VOGTLE ELECTRIC GENERATING PLANT

GEORGIA POWER COMPANY

SEISMIC ANALYSIS REPORT

Prepared

by

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VEGP-SEISMIC ANALYSIS REPORT

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1.0 INTRODUCTION

The purpose of this report is to describe the seismic analysis methodology used in Vogtle Electric Generating Plant (VEGP) to obtain design structure accelerations and in-structure response spectra for Category 1 structures. The Category 1 structures are as follows:

- Containment Building
- Containment Internal Structure
- Auxiliary Building
- Control Building
- Fuel Handling Building
- NSCW Tower and Valve House
- Diesel Generator Building
- Auxiliary Feedwater Pumphouse
- Category 1 Tanks
- Diesel Fuel Oil Storage Tank Pumphouse
- Category 1 Tunnels

2.0 DESIGN BASES

2.1 GENERAL

VEGP seismic design methodology is based on the Standard Review Plan (SRP) (11/24/75) in effect in the years 1977 and 1978, during which period the VEGP seismic design methodology evolved. Meetings were held with the Nuclear Regulatory Commission (NRC) during this period to gain concurrence on this methodology. The concerns expressed by the NRC staff in these meetings were addressed in the Preliminary Safety Analysis Report (PSAR) Supplements No. 3 and No. 4, and in the Georgia Power Company (GPC) letter to the NRC dated February 20, 1978, in which VEGP committed to multiply the envelope in-structure response spectra for the deeply embedded Category 1 structures by a scaling factor of 1.5. The basis for the 1.5 scaling factor is provided in section 2.3. The scaling factor value of 1.5 was later incorporated through PSAR Supplement No. 5 of November 17, 1978.

The NRC accepted the VEGP seismic design methodology in their letter dated March 27, 1978, subject to the completion of the confirmatory study and sensitivity study in order to confirm the conservatism in the VEGP seismic analysis methodology. The confirmatory study addressed the NRC concerns on comparing the results of the finite element and impedance methods of soil-structure interaction analysis. The sensitivity study provided the justification for applying the deconvolved control motions at the foundation levels of deeply embedded Category 1 structures. The NRC also requested that the seismic analysis includes consideration of a torsional moment no less than that required by the Uniform Building Code (to account for the seismic wave propagation effects), in addition to the effects resulting from the actual geometric eccentricity between the center of mass and center of rigidity at each level of the structure.

The reports on the confirmatory study and the sensitivity study together with the description of the methodology to account for torsion caused by the seismic wave propagation effects were submitted to the NRC in the GPC letter dated November 13, 1978.

Therefore, PSAR Supplements No. 3, No. 4, and No. 5, together with the consideration of a torsional moment no less than that required by the Uniform Building Code to account for the seismic wave propagation effects, form the basis for the VEGP seismic design. The details of the seismic design bases are described in the following sections.

2.2 SEISMIC INPUT

Based on the plant site geologic and seismologic investigations, the peak ground acceleration for the safe shutdown earthquake (SSE) and the operating basis earthquake (OBE) are established as 0.20g and 0.12g, respectively. The horizontal and vertical components of the VEGP free-field design response spectra are provided in figures 2-1 and 2-2 for the SSE, and in figures 2-3 and 2-4 for the OBE. The design response spectra are in conformance with Regulatory Guide 1.60, Design Response Spectra for Seismic Design of Nuclear Power Plants.

The three components of the design basis earthquakes are considered to act simultaneously along two mutually orthogonal horizontal directions and the vertical direction. The responses due to the three-component earthquake excitation are combined using the Square Root of the Sum of the Squares (SRSS) criteria in conformance with Regulatory Guide 1.92, Combining Modal Responses and Spatial Components in Seismic Response Analysis.

The damping values used for fixed-base structures and components in the seismic analysis of Category 1 structures are the same as those provided in Regulatory Guide 1.61, Damping Values for Seismic Design of Nuclear Power Plants. Refer to section 3.1 for actual values.

2.3 SOIL-STRUCTURE INTERACTION EFFECTS

2.3.1 Shallowly Embedded Structures

The impedance method of soil-structure interaction analysis is used for shallowly embedded structures, and the control motion is applied at the foundation level in the free-field.

2.3.2 Deeply Embedded Structures

The finite element method of soil-structure interaction analysis is used for deeply embedded structures with the control motion applied at the finished grade level in the free-field. The envelope in-structure response spectra curves are obtained by considering the effects of variation of soil shear moduli, with upper-bound values equal to 1.5 times the mean values and lower-bound values equal to the mean values divided by 1.5. The resulting response spectra are multiplied by the scaling factor of 1.5. The basis for the 1.5 scaling factor is described below.

Deconvolved free-field time-history motions were obtained at the elevations of Category 1 structural foundations with the control motion applied at the finished grade level in the free-field, and corresponding response spectra were generated. Considering the variation of soil properties, envelope response spectra for each Category 1 foundation level were developed. A comparison of the envelope response spectra thus obtained in the free-field at the foundation levels of deeply embedded Category 1 structures was made with 60 percent of the free-field design response spectra. A scaling factor of 1.5 was selected so that when the envelope response spectra curves are multiplied by the scaling factor, the 60 percent free-field design spectra are essentially enveloped. This is consistent with the requirements of the SRP (11/24/75).

2.4 SEISMIC WAVE PROPAGATION EFFECTS

To account for the seismic wave propagation effects, torsional moments no less than those required by the Uniform Building Code are considered in the design of Category 1 structures, equipment, and systems. This torsional moment is additive to the effects resulting from the actual geometric eccentricity between the center of mass and center of rigidity at each level of the structure.

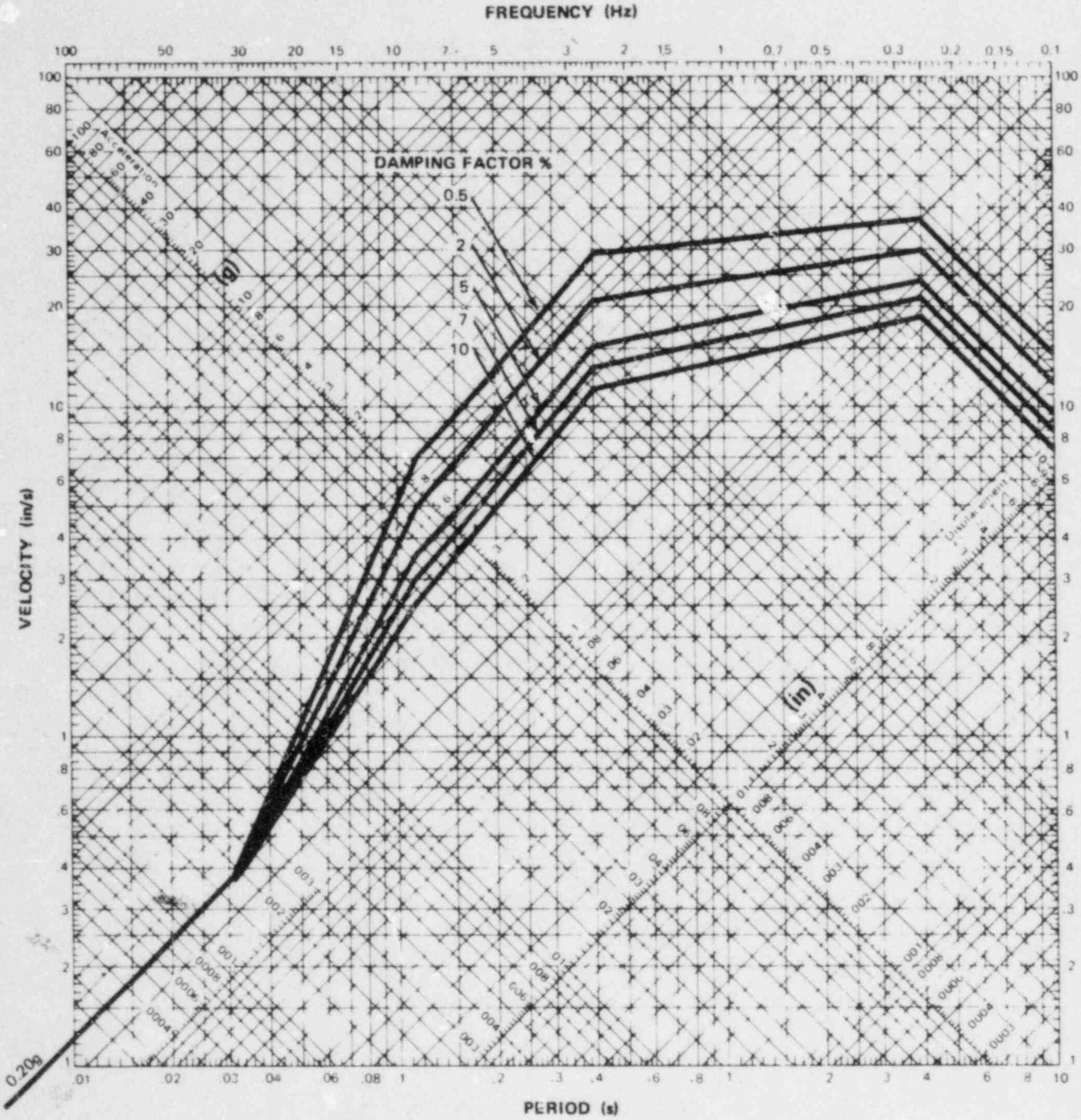


Figure 2-1
FREE-FIELD SAFE SHUTDOWN EARTHQUAKE
HORIZONTAL RESPONSE SPECTRA

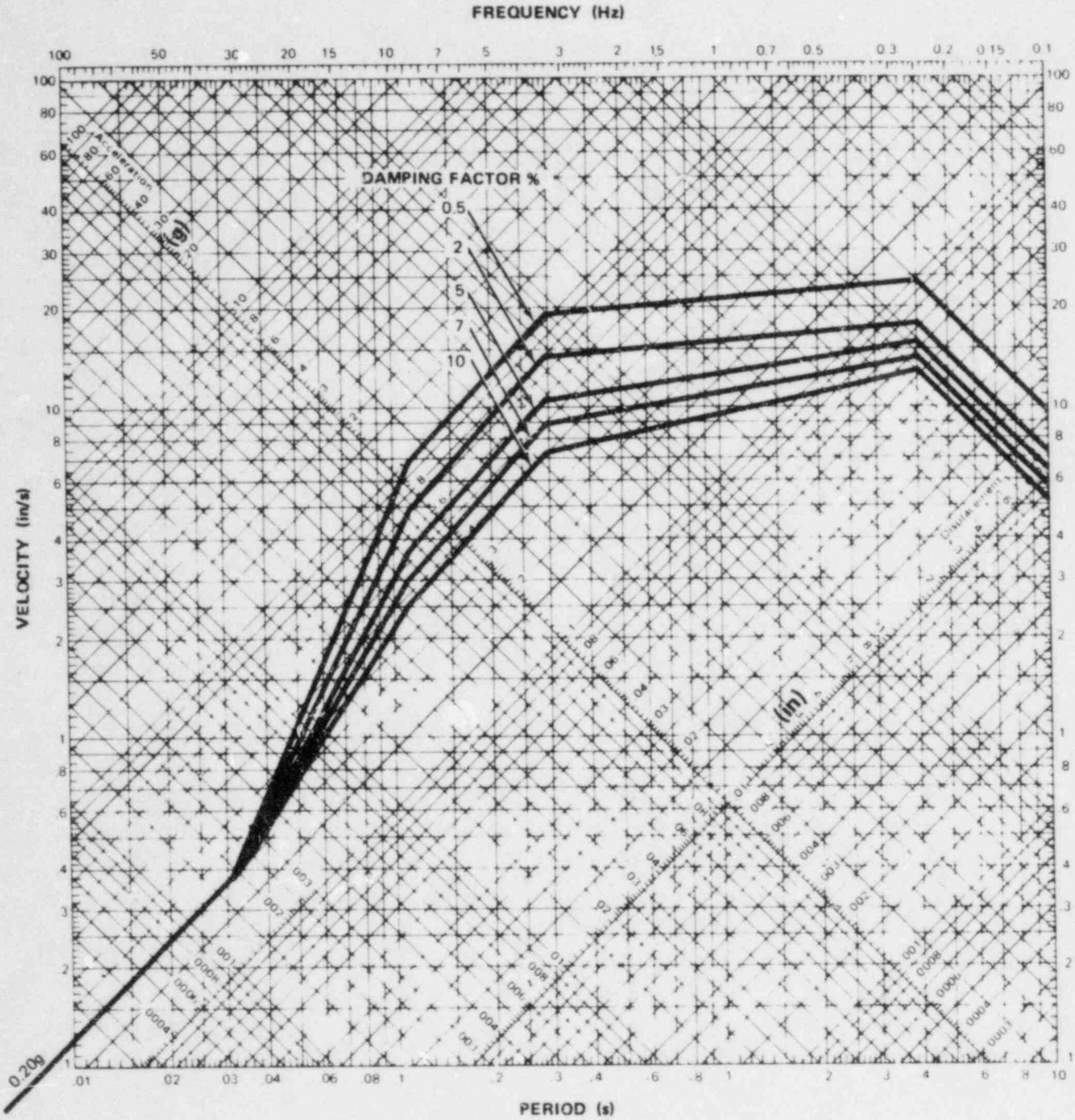


Figure 2-2
FREE-FIELD SAFE SHUTDOWN EARTHQUAKE
VERTICAL RESPONSE SPECTRA

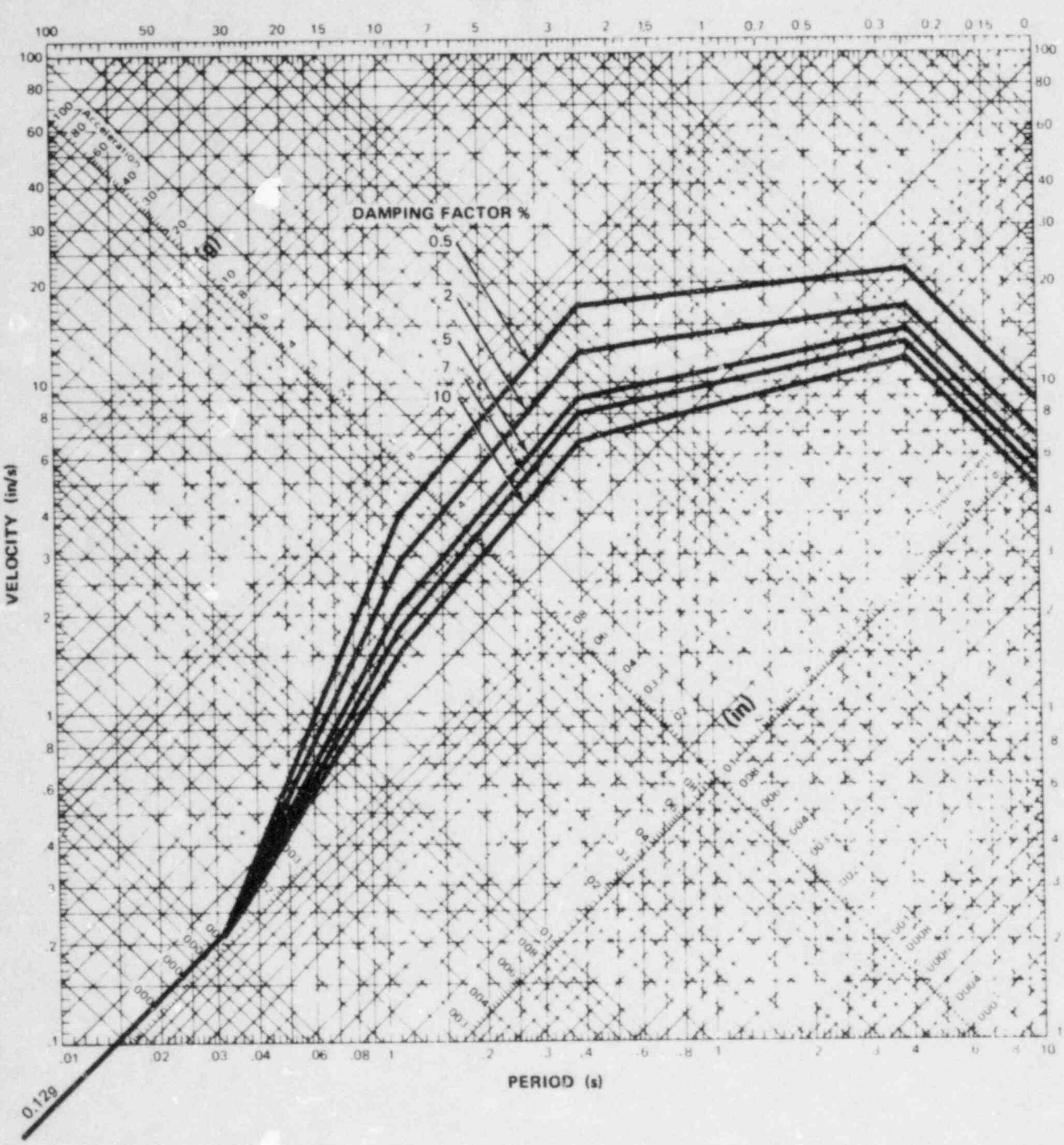


Figure 2-3
FREE-FIELD OPERATING BASIS EARTHQUAKE
HORIZONTAL RESPONSE SPECTRA

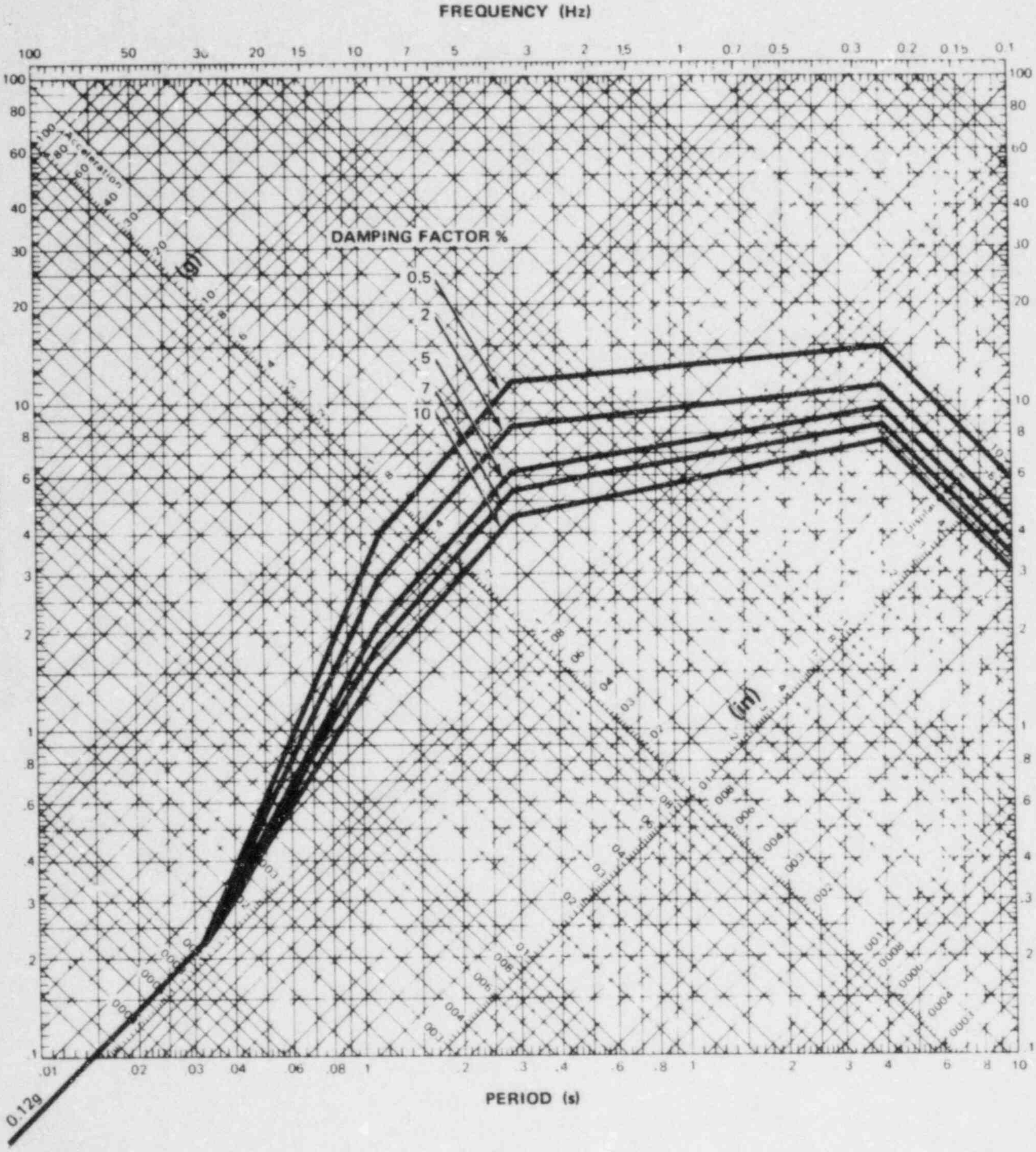


Figure 2-4
FREE-FIELD OPERATING BASIS EARTHQUAKE
VERTICAL RESPONSE SPECTRA

3.0 MATERIAL PROPERTIES

3.1 STRUCTURE PROPERTIES

The concrete material properties used in the development of Category 1 structure models are based on the design compressive strength of concrete (f'_c) of the corresponding building. The values for f'_c of the Category 1 structures are provided below.

Containment shell structure	6000 psi
Containment internal structure	5000 psi
Auxiliary building	5000 psi
All others	4000 psi

The steel members used in the structures have a yield stress of 36 ksi with an elastic modulus value of 29,000 ksi.

The damping values used are shown in table 3-1. These values are the same as those provided in Regulatory Guide 1.61, Damping Values for Seismic Design of Nuclear Power Plants.

3.2 SOIL PROPERTIES

3.2.1 Description of Plant Site Soil Strata

The depth of bedrock below the plant site is approximately 950 feet. The nominal finished grade level is elevation 220'-0". The explored depth at the site indicates an overburden which may be divided into the three distinct soil strata listed below.

A. Upper sand stratum - Sands and clayey sands, varying from loose to dense, to a depth of 75 to 90 feet.
B. Marl bearing stratum - Very hard, sandy, calcareous marl about 65 feet thick.
C. Lower sand stratum - Clean to silty, medium- to fine-grained dense sands below the marl to the bedrock level.

In the power block area which encompasses all Category 1 structures, the upper sand stratum material and approximately the top 5 feet of clay marl bearing stratum are removed to approximately elevation 130'-0". Densely compacted sand and silty sand

Category 1 backfill is placed on the top of the marl bearing stratum up to the design elevations of Category 1 structure foundations, with the exception of the auxiliary building and the nuclear service cooling water (NSCW) towers, which are founded directly on the marl bearing stratum. Category 1 backfill is also placed against exposed sides of Category 1 structures up to grade elevation.

3.2.2 Dynamic Soil Properties

The soil properties used in VEGP soil-structure interaction analyses are based on the field geophysical surveys and dynamic testing of soil material.

The low strain shear modulus for the lower sand stratum is computed using a shear wave velocity of 1800 ft/s, which is based on field geophysical survey data. The strain-dependent shear modulus and damping curves (figures 3-1 and 3-4) are based on the standard curves proposed by Seed and Idriss (reference 1).

The low strain shear modulus for the marl bearing stratum is computed using a shear wave velocity of 1700 ft/s, which is based on field geophysical survey data. Because the marl is essentially a hard clay and is over consolidated with undrained shear strengths in excess of 10 k/ft^2, the shear modulus will decrease with increasing shear strain at a lesser rate than that of applicable soft clays, and the damping in this stratum would be somewhat lower than those for soft clays. The strain-dependent shear modulus and damping curves (figures 3-2 and 3-5) adopted for marl bearing stratum are, therefore, based on the standard curves proposed by Seed and Idriss for soft clays with appropriate modifications to account for this in-situ soil condition.

The soil properties of the Category 1 backfill are obtained from the dynamic testing of the backfill. The bases for the soil properties used in the seismic analyses are provided in "Report on Dynamic Properties for Compacted Backfill," February 1978 (transmitted to NRC in GPC letter GN-252). Values of low strain shear modulus (at strain less than or equal to 10^{-4} percent) of the compacted backfill are computed using the expression $G = 1000\ K_2\ (\sigma'_m)^{\frac{1}{2}}$, where G is the shear modulus in lb/ft^2; σ'_m is the mean principal effective stress in lb/ft^2; and K_2 is a coefficient reflecting primarily the effect of void ratio or relative density and the strain amplitude of the motions. For the specified conditions, K_2 is taken as 80. The unit weights of compacted backfill in moist and saturated conditions are 123 lb/ft^3 and 133 lb/ft^3, respectively. The strain-dependent shear modulus and damping curves adopted for Category 1 backfill are provided in figures 3-3 and 3-6.

TABLE 3-1

DAMPING VALUES FOR FIXED BASE STRUCTURES AND COMPONENTS

Structure or Component	Percent of Critical Damping Per Mode	
	OBE	SSE
Equipment and large-diameter piping systems (pipe diameter in excess of 12 in.)	2	3
Small-diameter piping systems (pipe diameter equal to or less than 12 in.)	1	2
Welded steel structures	2	4
Bolted steel structures	4	7
Prestressed concrete structures	2	5
Reinforced concrete structures	4	7

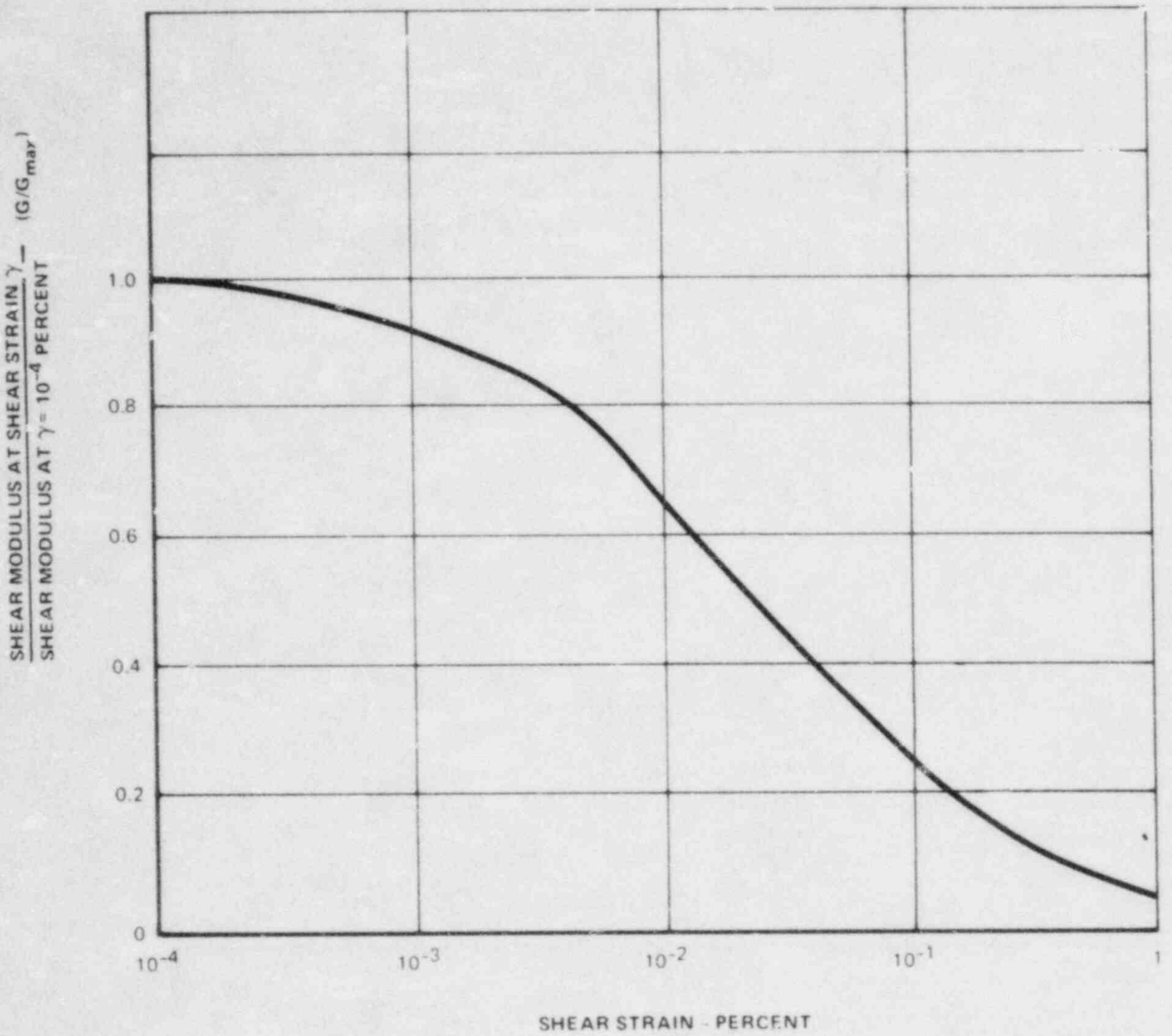


Figure 3-1
G/G_{max} VS SHEAR STRAIN FOR
LOWER SAND STRATUM

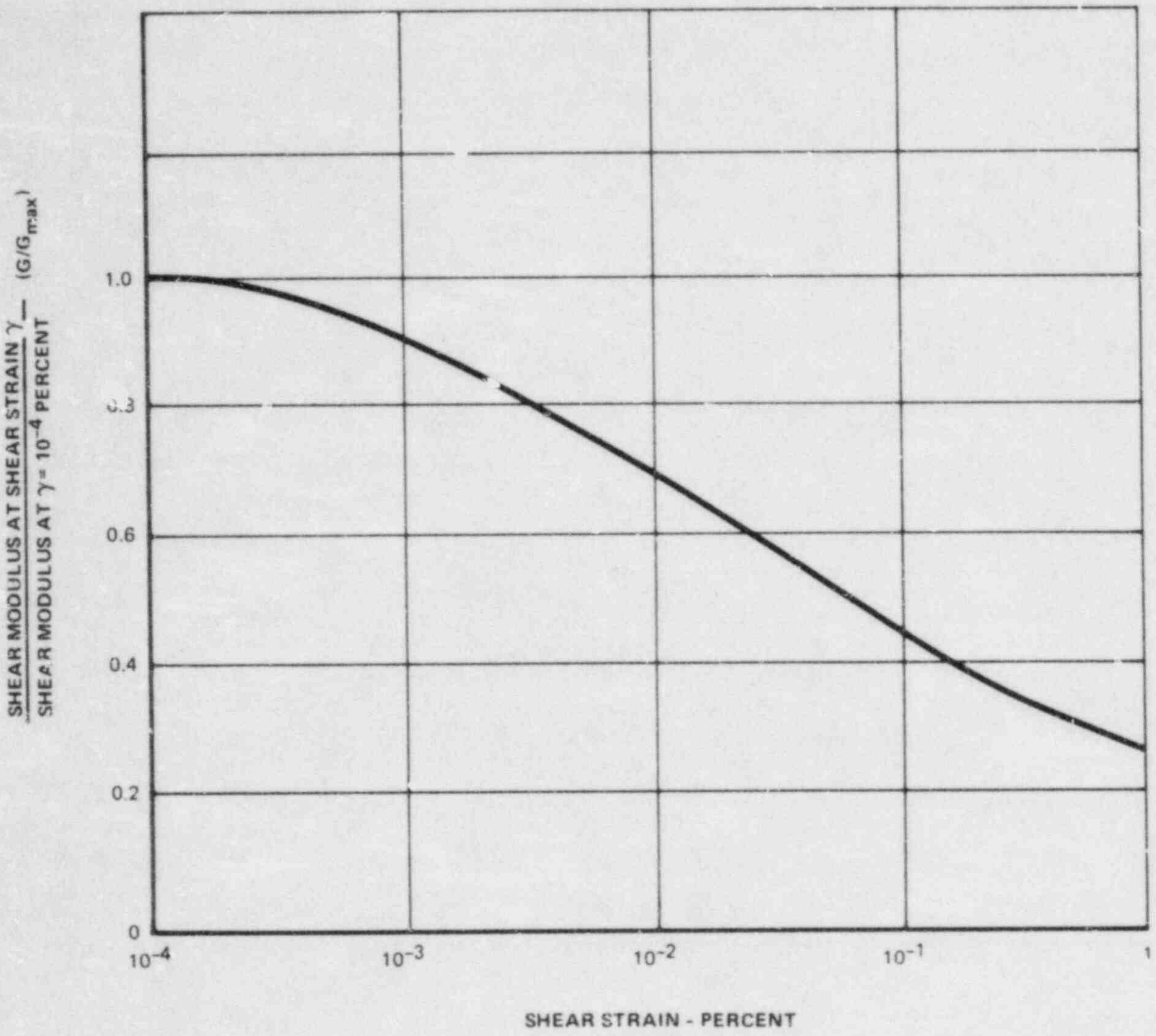


Figure 3-2
G/G_{max} VS SHEAR STRAIN FOR MARL BEARING STRATUM

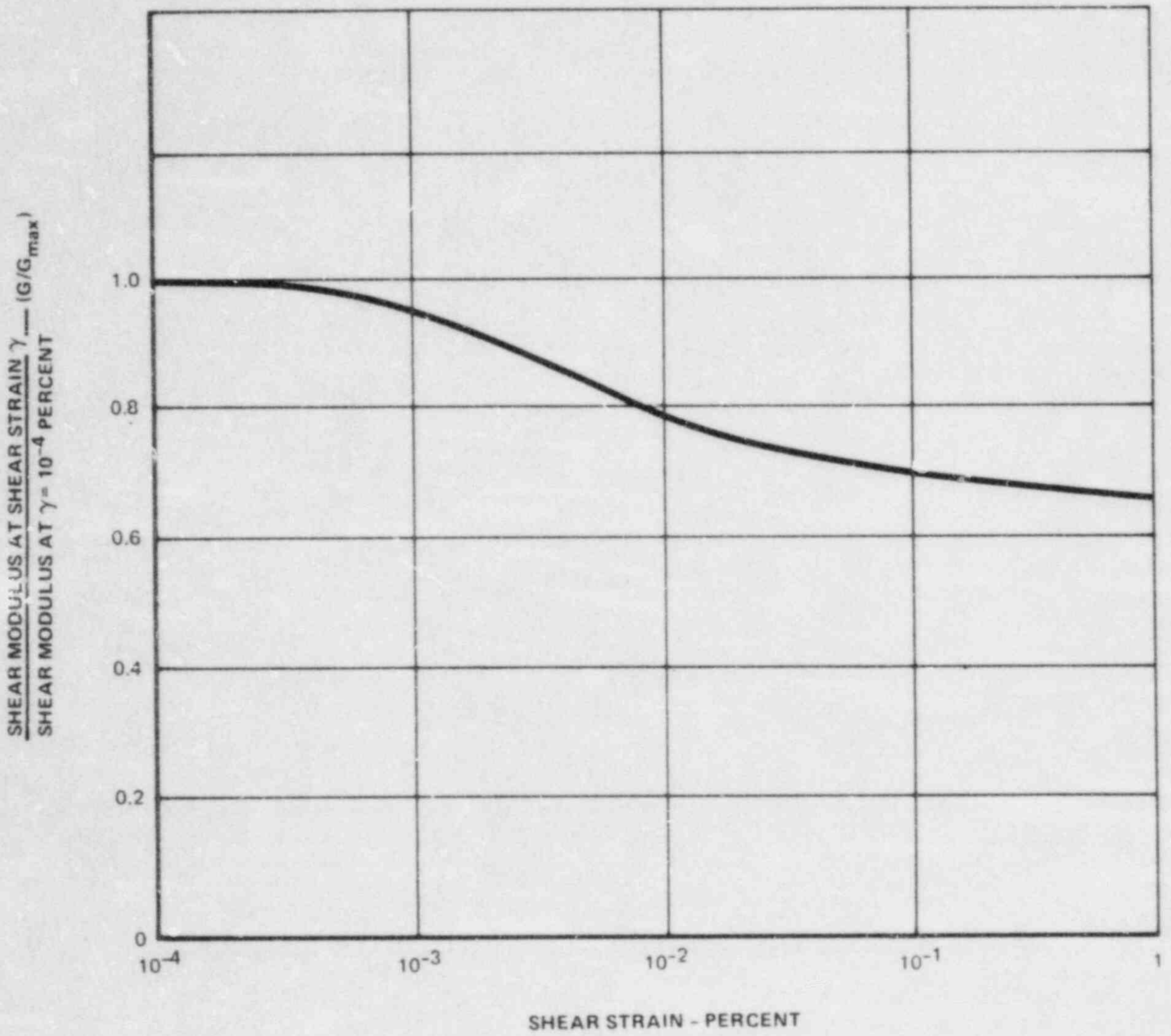


Figure 3-3
G/G_{max} VS SHEAR STRAIN FOR COMPACTED SAND BACKFILL

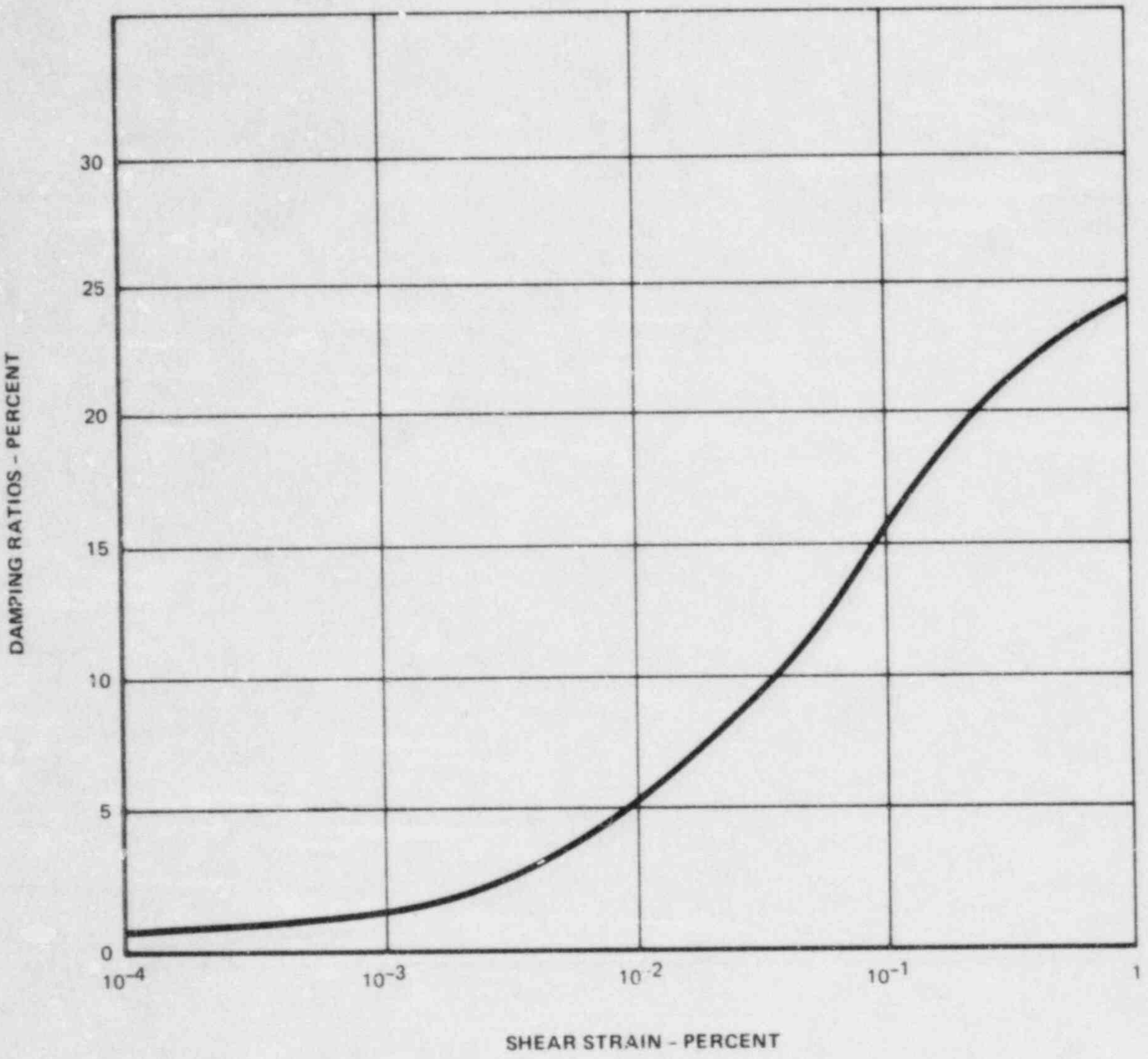


Figure 3-4
DAMPING RATIOS VS SHEAR STRAIN
FOR LOWER SAND STRATUM

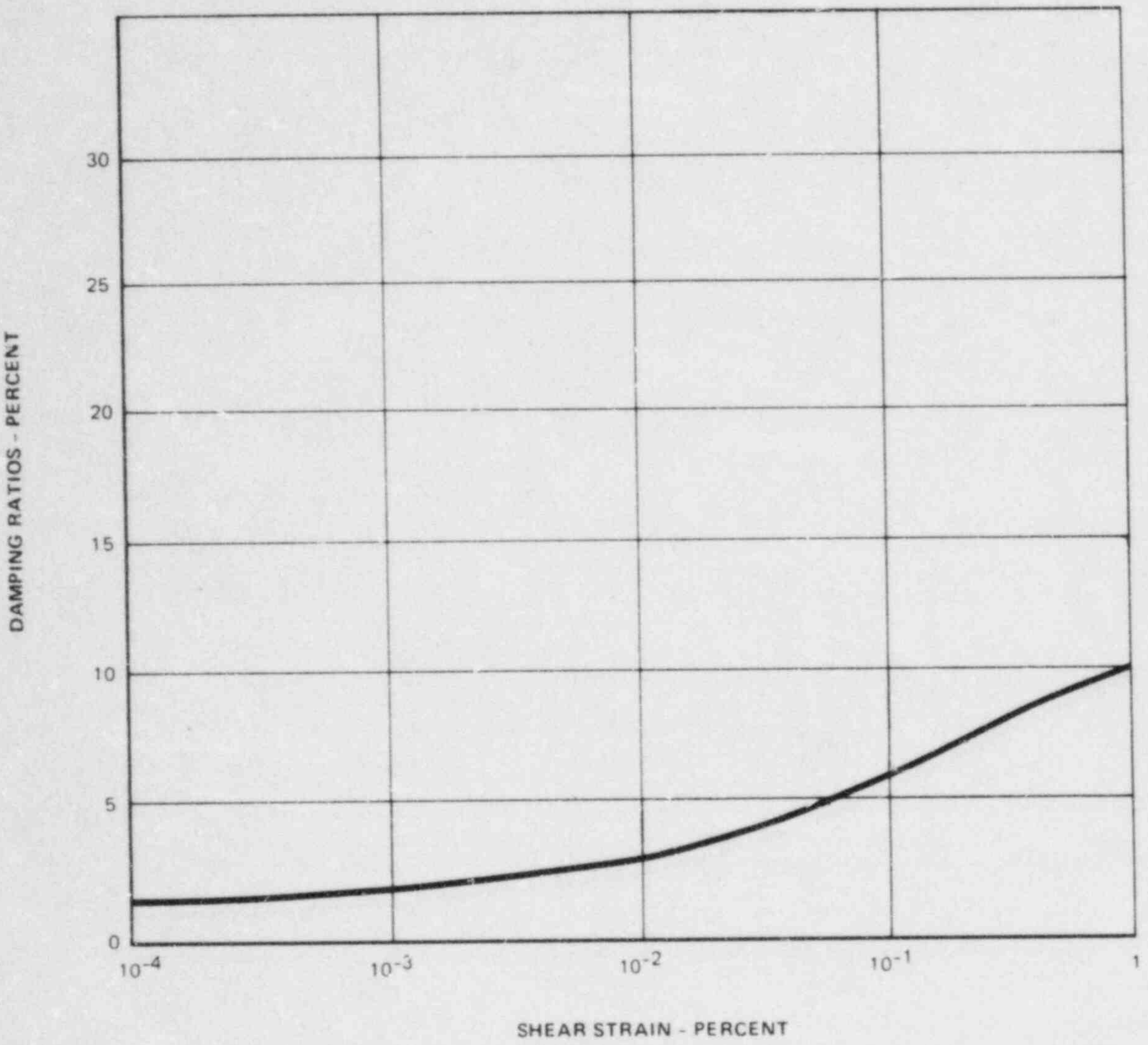


Figure 3-5
DAMPING RATIOS VS SHEAR STRAIN
FOR MARL BEARING STRATUM

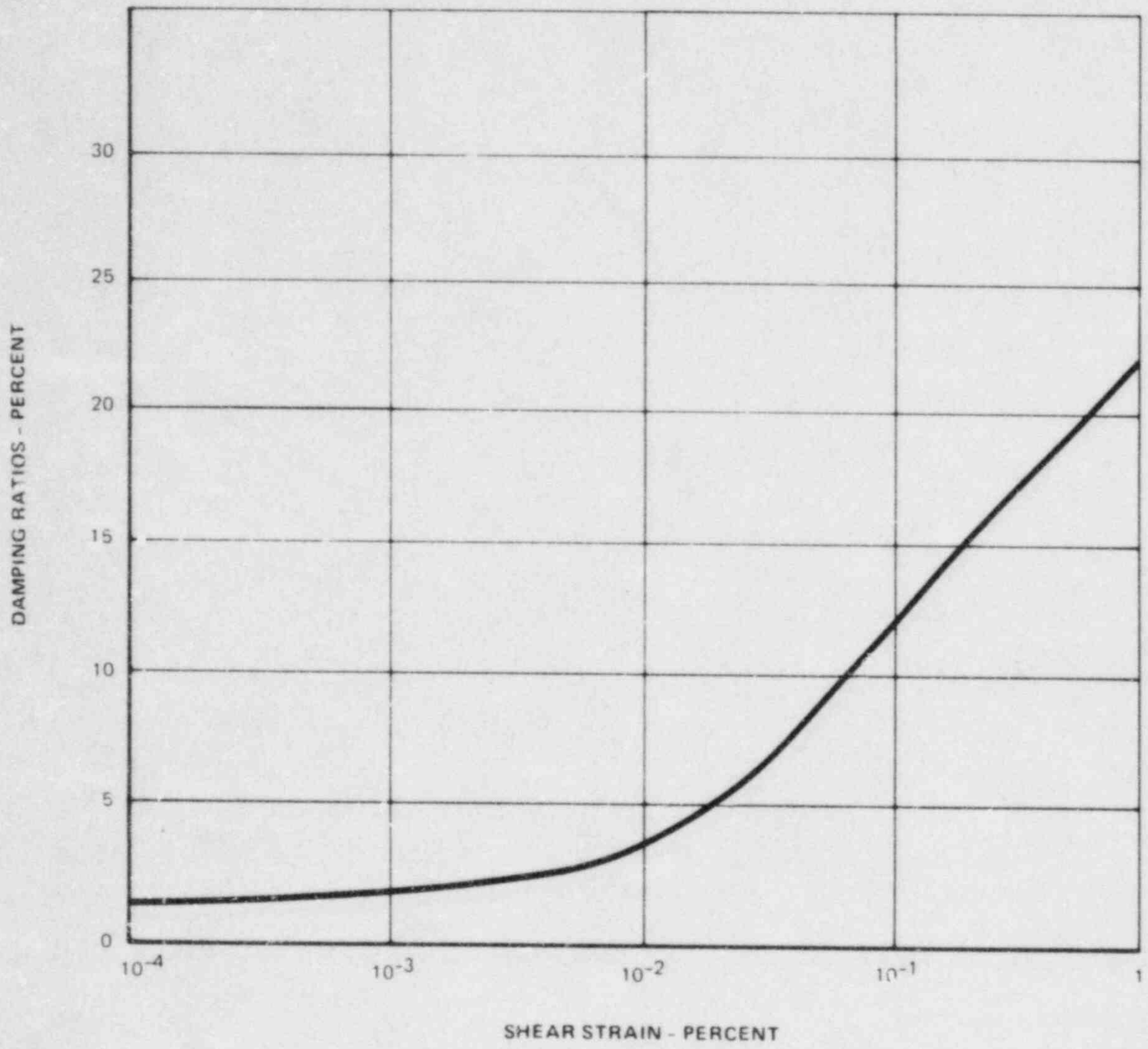


Figure 3-6
DAMPING RATIOS VS SHEAR STRAIN
FOR COMPACTED SAND BACKFILL

4.0 STRUCTURE MODELS

Structure models are prepared for use in the soil-structure interaction analyses. This section describes the development of the structure models. In addition, their fixed-base frequencies and associated modal participation factors are provided to illustrate their dynamic characteristics.

4.1 MODELING TECHNIQUES FOR STRUCTURES

To compute the seismic response of Category 1 structures subjected to the design earthquakes, mathematical models are first developed to represent the structures. The techniques used to develop the mathematical models from which mass and stiffness matrices can be formulated are in accordance with BC-TOP-4A (reference 2).

The structure is modeled as a system of lumped masses located at elevations of mass concentrations (e.g. foundations, floors, or supports of major Category 1 equipment). Generally, each lumped mass has six dynamic degrees of freedom, i.e., three translational and three rotational components. The derivation of the stiffness matrix associated with the dynamic degrees of freedom is accomplished by an assembly of elastic structural elements between mass nodes. The BSAP (Bechtel Structural Analysis Program) computer program is utilized to assemble the global mass and stiffness matrices of the lumped parameter models, and to perform the fixed-base free vibration modal analyses. BSAP is a general purpose finite element computer program used for static or dynamic analysis of three-dimensional structural systems.

4.1.1 Shear Wall Structures

Included in this group of structures are the auxiliary building, control building, fuel handling building, diesel generator buildings, and auxiliary feedwater pumphouses. The following modeling techniques are used for shear wall structures:

A. Masses are lumped at each floor level and at desired equipment support locations. The corresponding inertial properties are then calculated for each lumped mass.

B. Walls are modeled as beam elements running vertically from floor to floor with the shear area being effective in either the north-south or east-west direction. The walls running north-south are considered effective in shear in the north-south direction only. Similarly, the east-west walls are considered effective for carrying shear in the east-west direction only. Each beam element is located at the center of gravity of the corresponding wall cross-section.

C. The slabs are assumed to act as infinitely rigid diaphragms. Hence all the ends of beam elements at each floor level are rigidly linked to the lumped mass at that level.

D. For the fuel handling building, the hydrodynamic effects are represented by equivalent mass-spring models based on the modeling techniques described in TID-7024 (reference 3).

E. The fixed base node of the structure is located at the bottom of the basemat, and is connected to the lumped mass node at the basemat level by a rigid beam element.

4.1.2 Shell Structures

Included in this group of structures are the containment buildings, NSCW towers, and Category 1 tanks (condensate storage tanks, refueling water storage tanks, and the reactor makeup water storage tanks). The following modeling techniques are used for shell structures.

A. For structures having continuous mass distributions without any specific mass concentrations, a sufficient number of mass points are chosen so that the vibration modes of interest can be properly defined. These masses are located at equal distances through the height of the shell with slight adjustments to select elevations of interest. The corresponding inertial properties are then calculated for each lumped mass.

B. Stiffness properties for a single beam element are calculated for the shell cross-section between lumped mass nodes.

C. For the NSCW tower and Category 1 tanks, the hydrodynamic effects are represented by equivalent mass-spring models based on the modeling techniques described in TID-7024 (reference 3).

D. The fixed base node of the structure is located at the bottom of the basemat, and is connected to the lumped mass node at the basemat level by a rigid beam element.

The modeling details specific to each building are provided in the following subsections.

4.2 CONTAINMENT BUILDING

The Unit 1 model is described in this section. The Unit 2 model is the mirror image of the Unit 1 model. The lumped parameter models of the containment shell and the internal structure have a total of 14 lumped mass nodes as shown in figures 4-1 and 4-2. Since the north steam generator compartment of the internal structure is not connected to the south steam generator compartment above elevation 218'-0", the structure is represented with two branches above elevation 218'-0". The horizontal and vertical inertia components of the nuclear steam supply system (NSSS) are lumped to the corresponding structure mass nodes. Tables 4-1 through 4-6 give the coordinates, masses and stiffness properties associated with each model.

The fixed-base frequencies of the first few modes are 4.0, 4.0, 8.9, 11.6, 11.6 and 12.2 cps for the containment shell, and 12.8 and 14.4 cps for the containment internal structure. Fixed-base modal frequencies and participation factors are listed in tables 4-7 and 4-8.

4.3 AUXILIARY BUILDING

The auxiliary building is a concrete shear wall structure. Its lumped parameter model has 10 lumped masses with 60 dynamic degrees of freedom as shown in figure 4-3. Masses are lumped at the individual floor levels. Since the Unit 1 slab diaphragm and Unit 2 slab diaphragm are not interconnected at elevations 240'-0" and 260'-0", the structure is represented with two branches at these levels. Beam elements are utilized to represent the walls between the floors. The end nodes of the beams are rigidly linked to the appropriate mass nodes. The BSAP computer program is utilized to assemble the stiffness matrices of the various beam elements into a global stiffness matrix the size of which is compatible with the total number of dynamic degrees of freedom of the model. The coordinates and masses associated with the lumped parameter nodes are given in tables 4-9 through 4-10.

The fixed-base frequencies for the first few modes are 5.5, 6.7, 7.0, and 12.5 cps. Fixed-base modal frequencies and participation factors are listed in table 4.11.

4.4 CONTROL BUILDING

The control building is a concrete shear wall structure. Its lumped parameter model has 7 lumped masses with 42 dynamic degrees of freedom as shown in figure 4-4. Masses are lumped at the individual floor levels. The branch represents the main steam isolation valve room, which is not connected to the rest of the building with a slab diaphragm at elevations 240'-0" and 260'-0". Beam elements are utilized to represent the walls between the floors. The end nodes of the beams are rigidly linked to the appropriate mass nodes. The BSAP computer program is utilized to assemble the stiffness matrices of the various beam elements into a global stiffness matrix, the size of which is compatible with the total number of dynamic degrees of freedom of the model. The coordinates and masses associated with the lumped parameter nodes are given in tables 4-12 through 4-13.

The fixed-base frequencies of the first few modes are 0.8 and 1.6 cps for the branch, and 3.8, 7.6, 7.9, 8.9, and 10.5 cps for the main structure. Fixed-base modal frequencies and participation factors are listed in table 4-14.

4.5 FUEL HANDLING BUILDING

The fuel handling building is a concrete shear wall structure. Its lumped parameter model, shown in figure 4-5, includes the hydrodynamic effects of the liquid in the spent fuel pools. Masses are lumped at all structure floor levels, and at four nodes to represent the N-S and E-W sloshing characteristics of the liquid mass in the Unit 1 and Unit 2 spent fuel pools. Since the Unit 1 slab diaphragm and Unit 2 slab diaphragm are not interconnected at elevation 263'-8", the structure is represented with two branches at this level. Altogether 46 dynamic degrees of freedom are considered. Beam elements represent shear walls and truss elements are used to model the liquid sloshing effects. The sloshing part of the horizontal inertia of the liquid and the sloshing frequency is computed using TID-7024 (reference 3). The stiffness of the truss element connecting the sloshing liquid mass to the structure mass is selected to model the appropriate sloshing frequency. The rigid part of the horizontal inertia of the liquid is lumped to the corresponding structure mass node.

The vertical inertia of these masses are lumped at the base of the spent fuel pools. The BSAP computer program is utilized to assemble the stiffness matrices of the various beam and truss elements into a global stiffness matrix, the size of which is compatible with the total number of dynamic degrees of freedom of the model. The coordinates and masses associated with the lumped mass nodes are given in tables 4-15 through 4-16.

The sloshing liquid masses have frequencies of 0.23 and 0.27 cps. The fixed-base structural frequencies of the first few modes are 6.1, 6.8, 10.4 and 11.6 cps. Fixed-base modal frequencies and participation factors are listed in table 4-17.

4.6 NSCW TOWER AND VALVE HOUSE

The NSCW tower is classified as a shell structure. Its lumped parameter model includes the hydrodynamic effects of the water in the tower. The fixed-base stick model of the NSCW tower is shown in figure 4-6. The offset of the lumped masses at and below the grade level results from the eccentricity caused by the local thickening of the shell wall below grade on one side of the shell. The vertical flexibility of the eliminator beams and the fill beams, at elevations 230'-9" and 242'-5" respectively, are represented by equivalent mass-spring models. Altogether 62 dynamic degrees of freedom are considered. Beam elements are used to represent the equivalent structure stiffness of the shell and truss elements are used to model the water sloshing effects. The sloshing part of the horizontal inertia of the water and sloshing frequency is computed using TID-7024 (reference 3). The stiffness of the truss element connecting the sloshing water mass (nodes 14 and 15) to the structure mass is selected to model the appropriate sloshing frequency. The constrained and rigid parts of the horizontal inertia of the water (nodes 9 and 12) are rigidly connected to the structure nodes. The vertical inertia of the water mass is lumped to the base of the tower. Tables 4-18 through 4-20 give the coordinates, masses and stiffness properties associated with the lumped parameter model.

The sloshing frequency of the water mass is 0.18 cps. The fixed-base structural frequencies of the first few modes are 5.4, 6.8, 6.8, 14.7, 14.7 and 16.9 cps. Fixed-base modal frequencies and participation factors are listed in table 4-21.

The NSCW valve house is a one-story concrete shear wall structure adjacent to the 136-foot high NSCW tower. The valve house extends 20 feet below grade and follows the curvature of the cooling tower periphery. The 136-foot high NSCW tower extends approximately 90 feet below grade and is much larger than the valve house in both size and mass, i.e., the mass of the NSCW tower is approximately ten times greater than the mass of the valve house. Therefore, the seismic response of the valve house is considered to be dictated by the driving influence of the adjacent massive NSCW tower. Thus, a lumped parameter model of the valve house is not needed, and the response spectra of the NSCW tower at grade is used as the response spectra of the valve house.

4.7 DIESEL GENERATOR BUILDING

The diesel generator building is a concrete shear wall structure. Its lumped parameter model has 3 lumped masses with 18 dynamic degrees of freedom as shown in figure 4-7. Masses are lumped at the individual floor levels. Beam elements are utilized to represent the walls between the floors. The end nodes of the beams are rigidly linked to the appropriate mass nodes. The BSAP computer program is utilized to assemble the stiffness matrices of the various beam elements into a global stiffness matrix, the size of which is compatible with the total number of dynamic degrees of freedom of the model. The coordinates and masses associated with the lumped parameter model are given in tables 4-22 through 4-23.

The fixed-base frequencies of the first few modes are 9.0, 13.5, 16.6, 28.5, and 29.4 cps. Fixed-base modal frequencies and participation factors are listed in table 4-24.

4.8 AUXILIARY FEEDWATER PUMPHOUSE

The auxiliary feedwater pumphouse is a concrete shear wall structure. Its lumped parameter model has one lumped mass with 6 dynamic degrees of freedom as shown in figure 4-8. There are 8 beam elements representing the walls between the floors. The end nodes of the beams are rigidly linked to the mass node. The basemat mass is not included in the fixed-base model since the basemat serves as the point of fixity for the fixed-base modal analysis. However, the basemat mass is included in the subsequent soil-structure interaction analysis. Tables 4-25 through 4-27 give the coordinates, masses and stiffness properties associated with the lumped parameter model.

The fixed-base frequencies for the first few modes are 35.4, 38.5, 68.3 and 90.9 cps. Fixed-base modal frequencies and participation factors are listed in table 4-28.

4.9 CATEGORY 1 TANKS

The methodology used to create the lumped parameter model of the condensate storage tanks, which is a representative Category 1 tank structure, is described as follows.

The condensate storage tanks are cylindrical concrete shell structures which share a common basemat. A concrete missile protection structure for equipment and piping is situated between the two tank shell structures, and is structurally independent above the basemat. Lumped parameter models are provided for each tank and the missile protection structure. The hydrodynamic effects of the water in each tank is considered in the development of the models. The fixed-base lumped parameter model of the condensate storage tanks is shown in figure 4-9. Altogether 72 dynamic degrees of freedom are considered. Beam elements are used to represent the structure stiffness and truss elements are used to model the water sloshing effects. The sloshing part of the horizontal inertia of the liquid mass and sloshing frequency is computed using TID-7024 (reference 3). The stiffness of the truss element connecting the sloshing water mass (nodes 16 through 19) to the structure mass is selected to model the appropriate sloshing frequency. The rigid and constrained parts of the horizontal inertia of the water (nodes 12 through 15) are rigidly connected to the structure nodes. The vertical inertia of the water mass is lumped to the basemat of the tanks. Tables 4-29 through 4-31 provide the coordinates, masses and stiffness properties associated with the lumped parameter model.

The sloshing frequency of the water mass is 0.26 cps. The fixed-base structural frequencies of the first few modes are 12.1, 12.1, 12.2, 12.2, 14.8 and 23.0 cps. Fixed-base modal frequencies and participation factors are listed in table 4-32.

TABLE 4-1

CONTAINMENT SHELL MODEL

(Nodal Coordinates in Local Coordinate System)

Node	X (ft)	Y (ft)	Z (ft)	Elevation (ft)	Remarks
1	0.0	0.0	171.8	171.8	Bottom of shell
2	0.0	0.0	193.8	193.8	
3	0.0	0.0	220.0	220.0	Grade level
4	0.0	0.0	258.4	258.4	
5	0.0	0.0	290.7	290.7	
6	0.0	0.0	323.0	323.0	Springline
7	0.0	0.0	361.0	361.0	
8	0.0	0.0	399.0	399.0	Top of dome
9	7.8	0.0	163.9	163.9	Basemat
10	0.0	0.0	143.5	143.5	Bottom of basemat (Fixed base)
11	0.0	0.0	163.9	163.9	

TABLE 4-2

CONTAINMENT SHELL MODEL

(Mass Properties)

Node	Translational Inertia ($K-sec^2/ft$)			Rotational Inertia ($K-sec^2-ft$)		
	TX	TY	TZ	RX	RY	RZ
2	190.1	190.1	190.1	487400.	487400.	982700.
3	254.8	254.8	254.8	648280.	648280.	1317200.
4	279.9	279.9	279.9	712378.	712378.	1450350.
5	263.3	263.3	263.3	682892.	682892.	1377180.
6	312.8	312.8	312.8	745329.	745329.	1538220.
7	281.2	281.2	281.2	723763.	723763.	917160.
8	182.0	182.0	182.0	437454.	437454.	235910.
9	2082.0	2082.0	2214.0	3241438.	4302475.	6810003.

TABLE 4-3

CONTAINMENT SHELL MODEL

(Stiffness Properties)

Beam Element No.	Axial Cross-Sectional Area (ft^2)	Shear Area (ft^2)	Torsional Moment of Inertia (ft^4)	Moment of Inertia About Local Y-Axis (ft^4)	Moment of Inertia About Local Z-Axis (ft^4)	Modulus of Elasticity (k/ft^2)	Poisson's Ratio μ
1	60	20	160000	84000	80000	1.0E+09(1)	0.25
2	1694	847	8754680	4377340	4377340	609739	0.25
3	1694	847	8754680	4377340	4377340	609739	0.25
4	1694	847	8754680	4377340	4377340	609739	0.25
5	1694	847	8754680	4377340	4377340	609739	0.25
6	1694	847	8754680	4377340	4377340	609739	0.25
7	1624	812	8377780	4188890	4188890	609739	0.25
8	1440	720	7383900	3691950	3691950	609739	0.25

(1) This value is selected to model the 'rigid' beam stiffness.

TABLE 4-4

CONTAINMENT INTERNAL STRUCTURE MODEL

(Nodal Coordinates in Local Coordinate System)

Node	X (ft)	Y (ft)	Z (ft)	Elevation (ft)	Remarks
1	0.0	0.0	171.8	171.8	Top of basemat
2	-2.2	0.0	195.0	195.0	
3	-5.7	-2.6	218.0	218.0	Operating level
4	4.3	-38.2	236.0	236.0	South steam generator compartment
5	6.0	37.8	236.0	236.0	North steam generator compartment
6	-6.5	-55.5	258.0	258.0	South steam generator compartment
7	12.4	53.4	258.0	258.0	North steam generator compartment
8	0.0	0.0	195.0	195.0	
9	0.0	0.0	218.0	218.0	Operating level
10	6.0	-33.0	218.0	218.0	Operating level
11	6.0	-33.0	236.0	236.0	
12	6.0	33.0	218.0	218.0	Operating level
13	6.0	33.0	236.0	236.0	
14	0.0	-58.0	236.0	236.0	
15	0.0	-58.0	258.0	258.0	
16	0.0	55.0	236.0	236.0	
17	0.0	55.0	258.0	258.0	
18	7.8	0.0	163.9	163.9	Basemat (Fixed base)

TABLE 4-5

CONTAINMENT INTERNAL STRUCTURE MODEL

(Mass Properties)

Node	Translational Inertia ($K-sec^2/ft$)			Rotational Inertia ($K-sec^2-ft$)		
	TX	TY	TZ	RX	RY	RZ
2	359.9	359.9	308.7	310178.	377776.	638363.
3	406.6	406.6	325.6	393408.	399098.	694171.
4	23.1	23.1	23.1	4305.	10110.	13395.
5	23.1	23.1	23.1	4055.	10131.	13258.
6	2.9	2.9	2.9	125.	1379.	1390.
7	2.9	2.9	2.9	117.	1426.	1430.

