TASK REPORT

ON

DEVELOPMENT OF SEISMIC ACCELERATION RESPONSE SPECTRA FOR DIESEL GENERATOR BUILDING OF SEQUOYAH NUCLEAR PLANT

PART 1: DESIGN BASIS SSE INPUT

Prepared for

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TABLE OF CONTENTS

Part 1

SECTION		PAGE
1	INTRODUCTION	1-1
2	DESCRIPTION OF ANALYSIS METHOD	2-1
3	SEISMIC GROUND MOTION INPUT	3-1
4	ANALYSIS MODELS	4-1
5	ANALYSIS SCOPE	5-1
6	ANALYSIS RESULTS	6-1
7	COMPARISON OF RESULTS	7-1
8	SUMMARY AND CONCLUSIONS	8-1
9	REFERENCES	9-1
	Figures	
	Tables	
Appendix A	Envelopes of Average ARS Plots for Individual Soil Cases	
Appendix B	Final Envelopes of Average ARS Plots for Enveloping the Results of Three Soil Cases	
Appendix C	Comparisons of ARS Envelopes of the Current Analysis with the original Design Basis ARS	

TASK REPORT ON DEVELOPMENT OF SEISMIC ACCELERATION RESPONSE SPECTRA FOR DIESEL GENERATOR BUILDING OF SEQUOYAH NUCLEAR PLANT

Part 1: Design Basis SSE Input

1. INTRODUCTION

This report presents the seismic analysis methodology, analysis models, analysis scope, and analysis results obtained for the Diesel Generator (DG) building of the Sequoyah Nuclear Plant. Part 1 of this report describes the analyses performed for the design basis seismic ground motion input of the Safe Shutdown Earthquake (SSE) for the plant. The objective of the analysis is to develop the seismic floor acceleration response spectra (ARS) for comparison with the design basis ARS for the building.

Since the DG building is supported by a layer of soil deposit above the underlying rock at the plant site and the structure is partially embedded in the soil deposit, the seismic response analysis for the building requires the consideration of the free-field response of the soil deposit above rock as well as the soil-structure interaction (SSI) effect including the effect of embedment. Thus, in performing the seismic response analysis for the building, the free-field response of the soil deposit is analyzed using the one-dimensional (1-D) soil column wave propagation analysis computer program SHAKE (Reference 1), and the SSI response of the structure is analyzed using the recently developed three-dimensional (3-D) finite element SSI analysis computer program SASSI (Ref. 2).

Section 2 of Part 1 of this report presents the analysis assumptions and methods for determining the seismic response of the soil deposit and the building.

Section 3 describes the seismic input motions for the seismic response analysis. Section 4 describes the seismic analysis models used for the response analysis. Section 5 presents the analysis cases considered in the seismic analysis. Section 6 presents the analysis results obtained. Section 7 presents the comparison of the response results obtained in the current analysis with the corresponding original design basis responses. Section 8 summarizes the conclusions.

2. DESCRIPTION OF ANALYSIS METHOD

Since the DG building is supported by a layer of approximately 70 ft. thick of soil deposit above the rock foundation for the plant, the determination of the seismic response for the building requires, in addition to the determination of SSI response of the structure, the determination of free-field soil response above rock subjected to the design seismic input motion which is defined at the surface of rock of the plant. The analysis for the free-field seismic response of the soil deposit assumes that the soil profile is horizontally layered and the seismic input motion is vertically propagating plane shear and compression incidence waves, such that the analysis can be performed using the 1-D wave propagation analysis methodology for a soil column utilizing the computer program SHAKE (Ref. 1).

For the SHAKE analysis of the soil deposit, the design seismic input motion defined at the rock surface of the site is prescribed in the form of rock outcrop motion. Using this form of input, the soil-rock interaction effect is considered in determining the soil response. This interaction takes place in the sense that the energy of seismic waves reflected form the free surface of the soil deposit is permitted to dissipate into the underlying rock medium. This form of input motion is also more consistent with the definition of design response spectra since such a definition is usually based on the study of surface-recorded ground motions rather than the motions recorded at depth.

In the SHAKE analysis of free-field soil response, the low-strain soil shear moduli of the soil layers are based on the results of site geophysical survey (Ref. 3). In order to account for the variability in soil shear modulus, analyses are performed by varying the soil shear moduli as determined from the geophysical survey data by $\pm$ 50%. Furthermore, since soil materials usually exhibit nonlinear hysteresis behavior as a function of shear strain in soil under clyclic loading

conditions, the SHAKE analysis of seismic soil response also considers the strain-dependency of soil properties based on the variation curves for normalized shear modulus and damping factor as functions of shear strain developed for sand by Seed and Idriss (Ref. 4).

The SSI response of the DG building is determined using the newly-developed 3-D finite element SSI analysis computer program SASSI (Ref. 2). In the SASSI analysis, the free-field soil surface response motion as determined from the SHAKE analysis is used as the input prescribed at the ground surface. Consistent with the assumption for the SHAKE analysis, the input motion to the SASSI analysis is also assumed to be caused by vertically propagating plane seismic shear and compression waves. Since SASSI is a linear SSI analysis computer program, the equivalent linear soil properties used for the SASSI analysis are based on the strain-compatible soil shear moduli and damping values as resulted from the SHAKE iterative, equivalent linear analysis of free-field soil response. In this manner, the primary effect of strain dependency of soil properties caused by the free-field soil response is included in the SASSI SSI response analysis.

The computer program SHAKE applied to the analysis of free-field soil response reported herein is a Bechtel version (CE915-SHAKE3) which was obtained from the University of California, Berkeley, and implemented on the Bechtel UNIVAC computer system. This version of SHAKE has been tested and verified on the UNIVAC computer system and the results of verification are documented in the validation report for the program (Ref. 5). Additional validation has also been performed for the analysis reported in Ref. 6 and the results of validation are documented in the calculation files which form the basis for the report in Ref. 6.

The version of SASSI computer program applied to the SSI analysis of the DG building reported herein was obtained by Bechtel from the University of

California, Berkeley, and implemented in the CDC CRAY-XMP computer system. This version has undergone extensive testing and validation by benchmarking the SASSI solutions with a comprehensive set of available published solutions. The results of the program validation are documented in the program validation calculation files (Ref. 7). The program validation results have been reviewed in detail by the NRC consultants and the validity of the program verification is confirmed in the NRC consultant's report (Ref. 8).

3. SEISMIC GROUND MOTION INPUT

The horizontal acceleration time histories for the design basis SSE used as the control motion input for the seismic response analysis of the DG building are the four design basis OBE artificial earthquake acceleration time histories A, B, C, and D for the Sequoyan Nuclear Plant scaled up by a factor of 2. The vertical acceleration time histories used are 2/3 of the corresponding horizontal time histories for the SSE. The control motion for the DG building seismic response analysis is prescribed as rock outcrop motion at El. 650' which is the elevation of the soil-rock interface. The motion is considered to be caused by vertically propagating plane seismic incidence shear waves for the horizontal components and compression waves for the vertical component of the input motion.

The maximum (cut-off) frequency of the input earthquake acceleration time histories considered for the SHAKE free-field soil response analysis is 33 Hz in accordance with the requirement of the NRC Standard Review Plan. The maximum frequency for the SASSI SSI response analysis for the DG building is prescribed consistent with the maximum significant frequency of the free-field soil response motion at the soil surface which is used as the input motion for the SASSI analysis.

4. ANALYSIS MODELS

For the SHAKE analysis of free-field soil response, the 1-D soil column model used is shown in Figure 1. As shown, the model consists of four soil layers above a rock halfspace. The properties of the top soil layer between El. 722' (grade) and El. 712' are designated as Soil #1; the properties of the second soil layer between El. 712' and El. 692' are designated as Soil #2; the properties of the third soil layer between El. 692' and El. 678' are designated as Soil #3; and the properties of the fourth soil layer between El. 678' and El. 650' (soil-rock interface) are designated as Soil #4. The mean, lower-bound (-50% of mean), and upper-bound (+50% of mean) low-strain soil properties for all four soil layers and the the properties of rock halfspace are also shown in Figure 1. These properties are derived from the TVA calculation file for the DG building as contained in Ref. 9. The ground water table is taken to be at El. 692' in accordance with Ref. 9. Since the SHAKE analysis does not have limitations on layer thickness as a function of cutoff frequency, averaging of the soil properties as used in Ref. 9 has been applied to obtain the properties for a reduced number of soil layers for the SHAKE analysis reported herein.

The strain-dependent variation curves for normalized soil shear modulus vs. shear strain and soil damping ratio vs. shear strain for Soil #1, #2, and #3 used for the SHAKE analysis are the standard sand curves as obtained from Ref. 4. These curves are shown in Figures 2 and 3. The strain-dependent curves used for Soil #4, which is a layer of weathered shale, are based on the curves derived in Ref. 9. These curves are shown in Figures 4 and 5.

For the SASSI analysis of the SSI response for the DG building, the 3-D lumped-mass stick model for the building as developed for the STARDYNE analysis of Ref. 9, is directly used. This model is shown in Figure 6. The fixed-base structure modal properties for the 3-D lumped mass model as reconstructed from Ref. 9 for the SASSI analysis are shown in Table 1.

These modal properties compare closely with the corresponding properties as obtained from the STARDYNE analysis of Ref. 9. The fixed-base structure damping ratio used for the SSE analysis is uniformly 7% for all modes of the fixed-base structure.

The foundation model for the DG building for the SASSI SSI analysis consists of a 3-D brick finite element model for the embedded DG building basemat between El. 722' (grade and top of basemat) and El. 712' (bottom of basemat). The finite element mesh of the foundation model is shown in Figure 7. This finite elment mesh applies also for the brick finite element foundation soil model for the excavated soil volume displaced by the embedded DG building basemat. This foundation modelling technique is unique to the SASSI SSI analysis methodology which adopts the so-called "flexible volume substructuring" method (Ref. 2).

The connection between the brick finite element model for the basemat and the 3-D lumped-mass stick model for the DG building above the basemat is accomplished by connecting the base of the stick model to a set of rigid beams attached to the top of the finite element model for the basemat, simulating the connections of structural walls to the basemat. The finite element mesh for the SASSI foundation model is sized to pass the highest significant frequency of the free-field soil response motion as determined from the SHAKE free-field soil response analysis.

The structural damping for the brick finite element model of the basemat is prescribed as 7%, and the soil hysteresis damping for the brick finite element foundation soil model is prescribed as the strain-compatible values resulting from the SHAKE free-field soil response analysis.

5. ANALYSIS SCOPE

The seismic response analyses for the DG building for the SSE condition have been performed for three soil cases, namely, the mean, lower-bound, and upper-bound soil cases with the mean, lower bound (-50% of mean), and upper-bound (+50% of mean) low-strain soil shear moduli, respectively. For each soil case, analyses have been performed separately for each of the three directions of input, namely, the horizontal NS and EW, and the vertical directions of input. For the analysis in each direction, all four design acceleration time histories A, B, C, and D for the SSE have been used as the input. Thus, the total analysis scope consists of 24 separate SHAKE free-field soil response analyses (i.e., 3 soil cases x 2 directions x 4 time histories) and 36 separate SASSI seismic SSI response analyses (i.e., 3 soil cases x 3 directions x 4 time histories).

In the SHAKE analysis, the strain-compatible soil properties for each soil case subjected to the four (A, B, C, and D) SSE horizontal time history inputs are first obtained, then the averaged strain-compatible soil properties applicable for each soil case are obtained as the average of the four sets of strain-compatible soil properties resulting from the four horizontal time history inputs. These properties are shown in Table 2. The averaged strain-compatible soil properties as obtained for each soil case are finally used as the equivalent linear soil properties for the SASSI SSI model for each corresponding soil case. The averaged properties as obtained are also used for the second-step SHAKE analyses without further soil property strain-compatibility iterations for determining the free-field soil surface response motions (horizontal and vertical) for each of the four time history inputs and for each soil case. This results in 12 horizontal and 12 vertical free-field soil surface response time histories which are compatible with the averaged strain-compatible soil properties for each soil case. These motions are subsequently used as the input for 36 (12 horizontal NS, 12 horizontal EW, and 12 vertical) SASSI SSI response analyses.

6. ANALYSIS RESULTS

The results of SHAKE free-field soil response analyses consist of three sets of strain-compatible soil properties corresponding to the mean, lower-bound, and upper-bound soil cases, and 24 strain-compatible free-field soil surface response acceleration time histories (12 for horizontal inputs and 12 for vertical inputs). For each of these time histories, the 1, 2, and 5% damping acceleration response spectra (ARS) have been calculated and the resulting spectra are averaged for the four input time histories A, B, C, and D. This results in 6 averaged ARS (one horizontal and one vertical for each of the 3 soil cases) for the free-field soil response motions at the ground surface for each spectral damping value. These ARS are plotted and compared with the corresponding averaged ARS for the free-field soil response motions at the soil-rock interface (El. 650') and the averaged ARS for the input motions at the rock outcrop in Figures A-1 through A-18 in Appendix A. The same comparisons for the envelopes of averaged ARS for 3 soil cases are shown in Figures B-1 through B-6 in Appendix B.

The results of SASSI seismic SSI response analyses consists of 15 acceleration response time histories at selected locations and directions for the DG building for each of the 36 separate SASSI analyses, resulting in a total of 540 response time history outputs. The 15 response time histories selected for each SASSI analysis case consist of 5 selected response time histories for each of the three floor elevations at El. 753.5' (roof), El. 739.75' (second floor), and El. 722' (top of basemat). The 5 selected response time histories for each floor elevation consist of 4 horizontal response time histories (NS and EW response time histories at 2 extreme edge locations of the floor) and one vertical response time history at the center of mass location for the floor. A comparative study performed at the early stage of the analysis shows that the floor response ARS for these 5 selected time histories envelope the floor response ARS for the response motions at 5 selected locations (4 extreme edge locations and the center of mass location) for each floor.

For each of the 540 response time histories obtained from SASSI analyses, the 1, 2, and 5% damping floor response ARS have been calculated, resulting in a total of 1620 ARS curves. These ARS curves are subsequently post-processed as described in the following:

(1) The 540 ARS curves for each spectral damping are first combined, using the square-root-of-the-sum-of-squares (SRSS) procedure, for the co-directional response resulting from three directions of input for the same soil case and the same time history input. This reduces the 540 ARS curves to 180 curves for each spectral damping.

(2) The 180 ARS curves for each spectral damping as obtained from Step 1 are then averaged for the four time history inputs (i.e., time histories A, B, C, and D). This reduces the 180 curves to 45 averaged ARS curves for each spectral damping.

(3) The 45 averaged ARS curves for each spectral damping as obtained from Step 2 are compared and enveloped for each floor elevation to obtain 27 envelopes of average ARS curves (3 directions per floor x 3 floor elevations x 3 soil cases) for each spectral damping.

(4) The 27 envelopes of average ARS curves for each spectral damping as obtained from Step 3 above are finally combined by enveloping the curves for 3 soil cases, resulting in 9 final envelopes of average ARS curves (3 directions per floor x 3 floor elevations) for each spectral damping.

The 27 envelopes of average ARS curves for 1, 2, and 5% spectral damping values for individual soil cases as obtained from Step 3 above are plotted as shown in Figure A-19 through A-45 of Appendix A. The 9 final envelopes of ARS curves for 1, 2, and 5% damping values as obtained from enveloping results for 3 soil cases in Step 4 above are plotted and shown in Figures B-7 through B-15 of Appendix B.

7. COMPARISON OF RESULTS

The final results of SASSI analyses in terms of the 1% damping final ARS envelopes for three soil cases (i.e., the 1% damping ARS envelopes shown in Figures B-7 through B-15 of Appendix B) are compared with the corresponding original (old) design basis ARS curves in Figures C-1 through C-9 of Appendix C, for each of the three directions of response and for each of the three floor elevations in the DG building. In Figures C-3, C-6 and C-9 which compare the vertical response ARS envelopes at three elevations of the DG building, the comparisons are also made with the new vertical design basis ARS which were developed subsequent to the establishment of the original design basis ARS.

As shown by the comparison in these figures, the final floor response ARS envelopes as obtained in the current analysis are enveloped by the original design basis ARS as well as by the new vertical design basis ARS with a significant margin in the spectral peak frequency region.

8. SUMMARY AND CONCLUSIONS

The seismic response of the Diesel Generator (DG) building subjected to the design SSE ground motion input for the Sequoyah Nuclear Plant has been analyzed using the 3-D finite element SSI analysis computer program SASSI to develop the floor acceleration response spectral envelopes, taking into account the amplified soil response above rock based on the 1-D soil column wave propagation analysis computer program SHAKE. The analyses have been performed for three soil cases with the mean, lower-bound, and upper-bound soil properties to account for the variation of the low-strain soil shear moduli as derived from the seismic geophysical survey data. For each soil case, the strain-dependency of soil shear moduli and damping values have also been incorporated in the analysis. All four SSE design time histories have been used as the seismic input for the analysis. The seismic input motions are considered to be rock outcrop motions defined at the surface of rock at the plant site.

The envelopes of average acceleration response spectra (ARS) for 3 spectral damping ratios (1, 2, and 5%) for 3 directions of response (NS, EW, and Vertical), at three elevations of the DG building (roof, second floor, and top of basemat) have been developed for each soil case. These ARS envelopes are plotted in Figures A-19 through A-45 of Appendix A. The final envelope of average ARS curves obtained by enveloping results for all three soil cases are plotted in Figures B-7 through B-15 of Appendix B.

The comparisons of the final envelopes of average ARS curves as obtained in the current analysis with the original (old) and new design basis ARS for 1% spectral damping ratio are shown in Figures C-1 through C-9 of Appendix C. As shown in these comparisons, the final envelope of average ARS curves obtained in the current analysis are enveloped by the original design basis ARS with significant margins. Thus, the design basis ARS for the DG building for the SSE are conservative with a significant margin of conservatism relative to the ARS envelopes developed in the analysis reported herein which has utilized the current state-of-the-art analysis methodology and computer programs.

9. REFERENCES

(1) Schnabel, P.B., Lysmer, J., and Seed, H.B., "SHAKE - A Computer Program for Earthquake Response Analysis of Horizontally Layered Sites," Report No. EERC 72-12, University of California, Berkeley, December 1972.

(2) Lysmer, J., Tabatabaie-Raissi, M., Tajirian, F., Valdani, S., and Ostadan, F., "SASSI - A System for Analysis of Soil-Structure Interaction," Report No. UCB/GT/81-02, Geotechnical Engineering, University of California, Berkeley, April 1981.

(3) Sequoyah Nuclear Plant, Final Safety Analysis Report, Sections 2.5 and 3.7.

(4) Seed, H. B. and Idriss, I. M., "Soil Moduli and Damping Factors for Dynamic Response Analysis," Report No. EERC 70-10, University of California, Berkeley, December 1970.

(5) Davie, J. R., "Verification Report for Computer Program SHAKE3, Version No. A1-1," Revision 1, Bechtel Power Corporation, February 1985.

(6) Bechtel North American Power Corporation," Task Report on Development of Horizontal Seismic Acceleration Response Spectra for Auxiliary Building ERCW Pipe Tunnel,", Report prepared for TVA Sequoyah Nuclear Plant, January 25, 1988.

(7) Bechtel Western Power Corporation, "SASSI Computer Program Validation", Bechtel Calculation No. DCPP-LTSP-SSI 2-01 through 2-20, January 1986.

(8) NRC letter from Charles M. Tramell, NRC Project Manager, to Licensee, Pacific Gas and Electric Company (PG&E), dated August 27, 1987, on "Trip Report - Audit of Calculational Programs to Evaluate Potential Soil-Structure Interaction Effects - June 9 through 11, 1987," Diablo Canyon Power Plant, Long Term Seismic Program.

(9) TVA Calculations, "Sequoyah Nuclear Plant - Diesel Generator Building 3-D Earthquake Study", RIMS No. B41 '87 0521 020, May 12, 1987; and "Geophysical Properties for Seismic Analysis of Diesel Generator Building," RIMS No. B41 '87 0715 001, June 9, 1986.

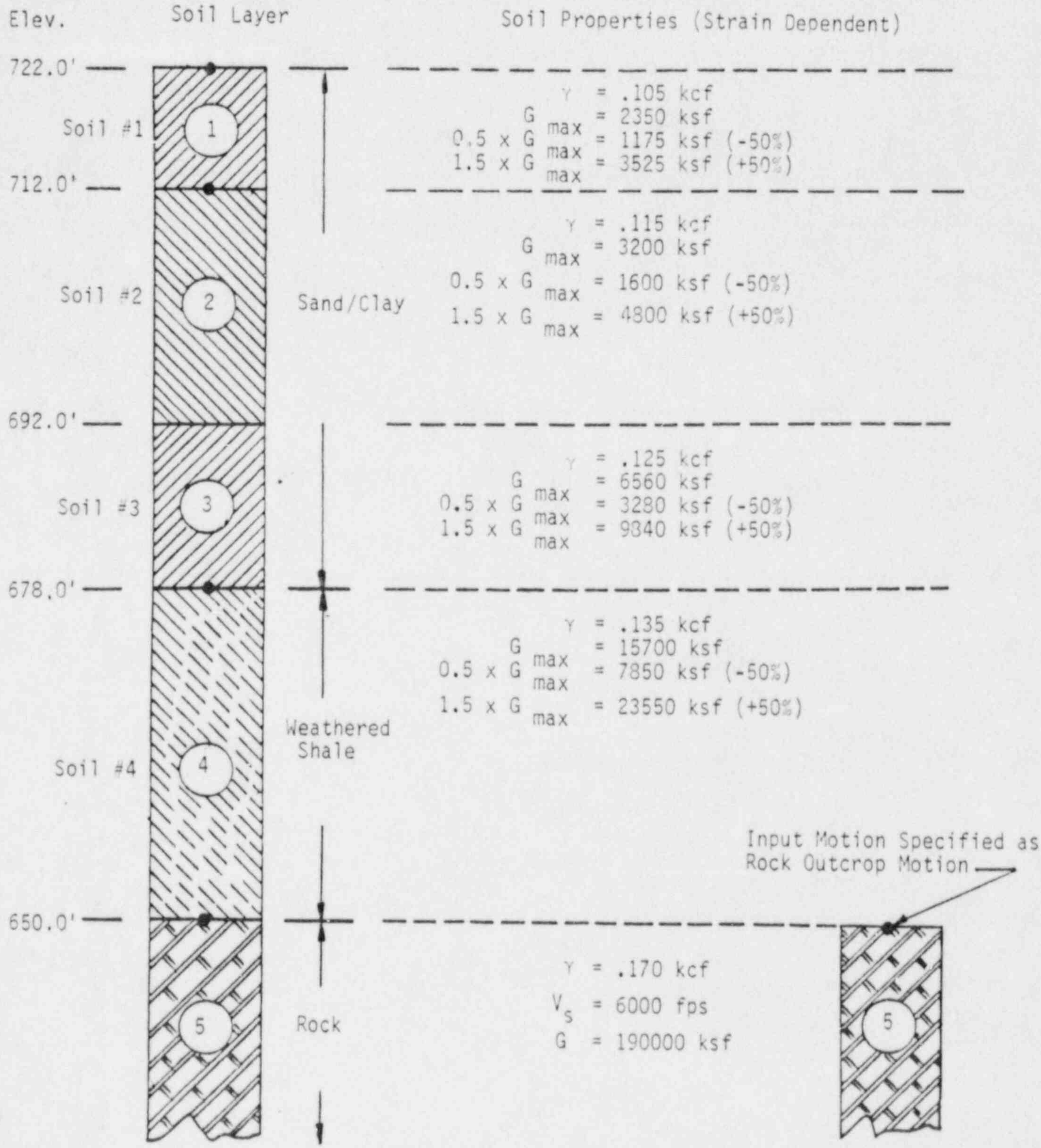


Figure 1. SHAKE Analysis Model and Properties

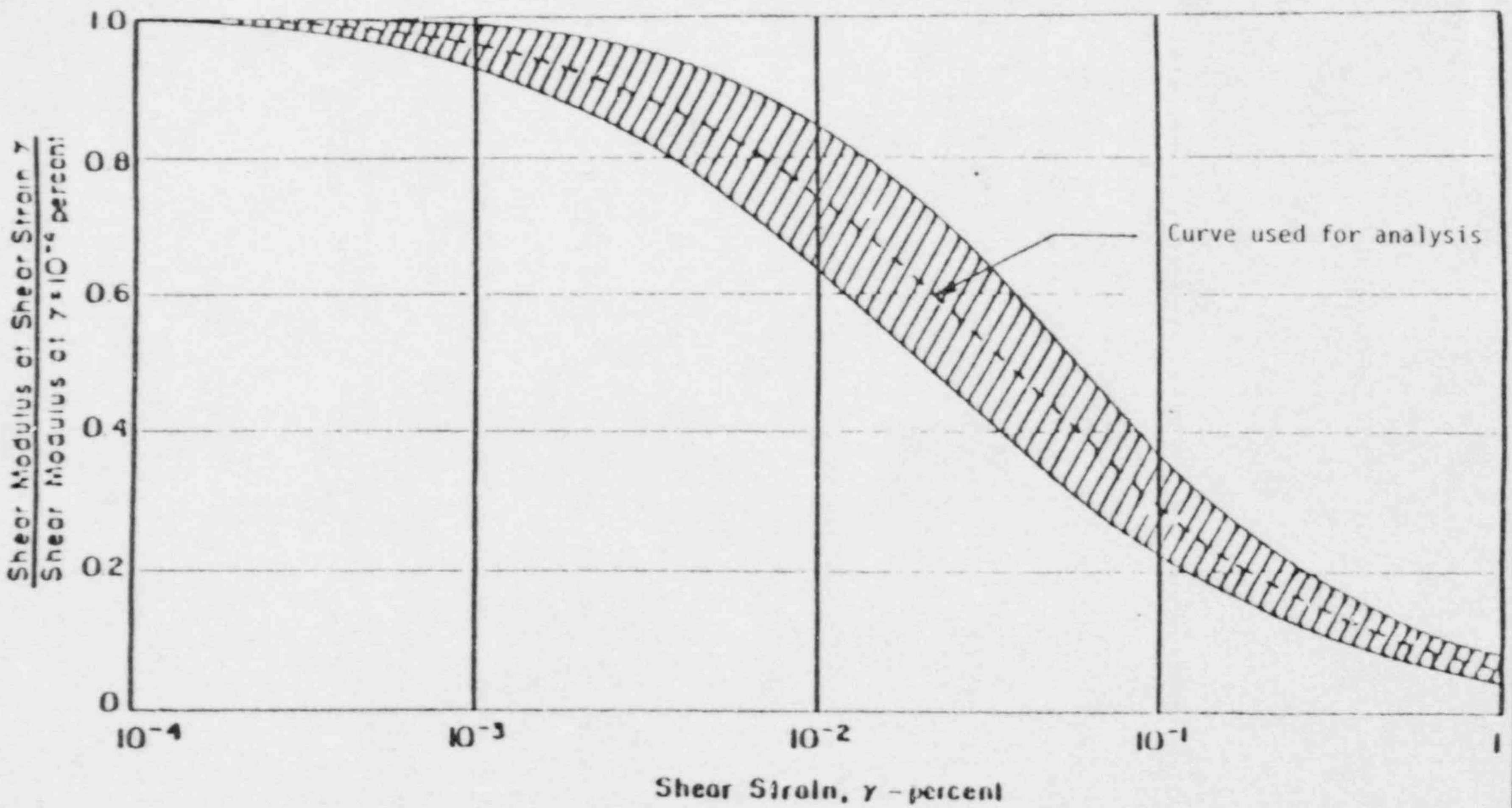


Figure 2. VARIATION OF SHEAR MODULUS WITH SHEAR STRAIN FOR SANDS
(AFTER SEED AND IDRISS 1970)

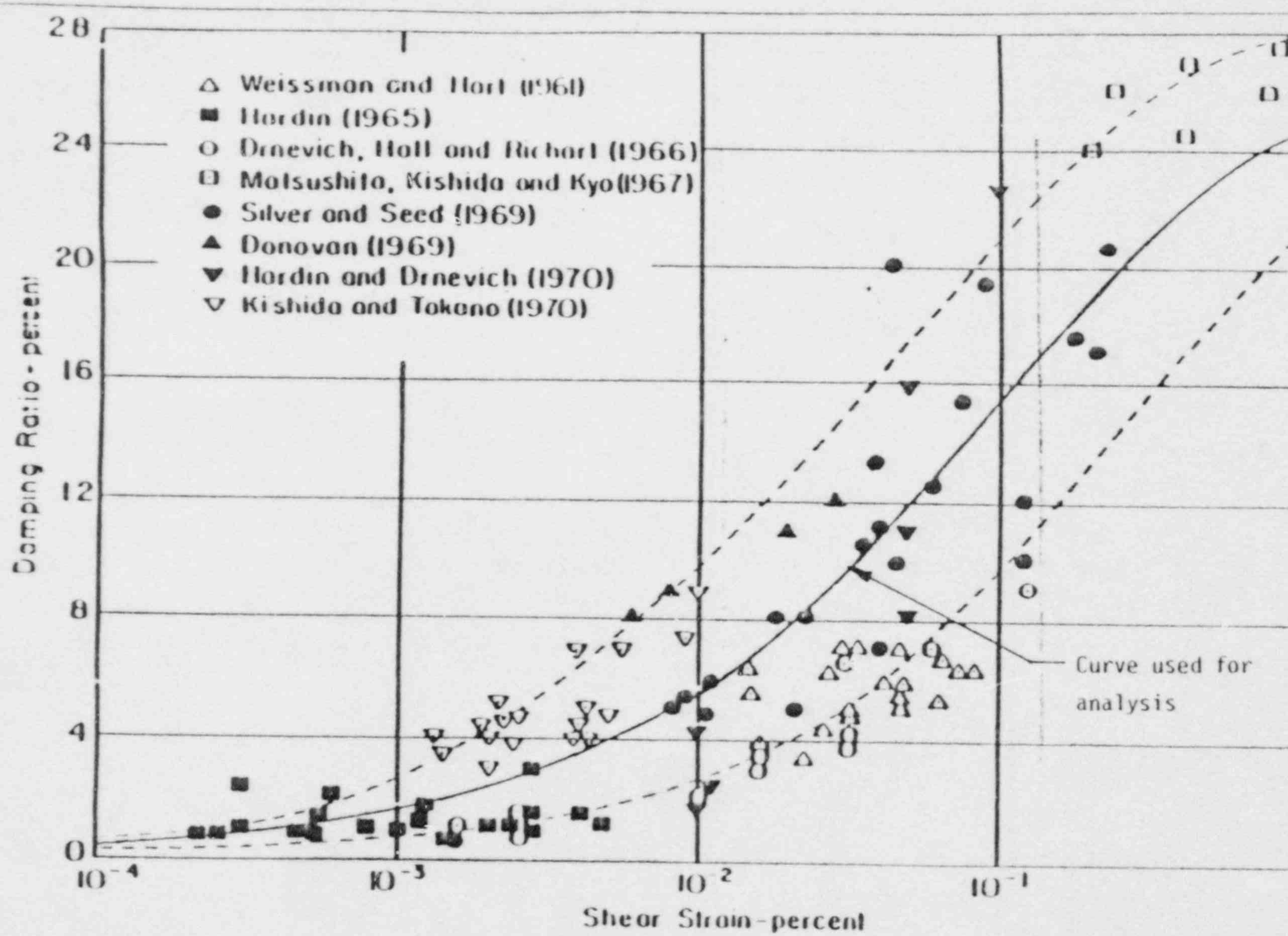


Figure 3. DAMPING RATIOS FOR SANDS

(AFTER SEED AND IDRISS, 1970)

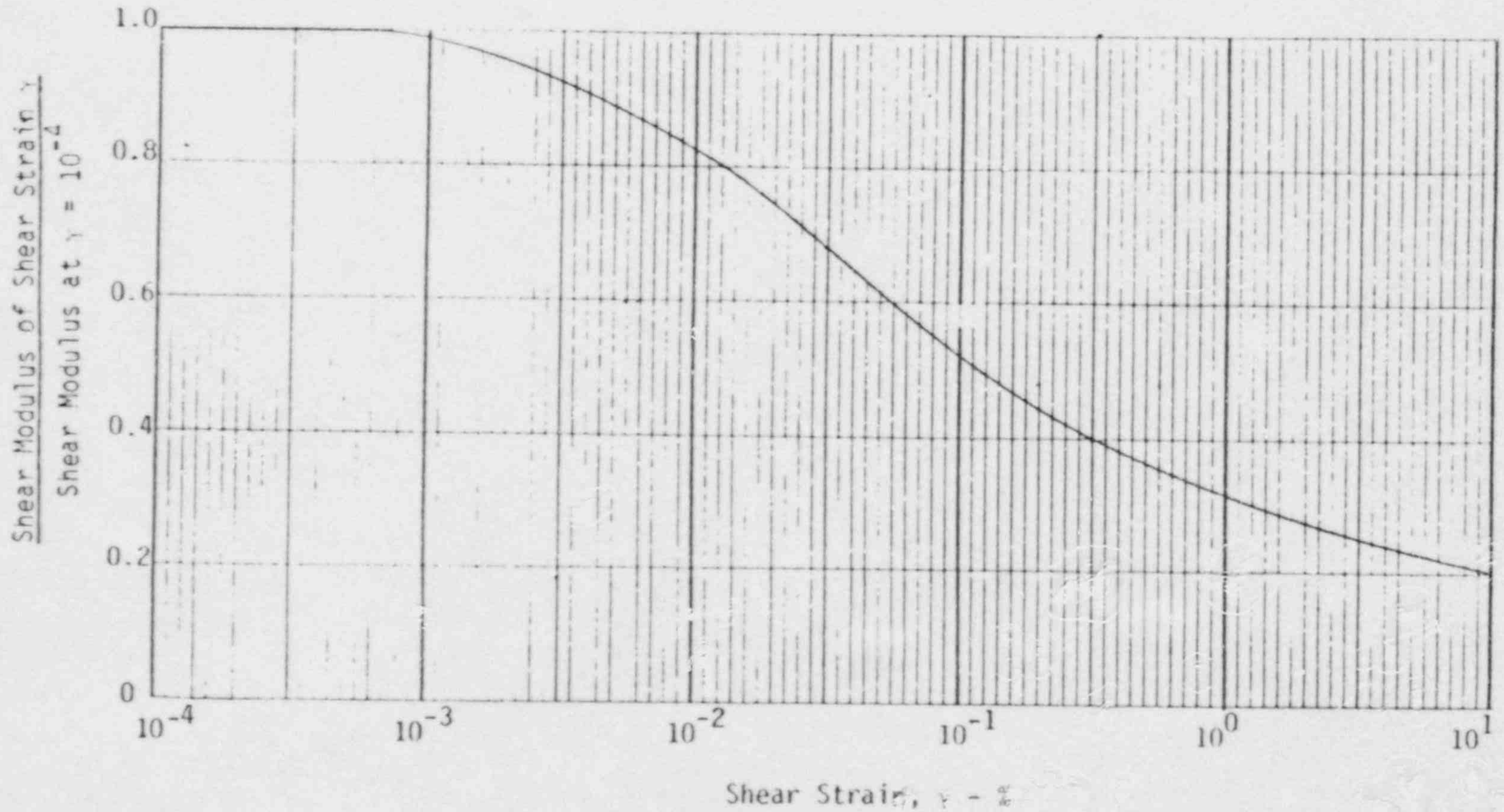


Figure 4. Variation of Shear Modulus with Shear Strain for Weathered Shale (Ref. 9)

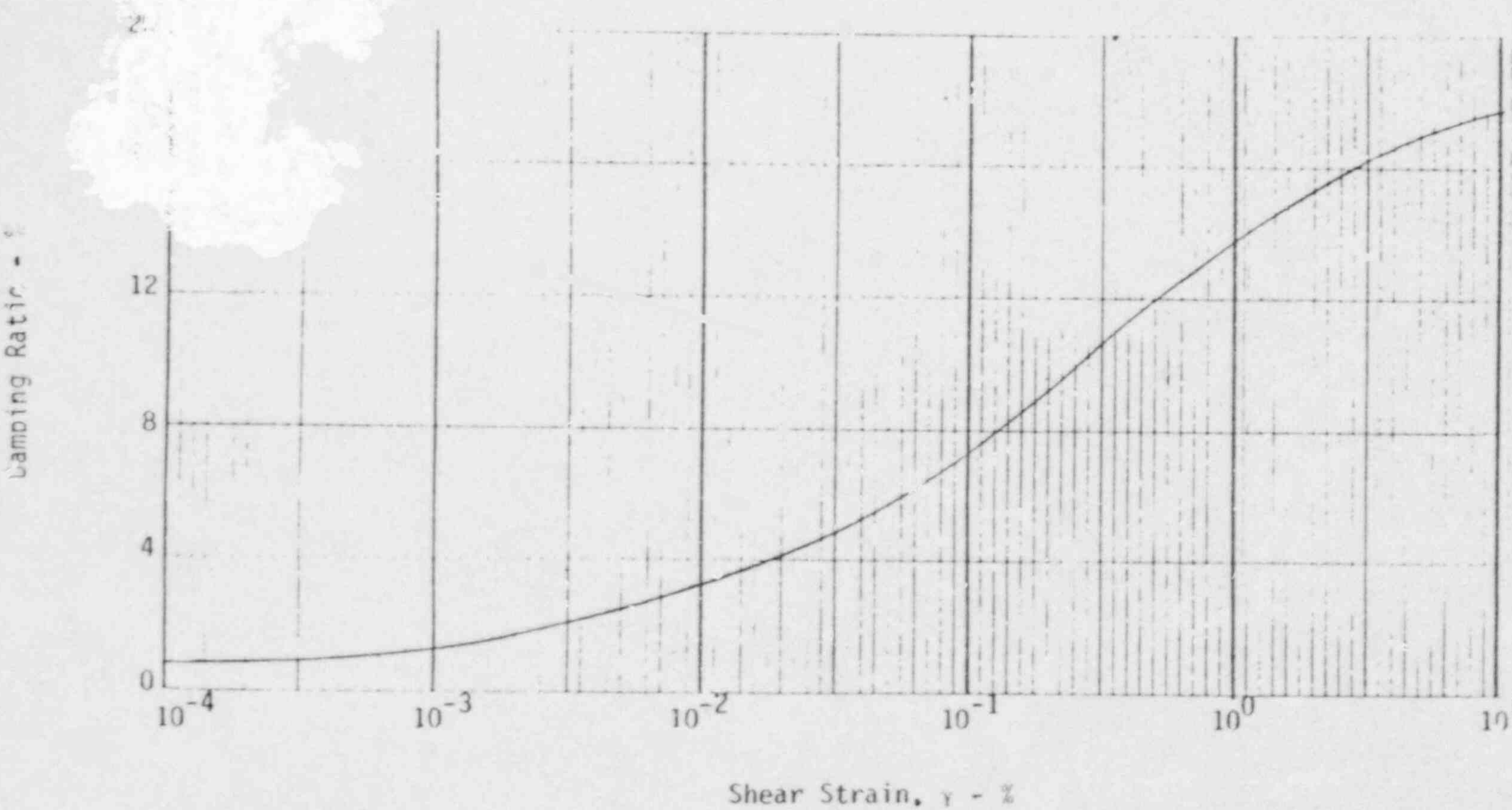


Figure 5. Variation of Damping Ratio with Shear Strain for Weathered Shale (Ref. 9)

