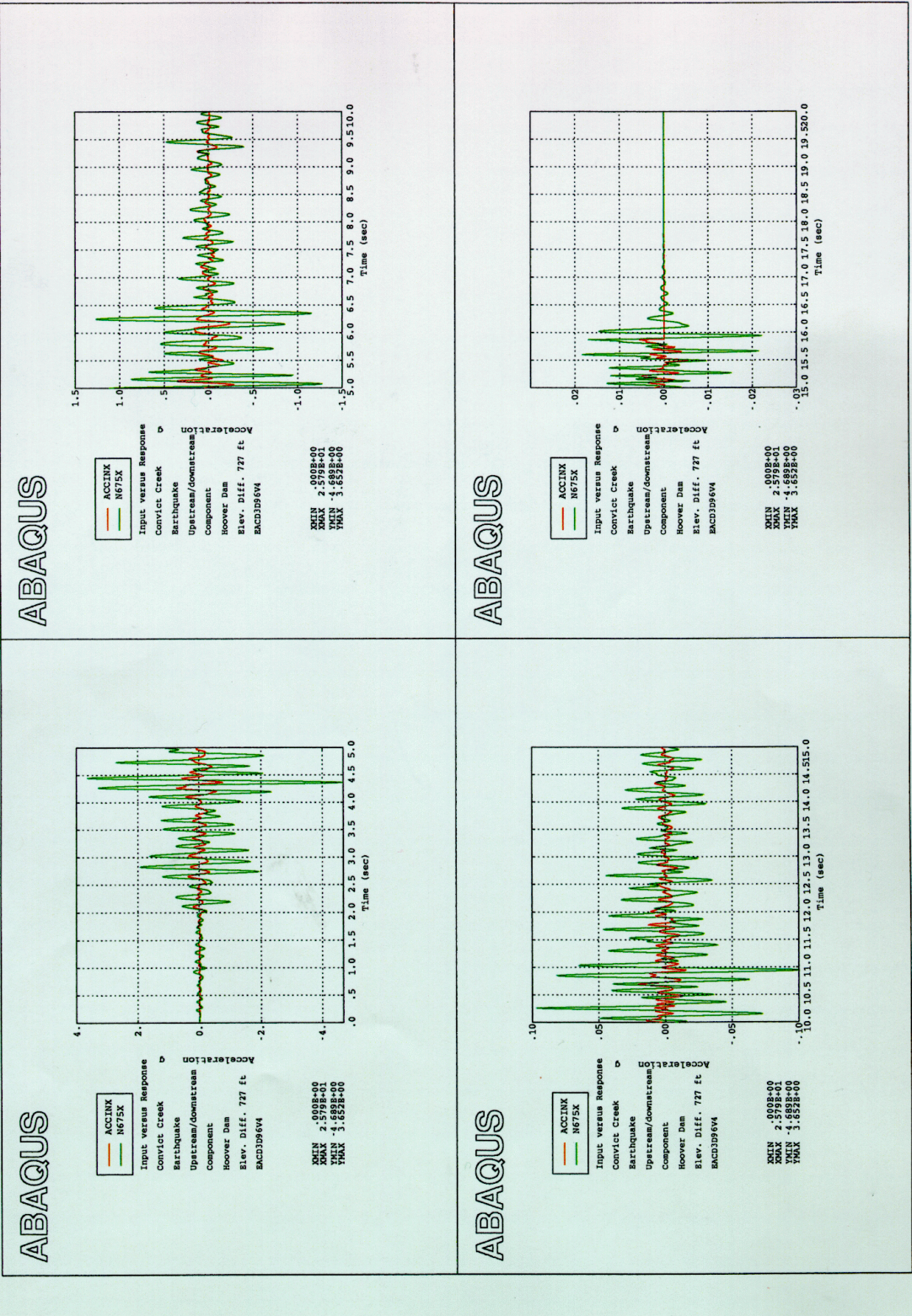




Figure C6