TABLE 4-6

CONTAINMENT INTERNAL STRUCTURE MODEL

(Stiffness Properties)

Beam Element No.	Axial Cross-Sectional Area (ft^2)	Shear Area Local Y-Axis (ft^2)	Shear Area Local Z-Axis (ft^2)	Torsional Moment of Inertia (ft^4)	Moment of Inertia About Local Y-Axis (ft^4)	Moment of Inertia About Local Z-Axis (ft^4)	Modulus of Elasticity (k/ft^2)	Poisson's Ratio μ
1	2870	1066	995	4735994	2202361	2533633	556618	0.25
2	2492	1217	702	5464150	2079600	3384550	556618	0.25
3	444	232	144	168958	55016	113942	556618	0.25
4	444	232	144	168958	55016	113942	556618	0.25
5	27	10	15	13500	2700	10800	556618	0.25
6	27	10	15	13500	2700	10800	556618	0.25

TABLE 4-7

CONTAINMENT SHELL FIXED-BASE MODEL

(Free Vibration Analysis)

Mode No.	Frequency (cps)	Modal Participation Factor		
		x	y	z
1	4.0	-0.000	35.775	-0.000
2	4.0	-35.726	-0.000	-0.018
3	8.9	0.000	0.043	0.000
4	11.6	-0.000	18.841	0.000
5	11.6	18.659	0.000	0.004
6	12.2	0.000	0.000	-38.836
7	21.3	0.000	7.548	-0.000
8	21.3	-7.278	0.000	-0.055
9	24.4	0.000	8.079	-0.000
10	24.4	-7.746	0.000	0.019
11	26.5	0.000	-0.143	-0.000
12	32.3	-0.000	-6.936	0.000
13	32.4	6.378	-0.000	0.047
14	36.0	0.000	0.000	12.661
15	37.3	0.000	-3.522	-0.000
16	37.3	3.124	0.000	-0.049
17	40.4	-0.000	0.291	0.000
18	40.8	-0.928	0.000	-0.145
19	40.8	0.000	1.070	0.000
20	44.6	-0.000	3.262	-0.000

TABLE 4-8

CONTAINMENT INTERNAL STRUCTURE FIXED-BASE MODEL

(Free Vibration Analysis)

Mode No.	Frequency (cps)	Modal Participation Factor		
		x	y	z
1	12.8	-0.164	26.631	-0.154
2	14.4	27.325	0.170	0.388
3	23.2	0.705	-0.324	-0.095
4	26.5	0.282	3.392	0.028
5	27.3	3.723	-0.582	-0.433
6	27.4	-0.516	-3.621	0.797
7	28.8	0.536	-1.119	0.288
8	33.3	-0.316	-7.308	2.550
9	37.1	-5.995	2.099	9.395
10	38.3	-2.220	-4.889	-0.705
11	41.5	2.446	-0.382	20.740
12	43.6	-0.922	-0.197	-8.047
13	46.3	0.071	-0.800	-0.894
14	47.7	2.828	0.129	-3.479
15	48.6	-0.424	0.316	-0.390
16	50.9	0.505	-0.209	-1.593
17	54.4	-0.192	0.060	4.632
18	55.6	-0.014	0.048	-0.172
19	58.1	0.530	0.089	-0.775
20	58.9	-0.354	0.079	-2.070

TABLE 4-9

AUXILIARY BUILDING MODEL

(Nodal Coordinates in Local Coordinate System)

Node	X (ft)	Y (ft)	Z (ft)	Elevation (ft)	Remarks
679	217.0	63.0	3.0	119.25	Basemat
680	217.0	65.0	27.25	143.5	
681	219.0	59.0	54.25	170.5	
682	217.0	58.0	78.75	195.0	
683	215.0	61.0	103.75	220.0	Grade level
684	338.0	55.0	123.75	240.0	
685	97.0	55.0	123.75	240.0	
686	336.0	61.0	143.75	260.0	
687	98.0	61.0	143.75	260.0	
688	217.0	61.0	172.0	288.25	Top of structure
689	217.0	63.0	-7.0	109.25	Bottom of basemat (Fixed base)

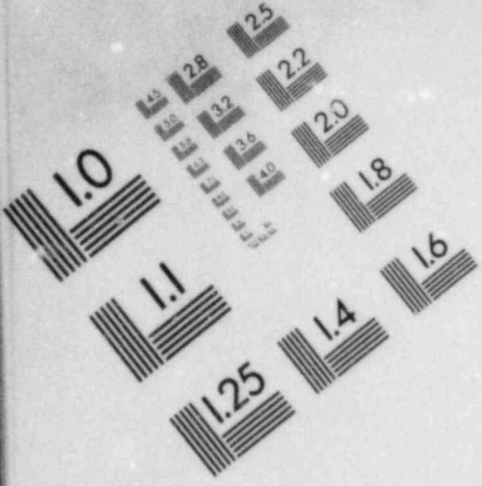
TABLE 4-10

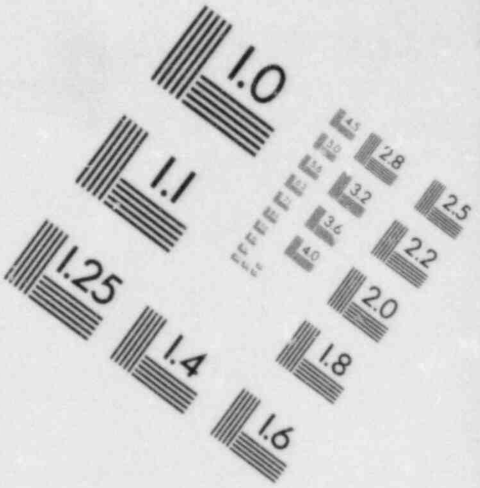
AUXILIARY BUILDING MODEL

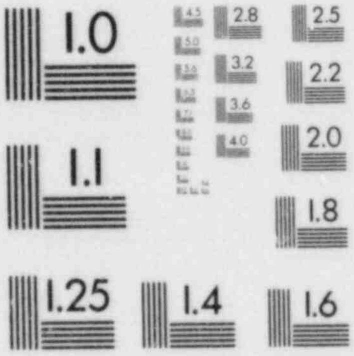
(Mass Properties)

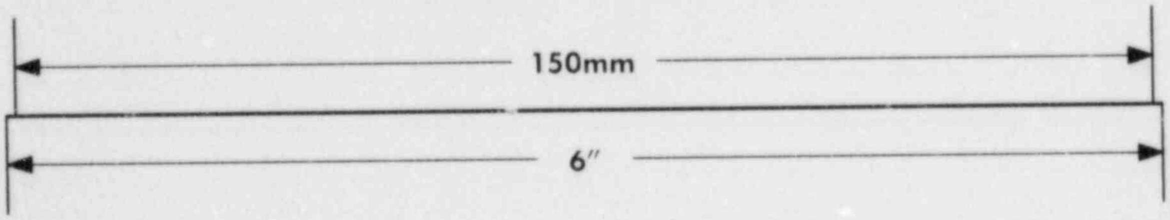
Node	Translational Inertia ($K\text{-}sec^2/ft$)			Rotational Inertia ($K\text{-}sec^2\text{-}ft$)		
	TX	TY	TZ	RX	RY	RZ
679	3996.	3996.	3996.	6026×10^3	62471×10^3	68115×10^3
680	2757.	2757.	2757.	4470×10^3	44136×10^3	48278×10^3
681	2765.	2765.	2765.	4010×10^3	38241×10^3	42018×10^3
682	2516.	2516.	2516.	3570×10^3	34077×10^3	39055×10^3
683	1548.	1548.	1548.	1967×10^3	23588×10^3	25317×10^3
684	627.	627.	627.	860.4×10^3	2039×10^3	2874×10^3
685	627.	627.	627.	860.4×10^3	2039×10^3	2874×10^3
686	480.	480.	480.	694.4×10^3	1704×10^3	2384×10^3
687	480.	480.	480.	694.4×10^3	1704×10^3	2384×10^3
688	117.	117.	117.	201.7×10^3	37.225×10^3	231.86×10^3

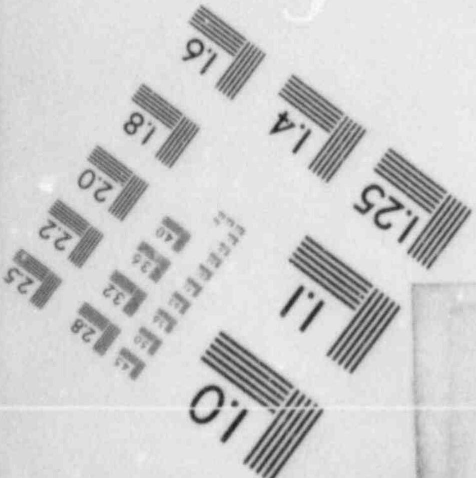
IMAGE EVALUATION
TEST TARGET (MT-3)

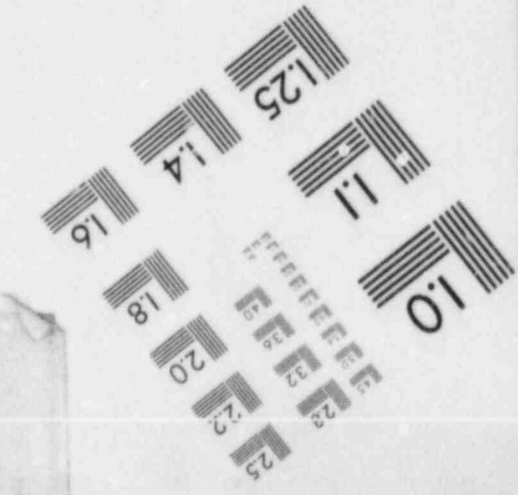












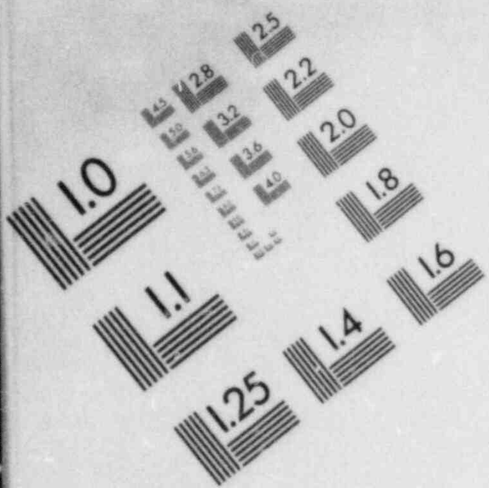
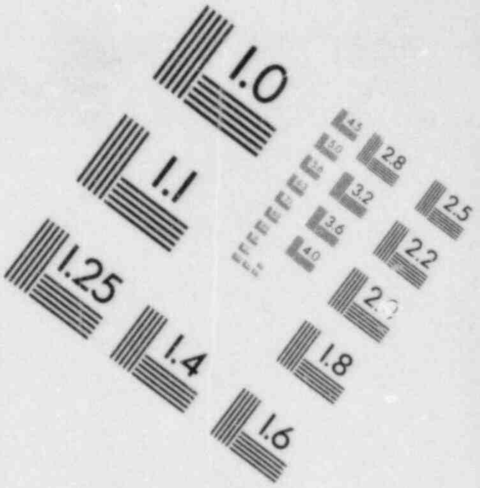
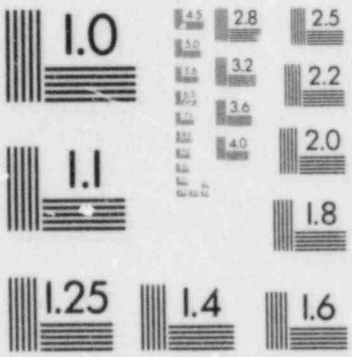
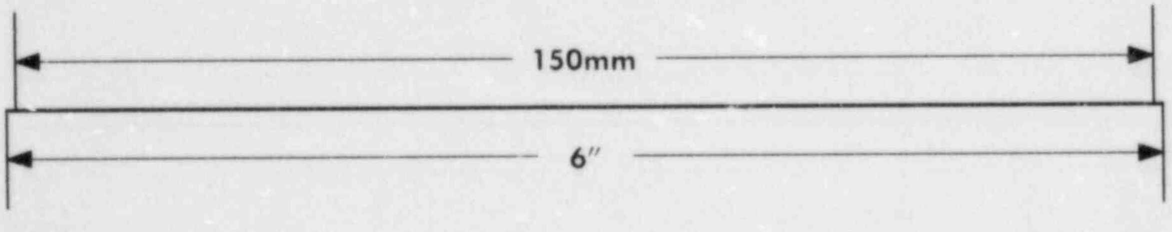
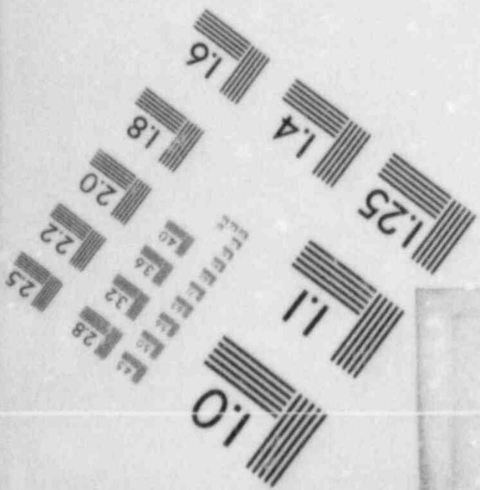


IMAGE EVALUATION
TEST TARGET (MT-3)









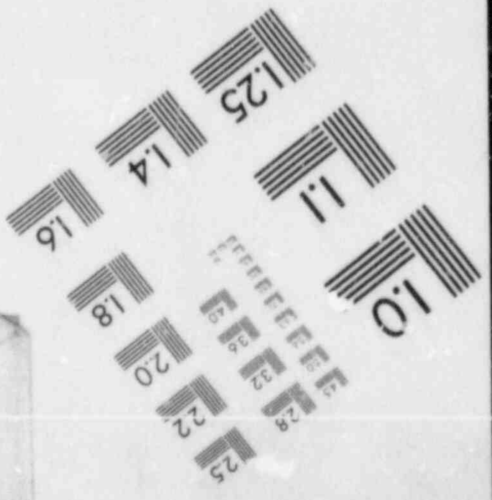


TABLE 4-11

AUXILIARY BUILDING FIXED-BASE MODEL

(Free Vibration Analysis)

Mode No.	Frequency (cps)	Modal Participation Factor		
		x	y	z
1	5.5	-1.137	91.900	0.148
2	6.7	78.601	4.628	0.016
3	7.0	56.429	-4.691	-0.019
4	12.5	-0.123	-42.729	0.330
5	14.3	-10.329	2.327	0.033
6	15.1	-18.639	-1.558	0.939
7	16.6	3.134	-0.069	-93.112
8	16.9	-29.082	0.586	-12.322
9	17.5	0.421	25.533	-0.874
10	17.7	0.091	-5.888	-16.675
11	18.6	-16.656	-1.197	3.523
12	18.8	-3.808	2.543	-3.373
13	19.7	1.499	3.159	0.079
14	21.7	-1.999	-0.288	0.071
15	22.0	0.481	-6.142	10.103
16	24.7	-21.790	0.388	0.208
17	26.5	-0.867	-23.491	1.074
18	26.7	-11.513	1.756	-0.002
19	28.9	-0.554	-1.160	-4.531
20	29.1	1.195	-2.155	-1.196

TABLE 4-12

CONTROL BUILDING MODEL

(Nodal Coordinates in Local Coordinate System)

Node	X (ft)	Y (ft)	Z (ft)	Elevation (ft)	Remarks
970	0.0	97.6	-7.0	173.0	Bottom of basemat (Fixed base)
971	0.0	97.6	0.0	180.0	Basemat
972	0.1	103.9	23.0	203.0	
973	3.1	102.8	42.75	222.75	Grade level
974	-25.4	82.5	62.75	242.75	
975	-24.9	84.9	82.75	262.75	
976	-1.0	78.6	102.50	282.50	Top of structure
977	20.6	30.5	82.75	262.75	MSIV Room branch

TABLE 4-13

CONTROL BUILDING MODEL

(Mass Properties)

Node	Translational Inertia ($K\text{-}sec^2/ft$)			Rotational Inertia ($K\text{-}sec^2\text{-}ft$)		
	TX	TY	TZ	RX	RY	RZ
971	3213.	3213.	3213.	6415342.	66028304.	72351317.
972	1957.	1957.	1957.	3767571.	45481514.	49184783.
973	1933.	1933.	1933.	3377283.	42735064.	46062456.
974	767.	767.	767.	1724017.	7307881.	9003405.
975	798.	798.	798.	1714790.	4082555.	5771755.
976	590.	590.	590.	975454.	967462.	1932985.
977	91.	91.	91.	30996.	23563.	41872.

TABLE 4-14

CONTROL BUILDING FIXED-BASE MODEL

(Free Vibration Analysis)

Mode No.	Frequency (cps)	Modal Participation Factor		
		x	y	z
1(1)	0.8	-1.659	9.581	-0.006
2(1)	1.6	-0.475	-0.114	-9.640
3	3.8	-1.973	-59.543	0.179
4	7.6	-27.199	25.647	-32.366
5	7.9	-6.913	-25.735	-37.679
6	8.9	59.210	6.162	-19.049
7	10.5	-3.801	-12.332	-0.524
8	10.7	9.346	13.593	-2.058
9	15.7	2.538	0.819	-33.835
10	16.0	-6.596	6.324	1.913
11	18.4	-38.427	2.400	-8.657
12	19.5	-3.707	6.966	4.608
13	20.6	-7.130	-4.326	31.246
14	23.7	0.908	-20.656	-9.787
15	27.7	-0.137	16.825	-2.348
16	28.8	-10.063	-1.728	-1.145
17	31.1	-1.969	-2.042	7.821
18	40.5	-10.407	-0.800	-1.109
19	40.8	-0.850	0.010	0.226
20	43.9	-8.397	0.842	-0.912

(1) MSIV Room modes

TABLE 4-15

FUEL HANDLING BUILDING MODEL

(Nodal Coordinates in Local Coordinate System)

Node	X (ft)	Y (ft)	Z (ft)	Elevation (ft)	Remarks
238	0.0	32.98	-6.0	154.	Bottom of basemat (Fixed base)
241	0.0	32.98	0.0	160.	Basemat
243	0.0	38.36	19.0	179.	
244	0.0	39.58	40.0	200.	
245	-46.0	40.0	47.75	207.75	Liquid mass TX only
246	-45.0	41.0	48.8	208.8	Liquid mass TY only
247	46.0	40.0	47.75	207.75	Liquid mass TX only
248	45.0	41.0	48.8	208.8	Liquid mass TY only
249	0.0	34.66	60.0	220.	Grade level
250	-60.4	30.6	103.7	263.7	Unit 2 branch
251	60.0	30.8	103.7	263.7	Unit 1 branch
252	1.35	36.25	128.2	288.2	Top of structure

TABLE 4-16

FUEL HANDLING BUILDING MODEL

(Mass Properties)

Node	Translational Inertia ($K\text{-}sec^2/ft$)			Rotational Inertia ($K\text{-}sec^2\text{-}ft$)		
	TX	TY	TZ	RX	RY	RZ
241	316.	316.	316.	145718.	2059979.	2197787.
243	758.	803.	1032.	524862.	3116476.	2992480.
244	811.	758.	643.	422857.	2079099.	2705622.
245	43.	0.	0.	0.	0.	0.
246	0.	29.5	0.	0.	0.	0.
247	43.	0.	0.	0.	0.	0.
248	0.	29.5	0.	0.	0.	0.
249	510.	525.	474.	310336.	2090746.	2385320.
250	145.	145.	145.	91366.	69106.	131154.
251	151.	151.	151.	94330.	70167.	134708.
252	182.	182.	182.	115822.	416338.	512432.

TABLE 4-17

FUEL HANDLING BUILDING FIXED-BASE MODEL

(Free Vibration Analysis)

Mode No.	Frequency (cps)	Modal Participation Factor		
		x	y	z
1(1)	0.23	9.282	-0.000	-0.000
2(1)	0.23	-0.000	0.000	-0.000
3(1)	0.27	0.000	-7.689	0.000
4(1)	0.27	-0.000	-0.027	0.000
5	6.1	0.117	36.069	-0.240
6	6.8	45.065	-0.125	-0.017
7	10.4	-7.069	-0.233	-0.011
8	11.6	-21.546	-0.001	-0.040
9	13.3	0.010	-32.338	0.592
10	19.6	-0.659	-0.377	-0.431
11	20.6	-0.022	0.538	-41.699
12	22.1	-0.008	0.134	0.012
13	23.7	-0.668	0.426	2.208
14	23.9	-0.183	-3.459	0.878
15	27.9	-0.013	12.933	6.787
16	29.7	1.634	-0.451	-0.742
17	34.3	-0.059	-4.398	-12.120
18	34.8	-0.139	3.530	-24.754
19	36.7	-2.810	-0.471	0.428
20	38.2	-0.859	0.603	1.209

(1) Liquid sloshing modes

TABLE 4-18

NSCW TOWER MODEL (Sheet 1 of 2)

(Nodal Coordinates in Local Coordinate System)

Node	X (ft)	Y (ft)	Z (ft)	Elevation (ft)	Remarks
1	0.0	0.0	137.0	137.0	
2	0.0	0.0	152.0	152.0	
3	0.0	0.0	180.0	180.0	
4	0.0	0.0	195.42	195.42	
5	0.0	0.0	200.0	200.0	
6	0.0	0.0	209.75	209.75	
7	0.0	0.0	218.5	218.5	
8	0.0	0.0	128.0	128.0	Bottom of basemat (Fixed base)
9	0.0	0.0	144.42	144.42	Water mass
10	-2.1	2.1	137.0	137.0	Basemat
11	-7.7	7.7	152.0	152.0	
12	0.0	0.0	176.5	176.5	Water mass
13	-9.1	9.1	180.0	180.0	
14	-1.0	0.0	195.42	195.42	Water mass
15	0.0	1.0	195.42	195.42	Water mass
16	-9.43	9.43	200.0	200.0	
17	-9.7	9.7	209.75	209.75	
18	-4.75	4.75	218.5	218.5	Grade level
19	0.0	0.0	231.75	231.75	Fill beam

TABLE 4-18

NSCW TOWER MODEL (Sheet 2 of 2)

(Nodal Coordinates in Local Coordinate System)

Node	X (ft)	Y (ft)	Z (ft)	Elevation (ft)	Remarks
20	0.0	0.0	230.75	230.75	
21	0.0	0.0	243.4	243.4	Eliminator beam
22	0.0	0.0	242.4	242.4	
23	0.0	0.0	250.91	250.91	Top of structure

TABLE 4-19

NSCW TOWER MODEL

(Mass Properties)

Node	Translational Inertia ($K-sec^2/ft$)			Rotational Inertia ($K-sec^2-ft$)		
	TX	TY	TZ	RX	RY	RZ
9	173.85	173.85	0.	0.	0.	0.
10	402.9	402.9	1354.7	766030.	766030.	587266.
11	134.0	134.0	134.0	152355.	152355.	281312.
12	551.0	551.0	0.	0.	0.	0.
13	126.0	126.0	126.0	141136.	141136.	269060.
14	238.0	0.	0.	0.	0.	0.
15	0.	238.0	0.	0.	0.	0.
16	78.0	78.0	78.0	86139.	86139.	167632.
17	49.7	49.7	49.7	54047.	54047.	106385.
18	49.0	49.0	49.0	43309.	43309.	84579.
19	0.	0.	31.65	0.	0.	0.
20	85.25	85.25	53.60	58578.	58578.	114010.
21	0.	0.	13.77	0.	0.	0.
22	70.57	70.57	56.80	56906.	56906.	107529.
23	112.6	112.6	112.6	64951.	64951.	123545.

TABLE 4-20

NSCW TOWER MODEL (Sheet 1 of 2)

(Stiffness Properties)

Beam Element No.	Axial Cross-Sectional Area (ft^2)	Shear Area (ft^2)	Torsional Moment of Inertia (ft^4)	Moment of Inertia About Local Y-Axis (ft^4)	Moment of Inertia About Local Z-Axis (ft^4)	Modulus of Elasticity (k/ft^2)	Poisson's Ratio μ
1	12	7	22000	14000	14000	1.0E+09 (1)	0.25
2	12	7	22000	14000	14000	1.0E+09 (1)	0.25
3	1760	979	3842740	1960166	1960166	519120	0.25
4	1157	677	2062540	1229862	1229862	519120	0.25
5	12	7	22000	14000	14000	1.0E+09 (1)	0.25
6	1157	677	2062540	1229862	1229862	519120	0.25
7	1157	677	2062540	1229862	1229862	519120	0.25
8	1157	677	2062540	1229862	1229862	519120	0.25
9	780	649	25278	563913	563913	519120	0.25
10	1206	718	1957486	1001360	1001360	519120	0.25
11	1206	718	1957486	1001360	1001360	519120	0.25

(1) This value is selected to model the 'rigid' beam stiffness.

TABLE 4-20

NSCW TOWER MODEL (Sheet 2 of 2)

(Stiffness Properties)

Truss Element No.	Modulus of Elasticity (k/ft^2)	Axial Cross-Sectional Area (ft^2)
1	1.0	320
2	1.0	320
3	1.0	667800
4	1.0	172100

TABLE 4-21

NSCW TOWER FIXED-BASE MODEL

(Free Vibration Analysis)

Mode No.	Frequency (cps)	Modal Participation Factor		
		x	y	z
1(1)	0.18	10.913	-10.918	0.000
2(1)	0.18	10.918	10.913	0.000
3	5.4	-0.576	-0.576	0.000
4	6.8	-22.045	22.045	-0.940
5	6.8	22.086	22.086	0.000
6	14.7	-10.668	10.668	3.209
7	14.7	-10.508	-10.508	-0.000
8	16.9	-0.635	0.635	-14.661
9	19.6	1.368	1.368	0.000
10	19.8	-0.306	0.306	-15.499
11	25.8	-0.117	0.117	-11.307
12	31.5	-0.481	0.481	1.242
13	31.7	0.489	0.489	-0.000
14	43.5	-1.420	1.420	1.628
15	44.5	-1.646	-1.646	0.000
16	54.9	-4.516	-4.516	0.000
17	56.8	1.170	-1.170	-6.295
18	58.1	-5.666	-5.666	0.000
19	58.3	7.546	-7.546	1.454
20	64.5	-0.911	-0.911	0.000

(1) Water sloshing modes

TABLE 4-22

DIESEL GENERATOR BUILDING MODEL

(Nodal Coordinates in Local Coordinate System)

Node	X (ft)	Y (ft)	Z (ft)	Elevation (ft)	Remarks
31	46.0	-57.0	213.0	213.0	Bottom of basemat (Fixed base)
32	46.1	-56.9	218.5	218.5	Basemat (Grade level)
33	45.3	-58.6	251.5	251.5	
34	41.5	-62.9	271.1	271.1	Top of structure

TABLE 4-23

DIESEL GENERATOR BUILDING MODEL

(Mass Properties)

Node	Translational Inertia ($K\text{-}sec^2/ft$)			Rotational Inertia ($K\text{-}sec^2\text{-}ft$)		
	TX	TY	TZ	RX	RY	RZ
32	425.2	425.2	425.2	502890.	339440.	818870.
33	268.6	268.6	268.6	350855.	240607.	572406.
34	111.2	111.2	111.2	79676.	85200.	162507.

TABLE 4-24

DIESEL GENERATOR BUILDING FIXED-BASE MODEL

(Free Vibration Analysis)

Mode No.	Frequency (cps)	Modal Participation Factor		
		x	y	z
1	9.0	19.346	-0.156	0.067
2	13.5	0.319	19.368	0.395
3	16.6	2.229	-1.420	-0.008
4	28.5	-1.309	-0.810	14.503
5	29.4	1.395	-0.799	12.214
6	35.1	-0.006	2.903	4.694
7	38.1	0.115	0.303	2.070
8	40.4	-0.206	0.005	-1.222
9	45.5	-0.066	-0.588	1.316
10	82.3	0.044	-0.139	-1.576
11	91.9	0.053	-0.055	1.058
12	107.5	-0.052	-0.015	-0.003
13	109.1	0.041	0.102	-0.522
14	147.3	20.518	-0.073	-0.350
15	147.6	-0.067	-20.388	0.347
16	217.9	-0.005	1.346	-0.236
17	234.9	0.367	0.377	20.288
18	263.9	0.899	0.000	-0.021

TABLE 4-25

AUXILIARY FEEDWATER PUMPHOUSE MODEL

(Nodal Coordinates in Local Coordinate System)

Node	X (ft)	Y (ft)	Z (ft)	Elevation (ft)	Remarks
1	0.0	0.0	2.5	215.8	Basemat (Fixed base)
2	-19.0	-0.4	2.5	215.8	
3	19.0	-0.4	2.5	215.8	
4	0.0	35.6	2.5	215.8	
5	0.0	20.6	2.5	215.8	
6	0.0	5.6	2.5	215.8	
7	0.0	-13.4	2.5	215.8	
8	0.0	-36.4	2.5	215.8	
9	0.0	0.0	0.0	213.3	
10	0.0	0.0	18.8	232.1	Top of structure
11	-19.0	-0.4	18.8	232.1	
12	19.0	-0.4	18.8	232.1	
13	0.0	35.6	18.8	232.1	
14	0.0	20.6	18.8	232.1	
15	0.0	5.6	18.8	232.1	
16	0.0	-13.4	18.8	232.1	
17	0.0	-36.4	18.8	232.1	

TABLE 4-26

AUXILIARY FEEDWATER PUMPHOUSE MODEL

(Mass Properties)

Node	Translational Inertia ($K-sec^2/ft$)			Rotational Inertia ($K-sec^2-ft$)		
	TX	TY	TZ	RX	RY	RZ
10	66.12	66.12	66.12	30681.4	13130.7	40079.5

TABLE 4-27

AUXILIARY FEEDWATER PUMPHOUSE MODEL

(Stiffness Properties)

Beam Element No.	Axial Cross-Sectional Area (ft^2)	Shear Area Local Y-Axis (ft^2)	Shear Area Local Z-Axis (ft^2)	Torsional Moment of Inertia (ft^4)	Moment of Inertia About Local Y-Axis (ft^4)	Moment of Inertia About Local Z-Axis (ft^4)	Modulus of Elasticity (k/ft^2)	Poisson's Ratio μ
1	148	0	126	100	67537	49	519000	0.25
2	64	0	54	100	5461	21	519000	0.25
3	148	0	126	100	67537	49	519000	0.25
4	80	68	0	100	27	10667	591000	0.25
5	80	68	0	100	27	10667	591000	0.25
6	80	68	0	100	27	10667	591000	0.25
7	80	68	0	100	27	10667	591000	0.25
8(1)	1	0	0	307424	10	10	591000	0.25

(1) Beam element utilized to represent the combined torsional stiffness of the structure.

TABLE 4-28

AUXILIARY FEEDWATER PUMPHOUSE FIXED-BASE MODEL

(Free Vibration Analysis)

Mode No.	Frequency (cps)	Modal Participation Factor		
		x	y	z
1	35.4	8.095	-0.000	0.000
2	38.5	0.000	8.115	0.022
3	68.3	-0.216	-0.000	0.000
4	90.9	0.000	0.000	-8.067
5	98.5	0.740	-0.000	0.000
6	102.9	0.000	-0.508	-1.019

TABLE 4-29

CONDENSATE STORAGE TANK MODEL (Sheet 1 of 2)

(Nodal Coordinates in Local Coordinate System)

Node	X (ft)	Y (ft)	Z (ft)	Elevation (ft)	Remarks
1	0.0	26.0	53.2	269.2	Top (North tank)
2	0.0	26.0	42.25	258.25	
3	0.0	26.0	29.5	245.5	
4	0.0	26.0	16.75	232.75	
5	-22.6	0.0	30.1	246.1	Missile protection structure
6	0.0	-26.0	53.2	269.2	Top (South tank)
7	0.0	-26.0	42.25	258.25	
8	0.0	-26.0	29.5	245.5	
9	0.0	-26.0	16.75	232.75	
10	0.0	0.0	4.0	220.0	Basemat
11	0.0	0.0	0.0	216.0	Bottom of basemat (Fixed base)
12	0.0	26.0	36.0	252.0	Water mass
13	0.0	-26.0	36.0	252.0	Water mass
14	0.0	26.0	10.5	226.5	Water mass
15	0.0	-26.0	10.5	226.5	Water mass
16	0.5	27.0	39.0	255.1	Water mass
17	1.5	26.0	39.0	255.1	Water mass
18	0.5	-25.0	39.0	255.1	Water mass
19	1.5	-26.0	39.0	255.1	Water mass

TABLE 4-29

CONDENSATE STORAGE TANK MODEL (Sheet 2 of 2)

(Nodal Coordinates in Local Coordinate System)

Node	X (ft)	Y (ft)	Z (ft)	Elevation (ft)	Remarks
20	0.5	26.0	39.0	255.1	
21	0.5	-26.0	39.0	255.1	
22	-24.1	-1.3	30.1	246.1	
23	-24.1	-1.3	4.0	220.0	Top of Basemat
24	0.0	26.0	4.0	220.0	Top of Basemat
25	0.0	-26.0	4.0	220.0	Top of Basemat

TABLE 4-30

CONDENSATE STORAGE TANK MODEL

(Mass Properties)

Node	Translational Inertia ($K\text{-}sec^2/ft$)			Rotational Inertia ($K\text{-}sec^2\text{-}ft$)		
	TX	TY	TZ	RX	RY	RZ
1	22.77	22.77	22.77	4378.	4378.	8637.
2	17.17	17.17	17.17	4782.	4782.	9100.
3	17.17	17.17	17.17	4782.	4782.	9100.
4	17.17	17.17	17.17	4782.	4782.	9100.
5	12.51	12.51	12.51	1686.	1171.	2275.
6	22.77	22.77	22.77	4378.	4378.	8637.
7	17.17	17.17	17.17	4782.	4782.	9100.
8	17.17	17.17	17.17	4782.	4782.	9100.
9	17.17	17.17	17.17	4782.	4782.	9100.
10	77.05	77.05	348.13	89120.	29890.	119350.
11	120.51	120.51	120.51	139390.	46750.	186680.
12	69.34	69.34	0.	0.	0.	0.
13	69.34	69.34	0.	0.	0.	0.
14	38.31	38.31	0.	0.	0.	0.
15	38.31	38.31	0.	0.	0.	0.
16	0.	20.68	0.	0.	0.	0.
17	20.68	0.	0.	0.	0.	0.
18	0.	20.68	0.	0.	0.	0.
19	20.68	0.	0.	0.	0.	0.

TABLE 4-31
CONDENSATE STORAGE TANK MODEL (Sheet 1 of 2)
(Stiffness Properties)

Beam Element No.	Axial Cross-Sectional Area (ft^2)	Shear Area (ft^2)	Torsional Moment of Inertia (ft^4)	Moment of Inertia About Local Y-Axis (ft^4)	Moment of Inertia About Local Z-Axis (ft^4)	Modulus of Elasticity (k/ft^2)	Poisson's Ratio μ
1	289	153	152895	76448	76448	519120	0.25
2	289	153	152895	76448	76448	519120	0.25
3	289	153	152895	76448	76448	519120	0.25
4	289	153	152895	76448	76448	519120	0.25
5	73	62.	2538	14754	7130	519120	0.25
6	289	153	152895	76448	76448	519120	0.25
7	289	153	152895	76448	76448	519120	0.25
8	289	153	152895	76448	76448	519120	0.25
9	289	153	152895	76448	76448	519120	0.25
10	289	153	152895	76448	76448	15600000(1)	0.25
11	289	153	152895	76448	76448	15600000(1)	0.25
12	289	153	152895	76448	76448	15600000(1)	0.25
13	289	153	152895	76448	76448	15600000(1)	0.25
14	289	153	152895	76448	76448	15600000(1)	0.25

(1) This value is selected to model the 'rigid' beam stiffness.

TABLE 4-31

CONDENSATE STORAGE TANK MODEL (sheet 2 of 2)

(Stiffness Properties)

Truss Element No.	Modulus of Elasticity (k/ft^2)	Axial Cross-Sectional Area (ft^2)
1	1.0	56
2	1.0	56
3	1.0	56
4	1.0	56

TABLE 4-32

CONDENSATE STORAGE TANK FIXED-BASE MODEL

(Free Vibration Analysis)

Mode No.	Frequency (cps)	Modal Participation Factor		
		x	y	z
1(1)	0.26	0.000	6.434	-0.000
2(1)	0.26	-6.434	0.000	-0.000
3(1)	0.26	-0.000	-0.058	0.000
4(1)	0.26	0.000	0.000	-0.000
5	12.1	-0.221	17.596	-0.000
6	12.1	-17.597	-0.220	-0.004
7	12.2	0.000	0.001	0.000
8	12.2	-0.000	0.000	-0.000
9	14.8	-0.534	0.530	0.006
10	23.0	-3.337	-0.243	0.184
11	26.6	0.156	-3.423	0.098
12	29.2	-0.002	0.052	-0.002
13	29.3	0.000	0.000	-0.000
14	32.2	0.008	6.719	0.001
15	32.2	6.730	-0.007	-0.003
16	32.2	-0.000	0.011	0.001
17	32.3	0.000	0.000	0.000
18	42.5	0.000	-0.058	0.003
19	42.8	-0.002	-0.001	-11.830
20	49.8	3.373	-0.109	-0.017

(1)Water sloshing modes

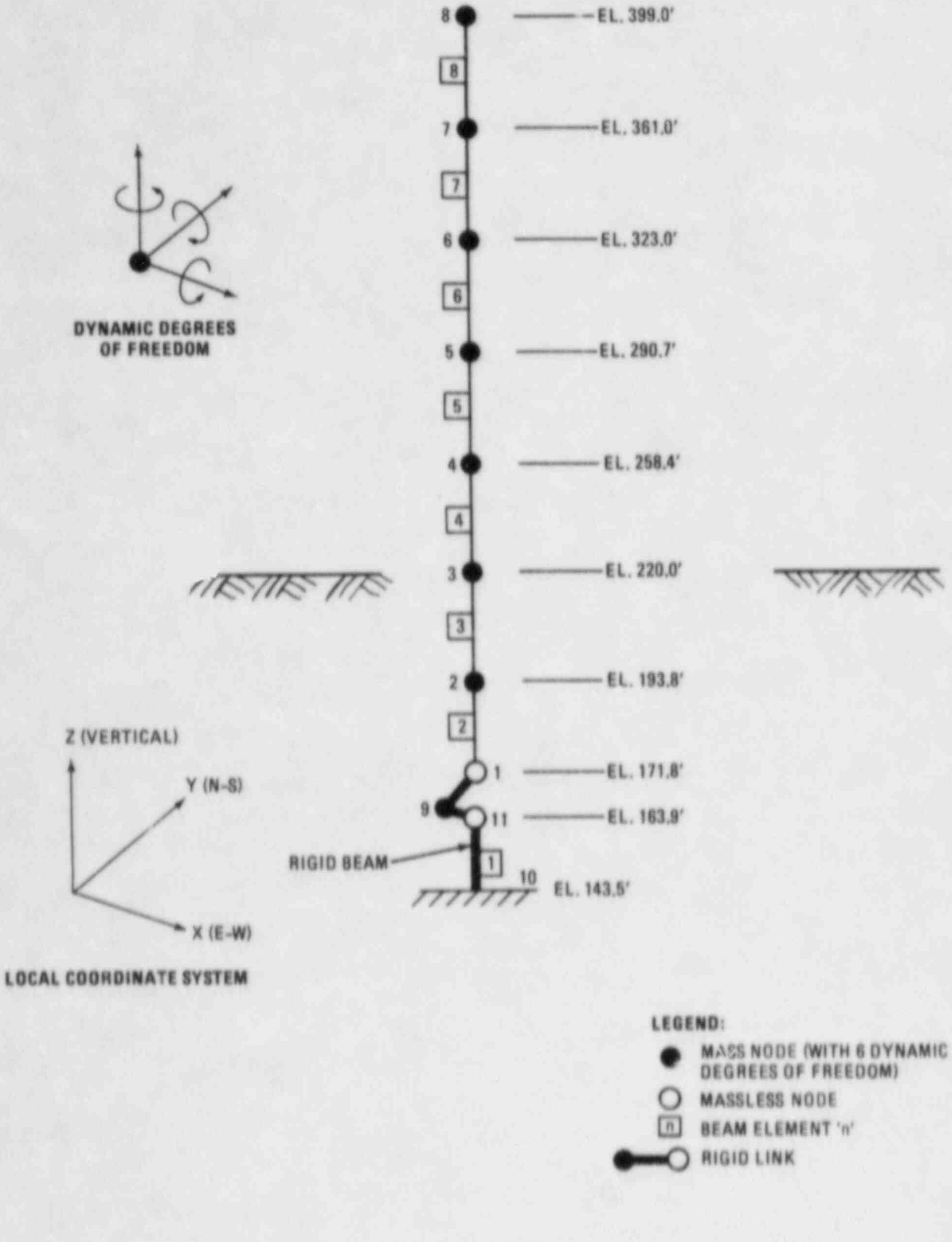


Figure 4-1
CONTAINMENT SHELL FIXED-BASE MODEL

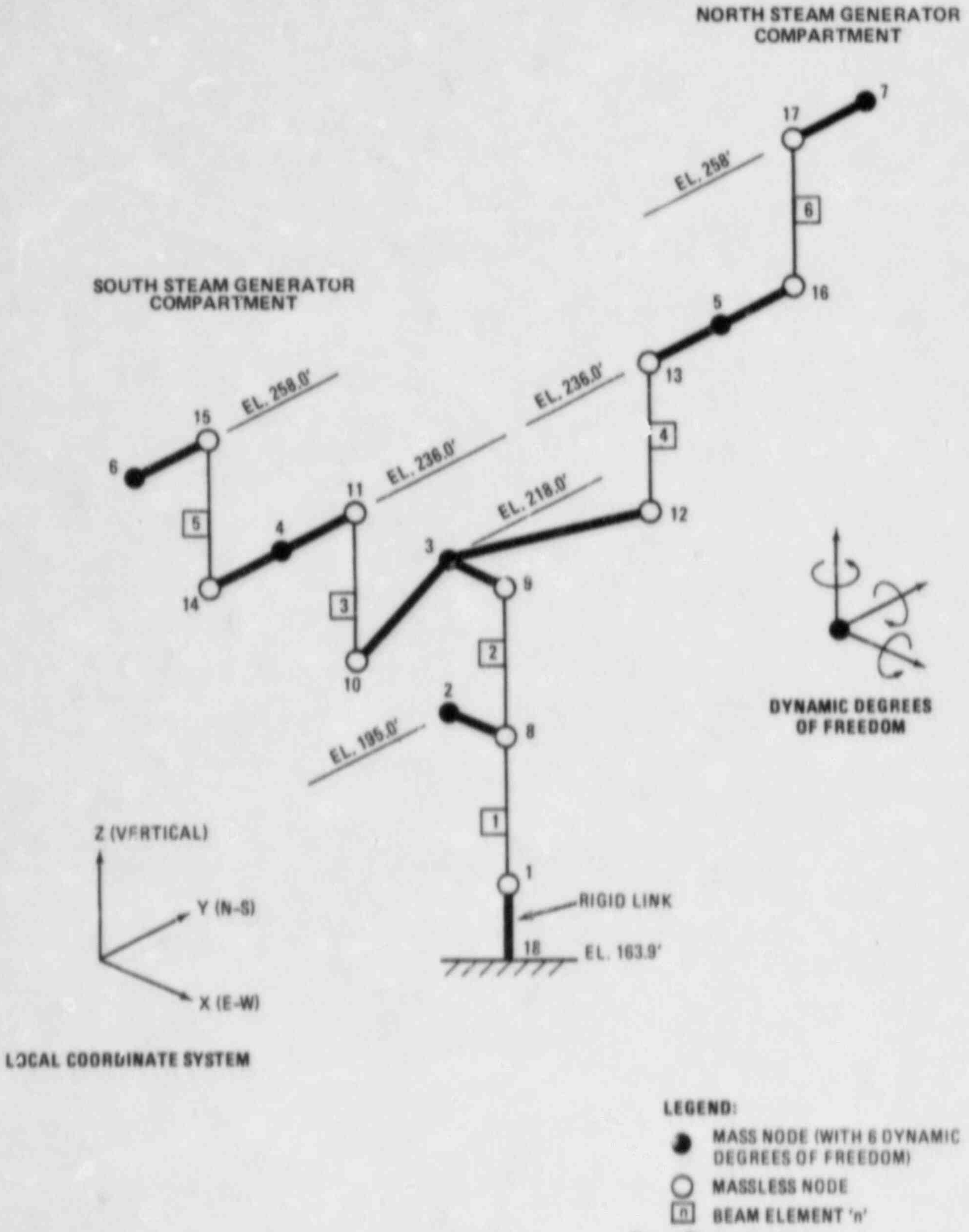


Figure 4-2
CONTAINMENT INTERNAL STRUCTURE FIXED-BASE MODEL

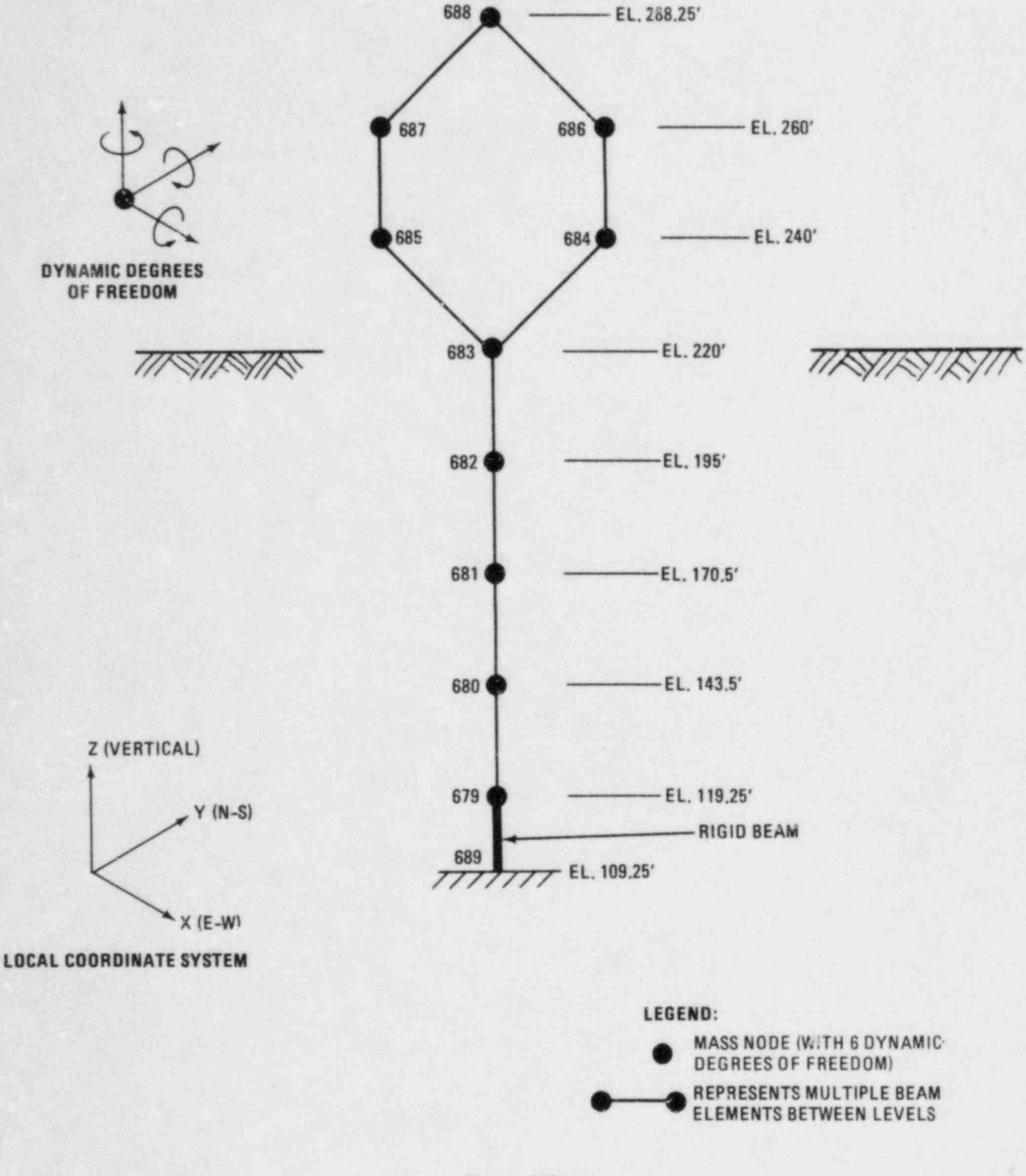


Figure 4-3
AUXILIARY BUILDING FIXED-BASE MODEL

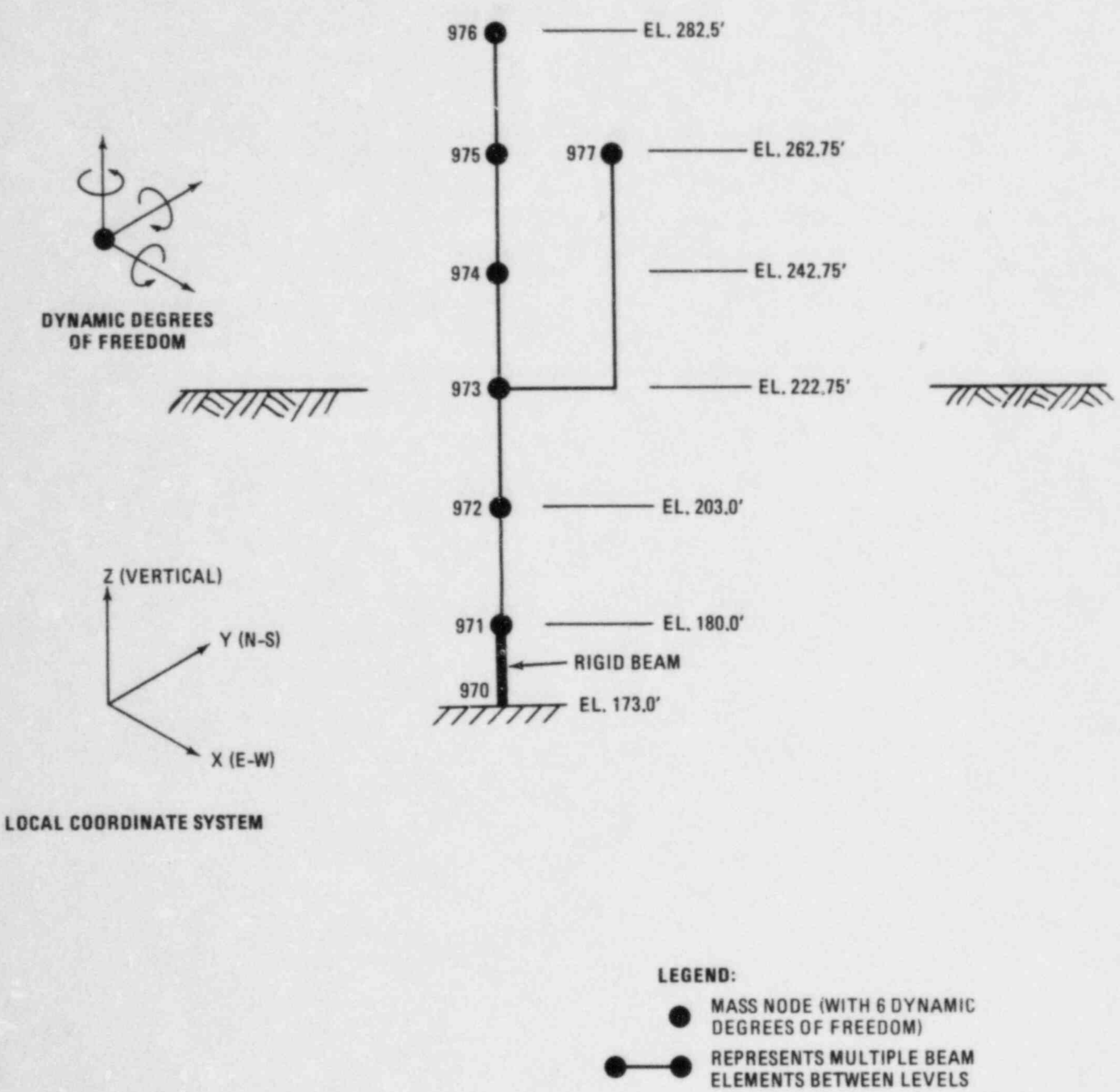


Figure 4-4
CONTROL BUILDING FIXED-BASE MODEL

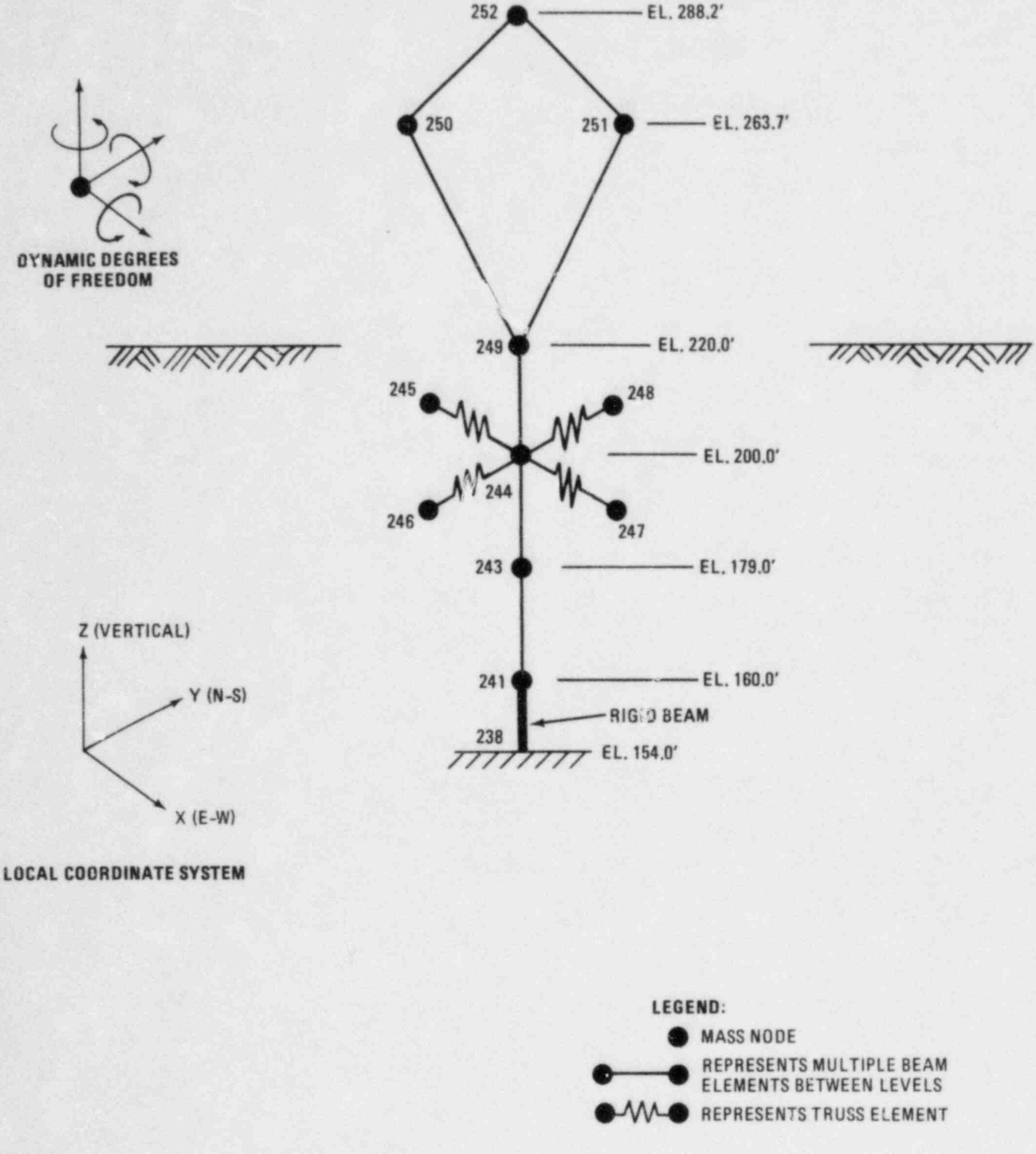


Figure 4-5
FUEL HANDLING BUILDING FIXED-BASE MODEL

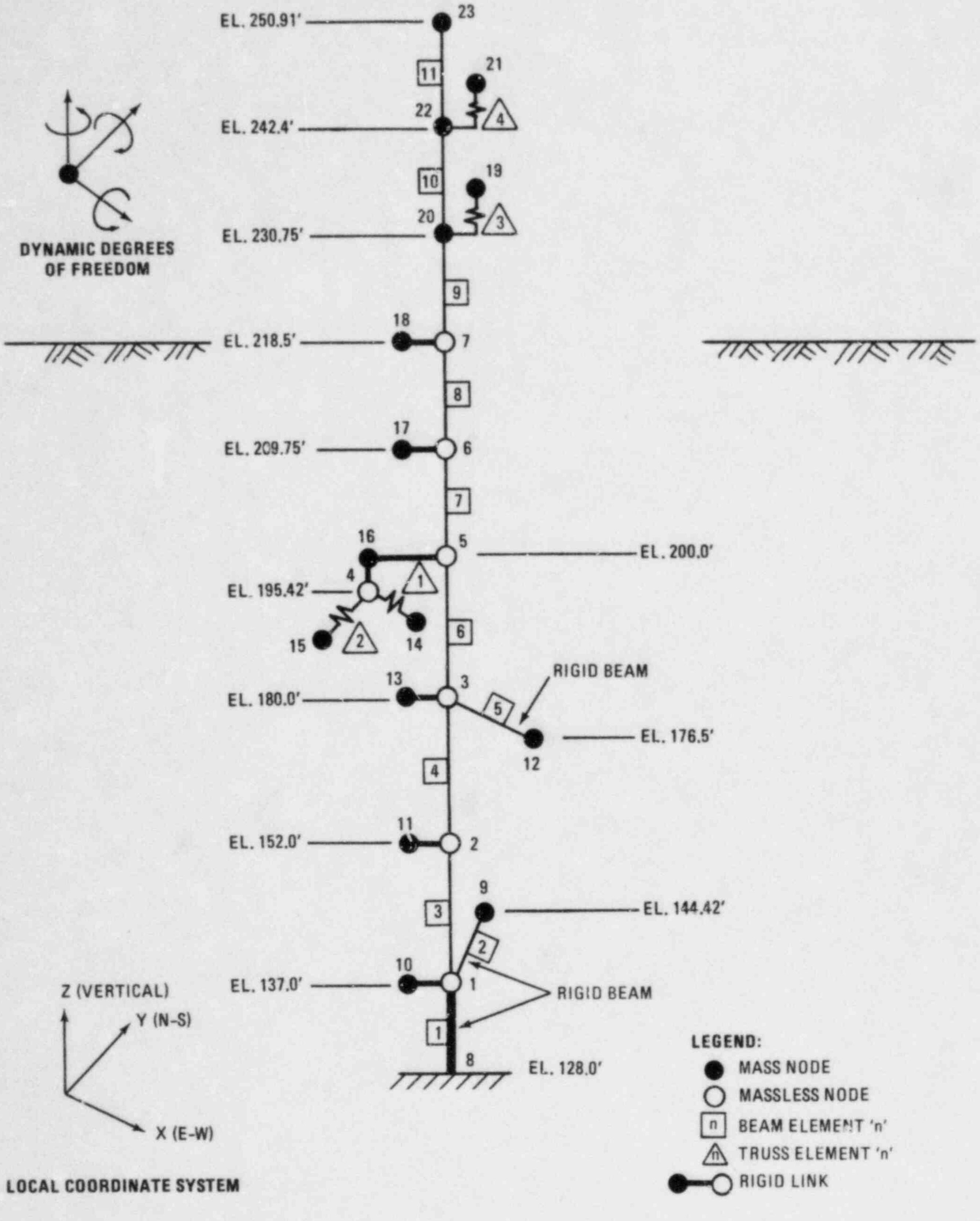


Figure 4-6
NSCW TOWER FIXED-BASE MODEL

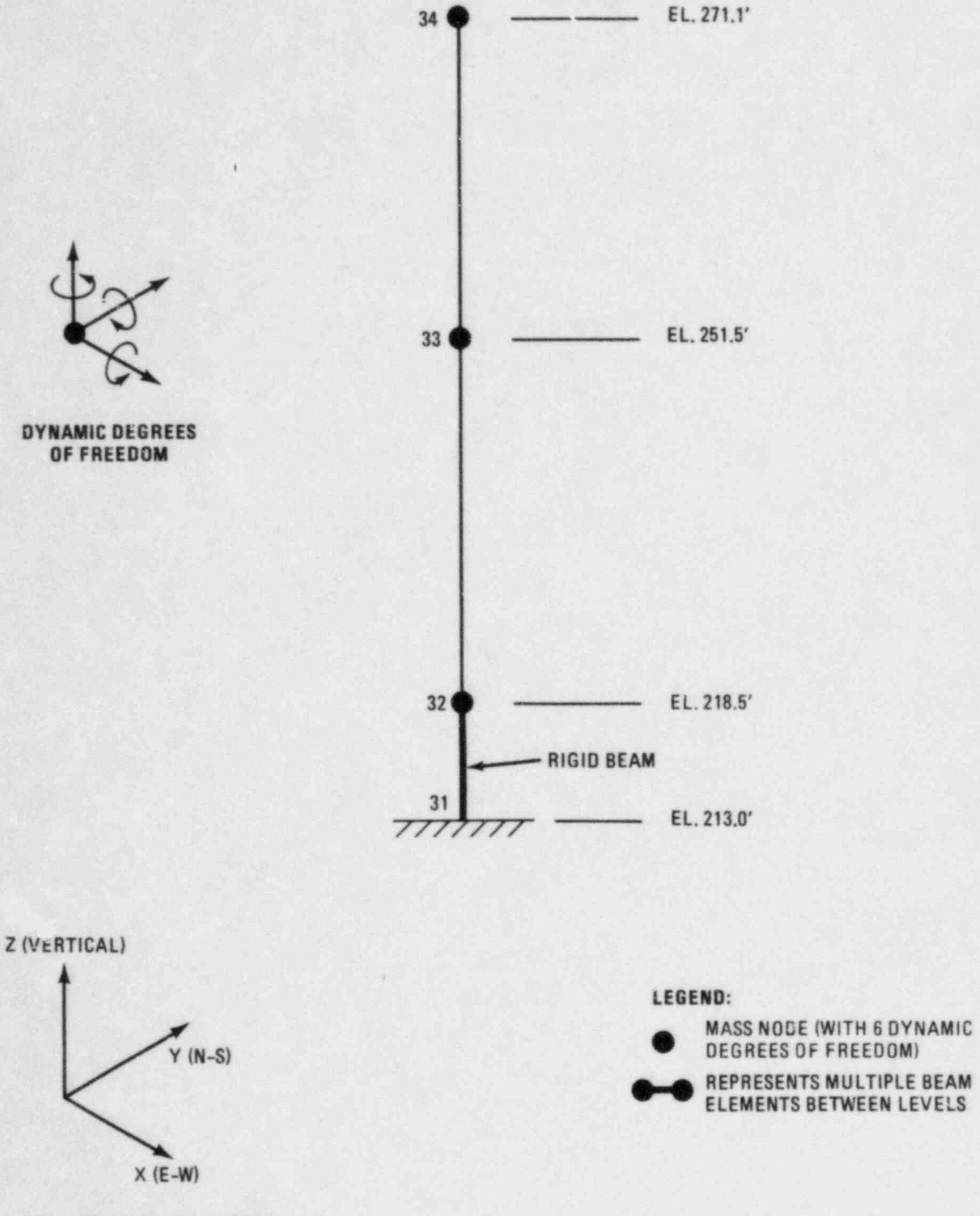


Figure 4-7
DIESEL GENERATOR BUILDING FIXED-BASE MODEL

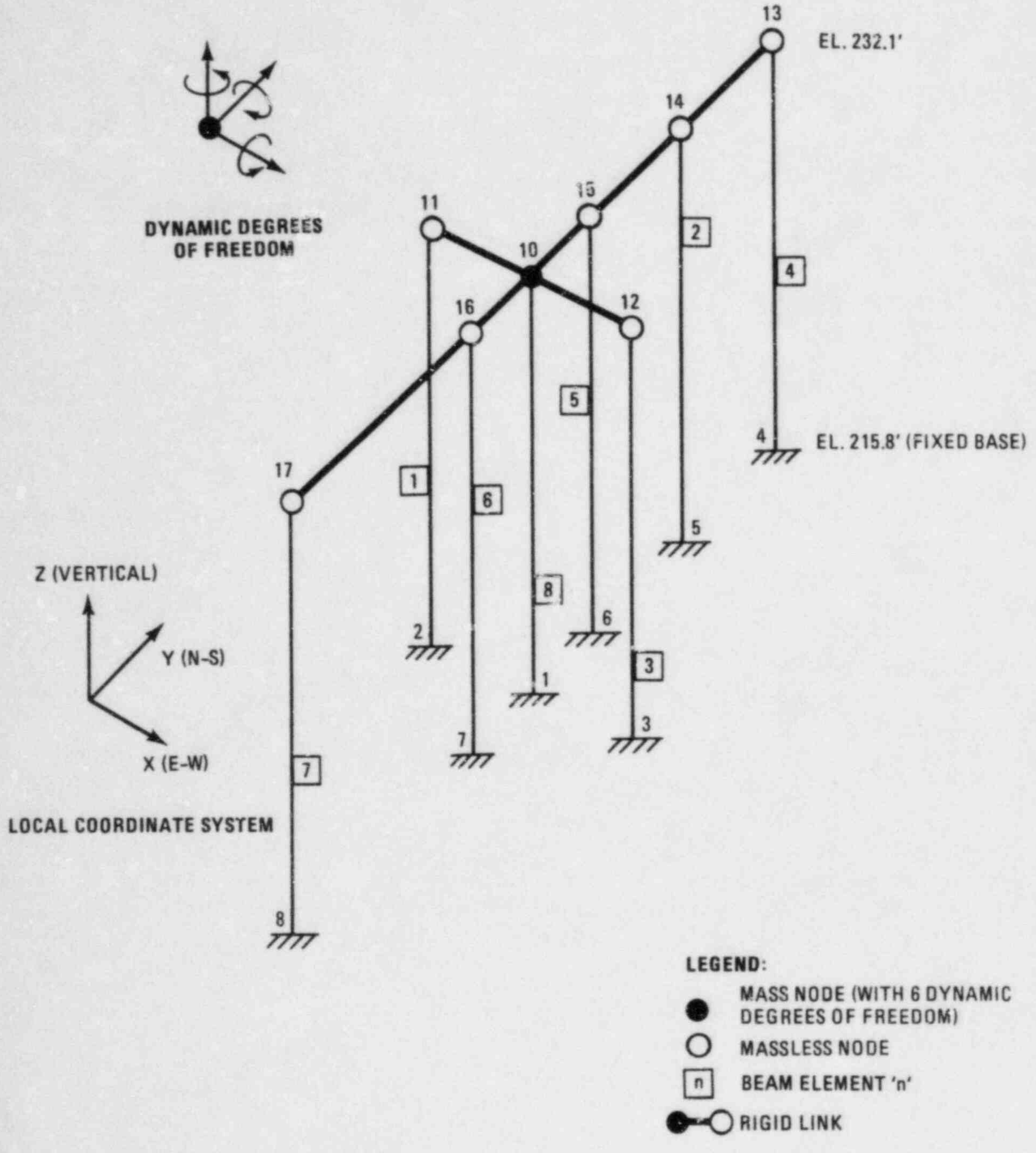


Figure 4-8
AUXILIARY FEEDWATER PUMPHOUSE FIXED-BASE MODEL

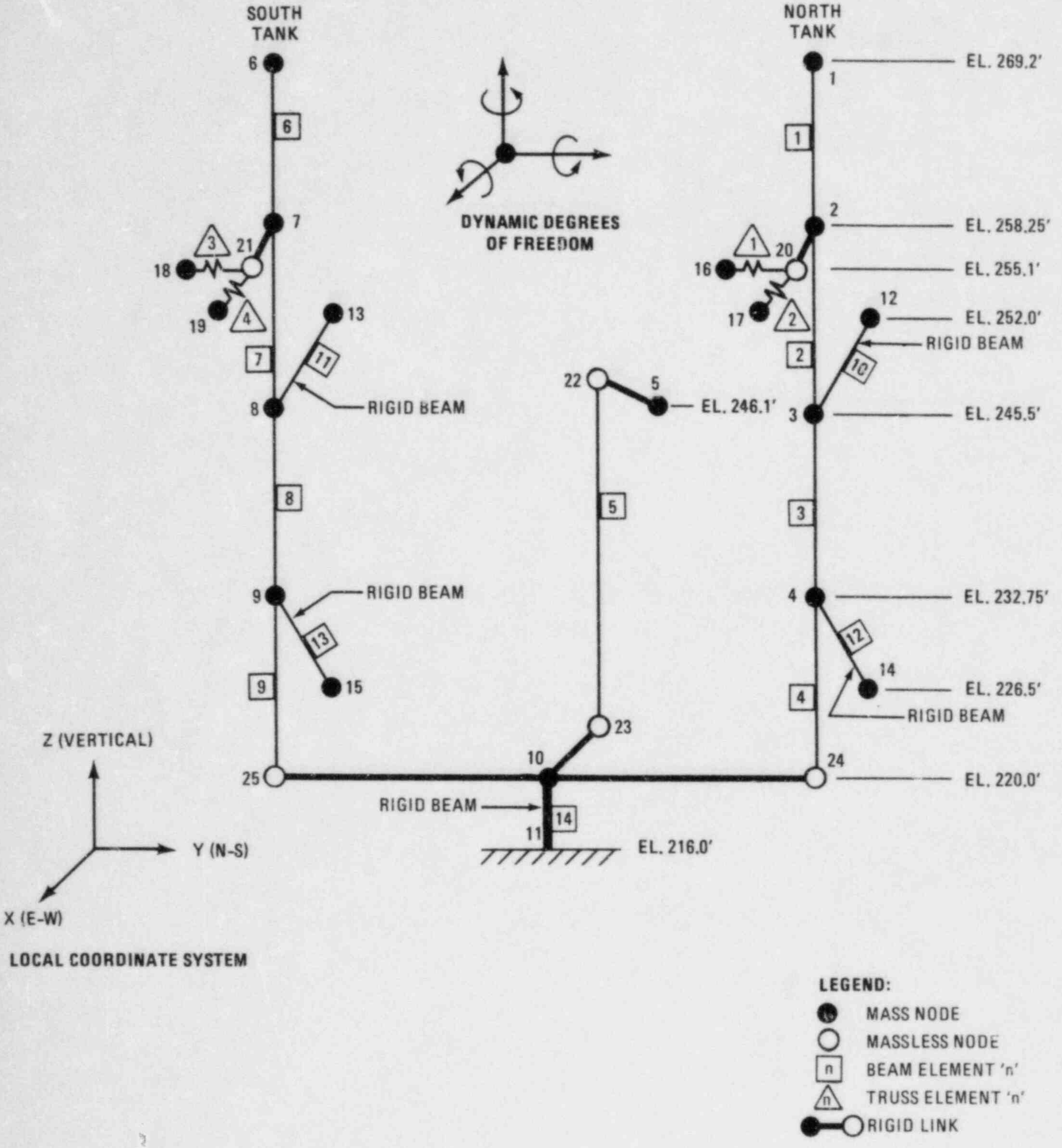


Figure 4-9
CONDENSATE STORAGE TANK FIXED-BASE MODEL

5.0 SEISMIC INPUT

Synthetic free-field earthquake acceleration time-histories are used as the basic input in the dynamic seismic analysis of Category 1 structures performed to obtain the design structure accelerations and in-structure response spectra.

The basis for the generation of the synthetic time-histories is discussed in section 2.5 of BC-TOP-4A (reference 2). Figures 5-1 and 5-2 show the synthetic free-field acceleration time-history motions in the horizontal and vertical directions. Comparison between the free-field time-history response spectra and the design response spectra for both horizontal and vertical motions, and the frequencies at which the spectra values are calculated are provided in section 2.5 of BC-TOP-4A.

In order to obtain the input time-history to the FLUSH computer program that is used for the soil-structure interaction analyses of deeply embedded structures, the digitization interval of the synthetic time-history records needed to be modified. The time interval of the original 24 sec. time-histories is increased from 0.005 sec. to 0.01 sec. through the use of the computer program SHAKE. The FLUSH computer program requires that the total number of time steps in the time-history record be 2^n, where n is an integer. To satisfy this requirement, 2048 ($2^{11} = 2048$) step time-history records are chosen. These 20.48 sec. synthetic time-history records are developed by adopting the first 18 sec. of the time-histories obtained from SHAKE followed by a quiet zone of 2.48 sec. The differences between the response spectra derived from these motions and the response spectra obtained from the original time-histories are insignificant. The horizontal and vertical synthetic time-history motions are scaled to 0.20g and 0.12g to obtain, respectively, the SSE free-field design time-history and the OBE free-field design time-history.

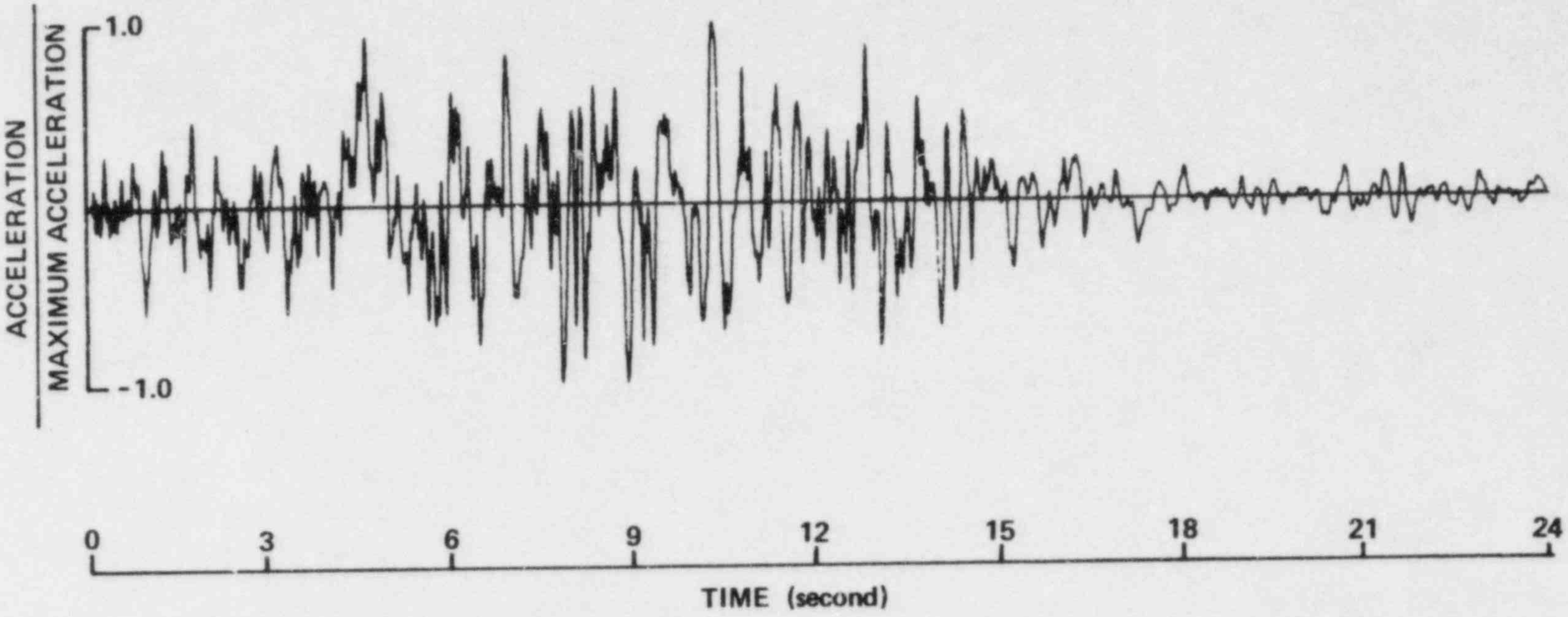


Figure 5-1
SYNTHETIC FREE-FIELD HORIZONTAL
ACCELERATION TIME HISTORY

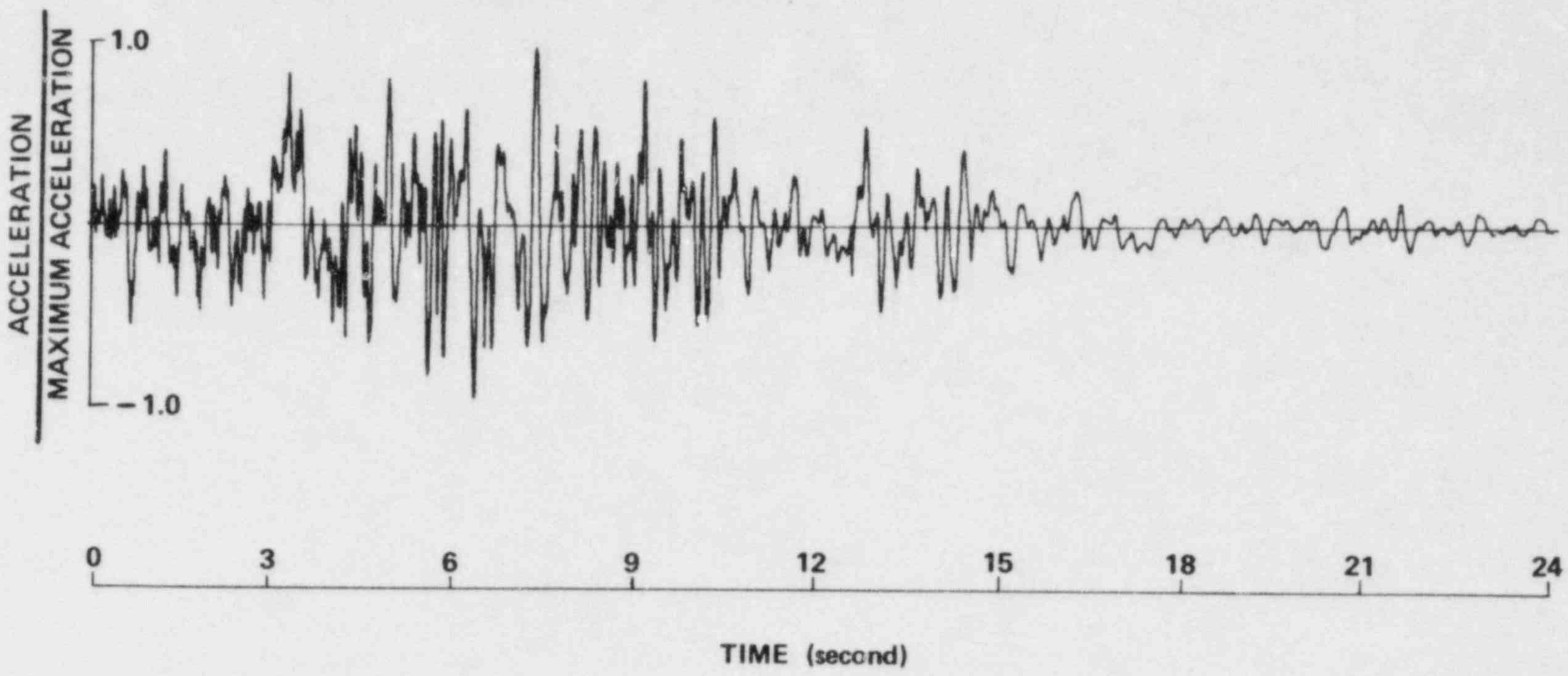


Figure 5-2
SYNTHETIC FREE-FIELD VERTICAL
ACCELERATION TIME HISTORY

6.0 SOIL-STRUCTURE INTERACTION ANALYSES

6.1 ANALYSIS METHODOLOGY

The half-space (impedance) modeling method and the finite element modeling method are the standard methods used in the soil-structure interaction analyses of structures. Since for surface structures the distribution of free-field motions with depth in the underlying soil has no influence on the structural response, either method is acceptable. For embedded structures, however, consideration of the variation of motions with depth is essential if adequate evaluations of soil and structural response are to be obtained without undue conservatism. The finite element method is particularly well suited for evaluating the response of embedded structures since it can readily provide consideration of the variation of soil characteristics with depth, the different non-linear deformation and energy absorbing capacities of the various soil strata, the variation of motions with depth, and the effects of adjacent structures on each other.