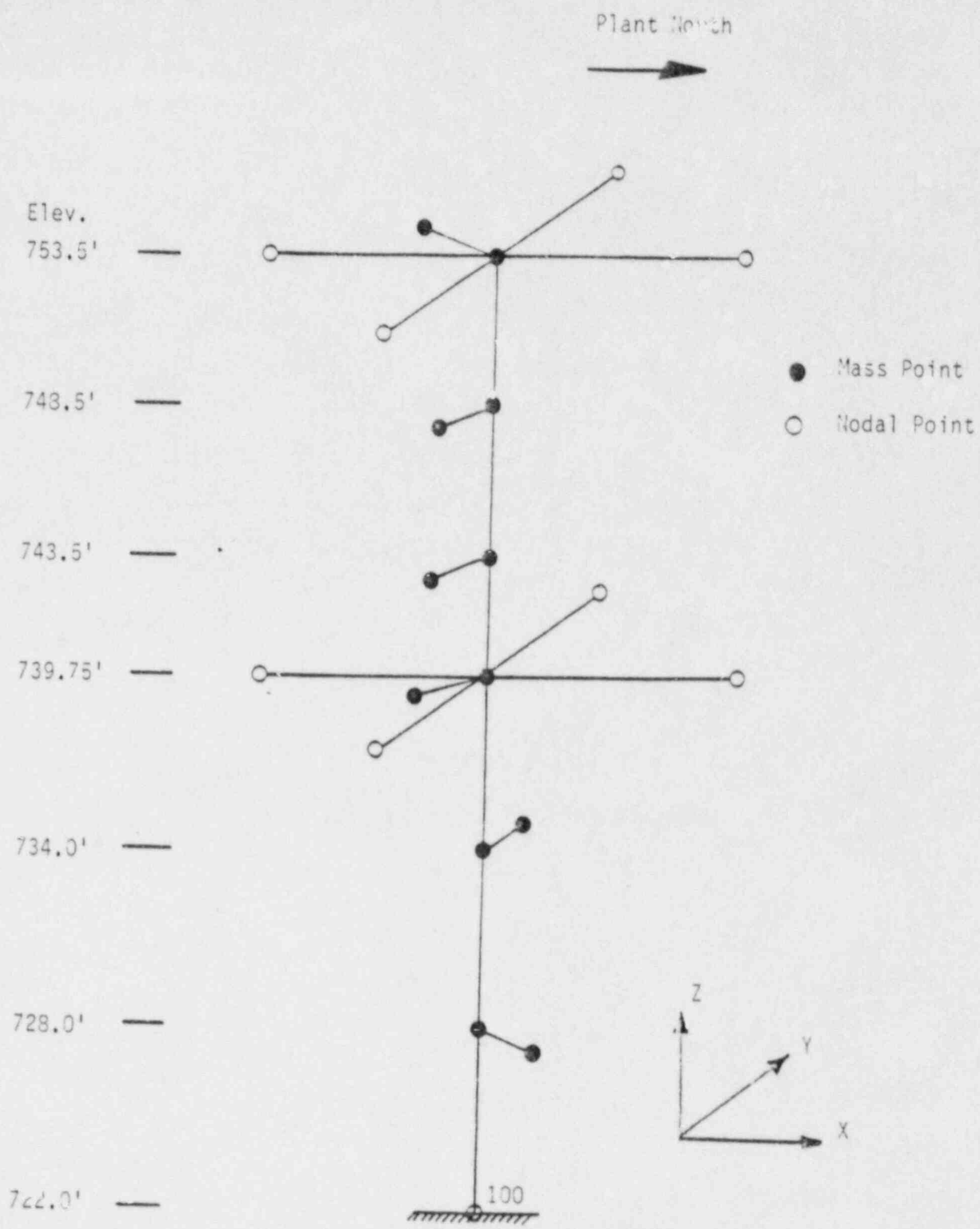


Figure 6. 3-D Lumped-Mass Stick Model of DG Building

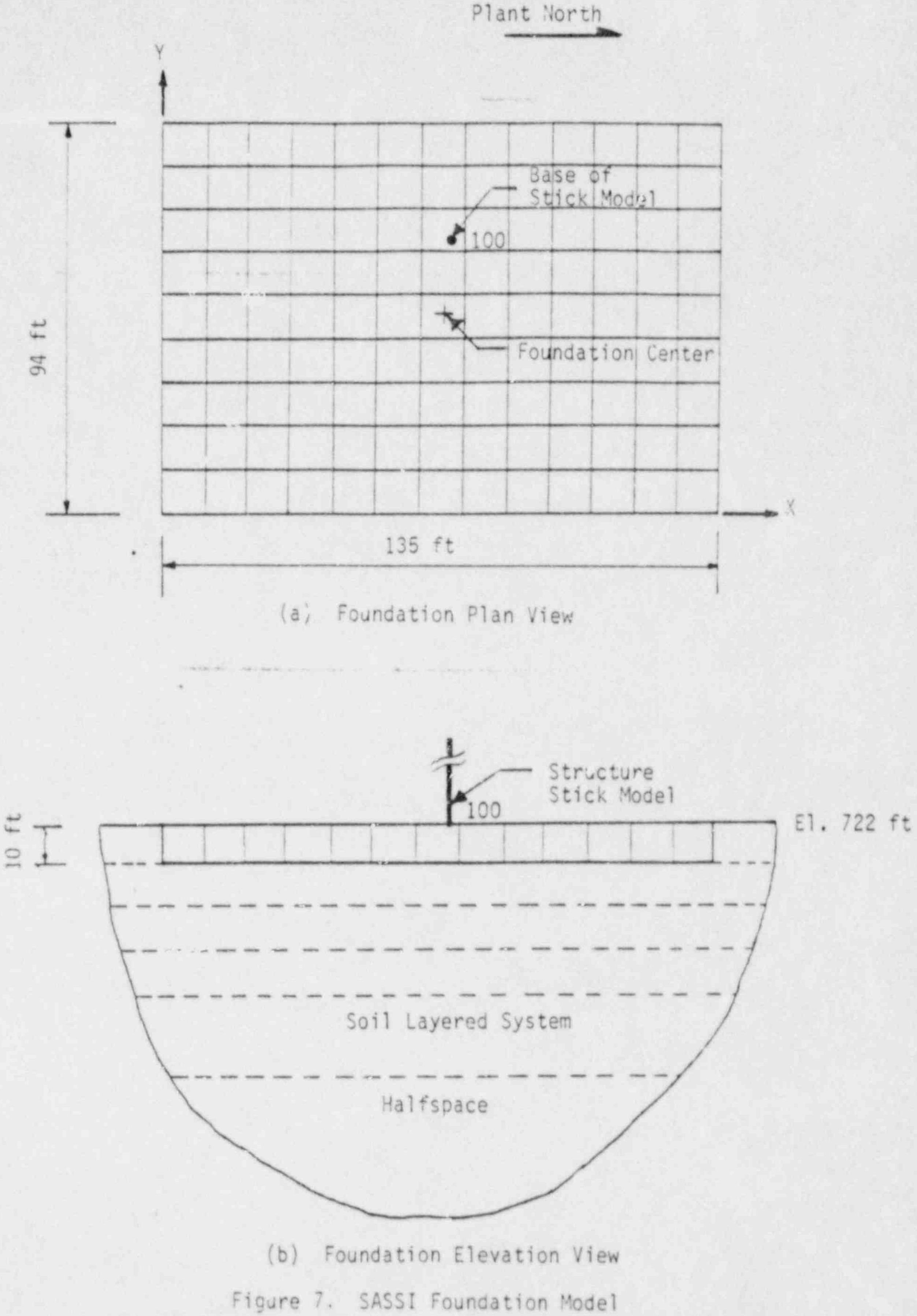


Figure 7. SASSI Foundation Model

Table 1

Modal Properties of Fixed-Base Structure

Mode No.	Frequency (cps)	Modal Mass ($Kips\text{-}Sec^2/Ft$) X (N-S)	Y (E-W)	Z (Vertical)
1	11.18	.027	.605	.000
2	22.66	264.884	.021	.000
3	23.71	.017	292.792	.000
4	42.63	.037	.022	.000
5	51.93	40.085	.000	.000
6	52.63	.000	.000	287.303
	Summations	305.050	293.440	287.303
	Total Mass	324.717	324.717	324.717

Table 2

Strain-Compatible Soil Properties From
SHAKE Analysis for Design Basis SSE

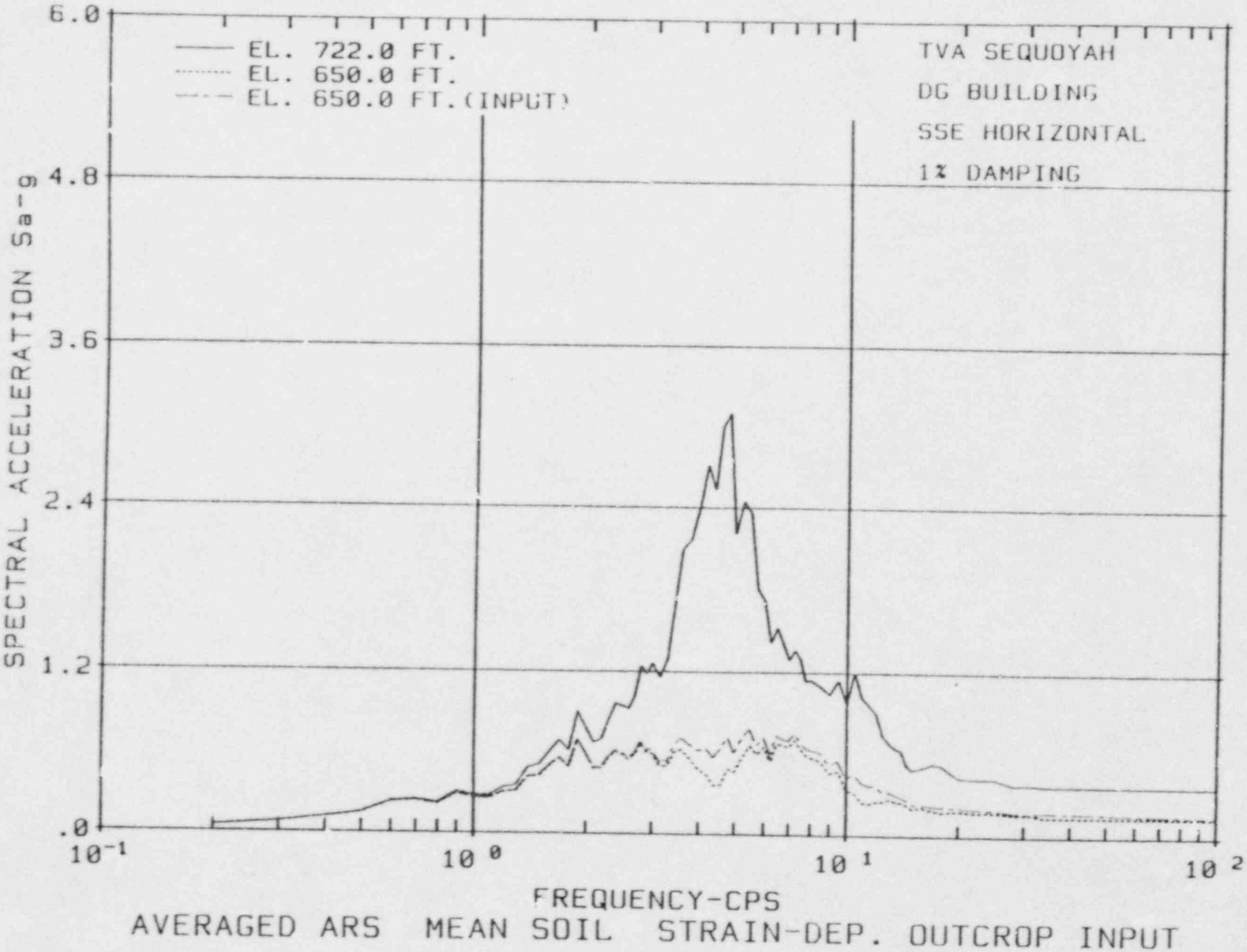
Layer No.	Layer Thickness (ft)	Lower Bound Soil (0.5xGmax)		Mean Soil (1.0xGmax)		Upper Bound Soil (1.5xGmax)	
		G (ksf)	β(%)	G (ksf)	β(%)	G (ksf)	β(%)
1	10	777	7.2	1850	4.8	3040	3.5
2	20	585	13.9	1820	9.0	3295	6.8
3	14	1527	11.3	4265	7.5	7287	5.8
4	28	6127	3.7	13530	2.8	21135	2.4

Appendix A

Envelopes of Average ARS Plots for Individual Soil Cases

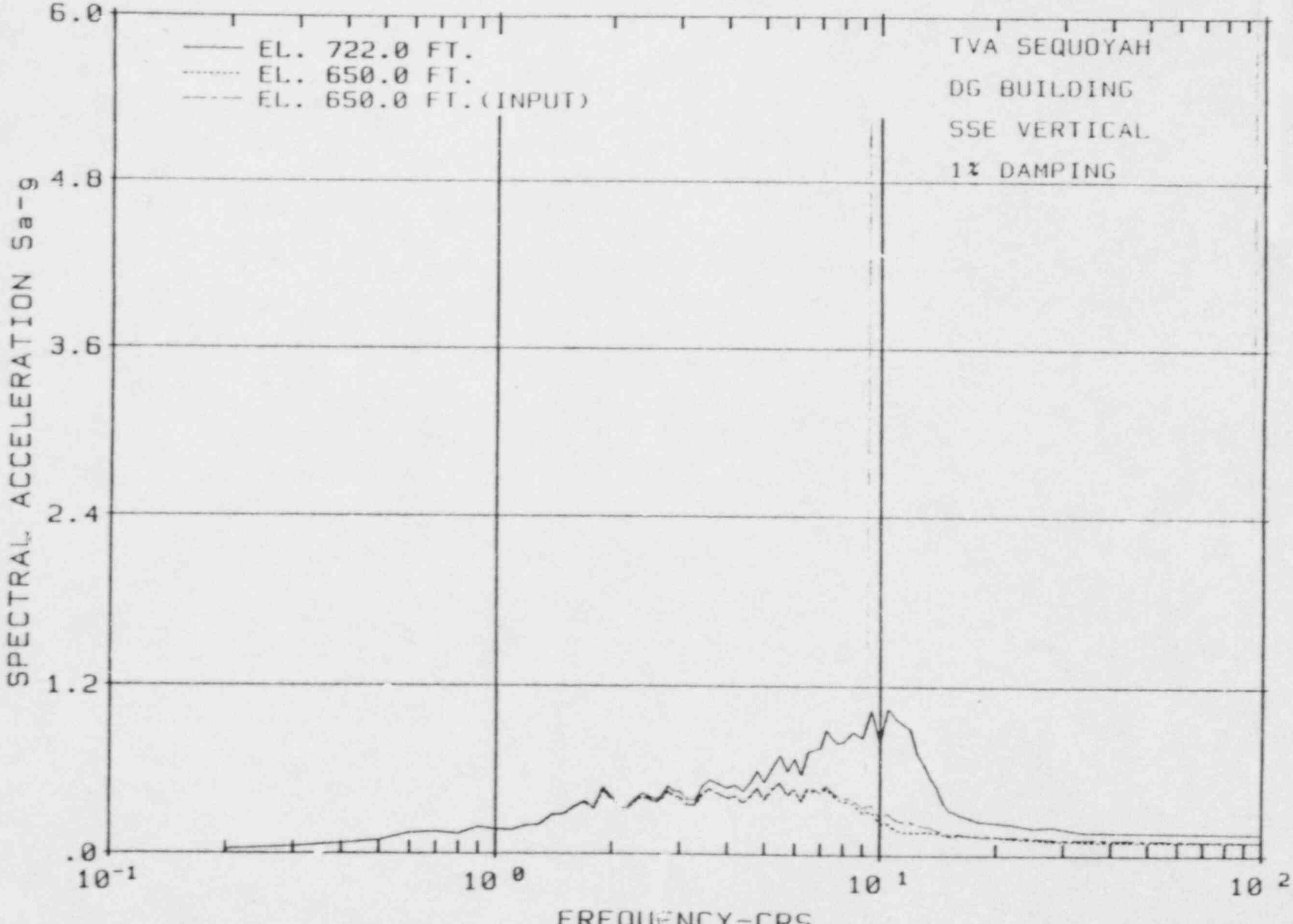
Figure Numbers for the Selected SQN-DG Building Response Locations for the Envelope of Average ARS for SSE for Individual Soil Case

Locations		1% Damping			2% Damping			5% Damping		
		Mean Soil	Lower-Bound Soil	Upper-Bound Soil	Mean Soil	Lower-Bound Soil	Upper-Bound Soil	Mean Soil	Lower-Bound Soil	Upper-Bound Soil
Free-Field Soil Surface (El. 722.0')	H	A-1	A-7	A-13	A-3	A-9	A-15	A-5	A-11	A-17
	V	A-2	A-8	A-14	A-4	A-10	A-16	A-6	A-12	A-18
Soil-Rock Interface (El. 650.0')	H	A-1	A-7	A-13	A-3	A-9	A-15	A-5	A-11	A-17
	V	A-2.	A-8	A-14	A-4	A-10	A-16	A-6	A-12	A-18
Rock Outcrop (El. 650.0')	H	A-1	A-7	A-13	A-3	A-9	A-15	A-5	A-11	A-17
	V	A-2	A-8	A-14	A-4	A-10	A-16	A-6	A-12	A-18
DG Building Roof (El. 753.5')	NS	A-19	A-28	A-37	A-19	A-28	A-37	A-19	A-28	A-37
	EW	A-20	A-29	A-38	A-20	A-29	A-38	A-20	A-29	A-38
	V	A-21	A-30	A-39	A-21	A-30	A-39	A-21	A-30	A-39
Second Floor (El. 739.75')	NS	A-22	A-31	A-40	A-22	A-31	A-40	A-22	A-31	A-40
	EW	A-23	A-32	A-41	A-23	A-32	A-41	A-23	A-32	A-41
	V	A-24	A-33	A-42	A-24	A-33	A-42	A-24	A-33	A-42
Top of Base Slab (El. 722.0')	NS	A-25	A-34	A-43	A-25	A-34	A-43	A-25	A-34	A-43
	EW	A-26	A-35	A-44	A-26	A-35	A-44	A-26	A-35	A-44
	V	A-27	A-36	A-45	A-27	A-36	A-45	A-27	A-36	A-45



6.0
4.8
3.6
2.4
1.2
.0
SPECTRAL ACCELERATION Sa-g
EL. 722.0 FT.
EL. 650.0 FT.
EL. 650.0 FT.(INPUT)
TVA SEQUOYAH
DG BUILDING
SSE HORIZONTAL
1% DAMPING
10^-1
10^0
10^1
10^2
FREQUENCY-CPS
AVERAGED ARS MEAN SOIL STRAIN-DEP. OUTCROP INPUT

Figure A-1



AVERAGED ARS MEAN SOIL STRAIN-DEP. OUTCROP INPUT

Figure A-2

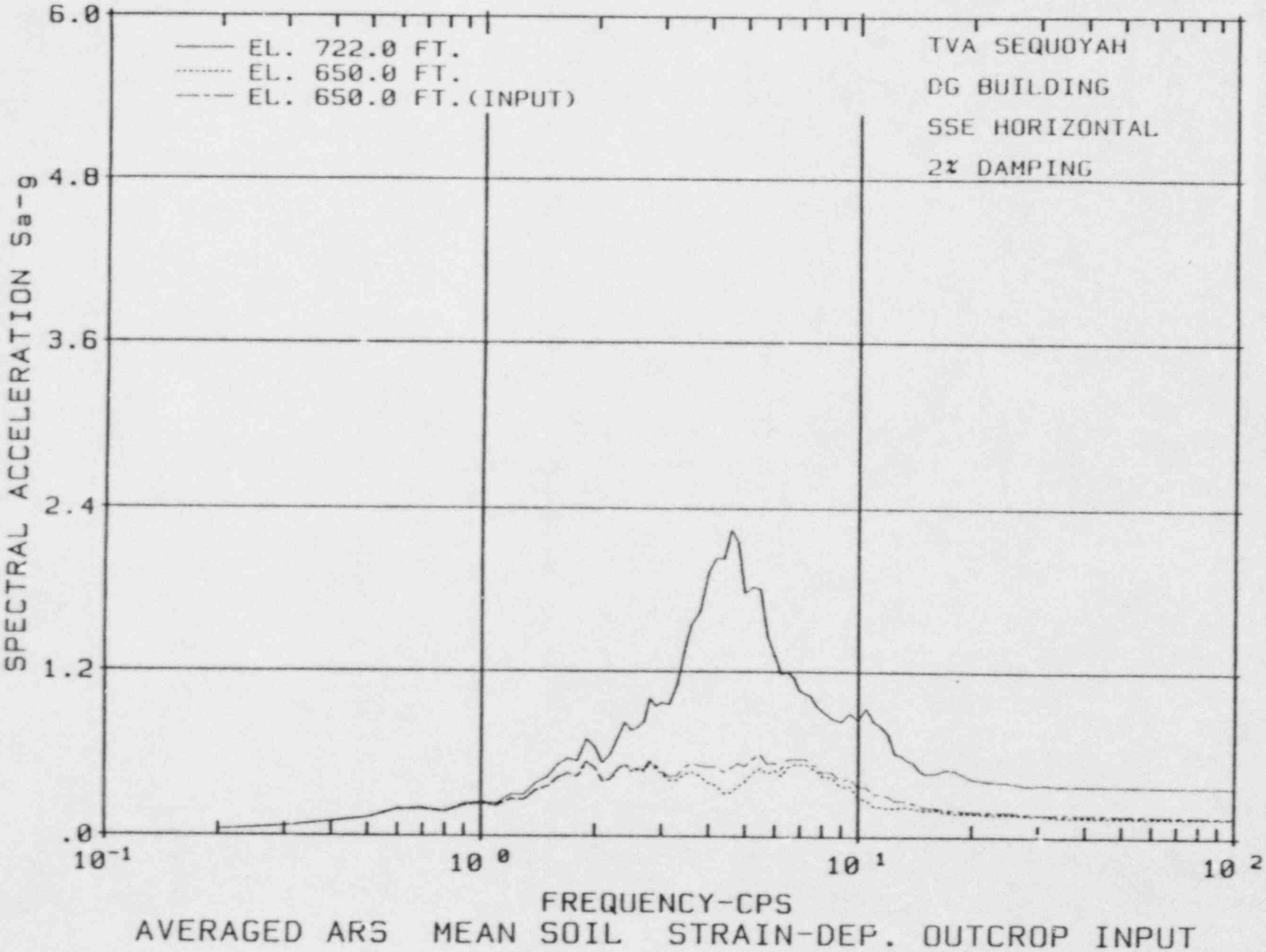
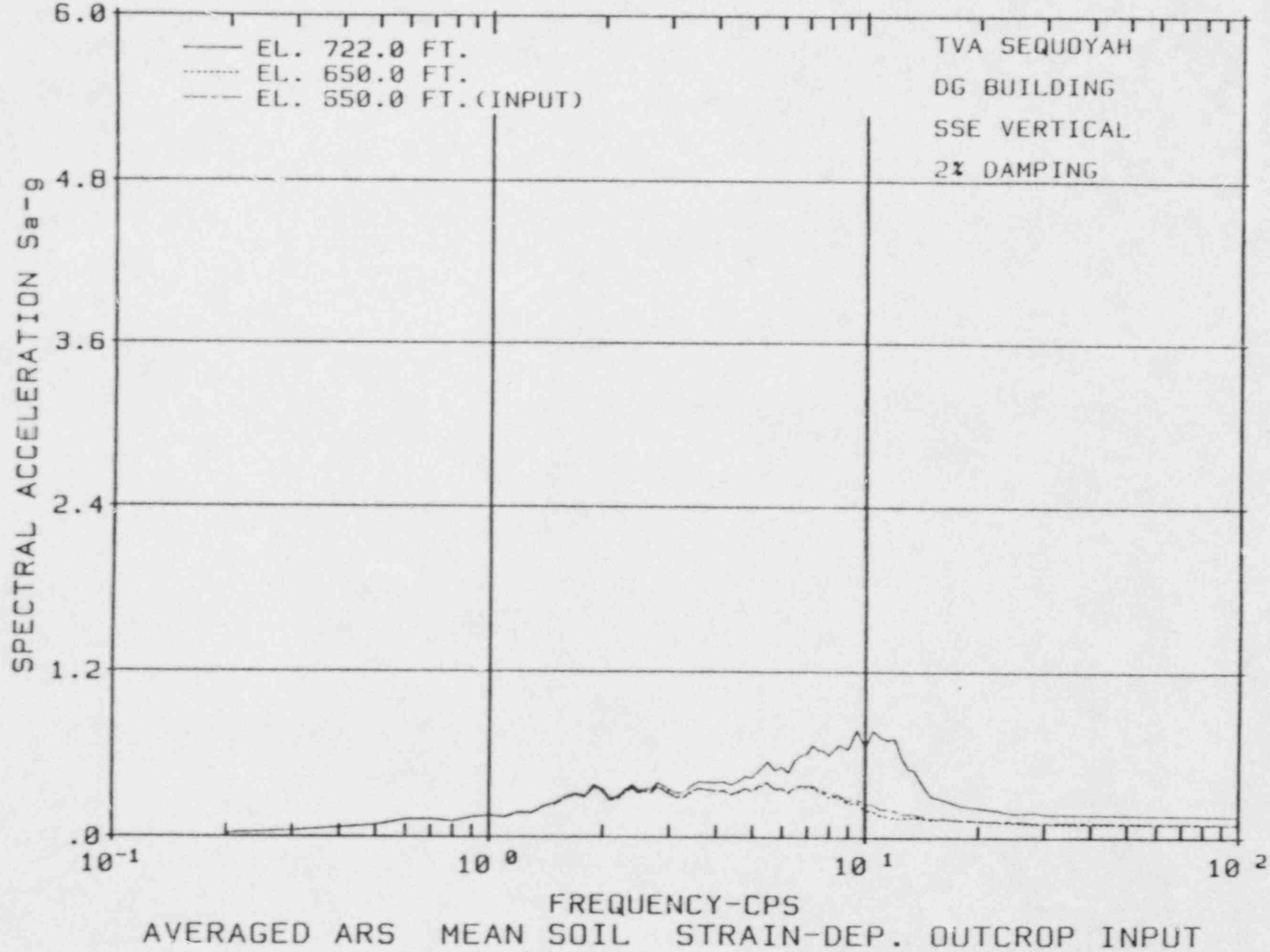
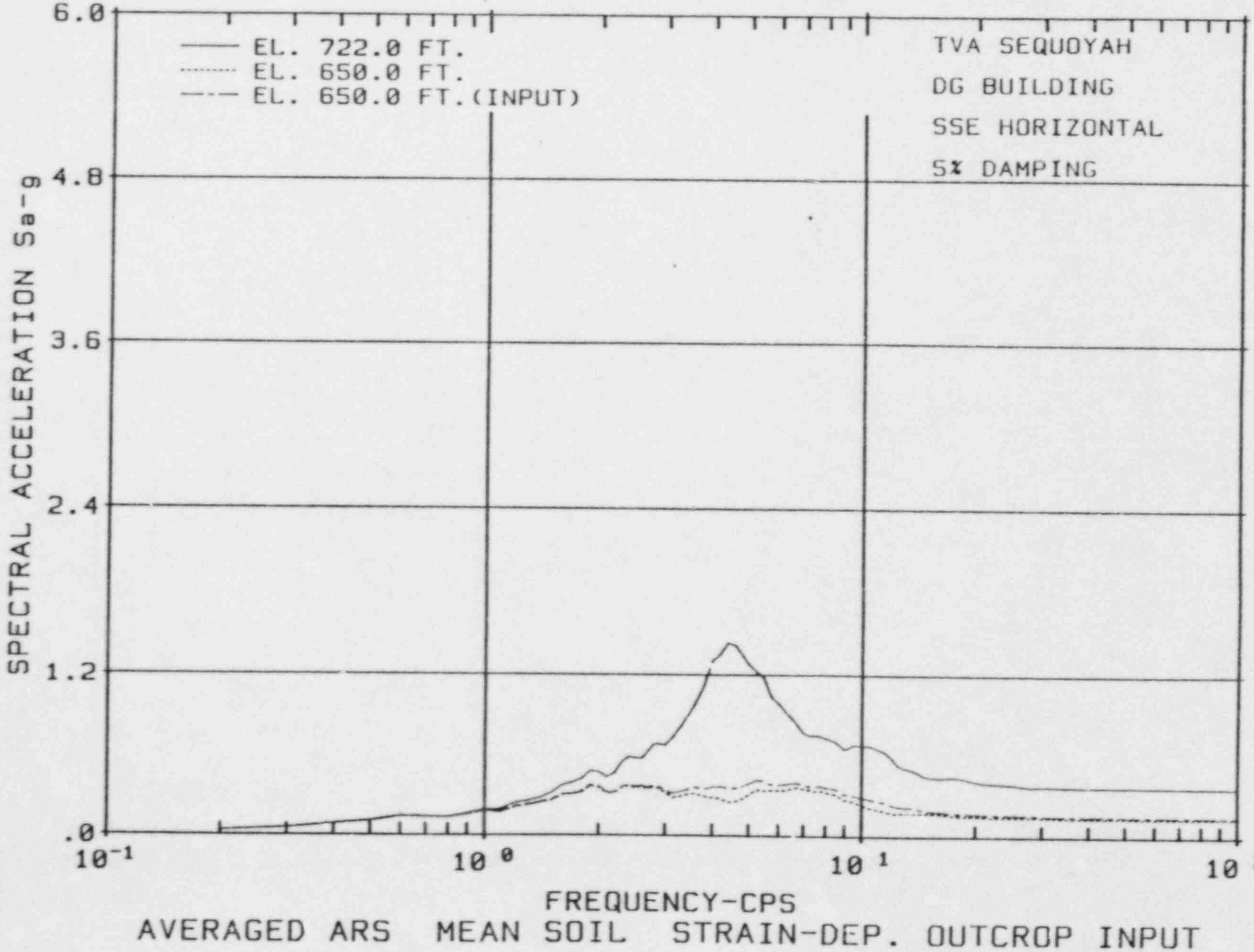

EL. 722.0 FT.
EL. 650.0 FT.
EL. 650.0 FT.(INPUT)
TVA SEQUOYAH
DG BUILDING
SSE HORIZONTAL
2% DAMPING
SPECTRAL ACCELERATION Sa-g
6.0
4.8
3.6
2.4
1.2
.0
10-1
10 0
10 1
10 2
FREQUENCY-CPS
AVERAGED ARS MEAN SOIL STRAIN-DEP. OUTCROP INPUT

Figure A-3



EL. 722.0 FT.
EL. 650.0 FT.
EL. 550.0 FT.(INPUT)
TVA SEQUOYAH
DG BUILDING
SSE VERTICAL
2% DAMPING
SPECTRAL ACCELERATION Sa-g
6.0
4.8
3.6
2.4
1.2
.0
10-1
10 0
10 1
10 2
FREQUENCY-CPS
AVERAGED ARS MEAN SOIL STRAIN-DEP. OUTCROP INPUT

Figure A-4



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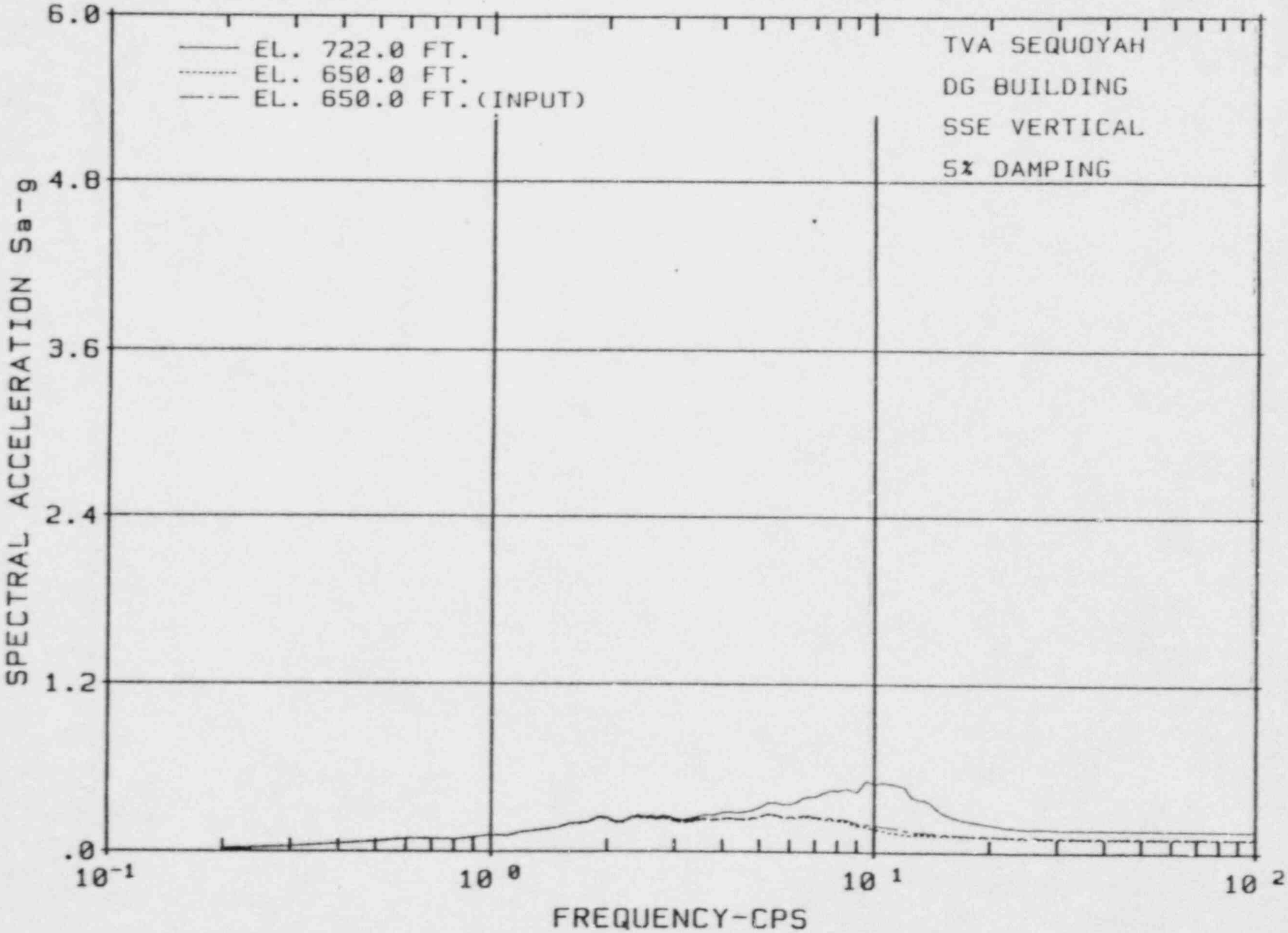
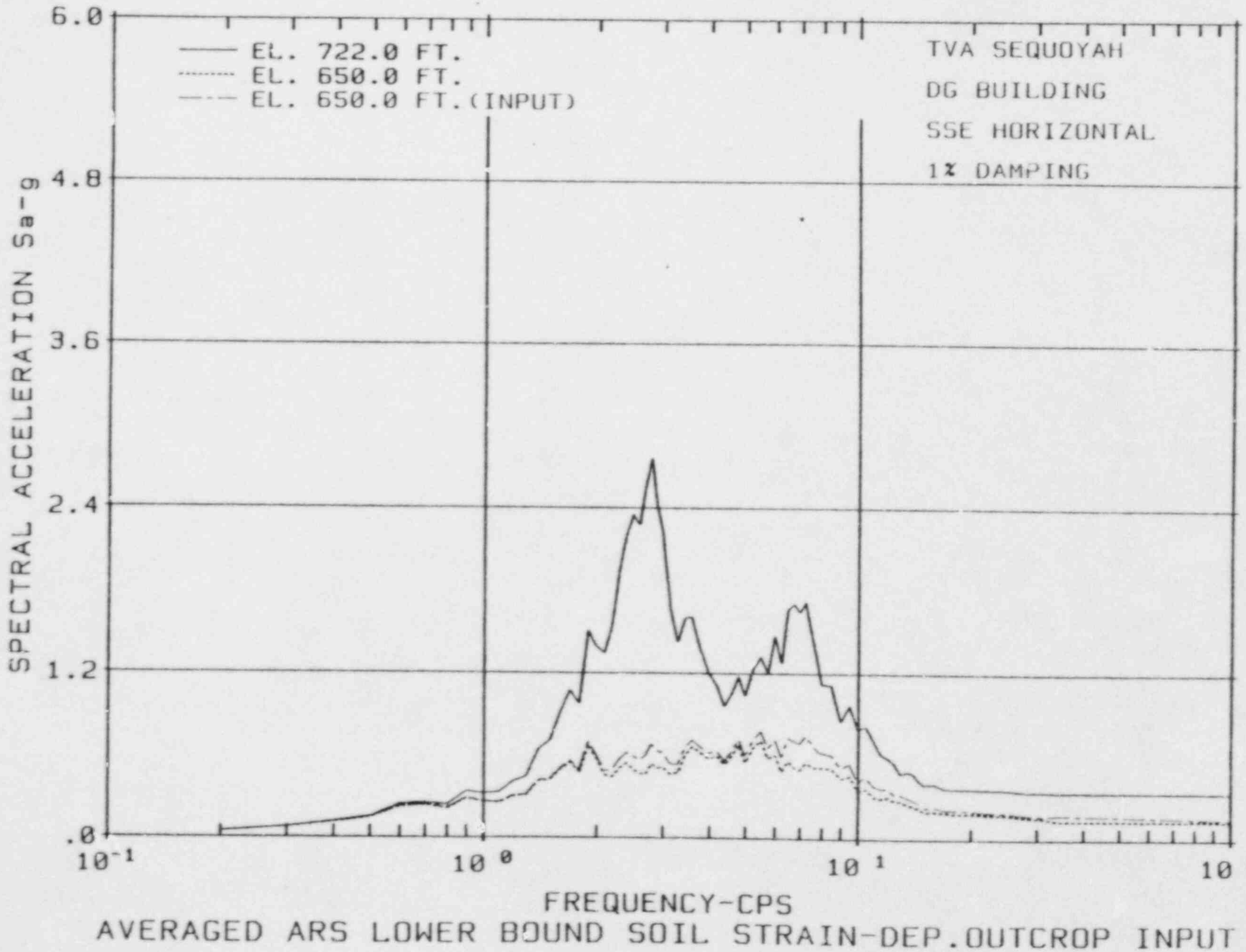
4.8
3.6
2.4
1.2
.0
SPECTRAL ACCELERATION Sa-g
EL. 722.0 FT.
EL. 650.0 FT.
EL. 650.0 FT.(INPUT)
TVA SEQUOYAH
DG BUILDING
SSE HORIZONTAL
5% DAMPING
10⁻¹
10⁰
10¹
10²
FREQUENCY-CPS
AVERAGED ARS MEAN SOIL STRAIN-DEP. OUTCROP INPUT