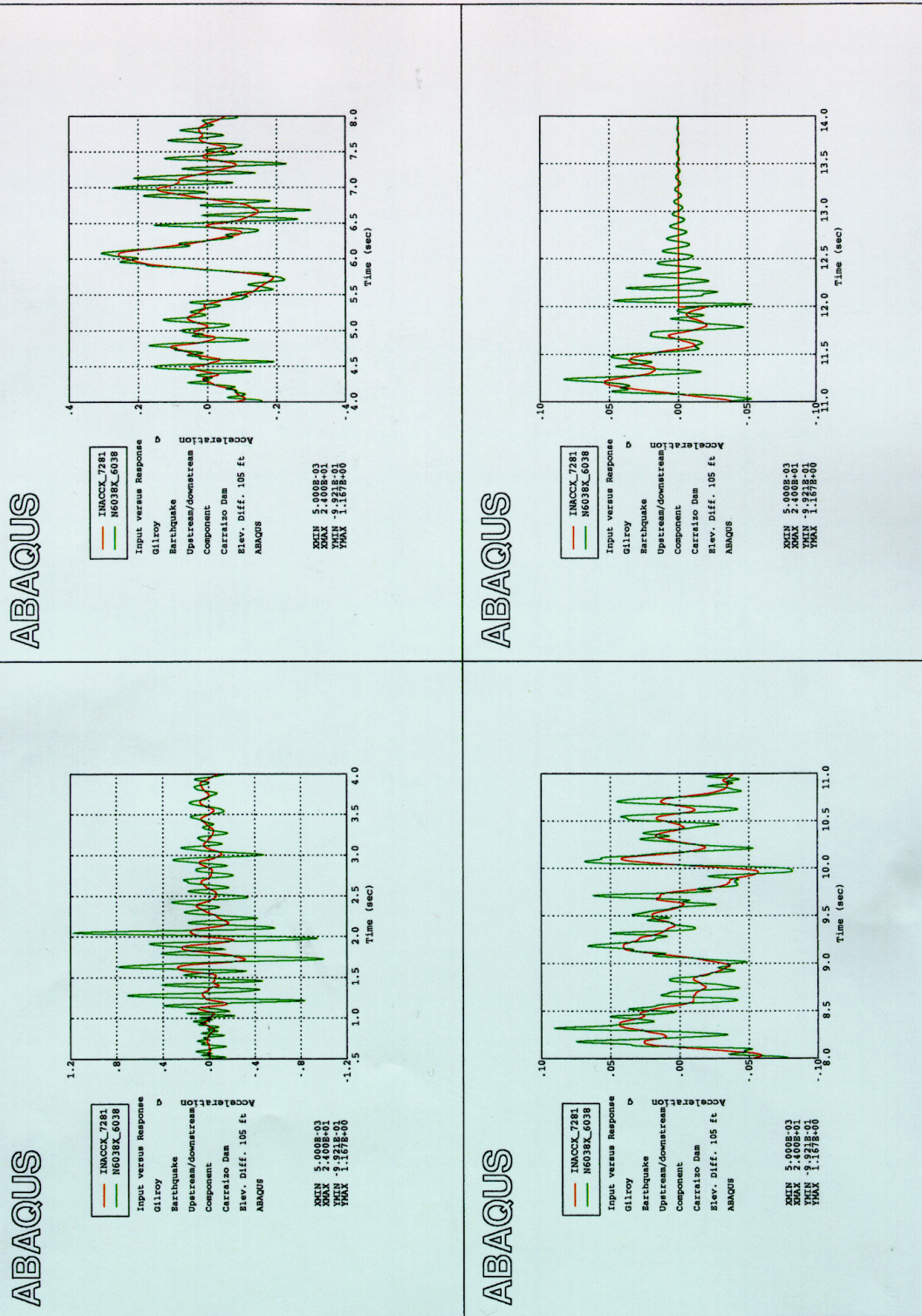


Figure C7