The VEGP soil-structure interaction analyses of deeply embedded Category 1 structures are performed using the finite element method with the control motion applied at the finished grade level in the free-field. Embedment depths of Category 1 structures are provided in table 6-1. The containment building and containment internal structures, auxiliary building, control building, fuel handling building, and NSCW tower are classified as deeply embedded structures.

For shallowly embedded Category 1 structures, the soil-structure interaction analyses are performed using the impedance method with the control motion applied at the foundation levels of the structures in the free-field. The diesel generator building, auxiliary feedwater pumphouse, and Category 1 tanks (condensate storage tanks, refueling water storage tank, and reactor makeup water storage tank) are classified as shallowly embedded structures.

Buried structures are surrounded by soil and essentially move with the ground. The response of the structure is the same as that of the ground and, therefore, no soil-structure interaction analysis is performed for buried structures. The diesel fuel oil storage tank pumphouse and Category 1 tunnels are classified as buried structures.

6.2 DEEPLY EMBEDDED STRUCTURES

6.2.1 FLUSH Computer Program

The computer program FLUSH (reference 4) is used to perform the soil-structure interaction analyses of deeply embedded Category 1 structures. FLUSH utilizes the complex response method to perform the finite element method of soil-structure interaction analyses. The soil system is represented as a two-dimensional finite element model. The model consists of two types of elements: displacement-compatible isoparametric quadrilateral elements (solid elements) and linear bending elements (beam elements). In the complex response method, the stiffness matrix including the material damping is formed using the complex shear moduli to simulate damping effects. By this approach, the equations of motion are reduced to a set of linear complex equations at each discrete frequency and are solved in the frequency domain to obtain the structural response.

Transmitting boundaries are used at the vertical edges of the soil model to simulate, with a finite number of degrees of freedom, the infinite extent of the soil. The transmitting boundary conditions are computed using the iterated soil properties from the free-field computations to couple all the boundary points. The forces related to the energy transmission are then included in the equations of motion in the frequency domain to represent the dynamic effects of the semi-infinite viscoelastic soil system at the vertical boundaries of the model. These boundaries constitute perfect absorbers for any kind of waves impinging with arbitrary incidence. A closed-form comparison study by Kausel and Roesset (reference 5) concludes that these transmitting boundaries are consistent (non-local) boundary conditions that can be placed immediately adjoining the region of interest (e.g. next to an embedded structure). FLUSH suggests a minimum of one column of soil elements adjacent to the embedded structure. In the VEGP finite element models for the seismic analysis, the transmitting boundaries are located at a minimum of three elements away from the embedded structures.

6.2.2 Soil Modeling

As described in paragraph 6.2.1, the soil-structure interaction analyses of deeply embedded structures are performed using the FLUSH computer program, in which the non-linear characteristics of the soil can be accounted for by use of strain-compatible soil properties (see figures 3-1 through 3-6) through an iterative procedure. In each iteration, the analysis is linear but the soil properties are adjusted from iteration to iteration until the computed strains are compatible with the soil properties used in the analysis. Using this approach, an appropriate strain-dependent soil property is assigned to each element.

Since the depth to bedrock below the plant finished grade is large (approximately 950 feet), practical considerations make it necessary to limit the depth of the finite-element soil-structure interaction model to a smaller value. The criterion used to determine the depth of the model is that the control motion for each finite-element model shall be deconvolved to one-half the structure width below the structure foundation. Accordingly, the depth of a model is selected such that the distance between the structure foundation and base of the finite-element model is a minimum of about one-half the structure width. The depths and number of layers used for the various FLUSH models, which are described in section 6.2.3, are provided below:

FLUSH Model No.	Finished Grade Elevation (ft)	Lowest Foundation Elevation (ft)	Base Elevation of Model (ft)	Depth of Model Used (ft)	No. of Soil Layers Used
1	220	109	-110	330	30
2	220	144	+1	219	24
3	220	173	-74	294	28
4	220	109	+1	219	24
5	220	109	+1	219	24
6	220	128	+20	200	23

The comparison of the deconvolved free-field response spectra at the foundation levels of structures obtained from the 330 feet deep model with those from the other models with shallower depths shows that they are essentially the same. In addition, the comparison of the strain-dependent soil properties of the soil elements in the bottom-most layers in the soil-structure interaction finite-element models with those of the corresponding layers in the free field shows that they are very close, confirming that the model depths are large enough to preclude any significant influence of the model bases on the structure response other than the free-field effects.

The soil layers and the associated free-field soil properties, on the basis of which the finite element soil-structure interaction analyses of deeply embedded structures are performed, are provided in figure 6-1.

In the analyses for the vertical component of the earthquake, the soil properties for the layers below the water table are based on the iterated strain-dependent soil properties or the compression wave velocity of water, whichever is greater. This is consistent with the assumption that, in saturated soils, the compression wave would travel with the compression wave velocity of the soil medium or the compression wave velocity of water, whichever is greater. The compression wave velocity of water is taken as 5000 ft/sec.

6.2.3 Soil-Structure Models

The procedure for computing the three-dimensional response of the structures using the two-dimensional FLUSH soil model is described below. This procedure combines a two-dimensional finite element representation of soil with a three-dimensional representation of structures.

A fixed-base three-dimensional lumped mass model of the structure is developed and expressed in the form of stiffness and mass matrices (see section 4.0). A two-dimensional model of the soil with the structure removed is prepared and all nodes in contact with the structure (henceforth called common nodes) are identified. The soil model is one unit wide in the out-of-plane dimension. To ensure compatibility with the unit width soil model, the stiffness and mass matrices of the structure are divided by the equivalent width (out-of-plane dimension) of the structure.

A base eccentricity sometimes exists between the structure and the soil plane, especially when more than one structure exists in a single soil model. When this occurs, a mathematical coordinate transformation is performed to relate the base node of the structure to the plane of the soil model.

The structure nodes associated with the common nodes have degrees of freedom only in the plane of the soil model in order that the FLUSH program can be executed. Thus, the degrees of freedom of the structure common nodes are mathematically transformed to be compatible with the degrees of freedom of the soil common nodes. There is no requirement that the degrees of freedom for the remaining structure nodes (henceforth called free nodes) be reduced.

After the common degrees of freedom have been made compatible both in the structure and in the soil, the total soil-structure system is then assembled in global matrices and the solution is accomplished by FLUSH, as in a standard finite element problem.

A power block plan view showing the foundation elevations of the deeply embedded structures together with the sections considered for the six FLUSH models is shown in figure 6-2. The six FLUSH models are shown in figures 6-3 through 6-8. The first is an east-west model which includes the auxiliary building. The second is also an east-west model which consists of the containment building Unit 2, the fuel handling building, and the containment building Unit 1. The effect of the diesel generator buildings on the response of the containment building is accounted for by modeling their inertial properties with structural layers in the soil finite-element model. The third is an east-west model which includes the control building. The fourth is a north-south model which includes the auxiliary building, containment building Unit 1, and the control building. In FLUSH models 4 and 5, the effect of the turbine building, located adjacent to the control building, is considered by modeling it as a structural layer in the soil finite-element model with proper inertial properties. Since the mass of the radwaste transfer building, located adjacent to the auxiliary building, is less than 5 percent of the mass of the auxiliary building, its effect on the response of the auxiliary building is considered insignificant. The fifth is also a north-south model which includes the auxiliary building, the fuel handling building, and the control building. The sixth is a model which includes a nuclear service cooling water (NSCW) tower. Considering the plant layout, it is assumed that there is no significant interaction between each of the nuclear service cooling water (NSCW) towers and the rest of the structures.

Shear moduli based on the design mean value, shear moduli with upper-bound values equal to 1.5 times the mean values, and lower-bound values equal to the mean values divided by 1.5 are considered in the analysis. The mean values of low strain shear moduli are computed as described in section 3.2.2.

The generation of the design time-history motions is described in section 5.0. This ground motion is defined for the free-field and is applied at the nominal finished grade level (elevation 220'-0") of the site.

6.2.4 Soil-Structure Interaction Analyses

The time-history at the base of the idealized soil profile is obtained through deconvolution in the free-field of the design acceleration time-history specified at finished grade level. The time-history thus obtained is applied at the base of the soil-structure interaction system. The resulting time-history responses are used to generate the in-structure response spectra at selected structure elevations. Three sets of analyses are performed to account for the variation of soil parameters as indicated in section 2.3.2, using appropriate cutoff frequencies. Response spectra obtained by considering the variation of soil properties are enveloped. Three component earthquake effects are accounted for by combining these response spectra using the SRSS criteria, in accordance with Regulatory Guide 1.92, Combining Modal Responses and Spatial Components in Seismic Response Analysis. The response spectra curves are then multipled by the scaling factor of 1.5 (see section 2.1). The zero period accelerations of the response spectra are the structure design accelerations.

The in-structure response spectra are computed at the frequencies given in table 6-2. These frequencies are selected using the suggested frequency intervals in Regulatory Guide 1.122, Development of Floor Design Response Spectra for Seismic Design of Floor-Supported Equipment or Components. The additional horizontal response to account for torsion due to seismic wave propagation effects are considered as described in section 7.2. Also in accordance with Regulatory Guide 1.122, the computed floor response spectra are smoothed and peaks associated with each of the structural frequencies broadened by ±15 percent. As described in section 4.6, the response spectra developed at elevation 220'-0" of the NSCW tower are applicable for the NSCW valve house.

Figure 6-9 provides a flow chart which traces the various steps performed to develop the design floor response spectra. Tables 6-3 through 6-7 provide structure accelerations to be used in the design of the structures.

6.3 SHALLOWLY EMBEDDED STRUCTURES

6.3.1 Soil Impedances

The impedance (half-space) method is used for the seismic analyses of shallowly embedded Category 1 structures. In using the impedance method, the dynamic force-displacement characteristics of the foundation are represented by the foundation impedances. As a result of the inertia properties of the structure, the forces developed between the foundation and the soil produce motions different from the free-field motion. The foundation impedances are functions of the basemat geometry, elastic properties of the foundation medium, and forcing frequencies. They are represented by a mechanical analog composed of equivalent springs and dampers. The equivalent dampers represent two sources of damping which occur in soil-structure interaction. One source is the internal damping of the soil, and is referred to as material damping. The other is radiation damping and represents the propagation of wave energy away from the foundation.

Due to the three distinct soil strata (section 3.2) which exist below the shallowly embedded structures, it is necessary that the impedance functions be calculated for a layered foundation media rather than for a uniform foundation media. The techniques used to obtain the impedance functions for layered media are provided in Appendix A. The soil layers and the associated soil properties used are provided in figure 6-1. These properties are obtained from averaging the iterated strain-dependent values within a specified layer with consideration given to the effects of the increase in confinement pressure under the building structure on these values. The soil profile and the basemat geometry of a given structure are input to the computer programs GLAYER and CLA. (GLAYER computes Green's function for an arbitrarily shaped foundation on a layered soil medium; utilizing Green's function, CLA computes the frequency-dependent impedance functions for the soil media.) From the CLA results, the corresponding frequency-dependent soil impedance curves (6 springs and 6 damping coefficients) are obtained. Similarly, the translational soil impedance in the vertical direction is calculated using the same computer programs, but including the effects of the groundwater table, since the water is considered effective in transmitting the seismic wave vertically. A compression wave velocity of 5000 ft/sec. is used for layers below the groundwater table.

Initial frequency-independent soil impedances are estimated using BC-TOP-4A and associated frequencies are calculated. Based on these frequencies, the soil impedance versus frequency curves are utilized to obtain frequency-dependent soil impedances. If these impedances are not compatible with the initial values, then improved values are obtained by iteration.

6.3.2 Soil-Structure Interaction Analysis

The fixed-base structure frequencies and mode shapes obtained from section 4.0 together with the converged soil impedances are input to the GEMD computer program, which computes the composite modal damping of the soil-structure system. For conservatism, any computed composite modal dampings exceeding 10 percent of critical are replaced by a maximum of 10 percent of critical except for those modes that are associated with rigid body translation or rotation of the structure.

The modal dampings and soil impedances calculated above, along with the structure stiffness and mass properties, are used as input to the BSAP computer program where the soil-structure system modal analysis is performed. The number of modes to be included in the time-history analysis of a given structure is selected on the basis of cumulative modal mass associated with those modes and the frequency of the highest mode considered. The total number of modes chosen in any one model corresponds to 99 percent of the cumulative modal mass having participated in each of the three orthogonal directions and the frequency of the highest mode considered being equal to or greater than 33 cps. The soil-structure system frequencies and participation factors of the lumped parameter models are listed in tables 6-8 through 6-13.

The 20.48 sec. free-field acceleration time history (section 5.0) is applied at the foundation levels of the lumped parameter models in the time-history analysis. The resulting modal responses are superimposed in accordance with BC-TOP-4A to obtain the total time-history response for each dynamic degree of freedom in the model. These time-history responses are used to generate in-structure response spectra at selected structure levels. At a given structure level, response spectra are obtained for each of the six dynamic degrees of freedom (three translational and three rotational). These response spectra represent the response at the center of mass of that level. The translational response obtained at the extreme corner of a building exceeds the translational response obtained at the center of mass due to the rigid body rotation of the floor. The additional translational response due to the rotation of the lumped mass node is obtained as the product of the rotational response spectra and the perpendicular distance from the lumped mass node to the extreme point in the building. This translational response is then added by absolute sum combination to the corresponding translational response spectra of the lumped mass node. Responses are thus obtained for each of the three orthogonal earthquake components under OBE and SSE events. Three component earthquake effects are considered by combining these response spectra using the SRSS criteria in accordance with Regulatory Guide 1.92, Combining Modal Responses and Spatial Components in Seismic Response Analysis. The zero period accelerations of the response spectra are the structure design accelerations.

The floor response spectra are computed at the frequencies given in table 6-2. These frequencies are selected using the suggested frequency intervals in Regulatory Guide 1.122, Development of Floor Design Response Spectra for Seismic Design of Floor-Supported Equipment or Components. The additional horizontal response to account for torsion due to seismic wave propagation effects are considered as described in section 7.2. Also in accordance with Regulatory Guide 1.122, the computed floor response spectra are smoothed and peaks associated with each of the structural frequencies broadened by ±15 percent.

Figure 6-10 provides a flow chart which traces the various steps performed to develop the design floor response spectra. Tables 6-14 through 6-16 provide structure accelerations to be used in the design of the structures.

6.4 BURIED STRUCTURES

Buried structures are surrounded by soil and essentially move with the ground. The response of the structure is the same as that of the ground and, therefore, no separate soil-structure interaction analysis is performed for buried structures. As an added conservatism, the design structure accelerations and response spectra for the Category 1 tunnels and diesel fuel oil storage tank pumphouse are obtained from the free-field ground accelerations and response spectra by multiplying them by a factor of 1.25. This results in design structure acceleration values of 0.15g and 0.25g respectively for OBE and SSE conditions.

6.5 DESIGN RESULTS

The structure acceleration values used in the design of structures are provided in tables 6-3 through 6-7 for deeply embedded Category 1 structures, and in tables 6-14 through 6-16 for shallowly embedded Category 1 structures. The values used for buried structures are described in section 6.4.

Design in-structure response spectra for selected levels in major Category 1 structures are provided in Appendix B.

TABLE 6-1

EMBEDMENT DEPTHS OF CATEGORY 1 STRUCTURES(3)

Structure	Foundation(1) Embedment Depth (ft)	Least Foundation Width (ft)	Structure(2) Height (ft)
Containment building	61	154	243
Auxiliary building	111	129	179
Control building	47	148(4)	140
Fuel handling building	66	76	134
NSCW towers	89	100	136
Diesel generator building	9	92	71
Condensate storage tanks	4	63	60
Refueling water storage tank	3	62	66
Reactor makeup water tank	2	51	46
Auxiliary feed-water pumphouse	7	40	31
NSCW valve house	20	20	50

(1) Distance from bottom of foundation to plant grade level.

(2) Distance from bottom of foundation to highest point of structure.

(3) Buried structures are not included in this table.

(4) Typical width for most parts of the foundation.

TABLE 6-2

FREQUENCIES FOR FLOOR RESPONSE SPECTRA CALCULATIONS (Hz)

0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.1, 1.2,
1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9, 2.0, 2.1, 2.2, 2.3,
2.4, 2.5, 2.6, 2.7, 2.8, 2.9, 3.0, 3.15, 3.3, 3.45, 3.6,
3.8, 4.0, 4.2, 4.4, 4.6, 4.8, 5.0, 5.25, 5.5, 5.75, 6.0,
6.25, 6.5, 6.75, 7.0, 7.25, 7,5, 7.75, 8.0, 8.5, 9.0, 9.5,
10, 10.5, 11, 11.5, 12, 12.5, 13, 13.5, 14, 14.5, 15,
16, 17, 18, 20, 22, 25, 28, 31, 34

TABLE 6-3

CONTAINMENT BUILDING DESIGN STRUCTURE ACCELERATION VALUES

Description	Node	Elevation	SSE (g's)			OBE (g's)		
			E-W	N-S	Vert.	E-W	N-S	Vert.
Basemat[(1)]	1	163.9'	0.21	0.20	0.38	0.14	0.13	0.23
Contmt[(2)] Internal Concrete Structure	2	195.0'	0.21	0.22	0.45	0.15	0.15	0.29
	3	218.0'	0.24	0.27	0.48	0.17	0.20	0.32
	4	236.0'	0.25	0.30	0.41	0.18	0.23	0.27
	5	236.0'	0.25	0.30	0.43	0.18	0.23	0.27
	6	258.0'	0.32	0.37	0.41	0.21	0.28	0.27
	7	258.0'	0.31	0.38	0.43	0.21	0.29	0.27
Contmt[(1)] Shell & Dome	2	193.8'	0.22	0.22	0.34	0.15	0.15	0.22
	3	220.0' (grade level)	0.25	0.25	0.35	0.17	0.17	0.23
	4	258.4'	0.31	0.31	0.41	0.22	0.22	0.27
	5	290.7'	0.38	0.38	0.42	0.26	0.26	0.28
	6	323.0'	0.45	0.45	0.43	0.30	0.30	0.30
	7	361.0'	0.54	0.54	0.44	0.36	0.36	0.30
	8	399.0'	0.64	0.64	0.45	0.44	0.44	0.26

(1) Refer to figure 4-1 for nodal designation

(2) Refer to figure 4-2 for nodal designation

TABLE 6-4

AUXILIARY BUILDING DESIGN STRUCTURE ACCELERATION VALUES

Node[1]	Elevation	SSE (g's)			OBE (g's)		
		E-W	N-S	Vert.	E-W	N-S	Vert.
679	119'-3"	0.18	0.19	0.29	0.11	0.12	0.18
680	143'-6"	0.19	0.19	0.29	0.12	0.12	0.19
681	170'-6"	0.21	0.22	0.30	0.13	0.14	0.19
682	195'-0"	0.22	0.25	0.30	0.14	0.16	0.19
683	220'-0" (grade level)	0.24	0.28	0.30	0.15	0.18	0.20
684	240'-0"	0.26	0.33	0.36	0.16	0.21	0.23
685	240'-0"	0.26	0.33	0.36	0.16	0.21	0.23
686	260'-0"	0.26	0.34	0.36	0.17	0.22	0.23
687	260'-0"	0.26	0.34	0.36	0.17	0.22	0.23
688	288'-2"	0.38	0.36	0.36	0.25	0.24	0.23

(1) Refer to figure 4-3

TABLE 6-5

CONTROL BUILDING DESIGN STRUCTURE ACCELERATION VALUES

Node(1)	Elevation	SSE (g's)			OBE (g's)		
		E-W	N-S	Vert.	E-W	N-S	Vert.
971	180'-0"	0.26	0.26	0.40	0.15	0.17	0.24
972	200'-0"	0.28	0.26	0.40	0.17	0.18	0.24
973	220'-0" (grade level)	0.29	0.27	0.42	0.18	0.19	0.25
974	240'-0"	0.37	0.49	0.67	0.24	0.33	0.44
975	260'-0"	0.45	0.58	0.72	0.30	0.40	0.53
976	280'-0"	0.52	0.73	0.88	0.35	0.53	0.69

(1) Refer to figure 4-4

TABLE 6-6

FUEL HANDLING BUILDING DESIGN STRUCTURE ACCELERATION VALUES

Node[1]	Elevation	SSE (g's)			OBE (g's)		
		E-W	N-S	Vert.	E-W	N-S	Vert.
241	160'-0"	0.24	0.21	0.39	0.16	0.14	0.24
243	179'-0½"	0.34	0.25	0.41	0.22	0.17	0.27
244	200'-0"	0.37	0.27	0.42	0.24	0.19	0.28
249	220'-0" (grade level)	0.39	0.30	0.43	0.25	0.20	0.29
250	263'-8"	0.54	0.41	0.46	0.35	0.28	0.31
251	263'-8"	0.54	0.42	0.46	0.35	0.28	0.31
252	288'-2"	0.61	0.49	0.49	0.42	0.33	0.33

(1) Refer to figure 4-5

TABLE 6-7

NSCW TOWER DESIGN STRUCTURE ACCELERATION VALUES

Description	Node(1)	Elevation	SSE (g's)		OBE (g's)	
			Horiz.	Vert.	Horiz.	Vert.
Basemat	10	137.0'	0.19	0.25	0.12	0.15
	11	152.0'	0.19	0.25	0.12	0.15
	13	180.0'	0.22	0.25	0.13	0.15
	16	200.0'	0.23	0.26	0.14	0.15
	17	209.8'	0.24	0.26	0.15	0.16
Grade Level	18	218.5'	0.25	0.27	0.15	0.16
Fill Beams	19	230.8'	--(2)	0.25	--(2)	0.15
Shell	20	230.8'	0.25	0.27	0.15	0.16
Eliminator Beams	21	242.4'	--(2)	0.34	--(2)	0.24
Shell	22	242.4'	0.26	0.26	0.16	0.16
Top of Tower	23	250.9'	0.27	0.26	0.16	0.16

(1) Refer to figure 4-6

(2) The horizontal acceleration values are the same as of the shell at the corresponding elevation

TABLE 6-8

DIESEL GENERATOR BUILDING SOIL-STRUCTURE SYSTEM (OBE)
(Free Vibration Analysis)

Mode No.	Frequency (cps)	Modal Participation Factor		
		X	Y	Z
1	3.8	-25.396	-0.191	0.342
2	4.1	-0.201	-26.111	-0.525
3	5.9	1.518	-0.828	0.029
4	7.3	2.446	4.704	-25.669
5	7.6	-3.234	9.811	9.602
6	7.7	11.751	1.793	7.258
7	16.3	-1.776	0.000	0.149
8	22.9	-0.018	-0.936	0.093
9	23.6	-0.130	0.095	0.001
10	31.6	0.090	0.002	0.007
11	38.9	0.006	-0.068	0.144
12	41.0	0.009	0.009	-0.854
13	42.8	-0.003	-0.036	-0.189
14	49.4	0.049	-0.003	0.030
15	52.6	-0.006	-0.025	-0.086
16	83.0	0.002	-0.003	-0.025
17	92.4	-0.002	0.001	-0.012
18	109.4	-0.001	-0.001	0.004

TABLE 6-9

DIESEL GENERATOR BUILDING SOIL-STRUCTURE SYSTEM (SSE)
(Free Vibration Analysis)

Mode No.	Frequency (cps)	Modal Participation Factor		
		X	Y	Z
1	3.8	25.260	-0.189	0.354
2	4.0	-0.197	-26.125	-0.527
3	5.8	1.487	-0.826	0.033
4	7.1	2.385	4.244	-26.194
5	7.5	-2.988	10.001	8.645
6	7.5	12.120	1.700	6.554
7	16.3	-1.766	0.001	0.141
8	22.9	-0.018	-0.905	0.089
9	23.6	-0.129	0.093	0.001
10	31.6	0.089	0.002	0.006
11	38.9	0.006	-0.066	0.140
12	40.9	0.008	0.008	-0.815
13	42.7	-0.003	-0.035	-0.179
14	49.3	0.048	-0.002	0.028
15	52.6	-0.006	-0.024	-0.082
16	83.0	0.002	-0.003	-0.024
17	92.4	-0.002	0.001	-0.012
18	109.4	-0.001	-0.001	0.004

TABLE 6-10

AUXILIARY FEEDWATER PUMPHOUSE SOIL-STRUCTURE SYSTEM (OBE)
(Free Vibration Analysis)

Mode No.	Frequency (cps)	Modal Participation Factor		
		X	Y	Z
1	7.6	-10.588	0.000	-0.000
2	7.8	-0.000	-10.781	-0.001
3	10.5	0.013	0.000	-0.000
4	12.0	-0.000	3.719	-0.005
5	13.2	-4.236	-0.000	0.000
6	14.4	-0.000	-0.001	-11.405
7	59.9	0.000	0.217	0.000
8	61.4	0.200	-0.000	0.000
9	96.2	0.003	0.000	-0.000
10	130.4	-0.000	-0.000	-0.143
11	143.0	0.000	0.000	0.021
12	143.2	0.000	-0.000	-0.000

TABLE 6-11

AUXILIARY FEEDWATER PUMPHOUSE SOIL-STRUCTURE SYSTEM (SSE)
(Free Vibration Analysis)

Mode No.	Frequency (cps)	Modal Participation Factor		
		X	Y	Z
1	7.4	-10.456	0.000	-0.000
2	7.4	-0.000	-10.810	-0.001
3	10.1	0.012	0.000	-0.000
4	11.5	-0.000	3.634	-0.005
5	12.6	-4.553	-0.000	0.000
6	13.6	-0.000	-0.001	-11.405
7	59.9	0.000	0.197	0.000
8	61.3	0.194	-0.000	0.000
9	96.1	-0.003	-0.000	0.000
10	130.3	0.000	0.000	0.127
11	143.0	0.000	0.000	0.018
12	143.1	0.000	-0.000	-0.000

TABLE 6-12

CONDENSATE STORAGE TANK SOIL-STRUCTURE SYSTEM (OBE)
(Free Vibration Analysis)

Mode No.	Frequency (cps)	Modal Participation Factor		
		X	Y	Z
1(1)	0.26	-6.458	0.000	-0.000
2(1)	0.26	0.000	6.456	-0.000
3(1)	0.26	-0.000	-0.029	0.000
4(1)	0.26	0.000	0.000	0.000
5	4.3	22.170	-0.013	0.250
6	4.4	0.013	22.541	-0.000
7	6.7	0.001	0.158	0.003
8	7.2	-0.392	0.001	25.086
9	9.0	-0.000	8.034	-0.000
10	10.0	9.035	0.000	0.476
11	12.2	0.000	-0.000	-0.000
12	14.7	0.041	0.001	0.001
13	15.7	0.008	0.017	0.001
14	21.8	0.032	0.761	0.001
15	22.1	0.089	-0.334	-0.007
16	28.4	0.013	0.292	-0.007
17	29.3	0.000	-0.000	0.000
18	30.9	0.003	0.016	-0.001
19	32.3	0.000	0.000	-0.000

(1) Water sloshing modes

TABLE 6-13

CONDENSATE STORAGE TANK SOIL-STRUCTURE SYSTEM (SSE)
(Free Vibration Analysis)

Mode No.	Frequency (cps)	Modal Participation Factor		
		X	Y	Z
1(1)	0.26	-6.459	0.000	-0.000
2(1)	0.26	0.000	6.457	-0.000
3(1)	0.26	-0.000	-0.030	0.000
4(1)	0.26	0.000	0.000	0.000
5	4.2	22.135	-0.012	0.252
6	4.3	0.011	22.493	-0.000
7	6.6	0.001	0.165	0.003
8	7.2	-0.404	0.000	25.086
9	8.8	-0.000	8.167	-0.000
10	9.8	9.119	0.000	0.500
11	12.2	0.000	-0.000	-0.000
12	14.7	0.037	0.002	0.001
13	15.6	0.008	0.017	0.001
14	21.8	-0.030	-0.756	-0.001
15	22.1	0.092	-0.302	-0.007
16	28.4	0.013	0.283	-0.007
17	29.3	0.000	-0.000	0.000
18	30.9	0.003	0.016	-0.001
19	32.3	0.000	0.000	-0.000

(1) Water sloshing modes

Table 6-14

DIESEL GENERATOR BUILDING DESIGN STRUCTURE ACCELERATION VALUES

Node(1)	Elevation	SSE (g's)			OBE (g's)		
		E-W	N-S	Vert.	E-W	N-S	Vert.
32	219'-0" (grade level)	0.26	0.26	0.31	0.16	0.16	0.19
33	254'-0"	0.32	0.29	0.32	0.20	0.18	0.20
34	274'-0"	0.35	0.31	0.32	0.22	0.19	0.20

(1) Refer to figure 4-7

TABLE 6-15

AUXILIARY FEEDWATER PUMPHOUSE DESIGN STRUCTURE ACCELERATION VALUES

Node(1)	Elevation	SSE (g's)			OBE (g's)		
		E-W	N-S	Vert.	E-W	N-S	Vert.
1	216'	0.24	0.24	0.24	0.14	0.14	0.14
10	232'	0.25	0.25	0.25	0.15	0.15	0.14

(1) Refer to figure 4-8

TABLE 6-16

CONDENSATE STORAGE TANK DESIGN STRUCTURE ACCELERATION VALUES

Description	Node(1)	Elevation	SSE (g's)		OBE (g's)	
			Horiz.	Vert.	Horiz.	Vert.
Basemat (grade level)	10	220'-0"	.27	.33	.16	.20
Tank Mid-height	3,8	245'-6"	.32	.33	.19	.20
Missile Protection Structure	5	246'-1"	.32	.33	.19	.20
Roof	1,6	269'-3"	.37	.33	.22	.20

(1) Refer to figure 4-9

						SSE				OBE			
						ITERATED STRAIN-DEPENDENT PROPERTIES							
				UNIT WT (LB/FT^3)	LOW STRAIN V_s MAX (ft/s)	V_s (1)	β (1)	$V_{s(AVE.)}$ (2)	$\beta_{(AVE.)}$ (2)	V_s (1)	β (1)	$V_{s(AVE.)}$ (2)	$\beta_{(AVE.)}$ (2)
el 220'	1	3'	COMPACTED BACKFILL	(123)	[illegible]	[illegible]	0.027	–	–	[illegible]	0.025	–	–
	2	4'			651	587	0.030	818	0.043	[illegible]	0.027	841	0.031
	3	4'			754	670	0.032			649	0.029		
	4	4'			827	728	0.033			748	0.030		
el 200'	5	5'			831	780	0.037			801	0.031		
	6	6'			954	832	0.040			852	0.031		
el 194'	7	7'			1015	882	0.044	991	0.051	902	0.032	1014	0.033
	8	7'			1070	927	0.046			948	0.032		
	9	7'			1118	967	0.048			987	0.033		
	10	6'			1158	999	0.049			1020	0.033		
	11	7'			1194	1029	0.050			1050	0.033		
el 160' ▽	12	8'		(133)	1177	1012	0.052	1057	0.056	1033	0.035	1080	0.037
el 150'	13	8'			1198	1028	0.054			1049	0.037		
	14	7'			1216	1042	0.055			1063	0.038		
	15	9'			1236	1057	0.057			1079	0.039		
el 128'	16	9'	MARL	(115)	1700	1329	0.035	1307	0.038	1382	0.029	1362	0.032
	17	10'			↓	1324	0.036			1373	0.030		
el 100'	18	10'			↓	1319	0.037			1367	0.030		
	19	11'			↓	1314	0.037			1362	0.031		
	20	14'			↓	1309	0.038			1357	0.032		
	21	16'			↓	1303	0.039			1352	0.032		
el 58' el 50'	22	19'	LOWER SAND STRATUM	(115)	1800	1254	0.091	1181	0.104	1416	0.064	1358	0.075
	23	19'			↓	1235	0.094			1400	0.067		
	24	19'			↓	1219	0.097			1386	0.069		
el 0'	25	19'			↓	1206	0.099			1374	0.071		
	26	19'			↓	1194	0.101			1364	0.073		
el -50'	27	18'			↓	1184	0.103			1354	0.075		
	28	18'			↓	1176	0.105			1346	0.076		
	29	18'			↓	1167	0.106			1338	0.077		
el -100'	30	18'			↓	1159	0.108			1331	0.079		
el -110'								3000	0.010			3000	0.010
								INFINITE				INFINITE	

14409-4

NOTES:

(1) SHEAR WAVE VELOCITY (V_S) AND DAMPING VALUE (β) USED IN THE SOIL-STRUCTURE INTERACTION ANALYSES OF DEEPLY EMBEDDED STRUCTURES.

(2) SHEAR WAVE VELOCITY (V_S) AND DAMPING VALUE (β) USED IN THE SOIL-STRUCTURE INTERACTION ANALYSES OF SHALLOWLY EMBEDDED STRUCTURES.

Figure 6-1

SOIL LAYERS AND PARAMETERS

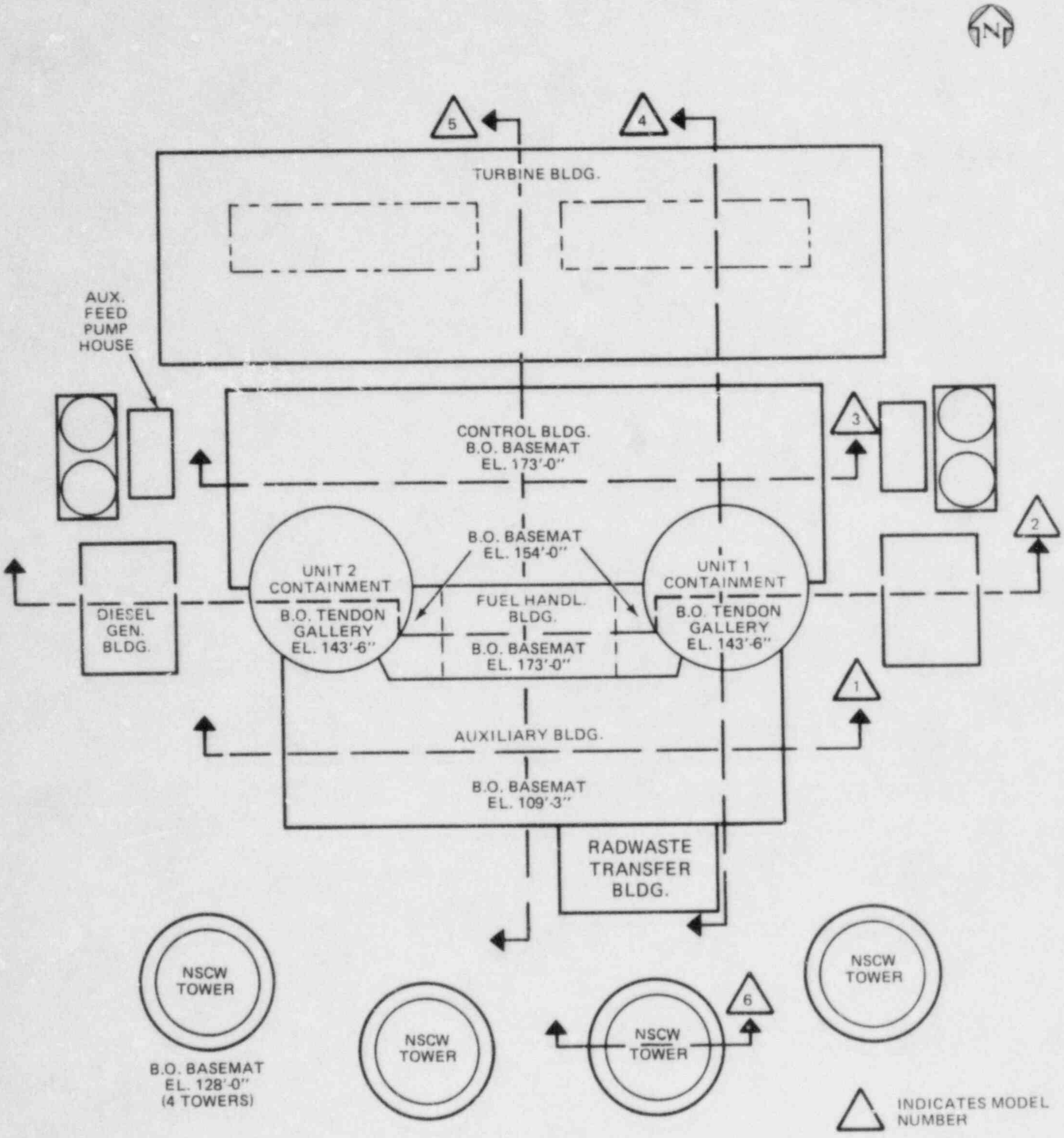
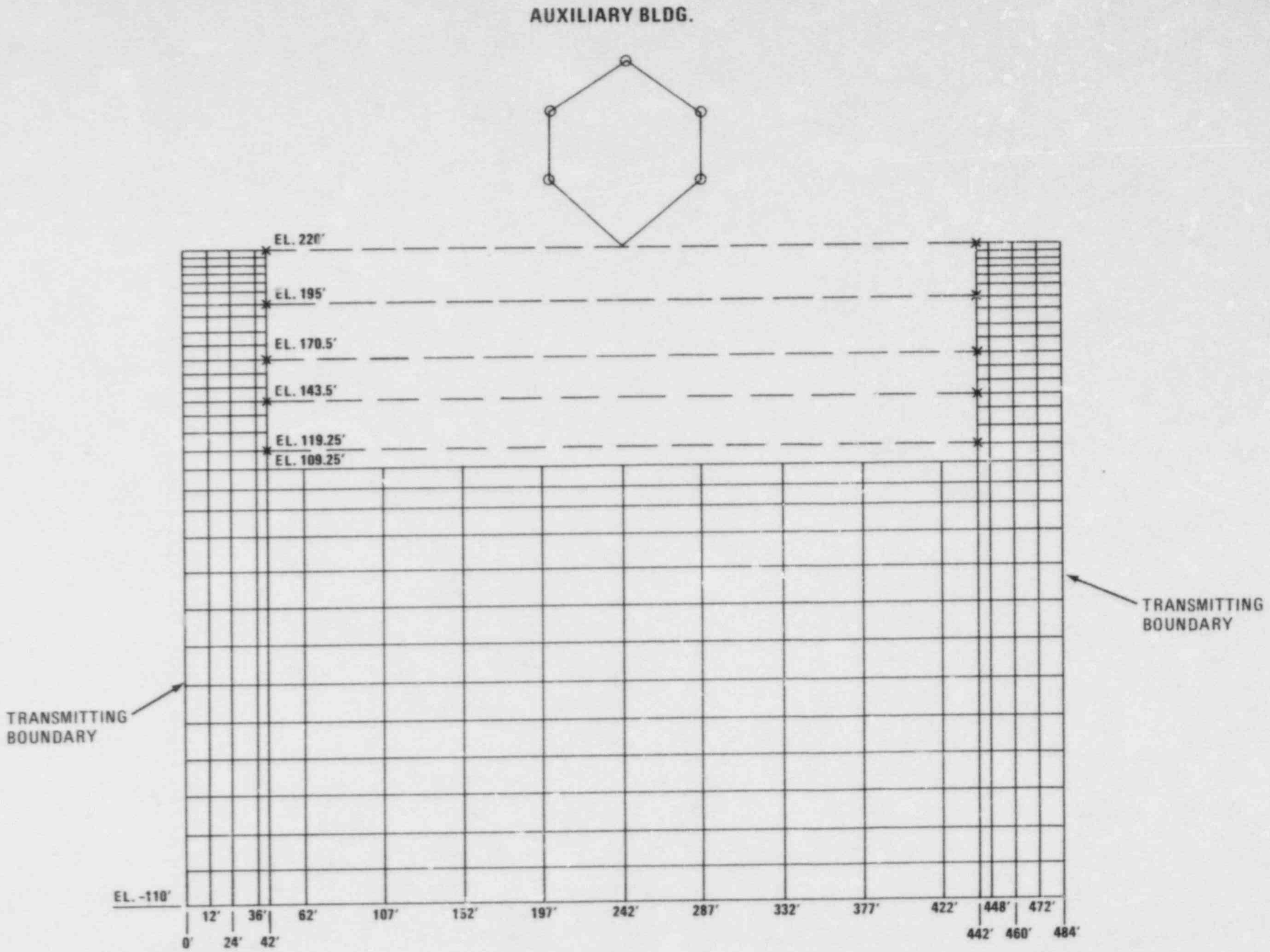
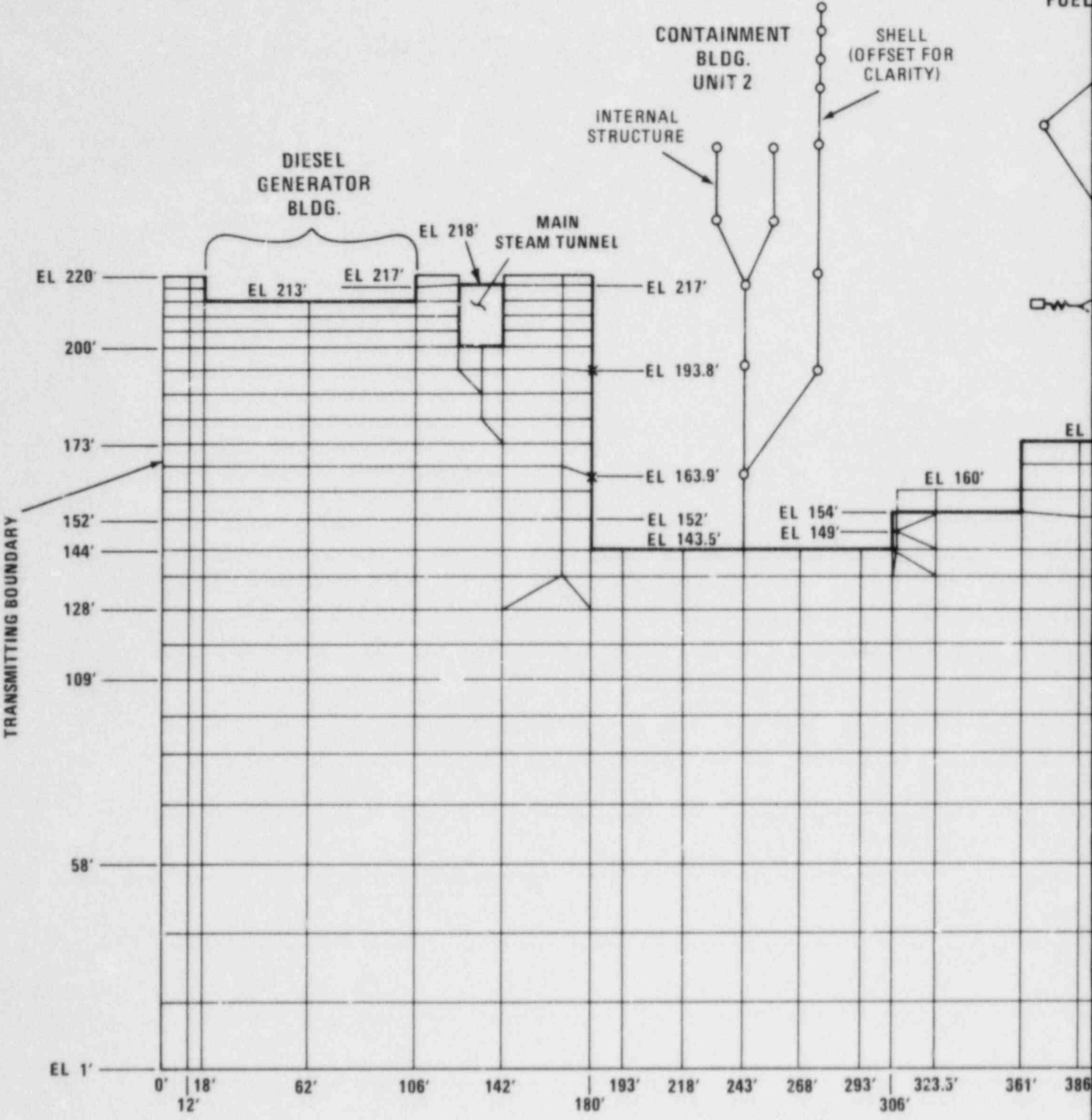


Figure 6-2
POWER BLOCK PLAN VIEW SHOWING SECTIONS
FOR FINITE ELEMENT SOIL-STRUCTURE
INTERACTION FLUSH MODELS



NOTE: VERTICAL DIMENSIONS OF THE SOIL LAYERS ARE THE SAME AS THOSE PROVIDED IN FIGURE 6-1.

Figure 6-3
FLUSH MODEL 1



NOTE: VERTICAL DIMENSIONS OF THE SOIL LAYERS ARE THE SAME AS THOSE PROVIDED IN FIGURE 6-1.

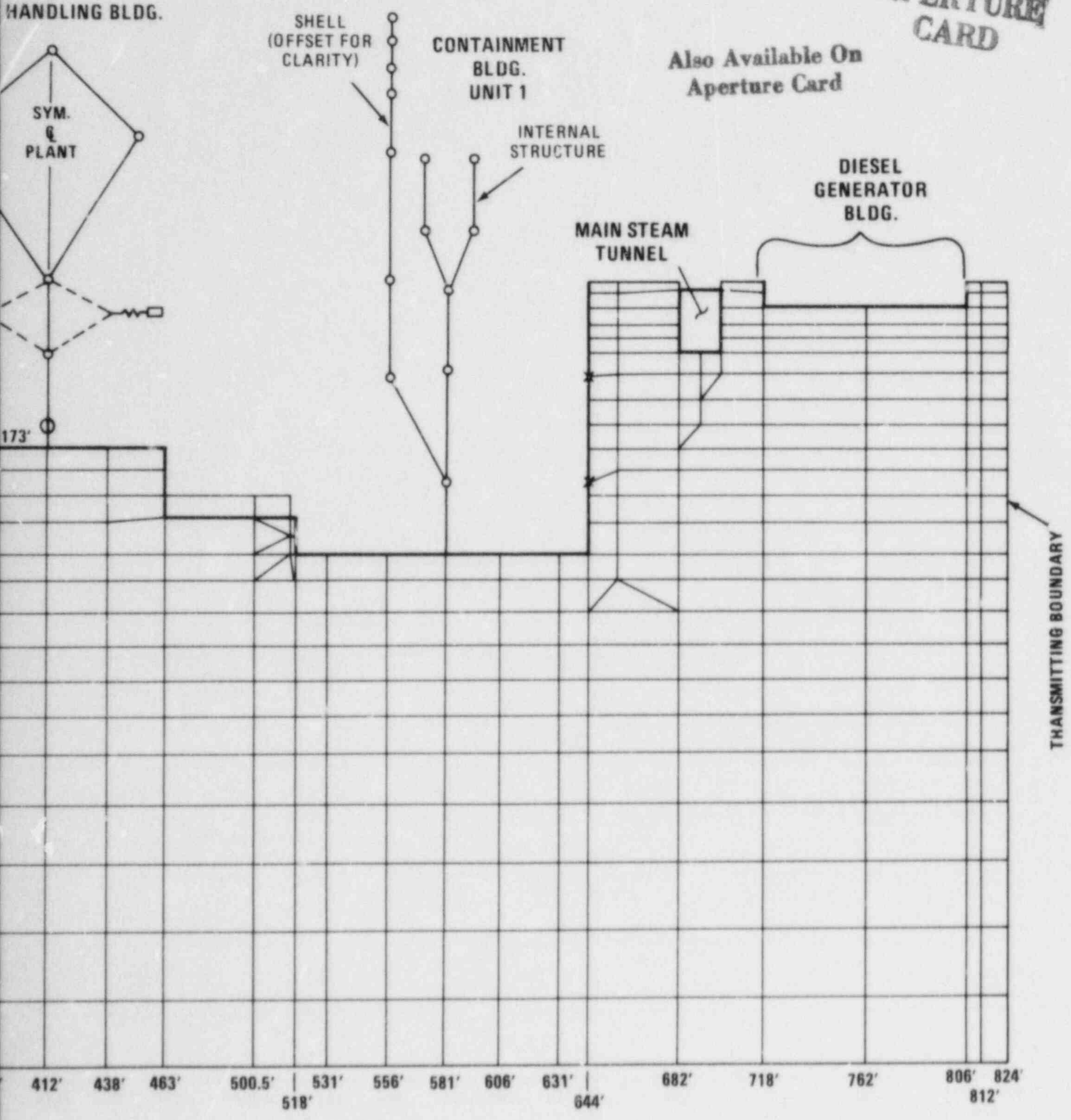
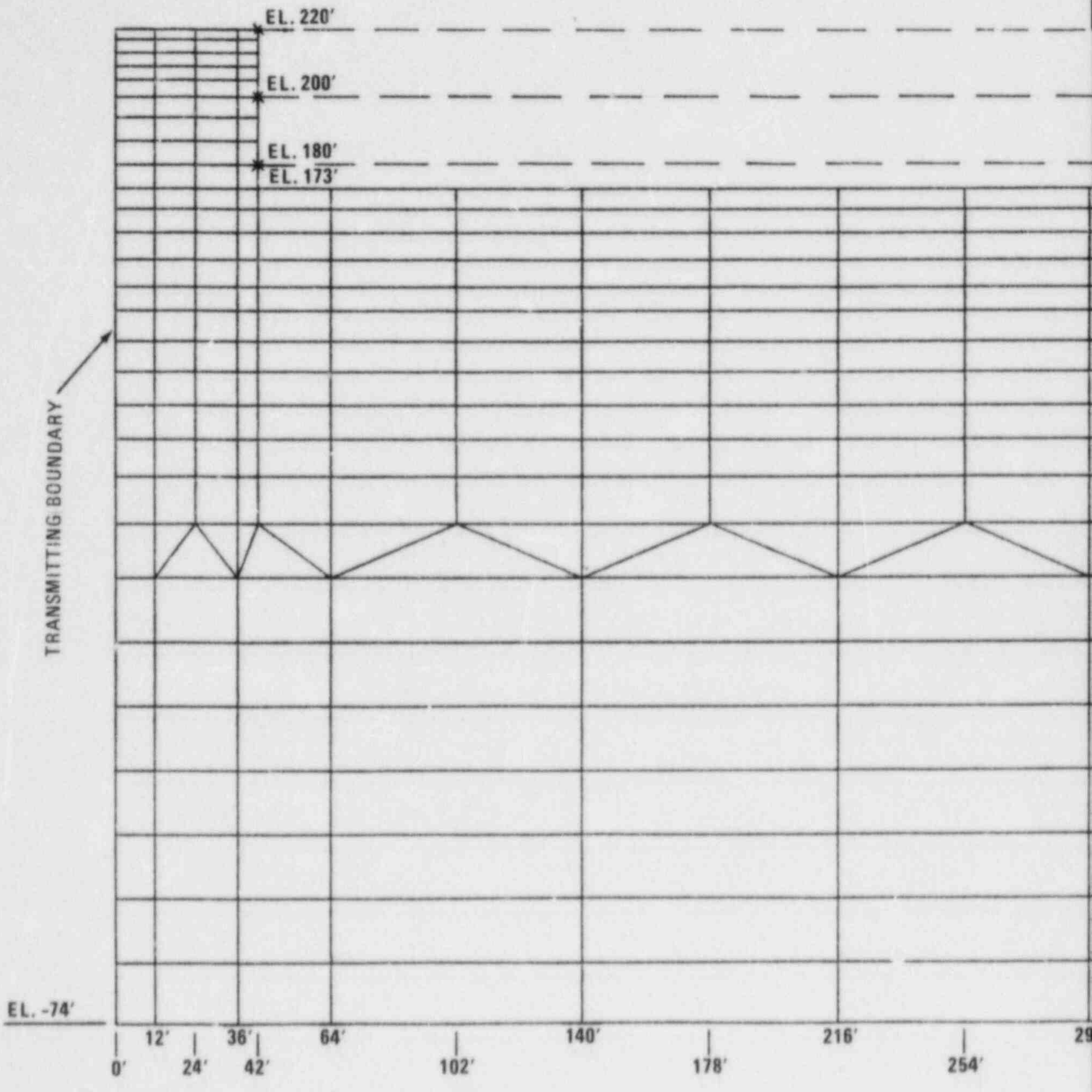


Figure 6-4
FLUSH MODEL 2

CONTRO



NOTE: VERTICAL DIMENSIONS OF THE SOIL LAYERS ARE THE SAME AS THOSE PROVIDED IN FIGURE 6-1.

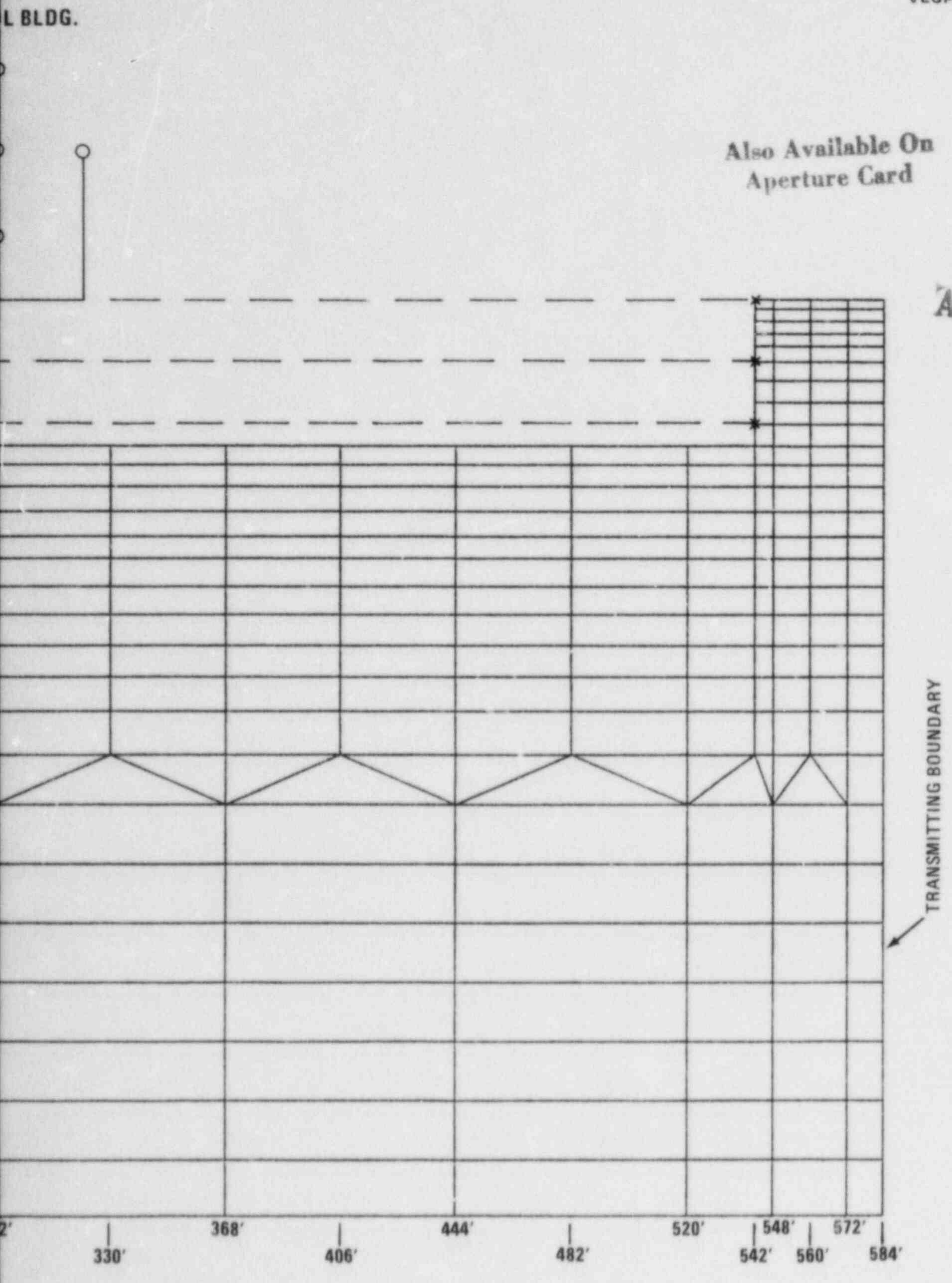
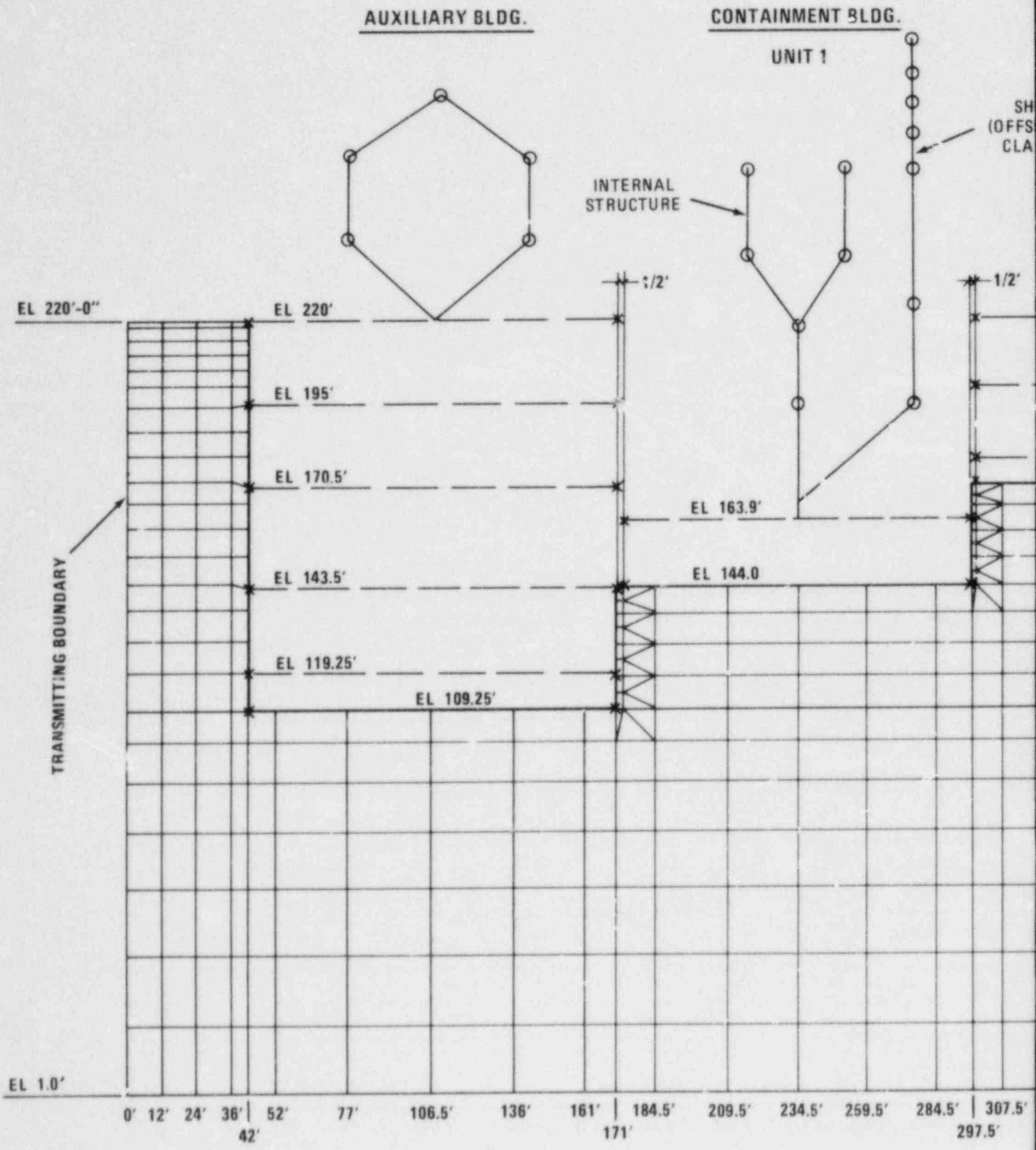


Figure 6-5
FLUSH MODEL 3



NOTE: VERTICAL DIMENSIONS OF THE SOIL LAYERS ARE THE SAME AS THOSE PROVIDED IN FIGURE 6-1.

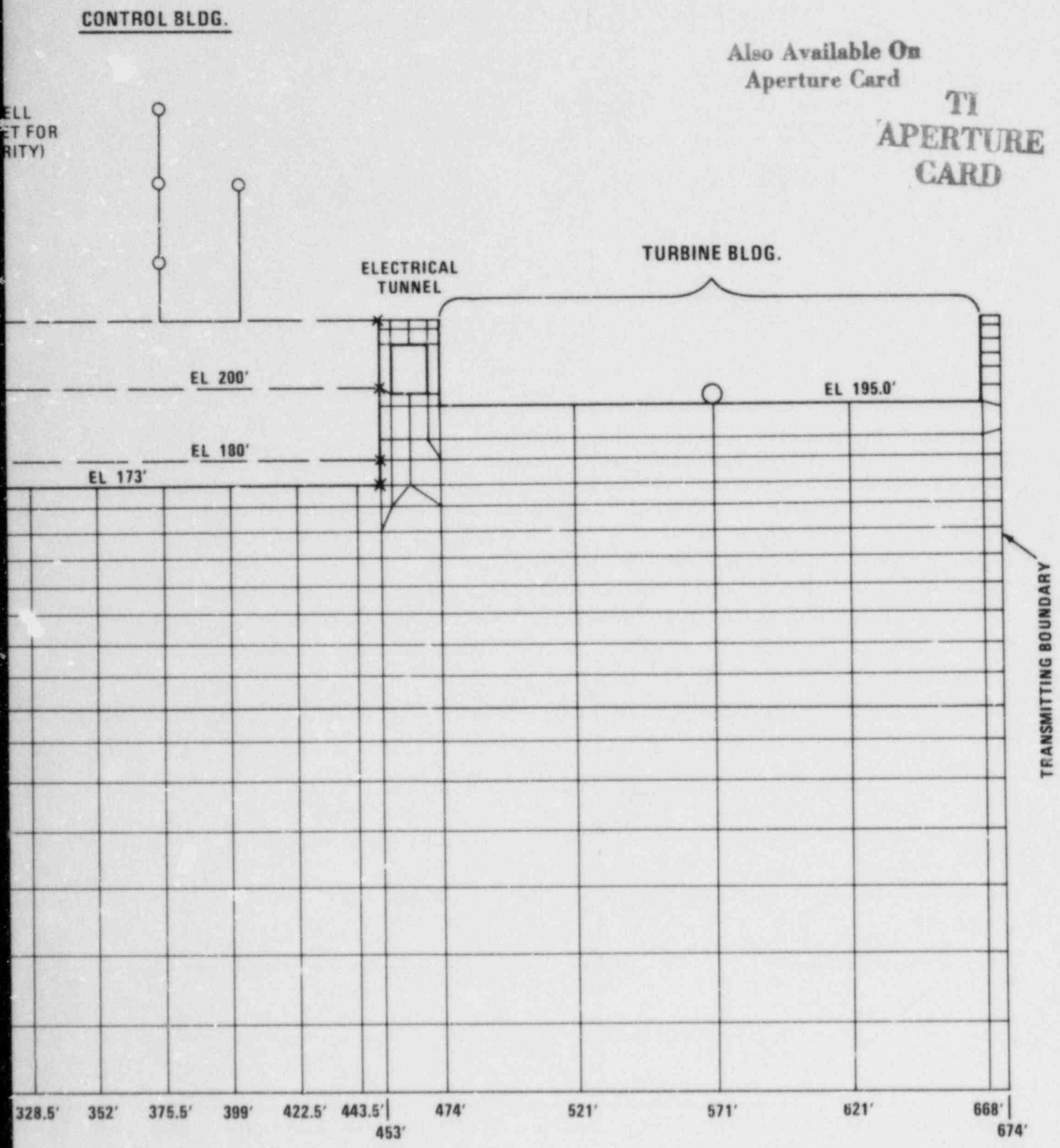
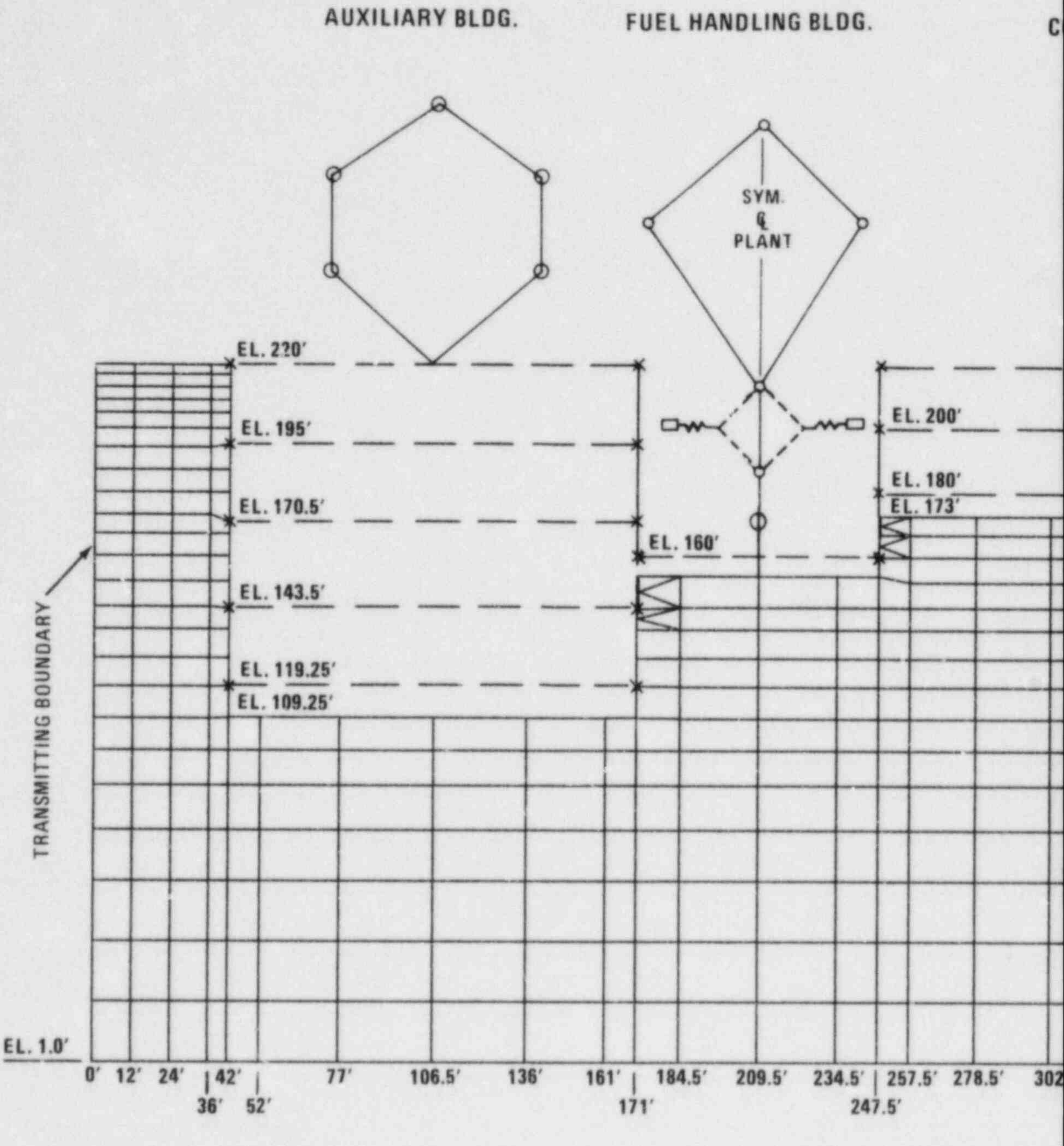


Figure 6-6
FLUSH MODEL 4



NOTE: VERTICAL DIMENSIONS OF THE SOIL LAYERS ARE THE SAME AS THOSE PROVIDED IN FIGURE 6-1.