Figure A-5



AVERAGED ARS MEAN SOIL STRAIN-DEP. OUTCROP INPUT

Figure A-6



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3.6
2.4
1.2
.0
SPECTRAL ACCELERATION Sa-g
EL. 722.0 FT.
EL. 650.0 FT.
EL. 650.0 FT.(INPUT)
TVA SEQUOYAH
DG BUILDING
SSE HORIZONTAL
1% DAMPING
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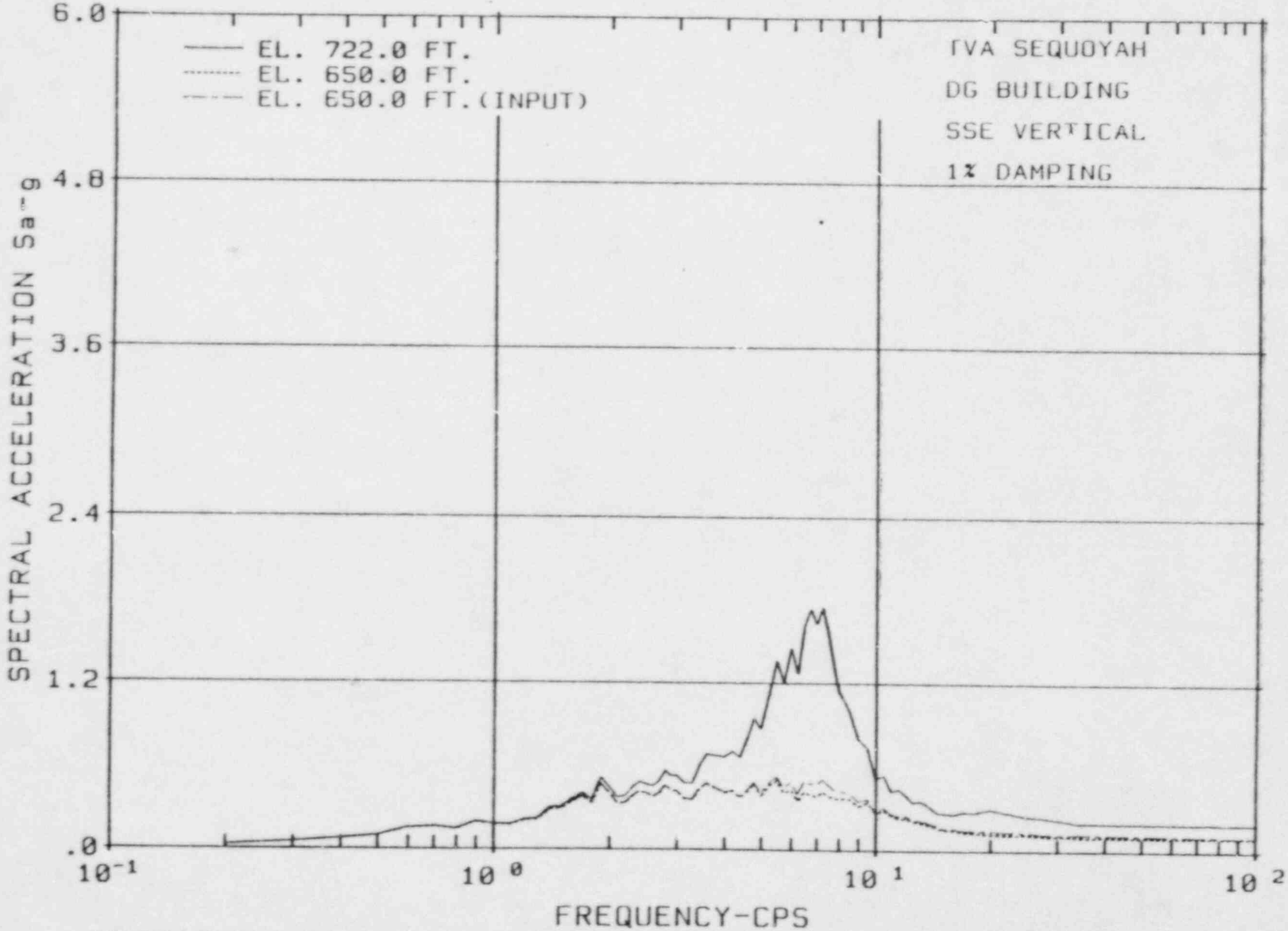
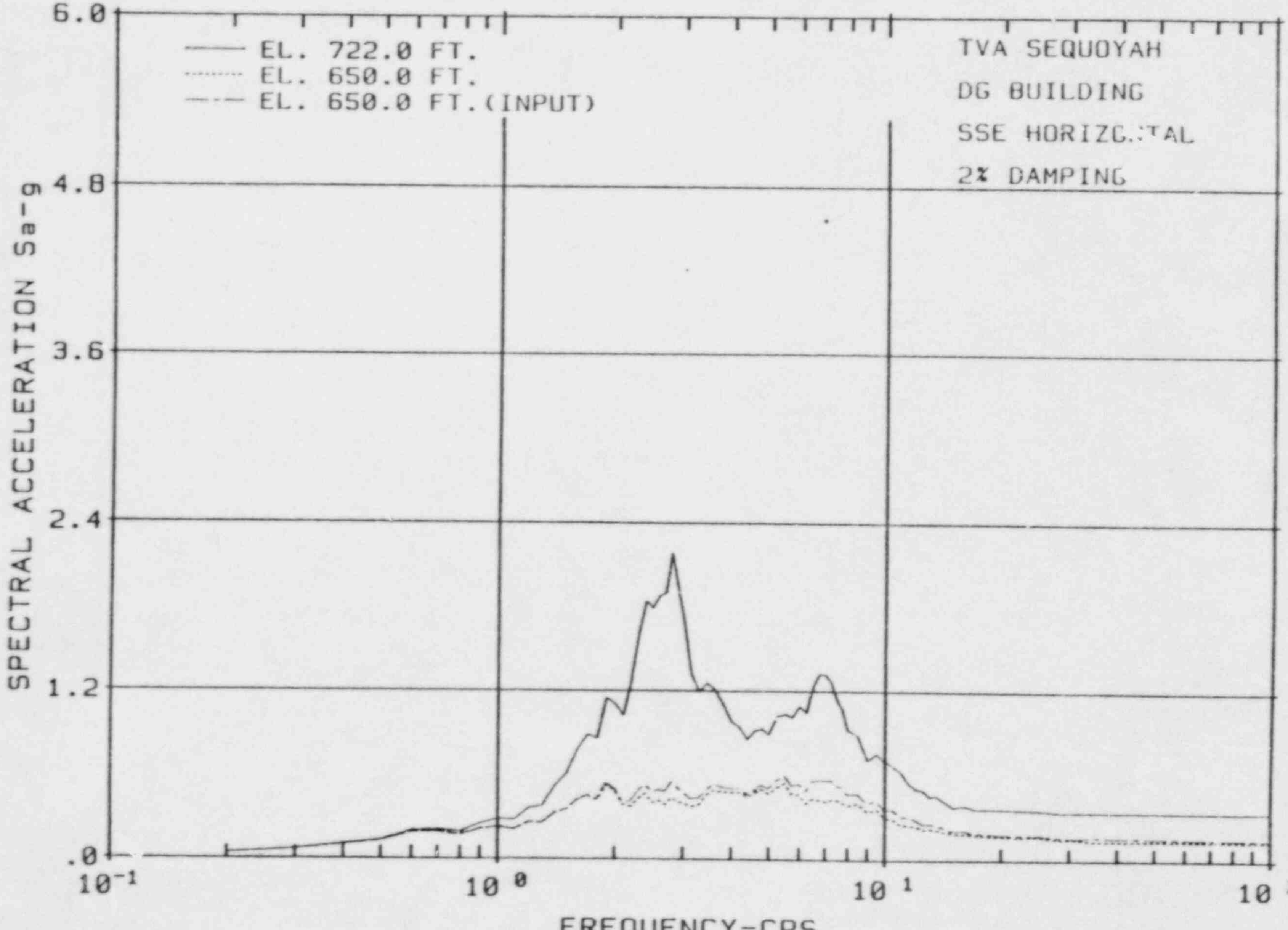
10 1
10 2
FREQUENCY-CPS
AVERAGED ARS LOWER BOUND SOIL STRAIN-DEP.OUTCROP INPUT

Figure A-7



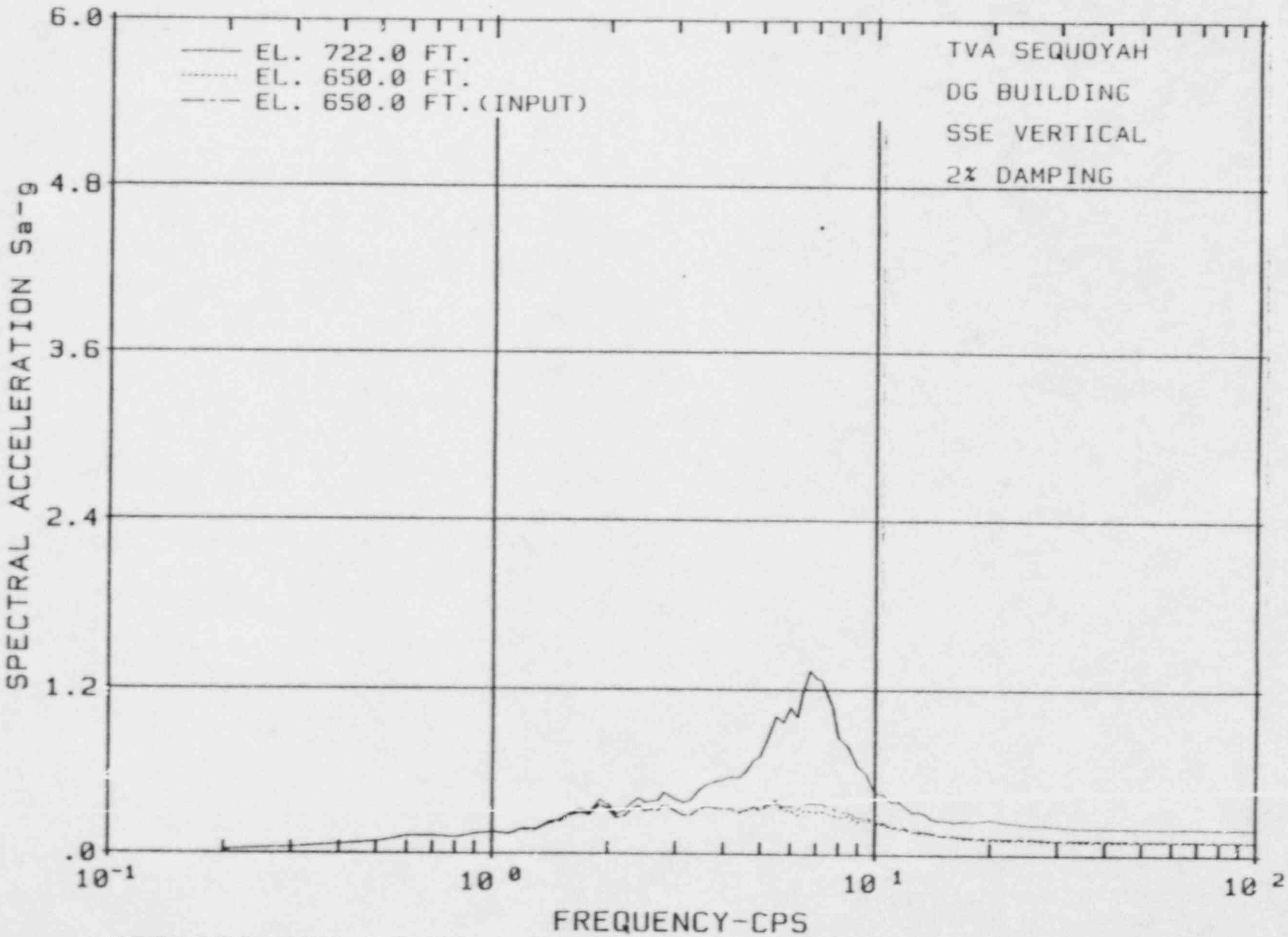
AVERAGED ARS LOWER BOUND SOIL STRAIN-DEP. OUTCROP INPUT

Figure A-8



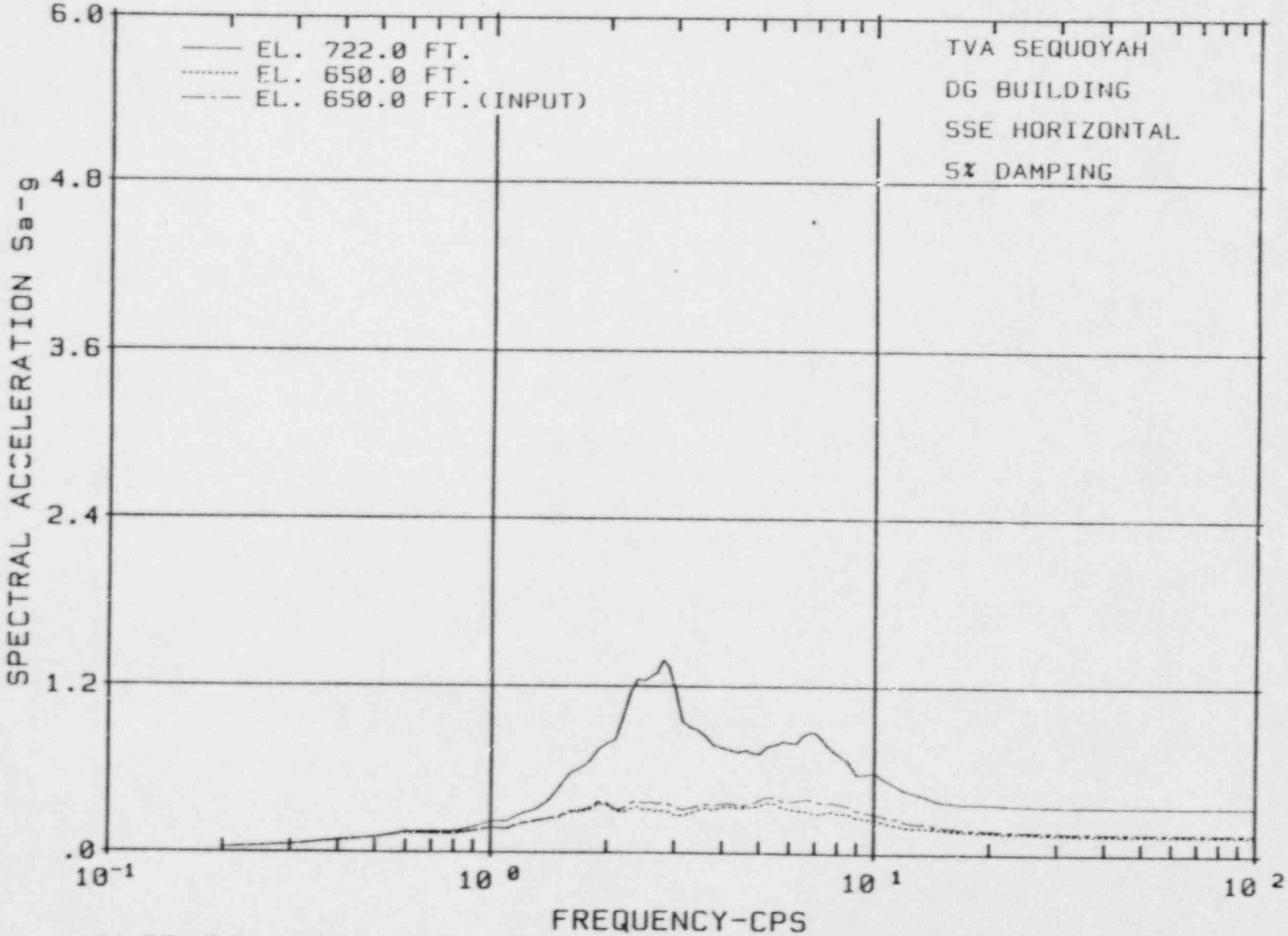
AVERAGED ARS LOWER BOUND SOIL STRAIN-DEP.OUTCROP INPUT

Figure A-9



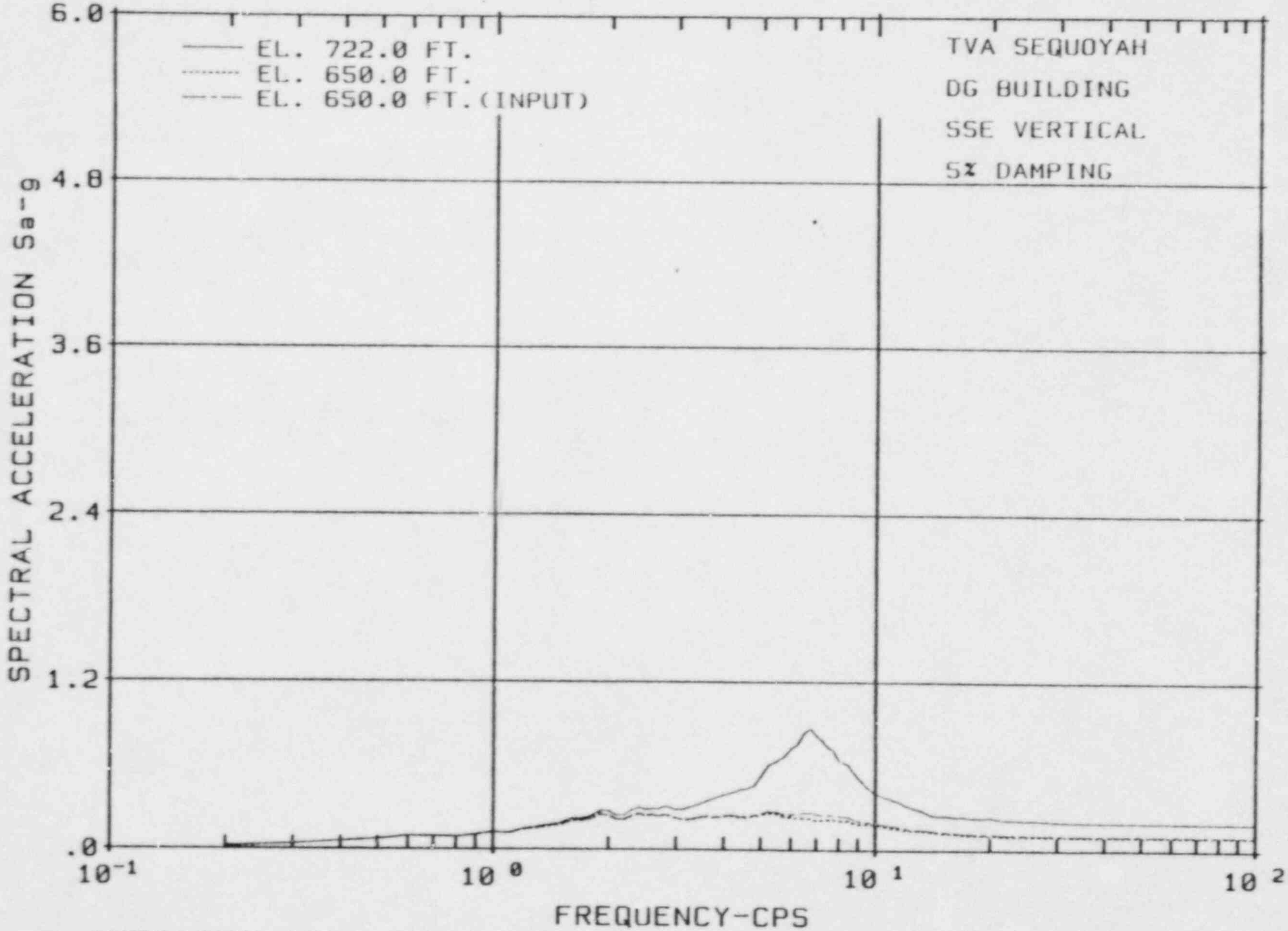
AVERAGED ARS LOWER BOUND SOIL STRAIN-DEP. OUTCROP INPUT