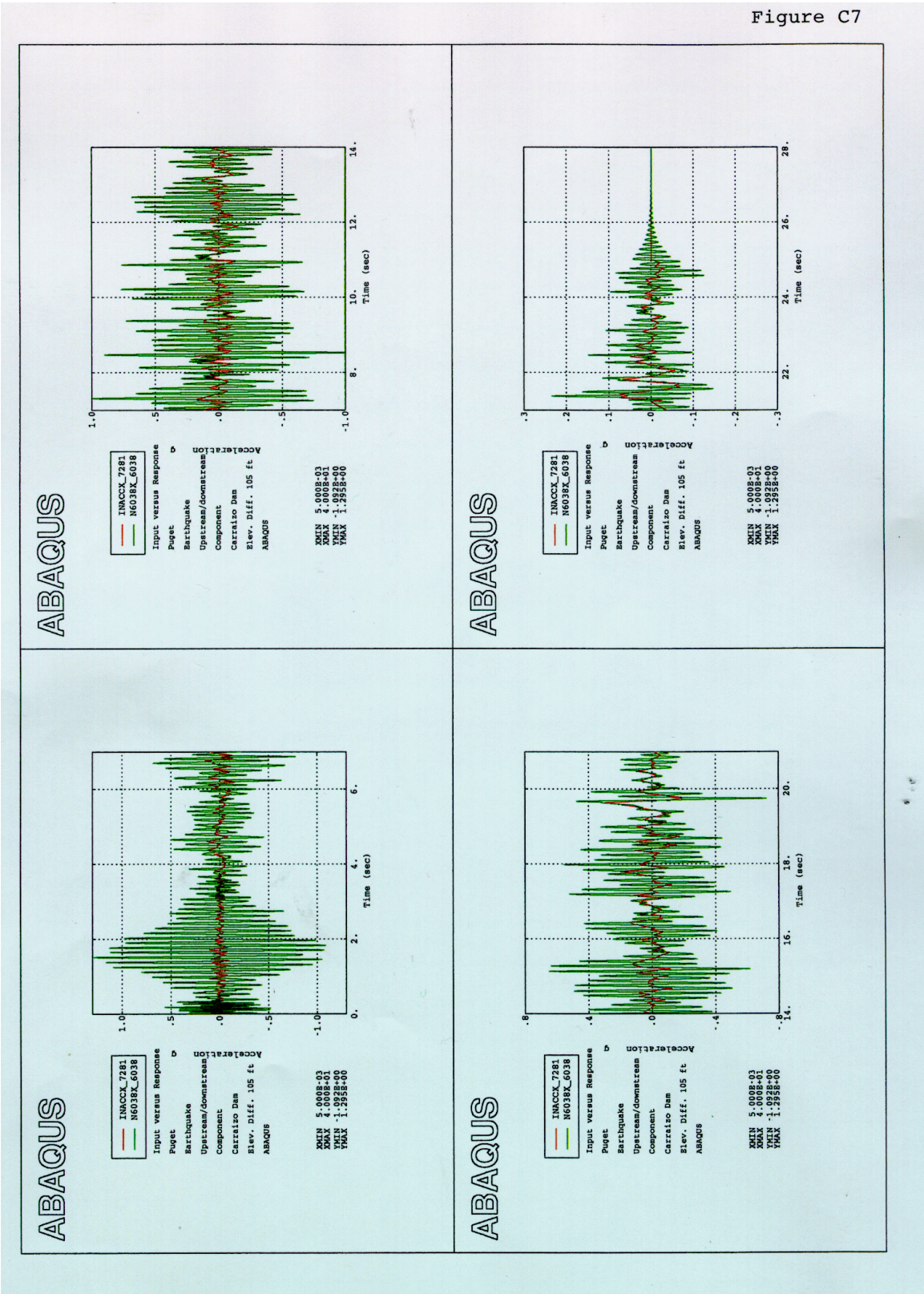


Figure C8

