SUMMARY TABLE OF CONTENTS

CHAPTER 1

GENERAL INFORMATION

TABLE OF CONTENTS

CHAPTER 1

TABLES

CHAPTER 1

FIGURES

CHAPTER 1

GENERAL INFORMATION

1.1 PURPOSE OF REPORT

The purpose of this Design Assessment Report (DAR) is to present evidence that the Limerick Generating Station (LGS) design margins are adequate if the plant should be subjected to the recently defined thermohydrodynamic loads that result from safety relief valve (SRV) operations and/or discharges during a loss-of-coolant accident (LOCA) in a GE boiling water reactor (BWR).

1.2 BACKGROUND

The history of the recently defined Mark II thermohydrodynamic loading issue is based on two distinctive events. First, in April 1972, at the German AEG-Kraftwerk Union Wurgassen Nuclear Plant, a boiling water reactor (BWR) safety relief valve (SRV) was opened during startup testing and failed to close. The reactor remained at full pressure, and the valve discharged reactor steam into the containment suppression chamber until the suppression pool water heated from just above ambient to almost 170°C (in approximately 30 minutes). Pulsating condensation developed and large impulsive forces with substantial underpressure amplitudes acted upon the containment, eventually causing leakage from the bottom liner plate. Therefore, concern was expressed that the structural integrity of other BWR pressure containment systems could be sensitive to SRV induced dynamic loads. The Nuclear Regulatory Commission (NRC) issued Bulletin 74-14 to all BWR owners on November 14, 1974, to alert them to the potential problems of condensation instability (Wurgassen effect) due to SRV operation. The NRC requested verification that BWR suppression pools had been designed to withstand loads similar to those being experienced.

Secondly, in January 1975, the General Electric - Nuclear Energy Program Division (GE-NEPD) identified the dynamic loading conditions due to loss-of-coolant accident (LOCA) hydrodynamic phenomena that result from vent clearing and poolswell. These loads had not been fully considered in the design criteria of Mark II BWR containments.

It became evident that a complex technical issue existed for all Mark II plants. Philadelphia Electric took part in the formation of a unified utility group to address the matter. A Mark II BWR containment owners group was formed in June 1975 to define the suppression pool dynamic loads and to explore ways to assess their impact. As the direct result of action taken by the Mark II containment owners organization, a generic Dynamic Forcing Function Information Report (DFFR) was issued jointly by GE-NEPD and Sargent and Lundy for the Mark II owners in September 1975 (Section 1.3).

1.3 MARK II CONTAINMENT PROGRAM

Philadephia Electric is a member of the Mark II owners group that was formed in June 1975 to define and investigate the dynamic loads due to SRV discharge and LOCA. The methods for calculating these hydrodynamic loads are described in the DFFR (Reference 1.3-1). The DFFR also specifies load combinations for plant design assessment. The methods provided in the DFFR are based on a combination of analytical models, test data, and engineering judgment. The methods and information provided are sufficient for use in a conservative evaluation of the design adequacy of Mark II structures and components.

The Mark II Owners Group Containment Program concentrated initially on the tasks required for the licensing of the lead plants (Zimmer, LaSalle, and Shoreham). This Lead-Plant Program established interim bounding loads appropriate for the anticipated life of each of the lead plants. The NRC acceptance criteria for the lead plant LOCA and SRV load definitions are described in NUREG 0487 (Reference 1.3-2) and NUREG 0487 Supplements 1 and 2 (References 1.3-3 and 1.3-4, respectively).

The remainder of the Mark II Owners Group Program concentrated on the tasks required to license the long-term plants, which include LGS. The NRC acceptance criteria for the long-term plant LOCA and SRV load definitions are described in NUREG 0808 (Reference 1.3-5) and NUREG 0802 (Reference 1.3-6), respectively. The objectives of the Long-Term Program were (a) to provide justification, by tests and analyses, for refinement of selected lead-plant bounding loads, and (b) to provide additional confirmation of certain loads used in the Lead-Plant Program.

As a task separate from the Mark II Owners Group Program, a Mark II SRV discharge line T-quencher device and load specification was developed in 1978 by Kraftwerk Union (KWU) for Pennsylvania Power and Light (PP&L) for use in the Susquehanna Steam Electric Station (SSES). The T-quencher provides a reduction in the containment wall loads as compared to the loads generated by the original Ramshead quencher design. The T-quencher also promotes effective heat transfer and condensation of discharge steam in the suppression pool. Philadelphia Electric Company decided to use the same T-quencher design for LGS. Following this decision, KWU compared the LGS and SSES SRV-related parameters and concluded that the same T-quencher load specification could be used by Philadelphia Electric for the LGS containment analysis. The LGS and SSES SRV-related parameters are compared in Table 4.1-1.

The quencher load specification was submitted to the NRC by PP&L in April 1978. In addition, a full-scale SSES-unique unit cell test (Chapter 8) was performed by KWU in 1979. This test verifies KWU's design approach for the quencher load specification used for LGS.

Table 1.3-1 provides a summary of the LGS licensing basis as a result of the Mark II Containment Program.

Table 1.3-2 presents a summarizing review of the LGS suppression pool dynamic loadings. This is achieved by comparing the NRC Acceptance Criteria with the LGS plant-unique position.

1.3.1 REFERENCES

1.3-1 "Mark II Containment Dynamic Forcing Function Information Report", NEDO-21061, Revision 4, General Electric Co., November 1981.

1.3-2 "Mark II Containment Lead Plant Program Load Evaluation and Acceptance Criteria", NUREG-0487, NRC, October 1978.

1.3-3 "Mark II Containment Lead Plant Program Load Evaluation and Acceptance Criteria", NUREG-0487, Supplement 1, NRC, September 1980.

1.3-4 "Mark II Containment Lead Plant Program Load Evaluation and Acceptance Criteria", NUREG-0487, Supplement 2, NRC, February 1981.

1.3-5 "Mark II Containment Program Load Evaluation and Acceptance Criteria", NUREG-0808, NRC, August 1981.

1.3-6 "Safety/Relief Valve - Quencher Loads Evaluation Reports - BWR Mark II and III Containments", NUREG-0802 (draft), NRC, November 1981.

I. MARK II GENERIC PROGRAM

A. LOCA-RELATED TASKS

TASK NUMBER	ACTIVITY	ACTIVITY TY
A.1	"4T" PROGRAM	Phase I Tes
		Phase I Ap Memorandu
		Phase II & Report
		Applicatior
A.2	POOLSWELL MODEL REPORT	Model Repo
A.3	IMPACT TESTS	PSTF 1/3 Sc
		Mark I 1/1
A.4	IMPACT MODEL	PSTF 1/3 S
		Mark I 1/1
A.5	LOADS ON SUBMERGED STRUCTURES	LOCA/RH Ai
		LOCA/RH Wa
		Applicatio
		1/4 Scalin
A.5.5	RING VORTEX MODEL, PHASE I	Model Deve
A.5.7	RING VORTEX MODEL, PHASE II	Model Exte Steam Cond Methods
A.6	CHUGGING ANALYSIS AND TESTING	Single Cel
		Multivent
		4T FSI Rep

PE	DOCUMENTATION	DOC DATE	USED FOR LGS LICENSING
t Report	NEDE-13442-01-P	5/76	Yes
	NEDO-13442-01	6/76	Yes
plication m	Application Memorandum	6/76	Yes
III Test	NEDE-13468-P	12/76	Yes
	NEDO-13468	3/77	Yes
Memorandum	NEDE-23678-P	1/77	Yes
	NEDO-23678	1/77	Yes
t	NEDE-21544-P	12/76	Yes
	NEDO-21544	2/77	Yes
ale Tests	NEDE-13426-P	8/75	Yes
	NEDO-13426	8/75	Yes
Scale Tests	NEDC-20989-2P	9/75	No
	NEDO-20989-2	9/75	No
ale Tests	NEDE-13426-P	8/75	Yes
	NEDO-13426	8/75	Yes
Scale Tests	NEDC-20989-2P	9/75	No
	NEDO-20989-2	9/75	No
Bubble Model	NEDE-21471-P	9/77	No
	NEDO-21471	9/77	No
ter Jet Model	NEDE-21472-P	9/77	Yes
	NEDO-21472	9/77	Yes
ns Memorandum	NEDE-21730-P	12/77	Yes
	NEDO-21730	7/78	Yes
Tests	NEDE-23817-P	9/78	No
lopment	Letter Report	5/79	No
nsion ensation	Burns & Roe Proprietary Report, Plant DAR's	9/80	No
	Burns & Roe Non-Proprietary Report	9/80	No
Report	NEDE-23703-P	9/77	Yes
	NEDO-23703	9/77	Yes
Model	NEDC-21669-P	2/78	Yes
	NEDO-21669	2/78	Yes
ort	NEDE-23710-P	4/78	Yes
	NEDO-23710	9/78	Yes

TABLE 1.3-1

TASK NUMBER	ACTIVITY	ACTIVITY TYPE
A.7	CHUGGING SINGLE VENT	CREARE Report
A.9	ERPI TEST EVALUATION	EPRI-4T Compar
-	EPRI 1/13 SCALE TESTS	3D Tests
-	EPRI SINGLE CELL TESTS	Unit Cell Test
A.11	MULTIVENT SUBSCALE TESTING AND ANALYSIS	Preliminary MV Plan
		MV Test Progra Procedures -
		Phase I Test R
		MV Test Progre Procedures -
		Phase II Test
		CONMAP Tests
		MHM Verificati 1/10 Scale
		Scaling and Da Correlation
A.13	SINGLE VENT LATERAL LOADS	Dynamic Analys
		Summary Repor
		Responses to
A.13	NEW LATERAL LOADS	Dynamic Analys
		Method for Mu Application
A.16	IMPROVED CHUGGING LOAD DEFINITION	Impulse Evalu Improved Chug
A.17	CONDENSATION OSCILLATION TESTING, ANALYSIS AND IMPROVED CO LOAD DEFINITION	4TCO Test
		Improved CO L Definition

	DOCUMENTATION	DOC DATE	USED FOR LGS LICENSING
	NEDE-21851-P	6/78	Yes
	NEDO-21851	6/78	Yes
ison	NEDO-21667	8/77	Yes
	EPRI NP-441	4/77	Yes
s	EPRI NP-1353	3/80	Yes
Program	NEDO-23697	12/77	Yes
m Plan & Phase I	NEDO-23697A, Rev. 1	1/79	Yes
eport	NEDE-24781-1-P	1/80	Yes
ss Plan & Phase II	NEDO-23697A, Rev. 1, Supp. 1	8/79	Yes
Report	NEDE-25289-1-P	8/80	Yes
	NEDO-25289-1	11/80	Yes
	CREARE Report TN-297	6/79	Yes
on			
	NEDE-25116-P	5/79	Yes
	NEDO-25116	8/79	Yes
ta	NEDE-24300-P	4/81	Yes
	NEDO-24300	7/81	Yes
sis	NEDE-24106-P	3/78	Yes
	NEDO-24106	3/78	Yes
t	NEDE-23806-P	10/78	Yes
	NEDO-23806	12/78	Yes
RC Questions	Letter Report	1/81	Yes
sis Report	NEDE-24794-P	3/80	Yes
	NEDE-24794-P Errata	9/80	Yes
	NEDO-24794	3/80	Yes
ltiple Vent	Letter Report	4/80	Yes
ation	Letter Report	6/78	No
Load	NEDE-24822-P	5/80	Yes
	NEDE-24822-P Errata	8/80	Yes
	NEDO-24822	6/80	Yes
	NEDO-24822 Errata	8/80	Yes
	NEDE-24811-P	5/80	Yes
	NEDE-24811-P Errata	9/80	Yes
	NEDO-24811	7/80	Yes
	NEDO-24811 Errata	9/80	Yes
oad	NEDE-24288-P	11/80	Yes
	NEDO-24288	2/81	Yes

TABLE 1.

TASK NUMBER	ACTIVITY	ACTIVITY T
A.22	A.16 SOURCE EVALUATION	Confirm/Re Based on 4TCO Chugg key runs
B.	SRV - RELATED TASKS	
B.1	QUENCHER EMPIRICAL MODEL	DFFR Model Supporting
B.2	RAMSHEAD MODEL	DFFR MODEL Supporting Analysis
B.3	MONTICELLO IN-PLANT SRV TESTS	Preliminar Hydrodynam
B.5	SRV QUENCHER IN-PLANT CAORSO TESTS	Test Plant Test Plan Test Plan Test Summa
	Phase I	Test Repor
	Phase II	Test Repor
	Re-evaluate	AMN Report
B.5.1	EXTENDED BLOWDOWN	Test Repor
B.6	THERMAL MIXING MODEL	Analytical
B.10	MONTICELLO FSI	Analysis
B.11	DFFR RAMSHEAD MODEL TO MONTICELLO DATA	Data/Mode

PE	DOCUMENTATION	DOC DATE	USED FOR LGS LICENSING
ise Source 4TCO Data	NEDE-24302-P	4/81	Yes
ng Data - Six	NEDE-24285-P	1/81	Yes
	NEDO-24285		Yes
	NEDE-21061-P	9/76	No
	NEDO-21061	9/76	No
Data	NEDE-21078-P	5/75	No
	NEDO-21078	10/75	No
	NEDE-21061-P	9/76	No
	NEDO-21062	9/76	No
Data	NEDE-21062-P	7/75	No
	NEDO-21062	7/75	No
	NEDE-20942-P	5/75	No
	NEDO-20942	5/75	No
Test Report	NEDC-21465-P	12/76	No
	NEDO-21465	12/76	No
c Report	NEDC-21581-P	8/77	No
	NEDO-21581	8/77	No
	NEDM-20988 Rev. 2	12/76	No
ddendum 1	NEDM-20988 Rev.2, Add.1	10/77	No
ddendum 2	NEDM-20988 Rev.2, Add.2	4/78	No
y	Letter Report	3/79	No
	NEDE-25100-P	5/79	No
	NEDE-25100-P Errata	2/81	No
	NEDO-25100	8/79	No
	NEDO-25100 Errata	2/81	No
	NEDE-24757-P	5/80	No
	NEDO-24757	7/80	No
	NEDE-24835-P	3/81	No
	NEDE-24798-P	7/80	No
	NEDO-24798	8/80	No
Model	NEDC-23689-P	3/78	No
	NEDO-23689	3/78	No
FSI	NEDO-23834	6/78	No
Comparison	NSC-GEN 0394	9/77	No

TASK NUMBER	ACTIVITY	ACTIVITY T
B.12	RAMSHEAD SRV METHODOLOGY SUMMARY	Analytical
C.	MISCELLANEOUS TASKS	
C.0	SUPPORTING PROGRAM	Supp Prog Supp Prog
C.1	DFFR REVISIONS	Revision 1
		Revision 2
		Revision 3
		Revision 4
C.3	NRC ROUND 1 QUESTIONS	DFFR Rev. DFFR Rev.
		DFFR Round
C.5	SRSS JUSTIFICATION	Interim Re SRSS Repor
C.5.1	SRSS PROGRAM SUMMARY	SRSS Execu
C.5.2	SRSS APPLICATION CRITERIA	SRSS Crite SRSS Crite
C.5.3	SRSS JUSTIFICATION CRITERIA	SRSS Justi SRSS Crite
C.5.4	BROOKHAVEN REPORT CRITIQUE	BNL Critic
C.6	NRC ROUND 2 QUESTIONS	DFFR Amend
		DFFR Amend
		DFFR Amend
		DFFR Rev.

S DAR

-1 (CONT'D)

PE	DOCUMENTATION	DOC DATE	USED FOR LGS LICENSING
Methods	NEDO-24070	10/77	No
eport	NEDO-21297	5/76	No
eport Rev. 1	NEDO-21297 Rev. 1	4/78	No
	NEDE-21061-P Rev. 1	9/75	No
	NEDO-21061 Rev. 1	9/75	No
	NEDE-21061-P Rev. 2	9/76	No
	NEDO-21061 Rev. 2	9/76	No
	NEDE-21061-P Rev. 3	6/78	Yes
	NEDO-21061 Rev. 3	6/78	Yes
	NEDO-21061 Rev. 4	11/81	Yes
	NEDO-21061 Rev. 2	9/76	Yes
, Amendment 1	NEDO-21061 Rev. 2 Amendment 1	12/76	Yes
1 Questions	Letter Report	6/78	Yes
ort	(NEDE-24010)	4/77	Yes
	NEDE-24010-P	7/77	Yes
	NEDO-24010	7/77	Yes
ive Summary	Summary Report	4/78	Yes
ia Application	NEDO-24010, Supp. 1	10/78	Yes
ia Basis	NEDO-24010-P, Supp. 2	12/78	Yes
ication Supp.	NEDO-24010, Supp. 3	8/79	Yes
ia Evaluation	Letter Report	1/80	Yes
e	EDAC 134-242-03	1/80	Yes
2	NEDE-21061-P Rev. 2 Amend. 2	6/77	Yes
	NEDO-21061 Rev. 2 Amend. 2	6/77	Yes
2, Supp 1	NEDO-21061 Rev. 2 Amend. 2 Supp. 1	8/77	Yes
2, Supp 2	NEDO-21061-P Rev. 2 Amend. 2 Supp. 2	9/77	Yes
, Appendix A-2	NEDE-21061-P Rev. 3 Appendix A-2		Yes
	NEDO-21061 Rev. 3 Appendix A-2		Yes

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TABLE 1.

TASK NUMBER	ACTIVITY	ACTIVITY T
C.7	JUSTIFICATION OF "4T" BOUNDING LOADS	Chugging L Justificat
C.8	SRV AND CHUGGING FSI	Prestresse Reinforced Steel
C.9	MONITOR WORLD TESTS	Monitor Te
C.11	MASS ENERGY RELEASE	SRV Pool T Analysis A and Justi
		Methods f mass and for SRV d
C.13	LOAD COMBINATIONS AND FUNCTIONAL CAPABILITY CRITERIA	Criteria
C.14	NRC ROUND 3 QUESTIONS	Letter Re DFFR Roun
C.15	SUBMERGED STRUCTURE CRITERIA	NRC Quest
C.16	QUENCHER MASS ENERGY CUTOFF	Quencher Limit

YPE	DOCUMENTATION	DOC DATE	USED FOR LGS LICENSING
oads	NEDE 23617-P	7/77	Yes
ion	NEDO 23617	7/77	Yes
	NEDE 24013-P	6/77	Yes
	NEDO 24013	7/77	Yes
	NEDE 24014-P	6/77	Yes
	NEDO 24014	7/77	Yes
	NEDE 24015-P	6/77	Yes
	NEDO 24015	7/77	Yes
	NEDE 24016-P	6/77	Yes
	NEDO 24016	7/77	Yes
	NEDE 24017-P	6/77	Yes
	NEDO 24017	7/77	Yes
	NEDE 23627-P	6/77	Yes
	NEDO 23627	7/77	Yes
d Concrete Concrete	NEDE 21936-P	7/78	Yes
	NEDO 21936	8/78	Yes
sts	None		No
emperature ssumptions ication	Letter Report-Revision 0	4/80	Yes
	Letter Report-Revision 1	1/81	Yes
r calculating nergy release scharges	Letter Report	5/81	Yes
ustification	NEDO 21985	9/78	Yes
ort	Letter Report	6/78	Yes
3 Questions	Letter Report	6/78	Yes
on Responses	Letter Report	4/80	Yes
emperature	Letter Report	1/81	Yes

TABLE 1.3-

II. KWU Tests and Reports

Document Number	Title	Documentatio
1.	Formation and oscillation of a spherical gas bubble	AEG - Report
2.	Analytical model for clarification of pressure pulsation in the wetwell after vent clearing	AEG - Report
3.	Tests on mixed condensation with model quenchers	KWU - Repor
4.	Condensation and vent clearing tests at GKM with quenchers	KWU - Repor
5.	Concept and design of the pressure relief system with quenchers	KWU - Repor
6.	KKB vent clearing with quencher	KWU - Repor
7.	Experimental approach to vent clearing in a model tank	KWU - Repor
8.	Anticipated data for blowdown tests with pressure relief system during the non-nuclear hot functional test at nuclear power station Brunsbuttel (KKB)	KWU - Repo
9.	Results of the non-nuclear hot functional tests with the pressure relief system in the nuclear power station Brunsbuttel	KWU - Repo
10.	Analysis of the loads measured on the pressure relief system during the non-nuclear hot functional test at KKB	KWU - Repo

	Document Date	Used for LGS Licensing
2241	12/72	Yes
2208	3/72	Yes
2593	5/73	Yes
2594	5/73	Yes
2703	7/73	Yes
2796	10/73	Yes
3129	7/75	Yes
t 3141		Yes
t 3267	12/74	Yes
t 3346	4/75	Yes

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TABLE 1.

Document Number	Title	Documentat
11.	KKB - Listing of test parameters and important test data of the non-nuclear hot functional tests with the pressure relief system	KWU - Work R 521/40
12.	KKB - Results from nuclear startup testing of pressure relief system	KWU-Workin R 142-13
13.	Results of the non-nuclear hot functional tests with the pressure relief system in the nuclear power station Phillipsburg	KWU - Work R 142-38
14.	KKPI - Listing of test parameters and important test data of the non-nuclear hot functional tests with the pressure relief system	KWU - Work R 521/41
15.	KKB hot test results, loads on internals in pool of the suppression chamber during pressure relief processes	KWU - Work R 113/2

on	Document Date	Used for LGS Licensing
ng Report 77	8/77	Yes
Report /76	9/76	Yes
ng Report 77	3/77	Yes
ng Report 77	8/77	Yes
ng Paper	11/74	Yes

TABLE 1.3-2

COMPARISON OF LGS LICENSING BASIS WITH NRC ACCEPTANCE CRITERIA

Load or Phenomenon	NRC Acceptance Criteria	Criteria Source	LGS Position
I. LOCA Related Hydrodynamic Loads			
A. Submerged Boundary Loads During Vent Clearing	24 psi overpressure added to local hydrostatic Pressure below vent exit (walls and basemat) - linear attenuation to pool surface.	NUREG-0487 Supplement 1	Acceptable
B. Poolswell Loads			
1. Poolswell Analytical Model			
a. Air-Bubble Pressure	Calculated by the poolswell analytical model (PSAM) used in calculation of submerged boundary loads.	NUREG-0487	Acceptable
b. Poolswell Elevation	Use PSAM with polytropic exponent of 1.2 to a maximum swell height which is the greater of 1.5 x vent submergence or the elevation corresponding to the drywell floor	NUREG-0487 Supplement 1	Acceptable

TABLE 1.3-2 (Continued)

Load or Phenomenon	NRC Acceptance Criteria	Criteria Source	LGS Position
	uplift ΔP=2.5 psid.		
c. Poolswell Velocity	Velocity history vs. pool elevation predicted by the PSAM used to compute impact loading on small structures and drag on gratings between initial pool surface and maximum pool elevation and steady-state drag between vent exit and maximum pool elevation. Analytical velocity variation is used up to maximum velocity. Maximum velocity applies thereafter up to maximum poolswell. PSAM predicted velocities multiplied by a factor of 1.1.	NUREG-0487	Acceptable
d. Poolswell Acceleration	Acceleration predicted by the PSAM. Pool acceleration is used in the calculation of acceleration loads on submerged components during poolswell.	NUREG-0487	Acceptable

Load or Phenomenon	NRC Acceptance Criteria	Criteria Source	LGS Position
e. Wetwell Air Compression	Wetwell air compression is calculated by PSAM consistent with maximum poolswell elevation in B.1.b.	NUREG-0487 Supplement 1	Acceptable
f. Drywell Pressure	Methods of NEDM-10320 and NEDO-20533 Appendix B. Used in PSAM to calculate poolswell loads.	NUREG-0487	Acceptable
2. Loads on Submerged Boundaries	Maximum bubble pressure predicted by the PSAM added uniformly to local hydrostatic pressure below vent exit (walls and basemat) - linear attenuation to pool surface. Applied to walls up to maximum poolswell elevation.	NUREG-0487	Acceptable
3. Impact Loads			
a. Small Structures	1.35 x Pres[illegible]-Velocity correlation f[illegible] pipes and I beams based on PSTF impulse data and flat pool assumption. Variable pulse duration.	NUREG-0487	Acceptable

TABLE 1.3-2 (Continued)

Load or Phenomenon	NRC Acceptance Criteria	Criteria Source	LGS Position
b. Large Structures	None - Plant unique load where applicable.	NUREG-0487	Not Applicable No large structures
c. Grating	P drag vs. grating area correlation and pool velocity vs. elevation. Pool velocity from the PSAM. P drag multiplied by dynamic load factor.	NUREG-0487	Acceptable
4. Wetwell Air Compression			
a. Wall Loads	Direct application of the PSAM calculated pressure due to wetwell compression.	NUREG-0487	Acceptable
b. Diaphragm Upward Loads	5.5 psid for diaphragm loadings only.	NUREG-0808	Acceptable
5. Asymmetric LOCA Pool	Use 20 percent of maximum bubble pressure statically applied to 1/2 of the submerged boundary.	NUREG-0487 Supplement 1	Acceptable

Load or Phenomenon	NRC Acceptance Criteria	Criteria Source	LGS Position
C. Steam Condensation and Chugging Loads			
1. Downcomer Lateral Loads			
a. Single-Vent Loads (24 in.)	Dynamic load to end of vent. Half sine wave with a duration of 3 to 6 ms and corresponding maximum amplitudes of 65 to 10 Klbf.	NUREG-0808	Acceptable
b. Multiple-Vent Loads (24 in.)	Prescribed variation of load per vent vs. number of vents. Determined from single vent dynamic load specification and multivent reduction factor.	NUREG-0808	Acceptable
c. Single/Multiple vent loads (28 in.)	Multiply basic vent loads by factor f=1.34	NUREG-0808	Not Applicable

Load or Phenomenon	NRC Acceptance Criteria	Criteria Source	LGS Position
2. Submerged Boundary Loads			
a. High/Medium Steam Flux Condensation Oscillation Load	Bounding CO pressure histories observed in 4TCO tests. Inphase application.	NUREG-0808	Acceptable
c. Low Steam Flux Chugging Load	Conservative set of 10 sources derived from 4TCO tests. Applied to plants using the IWEGS/MARS acoustic model. Source desynchronization of 50 ms or alternate load using 7 sources derived from the 4TCO key chugs without averaging.	NUREG-0808	Acceptable
- Symmetric Load	All vents use source of equal strength for each of the sources.		
- Asymmetric Load Case	Source strengths $S\pm = S(1\pm\alpha)$ applied to all vents on + and - side of containment. Sources based on the symmetric		

Load or Phenomenon	NRC Acceptance Criteria	Criteria Source	LGS Position
	sources. Asymmetric parameter α based on rms moment method of interpreting experimental 4TCO single-vent and JAERI multivent data.		
II. SRV Related Hydrodynamic Loads			
A. Pool Temperatures Limits	For plants using a discharge device with the exact hole pattern as described in the SSES DAR Section 4.1, the following limits shall apply:	NUREG-0783	
	1. For all plant transients involving SRV operations during which steam flux exceeds 94 lb_m/ft^2-sec, the local pool temperature shall not exceed 200°F.	NUREG-0783	Acceptable

TABLE 1.3-2 (Continued)

Load or Phenomenon	NRC Acceptance Criteria	Criteria Source	LGS Position
	2. For all plant transients involving SRV operations during which steam flux is less than 42 lb_m/ft^2-sec, the local pool temperature shall be at least 20°F subcooled. This is equivalent to a temperature of 210°F with quencher submergence of 14 feet.	NUREG-0783	Acceptable
	3. For all plant transients involving SRV operations during which steam flux is between 42 and 94 lb_m/ft^2-sec, the local pool temperature can be determined by linear interpolation between the temperatures defined in items 1 and 2 above.	NUREG-0783	Acceptable

Load or Phenomenon	NRC Acceptance Criteria	Criteria Source	LGS Position
B. Air Clearing Loads	The T-quencher load specification described in Section 4.1 of the SSES DAR may be applied for evaluation of SRV containment boundary pressure loads with the following restrictions:	NUREG-0802	Acceptable
	1. All valves load case The DLV and DLWL combinations must lie below the limit line of Fig. A1 defined in the criteria where: a. DLV shall be equal to the arithmetic average of all discharge line volumes (m^3) b. DLWL shall be equal to the quencher submergence at high water level (m)	NUREG-0802	Acceptable

Load or Phenomenon	NRC Acceptance Criteria	Criteria Source	LGS Position
	2. ADS Load Case The DLV and DLWL combinations must lie below the limit line of Fig. A2 defined in the criteria where: a. DLV shall be equal to the arithmetic average of all ADS discharge line volumes (m^3) b. DLWL shall be equal to the differences between the plant downcomer exit elevation and the quencher center line elevation (m)	NUREG-0802	Acceptable
	3. Frequency Range For the single valve and asymmetric load cases, the timewise compression of the design pressure signatures shall be increased to provide an	NUREG-0802	Acceptable

Load or Phenomenon	NRC Acceptance Criteria	Criteria Source	LGS Position
	overall dominant frequency range that extends up to 11 Hz.		
	4. Vertical Pressure Distribution The maximum pressure amplitudes shall be applied uniformly to the containment and pedestal walls up to an elevation 2.5 feet above the quencher centerline.	NUREG-0802	Acceptable
C. Quencher Arm and Tie Down Loads	The T-quencher load specification described in SSES DAR Section 4.1 may be applied for evaluation of quencher and quencher support subject to the following restrictions:	NUREG-0802	Acceptable
	1. Discharge Line Volume and Water Leg Length The acceptance criteria are applicable only for plants whose discharge line air volumes are	NUREG-0802	Acceptable

TABLE 1.3-2 (Continued)

Load or Phenomenon	NRC Acceptance Criteria	Criteria Source	LGS Position
	between 1.5 and 4 m^3 and normal discharge line water leg length is less than 7 m.		
	2. Quencher Arm Loads During SRV Opening For quenchers with discharge line air volumes greater than 2.1 m^3, the following modifications shall be made for quencher arm loads specified in SSES DAR Table 4-10: a. The external load shall be increased from 29 to 43 kN b. The bending moment on welding seam shall be raised from 19 to 28 kN-m For quenchers with discharge line air volumes less than 2.1 m^3, the following increments shall be added to the above modification:	NUREG-0802	Under Evaluation

Load or Phenomenon	NRC Acceptance Criteria	Criteria Source	LGS Position
	a. The increment in external load shall be calculated by 9.6*(2.1-DLV)		
	b. The increment in bending moment shall be calculated by 6.3* (2.1-DLV)		
	3. Total Quencher Loads During SRV Opening	NUREG-0802	Under Evaluation
	For quenchers with discharge line air volume greater than 2.1 m³, the external load on the quencher, specified in SSES DAR Table 4-7, shall be increased from 44 to 58 kN.		
	For quenchers with discharge line air volumes less than 2.1 m³, an increment in external load calculated by 12.7* (2.1-DLV) shall be added to the above modification.		

Load or Phenomenon	NRC Acceptance Criteria	Criteria Source	LGS Position
	4. Loads During Irregular Condensation The external load specified in SSES DAR Table 4-9 shall be increased from 17.5 to 30 kN. The external load on quencher arm, specified in SSES DAR Table 4-12, shall be increased from 14.5 to 50 kN. The bending moment specified in the same table shall be increased from 9 to 31 kN-m.	NUREG-0802	Under Evaluation
III. LOCA/SRV Submerged Structure Loads			
A. LOCA Downcomer Jet Load	Alternate methodology presented in Zimmer DAR may be applied.	NUREG-0487 Supplement 1	Acceptable
B. SRV T-Quencher Jet	SRV T-quencher jet loads may be neglected beyond a 5 ft cylindrical zone of influence. Cylinder should be extended 10 hole diameters on the arm with holes in the	NUREG-0487	Acceptable

Load or Phenomenon	NRC Acceptance Criteria	Criteria Source	LGS Position
	end cap.		
C. LOCA Air Bubble Drag Loads	Calculate based on methods described in NEDE-21471 subject to the following constraints and modifications:	NUREG-0487	Applying plant-unique methodology defined in LGS DAR Section 4.2.1.5
	1. To account for bubble asymmetry, accelerations and velocities shall be increased 10%.	NUREG-0487	Acceptable
	2. For standard drag in accelerating flow fields, use draft coefficients presented in Zimmer FSAR attachment 1.k with following modifications:	NUREG-0487 Supplement 1	Acceptable
	a. Use $C_H = C_m^{-1}$ in the F_A formula		
	b. For noncylindrical structures, use lift coefficient for		

Load or Phenomenon	NRC Acceptance Criteria	Criteria Source	LGS Position
	appropriate shape or $C_L = 1.6$		
	c. The standard drag coefficient for poolswell and SRV oscillating bubbles should be based on data for structures wi'h sharp edges.		
	3. For equivalent uniform flow velocity and acceleration calculations, structures are segmented into small sections such that $1.0 \leq L/D \leq 1.5$. The loads are then applied to the geometric center of each segment. This approach, as presented in Zimmer FSAR attachment 1.k, may be applied.	NUREG-0487 Supplement 1	Acceptable
	4. A detailed metho-	NUREG-0487	Acceptable

Load or Phenomenon	NRC Acceptance Criteria	Criteria Source	LGS Position
	dology on the approach for considering interference effects as presented in Zimmer FSAR Attachment 1.k may be applied.	Supplement 1	
	5. Formula 2-23 of NEDE-21730 shall be modified by replacing M_H by $\rho_{FB} V_A$ where V_A is obtained from Tables 2-1 & 2-2.	NUREG-0487	Acceptable
D. SRV Air Bubble Drag Load	No criteria specified for T-quencher		Applying plant-unique methodology defined in LGS DAR Section 4.1.4
E. Steam Condensation Drag Loads	No criteria specified		Applying plant-unique methodology defined in LGS DAR Section 4.2

TABLE 1.3-2 (Continued)

Load or Phenomenon	NRC Acceptance Criteria	Criteria Source	LGS Position
IV. Secondary Loads			
1. Sonic Wave Load	Negligible Load	NUREG-0487	Acceptable
2. Compressive Wave Load	Negligible Load	NUREG-0487	Acceptable
3. Fallback Load on Submerged Boundary	Negligible Load	NUREG-0487	Acceptable
4. Thrust Loads	Momentum balance	NUREG-0487	Acceptable
5. Friction Drag Loads on Vents	Standard friction drag calculations	NUREG-0487	Acceptable
6. Vent Clearing Loads	Negligible Load	NUREG-0487	Acceptable

1.4 PLANT DESCRIPTION

The Limerick Generating Station (Units 1 and 2) is located on the east bank of the Schuylkill River in Limerick Township of Montgomery County, Pennsylvania, approximately 1.7 miles southeast of the limits of the Borough of Pottstown and approximately 20.7 miles northwest of the Philadelphia city limits.

Each of the LGS units employs a General Electric Company boiling-water reactor (BWR) designed to operate at a rated core thermal power of 3293 MWt (100% steam flow) with a corresponding gross electrical output of 1092 MWe. Approximately 37 MWe are used for auxiliary power, resulting in a net electrical output of 1055 MWe.

Commercial operation of LGS Unit 1 is scheduled for January 1985 and Unit 2 for July 1987.

1.4.1 PRIMARY CONTAINMENT

The containment is a reinforced concrete structure consisting of a cylindrical suppression chamber beneath a truncated conical drywell. Figures 1.4-1 and 1.4-2 show the cross section of the containment and suppression chamber (including pedestal), respectively. The conical portion of the primary containment (drywell) encloses the reactor vessel, reactor coolant recirculation loops, and associated components of the reactor coolant system. The drywell is separated from the wetwell, i.e, the pressure suppression chamber and pool, by the drywell floor, also named the diaphragm slab. The cone and cylinder form a structurally integrated reinforced concrete vessel, lined with steel plate and closed at the top of the drywell with a steel domed head. The carbon steel liner plate is anchored to the concrete by structural steel members embedded in the concrete and welded to the liner plate.

The entire containment is structurally separated from the surrounding reactor building except at the base foundation slab (a reinforced concrete mat, top lined with a carbon steel liner plate) where a seismic gap filled with roloform is provided between the two adjoining foundation slabs. The containment structure dimensions and parameters are listed in Tables 1.4-1 and 1.4-2.

Major systems and components in the containment include the vent pipe system (downcomers) connecting the drywell and wetwell, vacuum relief system, containment cooling system, and main steam relief valve (MSRV) discharge piping and associated quencher components. Figure 1.4-3 shows the locations and orientation of the quenchers and discharge piping.

1.4.1.1 Penetrations

Services and communications between the inside and the outside of the containment are performed through penetrations. Basic penetration types include pipe penetrations, electrical penetrations, and access hatches (equipment hatches, personnel lock, suppression chamber access hatches, and control rod drive (CRD) removal hatch). Each penetration consists of a pipe sleeve with an annular ring welded to it. The ring is embedded in the concrete wall and provides an anchorage for the penetration to resist normal operating and accident loads. The pipe sleeve is also welded to the containment liner plate to provide a leaktight penetration.

1.4.1.2 Internal Structures

The internal structures consist of reinforced concrete and structural steel and have the major functions of supporting and shielding the reactor vessel, supporting the piping and equipment, and forming the pressure suppression boundary. These structures include the diaphragm slab, the reactor pedestal (a concentric cylindrical reinforced concrete shell resting on the containment base foundation slab and supporting the reactor vessel; Figure 1.4-2 shows pedestal cross section), the reactor shield wall, the suppression chamber columns (hollow steel pipe columns supporting the diaphragm slab), the drywell platforms, the seismic trusses, the quencher supports, and the reactor steam supply system supports.

TABLE 1.4-1

CONTAINMENT DESIGN PARAMETERS

	Drywell	Suppression Chamber
DRYWELL AND SUPPRESSION CHAMBER		
Internal design pressure, psig	55	55
External to internal design differential pressure, psid	5	5
Drywell deck design differential pressure, psid	30	
Design temperature, °F	340	220
Drywell net free volume including downcomers, ft³	248,950	
Suppression chamber free volume, ft³		
Low level		161,350
High level		149,425
Suppression pool water volume, ft³		
Low level		115,903
High level		127,756
Suppression pool net surface area, outside pedestal, ft²		4974
Supression pool depth, ft		
Low level		22'
Normal level		23'
High level		24'-3"
VENT SYSTEM		
Number of downcomers	87	
Nominal downcomer diameter, ft	2	
Total vent area, ft²	256.5	

TABLE 1.4-1 (Cont'd)

Downcomer submergence, ft	
Low water level	10'
Normal water level	11'
High water level	12'-3"
Downcomer loss coefficient	2.11

SAFETY RELIEF VALVES

Number	14

Spring Set Pressures, Mass Flow Rates:

Valve	Set Pressure (psig)	Mass Flow (lbm/hr) at 103% of Spring Set Pressure
A	1150	917,000
B	1150	917,000
C	1150	917,000
D	1140	909,000
E*	1140	909,000
F	1150	917,000
G	1150	917,000
H*	1130	901,500
J	1130	901,500
K*	1140	909,000
L	1130	901,500
M*	1140	909,000
N	1130	901,500
S*	1140	909,000

*ADS Valves

TABLE 1.4-1 (Cont'd)

SAFETY RELIEF VALVE DISCHARGE LINES

Nominal Diameter 12"

Length, Number of Bends, and Air Volume for each SRV Pipe:

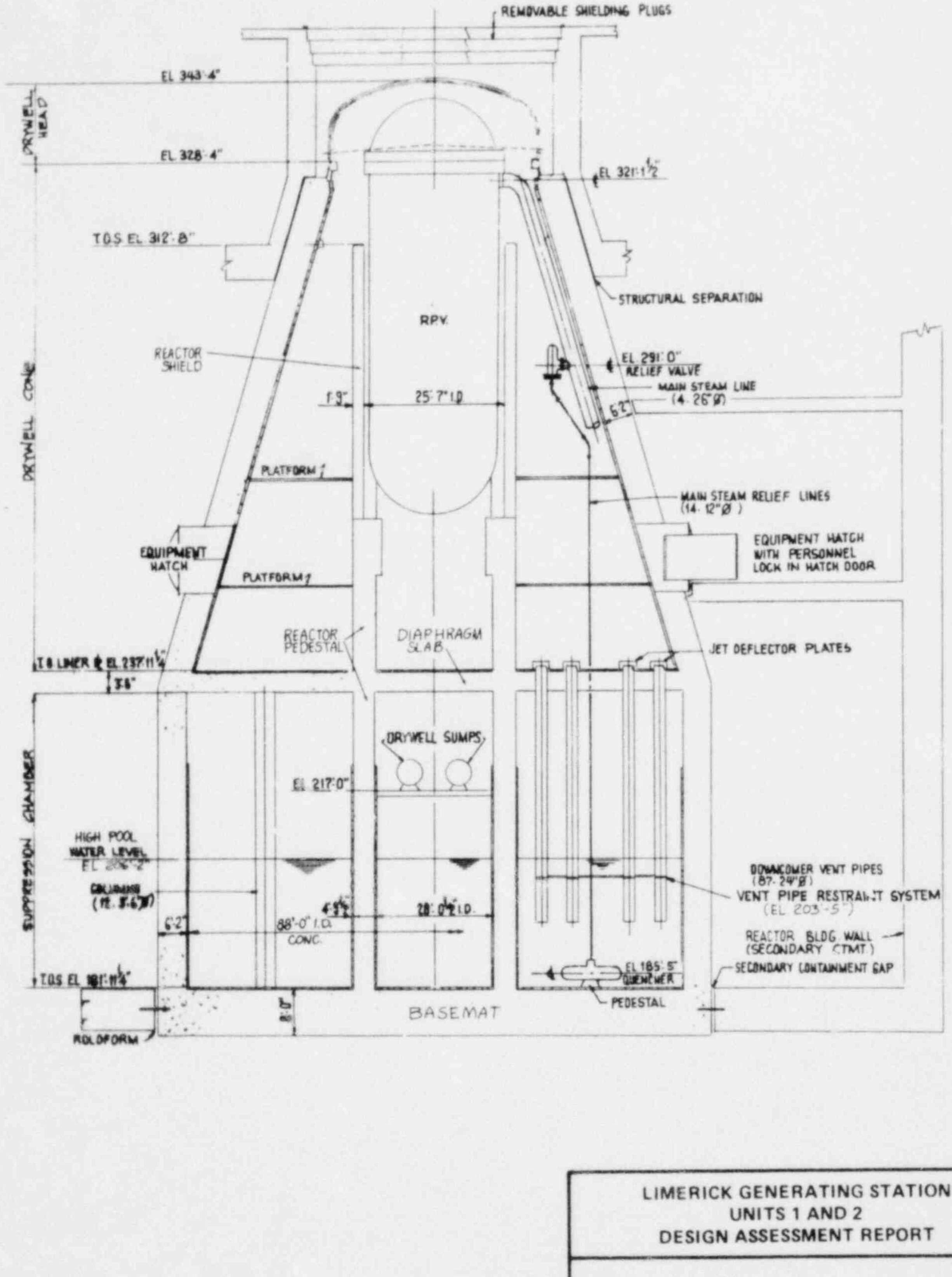
Valve	Bends	Length[1] (ft)	Volume[2] (ft^3)
A	9	142.2	94.3
B	7	115.1	74.2
C	7	115.3	75.4
D	9	142.2	94.8
E	9	133.6	89.1
F	11	134.0	88.3
G	11	134.6	88.5
H	11	138.1	91.2
J	7	116.1	76.0
K	12	131.6	86.2
L	10	131.6	85.8
M	13	134.9	88.2
N	10	142.2	93.8
S	12	140.0	93.2

(1) Line lengths are measured from the valve to the quencher inlet.
(2) Air volume is calculated up to pool normal water level.

TABLE 1.4-2

LGS CONTAINMENT DIMENSIONS

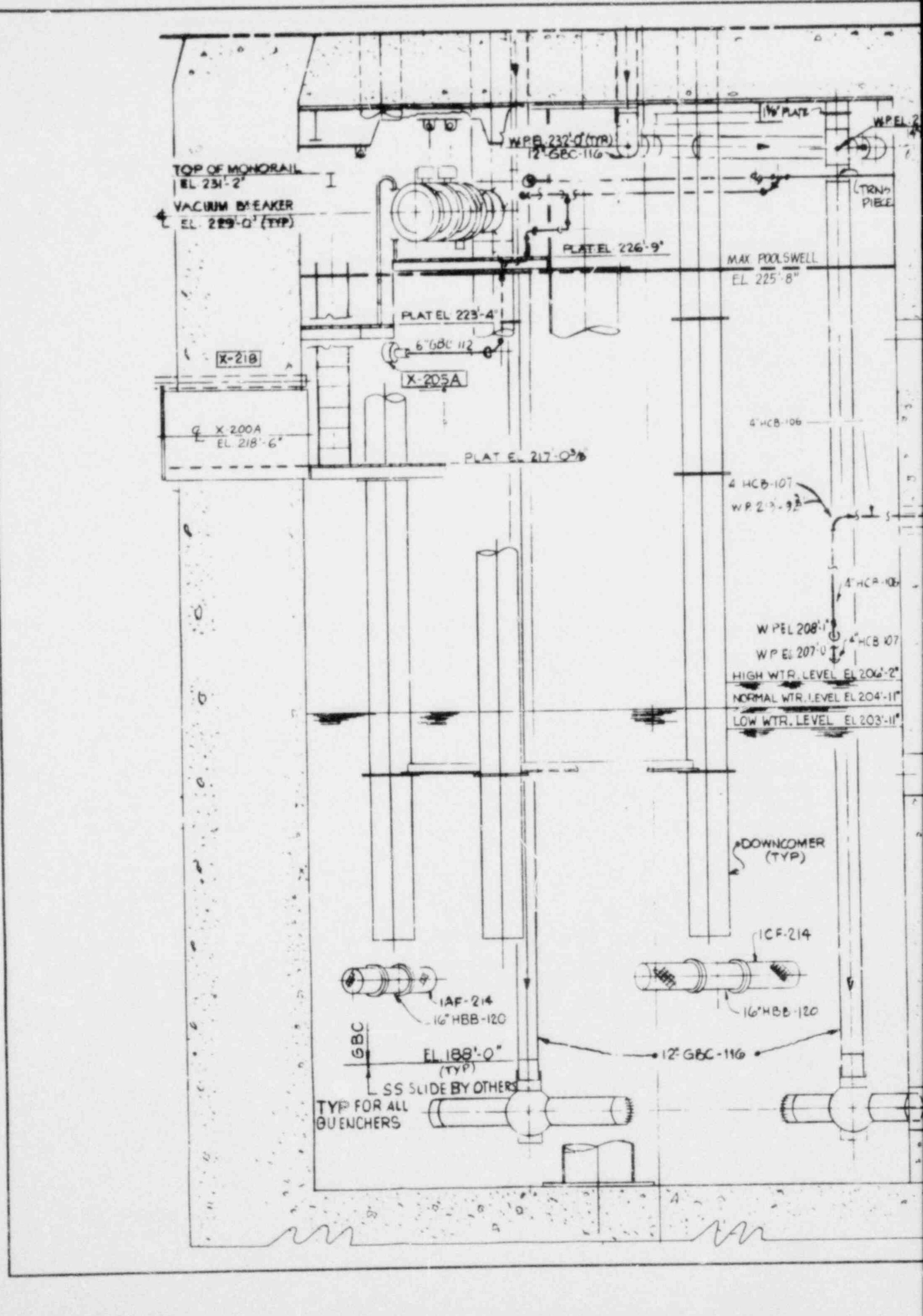
SUPPRESSION CHAMBER	
Inside Diameter	88 ft 0 in
Height	52 ft 6 in
Drywell	
Inside Diameter of Base	86 ft 4 in
Inside Diameter of Top	36 ft 4.5 in
Height	87 ft 9 in
REACTOR PEDESTAL	
Inside Diameter Below Diaphragm Slab	20 ft 0.5 in
Inside Diameter Above Diaphragm Slab	20 ft 3 in
Wall Thickness Below Diaphragm Slab	4 ft 9.5 in
Wall Thickness Above Diaphragm Slab	4 ft 5 in
Height	82 ft
REINFORCED CONCRETE THICKNESS	
Base Foundation Slab	8 ft 0 in
Containment Wall	6 ft 2 in
Diaphragm Slab	3 ft 6 in
STEEL LINER PLATE THICKNESS (FOR BASE FOUNDATION, CONTAINMENT WALL, AND DIAPHRAGM SLAB)	0.25 in
SUPPRESSION CHAMBER COLUMNS	
Outside Diameter	3 ft 6 in
Wall Thickness	1.25 in
Height	52 ft 3 in



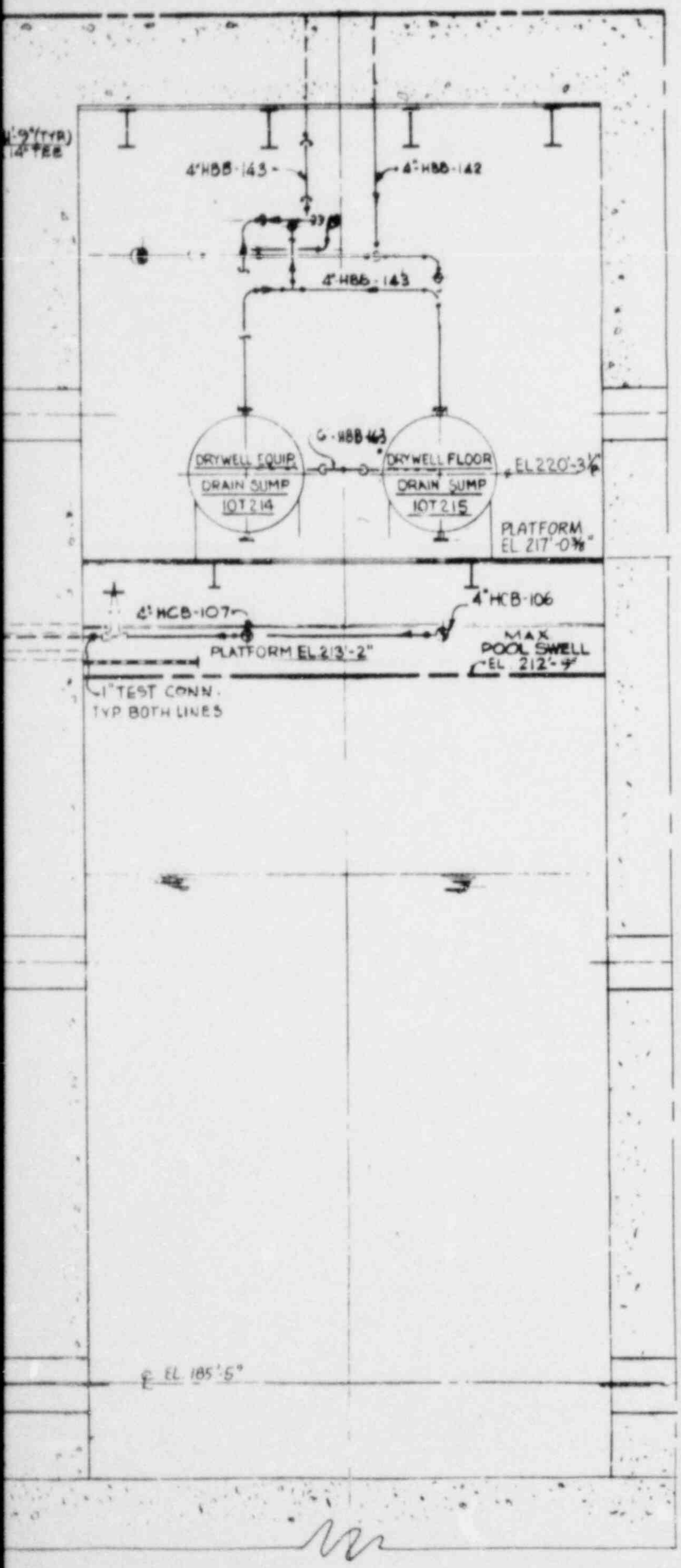
LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CROSS SECTION OF CONTAINMENT

FIGURE 1.4-1



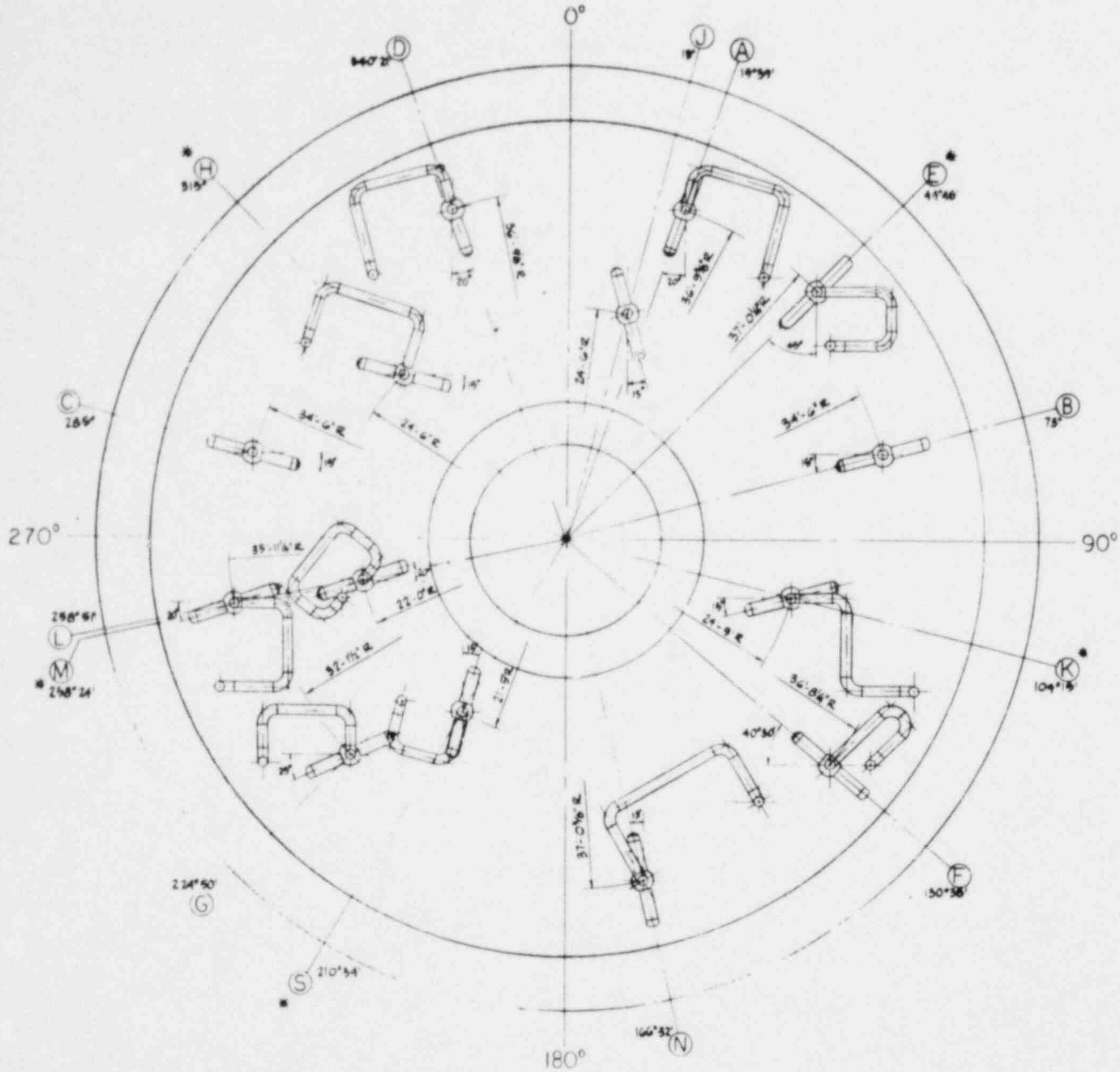
TOP OF MONORAIL
EL 231'-2"
VACUUM BREAKER
EL 229'-0" (TYP)
W.P. EL 232'-0" (TYP)
12" GBC-116
1¾" PLATE
TRNS PIECE
PLAT EL 226'-9"
MAX POOLSWELL
EL 225'-8"
PLAT EL 223'-4"
6" GBC 112
X-218
X-205A
X-200A
EL 218'-6"
PLAT EL 217'-0⅜"
4" HCB-106
4" HCB-107
4" HCB-108
W P EL 208'-1"
W P EL 207'-0
4" HCB 107
HIGH WTR. LEVEL EL 206'-2"
NORMAL WTR. LEVEL EL 204'-11"
LOW WTR. LEVEL EL 203'-11"
DOWNCOMER (TYP)
1CF-214
1AF-214
16" HBB-120
16" HBB-120
GBC
EL 188'-0" (TYP)
12" GBC-116
SS SLIDE BY OTHERS
TYP FOR ALL QUENCHERS



LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

SUPPRESSION CHAMBER AND PEDESTAL INTERIOR – SECTION VIEW

FIGURE 1.4-2



PLAN AT EL 181'-11"

* A.D.S VALVES H,M,K,E,S

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

QUENCHER LOCATIONS AND ORIENTATION

FIGURE 1.4-3

CHAPTER 2

SUMMARY

TABLE OF CONTENTS

CHAPTER 2

SUMMARY

2.1 SRV LOAD DEFINITION SUMMARY

2.1.1 SRV LOAD DEFINITION SUMMARY

Hydrodynamic loads resulting from SRV actuation fall into two categories: loads on the SRV system itself (the discharge line and the discharge quencher device), and the loads on the suppression pool walls and submerged structures.

Loads on the SRV system during SRV actuation include loads on the SRV piping due to effects of steady backpressure, transient water slug clearing, and SRV line temperature. Determination of loading on the quencher body, arms, and support is based on transients resulting from valve opening (water clearing and air clearing), valve closing, and operation of an adjacent quencher.

Air clearing loads are examined for four loading cases: symmetric (all-valve) SRV actuation, asymmetric adjacent SRV actuation, single SRV actuation, and automatic depressurization system (ADS-five valves) actuation. Dynamic forcing functions for loading of the containment walls, pedestal, basemat, and submerged structures are developed using techniques discussed in Section 4.1. Loads on the SRV system due to SRV actuation are discussed in Section 4.1.3, and loads on suppression pool walls and submerged structures due to SRV actuation are discussed in Section 4.1.4. A full-scale, unit cell test program was conducted at the KWU laboratories to verify these SRV loading specifications. These tests are described in Chapter 8.

Adjacent structures indirectly affected by SRV loads include the reactor building, control structure, and associated equipment and components. The assessment methodology used in determining the SRV load effect on these adjacent structures is described in Section 7.1.1.2.

2.1.2 LOCA LOAD DEFINITION SUMMARY

The spectrum of LOCA-induced loads acting on the LGS containment structure is characterized by LOCA loads associated with

poolswell and condensation oscillation and chugging, as well as long-term and secondary LOCA loads.

The LOCA loads associated with poolswell result from short duration transients and include downcomer clearing loads, water jet loads, pollswell impact and drag loads, pool fallback drag loads, poolswell air bubble loads, and loads due to drywell and wetwell temperature and pressure transients. Techniques used to evaluate these loads are described in Section 4.2.1.

Condensation oscillations result from mixed flow (air/steam) and pure steam flow effects in the suppression pool. Chugging loads result from low mass flux pure steam condensation. The load definitions from these phenomena are contained in Section 4.2.2.

Long-term LOCA loads result from those wetwell and drywell pressure and temperature transients associated with design basis accidents (DBA), intermediate break accidents (IBA), and small break accidents (SBA). Their load definitions are contained in Section 4.2.4.

Structures directly affected by LOCA loads include the drywell walls and floor, wetwell walls, RPV pedestal, basemat, liner plate, columns, downcomers, downcomer bracing system, and wetwell piping. Their loading conditions are described in Section 4.2.5.

Adjacent structures indirectly affected by LOCA loads include the reactor building, control structure, and associated equipment and components. The assessment methodology used in determining the LOCA load effect on these adjacent structures is described in Section 7.1.1.2.

2.2 DESIGN ASSESSMENT SUMMARY

Design assessment of the LGS structures and components is achieved by analyzing the response of the structures and components to the load combinations explained in Chapter 5. In Chapter 7, predicted stresses and responses (from the loads defined in Chapter 4 and combined as described in Chapter 5) are compared with the applicable code allowable values identified in Chapter 6.

2.2.1 CONTAINMENT STRUCTURE, REACTOR BUILDING, AND CONTROL STRUCTURE ASSESSMENT SUMMARY

2.2.1.1 Containment Structure Assessment Summary

The primary containment walls, base slab, diaphragm slab, reactor pedestal and reactor shield are analyzed for the effects of SRV and LOCA in accordance with Table 5.2-1. The ANSYS finite element program is used for the dynamic analysis of structures.

Response spectra curves are developed at various locations within the containment structure to assess the adequacy of components. Stress resultants due to dynamic loads are combined with other loads in accordance with Table 5.2-1 to evaluate rebar and concrete stresses. Design safety margins are defined by comparing the actual concrete and rebar stresses at critical sections with the code allowable values. The assessment methodology of the containment structure is given in Section 7.1.1.1.

The containment mode shapes, modal frequencies, and hydrodynamic response spectra are given in Appendix A.