Figure A-10



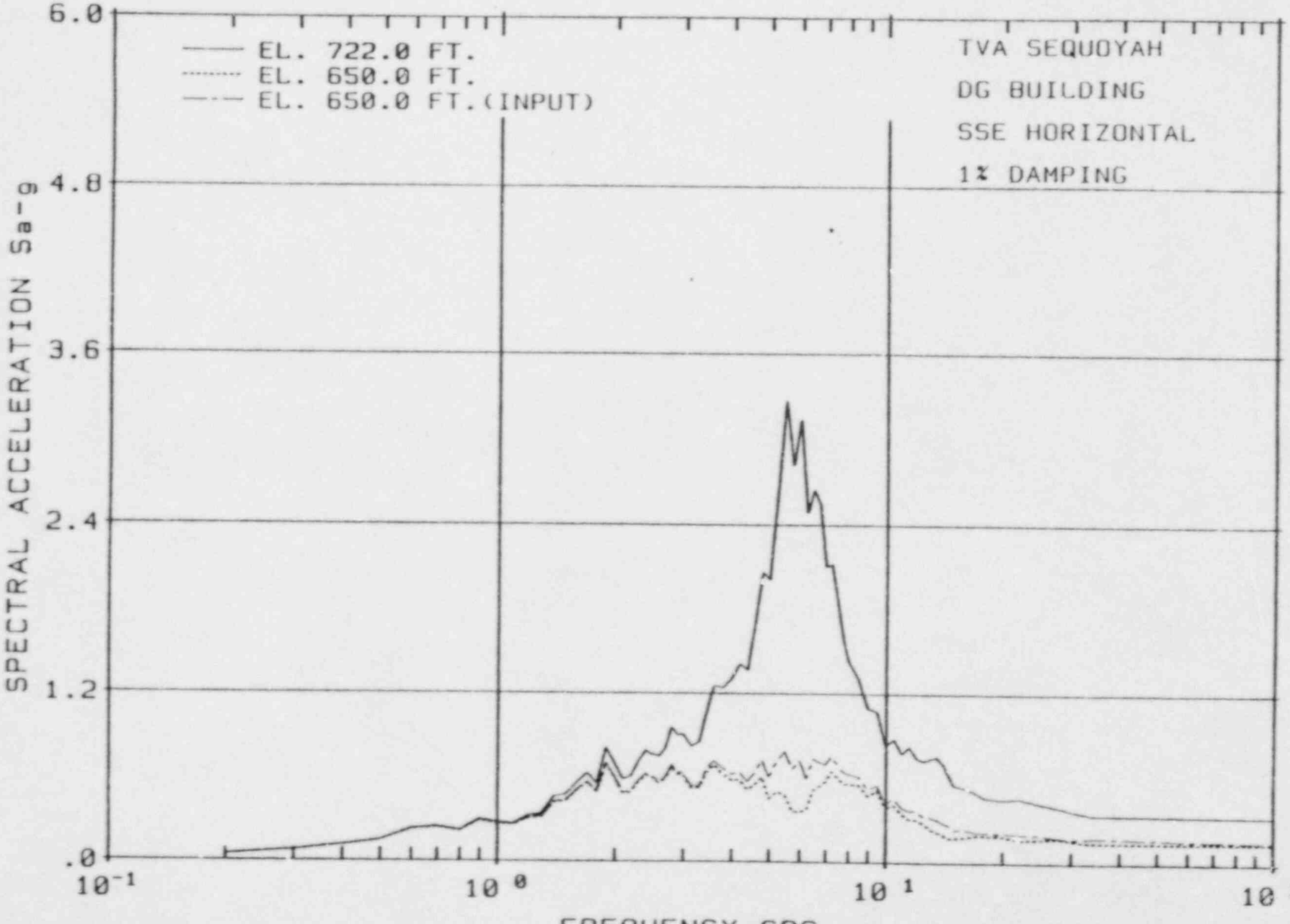
AVERAGED ARS LOWER BOUND SOIL STRAIN-DEP.OUTCROP INPUT

Figure A-11



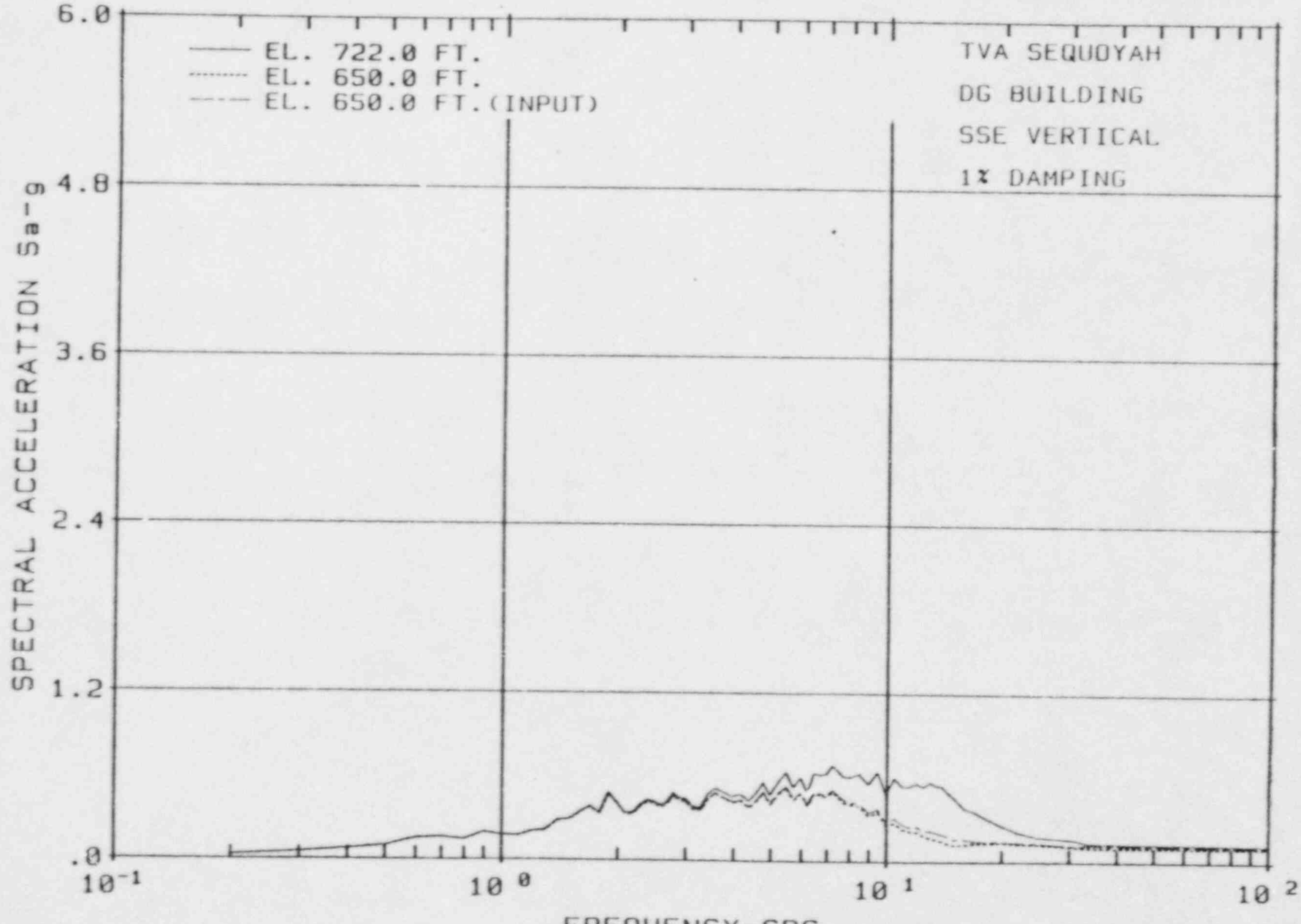
AVERAGED ARS LOWER BOUND SOIL STRAIN-DEP. OUTCROP INPUT

Figure A-12



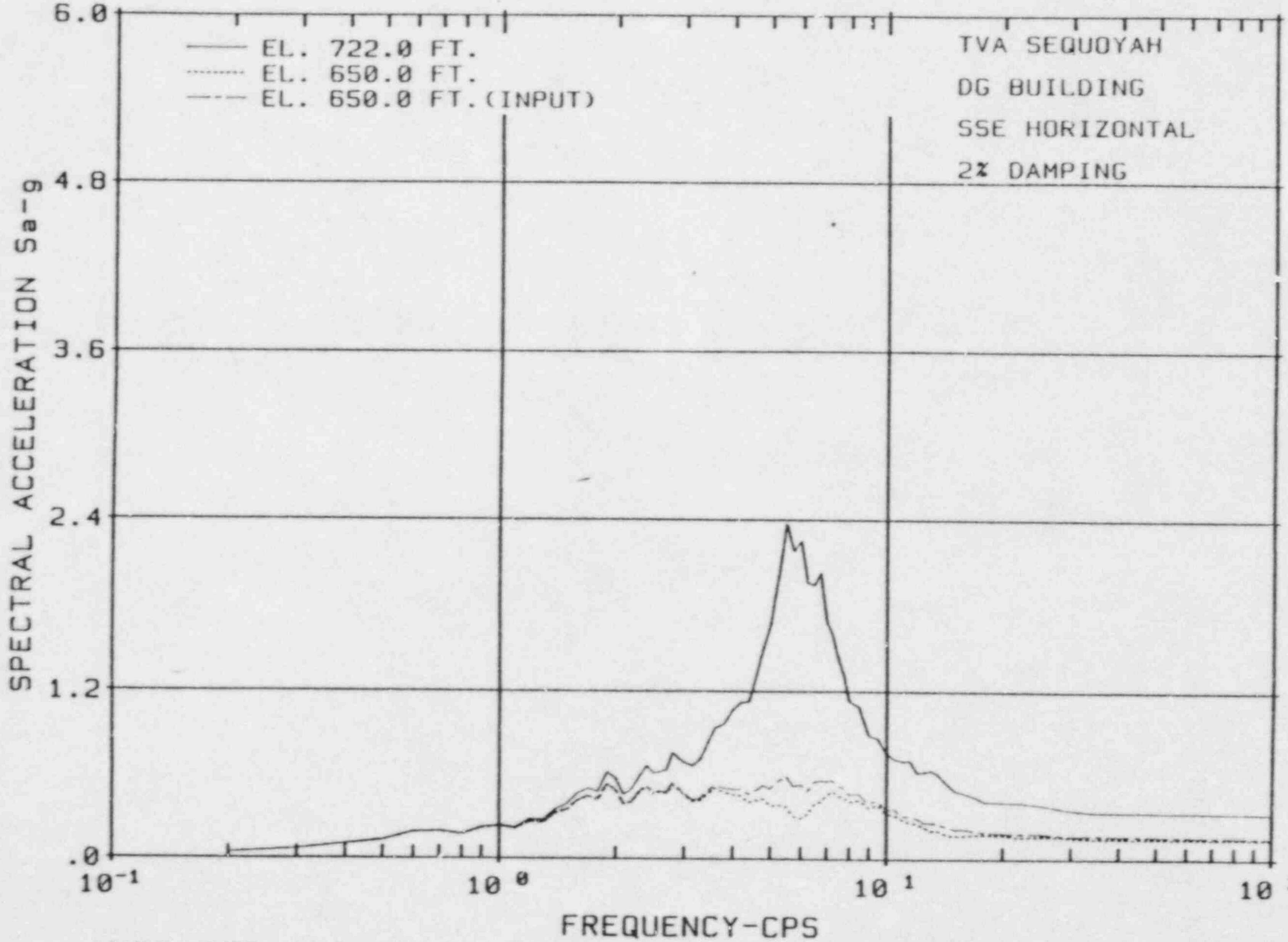
AVERAGED ARS UPPER BOUND SOIL STRAIN-DEP. OUTCROP INPUT

Figure A-13



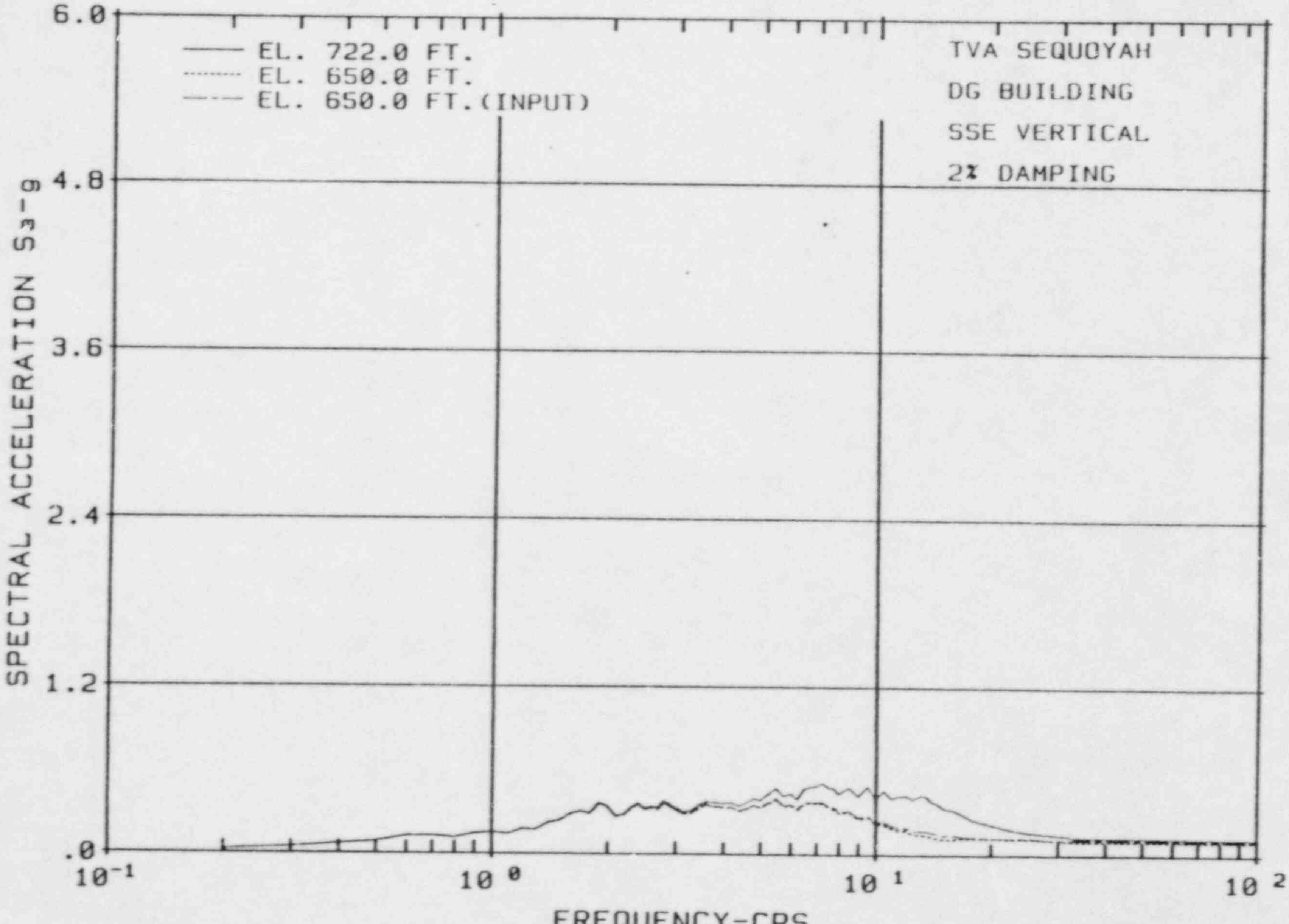
AVERAGED ARS UPPER BOUND SOIL STRAIN-DEP. OUTCROP INPUT

Figure A-14



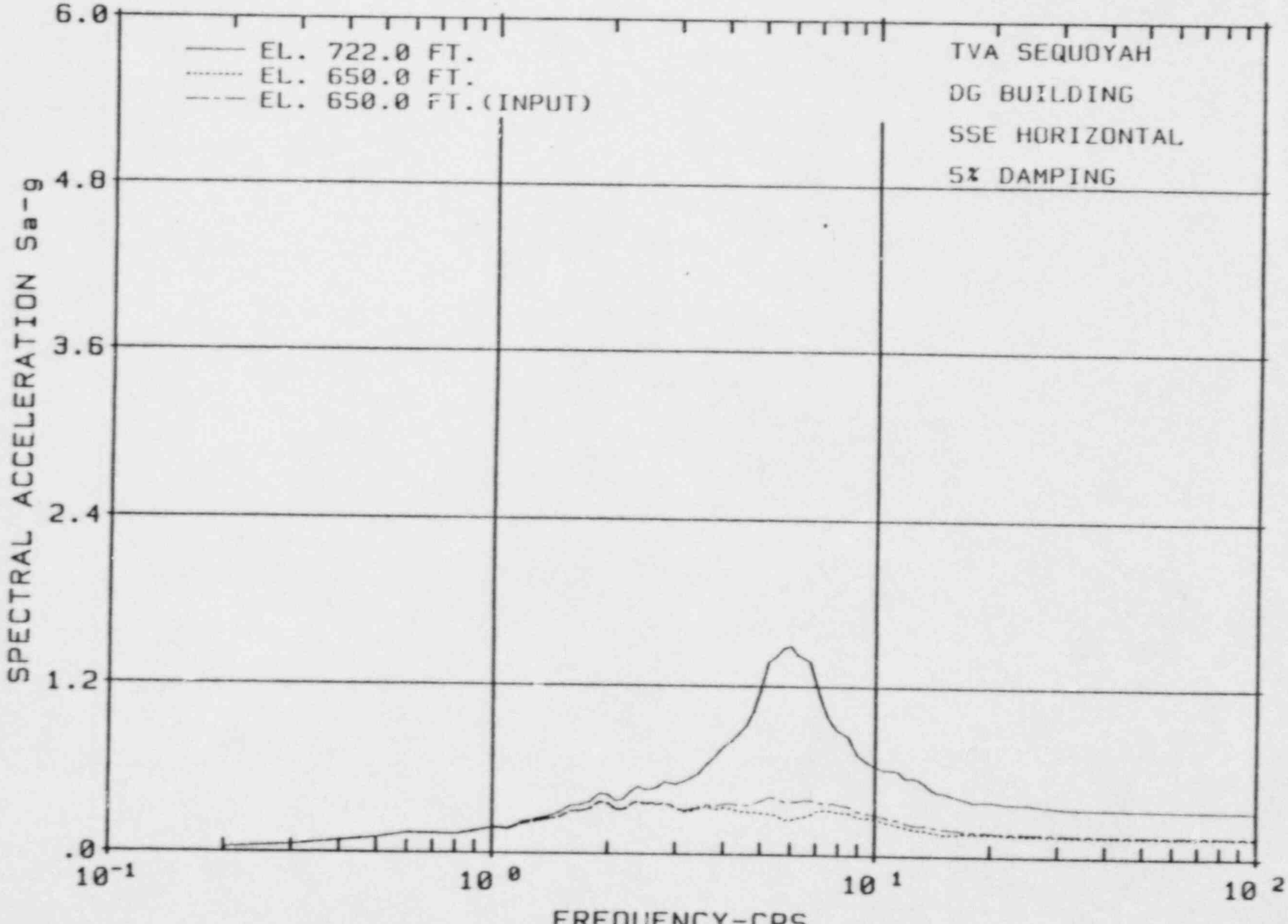
AVERAGED ARS UPPER BOUND SOIL STRAIN-DEP. OUTCROP INPUT

Figure A-15



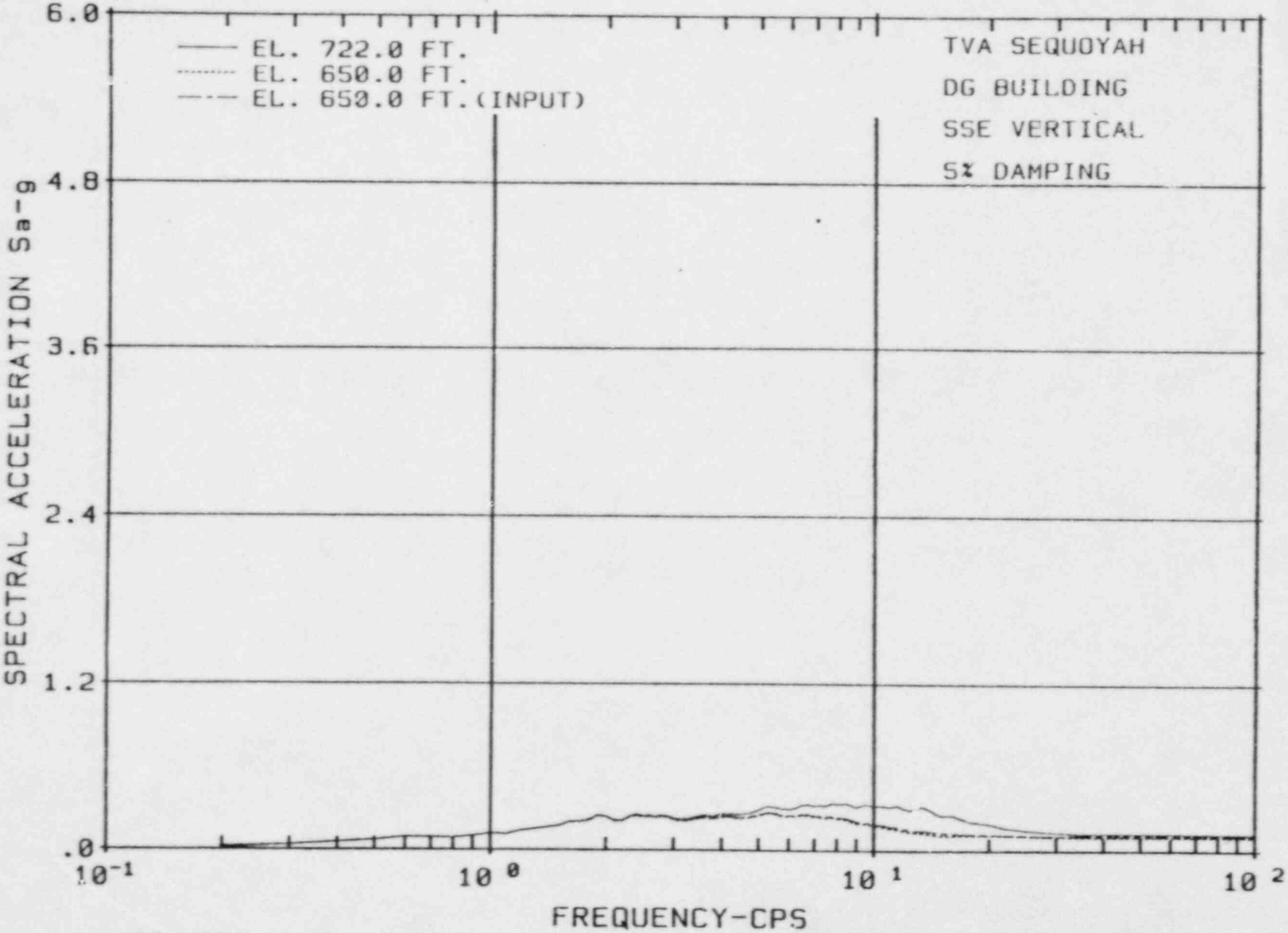
AVERAGED ARS UPPER BOUND SOIL STRAIN-DEP. OUTCROP INPUT

Figure A-16



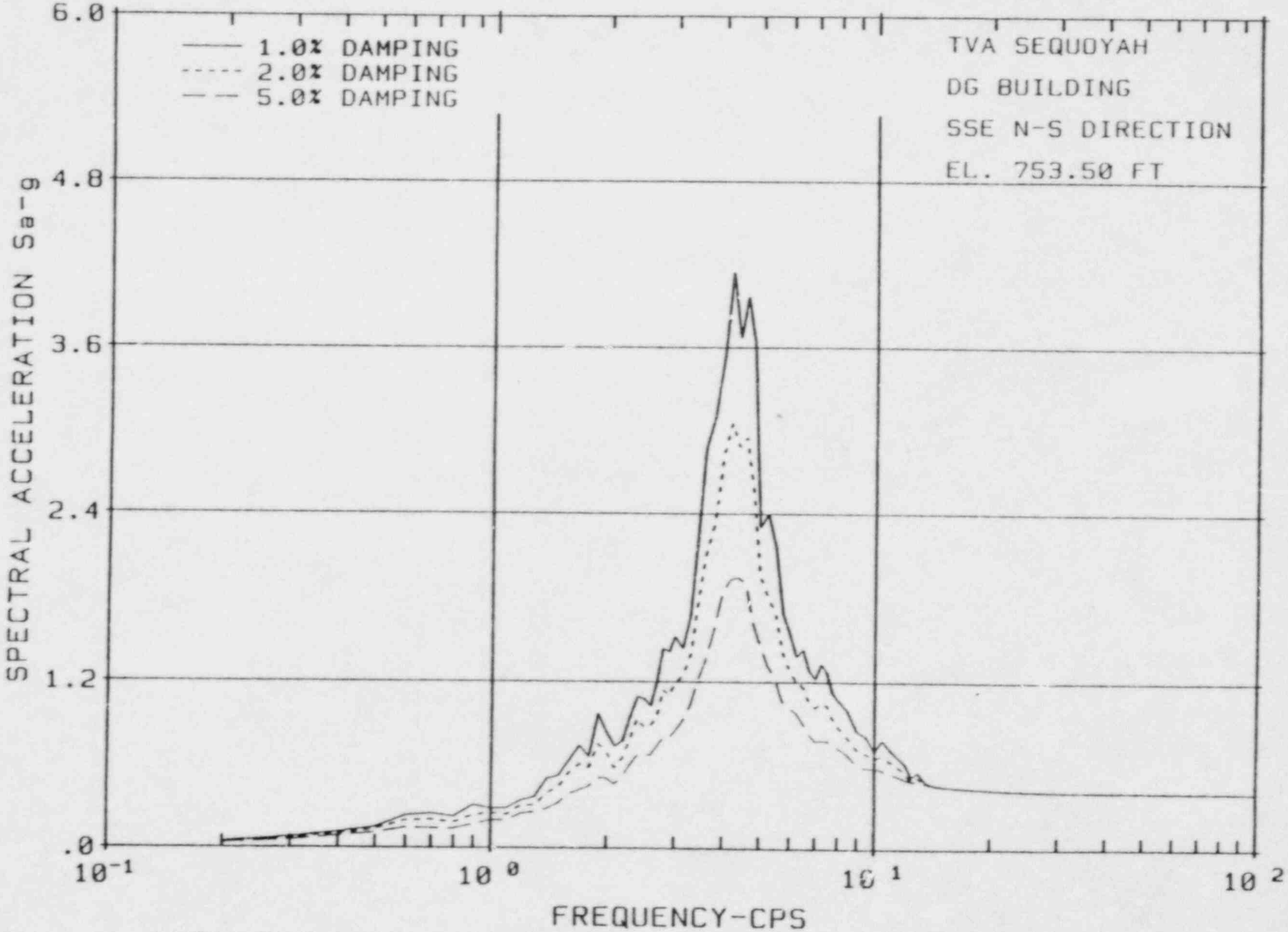
AVERAGED ARS UPPER BOUND SOIL STRAIN-DEP. OUTCROP INPUT

Figure A-17



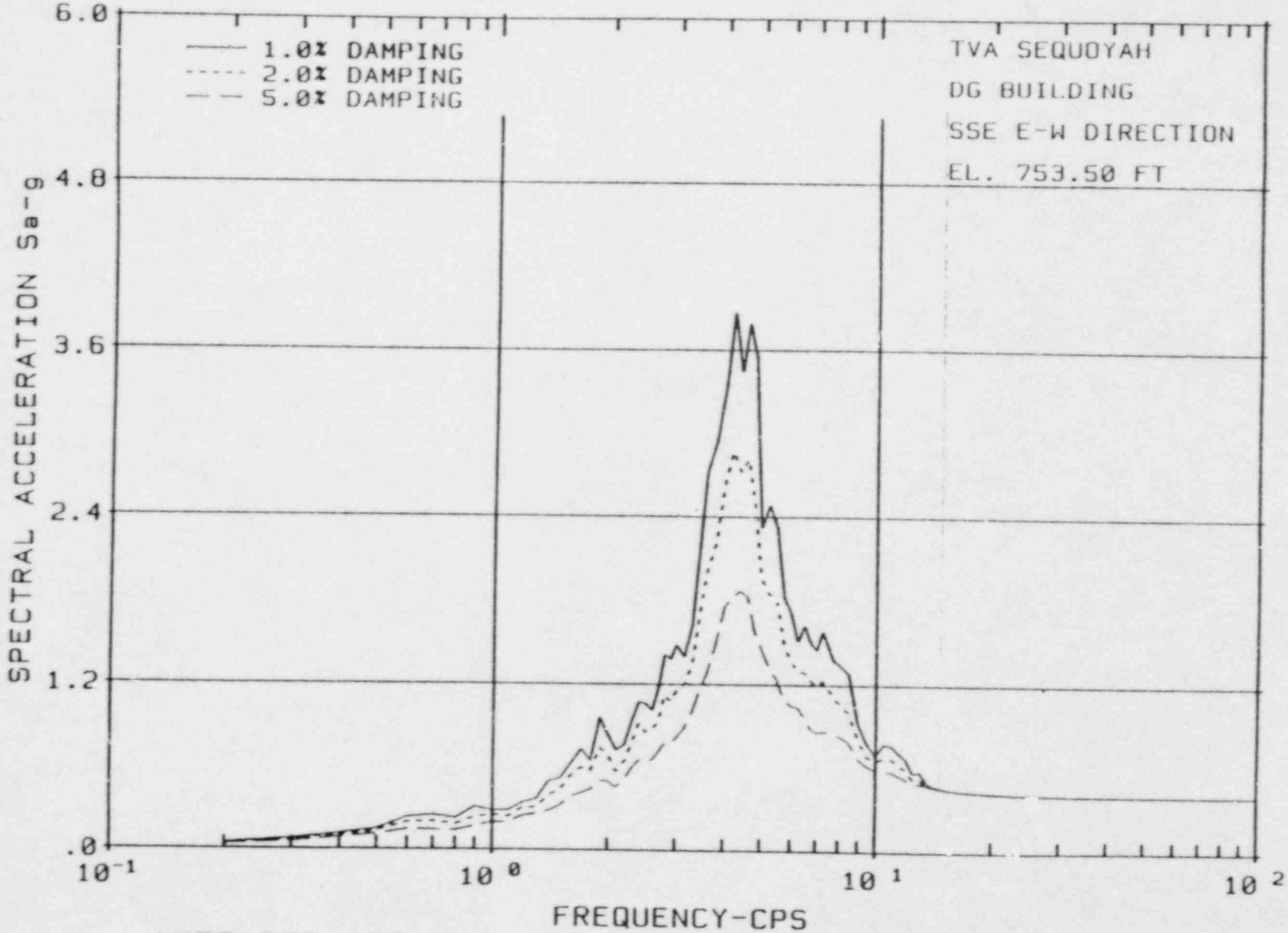
AVERAGED ARS UPPER BOUND SOIL STRAIN-DEP. OUTCROP INPUT

Figure A-18



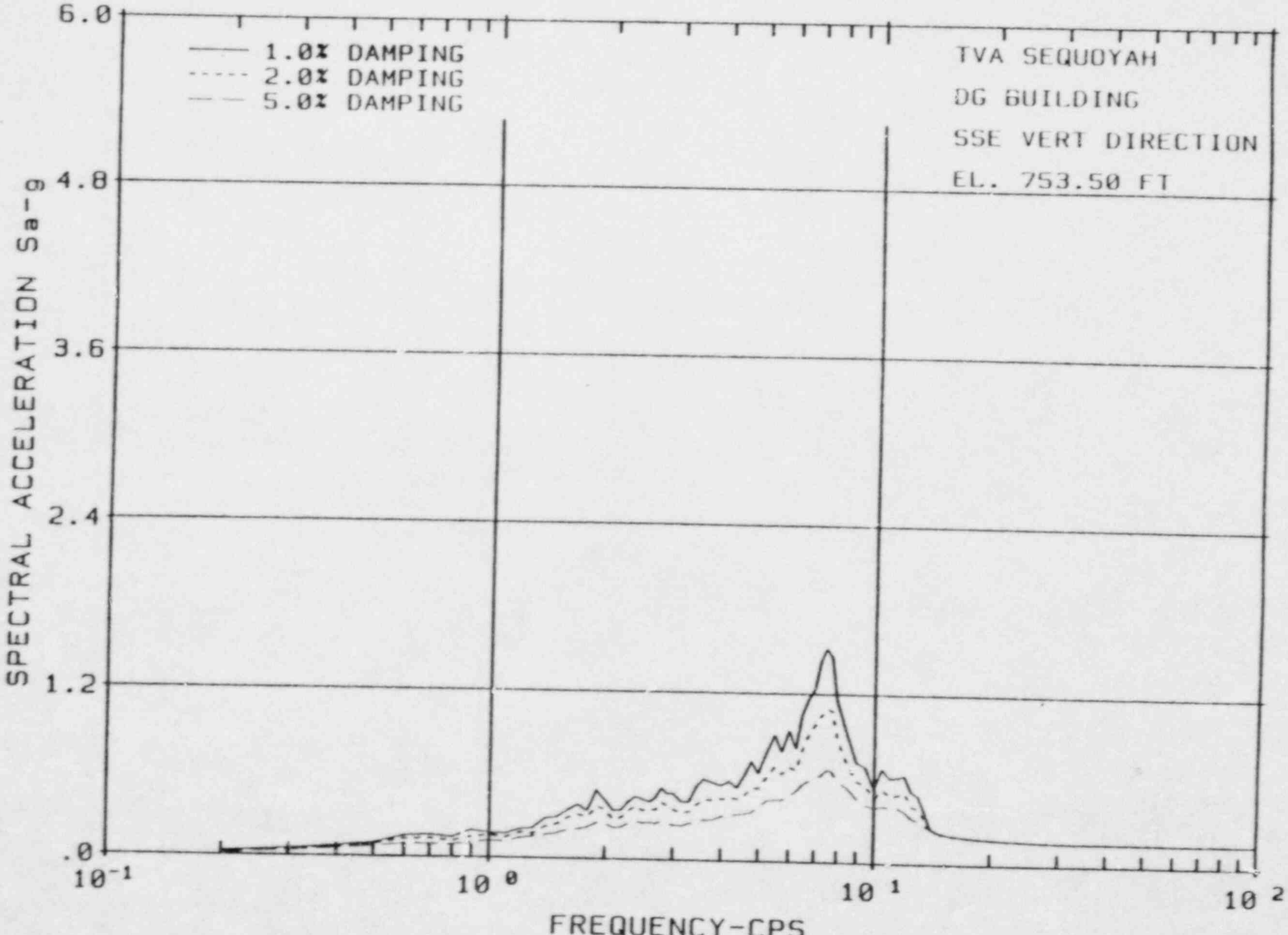
AVERAGED ARS MEAN SOIL STRAIN-DEP. OUTCROP INPUT

Figure A-19



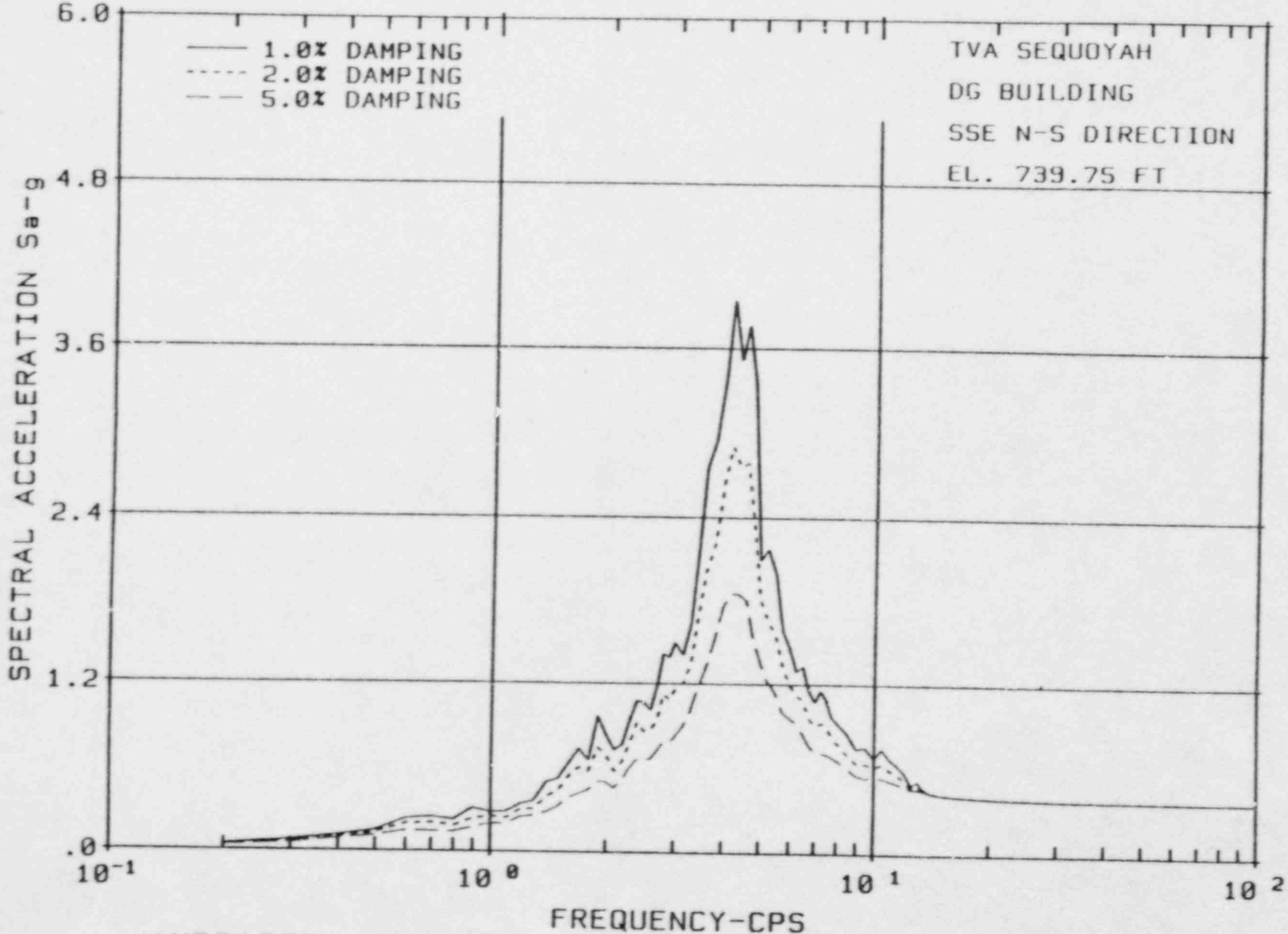
AVERAGED ARS MEAN SOIL STRAIN-DEP. OUTCROP INPUT

Figure A-20



AVERAGED ARS MEAN SOIL STRAIN-DEP. OUTCROP INPUT

Figure A-21



AVERAGED ARS MEAN SOIL STRAIN-DEP. OUTCROP INPUT

Figure A-22

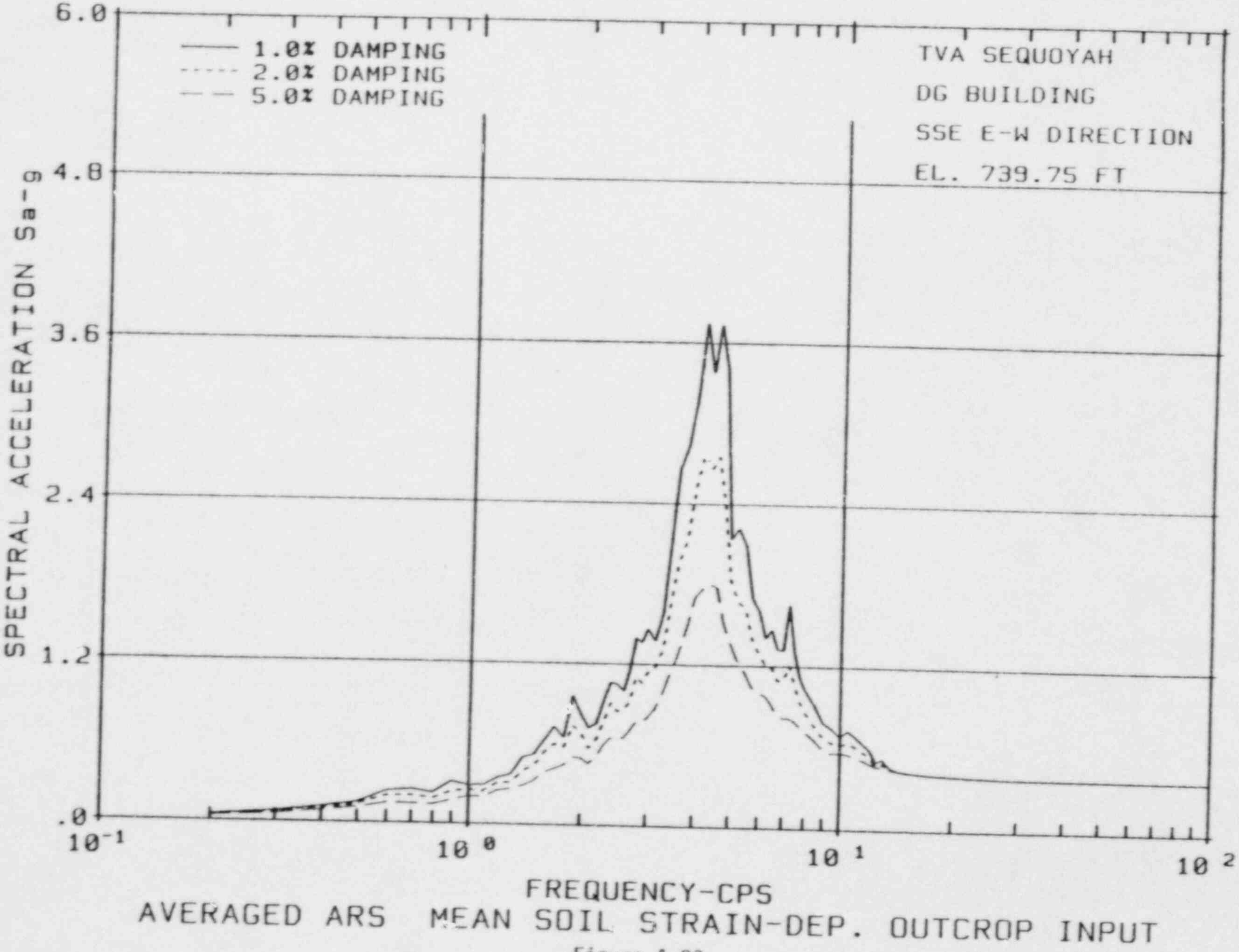
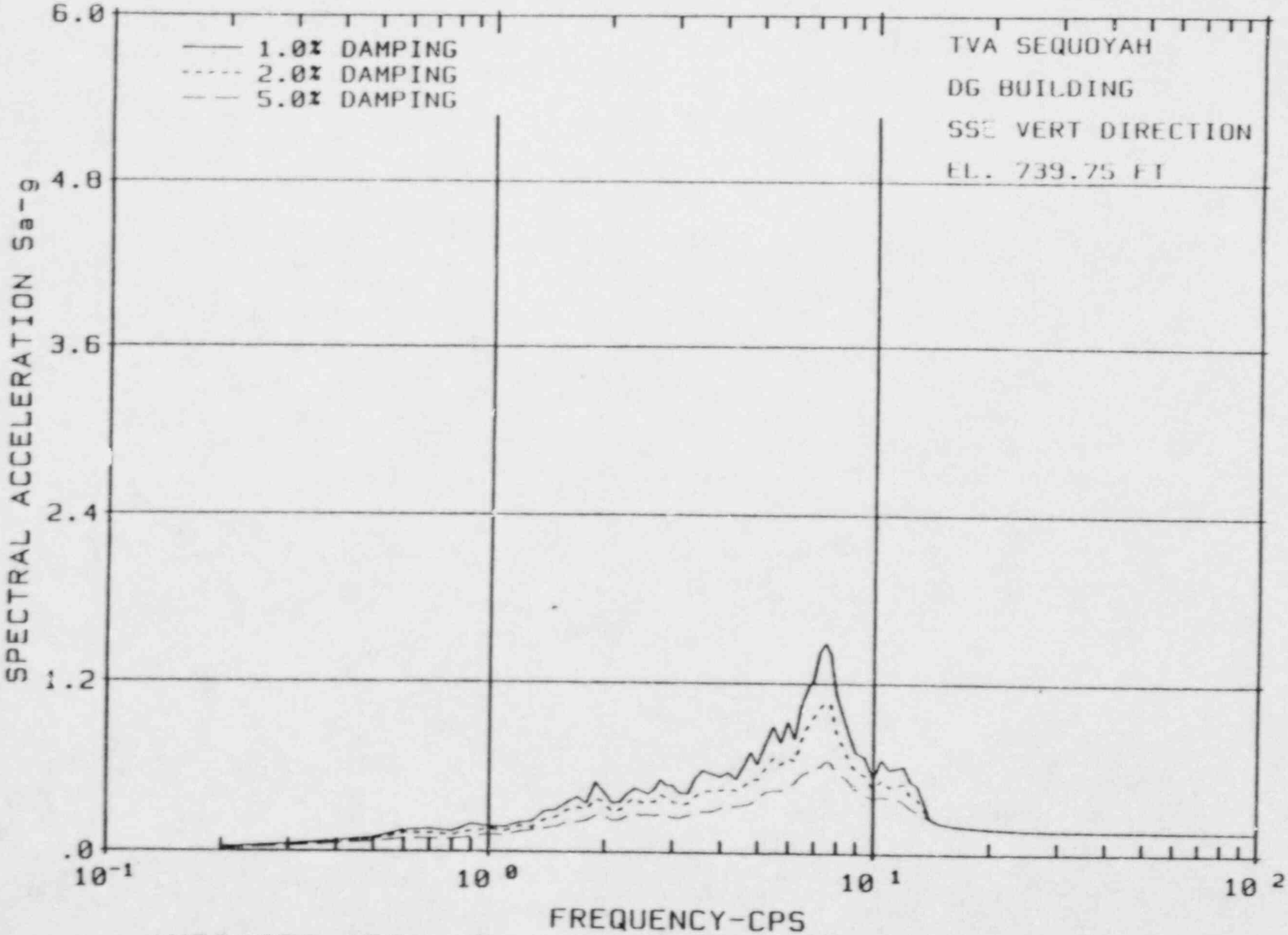
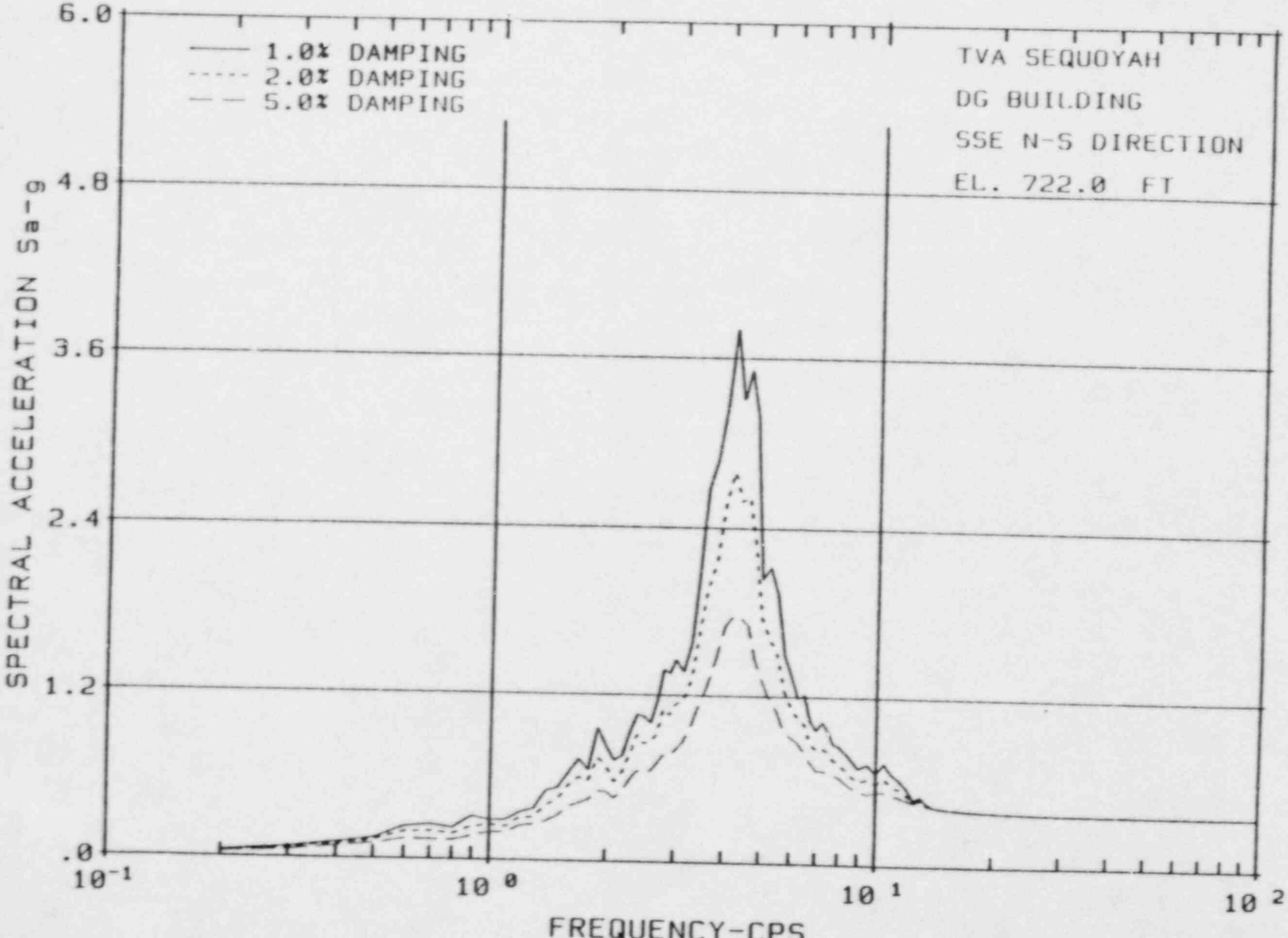

6.0
4.8
3.6
2.4
1.2
.0
SPECTRAL ACCELERATION Sa-g
1.0% DAMPING
2.0% DAMPING
5.0% DAMPING
TVA SEQUOYAH
DG BUILDING
SSE E-W DIRECTION
EL. 739.75 FT
10^{-1}
10^{0}
10^{1}
10^{2}
FREQUENCY-CPS
AVERAGED ARS MEAN SOIL STRAIN-DEP. OUTCROP INPUT

Figure A-23



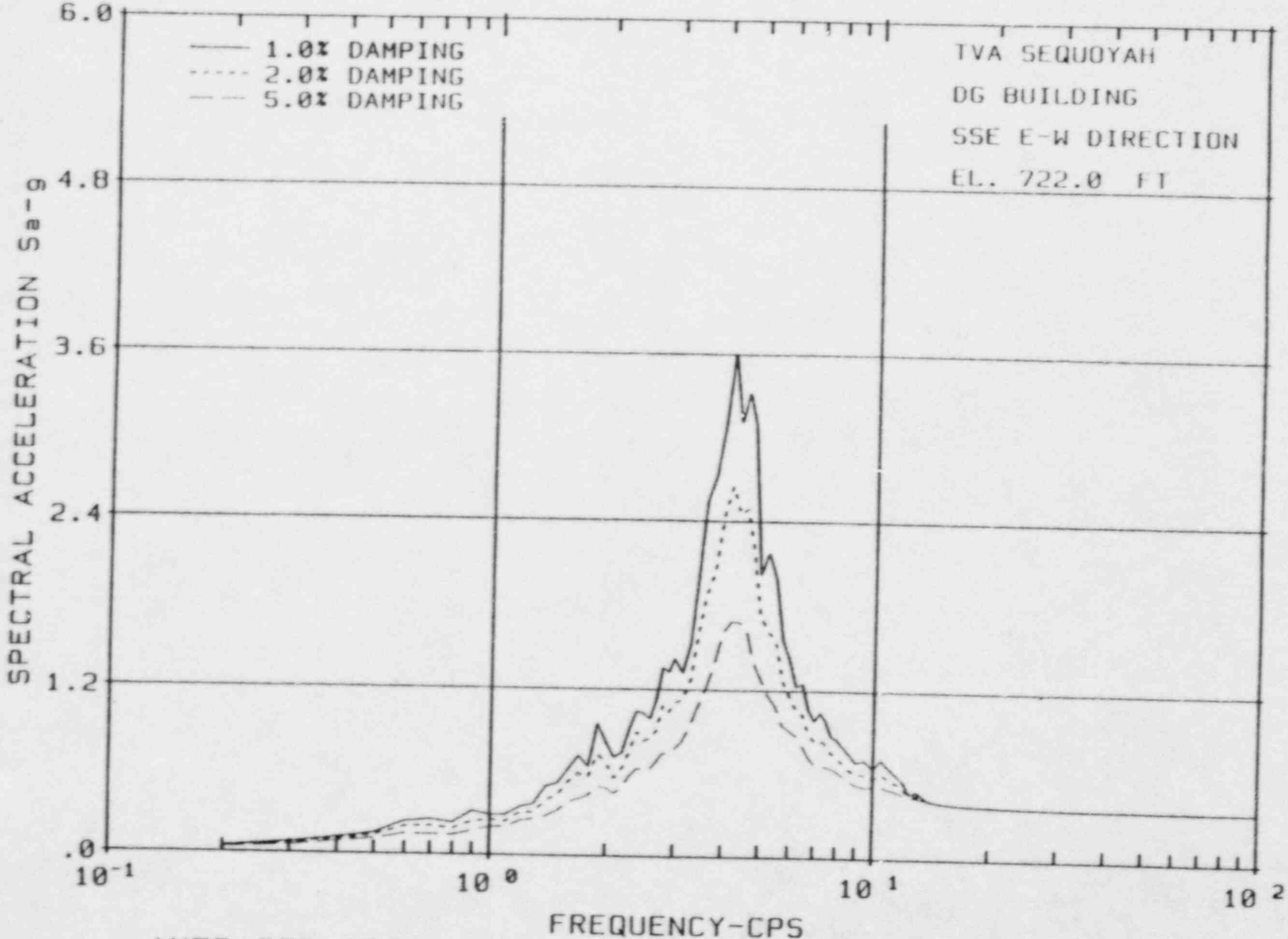
AVERAGED ARS MEAN SOIL STRAIN-DEP. OUTCROP INPUT

Figure A-24



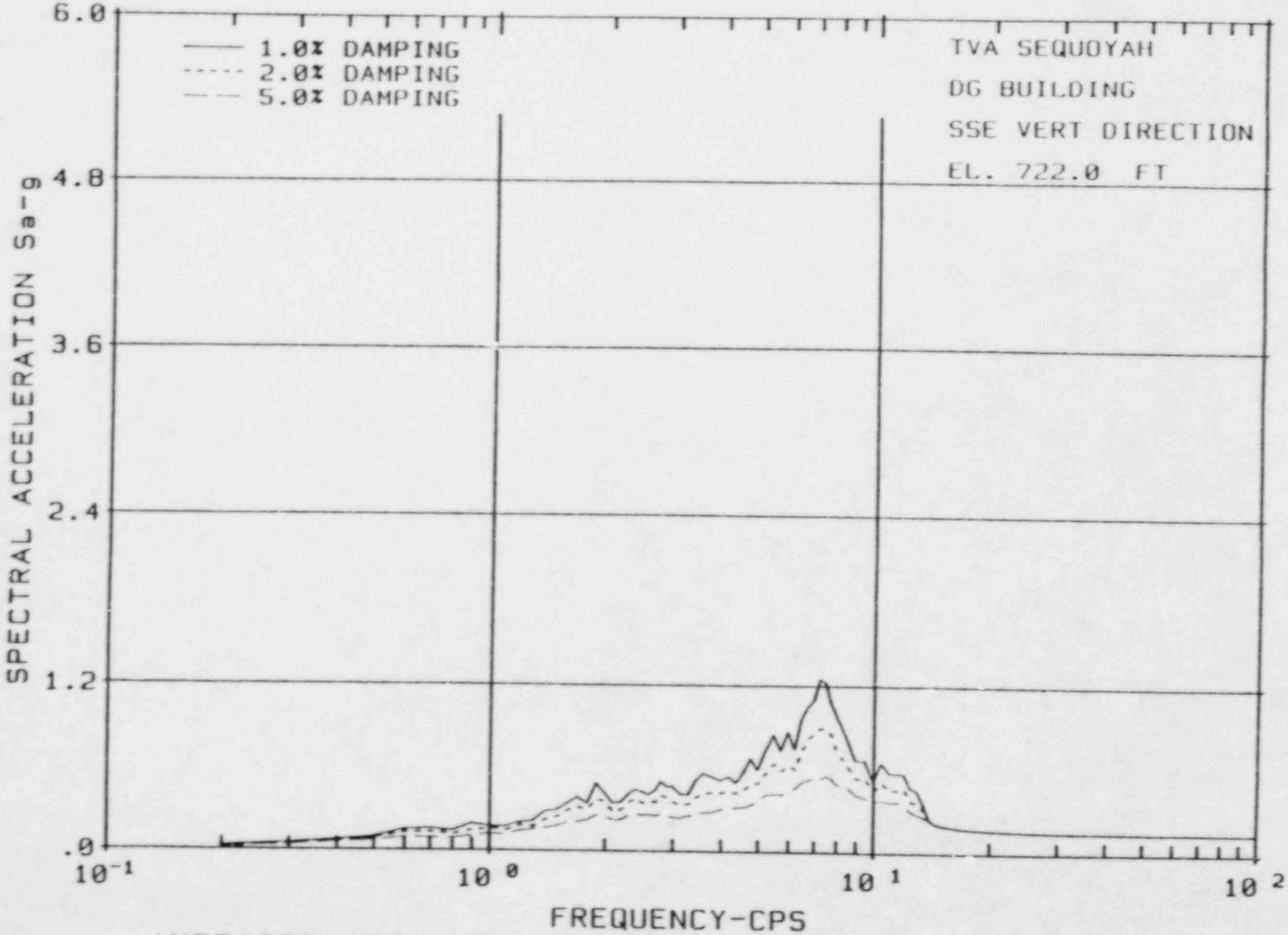
AVERAGED ARS MEAN SOIL STRAIN-DEP. OUTCROP INPUT

Figure A-25



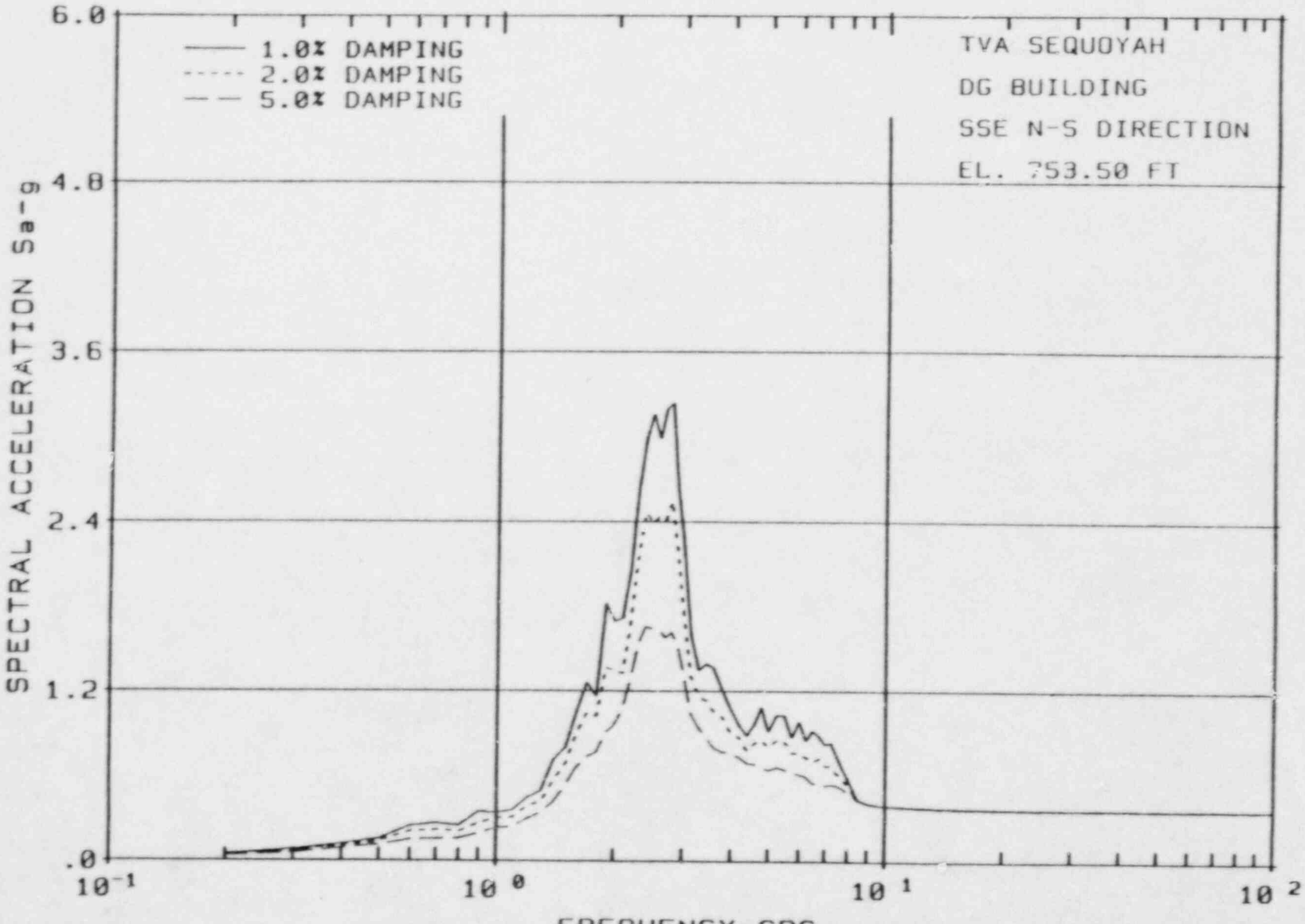
AVERAGED ARS MEAN SOIL STRAIN-DEP. OUTCROP INPUT