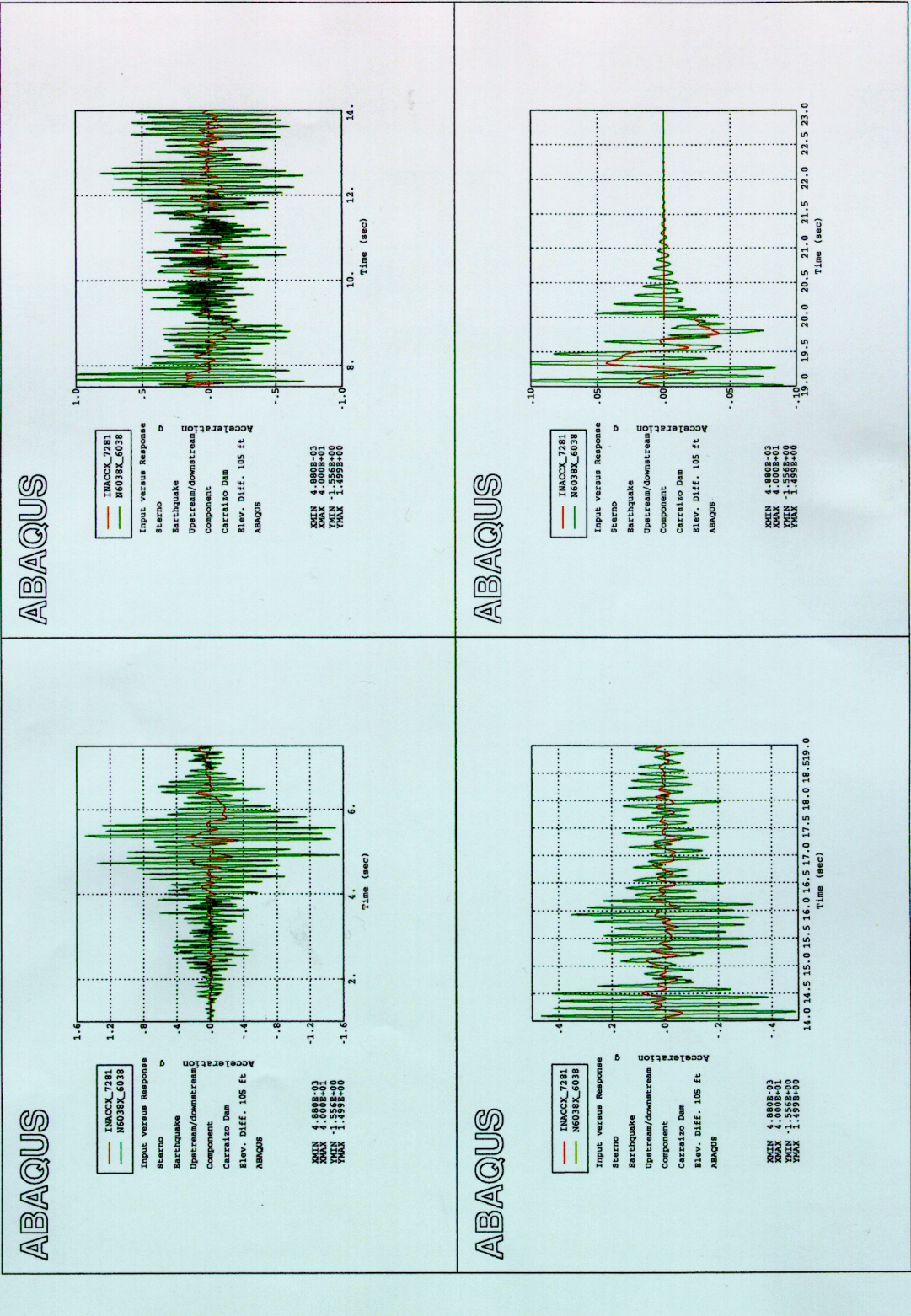
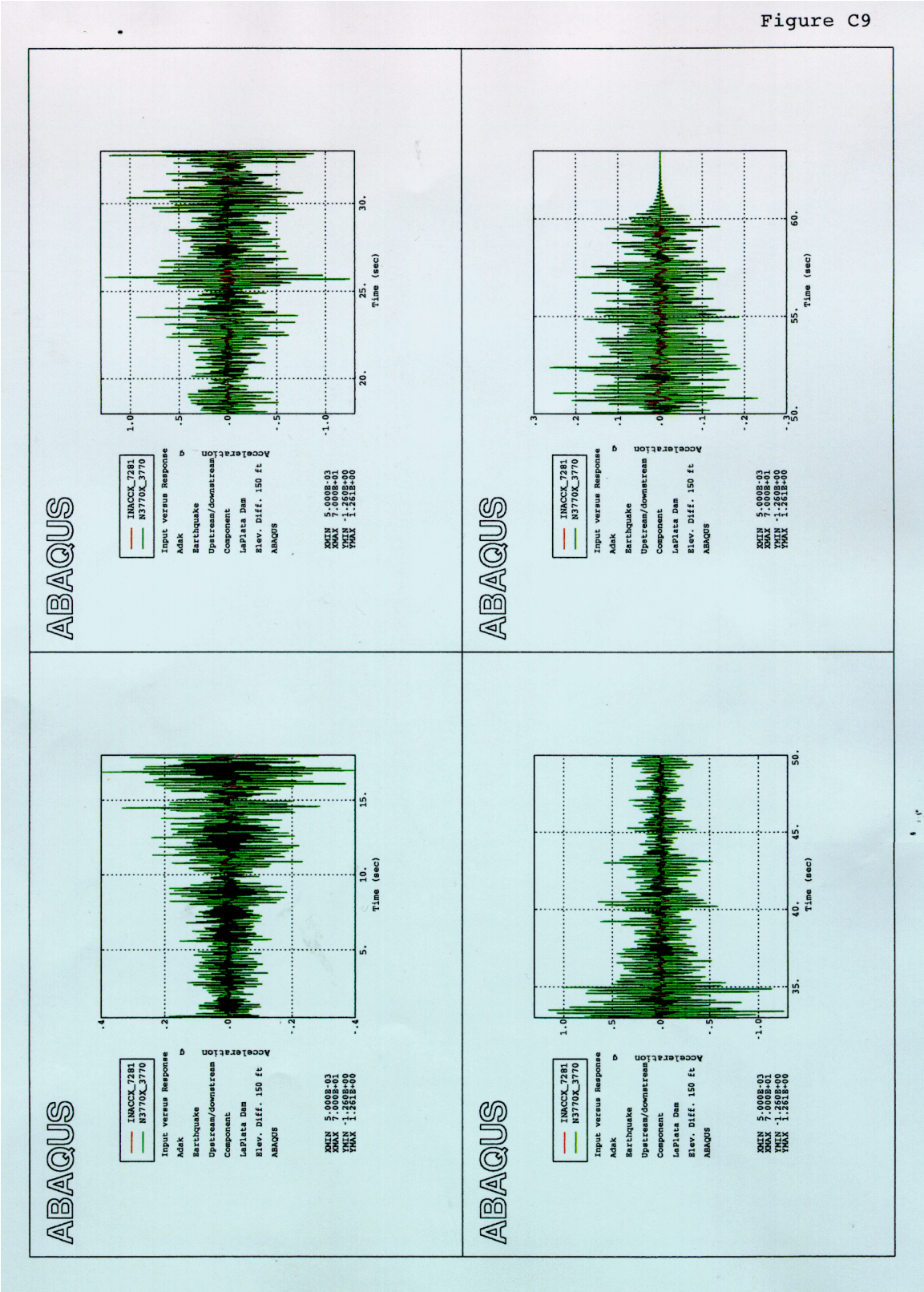
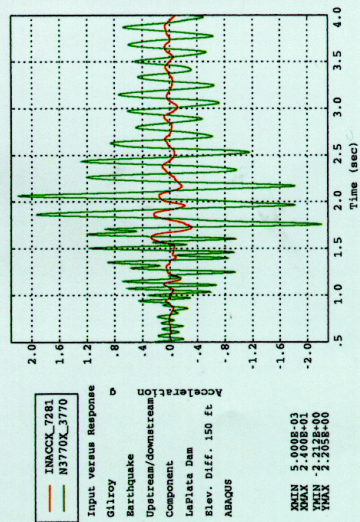