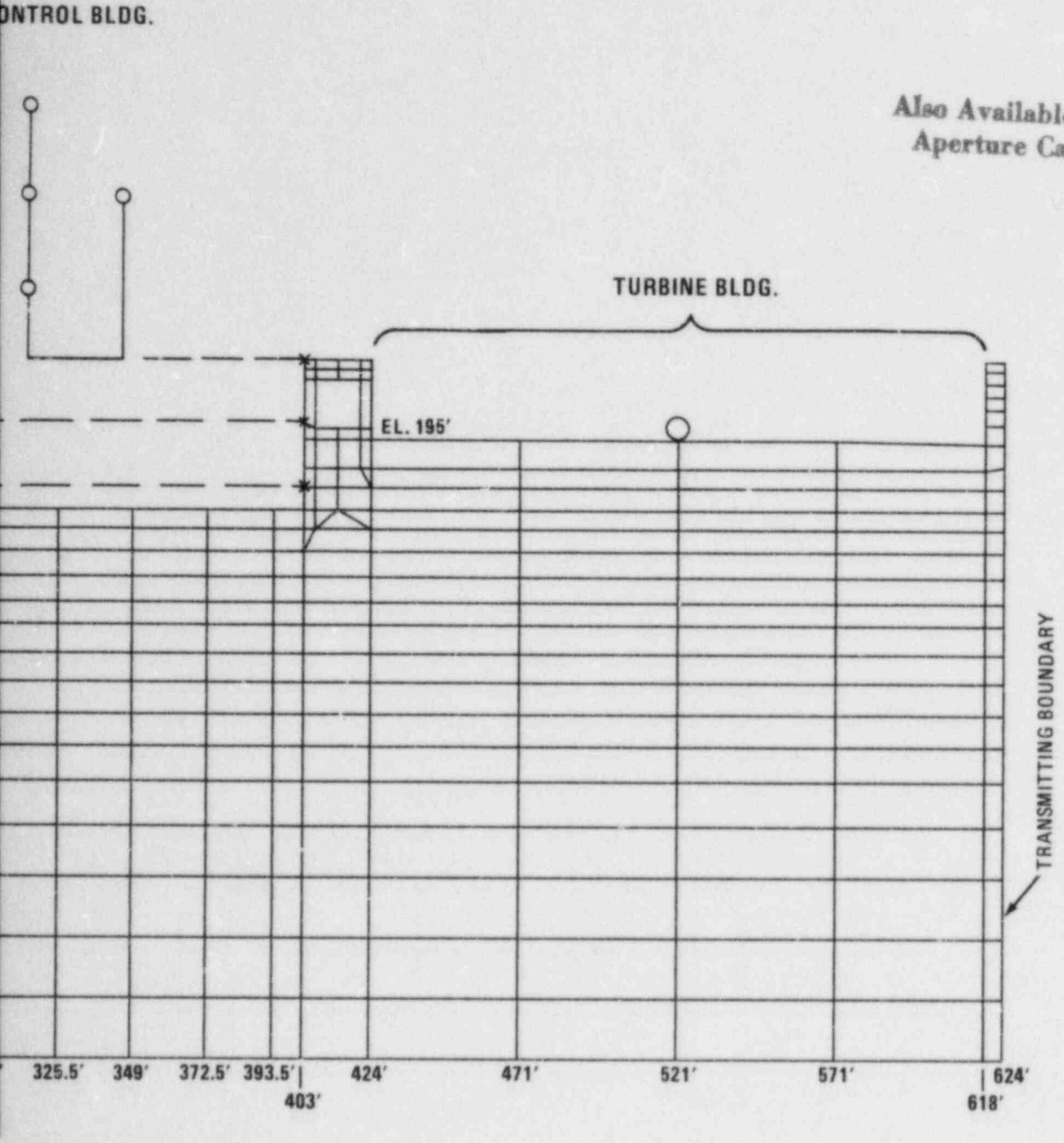
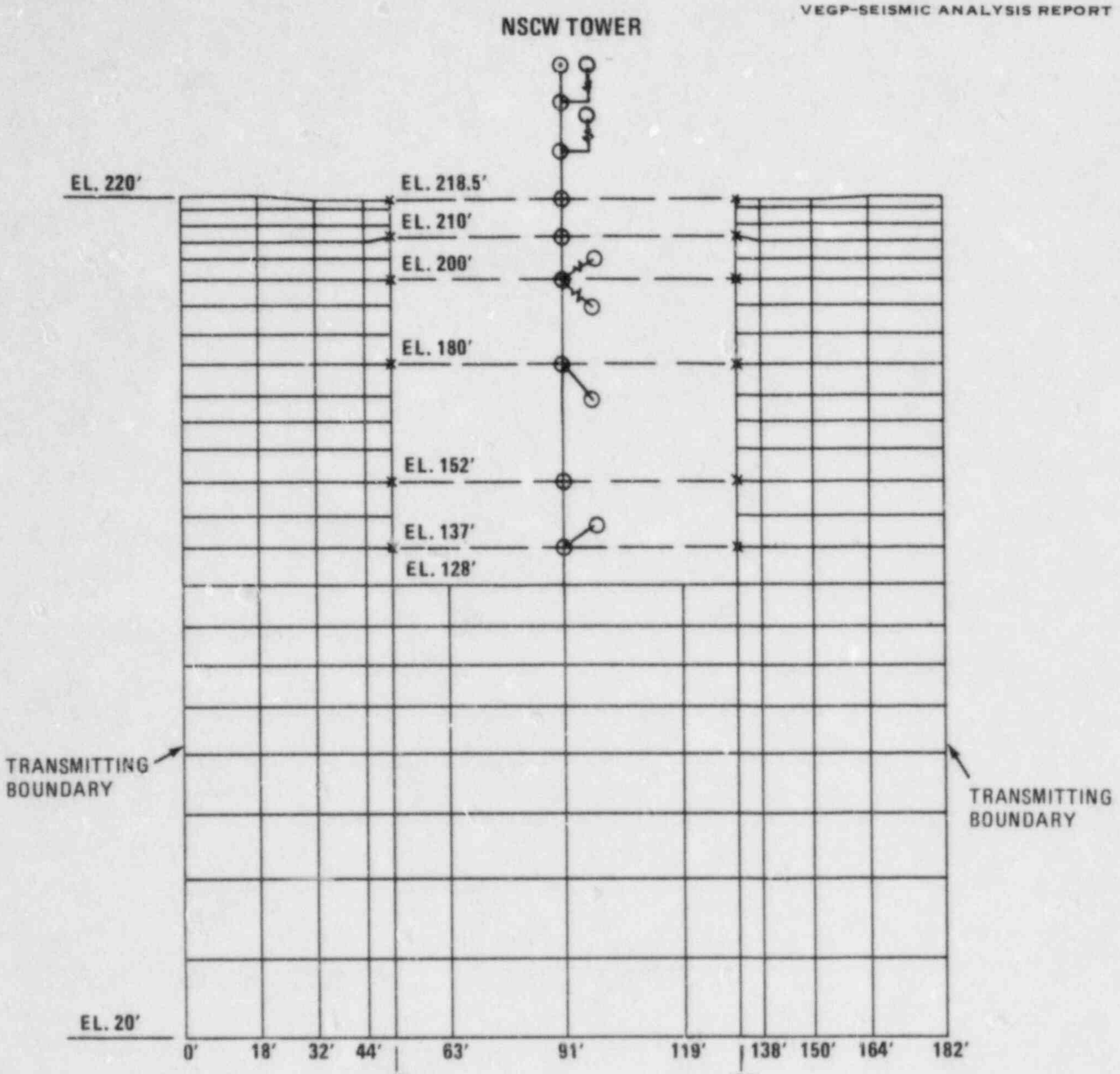
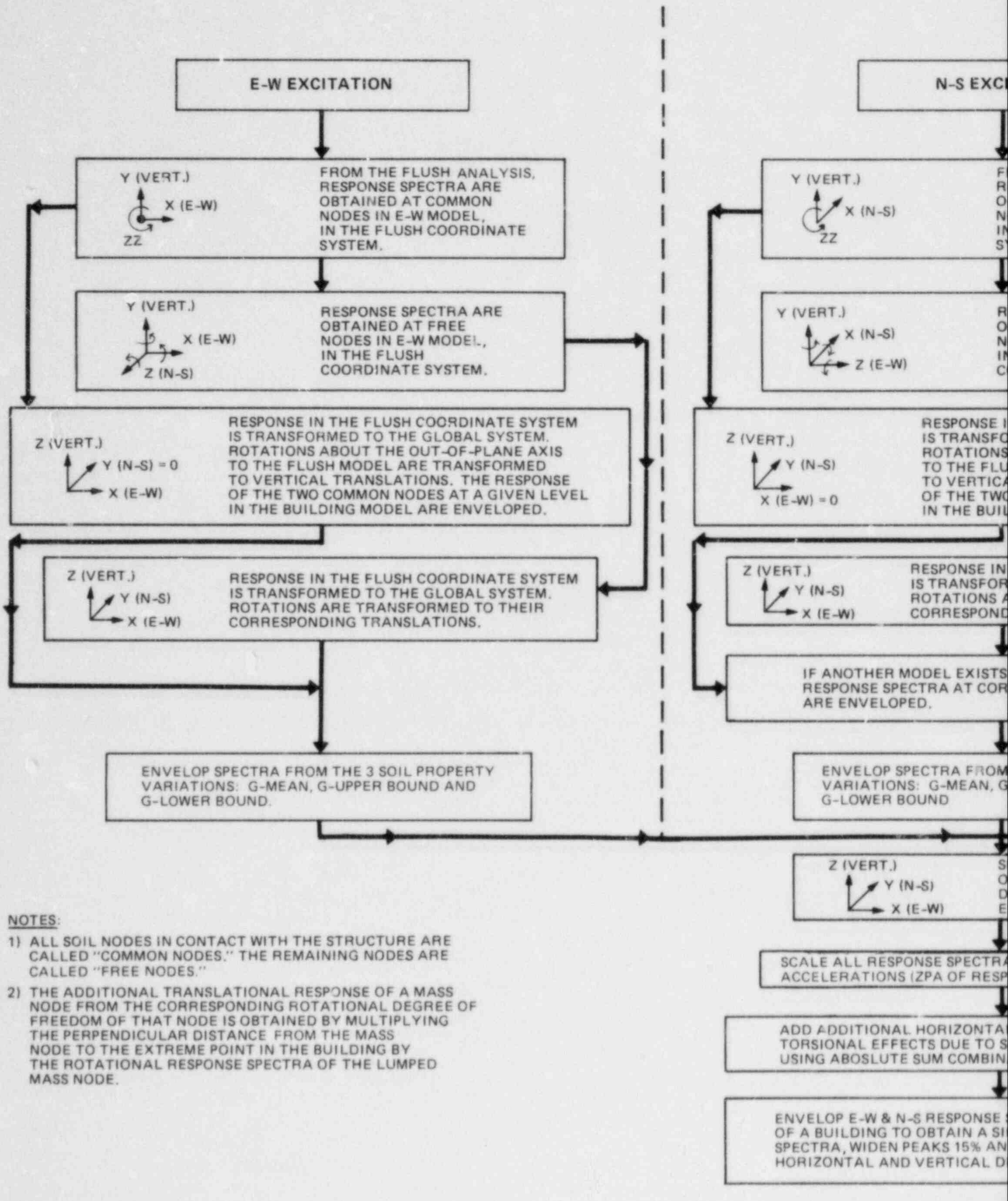


Figure 6-7
FLUSH MODEL 5



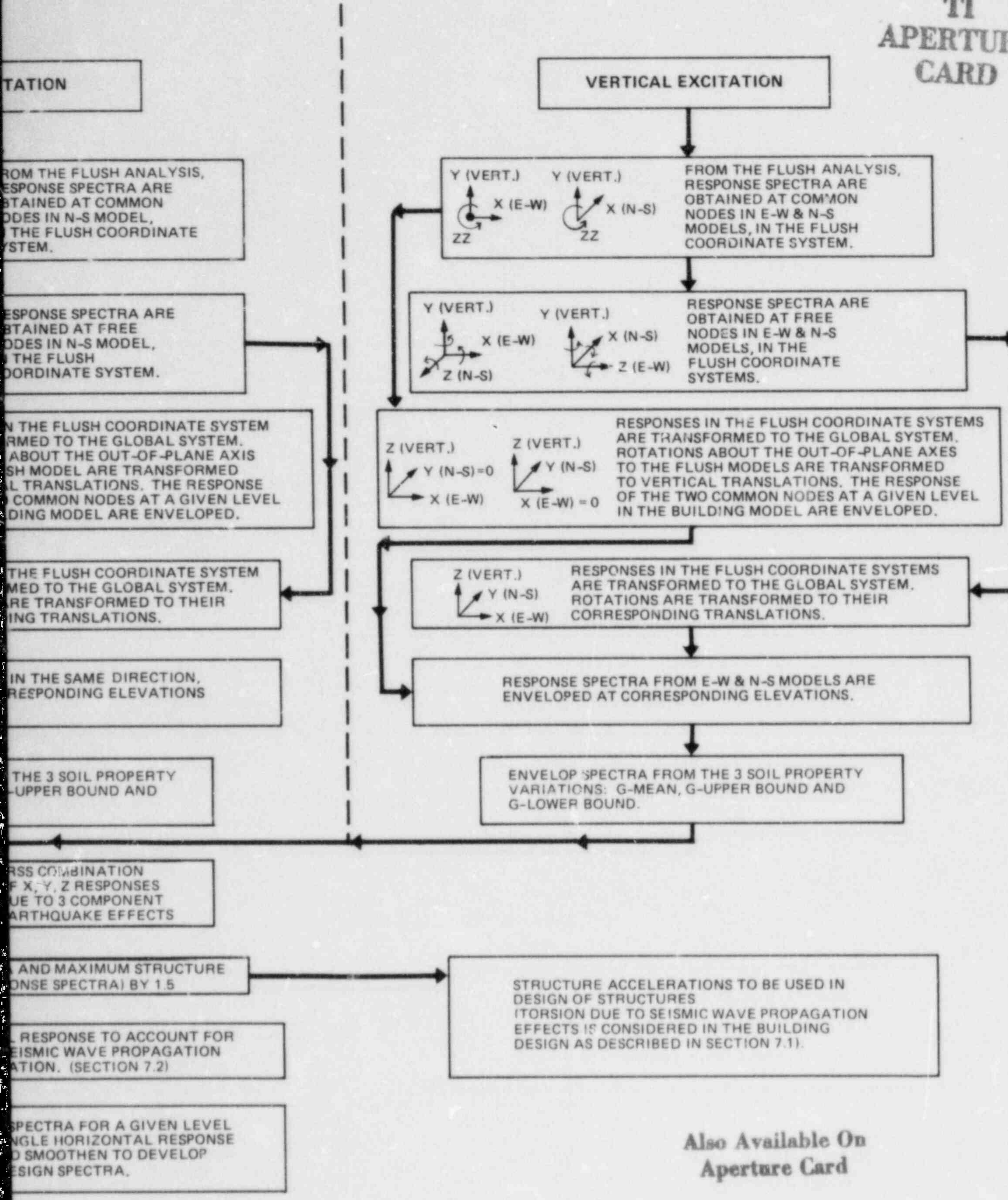
NOTE: VERTICAL DIMENSIONS OF THE SOIL LAYERS ARE THE SAME AS THOSE PROVIDED IN FIGURE 6-1.

Figure 6-8
FLUSH MODEL 6



NOTES:

1) ALL SOIL NODES IN CONTACT WITH THE STRUCTURE ARE CALLED "COMMON NODES." THE REMAINING NODES ARE CALLED "FREE NODES."
2) THE ADDITIONAL TRANSLATIONAL RESPONSE OF A MASS NODE FROM THE CORRESPONDING ROTATIONAL DEGREE OF FREEDOM OF THAT NODE IS OBTAINED BY MULTIPLYING THE PERPENDICULAR DISTANCE FROM THE MASS NODE TO THE EXTREME POINT IN THE BUILDING BY THE ROTATIONAL RESPONSE SPECTRA OF THE LUMPED MASS NODE.



TATION

ROM THE FLUSH ANALYSIS,
ESPONSE SPECTRA ARE
BTAINED AT COMMON
ODES IN N-S MODEL,
THE FLUSH COORDINATE
YSTEM.

ESPONSE SPECTRA ARE
BTAINED AT FREE
ODES IN N-S MODEL,
THE FLUSH
OORDINATE SYSTEM.

N THE FLUSH COORDINATE SYSTEM
RMED TO THE GLOBAL SYSTEM.
ABOUT THE OUT-OF-PLANE AXIS
SH MODEL ARE TRANSFORMED
L TRANSLATIONS. THE RESPONSE
COMMON NODES AT A GIVEN LEVEL
DING MODEL ARE ENVELOPED.

THE FLUSH COORDINATE SYSTEM
MED TO THE GLOBAL SYSTEM.
RE TRANSFORMED TO THEIR
ING TRANSLATIONS.

IN THE SAME DIRECTION,
RESPONDING ELEVATIONS

THE 3 SOIL PROPERTY
-UPPER BOUND AND

RSS COMBINATION
F X, Y, Z RESPONSES
UE TO 3 COMPONENT
ARTHQUAKE EFFECTS

AND MAXIMUM STRUCTURE
ONSE SPECTRA) BY 1.5

L RESPONSE TO ACCOUNT FOR
EISMIC WAVE PROPAGATION
ATION. (SECTION 7.2)

SPECTRA FOR A GIVEN LEVEL
NGLE HORIZONTAL RESPONSE
SMOOTHEN TO DEVELOP
ESIGN SPECTRA.

VERTICAL EXCITATION

FROM THE FLUSH ANALYSIS, RESPONSE SPECTRA ARE OBTAINED AT COMMON NODES IN E-W & N-S MODELS, IN THE FLUSH COORDINATE SYSTEM.

RESPONSE SPECTRA ARE OBTAINED AT FREE NODES IN E-W & N-S MODELS, IN THE FLUSH COORDINATE SYSTEMS.

RESPONSES IN THE FLUSH COORDINATE SYSTEMS ARE TRANSFORMED TO THE GLOBAL SYSTEM. ROTATIONS ABOUT THE OUT-OF-PLANE AXES TO THE FLUSH MODELS ARE TRANSFORMED TO VERTICAL TRANSLATIONS. THE RESPONSE OF THE TWO COMMON NODES AT A GIVEN LEVEL IN THE BUILDING MODEL ARE ENVELOPED.

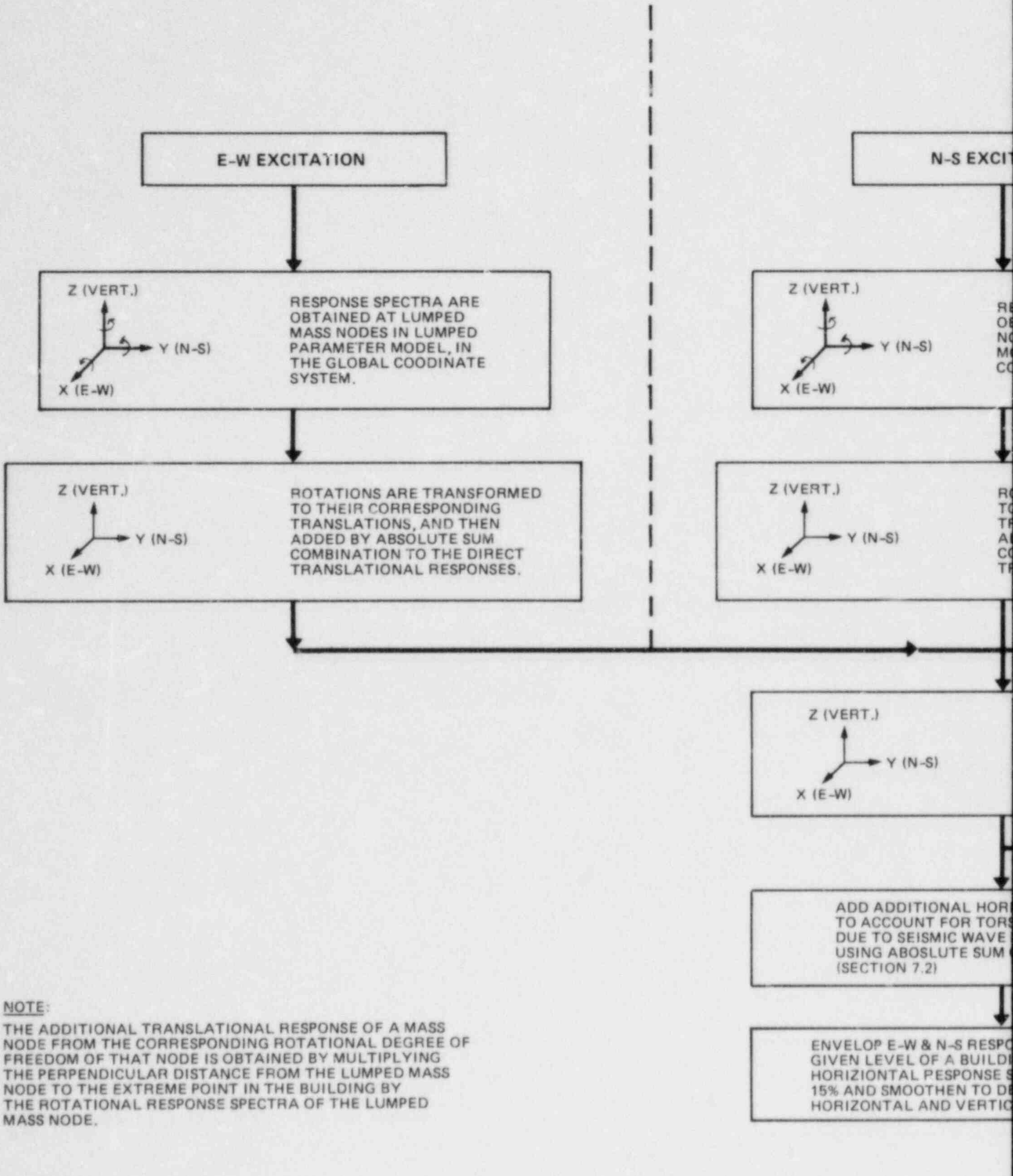
RESPONSES IN THE FLUSH COORDINATE SYSTEMS ARE TRANSFORMED TO THE GLOBAL SYSTEM. ROTATIONS ARE TRANSFORMED TO THEIR CORRESPONDING TRANSLATIONS.

RESPONSE SPECTRA FROM E-W & N-S MODELS ARE ENVELOPED AT CORRESPONDING ELEVATIONS.

ENVELOP SPECTRA FROM THE 3 SOIL PROPERTY VARIATIONS: G-MEAN, G-UPPER BOUND AND G-LOWER BOUND.

STRUCTURE ACCELERATIONS TO BE USED IN DESIGN OF STRUCTURES (TORSION DUE TO SEISMIC WAVE PROPAGATION EFFECTS IS CONSIDERED IN THE BUILDING DESIGN AS DESCRIBED IN SECTION 7.1).

Figure 6-9
GENERATION OF FLOOR RESPONSE SPECTRA
FOR DEEPLY EMBEDDED STRUCTURES



NOTE:

THE ADDITIONAL TRANSLATIONAL RESPONSE OF A MASS NODE FROM THE CORRESPONDING ROTATIONAL DEGREE OF FREEDOM OF THAT NODE IS OBTAINED BY MULTIPLYING THE PERPENDICULAR DISTANCE FROM THE LUMPED MASS NODE TO THE EXTREME POINT IN THE BUILDING BY THE ROTATIONAL RESPONSE SPECTRA OF THE LUMPED MASS NODE.

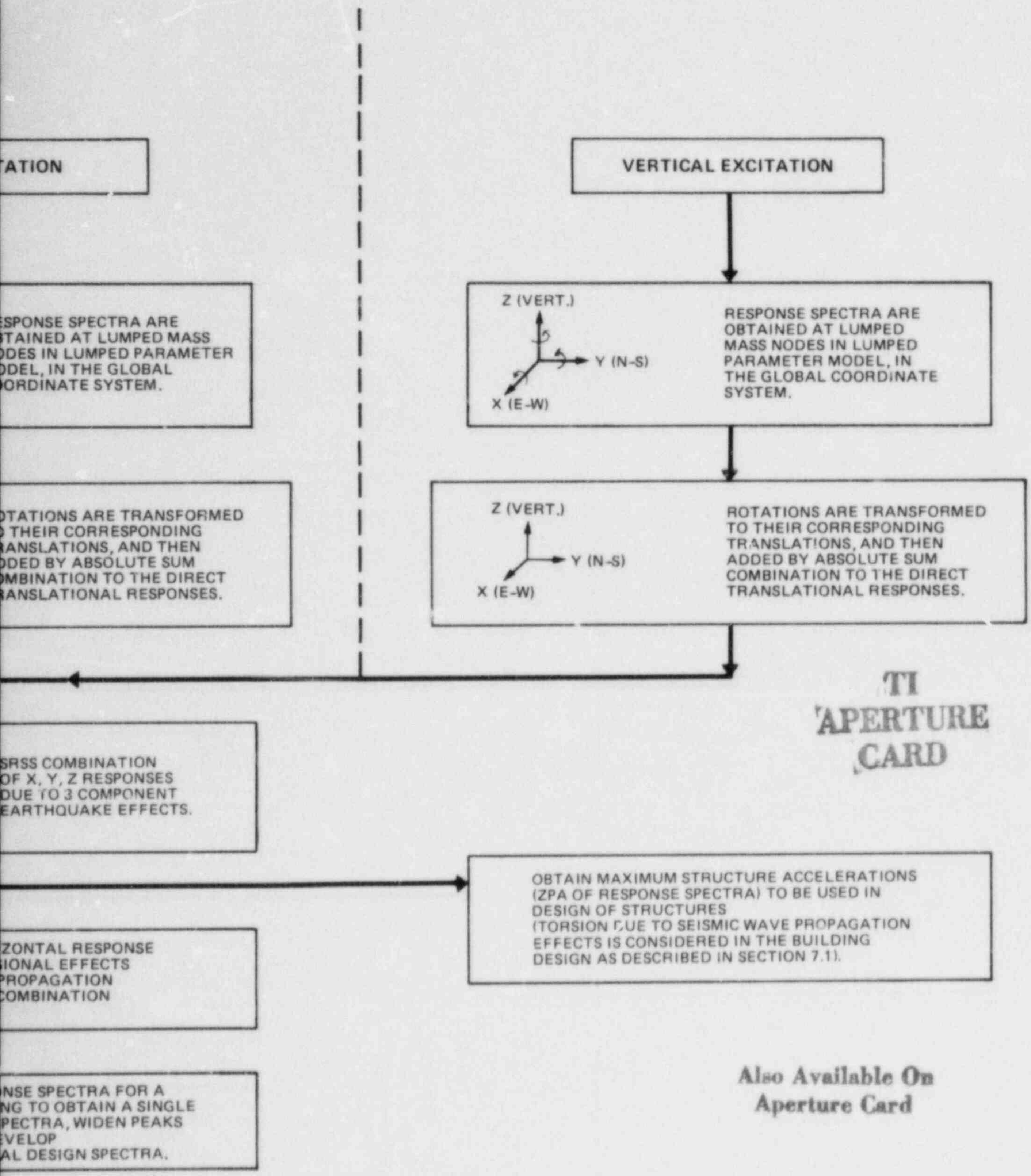


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Figure 6-10
GENERATION OF FLOOR RESPONSE SPECTRA FOR SHALLOWLY EMBEDDED STRUCTURES

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7.0 SEISMIC WAVE PROPAGATION EFFECTS

As part of the design basis (refer to section 2.1) Category 1 structures, systems and components are designed to resist a static seismic torsional moment of not less than that required by the Uniform Building Code, in addition to the effects resulting from the actual geometric eccentricity between the center of mass and center of rigidity at each level of the structure. The intent of the additional torsional requirement is to account for the torsional motion imparted to the structure due to the effects of seismic soil wave propagation. The methodology used for structures and equipment to account for torsional ground motion effects is described in the following sections.

7.1 CATEGORY 1 STRUCTURES

The seismic analyses of Category 1 structures, performed on the three-dimensional structure models, account for the actual geometric eccentricities between the centers of mass and the centers of rigidity of the structures. The accelerations obtained from these models are first calculated considering the three component earthquake effects as described in sections 6.2 and 6.3. These accelerations are used to determine the story shears at the various levels of a structure. In the design, the actual eccentricity at a given level is increased by 5 percent of the maximum building plan dimension at the corresponding level, and the design static seismic torsional moment is computed as the product of the augmented eccentricity and the story shear. This procedure applies to the two orthogonal horizontal directions.

7.2 EQUIPMENT, SYSTEMS AND COMPONENTS

The torsional motion imparted to the structure due to the effects of seismic wave propagation affects only the horizontal in-structure response spectra used for equipment qualification. The procedure used to obtain the effect of this torsional ground motion is described below.

A three-dimensional lumped parameter model of the structure with soil springs is utilized to compute the torsional spectra. The structure model accounts for the actual geometric eccentricities between the centers of mass and the centers of rigidity of the structure. The translational as well as the rotational stiffness and inertial characteristics are modeled. The foundation impedances consist of three translational (two horizontal and one vertical) and three rotational (two rocking and one torsional) springs and are based on the mean soil properties.

The model is analyzed using the design horizontal ground motion time-history conforming to the Regulatory Guide 1.60 horizontal response spectra applied in the free-field at the foundation level of the structure. The base shear computed from this analysis, multiplied by 5 percent of the maximum plan dimension at the foundation level, yields the incremental static torsional moment (T_s) at that level.

A torsional ground motion time-history conforming to the Regulatory Guide 1.60 horizontal response spectra is applied in the free-field at the foundation level of the structure. The maximum dynamic torsional moment (T_d) at the base of the structure is computed from this dynamic analysis.

The magnitude of the torsional ground motion is selected such that T_d at the base of the structure resulting from the torsional ground motion analysis is equal to the T_s resulting from the 5-percent eccentricity. The resulting response spectra from the torsional degree of freedom of the base node represents then the torsional response of the basemat. Multiplying this by the distance along the north-south and east-west direction of the extreme point in the building to the lumped mass node gives the maximum possible additional east-west and north-south horizontal response spectra of the basemat, respectively.

The torsional responses of the nodes at different levels of the building from the torsional ground motion analysis are used with the respective extreme point distances along the north-south and east-west directions to compute the additional horizontal in-structure response spectra at these levels.

The amplification of the torsional response of the structure as a function of height tends to be smaller than the amplification of the horizontal response of the structure. Therefore, as an added conservatism, the torsional input ground motion is increased so that the ratio between the maximum torsional acceleration at a given node (caused by the torsional ground motion) to the maximum horizontal acceleration at the node (caused by the horizontal ground motion) is maintained the same as at the foundation level of the structure.

The computed additional horizontal in-structure response spectra, to account for the torsional ground motion effects, are added absolutely to the horizontal in-structure response spectra obtained using the methods described in sections 6.2 and 6.3 (which inherently account for any torsional effects due to the actual geometric eccentricity which exists in the structure itself), before the broadening of the peaks and smoothing of the curves are done. The peaks of the response spectra resulting from the addition of these two spectra are then broadened and the curves smoothed to arrive at the final design in-structure response spectra for the horizontal direction.

The method applied to the NSCW tower is described below. This method is considered appropriate for the NSCW tower due to its large water mass.

Once the magnitude of the torsional ground motion is established so that the T_d at the base of the structure resulting from the torsional ground motion analysis is equal to the T_s resulting from the 5-percent eccentricity, the ratio of the horizontal acceleration at the extreme point in the basemat caused by the torsional ground motion to the maximum horizontal acceleration at the basemat caused by the horizontal ground motion is computed. The additional in-structure response spectra used to account for the torsional ground motion effects are computed by multiplying the horizontal in-structure response spectra developed using the methods described in sections 6.2 and 6.3 by this ratio.

8.0 EFFECTS OF FLOOR FLEXIBILITY ON RESPONSE SPECTRA

8.1 CONTAINMENT BUILDING

The purpose of this section is to assess the effects, if any, of the local flexibility of the containment internal structure floors on the floor design response spectra.

Floors exist both inside and outside of the secondary shield. Inside the secondary shield, the floors consist of structural steel members designed to be rigid. Outside the secondary shield, the floors consist of both structural steel members with grating and concrete slabs, spanning between the secondary shield and structural steel columns near the containment shell. Steel framing exists at four main elevations below the operating floor to support piping; cable trays; heating, ventilating, and air conditioning (HVAC) ducts; floor grating; and miscellaneous equipment. Steel framing is also provided at two elevations above the operating floor to support the containment coolers, containment auxiliary coolers, pre-access filtration units and hydrogen recombiners. The operating floor itself consists of structural steel framing and grating alternating with concrete floor slabs.

The mathematical model used for computing the in-structure response spectra, which includes the effects of the local flexibilities of floors, consists of a detailed (i.e., approximately 10,000 dynamic degrees of freedom) three-dimensional finite element model of the containment internal steel structure composed of beam elements, coupled with the lumped parameter model of the containment shell and internal concrete structure. Since the mass of each containment cooling unit is of the same order of magnitude as the mass of the local supporting structural steel, the analysis of the internal steel structure should consider any possible coupling effects between the cooler and the steel sub-structure. Therefore, simplified models of the containment cooling units and auxiliary cooling units are also included in the model. The masses of the remainder of the equipment, piping, cable trays and HVAC ducts attached to the internal steel structure are not large relative to the supporting steel, and therefore are considered as lumped masses at the appropriate support points in the development of the structural steel model. Soil-structure interaction effects are accounted for using the impedance method. Time-history analyses are performed, and considering the responses due to three component earthquake effects, response spectra are generated at the governing locations (i.e., midspans of beams and slabs) on the containment floors.

Evaluation of the horizontal floor response spectra indicates that there is no significant amplification of response due to floor flexibility. The vertical response spectra obtained from the three-dimensional structural steel finite element model is compared with the design response spectra (i.e., spectra generated using the methodology described in section 6.2). Based on the comparison, it is concluded that the design response spectra envelop the spectra obtained from the structural steel model. As an example, the vertical response spectra obtained at elevation 238'-0", at the governing cooler support location, is shown in figure 8-1 along with the design response spectra corresponding to that level.

8.2 OTHER CATEGORY 1 STRUCTURES

The purpose of this section is to address the effects of the vertical flexibility of the floor slabs on the seismic analysis of Category 1 concrete shear wall structures. Due to the wide range of slab frequencies (i.e., long slab spans and short slab spans) which exist in the control building, it is used as the representative shear wall structure to illustrate the analysis methodology used to evaluate the floor vertical flexibility effects on the floor response spectra.

Two different lumped mass structure models are used for the flexibility study, one being a rigid floor model (developed per the methodology described in section 4.1.1), the other a flexible floor model. The total mass at a given level of the lumped mass model includes the weight of the slabs, walls, equipment and systems. For the flexible floor model, half of the total mass at each level is taken to be the floor mass and the other half as the story mass. However, the effective mass which participates in the fundamental mode of vibration, for the case of a simply supported one-way slab with uniform mass, is half the slab mass. Therefore, in order to properly bound the limits of the problem, mass ratios of half of the total mass at each level and one-quarter of the total mass at each level are used to represent the flexible floor mass with the remaining mass as the story mass. For the flexible floor models, two cases, one with vertical floor frequency of 12.5 cps and the other with 8 cps, are considered. Soil-structure interaction effects are accounted for using the impedance method. Vertical time-history analyses of the rigid and flexible floor models are performed for OBE excitation. Story response spectra are generated at each level in the rigid floor model. Both floor response spectra and story response spectra are obtained at each level in the flexible floor models. The story response spectra from the rigid floor model are compared with the story and floor response spectra from the flexible floor model with no significant differences observed.

Therefore, it is concluded that the effects of vertical flexibility on the control building floor seismic accelerations and response spectra are insignificant, as long as the fundamental floor system frequency is equal to or higher than 8 cps. The calculated frequencies of the various slab-beam-girder systems located in the control building demonstrate that the lowest frequency is 9 cps.

Evaluations are made of other Category 1 concrete shear wall structures to determine the minimum required frequencies for floor systems. The calculated frequencies in these buildings demonstrate conformance with this frequency criteria.

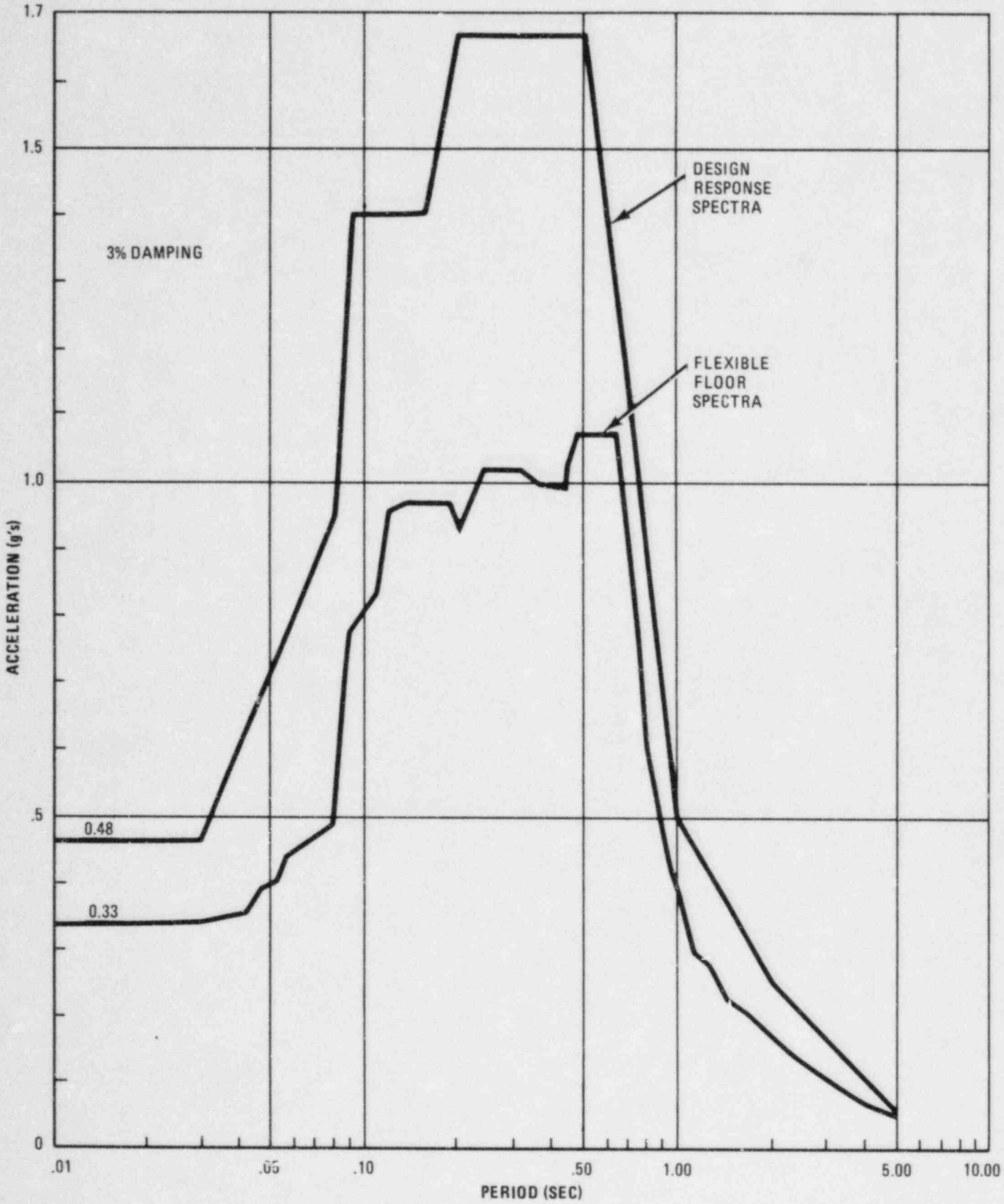

Figure 8-1
COMPARISON OF SSE VERTICAL RESPONSE SPECTRA AT EL. 238 FT. OF THE CONTAINMENT INTERNAL STRUCTURE

9.0 MISCELLANEOUS ANALYSES

9.1 INTERACTION OF NON-CATEGORY 1 STRUCTURES WITH CATEGORY 1 STRUCTURES

The equipment building is a non-Category 1 structure, which forms part of the control building and fuel handling building. It is designed to withstand the seismic loadings to the same criteria specified for Category 1 structures.

The turbine building, radwaste transfer building and Category 2 tunnels are the only other non-Category 1 structures adjacent to Category 1 structures. The turbine building and radwaste transfer building are designed for SSE loadings to demonstrate that under earthquake loadings they will not collapse on any Category 1 structure. The Category 2 tunnels are designed to maintain their structural integrity under earthquake conditions.

9.2 STRUCTURE DISPLACEMENTS

In order to provide seismic anchor motions for use in piping analysis, relative structure displacements are calculated under seismic conditions. The maximum horizontal structure-to-structure relative displacement during a safe shutdown earthquake at any elevation, for any two structures, is less than 2 inches. The maximum horizontal structure-to-structure relative displacement at grade elevation 220'-0", for any two structures, is about 1 inch. A structure-to-structure seismic gap of 5 1/2 inches separates all Category 1 buildings. Tunnels that are located below grade maintain a minimum tunnel-to-tunnel/building seismic gap of 3 inches. The provided structure-to-structure seismic gaps have a factor of safety of at least two over the maximum calculated structure-to-structure relative displacement. This factor ensures that the buildings will not impact against each other during the design seismic conditions and is a large enough physical separation to account for any variability and uncertainties associated with the parameters used in the analysis.

9.3 EVALUATION OF LAYOUT CHANGES

This section provides the criteria by which each Category 1 structure model is evaluated for potential influence of layout changes in the structure after the seismic analysis was performed. An evaluation of each structure model (i.e., lumped mass stick model) is made to determine if it represents the current layout of the structure. If the changes, which have occurred since the original structure model was created, appear insignificant then no further investigation is required and the structure model is said to represent the current configuration of the building. However, if the changes in layout are not obvious as to their impact on the analysis results, then the model is updated based on the most current design information concerning the structure and supported equipment and/or components.

A fixed-base modal analysis of the updated model is then performed, and the resulting frequencies are compared to those of the original model. The original model is determined to be adequate if the frequencies of the corresponding modes are found to be within 10 percent of each other. However, if the difference between corresponding frequencies is greater than 10 percent then the updated model is coupled with the soil system, and the soil-structure system free vibration analysis is performed. Again the difference between the corresponding frequencies of the updated model and the original model are calculated with a maximum difference of 5 percent allowed. If the 5 percent criteria is not satisfied the process is continued and floor response spectra are developed for the updated model and then compared to those obtained from the original model. If there is no significant difference between response spectra obtained from the two models then the original model is determined to represent the current configuration of the structure. If there is significant difference, revised response spectra are issued and associated impact on structure design and equipment qualification is evaluated, and any necessary action needed to demonstrate conformance with the revised response spectra is taken. To date there has been no need to revise any design response spectra.

A story was added to a portion of the control building structure between elevation 280'-0" and 301'-0". However, the addition of this new level along with changes in layout at existing elevations do not adversely affect the design response spectra at the existing floor levels. Design floor acceleration values are developed for the added level.

10.0 CONCLUSION

The Seismic Analysis Report demonstrates that the VEGP seismic design bases and analysis methodology are in accordance with the licensing commitments made in PSAR Supplements No. 3, 4, and 5 and meet the requirements specified in NRC to GPC letter, dated March 27, 1978.

11.0 REFERENCES

1. Seed, H. B., and Idriss, I. M., "Soil Moduli and Damping Factors for Dynamic Response Analysis," Earthquake Engineering Research Center, University of California, Report No. EERC 70-10, Berkeley, California, December 1970.

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APPENDIX A

IMPEDANCE FUNCTIONS FOR AN ARBITRARILY SHAPED FOUNDATION ON A LAYERED MEDIUM

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IMPEDANCE FUNCTIONS FOR AN ARBITRARILY SHAPED FOUNDATION ON A LAYERED MEDIUM

This appendix describes the procedure used to compute the impedance functions for an arbitrarily shaped foundation resting on a layered soil medium, for use in the soil-structure interaction analysis as specified in section 6.3.

The analytical techniques to obtain the impedance functions for flat rigid foundations of arbitrary shape placed on the surface of an elastic half-space have been developed by Wong and Luco$^{(1)}$. The equation of motion for the forced steady-state vibrations of an elastic half-space excited by harmonic loads distributed over a region S of the plane surface (Figure 1) is

$$(c^2-\beta^2)\ \nabla(\nabla\cdot u) + \beta^2\nabla^2 u + \omega^2 u = 0, \chi_3 \geq 0 \qquad (1)$$

in which u is the displacement vector $(u_1, u_2\ u_3)e^{i\omega t}$ in the cartesian system of co-ordinates (χ_1, χ_2, χ_3) such that $\chi_3 = 0$ corresponds to the surface of the half-space with $\chi_3 > 0$ representing the points within the half-space. c and β are the compressional and shear wave velocities, respectively.

Assuming that the surface tractions on the loaded region S are known, or equivalently, assuming that the stress components σ_{j3} $(j = 1,2,3)$ on S are known, then a solution of equation (1) satisfying the mixed boundary-value problem on $\chi_3 = 0$, in which displacements are prescribed along the contact between the

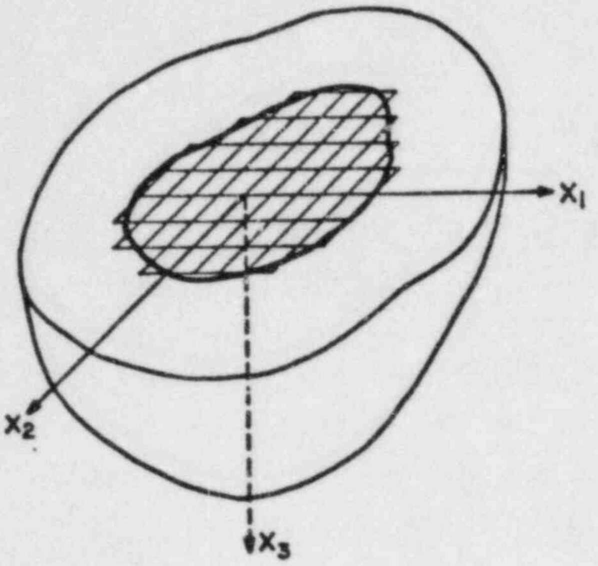

Figure 1. Description of the Model and Coordinate System

foundation and the soil while tractions are prescribed on the soil surface not covered by the foundation, is given by

$$u_i(x_1,x_2,0) = -\sum_{j=1}^{3} \int_S G_{ij}\left(x_1-x_1^o,x_2-x_2^o,0\right)\sigma_{j3}\left(x_1^o,x_2^o,0\right)\, dx_1^o dx_2^o \qquad (2)$$

for $x_3 = 0$. In equation (2), $G_{ij}\left(x_1-x_1^o,x_2-x_2^o,0\right)$ denotes the ith displacement component at $(x_1,x_2,0)$ generated by a unit harmonic load acting at $\left(x_1^o,x_2^o,0\right)$.

To solve this integral equation (2) for an arbitrary shaped foundation the following numerical procedure is used:

1. The region S is divided into n rectangular sub-regions $S_k (k = 1,2,\ldots,n)$ as indicated in Figure 1.

2. The stress components σ_{j3} are assumed to have constant values $\sigma_{j3}^{(k)}$ within each subregion S_k.

3. The boundary conditions are satisfied approximately by matching the average displacements within each

subregion to the average value of the required compatible displacements.

Using the above approximations, the integral equation (2) can be expressed in matrix equations as

$$\begin{Bmatrix} \bar{\underset{\sim}{u}}_1 \\ \bar{\underset{\sim}{u}}_2 \\ \vdots \\ \bar{\underset{\sim}{u}}_n \end{Bmatrix} = \begin{bmatrix} [\phi]_{11} & [\phi]_{12} & \cdots & [\phi]_{1n} \\ [\phi]_{21} & [\phi]_{22} & \cdots & [\phi]_{2n} \\ \vdots & \vdots & & \vdots \\ [\phi]_{n1} & [\phi]_{n2} & \cdots & [\phi]_{nn} \end{bmatrix} \begin{Bmatrix} \sigma_{j3}^{(1)}A_1 \\ \sigma_{j3}^{(2)}A_2 \\ \vdots \\ \sigma_{j3}^{(n)}A_n \end{Bmatrix} \qquad (3)$$

in which

$\bar{\underset{\sim}{u}}_i$ = $\left\{\bar{u}_{1i}, \bar{u}_{2i}, \bar{u}_{3i}\right\}^T$ are average displacements in sub-region S_i

A_i = Area of sub-region S_i

$[\phi]_{ij}$ = a 3 x 3 compliance submatrix relating the average displacements at sub-region S_i to the tractions at sub-region S_j

To calculate the compliance submatrices, four linear integrals on the Green's functions are performed for point loads at the surface of a layered stratum. The formula for $[\phi]_{ij}$ is

$$[\phi]_{ij} = -\!\!\!\!\!\int_{S_i} ds \int_{S_j} ds_o [G(\omega, \underset{\sim}{r} - \underset{\sim}{r}_o, \underset{\sim}{P})] \qquad (4)$$

in which [G] is the 3 x 3 Green's function matrix relating the displacement at the observation point $\underset{\sim}{r} = \left\{x_1, x_2, 0\right\}^T$ due to a set of point loads at the source point $\underset{\sim}{r}_o = \left\{x_1^o, x_2^o, 0\right\}^T$. $\underset{\sim}{P}$ is the property vector associated with the underlying half-space. By use of the average displacement matching approximation, the following symmetry exists even if $A_i \neq A_j$.

$$[\phi]_{ij}{}^{T} = [\phi]_{ji} \qquad (5)$$

The property vector $\underset{\sim}{P}$ for a horizontally layered stratum can be characterized as

$$\underset{\sim}{P} = \left\{ m, \mu_i, \beta_i, \rho_i, h_i, \nu_i, \xi_i \right\}$$

where

m = the number of layers
μ_i = the shear modulus of the ith layer
β_i = the shear wave velocity of the ith layer
ρ_i = the mass density of the ith layer
h_i = the thickness of the ith layer
ν_i = the Poisson's ratio of the ith layer
ξ_i = the critical damping coefficient of the ith layer

The matrix [G] contains six independent elements. In order to reduce the number of independent variables and to render [G] dimensionless, a new matrix [G′] may be defined in the polar coordinate system $\{r,\psi,z\}$, shown in Figure 2.

$$\left[G(\omega, \underset{\sim}{r} - \underset{\sim}{r}_o, \underset{\sim}{P}) \right] = \frac{1}{\bar{\mu} r} \left[G'(b_o, \psi, \underset{\sim}{P}') \right] \qquad (6)$$

where

$$r = |\underset{\sim}{r} - \underset{\sim}{r}_o| = \sqrt{\left(x_1 - x_1^o\right)^2 + \left(x_2 - x_2^o\right)^2}$$

$$\psi = \arg(\underset{\sim}{r} - \underset{\sim}{r}_o) = \tan^{-1}\left(\frac{x_2 - x_2^o}{x_1 - x_1^o}\right)$$

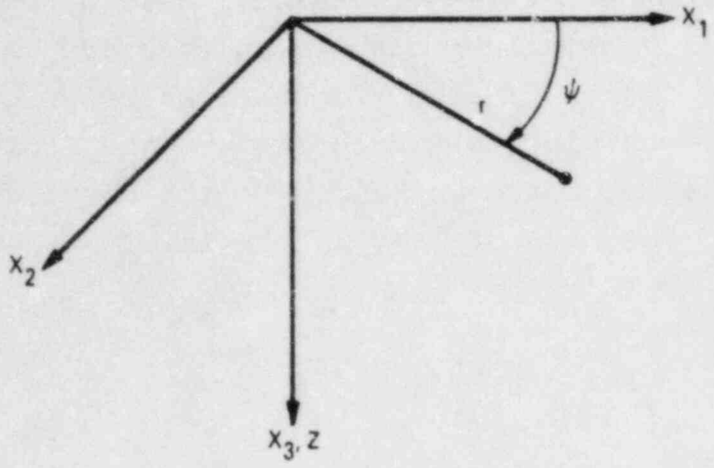

Figure 2. Description of Polar Coordinate System

$$b_o = \frac{\omega r}{\bar{\beta}}$$

$$\underset{\sim}{P}' = \left\{ m, \mu_i', \beta_i', \rho_i', h_i', \nu_i, \xi_i \right\}$$

is the normalized property vector in which

$$\mu_i' = \frac{\mu_i}{\bar{\mu}}$$

$$\beta_i' = \frac{\beta_i}{\bar{\beta}}$$

$$\rho_i' = \frac{\rho_i}{\bar{\rho}}$$

$$h_i' = \frac{\omega h_i}{\bar{\beta}}$$

The reference values of $\bar{\mu}$, $\bar{\beta}$ and $\bar{\rho}$, used to normalize $\underset{\sim}{P}'$ and [G′], are usually taken to be those of the top layer.

The dimensionless matrix [G′] is a function of four variables, f_{rr}, $f_{\psi r}$, f_{rz}, and f_{zz}, which are the Green's functions in polar coordinate system.

The Green's functions for three dimensional wave propagation in layered viscoelastic media have been formulated and solved by Luco and Apsel(2)(3). In frequency domain, solution of the Green's functions in polar coordinates, which involve the Hankel transform-type integral representations of the displacement and stress components, can be expressed in the form

$$I_n(b_o) = \int_0^{\alpha} F(k,\omega,\underset{\sim}{P}') \, J_n(kb_o) \, dk \qquad (7)$$

for the concentrated point load applied at surface and displacement at the free surface observed at b_o distance from the load point. The Kernel F depends upon wave number k, frequency ω and layer properties $\underset{\sim}{P}'$; whereas, the Bessel functions J_n depend only upon kb_o. The F integrands are evaluated in terms of factorizations of the upgoing and downgoing wave amplitudes in each layer. The semi-infinite integral in equation (7) can be reduced to the following finite integral

$$I_n(b_o) = I_n(0) + \int_0^{k_\ell} [F(k,\omega,\underset{\sim}{P}') - F(k,0,P')] \, J_n(kb_o) \, dk \qquad (8)$$

in which the upper limit of integration, k_ℓ, is defined by the convergence of the dynamic integrands to the static integrands, and $I_n(0)$ represents the static ($\omega = 0$) integrals. Since the radial dependence b_o, appears only in the Bessel functions J_n, it is expedient to calculate the integrals begin at $b_o = 0$ and end at $b_o = \frac{\omega r_{max}}{\bar{\beta}}$ (r_{max} is the maximum length of the foundation) in equally spaced interval. This precalculated Green's function table can be repeatedly used in solving the compliance submatrices $[\phi]_{ij}$ in the integral equation (4) using Gaussian quadrature.

For a rigid foundation, the average displacements $\bar{\underset{\sim}{u}}_i$, evaluated at the center of sub-region S_i are given by

$$\begin{aligned} \bar{u}_{1i}\left(\chi_1^i,\chi_2^i,0\right) &= \Delta_1 - \theta_3\chi_2^i \\ \bar{u}_{2i}\left(\chi_1^i,\chi_2^i,0\right) &= \Delta_2 + \theta_3\chi_1^i \\ \bar{u}_{3i}\left(\chi_1^i,\chi_2^i,0\right) &= \Delta_3 + \theta_1\chi_2^i - \theta_2\chi_1^i \end{aligned} \tag{9}$$

where Δ_i $(i = 1,2,3)$ correspond to the amplitudes of the translational displacements at (0,0,0), while θ_i $(i = 1,2,3)$, which are assumed to be small, correspond to the amplitudes of the rotational displacements about the χ_i $(i = 1,2,3)$ axes. From the equation (3), the three corresponding traction components $\sigma_{j3}^{(k)}A_k$ can be expressed in terms of $\bar{\underset{\sim}{u}}_i$, by inverting the matrix $[\phi]$. By substituting for $\bar{\underset{\sim}{u}}_i$ from equation (9), the surface tractions on the contact area may be expressed in terms of the translation Δ_i and rotation θ_i of the rigid foundation. Finally, the total harmonic load, with components (P_1,P_2,P_3), and the total harmonic moment with components (M_1,M_2,M_3), acting on the contact area can be expressed in terms of traction components, by means of the following relationships

$$\begin{aligned} P_i &= -\sum_{j=i}^{n} \sigma_{i3}^{(j)}A_j \qquad (i = 1,2,3) \\ M_1 &= -\sum_{j=1}^{n} \chi_2^j\sigma_{33}^{(j)}A_j \\ M_2 &= -\sum_{j=1}^{n} \chi_1^j\sigma_{33}^{(j)}A_j \\ M_3 &= -\sum_{j=1}^{n}\left[\chi_1^j\sigma_{23}^{(j)}A_j - \chi_2^j\sigma_{13}^{(j)}A_j\right] \end{aligned} \tag{10}$$

Substitution for contact tractions in terms of Δ_i and θ_i into equation (10) leads to the desired force-displacement relationship for the rigid foundation

$$\begin{Bmatrix} P \\ M \end{Bmatrix} = [K] \begin{Bmatrix} \Delta \\ \theta \end{Bmatrix}$$

where [K] is the complex frequency dependent impedance functions for flat rigid foundations placed on the surface of an elastic half-space.

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2. Luco, J. E., and Apsel, R. J., "On the Green's Functions for the Layered Half Space," Part 1, Bulletin of the Seismological Society of America, Vol 73, pp 901-929, 1983.

3. Apsel, R. J., and Luco, J. E., "On the Green's Functions for the Layered Half Space," Part 2, Bulletin of the Seismological Society of America, Vol 73, pp 931-951, 1983.

APPENDIX B

DESIGN IN-STRUCTURE RESPONSE SPECTRA

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DESIGN IN-STRUCTURE RESPONSE SPECTRA

This appendix contains design in-structure response spectra for selected levels in major Category 1 structures.

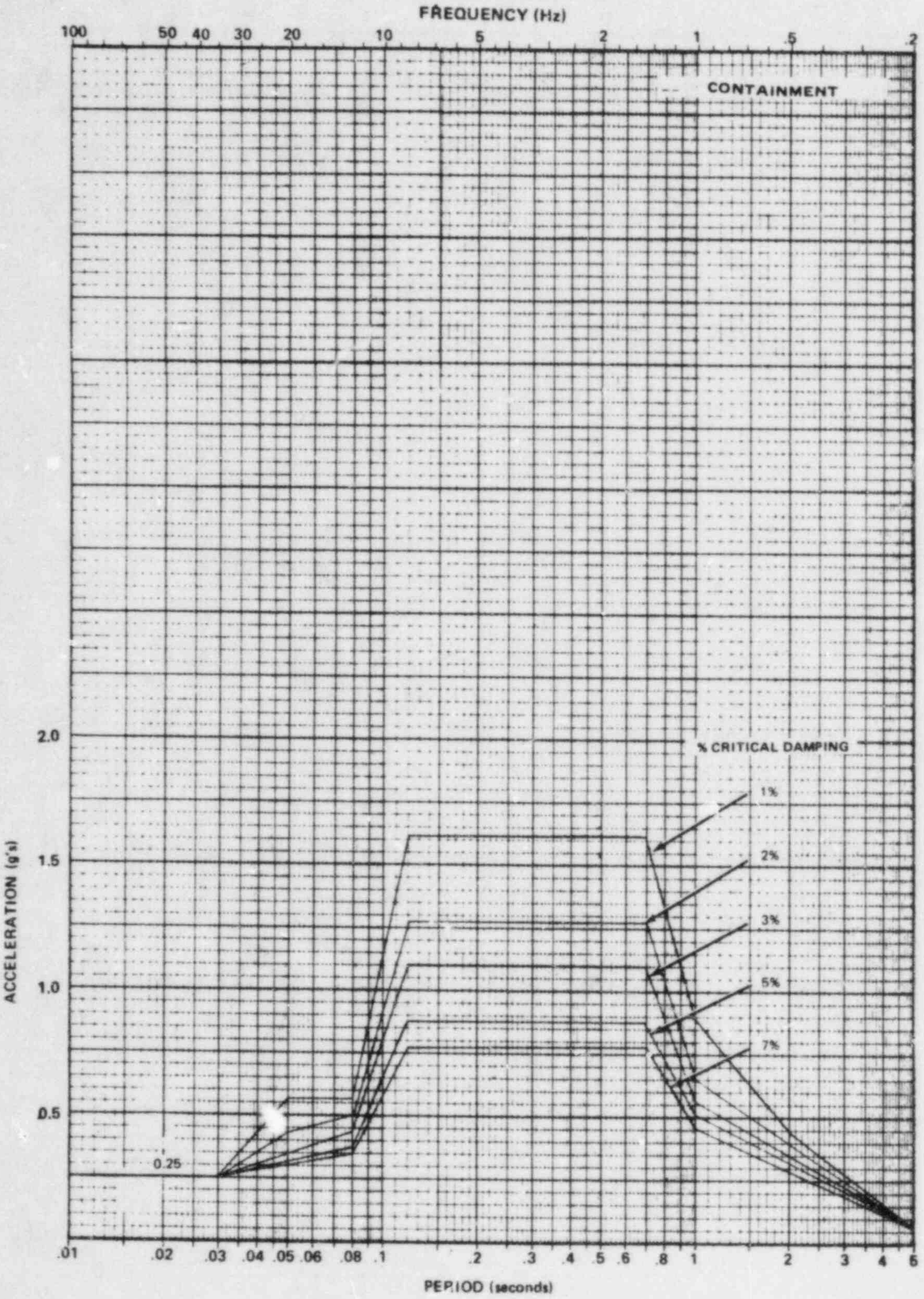

Figure B-1
SAFE SHUTDOWN EARTHQUAKE
HORIZ. ACCEL. RESPONSE SPECTRA
EL. 169 FT. 0 IN.

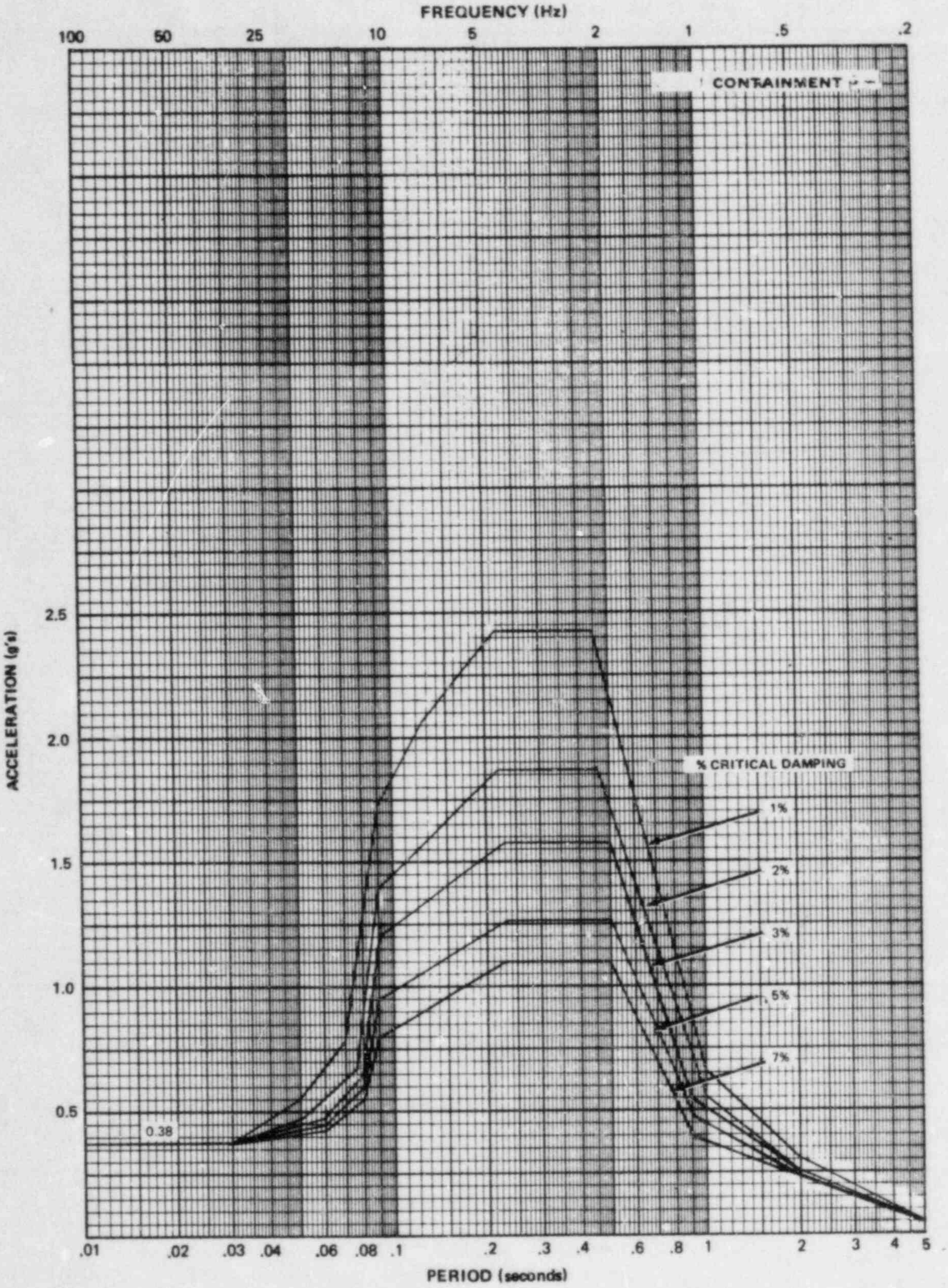

Figure B-2
SAFE SHUTDOWN EARTHQUAKE
VERTICAL ACCEL. RESPONSE SPECTRA
EL. 169 FT. 0 IN.

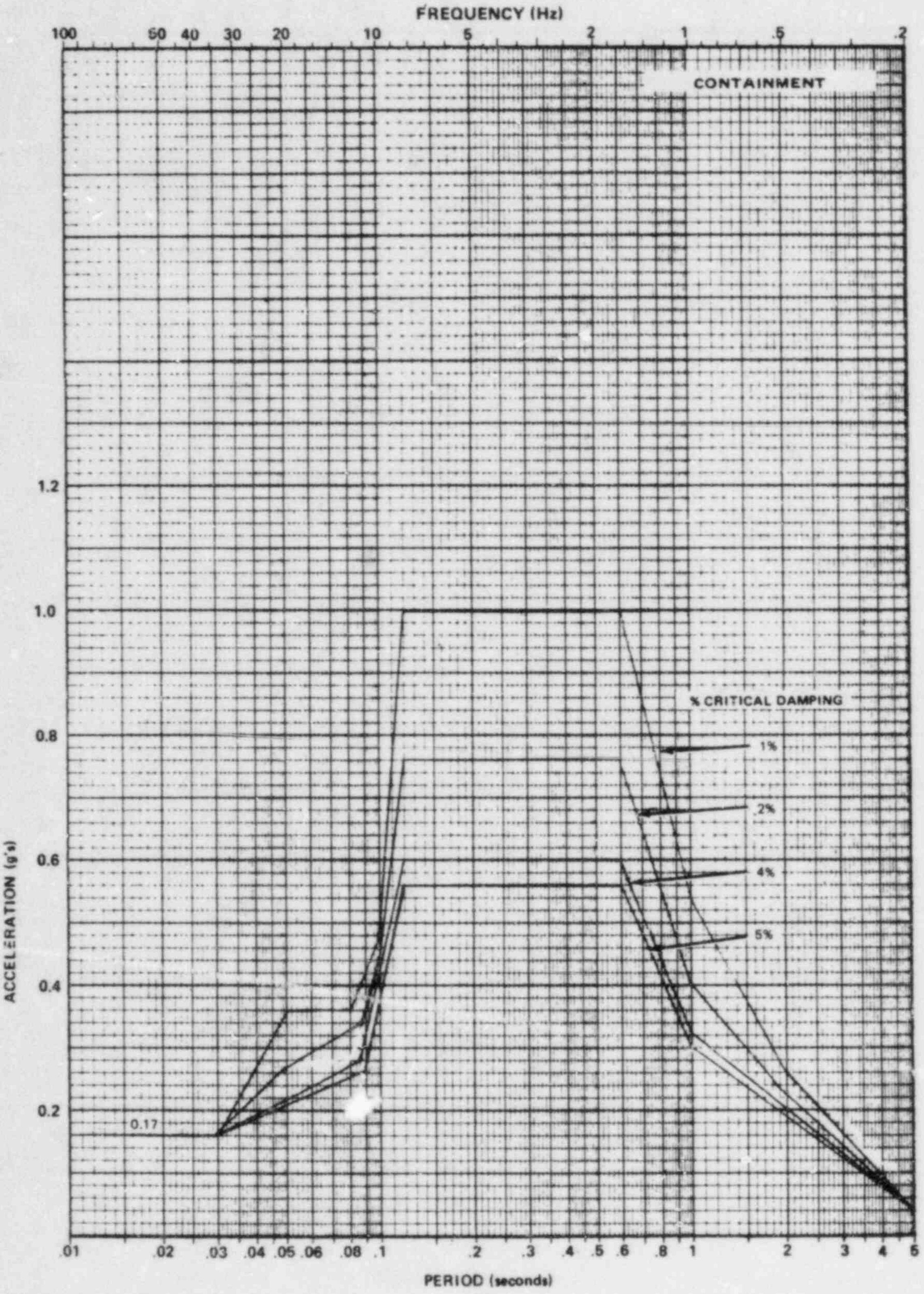

Figure B-3
OPERATING BASIS EARTHQUAKE
HORIZ. ACCEL. RESPONSE SPECTRA
EL. 169 FT. 0 IN.