Figure A-26



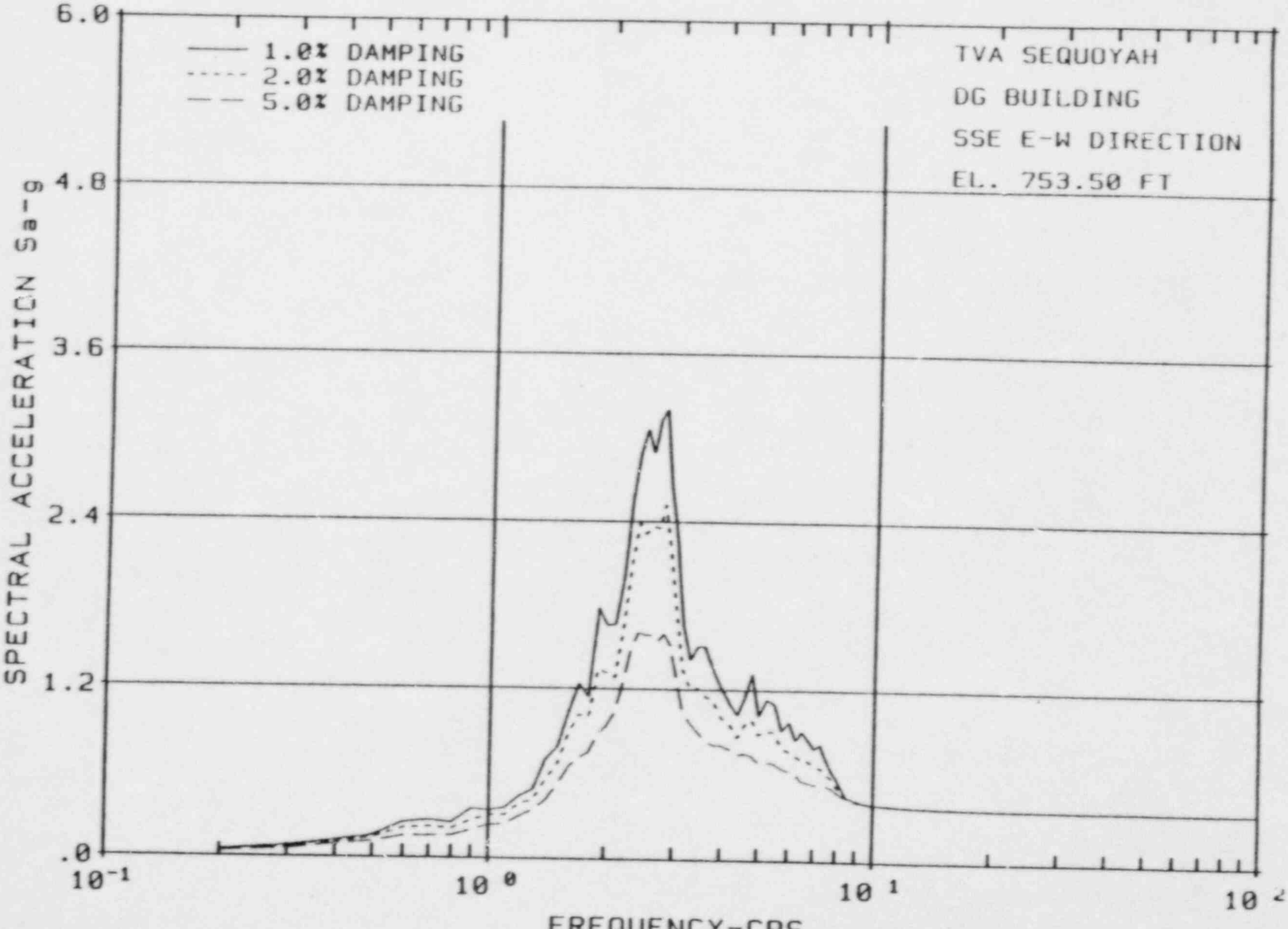
AVERAGED ARS MEAN SOIL STRAIN-DEP. OUTCROP INPUT

Figure A-27



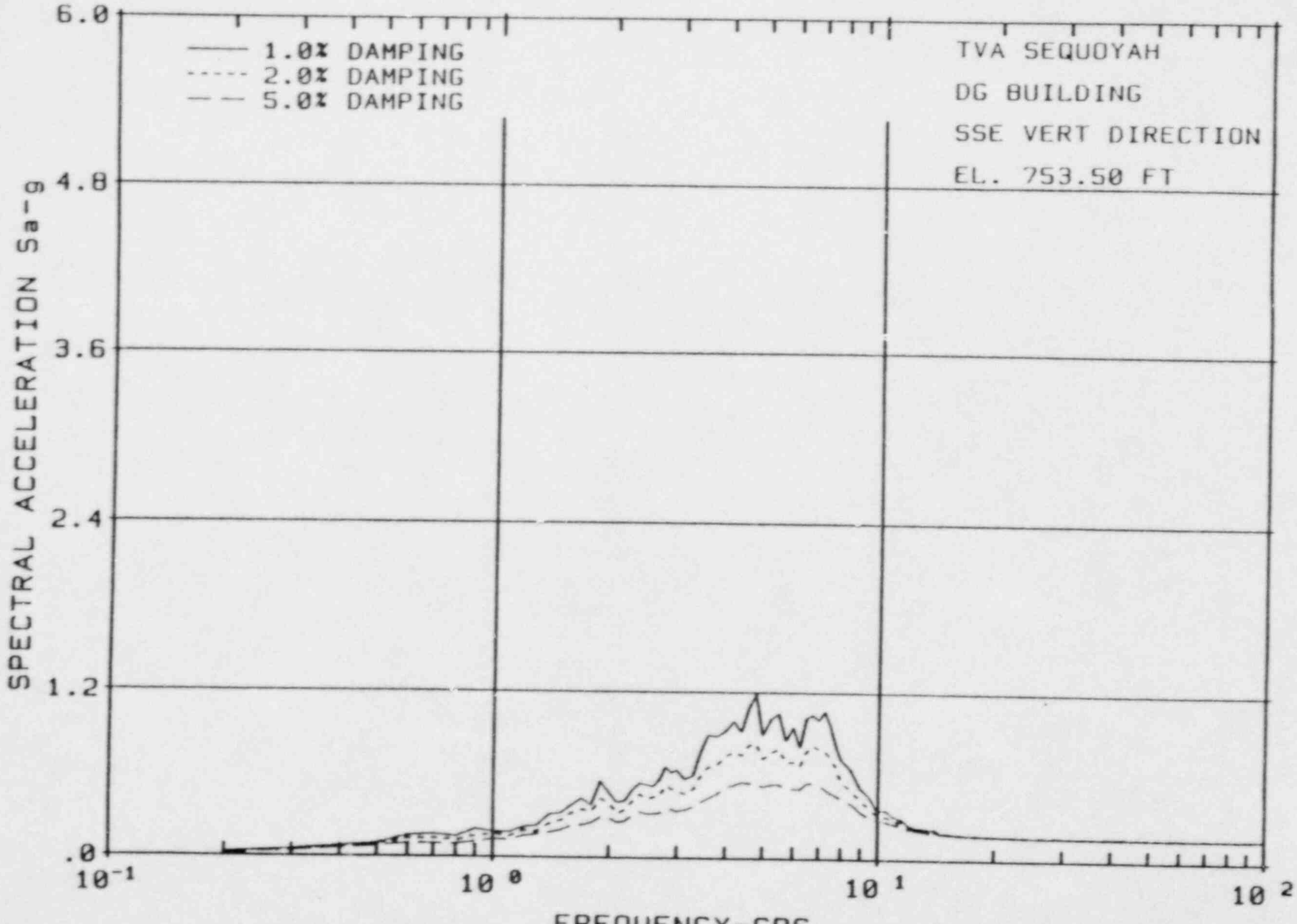
AVERAGED ARS LOWER-BOUND SOIL STRAIN DEP. OUTCROP INPUT

Figure A-28



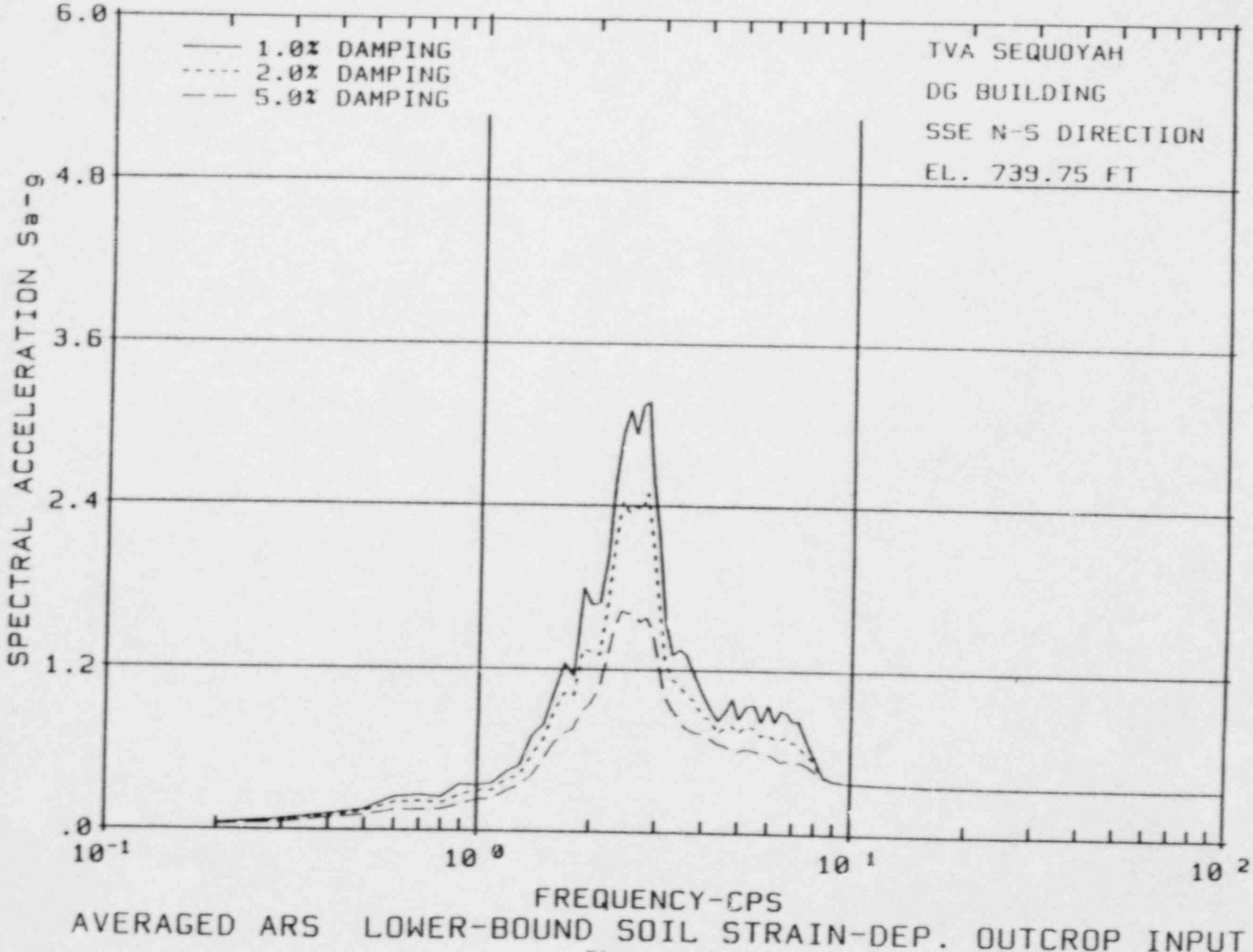
AVERAGED ARS LOWER-BOUND SOIL STRAIN-DEP. OUTCROP INPUT

Figure A-29



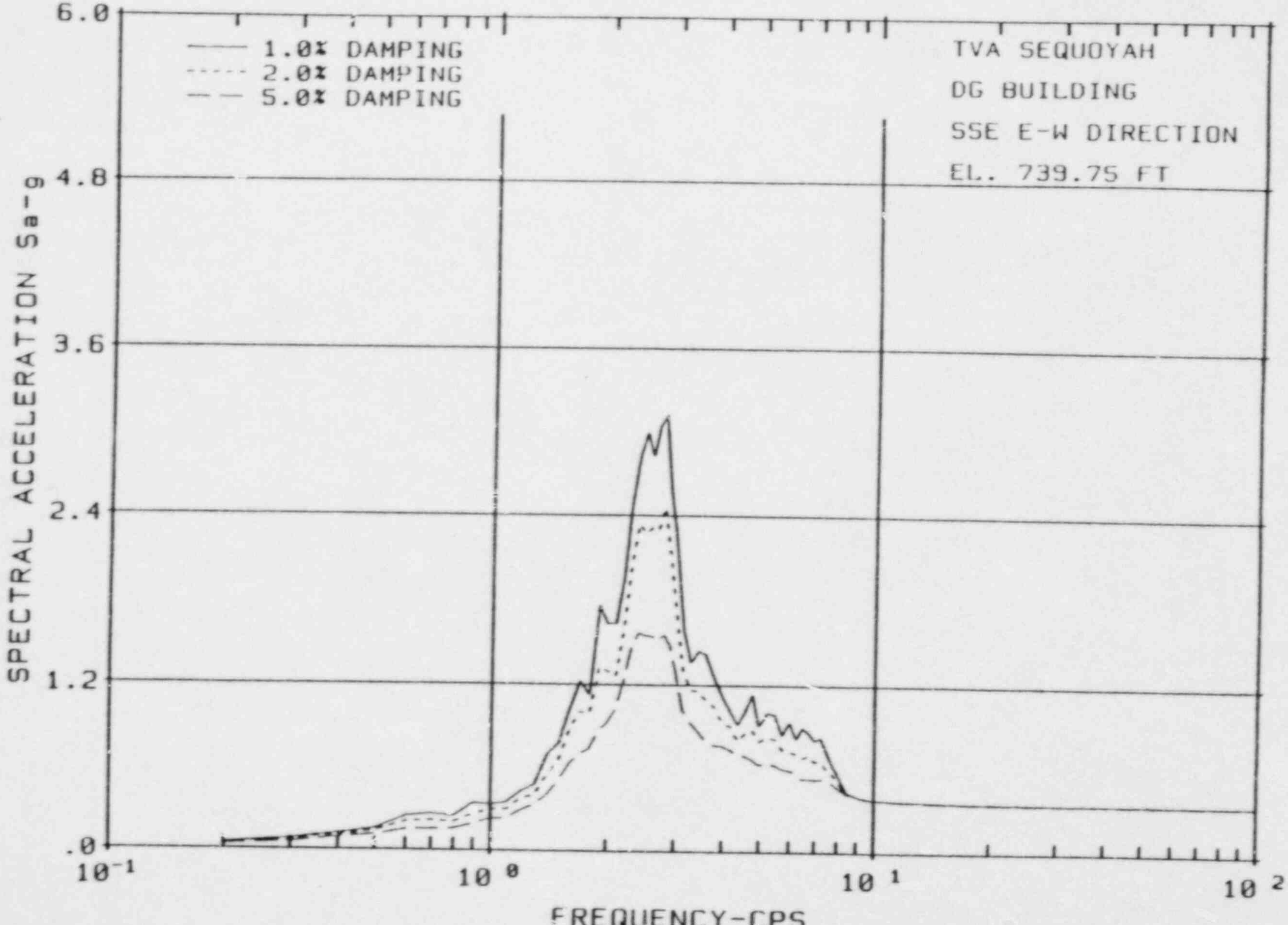
AVERAGED ARS LOWER-BOUND SOIL STRAIN-DEP. OUTCROP INPUT

Figure A-30



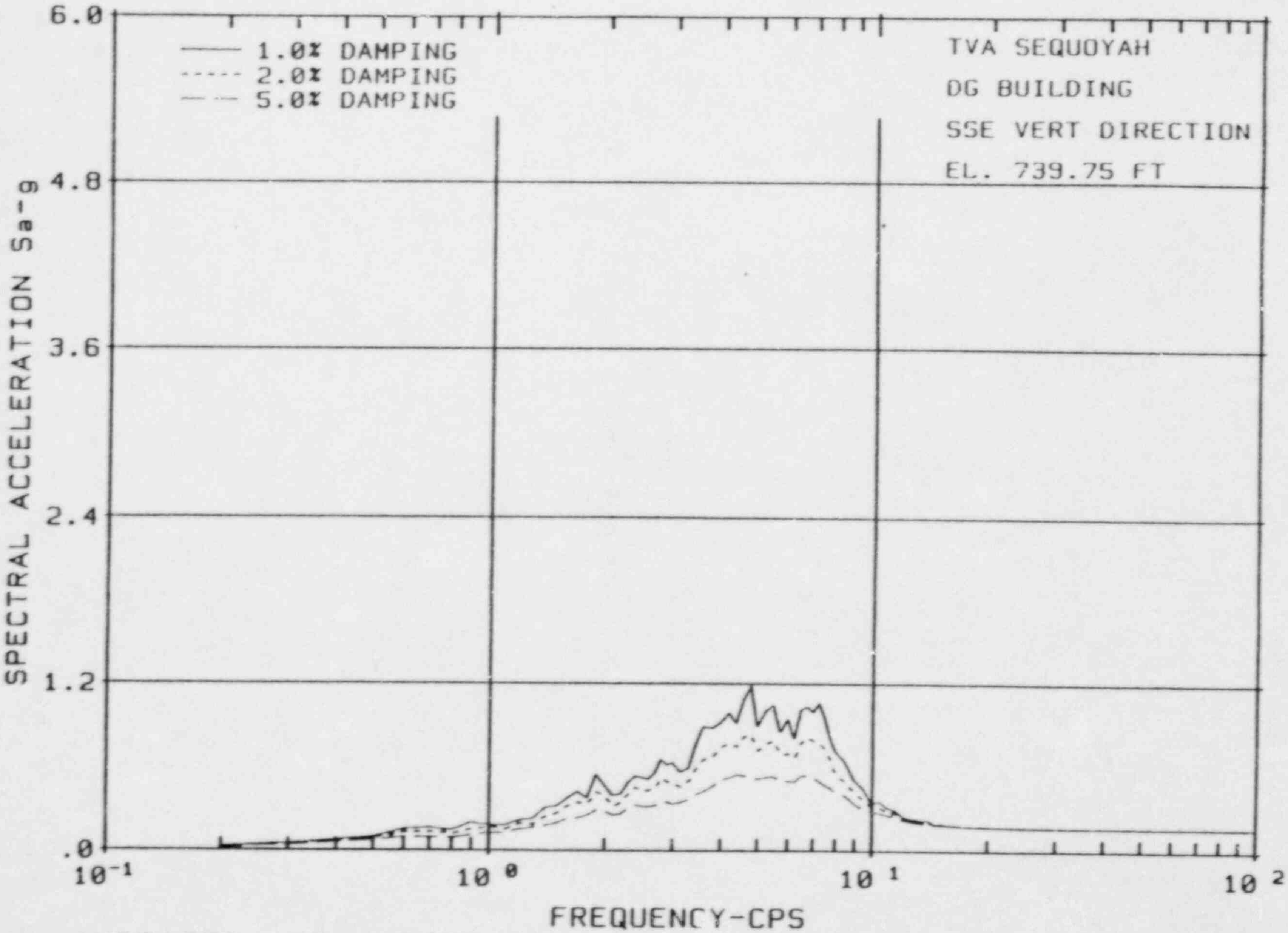
6.0
4.8
3.6
2.4
1.2
.0
SPECTRAL ACCELERATION Sa-g
1.0% DAMPING
2.0% DAMPING
5.0% DAMPING
TVA SEQUOYAH
DG BUILDING
SSE N-S DIRECTION
EL. 739.75 FT
10^{-1}
10^{0}
10^{1}
10^{2}
FREQUENCY-CPS
AVERAGED ARS LOWER-BOUND SOIL STRAIN-DEP. OUTCROP INPUT

Figure A-31



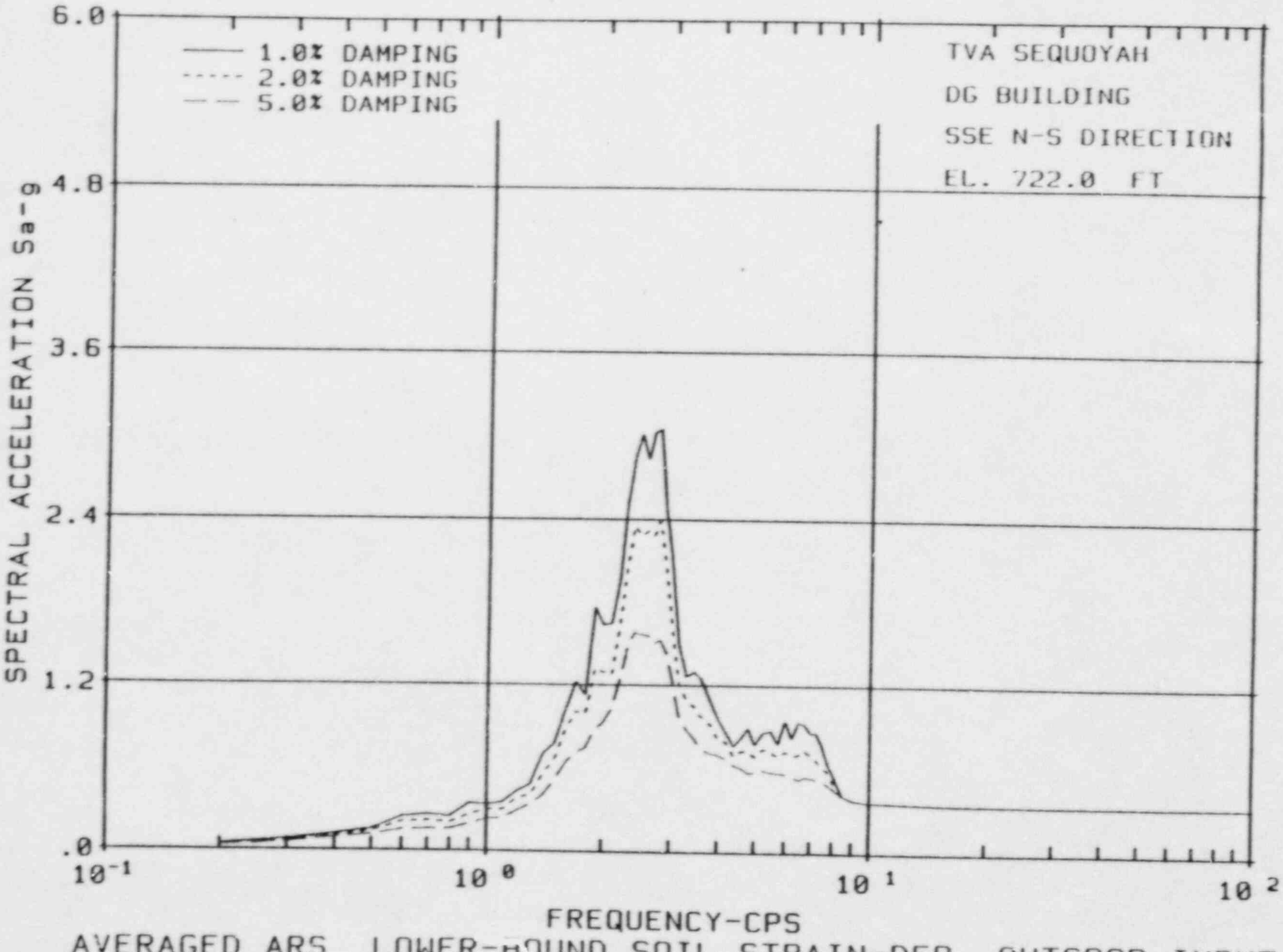
AVERAGED ARS LOWER-BOUND SOIL STRAIN-DEP. OUTCROP INPUT

Figure A-32



AVERAGED ARS LOWER-BOUND SOIL STRAIN-DEP. OUTCROP INPUT

Figure A-33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3.6
2.4
1.2
.0
SPECTRAL ACCELERATION Sa-g
1.0% DAMPING
2.0% DAMPING
5.0% DAMPING
TVA SEQUOYAH
DG BUILDING
SSE N-S DIRECTION
EL. 722.0 FT
10^-1
10^0
10^1
10^2
FREQUENCY-CPS
AVERAGED ARS LOWER-BOUND SOIL STRAIN-DEP. OUTCROP INPUT

Figure A-34

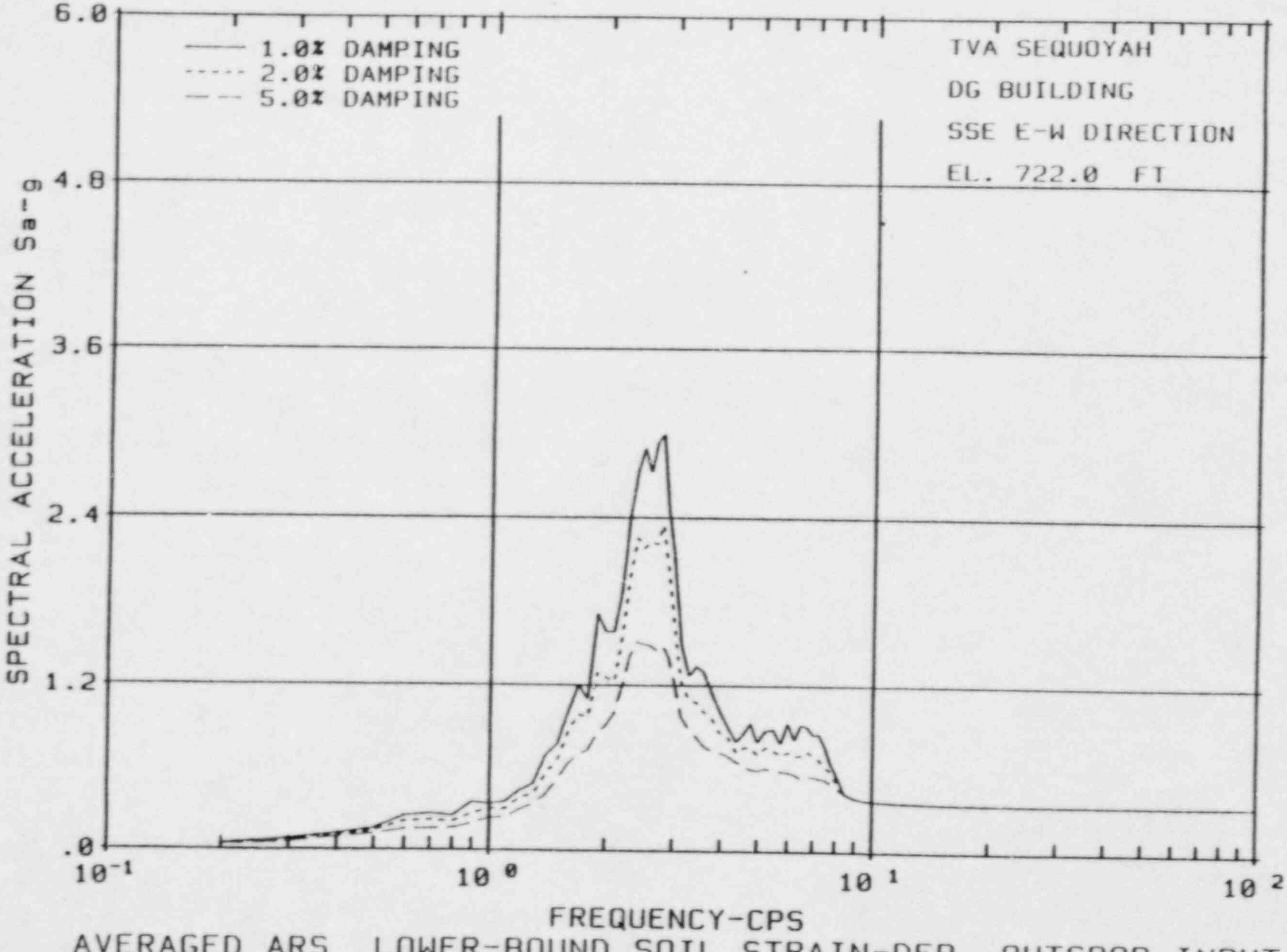
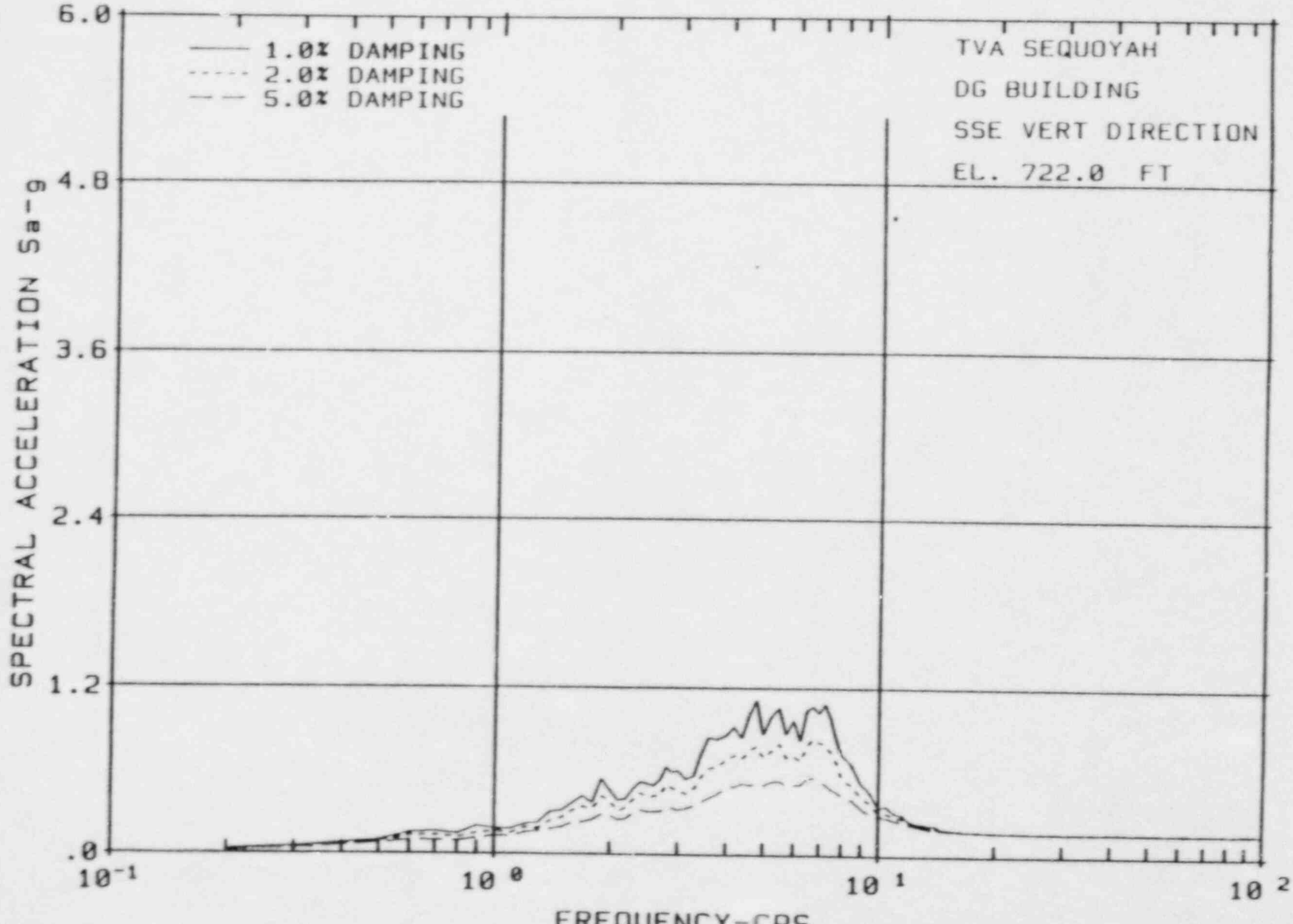
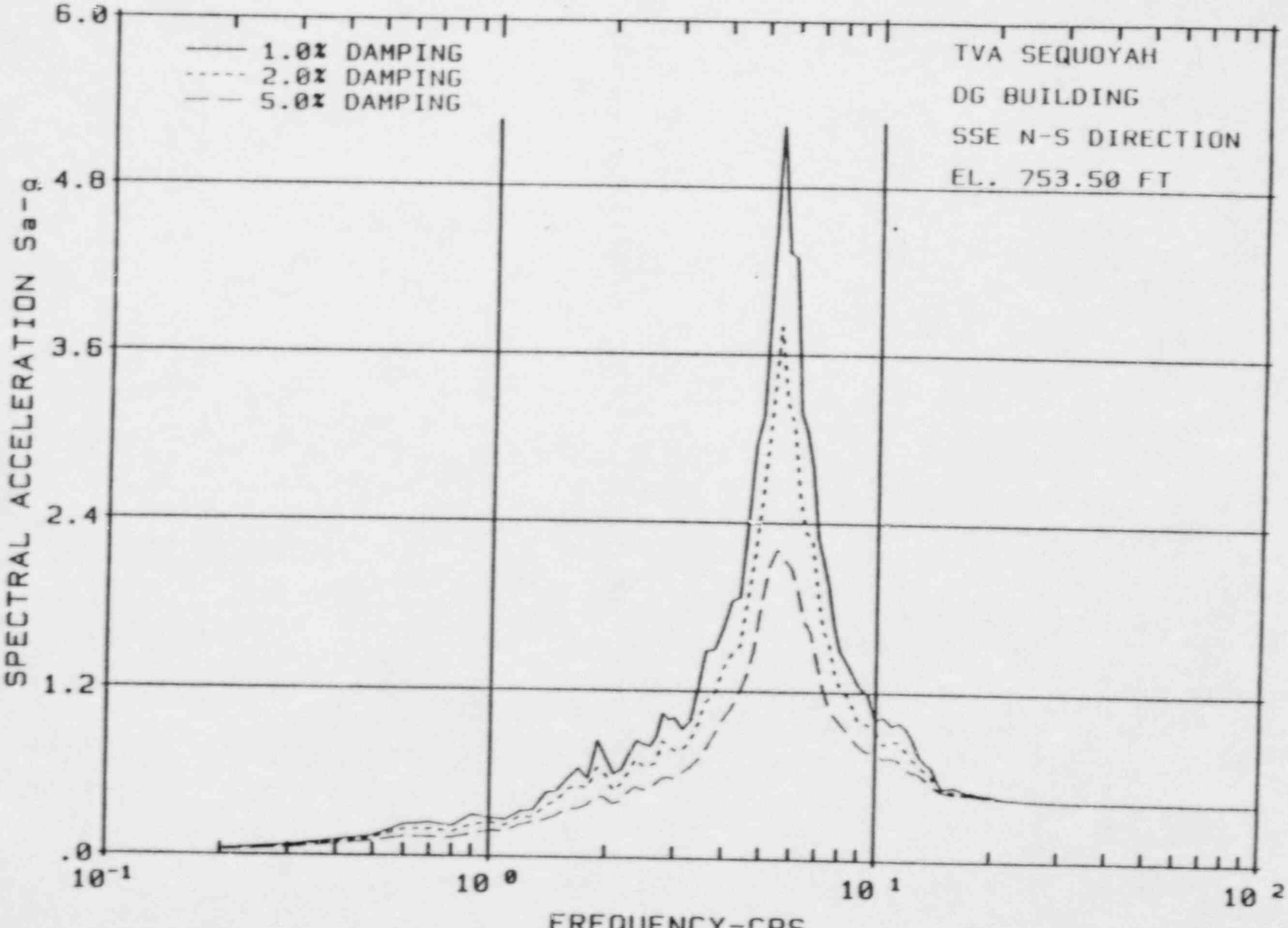

6.0
4.8
3.6
2.4
1.2
.0
SPECTRAL ACCELERATION Sa-g
1.0% DAMPING
2.0% DAMPING
5.0% DAMPING
TVA SEQUOYAH
DG BUILDING
SSE E-W DIRECTION
EL. 722.0 FT
10^{-1}
10^{0}
10^{1}
10^{2}
FREQUENCY-CPS
AVERAGED ARS LOWER-BOUND SOIL STRAIN-DEP. OUTCROP INPUT