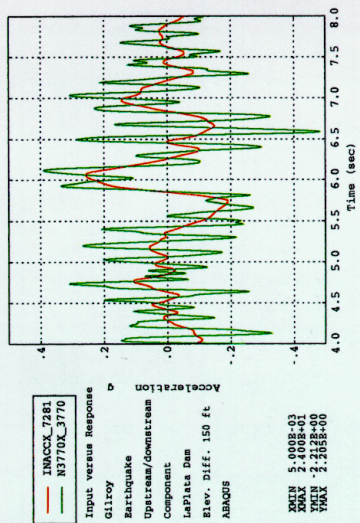
Figure C9



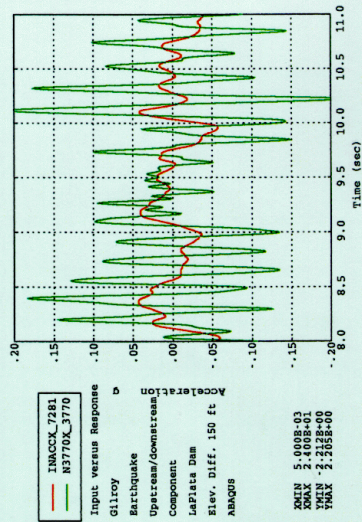
ABAQUS



ABAQUS



ABAQUS



ABAQUS

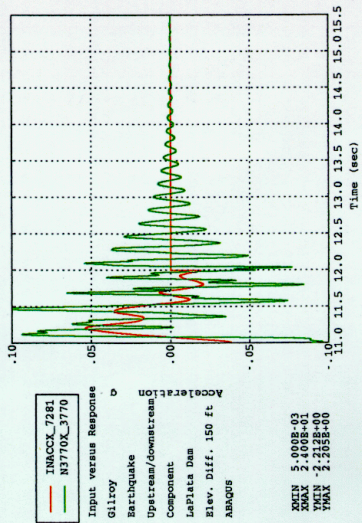


Figure C10

Figure C11