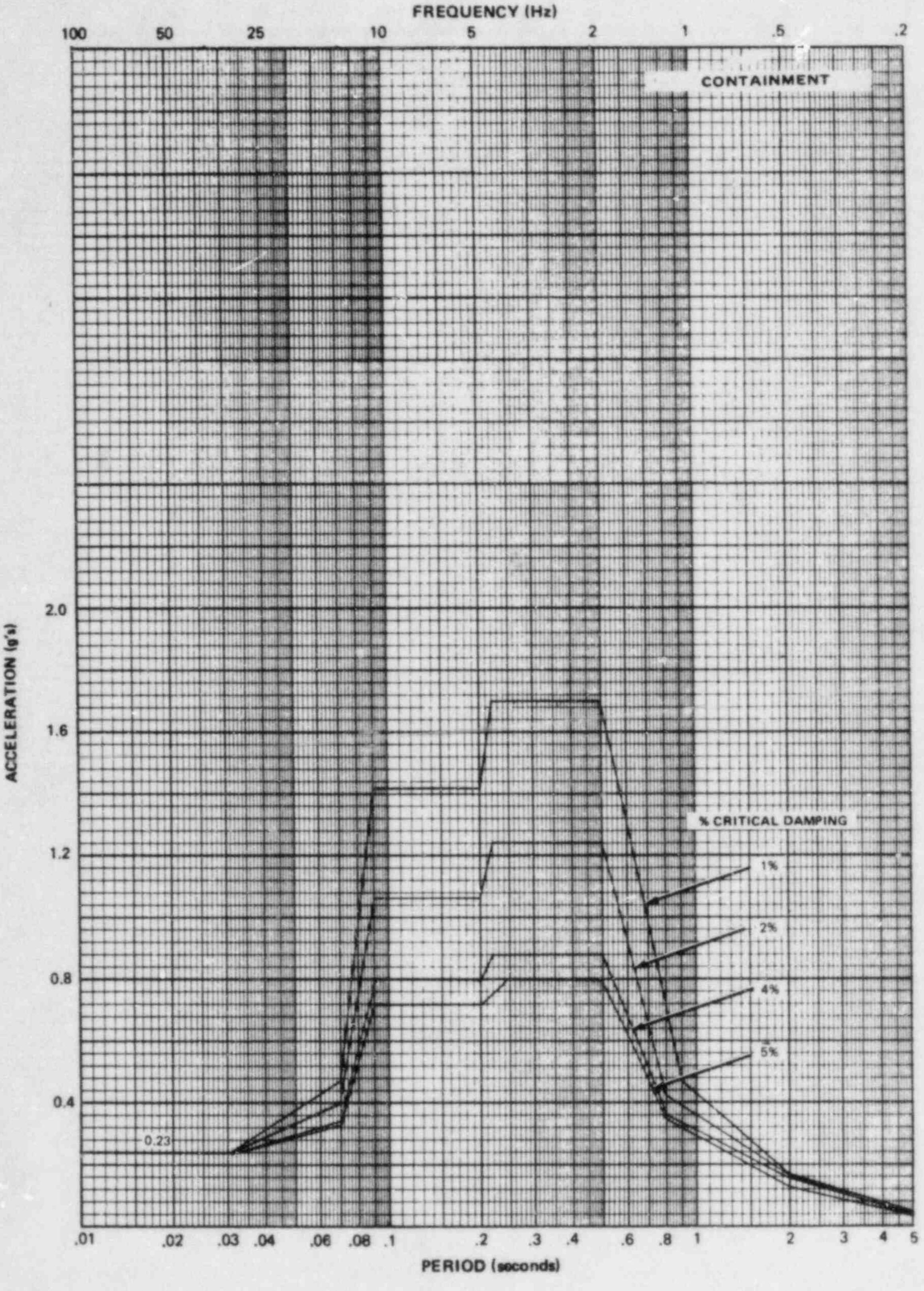

Figure B-4
OPERATING BASIS EARTHQUAKE
VERTICAL ACCEL. RESPONSE SPECTRA
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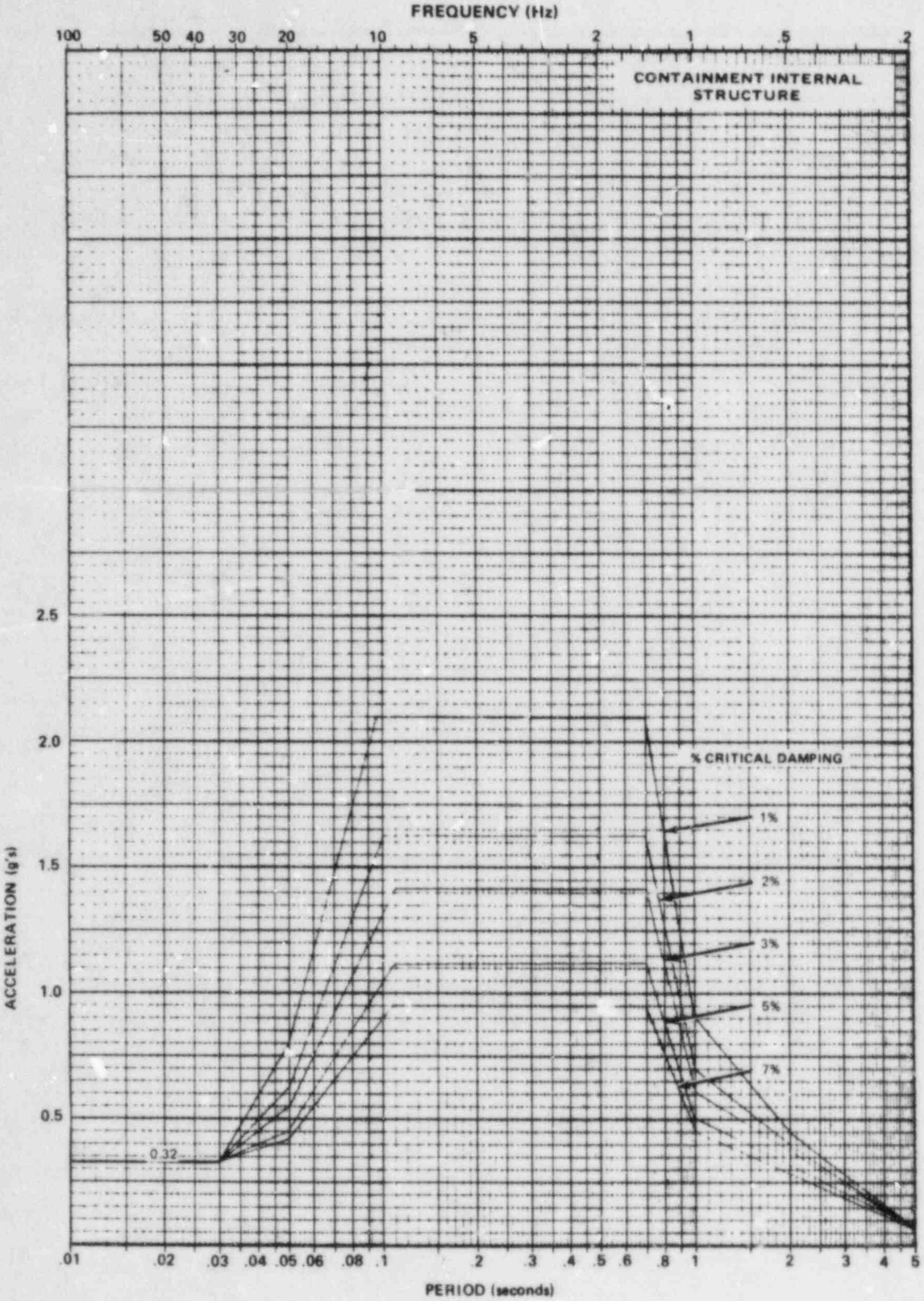


Figure B-5
SAFE SHUTDOWN EARTHQUAKE
HORIZ. ACCEL. RESPONSE SPECTRA
EL. 220 FT. 0 IN.

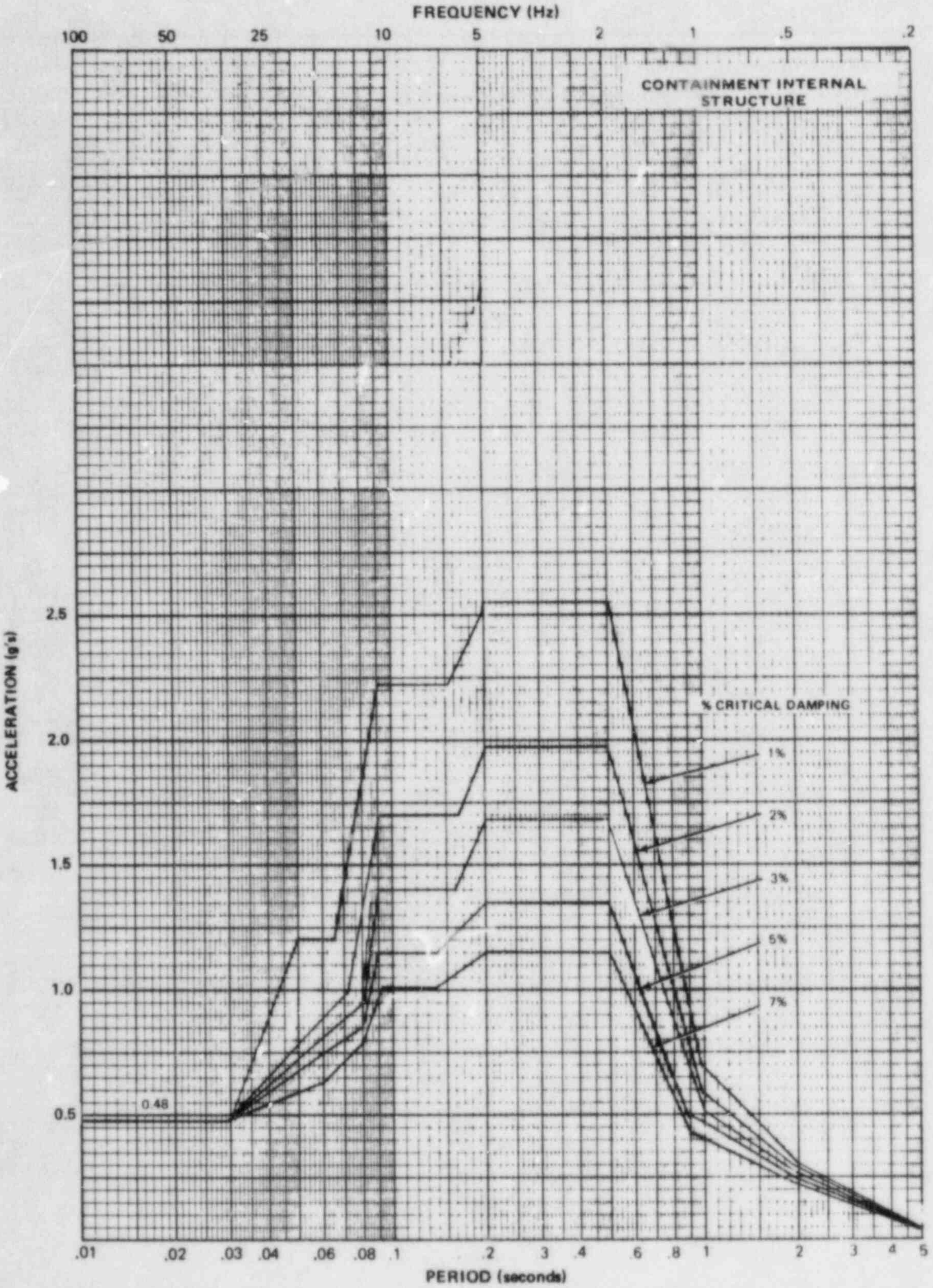


Figure B-6
SAFE SHUTDOWN EARTHQUAKE
VERTICAL ACCEL. RESPONSE SPECTRA
EL. 220 FT. 0 IN.

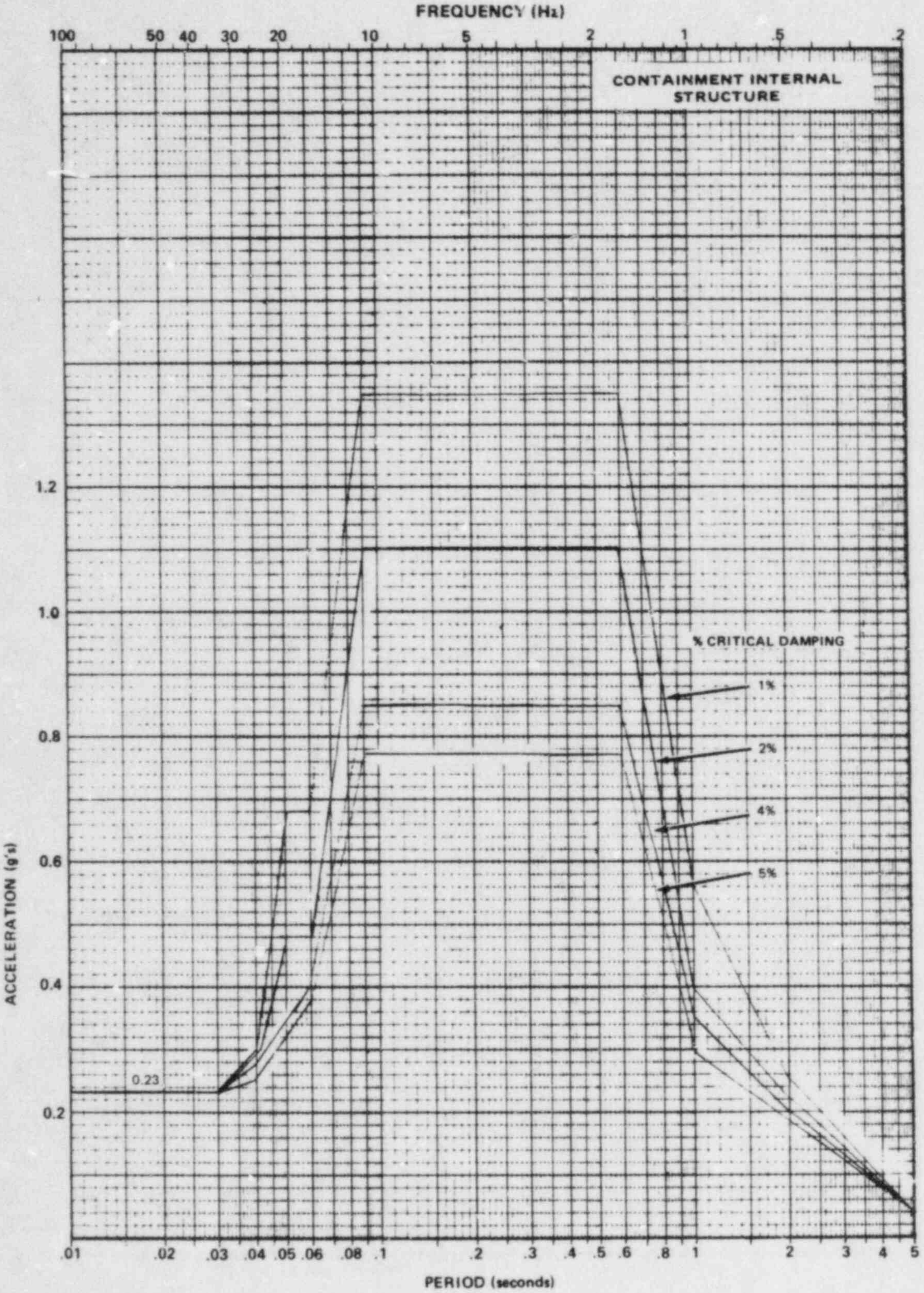


Figure B-7
OPERATING BASIS EARTHQUAKE
HORIZ. ACCEL. RESPONSE SPECTRA
EL. 220 FT. 0 IN.

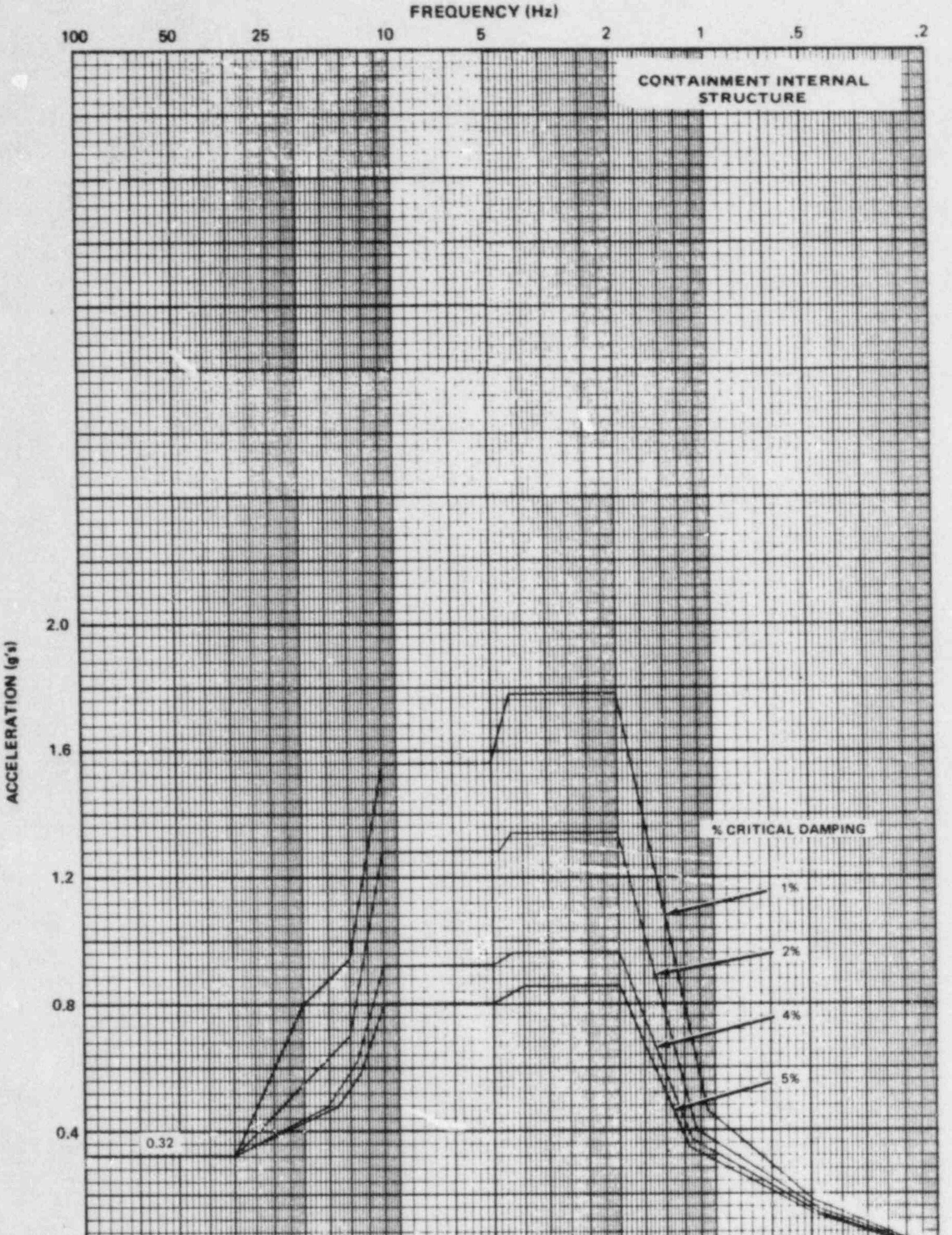
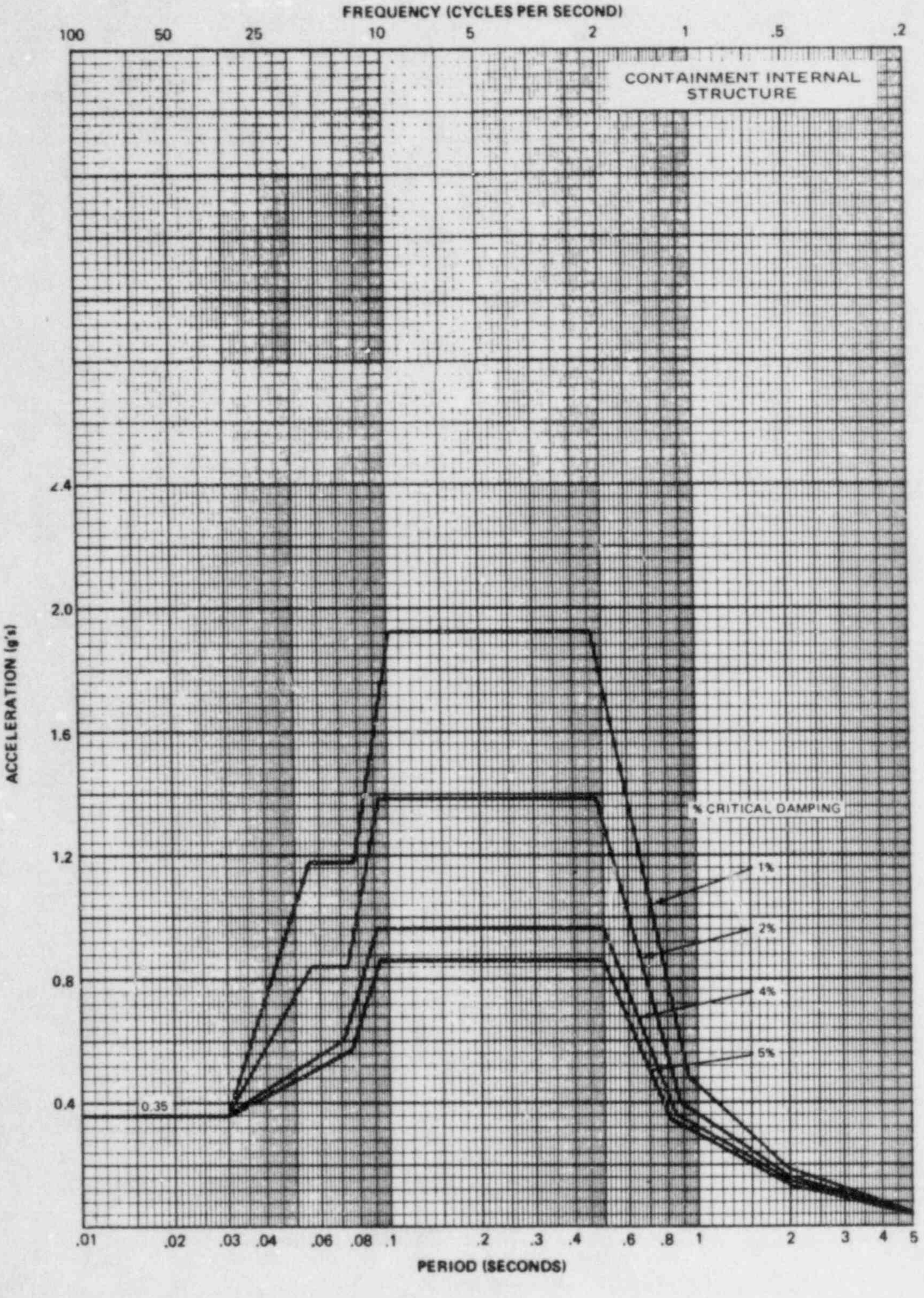


Figure B-8
OPERATING BASIS EARTHQUAKE
VERTICAL ACCEL. RESPONSE SPECTRA
EL. 220 FT. 0 IN.

Figure B-9
SAFE SHUTDOWN EARTHQUAKE
HORIZ. ACCEL. RESPONSE SPECTRA
EL. 261 FT. 0 IN.



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SAFE SHUTDOWN EARTHQUAKE
VERTICAL ACCEL. RESPONSE SPECTRA
EL. 261 FT. 0 IN.

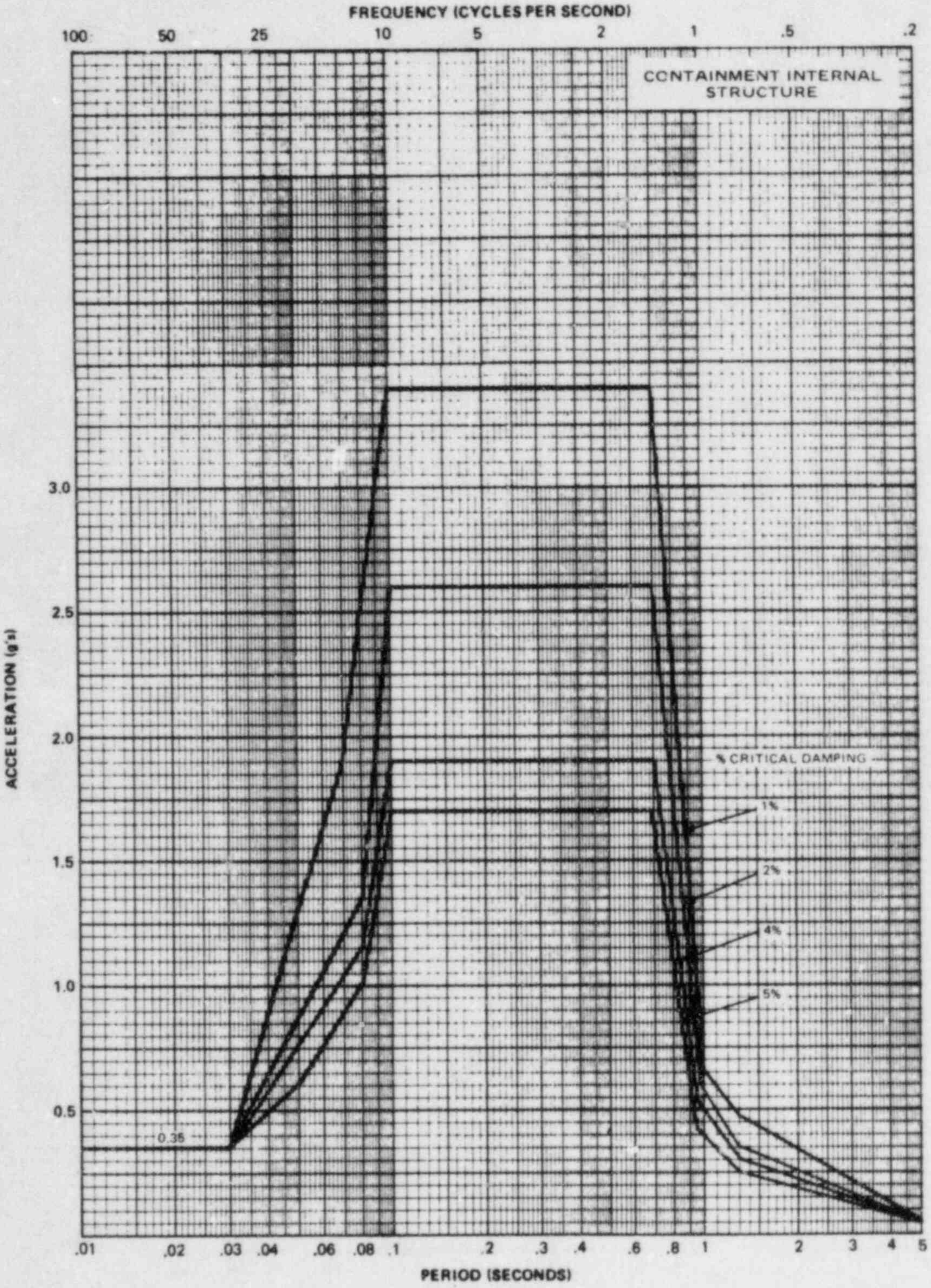

Figure B-11
OPERATING BASIS EARTHQUAKE
HORIZ. ACCEL. RESPONSE SPECTRA
EL. 261 FT. 0 IN.

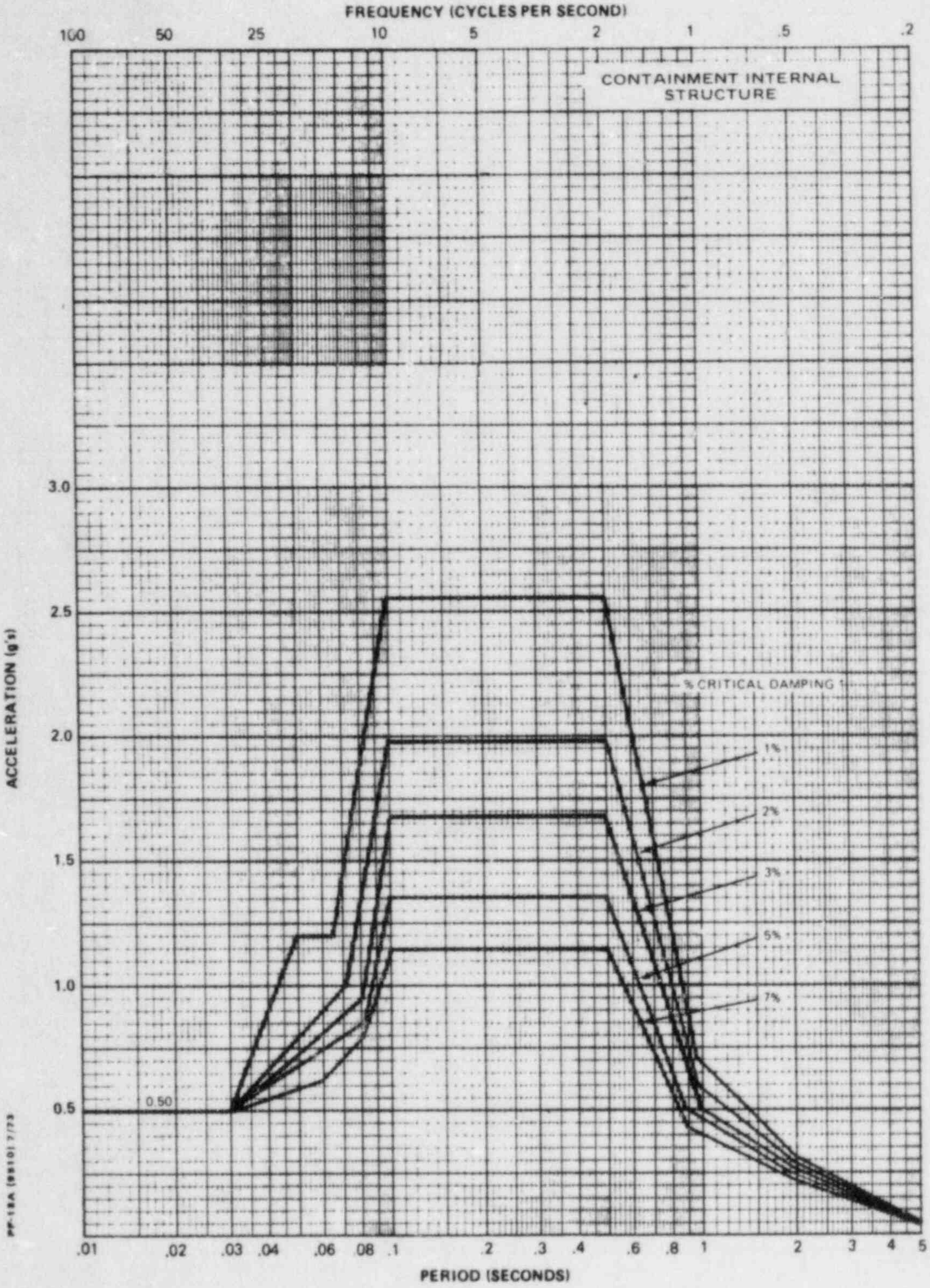

Figure B-12
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VERTICAL ACCEL. RESPONSE SPECTRA
EL. 261 FT. 0 IN.

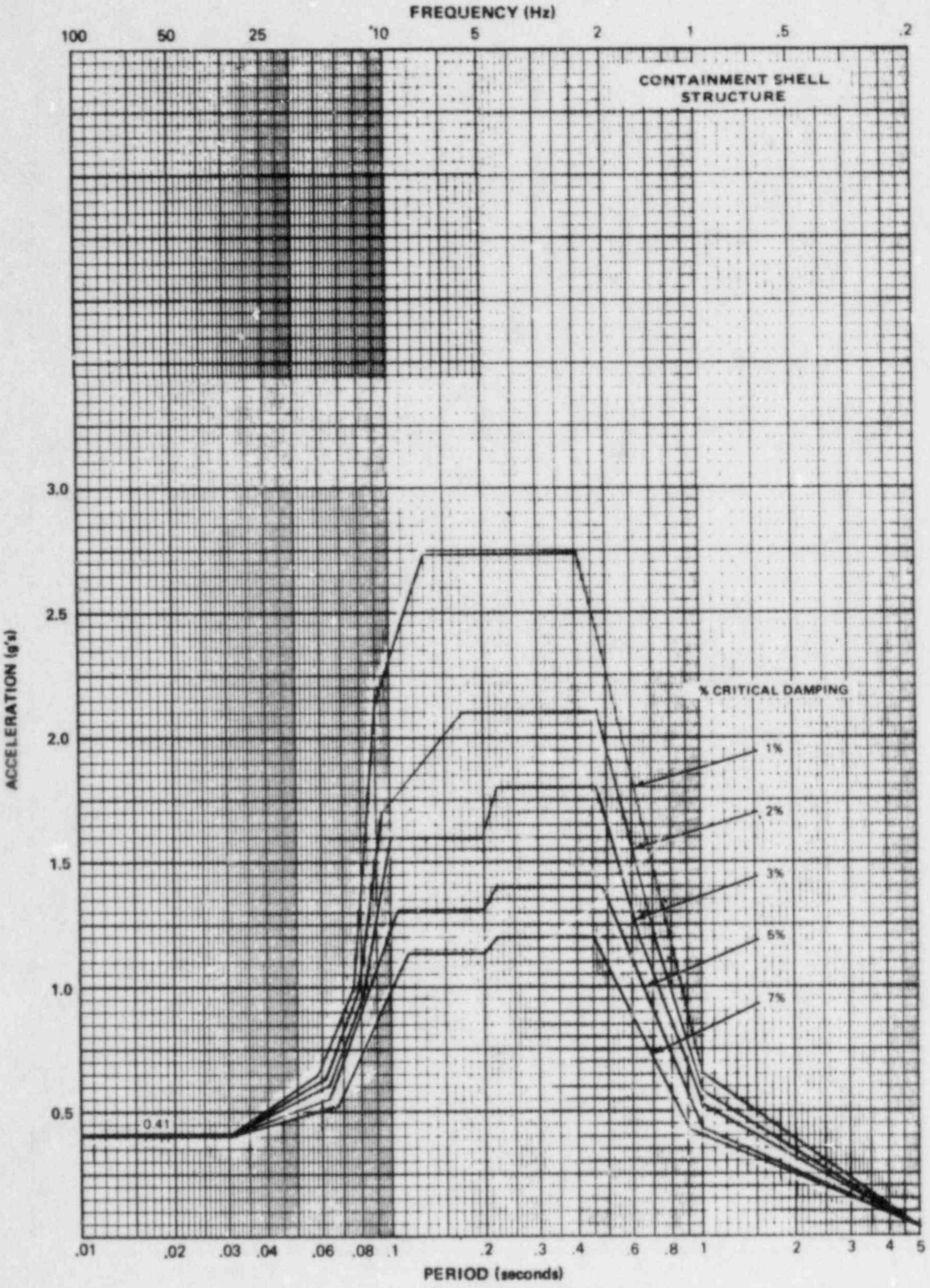

Figure B-13
SAFE SHUTDOWN EARTHQUAKE
VERTICAL ACCEL. RESPONSE SPECTRA
EL. 220 FT. 0 IN.

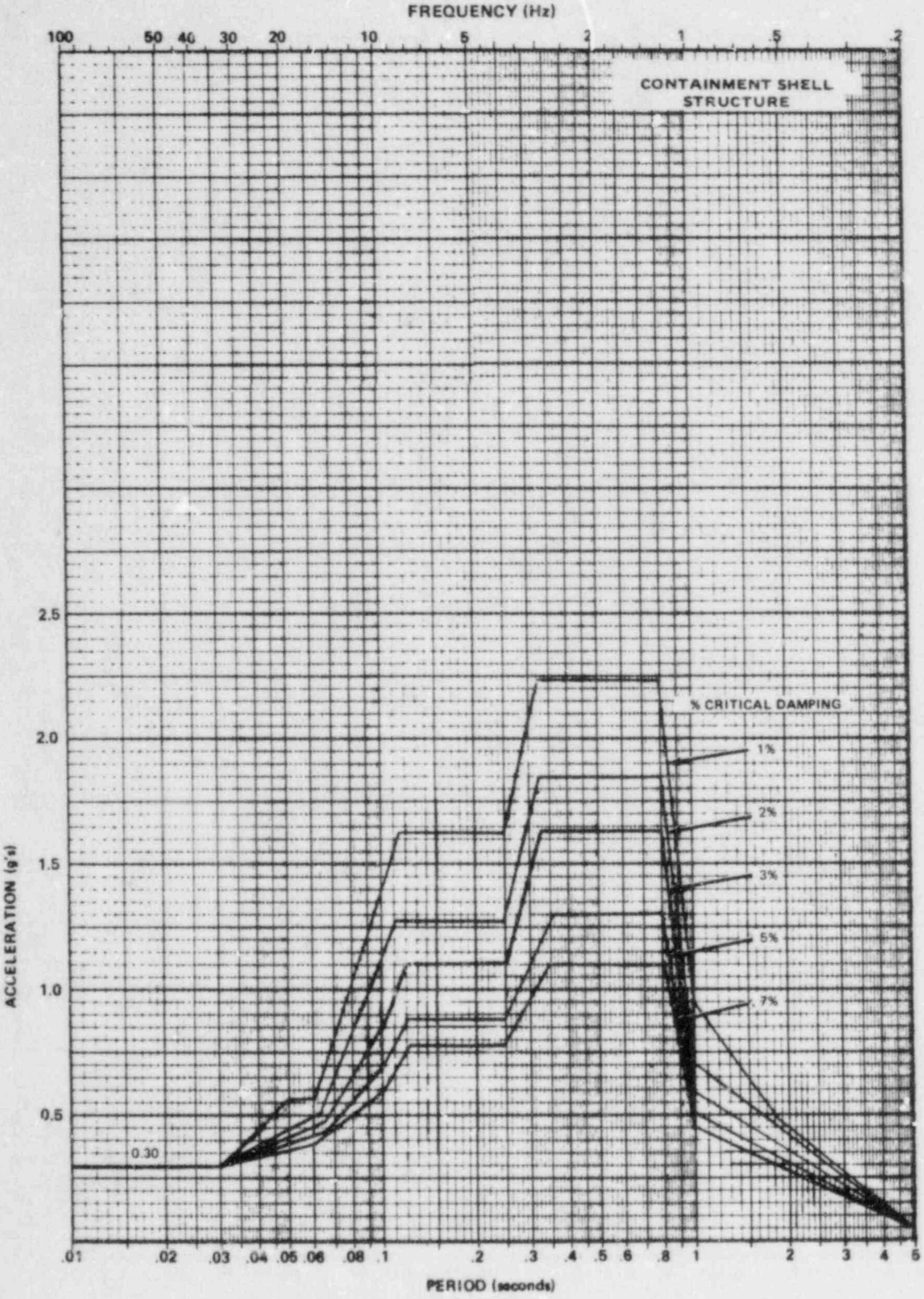

Figure B-14
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HORIZ. ACCEL. RESPONSE SPECTRA
EL. 220 FT. 0 IN.

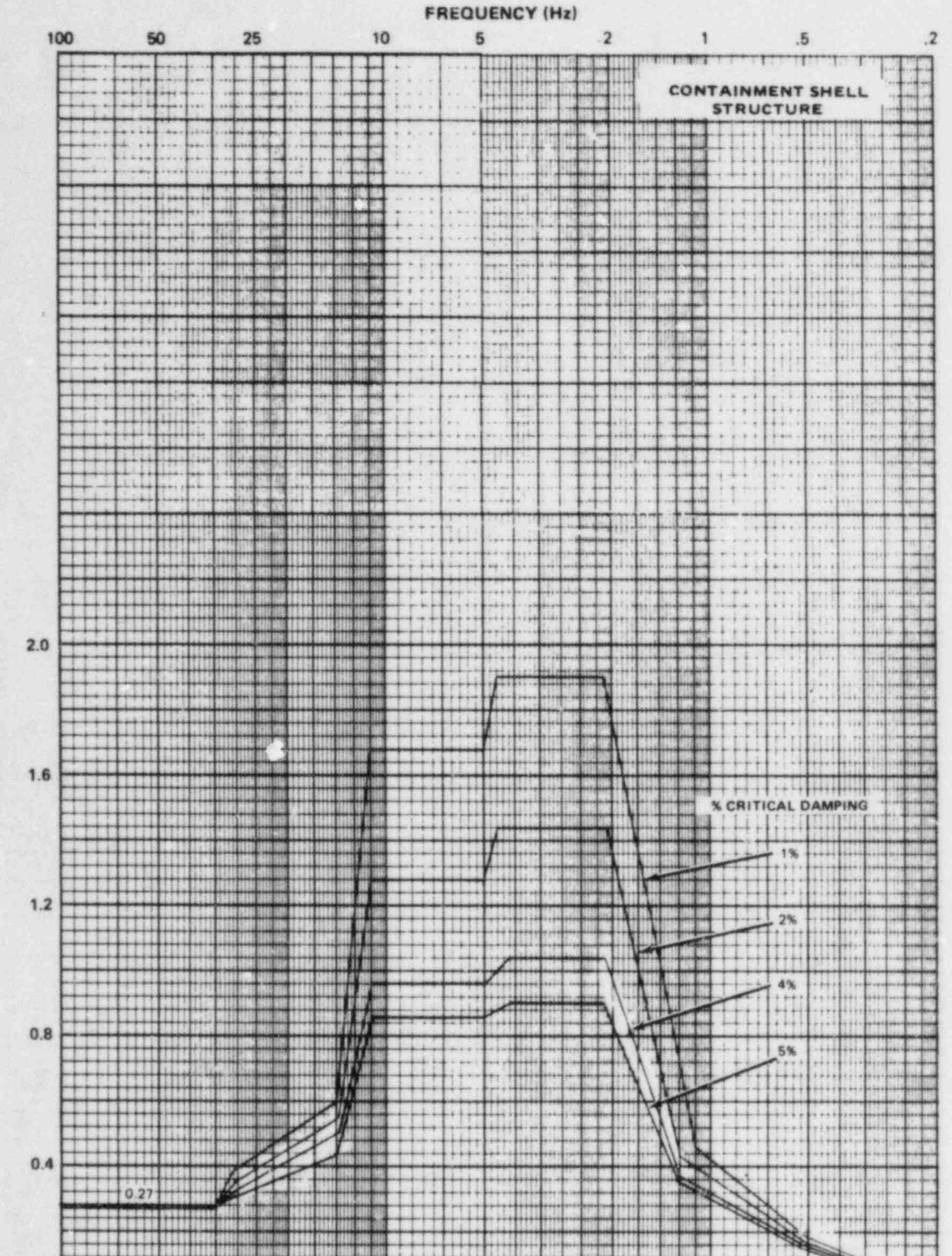


Figure B-15
OPERATING BASIS EARTHQUAKE
VERTICAL ACCEL. RESPONSE SPECTRA
EL. 220 FT. 0 IN.

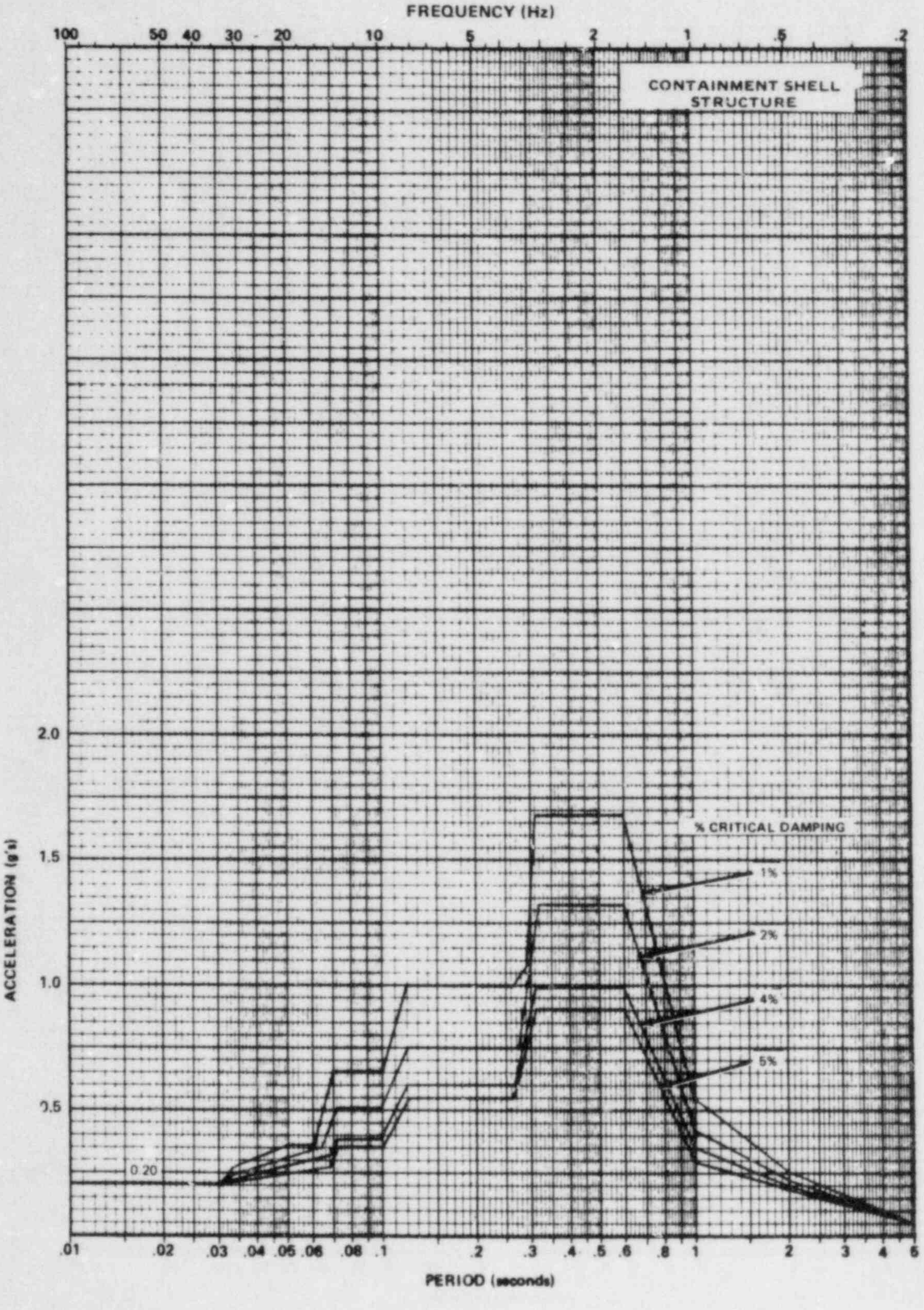


Figure B-16
OPERATING BASIS EARTHQUAKE
HORIZ. ACCEL. RESPONSE SPECTRA
EL. 220 FT. 0 IN.

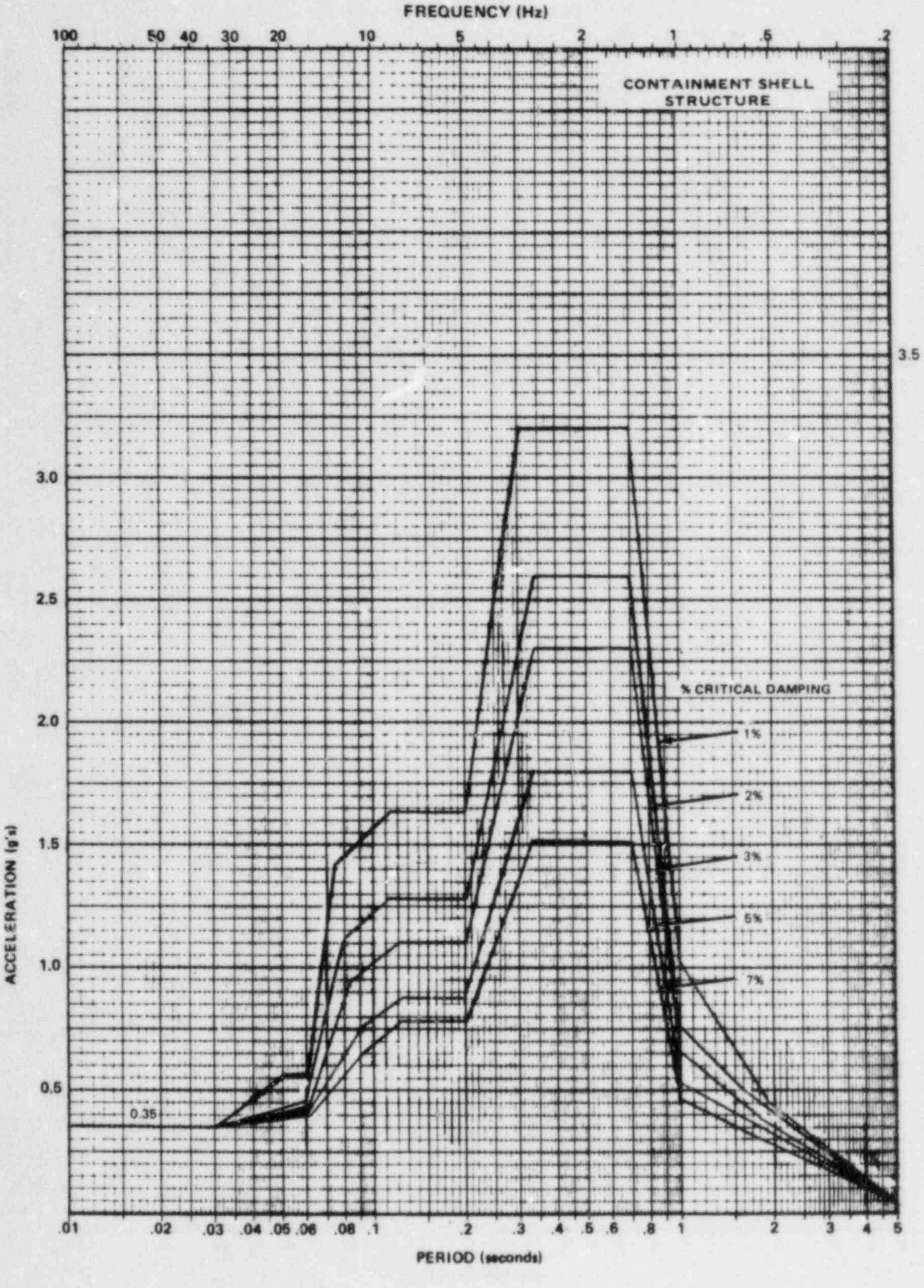


Figure B-17
SAFE SHUTDOWN EARTHQUAKE
HORIZ. ACCEL. RESPONSE SPECTRA
EL. 258 FT. 0 IN.

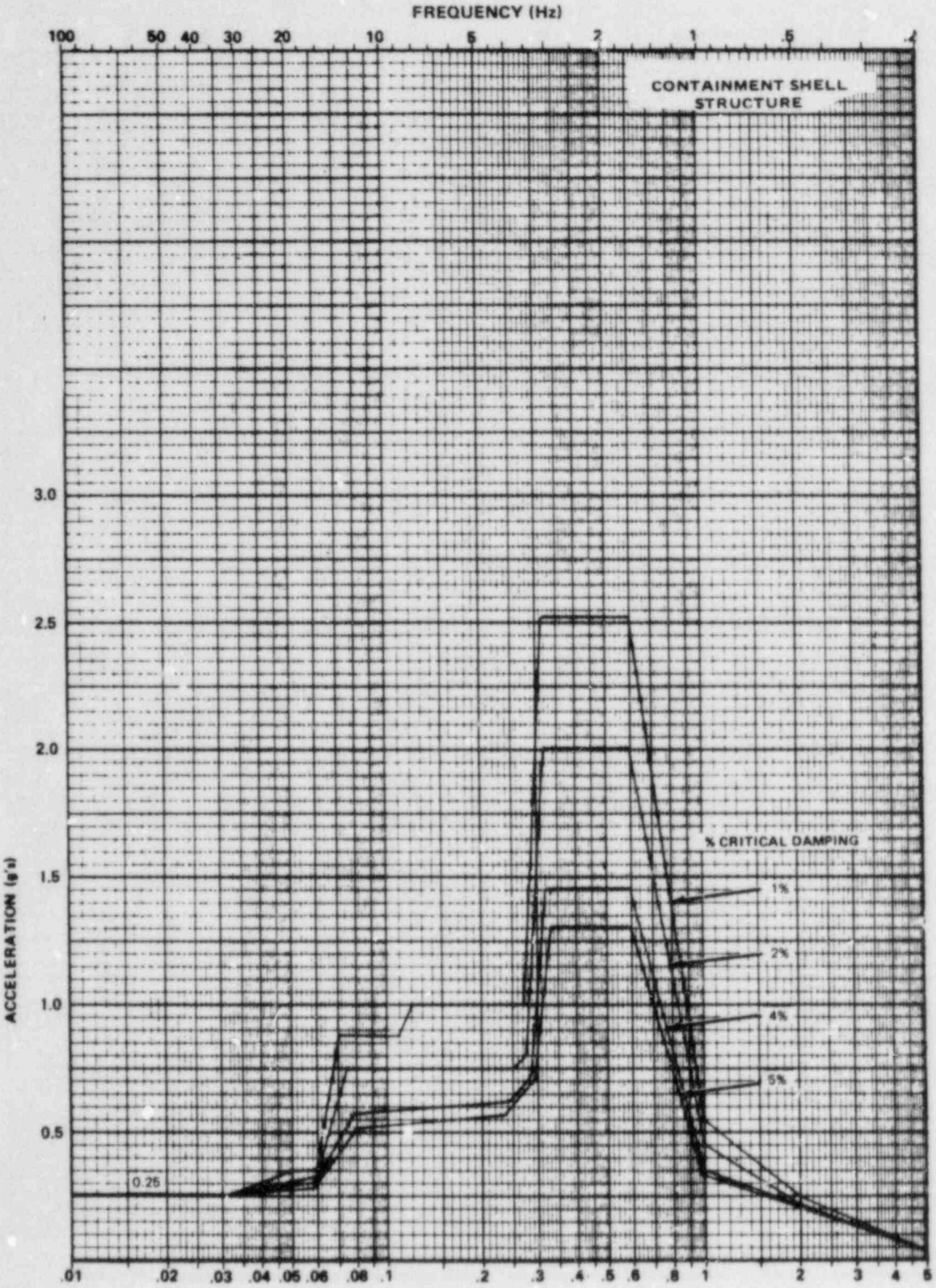


Figure B-18
OPERATING BASIS EARTHQUAKE
HORIZ. ACCEL. RESPONSE SPECTRA
EL. 258 FT. 0 IN.

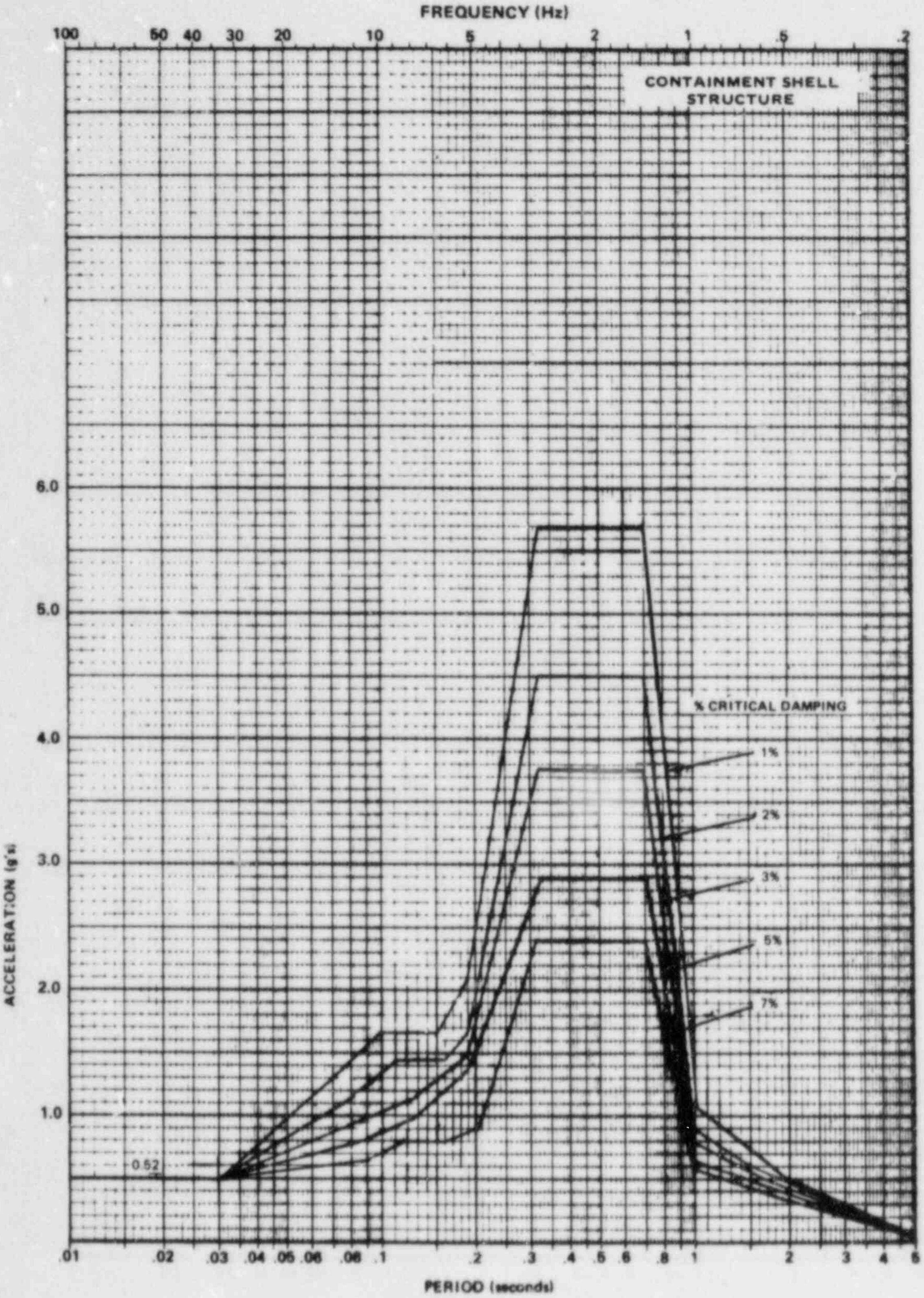


Figure B-19
SAFE SHUTDOWN EARTHQUAKE
HORIZ. ACCEL. RESPONSE SPECTRA
EL. 323 FT. 0 IN.

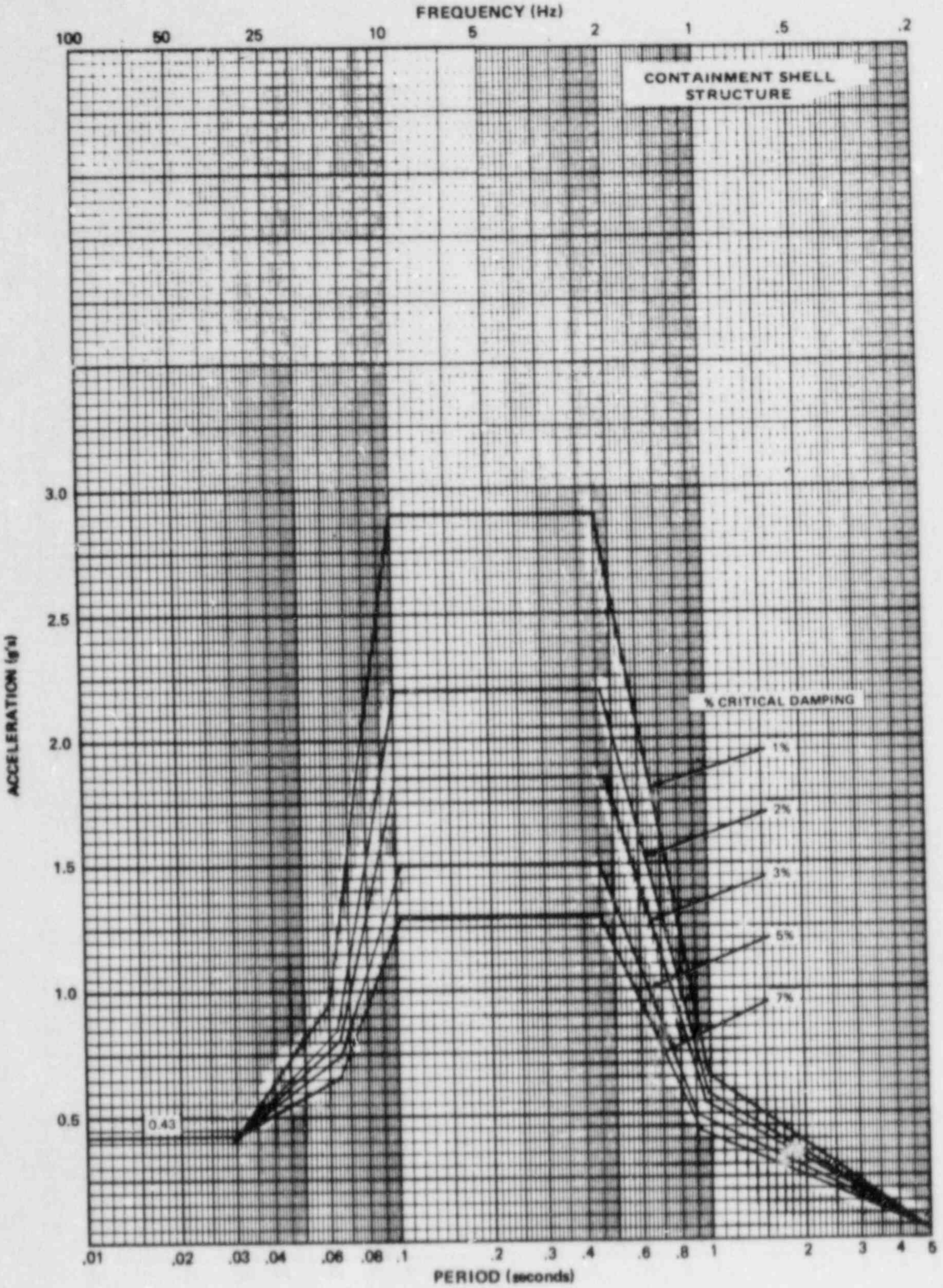


Figure B-20
SAFE SHUTDOWN EARTHQUAKE
VERTICAL ACCEL. RESPONSE SPECTRA
EL. 323 FT. 0 IN.

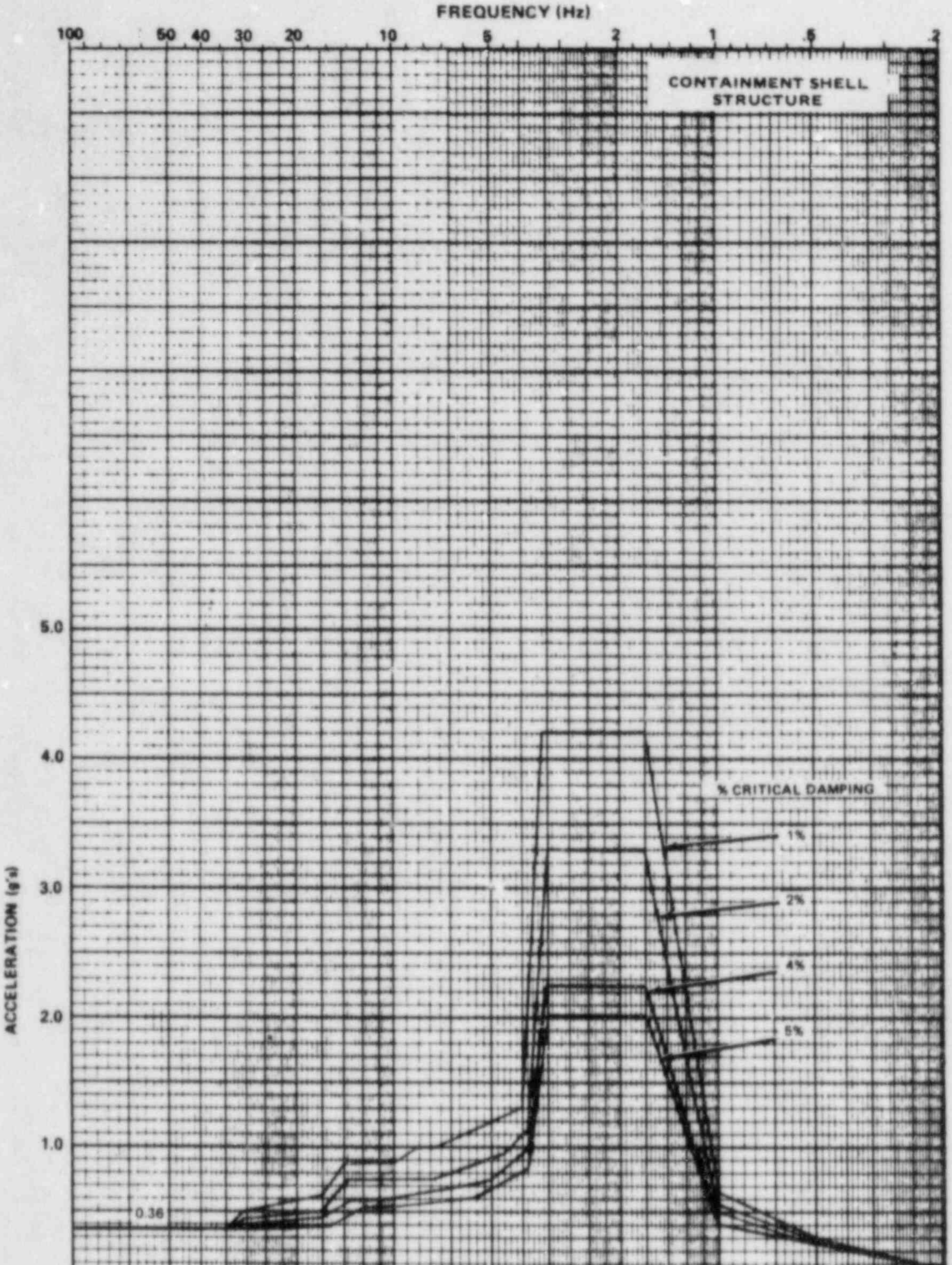


Figure B-21
OPERATING BASIS EARTHQUAKE
HORIZ. ACCEL. RESPONSE SPECTRA
EL. 323 FT. 0 IN.

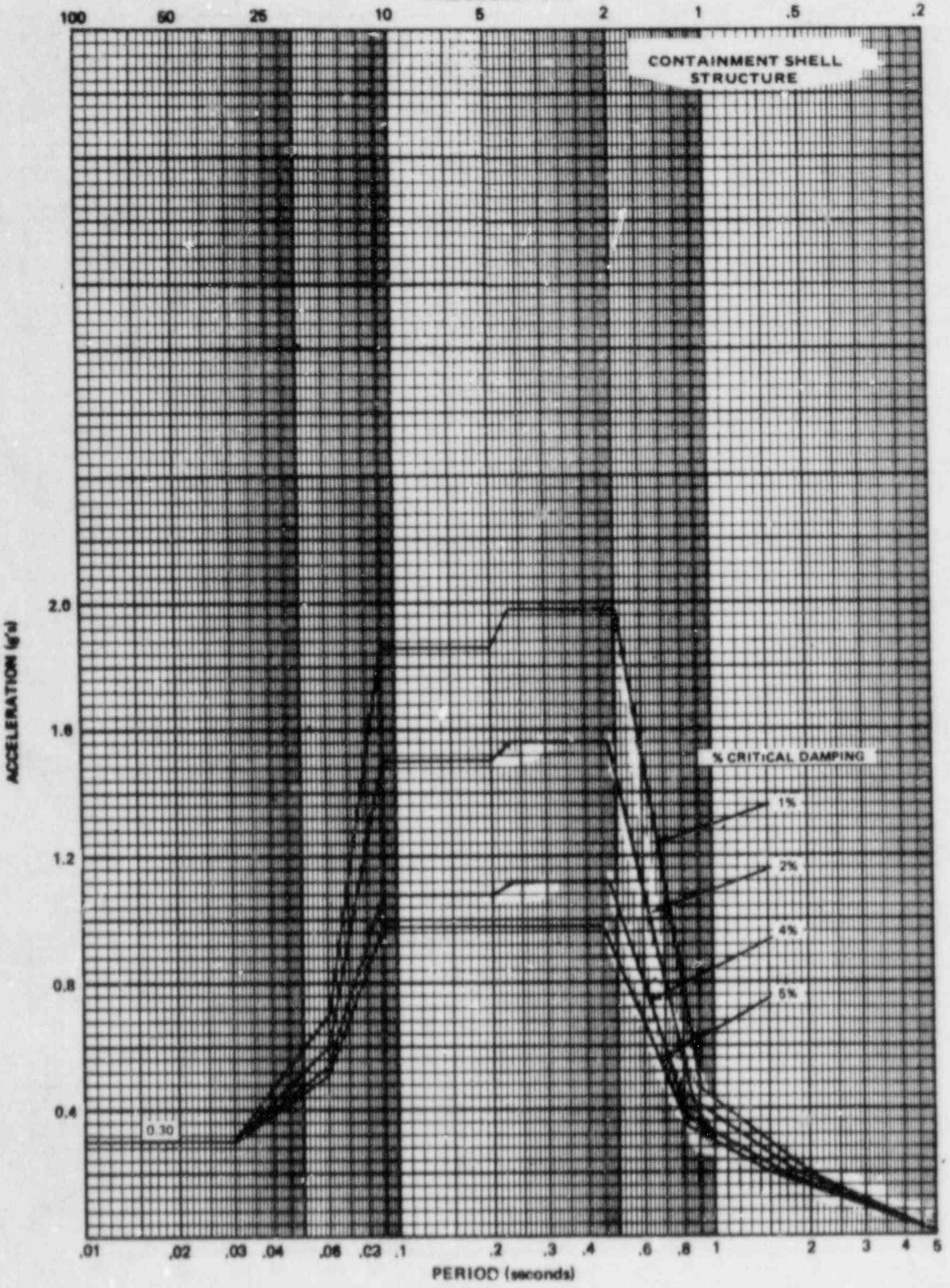


Figure B-22
OPERATING BASIS EARTHQUAKE
VERTICAL ACCEL. RESPONSE SPECTRA
EL. 323 FT. 0 IN.

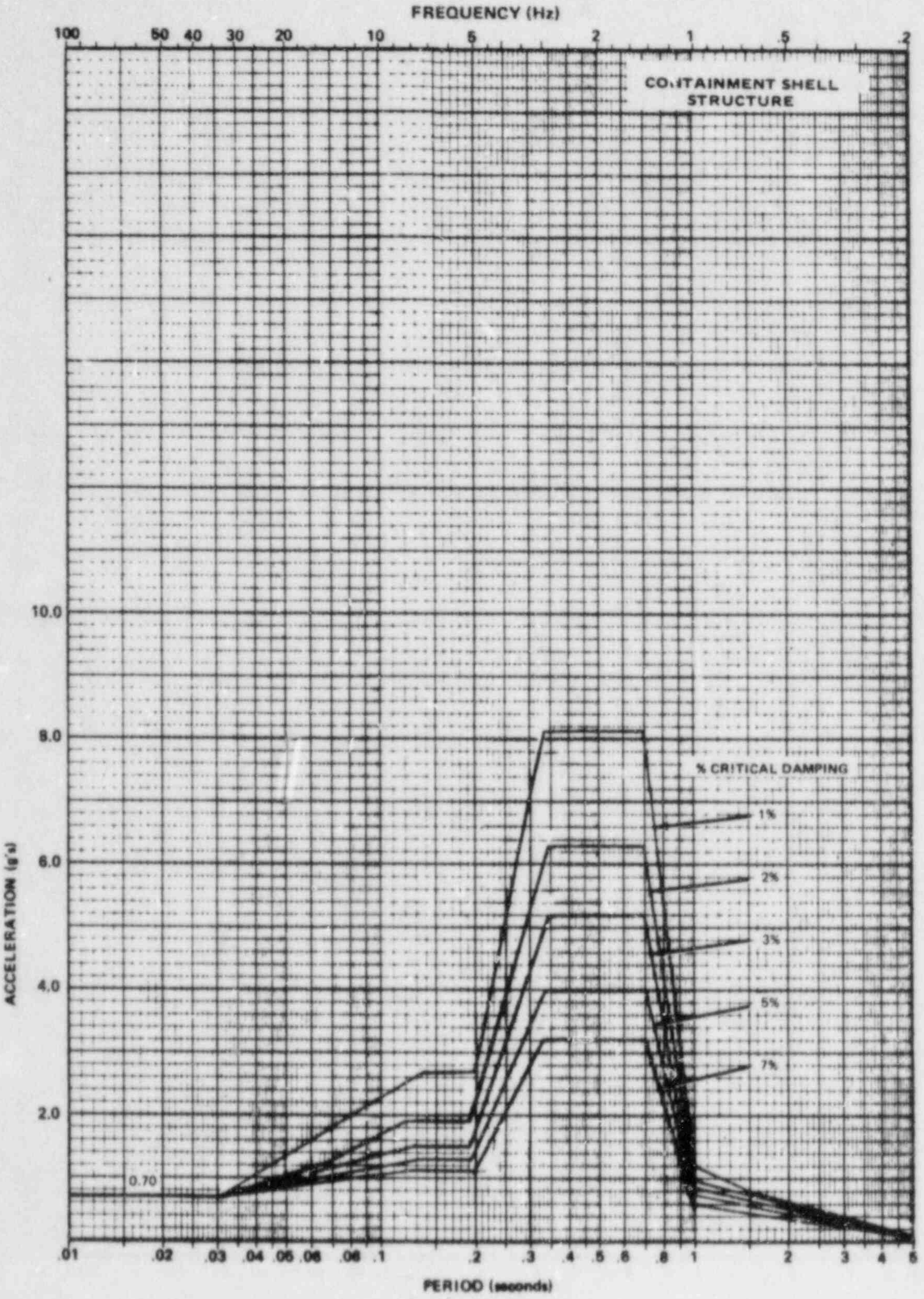
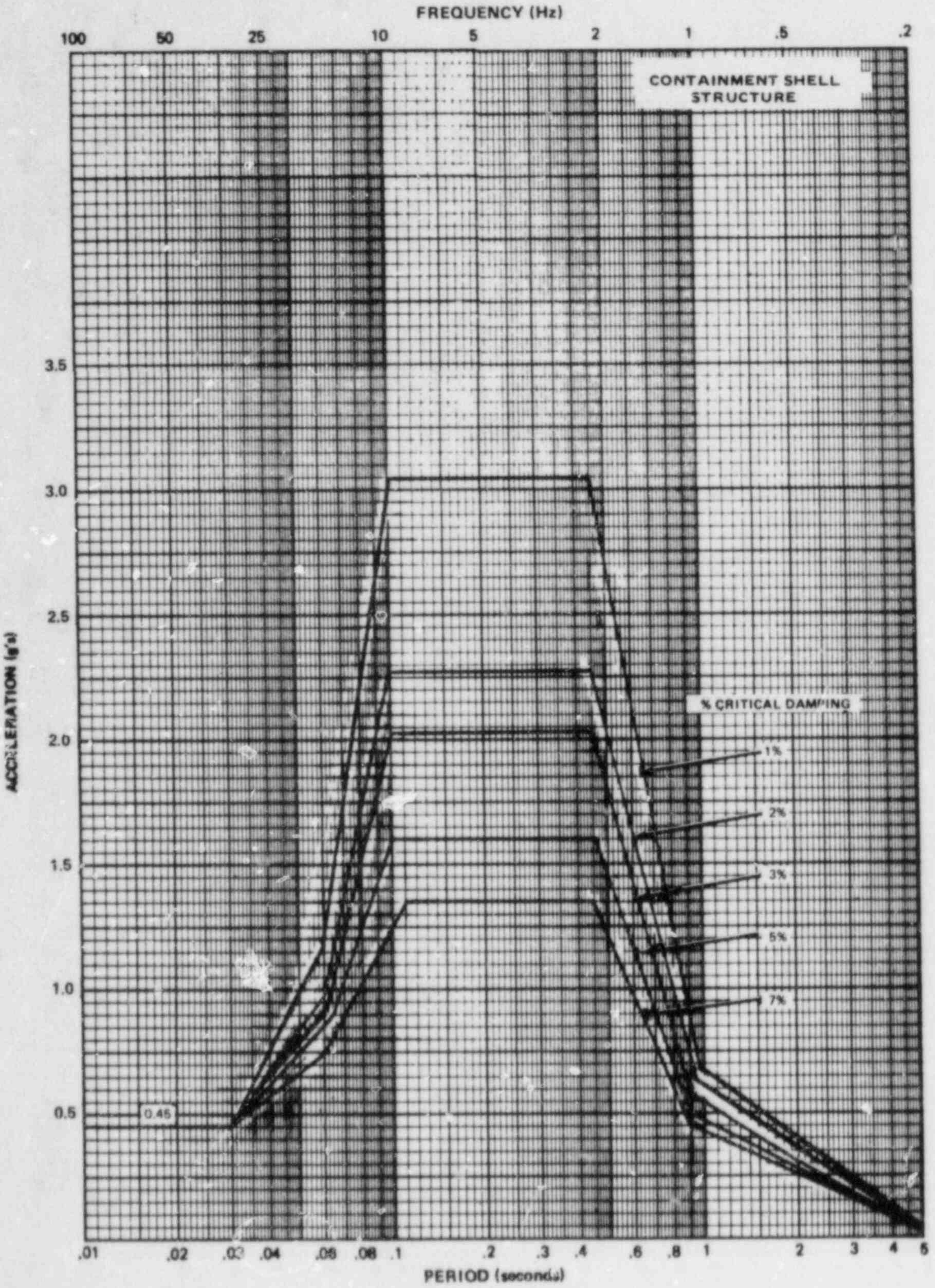


Figure B-23
SAFE SHUTDOWN EARTHQUAKE
HORIZ. ACCEL. RESPONSE SPECTRA
EL. 400 FT. 0 IN.