The results of the structural assessment of the containment structure are given in Appendix D.

2.2.1.2 Reactor and Control Structure Building Assessment Summary

The reactor building and control structure are assessed for the effects of SRV and LOCA loads in accordance with Table 5.2-1 and Table 5.3-1.

Pressure time histories in the wetwell are used to investigate the reactor building and control structure response to SRV and LOCA loads. Maximum time history force responses and broadened response spectra curves are approximately used to assess the adequacy of associated structural components. The assessment methodology of the reactor building and control structure is presented in Section 7.1.1.2.

The mode shapes and hydrodynamic response spectra of the reactor building and control structure are presented in Appendix B.

The results of the structural assessment are summarized in Appendix E.

2.2.2 CONTAINMENT SUBMERGED STRUCTURES ASSESSMENT SUMMARY

Load combinations for the downcomer bracing and suppression chamber columns are presented in Table 5.3-1. Load combinations for the downcomers are presented in Table 5.5-1. The hydrodynamic design assessment methodology for the downcomers, bracing, and columns is presented in Sections 7.1.2 and 7.1.4. The results of the analysis are presented in Appendix D.

The suppression pool liner plate loads are combined in accordance with Table 5.2-1. Results from the analysis indicate that no structural modification is required (see Sections 7.1.3 and 7.2.1.5).

2.2.3 PIPING SYSTEMS ASSESSMENT SUMMARY

Containment and reactor building piping systems are being analyzed by the methods presented in Section 7.1.5. The load combinations for piping are described in Table 5.6-1. The results of the analysis are presented in Appendix F.

2.2.4 NSSS ASSESSMENT SUMMARY

To be provided later.

2.2.5 EQUIPMENT ASSESSMENT SUMMARY

Non-NSSS safety related equipment in the containment, reactor building and control structure are assessed by the methods contained in Section 7.1.7. Loads are combined as shown in Table 5.8-1. The results of the analysis are presented in Appendix H.

2.2.6 ELECTRICAL RACEWAY SYSTEM ASSESSMENT SUMMARY

Electrical raceway system loads are combined in accordance with Table 5.9-1. The assessment methodology and analysis results are presented in Chapter 7.

2.2.7 HVAC DUCT SYSTEM ASSESSMENT SUMMARY

HVAC duct system loads are combined in accordance with Table 5.10-1. The assessment methodology and analysis results are presented in Chapter 7.

2.2.8 SUPPRESSION POOL TEMPERATURE MONITORING SYSTEM (SPTMS) ASSESSMENT SUMMARY

SPTMS adequacy assessment and suppression pool temperature response to SRV discharge are presented in Appendix I.

CHAPTER 3

SRV DISCHARGE AND LOCA TRANSIENT DESCRIPTION

TABLE OF CONTENTS

CHAPTER 3

SRV DISCHARGE AND LOCA TRANSIENT DESCRIPTION

3.1 DESCRIPTION OF SAFETY RELIEF VALVE DISCHARGE

Limerick Generating Station is equipped with a safety relief system that condenses reactor steam in a suppression chamber pool. By this arrangement, reactor steam is conducted to the wetwell via fast-acting safety relief valves and quencher-equipped discharge lines. This section discusses the causes of SRV discharge, describes the SRV discharge process, and identifies the resultant SRV discharge actuation cases. Section 4.1 presents a quantitative description of specific SRV-related loads.

3.1.1 CAUSES OF SRV DISCHARGE

During certain reactor operating transients, the SRVs may be actuated (by pressure, by electrical signal, or by operator action) for rapid relief of pressure in the reactor pressure vessel. The following reactor operating transients have been identified as those which may result in SRV actuation:

a. Turbine generator trip (with bypass or without)

b. Main steam line isolation valve (MSIV) closure

c. Loss of condenser vacuum

d. Feedwater controller failure - maximum demand

e. Pressure regulator failure - closed

f. Generator load rejection (with and without bypass)

g. Loss of ac or auxiliary power

h. Loss of feedwater flow

i. Trip of two recirculation pumps

j. Recirculation flow control failure - decreasing flow

k. Inadvertent safety relief valve opening

l. Control rod withdrawal error

m. Anticipated transient without scram (ATWS)

n. Failure of shutdown cooling

A description of these transients is provided in Chapter 15 of the FSAR.

3.1.2 DESCRIPTION OF THE SRV DISCHARGE PHENOMENA AND SRV LOADING CASES

Before an individual safety relief valve opens, the water level in the discharge line is approximately equal to the water level in the pool. As a valve opens, steam flows into the discharge line air space between the valve and the water column and mixes with the air. Because the downstream portion of the discharge line contains a water slug, the pressure inside the line increases. The increased pressure expels the water slug from the SRV discharge line and quencher. The magnitude of the water clearing pressure is primarily influenced by the steam flow rate through the valve, the degree to which entering steam is condensed along the discharge line walls, the volume of the discharge line airspace, and the volume of the water slug to be accelerated.

The clearing of water is followed by an expulsion of the enclosed air-steam. The exhausted gas forms an oscillating system with the surrounding water, where the gas acts as the spring and the water acts as the mass. This oscillating system is the source of short-term air clearing loads.

As the air-steam mixture oscillates in the pool, it also rises because of buoyancy and eventually breaks through the pool water surface, at which time air clearing loads cease. When all the air leaves the safety relief system, steam flows into the suppression pool through the quencher holes and condenses. The SSES quencher design ensures stable condensation even with elevated pool water temperature.

The SRV actuation cases resulting from the transients listed in Section 3.1.1 are classified as being bounded by one of the following cases:

a. Symmetric all-valve, or abnormal operating transient (AOT) discharge

b. Asymmetric discharge

c. Single valve discharge

d. Automatic depressurization system (ADS) discharge

The symmetric discharge case is classified as the type of SRV discharge that would follow rapid isolation of the vessel from the turbine such as turbine trip, closure of all MSIVs, loss of condenser vacuum, etc. As pressure builds up following isolation of the vessel, the SRVs actuate sequentially according to the pressure set ponts of the valves. This may or may not result in actuation of all the SRVs, but for conservatism in loading considerations, all valves are assumed to actuate simultaneously.

Asymmetric discharge is defined as the firing of the SRVs for the three adjacent quencher devices which results in the greatest assymmetric pressure loading on the containment. This situation is hypothesized when, following a reactor scram and isolation of the vessel, decay heat raises vessel pressure so that low set point valves actuate. If, during this time of discharge of decay heat energy, manual actuation of the two other adjacent SRVs that comprise the asymmetric case is assumed, this actuation would result in the maximum asymmetric pressure load on the containment.

The single valve discharge case is classified as the firing of the SRV which gives the single largest hydrodynamic load. Transients that could potentially initiate such a case are an inadvertent SRV discharge or design basis accident (DBA). Refer to Section 3.2.3 for a discussion of the latter possibility.

The ADS discharge is defined as the simultaneous actuation of the five SRVs associated with the ADS. Figure 1.4-3 shows the location of the quencher devices associated with the ADS valves. The ADS is assumed to actuate during an intermediate break accident (IBA) or small break accident (SBA). (The IBA and SBA are described in Sections 3.2.2 and 3.3.1, respectively.) The effects of an increased suppression pool temperature (resulting from steam condensation during the LOCA transient) and increased

suppression chamber pressure (resulting from clearing of the drywell air into the pool during the transient) are considered in the calculation of pressure loadings for the ADS discharge case.

Section 4.1.4.2 describes the loads resulting from symmetric, asymmetric, single valve, and ADS discharge transients.

3.2 DESCRIPTION OF LOSS-OF COOLANT ACCIDENT

This event involves the postulation of a spectrum of piping breaks inside the containment varying in size, type, and location. For the analysis of hydrodynamic loadings on the containment, the postulated LOCA event is identified as a small break accident (SBA), an intermediate break accident (IBA), or a design basis accident (DBA).

3.2.1 SMALL BREAK ACCIDENT (SBA)

This section discusses the containment transient associated with small primary system blowdowns. The primary system ruptures in this category are those ruptures that will not result in reactor depressurization from either loss of reactor coolant or automatic operation of the ECCS equipment, i.e., those ruptures with a break size less than 0.1 sq ft.

The following sequence of events is assumed to occur. With the reactor and containment operating at the maximum normal conditions, a small break occurs that allows blowdown of reactor steam or water to the drywell. The resulting pressure increase in the drywell leads to high drywell pressure signal that scrams the reactor and activates the containment isolation system. The drywell pressure continues to increase at a rate dependent upon the size of the steam leak. The pressure increase lowers the water level in the downcomers. At this time, air and steam enter the suppression pool at a rate dependent upon the size of the leak. Once all the drywell air is carried over to the suppression chamber, pressurization of the suppression chamber ceases and the system reaches an equilibrium condition. The drywell contains only superheated steam, and continued blowdown of reactor steam condenses in the suppression pool. The principal loading condition in this case is the gradually increasing pressure in the drywell and suppression pool chamber and the loads related to the condensation of steam at the end of the vents.

3.2.2 INTERMEDIATE BREAK ACCIDENT (IBA)

This section discusses the containment transient associated with intermediate primary system blowdowns. This classification covers breaks for which the blowdown will result in limited reactor depressurization and operation of the ECCS, i.e., the break size is equal to slightly greater than 0.1 sq ft.

Following the break, the drywell pressure increases at approximately 1.0 psi/sec. This drywell pressure transient is sufficiently slow so that the dynamic effect of the water in the vents is negligible and the vents will clear when the drywell-to-suppression chamber differential pressure is equal to the hydrostatic pressure corresponding to the vent submergence. The resulting pressure increase in the drywell will lead to a high drywell pressure signal that will scram the reactor and activate the containment isolation system. Approximately 5 seconds after the 0.1 sq ft break occurs, air, steam, and water will be condensed, and the air will rise to the suppression chamber free space. The continual purging of drywell air to the suppression chamber will result in a gradual pressurization of both the wetwell and drywell. The ECCS will be initiated by the break and will provide emergency cooling of the core. The operation of these systems is such that the reactor will be depressurized in approximately 600 seconds. This will terminate the blowdown phase of the transient. The principal loading condition in this case will be gradually increasing pressure in the drywell and suppression chamber and the loads related to the condensation of steam at the end of the vents.

3.2.3 DESIGN BASIS ACCIDENT (DBA)

An occurrence of events that could result in a DBA (instantaneous rupture of main steam or recirculation line) is a remote possibility. Because such an accident provides an upper limit estimate to the resultant effects for this category of pipe breaks, it is evaluated without causes being identified. For Limerick, an assumed instantaneous double-ended rupture of a recirculation line causes the maximum drywell pressure and therefore the governing LOCA hydrodynamic loads.

The sequence of events immediately following the rupture of a recirculation line has been determined. A drywell high pressure signal is almost instantaneously sensed, initiating a scram and containment isolation and signaling the HPCI, CS and LPCI to start. The flow in both sides of the break will accelerate to the maximum allowed by the critical flow considerations. In the side adjacent to the suction nozzle, the flow will correspond to critical flow in the pipe cross section. In the side adjacent to the injection nozzle, the flow will correspond to critical flow at the 10 jet pump nozzles associated with the broken loop. In addition, the cleanup line cross-tie will add to the critical flow area. This high rate of flow out of the ruptured recirculation line results in a drywell pressure rise of approximately 44 psig in 13.7 seconds (refer to FSAR Table 6.2-5 and DAR Figure 4.2-11).

This rapid increase in drywell pressure accelerates the water initially in the containment vent system out through the vents. Immediately following vent water clearing, a coalescing air/steam bubble starts to form at the downcomer exits. Initially, the bubble pressure is essentially equal to the current drywell pressure. As the flow of air/steam from the drywell becomes established in the vent system, the initial vent exit bubble expands, thus accelerating upward the suppression pool water above the vent exits. The steam fraction of the flow is condensed, but continued injection of drywell air and expansion of the air bubble results in a rapid rise in the suppresion pool surface known as poolswell.

Following the poolswell and fallback, there is a period of high steam flow rate through the containment vent system. For large primary system ruptures, reactor blowdown and, therefore, vent steam condensation last for approximately 40 seconds (approximately 60 seconds for MSLB, see FSAR Tables 6.2-10 and 6.2-11).

Shortly after a DBA, the ECCS pumps (HPCI, CS, and LPCI) automatically start pumping condensate storage tank water or suppression pool water into the reactor pressure vessel. Within 40 seconds, all ECCS pumps are at rated flow (FSAR Table 6.3-2). This floods the reactor core until water starts to cascade into the drywell from the break. The time at which this occurs would depend upon break size and location. Because the drywell would be full of steam at the time of vessel flooding, the sudden introduction of cold water causes steam condensation and drywell depressurization. When the drywell pressure falls below the suppression chamber pressure, the drywell vacuum relief system is actuated and air from the suppression chamber enters the drywell. Eventually, sufficient air returns to the drywell to equalize the pressures. Similarly, small differential pressures between the drywell and the suppression chamber can be produced if the containment spray system is actuated, condensing steam in the drywell.

Following the vessel flooding and drywell/suppression chamber pressure equalization phase of the accident, suppression pool water will be continuously recirculated through the core by the ECCS pumps. The energy associated with the core decay heat will result in a slow heatup of the suppression pool. The suppression pool temperature is controlled by the RHR heat exchangers. The capacity of these heat exchangers is such that the maximum suppression pool temperature increase is reached after several hours. The suppression pool can experience a peak temperature of 212.5°F under worst case conditions (FSAR Table 6.2-6). The post-LOCA containment heatup and pressurization transient is

terminated when the RHR heat exchangers reduce the pool temperature and containment pressure to nominal values.

The primary loads on the containment generated by a DBA are the pressure build-ups in the drywell and suppression chamber, and loads resulting from various modes of steam condensation at the vent ends. The high rate of system depressurization resulting from a DBA militates against the firing of an SRV; however, for conservatism, SRV discharges are considered coincident with the DBA for containment structural loading purposes (Table 5.2-1).

CHAPTER 4

LOAD DEFINITION

TABLE OF CONTENTS

CHAPTER 4

TABLE OF CONTENTS (Continued)

CHAPTER 4

TABLES

CHAPTER 4

FIGURES

CHAPTER 4

FIGURES (Continued)

4.2 LOCA LOAD DEFINITION

Sections 4.2.1 and 4.2.2 discuss the numerical definition of loads resulting from a LOCA in the LGS containment. The LOCA loads are divided into four groups:

a. Short-term LOCA loads associated with poolswell (Section 4.2.1)

b. Condensation oscillation and chugging loads (Section 4.2.2)

c. Secondary loads (Section 4.2.3)

d. Long-term LOCA loads (Section 4.2.4)

The application of these loads to the various components and structures on the LGS containment is discussed in Section 4.2.5.

4.2.1 LOCA LOADS ASSOCIATED WITH POOLSWELL

In the first few seconds following a postulated LOCA, a mixture of air and steam is carried through the containment downcomers into the suppression pool. The loads associated with the transfer of the air/steam mixture are referred to as poolswell loads. A description of the LOCA/poolswell transient is given in Section 3.2.3. The LOCA loads associated with poolswell are listed in Table 4.2-1.

4.2.1.1 Wetwell/Drywell Pressures During Poolswell

The drywell pressure transient used for the poolswell portion of the LOCA transient ($\leq$2.0 sec) is tabulated in Table 4.2-2. This drywell pressure transient includes the blowdown effects of pipe inventory and reactor subcooling and is the highest possible drywell pressure case for poolswell. This drywell pressure transient is calculated using the method documented in Reference 4.2-1.

The short-term wetwell pressure transient due to poolswell is calculated by applying the poolswell model contained in Reference 4.2-2 and Reference 1.3-1, section 4.2.2. Input used for calculation of the LGS unique poolswell transient is shown in Table 4.2-3.

The short-term wetwell pressure transient calculated with the poolswell code is shown in Figure 4.2-3. The short-term wetwell pressure peak is 53.644 psia (38.944 psig).

4.2.1.1.1 Differential Pressure Load on Diaphragm Floor

A vertical load on the diaphragm floor will occur because of the pressure difference between the drywell and the wetwell airspace. Normally, the net load acts downward, although an upward load may occur due to rapid pressurization of the wetwell airspace during the poolswell transient. A value of 5.5 psid will be used as a design value for the upward load on the diaphragm floor in Mark II containments, as recommended in Reference 1.3-5 and section 4.2.5.2 of Reference 1.3-1.

4.2.1 2 Submerged Boundary Loads During Vent Clearing

The submerged jet formed by the expulsion of the water leg in the downcomers creates a vent clearing load on the basemat and the submerged wetwell walls. This loading is defined by Reference 4.2-3 as a 24 psi overpressure statically applied with hydrostatic pressure to surfaces below the vent exit, linearly attenuating to zero at the pool surface (Figure 4.2-1). This load is applied during vent clearing as required by Reference 1.3-5, section 2.1.2.1.

4.2.1.3 LOCA Jet Loads

During the vent clearing stage, induced velocity and acceleration fields are created in the suppression pool. These induced fields produce drag forces on submerged structures. The original methodology employed to predict the drag forces is contained in Reference 4.2-4 (often called the Moody jet model) and is an analytical representation of an unsteady water jet discharging into a suppression pool. The jet is made up of constant velocity fluid particles traveling at the speed at which they exited the discharge pipe. The jet front is described as the locus of points through which a particle overtakes the one exiting immediately before it. No velocities or accelerations are defined in the fluid external to the jet.

Reference 1.3-2, subsection III.D.1.a, proposed that velocity and acceleration be predicted throughout the pool using the potential function of a sphere at the jet front. A modification of the load calculated at jet impingement was also required. The

acceptance criterion was a simple method to determine a bounding jet load for all structures below the downcomer exits.

The Moody jet model was clearly derived for jets with constant or linearly increasing acceleration. However, the vent clearing transients predicted for Mark II plants typically have an increase in acceleration greater than linear. Strict application of Reference 4.2-4 leads to unrealistic mathematical results. Two interpretations of the results are possible depending on the time base employed. Examining the jet in "real time" (Reference 4.2-4), a jet can be seen with two independent fronts traveling at different speeds at different locations which coincide only at the point of jet dissipation. On the other hand, if the "exit time" (τ) is used as a basis, the jet reverses and moves backward in both space and "real time" before dissipation. Clearly neither of these observations is of much use in calculating loads on structures.

To overcome the difficulties of using this model, an alternative methodology has been formulated. The jet front will be described by the motion of the particle having traveled the farthest at any instant in time. This will be identical to the Moody jet motion for jets with linearly increasing acceleration but will yield a single continuous velocity and acceleration time history even if the acceleration increases more rapidly.

A sphere is then placed at the jet front generating a potential flow described by the following function:

$$\phi = \frac{-3}{8\pi} U_j V_w \frac{\cos\theta}{r^2} \qquad (4.2\text{-}1)$$

where:

(r, θ) = spherical coordinates from the sphere center to some position in the suppression pool with θ measured from the jet direction

U_j = the velocity of the sphere determined by the velocity of the particle having traveled the farthest at the instant in the time the draft forces are being computed

V_w = the initial volume of water in the vent.

The local velocity, U_∞, and acceleration, $\dot{U}_\infty$, are then calculated from the above relation by the methods of Reference 4.2-4. Once and local velocity and acceleration are know, the drag forces are computed from Reference 4.2-5 as follows:

$$F_A = \frac{\dot{U}_{\infty n} \upsilon \rho}{g_c} \qquad (4.2\text{-}2)$$

$$F_S = \frac{C_D A_x U_{\infty n}^2 \upsilon \rho}{2g_c}$$

where:

F_A = the acceleration drag

$\dot{U}_{\infty n}$ = the local acceleration field normal to the structure

υ = the acceleration drag volume for flow normal to the structure

ρ = the fluid density

F_S = the standard drag

C_D = the drag coefficient for flow normal to the structure

A_x = the projected structure area normal to $U_{\infty n}$

$U_{\infty n}$ = the local velocity field normal to the structure.

When the jet is predicted to dissipate, the sphere is traveling at the final jet velocity at the point of maximum jet penetration. This condition is used as the final load calculation point. The final jet velocity is that of the jet front just before the last particle leaving the vent reaches the jet front. The velocity of the last particle is disregarded.

The largest water jet loads on affected components are given in Table 4.2-5.

4.2.1.4 Boundary-Loads During Poolswell

During the poolswell transient, the high pressure air bubble that forms in the vicinity of the vent exit creates an increase in pressure on all suppression pool boundaries below the vent exit as well as those walls with which it is in direct contact. Boundaries that are between the bubble location and the point of maximum pool elevation also experience increased pressure loads corresponding to the increased pressure in the wetwell airspace, as well as the hydrostatic contribution of the water slug.

Reference 1.3-1, section 4.2.5, and Reference 1.3-5, section 2.1.2.5, describe the methodology for specification of these boundary loads. The poolswell analytical model is used to determine the maximum values of bubble pressure and wetwell airspace pressure. The analysis takes the maximum pool elevation as 1.5 times the initial submergence. Using this data, a static loading is applied to the containment structure as follows:

a. For the basemat - uniform pressure equal to the maximum bubble pressure superimposed on the hydrostatic load corresponding to a submergence from vent exit to the basemat

b. For the containment walls below the vent exit - maximum bubble pressure plus hydrostatic head corresponding to vertical distance from vent exit.

c. For the containment walls between the vent exit and maximum pool elevation - linear variation between maximum bubble pressure and maximum wetwell airspace pressure

d. For the containment walls above maximum pool elevation - maximum wetwell airspace pressure.

The pressure distribution used for the LGS analysis is shown in Figure 4.2-2.

4.2.1.5 Poolwell Asymmetric Air Bubble Load

The methodology used in Section 4.2.1.4 assumes that the air flow rate in each downcomer is equal, leading to a symmetric loading of the containment boundary. Concern has been expressed (Reference 1.3-2, subsection III.B.3.e) that circumferential variations in the downcomer air flow rate can occur, due to drywell air/steam mixture variation, that would result in variations in the bubble pressure load on the wetwell wall. This asymmetric loading condition is calculated by statically applying the maximum air bubble pressure, obtained from the PSAM computer code and listed in Table 4.2-6, to half of the submerged boundary and statically applying the hydrostatic pressure of the water column to the other half of the submerged boundary. The pressure load on the basemat and wetwell walls below the vent exit is the sum of the air pressure and the hydrostatic pressure. For the portion of the wall above the vent exit, the pressure increase due to the air bubble is linearly attenuated from the bubble pressure at the vent exit to zero at the pool surface. This increase is then added to the local hydrostatic pressure to obtain the total pressure. The time period of application of the load is from the termination of vent clearing until the maximum swell height is reached.

These loading conditions are conservative with respect to the NRC's long-term criteria for asymmetric bubble loads (Ref. 1.3-5, Appendix A).

4.2.1.6 Poolswell Impact Load

As the pool rises during poolswell, structures located between the initial suppression pool surface and the peak poolswell height are subject to the poolswell impact load. The poolswell maximum elevation is determined by the poolswell analytical model with polytropic exponent of 1.2 for wetwell air compression to a maximum swell height which is the greater of 1.5 times the maximum vent submergence or the elevation corresponding to the drywell floor uplift pressure of 2.5 psid (Ref. 1.3-1 and 1.3-5). For LGS, Reference 1.3-1 separates all impacted structures into two classes:

a. Impact loads on small structures (one dimension < 20 in.)

b. Impact loads on large structures (both dimensions > 20 in.). These structures are treated on a case-by-case basis.

There are plates to arrest the water flow from the highest pedestal opening. The impact loads on the "pedestal flow arrester" are equal to 308.6 lb. This value was computed based on the assumptions listed in Table 4.2-6.

Poolswell impact loads on small structures are determined as specified in Reference 1.3-5, Appendix A.

The PSAM computer runs summary is provided on Figures 4.2-3 through 4.2-7. These graphs present various poolswell plant-unique characteristics, including pressure-time, ΔP-time, velocity-time, velocity-height, and height-time parameters.

4.2.1.7 LOCA Air Bubble Submerged Structure Load

During the drywell air purge phase of a LOCA, an expanding bubble is created at the downcomer exits. These rapidly expanding bubbles create three-dimensional velocity and acceleration fields.

To determine the drag loads, the system was modeled acoustically by the inhomogeneous wave equation (Reference 4.2-8). A bubble source was developed from 4T test data and qualitative information. Table 4.2-7 presents major LOCA air bubble loads.

4.2.1.8 Poolswell Drag Load

Subsequent to bubble contact, all bubbles are assumed to coalesce into a blanket of air, and the poolswell drag loads are due to the slug of water rapidly accelerating upward. The loads act in the vertical direction only (except for lift forces that act in the transverse direction to the flow). The one-dimensional poolswell model is used to predict the velocity and acceleration at the structure location. As recommended in References 1.3-5 and 1.3-2 and consistent with Section 4.2.3.5 of Reference 1.3-1, the velocity is increased by 10% for additional conservatism to

account for possible bubble asymmetry. Once the flow field is known, the drag forces are calculated by the methods of Appendix C. This methodology conservatively estimates a standard drag coefficient for unsteady flow. This drag load applies to any structure located between the elevation of the vent exit and the peak poolswell height. The duration of the drag load begins when the vent clears, except for structures that are originally not submerged. For structures that are not submerged, the drag load duration is based on the slug transient time (Reference 4.2-6, page 4-78, step 3). Friction drag forces on vertical piping, downcomers, and columns are given in Table 4.2-8.

4.2.1.9 Poolswell Fallback Load

After the termination of poolswell, the slug of water falls under the influence of gravity, causing drag forces on structures located between the peak poolswell height and the vent exit. The motion of the water is described by the following equations:

$$H(t) = H_{max} - \frac{1}{2} gt^2 \qquad (4.2\text{-}3)$$

$$V_{FB}(t) = gt$$

$$\dot{V}_{FB} = g$$

where:

g = the acceleration of gravity

H(t) = the height above initial water level at time t

Hmax = the maximum swell height

t = the time (starting with t=0) at maximum swell height

The drag load is then calculated from the methods of Appendix C. The loading stops when H(t) has fallen below the structure or when H(t) has returned to the normal water level, whichever is calculated to occur first.

The poolswell fallback analysis of piping that has interference effects was performed by using the FORCE II computer code. The results indicate that the interference effects increase the vertical load component by a maximum of 16%, depending on the elevation. The fallback load on the pedestal flow arrester is given in Table 4.2.9.

4.2.2 CONDENSATION OSCILLATIONS AND CHUGGING LOADS

Condensation oscillation and chugging loads follow the poolswell loads in time. There are basically three loads in this secondary time period, i.e., from about 4 to 60 seconds after the break. Condensation oscillation is broken down into two phenomena, a mixed flow regime and a steam flow regime. The mixed flow regime is a relatively high mass flux phenomenon that occurs during the final period of air purging from the drywell to the wetwell when the mixed flow through the downcomer vents contains some air as well as steam. The steam flow portion of the condensation oscillation phenomena occurs after all the air has been carried over to the wetwell and a relatively high intermediate mass flux of pure steam flow is established.

Chugging is a pulsating condensation phenomenon that can occur either following the intermediate mass flux phase of a LOCA or during the class of smaller postulated pipe breaks that result in steam flow through the vent system into the suppression pool. A necessary condition for chugging to occur is that only pure steam flows from the LOCA vents. Chugging imparts a loading condition to the suppression pool boundary and all submerged structures.

4.2.2.1 Containment Boundary Loads Due to Condensation Oscillations

The containment boundary loads due to condensation oscillation are based on direct application of pressure measurements in the drywell and the suppression pool from the full-scale 4TCO tests, as described in Reference 1.3-1, section 4.3, and Reference 4.2-7.

The basic condensation oscillation load is a bounding load for any condensation oscillation condition expected during a hypothetical LOCA in the LGS plant. All 28 of the 4TCO test runs were analyzed to determine the bounding time periods. The criterion for the selection of these time periods was to bound the maximum power spectral density values observed at the bottom center pressure throughout the condensation oscillation period in

all runs -- in any 2.048-second block for all frequencies from 0 to 60 Hz -- in approximately 0.5 Hz increments. The selected time periods were independently confirmed to be bounding by the amplified-response-spectra analysis (Ref 4.2-7, Appendix A).

The pressure-response-spectrum envelope for the time periods selected is shown in Figure 4.2-8; the spatial pressure distribution is shown in Figure 4.2-9. The drywell pressure histories for the time periods defined in Reference 4.2-7 are applied uniformly throughout the drywell.

4.2.2.2 Pool Boundary Loads Due to Chugging

The Mark II generic chugging load definition was developed by applying the acoustic chugging methodology described in Reference 4.2-8 to the chugging data base provided by the Mark II 4T Condensation Oscillation (4TCO) Test Program (Reference 4.2-9). The definition of a chugging load starts with the identification of steam-bubble collapse as the fundamental excitation mechanism. The collapse produces acoustic responses in the suppression pool and the vents. The combined excitation of the suppression pool and vent response is characterized as a time-varying volumetric point source in the acoustic model. Point sources for the 4TCO facility are inferred from 4TCO wall pressures via the 4TCO acoustic model. These point sources can be applied to an acoustic model of the Mark II suppression pool because the bubble collapse and vent response in Mark II are correctly simulated by the prototypical 4TCO geometry and blowdown conditions. The multivent effects of variation in chug strength and chug time among vents are incorporated in the Mark II application (Reference 4.2-10).

Seven large (key) chugs from the 4TCO data base were used to develop design sources to be applied to the acoustic model of the Limerick containment. These design sources are to be applied desynchronized, using the set of chug start times having the smallest variance in one-thousand Monte Carlo trials drawn from a uniform distribution of start times having a width of 500 milliseconds (ms). The chug start times are randomly assigned to the vents in the Mark II containment.

The observation of vent desynchronization has been verified by determining the time delay between individual bubble collapses in the full-scale, 7-vent tests conducted by the Japan Atomic Energy Research Institute (JAERI). Conservatism is ensured by applying to the Mark II plant models a minimum estimate of the time window within which the individual bubble collapses must occur.

Two cases of source application are specified: symmetric and asymmetric. The symmetric case is defined as the desynchronized application of each of the design sources in turn, at every vent-exit location in the LGS pool. The definition of the asymmetric case starts with the identification of a design moment axis which divides the suppression pool into two halves. Adjustment factors are applied to the design sources to raise their strength on one side of the pool and lower their strength on the other side. This procedure and its rationale are described in Reference 4.2-10.

4.2.2.3 Downcomer Lateral Loads

During chugging and condensation oscillation, a downcomer will experience intermittent lateral loading. However, the 4TCO tests (Ref 4.2-9) have shown that the magnitude of the lateral loading in a Mark II facility during the condensation oscillation phase is relatively small compared to chugging-induced lateral loads. The chugging lateral load may be the result of asymmetric steam bubble collapse or the result of the impact on the vent caused by rapidly in-flowing water. In either case, the loads occur near the downcomer exit and have been observed to be impulsive in nature and random in both magnitude and direction. The stochastic nature of the loads appears unaffected by the proximity of other structures such as containment walls or another downcomer as close as three vent diameters away. The duration of an individual lateral load is typically less than a 10 ms half sine wave. The single vent, lateral load specification for LGS consists of a static-equivalent load of 10 kips and 6 ms for low intensity chugs, 30 kips and 3 ms for the high-intensity chugs, and 65 kips and 3 ms for the low-probability, very high-intensity chugs (Figure 4.2-10). This 65,000 lbf load (Ref 1.3-5) corresponds to the maximum load implied by extrapolation in the cold-pool tests of GKM II data with an exceedance probability of 0.1 per LOCA.

4.2.2.4 Multiple Vent Lateral Loads

Test data observations indicate that chugging forces on a single downcomer occur periodically in random directions for short time durations. The probability that the number of downcomers loaded with the maximum force in a particular time interval in the same direction is extremely small. Nonetheless, there is a small but finite probability that some fraction of the downcomers may experience a fraction of the load acting in the same direction at the same time.

The methodology used for deriving the lateral loads on the various downcomer group combinations that will result in a conservative assessment is described in Reference 1.3-5. The results indicate that a probability level of 10^{-4} for exceeding an impulse in 265 chugs is adequate for determining the total load on a group of downcomers. Phasing between vents is completely neglected. These two factors result in a conservative methodology for multiple vent lateral loads. The value of 265 chugs was reached based on consideration of a range of small liquid breaks (Ref 1.3-2).

4.2.2.5 Submerged Structure Loads Due to Condensation Oscillation and Chugging

Condensation oscillation and chugging create velocity and acceleration fields in the suppression pool that cause submerged structure drag loads. The pressure distributions corresponding to sources from the GE 700 series (Ref 4.2-10) are computed at several elevations (nodes) around the submerged structure using IWEGS/MARSOFT (for condensation oscillation) and IWEGS/MARS-P (for chugging). These pressure responses around the body of each level are then spatially integrated to obtain the dynamic load due to fluid motion (force per unit length).

$$F = \int P ds \qquad (4.2\text{-}4)$$

where p is the fluid pressure acting on an area increment ds = nds, n being the inward-pointing normal unit vector at ds. The submerged structure load is equal to double the dynamic load due to the effect of the hydrodynamic mass. Table 4.2-10 provides a summary of maximum force per unit length on various submerged structures for condensation oscillation and chugging phases.

4.2.3 SECONDARY LOADS

The previous sections have identified and specified loading methodologies that result in significant containment dynamic loads. In addition, several pool dynamic loads can occur that are considered secondary when compared to the previous loads or because the containment and related equipment response is small when subjected to them. The following sections identify the secondary loads and the load criteria to be applied to the LGS containment.

4.2.3.1 Downcomer Friction Drag Loads

Friction drag loads are experienced internally by the downcomers during vent clearing and subsequent air or steam flow. In addition, the downcomers experience an external drag load during poolswell. Using standard drag force calculation procedures, these loads are determined to be 0.6 and 0.3 kips per downcomer, respectively, and are not considered in the structural evaluation of the containment.

4.2.3.2 Sonic Waves

Immediately following the postulated instantaneous rupture of a large primary system pipe, a sonic wave front is created at the break location and propagates through the drywell to the vent system. This load has been determined to be negligible and, therefore, none is specified.

4.2.3.3 Compressive Wave

The compression of the air in the drywell and vent system causes a compressive wave to be generated in the downcomer water legs. This compressive wave propagates through the pool and causes a differential pressure loading on the submerged structures and on the wetwell wall. This load has been evaluated and is considered negligible.

4.2.3.4 Fallback Loads on Submerged Boundaries

During fallback, waterhammer-type loads could exist if the water slug remained intact during this phase. However, available test data indicate that this does not occur, and the fallback process consists of a relatively gradual setting of the pool water to its initial level as the air bubble percolates upward. This is based on visual observations during the EPRI tests (Ref 4.2-11) as well as indirect evidence provided by an examination of pool bottom pressure forces from the 4T, EPRI, foreign licensee, and Marviken tests. Thus, these loads are small and will not be considered.

4.2.3.5 Vent Clearing Loads on the Downcomers

The expulsion of the water leg in the downcomers at vent clearing creates a transient water jet in the suppression pool. This jet

formation may occur asymmetrically leading to lateral reaction loads on the downcomer. However, this load is bounded by the load specification during chugging and will not be considered for containment analysis.

4.2.3.6 Post-Poolswell Waves

Following the poolswell process, continued flow through the vent system generates random pool motion. The pool motion creates waves that have negligible impinging effects on the LGS wetwell wall and internal components.

4.2.3.7 Seismic Slosh

The computer code SOLA-3D was used to estimate the suppression pool seismic slosh hydrodynamic loads. The results indicate that seismic slosh loads in the LGS plant are much less than the LOCA chugging loads or the SRV air clearing bubble oscillation loads (on the order of a few psi at a relatively low frequency depending on location and direction).

The maximum wave (sloshing) height is 1.6 feet. The nodal force close to the pool bottom oscillates between 112 to 68 kips (including static load). Therefore, the bottom pressure rises to about 1.2 psi above the static pressure due to sloshing. The dominant frequency of the sloshing motion is 0.1 Hz, whereas the dominant frequency of the seismic acceleration is about 2 Hz.

4.2.3.8 Thrust Loads

Thrust loads are associated with the rapid venting of air and/or steam through the downcomers. To determine this load, a momentum balance for a control volume consisting of the drywell, diaphragm floor, and vents is taken. Results of the analysis indicate that the load reduces the downward pressure differential on the diaphragm.

4.2.4 LONG-TERM LOCA LOADS

The loss-of-coolant accident (LOCA) causes pressure and temperature transients in the drywell and wetwell due to mass and energy released from the line break. The drywell and wetwell pressure and temperature time histories are required to establish

the structural loading conditions in the containment because they are the basis for other containment hydrodynamic phenomena. The response must be determined for a range of parameters such as break size, reactor pressure, and containment initial conditions.

4.2.4.1 Design Basis Accident (DBA) Transients

The DBA LOCA for LGS is conservatively estimated to be a 3.538 ft^2 break of the recirculation line. This transient results in the maximum drywell pressure and therefore governs the LOCA hydrodynamic loads. The LGS-unique input for the analysis is shown in Table 4.2-4. Drywell and wetwell pressure and temperature reponses are shown in Figures 4.2-11 and 4.2-12. This description of the transient does not include the effect of reactor subcooling.

4.2.4.2 Intermediate Break Accident (IBA) Transients

The worst-case intermediate break for LGS is a 0.1 ft^2 break of a liquid line. The drywell and wetwell pressure and temperature responses are shown in Figures 4.2-13 and 4.2-14. This description of the transient does not include the effect of reactor subcooling.

4.2.4.3 Small Break Accident (SBA) Transients

Plant-unique SBA data for LGS is not available. The wetwell and drywell pressure and temperature transients for a typical Mark II containment are used to estimate the LGS containment response to these accidents. These curves are shown in Figure 4.2-15 (extracted from Reference 4.2-6).

4.2.5 LOCA LOADING HISTORIES FOR LGS CONTAINMENT COMPONENTS

The various components directly affected by LOCA loads are shown schematically in Figure 4.2-16. These components may in turn load other components as they respond to the LOCA loads. For example, lateral loads on the downcomer vents produce minor reaction loads in the drywell floor from which the downcomers are supported. The reaction load in the drywell floor is an indirect load resulting from the LOCA and is defined by the appropriate structural model of the downcomer/drywell floor system. Only the direct loading situations are described in detail here.
Table 4.2-11 is a LOCA load chart for LGS. This chart shows

which LOCA loads directly affect the various structures. Details of the loading time histories are discussed below.

4.2.5.1 LOCA Loads on the Containment Wall and Pedestal

Figure 4.2-17 shows the LOCA loading history for the LGS containment wall and the RPV pedestal. The wetwell pressure loads apply to the unwetted elevations in the wetwell; addition of the appropriate hydrostatic pressure is made for loads on the wetted elevations. Condensation oscillation and chugging loads are applied to the wetted elevations in the wetwell only. The poolswell air bubble load applies to the wetwell boundaries as shown in Figures 4.2-8 and 4.2-9.

4.2.5.2 LOCA Loads on the Basemat and Liner Plate

Figure 4.1-18 shows the LOCA loading history for the LGS basemat and liner plate. Wetwell pressures are applied to the wetted and unwetted portions of the liner plate as discussed in Section 4.2.6.1. The downcomer water jet impacts the basemat liner plate as does the poolswell air bubble load. Chugging and condensation oscillation loads are applied to the wetted portion of the liner plate.

4.2.5.3 LOCA Loads on the Drywell and Drywell Floor

Figure 4.2-19 shows the LOCA loading history for the LGS drywell and drywell floor. The drywell floor undergoes a vertically applied, continuously varying differential pressure, the upward component of which is especially prominent during poolswell when the wetwell airspace is highly compressed.

4.2.5.4 LOCA Loads on the Columns

Figure 4.2-20 shows the LOCA loading history for the LGS columns. Poolswell drag and fallback loads are minor because the column surface is oriented parallel to the poolswell and fallback velocities. The poolswell air bubble, condensation oscillations, and chugging will provide loads on the submerged (wetted) portion of the columns.

4.2.5.5 LOCA Loads on the Downcomers

Figure 4.2-21 shows the LOCA loading history for the LGS downcomers. The downcomer clearing load is a lateral load applied at the downcomer exit (in the same manner as the chugging lateral load) plus a vertical thrust load. Poolswell drag and fallback loads are minor because the downcomer surfaces are oriented parallel to the poolswell and fallback velocities. The poolswell air bubble load is applied to the submerged portion of the downcomer as are the chugging and condensation oscillation loads.

4.2.5.6 LOCA Loads on the Downcomer Bracing

Figure 4.23-22 shows the LOCA loading history for the LGS downcomer bracing system. This system is not subject to impact loads because it is submerged at elevation 203 feet, 5 inches. As a submerged structure, it is subject to poolswell drag, fallback, and air bubble loads. Condensation oscillations and chugging at the vent exit will also load the bracing system both through downcomer reaction (indirect load) and directly through the hydrodynamic loading in the suppression pool.

4.2.5.7 LOCA Loads on Wetwell Piping

Figure 4.2-23 shows the LOCA loading history for piping in the LGS wetwell. Because the wetwell piping occurs at a variety of elevations in the LGS wetwell, sections may be completely submerged, partially submerged, or initially uncovered. Piping may occur parallel to poolswell and fallback velocities, as with the main steam safety relief piping. For these reasons, there are a number of potential loading situations that arise, as shown in Table 4.2-12. In addition, the poolswell air bubble load applies to the submerged portion of the wetwell piping as do the condensation oscillation and chugging loads.

4.2.7 REFERENCES

4.2-1 A.J. James, "The General Electric Pressure Suppression Containment Analytical Model", General Electric Co, July 1971.

4.2-2 Ernst, "Mark II Pressure Suppression Containment Systems: An Analyt cal Model of the Pool Swell Phenomenon", NEDE 21544-P, December 1976.

4.2-3 Letter MFN-080-79, L.J. Sobon (General Electric Co.) to J.F. Stolz (NRC), Subject: Vent Clearing Pool Boundary Loads for Mark II Plants, March 20, 1979.

4.2-4 F.J. Moody, "Analytical Model for Liquid Jet Properties for Predicting Forces on Rigid Submerged Structures," NEDE-21472, General Electric Co., September 1977.

4.2-5 R. J. Ernst, et al, "Mark II Pressure Suppression Containment Systems: Loads on Submerged Structures - An Application Memorandum," NEDE-21730, General Electric Co., September 1977.

4.2-6 "Dynamic Forcing Function Information Report (DFFR)," Rev. 3, NEDO-21061, General Electric Co. and Sargent and Lundy Engineers, June 1978.

4.2-7 "Generic Condensation Oscillation Load Definition Report," NEDE-24288-P, General Electric Co., November 1980.

4.2-8 "Mark II Improved Chugging Methodology," General Electric Co., NEDE-24822-P, May 1980.

4.2-9 "4T Condensation Oscillation Test Program Final Test Report," NEDE-24811-P, General Electric Co. May 1980.

4.2-10 "Generic Chugging Load Definition," NEDE-24302-P, General Electric Co., April 1981.

4.2-11 R.L. Kian and B.J. Grossi, "Dynamic Modeling of a Mark II Pressure Suppression System," EPRI NP-441, Palo Alto, April 1977.

TABLE 4.2-1

SHORT-TERM LOCA LOADS ASSOCIATED WITH POOLSWELL

Load	
1.	Wetwell/drywell pressures during poolswell
2.	Poolswell impact loads
3.	Poolswell drag loads
4.	Downcomer clearing loads
5.	Downcomer water jet load
6.	Poolswell air bubble load
7.	Poolswell fallback load

TABLE 4.2-2

SHORT-TERM DRYWELL PRESSURE DURING POOLSWELL

Time (sec)	Pressure (psia)
0.0000	36.11
0.0600	36.29
0.1000	36.82
0.1200	37.08
0.1600	37.57
0.2000	38.04
0.2400	38.49
0.2800	38.91
0.3200	39.30
0.3600	39.67
0.4000	40.01
0.5000	40.75
0.6000	40.75
0.7000	41.39
0.8000	42.07
0.9000	42.80
1.0000	43.56
1.1000	44.603
1.2000	45.36
1.3000	46.08
1.4000	46.75

TABLE 4.2-3

LGS PLANT UNIQUE POOLSWELL CODE INPUT DATA

Downcomer area (each)	2.95 ft^2
Suppression pool free surface area (outside pedestal)	4973.89 ft^2
Maximum downcomer submergence	12.25 ft
Downcomer loss coefficient (without exit loss)	1.11
Number of downcomers	87
Initial wetwell pressure	15.45 psia
Wetwell free air volume	149,425 ft^3
Vent clearing time	0.7107 sec
Pool velocity at vent clearing	3.096 ft/sec
Initial drywell temperature	135°F
Initial drywell relative humidity	0.20
Downcomer friction coefficient, f	0.0115 (nominal)
Bubble initialization parameter (nominal)	50

TABLE 4.2-4

INPUT DATA FOR LGS LOCA TRANSIENTS

Drywell free air volume (including downcomers)	248,950 ft^3
Wetwell free air volume	149,425 ft^3
Maximum downcomer submergence	12.25 ft
Downcomer flow area (total)	256.5 ft^2
Downcomer loss coefficient	2.11
Initial drywell pressure	14.8 psia
Initial wetwell pressure	15.45
Initial drywell humidity	100%
Initial pool temperature	90°F
Estimated DBA break size	3.538 ft^2
Number of vents	87
Minimum suppression pool mass	5.83 x 10^6 lb
Initial vessel pressure	1,055 psia
Vessel and internals mass	2,940,300 lb
Vessel and internals overall heat	484.9 Btu/sec °F
Vessel and internals specific heat	0.123 Btu/lb

TABLE 4.2-5

LOCA WATER JET LOADS

Largest vertical downward force component acting on reactor spray pump suction line	488 lb/ft
Largest horizontal force component acting on reactor spray pump suction line	620 lb/ft
Increase in largest vertical/horizontal forces on reactor spray pump suction due to interference effects of pool wall	6 - 7%
Largest vertical force on closest MSRV discharge line (distance = 2 ft)	1207 lb /ft
Largest horizontal force on closest MSRV discharge line (distance = 2 ft)	1394 lb /ft

TABLE 4.2-6

POOLSWELL IMPACT LOAD ON PEDESTAL
FLOW ARRESTER

Maximum air bubble pressure (P)	48.25 psia
Pedestal pressure (nominal conservative value)	15.4 psia
Pedestal opening (A)	3.14 ft^2
Velocity in the pool (V)	0.0
Impact pressure	0.683 psi
Impact force	308.6 lb

Assumptions:

Water moves as a piston and impinges on the plate

Water flows in the pedestal opening as in a pipe with inlet and exit losses.

TABLE 4.2-7

POOLSWELL AIR BUBBLE LOADS

Water volume in downcomers	3142.16 ft^3
Pool surface area (outside pedestal)	4973.89 ft^2
Maximum poolswell after water discharge	18.88 ft
Height of downcomer water in the pool	7.58 in.(0.632 ft)
Maximum poolswell height (18.88 + 0.632 ft)	19.51 ft
Basemat hydrostatic pressure	10.51 psig
Downcomer tip hydrostatic pressure	5.20 psig
Maximum air bubble pressure	48.25 psia
Maximum pressure at basemat	58.76 psia
Maximum pressure at downcomer tip	48.25 psia
Maximum poolswell inside the pedestal	212 ft-10 in. (6.62 ft above the high water level)

TABLE 4.2-8

POOLSWELL WATER FRICTION DRAG LOADS

Friction drag loads on columns	
Number of columns	12
Surface area per column	214.55 ft^2
Friction force for 12 columns	5098 lbf
Shear stress	0.01375 lb /$in.^2$
Friction drag load on downcomers	
Number of downcomers	87
Surface area per downcomer	122.6 ft^2
Frictional drag coefficient	0.00216
Friction force for 87 downcomers	2112.2 lb
Friction drag load on MSRV pipes	1806 lb
Air friction drag inside downcomers	303 lb
Downcomer bracing loads	
Vertical load (8 in. nominal diameter)	1590 lb /ft
Horizontal load (8 in. nominal diameter)	1230 lb /ft
Vertical load (10 in. nominal diameter)	2190 lb /ft
Horizontal load (10 in. nominal diameter)	1690 lb /ft

TABLE 4.2-9

FALLBACK LOAD ON PEDESTAL FLOW ARRESTER

Maximum elevation	225.679 ft
Wetwell pressure (maximum)	53.685 psia
Hydrostatic pressure (225.679 ft - 222.5 ft)	1.38 psi
Velocity	7.827 fps
Impact pressure	0.825 psi
Impact force	373 lb

TABLE 4.2-10

MAXIMUM LOAD ON SUBMERGED STRUCTURES

Submerged Structure	Max CO Load (lb/in.)	Max Chugging Load (lb/in.)
MSRVDL	3.8	24.0
Downcomer	22.0	36.0
Bracer	0.8	25.2
Core spray line	0.22	6.6
HPCI line	22.0	22.0
RHR line	2.2	16.0
Column	38.0	170.0

TABLE 4.2-11

COMPONENT LOCA LOAD CHART FOR LGS

Structure Directly Affected	Load 1	2	3	4	5	6	7	8	9	10	11	12	13
Containment wall	X					X		X	X	X	X	X	X
Pedestal (incl. interior)	X					X		X	X	X	X	X	X
Basemat	X				X	X		X	X	X	X	X	X
Liner plate	X				X	X		X	X	X	X	X	X
Drywell floor	X										X	X	X
Drywell	X										X	X	X
Columns			X			X	X	X	X	X			
Downcomers			X	X		X	X	X	X	X			
Downcomer bracing			X			X	X	X	X	X			
Wetwell piping		X	X		X	X	X	X	X	X			

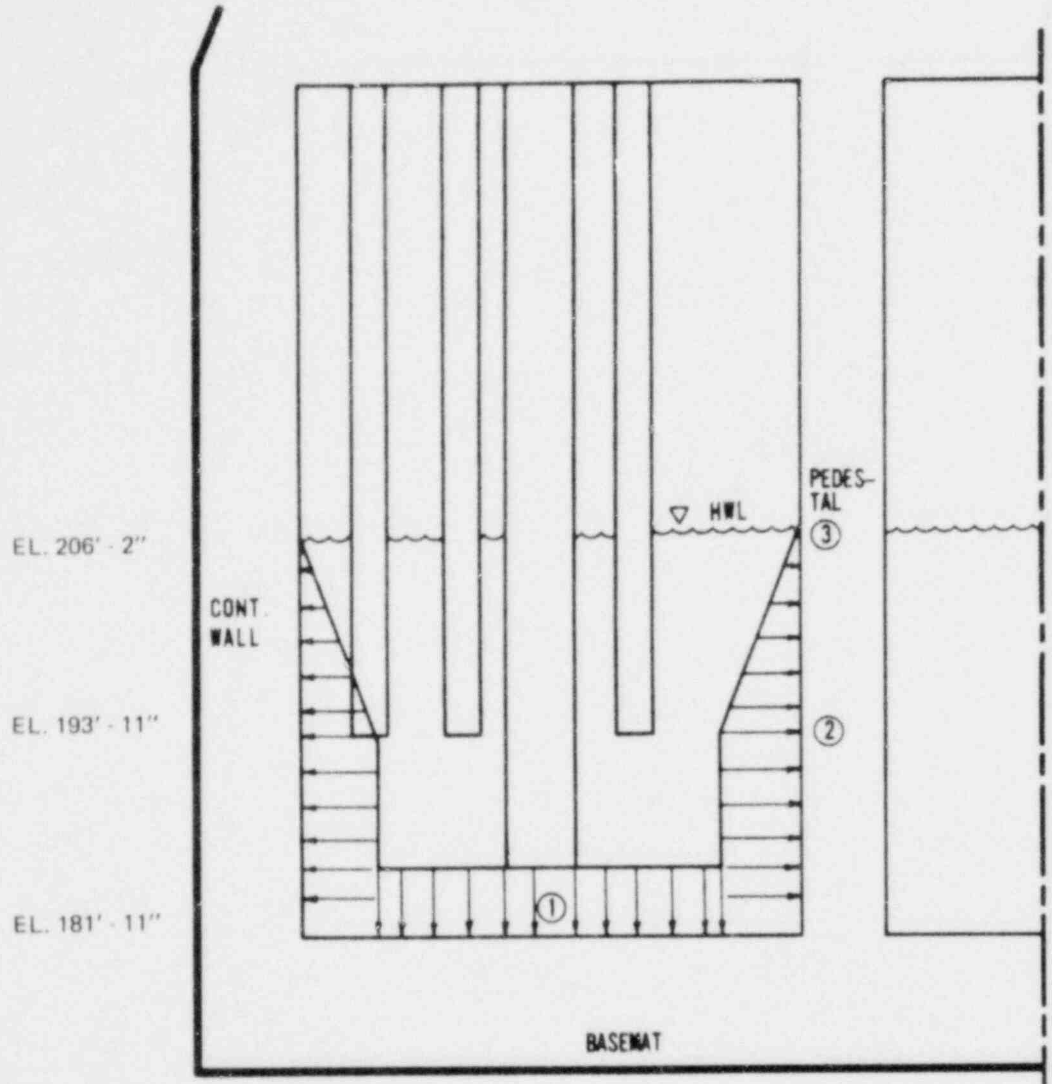
Load Legend

1 Wetwell/drywell pressure during poolswell
2 Poolswell impact load
3 Poolswell drag load
4 Downcomer clearing load
5 Downcomer water jet load
6 Poolswell air bubble load
7 Fallback load
8 High mass flux condensation load
9 Medium mass flux condensation load
10 Chugging load
11 Wetwell/drywell P and T during DBA
12 Wetwell/drywell P and T during IBA
13 Wetwell/drywell P and T during SBA

TABLE 4.2-12

WETWELL PIPING LOCA LOADING SITUATIONS

Piping Configuration	LOCA Load to be Applied
1 Completely Submerged	
(a) vertical	skin drag load only (Cf)
(b) horizontal	drag load (CD)
2 Partially Submerged	
(a) vertical	skin drag load only (Cf)
3 Initially Uncovered	
(a) vertical	skin drag load only (Cf)
(b) horizontal	impact load, then drag load (CD)



① 24 + 14.7 + 10.51 = 49.21 psia

② 24 + 14.7 + 5.2 = 43.9 psia

③ 0 + 14.7 + 0 = 14.7 psia

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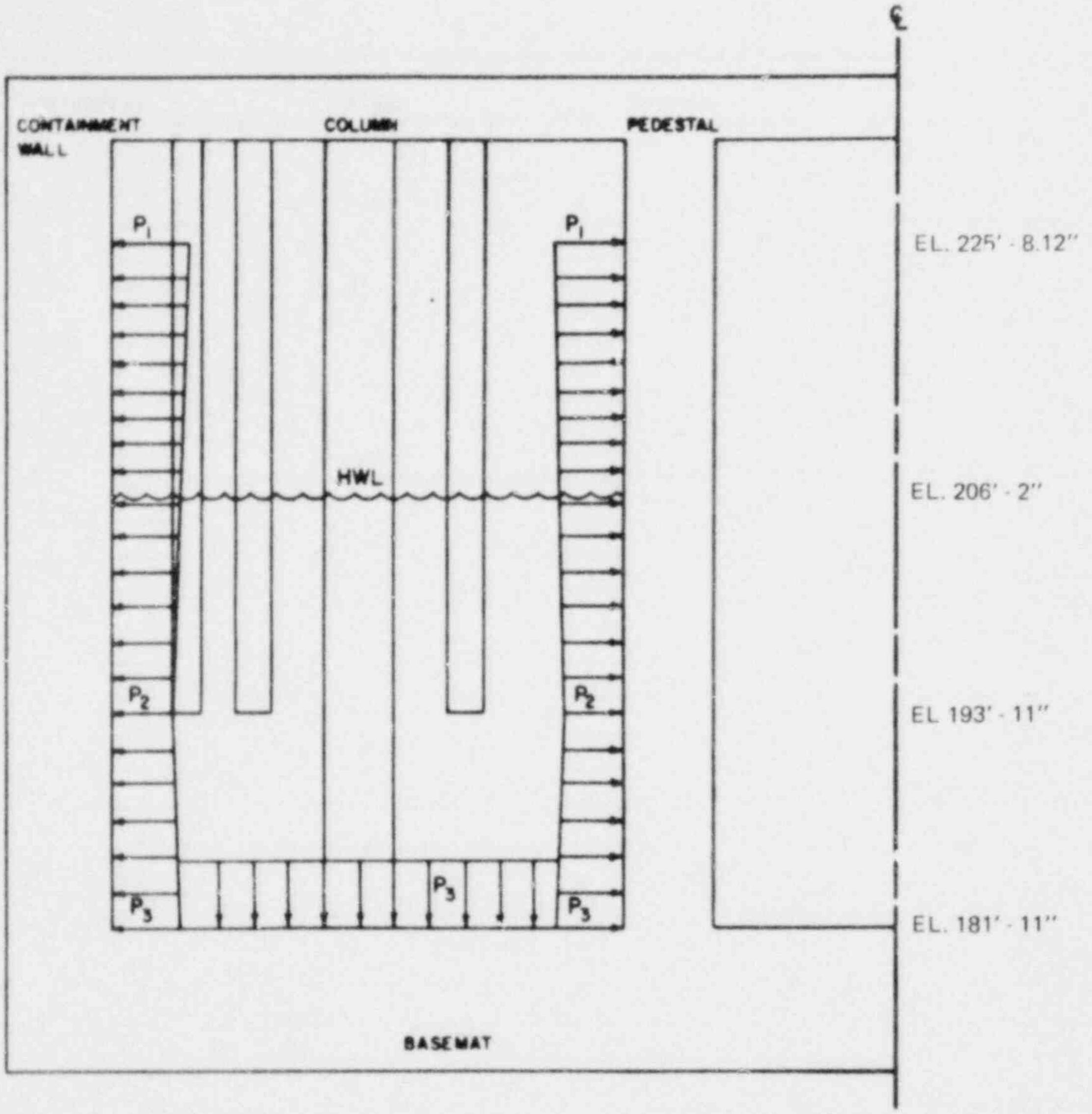
VENT CLEARING
PRESSURE DISTRIBUTION

FIGURE 4.2-1



P_1 = 53.64 psia

P_2 = 48.25 psia

P_3 = 58.76 psia

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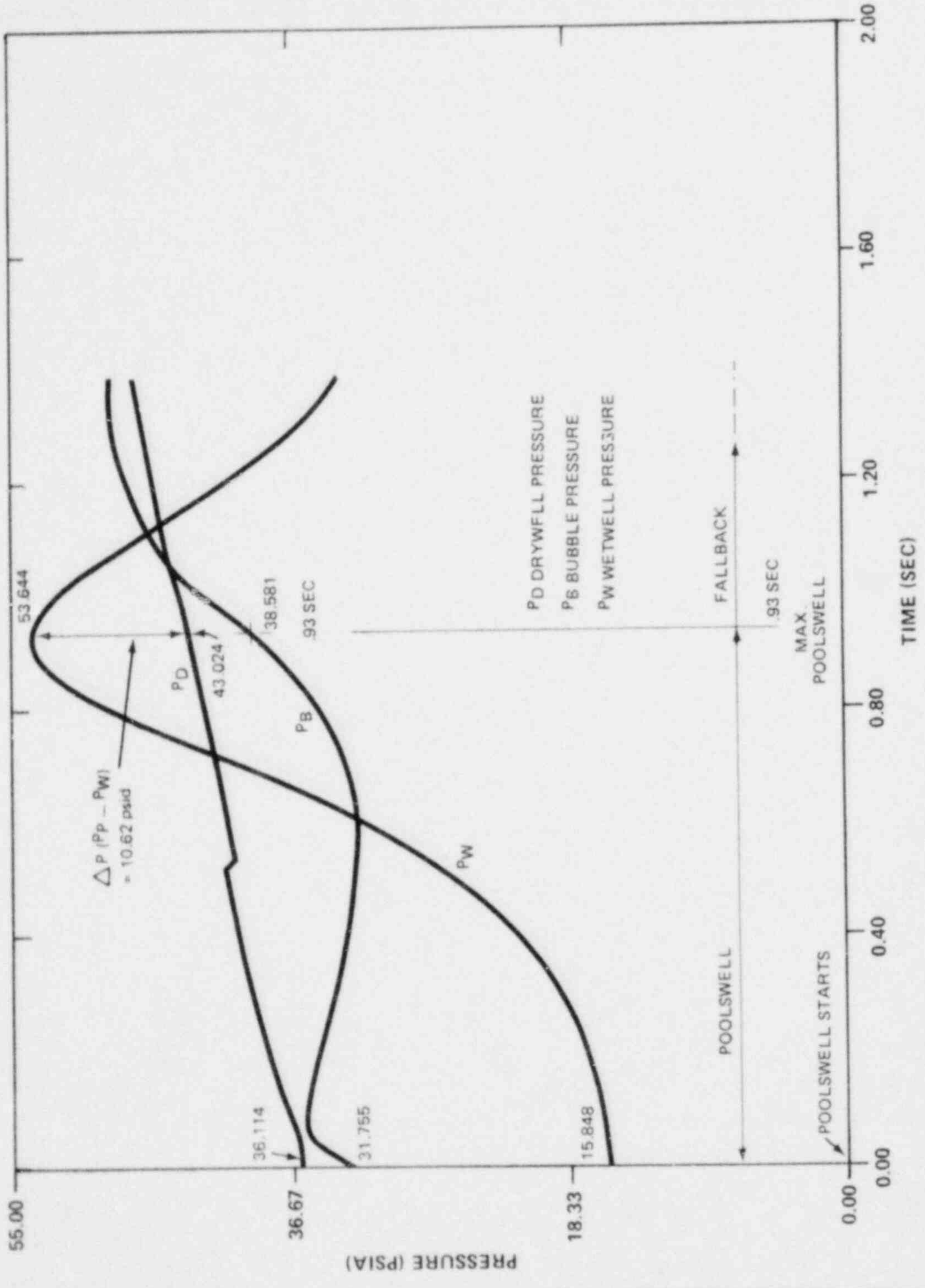
POOLSWELL AIR BUBBLE PRESSURE ON SUPPRESSION POOL WALLS