Figure A-35



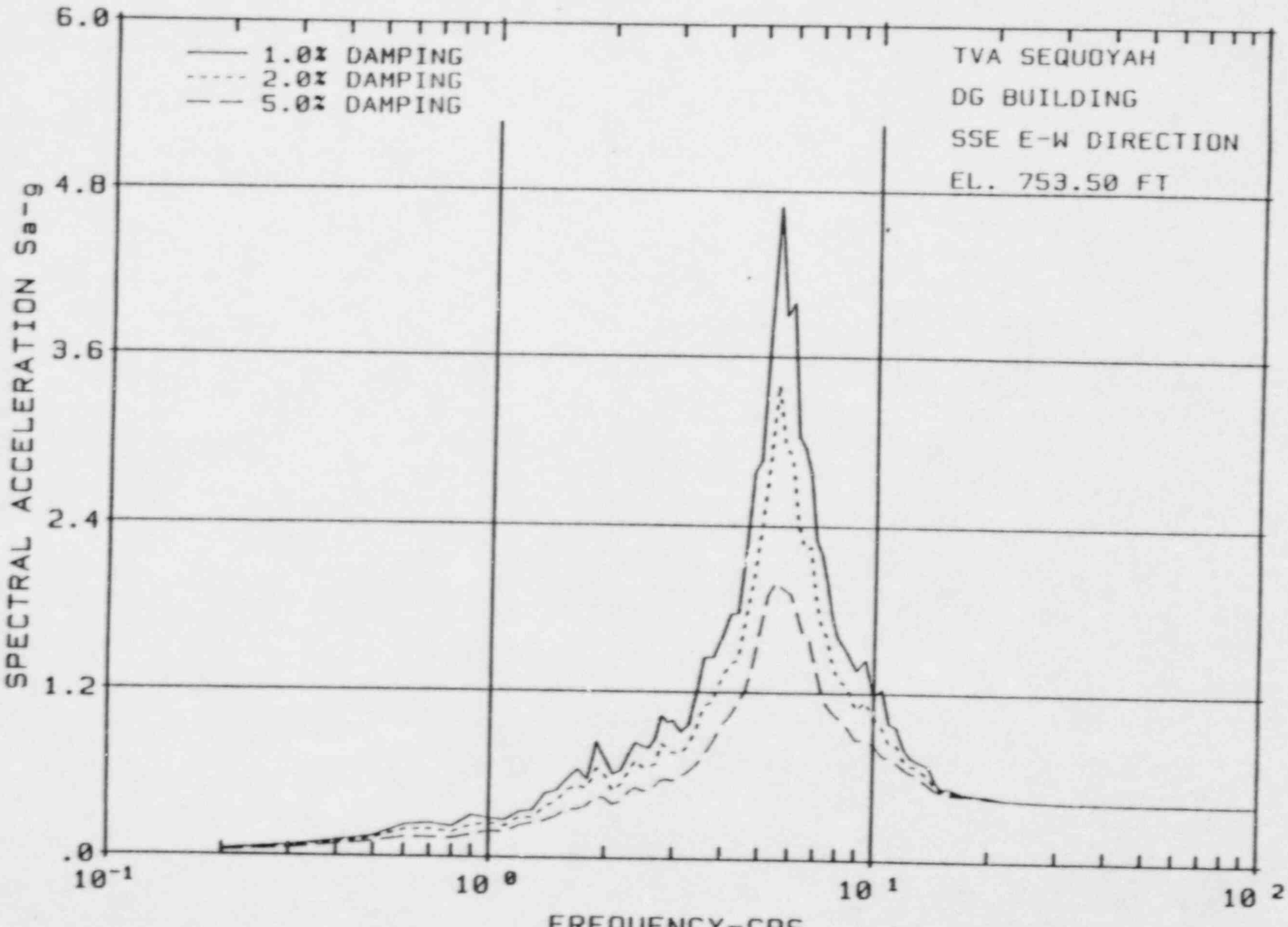
AVERAGED ARS LOWER-BOUND SOIL STRAIN-DEP. OUTCROP INPUT

Figure A-36



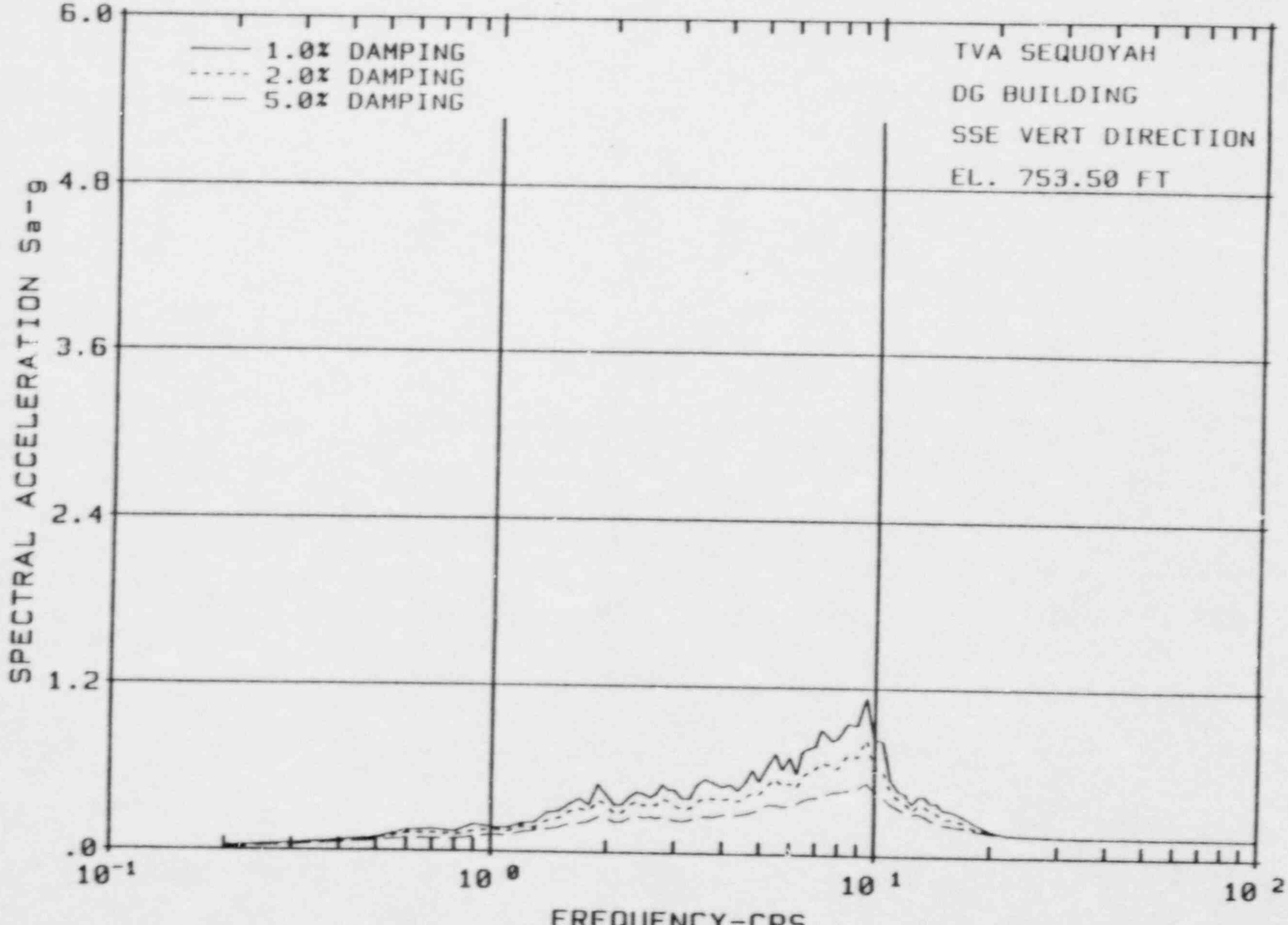
AVERAGED ARS UPPER-BOUND SOIL STRAIN DEP. OUTCROP INPUT

Figure A-37



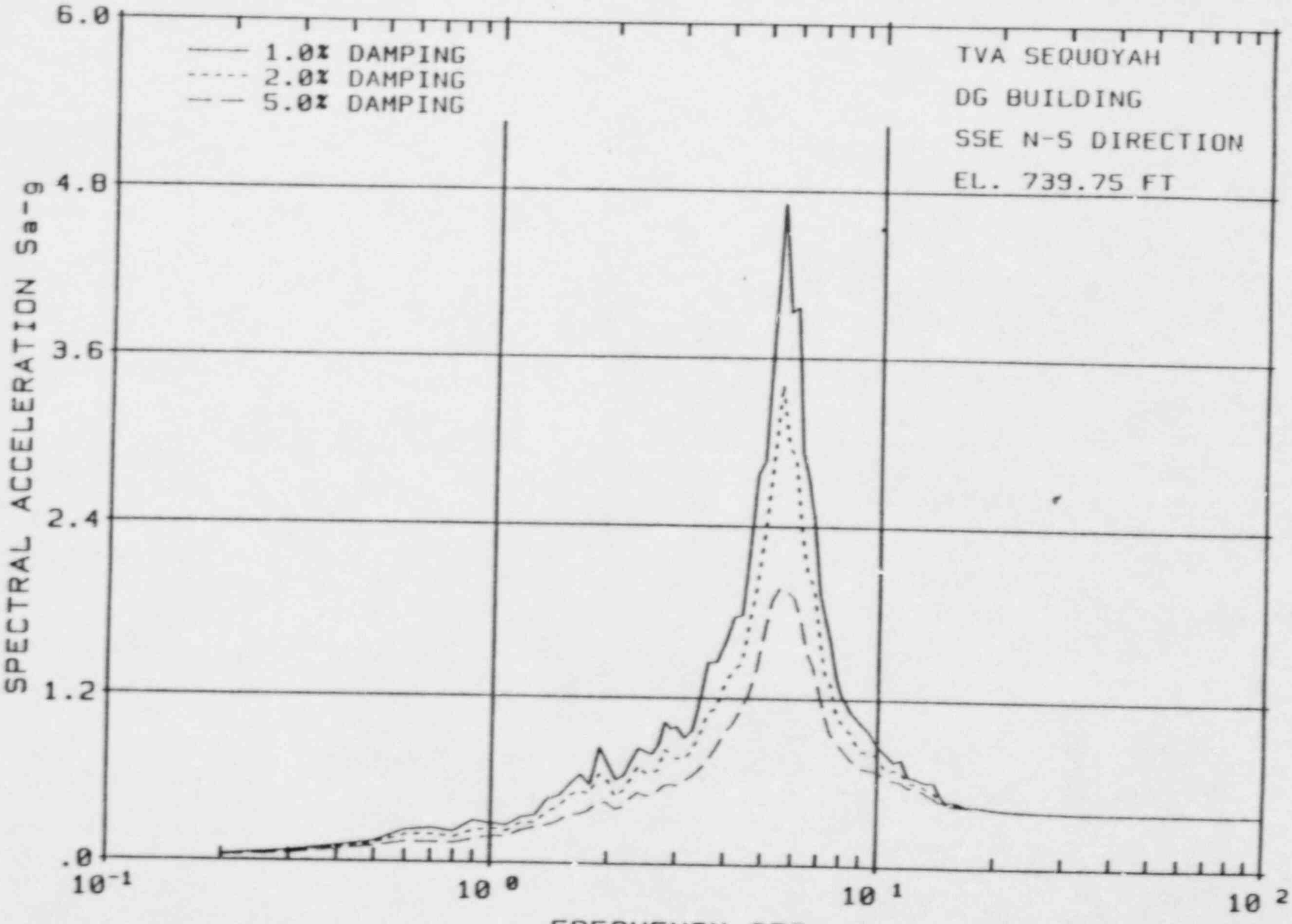
AVERAGED ARS UPPER-BOUND SOIL STRAIN-DEP. OUTCROP INPUT

Figure A-38



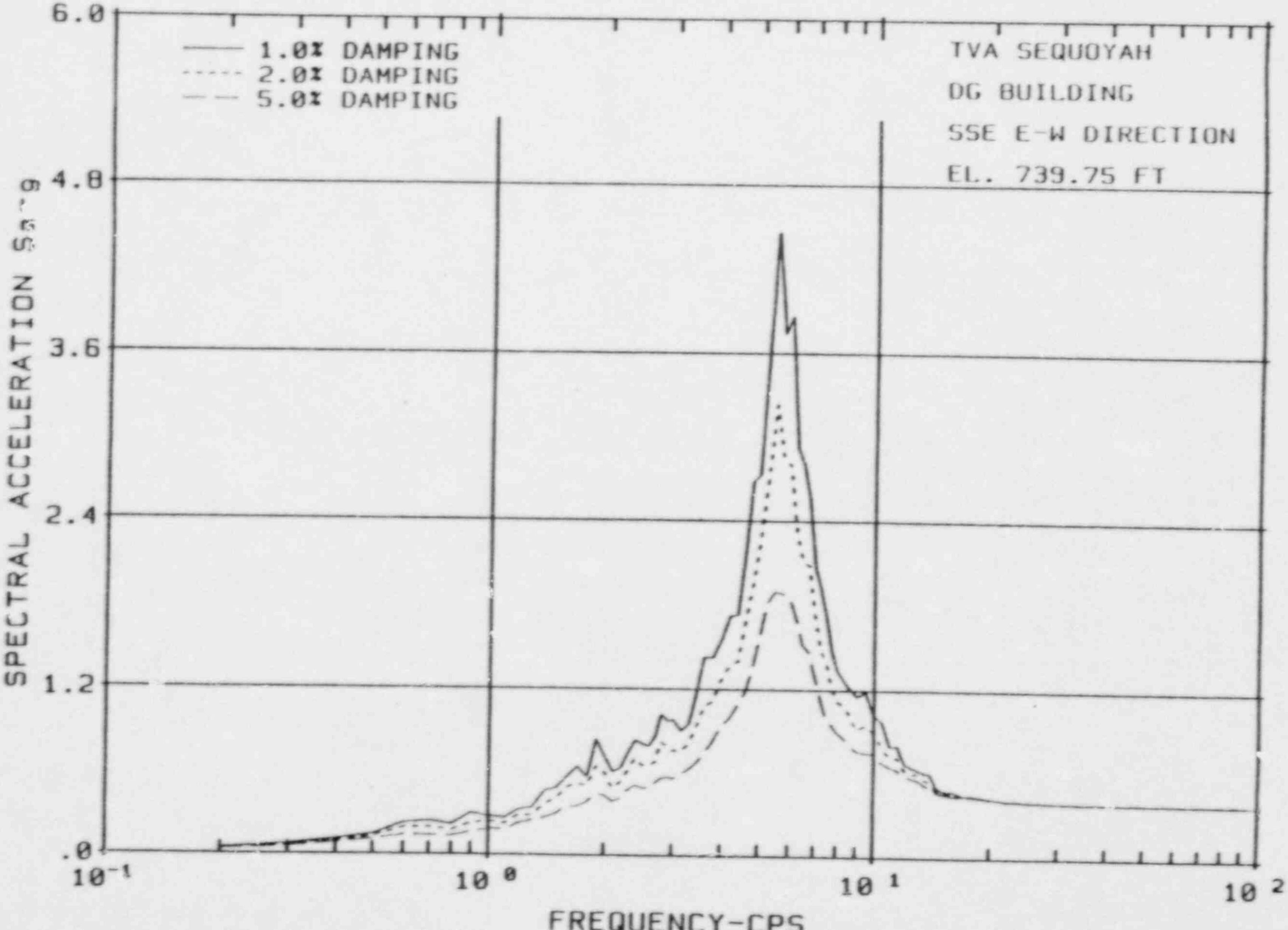
AVERAGED ARS UPPER-BOUND SOIL STRAIN-DEP. OUTCROP INPUT

Figure A-39



AVERAGED ARS UPPER-BOUND SOIL STRAIN-DEP. OUTCROP INPUT

Figure A-40



AVERAGED ARS UPPER-BOUND SOIL STRAIN-DEP. OUTCROP INPUT

Figure A-41

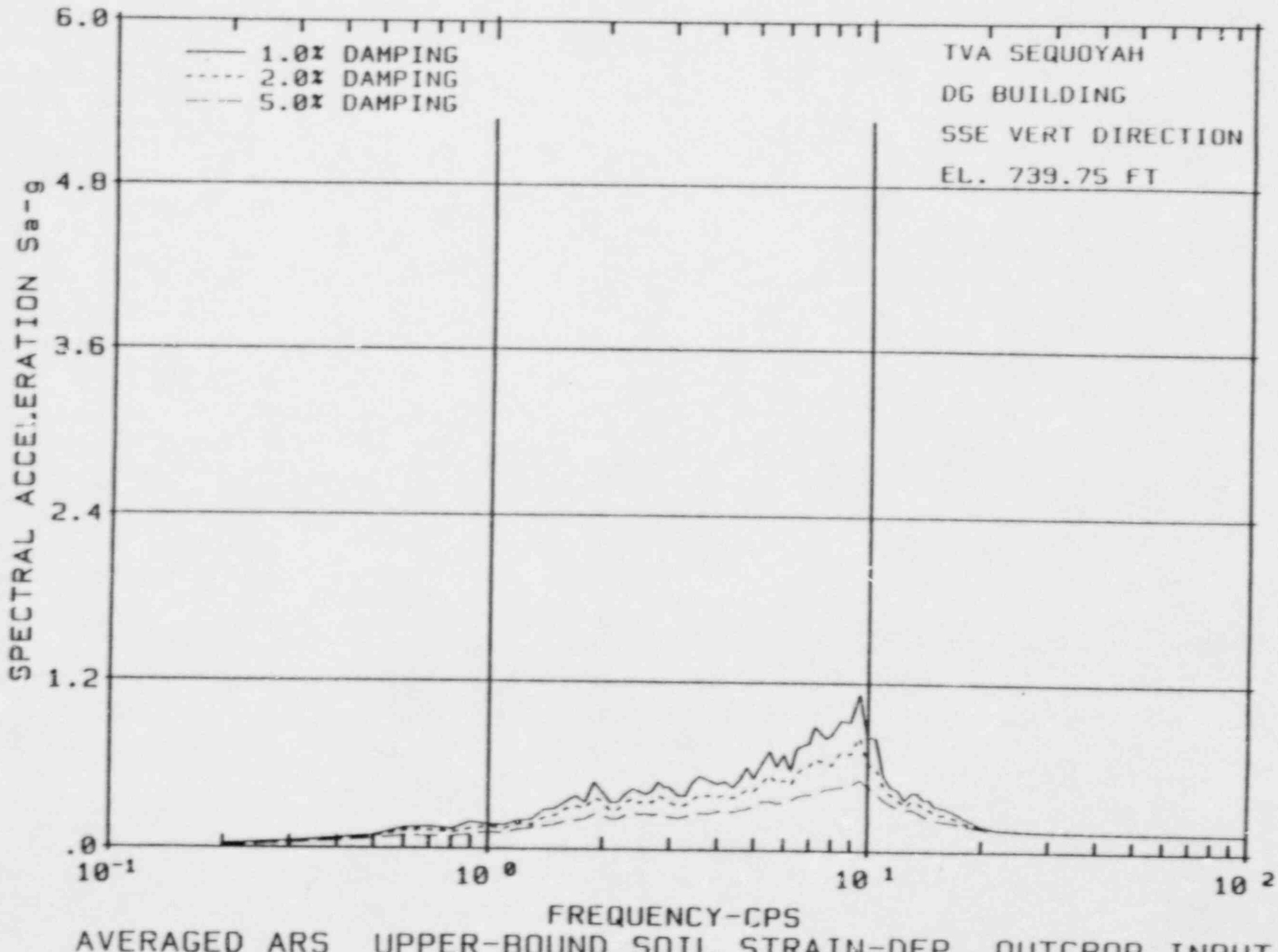
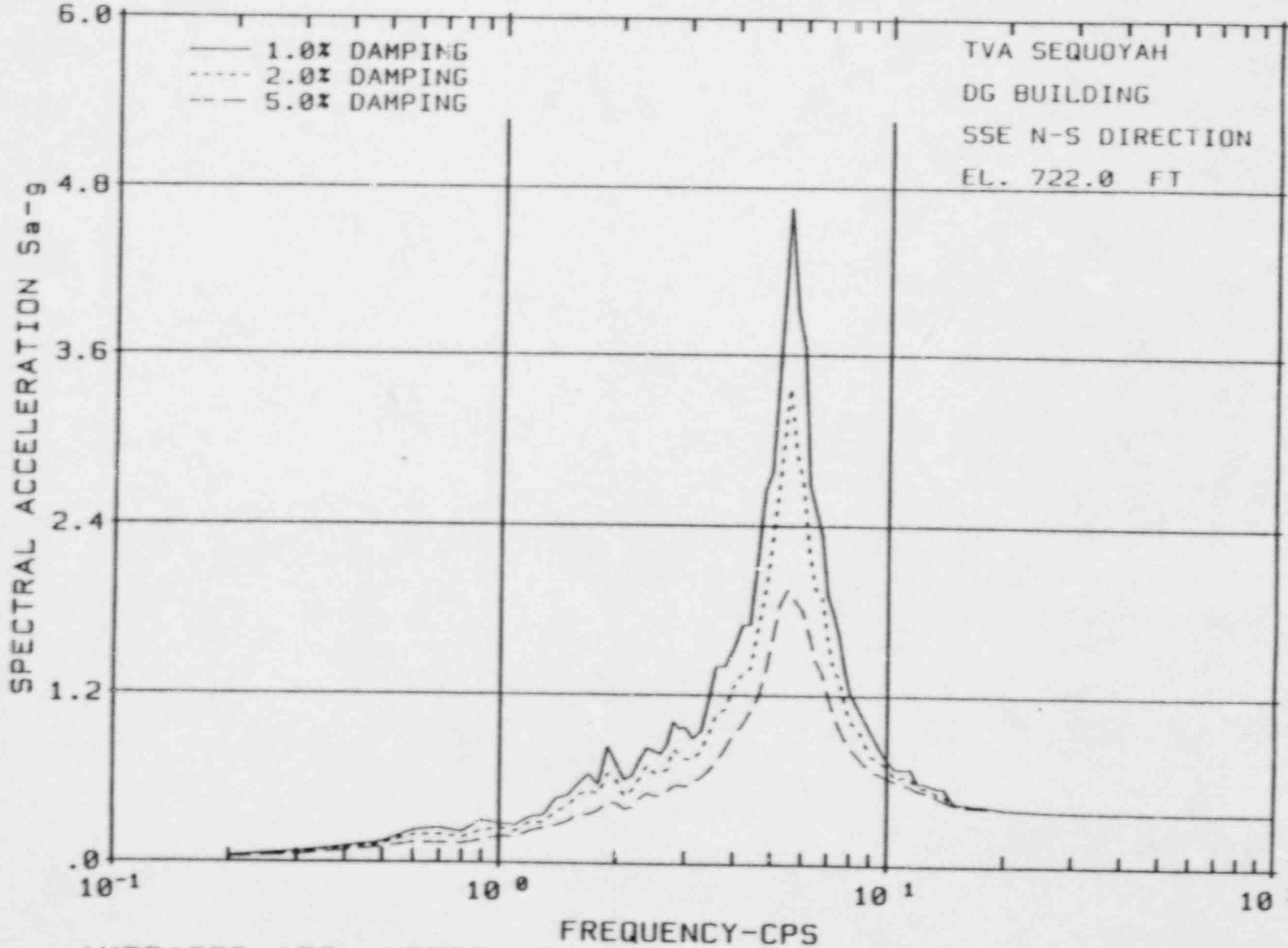
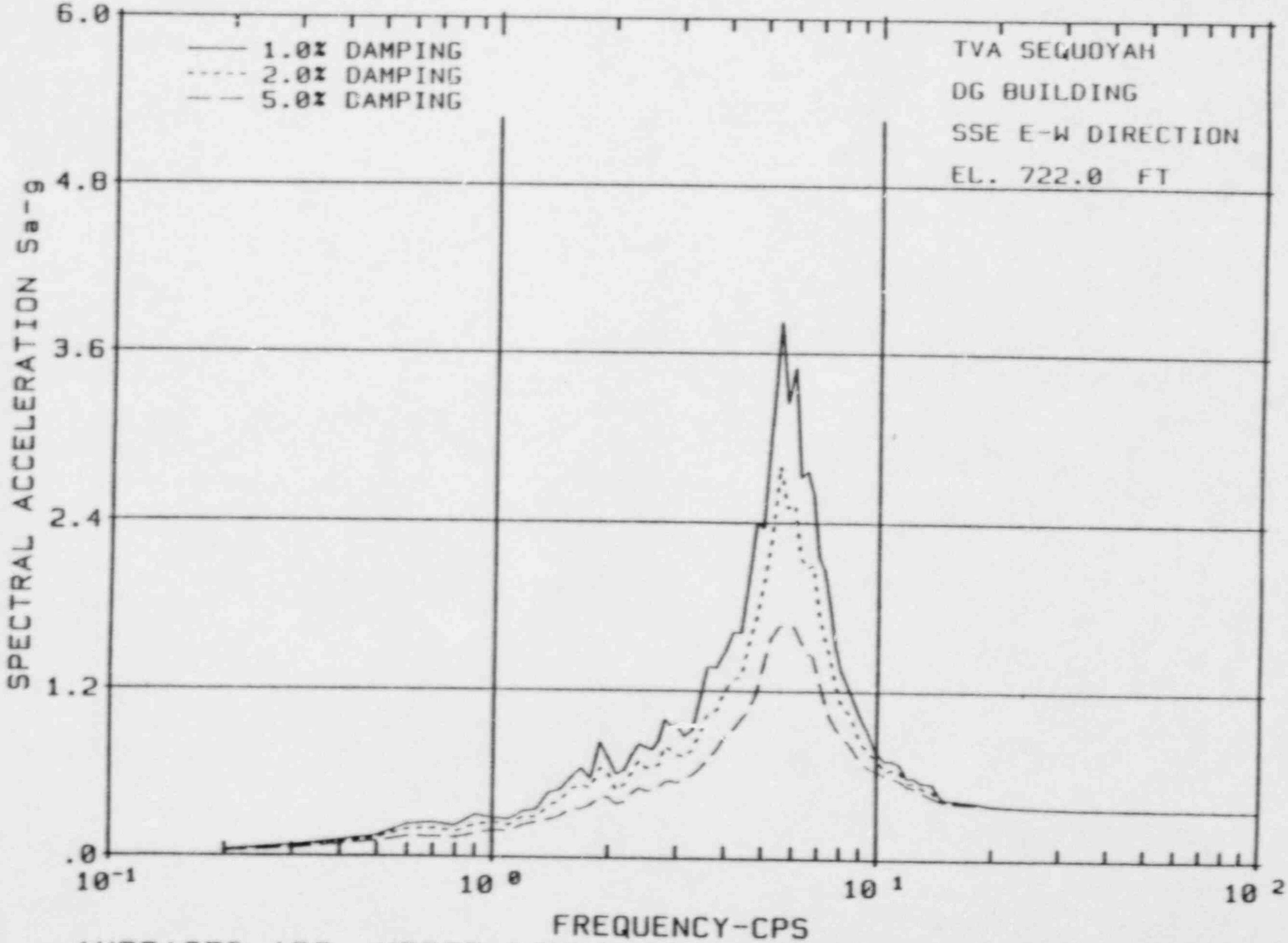

6.0
4.8
3.6
2.4
1.2
.0
SPECTRAL ACCELERATION Sa-g
1.0% DAMPING
2.0% DAMPING
5.0% DAMPING
TVA SEQUOYAH
DG BUILDING
SSE VERT DIRECTION
EL. 739.75 FT
10^{-1}
10^{0}
10^{1}
10^{2}
FREQUENCY-CPS
AVERAGED ARS UPPER-BOUND SOIL STRAIN-DEP. OUTCROP INPUT

Figure A-42



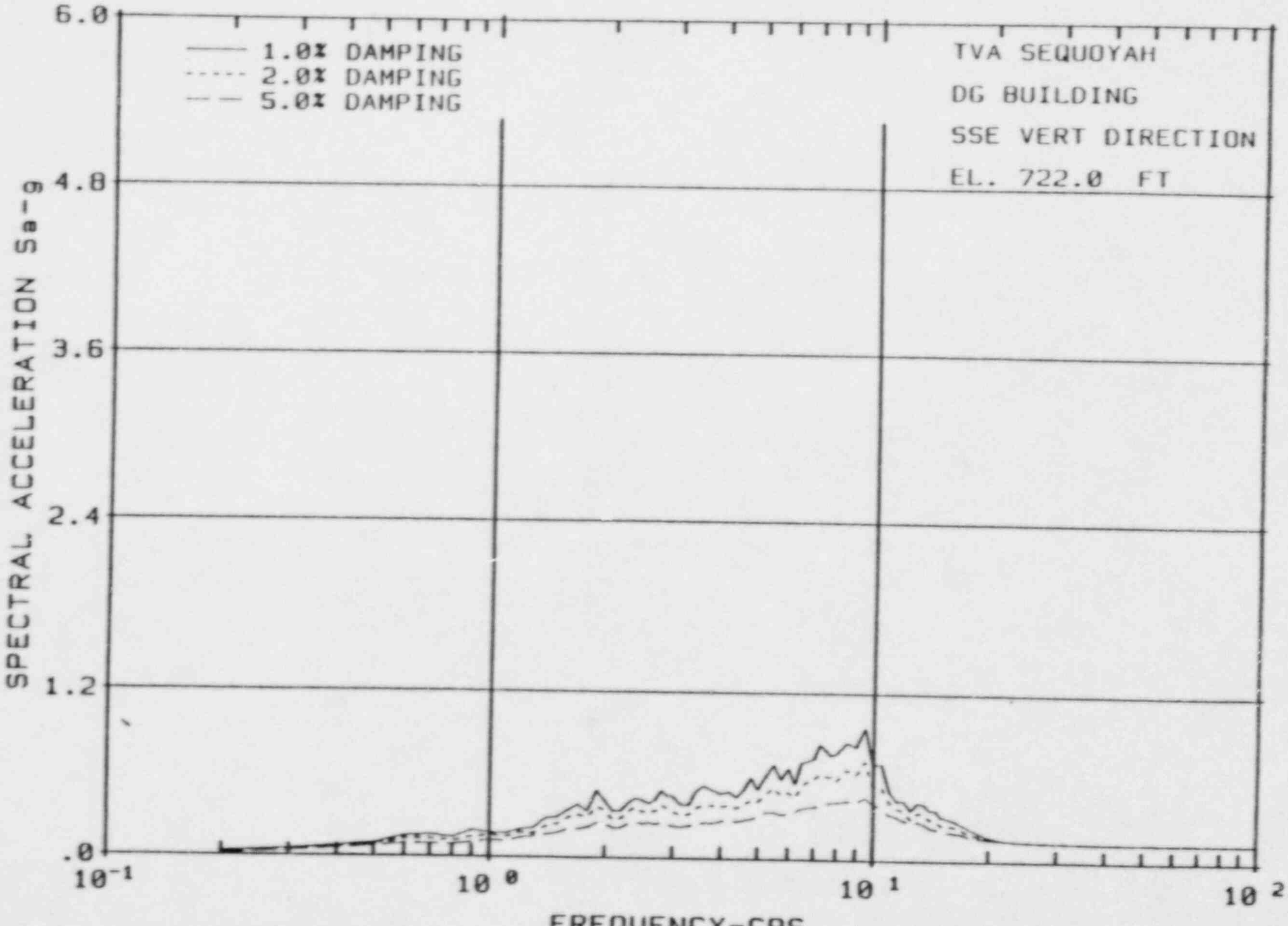
AVERAGED ARS UPPER-BOUND SOIL STRAIN-DEP. OUTCROP INPUT

Figure A-43



AVERAGED ARS UPPER-BOUND SOIL STRAIN-DEP. OUTCROP INPUT

Figure A-44



AVERAGED ARS UPPER-BOUND SOIL STRAIN-DEP. OUTCROP INPUT

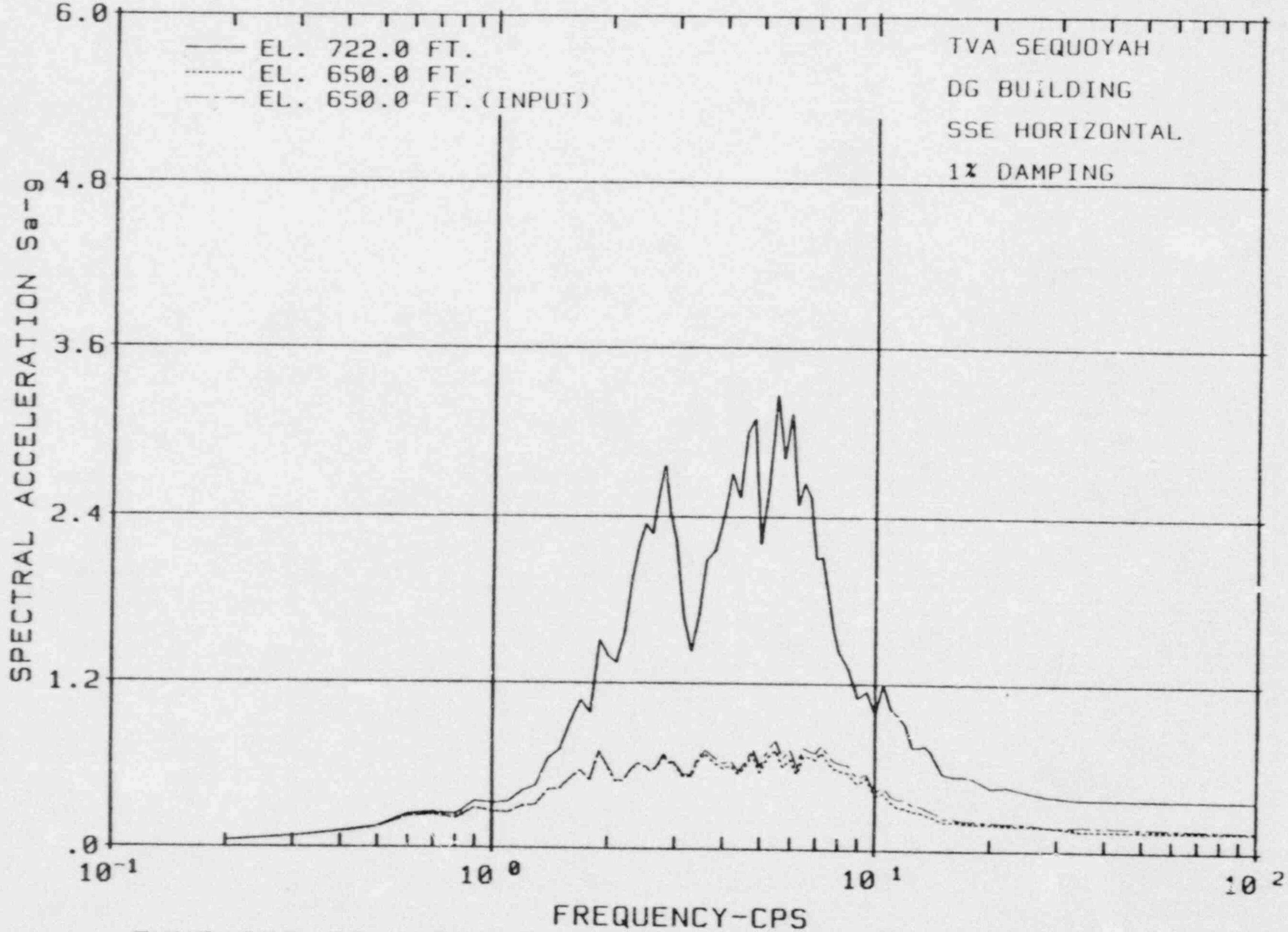
Figure A-45

Appendix B

Final Envelopes of Average [illegible]ots for Enveloping the Results of Th[illegible]il Cases

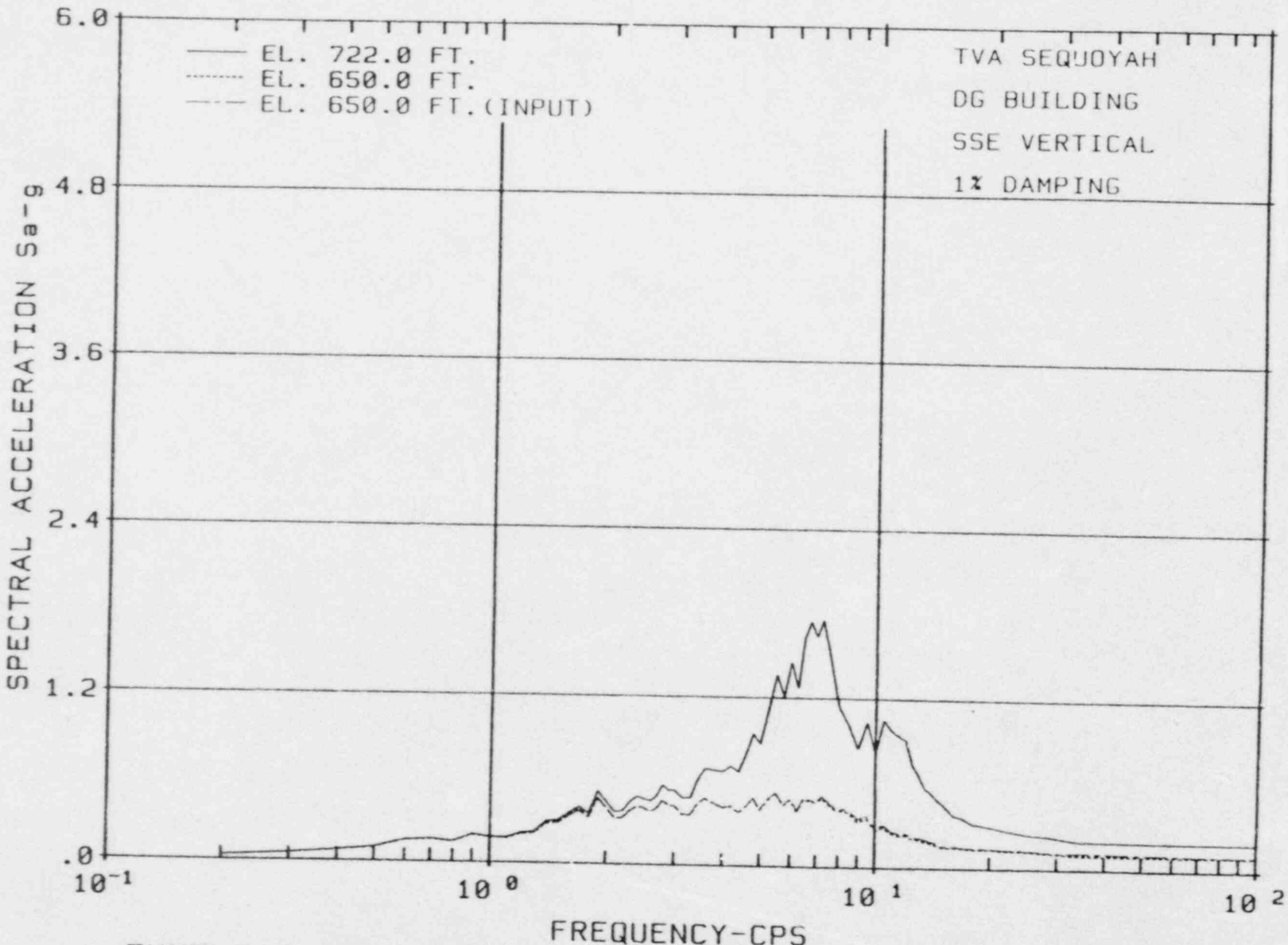
Figure Numbers for the Selected SQN-DG Building Response Locations for the Final Envelope of Average ARS for SSE Enveloping Results of All Soil Cases

Locations		1% Damping	2% Damping	5% Damping
Free-Field Soil				
Surface	H	B-1	B-3	B-5
(El. 722.0')	V	B-2	B-4	B-6
Soil-Rock	H	B-1	B-3	B-5
Interface	V	B-2	B-4	B-6
(El. 650.0')				
Rock Outcrop	H	B-1	B-3	B-5
(El. 650.0')	V	B-2	B-4	B-6
DG Building				
Roof	NS	B-7	B-7	B-7
(El. 753.5')	EW	B-8	B-8	B-8
	V	B-9	B-9	B-9
Second Floor	NS	B-10	B-10	B-10
(El. 739.75')	EW	B-11	B-11	B-11
	V	B-12	B-12	B-12
Top of	NS	B-13	B-13	B-13
Base Slab	EW	B-14	B-14	B-14
(El. 722.0')	V	B-15	B-15	B-15



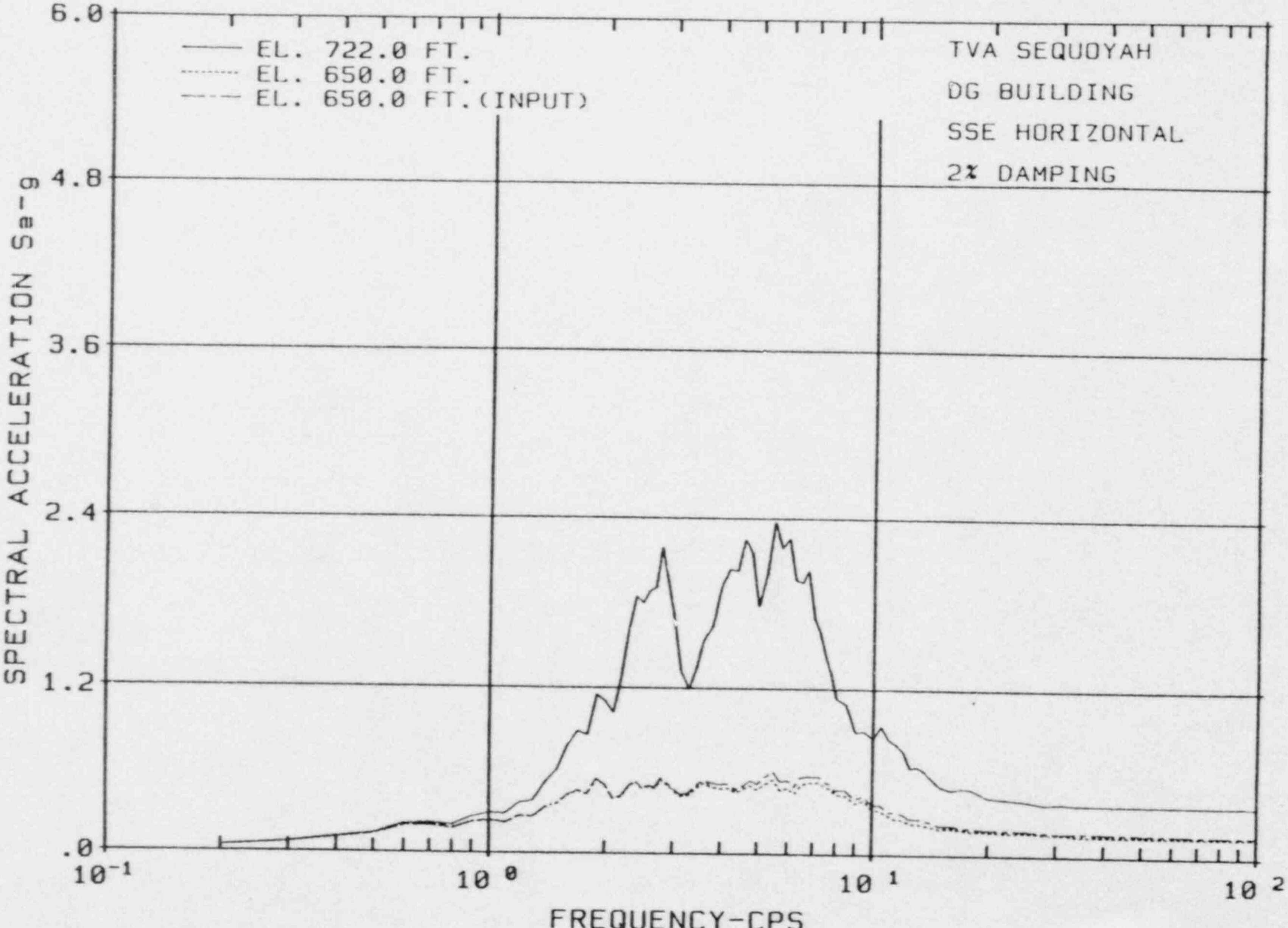
ENVELOPE OF AVERAGED ARS STRAIN-DEP. OUTCROP INPUT