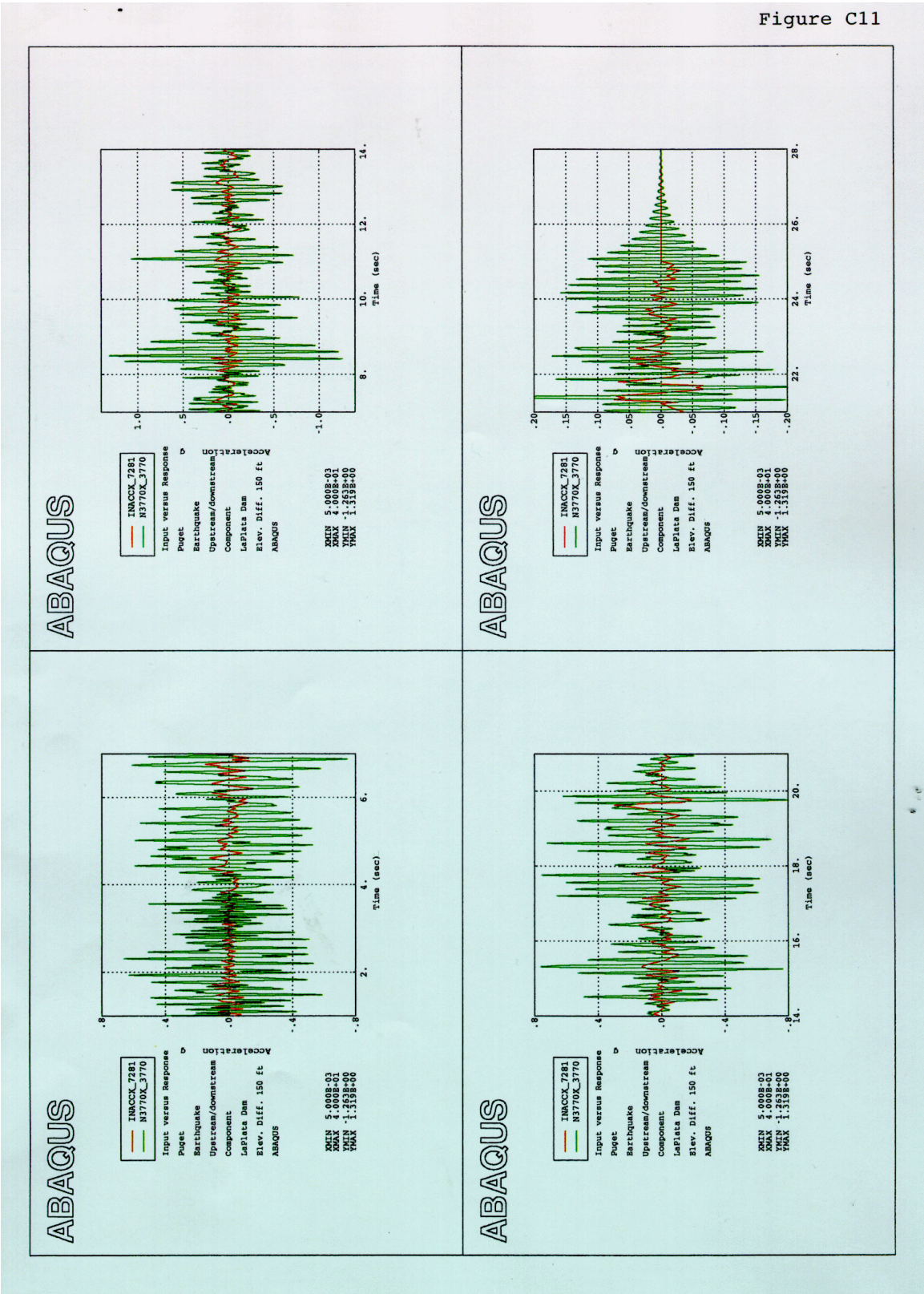
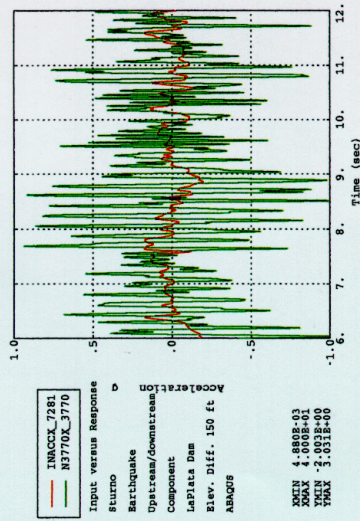
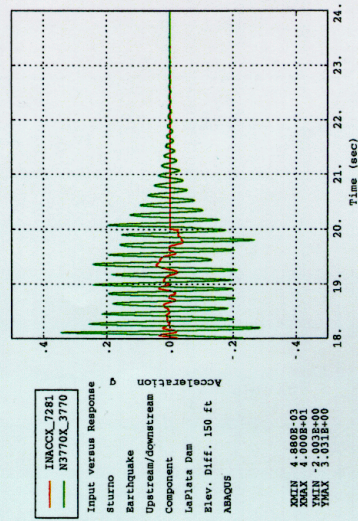


Figure C12

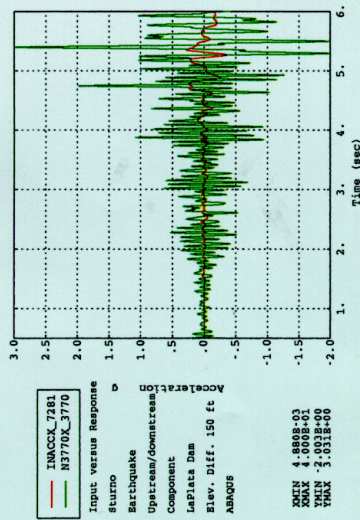
ABAQUS



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