FIGURE 4.2 - 2



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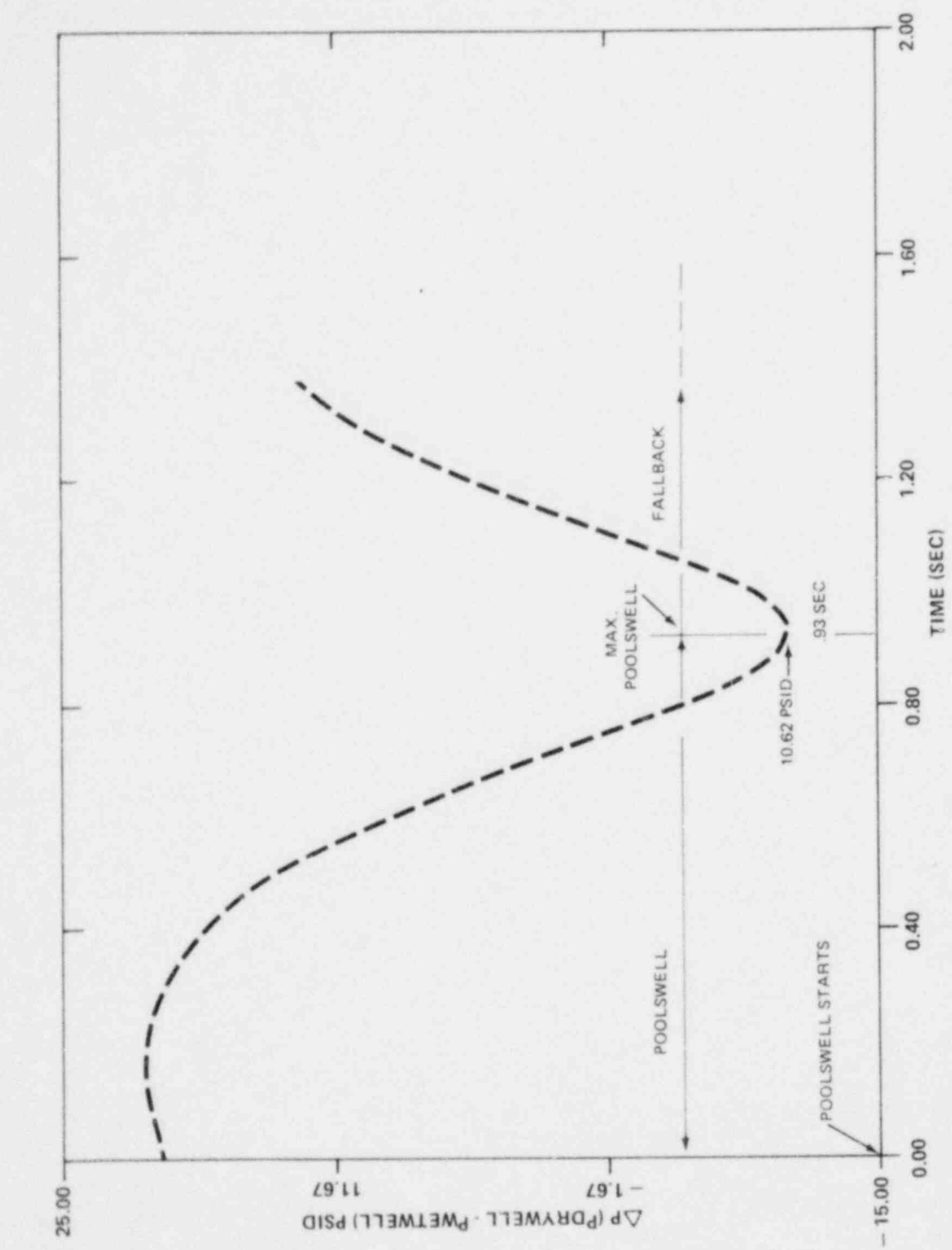
WETWELL, DRYWELL, AND
AIR BUBBLE PRESSURES
DURING POOLSWELL

FIGURE 4.2-3



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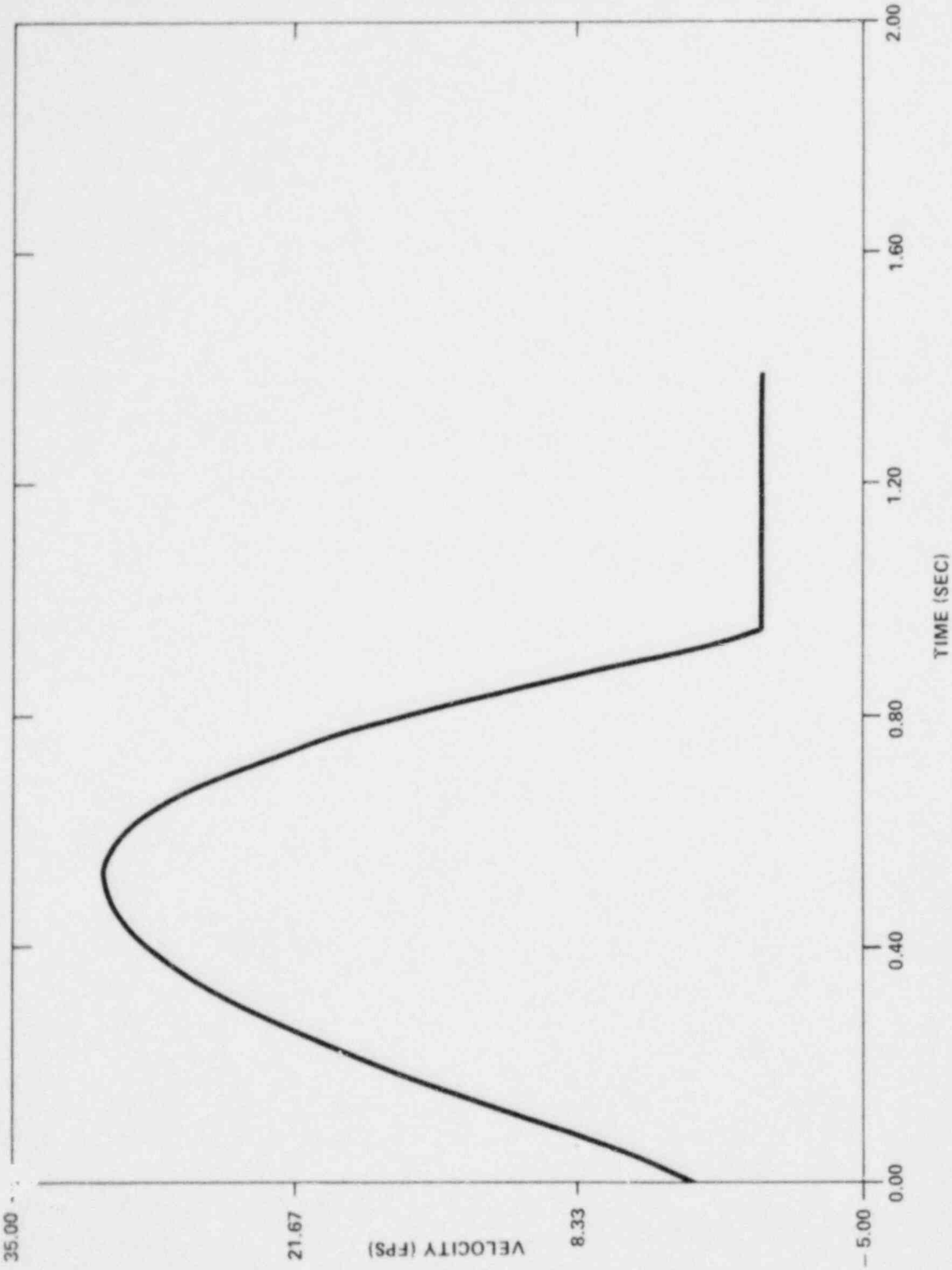
DRYWELL AND WETWELL
ΔP DURING POOLSWELL

FIGURE 4.2-4



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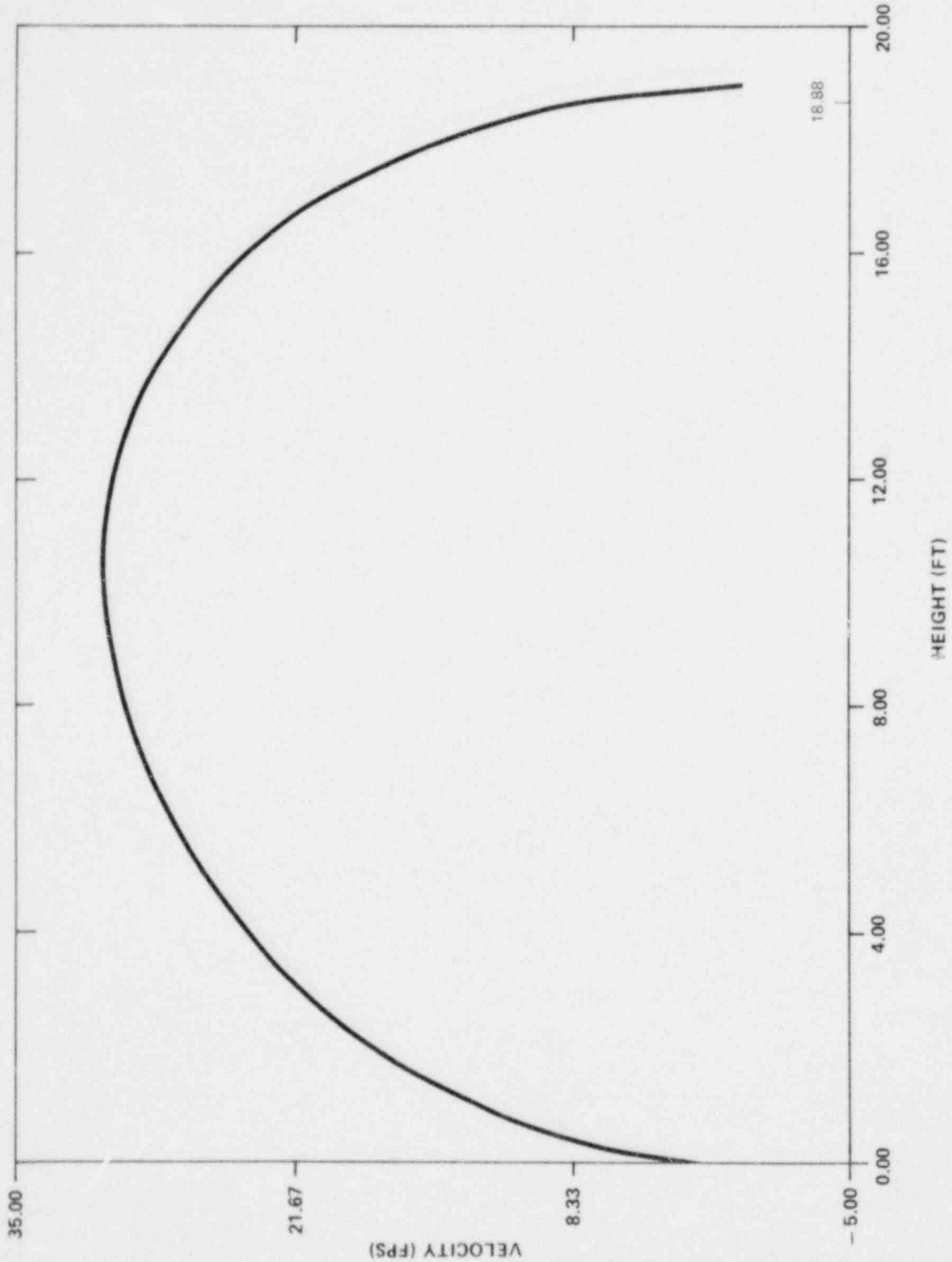
POOL SURFACE VELOCITY
DURING POOLSWELL

FIGURE 4.2-5



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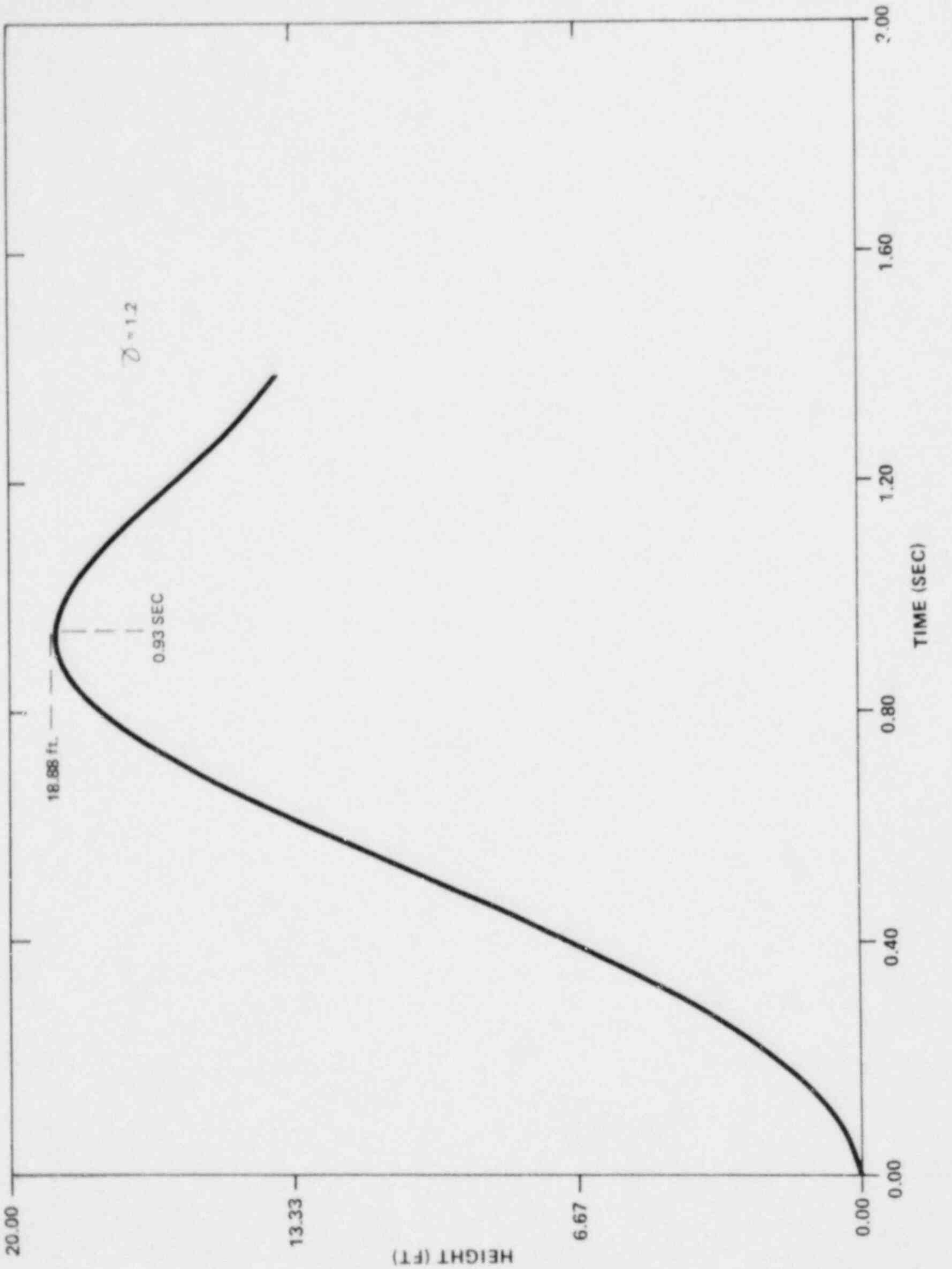
POOL SURFACE VELOCITY
VS. POOL HEIGHT

FIGURE 4.2-6



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UNITS 1 AND 2
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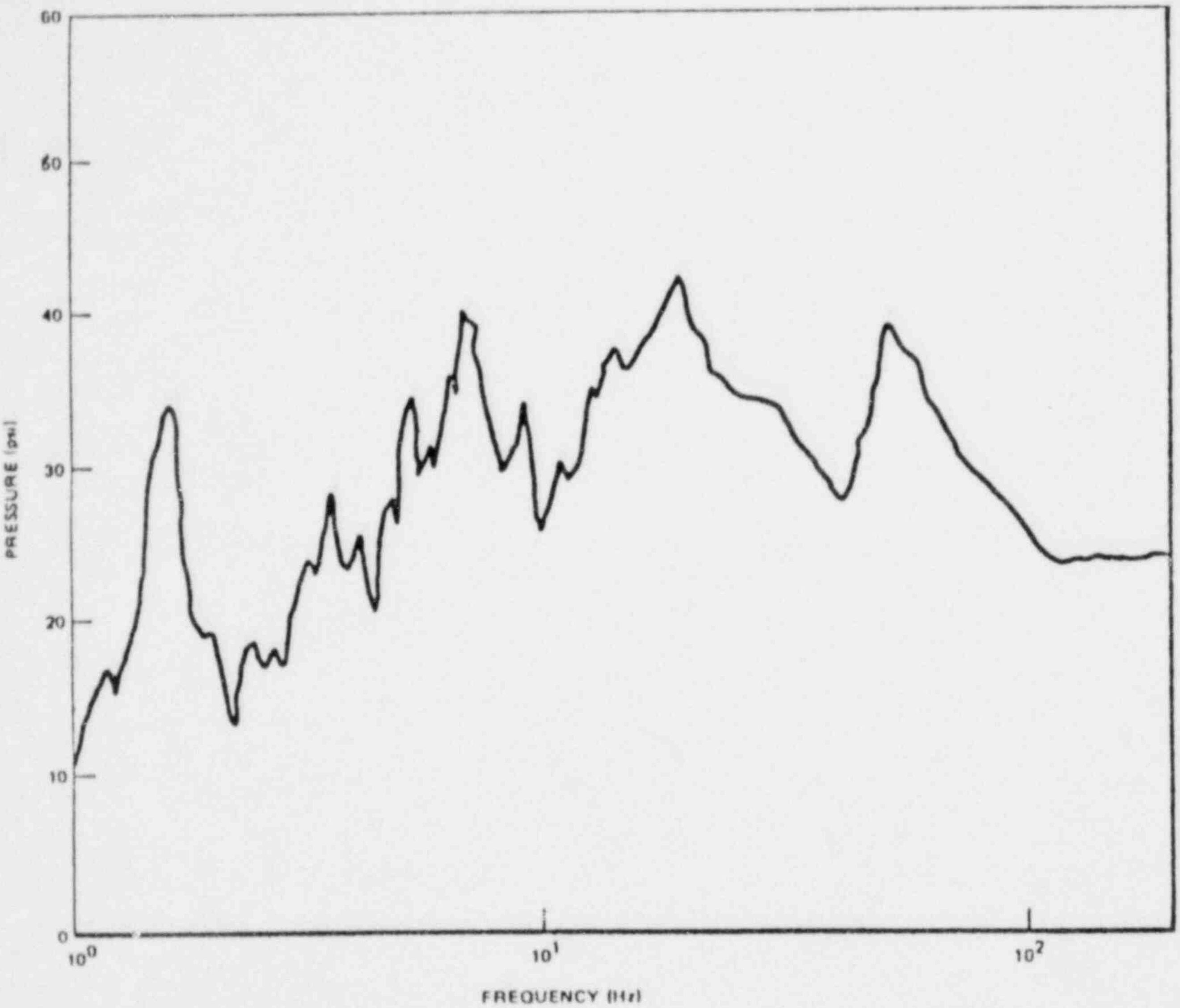
POOL HEIGHT DURING POOLSWELL

FIGURE 4.2-7



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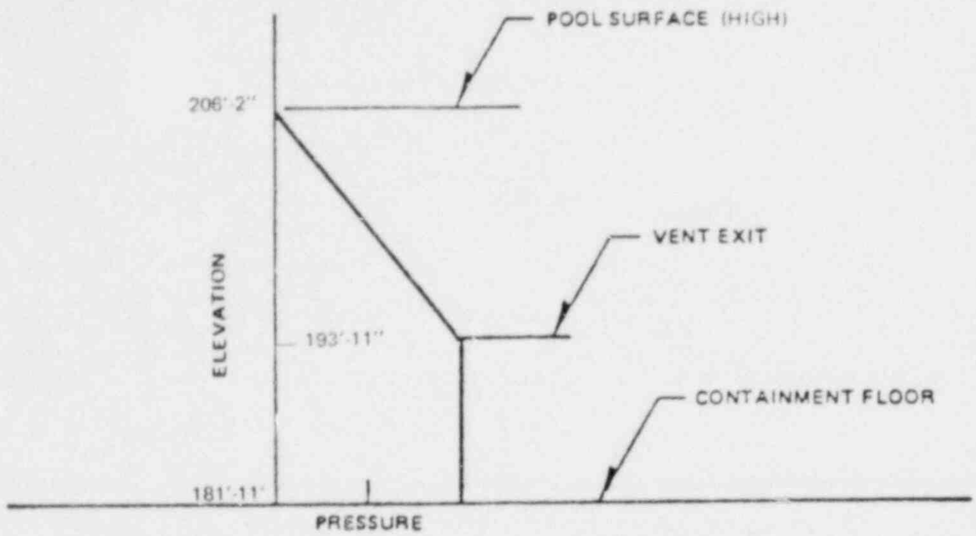
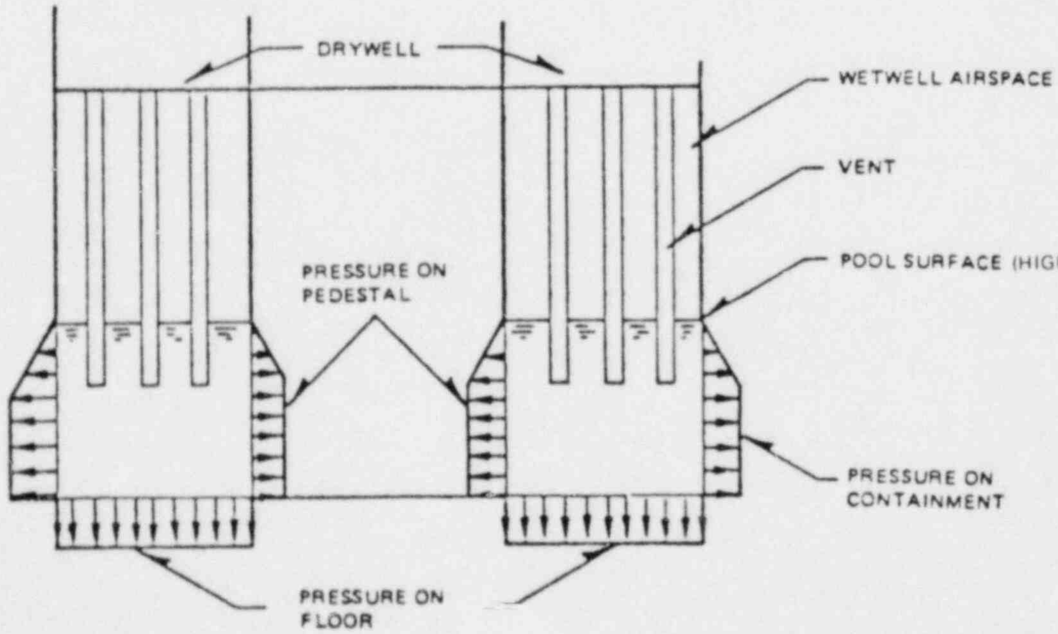
PRESSURE-RESPONSE-SPECTRUM ENVELOPE FOR TIME PERIODS SELECTED FOR CO LOAD DEFINITION

FIGURE 4.2-8



DETAIL OF PRESSURE DISTRIBUTION



OVERVIEW OF PRESSURE DISTRIBUTION

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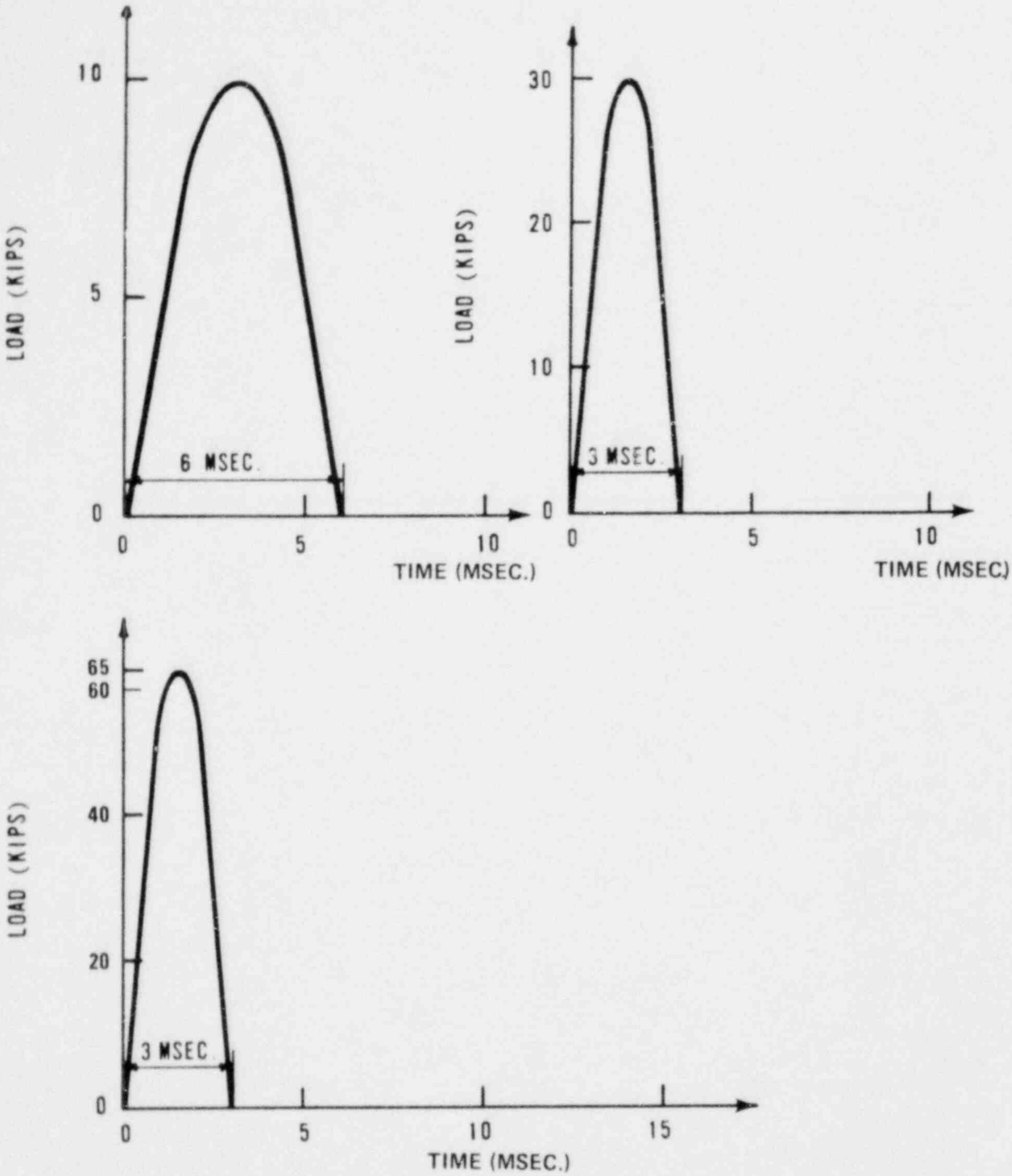
SPATIAL DISTRIBUTION
OF CO LOAD

FIGURE 4.2-9



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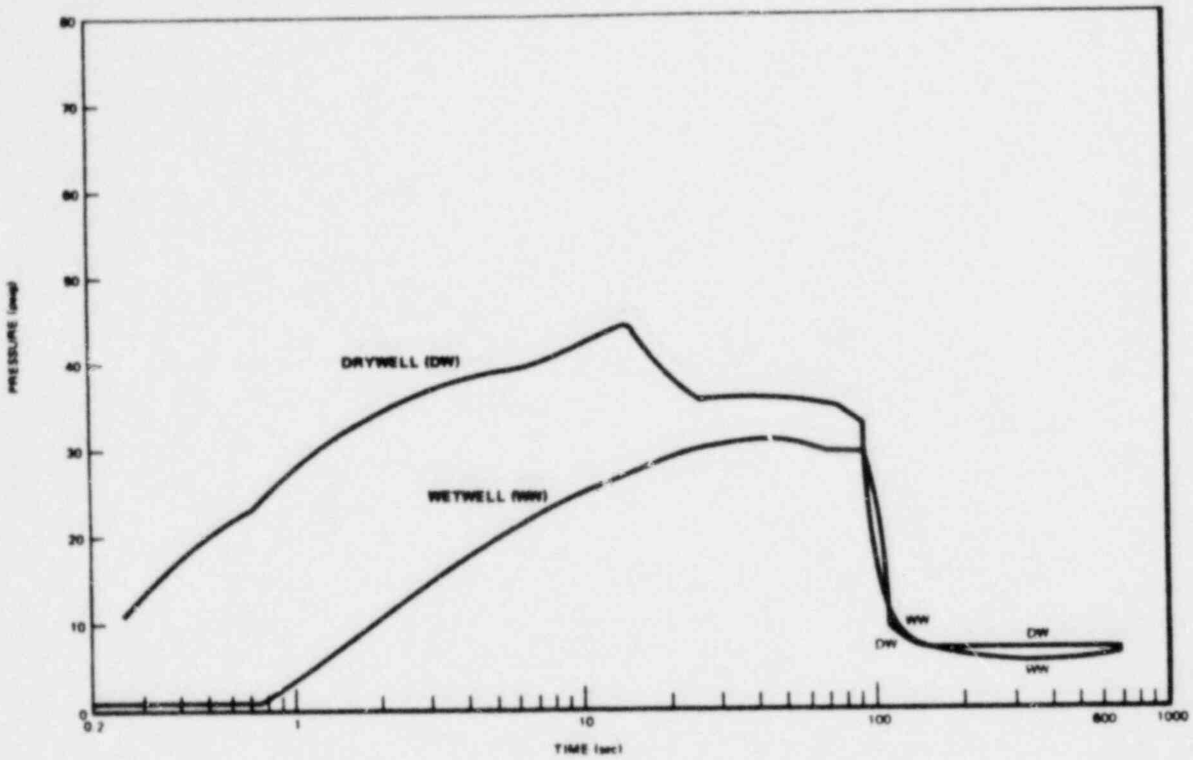
DYNAMIC DOWNCOMER
LATERAL LOAD
DUE TO CHUGGING

FIGURE 4.2-10



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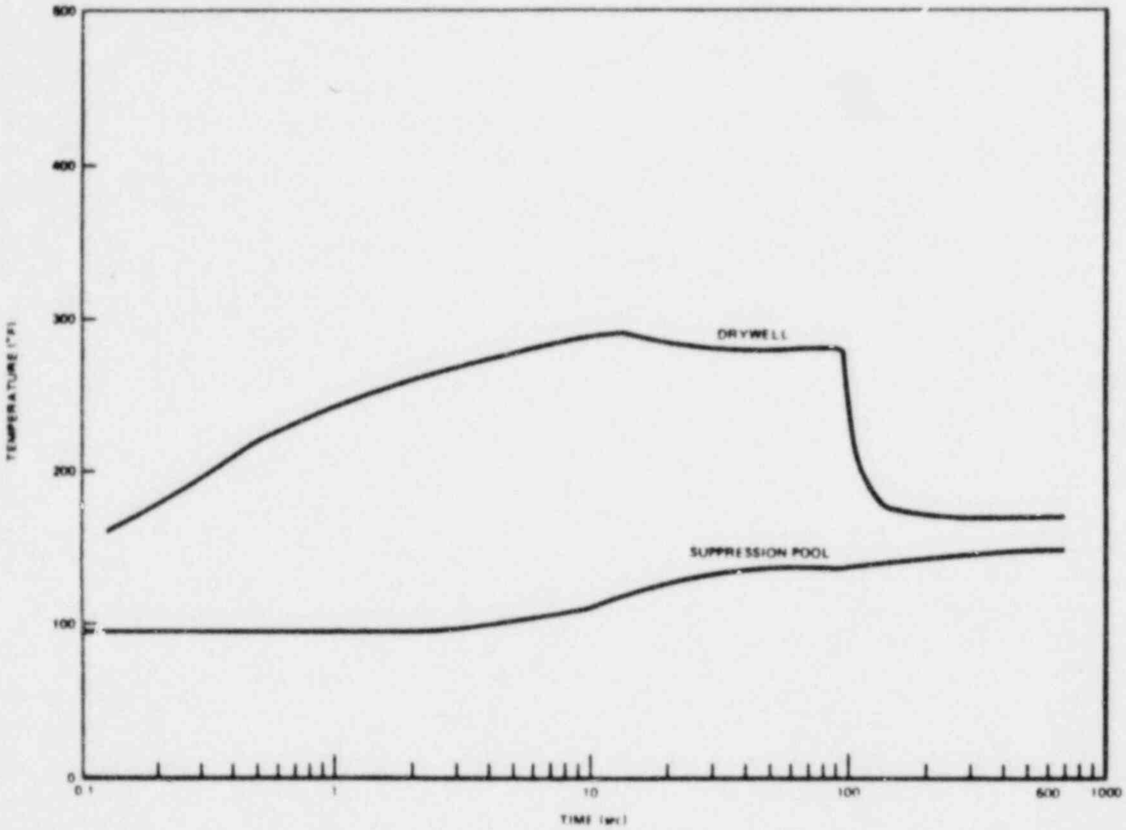
SHORT-TERM CONTAINMENT PRESSURE RESPONSE FOLLOWING RECIRCULATION LINE BREAK

FIGURE 4.2-11



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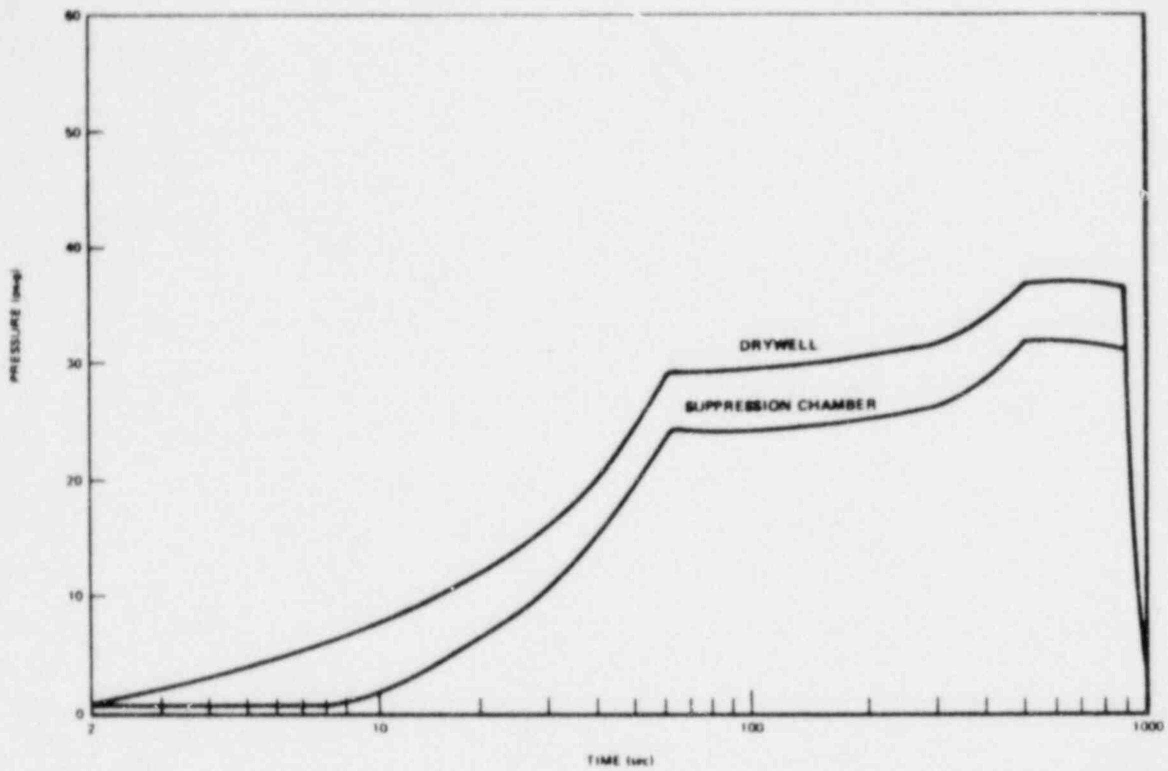
SHORT-TERM CONTAINMENT
TEMPERATURE RESPONSE
FOLLOWING RECIRCULATION
LINE BREAK

FIGURE 4.2-12



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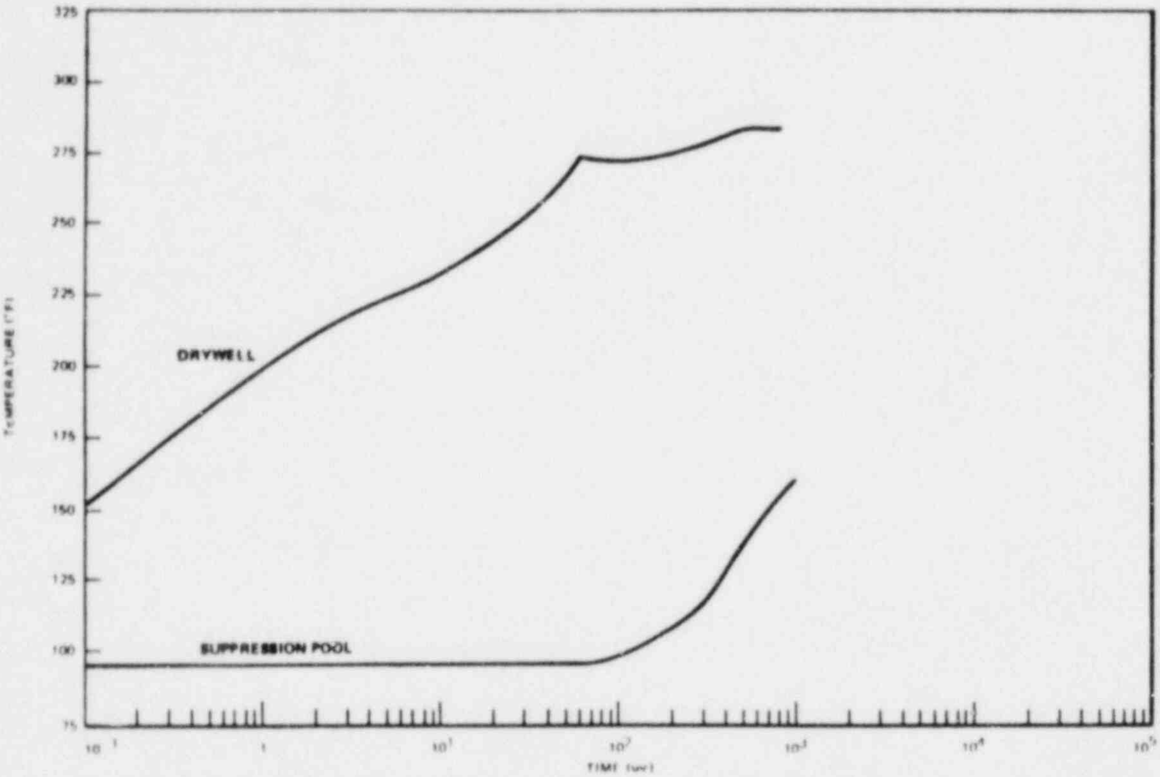
SHORT-TERM CONTAINMENT PRESSURE RESPONSE FOLLOWING AN INTERMEDIATE SIZE BREAK ($0.1\ ft^2$ LIQUID BREAK)

FIGURE 4.2-13



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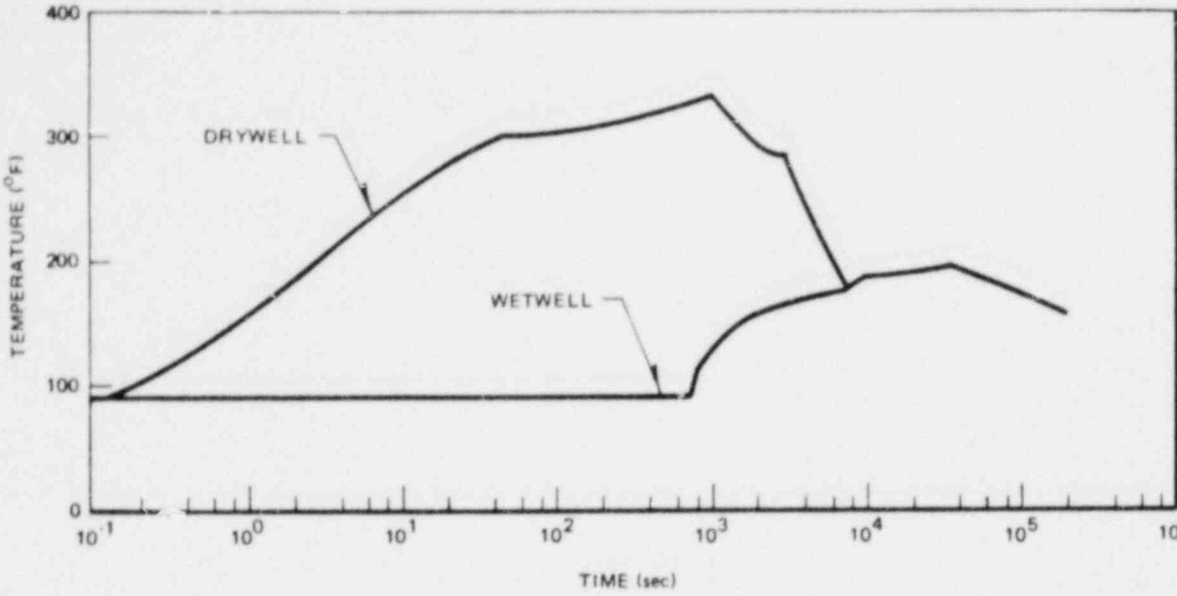
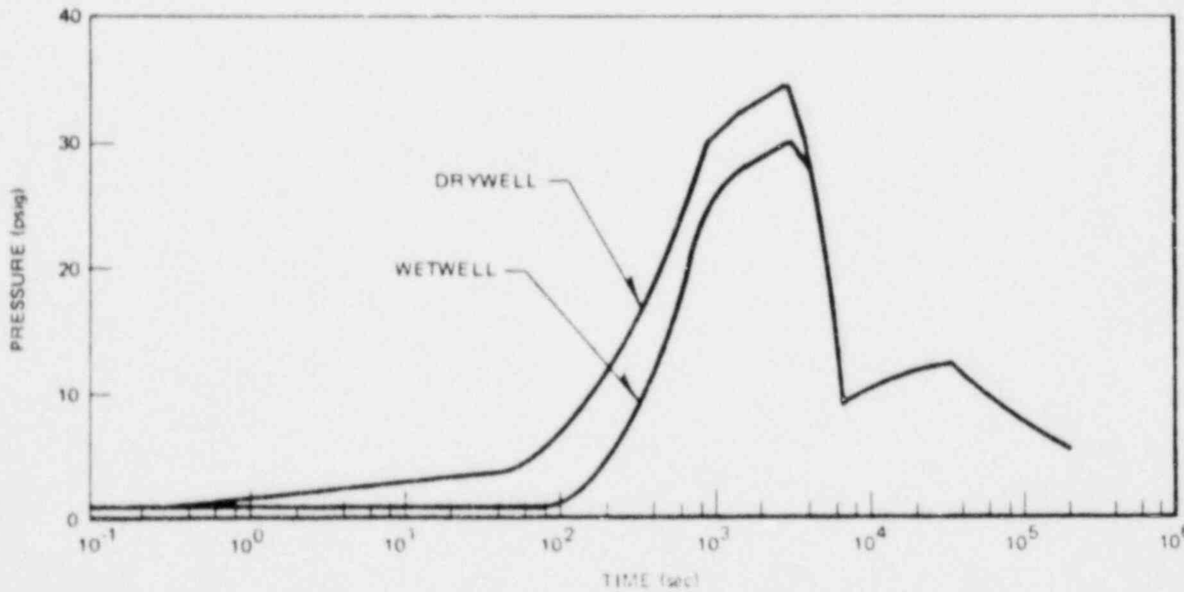
SHORT-TERM CONTAINMENT TEMPERATURE RESPONSE FOLLOWING AN INTERMEDIATE SIZE BREAK (0.1 ft^2 LIQUID BREAK)

FIGURE 4.2-14



CONTAINMENT TEMPERATURE RESPONSE FOLLOWING SMALL BREAK



CONTAINMENT PRESSURE RESPONSE FOLLOWING SMALL BREAK

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UNITS 1 AND 2
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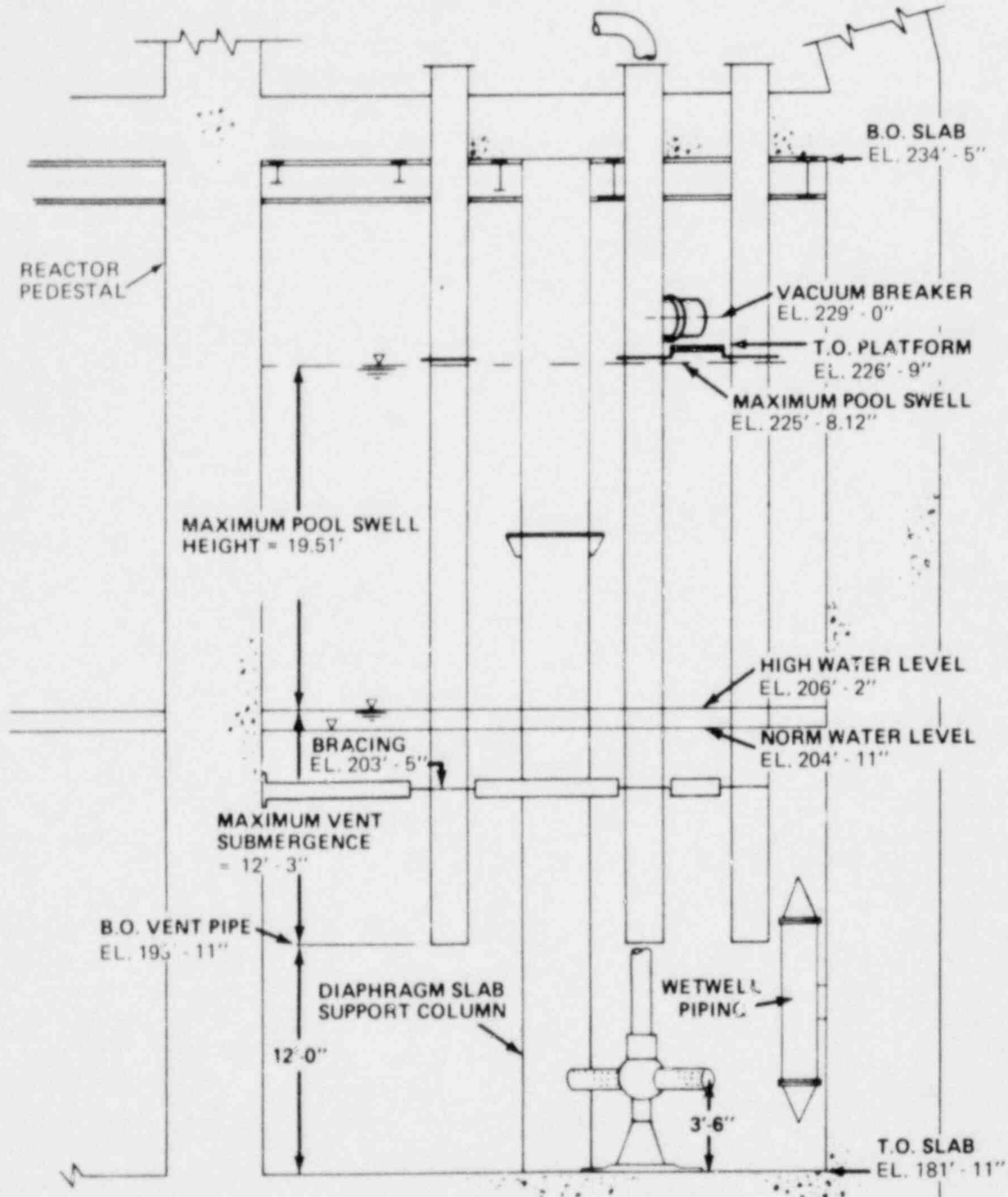
TYPICAL MARK II CONTAINMENT
RESPONSE TO THE SBA

FIGURE 4.2-15



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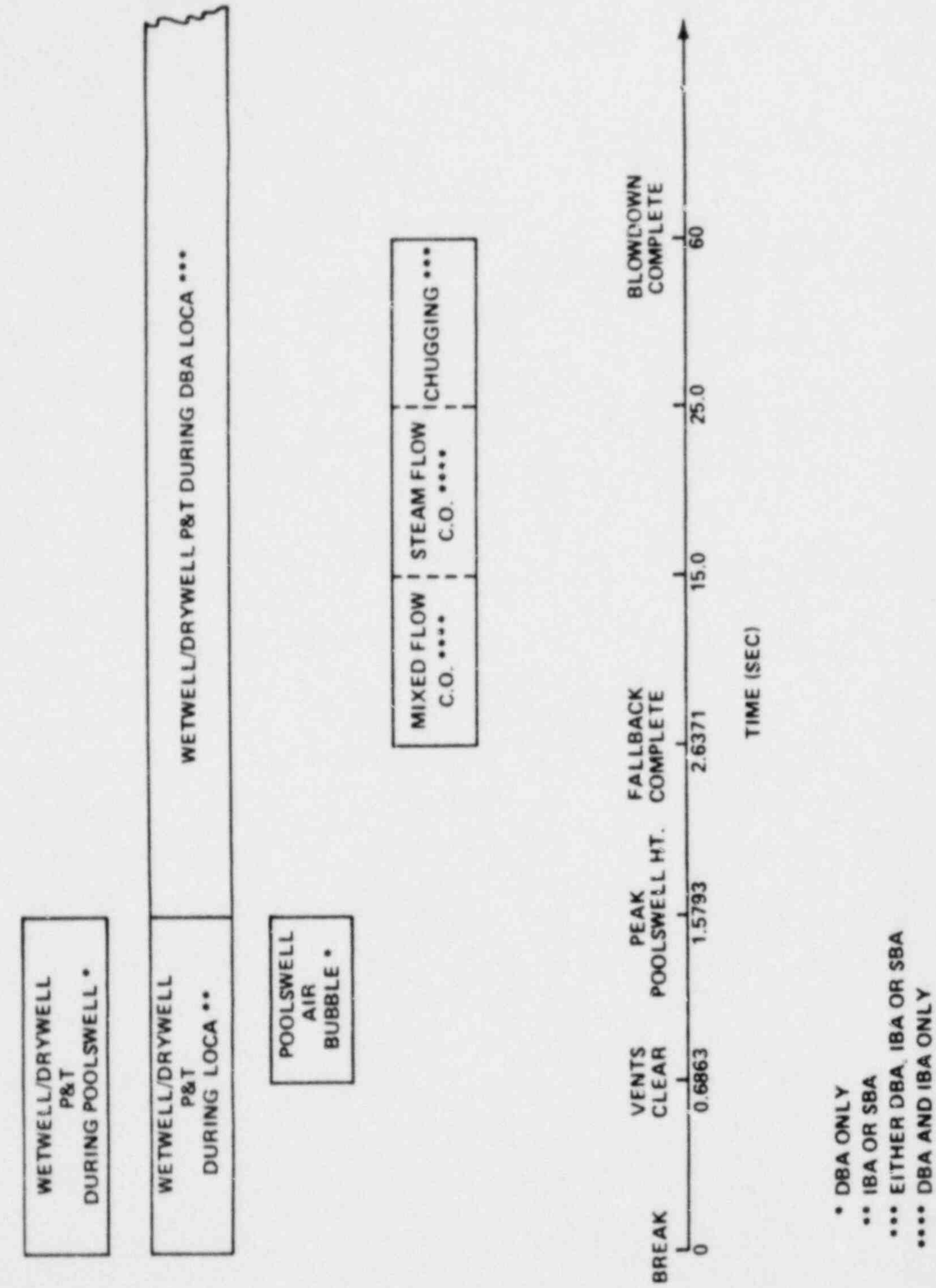
COMPONENTS
AFFECTED BY LOCA LOADS

FIGURE 4.2-16



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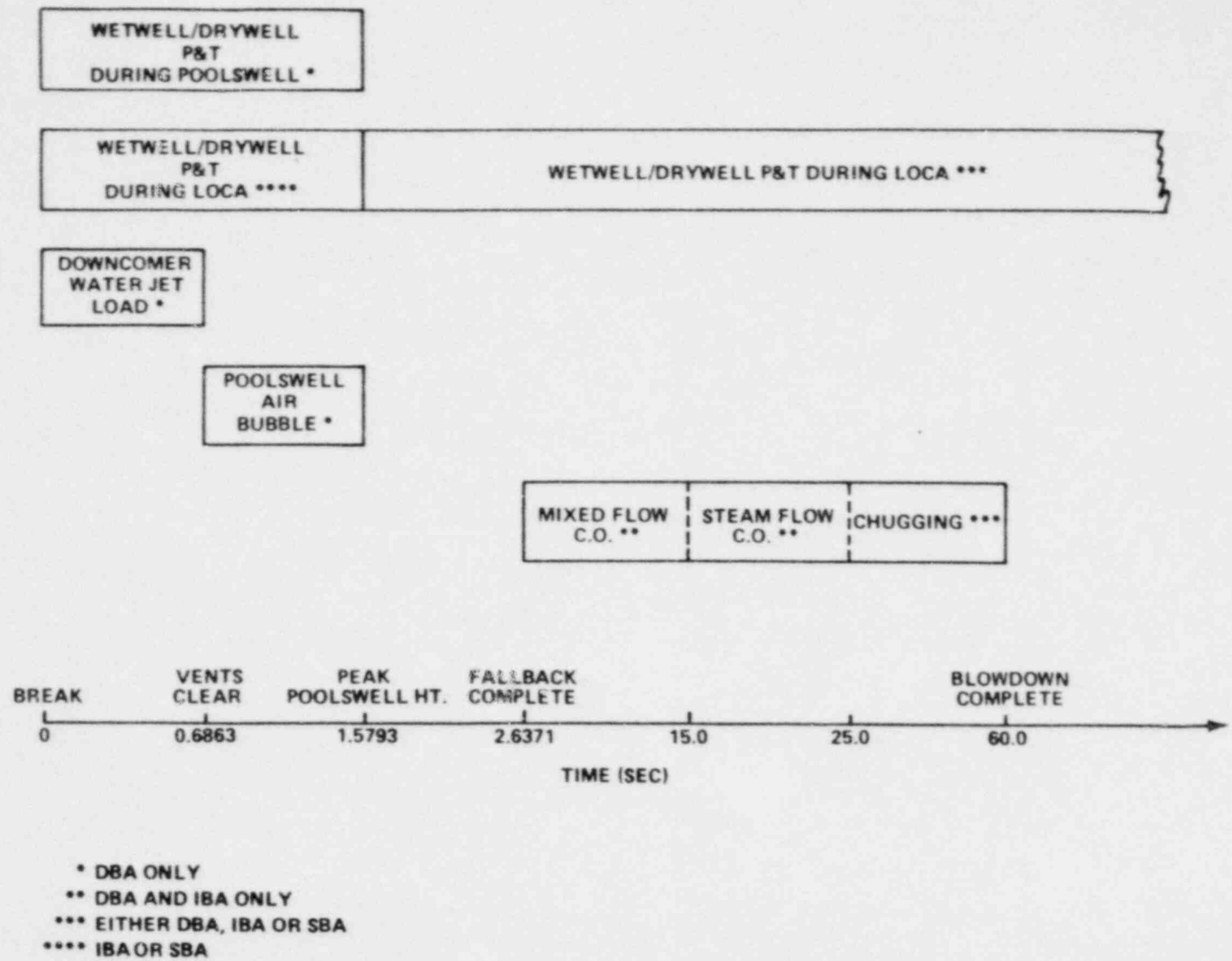
LOCA LOADING HISTORY
FOR THE CONTAINMENT WALL
AND PEDESTAL

FIGURE 4.2-17



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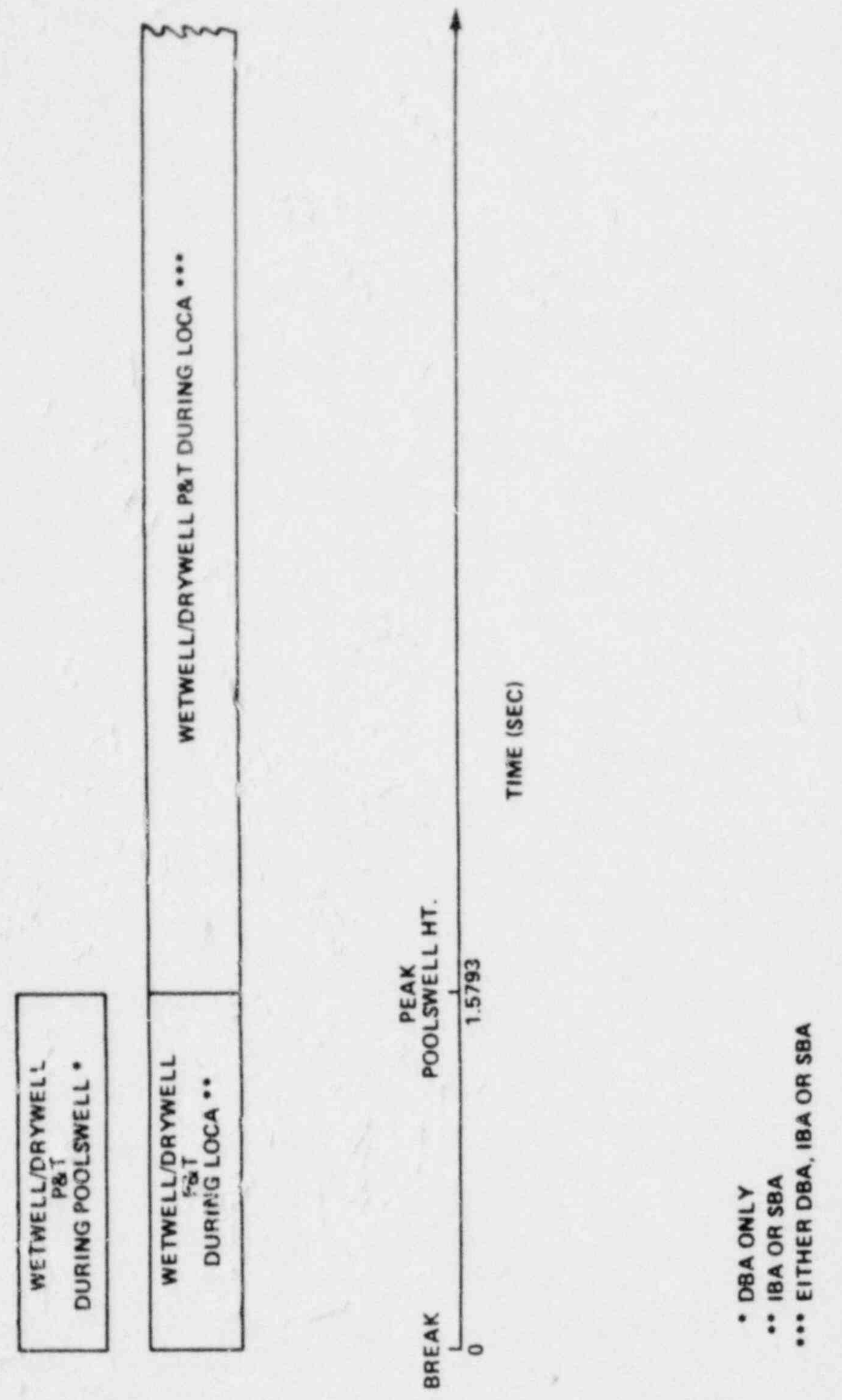
LOCA LOADING HISTORY FOR THE BASEMAT AND LINER PLATE