Figure B-1



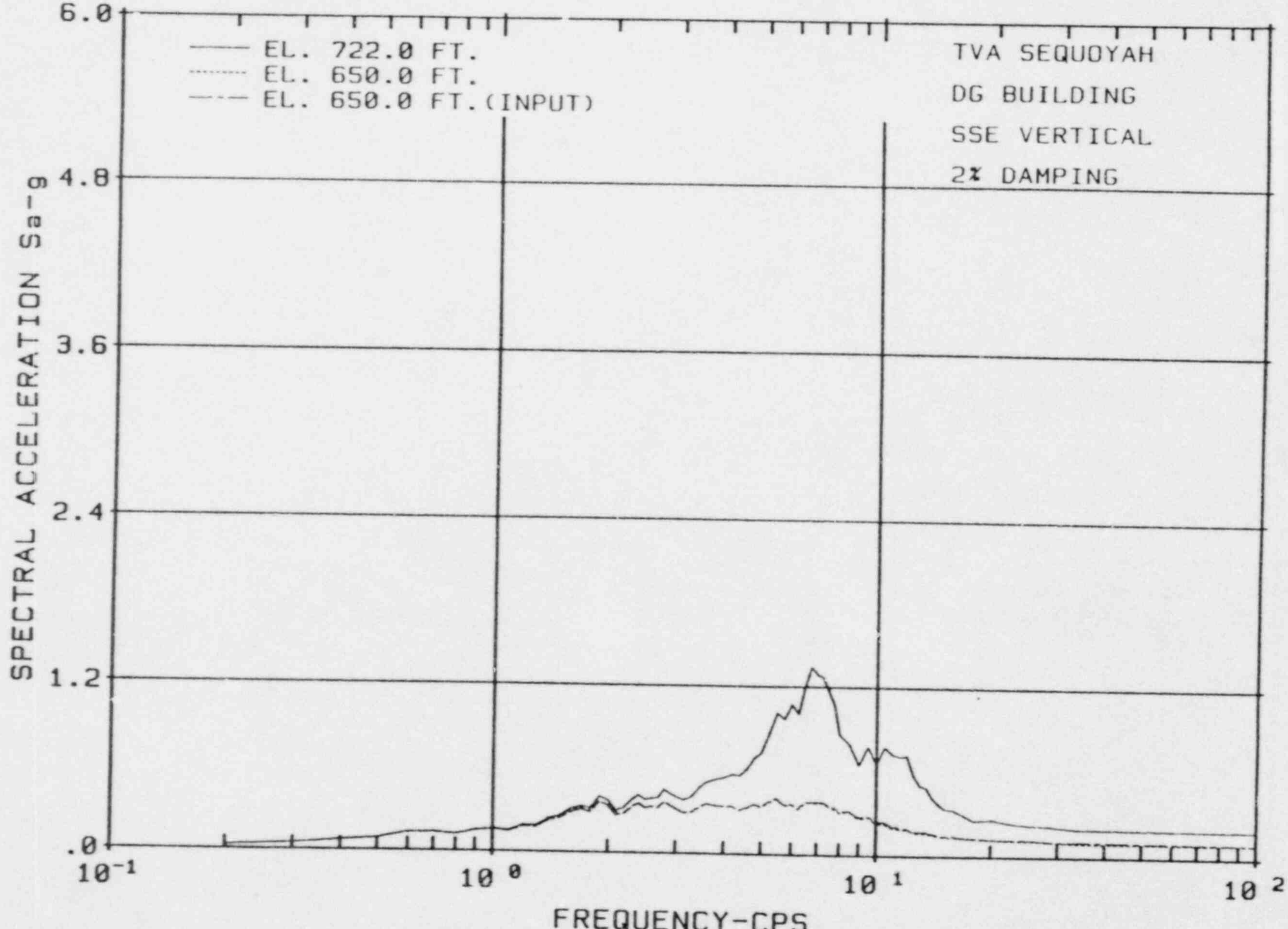
ENVELOPE OF AVERAGED ARS STRAIN-DEP. OUTCROP INPUT

Figure B-2



ENVELOPE OF AVERAGED ARS STRAIN-DEP. OUTCROP INPUT

Figure B-3



ENVELOPE OF AVERAGED ARS STRAIN-DEP. OUTCROP INPUT

Figure B-4

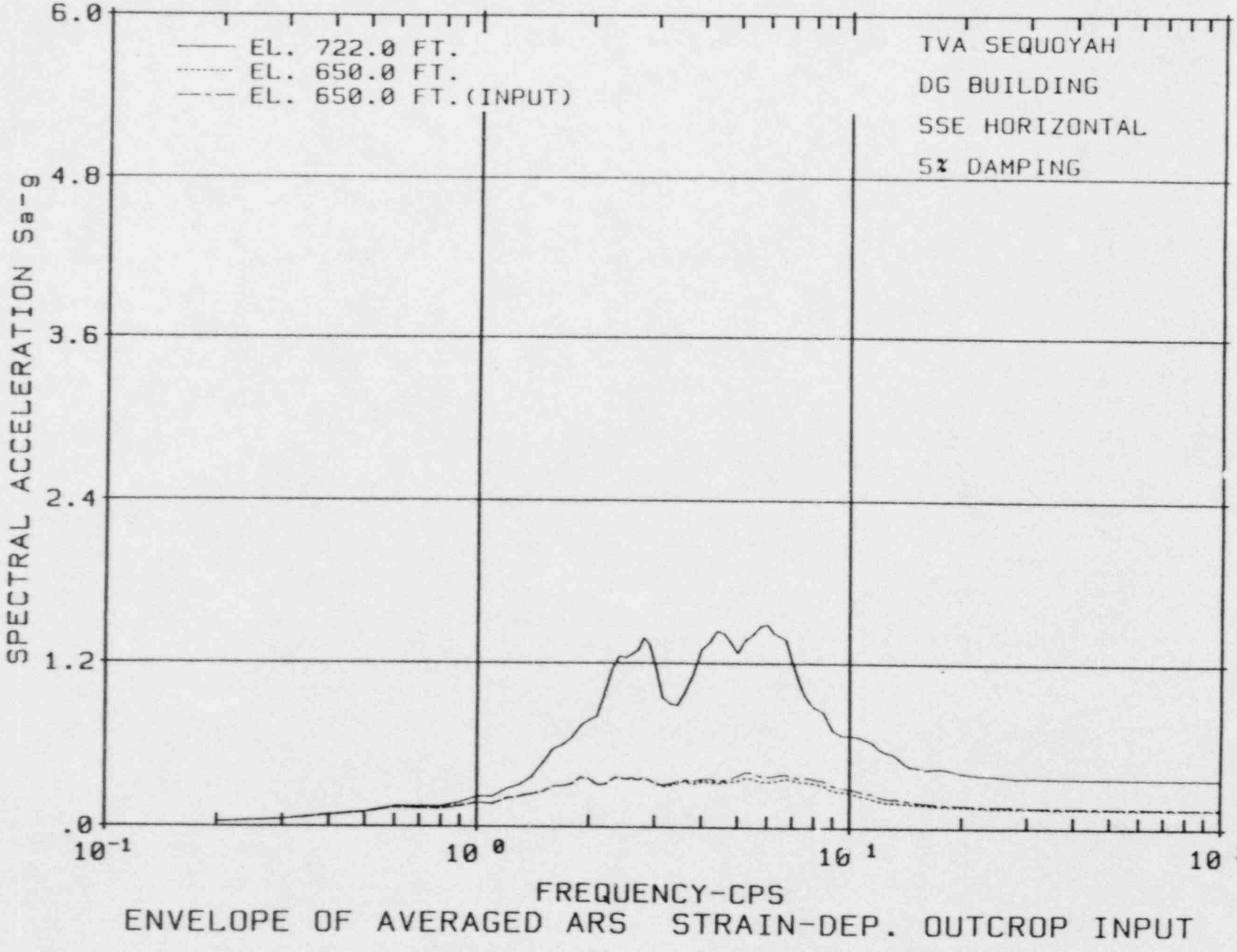
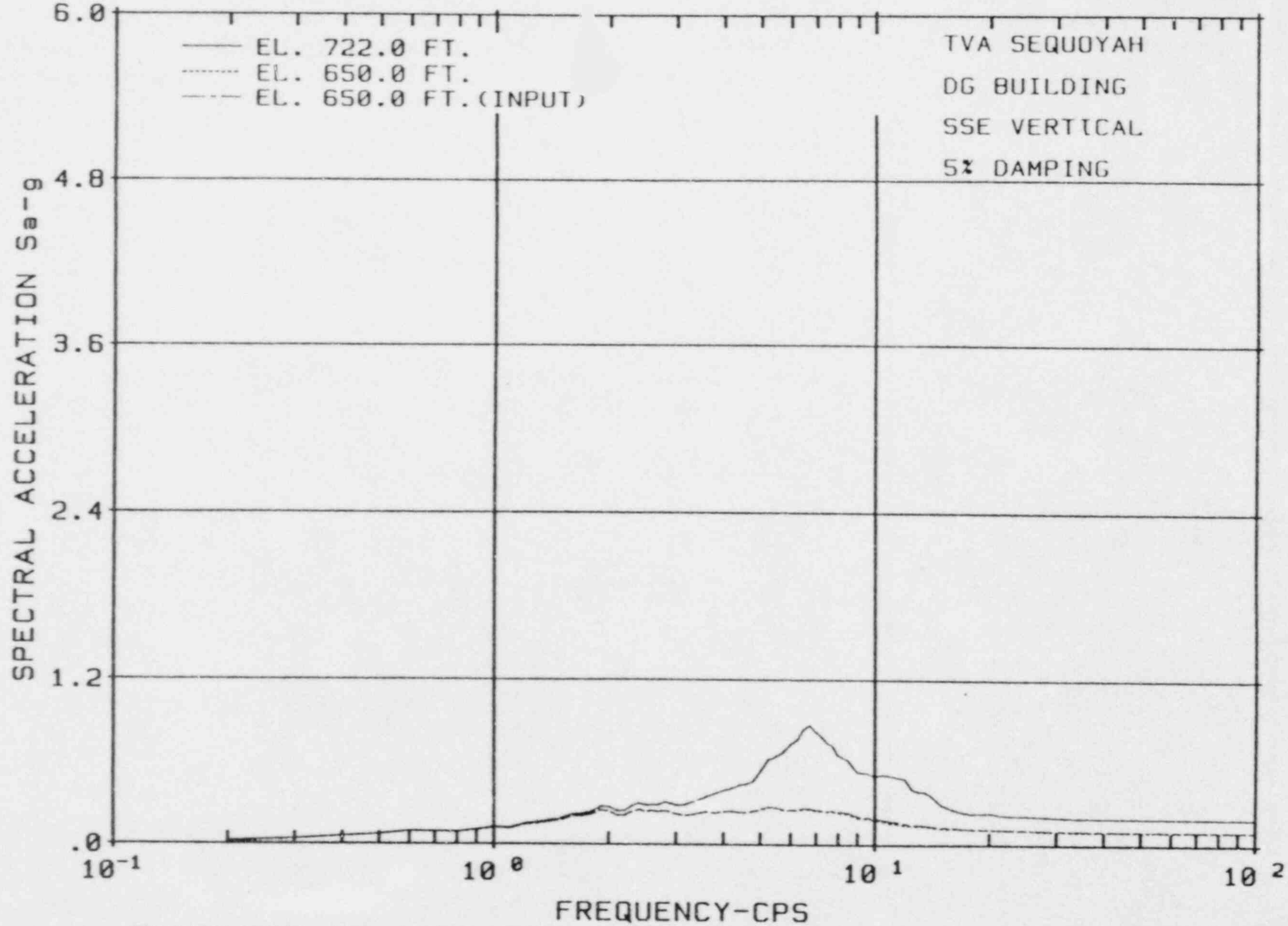
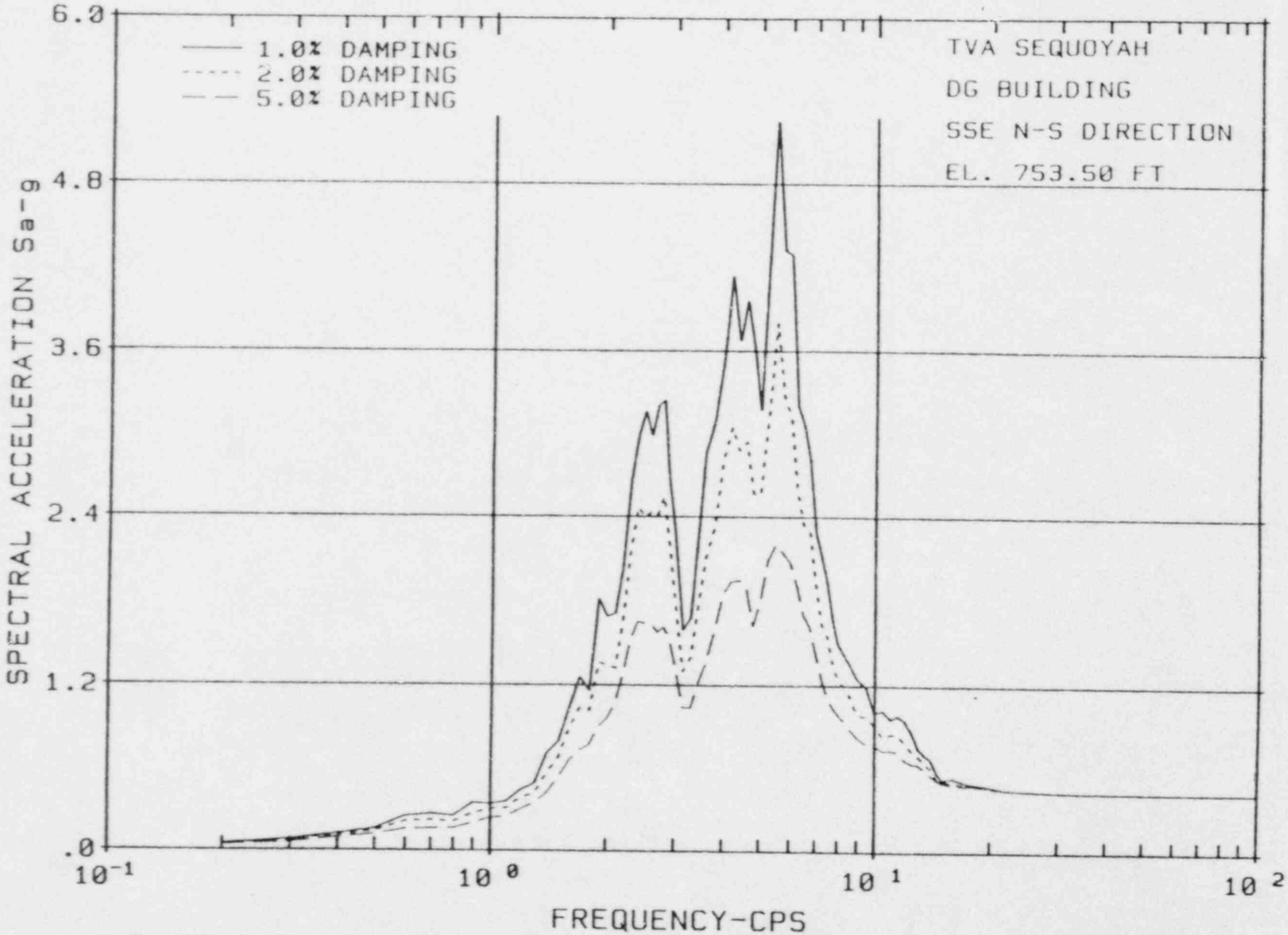

6.0
4.8
3.6
2.4
1.2
.0
SPECTRAL ACCELERATION Sa-g
EL. 722.0 FT.
EL. 650.0 FT.
EL. 650.0 FT.(INPUT)
TVA SEQUOYAH
DG BUILDING
SSE HORIZONTAL
5% DAMPING
10⁻¹
10⁰
10¹
10²
FREQUENCY-CPS
ENVELOPE OF AVERAGED ARS STRAIN-DEP. OUTCROP INPUT

Figure B-5



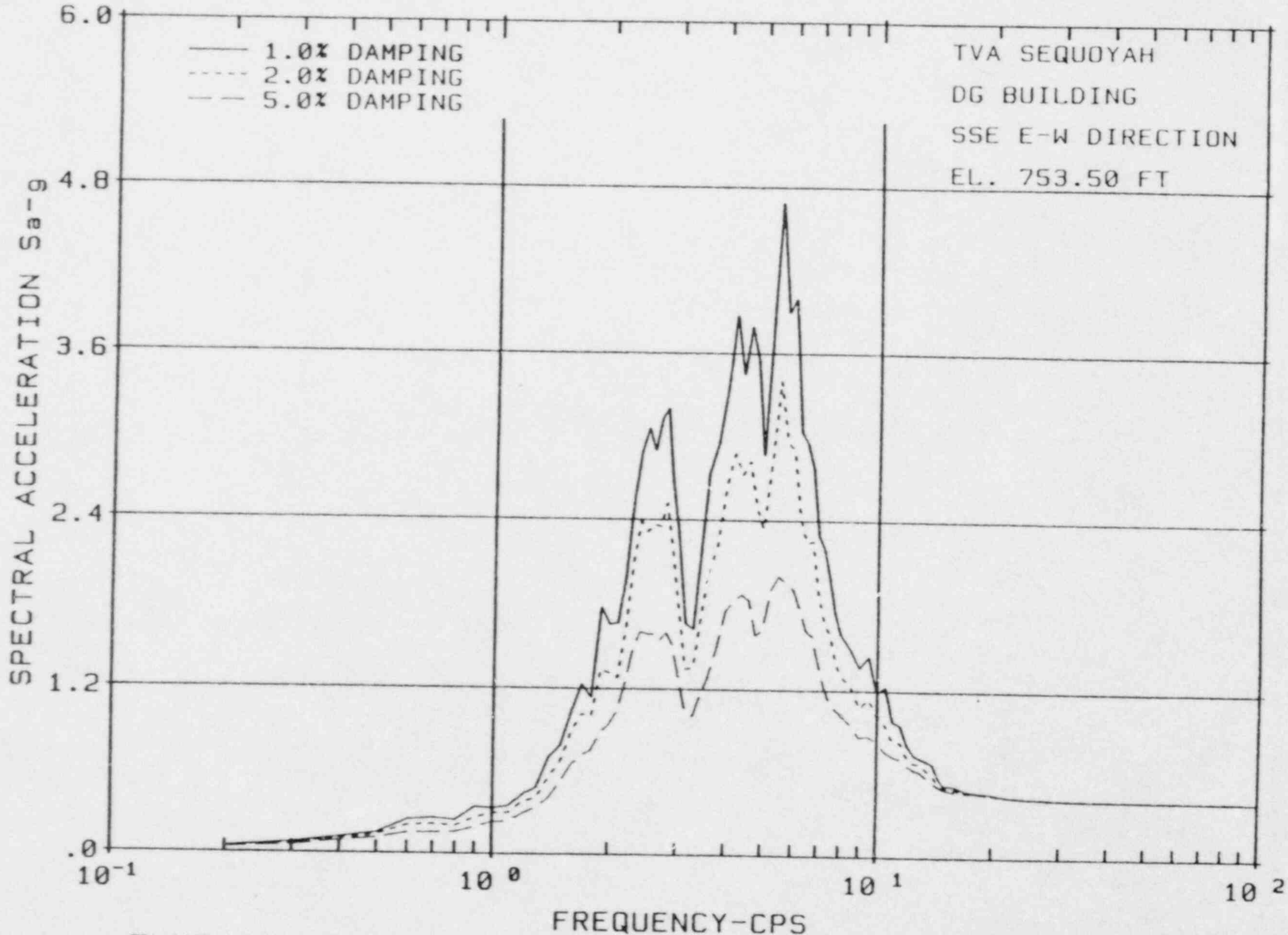
ENVELOPE OF AVERAGED ARS STRAIN-DEP. OUTCROP INPUT

Figure B-6



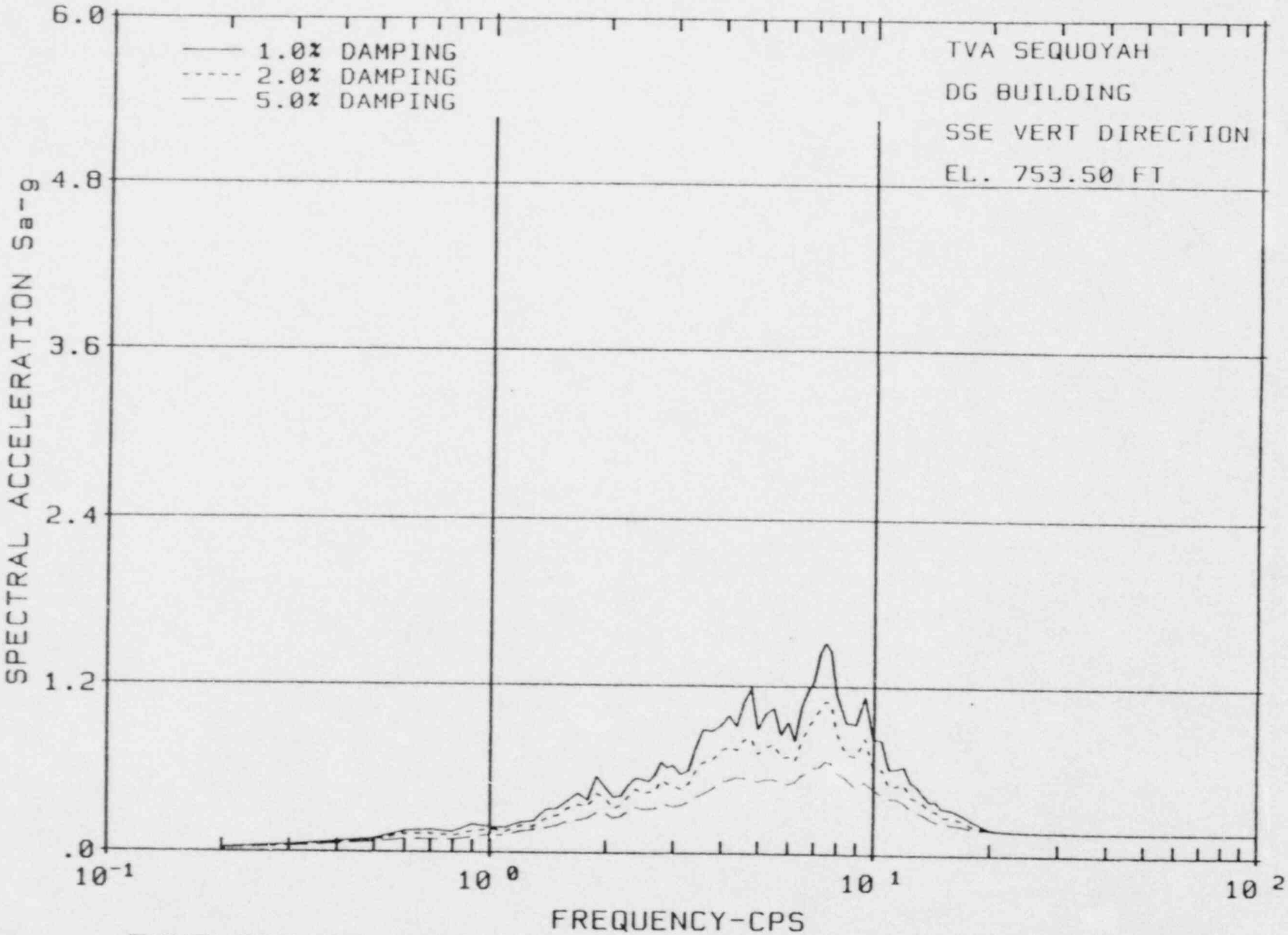
ENVELOPE OF AVERAGED ARS STRAIN-DEP. OUTCROP INPUT

Figure B-7



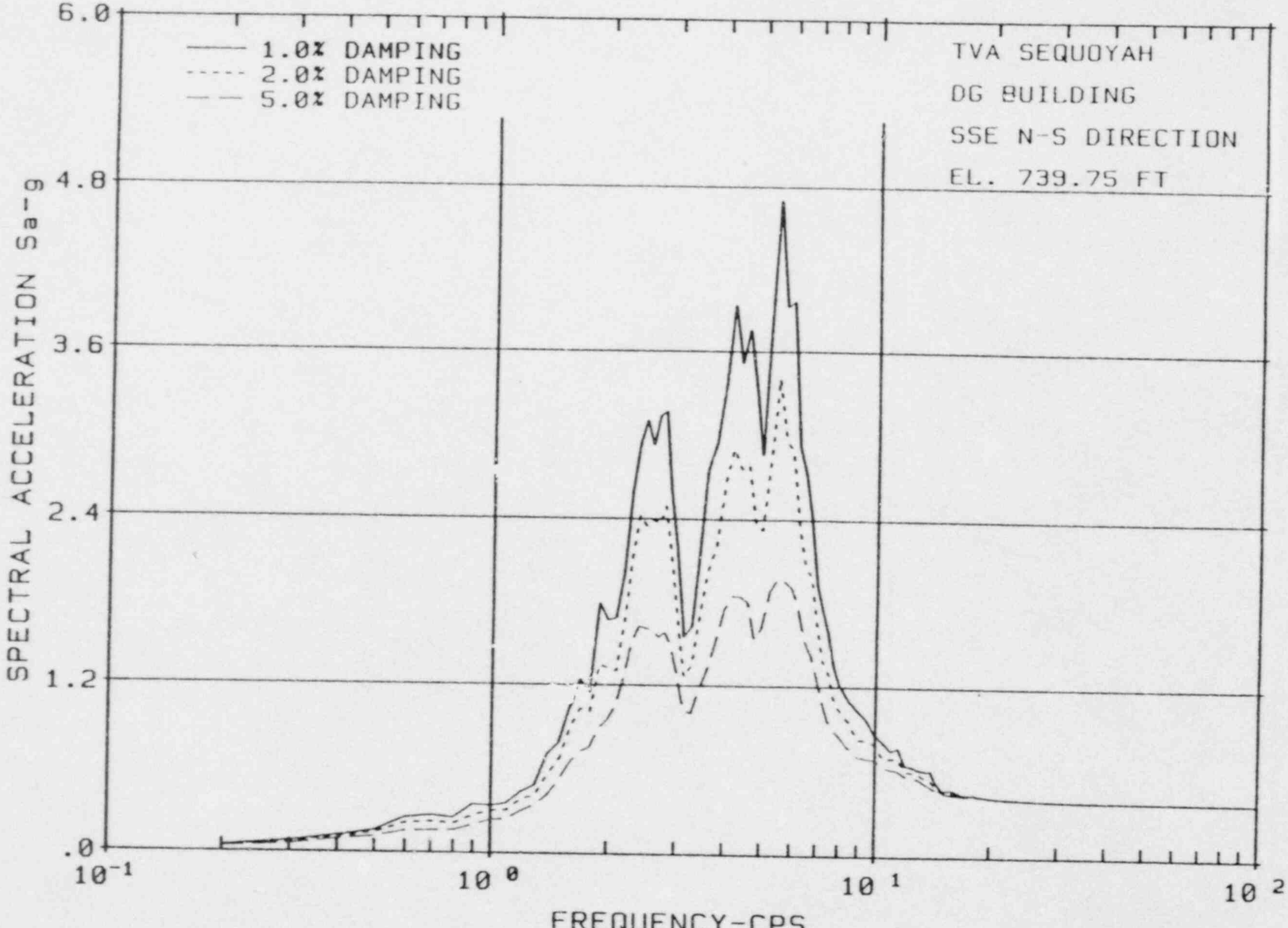
ENVELOPE OF AVERAGED ARS STRAIN-DEP. OUTCROP INPUT

Figure B-8



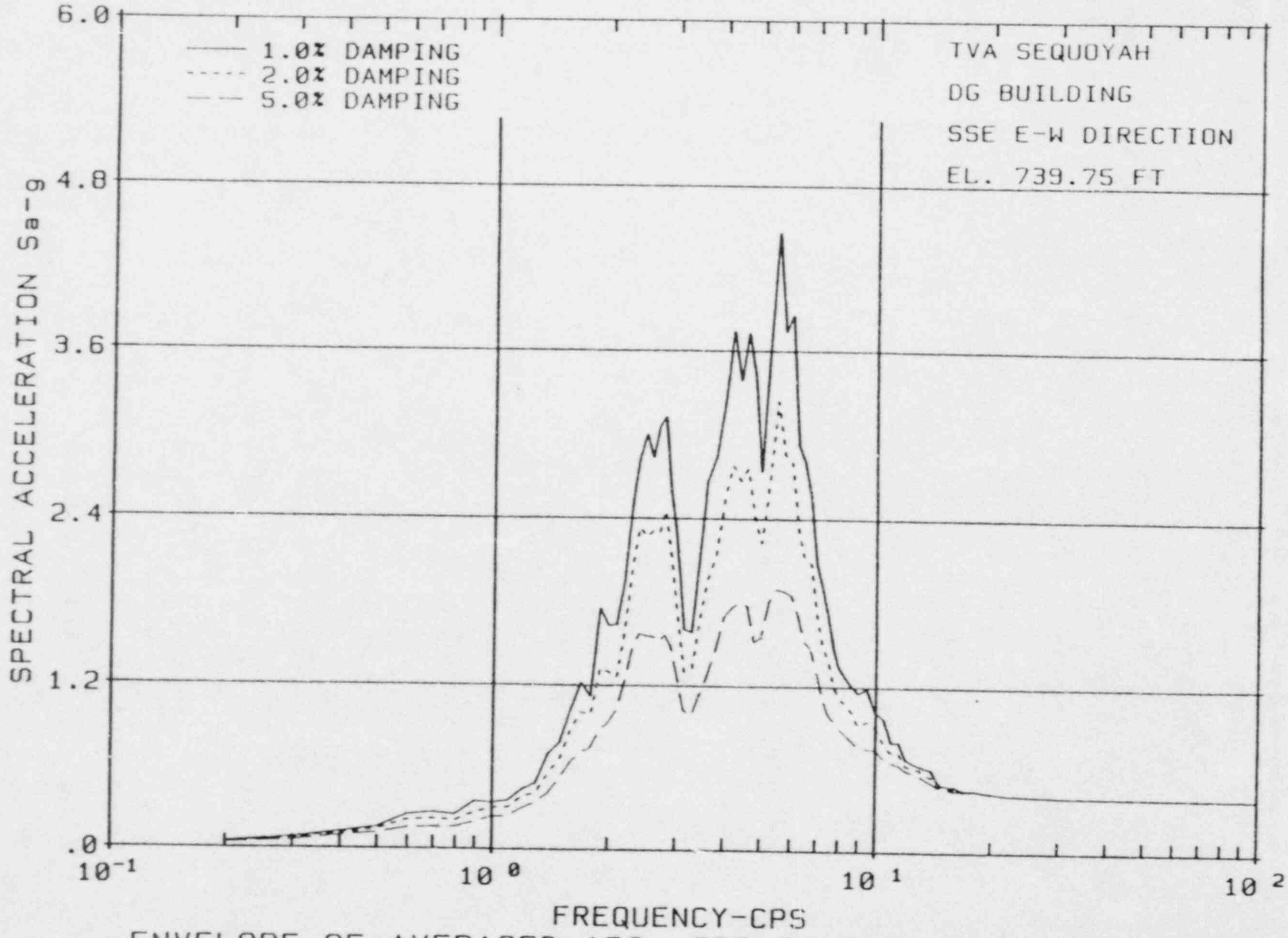
ENVELOPE OF AVERAGED ARS STRAIN-DEP. OUTCROP INPUT

Figure B-9



ENVELOPE OF AVERAGED ARS STRAIN-DEP. OUTCROP INPUT

Figure B-10



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SPECTRAL ACCELERATION Sa-g
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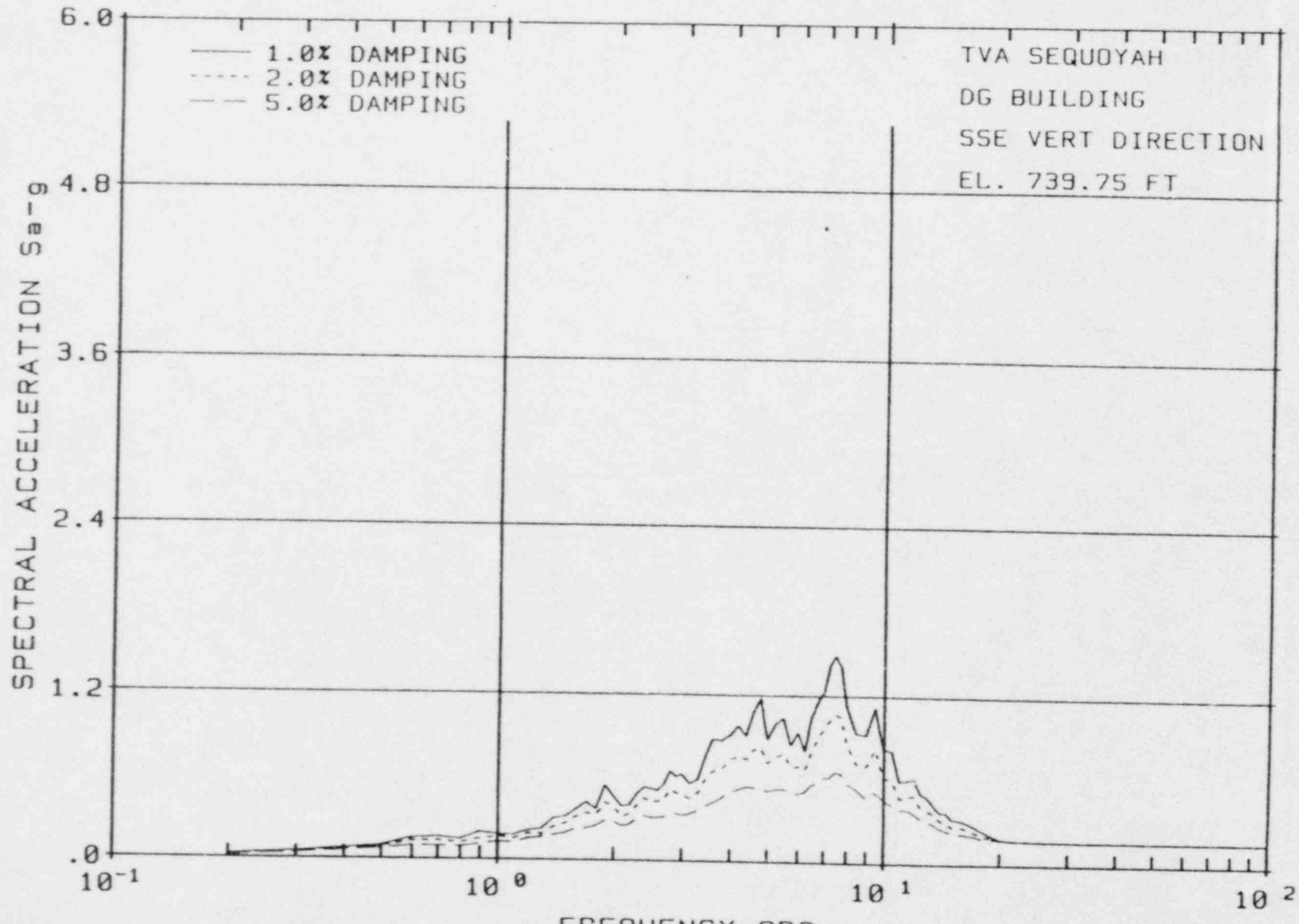
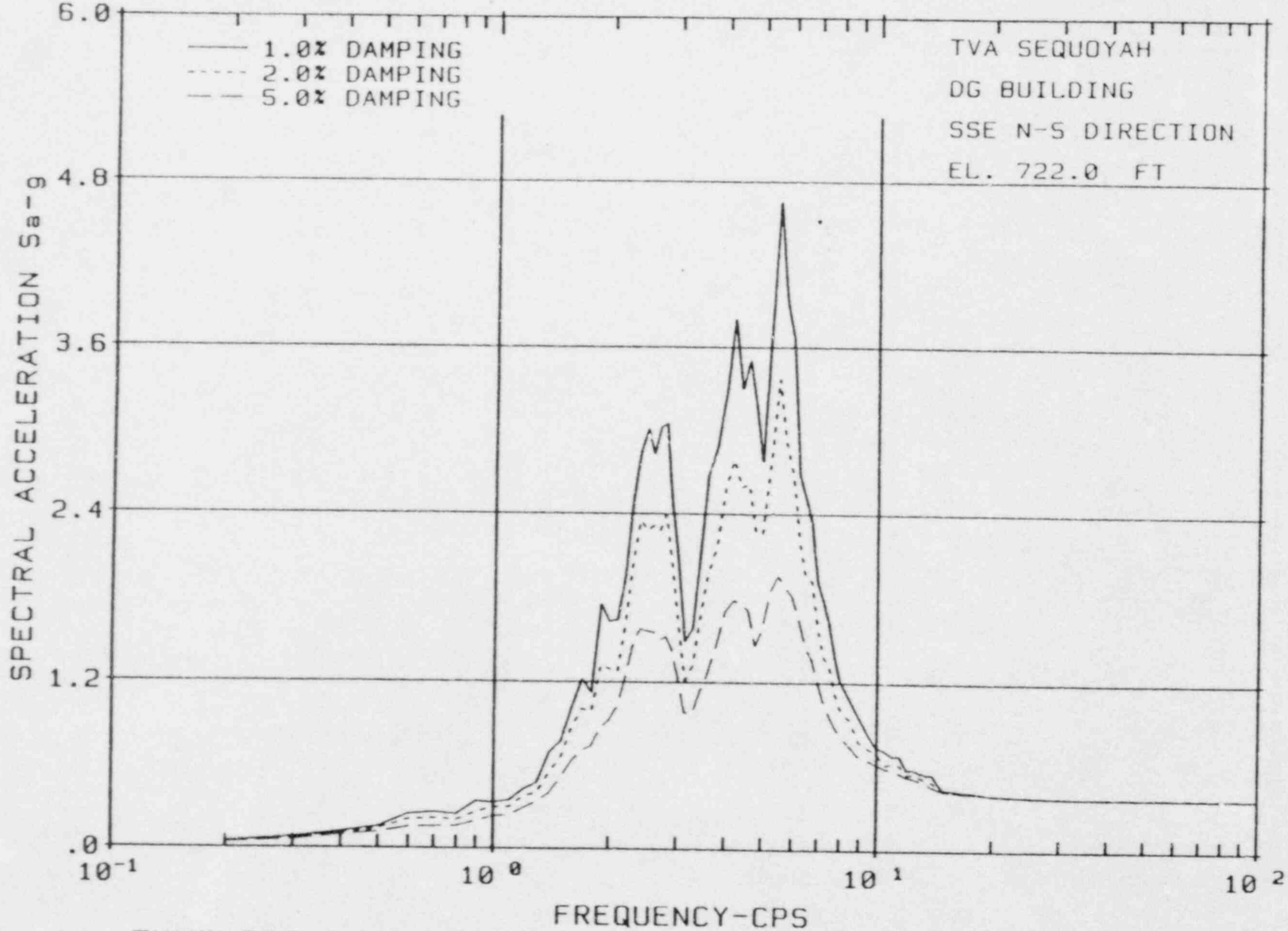
FREQUENCY-CPS
ENVELOPE OF AVERAGED ARS STRAIN-DEP. OUTCROP INPUT