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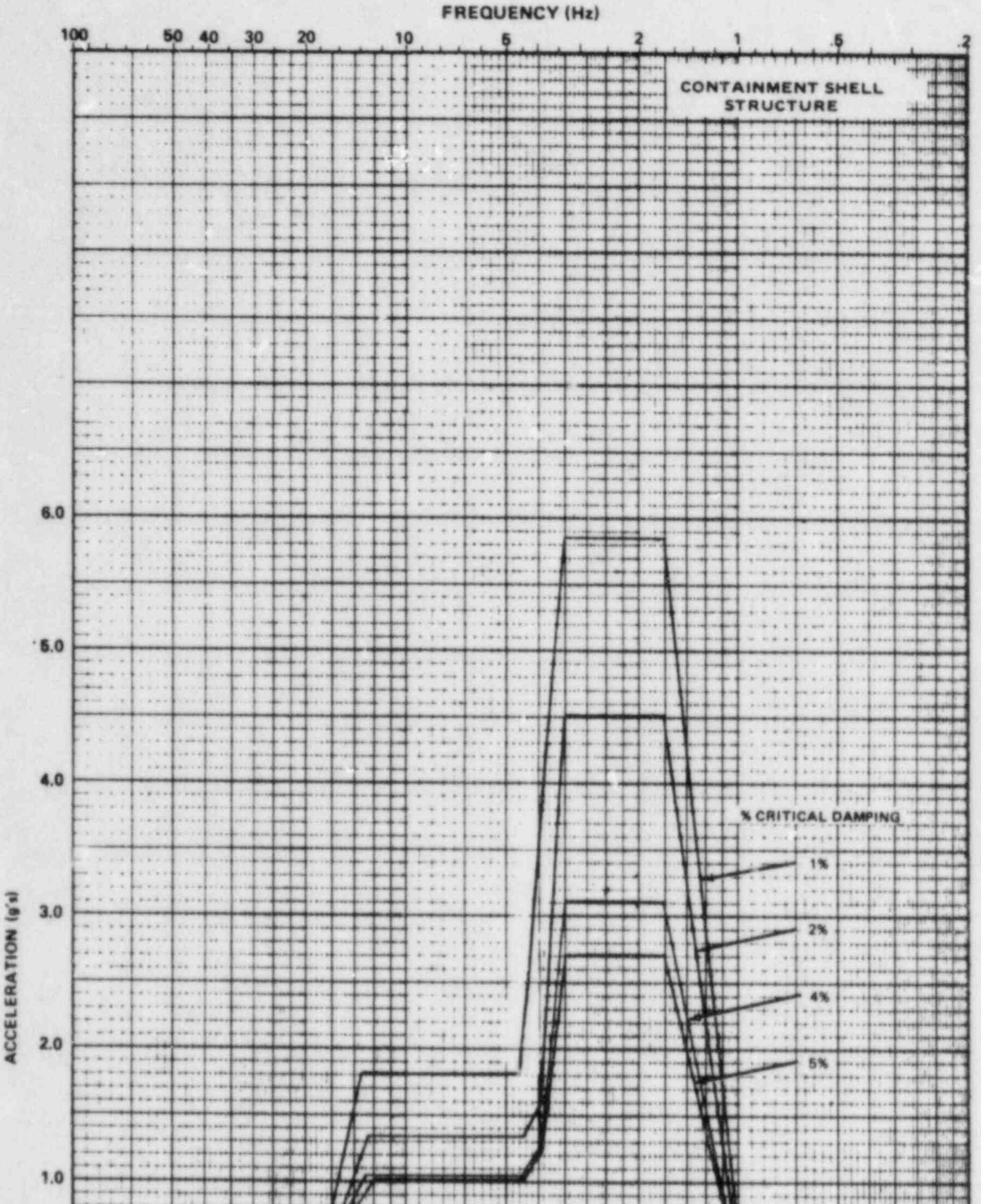
SAFE SHUTDOWN EARTHQUAKE
VERTICAL ACCEL. RESPONSE SPECTRA
EL. 400 FT. 0 IN.



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OPERATING BASIS EARTHQUAKE
HORIZ. ACCEL. RESPONSE SPECTRA
EL. 400 FT. 0 IN.

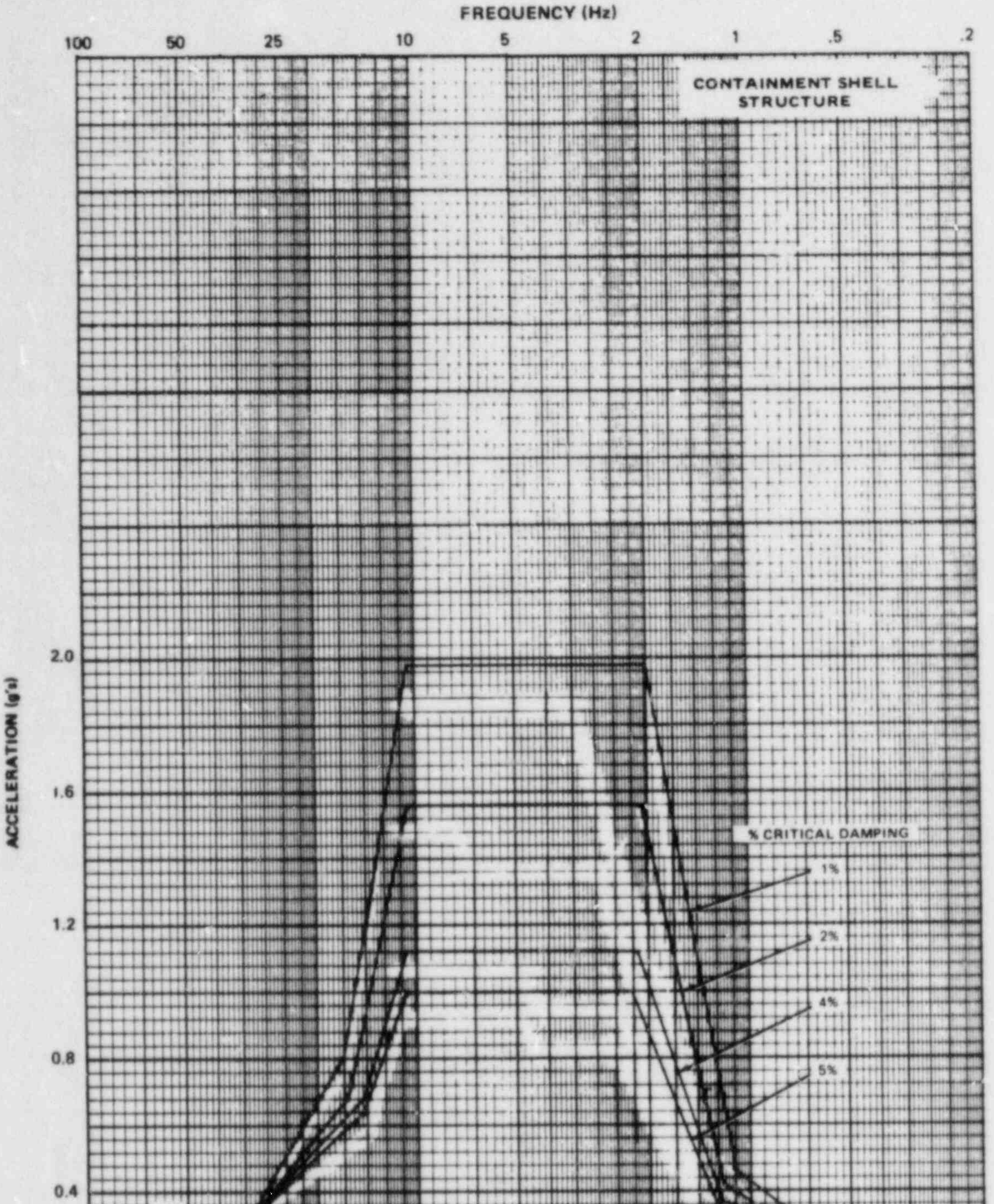

Figure B-26
OPERATING BASIS EARTHQUAKE
VERTICAL ACCEL. RESPONSE SPECTRA
EL. 400 FT. 0 IN.

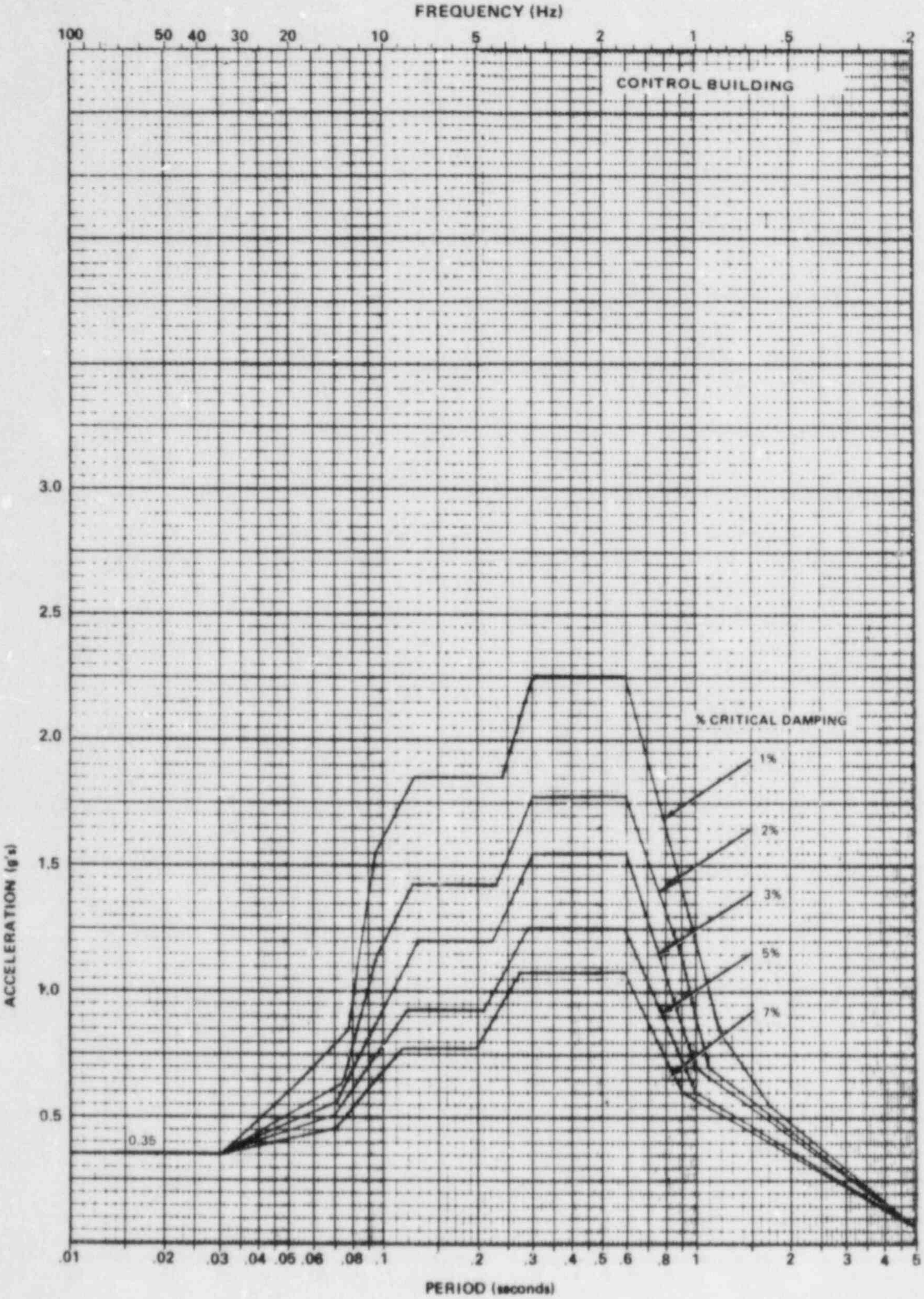

Figure B-27
SAFE SHUTDOWN EARTHQUAKE
HORIZ. ACCEL. RESPONSE SPECTRA
EL. 180 FT. 0 IN.

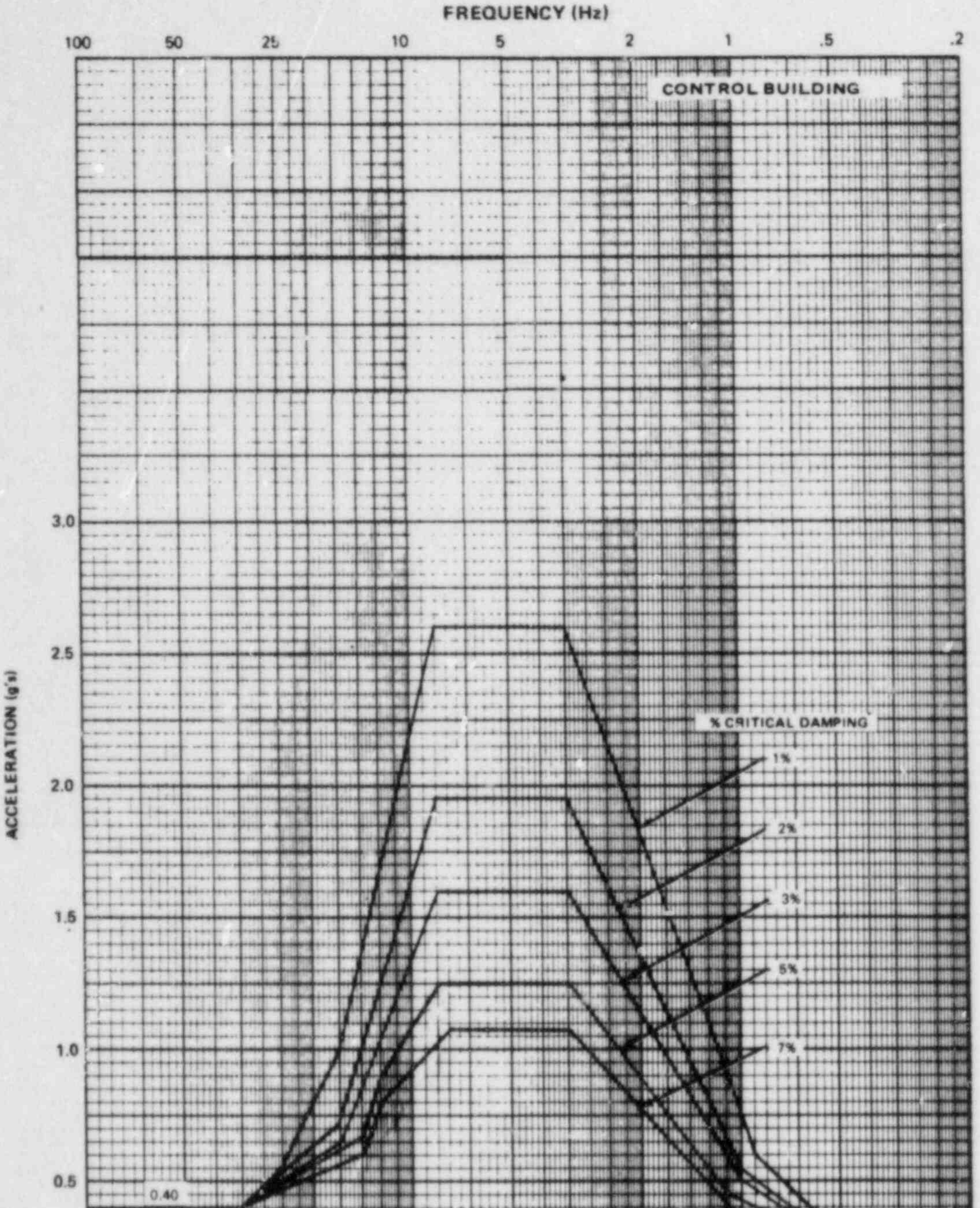

Figure B-28
SAFE SHUTDOWN EARTHQUAKE
VERTICAL ACCEL. RESPONSE SPECTRA
EL. 180 FT. 0 IN.

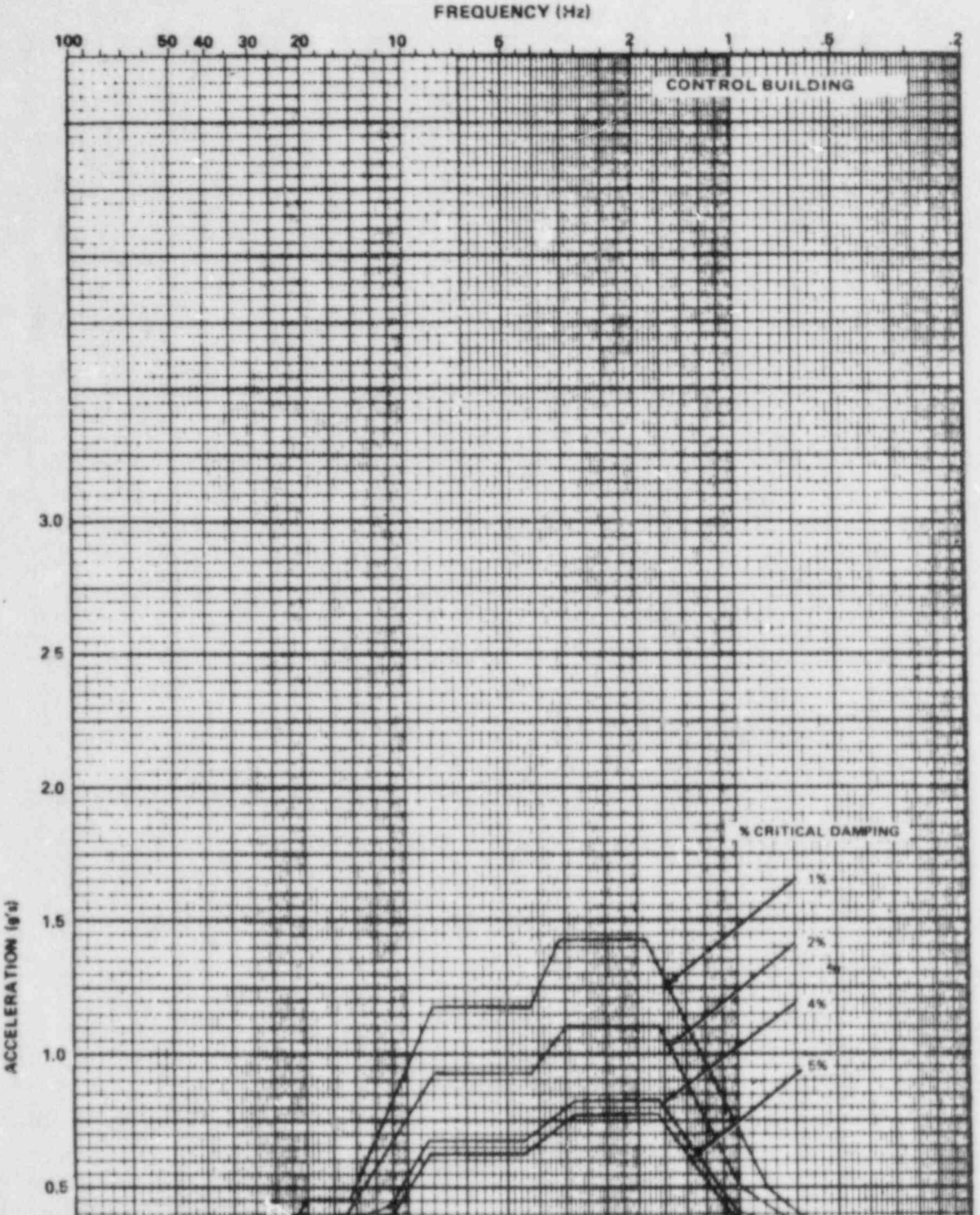

Figure B-29
OPERATING BASIS EARTHQUAKE
HORIZ. ACCEL. RESPONSE SPECTRA
EL. 180 FT. 0 IN.

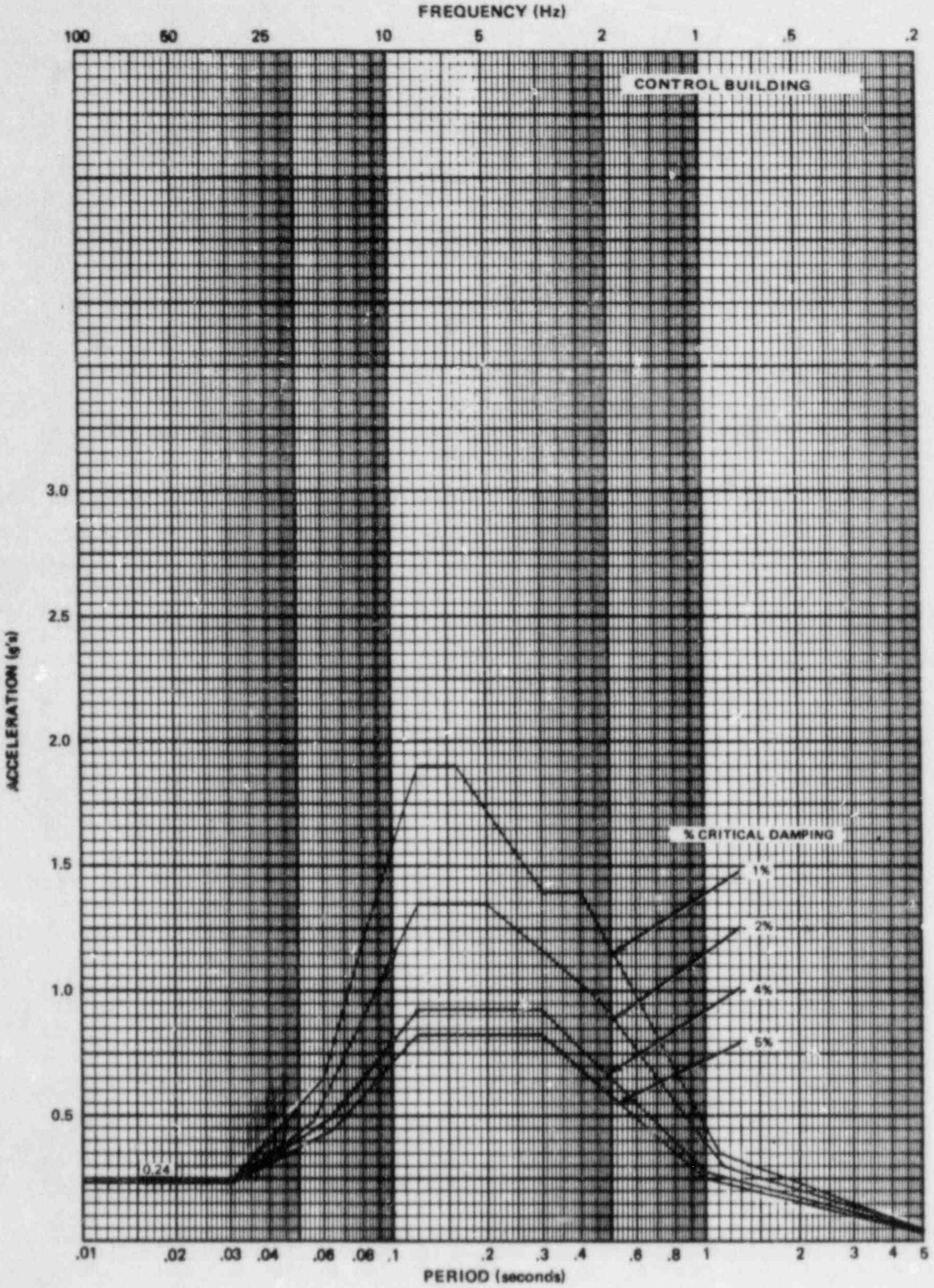

Figure B-30
OPERATING BASIS EARTHQUAKE
VERTICAL ACCEL. RESPONSE SPECTRA
EL. 180 FT. 0 IN.

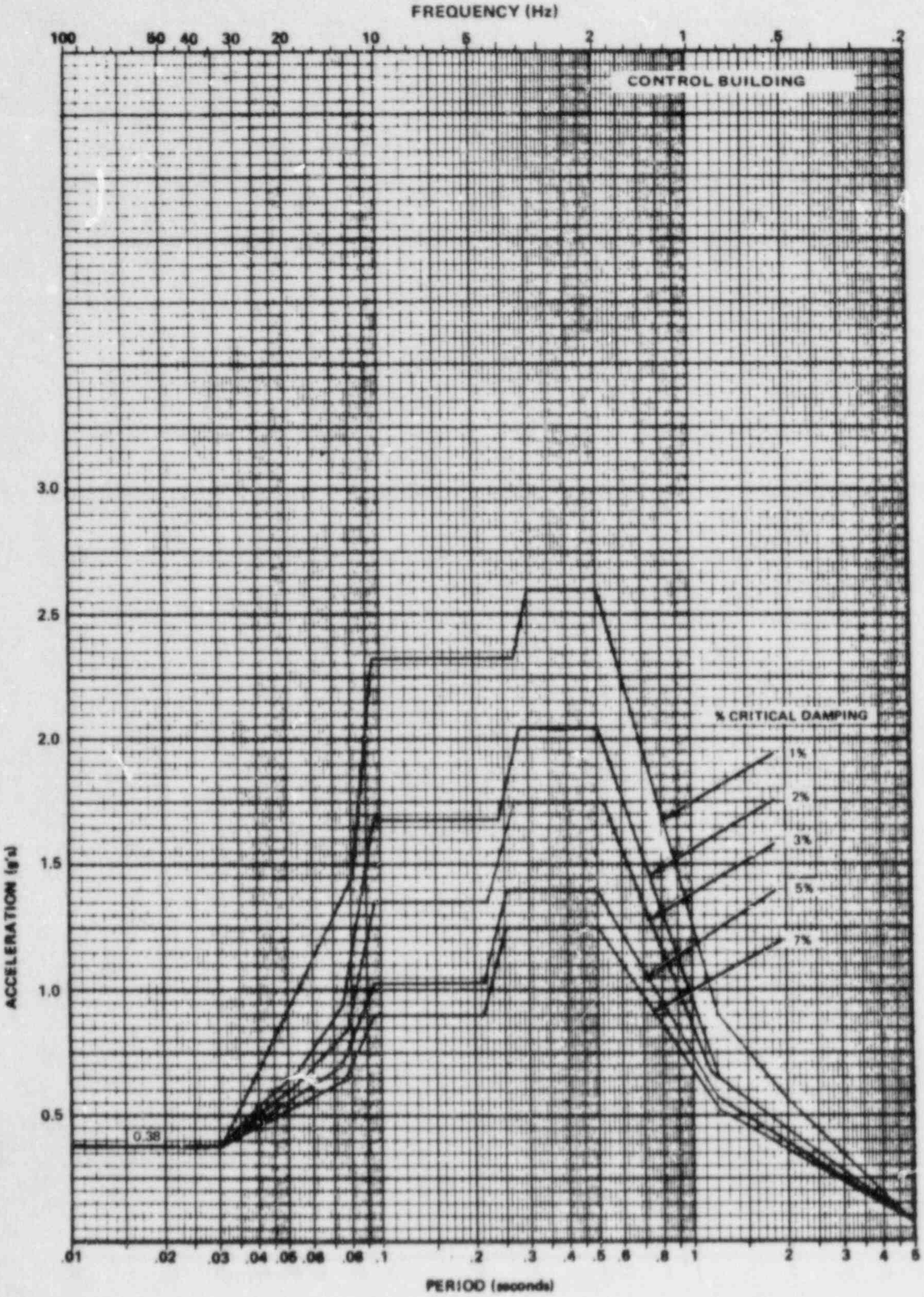

Figure B-31
SAFE SHUTDOWN EARTHQUAKE
HORIZ. ACCEL. RESPONSE SPECTRA
EL. 220 FT. 0 IN.

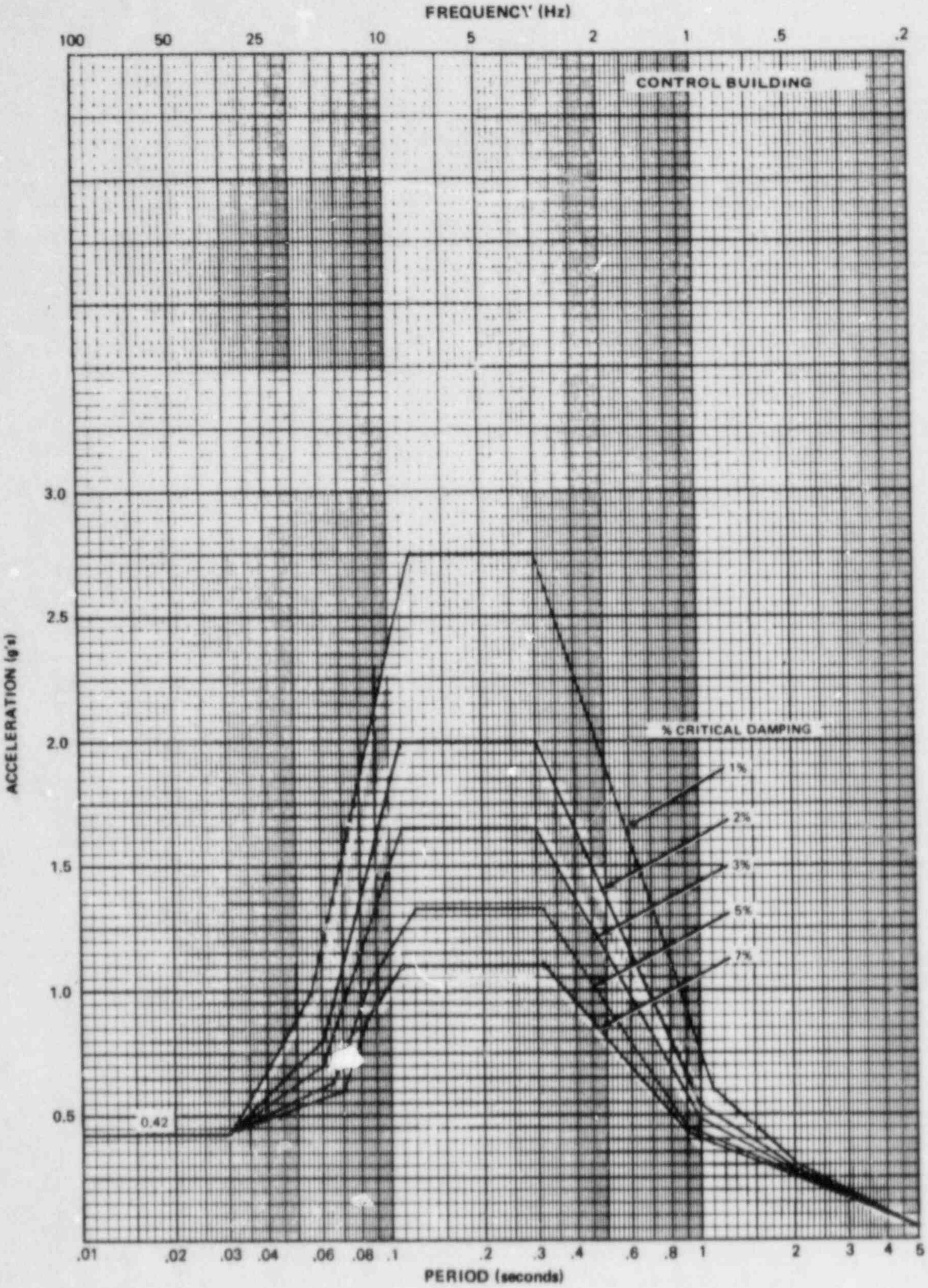

Figure B-32
SAFE SHUTDOWN EARTHQUAKE
VERTICAL ACCEL. RESPONSE SPECTRA
EL. 220 FT. 0 IN.

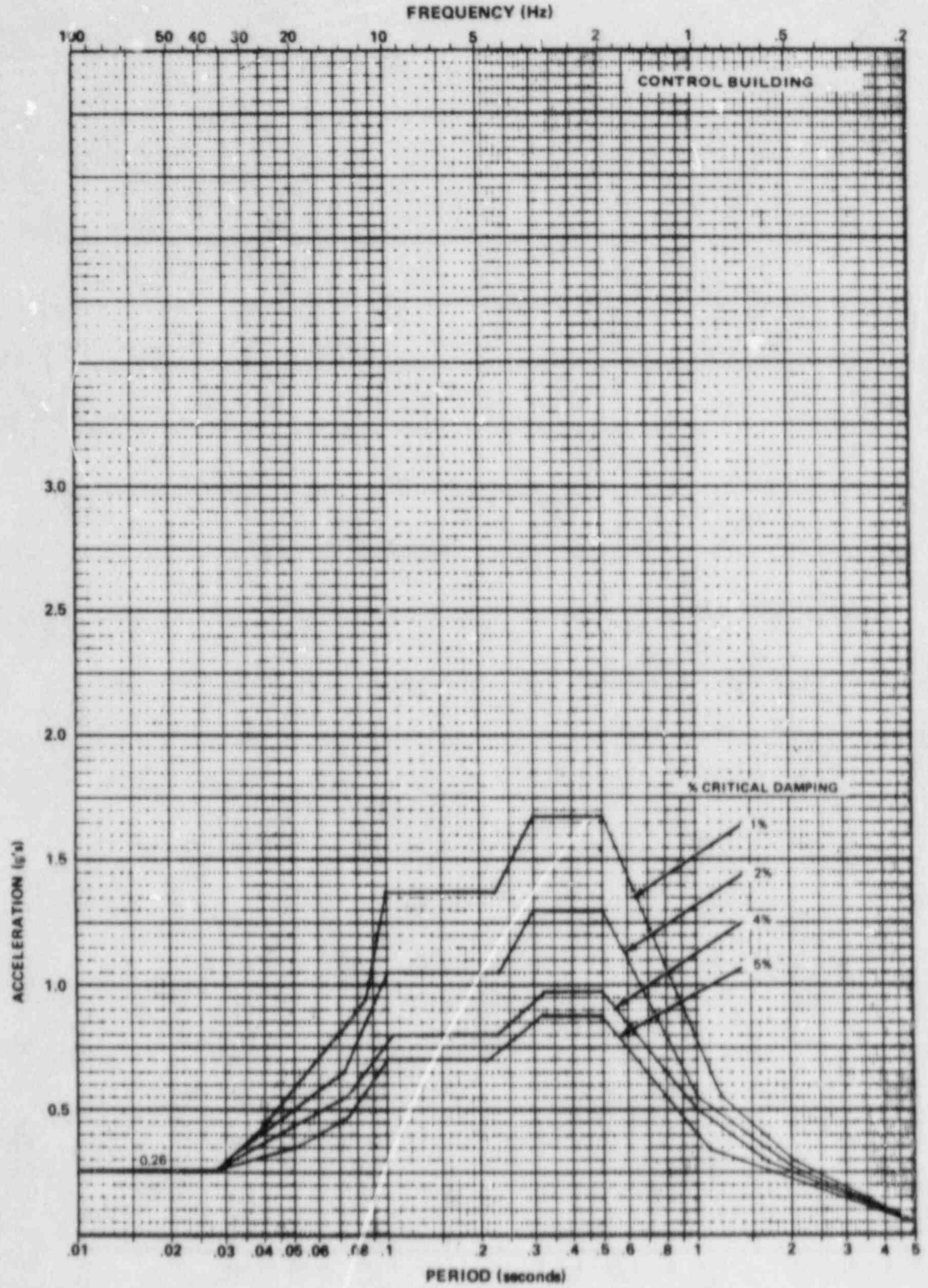

Figure B-33
OPERATING BASIS EARTHQUAKE
HORIZ. ACCEL. RESPONSE SPECTRA
EL. 220 FT. 0 IN.

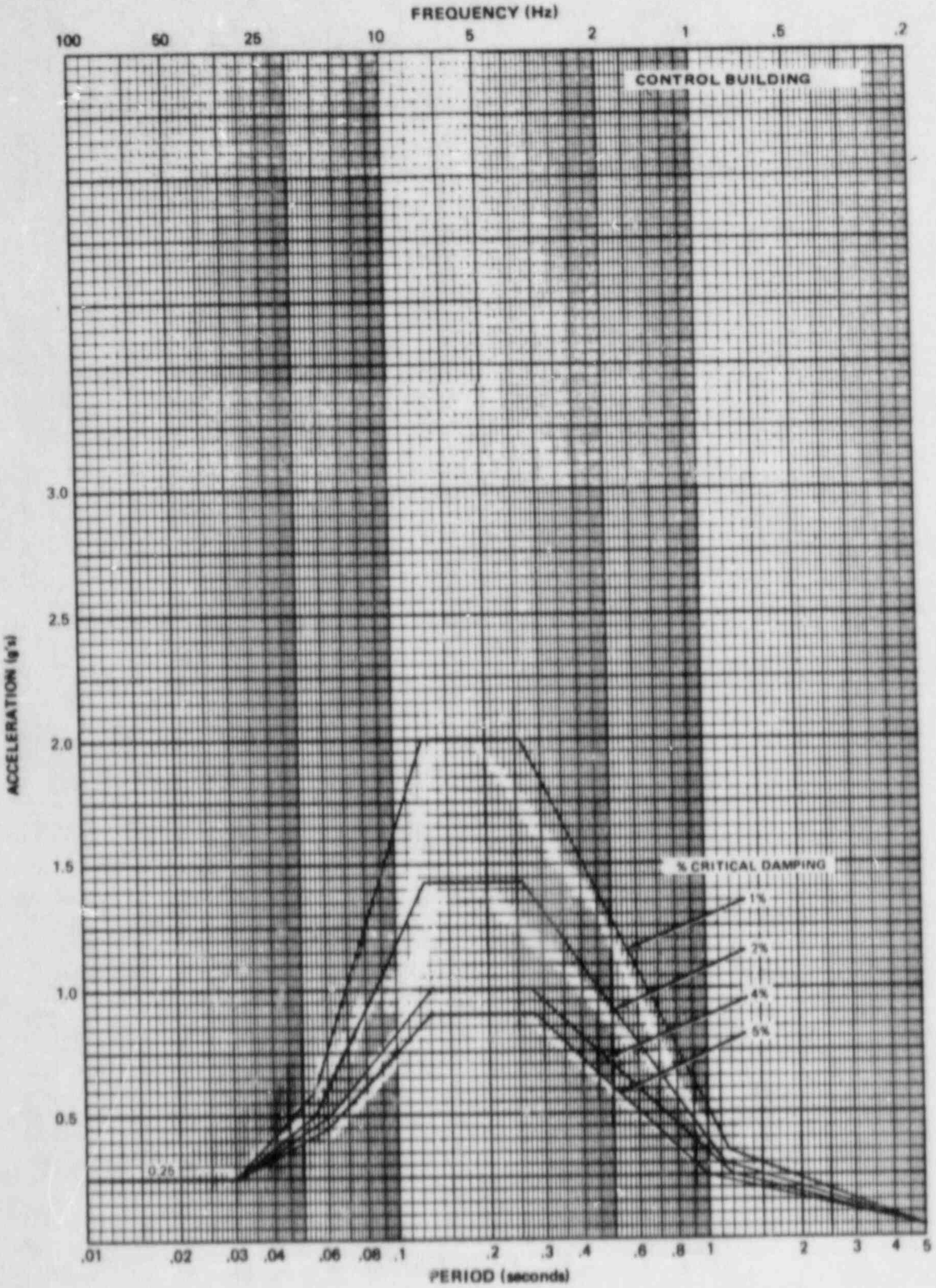

Figure B-34
OPERATING BASIS EARTHQUAKE
VERTICAL ACCEL. RESPONSE SPECTRA
EL. 220 FT. 0 IN.

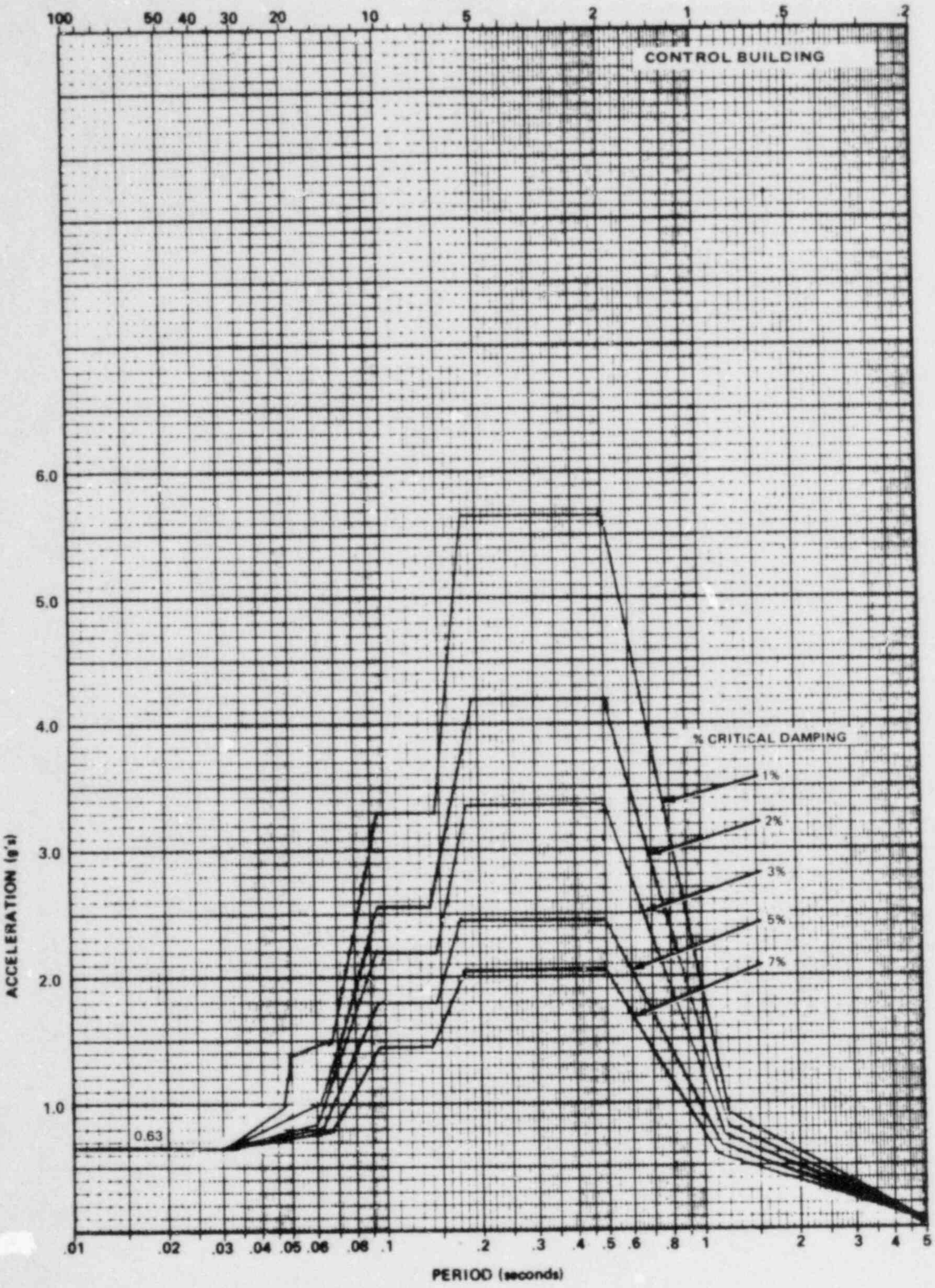

Figure B-35
SAFE SHUTDOWN EARTHQUAKE
HORIZ. ACCEL. RESPONSE SPECTRA
EL. 260 FT. 0 IN.

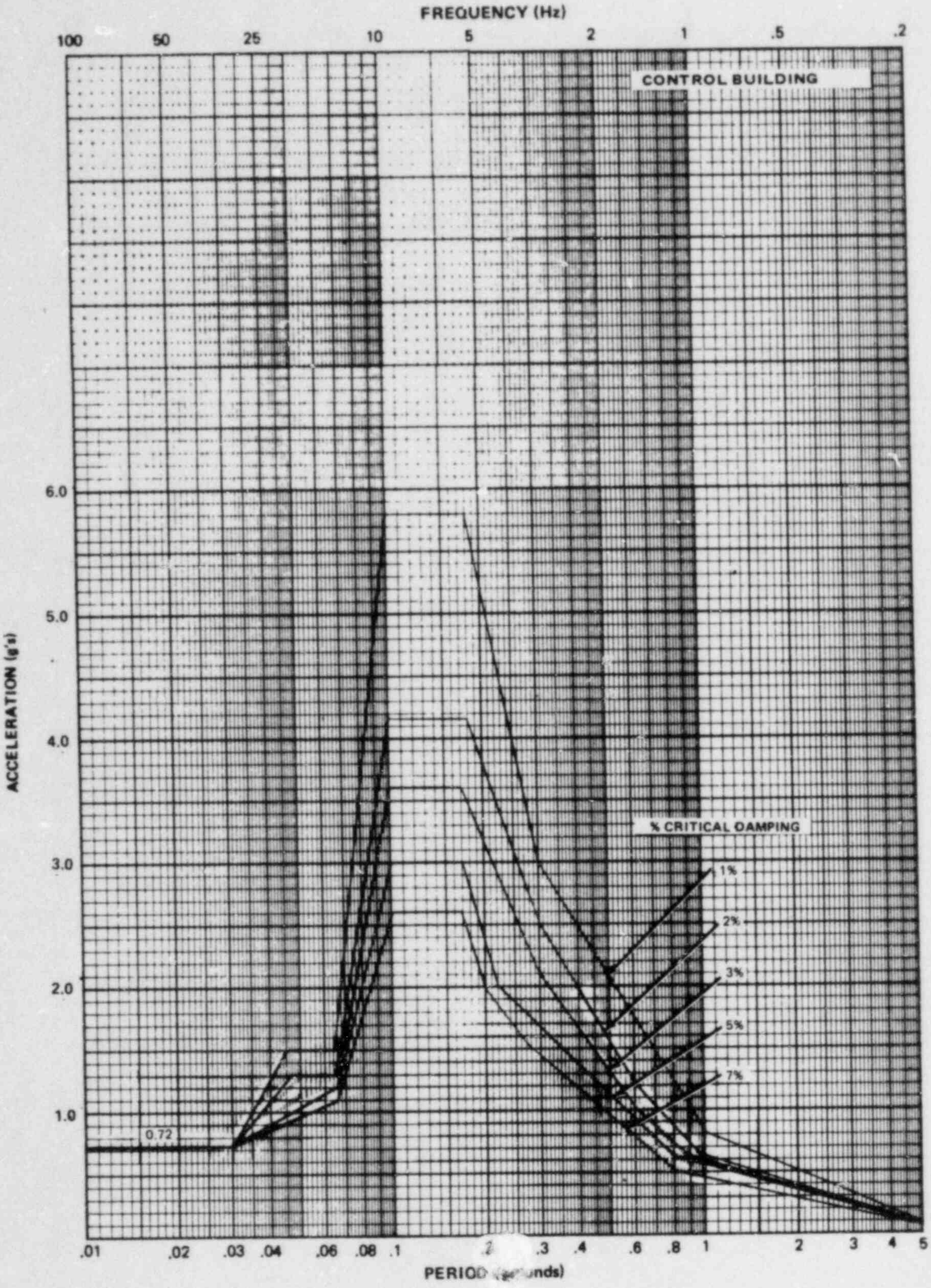

Figure B-36
SAFE SHUTDOWN EARTHQUAKE
VERTICAL ACCEL. RESPONSE SPECTRA
EL. 260 FT. 0 IN.

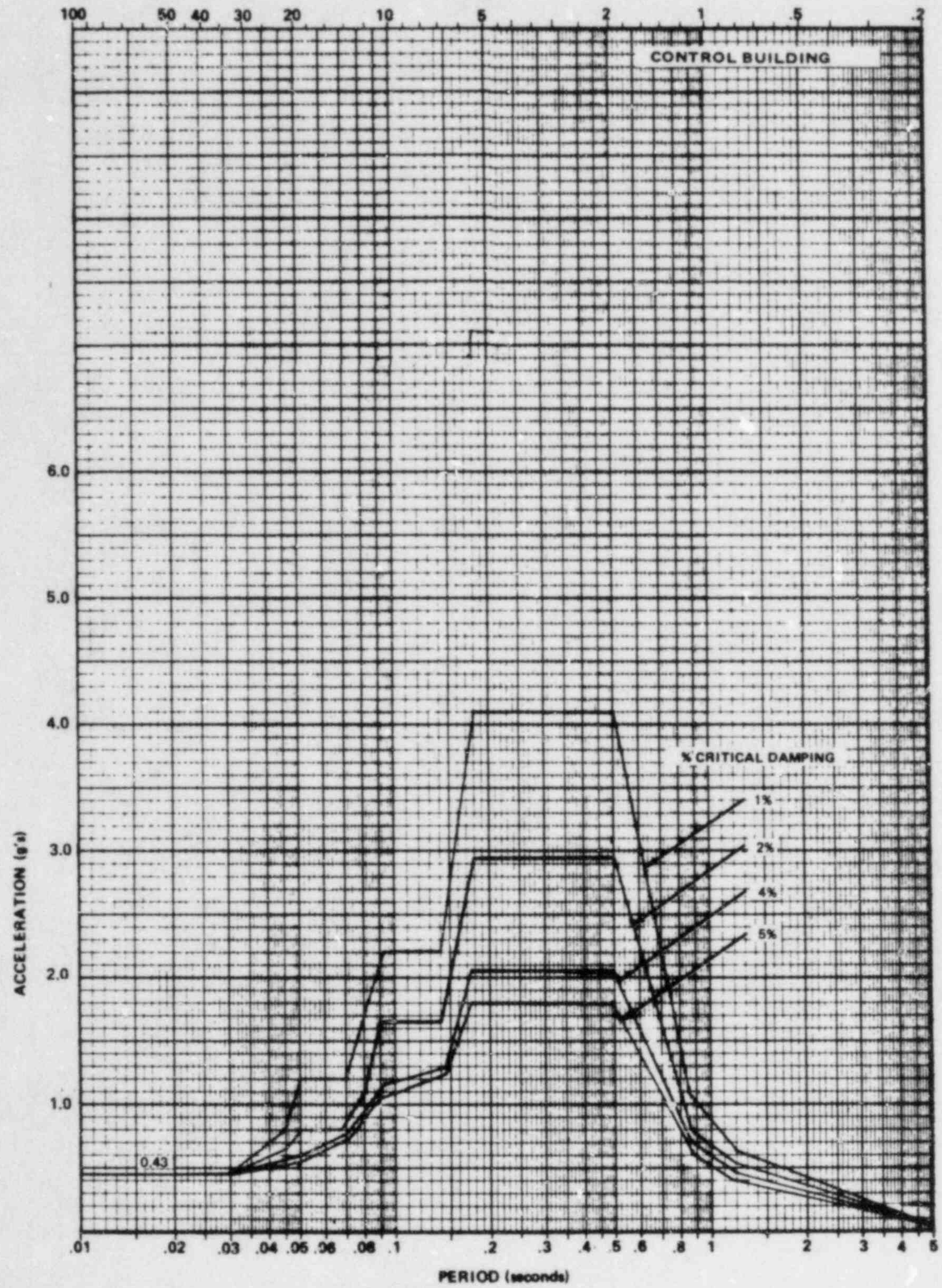

Figure B-37
OPERATING BASIS EARTHQUAKE
HORIZ. ACCEL. RESPONSE SPECTRA
EL. 260 FT. 0 IN.

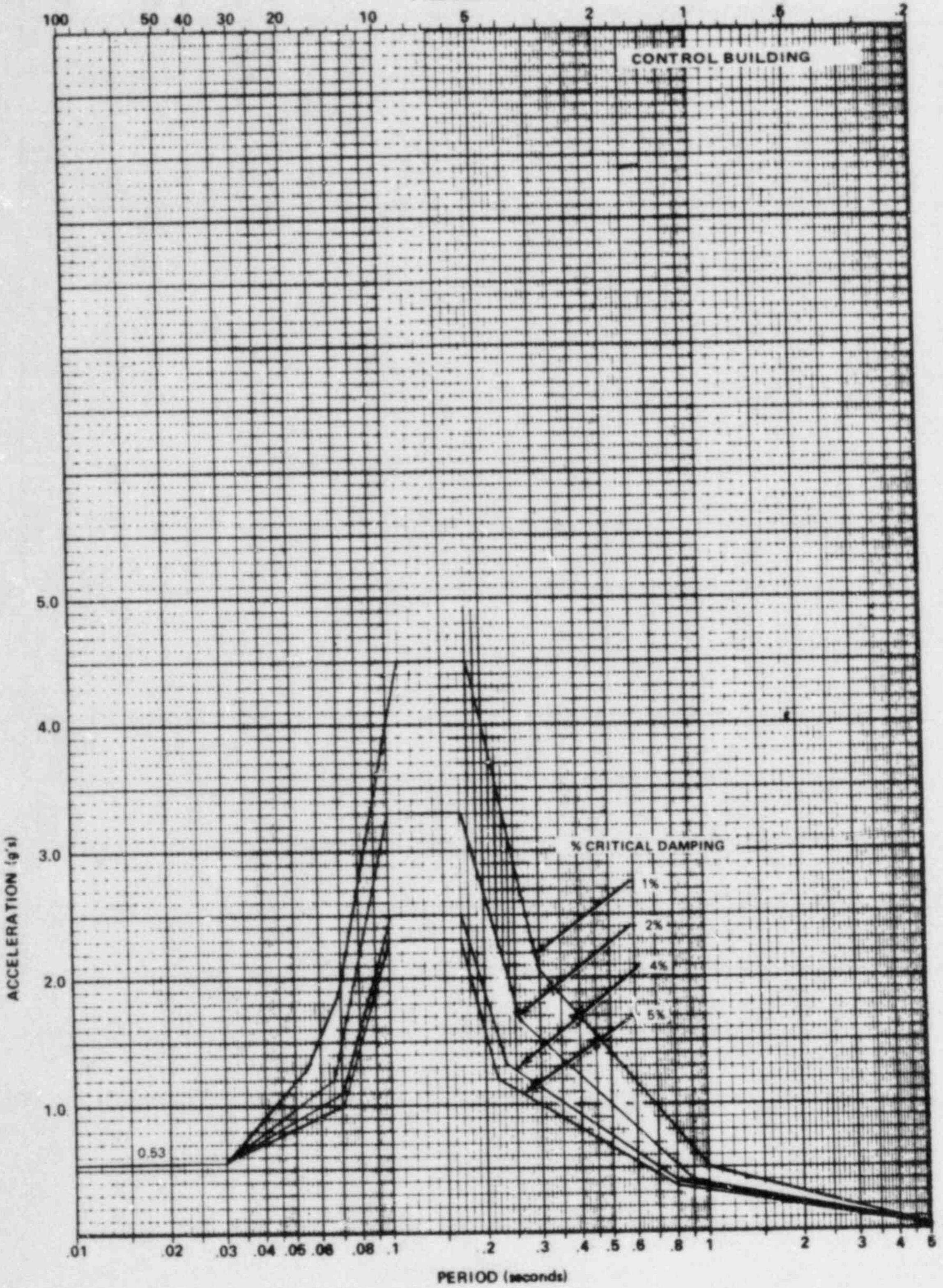

Figure B-38
OPERATING BASIS EARTHQUAKE
VERTICAL ACCEL. RESPONSE SPECTRA
EL. 260 FT. 0 IN.

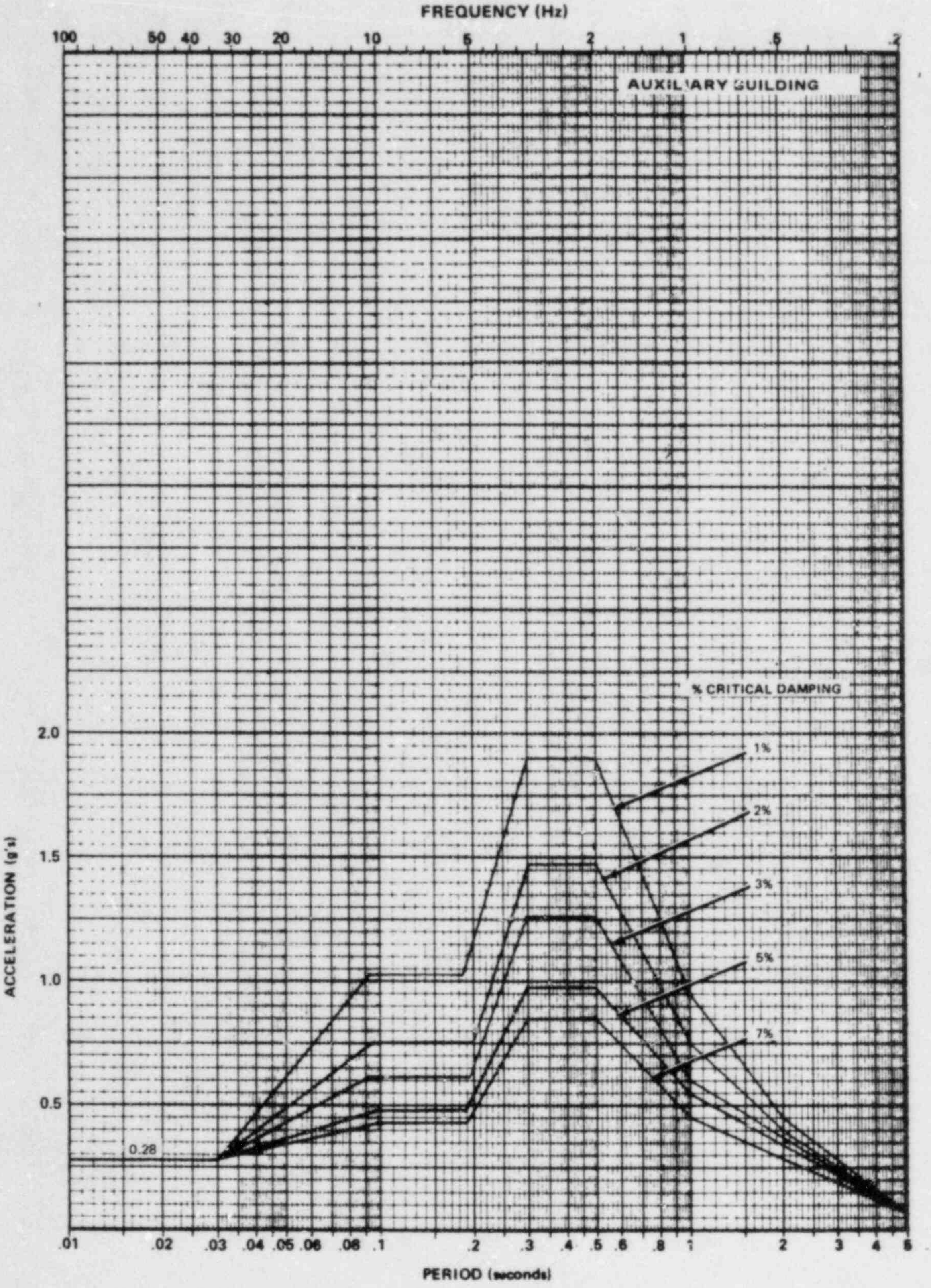

Figure B-39
SAFE SHUTDOWN EARTHQUAKE
HORIZ. ACCEL. RESPONSE SPECTRA
EL. 143 FT. 6 IN.

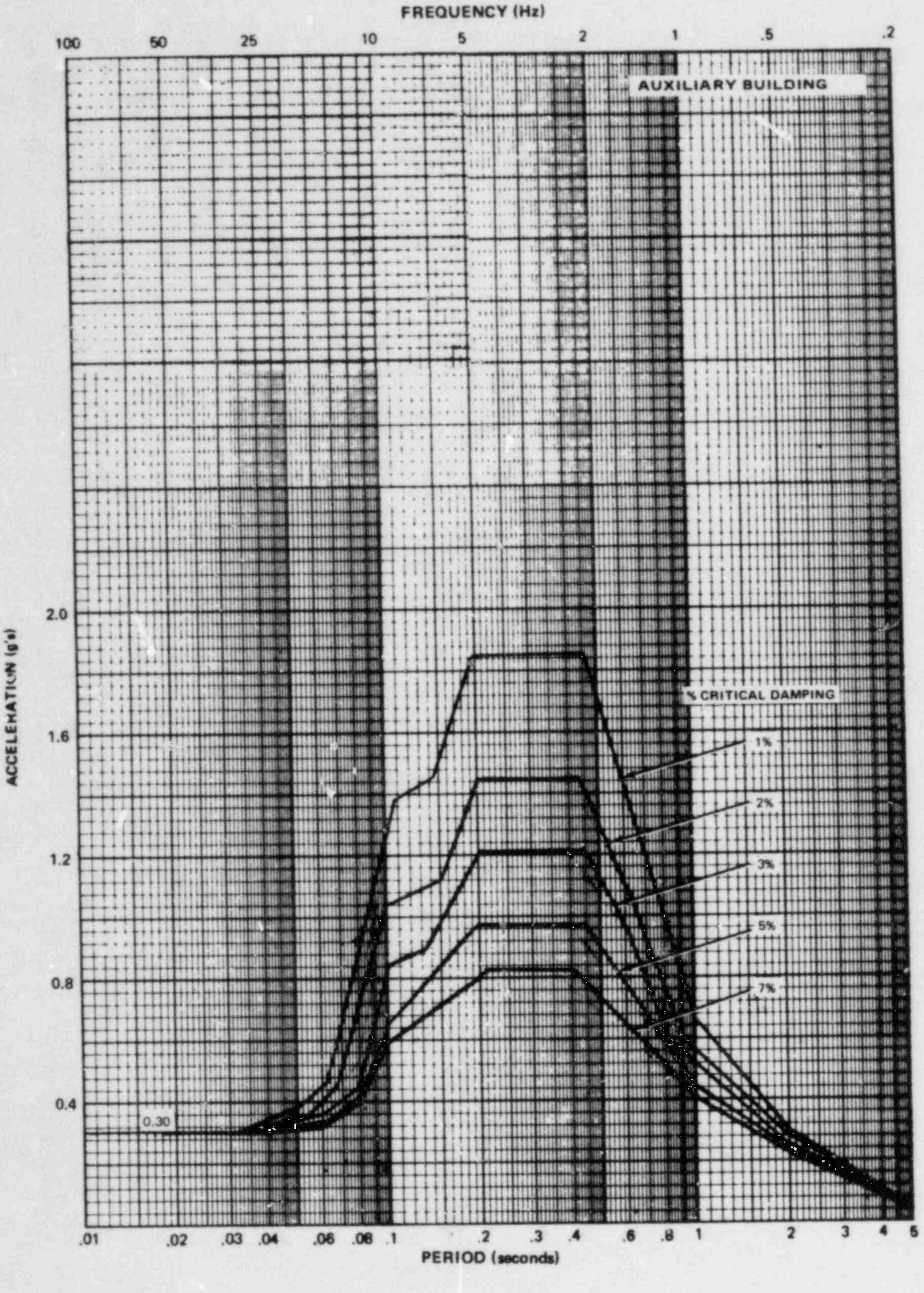

Figure B-40
SAFE SHUTDOWN EARTHQUAKE
VERTICAL ACCEL. RESPONSE SPECTRA
EL. 143 FT. 6 IN.

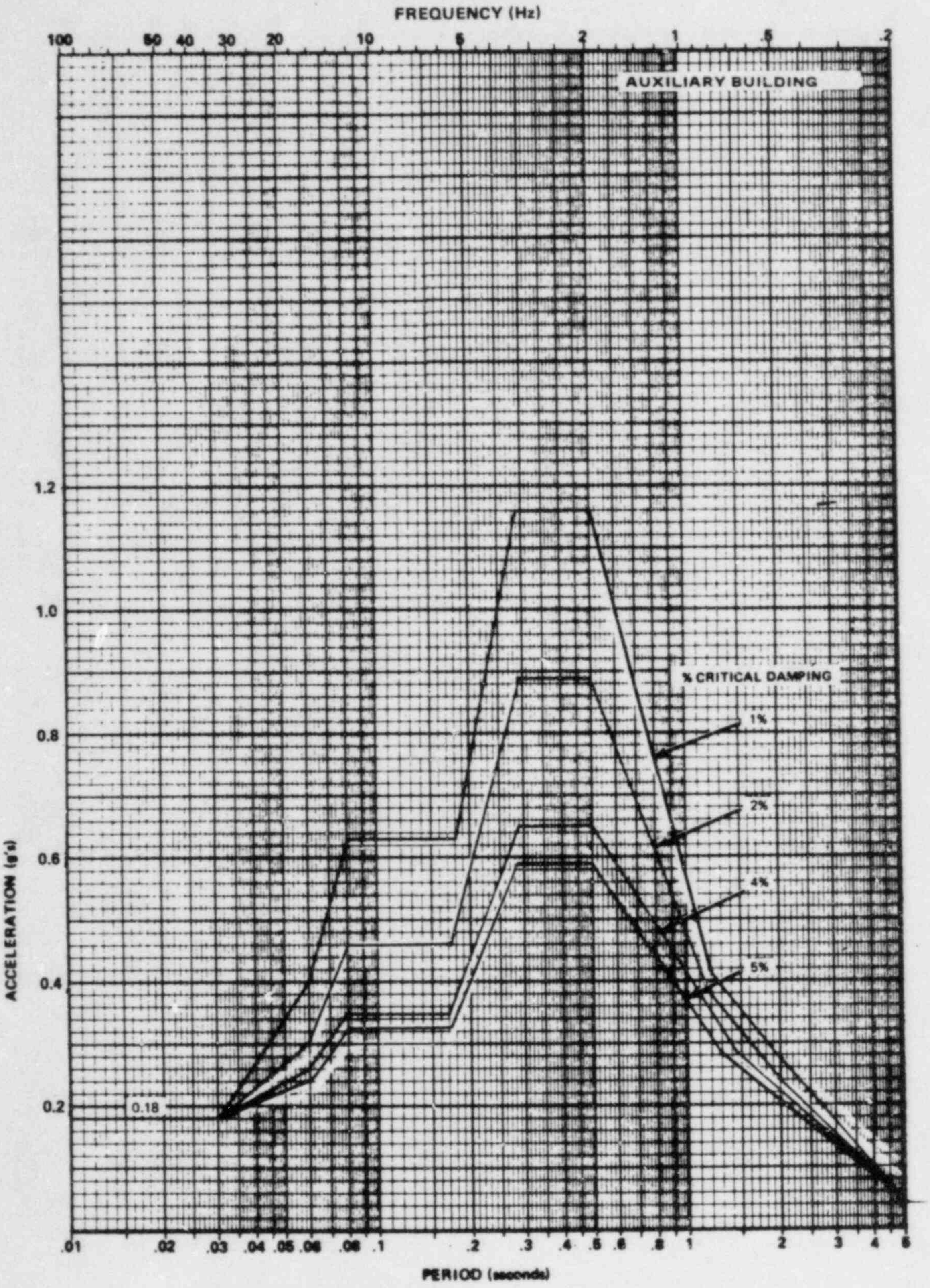

Figure B-41
OPERATING BASIS EARTHQUAKE
HORIZ. ACCEL. RESPONSE SPECTRA
EL. 143 FT. 6 IN.

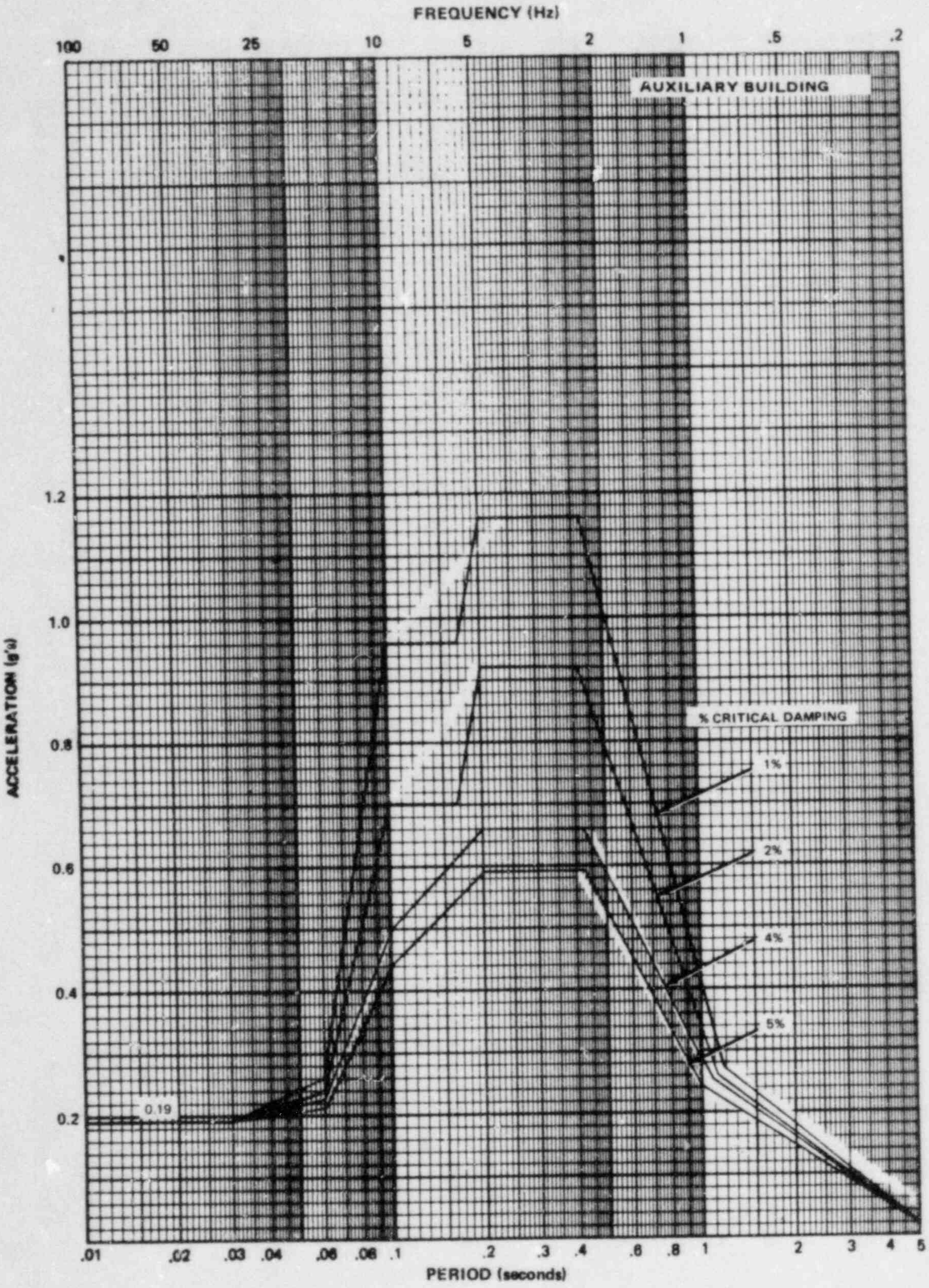

Figure B-42
OPERATING BASIS EARTHQUAKE
VERTICAL ACCEL. RESPONSE SPECTRA
EL. 143 FT. 6 IN.