FIGURE 4.2-18



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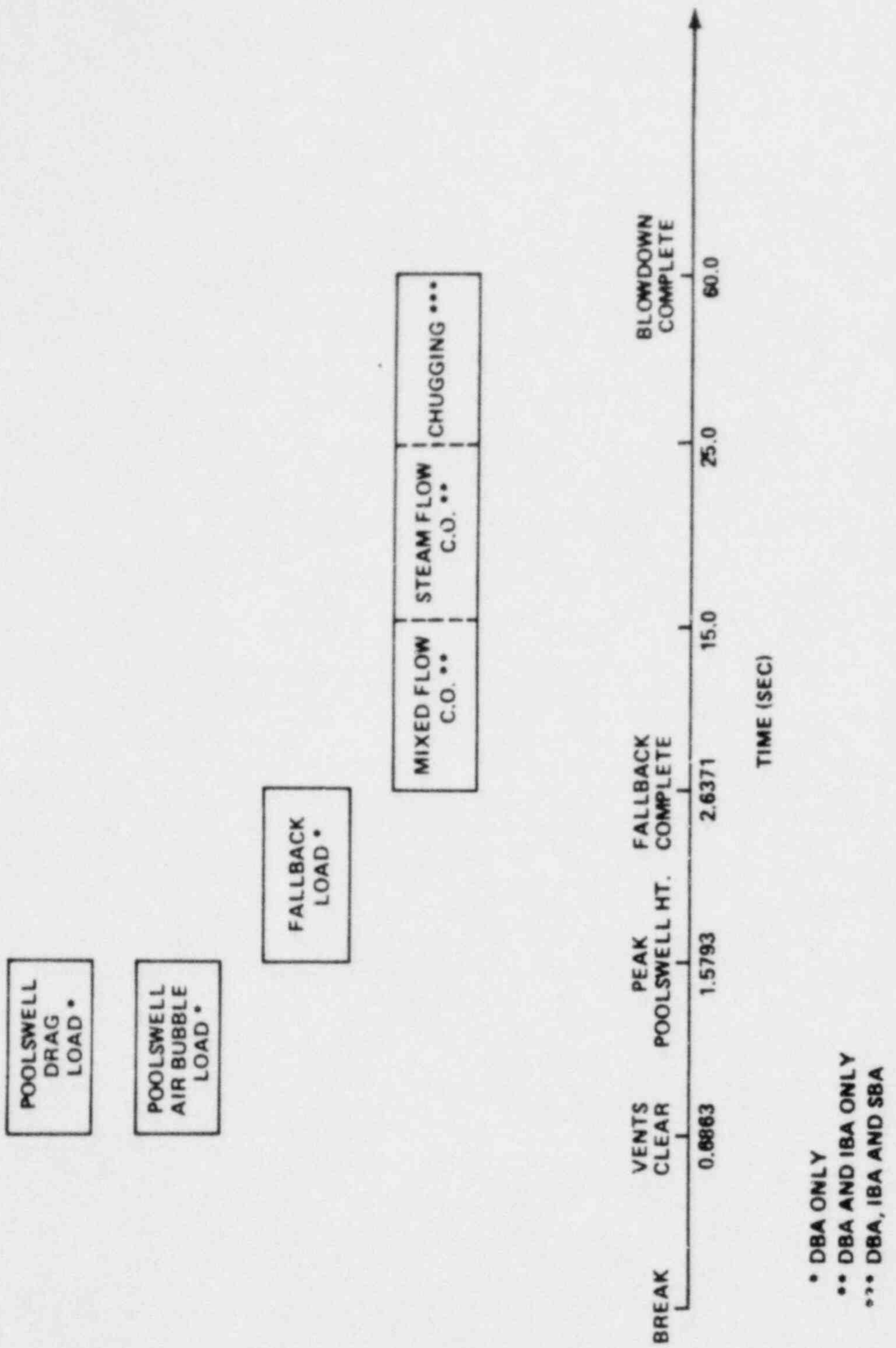
LOCA LOADING HISTORY FOR THE DRYWELL AND DRYWELL FLOOR

FIGURE 4.2-19



LIMERICK GENERATING STATION
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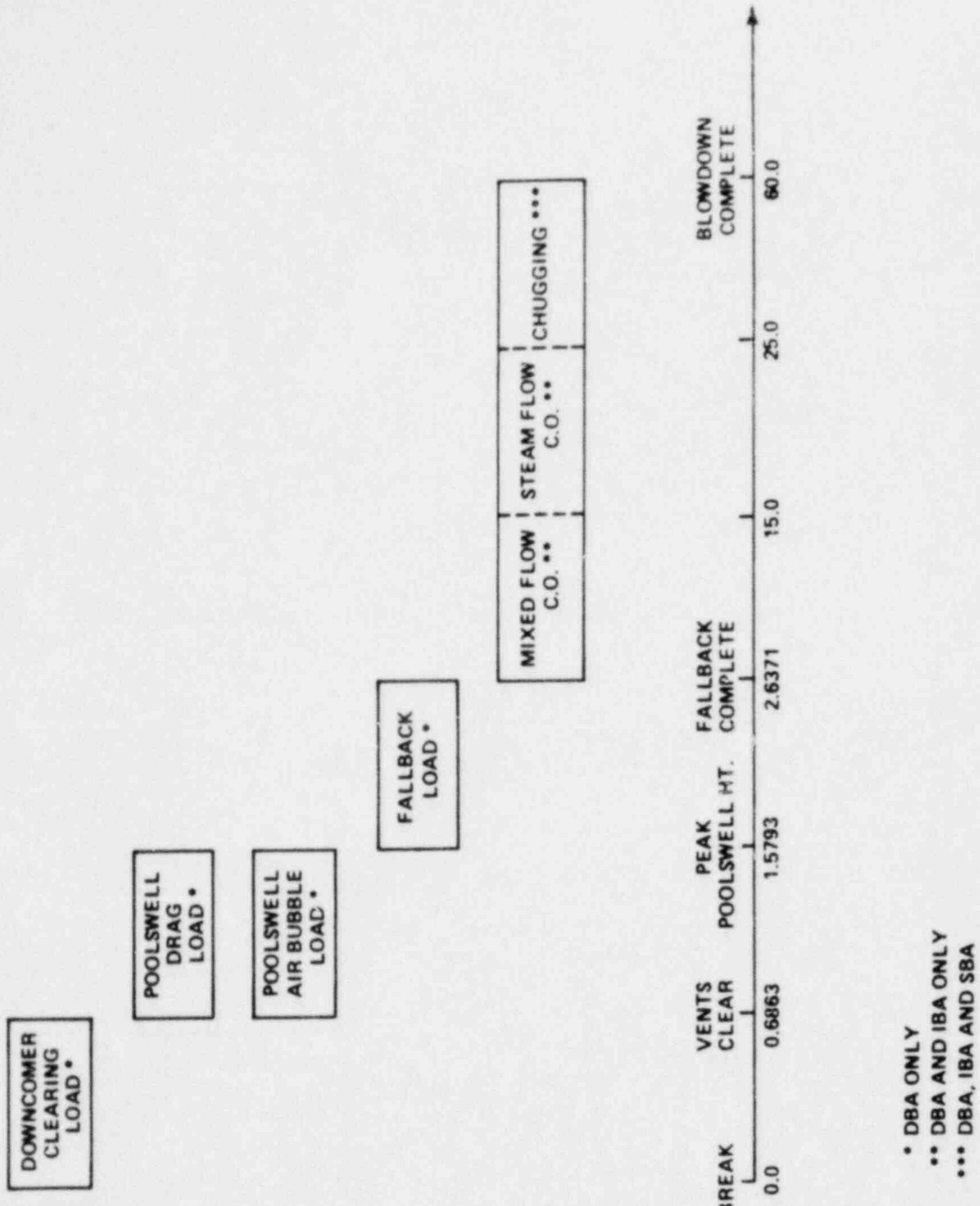
LOCA LOADING HISTORY
FOR THE COLUMNS

FIGURE 4.2-20



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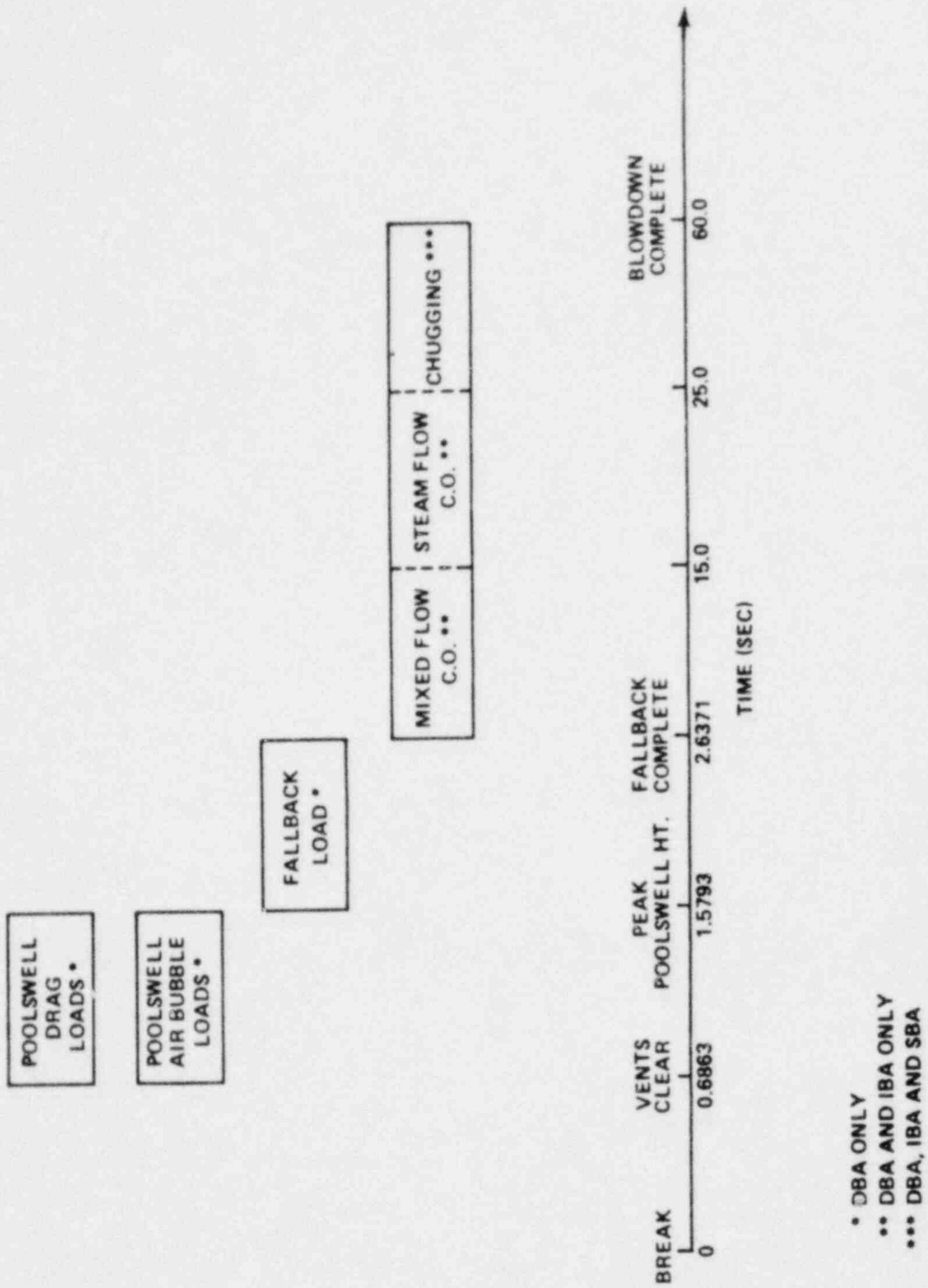
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

LOCA LOADING HISTORY
FOR THE DOWNCOMERS

FIGURE 4.2-21



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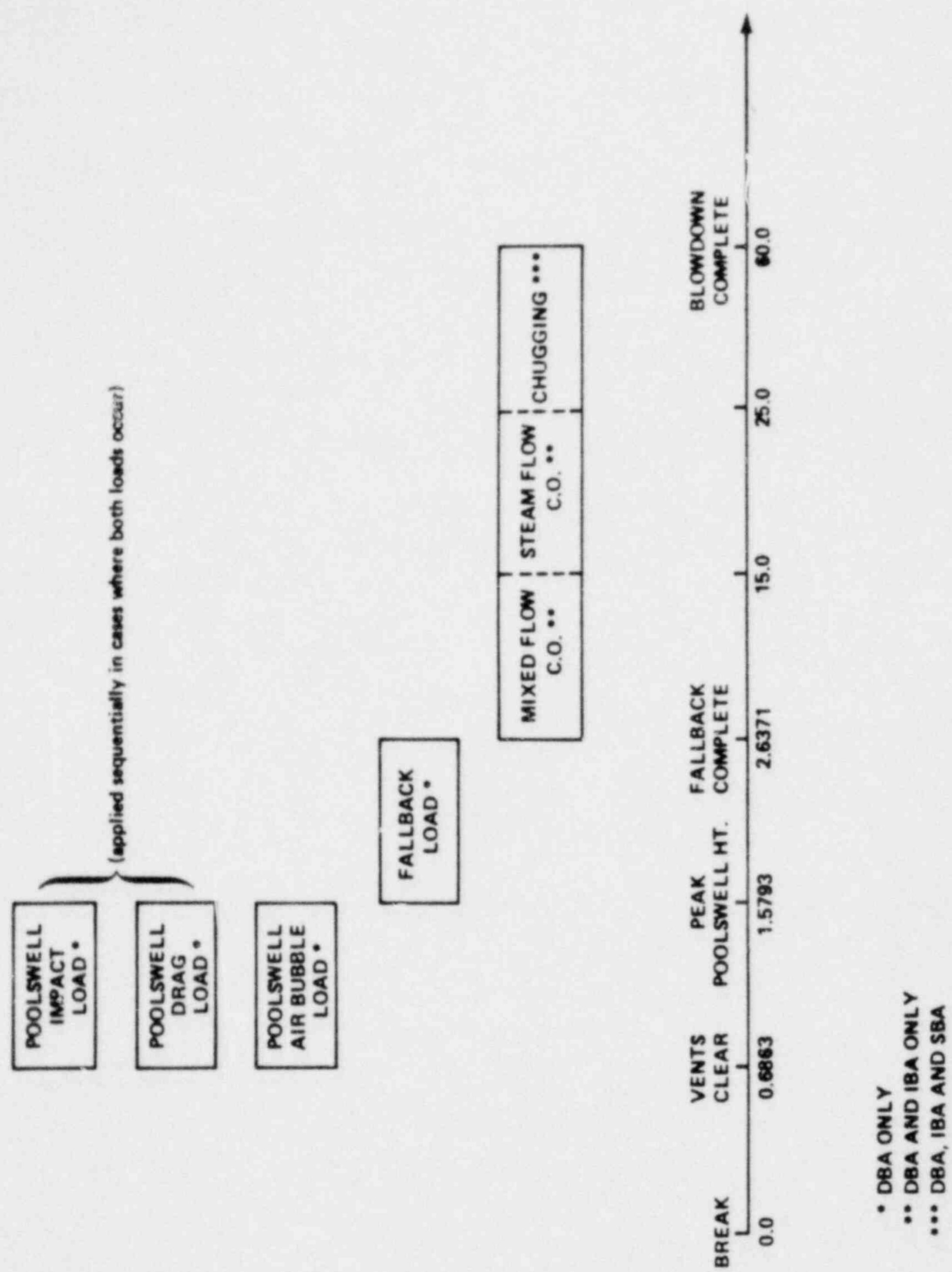
LOCA LOADING HISTORY
FOR THE DOWNCOMER
BRACING SYSTEM

FIGURE 4.2-22



LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

LOCA LOADING HISTORY
FOR THE WETWELL PIPING

FIGURE 4.2-23

CHAPTER 5

LOAD COMBINATIONS FOR STRUCTURES, PIPING, AND EQUIPMENT

TABLE OF CONTENTS

CHAPTER 5

TABLES

CHAPTER 5

FIGURES

CHAPTER 5

LOAD COMBINATIONS FOR STRUCTURES, PIPING, AND EQUIPMENT

5.1 INTRODUCTION

To verify the adequacy of mechanical and structural design, it is necessary first to define the load combinations to which structures, piping, and equipment may be subjected. In addition to the loads due to pressure, weight, thermal expansion, seismic, and fluid transients, hydrodynamic loads resulting from LOCA and SRV discharge are also considered in the design of structures, piping, and equipment in the drywell and suppression pool. This chapter specifies how the LOCA and SRV discharge hydrodynamic loads will be combined with the other loading conditions. For the load combinations discussed in this chapter, seismic and hydrodynamic responses are combined by the methods specified in Reference 1.3-1, section 5.1.2.

5.2 LOAD COMBINATIONS FOR CONCRETE DESIGN IN CONTAINMENT, REACTOR BUILDING, AND CONTROL STRUCTURE

The loads on the containment, its concrete internals (i.e., RPV pedestal, diaphragm slab), reactor building, and control structure are combined to assess the structural integrity in accordance with the design load combinations given in Table 5.2-1. The factored load approach is used in the assessment of the concrete structural components. The load factors adopted are based on the degree of certainty and probability of occurrence for the individual loads as discussed in Reference 5.2-1, section 5.1.2.

The loss-of-coolant accidents are characterized by several phenomena that result in non-concurrent loadings on the structures. Time sequences of occurrence of the various time dependent loads, as shown in Figures 5-5 through 5-20 of Reference 1.3-1, are taken into account to determine the most critical loading conditions.

TABL

LOAD COMBINATIONS FOR CONTAINMENT, REAC
CONTAINMENT LINER PLATE(1)

Equation	Load Condition	D	L	P_o	T_o	R_o	E_o	E_{ss}	P_B
1	Normal w/o Temp.	1.4	1.7	1.0	-	-	-	-	-
2	Normal w/Temp.	1.0	1.3	1.0	1.0	1.0	-	-	-
3	Normal Sev. Env.	1.0	1.0	1.0	1.0	1.0	1.25	-	-
4	Abnormal	1.0	1.0	-	-	-	-	-	1.25
4a	Abnormal	1.0	1.0	-	-	-	-	-	-
5	Abnormal Sev. Env.	1.0	1.0	-	-	-	1.1	-	1.1
5a	Abnormal Sev. Env.	1.0	1.0	-	-	-	1.1	-	-
6	Normal Ext. Env.	1.0	1.0	1.0	1.0	1.0	-	1.0	-
7	Abnormal Ext. Env.	1.0	1.0	-	-	-	-	1.0	1.0
7a	Abnormal Ext. Env.	1.0	1.0	-	-	-	-	1.0	-

Load Description

D = Dead Loads

L = Live Loads

P_o = Operating Pressure Loads

T_o = Operating Temperature Loads

R_o = Operating Pipe Reactions

SRV = Safety Relieve Valve Loads

DAR

5.2-1 (Page 1 of 2)

OR BUILDING, CONTROL STRUCTURE, AND
(CONSIDERING HYDRODYNAMIC LOADS)

A	T A	D A	R V	SRV(3)	AOT	ADS	ASYM	Single Valve	LOCA(4)
-	-	-	-	1.5	X(2)	X	X	-	
-	-	-	-	1.3	X	-	X	-	
-	-	-	-	1.25	X	-	X	-	
-	1.0	1.0	-	1.25	-	X	X	-	X
1.25	1.0	1.0	-	1.0	-	-	-	X	X
-	1.0	1.0	-	1.1	-	X	X	-	X
1.1	1.0	1.0	-	1.0	-	-	-	X	X
-	-	-	-	1.0	X	-	X	-	-
-	1.0	1.0	1.0	1.0	-	X	X	-	X
1.0	1.0	1.0	1.0	1.0	-	-	-	X	X

E_o = Operating-Basis Earthquake

E_{ss} = Safe Shutdown Earthquake

P_B = SBA or IBA (LOCA) Pressure Load

B_A = Pipe Break Temperatures Reaction Loads

P_A = DBA (LOCA) Pressure Load

T_A = Pipe Break Temperature Load

R_V = Reaction and jet forces associated with the pipe br

AOT = Abnormal Operating Transient

ADS = Automatic Depressurization System

ASYM = Asymmetric

---

(1) For liner plate, the coefficients are unity.

(2) X indicates applicability for the designated load c

(3) For columns designated AOT, ADS, ASYM, and Single V columns may be included in the load combination for Equation 1, either AOT or ASYM may be considered wi ASYM simultaneously.

(4) LOCA includes chugging, condensation oscillation, a

---

ak

mbination.

.ve, only one of the four possible
any one equation. For example, in
h the other loads but not both AOT and

d large air bubble loads.

5.3 STRUCTURAL STEEL LOAD COMBINATIONS

The load combinations for structural steel in the containment, reactor building, and control structure are given in Table 5.3-1. These combinations apply to the suppression chamber steel columns, the downcomer bracing, and miscellaneous structural steel within the containment, reactor building and control structure.

The loss-of-coolant accidents are characterized by several phenomena that result in non-concurrent loadings on the structures. Time sequences of occurrence of the various time dependent loads, as shown in figures 5-5 through 5-20 in Reference 1.3-1, are taken into account to determine the most critical loading conditions.

TABLE 5.3-1 (Page 1 of 2)

LOAD COMBINATIONS AND ALLOWABLE STRESSES FOR STRUCTURAL STEEL COMPONENTS (Suppression Chamber Columns, Downcomer Bracing, and Reactor Building Structural Steel)

Equation	Condition	Load Combination	Allowable Stress
1	Normal w/o Temp.	D+L+SRV	F_s
2	Normal w/Temp.	$D+L+T_o+SRV$	F_s
3	Normal/ Severe	$D+L+T_o+E+SRV$	1.25 F_s
4	Normal/ Extreme	$D+L+T_o+E'+SRV$	1.25 F_s
5	Abnormal	$D+L+P(T_o+T_a)+R$ +SRV+LOCA	(1)
6	Abnormal/ Severe	$D+L+P+(T_o+T_a)+R+E$ +SRV-LOCA	(1)
7	Abnormal/ Extreme	$D+L+P+(T_o+T_a)+R+E'$ +SRV+LOCA	(1)

(1) In no case shall the allowable stress exceed 0.90 Fy in bending, 0.85 Fy in axial tension or compression, and 0.50 Fy in shear. Where the design is governed by requirements of stability (local or lateral buckling), the actual stress shall not exceed $1.5F_s$.

TABLE 5.3-1 (Cont'd)

Notations:

F_s	=	Allowable stress according to the AISC, "Specification for the Design, Fabrication, and Erection of Structural Steel for Buildings," dated 1969, Part 1
Fy	=	Minimum specified yield strength
D	=	Dead load
L	=	Live load
T_o	=	Thermal effects during normal operating conditions including temperature gradients and equipment and pipe reactions
T_a	=	Added thermal effects (over and above operating thermal effects) that occur during a design accident
P	=	Design basis accident pressure load
R	=	Local force or pressure on structure due to postulated pipe rupture including the effects of steam/water jet impingement, pipe whip, and pipe reaction
E	=	Load due to operating basis earthquake
E'	=	Load due to safe shutdown earthquake
SRV	=	Safety relief valve loads
LOCA	=	Loads due to loss-of-coolant accident conditions (chugging, condensation oscillation, or large air bubble loads)

5.4 LINER PLATE LOAD COMBINATIONS

The liner plate and its anchorage system, being an integral part of the containment system, is assessed for the same load combinations listed in Table 5.2-1. However, for the liner system, the load factors are taken as unity and the acceptance criteria are specified in Section 6.4.

The loss-of-coolant accidents are characterized by several phenomena that result in non-concurrent loadings on the structures. Time sequences of occurrence of the various time dependent loads, as shown in Figures 5-5 through 5-20 in Reference 1.3-1 are taken into account to determine the most critical loading conditions.

5.5 DOWNCOMER LOAD COMBINATIONS

Load combinations for the downcomers are given in Table 5.5-1. These load combinations are based on the load combinations given in table 5-2 of Reference 1.3-1.

The loss-of-coolant accidents are characterized by several phenomena that result in non-concurrent loadings on the structures. Time sequences of occurrence of the various time dependent loads, as shown in figures 5-5 through 5-20 in Reference 1.3-1, are taken into account to determine the most critical loading conditions.

Table 5.5-1 (Page 1 of 2)

LOAD COMBINATIONS AND ALLOWABLE STRESSES FOR DOWNCOMERS

Equation	Condition	Load Combination	Allowable Stress
1	Upset	$D+P_0+SRV_{ALL}$	$1.5\ S_m$
2	Emergency	$D+P_0+SRV_{ALL}+E$	$2.25\ S_m$
3	Emergency	$D+P_{SBA}+SRV_{ADS}+E+LOCA(SBA)$	$2.25\ S_m$
4	Faulted	$D+P_0+SRV_{ALL}+E'$	$3\ S_m$
5	Faulted	$D+P_{IBA}+SRV_{ADS}+E+LOCA(IBA)$	$3\ S_m$
6	Faulted	$D+P_{SBA}$ (or P_{IBA}) $+SRV_{ADS}+E'+LOCA$(SBA or IBA)	$3\ S_m$
7	Faulted	$D+P_A+E'+LOCA(DBA)$	$3\ S_m$

Notations:

S_m = Maximum allowable stress

D = Dead weight of the downcomer

P_0 = Pressure differential between drywell and suppression chamber during normal operating condition

P_{SBA} = Pressure differential between drywell and suppression chamber during SBA.

P_{IBA} = Pressure differential between drywell and suppression chamber during IBA.

P_A = Pressure differential between drywell and suppression chamber during DBA.

SRV_{ALL} = Dynamic lateral pressure and inertia load due to the discharge of all 14 safety relief valves simultaneously.

Table 5.5-1 (Cont'd)

SRV ADS	=	Dynamic lateral pressure and inertia load due to the discharge of all 5 ADS safety relief valves simultaneously.
E	=	Load due to operating basis earthquake
E'	=	Load due to safe shutdown earthquake
LOCA	=	Loads due to chugging, condensation oscillation, or air bubble loads. The governing applicable loading case should be considered. The loads should include: 1. Lateral load at the tip of the downcomer 2. Horizontal and vertical inertial loads 3. Submerged structure loads

5.6 PIPING, QUENCHER, AND QUENCHER SUPPORT LOAD COMBINATIONS

LOCA loads considered on piping systems include poolswell impact loads, poolswell drag loads, downcomer water jet loads, poolswell air bubble loads, fallback drag loads, condensation oscillation loads, chugging loads, and inertial loading due to the acceleration of the containment structure produced by LOCA loads. Loads due to SRV discharge on piping systems include water clearing loads, air clearing loads, fluid transient loads on SRV discharge piping, reaction forces at the quencher, and inertial loading due to the acceleration of the containment structure produced by SRV discharge loads.

The load combinations and stress limits for piping systems are given in Table 5.6-1.

5.6.1 LOAD CONSIDERATIONS FOR PIPING INSIDE THE DRYWELL

Piping systems inside the drywell are subjected to inertial loading due to the acceleration of the containment produced by LOCA and SRV discharge loads in the wetwell. The SRV discharge piping in the drywell is also subjected to fluid transient forces due to SRV discharge.

5.6.2 LOAD CONSIDERATIONS FOR PIPING INSIDE THE WETWELL

All piping in the wetwell is subject to the inertial loading due to LOCA and SRV discharge.

Drag and impact loads due to LOCA and SRV discharge on individual pipes in the wetwell depend on the physical location of the piping. Other SRV discharge and LOCA loads applicable to piping in the wetwell are discussed in the paragraphs that follow.

Piping systems located below the suppression chamber water level are shown on Figures 5.6-1 and 5.6-2. In addition to the inertial loads, these piping systems are subjected to SRV air bubble and LOCA air bubble loads, condensation oscillation loads, and chugging loads. The SRV piping, quencher, and quencher support are also subject to fluid transient forces due to SRV discharge. Piping systems located within the jet impingement cone of the downcomer are also subjected to downcomer water jet loads.

Piping systems within the poolswell zone are shown on Figures 5.6-2, 5.6-3, and 5.6-4. All horizontal runs of these pipes are above the suppression chamber water level. The following loads, in addition to the inertial loads, act on these systems:

a. The horizontal runs of pipe below elevation 225'-8', experience poolswell impact, poolswell drag, and fallback drag loads.

b. The vertical portions of pipe in the water below elevation 225'-8" experience poolswell drag and fallback drag loads.

5.6.3 QUENCHER AND QUENCHER SUPPORT LOAD CONSIDERATIONS

The quencher and quencher supports are subjected to the following hydrodynamic loads in addition to the pressure, weight, thermal, and seismic loads:

a. Unbalanced loads on the quencher due to SRV water clearing and air clearing transients, irregular condensation, and steady-state blowdown.

b. Drag loads due to SRV discharge and LOCA.

c. SRV piping end loads.

d. Inertial loading due to the acceleration of the containment produced by SRV discharge and LOCA.

5.6.4 LOAD CONSIDERATIONS FOR PIPING IN THE REACTOR BUILDING

The effects of the inertial loading due to acceleration of the containment produced by SRV discharge and LOCA loads are evaluated for this piping.

TABLE 5.6-1

LOAD COMBINATIONS AND STRESS LIMITS FOR PIPING SYSTEMS

Equation	Condition	Load Combination	Stress Limit(1)
1	Design	PD	NB-3652, NC-3600, ND-3600
2	Normal	PD + DW	NB-3654, NC-3600, ND-3600
3	Upset	(a) $PO+DW+(OBE^2+SRV^2)^{1/2}$ (b) $PO+DW+(RVC^2+OBE^2)^{1/2}$ (c) $PO+DW+FV$ (d) $PO+DW+OBE+RVO$	NB-3654, NC-3600, ND-3600
4	Emergency	(a) $PO+DW+(OBE^2+SRV_{ADS}^2+SBA^2)^{1/2}$ (b) $PO+DW+(FV^2+OBE^2)^{1/2}$	NB-3655, NC-3600, ND-3600
5	Faulted	(a) $PO+DW+(OBE^2+SRV_{ADS}^2+IBA^2)^{1/2}$ (b) $PO+DW+(SSE^2+SRV_{ADS}^2+IBA^2)^{1/2}$ (c) $PO+DW+(SSE^2+DBA^2)^{1/2}$	NB-3656, ASME Code Case 1606

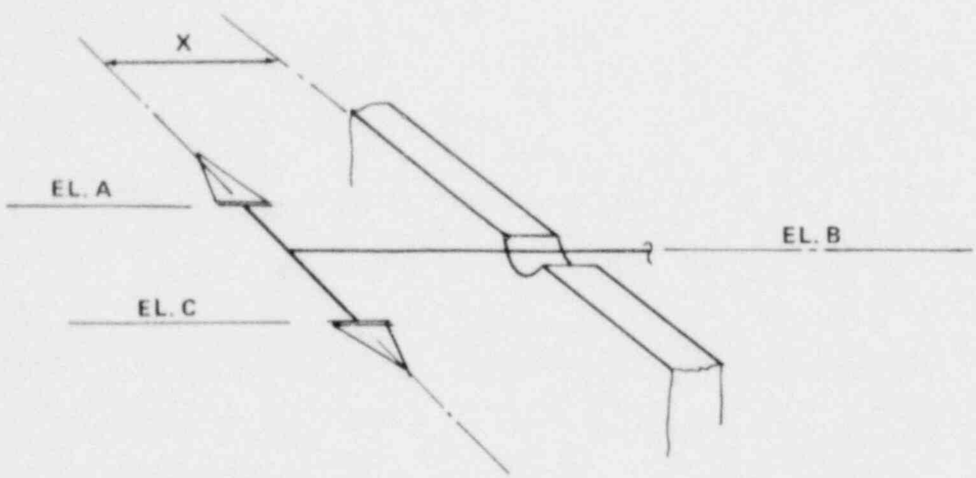
Notations:

PD	=	Design pressure
PO	=	Operating pressure
DW	=	Dead weight
OBE	=	Operating basis earthquake (inertia portion)
SSE	=	Safe shutdown earthquake (inertia portion)
SRV_x	=	Loads due to safety relief valve blow, axisymmetric or asymmetric
SRV_{ADS}	=	Load due to automatic depressurization SRV blow, axisymmetric
SBA	=	Small break accident
IBA	=	Intermediate break accident
DBA	=	Design basis accident
FV	=	Transient response of the piping system associated with fast valve closure (transients associated with valve closure times less than 5 seconds are considered)
RVC	=	Transient response of the piping system associated with relief valve opening in a closed system
RVO	=	Sustained load or response of the piping system associated with relief valve opening in an open system or last segment of the closed system with steady state load

TABLE 5.6-1 (Cont'd)

(1) The specified stress limits are subsections from the ASME Boiler and Pressure Vessel Code, Section III, Division 1, 1974.

LINE No.	QTY	SYSTEM	PENE-TRATION No.	TYPE OF PENE-TRATION	ELEVATION			DIMENSION X
					A	B	C	
16"-HBB-120	4	CORE SPRAY	X-206A, B, C, D	EMBEDDED	192'-0"	192'-0"	192'-0"	1'-6"
24"-HBB-117	4	RHR	X-203A, B, C, D	EMBEDDED	192'-0"	192'-0"	192'-0"	1'-11"
6"-HBB-102	1	RCIC	X-214	EMBEDDED	192'-9 1/8"	192'-0"	190'-0"	1'-1 7/8"
16"-HBB-109	1	HPCI	X-209	EMBEDDED	193'-5"	192'-0"	190'-7"	2'-1 1/2"

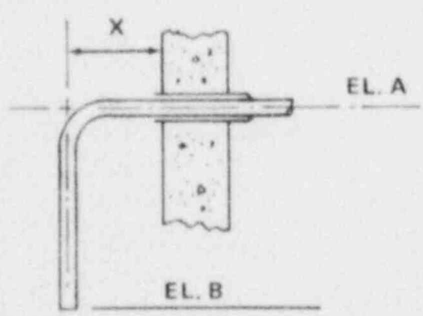


LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

STRESS DIAGRAMS AND TABLES FOR PIPING SYSTEMS BELOW SUPPRESSION CHAMBER WATER LEVEL

FIGURE 5.6-1

DWG No.	LINE No.	QTY	SYSTEM	PENETRATION No.	TYPE OF PENETRATION	ELEVATION A	ELEVATION B
B	4"-HBD-187	1	HPCI	X-212	EMBEDDED	207'-6"	199'-11"
B	4"-HBD-188	1	HPCI	X-236	EMBEDDED	207'-6"	199'-11"
A	24"-HBD-189	1	HPCI	X-210	SLEEVE	207'-6"	192'-8"
B	4"-HBD-171	2	CORE SPRAY	X-208B X-235	EMBEDDED	207'-6"	199'-11"
B	10"-HBD-169	2	CORE SPRAY	X-207A X-207B	EMBEDDED	207'-6"	199'-11"
A	18"-GBD-143	2	RHR	X-204A,B	SLEEVE	219'-0"	199'-11"
A	4"-GBD-144	2	RHR	X-226A	SLEEVE	207'-6"	199'-11"
A	12"-HBD-173	1	RCIC	X-215	SLEEVE	207'-6"	199'-11"
B	6"-HBB-139	1	RHR	X-240	EMBEDDED	207'-3 1/4"	199'-11"
A	10"-HBB-140	1	RHR	X-238	SLEEVE	267'-9"	199'-11"
A	10"-HBB-140	1	RHR	X-239	SLEEVE	207'-1"	199'-11"
C	4"-HCB-106	1	LIQ. AND SOLID RADWASTE	X-231A	SLEEVE	207'-7"	205'-1"
C	4"-HCB-107	1	LIQ. AND SOLID RADWASTE	X-231B	SLEEVE	207'-9"	204'-6"
B	2"-HBD-357	1	REACTOR CORE ISOLATION COOLING	X-217	EMBEDDED	207'-6"	199'-11"
B	2"-HBD-356	1	REACTOR CORE ISOLATION COOLING	X-216	EMBEDDED	207'-6"	199'-11"



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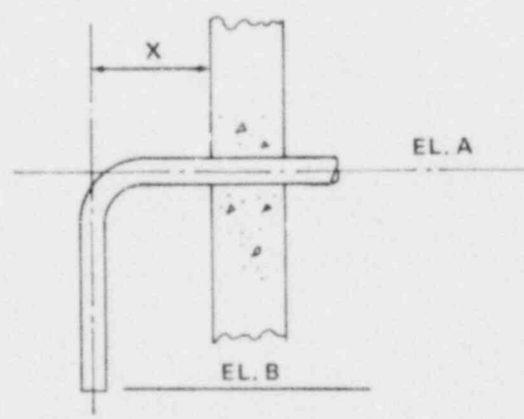

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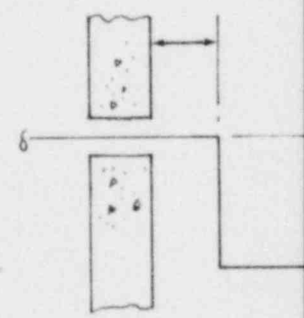
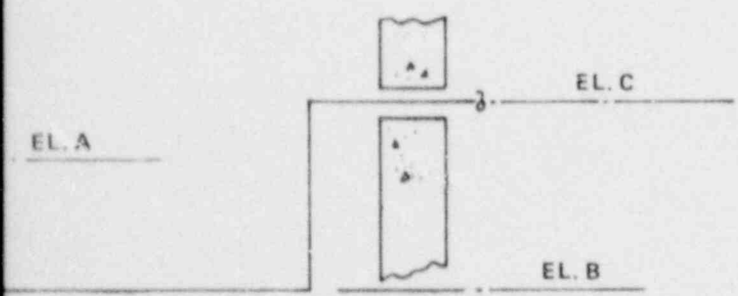


	DIMENSION
C	X
	1'-0''
	,'-0''
	6'-9''
	0'-9''
	1'-9''
	2'-6''
	0'-9''
	7'-3''
	1'-3''
	1'-6''
	1'-6''
13'-9''	–
13'-9''	–
	7 1/4''
	7 1/4''



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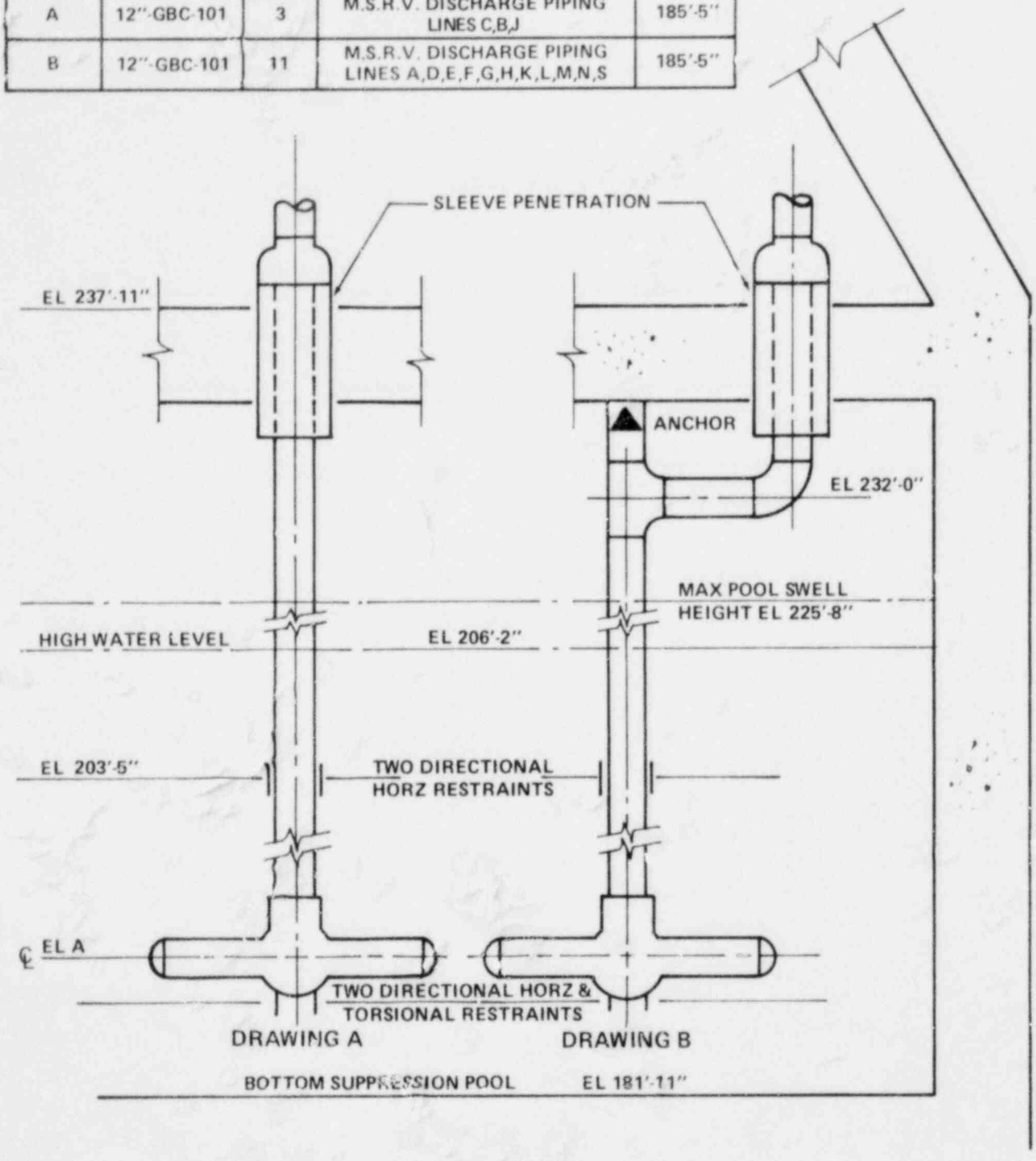
LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

STRESS DIAGRAMS AND TABLES
FOR PIPING SYSTEMS WITHIN
POOLSWELL ZONE

FIGURE 5.6-2

DWG. No.	LINE No.	QTY	SYSTEM	EL A
A	12"-GBC-101	3	M.S.R.V. DISCHARGE PIPING LINES C,B,J	185'-5"
B	12"-GBC-101	11	M.S.R.V. DISCHARGE PIPING LINES A,D,E,F,G,H,K,L,M,N,S	185'-5"



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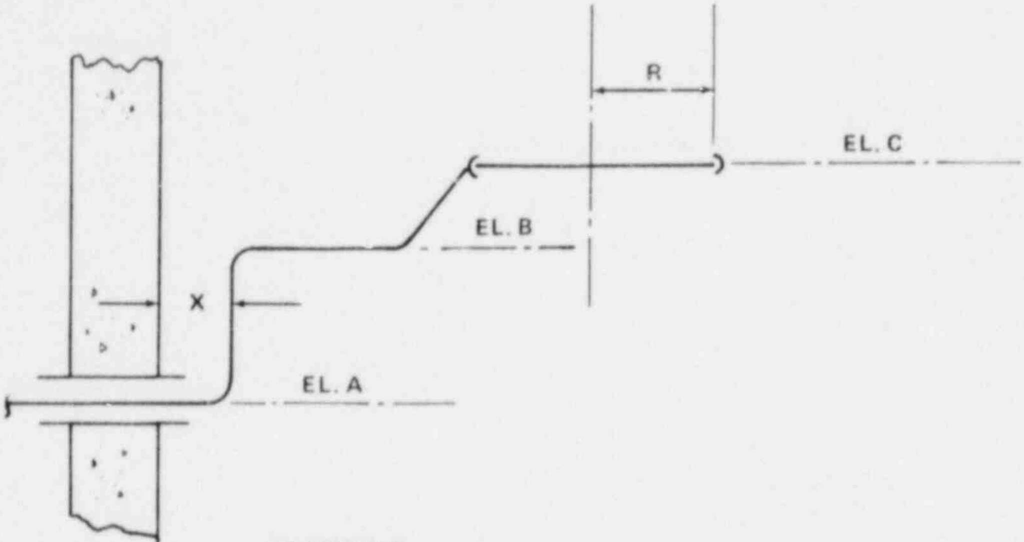
UNITS 1 & 2
DESIGN ASSESSMENT REPORT

STRESS DIAGRAMS AND TABLES FOR PIPING WITHIN POOLSWELL ZONE

FIGURE 5.6-3

DWG No.	LINE No.	QTY	SYSTEM	PENE-TRATION No.	RADIUS OF SPRAY RING, R	ELEVATION			DIMENSION
						A	B	C	X
A	6"-GBC-112	1	RHR	X-205A	21'-6"	222'-4 1/2"	229'-11 3/8"	230'-6"	3'-8"
B	6"-GBC-112	1	RHR	X-205B	32'-8"	222'-4 1/2"	–	230'-6"	3'-6 11/16"



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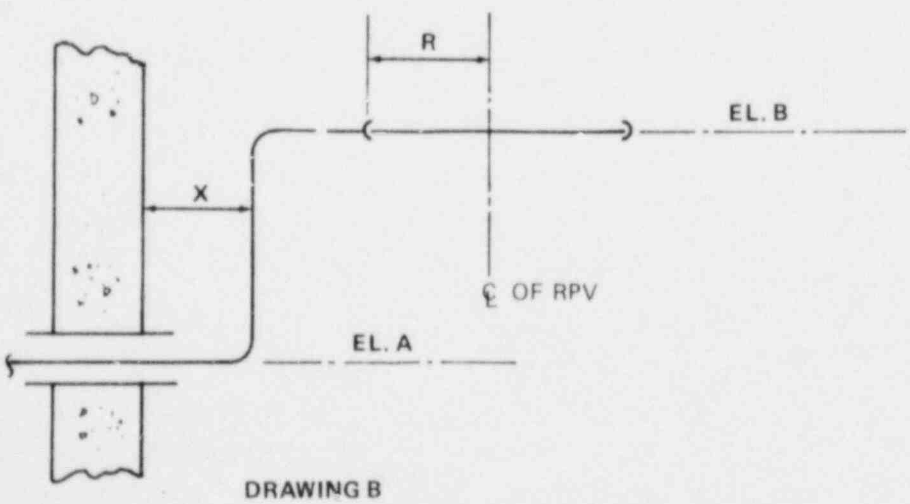

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DESIGN ASSESSMENT REPORT

STRESS DIAGRAMS AND TABLES FOR PIPING SYSTEMS WITHIN POOLSWELL ZONE

FIGURE 5.6-4

5.7 NSSS LOAD COMBINATIONS

To be provided later.

5.8 EQUIPMENT LOAD COMBINATIONS

Safety-related equipment located within the primary containment, reactor building, and control structure are assessed for the governing load combinations shown in Table 5.8-1.

TABLE 5.8-1

LOAD COMBINATIONS AND DAMPING VALUES FOR NON-NSSS SAFETY-RELATED EQUIPMENT IN THE PRIMARY CONTAINMENT, REACTOR BUILDING, AND CONTROL STRUCTURE

Equation	Condition	Load Combination	Damping[(1)]
1	Upset	a. $N+[OBE^2 + SRV^2]^{1/2}$	2%
		b. N+OBE	0.5%
2	Emergency	a. $N+[OBE^2 + SRV^2 + SBA^2]^{1/2}$	2%
3	Faulted	a. $N+[OBE^2 + SRV^2 + IBA^2]^{1/2}$	2%
		b. $N+[SSE^2 + SRV^2 + IBA^2]^{1/2}$	2%
		c. $N+[SSE^2 + DBA^2]^{1/2}$	2%
		d. Envelope of a, b & c	2%
		e. N+SSE	0.5%
4	Worst	a. Envelope of 1a, 2 and 3d	2%

Notations:

N = Normal loads (dead weight + operating temp.+ operating press.)
OBE = Operating basis earthquake loads
SSE = Safe shutdown earthquake loads
SRV = Safety relief valve discharge loads
SBA = Small break accident loads
IBA = Intermediate break accident loads
DBA = Design basis accident loads

(1) Where justified, a higher damping value may be used.

5.9 ELECTRICAL RACEWAY SYSTEM LOAD COMBINATIONS

Load combinations for the electrical raceway system are given in Table 5.9-1.

TABLE 5.9-1

LOAD COMBINATIONS AND ALLOWABLE STRESSES FOR ELECTRICAL RACEWAY SYSTEM

Equation	Condition	Load Combination	Allowable Stress
1	Normal	D+L+SRV	F_s
2[1]	Normal/Severe	D+E	[2]
3	Abnormal/Extreme	D+E'+SRV+LOCA	[2,3]

(1) Applies only to connections for fatigue considerations.

(2) The following equation is applicable for connections:

$$\frac{5n_{EQ}}{N_{OBE}} + \frac{n_{EQ}}{N_{SSE}} \leq 1.0$$

where:

n_{EQ} = Total number of load/stress cycles per earthquake.

N_{OBE} = Allowable number of load/stress cycles per OBE event.

N_{SSE} = Allowable number of load/stress cycles per SSE event.

(3) In no case shall the allowable stress exceed 0.90 Fy in bending, 0.85 Fy in axial tension or compression, and 0.50Fy in shear. Where the design is governed by requirements of stability (local or lateral buckling), the actual stress shall not exceed 1.5Fs.

Notations:

F = Allowable stress for normal condition

D = Dead weight of raceway and cables

L = A 200 lb concentrated live load is applied at any point on cable trays only between supports

E = Load due to operating basis earthquake (OBE)

Table 5.9-1 (Cont'd)

E' = Load due to safe shutdown earthquake (SSE)

SRV = Safety relief valve loads

LOCA = Loss-of-coolant accident loads

F_y = Minimum specified yield strength

5.10 HVAC DUCT SYSTEM LOAD COMBINATIONS

Load combinations for the HVAC duct system are given in Table 5.10-1.

TABLE 5.10-1

LOAD COMBINATIONS AND ALLOWABLE STRESSES FOR HVAC DUCT SYSTEMS

DUCTS

Equation	Condition	Load Combination	Allowable Stress
1	Normal	D+L+SRV	Fs
2	Normal	$D+P_M+SRV$	Fs
3	Abnormal	$D+P_T$	$1.25F_s$
4	Normal/Severe	$D+P_M+E$	$1.25F_s$ (1)
5	Normal/Severe	$D+P_M+E+SRV$	$1.25F_s$
6	Normal	D+Po	Fs
7	Normal/Severe	D+Po+E	$1.25F_s$
8	Normal/Extreme	D+Po+E'	(2)
9	Normal/Extreme	$D+P_M+E'+SRV$	(2)
10	Extreme/Abnormal	$D+P_O+P_A+E'+SRV+LOCA$	(2)
11	Extreme/Abnormal	When protection against tornado depressurization is required:	
12	Extreme/Abnormal	$D+P_O+W_D+SRV+LOCA$	(2)
		For ducts inside drywell of containment, the following additional load combination is also applicable:	
		$D+H_A+P_O+P_A+E'+SRV+LOCA$	(2)

DUCT SUPPORTS

Equation	Condition	Load Combination	Allowable Stress
1	Normal	D+L+SRV	Fs
2	Normal/Severe	D+E	$1.25F_s$ (1)
3	Normal/Severe	D+E+SRV	(1)
4	Extreme/Abnormal	D+E'+SRV+LOCA	(1)

TABLE 5.10-1 (Cont'd)

Notations

D	=	Dead load
L	=	Live load
P_O	=	Duct normal operating pressure load
P_T	=	Duct test pressure load
P_A	=	Design basis accident pressure load
P_M	=	Duct maximum operating pressure load, excluding PA & PT, e.g., fan cutoff pressure load
E	=	Load due to operating basis earthquake (OBE)
E'	=	Load due to safe shutdown earthquake (SSE)
W_D	=	Tornado depressurization load
H_A	=	Forces due to thermal expansion of HVAC ducts under accident conditions
SRV	=	Safety relief valve loads
LOCA	=	Loss-of-coolant accident loads
F_s	=	Allowable stress for steel, governed by AISI or AISC Codes, as applicable
F_y	=	Yield strength for steel (ASTM specification minimum)

(1) This value shall be Fs for transverse and longitudinal bracing and their connections.

(2) In no case shall be allowable stress exceed 0.90 Fy in bending, 0.85 Fy in axial tension or compression, and 0.50 Fy in shear. Where the design is governed by requirements of stability (local or lateral buckling), the actual stress shall not exceed 1.5 Fs.

CHAPTER 6

DESIGN CAPABILITY ASSESSMENT CRITERIA

TABLE OF CONTENTS

CHAPTER 6

DESIGN CAPABILITY ASSESSMENT CRITERIA

6.1 INTRODUCTION

The criteria by which the design capability is determined are discussed in this chapter. Design of the LGS is assessed as adequate when the design capability of the structures, piping, and equipment is greater than the loads (including LOCA and SRV discharge) to which the structures, piping, and equipment are subjected. Loading combinations are discussed in Chapter 5. The margins by which design capabilities exceed these loads are discussed in Chapter 7.

6.2 CONTAINMENT, REACTOR BUILDING, AND CONTROL STRUCTURE CAPABILITY ASSESSMENT CRITERIA

6.2.1 CONTAINMENT STRUCTURE CAPABILITY ASSESSMENT CRITERIA

The acceptance criteria detailed in the LGS FSAR Section 3.8.1.5 have been used to assess the structural integrity of the containment and internal structures. No changes are made in these acceptance criteria when the effects of the dynamic SRV discharge and LOCA loads are included.

6.2.2 REACTOR BUILDING AND CONTROL STRUCTURE CAPABILITY ASSESSMENT CRITERIA

The acceptance criteria for seismic Category I structures presented in the LGS FSAR Section 3.8.4.5 have been used to assess the structural integrity of the reactor building, control structure, and their components. No changes are made in these acceptance criteria when the effects of the dynamic SRV discharge and LOCA loads are included.

6.3 STRUCTURAL STEEL CAPABILITY ASSESSMENT CRITERIA

The allowable stresses for structural steel in the containment, reactor building, and control structure are given in Table 5.3-1. These criteria apply to the suppression chamber steel columns, the downcomer bracing, and miscellaneous structural steel within the containment, reactor building, and control structure.

6.4 LINER PLATE CAPABILITY ASSESSMENT CRITERIA

The strains in the liner plate and anchorage system (welds and anchors) from self-limiting loads such as dead load, creep, shrinkage, and thermal effects are limited to the allowable values specified in Table CC-3720-1 of Reference 6.4-1. The displacements of the liner anchorage are limited to the displacement values of Table CC-3730-1 of Reference 6.4-1.

Primary membrane stresses in the liner plate and anchorage system (welds and anchors) from mechanical loads such as SRV discharge and chugging are checked according to subsection NE-3221.1 of Reference 6.4-2. Primary plus secondary membrane plus bending stresses are checked according to subsection NE-3222.2 of Reference 6.4-2. Fatigue strength evaluation is based on subsection NE-3222.4 of Reference 6.4-2. Allowable design stress intensity values, design fatigue curves, and material properties that are used conform to subsection NA, Appendix I, of Reference 6.4-2.

The capacity of the liner plate anchorage is limited by the concrete pull-out to the service load allowable for concrete as specified in Reference 6.4-3.

6.4.1 REFERENCES

6.4-1 ASME Boiler and Pressure Vessel Code, Section III, Division 2, 1974.

6.4-2 ASME Boiler and Pressure Vessel Code, Section III, Division 1, 1974.

6.4-3 ACI 318, "Building Code Requirements for Reinforced Concrete", 1971 Edition.

6.5 DOWNCOMER CAPABILITY ASSESSMENT CRITERIA

The allowable stresses for the downcomers are given in Table 5.5-1. These allowable stresses are in accordance with subsection NE, Reference 6.4-2. As permitted by subsection NE-1120 for MC components, the downcomers are analyzed in accordance with subsection NB-3650 of Reference 6.4-2 However, the lower allowable stresses, S_m, from Table I-10.1 for MC components, are used when performing the analysis.

6.6 PIPING, QUENCHER, AND QUENCHER SUPPORT CAPABILITY SUPPORT ASSESSMENT CRITERIA

Piping in the containment and reactor building is analyzed in accordance with Reference 6.4-2, subsections NB-3600, NC-3600, and ND-3600, and ANSI B31.1 (Power Piping Code) for the loading described in Table 5.6-1. In addition to these code requirements, when piping is required to deliver rated flow during or following an emergency or faulted event, the functional capability requirement shall be met for the load combinations with the event.

The quencher is designed in accordance with Reference 6.4-2, subsection NC-3200, for the loading discussed in Section 5.6.3. The quencher support is designed in accordance with subsection NF3000 of Reference 6.4-2.

6.7 NSSS CAPABILITY ASSESSMENT CRITERIA

To be provided later.

6.8 EQUIPMENT CAPABILITY ASSESSMENT CRITERIA

6.8.1 ANALYSIS

Safety-related equipment located in the primary containment, reactor building, and control structure are analyzed to satisfy load combinations 1a, 1b, 2, 3d, and 3e of Table 5.8-1. The maximum load effects result from simultaneous exitation in all three principal directions for all combinations involving dynamic loads as detailed in Section 7.1.7.4.1.3. The operability of active components required to operate during a dynamic event is also considered.

6.8.2 TESTING

When safety-related equipment is qualified by testing, a test response spectrum (TRS) is derived to envelope the required response spectrum (RRS) for load combinations 1b, 3e, and 4 of Table 5.8-1. The minimum test sequence is to perform five runs of the TRS for load combination 1b, followed by one run of load combination 3e, then one run of load combination 4. Qualification is achieved if the equipment does not fail or malfunction during the test. Operability is verified before and after the test sequence. Active components required to function during a dynamic event are also operated during the test.

An example of a combined RRS and an enveloping TRS are presented in Appendix H.

6.8.3 COMBINED ANALYSIS TEST

Some equipment is qualified by a combination of analysis and testing procedures. Details of this method, as well as further documentation of the equipment qualification program, are presented in Appendix H.

6.9 ELECTRICAL RACEWAY SYSTEM CAPABILITY ASSESSMENT CRITERIA

The allowable stresses for the electrical raceway system are given in Table 5.9-1.

6.10 HVAC DUCT SYSTEM CAPABILITY ASSESSMENT CRITERIA

The allowable stresses for the miscellaneous steel for the HVAC duct system are given in Table 5.10-1.

CHAPTER 7

DESIGN ASSESSMENT

TABLE OF CONTENTS

CHAPTER 7

TABLE OF CONTENTS (Cont'd)

TABLE OF CONTENTS (Cont'd)

CHAPTER 7

TABLES

CHAPTER 7

FIGURES

CHAPTER 7

FIGURES (Cont'd)

CHAPTER 7

DESIGN ASSESSMENT

7.1 ASSESSMENT METHODOLOGY

Loads on LGS structures, piping, and equipment are defined in Chapter 4. The methods by which these loads are combined are discussed in Chapter 5. The criteria for establishing design capability are stated in Chapter 6.

This section describes the assessment methodology used in the final evaluation of structures, piping, and equipment.

7.1.1 CONTAINMENT, REACTOR BUILDING, AND CONTROL STRUCTURE ASSESSMENT METHODOLOGY

7.1.1.1 Containment Structure

7.1.1.1.1 Hydrodynamic Loads

7.1.1.1.1.1 Structural Models

The dynamic analysis for the structural response of the containment and internal structures due to the SRV discharge loads and LOCA loads is performed using the finite element method. The ANSYS (FSAR Section 3.8.7) finite element computer program was chosen for the transient dynamic analysis. Figure 7.1-1 shows the ANSYS finite element model. The concrete containment walls, slabs, RPV, RPV pedestal, and shield wall are modeled with shell elements. The refueling bellows and stabilizer truss are modeled with spar elements. The RPV internals are modeled with beam elements. The suppression pool fluid mass is modeled with lumped mass elements. The ANSYS model includes a total of 797 elements and 206 dynamic degrees of freedom.

The soil structure interaction is taken into consideration by modelling the soil using a series of discrete springs and dampers in three directions as shown in Figure 7.1-1. The properties of the discrete springs and dampers are calculated based on the

formulae for lumped parameter foundations found in Reference 7.1-1.

7.1.1.1.1.2 Damping

a. Structural Damping

The equations of motion for a discretized structure must include a term to account for viscous damping that is linearly proportional to the velocity. The equations of motion for a damped system are:

$$[M]\{\ddot{r}\} + [C]\{\dot{r}\} + [K]\{r\} = \{R(t)\} \qquad (7.1\text{-}1)$$

where [C] is the viscous damping matrix.

A viscous damping matrix of the form

$$[C] = \alpha [M] + \beta [K] \qquad (7.1\text{-}2)$$

was used (Reference 7.1-2) where α and β are proportionality constants that relate damping to the velocity of the nodes and the strain rates, respectively. This damping matrix leads to the following relation between α and β and the damping ratio of the ith mode C_i:

$$C_i = \alpha/2w_i + \beta w_i/2 \qquad (7.1\text{-}3)$$

where w is the natural frequency of the ith mode. For the usual case of only structural damping, $\alpha = 0$ and therefore $\beta = 2C_i/w_i$.

Because only a single value of β is permitted in the ANSYS input, the most dominant natural frequency of the structure is selected for the computation of β (Reference 7.1-3).