Figure B-11



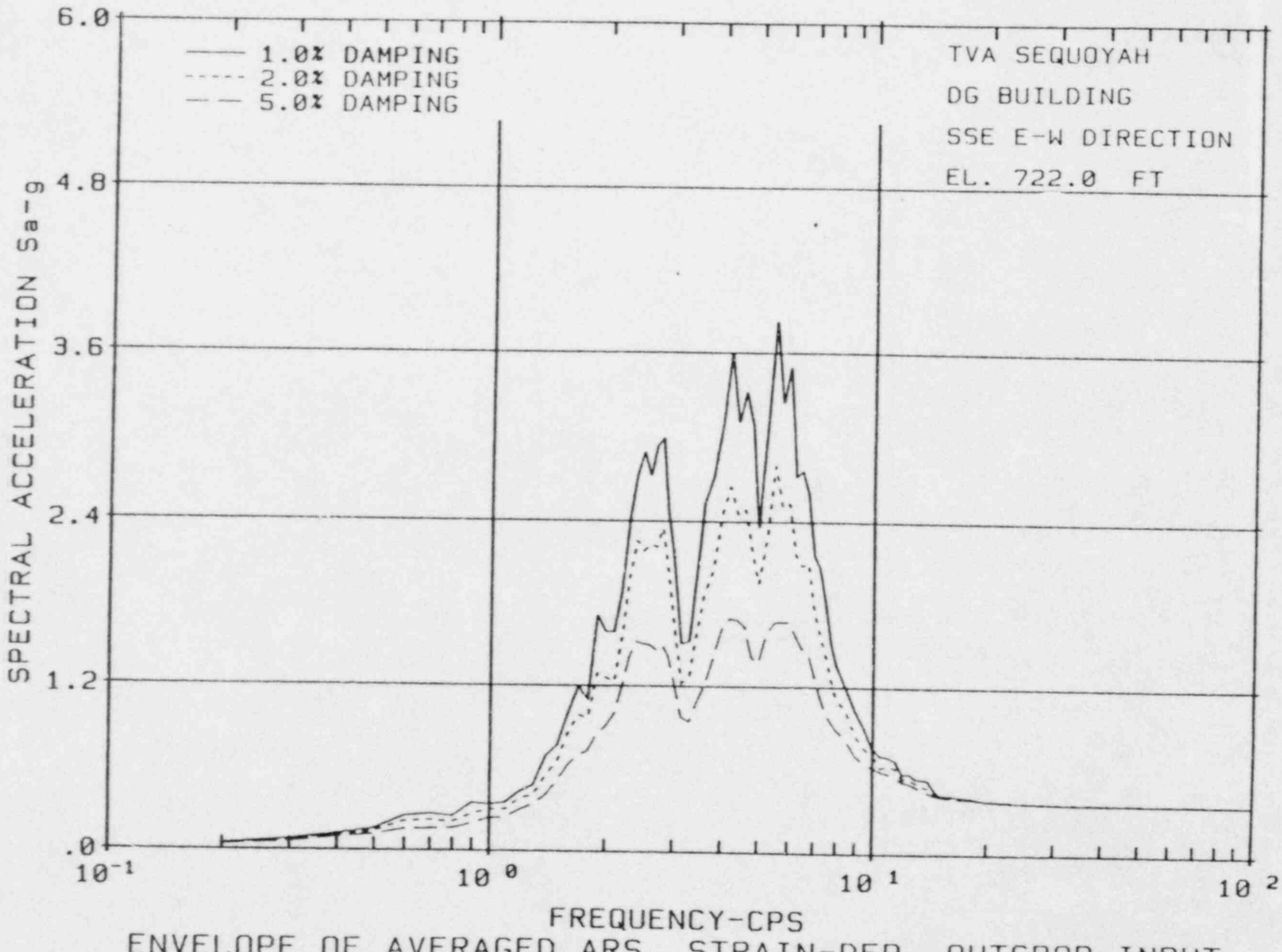
ENVELOPE OF AVERAGED ARS STRAIN-DEP. OUTCROP INPUT

Figure B-12



ENVELOPE OF AVERAGED ARS STRAIN-DEP. OUTCROP INPUT

Figure B-13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SPECTRAL ACCELERATION Sa-g
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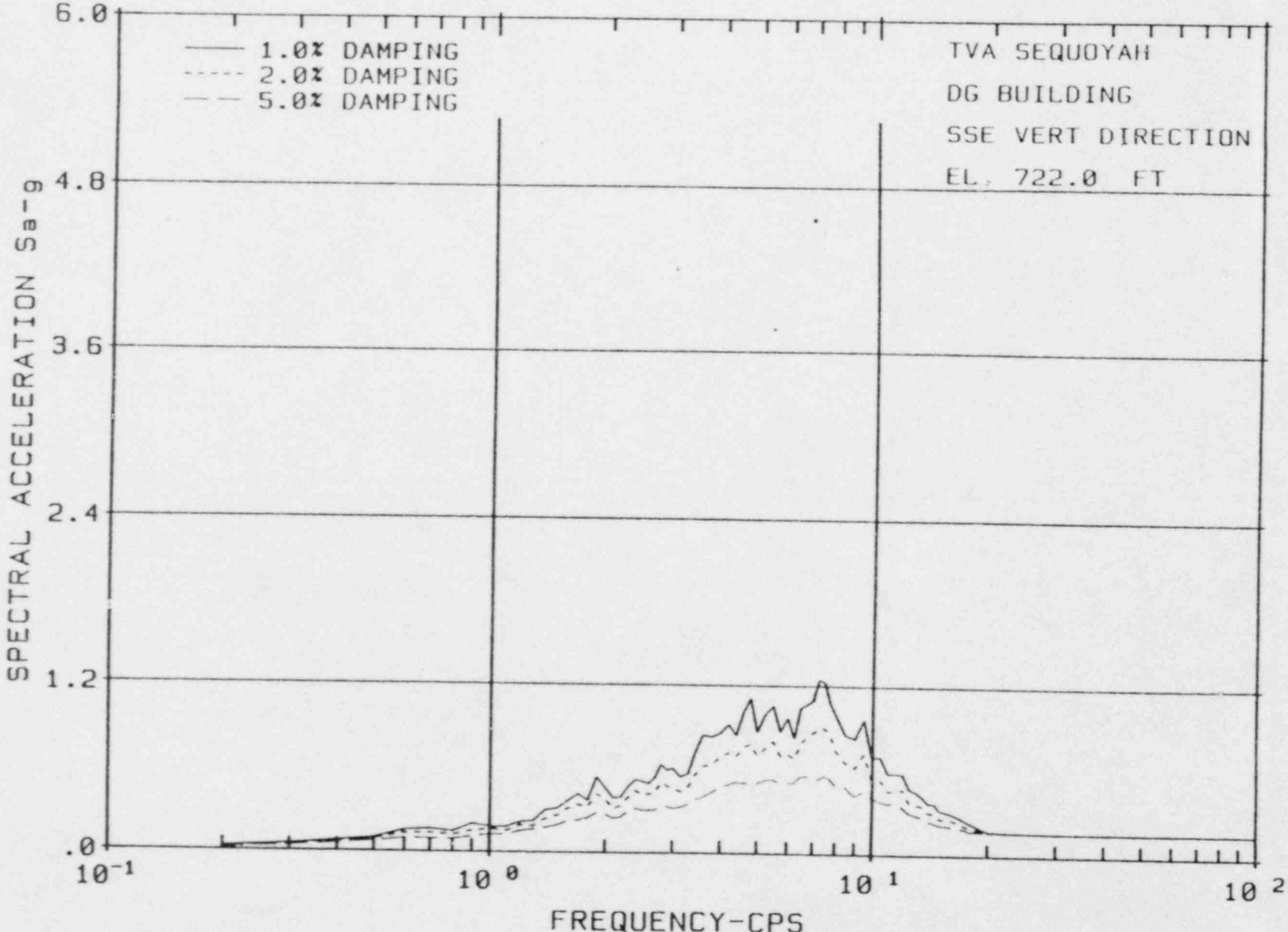
FREQUENCY-CPS
ENVELOPE OF AVERAGED ARS STRAIN-DEP. OUTCROP INPUT

Figure B-14

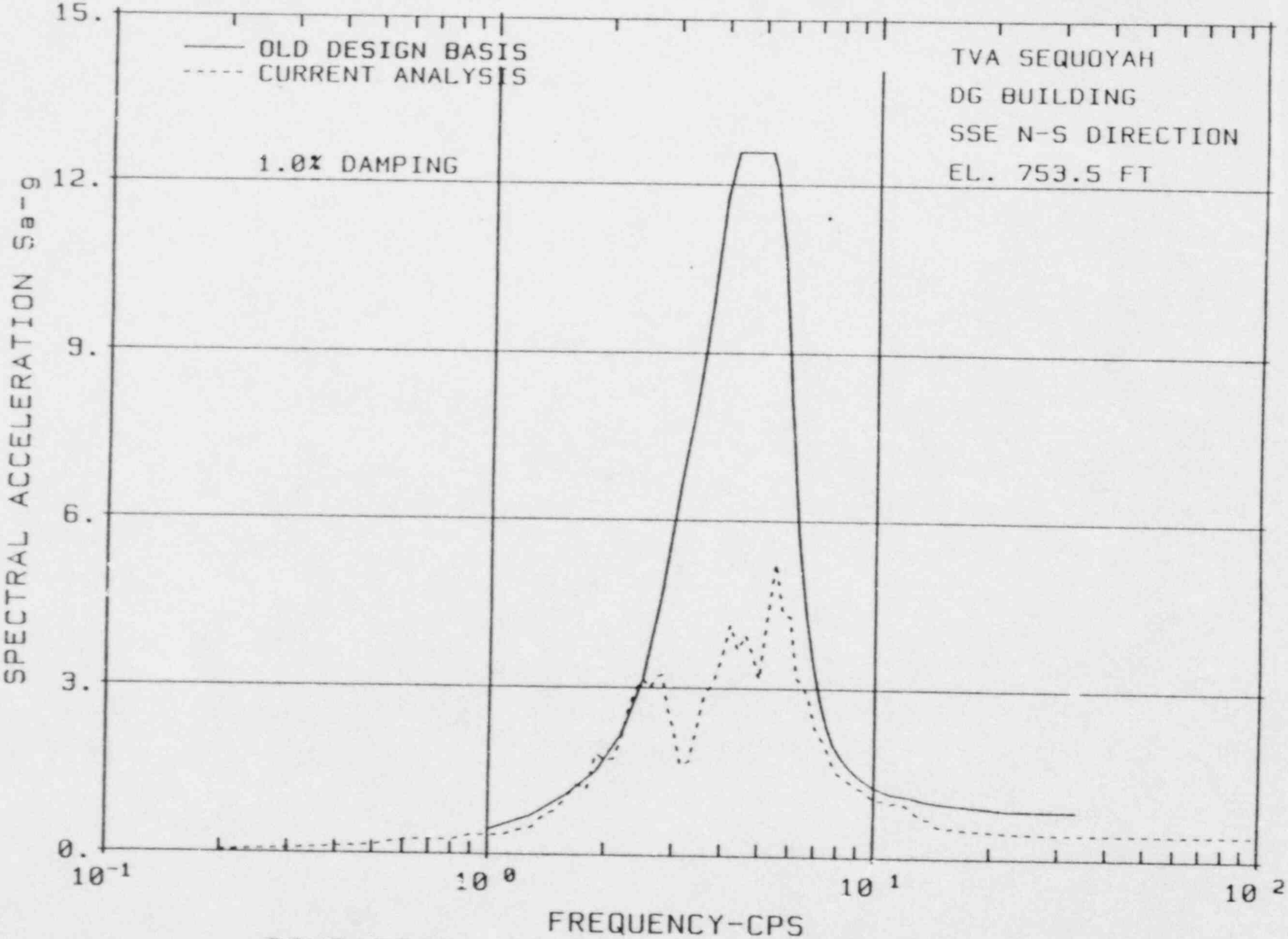


ENVELOPE OF AVERAGED ARS STRAIN-DEP. OUTCROP INPUT

Figure B-15

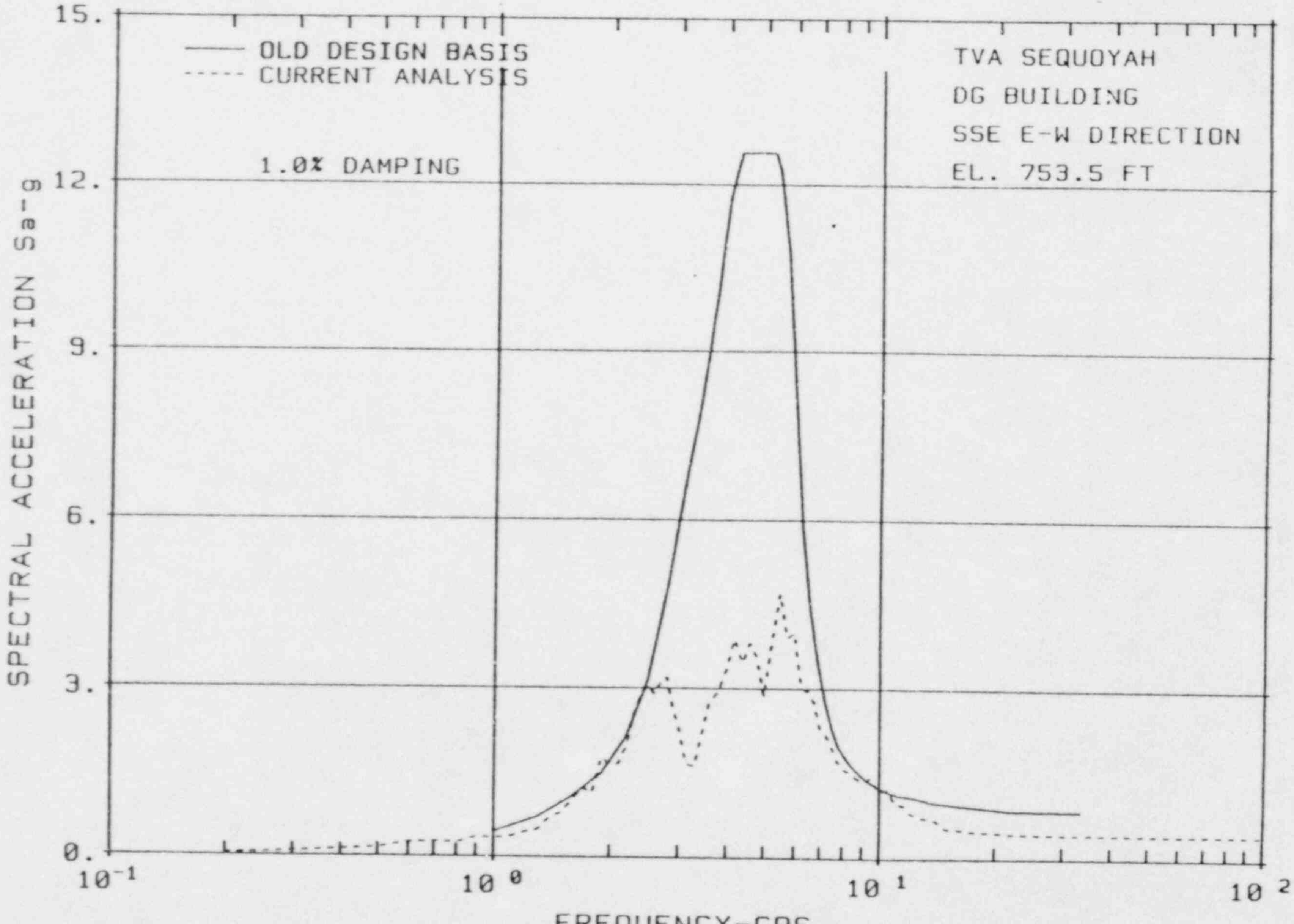
Appendix C

Comparisons of ARS Envelopes of the Current Analysis with the Original Design Basis ARS



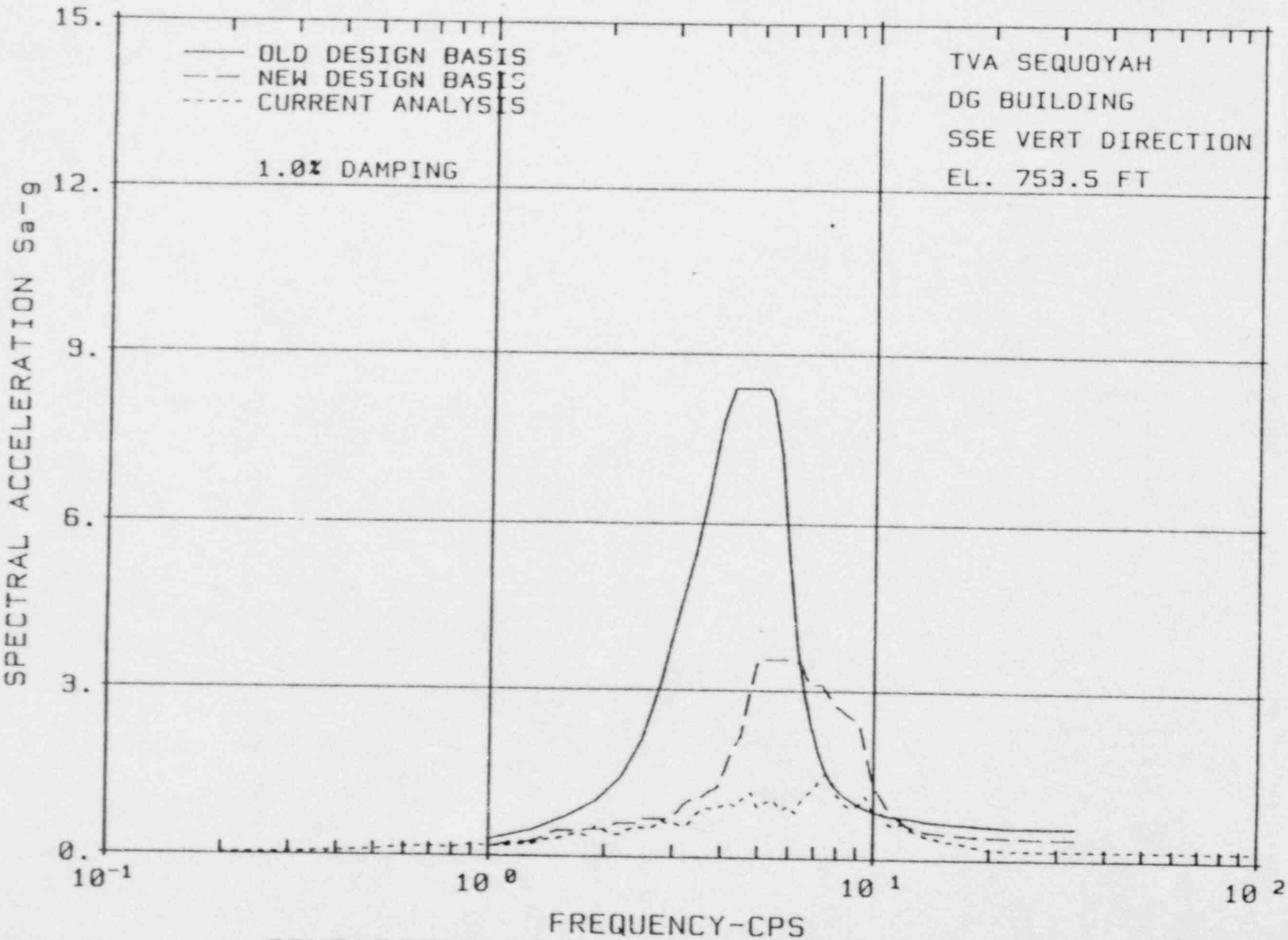
COMPARISON OF ENVELOPE OF AVERAGED ARS

Figure C-1



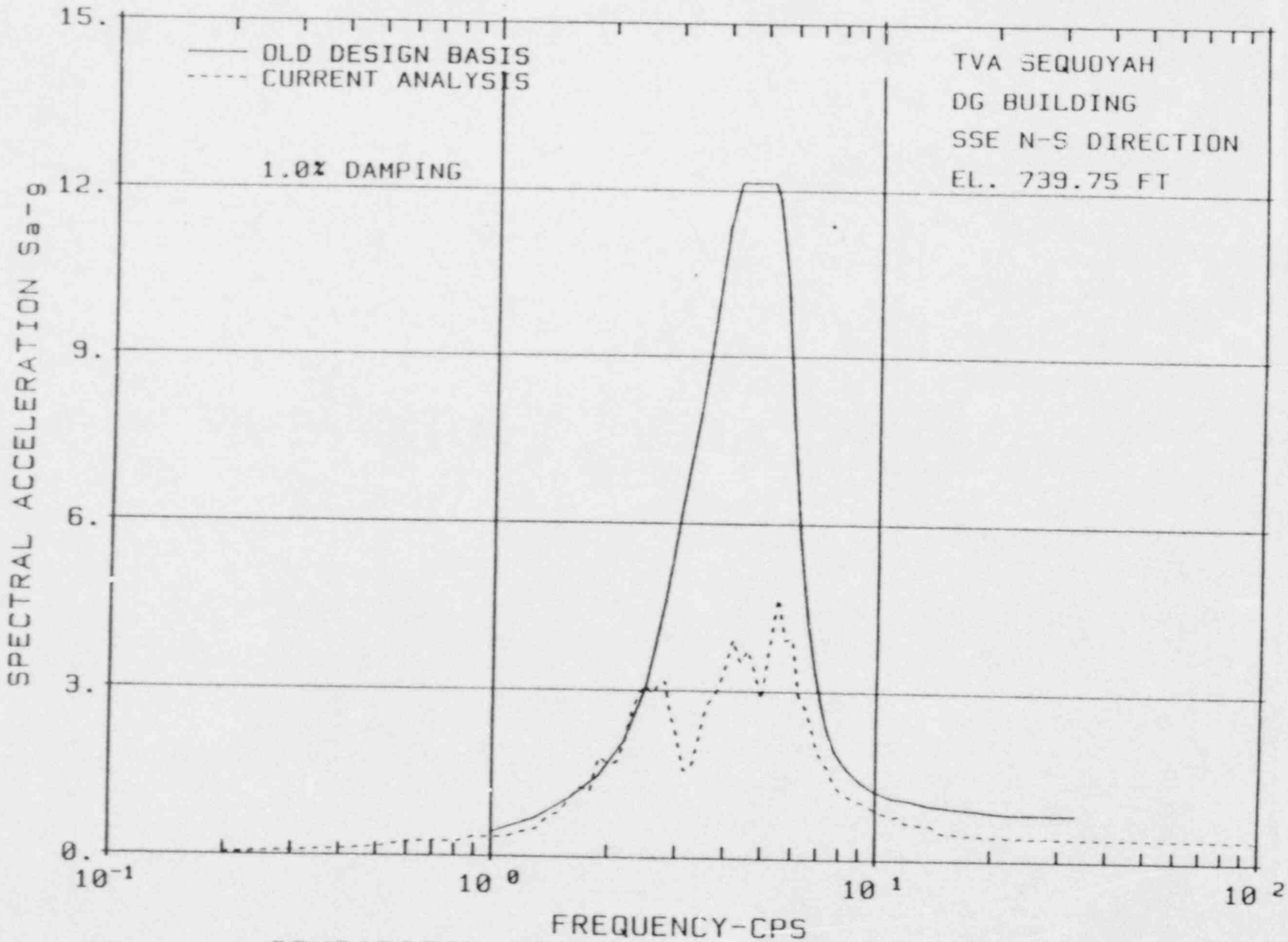
COMPARISON OF ENVELOPE OF AVERAGED ARS

Figure C-2



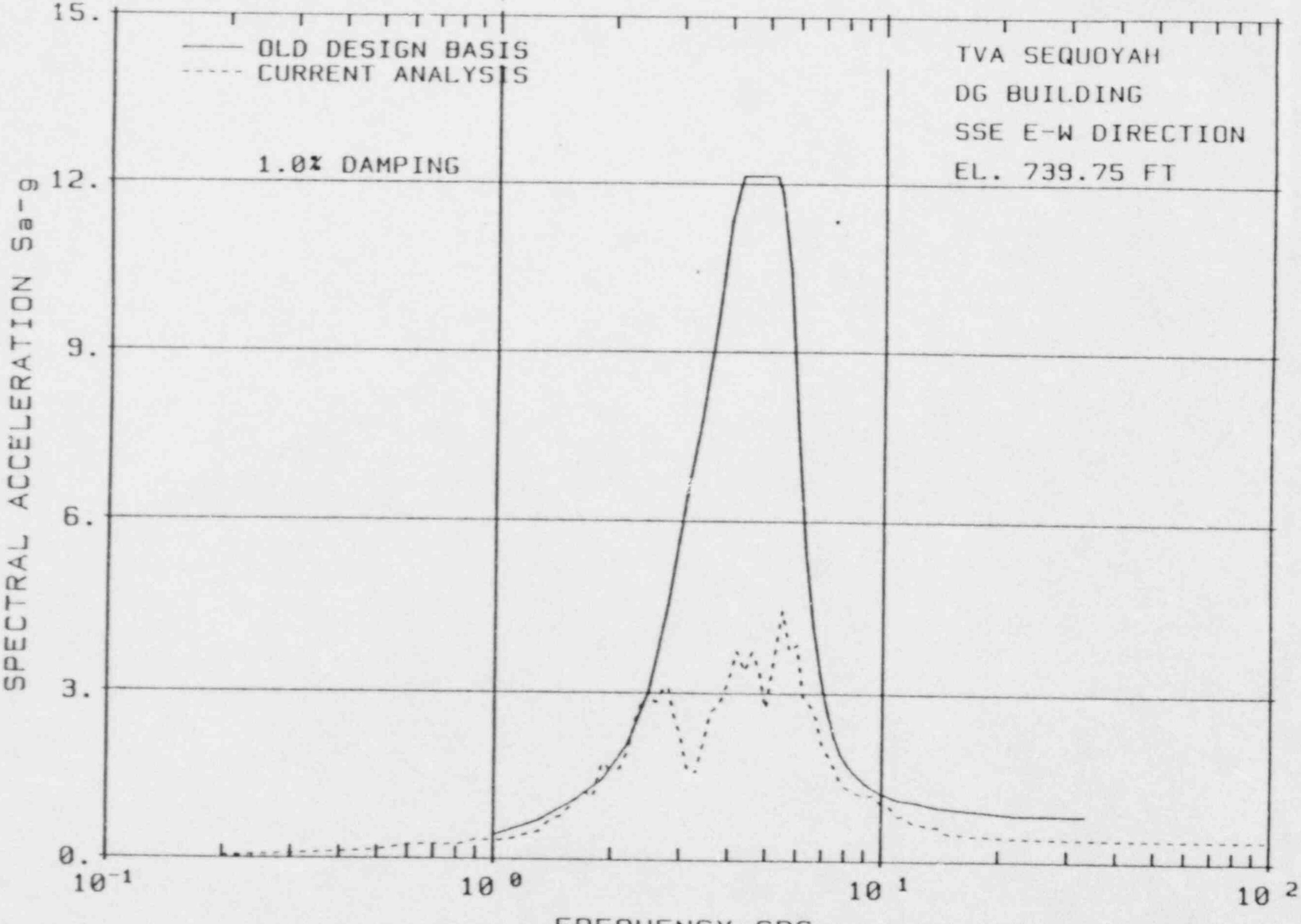
COMPARISON OF ENVELOPE OF AVERAGED ARS

Figure C-3



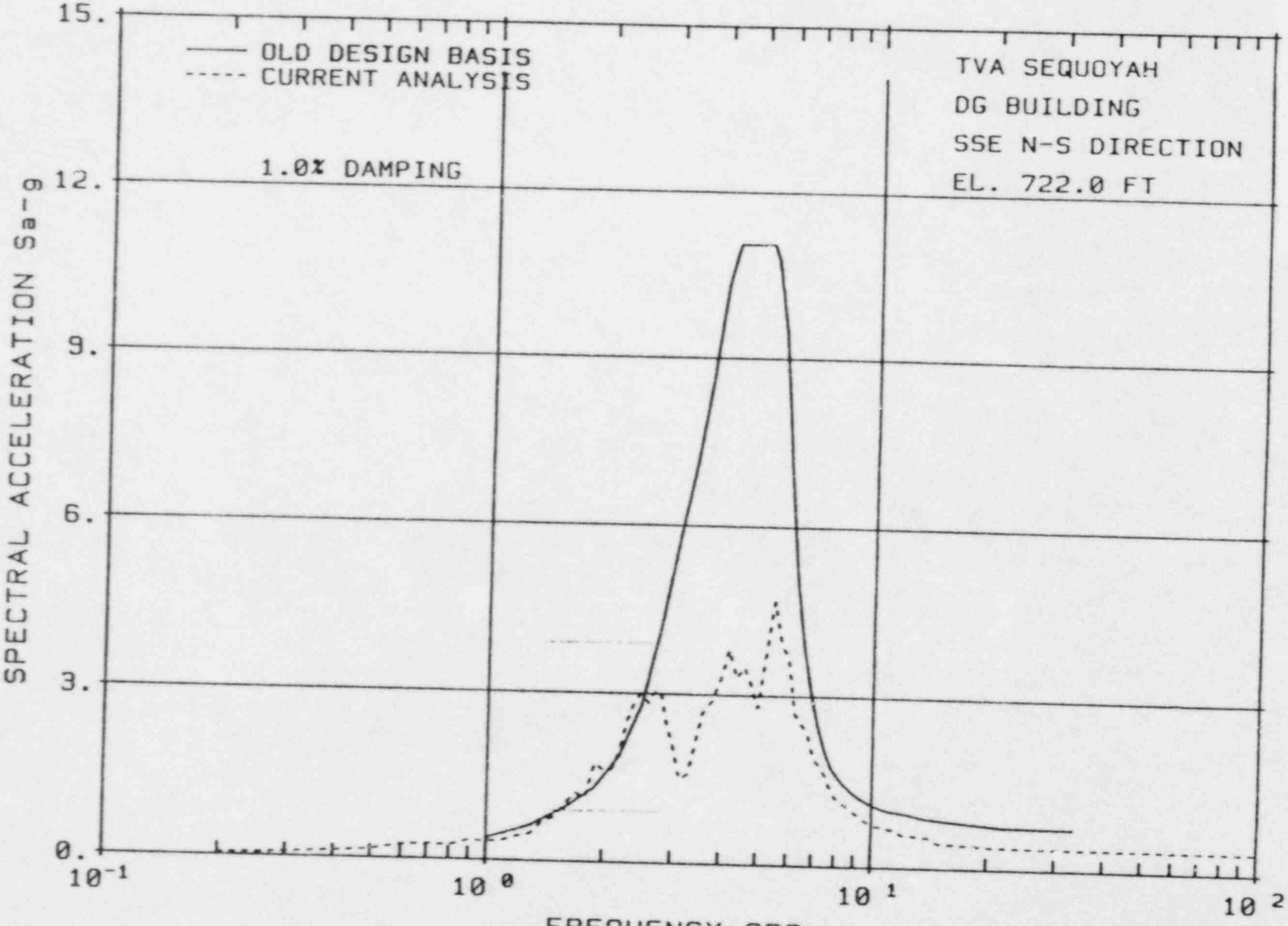
COMPARISON OF ENVELOPE OF AVERAGED ARS

Figure C-4



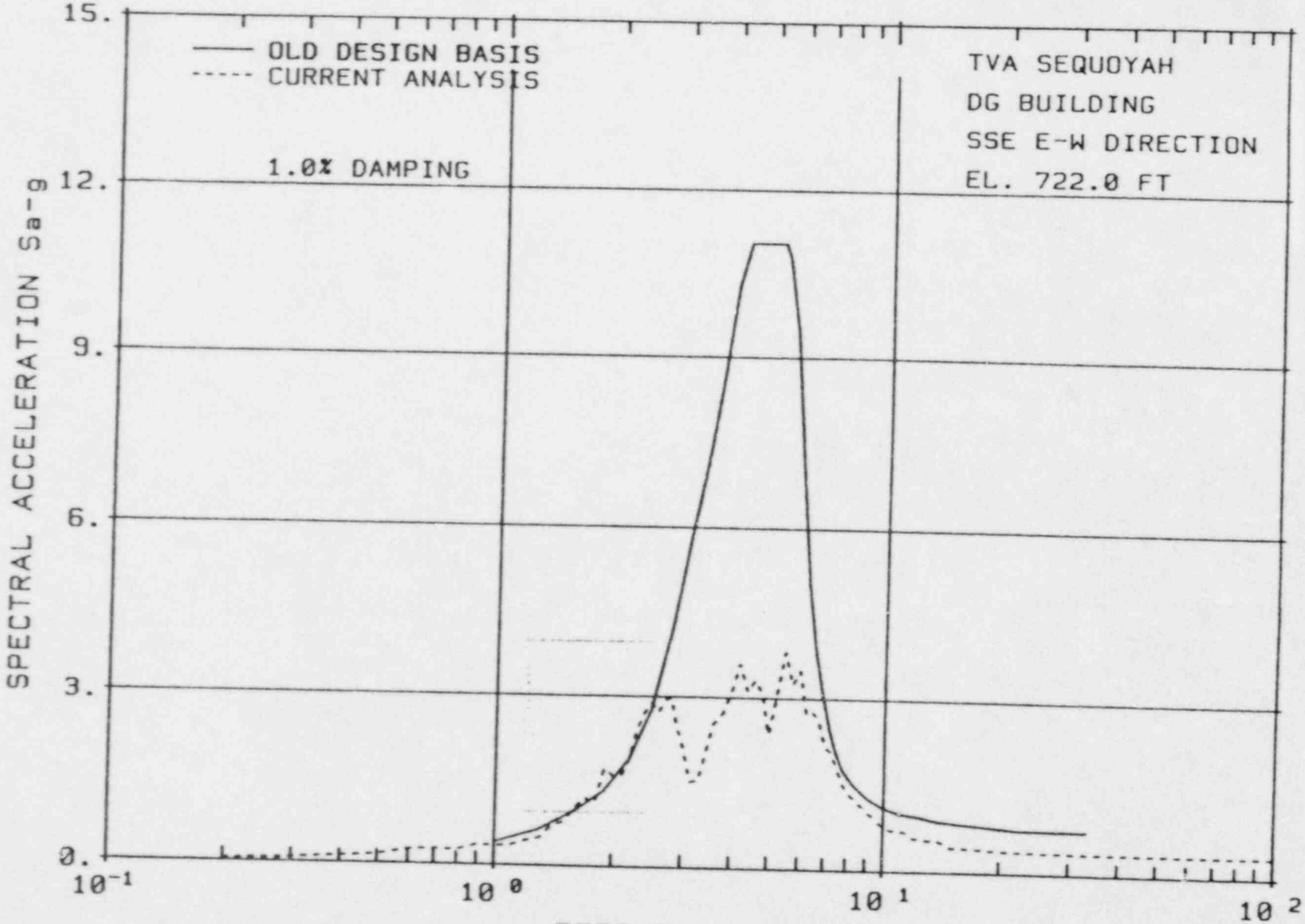
COMPARISON OF ENVELOPE OF AVERAGED ARS

Figure C-5



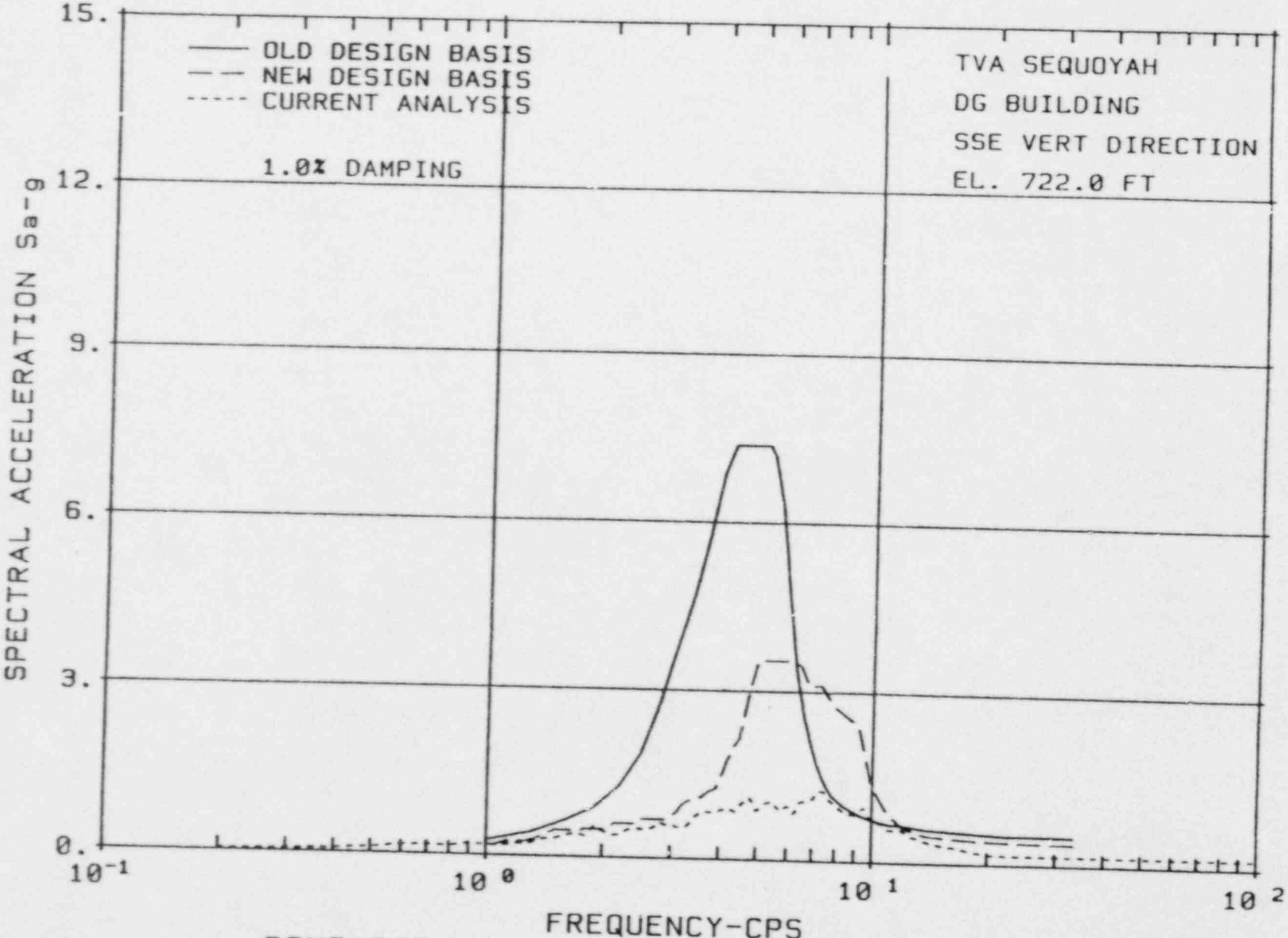
COMPARISON OF ENVELOPE OF AVERAGED ARS

Figure C-7



COMPARISON OF ENVELOPE OF AVERAGED ARS

Figure C-8



COMPARISON OF ENVELOPE OF AVERAGED ARS

Figure C-9