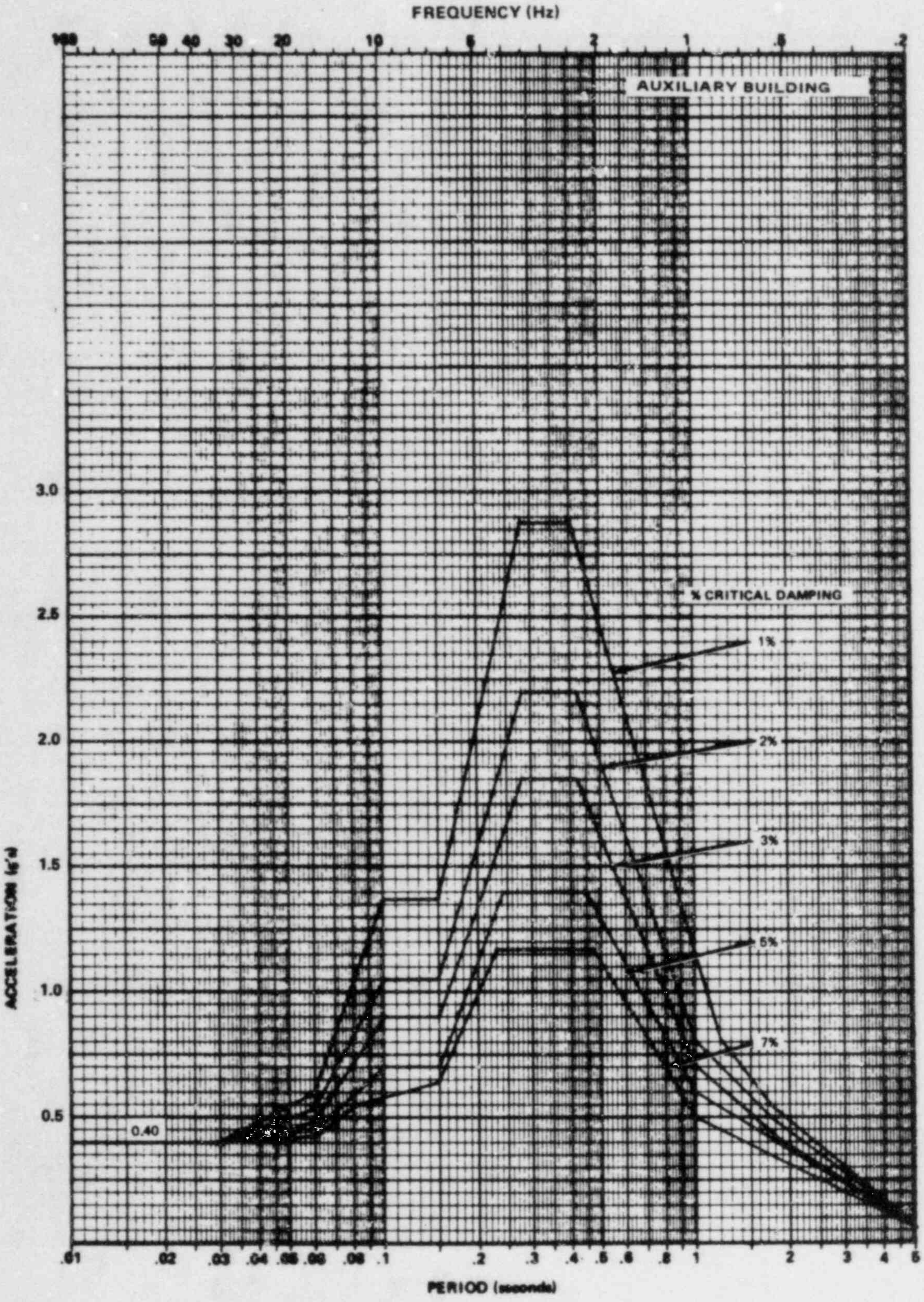

Figure B-43
SAFE SHUTDOWN EARTHQUAKE
HORIZ. ACCEL. RESPONSE SPECTRA
EL. 220 FT. 0 IN.

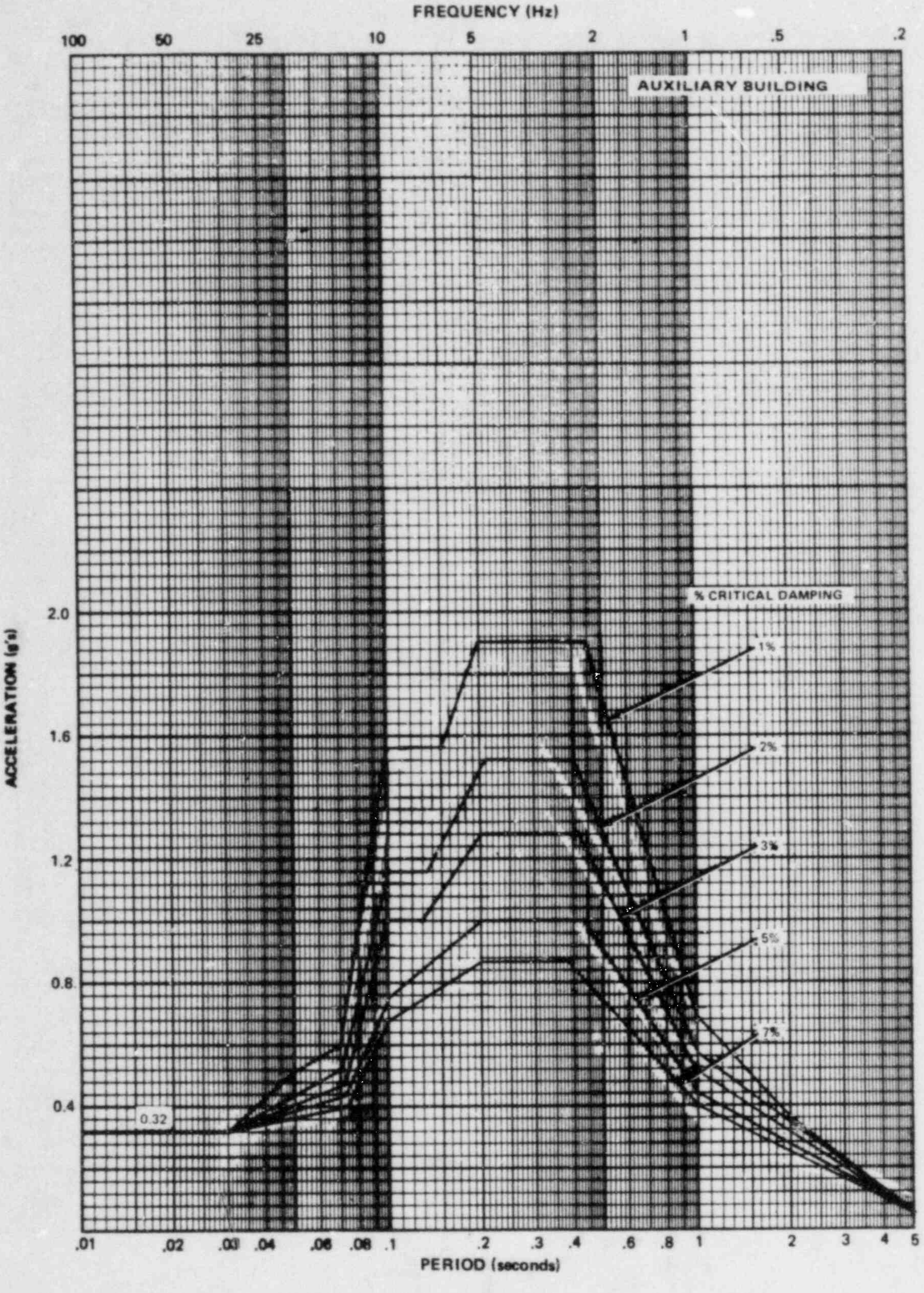

Figure B-44
SAFE SHUTDOWN EARTHQUAKE
VERTICAL ACCEL. RESPONSE SPECTRA
EL. 220 FT. 0 IN.

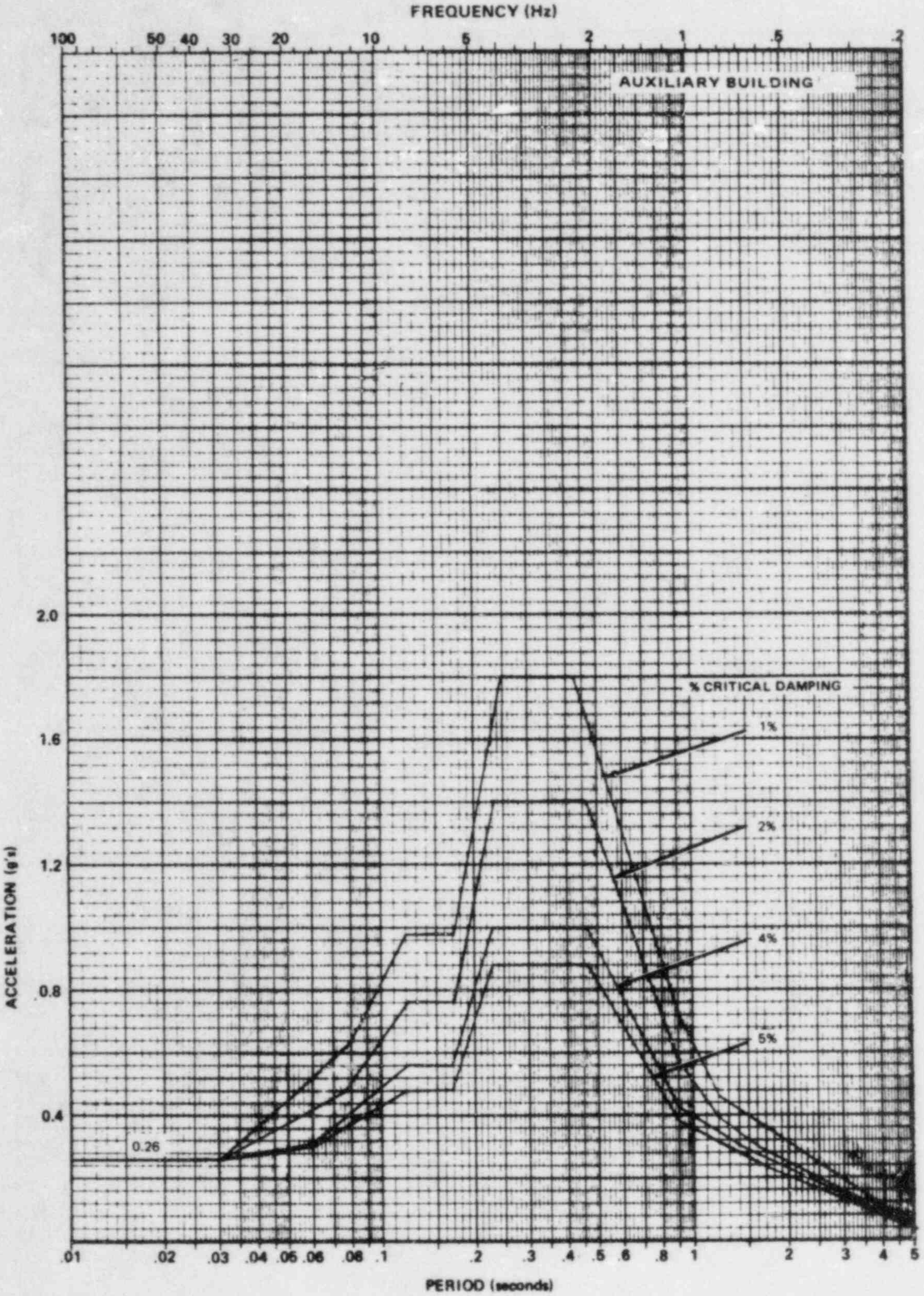

Figure B-45
OPERATING BASIS EARTHQUAKE
HORIZ. ACCEL. RESPONSE SPECTRA
EL. 220 FT. 0 IN.

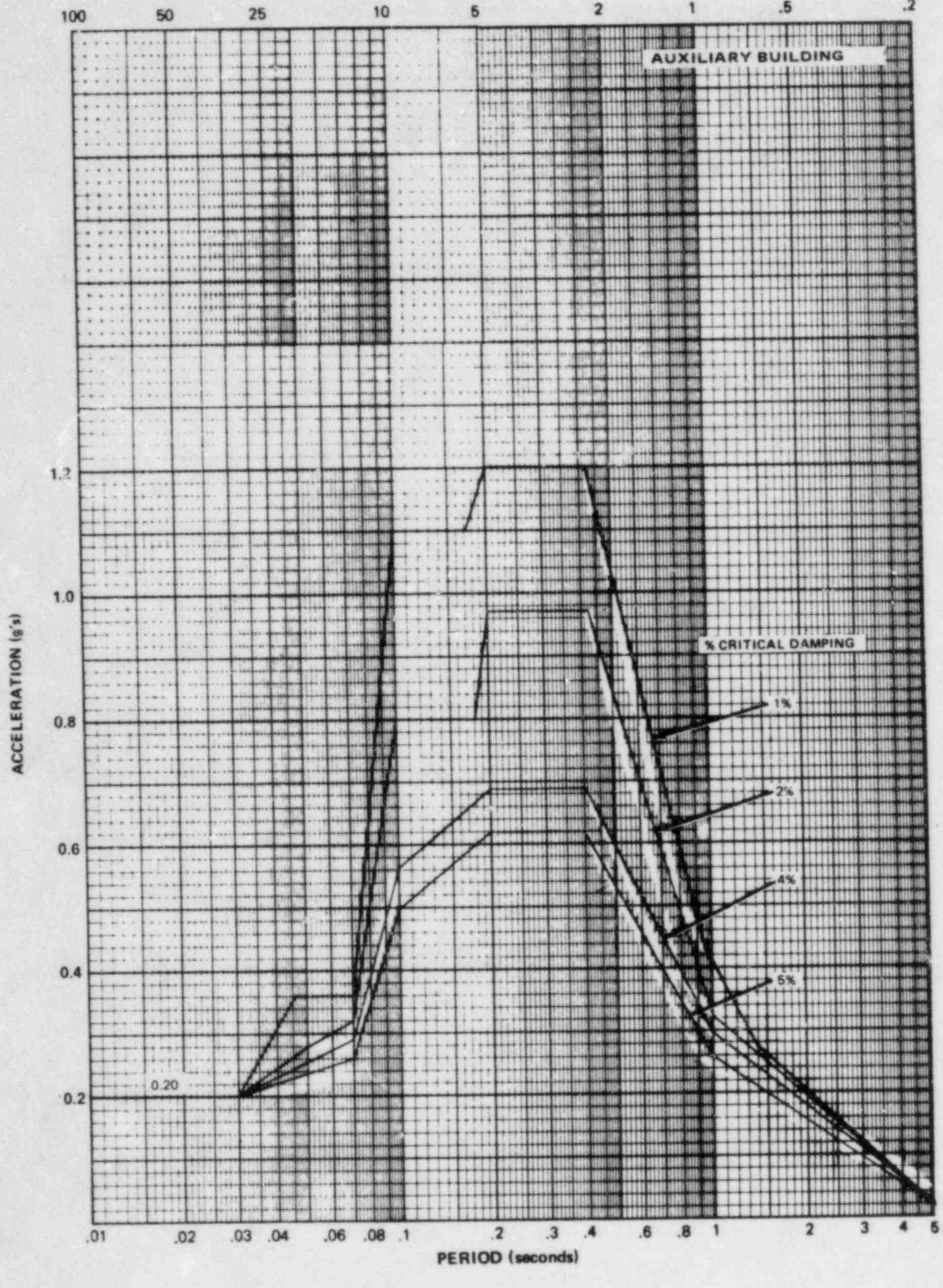

Figure B-46
OPERATING BASIS EARTHQUAKE
VERTICAL ACCEL. RESPONSE SPECTRA
EL. 220 FT. 0 IN.

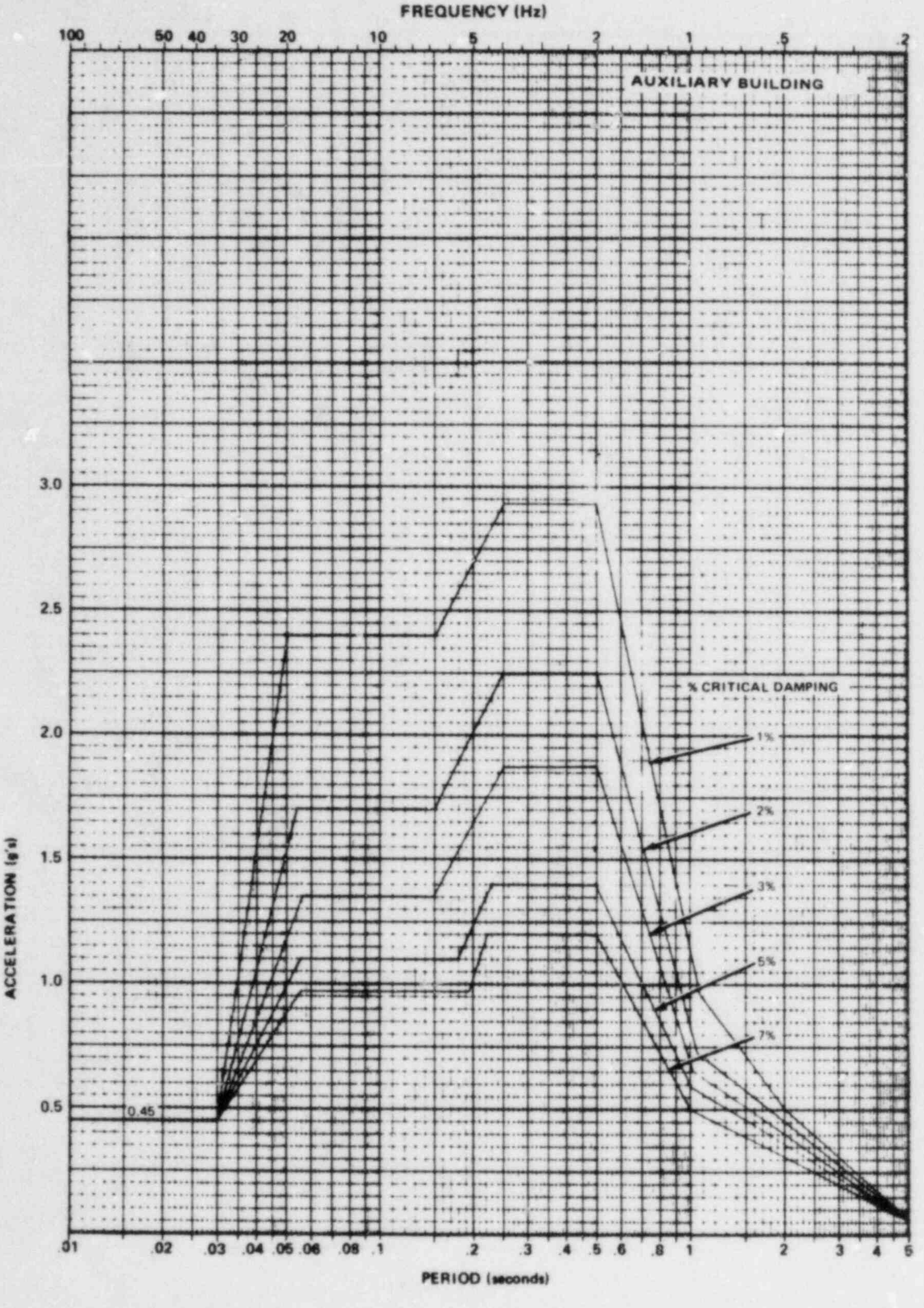

Figure B-47
SAFE SHUTDOWN EARTHQUAKE
HORIZ. ACCEL. RESPONSE SPECTRA
EL. 288 FT. 3 IN.

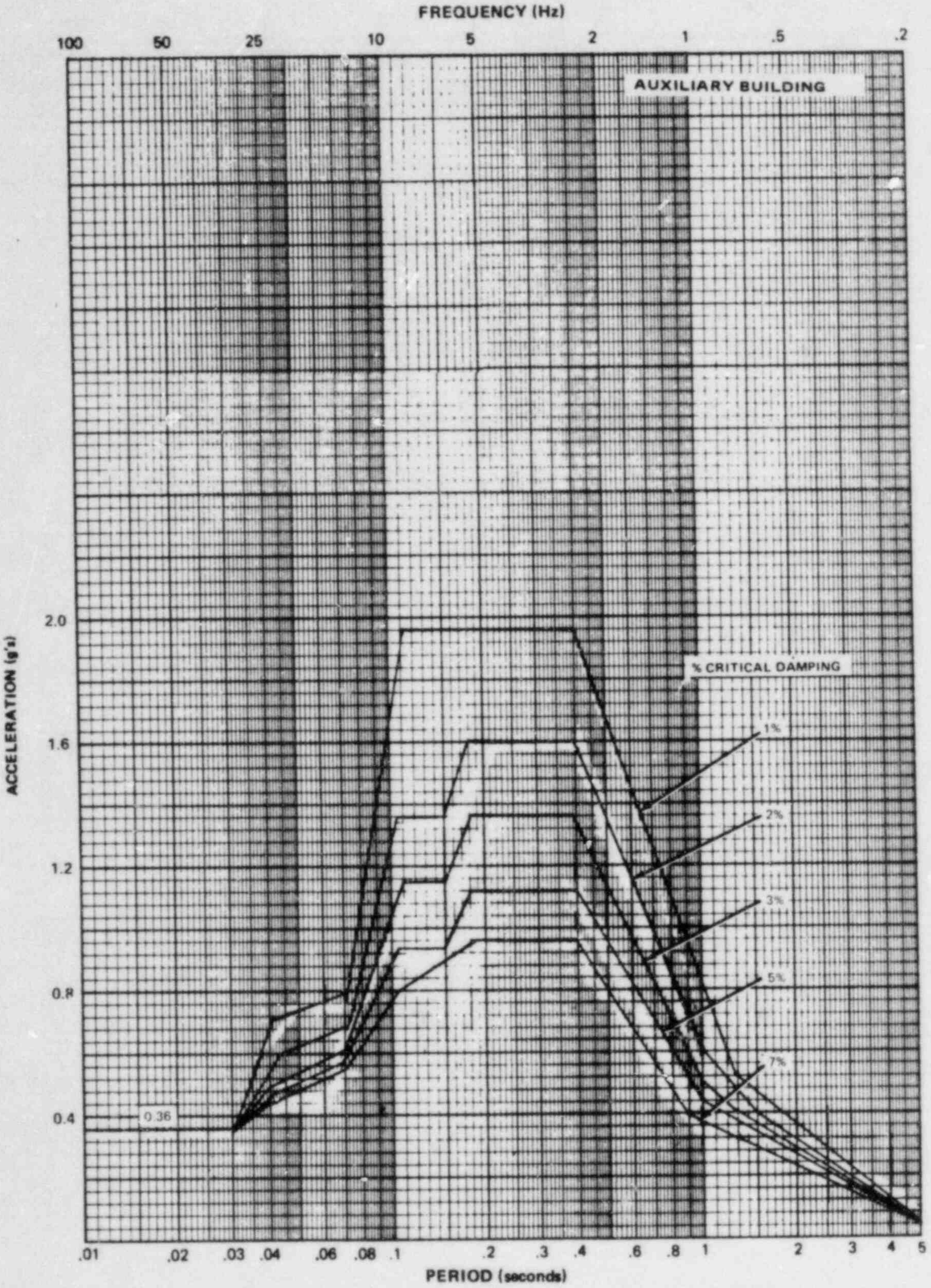

Figure B-48
SAFE SHUTDOWN EARTHQUAKE
VERTICAL ACCEL. RESPONSE SPECTRA
EL. 288 FT. 3 IN.

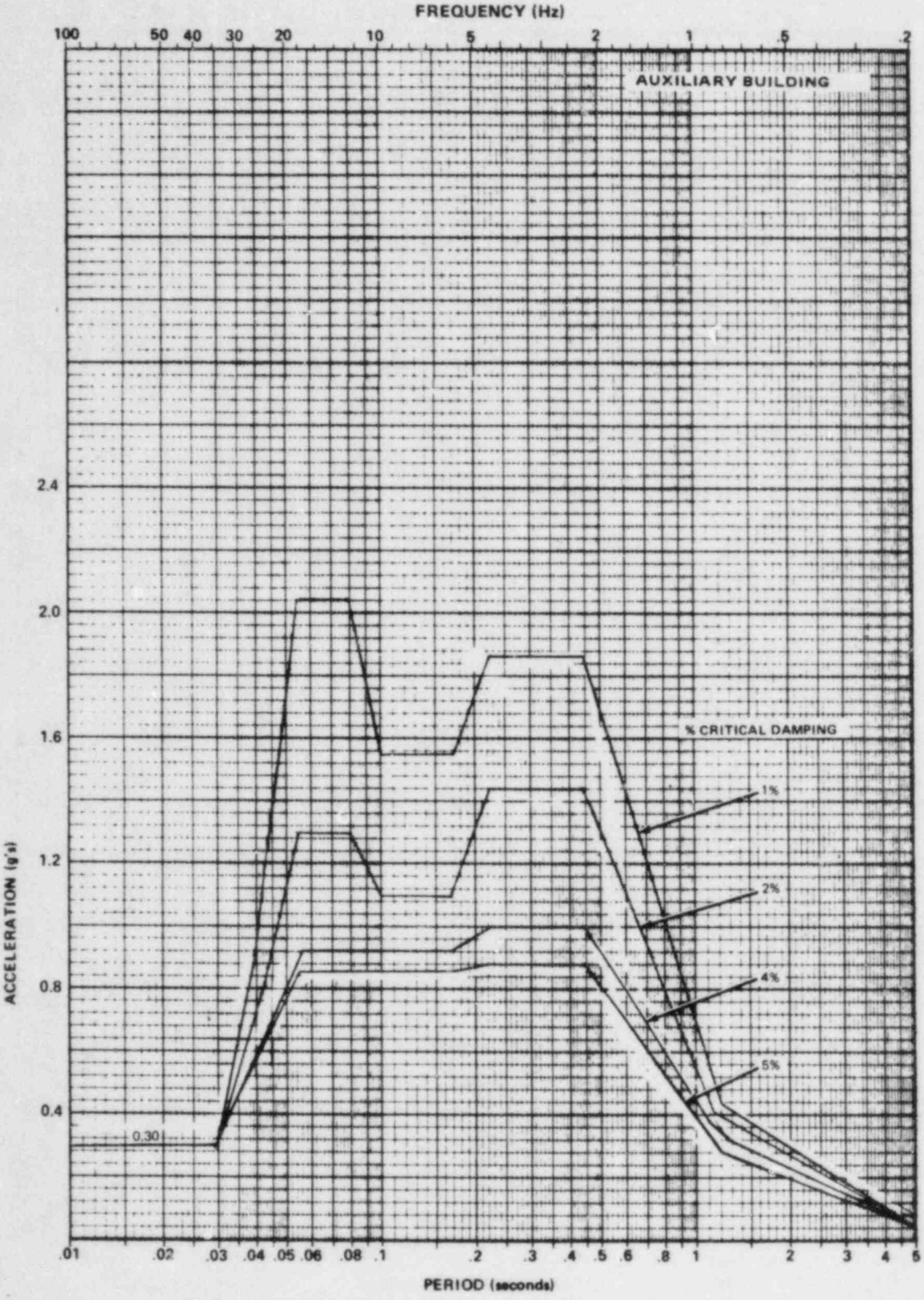

Figure B-49
OPERATING BASIS EARTHQUAKE
HORIZ. ACCEL. RESPONSE SPECTRA
EL. 288 FT. 3 IN.

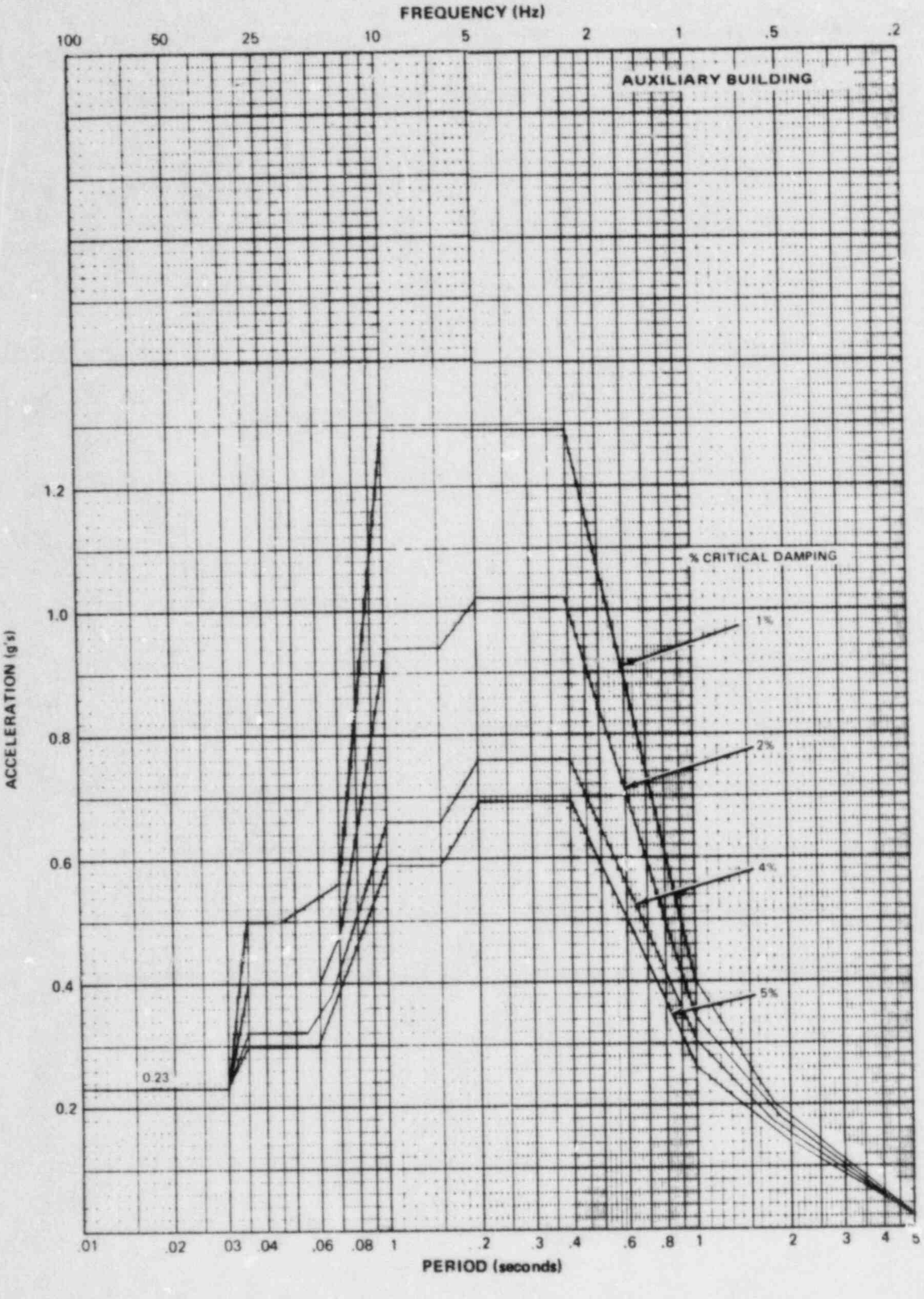

Figure B-50
OPERATING BASIS EARTHQUAKE
VERTICAL ACCEL. RESPONSE SPECTRA
EL. 288 FT. 3 IN.

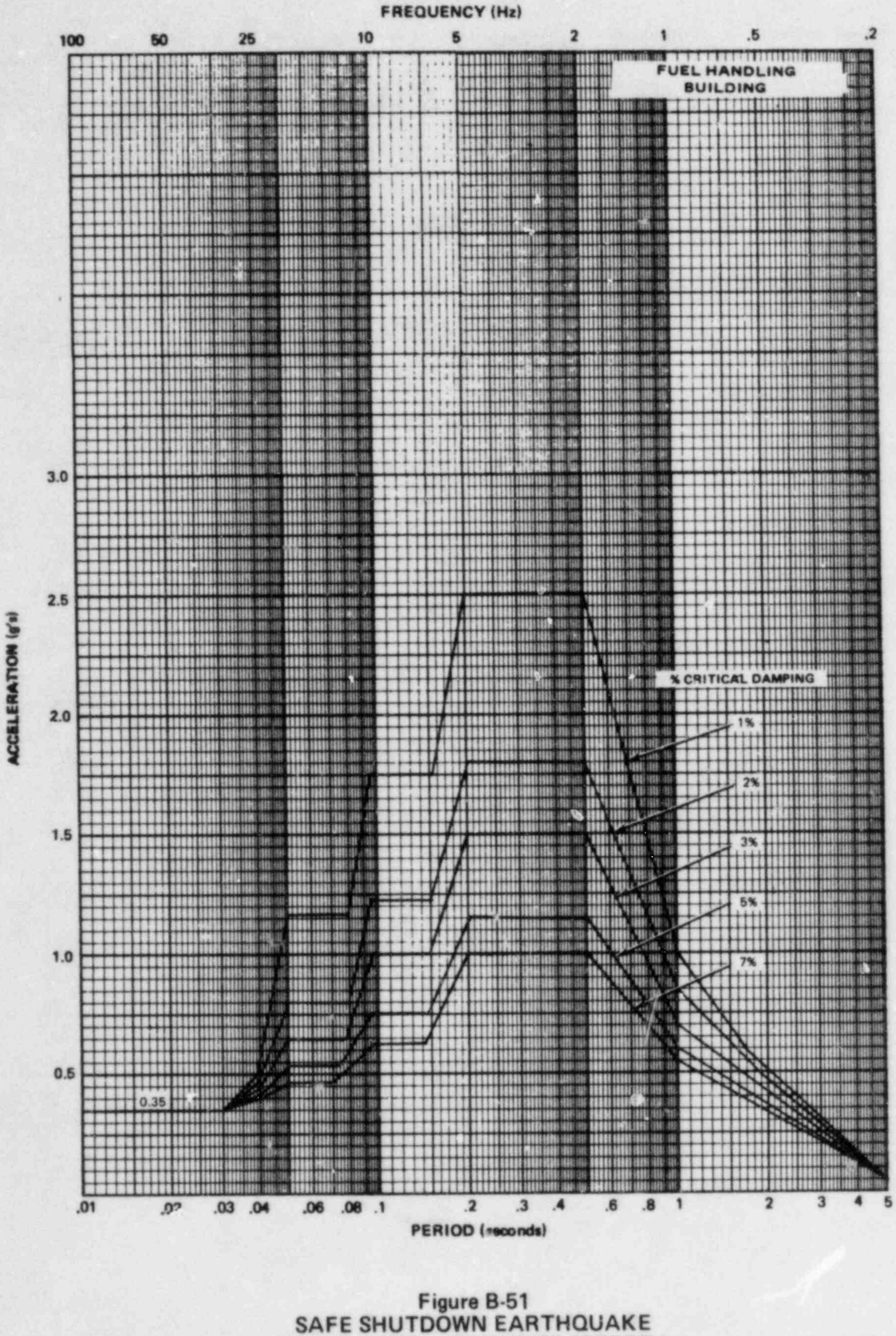

Figure B-51
SAFE SHUTDOWN EARTHQUAKE
HORIZ. ACCEL. RESPONSE SPECTRA
EL. 160 FT. 0 IN.

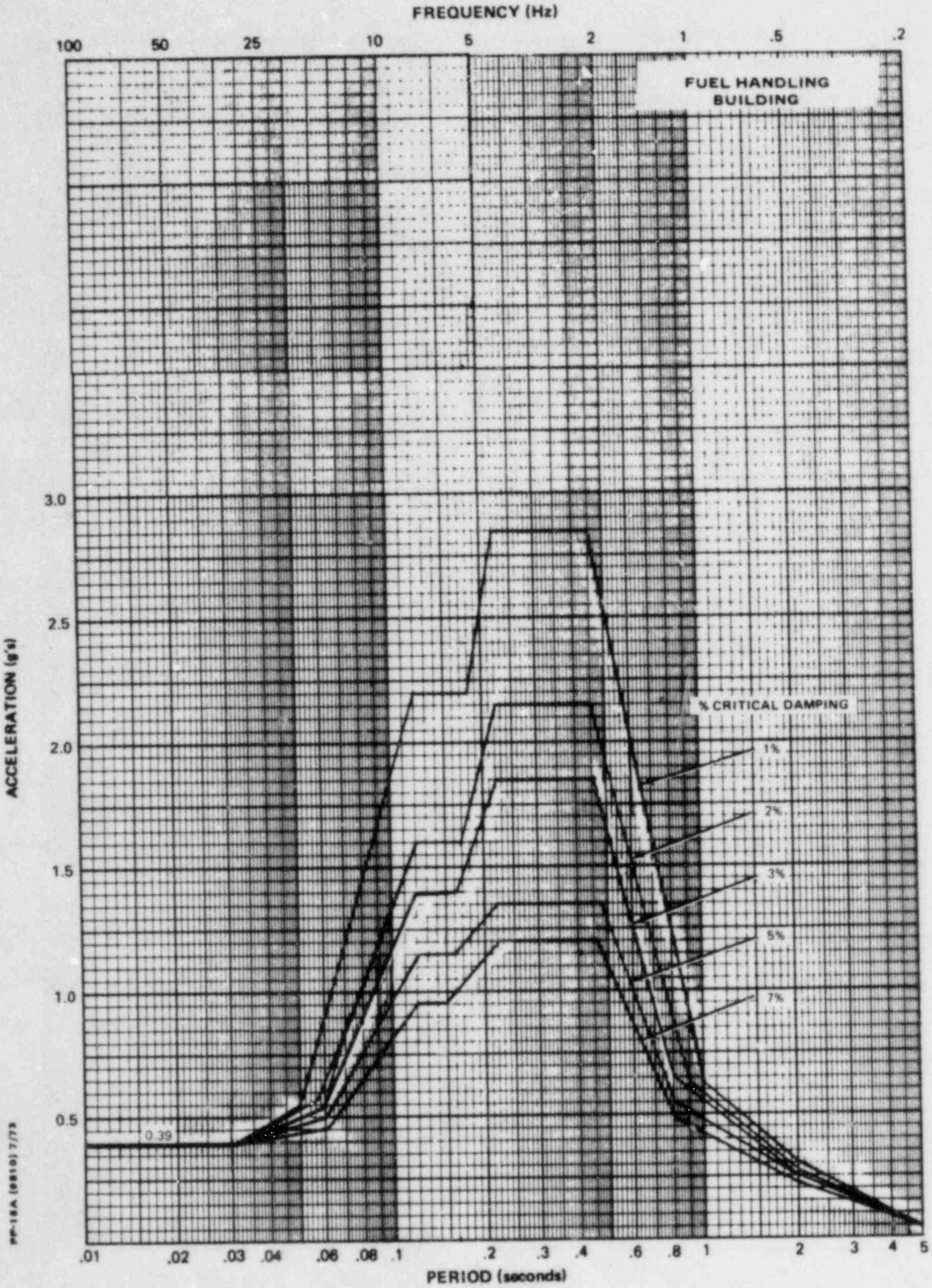

Figure B-52
SAFE SHUTDOWN EARTHQUAKE
VERTICAL ACCEL. RESPONSE SPECTRA
EL. 160 FT. 0 IN.

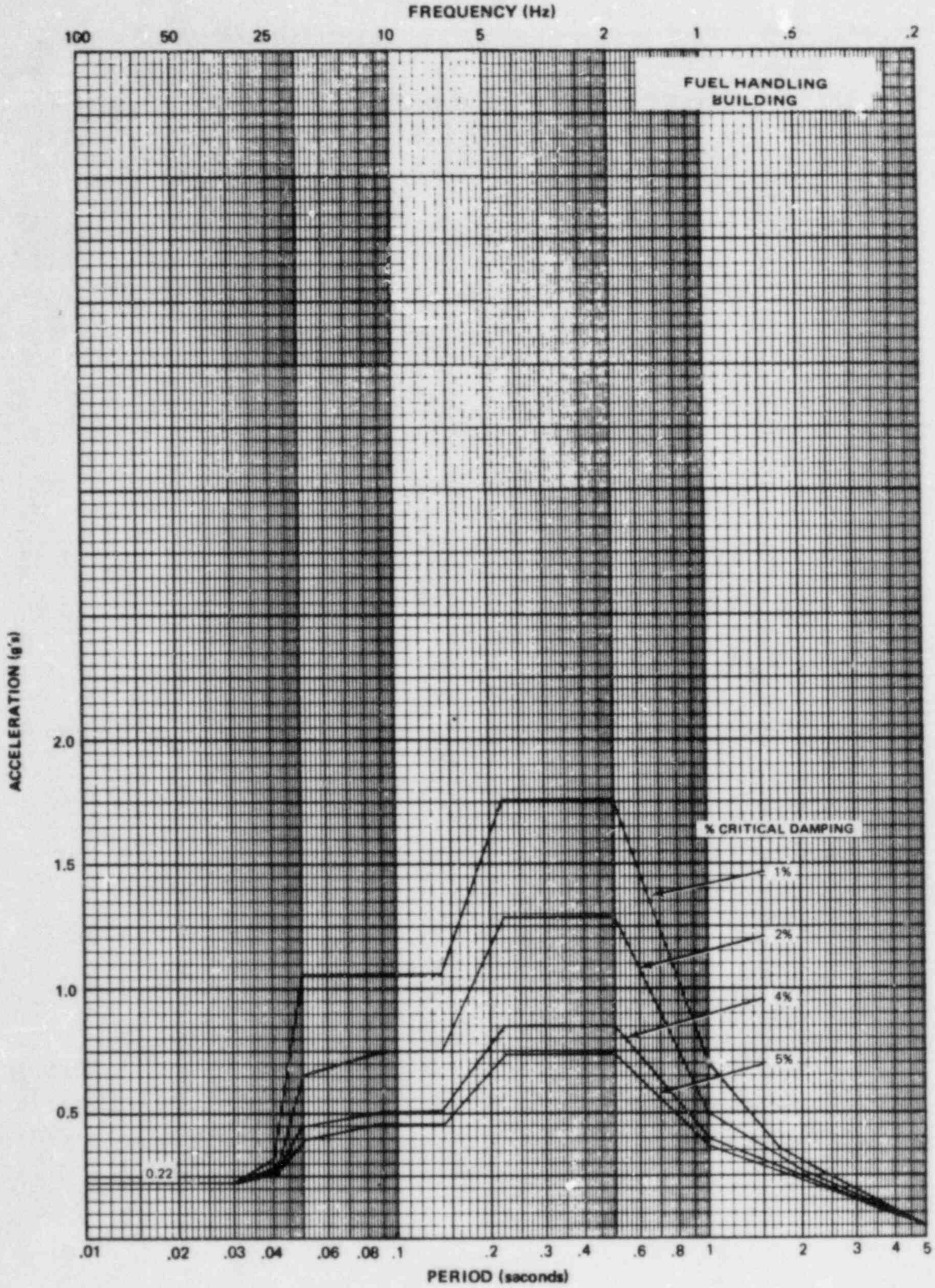

Figure B-53
OPERATING BASIS EARTHQUAKE
HORIZ. ACCEL. RESPONSE SPECTRA
EL. 160 FT. 0 IN.

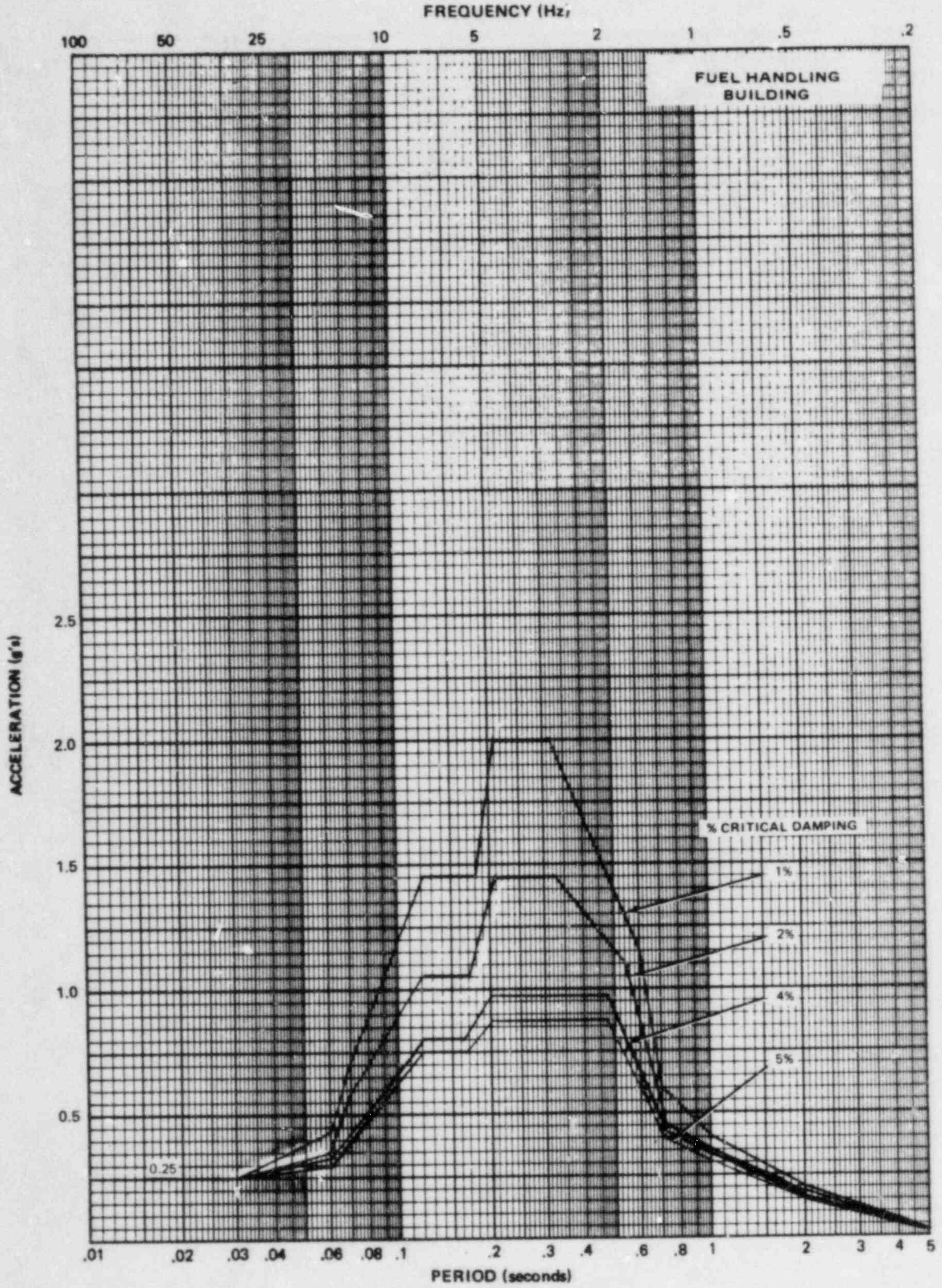

Figure B-54
OPERATING BASIS EARTHQUAKE
VERTICAL ACCEL. RESPONSE SPECTRA
EL. 160 FT. 0 IN.

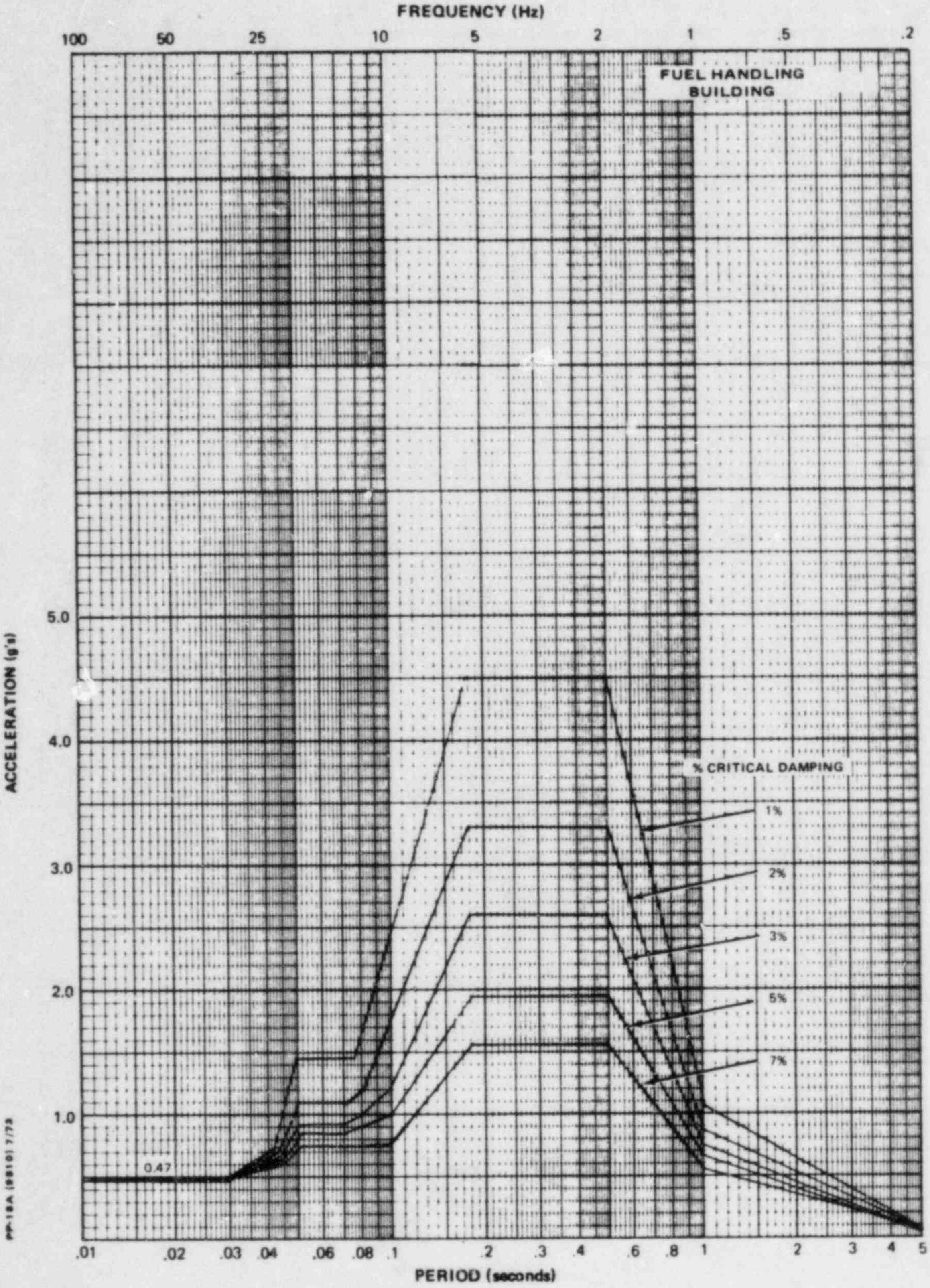

Figure B-55
SAFE SHUTDOWN EARTHQUAKE
HORIZ. ACCEL. RESPONSE SPECTRA
EL. 220 FT. 0 IN.

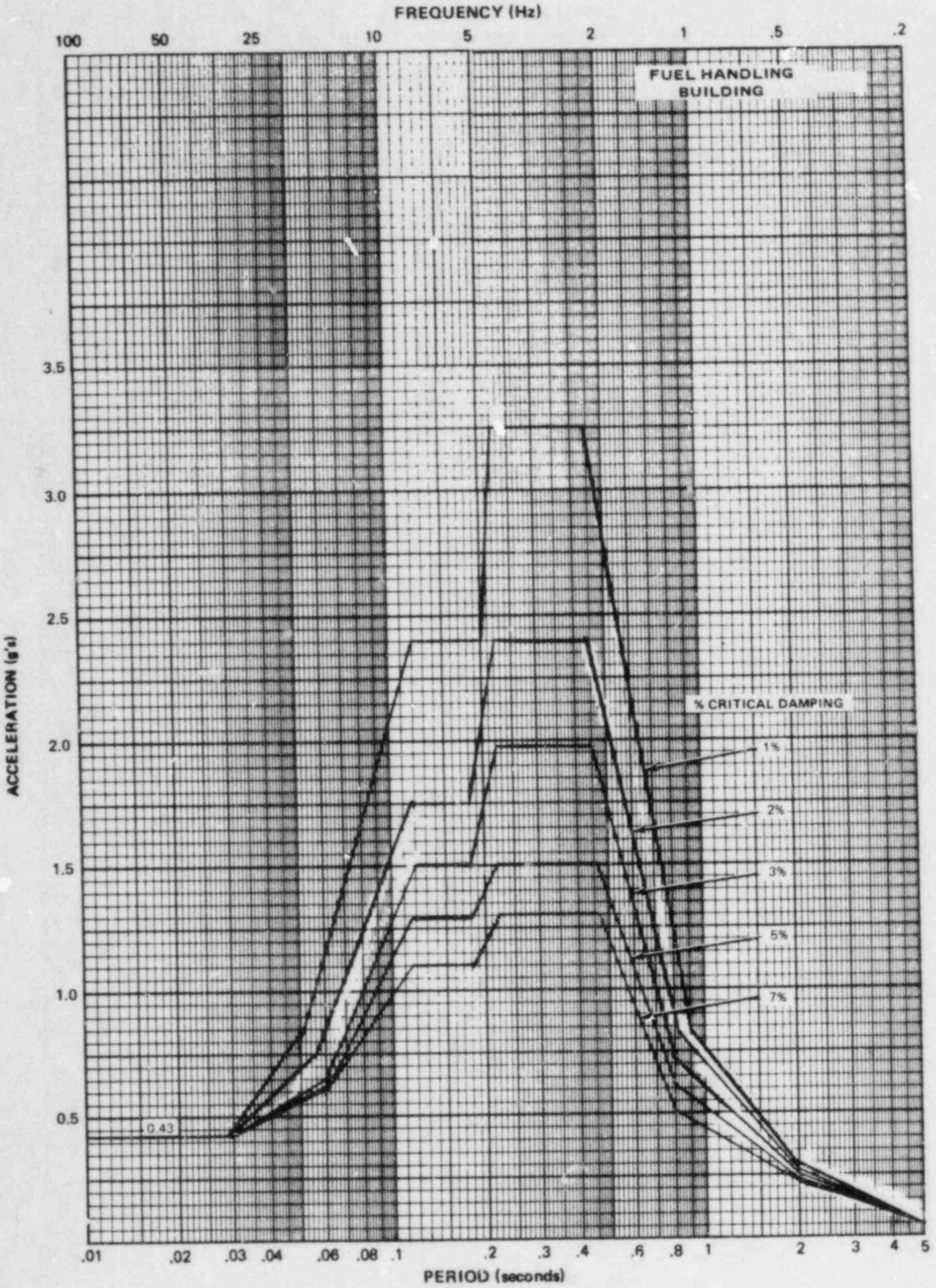

Figure B-56
SAFE SHUTDOWN EARTHQUAKE
VERTICAL ACCEL. RESPONSE SPECTRA
EL. 220 FT. 0 IN.

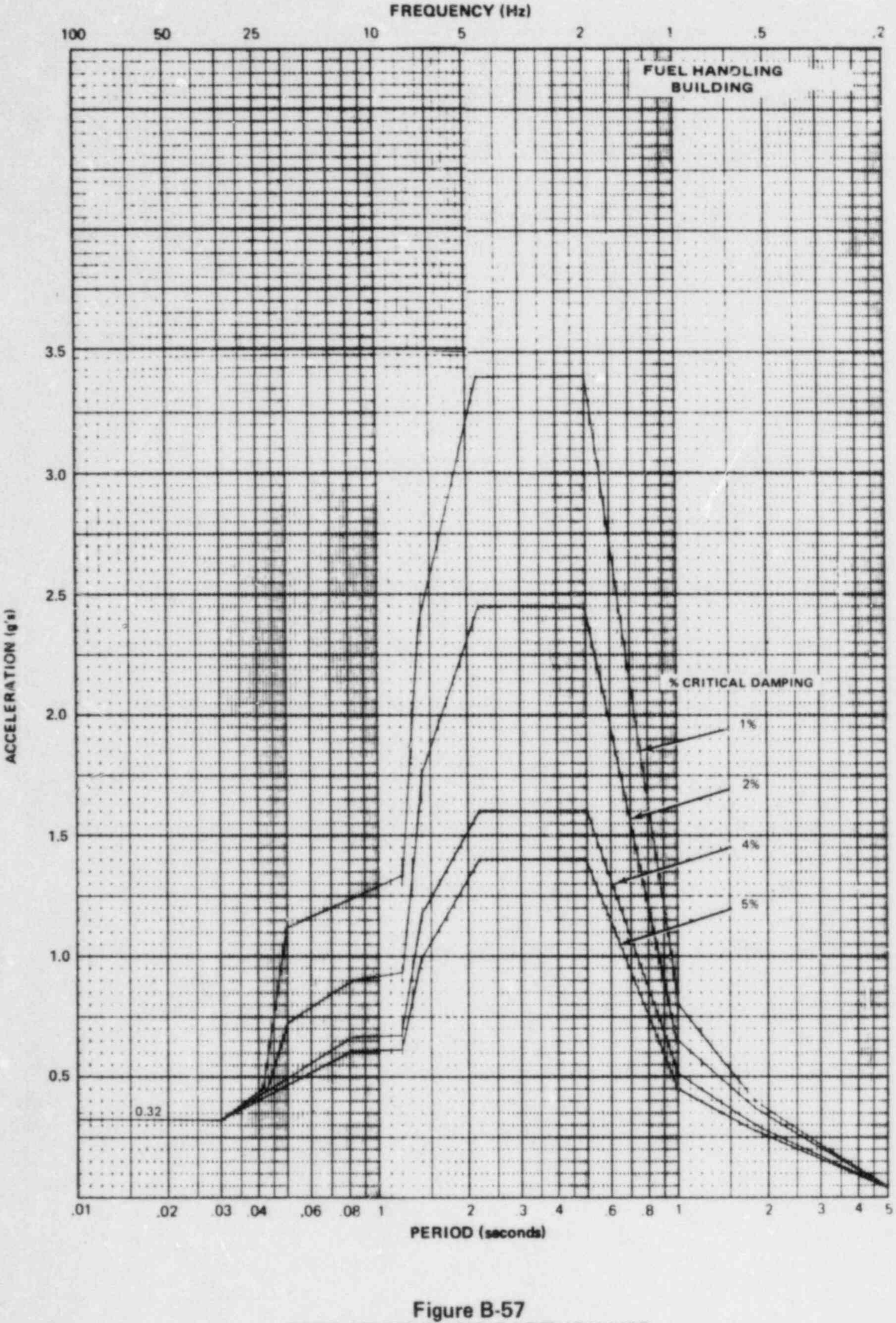

Figure B-57
OPERATING BASIS EARTHQUAKE
HORIZ. ACCEL. RESPONSE SPECTRA
EL. 220 FT. 0 IN.

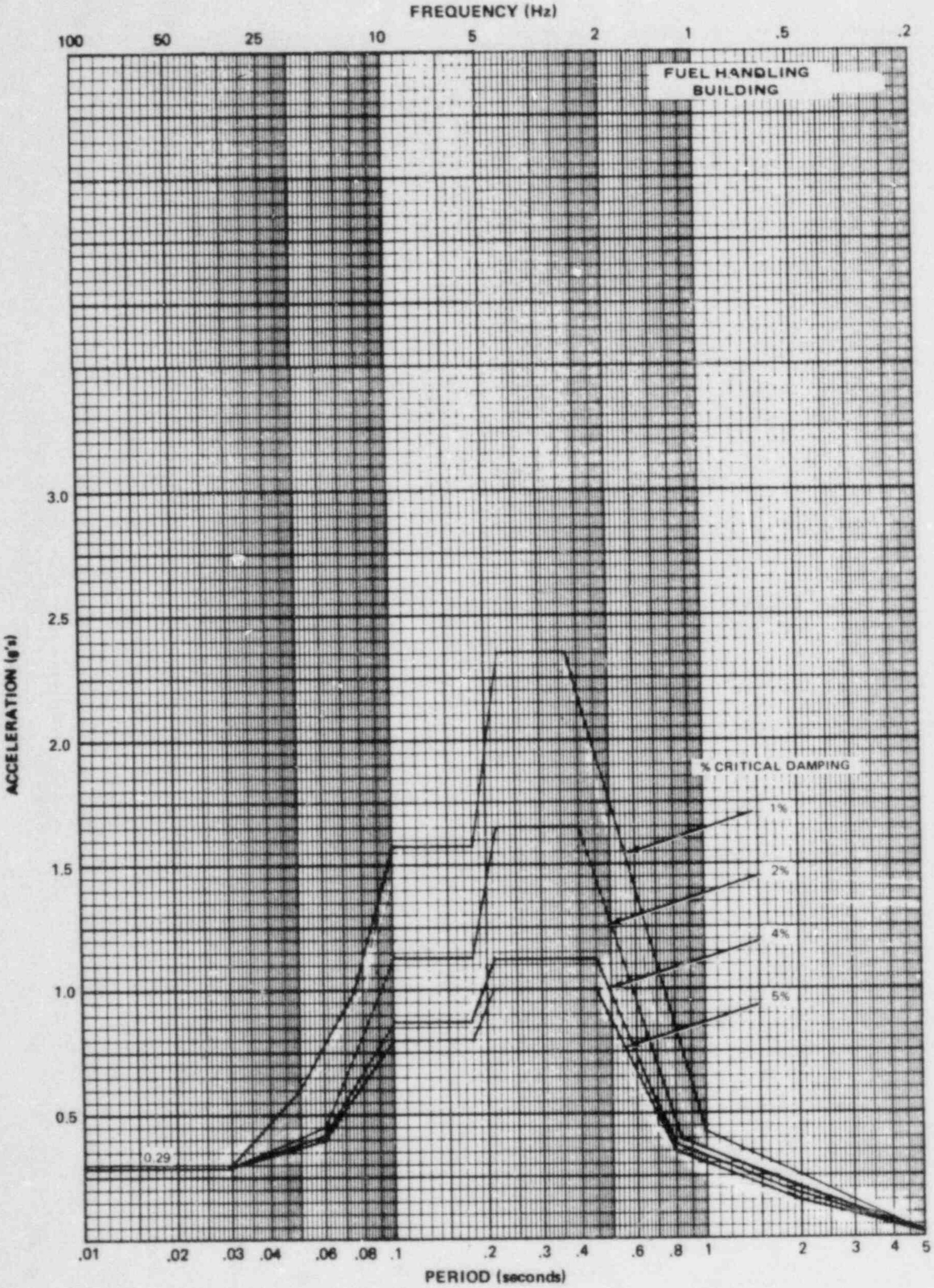

Figure B-58
OPERATING BASIS EARTHQUAKE
VERTICAL ACCEL. RESPONSE SPECTRA
EL. 220 FT. 0 IN.

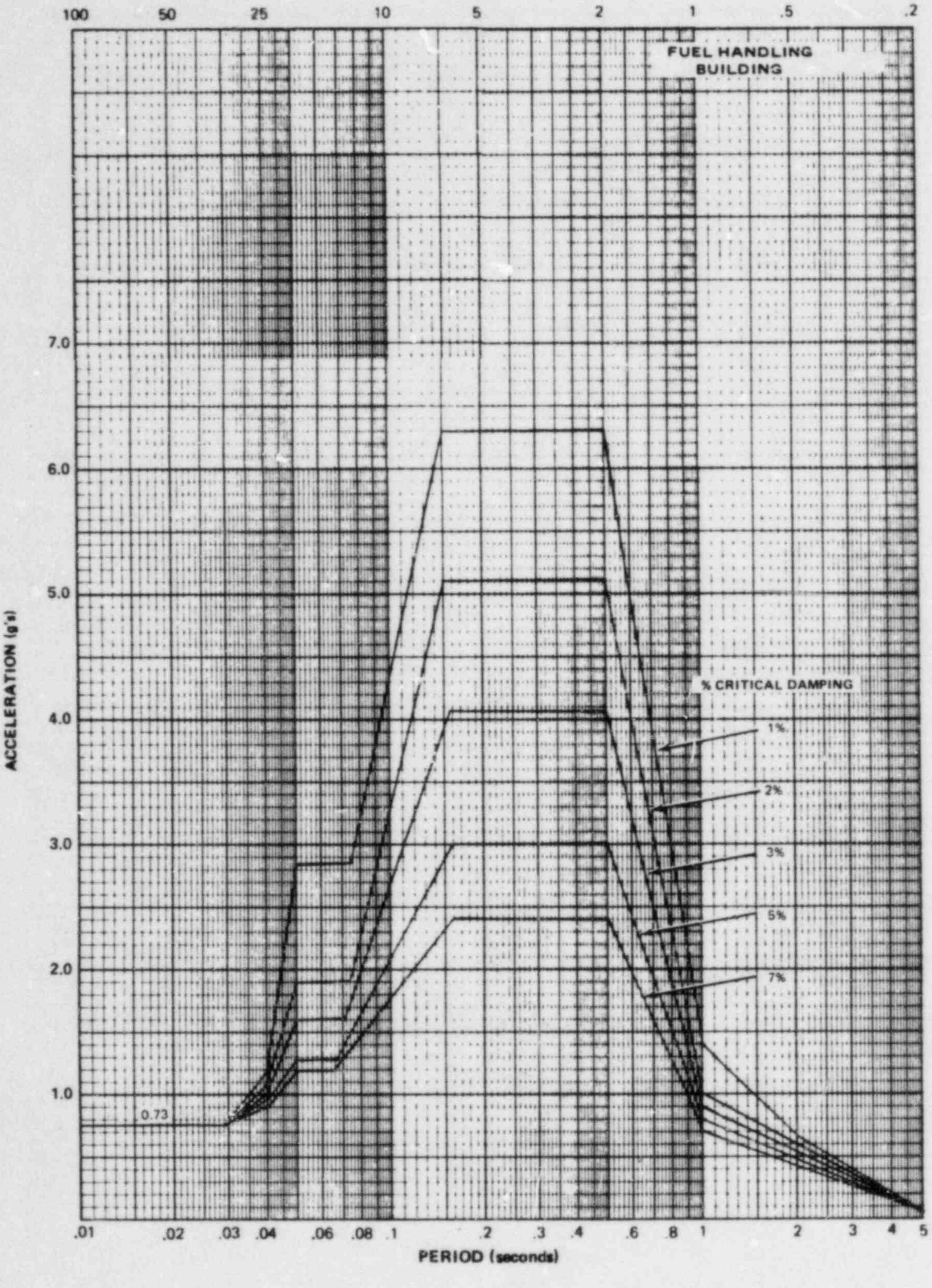

Figure B-59
SAFE SHUTDOWN EARTHQUAKE
HORIZ. ACCEL. RESPONSE SPECTRA
EL. 288 FT. 2 IN.

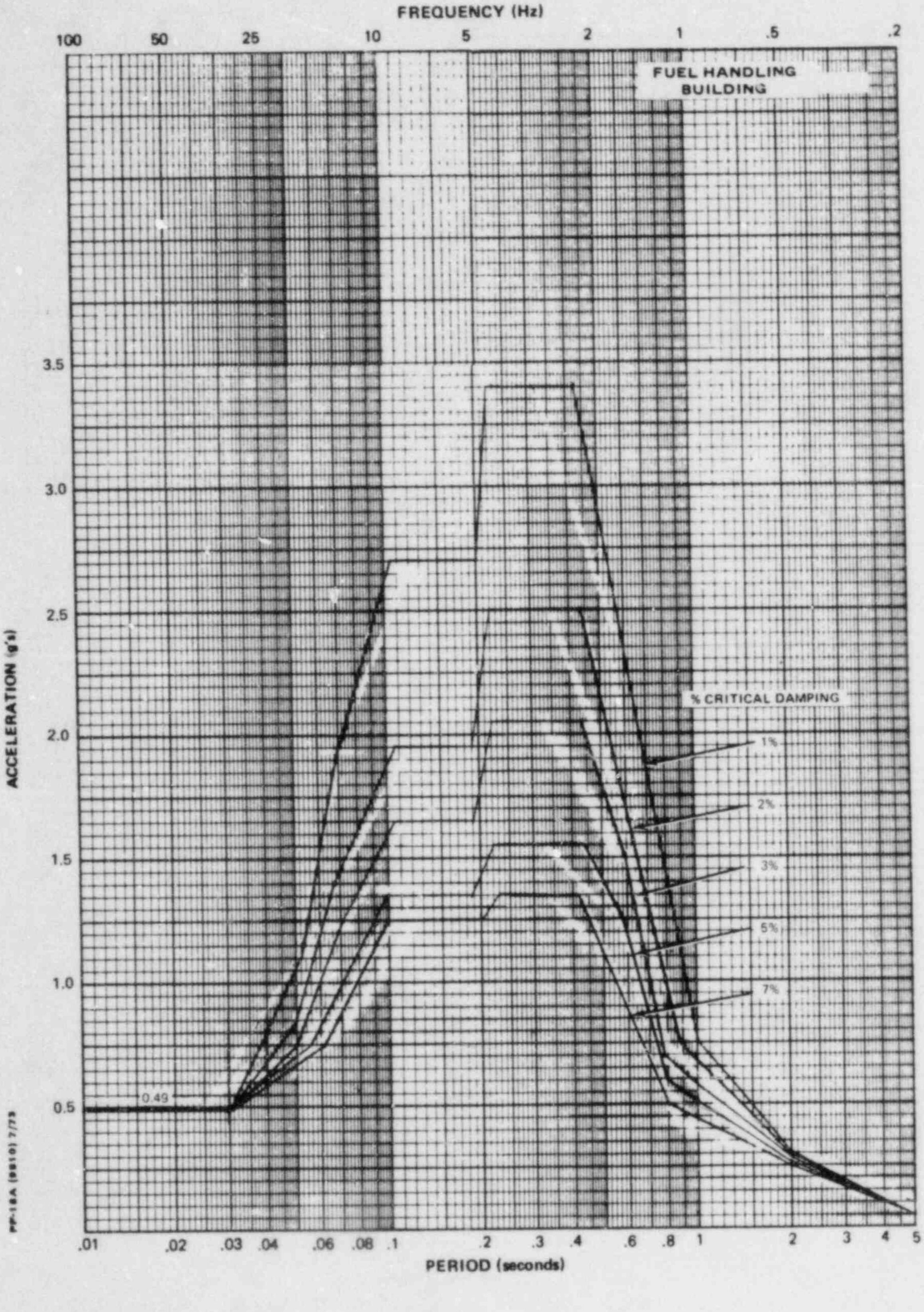

Figure B-60
SAFE SHUTDOWN EARTHQUAKE
VERTICAL ACCEL. RESPONSE SPECTRA
EL. 288 FT. 2 IN.