A value of β equal to 0.00063 is used in the ANSYS model which corresponds to structural modal damping of approximately 4 percent of critical at 20 Hz which is the most dominant natural frequency of the structure.

Figure 7.1-2 shows modal damping ratio versus modal frequency for structural stiffness-proportional-damping.

b. Soil Springs and Radiation Damping

The elastic half-space theory as described by Reference 7.1-1 was used to compute the values of the spring constants and dampers in the horizontal and vertical directions (KH, KV, CH & CV). The following parameters are used to represent the rock foundation:

G = Shear modulus of foundation medium

= 1.154×10^3 KSI

ν = Poisson's ratio of foundation medium

= 0.3

V_S = Shear wave velocity

= 6180 ft/sec

From which we get the following:

K_H = 3.37×10^6 K/in

C_H = 1.57×10^4 K-sec/in

$K_V = 3.96 \times 10^6$ K/in

$C_V = 2.72 \times 10^4$ K-sec/in

The above lumped foundation springs and dampers were then distributed to every node on the basemat according to the tributary area.

7.1.1.1.1.3 Fluid-Structure Interaction

A finite element fluid - structure interaction model was developed for the analysis of the containment structure. The water mass constitutes only 1/7 of the total mass of the reinforced concrete structure. The model used considers fluid - structure coupling by lumping the water mass in the suppression pool at each node of the wetted surface. The weighted area approach was considered to determine the fluid mass at each node of the suppression pool.

7.1.1.1.1.4 Supplementary Computer Programs

Supplementary computer programs were used for preprocessing and postprocessing of data generated for or by the ANSYS computer program.

Preprocessing programs called PREPRC1, PREPRC2, and PREPRC3 were developed to convert the SRV, condensation oscillation, and chugging pressure time histories into force time histories, respectively, acting at the associated nodes of the ANSYS model. The programs write the nodal force time histories onto a file for processing by ANSYS.

A postprocessor program was developed to calculate the nodal acceleration time history. This program is called DISQGE. It reads the structural response displacement time histories generated from ANSYS (displacement pass option), scans for the maximum displacements, and generates the acceleration time histories using the Fast Fourier Transformation method.

Bechtel in-house computer program MSPEC was used to compute the acceleration response spectrum obtained from DISQGE. The program also performs plotting and broadening of the spectrum.

A computer program ENVELOP was developed to envelope response spectra obtained from MSPEC.

Computer program SCALE was developed to scan the maximum absolute stresses generated by ANSYS (stress pass option). An explanation of SCALE is given in Section 7.1.1.1.1.6.2.

Verification of PREPRC1, PREPRC2, PREPRC3, DISQGE, ENVELOP, and SCALE are available for review.

7.1.1.1.1.5 Load Application

7.1.1.1.1.5.1 SRV Discharge Loads

The SRV discharge load used in the analyses was taken from the KWU load report (Ref. 4.1-2). The analyses were done for KWU SRV pressure traces 35, 76, and 82. Axisymmetric and asymmetric pressure distributions were considered. Chapter 4 contains a detailed SRV load definition. The load definition takes into account the variation in pressure amplitude and frequency in the input forcing functions by applying a change of key frequencies in the assumed range of 55 to 125 percent of original frequency content (included are 55, 67, 87, 100, and 125 percent of the original frequencies) and a pressure multiplier of 1.5 to each input load trace. A total of 15 axisymmetric load traces and 15 asymmetric load traces were used in the analyses.

7.1.1.1.1.5.2 LOCA Related Loads

The main LOCA loads that significantly affect the dynamic analysis are condensation oscillation (CO) and chugging loads.

The CO analysis was performed for two cases: the basic CO case and the CO-ADS case. Both CO and CO-ADS load definitions are based on direct application of measured pressure data from the 4TCO facility, a BWR Mark II prototypical unit cell used to produce expected bounding CO load data (Ref. 1.3-1). The CO load case is related to the basic CO load that covers all LOCA blowdown conditions resulting in CO, whereas the CO-ADS load case

is data associated with the combination of CO and ADS events. Both events (CO and CO-ADS) produce wall pressure loading of axisymmetric nature. The wetwell pressure load vector was appropriately applied to the ANSYS model for a dynamic analysis. Also considered in the analysis is associated drywell pressure load defined in Reference 1.3-1, based on a direct application of the measured drywell acoustic pressure time histories. A total of 17 time segments of CO and two time segments of CO-ADS are considered in the analysis.

The LGS Mark II chugging load pressure transients were calculated by Bechtel proprietary computer code IWEGS/MARS-P using GE700 series CHUG source data supplied by General Electric Company (Reference 1.3-1). The source data were based on measured data from 4TCO test facility, a BWR Mark II prototypical unit cell used to simulate the chugging loads during a postulated Mark II LOCA. A total of 14 chugging time histories are considered in the chugging analyses.

7.1.1.1.1.6 Analysis

7.1.1.1.1.6.1 Response Spectra Generation

Acceleration time histories, maximum structural displacements and accelerations, and broadened acceleration response spectra are developed for the analysis of piping, equipment, and NSS systems. Gross acceleration time histories are generated at the interface between pedestal and diaphragm slab, the stabilizer location at the containment wall, the top of drywell at the refueling bellows, and at the interface between wetwell wall and base slab.

The maximum containment response to SRV axisymmetric loads is obtained by enveloping the acceleration response spectra of the 15 axisymmetric SRV cases. Likewise, the response spectra for the 15 asymmetric SRV cases are enveloped.

The maximum containment response to the condensation oscillation loads is obtained by enveloping the acceleration response spectra of the 17 CO segments. Likewise, the response spectra of the two CO-ADS segments are enveloped.

The maximum containment response to the chugging loads is obtained by enveloping the acceleration response spectra of the 14 chugging cases.

The enveloped response spectra are furnished in two sets of damping values, the low and the high damping. The low damping values are 0.5, 1, 2, and 5 percent of critical. The high damping values are 7, 10, 15, and 20 percent of critical. The spectra are broadened by ±15 percent to account for the uncertainties in the structural modeling techniques and material properties.

7.1.1.1.1.6.2 Stress Analysis

The ANSYS computer program (stress pass option) is used to compute the force and moment resultants due to SRV and LOCA - related loads. A postprocessor program called SCALE is used to scan for the maximum absolute values of forces and moments in the circumferential and meridional directions.

The forces and moments due to chugging and condensation oscillation loads are considered for the load combinations including the LOCA loads. The governing forces and moments from the six different frequencies are used in the stress analysis.

7.1.1.1.2 Seismic Loads

Seismic loads constitute a significant loading in the structural assessment. The same seismic loads as those used in the initial building design are used. In that design, a dynamic analysis was made using discrete mathematical idealization of the entire structure using lumped masses. The resulting axial forces, moments, and shear forces at various levels due to the operating basis earthquake and the safe shutdown earthquake are used (FSAR Section 3.7). The effects of the seismic overturning moment and vertical accelerations are converted into forces at the elements.

7.1.1.1.3 Static and Thermal Loads

The loads under consideration are the static loads (dead load and accident pressure) and temperature loads (operating and accident temperature) which are all axisymmetrical.

a. To analyze the above static loads, an in-house computer program, FINEL (FSAR Section 3.8.7), is used. Moments, axial forces, and shear forces are computed by FINEL in an uncracked axisymmetric finite element containment model.

b. The operating and accident temperature gradients are computed using ME 620 (FSAR Section 3.8.7) computer program (Bechtel program).

c. The results from a, b, and the dynamic/seismic analysis are combined and applied to a containment element. The element contains data relative to rebar location, direction, and quantity and concrete properties. Within that wall element, force equilibrium and strain compatibility between the rebar and concrete is established by allowing the concrete to crack in tension. In this way, the stresses in the rebar and concrete are determined. The program used for this analysis is called CECAP (FSAR Section 3.8.7).

7.1.1.1.4 Load Combinations

All load combinations from equations 1 through 7a as presented in Table 5.1-1 have been analyzed. This was done under step c of Section 7.1.1.1.3.

The reversible nature of the structural responses due to the pool dynamic loads and seismic loads is taken into account by considering the peak positive and negative magnitudes of the response forces and maximizing the total positive and negative forces and moments governing the design.

Seismic and pool dynamic load effects are combined by conservatively summing the peak responses of each load by the absolute sum (ABS) method. Even though the square root sum of squares (SRSS) method is more appropriate because the peak effects of all loads may not occur simultaneously (Reference 7.1-4), the conservative ABS method is used in the design assessment of the containment and internal concrete structures to expedite licensing.

7.1.1.1.5 Design Assessment

Material stresses at the critical sections in the primary containment and internal concrete structure are analyzed using the CECAP computer program. Critical sections for bending moment, axial force and shear in three directions are located throughout the containment structure. Liner plate is not considered as a structural element. The CECAP program considers concrete cracking in the analysis of reinforced concrete

sections. CECAP uses an iterative technique to obtain stresses considering redistribution of forces due to cracking and, in the process, it reduces the thermal stresses due to the relieving effect of concrete cracking. The program is also capable of describing the spiral and transverse reinforcement stresses directly. The input data for the program consists of the uncracked forces, moments and shears calculated by FINEL, ANSYS, and seismic analysis. The loads are then combined in accordance with Table 5.1-1 with appropriate load factors.

7.1.1.2 Reactor Building and Control Structure

7.1.1.2.1 Hydrodynamic Loads

7.1.1.2.1.1 Load Definitions

The reactor building and control structure were analyzed for both the SRV discharge load and the LOCA condensation oscillation and chugging loads. Description of the different load cases are presented in Section 7.1.1.1.1.5.

7.1.1.2.1.2 Hydrodynamic Analysis Models

For the hydrodynamic loads described in Section 7.1.1.2.1.1, different mathematical models are constructed for the determination of the reactor building and control structure hydrodynamic responses. The mathematical models are presented in detail in the following sections and are summarized in Table 7.1-1.

7.1.1.2.1.2.1 SRV Analysis Models

The reactor building and control structure were modeled to simultate global structural response during SRV actuation. Included in the analyses were an axisymmetric model for axisymmetric SRV loads and flexible base vertical, N-S and E-W stick models, which use the ANSYS containment finite element model response as input for the asymmetric SRV loads. The mathematical models and analysis procedures are described below.

7.1.1.2.1.2.1.1 Axisymmetric SRV Analysis Model

An axisymmetric model, based on Bechtel proprietary code CE971-FESS, was created to generate vertical response data for the NSSS new loads' structure and equipment adequacy assessment. The axisymmetric model has been closely correlated with in-plant test data (Reference 7.1-5).

The model represents a containment system, adjacent structure (including reactor building and control structure), and the soil medium as shown in Figure 7.1-3. Fiaure 7.1-8 shows a mass-proportional and stiffness-proportional damping simulation. The containment system and soil medium were modeled as FESS axisymmetric finite elements, whereas the adjacent structure was simulated by a coupled stick model. Altogether, the model has a combination of 673 dynamic degrees of freedom.

The model was modified to simulate as-built conditions (i.e., concrete aging effect) and normal plant operating conditions (i.e., RPV mass, etc) for generation of response data used for associated equipment adequacy evaluation. The analytical elements have the material properties as shown below:

Element Material Type	Young's Modulus, E Kip/ft^2	Material Density, ρ $Kip.s^2/ft^4$	Poisson's Ratio	Shear Wave, Vs (Ft/s)
Concrete	0.0936E+6[1]	0.00446	0.22	-
Steel	0.4176E+7	0.01524	0.33	-
Soil Medium	0.432E+6	0.00481	0.30	5959[2]

[1]Aging effect taken into account

[2]The shear wave velocity, Vs, is used to simulate a soil shear modulus ($G=Vs^2\rho$), equal to 0.166 E+6 Kip/ft^2.

7.1.1.2.1.2.1.2 Asymmetric SRV Analysis Models

Analysis models for the asymmetric load include the combined use of the ANSYS finite element containment model response as input to the flexible base vertical, N-S horizontal and E-W horizontal stick models of the reactor building and control structure. The ANSYS containment model is shown in Figure 7.1-1, and the stick models are shown in Figures 7.1-4 and 7.1-5. The stick model damping uses the composite damping method (Reference 7.1-1).

The vertical stick model was taken from the verified axisymmetric (FESS) coupled model. This model has 46 dynamic degrees of freedom. The flexible base was similated by a soil spring and damper as recommended in the Bechtel design guide (Ref. 7.1-1).

The N-S and E-W analytical stick models were the same as those used in the seismic analyses. Each stick model has 12 dynamic degrees of freedom.

Input load data were taken from associated ANSYS containment analysis output data. This includes the use of a vertical input time-history at the adjacent structure base equal to an average vertical response acceleration time history (from ANSYS) at the containment wall base, multiplied by an attenuation factor (0.512 generated from axisymmetric free field analysis; 0.25 from in-plant test), and the use of horizontal input acceleration time history at the adjacent structure base equal to the gross motion generated from the associated containment ANSYS analysis data.

7.1.1.2.1.2.2 CO Analysis Model

The reactor building and control structure were modeled to simulate global structural response due to CO loads. Included in the analyses were an axisymmetric model for basic CO load case and CO-ADS combination load case, as was used in axisymmetric SRV analysis described in Section 7.1.1.2.1.2.1.1.

7.1.1.2.1.2.3 CHUG Analysis Models

The reactor building and control structure were modeled to simulate global structural response during various CHUG events. Included in the transient time history analyses were flexible base stick models presented in Section 7.1.1.2.1.2.1.2, which use the ANSYS containment model response as input for the CHUG

asymmetric loads, and an axisymmetric model for the CHUG equivalent axisymmetric loads. The mathematical models and analytical procedures are described below.

7.1.1.2.1.2.3.1 CHUG Asymmetric Analysis Models

Analysis models for the CHUG asymmetric loads, as were used for SRV asymmetric loads, include the combined use of the ANSYS finite element containment model response as input to the flexible base vertical, N-S horizontal and E-W horizontal stick models of the reactor building and control structure. The ANSYS containment model is shown in Figure 7.1-1, and the stick models are shown in Figures 7.1-4 and 7.1-5. The stick model damping used the composite damping method (Reference 7.1-1).

The vertical stick model used was a verified axisymmetric (FESS) coupled model. This model has 46 dynamic degrees of freedom. The flexible base was simulated by a soil spring and damper as recommended in the Bechtel design guide (Ref. 7.1-1).

The N-S and E-W analytical stick models were the same as were used in the seismic analyses. Each stick model has 12 dynamic degrees of freedom.

Input load data were taken from associated ANSYS containment analysis output data. This includes the use of a vertical input time history at the reactor building and control structure base equal to an average vertical response acceleration time history (from ANSYS) at the containment wall base, multiplied by an attenuation factor (0.512 generated from axisymmetric free field analysis; 0.25 from in-plant test), and the use of horizontal input acceleration time history at the reactor building and control structure base equal to the gross motion generated from the associated containment ANSYS analysis data (no attenuation factor being used).

7.1.1.2.1.2.3.2 CHUG Axisymmetric Analysis Model

An axisymmetric model, based on Bechtel proprietary code CE971-FESS, was created to generate vertical response data for the NSSS new loads' structure and equipment adequacy assessment.

Similar to the axisymmetric SRV analysis model (Section 7.1.1.2.1.2.1.1) and the axisymmetric CO analysis model

(Section 7.1.1.2.1.2.2), CHUG axisymmetric analysis model represents a containment system, an adjacent structure (including reactor building and control structure), and the soil medium as shown in Figure 7.1-3. The containment system and soil medium were modeled as FESS axisymmetric finite elements, whereas the adjacent structure was simulated by a coupled stick model. The model has a combination of 673 dynamic degrees of freedom. The model was modified to simulate as-built conditions (i.e., concrete aging effect) and normal plant operating conditions (i.e., RPV mass, etc), for generation of response data used for associated equipment adequacy evaluation.

The analytical elements have the material properties as shown in the table of Section 7.1.1.2.1.2.1.1.

7.1.1.2.1.2.4 Control Structure Floor/Local Models

Based on the excitation source at floor-wall junctions, analytical models for the selected floors were constructed to generate floor vertical response. Each floor considered was as a finite element model, with boundaries at walls simulated by clamped edges. Along the line of symmetry (N-S direction), symmetric boundary conditions were imposed in the construction of a "half model" for the transient analyses, i.e., SRV and CHUG loads.

To deal with dynamic problems of larger load duration, i.e., CO, CO-ADS, and seismic loads, a "quarter model" was formed by taking a symmetric line in the E-W direction of the "half model". Symmetric boundary were imposed similarly.

The half model (Figure 7.1-6) consists of 42 model nodes and 30 quadrilateral elements. By choosing five dynamic degrees of freedom (DDOF) to each interior node and three DDOF to each symmetric node, the model has 115 DDOF. Similarly, the quarter model has 9 model nodes and 6 quadrilateral elements (Figure 7.1-7), with 12 DDOF selected for analysis.

All floors considered have identical nodal coordinates and similar model material properties (i.e., equivalent floor thickness from beam-slab composite action and composite material density, etc).

Floor-supported steel girders have contributed a substantial portion of equivalent thickness calculated for slab-beam

composite action. The contribution are different in magnitude, depending upon girder size, and junction with or without shear connectors, etc. The floors, except that of El. 269 feet (control room), were built with shear connectors. The floor model at El 269 feet (control room) was verified by data correlation/comparison with an in-plant test.

In addition, the models were modified to simulate as-built conditions (e.g., concrete aging effect, etc). To deal with seismic events, the models were further modified to consider cracking effects.

Floor model material properties are shown in Table 7.1-2.

7.1.1.2.1.3 Hydrodynamic Analysis

7.1.1.2.1.3.1 Analysis Procedures

7.1.1.2.1.3.1.1 Axisymmetric Analysis Procedure

The axisymmetric analysis general procedure is to perform a time history analysis using equivalent axisymmetric input forcing vectors described in Sections 7.1.1.2.1.2.1.1, 7.1.1.2.1.2.2, and 7.1.1.2.2.2, using Bechtel proprietary code CE971-FESS. Acceleration response spectra (ARS) data are generated using the acceleration response time histories obtained from the time history analysis using Bechtel proprietary code CE789-MSPEC. All associated ARS data are enveloped, widened ±15 percent, and plotted, using Bechtel proprietary codes ENVLPS and MSPEC.

7.1.1.2.1.3.1.2 Asymmetric Analysis Procedure

The general analytical procedure for asymmetric analysis consists of generating input load vectors to ANSYS model from appropriate use of the load definition and applying ANSYS transient response for asymmetric loadings to adjacent structure decoupled stick models (N-S, E-W, and vertical). A transient analysis is performed using decoupled BSAP stick models for each load case. The acceleration response spectra (ARS) data are generated using the response acceleration time histories and Bechtel proprietary code CE789-MSPEC. All associated ARS data are enveloped, widened ±15 percent, and plotted.

7.1.1.2.1.3.1.3 Floor/Local Model Analysis Procedure

The floor model analysis general procedure is to perform a time history analysis using input forcing vectors taken from stick model analyses described in Sections 7.1.1.2.1.3.1.1 and 7.1.1.2.1.3.1.2 and using the model according to Bechtel proprietary code CE800-BSAP. ARS data are developed using the acceleration response time histories and Bechtel proprietary codes CE789-MSPEC and ENVLPS.

7.1.1.2.1.3.2 Generation of Response Data

7.1.1.2.1.3.2.1 Acceleration Response Spectra Data

7.1.1.2.1.3.2.1.1 SRV ARS Data

Two sets of ARS data were generated. One set is for SRV axisymmetric analysis and the other set is for SRV asymmetric analysis. The ARS data, enveloped from associated data and broadened ±15 percent at peak frequencies, represent global response, applicable to structural assessment and NSSS equipment (or other safety-related equipment) adequacy evaluations located at or near the adjacent structure walls and/or columns. The ARS at selected typical locations on the reactor building and control structure are presented in Appendix B.

7.1.1.2.1.3.2.1.2 CO ARS Data

Two sets of ARS data are generated. One set is for basic CO load case analysis and the other set is for the CO-ADS combination load case. Again, the ARS data, enveloped from associated data and broadened ±15 percent at all peak frequencies, represent global response. The data are applicable to structure and/or equipment adequancy assessment located at or near the adjacent structure walls and/or columns. The ARS at selected locations are presented in Appendix B.

7.1.1.2.1.3.2.1.3 CHUG ARS Data

Two sets of broadened ARS data are presented in Appendix B for appropriate use in structure and equipment adequacy assessment. Set one is for CHUG asymmetric analysis case, and set two is for the CHUG equivalent axisymmetric analysis case.

The ARS data for the CHUG asymmetric case were developed and plotted similar to the SRV asymmetric analysis case. The data plots include the broadened ARS data in the three global directions (vertical, N-S, and E-W axes).

The CHUG asymmetric vertical ARS data provide responses for the applicable areas for the NSSS equipment adequacy assessment. The N-S and E-W ARS data apply to all NSSS equipment situated in any location of the reactor building and control structure.

The ARS data for CHUG equivalent axisymmetric analysis cases were developed and plotted similar to SRV axisymmetric analysis cases.

Again, the data represent only global response, applicable to the NSSS equipment adequacy evaluations located at or near the adjacent structure walls and/or columns. Local/floor models are required for generating vertical ARS data for some floor-mounted equipment.

7.1.1.2.1.3.2.1.4 Hydrodynamic Local ARS Data

The local ARS data in the control structure were generated based on the floor/local model analytical procedure described in Sections 7.1.1.2.1.2.4 and 7.1.1.2.1.3.1.3. The data was broadened ±15 percent at all peaks of the data enveloped from associated dynamic events.

The dynamic events considered in the enveloping were SRV, CHUG, CO (basic), CO-ADS, and seismic.

The dynamic local ARS data are used for the structures, components, and floor-mounted equipment which are not applicable for analysis by the global ARS data.

7.1.1.2.2 Seismic Loads

The seismic analysis methodology is discussed in FSAR Section 3.7.2.1

7.1.1.2.3 Static Loads

The static loads are discussed in FSAR Section 3.8.4.3.

7.1.1.2.4 Load Combinations

All individual loads for concrete structures are combined with the appropriate load factors shown in Table 5.1-1, for analysis of all loading cor' . .ons.

Steel structures are checked for the load combinations listed in Table 5.3-1.

7.1.1.2.5 Design Assessment

Critical sections for bending moment, axial force, and shear in all three directions are located throughout the reactor building and control structure. Design capability at the critical sections is determined, and then the design capability is compared with the actual forces and moments acting on the sections under all the load combinations. This comparison yields design margins. The design margins are discussed in Section 7.2.

7.1.2 STRUCTURAL STEEL ASSESSMENT METHODOLOGY

7.1.2.1 Suppression Chamber Columns

The assessment methods used for non-hydrodynamic loads such as dead, live, pressure, temperature, seismic, and pipe rupture loads are described in FSAR Section 3.8.3.4.5.

The assessment methodology used for the hydrodynamic loads will be provided later.

7.1.2.2 Downcomer Bracing

The following covers the methodology used in the assessment of the bracing system at EL. 203' - 5" in the primary containment suppression pool.

7.1.2.2.1 Bracing System Description

The downcomer bracing system is designed as a two-dimensional truss system to provide horizontal support for 87 downcomers, 14 MSRV discharge lines, and other miscellaneous piping in the suppression pool. The bracing system is supported vertically by the 87 downcomers and at 12 anchor points around the RPV pedestal wall. The bracing system is made of stainless steel members connected to carbon steel collars at the downcomers and embeddment plates at the pedestal wall by high-strength stainless steel bolts. The bracing members consist of 10-inch and 12-inch diameter schedule 160 pipe sections, and 3-1/4 inch end connection plates.

The bracing system layout and typical connection details are shown in Figures 7.1-9 and 7.1-10. The mathematical model used in the bracing system is presented in Figure 7.1-11.

7.1.2.2.2 Loads

The bracing system is assessed for all plant operation induced loads described below. The basis for all hydrodynamic loads considered in the analysis is presented in Chapter 4.

7.1.2.2.2.1 SRV Discharge Loads

Discharge through the SRV discharge pipe creates horizontal as well as vertical loading on the bracing system due to unbalanced pressures. The horizontal (lateral) load is considered as acting on the downcomers and the SRV discharge pipes. The vertical load is considered acting on the bracing members alone. These loads are applied to the bracing system by considering them as equivalent static loads using a dynamic magnification factor which is obtained from the dynamic analysis of the downcomer, as described in Section 7.1.4.

The SRV discharge also induces hydrodynamic forces in the containment structure. Inertial forces of the bracing system, due to the response of the containment structure, are considered using hydrodynamic reponse spectra of the containment structure shown in Appendix A.

The lateral loads and the containment structure response form the complete SRV discharge load set on the bracing system.

7.1.2.2.2.2 LOCA Related Loads

Loss-of-coolant accidents are characterized by several phenomena that result with non-concurrent loadings on the bracing system as described in Section 4.2. These hydrodynamic loads induce accelerations of the containment structure, which in turn induce additional loads on the bracing system. These loads are obtained from the hydrodynamic acceleration response spectra shown in Appendix A.

In addition, the LOCA event induces lateral forces on the submerged portion and tip of downcomers. The loads include drag loads, pressure loads, and chugging tip load. The hydrodynamic analysis of a single downcomer for the lateral loads is presented in Section 7.1.4. The resulting reaction forces at the bracing support are applied as equivalent static load in accordance with section 3.1 of Reference 7.1-6.

7.1.2.2.2.3 Seismic Loads

The forces due to the seismic accelerations of the downcomers, the SRV lines, and the bracing members are obtained by analysis of these structures using the response spectra developed for OBE and SSE as described in FSAR Section 3.7.2.

7.1.2.2.2.4 Static Loads

The dead load of the bracing members is considered with allowance for buoyancy.

7.1.2.2.2.5 Thermal Load

The operating and accident temperature considered is 90 and 210°F, respectively. The reference temperature of the system is assumed to be 60°F.

7.1.2.2.2.6 Load Combinations

The load combinations and allowable stresses are described in Table 5.3-1. Although the loads on the bracing system under consideration act in random horizontal directions, each

individual load is applied on the system in the worst possible direction to find the maximum resultant forces.

7.1.2.2.3 Design Assessment

The two-dimensional truss model of the bracing system is analyzed for the static, thermal, and equivalent static hydrodynamic loads using the computer program STRUDL. The containment structure inertial load is analyzed for seismic and hydrodynamic responses using the computer program ANSYS. The bracing member forces due to the various loading conditions are combined by the absolute sum method and assessed for the conditions specified in Table 5.3-1.

7.1.3 LINER PLATE ASSESSMENT METHODOLOGY

FSAR Section 3.8.1.1 provides a description of the containment liner plate and its anchorage system.

The analysis and design of the liner plate anchorages for nonhydrodynamic loads is in accordance with Reference 7.1-7.

For the analysis of the liner plate and anchorages for hydrodynamic suction pressure loads, the contributing load on the liner is that due to the net negative pressure load. The net negative pressure load is determined from the dynamic negative pressure due to SRV actuation and/or LOCA chugging minus the static positive pressure due to the wetwell hydrostatic pressure and/or LOCA wetwell pressure. Figures 7.1-12 and 7.1-13 describe the loads on the base mat and suppression chamber wall liner plate for the normal and abnormal load conditions, respectively.

For the normal condition, the hydrostatic pressure on the base mat is 10.4 psi (positive) and the maximum negative pressure due to the actuation of all SRVs is 7.1 psi (negative). The distribution of these pressures on the suppression chamber wall is shown in Figure 7.1-12.

For the abnormal condition, the total positive pressure on the basemat is 35.4 psi which consists of 10.4 psi (positive) from hydrostatic pressure plus 25.0 (positive), from a small or intermediate break LOCA (Figure 7.1-13). The total maximum negative pressure on the basemat is 16.9 psi (negative) due to the axisymmetric chugging and SRV loads (Figure 7.1-14). The

maximum negative pressures from SRV actuation and chugging are combined for conservatism. It is recognized that the probability of these two phenomena producing peak negative pressures at the same time is very low. The combined pressure distribution due to hydrostatic, LOCA, SRV, and chugging is shown in Figure 7.1-15.

7.1.4 DOWNCOMER ASSESSMENT METHODOLOGY

7.1.4.1 Structural Model

There are 87, 24-inch OD, steel pipe downcomers running vertically down from the diaphragm slab. The downcomers are embedded in the diaphragm slab and extend downward to El. 193'-11", which is approximately 12 feet below high water level, as shown in Figure 1.4-2. All downcomers are supported laterally at El 203'-5" by the downcomer bracing system. Any vertical loads are transmitted by the bracing system to the downcomers and therefore to the diaphragm slab.

The structural model considers the downcomer as a vertical pipe fixed at the underside of the diaphragm slab with a spring in the horizontal direction at bracing level. This model is shown in Figure 7.1-16. The inertial effect of the water in the submerged portion of the downcomer (12 feet) was approximated by the addition of a equivalent mass of water lumped at the appropriate nodal points. The model is evaluated for three spring values for a representative support stiffness provided by the bracing system to the downcomers. The bracing spring is set to 50 k/in, 50 k/in, and 15000 k/in to represent the tangential mode, the radial mode, and rigid response of the bracing system.

7.1.4.2 Loads

The downcomer is subjected to static and dynamic loads due to normal, upset, emergency, and faulted conditions. Loading cases and combinations are described in Table 5.5-1. The SRV discharge loads are shown in Figures 4.1-20 through 4.1-32. Table 4.1-15 lists the pressure time history multiplier for the downcomers. The LOCA loads for determining inertial loads are shown in Figures 4.2-25 through 4.2-31. The chugging lateral load at the tip of the downcomer is shown in Figure 4.2-17A.

7.1.4.3 Analysis

Downcomers are analyzed for the specified loading conditions using the Bechtel computer program BSAP. The downcomers are analyzed for both the hydrodynamic loads acting directly on the submerged portions and the inertial forces due to containment responses to the hydrodynamic and seismic loads.

The hydrodynamic load analyses, due to SRV discharge and LOCA related loads acting on the submerged portion of the downcomers, are performed using the mode-superposition time history technique. The seismic and hydrodynamic load analyses, due to containment responses, are performed using the response-spectrum analysis procedure. Damping values used are equal to 2 percent of critical for OBE and SRV loads, and 7 percent of critical for SSE and LOCA loads.

7.1.4.4 Design Assessment

The resultant stresses in the downcomers due to the load combinations described in Table 5.5-1 are compared with the allowable stresses in accordance with the criteria given in Reference 6.4-2.

7.1.4.5 Fatigue Evaluation Of Downcomers In Wetwell Air Space

To be provided later

7.1.5 PIPING AND SRV SYSTEMS ASSESSMENT METHODOLOGY

The piping and SRV systems will be analyzed for the load combinations described in Table 5.6-1 using Bechtel computer programs ME101 and ME632. These programs are described in FSAR Section 3.9. Static and dynamic analysis of the piping and SRV systems are performed as described in the paragraphs below.

Static analysis techniques are used to determine the stresses due to steady state loads and/or dynamic loads having equivalent static loads.

Response spectra at the piping anchors are obtained from the dynamic analysis of the containment subjected to LOCA and SRV

loading. Piping systems are then analyzed for these response spectra following the method described in Reference 7.1-8.

Time history dynamic analysis of the SRV discharge piping subjected to fluid transient forces in the pipe due to relief valve opening is performed using Bechtel computer code ME632.

7.1.6 NSSS ASSESSMENT METHODOLOGY

To be provided later.

7.1.7 EQUIPMENT ASSESSMENT METHODOLOGY

Safety-related equipment located within the containment and the reactor and control buildings are subjected to hydrodynamic loads due to SRV LOCA discharge affects principally originating in the suppression pool of the containment structure. The equipment and equipment support are assessed to verify their adequacy to withstand these hydrodynamic loads in combination with seismic and all other applicable loads in accordance with the load combinations given in Table 5.8-1.

7.1.7.1 <u>Hydrodynamic loads</u>

7.1.7.1.1 SRV Discharge Loads

Loadings associated with the axisymmetric and asymmetric SRV discharges are described in Chapters 3 and 4. Acceleration response spectra at the various elevations where the equipment are located have been generated for all appropriate pressure history traces (Figures 4.1-20 through 4.1-22) for damping values of 1/2, 1, 2 and 5 percent. These have been enveloped into a single curve for each of the above damping values. Such enveloped curves are generated for each of the N-S, E-W and vertical directions. These curves form the basis for the SRV loads for equipment assessment.

7.1.7.1.2 LOCA Related Loads

Loadings associated with loss-of-coolant accident (LOCA) are described in Chapters 3 and 4. The various LOCA loadings considered include condensation oscillation and chugging loadings

(Section 4.2.2). Acceleration response spectra at various elevations where the equipment are located have been generated for the above LOCA loads for damping values of 1/2, 1, 2 and 5 percent. These have been enveloped into a single curve for each of the above damping values. Such enveloped curves are generated for each of the N-S, E-W and vertical directions. These curves form the basis for the LOCA loads for equipment assessment.

7.1.7.2 Seismic Loads

The details of seismic input and seismic loads are discussed in FSAR Section 3.7. The effects of both operating basis earthquake (OBE) and safe shutdown earthquake (SSE) are considered. These loads are provided in the form of acceleration response spectra at each floor for damping values of 1/2, 1, 2, and 5 percent for each of N-S, E-W and vertical directions.

7.1.7.3 Other Loads

In addition to hydrodynamic and seismic loads, other loads such as dead loads, live loads, operating loads, pressure loads, thermal loads, nozzle loads and equipment piping interaction loads, as applicable, are also considered.

7.1.7.4 Qualification Methods

The adequacy of the design of the equipment is assessed by one of the following:

a. Dynamic analysis

b. Testing under simulated conditions

c. Combination of testing and analysis.

The choice is based on the practicality of the method depending upon function, type, size, shape, and complexity of the equipment and the reliability of the qualification method.

In general, the requirements outlined in Reference 7.1-9 are followed for the qualification of equipment.

7.1.7.4.1 Dynamic Analysis

7.1.7.4.1.1 Methods and Procedures

The dynamic analysis of various equipment is classified into three groups according to the relative rigidity of the equipment based on the magnitude of the fundamental natural frequency described below.

a. Structurally simple equipment - comprised of that equipment which can be adequately represented by one degree of freedom system.

b. Structurally rigid equipment - Comprised of that equipment whose fundamental frequency is:

   1) greater than 33 Hz for the consideration of seismic loads, and,

   2) greater than 100 Hz for the consideration of hydrodynamic loads.

c. Structurally complex equipment - Comprised of that equipment which cannot be classified as structurally simple or structurally rigid.

When the equipment is structurally simple or rigid in one direction but complex in the other, each direction may be classified separately to determine the dynamic loads.

The appropriate response spectra for specific equipment are obtained from the response spectra for the elevation at which the equipment is located in a building for OBE, SSE, and hydrodynamic loads. This includes the vertical as well as both the N-S and E-W horizontal directions.

For equipment that is structurally simple, the dynamic loading (either seismic or hydrodynamic) consists of a static load corresponding to the equipment weight times the acceleration selected from the appropriate response spectrum. The acceleration selected corresponds to the equipment's natural frequency, if the equipment's natural frequency is known. If the

equipment's natural frequency is not known, the acceleration selected corresponds to the maximum value of the response spectra.

For equipment that is structurally rigid, the seismic load consists of a static load corresponding to the equipment weight times the acceleration at 33 Hz, selected from the appropriate response spectrum and the hydrodynamic loading consists of a static load corresponding to the equipment weight times the acceleration at 100 Hz, selected from the appropriate response spectrum.

For the analysis of structurally complex equipment, the equipment is idealized by a mathematical model that adequately predicts the dynamic properties of the equipment, and a dynamic analysis is performed using any standard analysis procedure. An acceptable alternative method of analysis is by static coefficient analysis for verifying structural integrity of frame type structures such as members physically similar to beams and columns that can be represented by a simple model. No determination of natural frequencies is made, and the response of the equipment is assumed to be the peak of the response spectrum at damping values in accordance with Section 7.1.7.4.1.2. This response is then multiplied by a static coefficient of 1.5 to take into account the effects of both multifrequency excitation and multimode response.

7.1.7.4.1.2 Appropriate Damping Values

The following damping values are used for the design assessment:

a. Load combinations involving OBE but not hydrodynamic loads -1/2%

b. Load combinations involving SSE but not hydrodynamic loads -1/2%

c. Load combinations involving hydrodynamic loads, or seismic and hydrodynamic loads - 2%

Higher damping values may be used where justified.

7.1.7.4.1.3 Three Components of Dynamic Motions

The responses such as internal forces, stresses, and deformations at any point from the three principal orthogonal directions of the dynamic loads are combined as follows.

The response value used shall be the maximum value obtained by adding the response due to vertical earthquake with the larger value of the responses due to one of the horizontal earthquakes by the absolute sum method.

For the other dynamic loads, the response value shall be obatained by combining the response due to three orthogonal directions of an individual load by the square root of the sum of the squares (SRSS) method.

7.1.7.4.2 Testing

In lieu of performing dynamic analysis, dynamic adequacy is established by providing dynamic test data. Such data must conform to one of the following:

a. Performance data of equipment that has been subjected to equal or greater dynamic loads (considering appropriate frequency range) than those to be experienced under the specified dynamic loading conditions.

b. Test data from comparable equipment previously tested under similar conditions that has been subjected to equal or greater dynamic loads than those specified.

c. Actual testing of equipment in operating conditions simulating, as closely as possible, the actual installation, the required loadings and load combinations.

A continuous sinusoidal test, sine beat test, or decaying sinusoidal test is used when the applicable floor acceleration spectrum is a narrow band response spectrum. Otherwise, random motion test (or equivalent) with broad frequency content is used.

The equipment to be tested is mounted in a manner that simulates the actual service mounting. Sufficient monitoring devices are

used to evaluate the performance of the equipment. With the appropriate test method selected, the equipment is considered to be qualified when the test response spectra (TRS) envelopes the required response spectra (RRS) and the equipment does not malfunction or fail. A new test does not need to be conducted if equipment requires only minor modifications such as additional bracings or change in switch model, etc, and if proper justification is given to show that the modifications would not jeopardize the strength and function of the equipment.

7.1.7.4.3 Cc] Analysis and Testing

There are several instances where the qualification of equipment by analysis alone or testing alone is not practical or adequate because of its size, or its complexity, or large number of similar configurations. In these instances, a combination of analysis and testing is the most practical. The following are general approaches:

a. An analysis is conducted on the overall assembly to determine its stress level and the transmissibility of motion from the base of the equipment to the critical components. The critical components are removed from the assembly and subjected to a simulation of the environment on a test table.

b. Experimental methods are used to aid in the formulation of the mathematical model for any piece of equipment. Mode shapes and frequencies are determined experimentally and incorporated into a mathematical model of the equipemnt.

7.1.8 ELECTRICA RACEWAY SYSTEM ASSESSMENT METHODOLOGY

To be provided later.

7.1.9 HVAC DUCT SYSTEM ASSESSMENT METHODOLOGY

To be provided later.

7.1.10 REFERENCES

7.1-1 "Seismic Analyses of Structures and Equipment for Nuclear Power Plants," BC-TOP-4A, Bechtel Power Corporation, November 1974.

7.1-2 Wilson, E. L, "A Computer Program for the Dynamic Stress Analysis of Underground Structures," USAEWES, Control Report 1-175, January 1968.

7.1-3 Desai and Abel, "Introduction to the Finite Element Method," Van Nostroid Reinold Co., 1972

7.1-4 "Technical Bases for the Use of SRSS Method for Combining Dynamic Loads for Mark II Plants," NEDE-24010-P, General Electric Co, July 1977.

7.1-5 SRV In-Plant Test Report

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7.1-7 T. E. Johnson, et al., "Containment Building Liner Plate Design Report," BC-TOP-1, Bechtel Corporation, San Francisco, December 1972.

7.1-8 "Seismic Analysis of Piping Systems," BP-TOP-1, Revision 2, Bechtel Power Corporation, San Francisco, January 1975.

7.1-9 IEEE Standard 344-1975, "Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations."

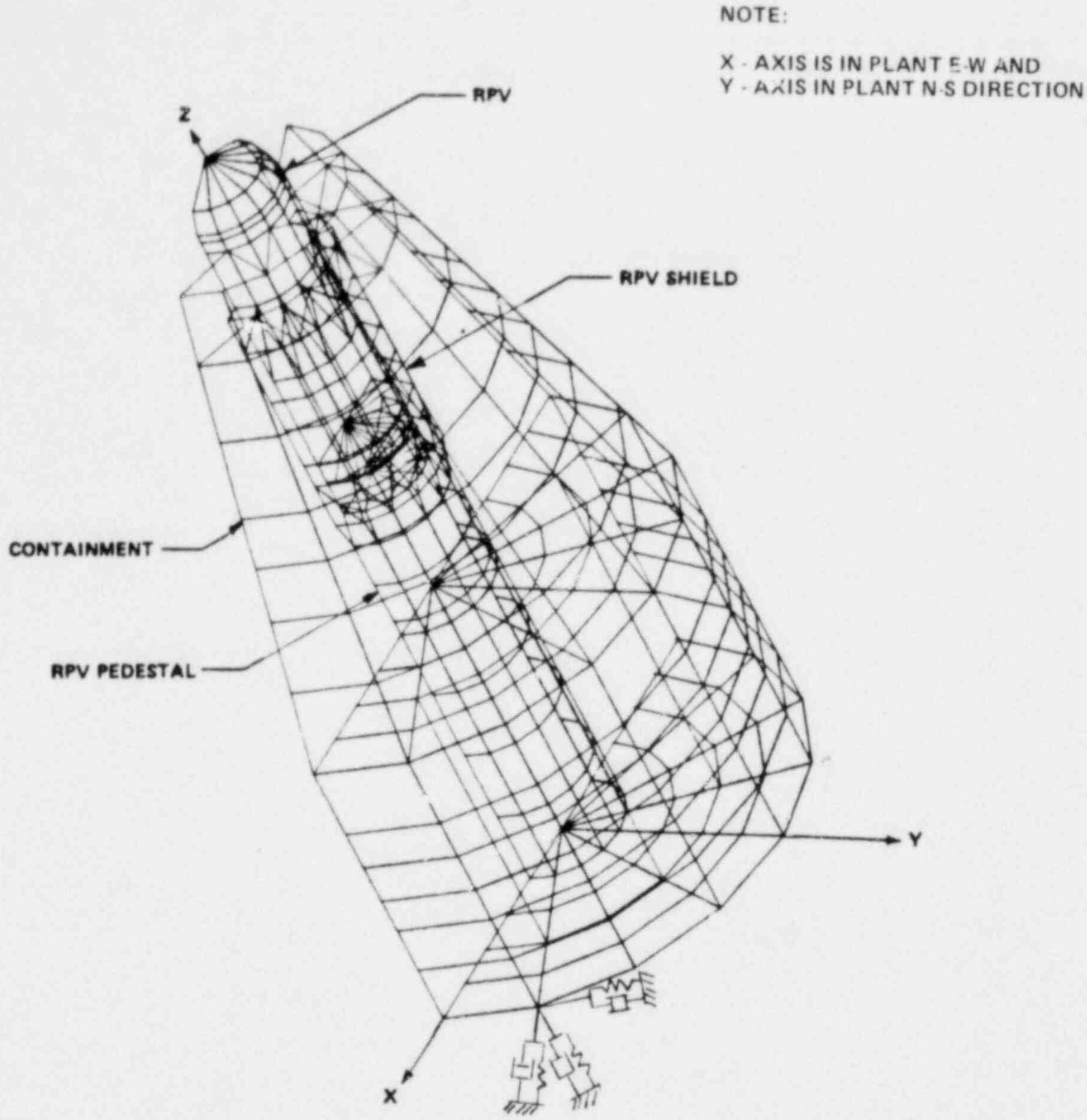
TABLE 7.1-1

REACTOR BUILDING AND CONT
SUMMARY OF HYDRODYNAMIC ANALYSES AND COR

LOAD CASE / MODEL (FIGURE NO.)	SRV AXISYMMETRIC	SRV ASYMMETRIC	BAS
Axisymmetric "FESS" Vertical Coupled Model (Fig. 7.1-3)	X		X
Vertical Flexible Base Stick Model (Fig. 7.1-4)		X	
Horizontal Flexible Base Stick Model (Fig. 7.1-5)		X	
Control Structure Floor Half Model (Fig. 7.1-6)	X	X	
Control Structure Floor Quarter Model (Fig. 7.1-7)			X

OL STRUCTURE:
ESPONDING MATHEMATICAL MODELS

CO		CHUGGING	
C	ADS	AXISYMMETRIC	ASYMMETRIC
	X	X	
			X
			X
		X	X
	X		



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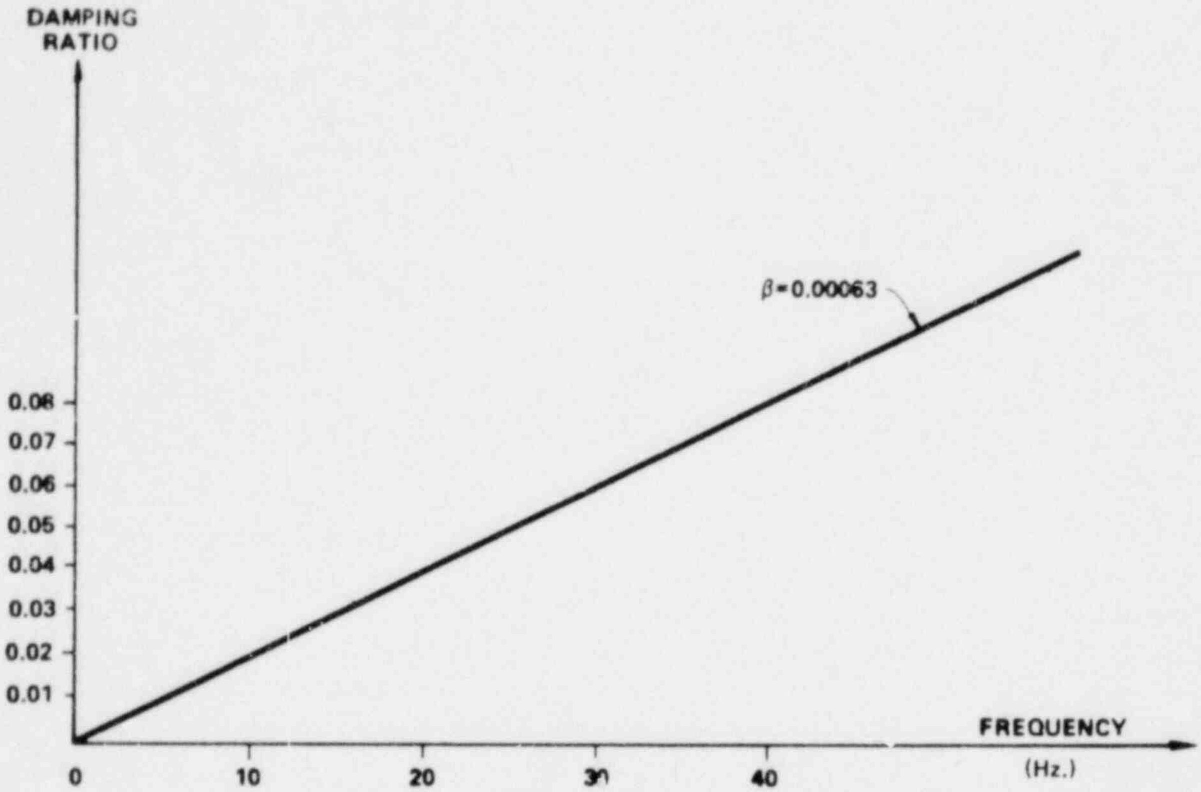
3-D CONTAINMENT
FINITE ELEMENT MODEL
(ANSYS MODEL)

FIGURE 7.1-1



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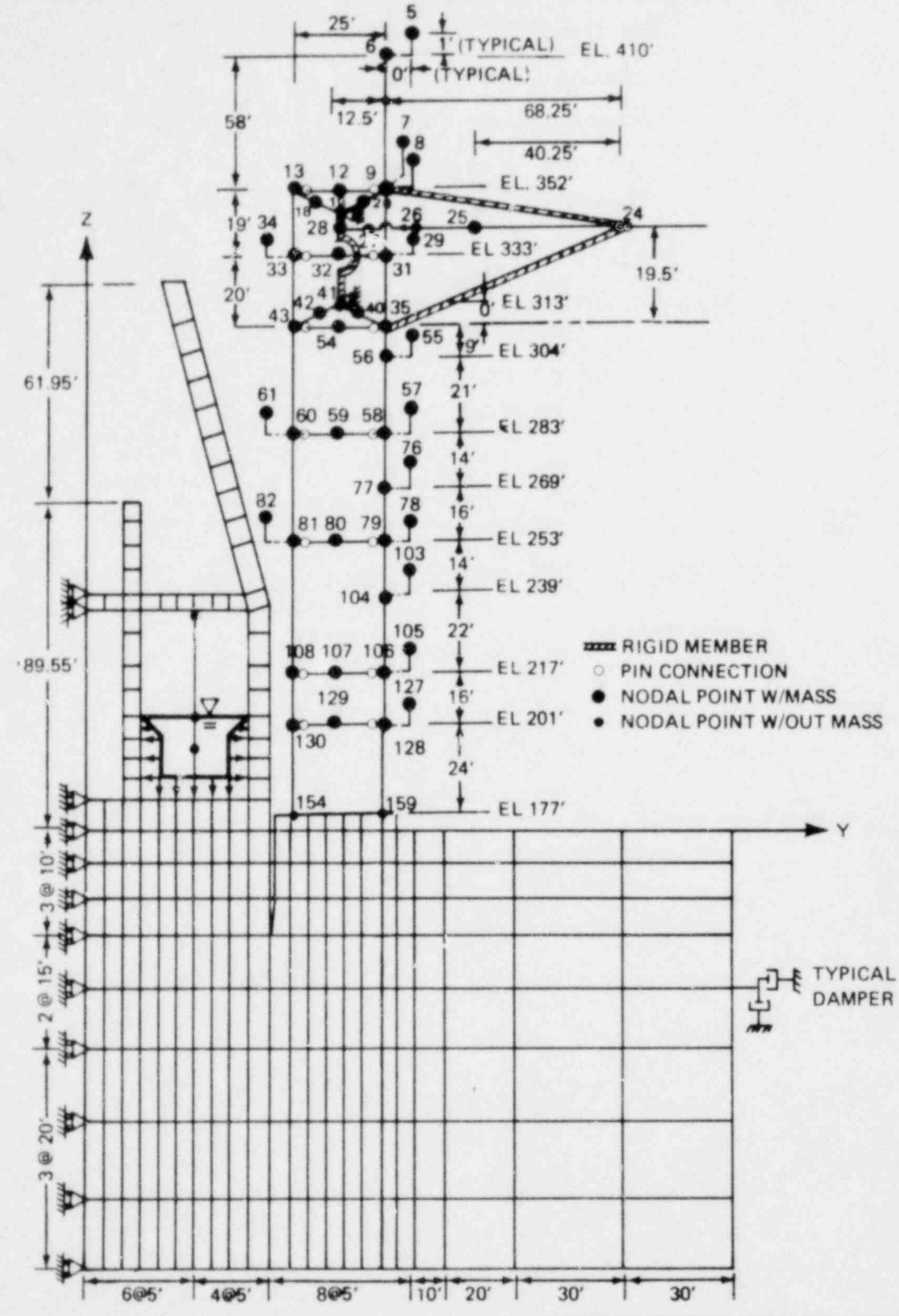
EQUIVALENT MODAL DAMPING RATIO VERSUS MODAL FREQUENCY FOR STRUCTURAL STIFFNESS PROPORTIONAL DAMPING (CONTAINMENT BUILDING)

FIGURE 7.1-2



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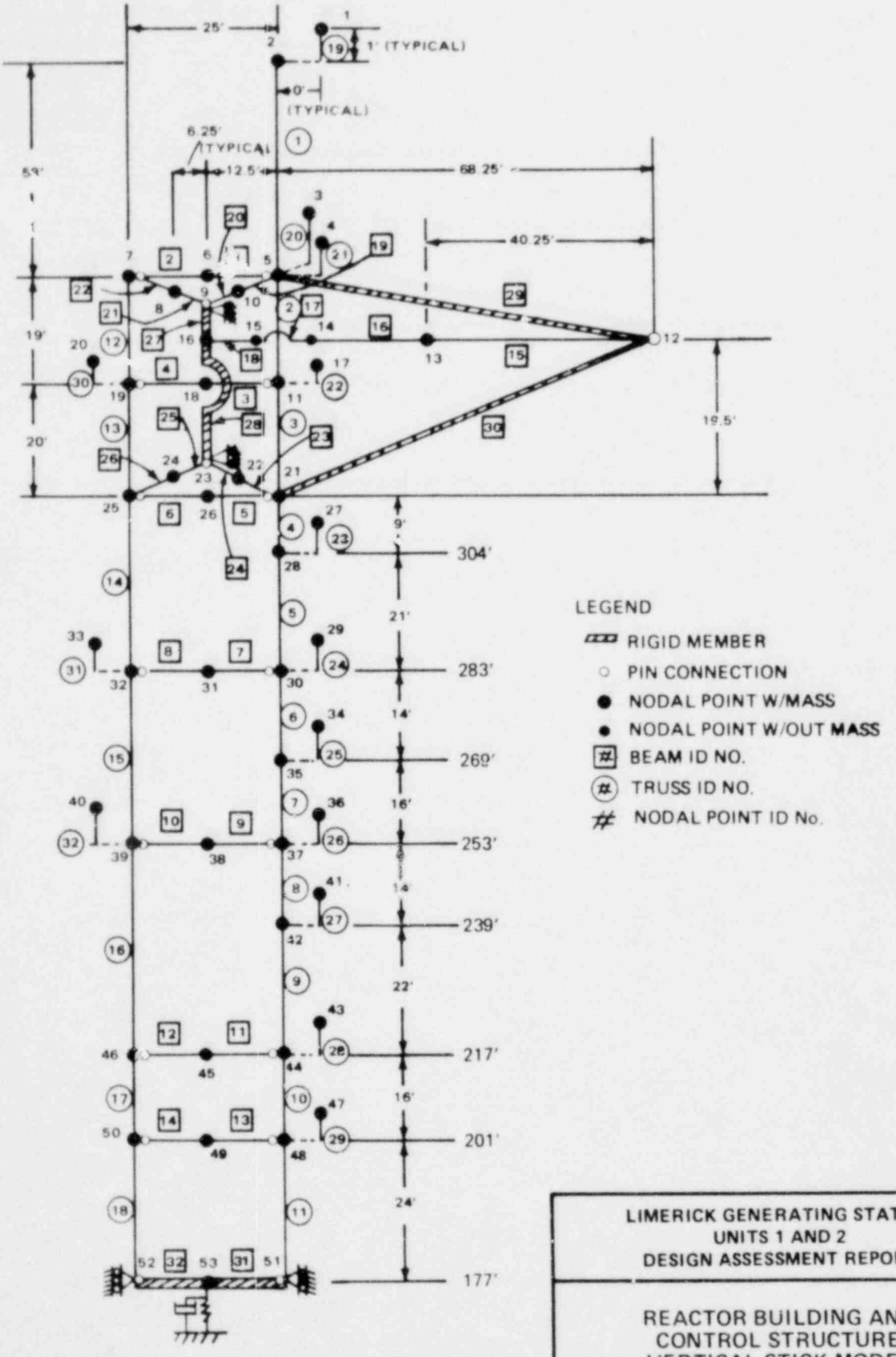
REACTOR BUILDING AND CONTROL STRUCTURE VERTICAL AXISYMMETRIC COUPLED MODEL (FESS)

FIGURE 7.1-3



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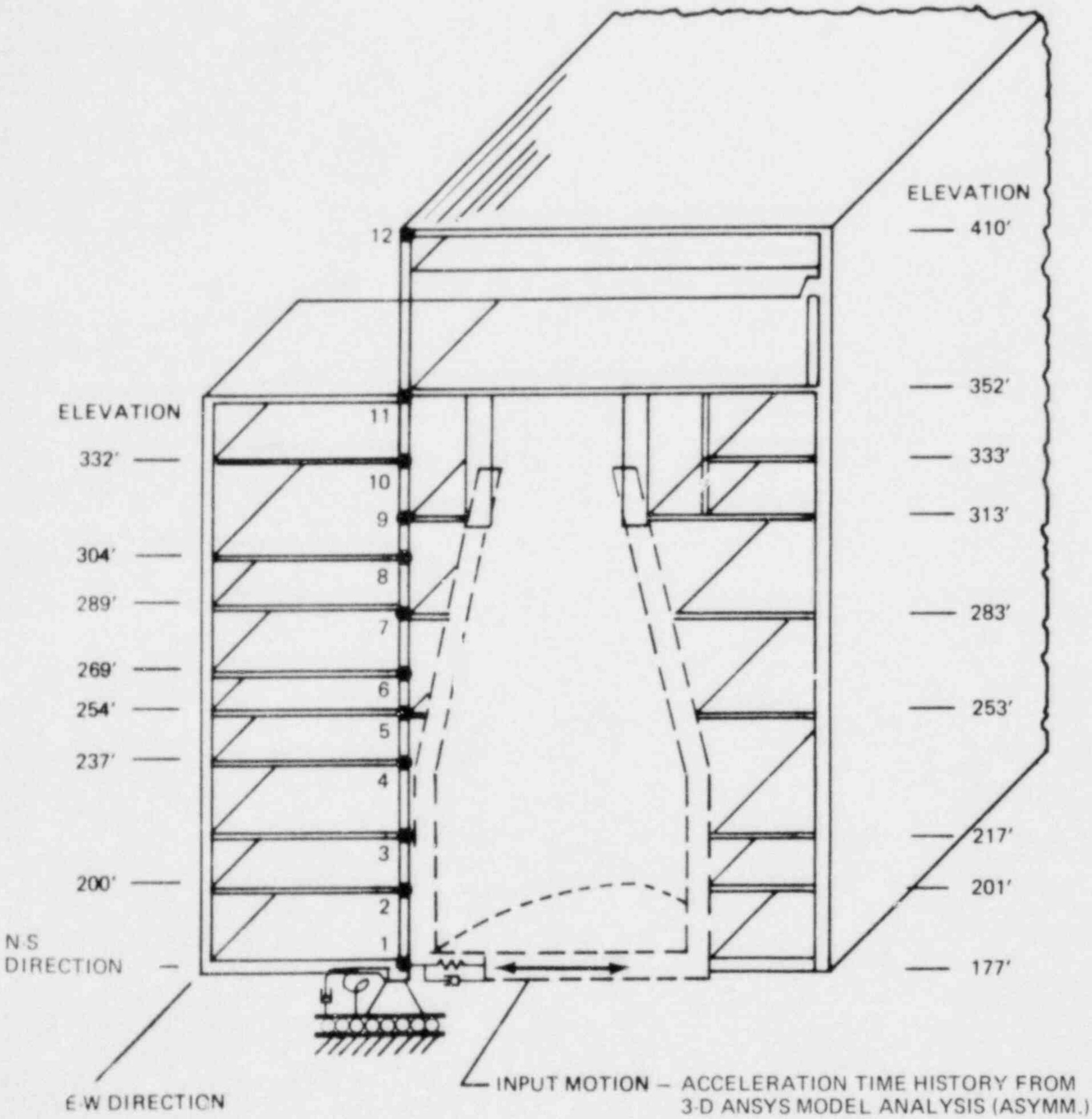
REACTOR BUILDING AND CONTROL STRUCTURE VERTICAL STICK MODEL

FIGURE 7.1-4



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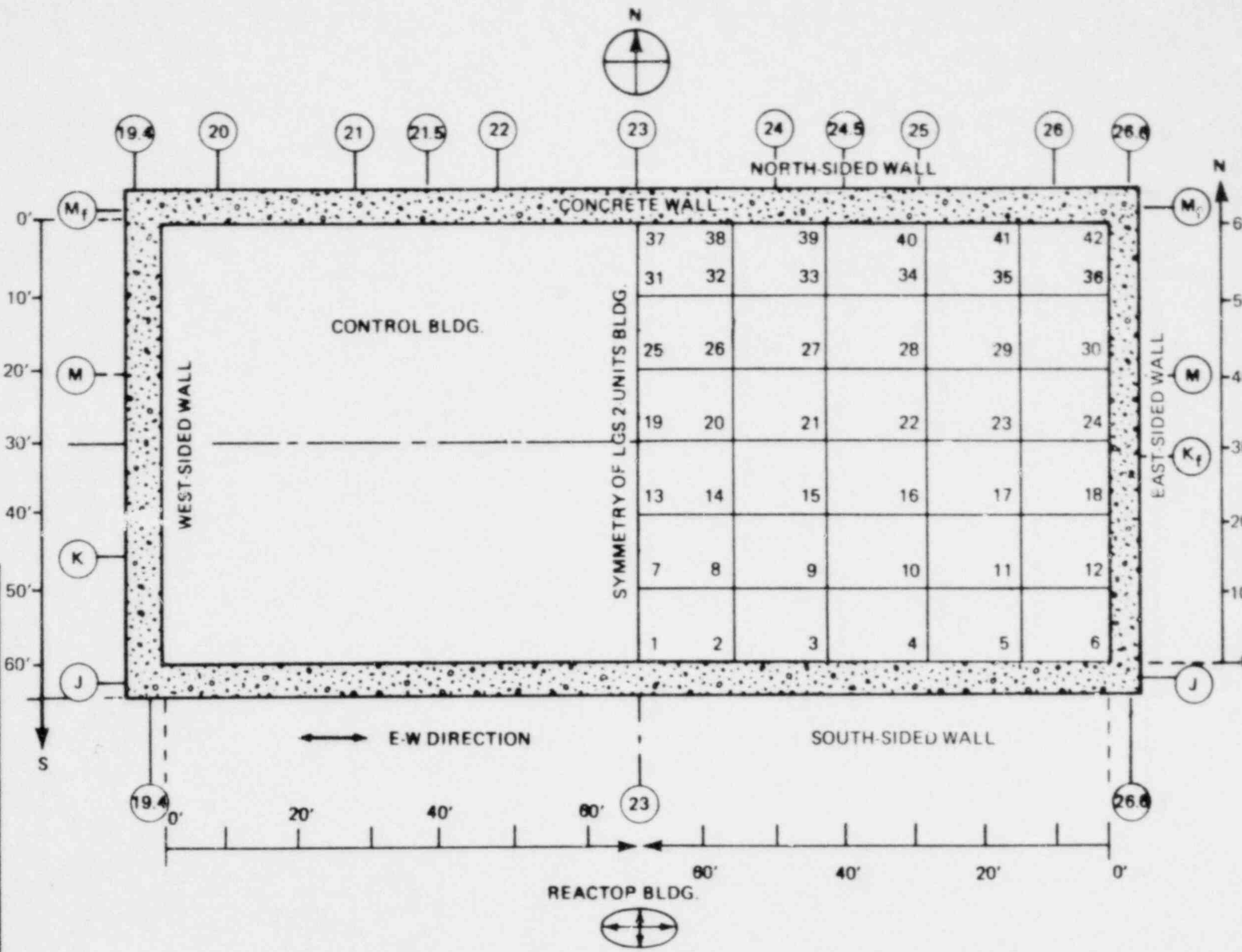
REACTOR BUILDING AND
CONTROL STRUCTURE
HORIZONTAL STICK MODEL

FIGURE 7.1-5



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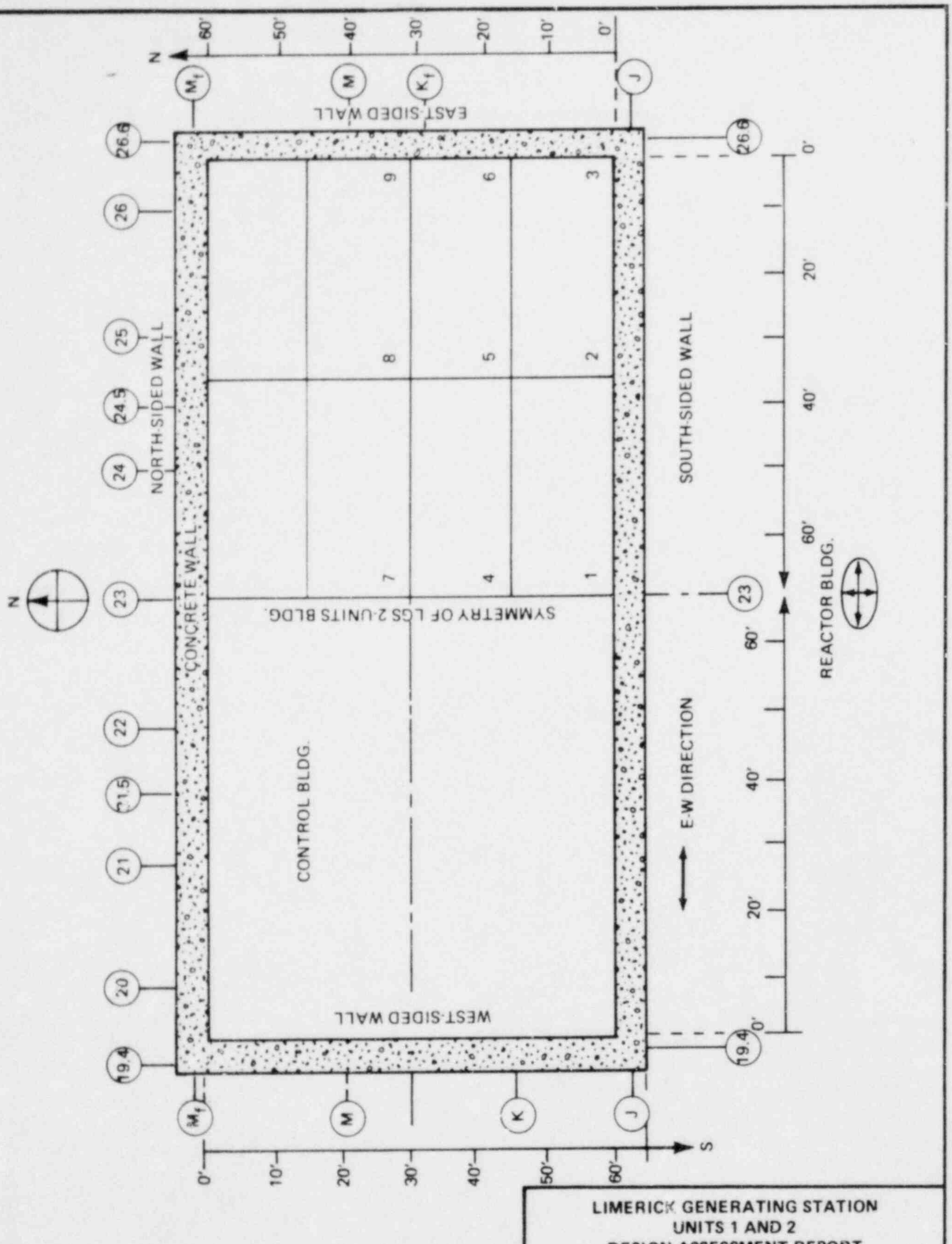
CONTROL STRUCTURE FLOOR
"HALF MODEL"

FIGURE 7.1-6



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UNITS 1 AND 2
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CONTROL STRUCTURE FLOOR
"QUARTER MODEL"

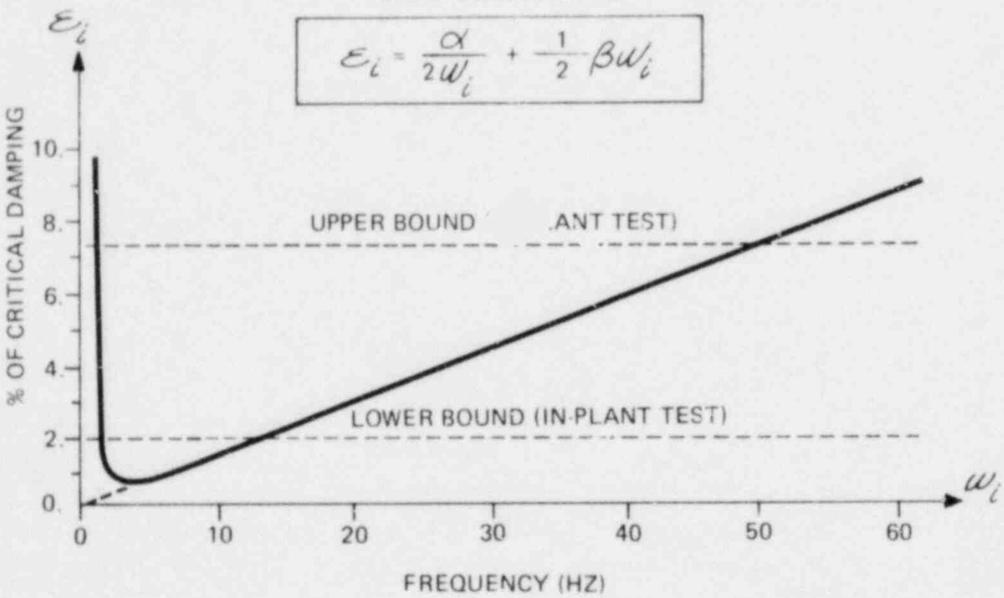
FIGURE 7.1-7

MASS–PROPORTIONAL STIFFNESS–PROPORTIONAL

$$[C] = \alpha[M] + \beta[K]$$

VARIABLE DAMPING

$$\varepsilon_i = \frac{\alpha}{2\omega_i} + \frac{1}{2}\beta\omega_i$$



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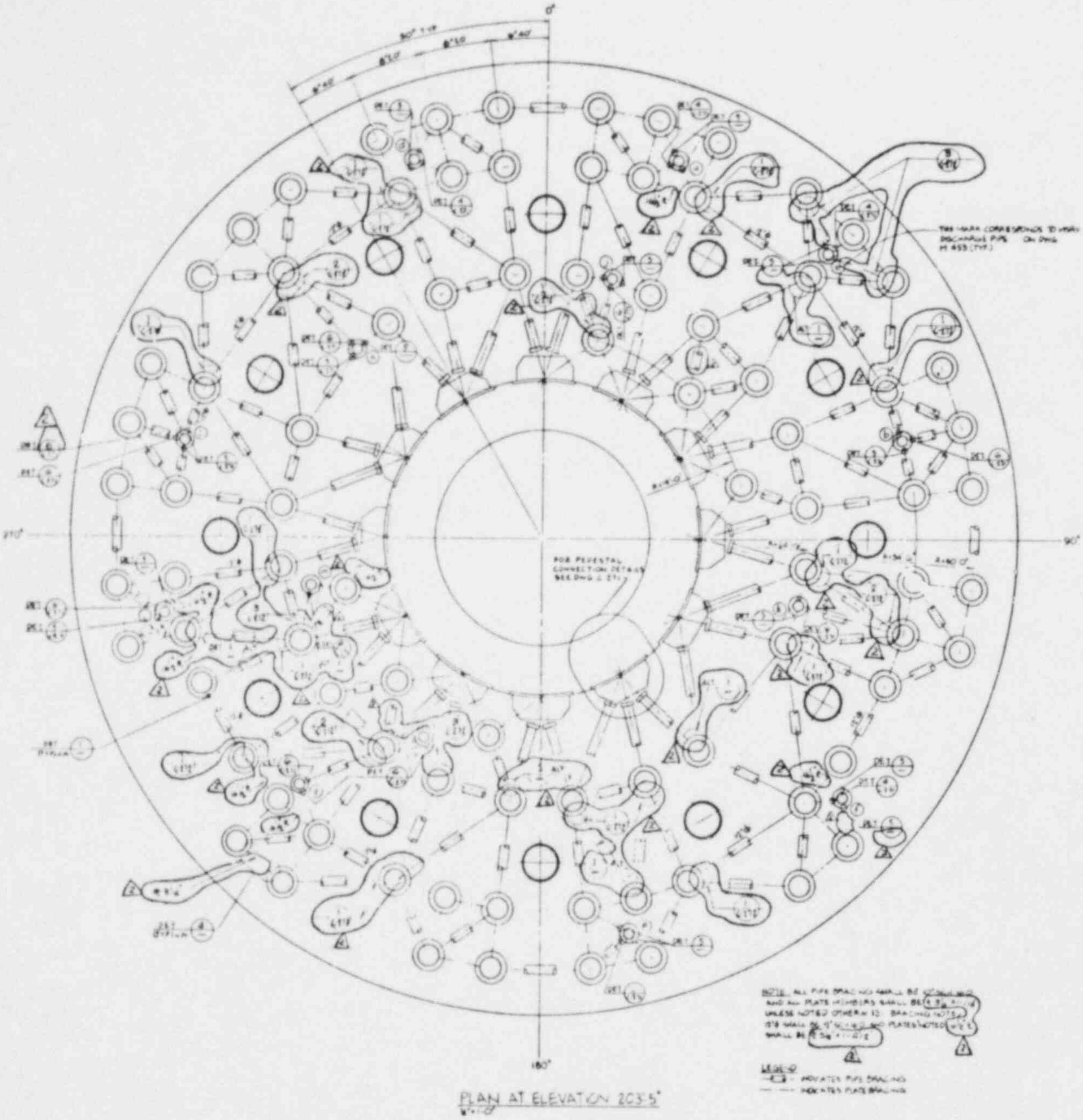
EQUIVALENT MODAL DAMPING RATIO VS. MODAL FREQ. FOR STRUCTURAL STIFFNESS PROPORTIONAL DAMPING (REACTOR BUILDING AND CONTROL STRUCTURE) **FIGURE** 7.1-8



NOTE: MISCELLANEOUS PIPING THAT IS LATERALLY SUPPORTED ON THE BRACING SYSTEM IS NOT SHOWN.

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UNITS 1 AND 2
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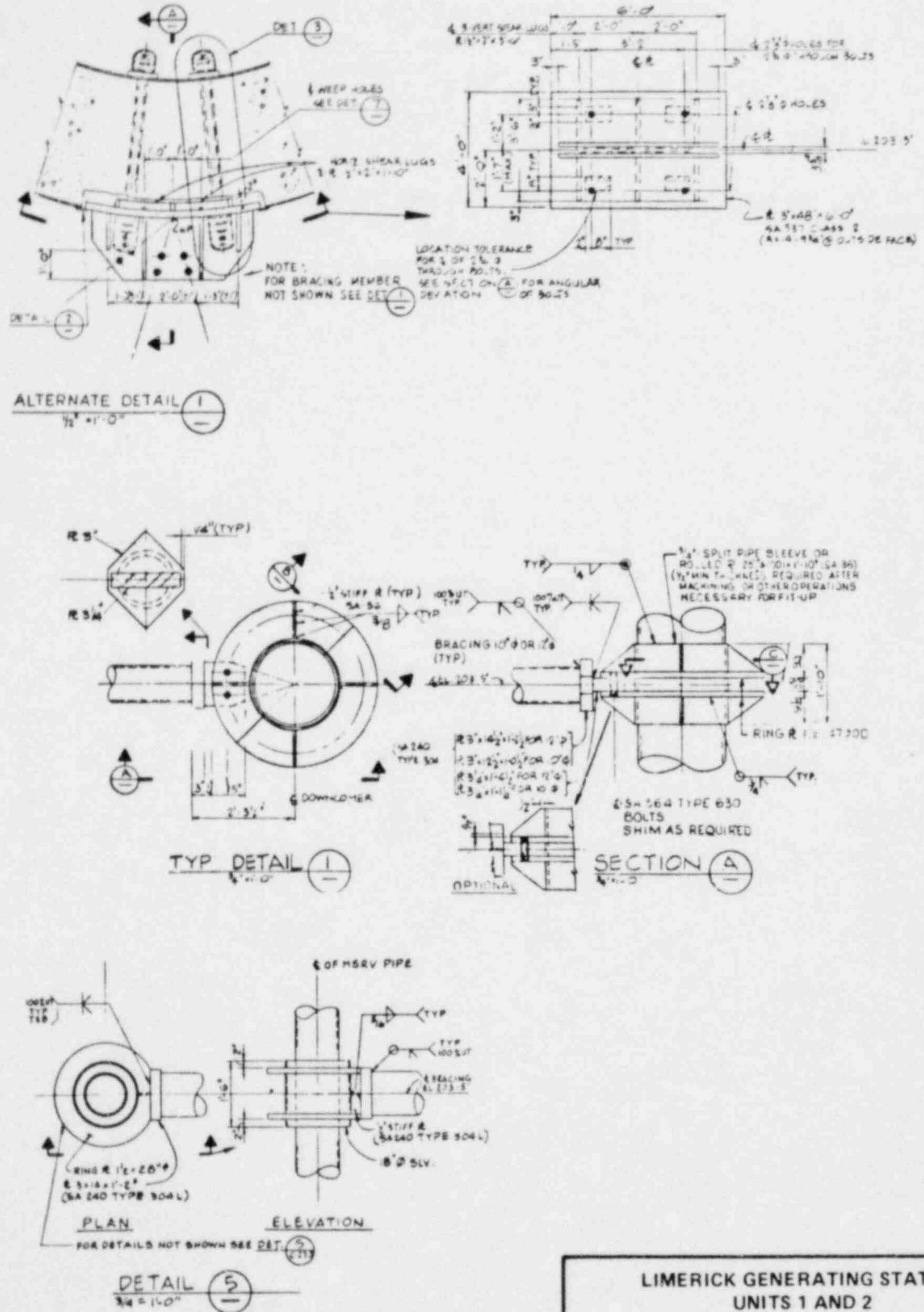
DOWNCOMER BRACING SYSTEM

FIGURE 7.1-9



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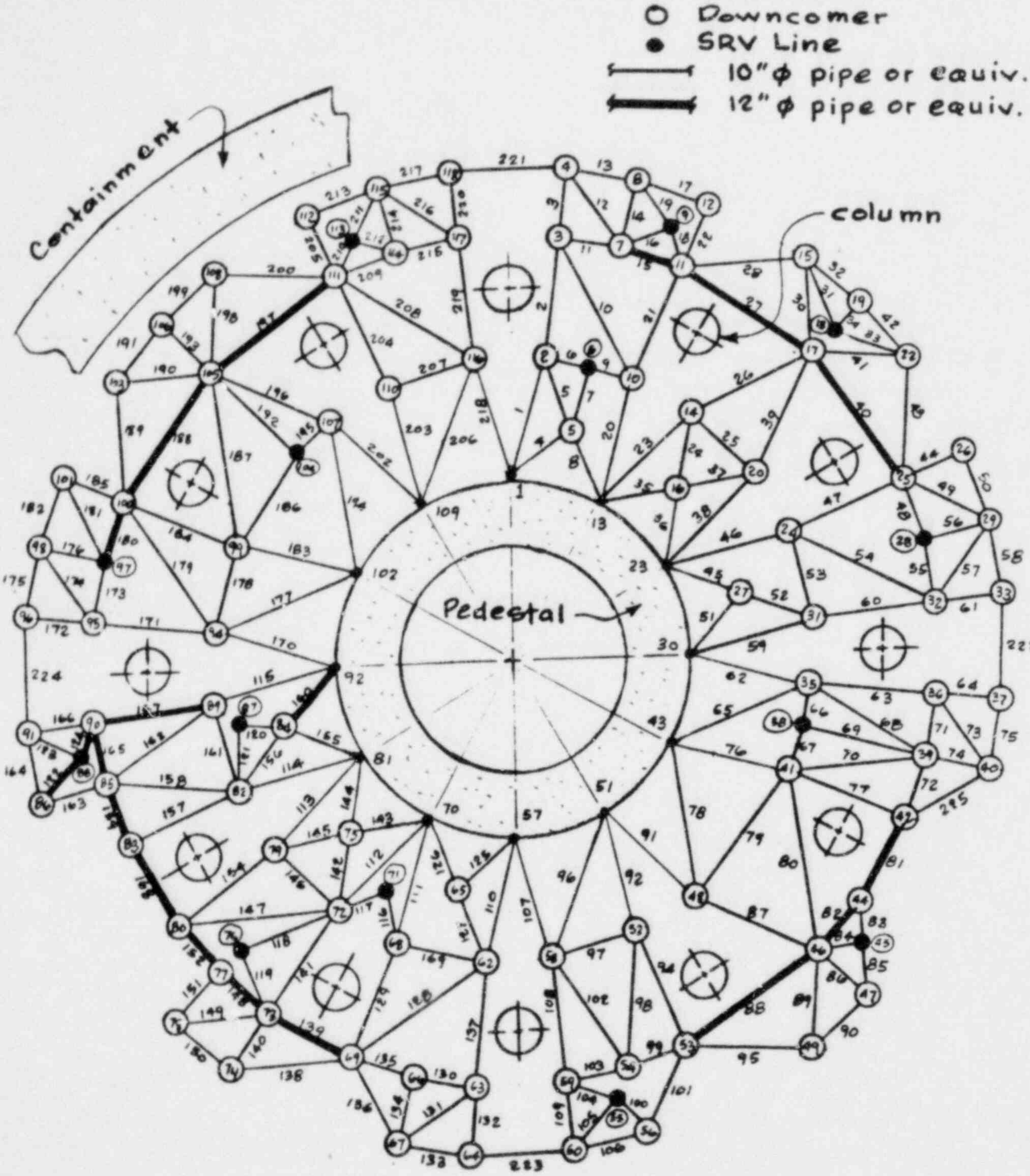
DOWNCOMER BRACING
SYSTEM DETAILS

FIGURE 7.1-10



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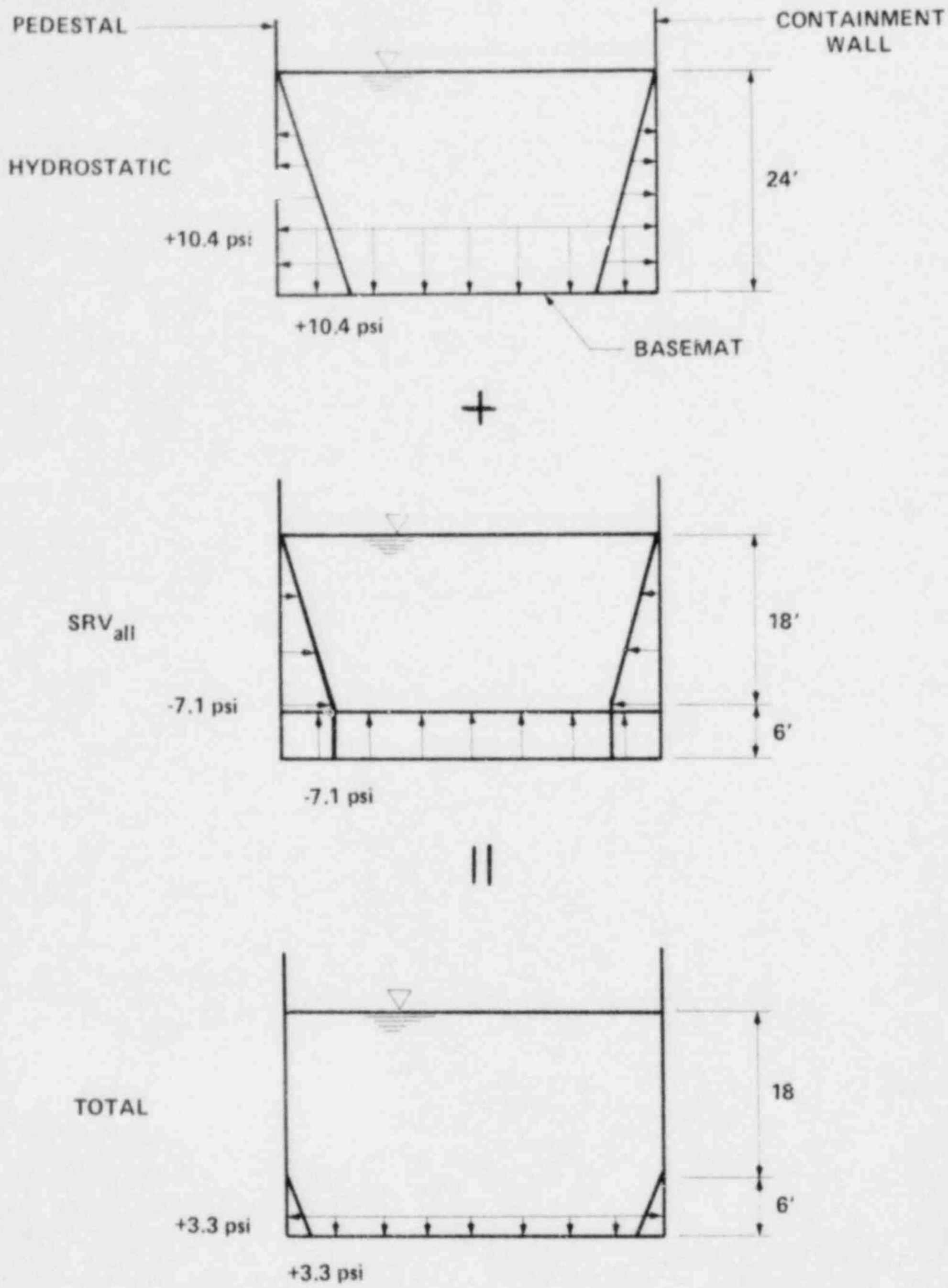
DOWNCOMER BRACING
MATHEMATICAL MODEL

FIGURE 7.1-11



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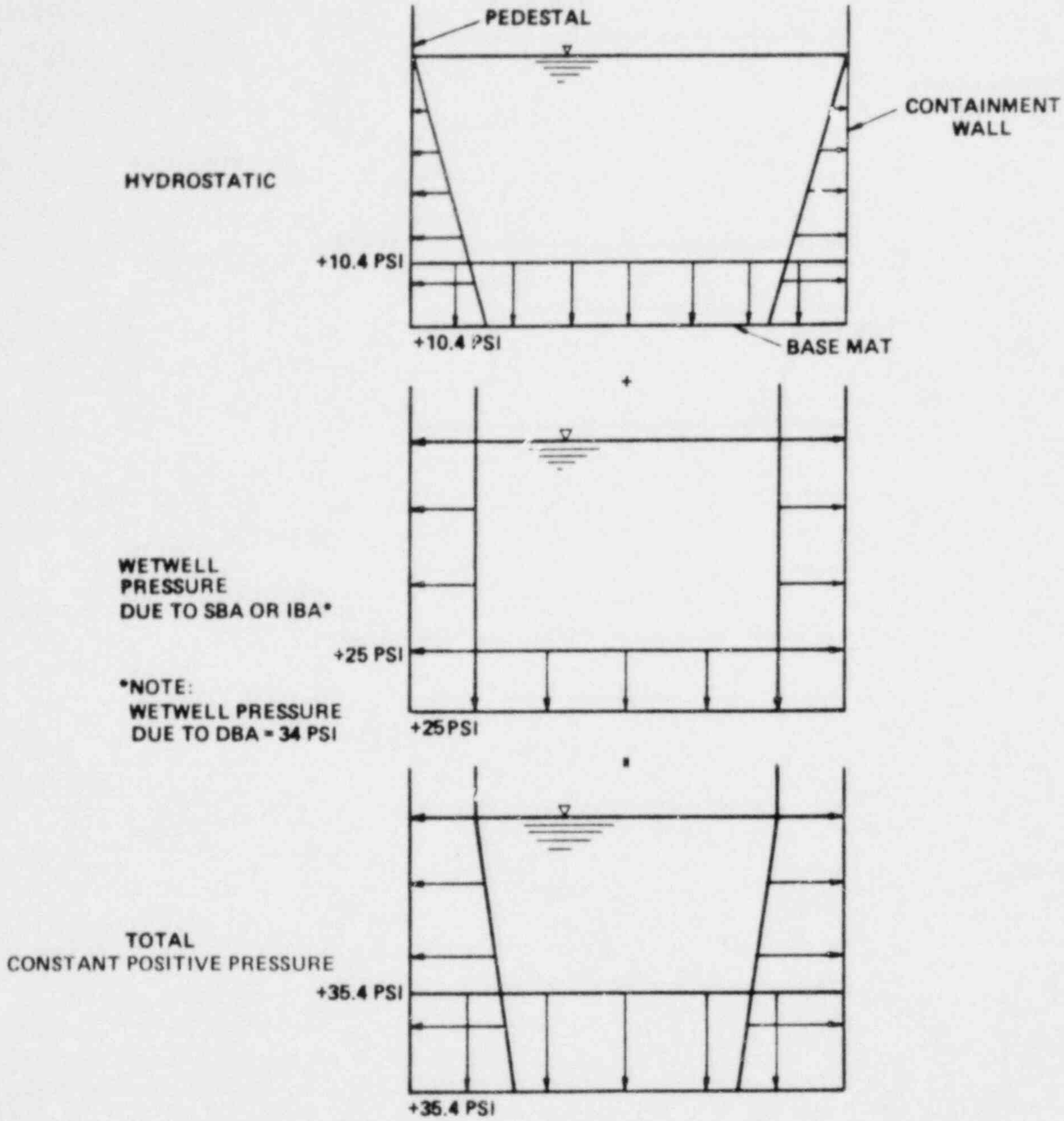
LINER PLATE PRESSURES
NORMAL CONDITION

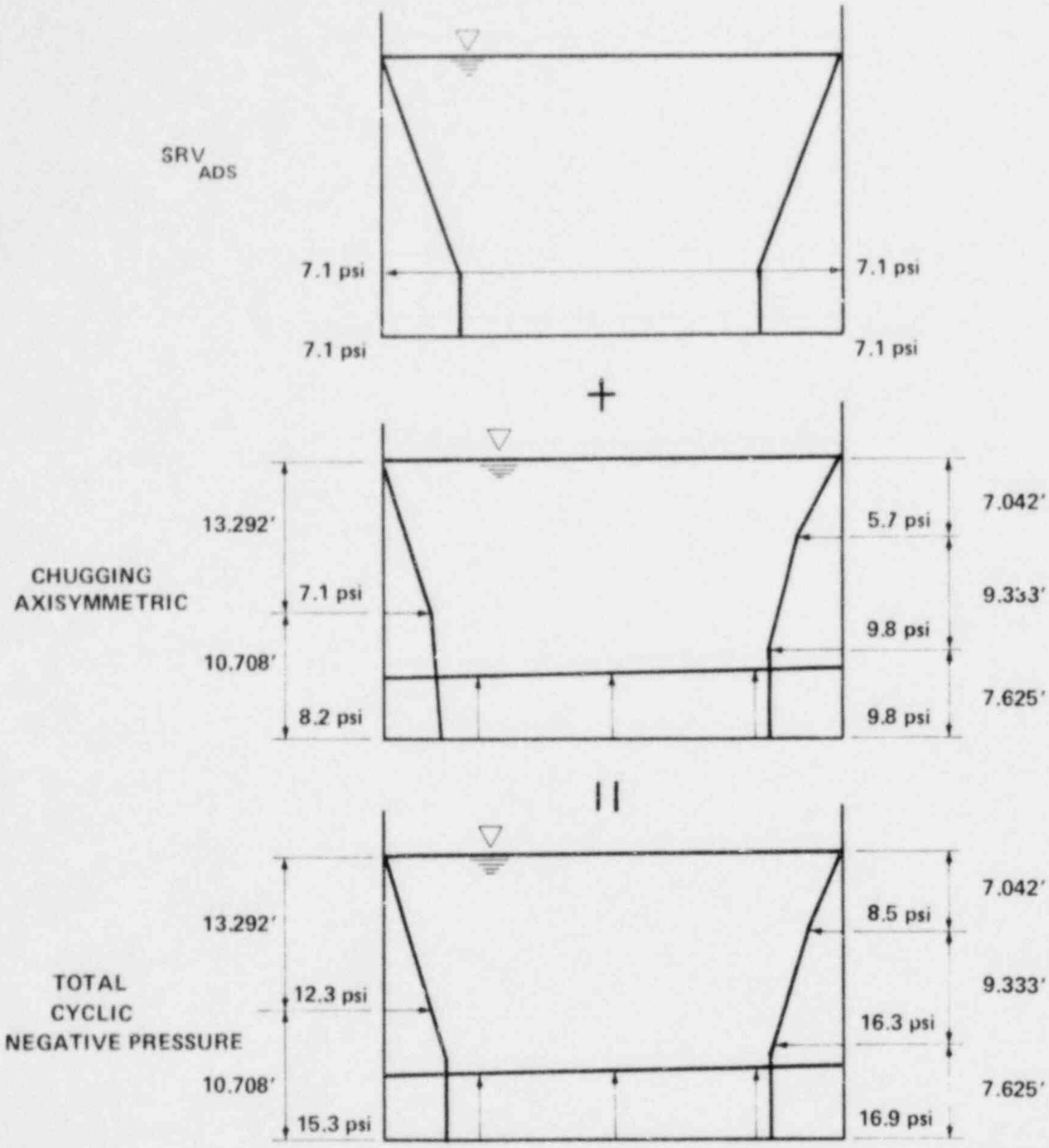
FIGURE 7.1-12



LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

LINER PLATE PRESSURES
ABNORMAL CONDITION

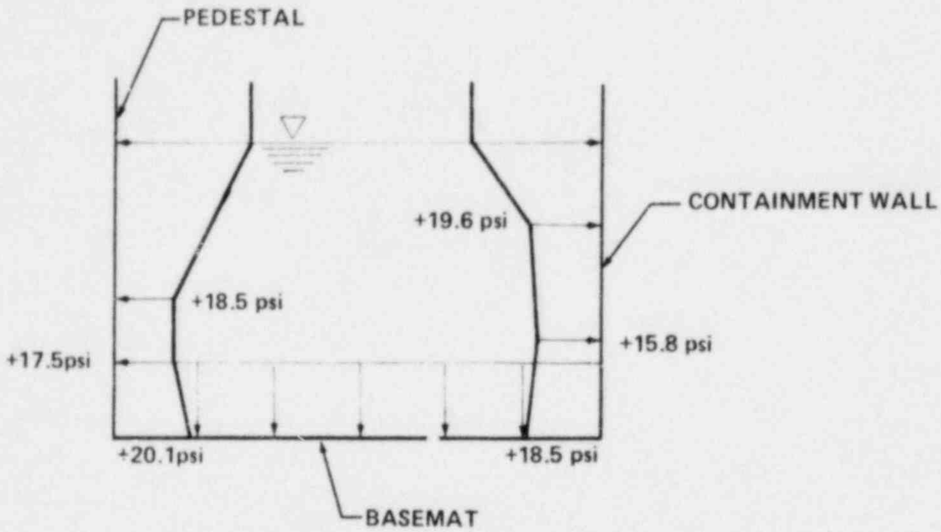
FIGURE 7.1-13



LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

LINER PLATE PRESSURES
ABNORMAL CONDITION

FIGURE 7.1-14

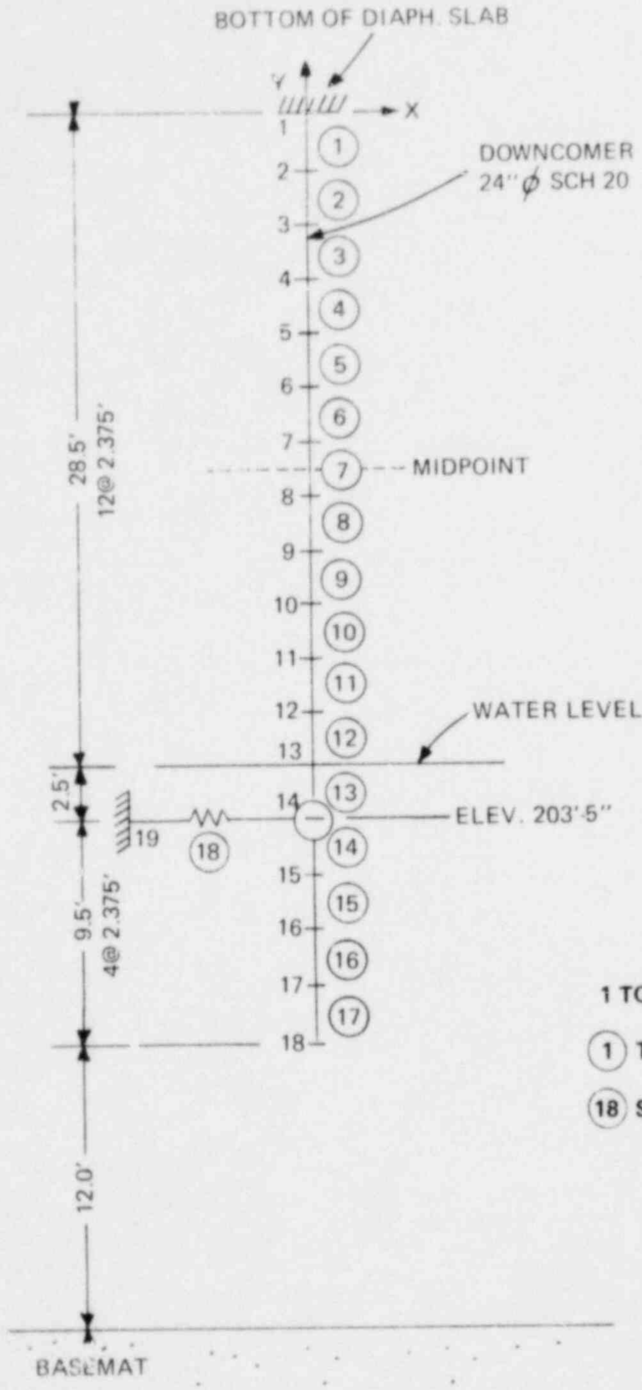


NET PRESSURE = TOTAL POSITIVE PRESSURE + TOTAL NEGATIVE PRESSURE

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

LINER PLATE PRESSURES
ABNORMAL CONDITION

FIGURE 7.1-15



1 TO 19 NODAL POINTS

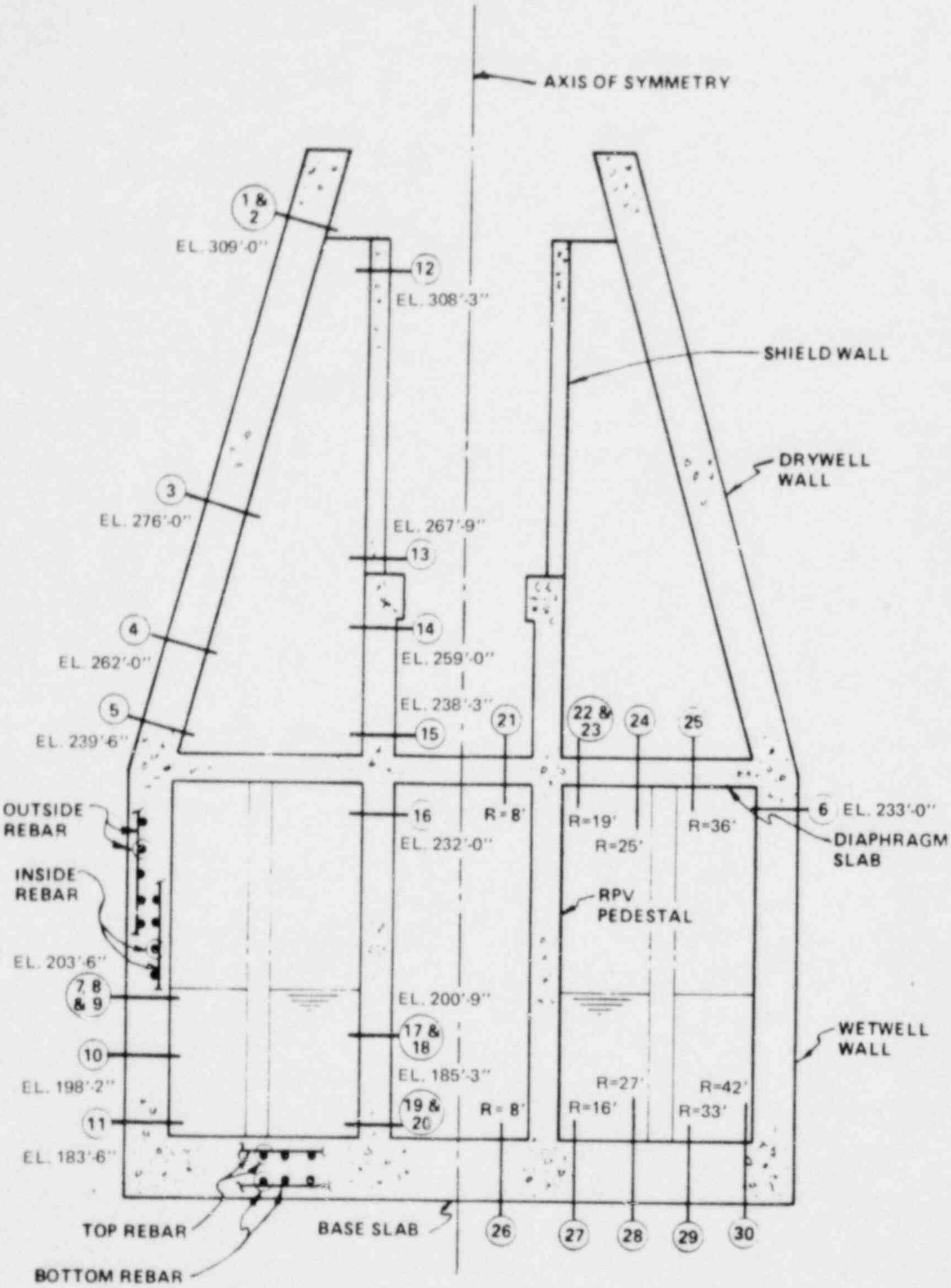
(1) TO (17) STRAIGHT PIPE ELEMENT

(18) SPRING-DAMPER ELEMENT

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

DOWNCOMER ANALYTICAL MODEL

FIGURE 7.1-16



LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

TYPICAL CONTAINMENT
STRUCTURE SHOWING
SECTION LOCATION

FIGURE 7.2-1

7.2 DESIGN CAPABILITY MARGINS

This section describes the design margins for structures, piping, and equipment resulting from the LGS design assessment which uses the methods of Section 7.1

7.2.1 STRESS MARGINS

Stresses at the critical sections for all of the structures, piping, and equipment described in Section 7.1 are evaluated for the loading combinations presented in Chapter 5.

7.2.1.1 Containment Structure

The detailed results from the structural assessment of the containment structure are summarized in Appendix D.1. Figure 7.2-1 shows the design sections in the basemat, containment walls, reactor pedestal, and the diaphragm slab that were considered in the structural assessment. The tables in Appendix D give the calculated maximum design stresses and margins for the load combinations listed in Table 5.1-1.

The summary of stresses for the various load combinations and corresponding design margin will be provided later.

7.2.1.2 Reactor Building and Control Structure

To be provided later.

7.2.1.3 Suppression Chamber Columns

To be provided later

7.2.1.4 Downcomer Bracing

The bracing member forces and the corresponding design margins due to the governing load combinations are given in Appendix D.2 for the critical bracing members.

7.2.1.5 Liner Plate

Because the negative pressure is less than the positive pressure, as discussed in the Section 7.1.3, the liner plate does not experience any net negative pressure. Therefore, there are no flexuous stresses induced in the liner plate.

7.2.1.6 Downcomers

The downcomer vibration mode shapes are calculated for the modal analyses using computer program BSAP. The mode shapes are shown in Appendix D, Figures (later) through (later), for the three representative bracing system spring stiffnesses. The equivalent water mass included in the model is equal to the downcomer volume.

The summary of stresses for the various load combinations and corresponding design margin will be provided later.

7.2.1.7 Electrical Raceway System

To be provided later.

7.2.1.8 HVAC Duct System

To be provided later.

7.2.2 ACCELERATION RESPONSE SPECTRA

7.2.2.1 Containment Structure

The method of analysis and load description for the acceleration response spectrum generation are outlined in Section 7.1.1.1.1.6.1. From a review of the acceleration response spectra curves for the containment structure, the maximum spectral accelerations are tabulated for 1 percent damping of critical. For SRV and LOCA loads, the maximum spectral accelerations are presented in Table 7.2-1.

The hydrodynamic acceleration response spectra of the containment structure are presented in Appendix A.2.

7.2.2.2 Reactor Building and Control Structure

The method of analysis and load applications for the computation of the hydrodynamic acceleration response spectrum in the reactor building and the control structure are described in Section 7.1.1.2. The response spectra of the reactor building and the control structure are shown in Appendix B.

TABLE 7.1-2

CONTROL STRUCTURE FLOOR MODEL MATERIAL PROPERTIES

Control Structure Floor Elevation (ft)	Slab Thickness t_c (ft)	Equivalent[1] Thickness t_{eff} (ft)	Composite density, ρ' $Kip.S^2/ft^4$
El. 217	1.25 2.125, 2.5	2.66 3.26	.002554 .003334
El. 239	1.0	2.93	.003241
El. 253	1.0	2.61	.002538
El. 269	1.5	2.63	.003219
El. 289	1.5	2.96	.002610
El. 304	1.0	2.50	.002145
El. 331	2, 1.5	3.595 2.965	.0040821 .0044573

[1] Equivalent floor thickness with composite density ρ' to take account of beam-slab composite action during vibration period.

TABLE 7.2-1

MAXIMUM SPECTRAL ACCELERATIONS OF CONTAINMENT DUE TO SRV AND LOCA LOADS AT 1% DAMPING

Type of Load		Direction	Elevation	Maximum Spectral Acceleration(g)	Structural Frequency (Hz)
SRV	Axisymmetric	Vertical	312'-8"	1.09	14
		Horizontal	198'-9"	1.88	38
	Asymmetric	Vertical	236'-2"	0.917	40
		Horizontal	207'-1"	1.15	25
CO		Vertical	236'-2"	3.2	40
		Horizontal	198'-9"	6.0	40
CO-ADS		Vertical	236'-2"	0.75	38
		Horizontal	205'-11"	1.16	42
Chugging		Vertical	236'-2"	1.76	40
		Horizontal	189'-5"	3.13	75

APPENDIX A

CONTAINMENT MODE SHAPES AND HYDRODYNAMIC RESPONSE SPECTRA

TABLE OF CONTENTS

APPENDIX A

LIST OF FIGURES

A.1 CONTAINMENT MODE SHAPES

The containment model is shown in Figure A.1-1. Figure A.1-2 shows containment frequencies from the modal analysis with water mass included as discussed in Section 7.1.1.1.1.3. Containment mode shapes are shown in Figures A.1-3 through A.1-25, covering mode shapes 1 through 23.

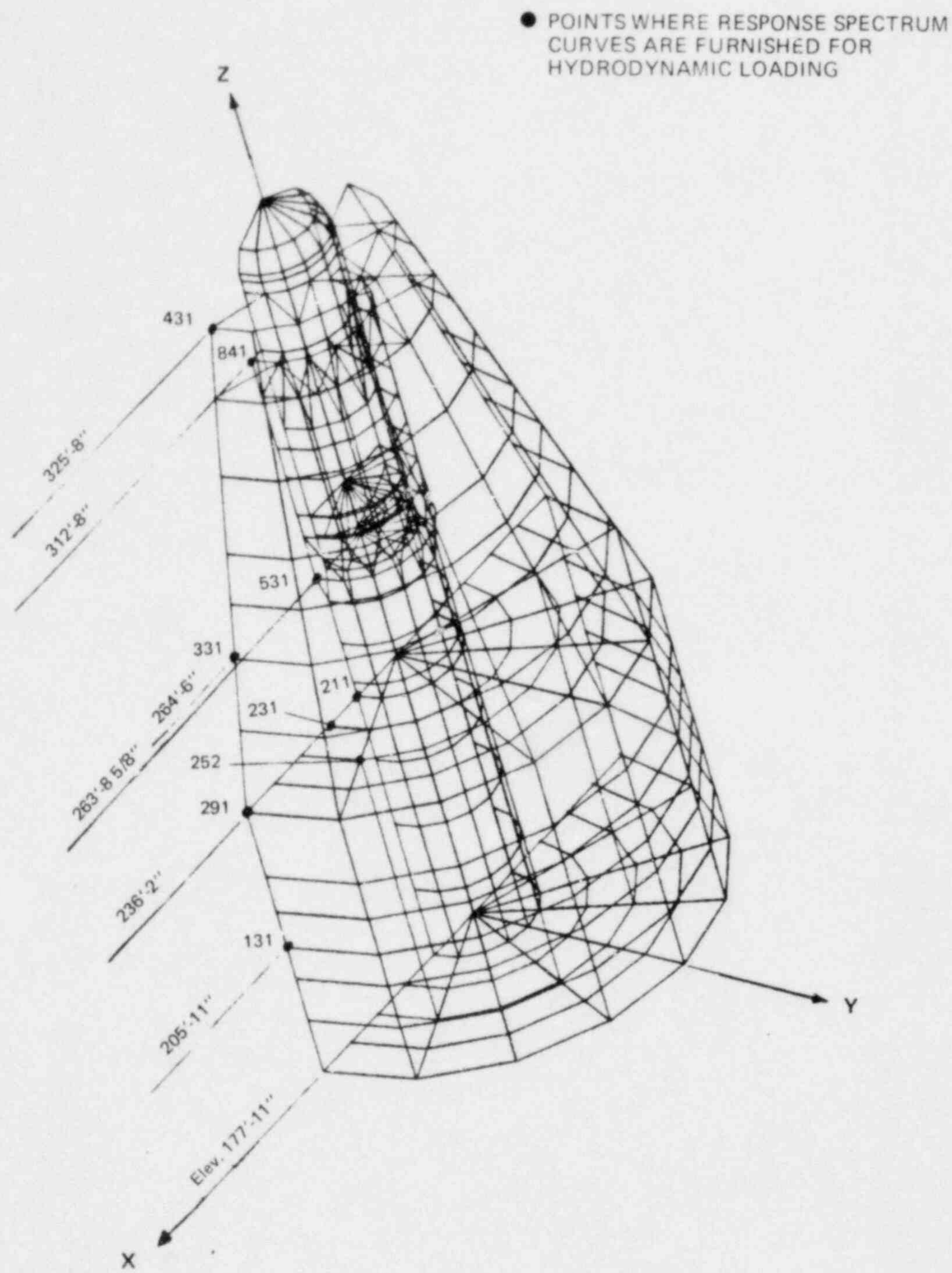
A.2 CONTAINMENT HYDRODYNAMIC RESPONSE SPECTRA

This appendix shows examples of the horizontal and vertical response spectra curves of the containment structure due to LOCA and SRV loading. Four spectral damping values, i.e., 0.005, 0.01, 0.02, and 0.05, are shown on each group of curves. The structural model of the containment is shown on Figure A.1-1. The modal frequencies and mode shapes are shown on Figures A.1-2 through A.1-25. The broadened response spectrum curves, shown on Figures A.2-1 through A.2-80, are submitted as representative examples of the containment structure response spectra. The loads under consideration are SRV and LOCA.

The KWU SRV loads consist of 3 pressure time histories. Five different time factors are applied to each pressure time history to account for possible variations in the frequency content. Therefore, a total of 15 axisymmetric and 15 asymmetric SRV load cases were analyzed.

The LOCA loads considered include 17 segments of condensation oscillation (CO), 2 segments of condensation oscillation with ADS (CO-ADS), and 14 cases of chugging.

Enveloped and broadened acceleration response spectra at selected nodes for the respective hydrodrodynamic loads are included in this report. The locations of the selected nodes are shown on Figure A.1-1. The hydrodynamic response spectra included at the selected nodes are shown on Figures A.2-1 through A.2-16 for SRV axisymmetric load, on Figures A.2-17 through A.2-32 for SRV asymmetric load, on Figures A.2-33 through A.2-48 for CO load, on Figures A.2-49 through A.2-64 for CO-ADS load, and on Figures A.2-65 through A.2-80 for chugging load. However, the chugging response spectra presented is the envelope spectra of all nodal points at the same elevation and radius. Therefore, the chugging spectra consist of representative spectra at containment locations with the same elevation and radius as the labeled nodal points on Figure A.1-1.



LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

MODEL FOR
CONTAINMENT RESPONSE SPECTRA

FIGURE A.1-1

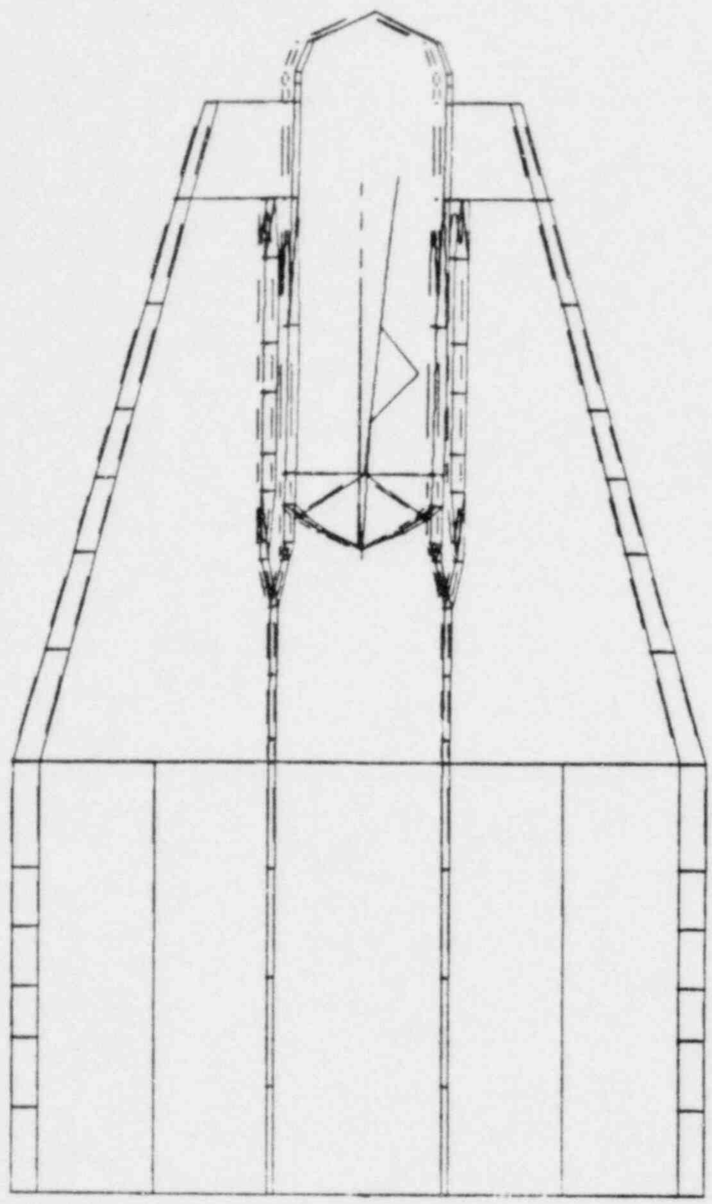
MODE NO.	FREQUENCY (Hz)	DIRECTION	LOCATION MAX. DISPLACEMENT
1	3.92	H	RPV INTERNAL
2	5.04	H	RPV INTERNAL
3	6.85	H	RPV INTERNAL
4	8.00	H	RPV INTERNAL
5	9.43	H	RPV INTERNAL
6	14.01	V	RPV INTERNAL
7	14.86	B	CONTAINMENT
8	16.59	H	RPV INTERNAL
9	18.32	V	CONTAINMENT
10	19.38	H	RPV INTERNAL
11	19.60	H	RPV INTERNAL
12	23.24	B	RPV SHIELD
13	23.94	B	RPV SHIELD
14	26.09	H	CONTAINMENT
15	26.42	H	PEDESTAL
16	27.88	B	CONTAINMENT
17	28.52	H	RPV SHIELD
18	32.08	V	RPV INTERNAL
19	32.54	H	CONTAINMENT
20	34.21	B	CONTAINMENT
21	34.87	H	RPV SHIELD
22	36.78	V	RPV INTERNAL
23	39.31	V	RPV INTERNAL