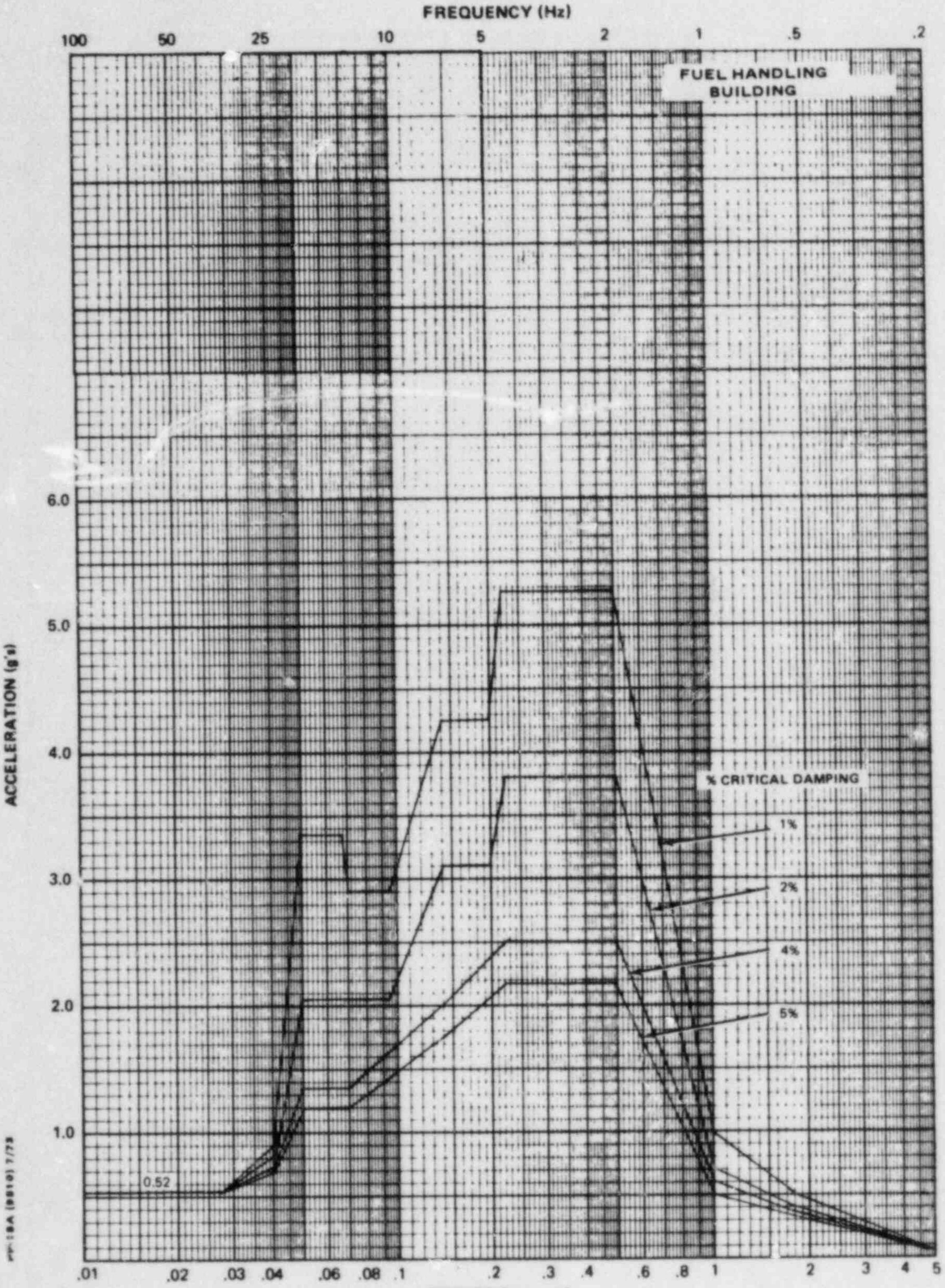

Figure B-61
OPERATING BASIS EARTHQUAKE
HORIZ. ACCEL. RESPONSE SPECTRA
EL. 288 FT. 2 IN.

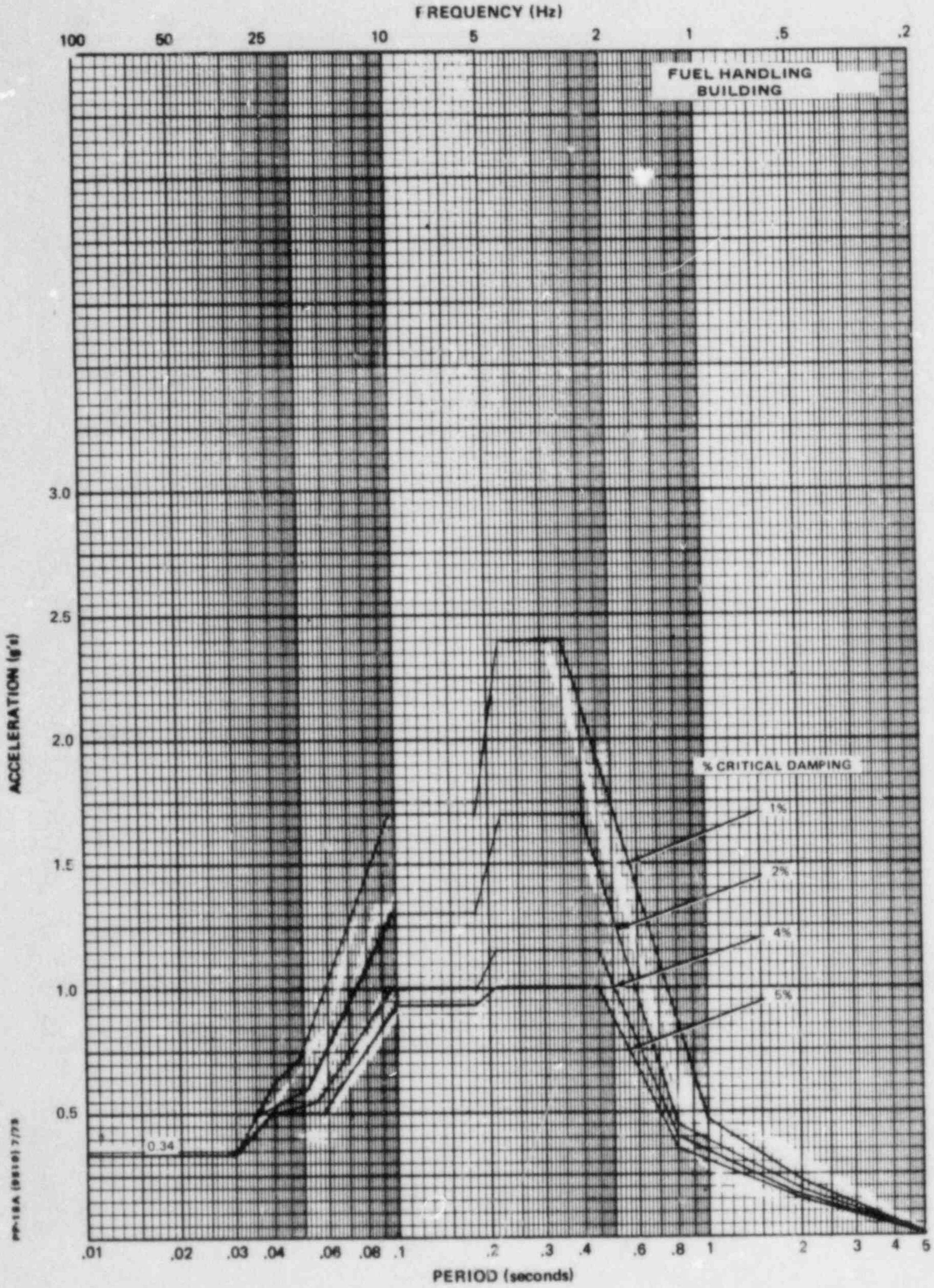

Figure B-62
OPERATING BASIS EARTHQUAKE
VERTICAL ACCEL. RESPONSE SPECTRA
EL. 288 FT. 2 IN.

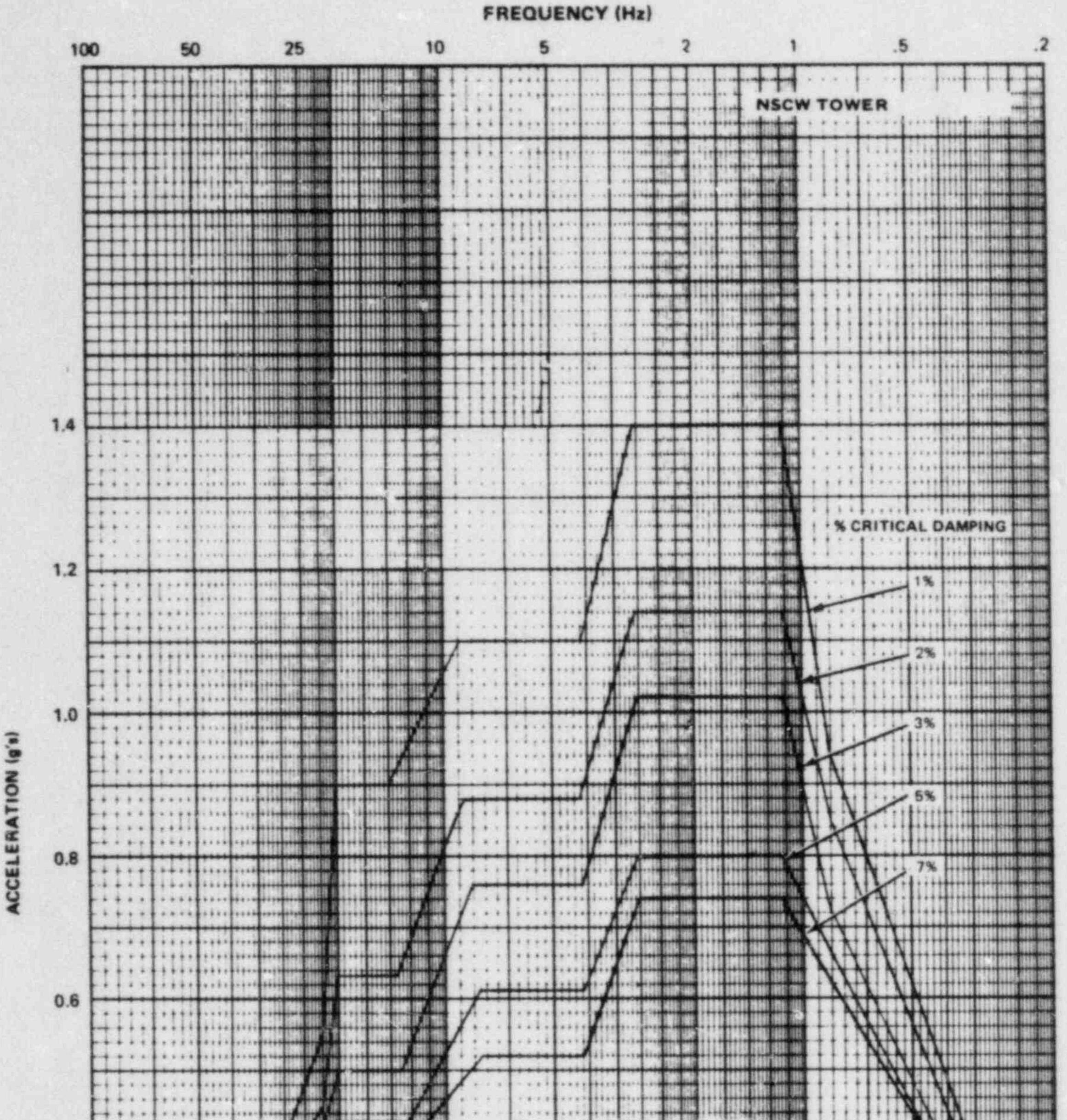

Figure B-63
SAFE SHUTDOWN EARTHQUAKE
HORIZ. ACCEL. RESPONSE SPECTRA
EL. 137 FT. 0 IN.

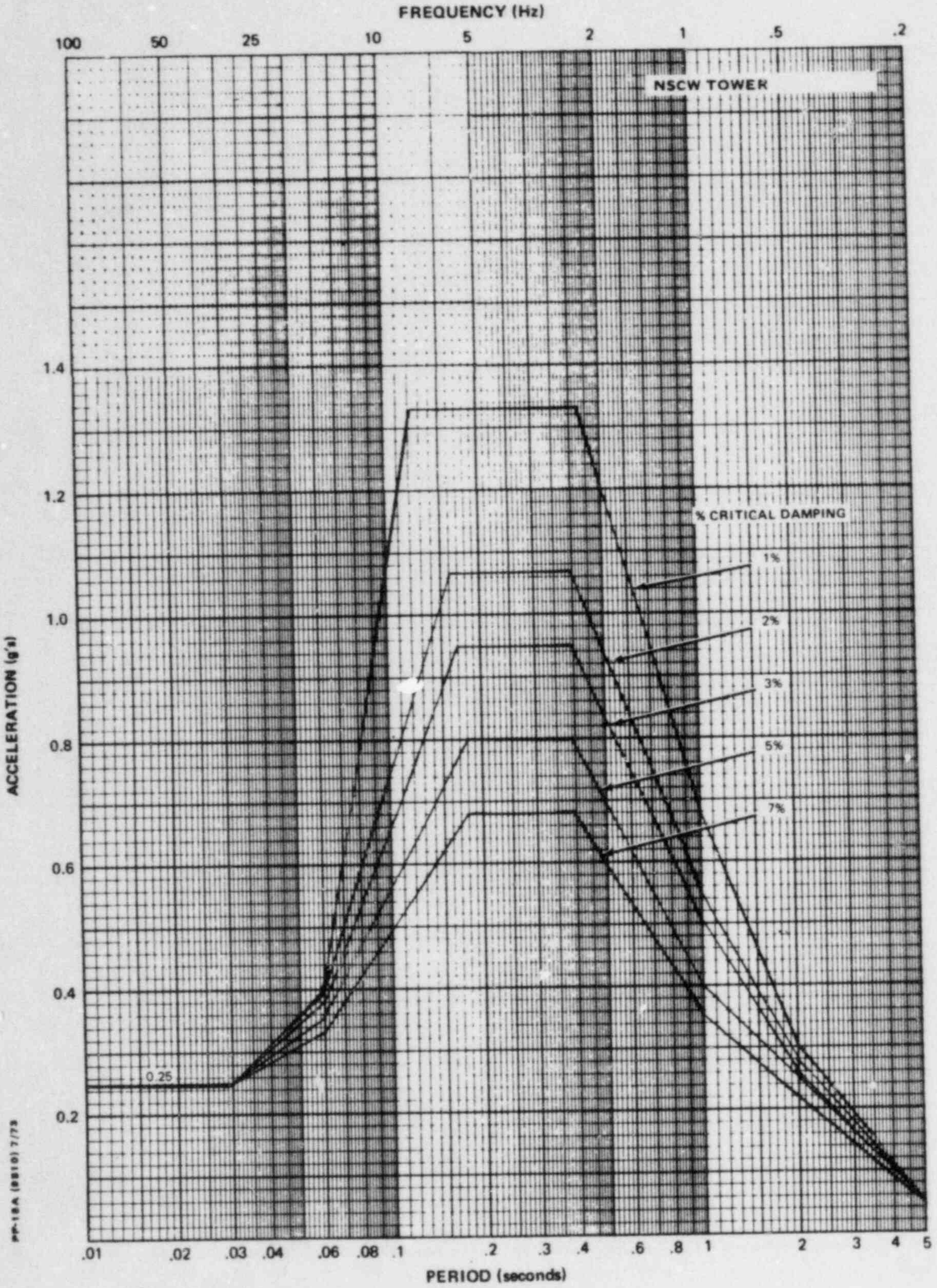

Figure B-64
SAFE SHUTDOWN EARTHQUAKE
VERTICAL ACCEL. RESPONSE SPECTRA
EL. 137 FT. 0 IN.

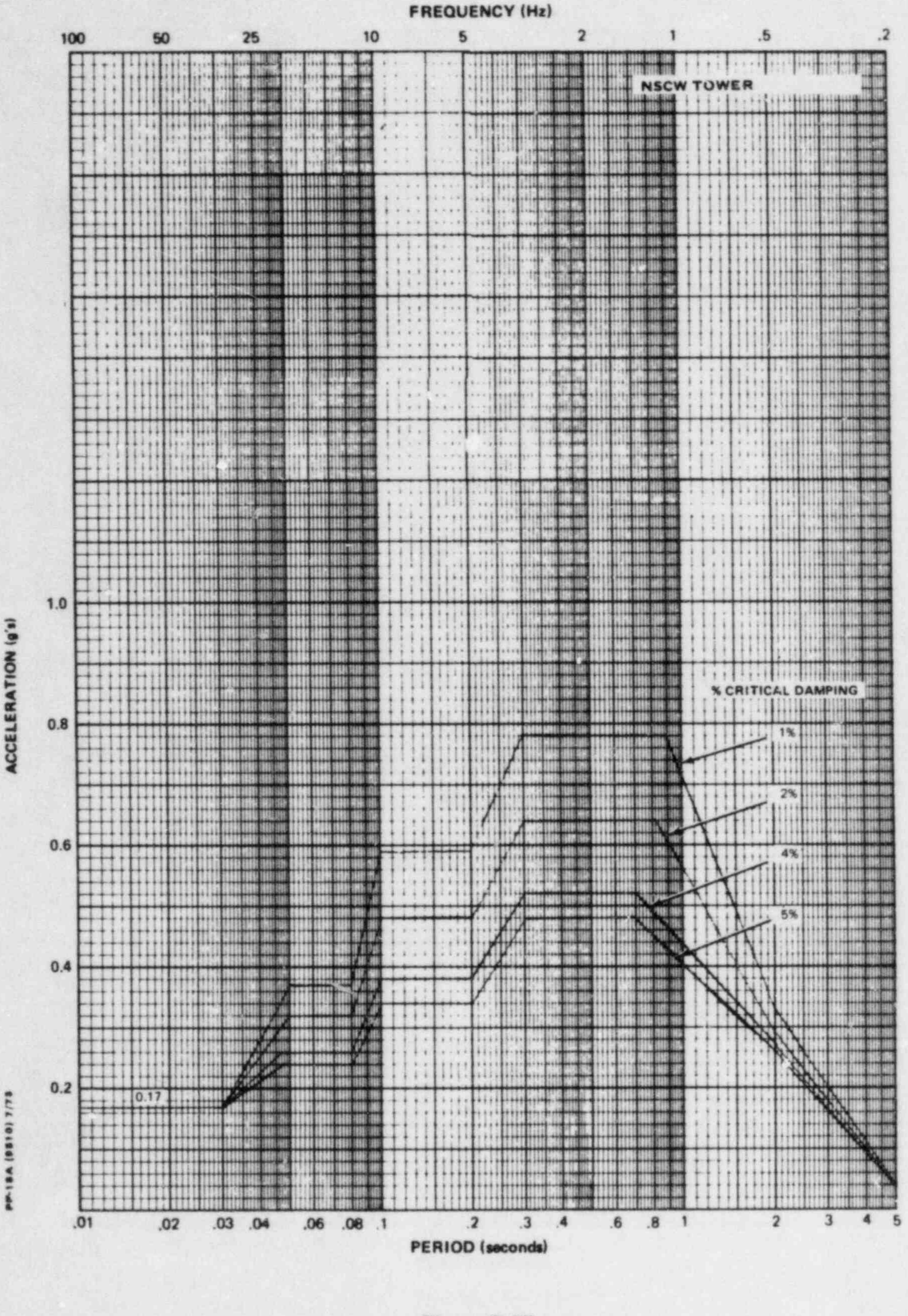

Figure B-65
OPERATING BASIS EARTHQUAKE
HORIZ. ACCEL. RESPONSE SPECTRA
EL. 137 FT. 0 IN.

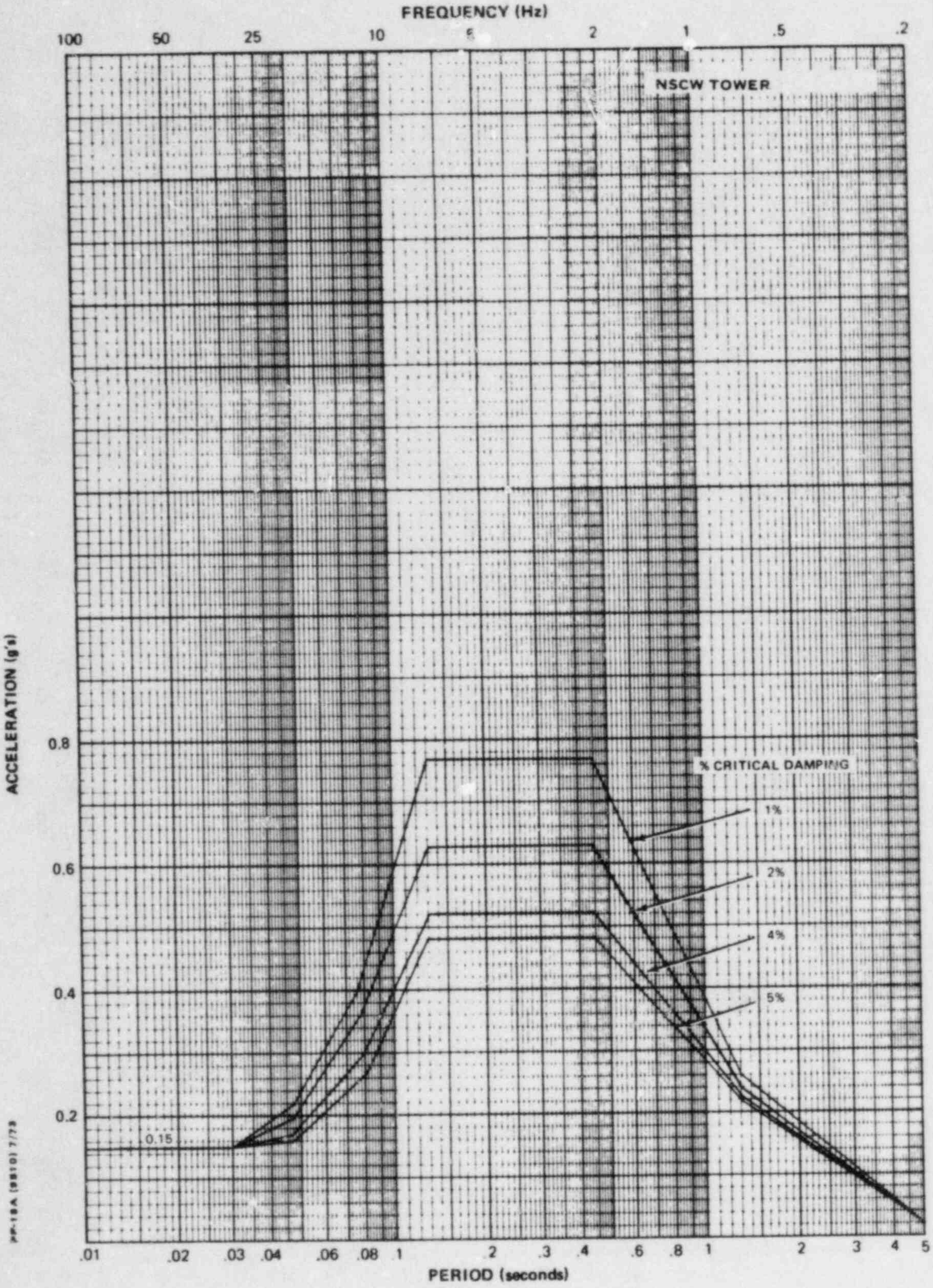

Figure B-66
OPERATING BASIS EARTHQUAKE
VERTICAL ACCEL. RESPONSE SPECTRA
EL. 137 FT. 0 IN.

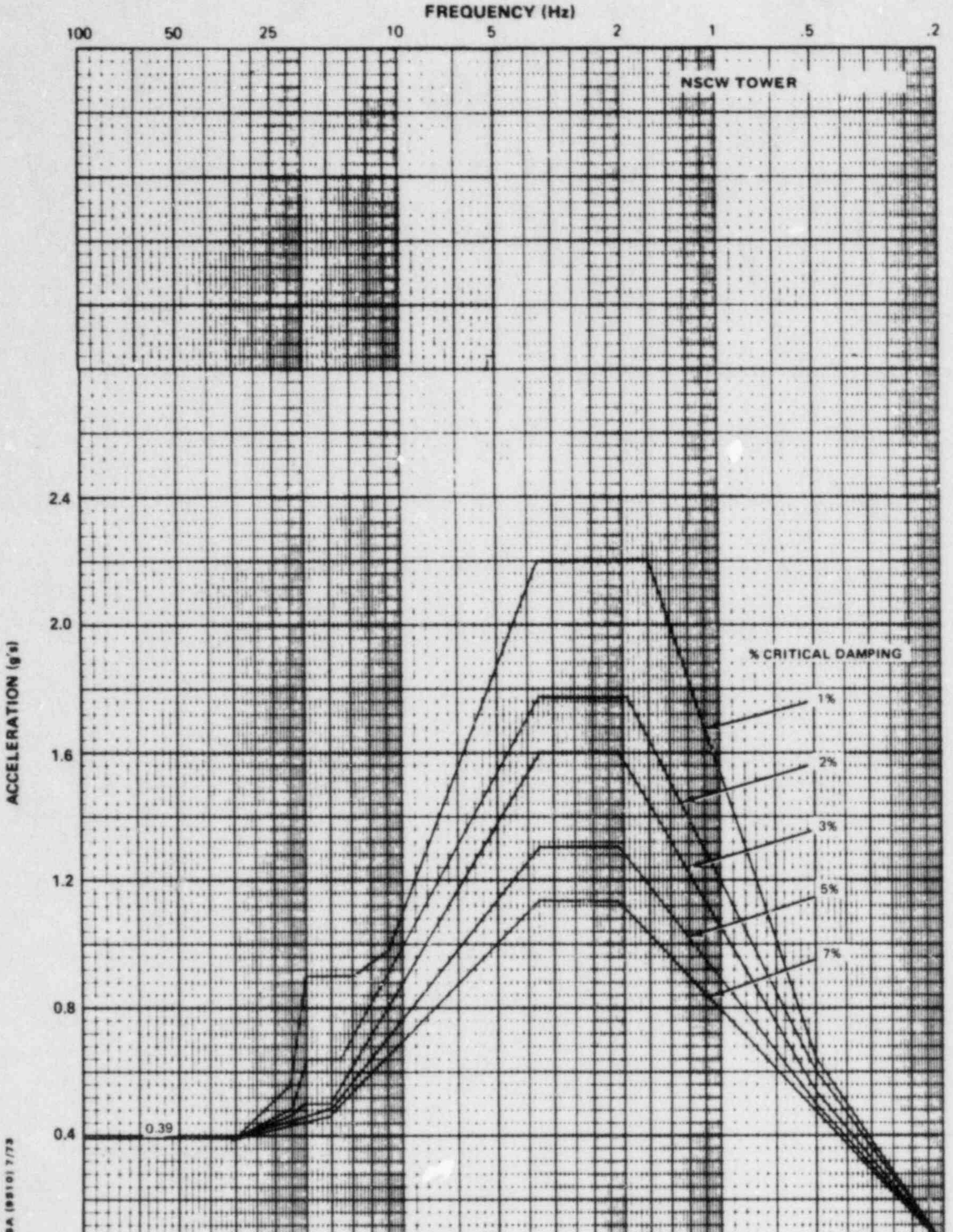

Figure B-67
SAFE SHUTDOWN EARTHQUAKE
HORIZ. ACCEL. RESPONSE SPECTRA
EL. 218 FT. 6 IN.

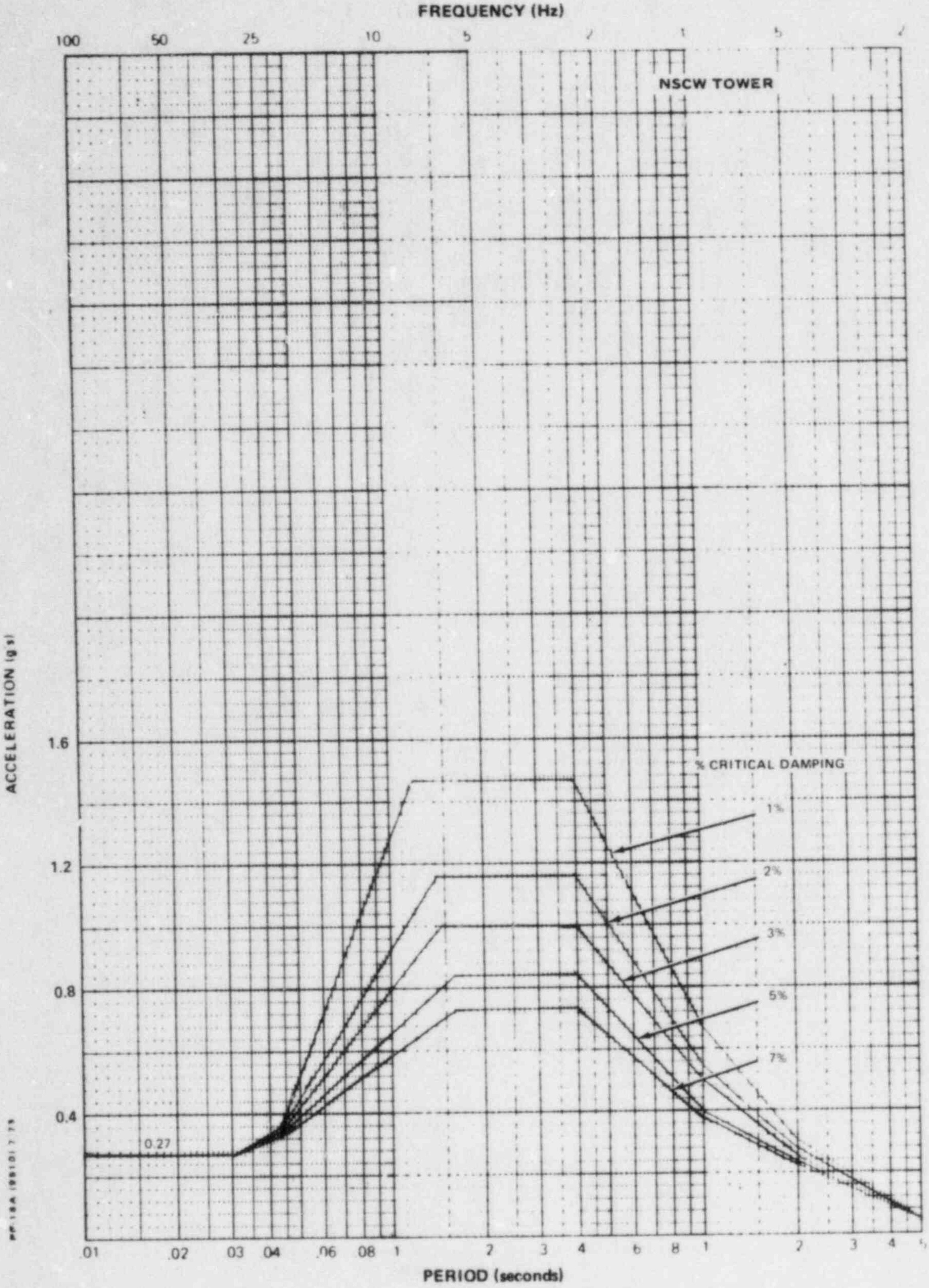

Figure B-68
SAFE SHUTDOWN EARTHQUAKE
VERTICAL ACCEL. RESPONSE SPECTRA
EL. 218 FT. 6 IN.

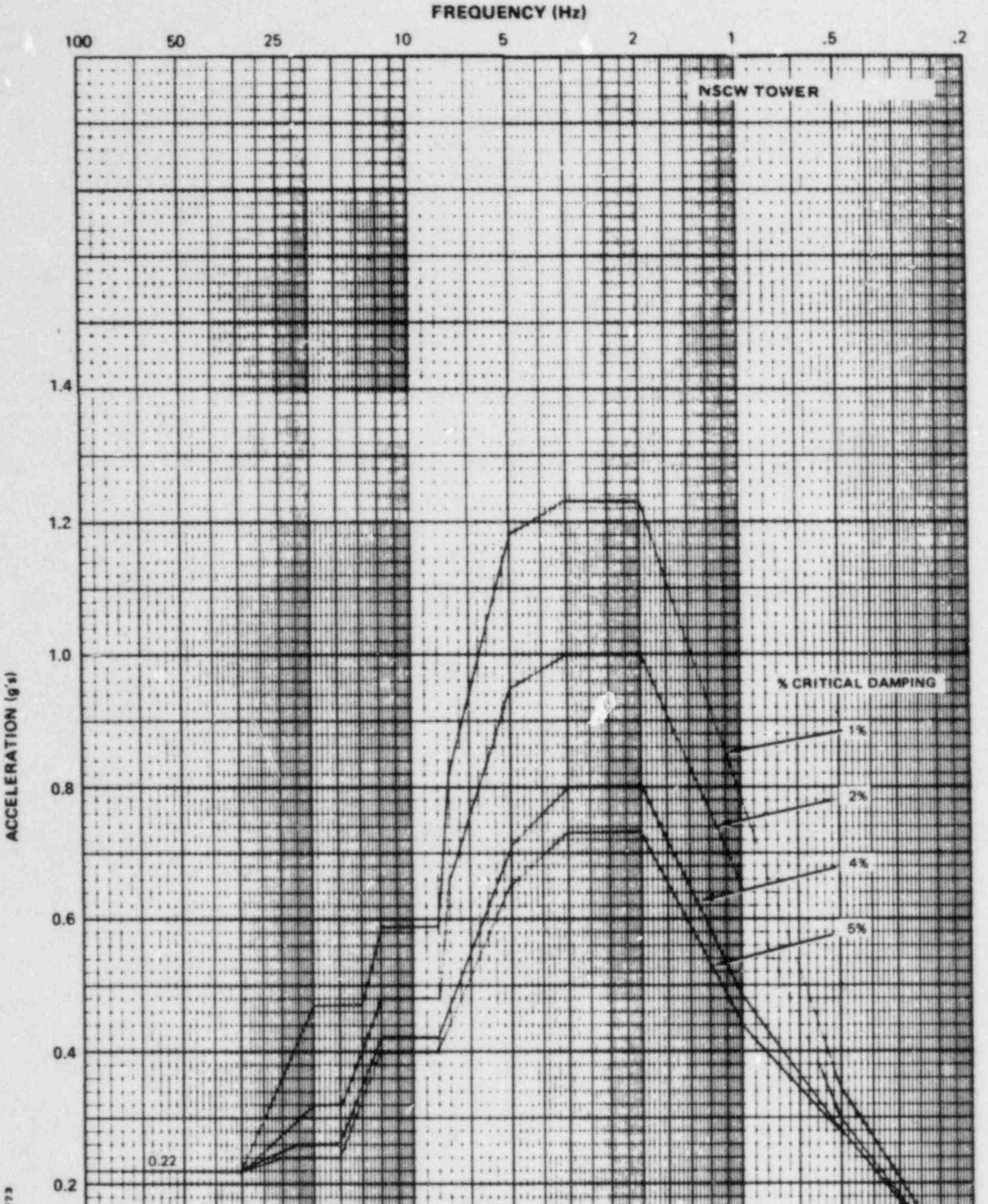

Figure B-69
OPERATING BASIS EARTHQUAKE
HORIZ. ACCEL. RESPONSE SPECTRA
EL. 218 FT. 6 IN.

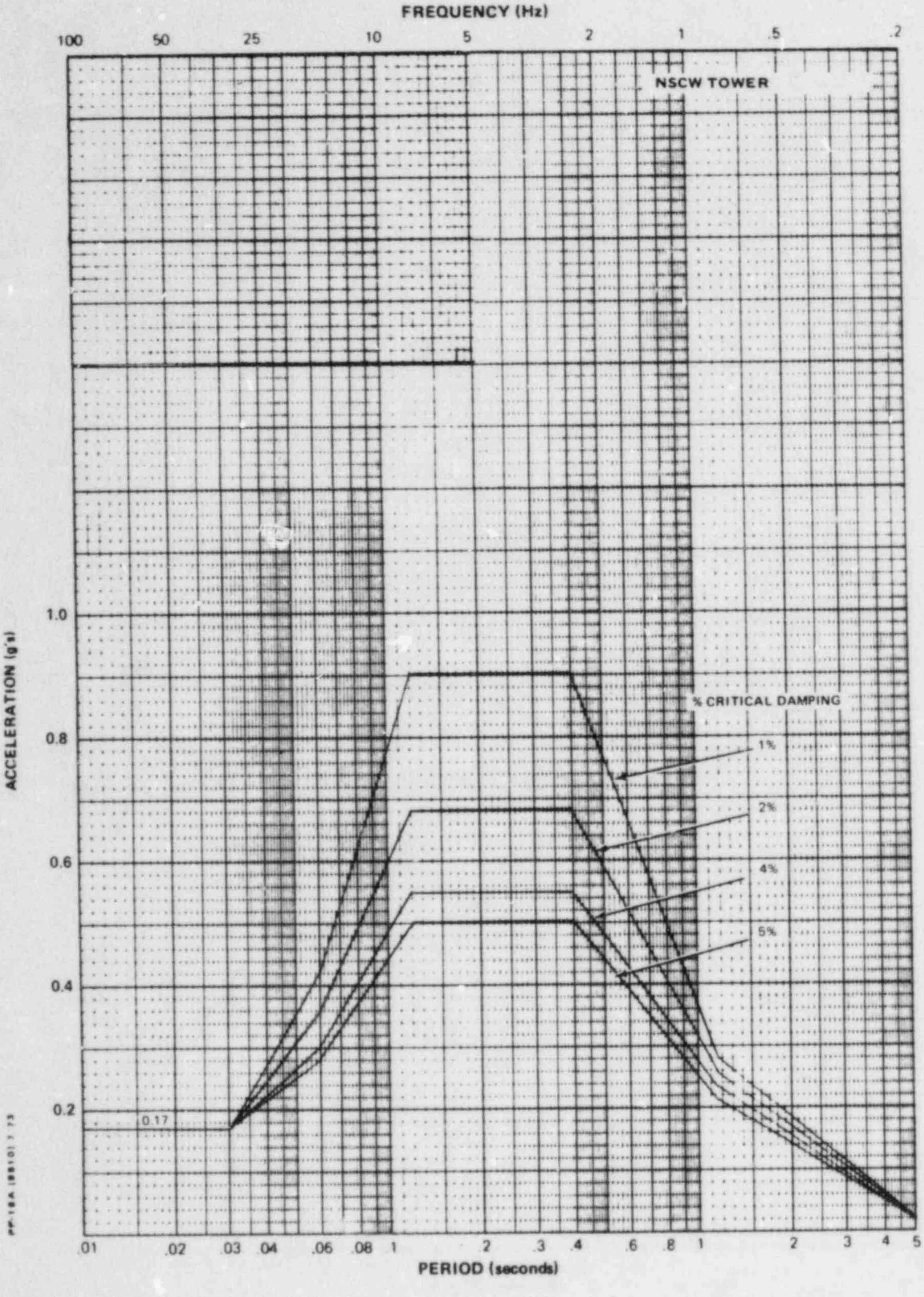

Figure B-70
OPERATING BASIS EARTHQUAKE
VERTICAL ACCEL. RESPONSE SPECTRA
EL. 218 FT. 6 IN.

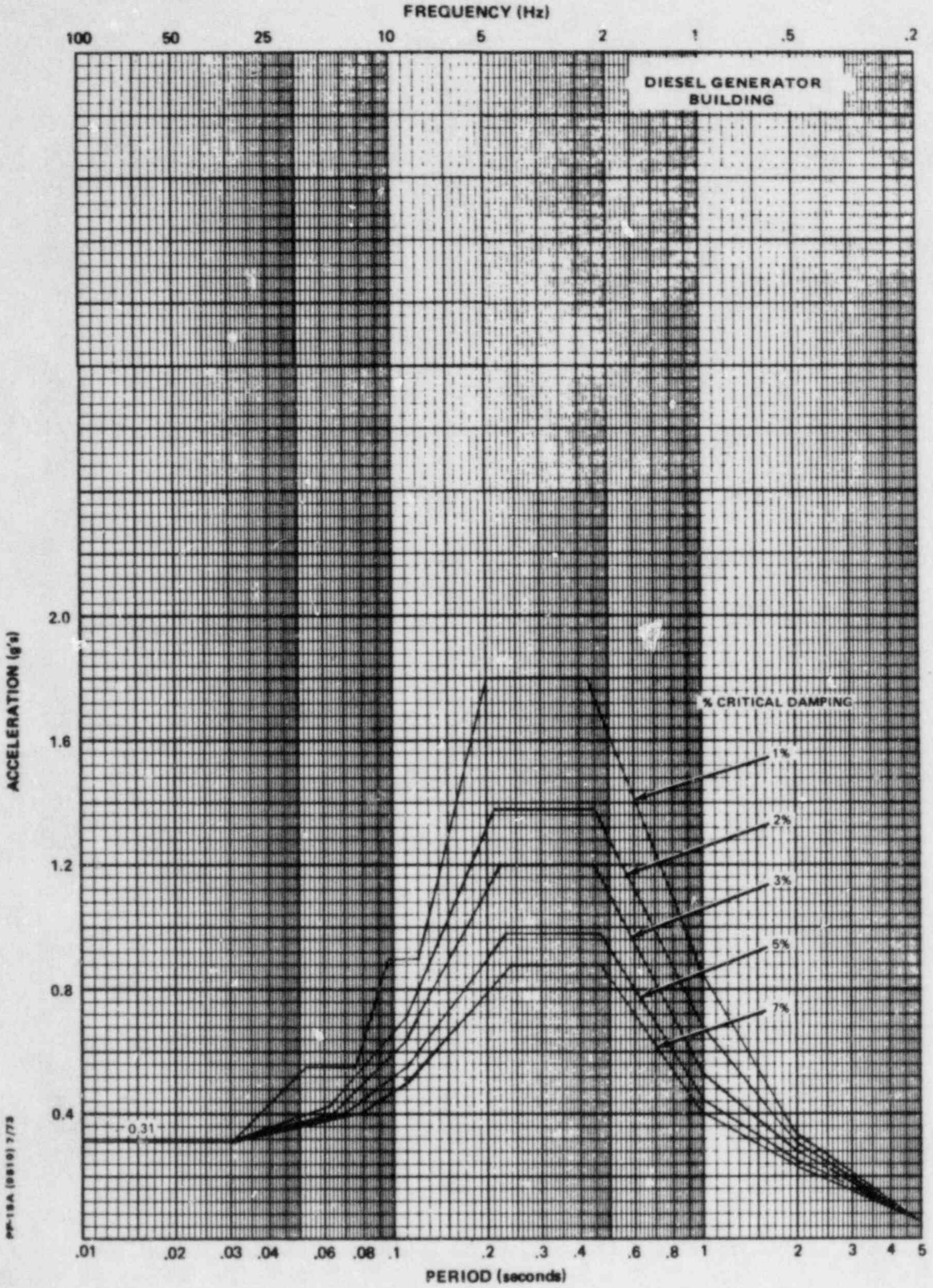

Figure B-71
SAFE SHUTDOWN EARTHQUAKE
HORIZ. ACCEL. RESPONSE SPECTRA
EL. 219 FT. 0 IN.

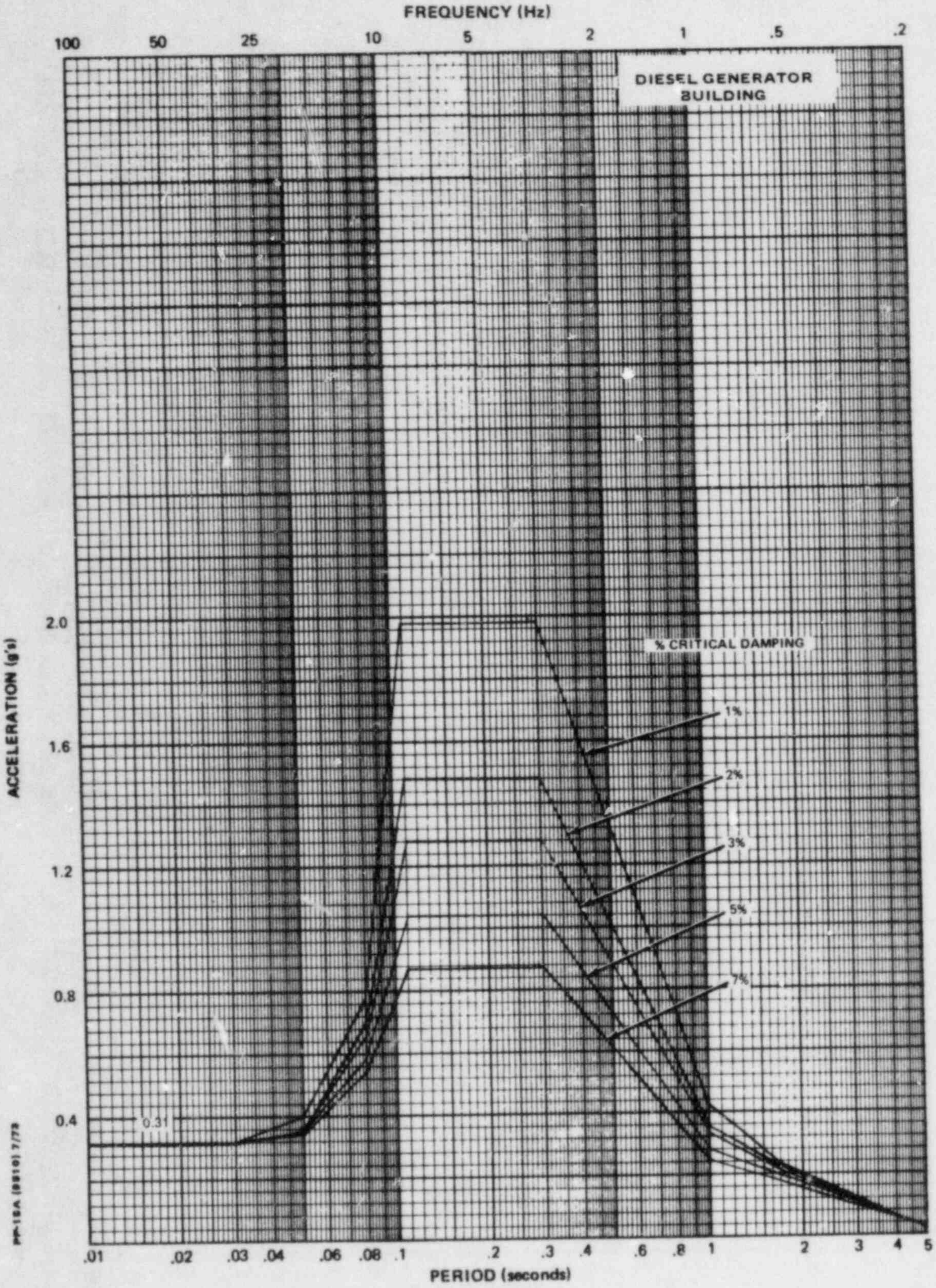

Figure B-72
SAFE SHUTDOWN EARTHQUAKE
VERTICAL ACCEL. RESPONSE SPECTRA
EL. 219 FT. 0 IN.

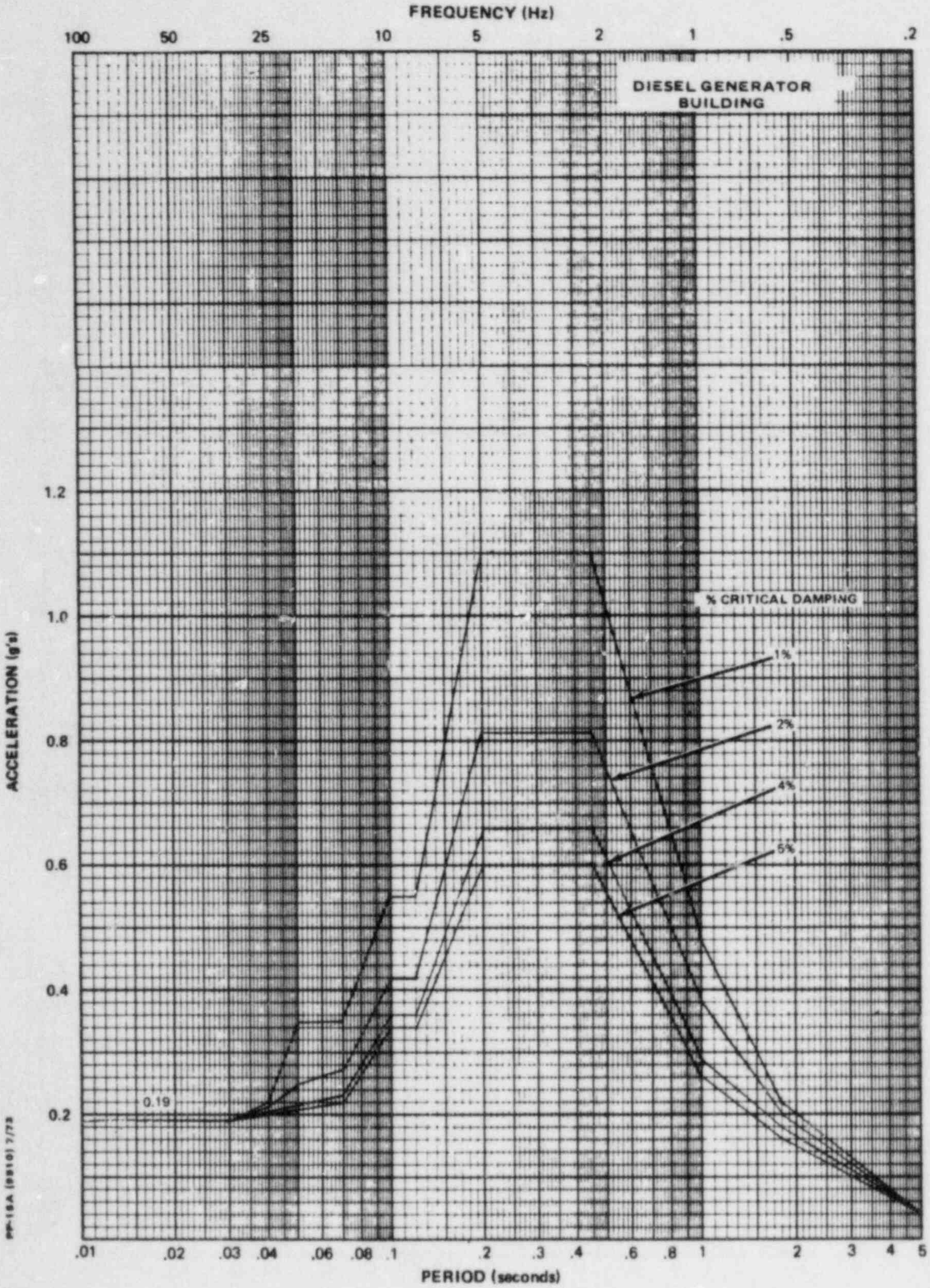

Figure B-73
OPERATING BASIS EARTHQUAKE
HORIZ. ACCEL. RESPONSE SPECTRA
EL. 219 FT. 0 IN.

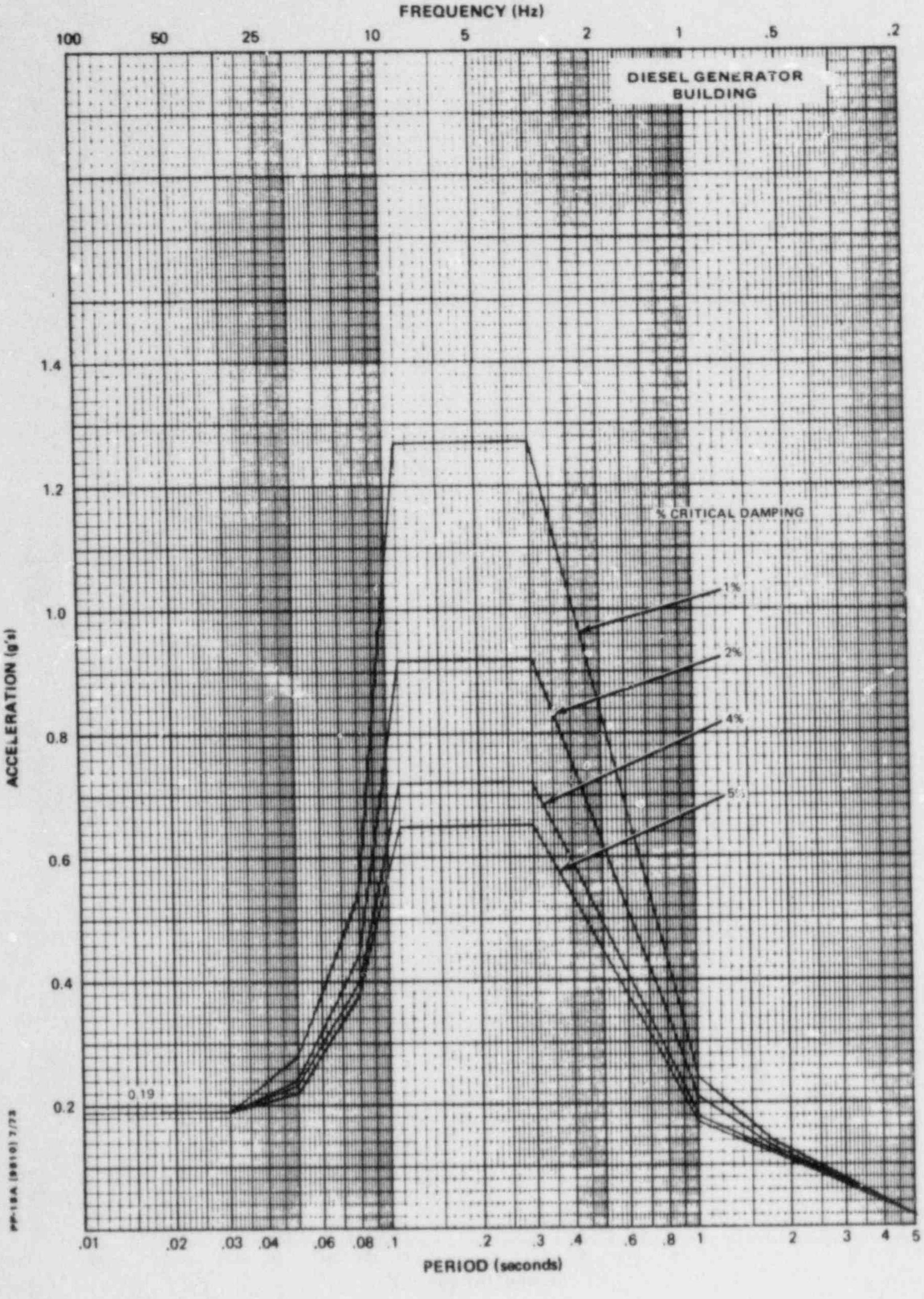

Figure B-74
OPERATING BASIS EARTHQUAKE
VERTICAL ACCEL. RESPONSE SPECTRA
EL. 219 FT. 0 IN.

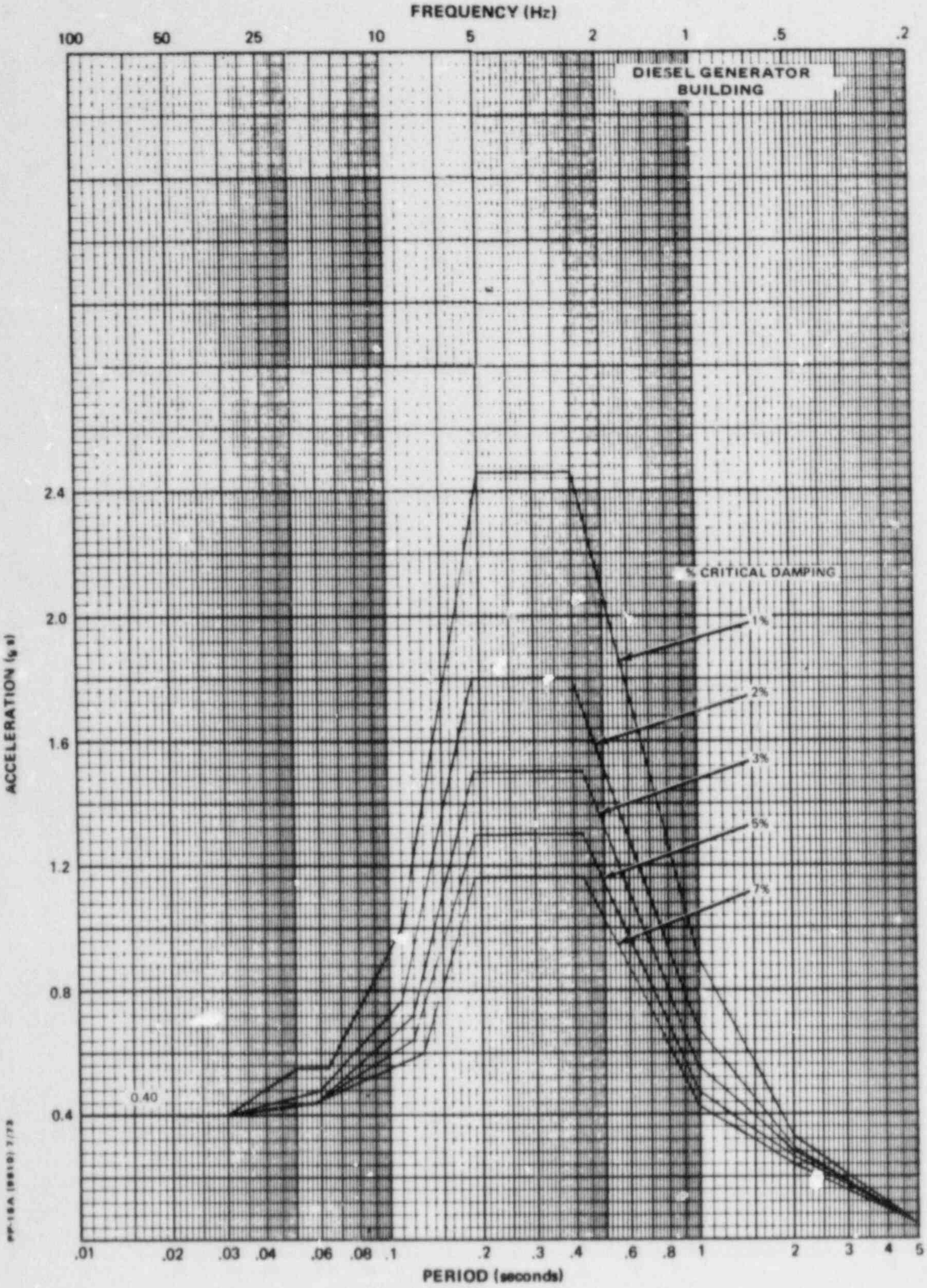

Figure B-75
SAFE SHUTDOWN EARTHQUAKE
HORIZ. ACCEL. RESPONSE SPECTRA
EL. 254 FT. 0 IN. EL. 274 FT. 0 IN.

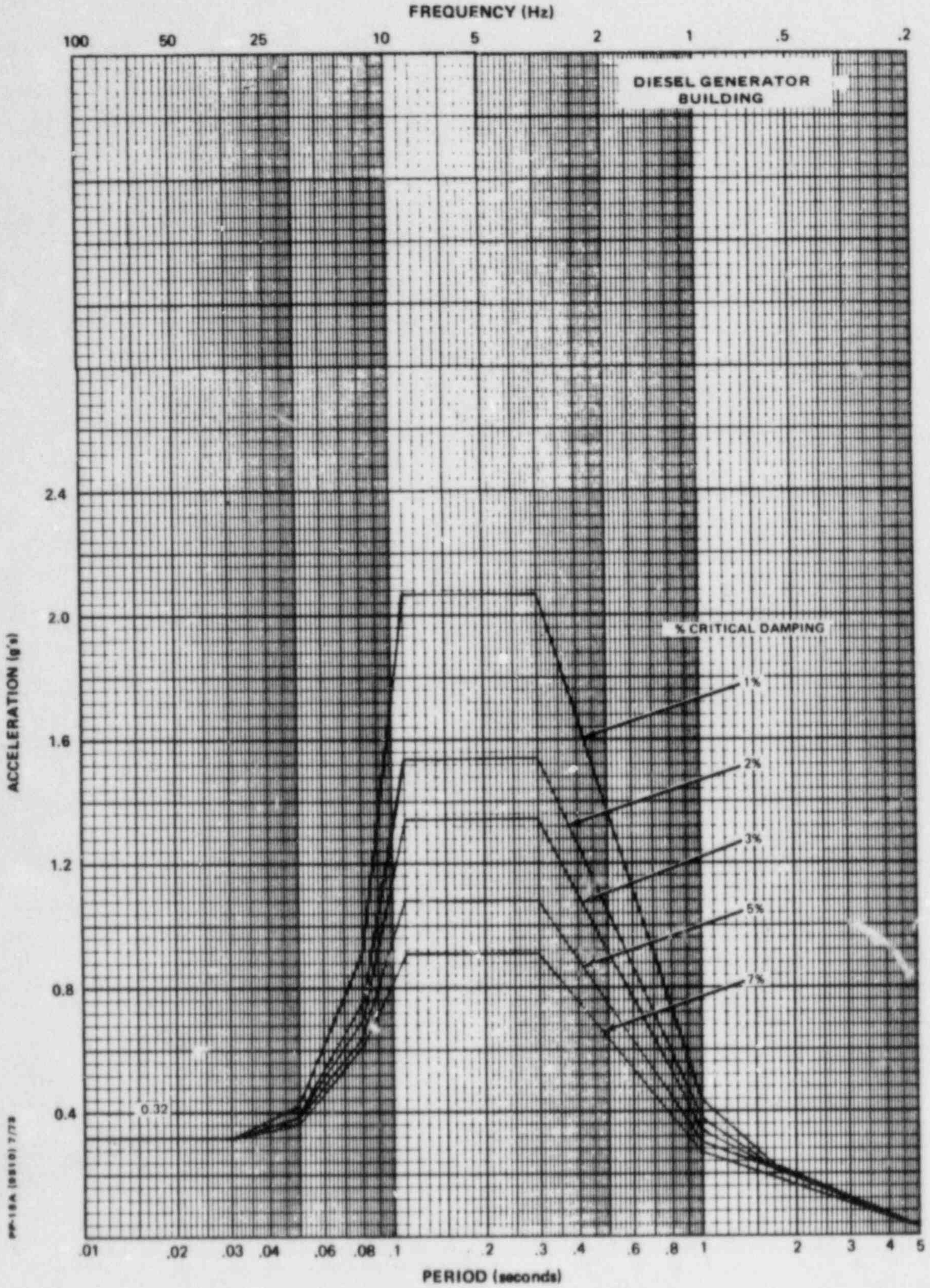

Figure B-76
SAFE SHUTDOWN EARTHQUAKE
VERTICAL ACCEL. RESPONSE SPECTRA
EL. 254 FT. 0 IN. EL. 274 FT. 0 IN.

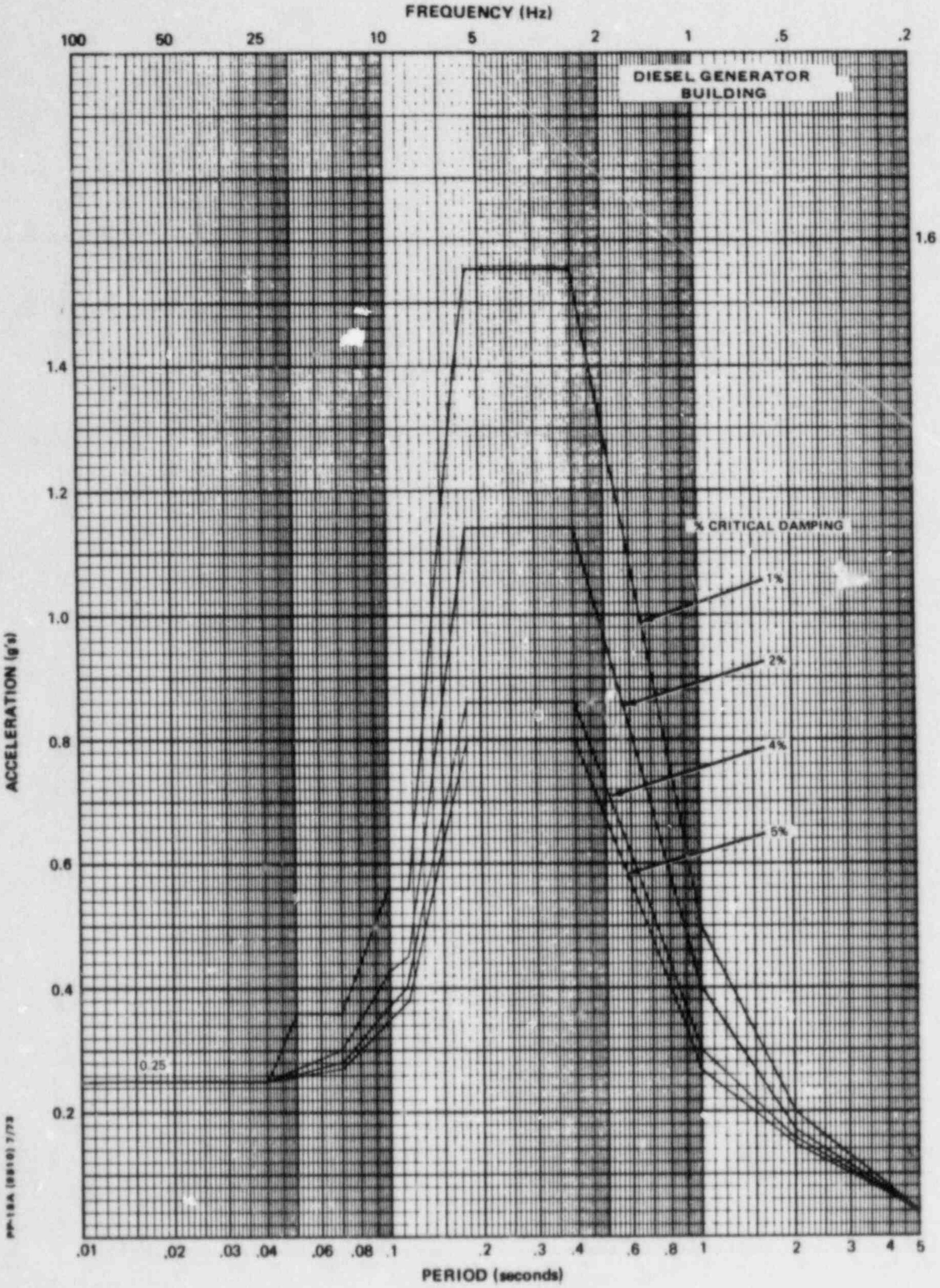

Figure B-77
OPERATING BASIS EARTHQUAKE
HORIZ. ACCEL. RESPONSE SPECTRA
EL. 254 FT. 0 IN. EL. 274 FT. 0 IN.

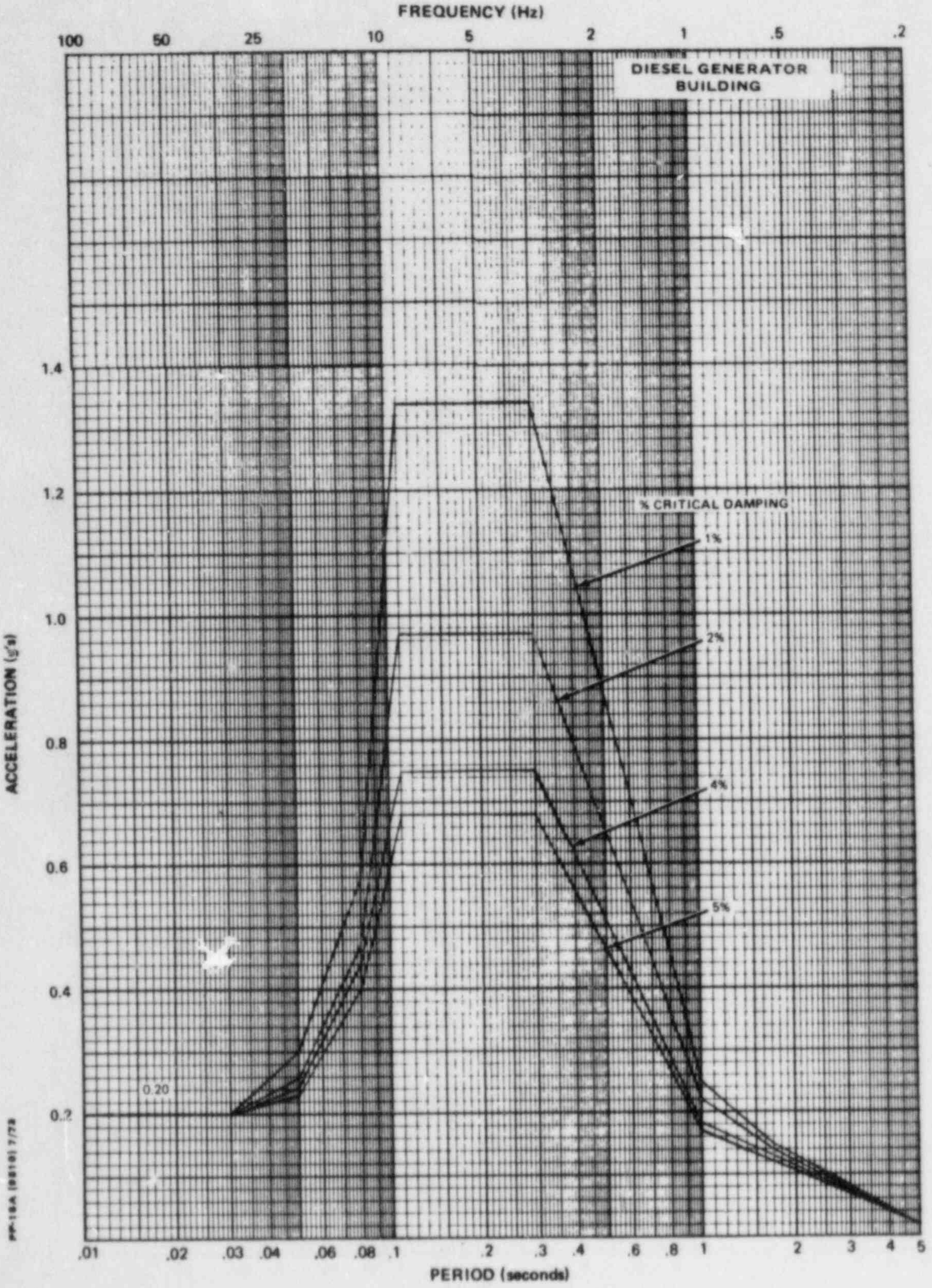

Figure B-78
OPERATING BASIS EARTHQUAKE
VERTICAL ACCEL. RESPONSE SPECTRA
EL. 254 FT. 0 IN. EL. 274 FT. 0 IN.