NOTES: H - HORIZONTAL
V - VERTICAL
B - BREATHING

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT MODES
AND FREQUENCIES

FIGURE A.1-2



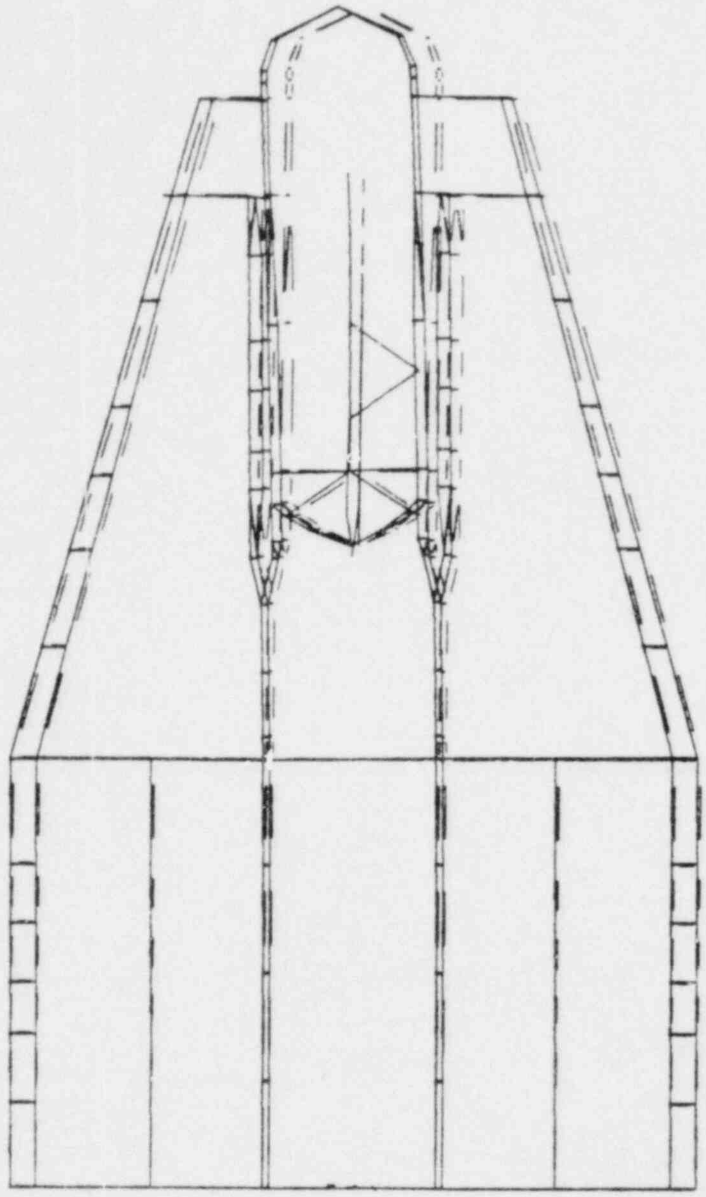
MODE 1
(WITH WATER MASS)

f = 3.92 Hz

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT MODE SHAPES

FIGURE A.1-3



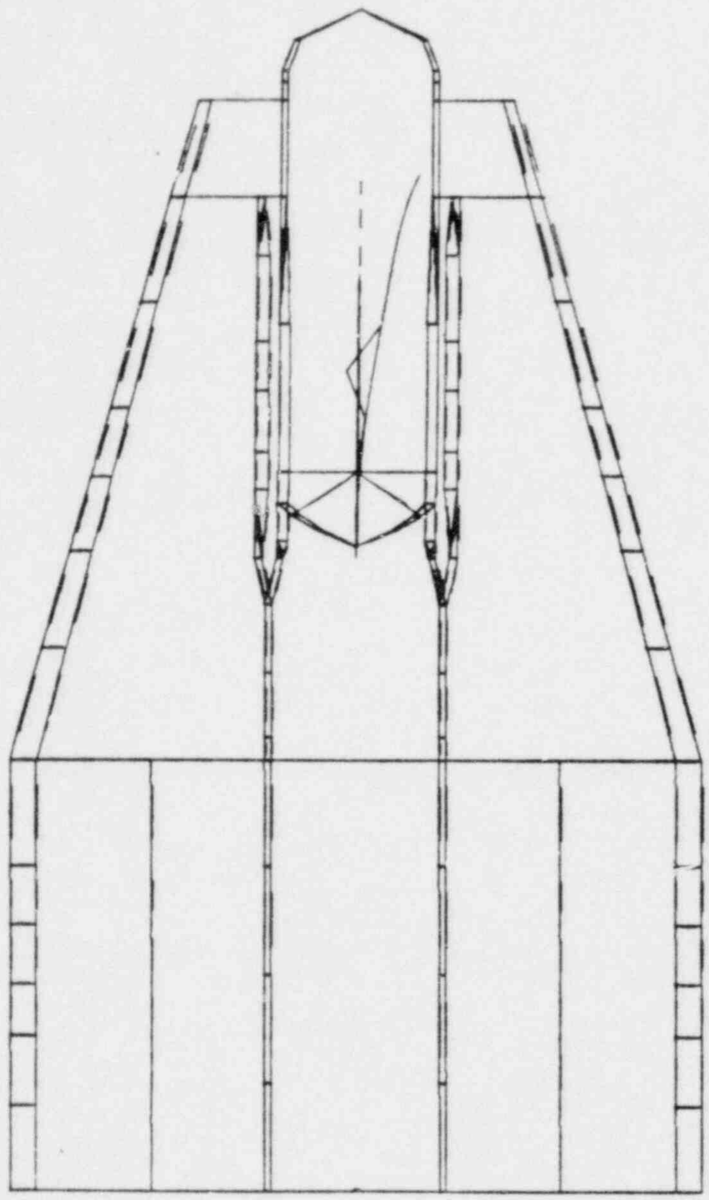
MODE 2
(WITH WATER MASS)

f = 5.04 Hz

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT MODE SHAPES

FIGURE A.1-4



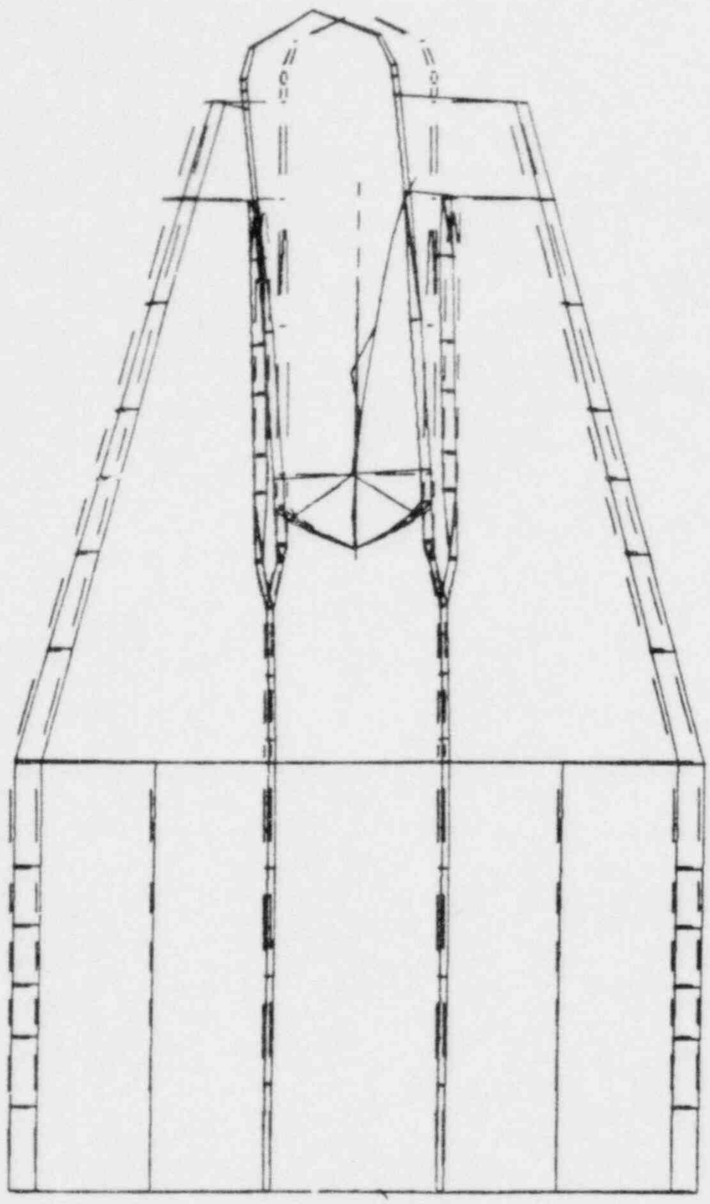
MODE 3
(WITH WATER MASS)

f = 6.85 Hz

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT MODE SHAPES

FIGURE A.1-5



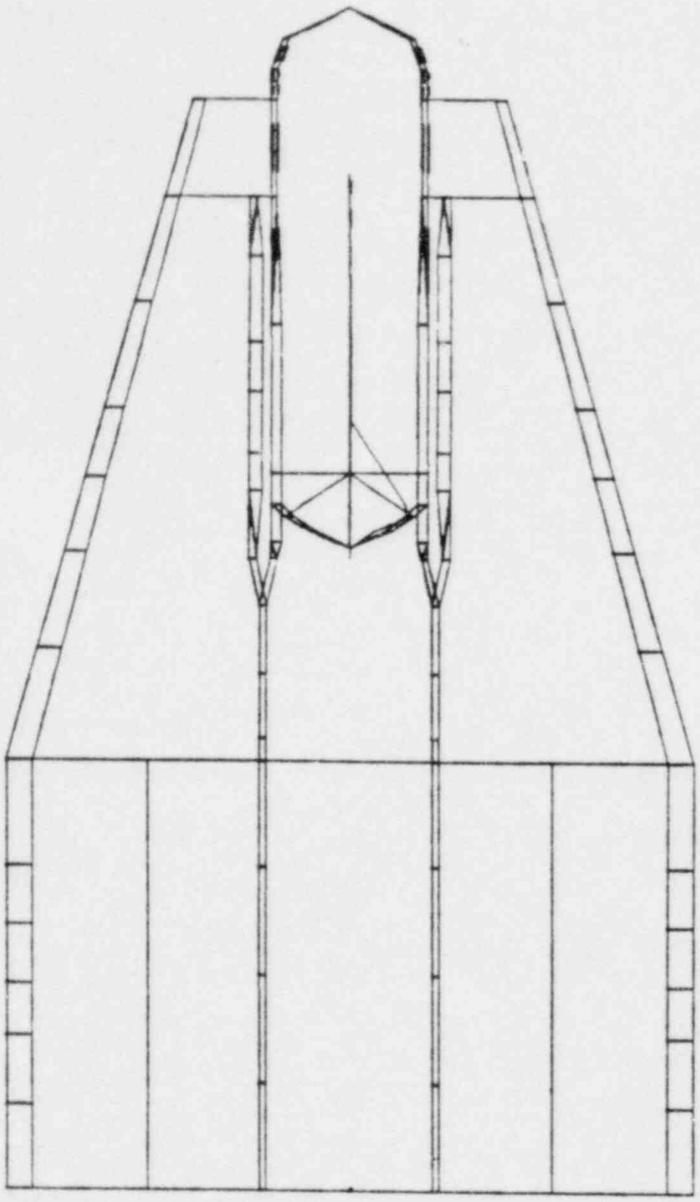
MODE 4
(WITH WATER MASS)

f = 8.00 Hz

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT MODE SHAPES

FIGURE A.1-6



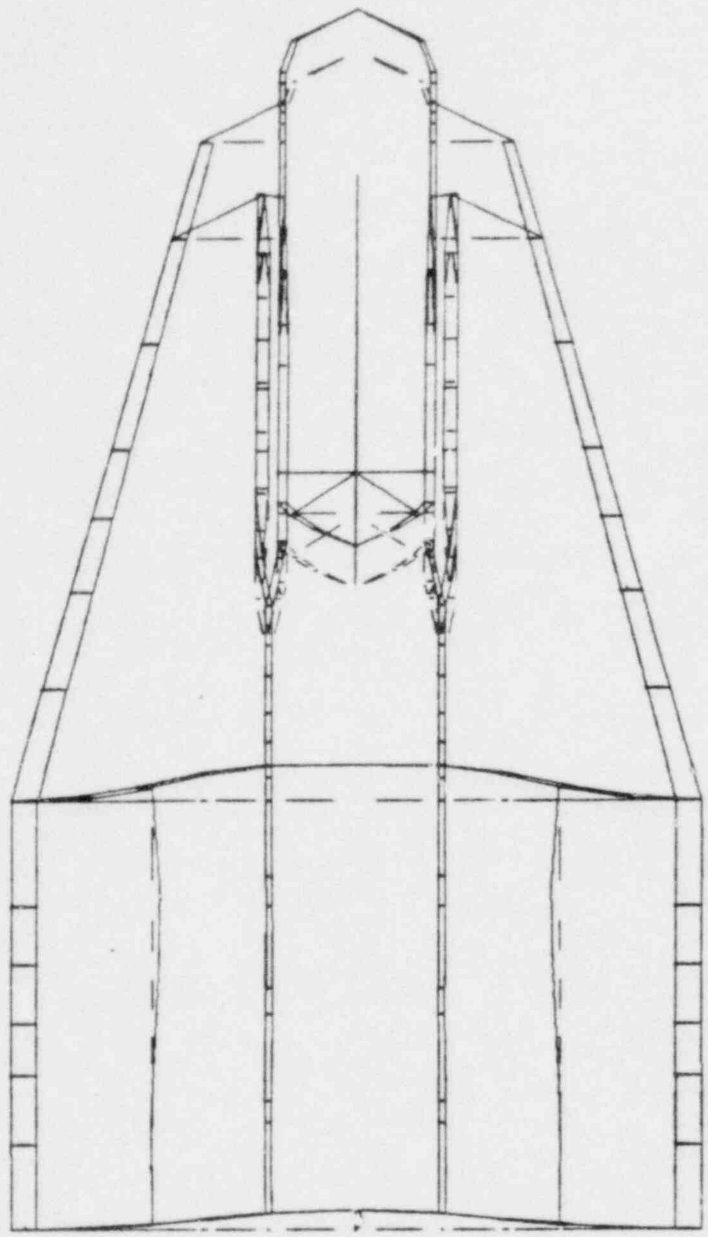
MODE 5
(WITH WATER MASS)

f = 9.43 Hz

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT MODE SHAPES

FIGURE A.1-7



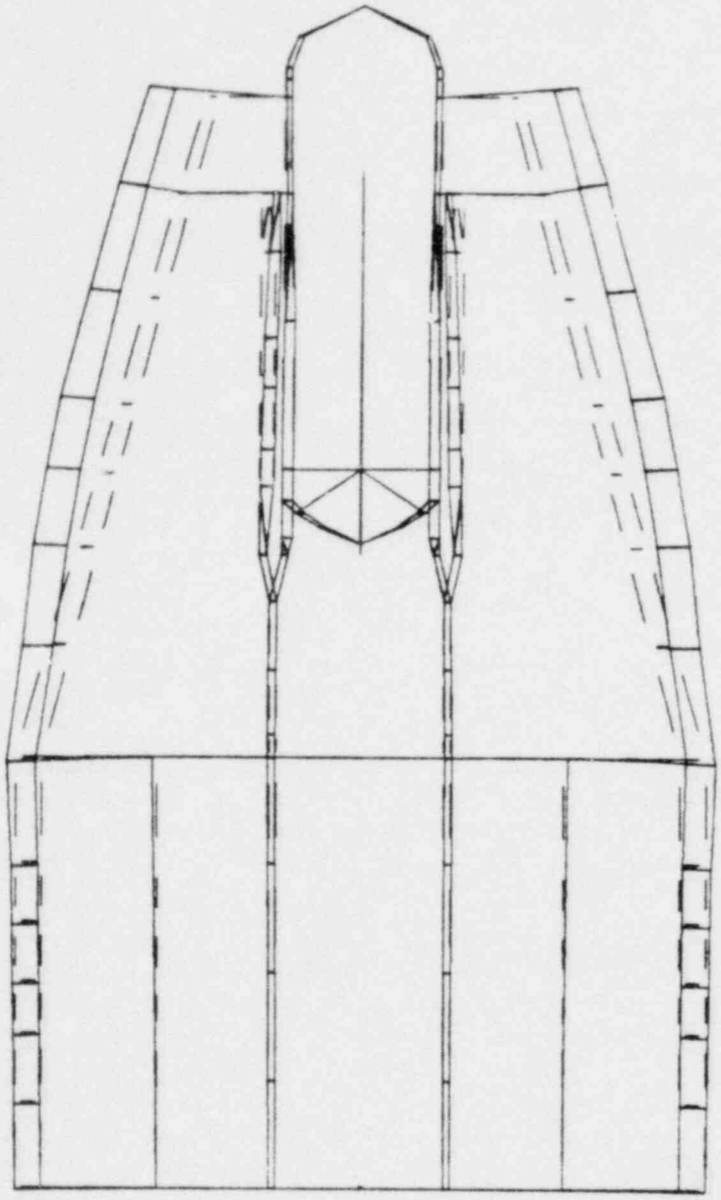
MODE 6
(WITH WATER MASS)

f = 14.01 Hz

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT MODE SHAPES

FIGURE A.1-8



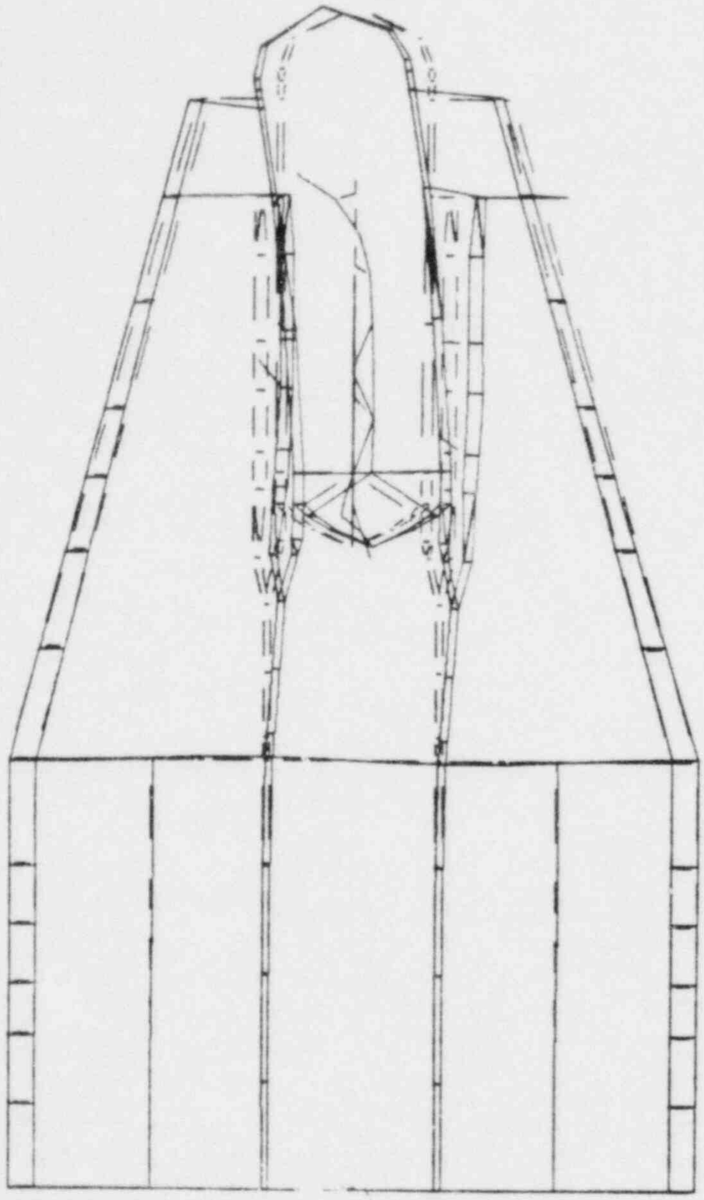
MODE 7
(WITH WATER MASS)

f = 14.86 Hz

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT MODE SHAPES

FIGURE A.1-9



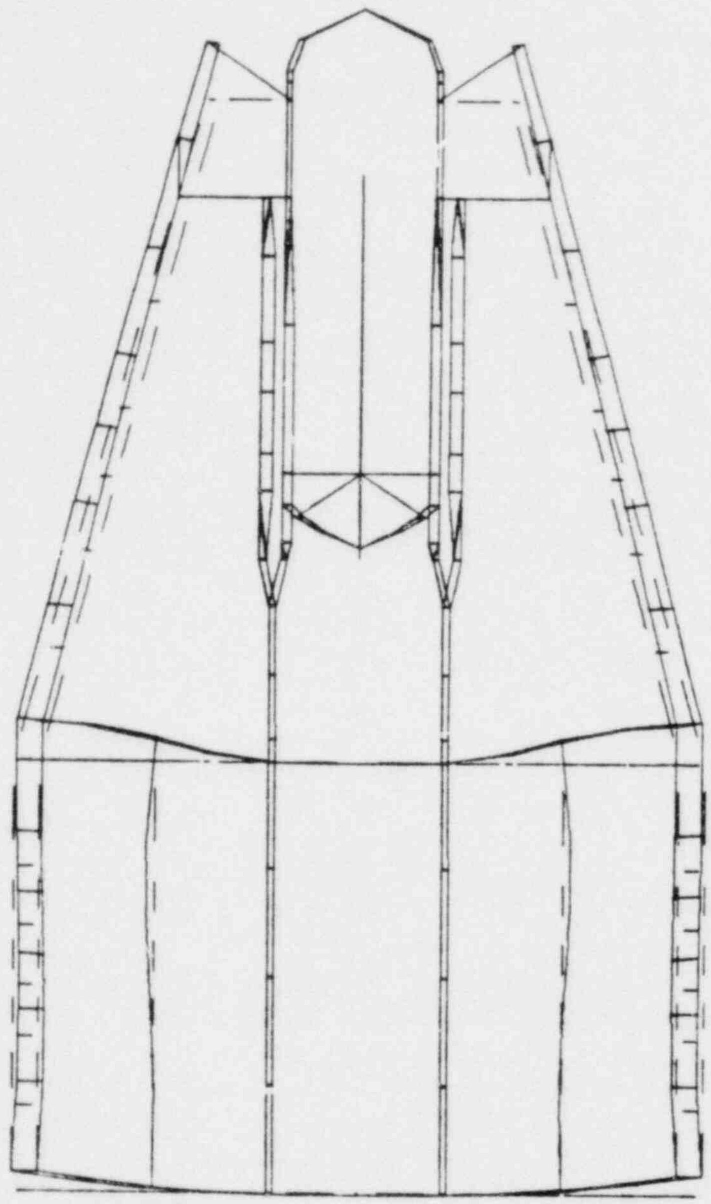
MODE 8
(WITH WATER MASS)

f = 16.59 Hz

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT MODE SHAPES

FIGURE A.1-10



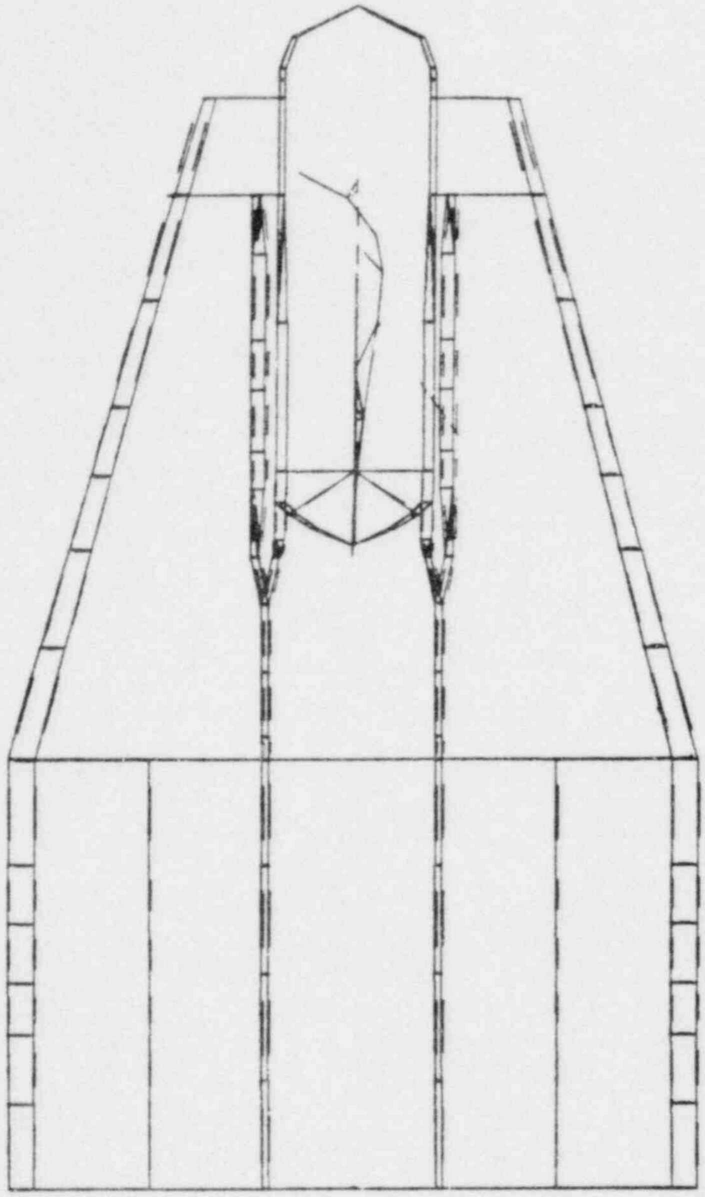
MODE 9
(WITH WATER MASS)

f = 18.32 Hz

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT MODE SHAPES

FIGURE A.1-11



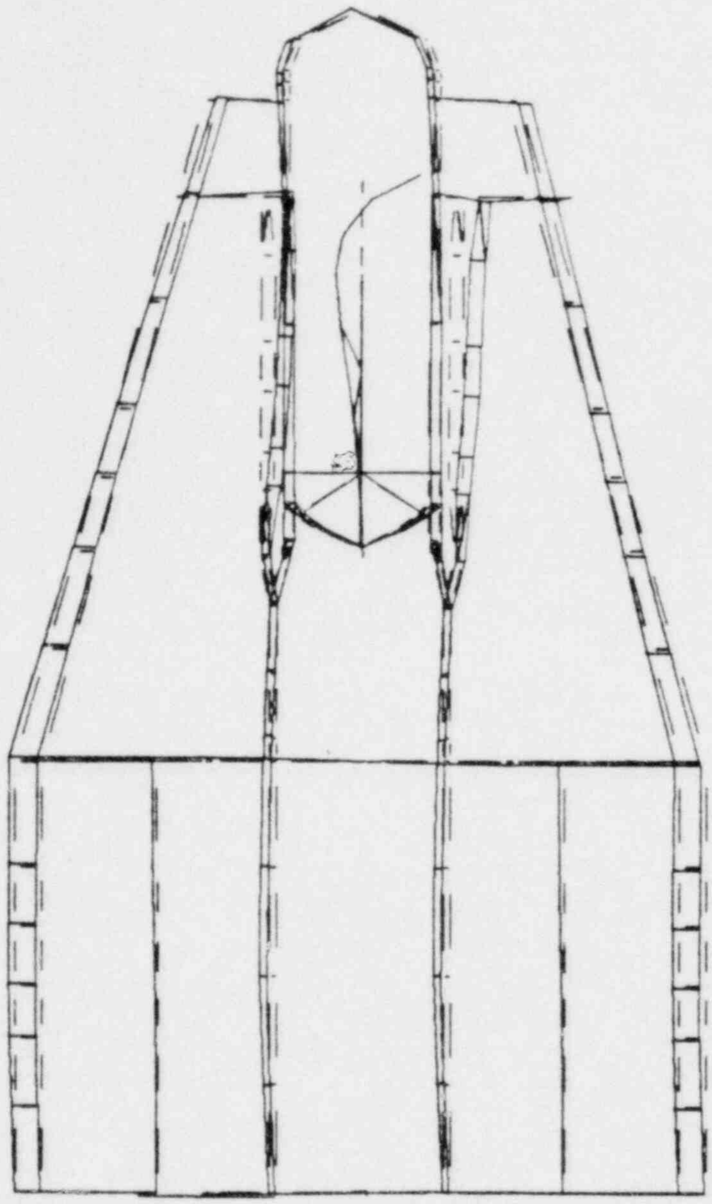
MODE 10
(WITH WATER MASS)

f = 19.38 Hz

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT MODE SHAPES

FIGURE A.1-12



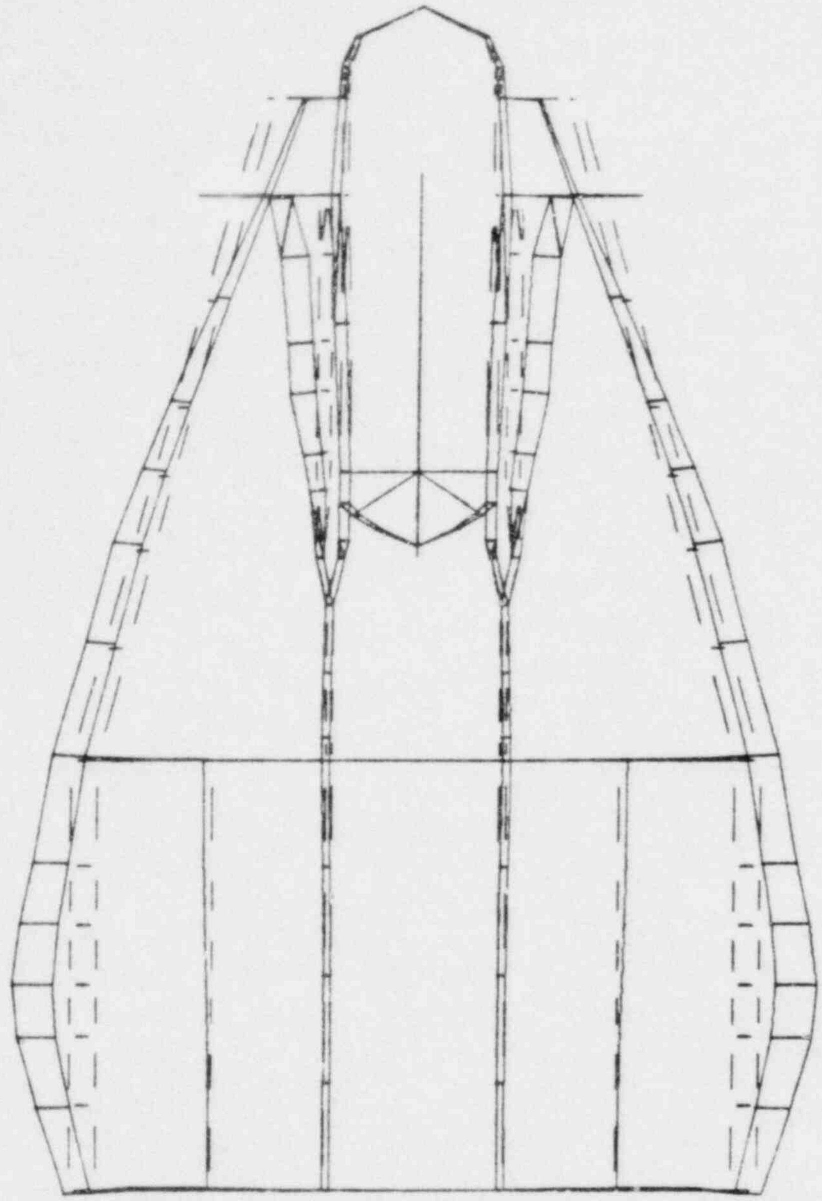
MODE 11
(WITH WATER MASS)

f = 19.60 Hz

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT MODE SHAPES

FIGURE A.1-13



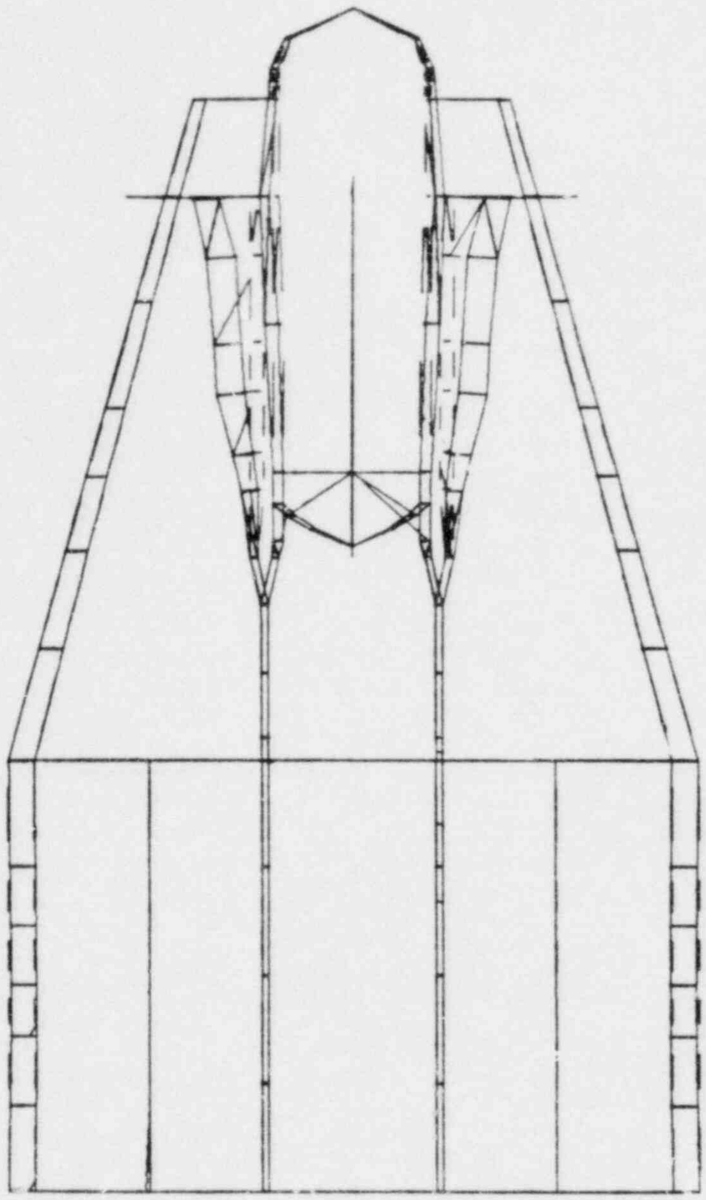
MODE 12
(WITH WATER MASS)

f = 23.24 Hz

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT MODE SHAPES

FIGURE A.1-14



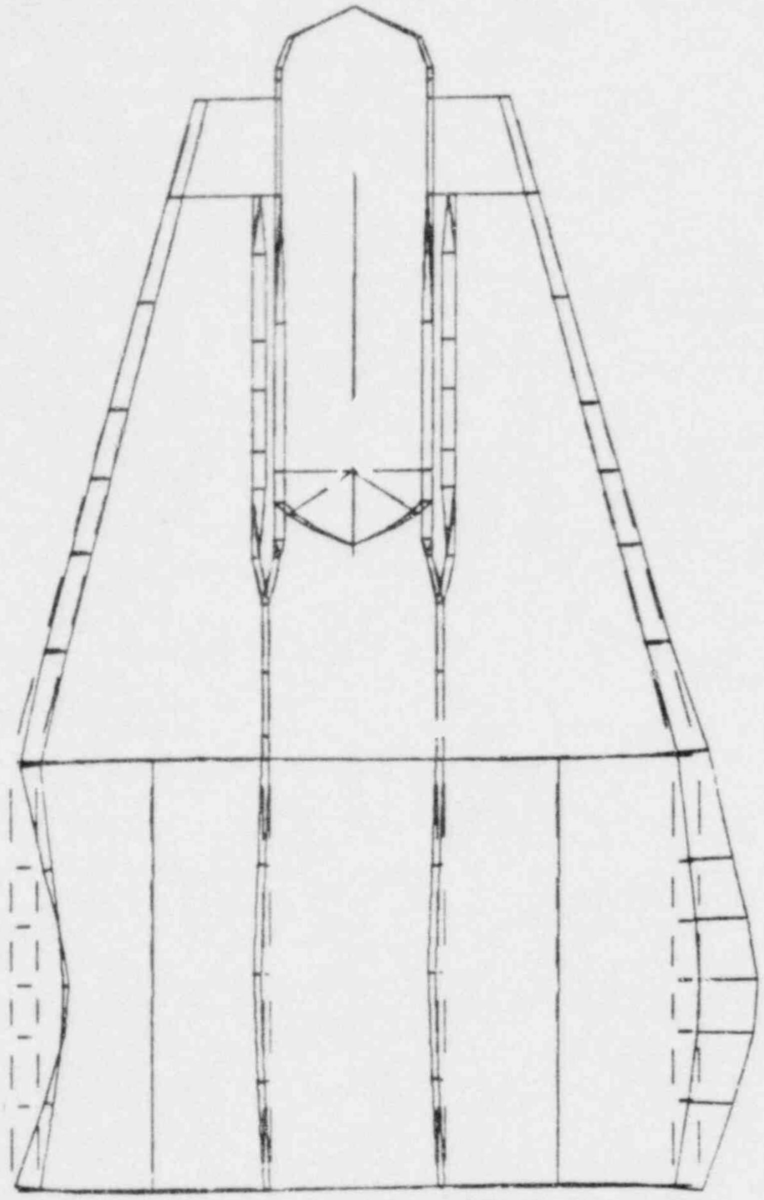
MODE 13
(WITH WATER MASS)

f = 23.94 Hz

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT MODE SHAPES

FIGURE A.1-15



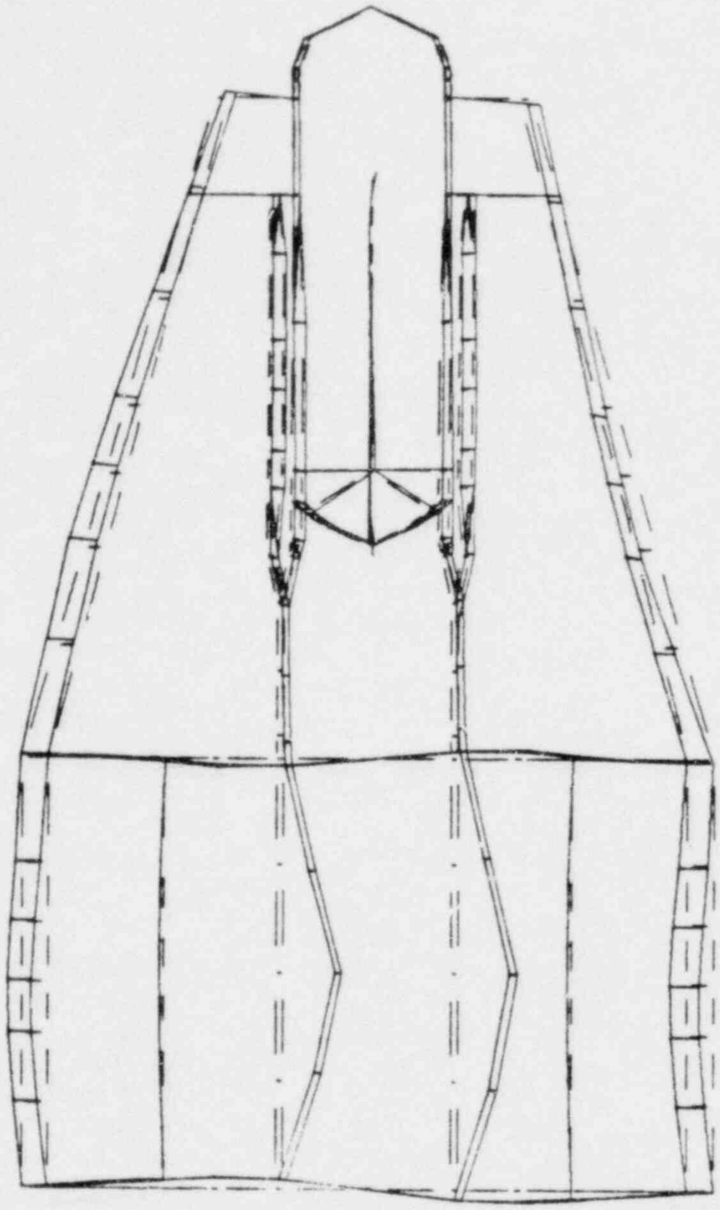
MODE 14
(WITH WATER MASS)

f = 26.09 Hz

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT MODE SHAPES

FIGURE A.1-16



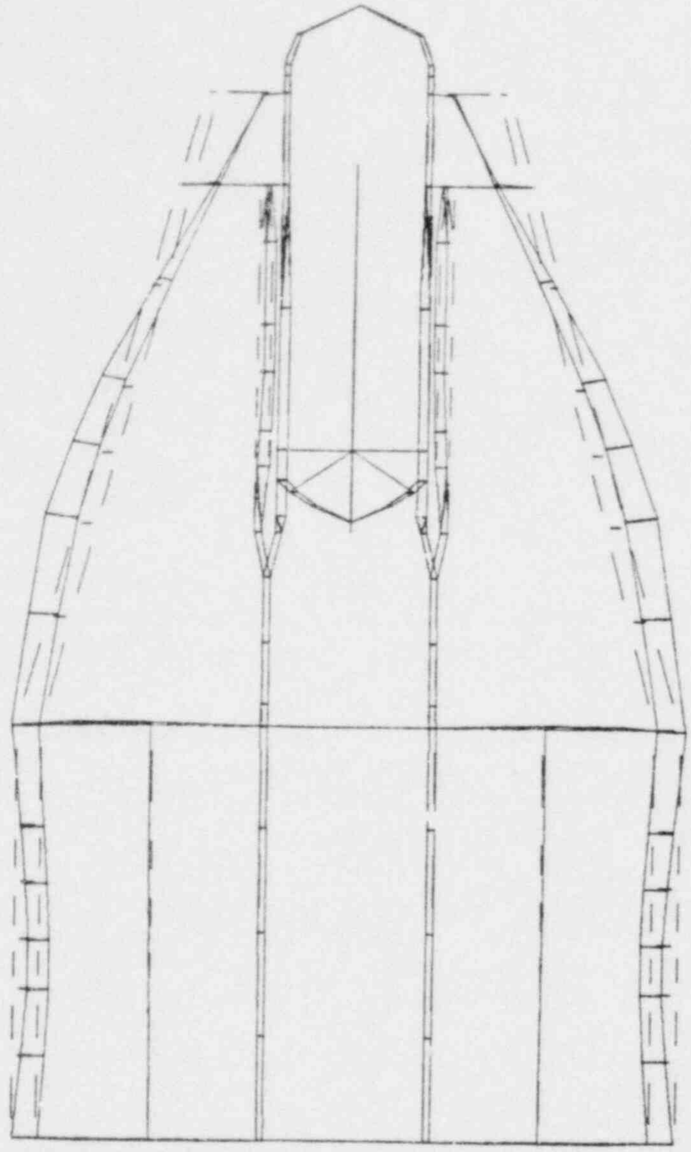
MODE 15
(WITH WATER MASS)

f = 26.42 Hz

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT MODE SHAPES

FIGURE A.1-17



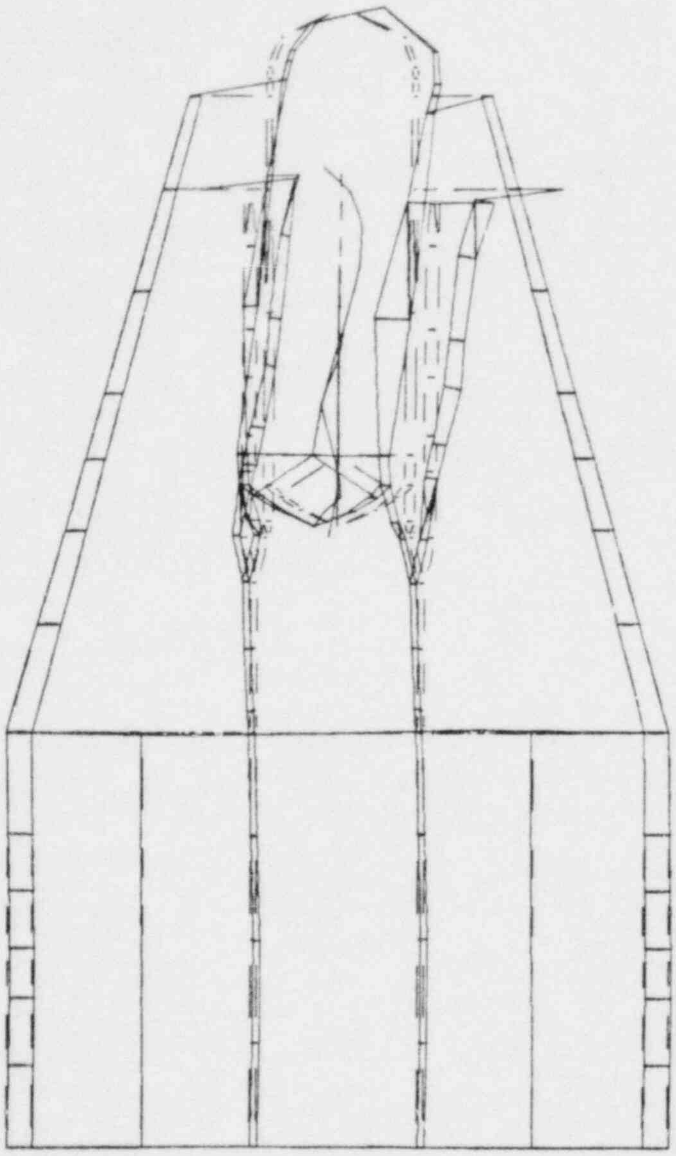
MODE 16
(WITH WATER MASS)

f = 27.88 Hz

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT MODE SHAPES

FIGURE A.1-18



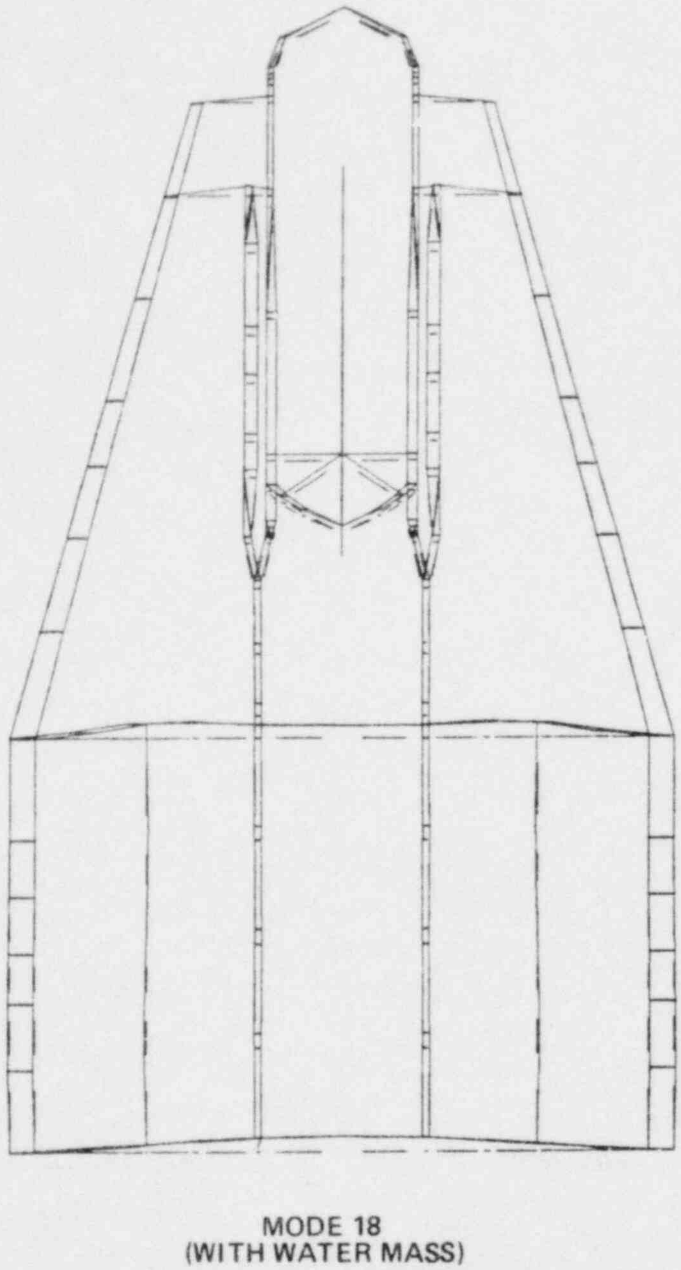
MODE 17
(WITH WATER MASS)

f = 28.52 Hz

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT MODE SHAPES

FIGURE A.1-19



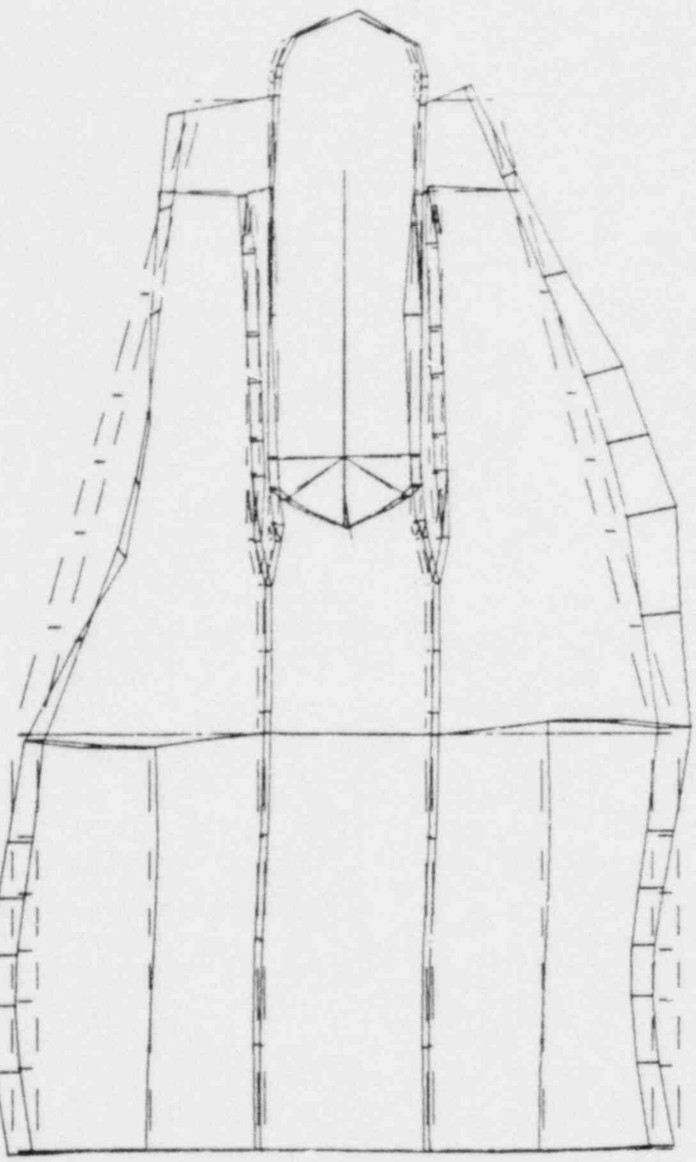
MODE 18
(WITH WATER MASS)

f = 32.08 Hz

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT MODE SHAPES

FIGURE A.1-20



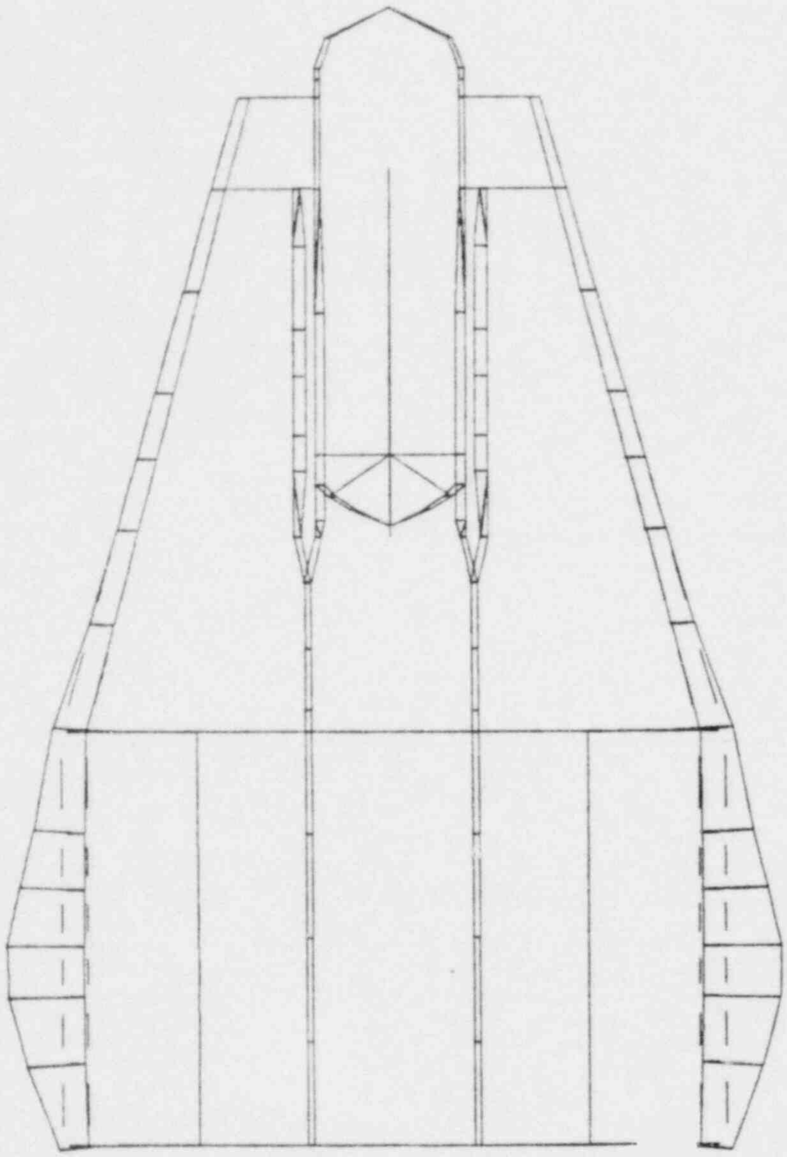
MODE 19
(WITH WATER MASS)

f = 32.54 Hz

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT MODE SHAPES

FIGURE A.1-21



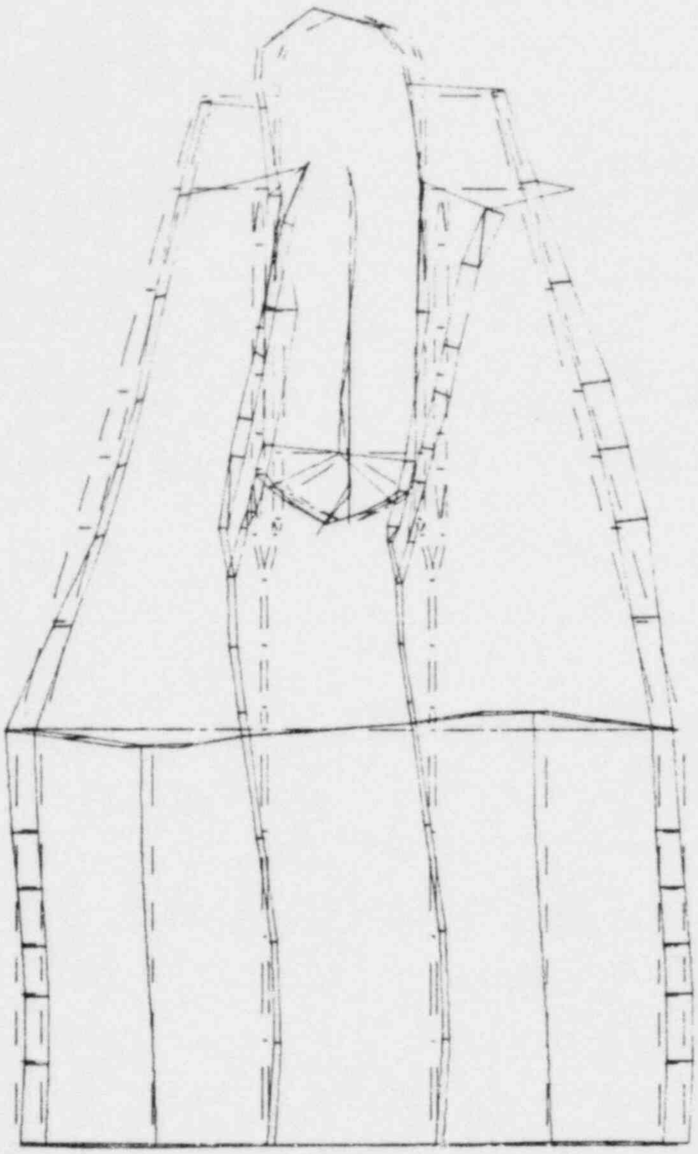
MODE 20
(WITH WATER MASS)

f = 34.21 Hz

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT MODE SHAPES

FIGURE A.1-22



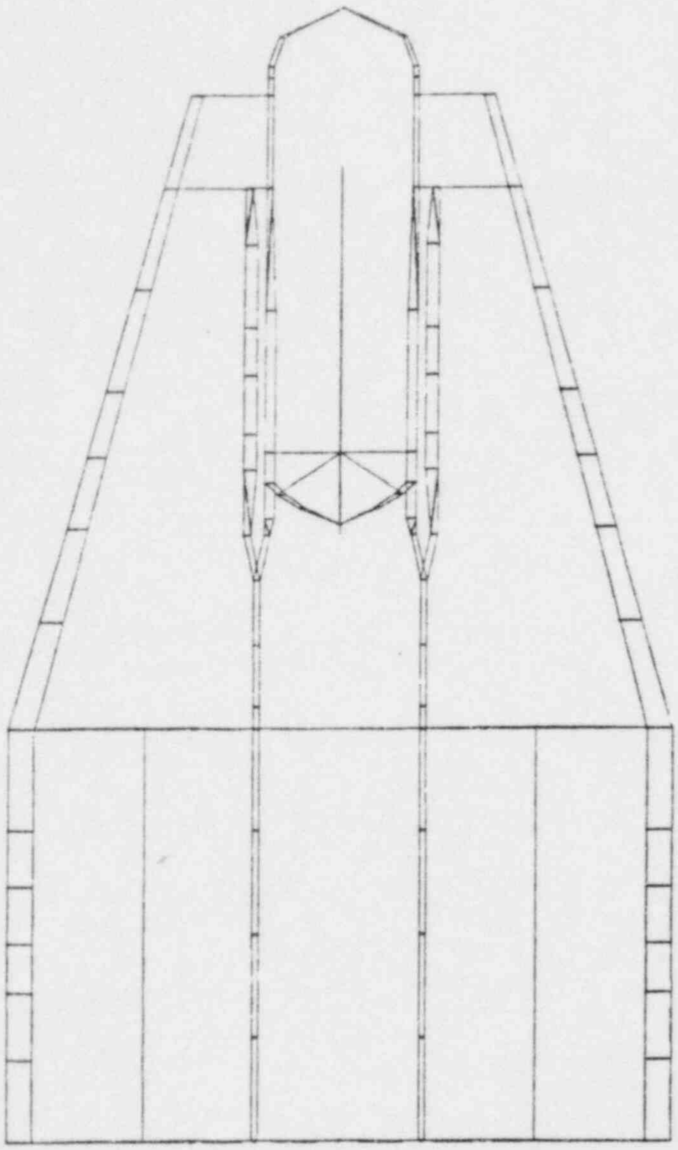
MODE 21
(WITH WATER MASS)

f = 34.87 Hz

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT MODE SHAPES

FIGURE A.1-23



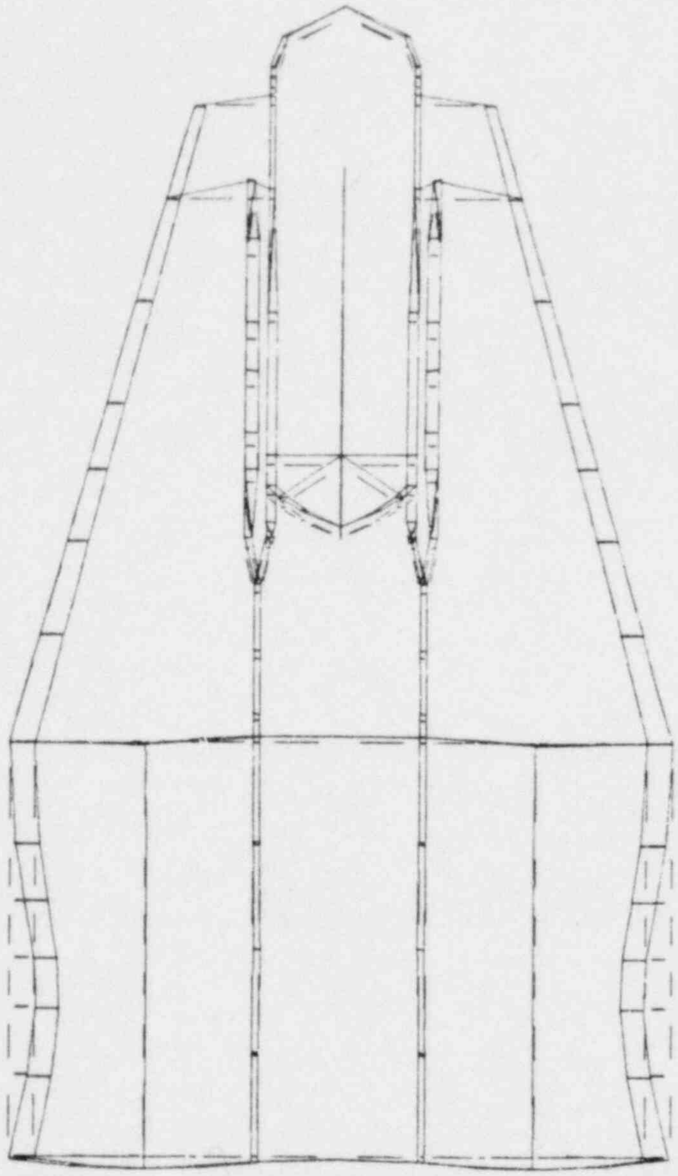
MODE 22
(WITH WATER MASS)

f = 36.78 Hz

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT MODE SHAPES

FIGURE A.1-24



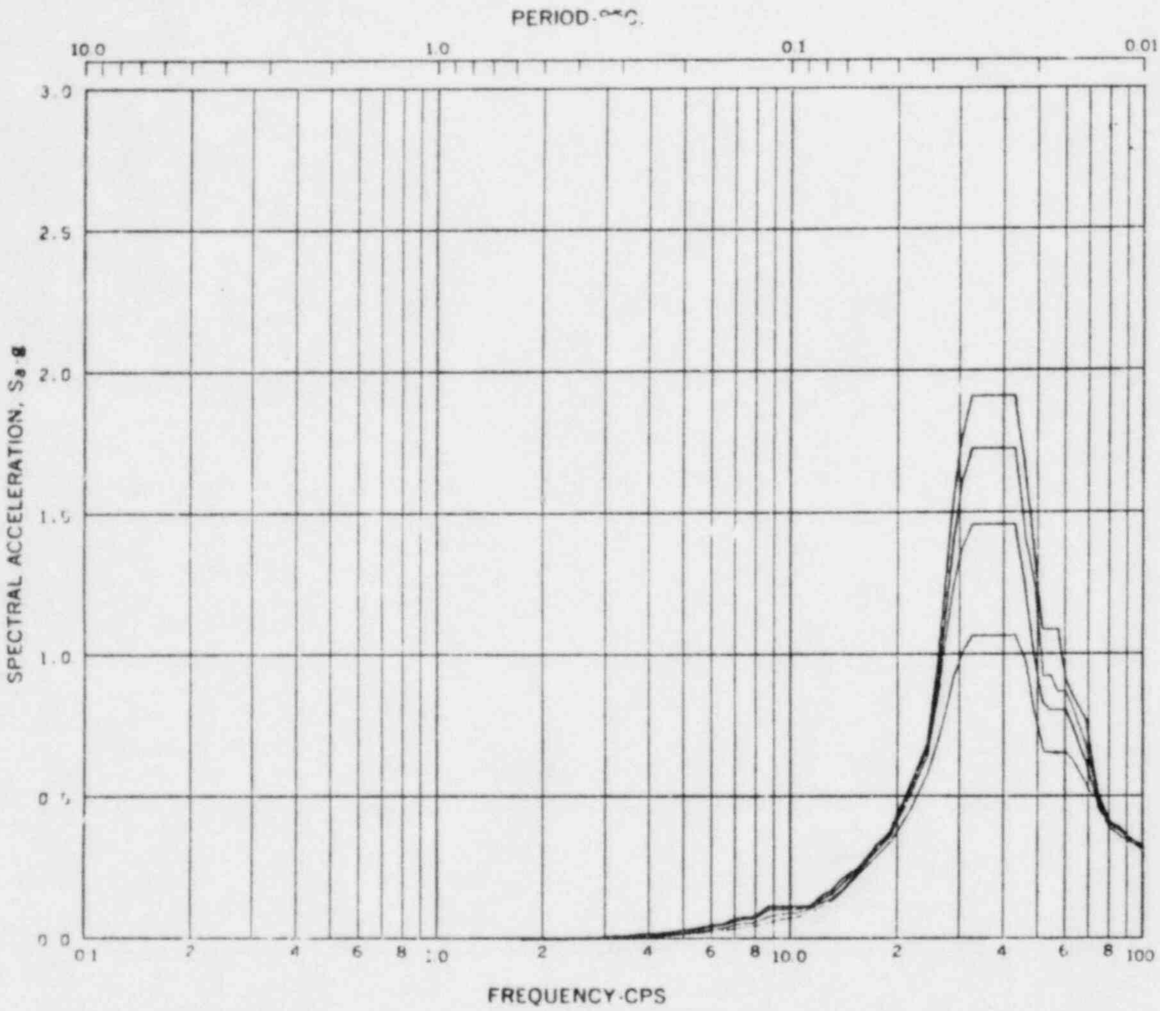
MODE 23
(WITH WATER MASS)

f = 39.31 Hz

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT MODE SHAPES

FIGURE A.1-25



Acceleration Spectra for WETWELL WALL

Load Case: SRV - AXISYMMETRIC

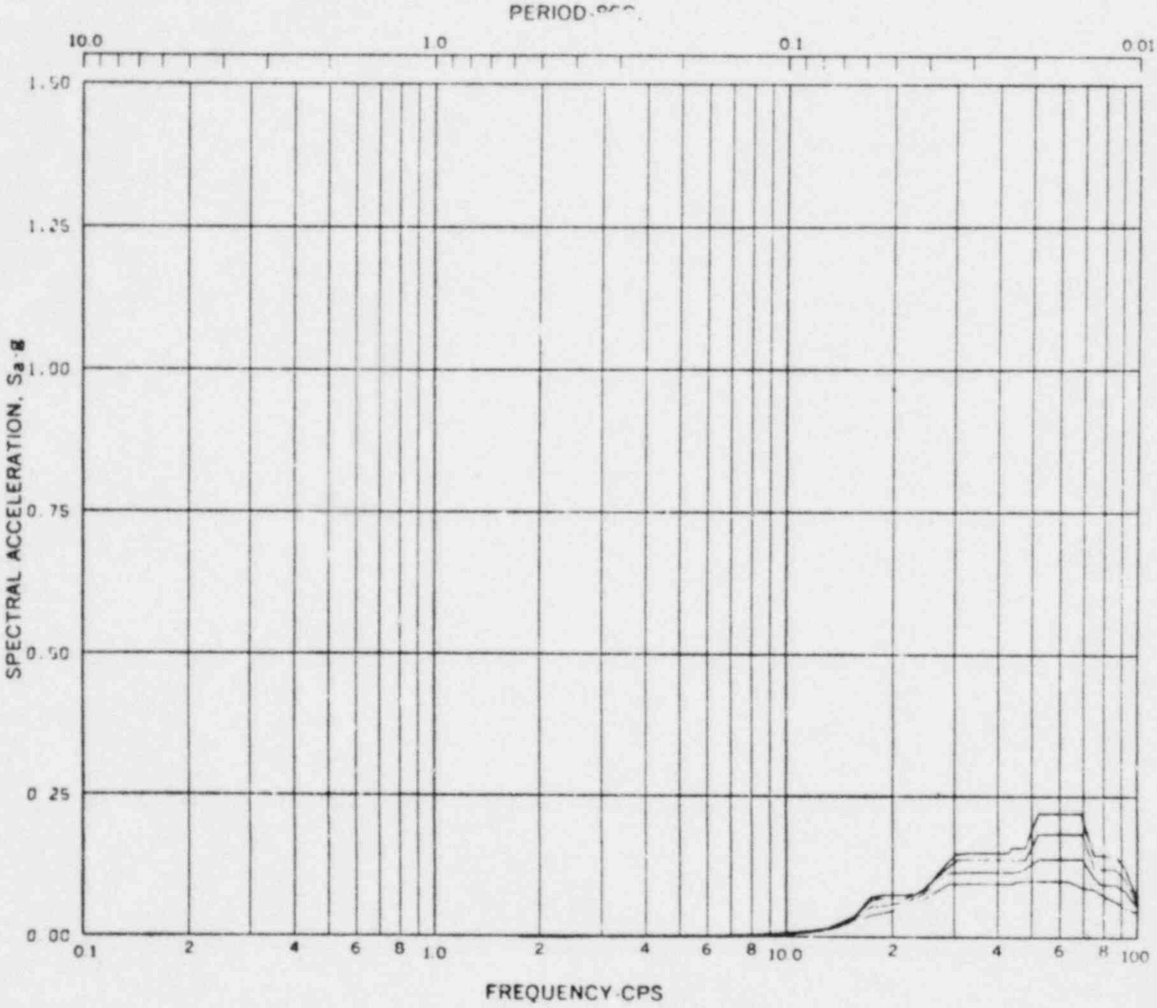
Node: 131 Direction: HORIZ Elev: 205'-11" Angle: 0°

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
SRV AXISYMMETRIC
DIRECTION X

FIGURE A.2-1



Acceleration Spectra for WETWELL WALL

Load Case: SRV - AXISYMMETRIC

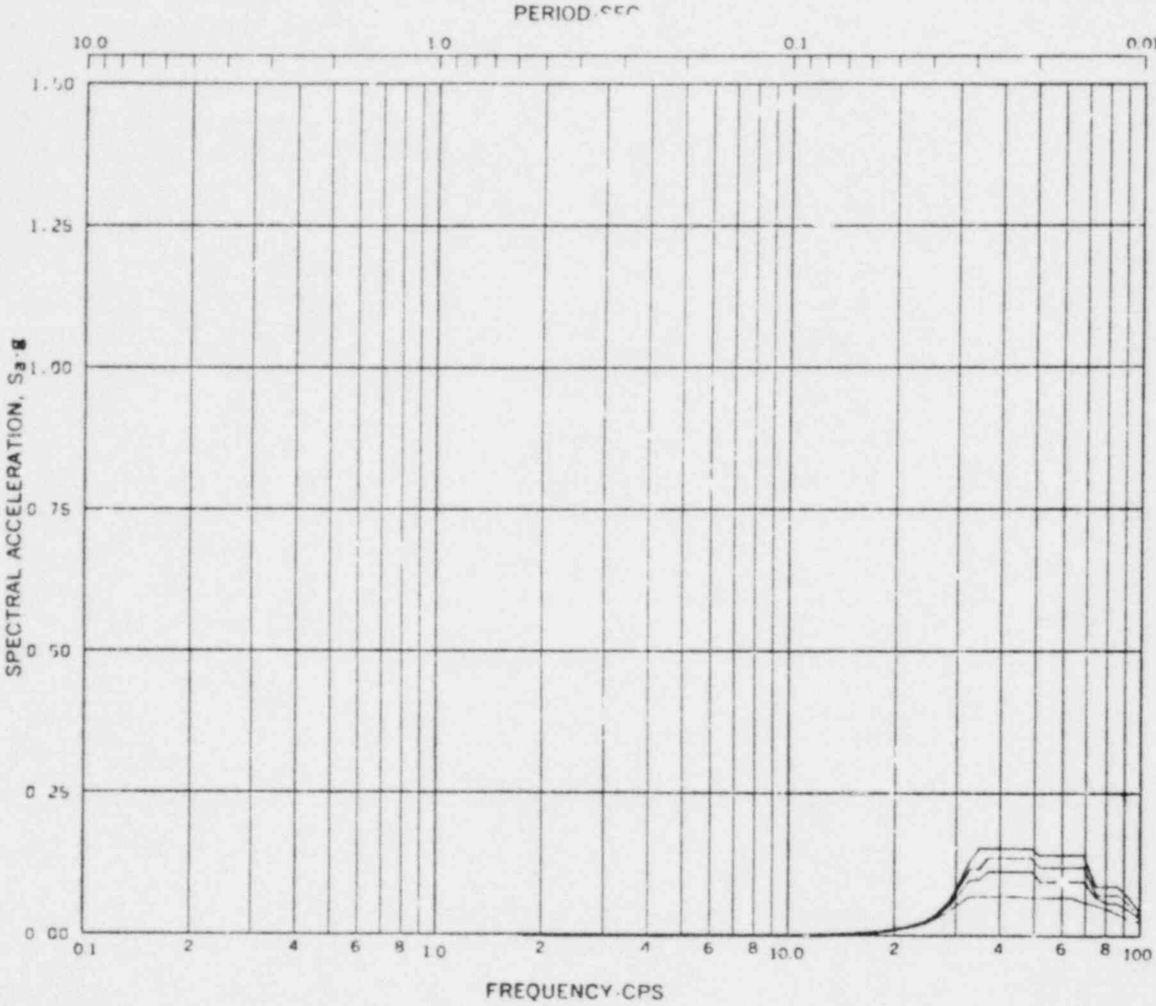
Node: 291 Direction: HORIZ Elev: 236'-2" Angle: 0°

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
SRV AXISYMMETRIC
DIRECTION X

FIGURE A.2-2



Acceleration Spectra for DRYWELL WALL

Load Case: SRV - AXISYMMETRIC

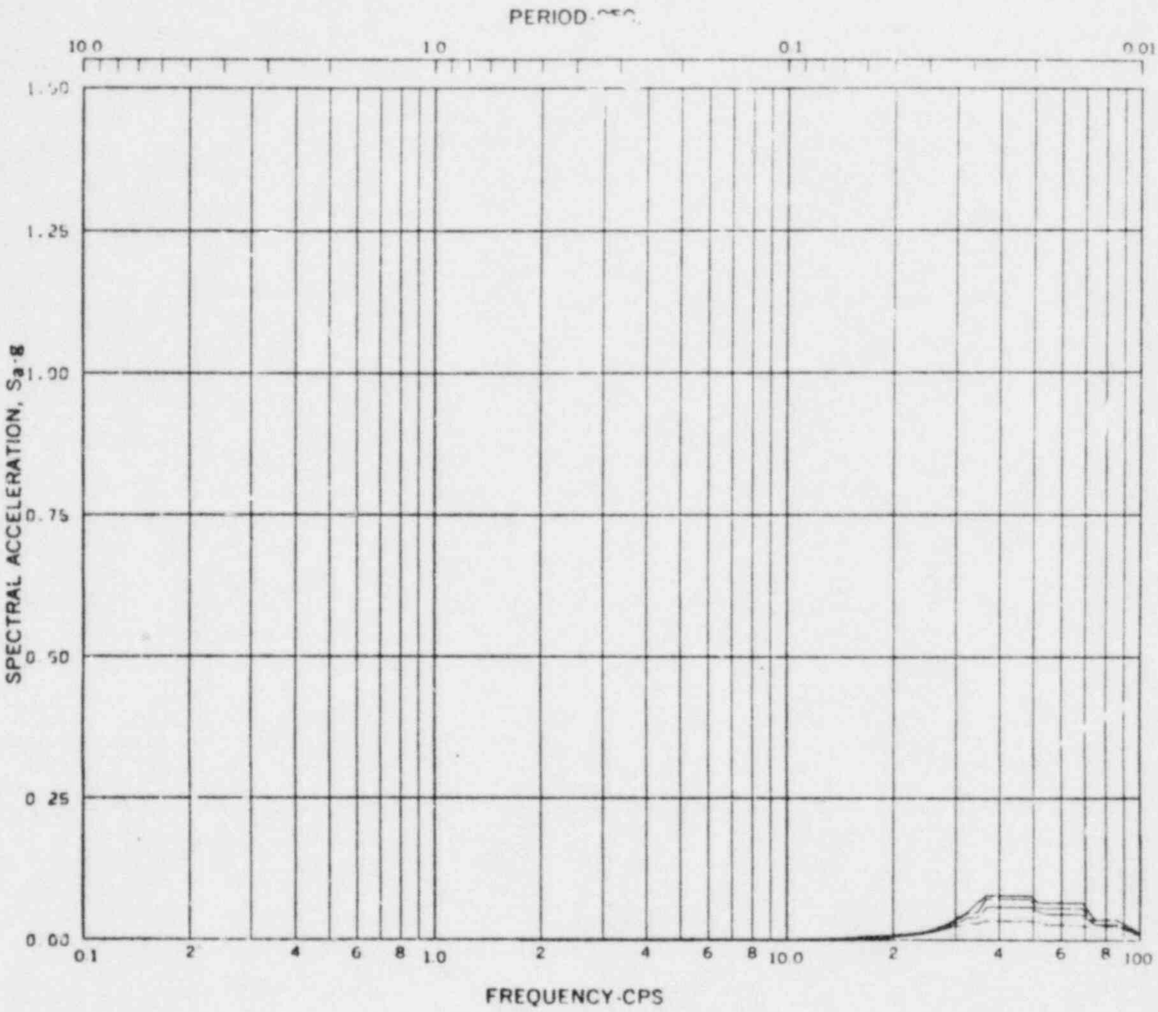
Node: 331 Direction: HORIZ Elev: 264'-6" Angle: 0°

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
SRV AXISYMMETRIC
DIRECTION X

FIGURE A.2-3



Acceleration Spectra for DRYWELL WALL

Load Case: SRV - AXISYMMETRIC

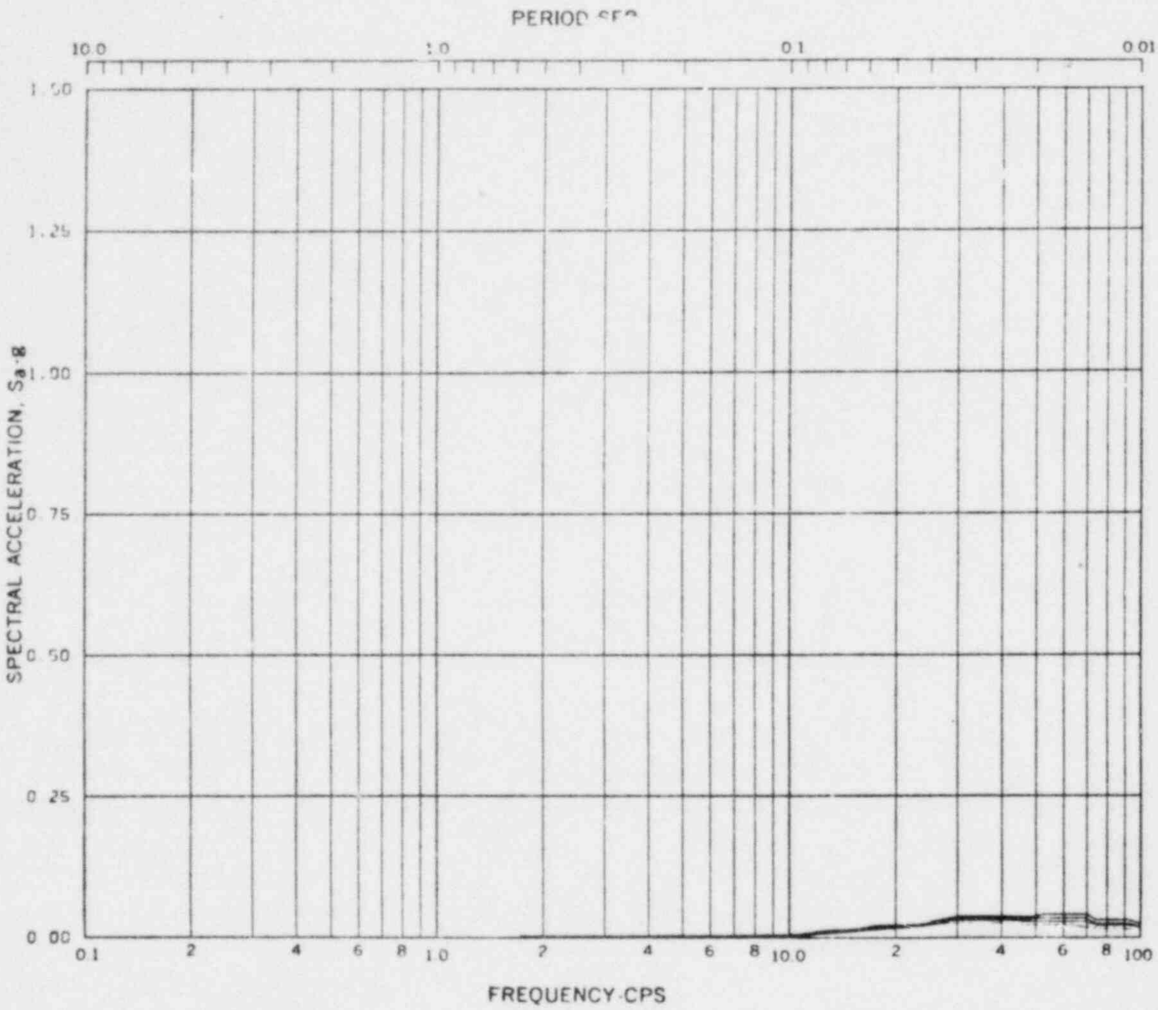
Node: 431 Direction: HORIZ Elev: 325'-8" Angle: 0°

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
SRV AXISYMMETRIC
DIRECTION X

FIGURE A.2-4



Acceleration Spectra for PEDESTAL

Load Case: SRV - AXISYMMETRIC

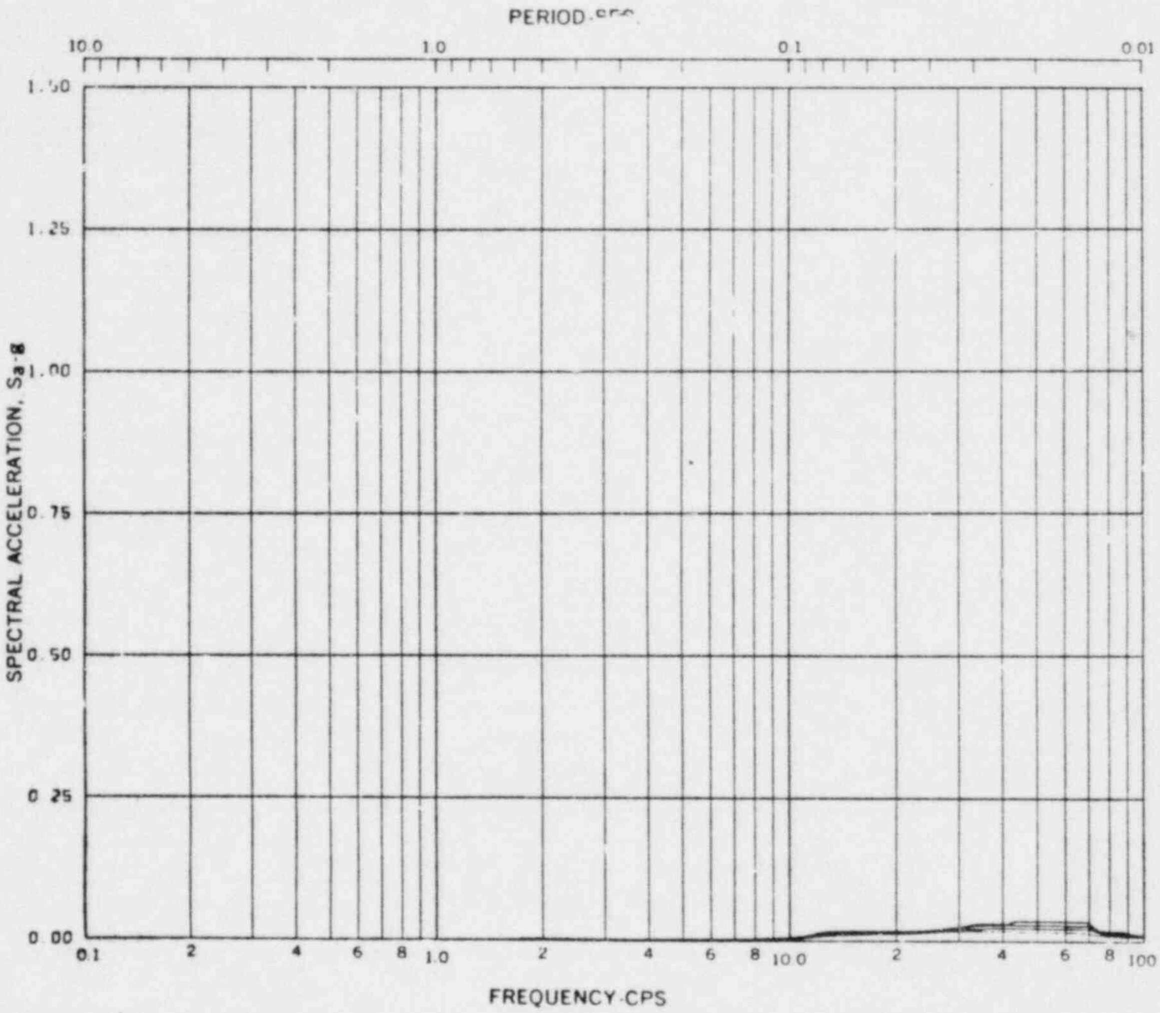
Node: 211 Direction: HORIZ Elev: 236'-2" Angle: 0°

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
SRV AXISYMMETRIC
DIRECTION X

FIGURE A.2-5



Acceleration Spectra for PEDESTAL

Load Case: SRV - AXISYMMETRIC

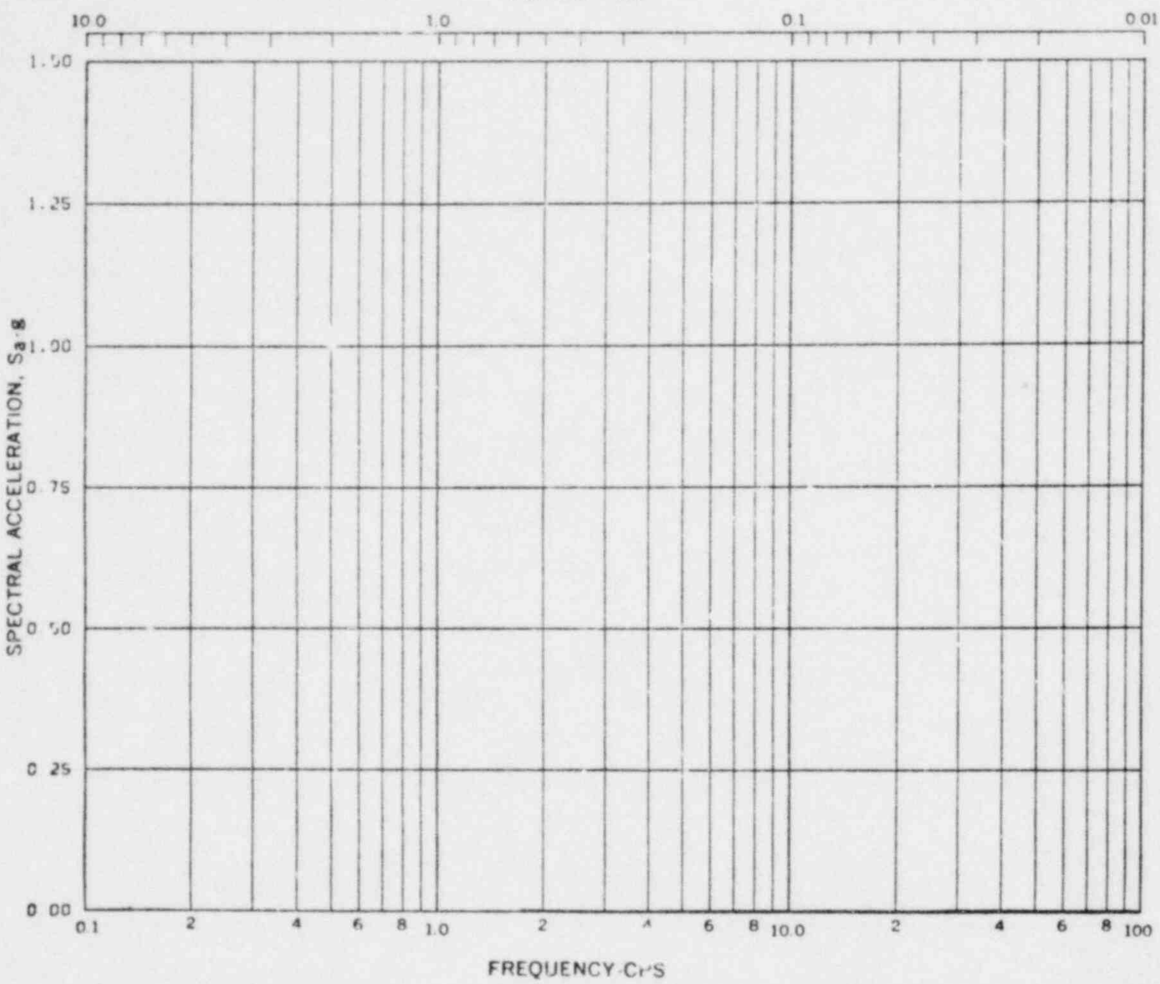
Node: 531 Direction: HORIZ Elev: 263'-8 5/8" Angle: 0°

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
SRV AXISYMMETRIC
DIRECTION X

FIGURE A. 2-6



Acceleration Spectra for SHIELD WALL

Load Case: SRV - AXISYMMETRIC

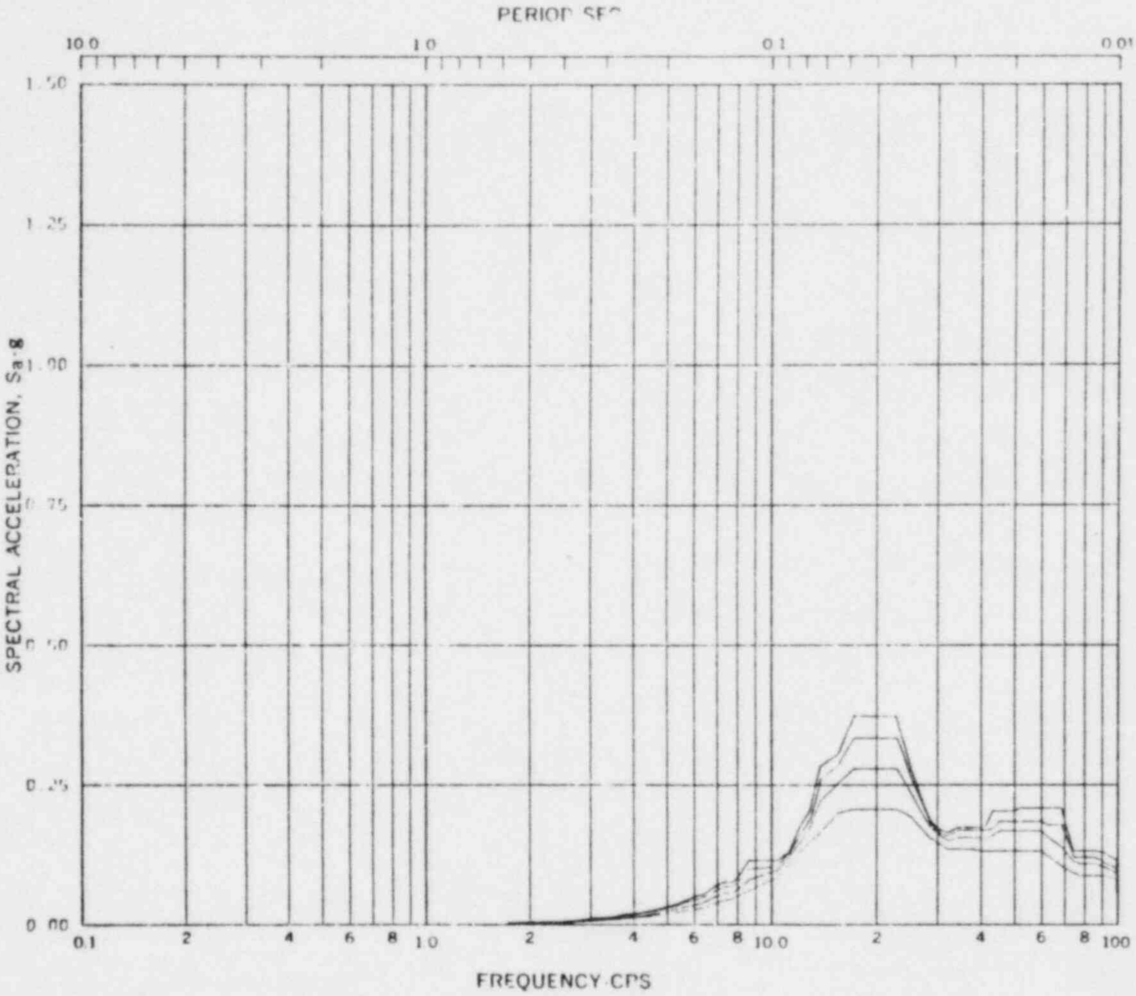
Node: 841 Direction: HORIZ Elev: 312'-8" Angle: 0°

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
SRV AXISYMMETRIC
DIRECTION X

FIGURE A.2-7



Acceleration Spectra for WETWELL WALL

Load Case: SRV - AXISYMMETRIC

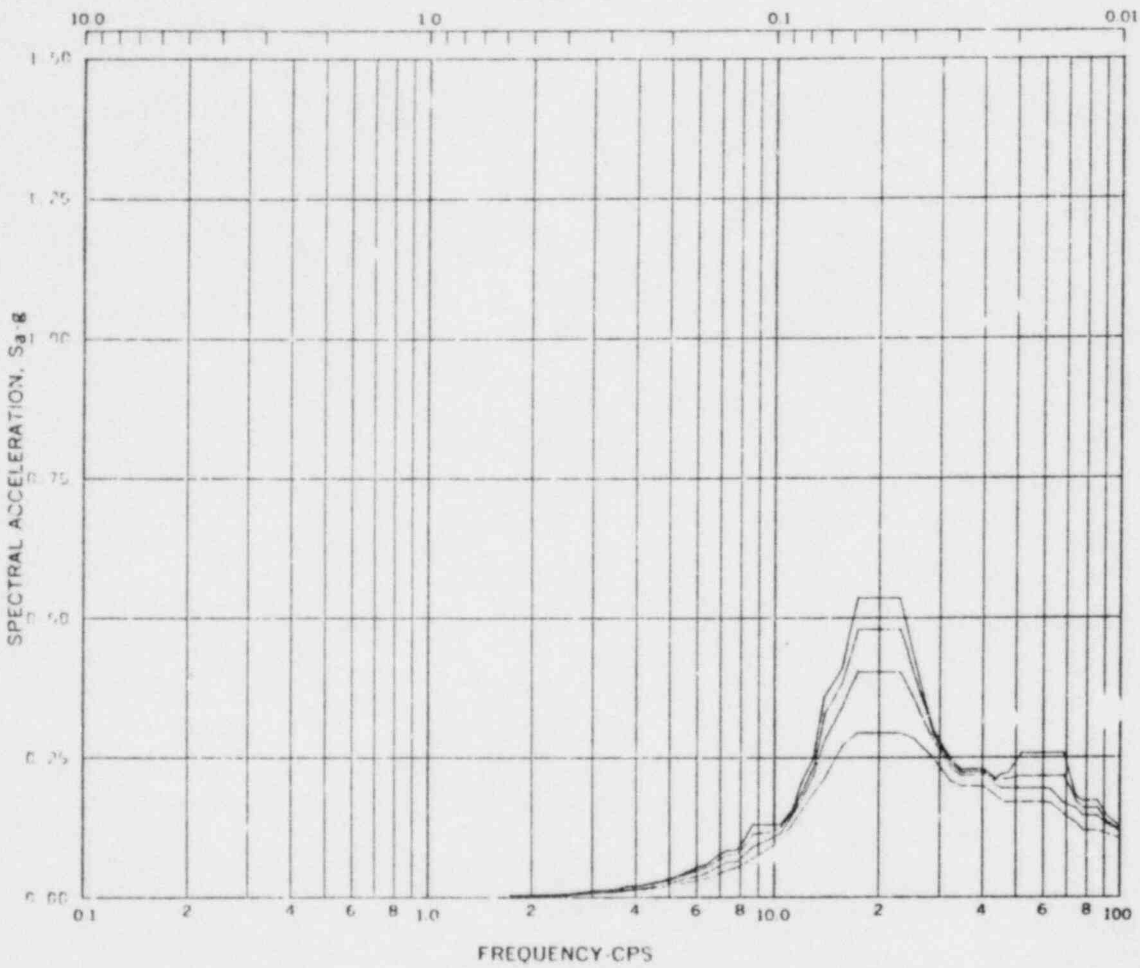
Node: 131 Direction: VERT Elev: 205'-11" Angle: 0°

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
SRV AXISYMMETRIC
DIRECTION Z

FIGURE A.2-8



Acceleration Spectra for WETWELL WALL

Load Case: SRV - AXISYMMETRIC

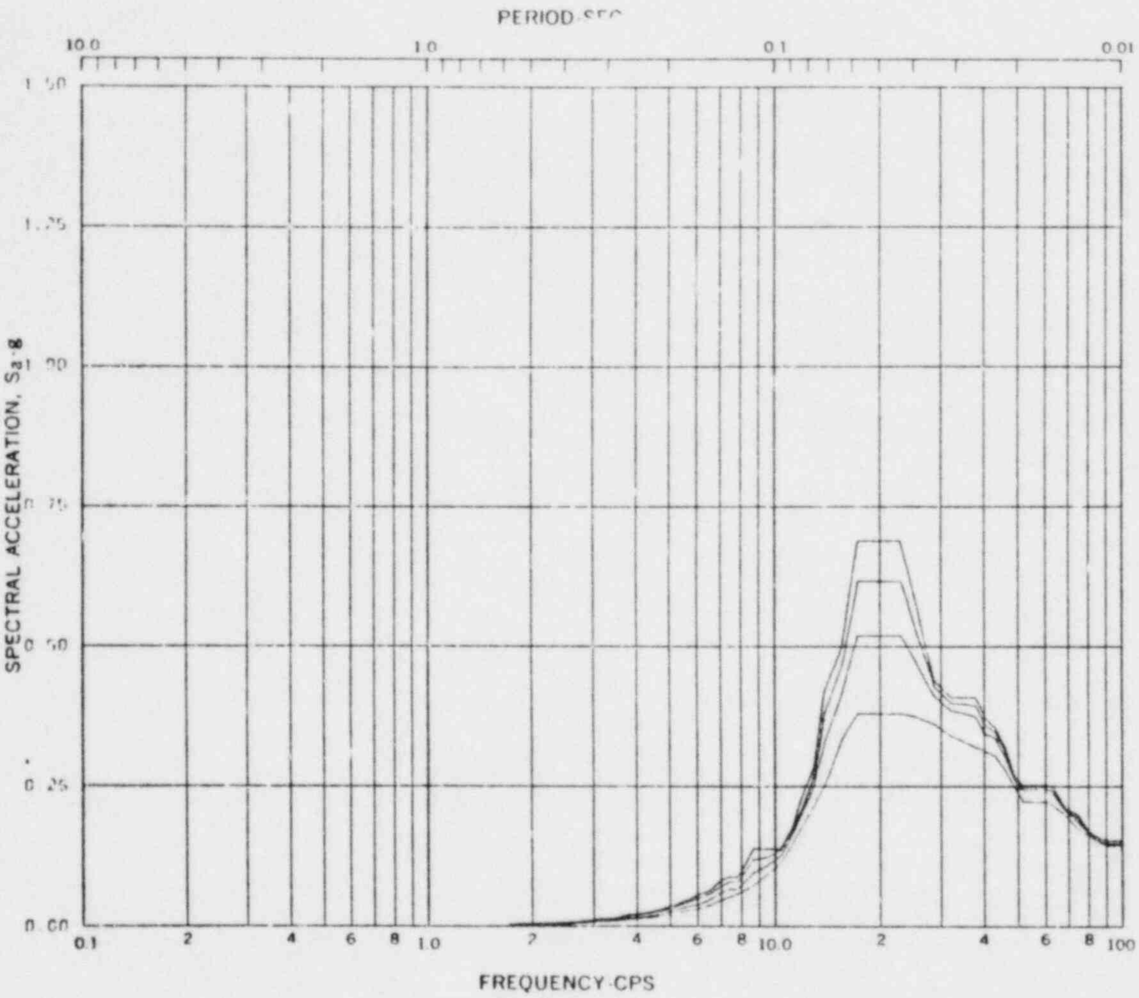
Node: 291 Direction: VERT Elev: 236'-2" Angle: 0°

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
SRV AXISYMMETRIC
DIRECTION Z

FIGURE A.2-9



Acceleration Spectra for DRYWELL WALL

Load Case: SRV - AXISYMMETRIC

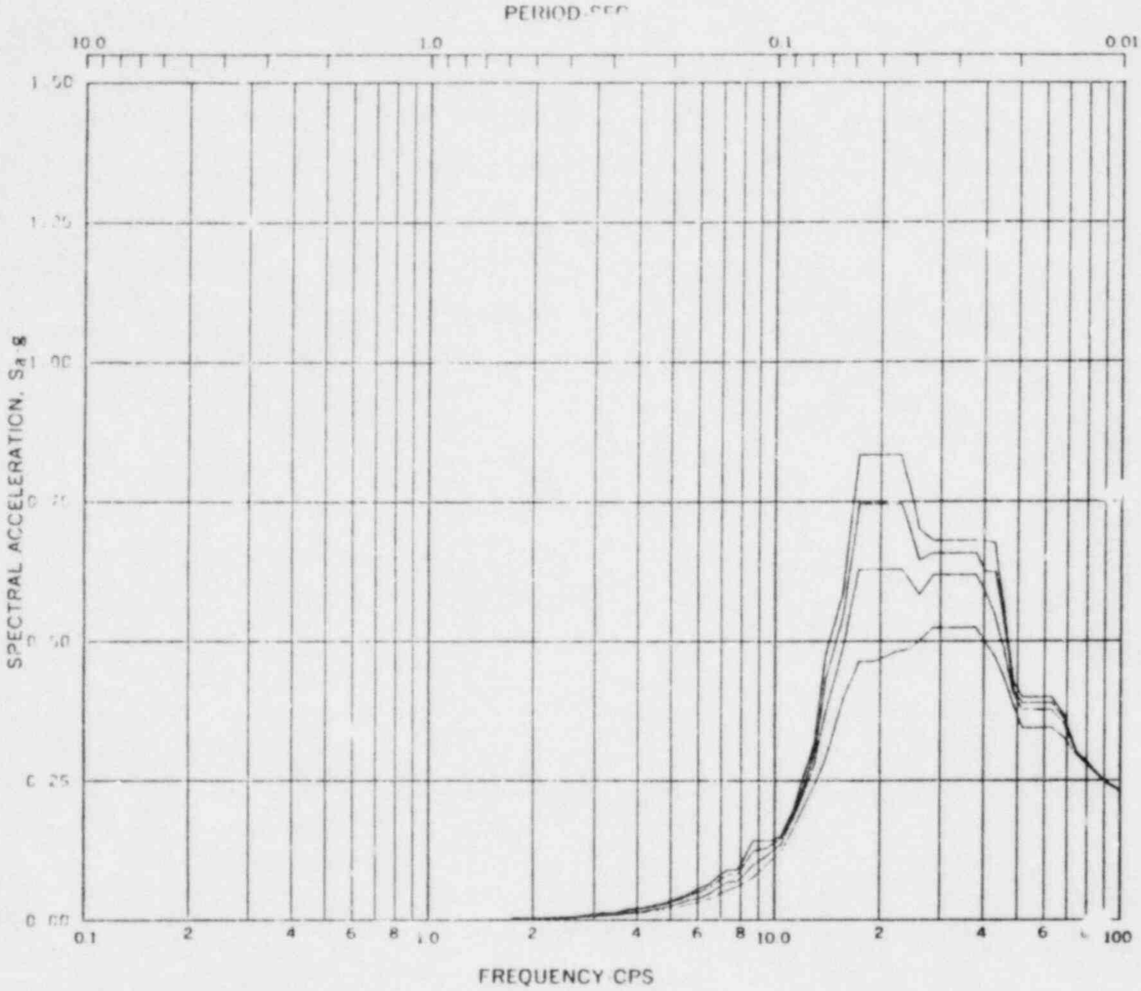
Node: 331 Direction: VERT Elev: 264'-6" Angle: 0°

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
SRV AXISYMMETRIC
DIRECTION Z

FIGURE A.2-10



Acceleration Spectra for DRYWELL WALL

Load Case: SRV - AXISYMMETRIC

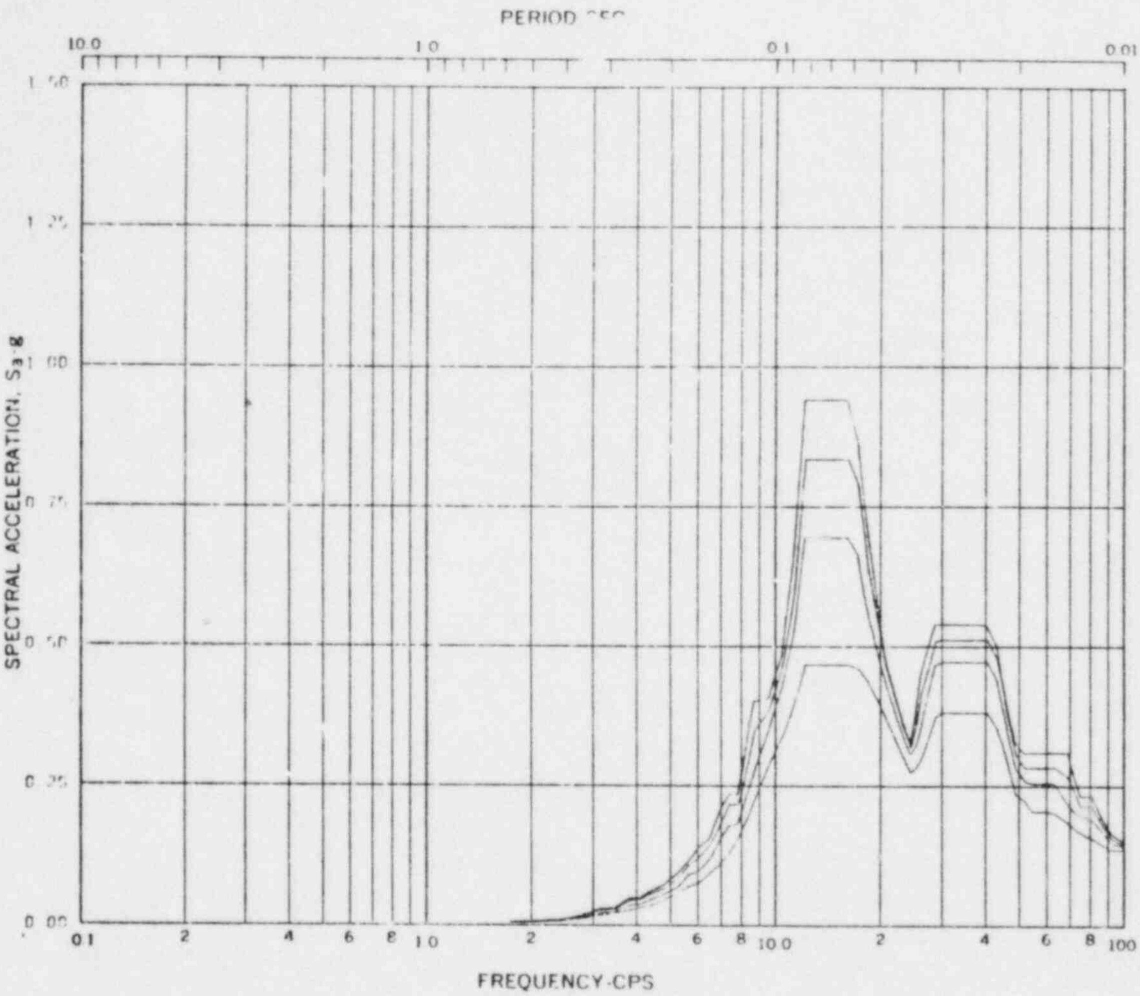
Node: 431 Direction: VERT Elev: 325'-8" Angle: 0°

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
SRV AXISYMMETRIC
DIRECTION Z

FIGURE A.2-11



Acceleration Spectra for PEDESTAL

Load Case: SRV - AXISYMMETRIC

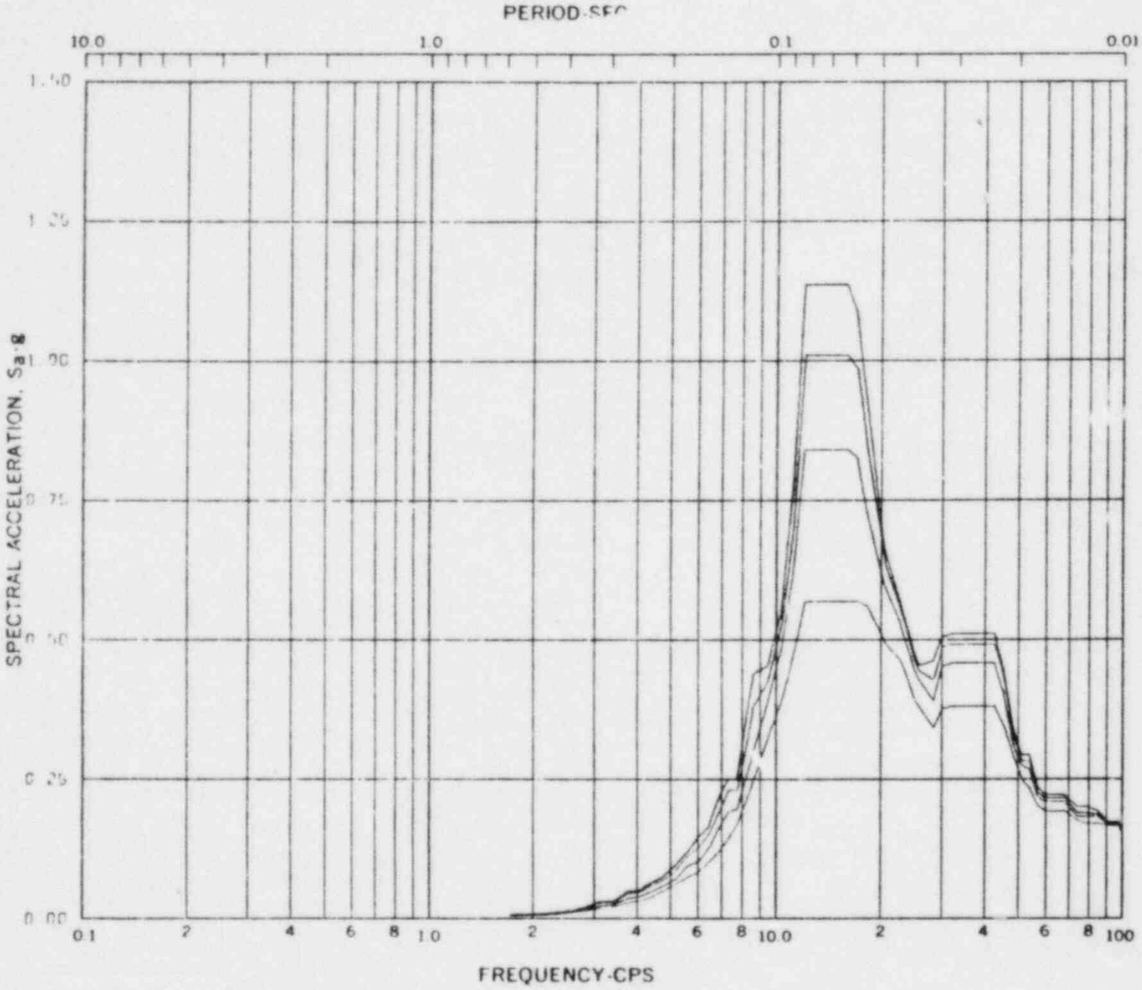
Node: 211 Direction: VERT Elev: 236'-2" Angle: 0°

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
SRV AXISYMMETRIC
DIRECTION Z

FIGURE A.2-12



Acceleration Spectra for PEDESTAL

Load Case: SRV - AXISYMMETRIC

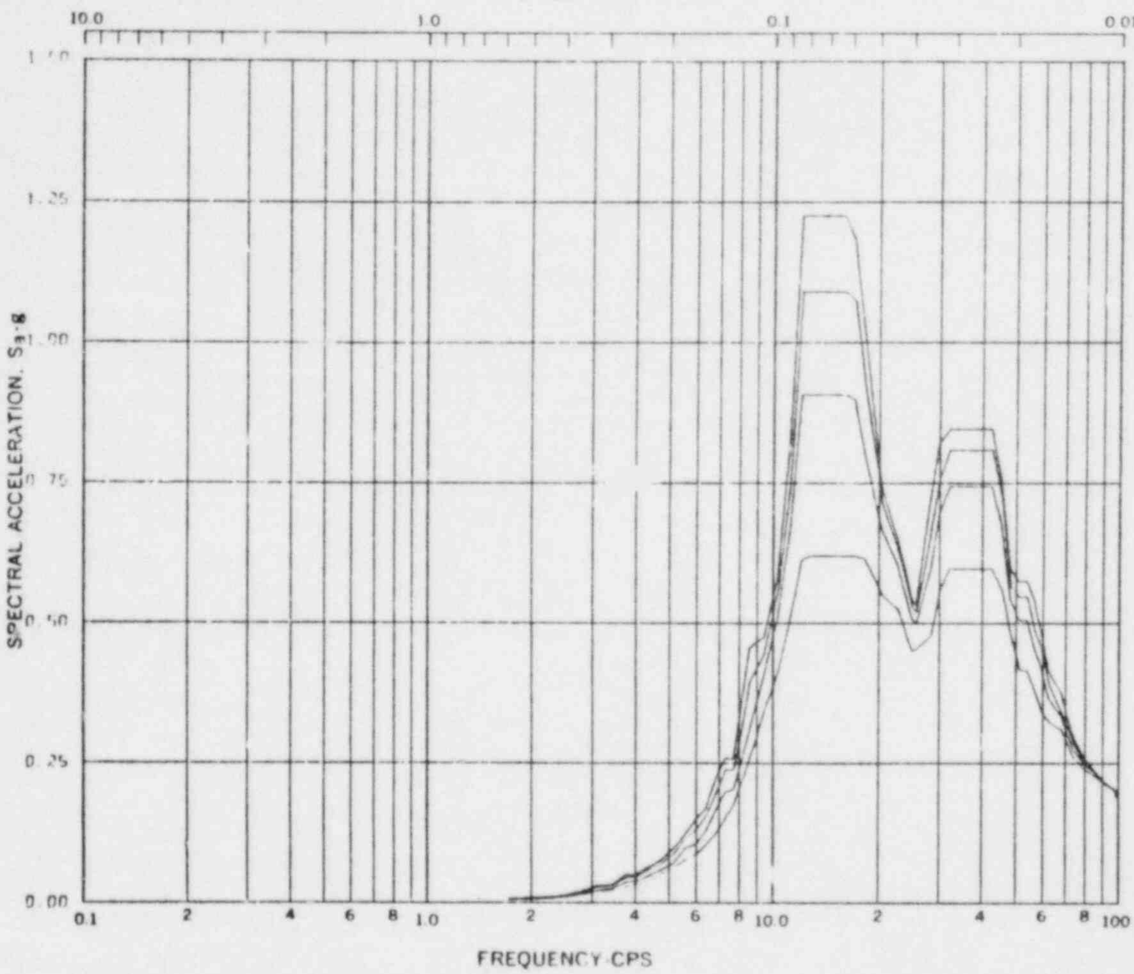
Node: 531 Direction: VERT Elev: 263'-8 5/8" Angle: 0°

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
SRV AXISYMMETRIC
DIRECTION Z

FIGURE A.2-13



Acceleration Spectra for SHIELD WALL

Load Case: SRV - AXISYMMETRIC

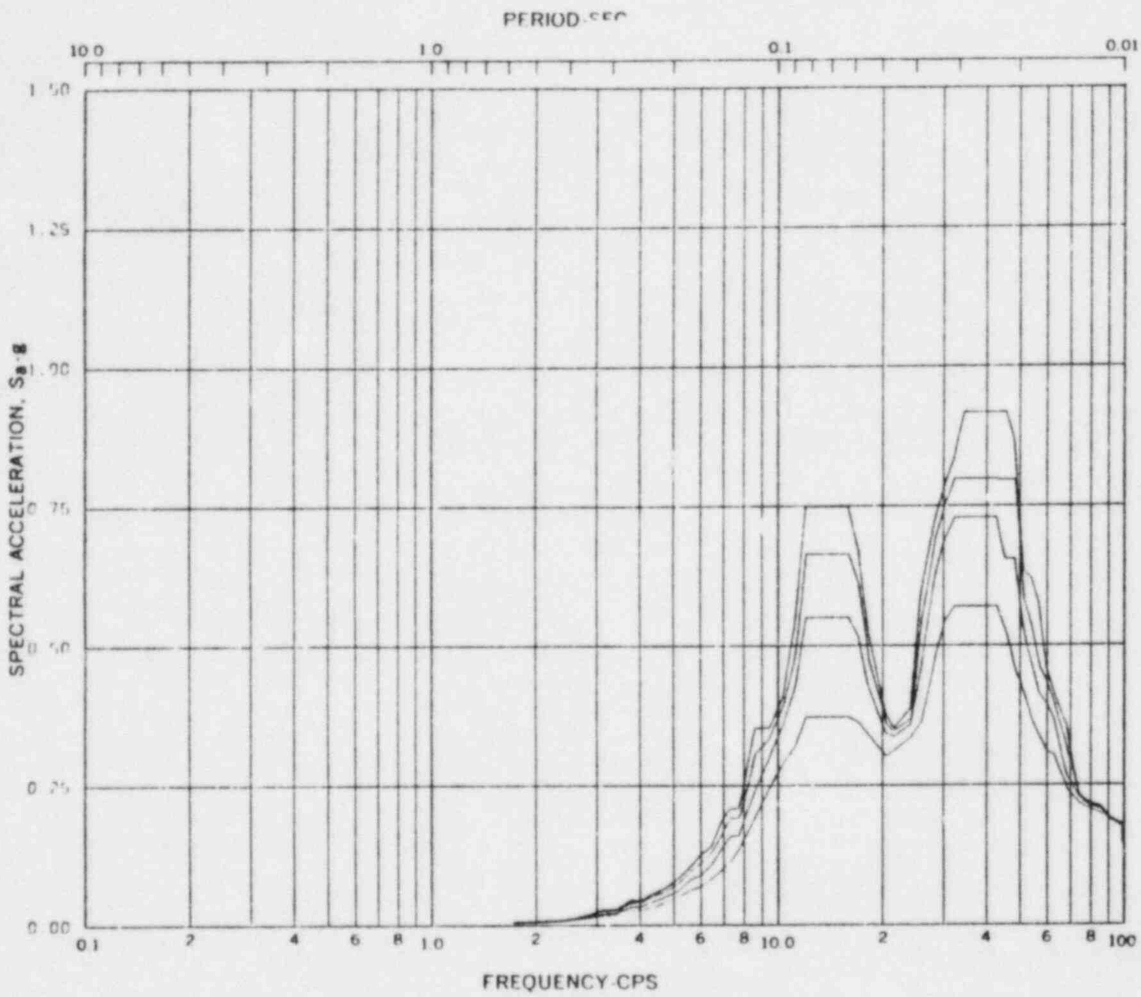
Node: 841 Direction: VERT Elev: 312'-8" Angle: 0°

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
SRV AXISYMMETRIC
DIRECTION Z

FIGURE A.2-14



Acceleration Spectra for DIAPHRAGM SLAB

Load Case: SRV - AXISYMMETRIC

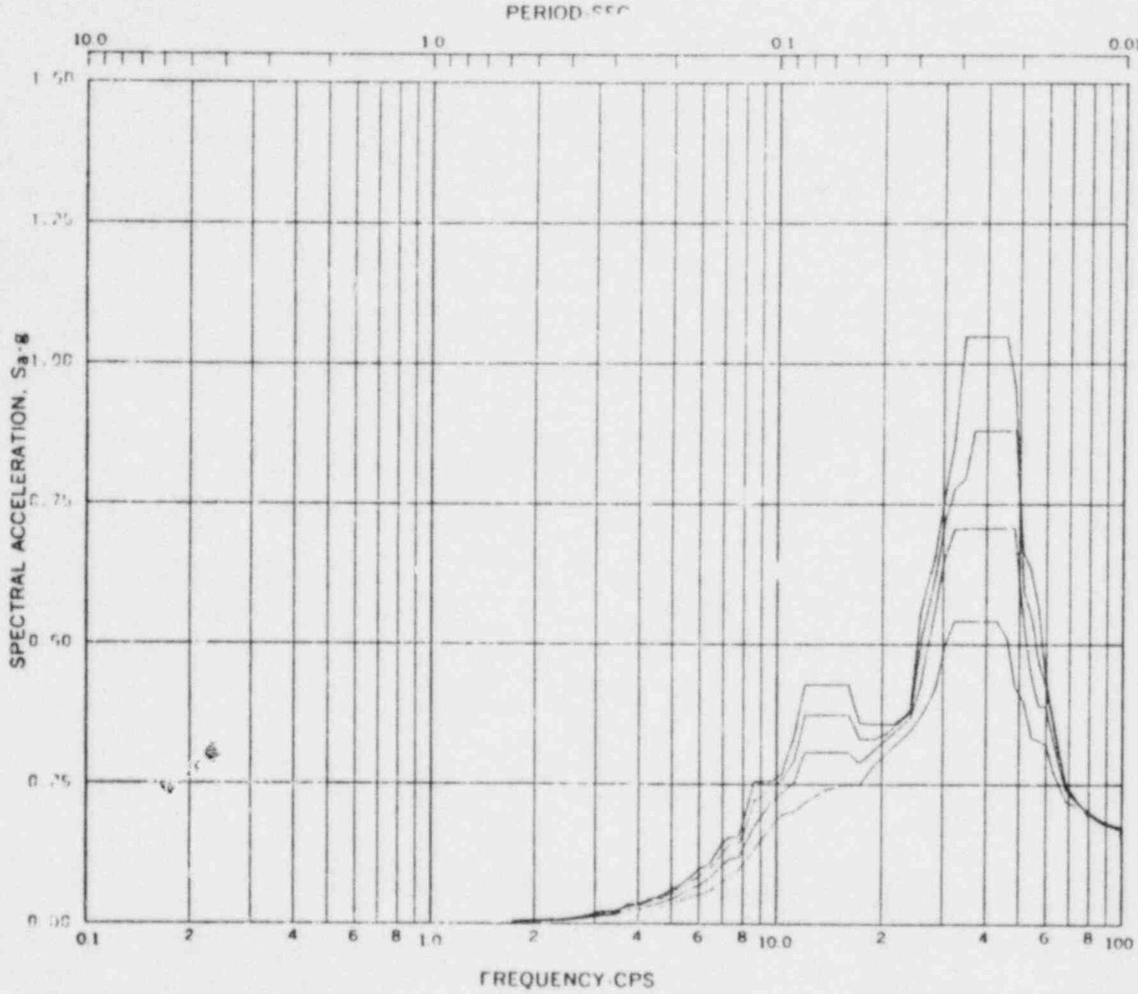
Node: 231 Direction: VERT Elev: 236'-2" Angle: 0°

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
SRV AXISYMMETRIC
DIRECTION Z

FIGURE A.2-15



Acceleration Spectra for DIAPHRAGM SLAB

Load Case: SRV - AXISYMMETRIC

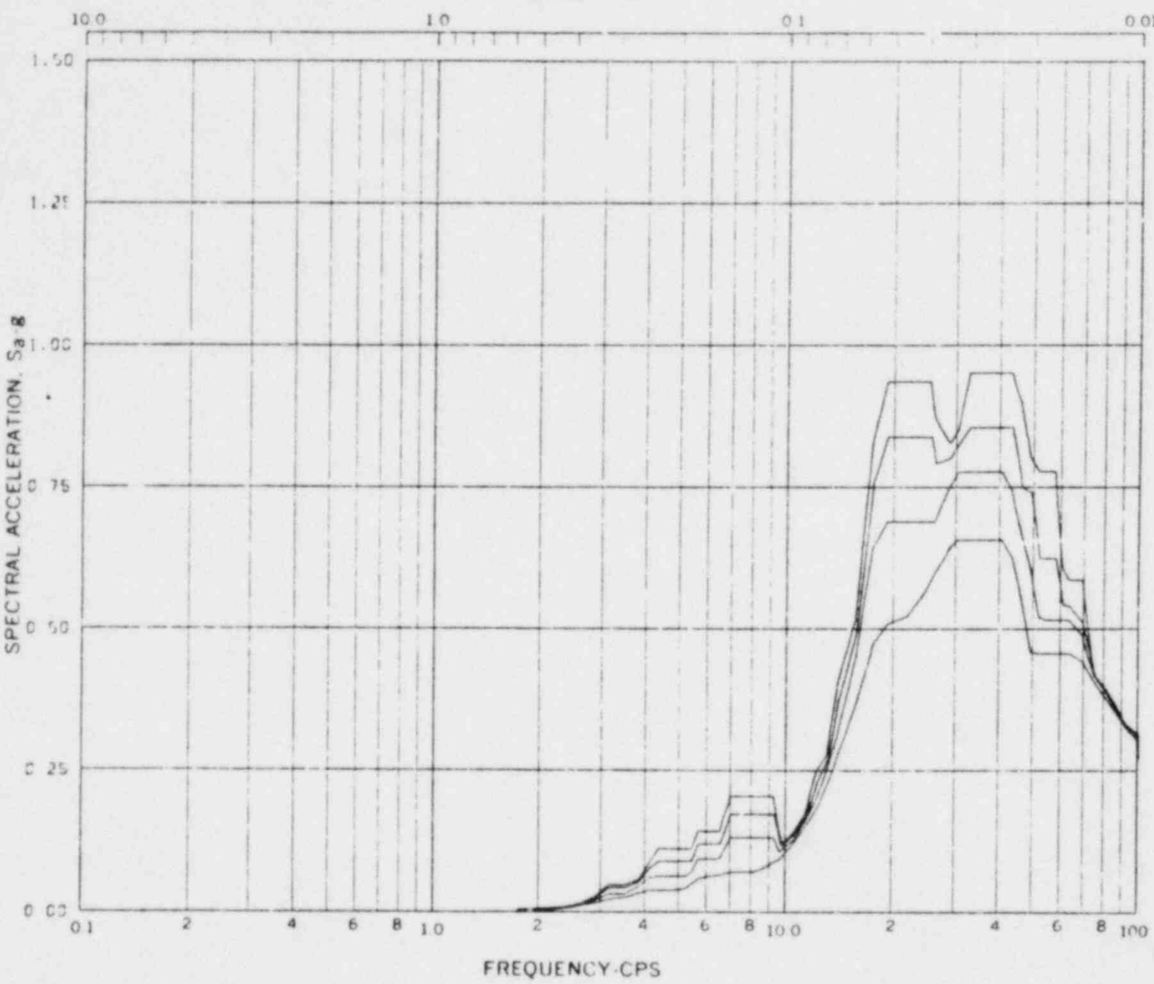
Node: 252 Direction: VERT Elev: 236'-2" Angle: 22°-30'

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
SRV AXISYMMETRIC
DIRECTION Z

FIGURE A.2-16



Acceleration Spectra for WETWELL WALL

Load Case: SRV - ASYMMETRIC

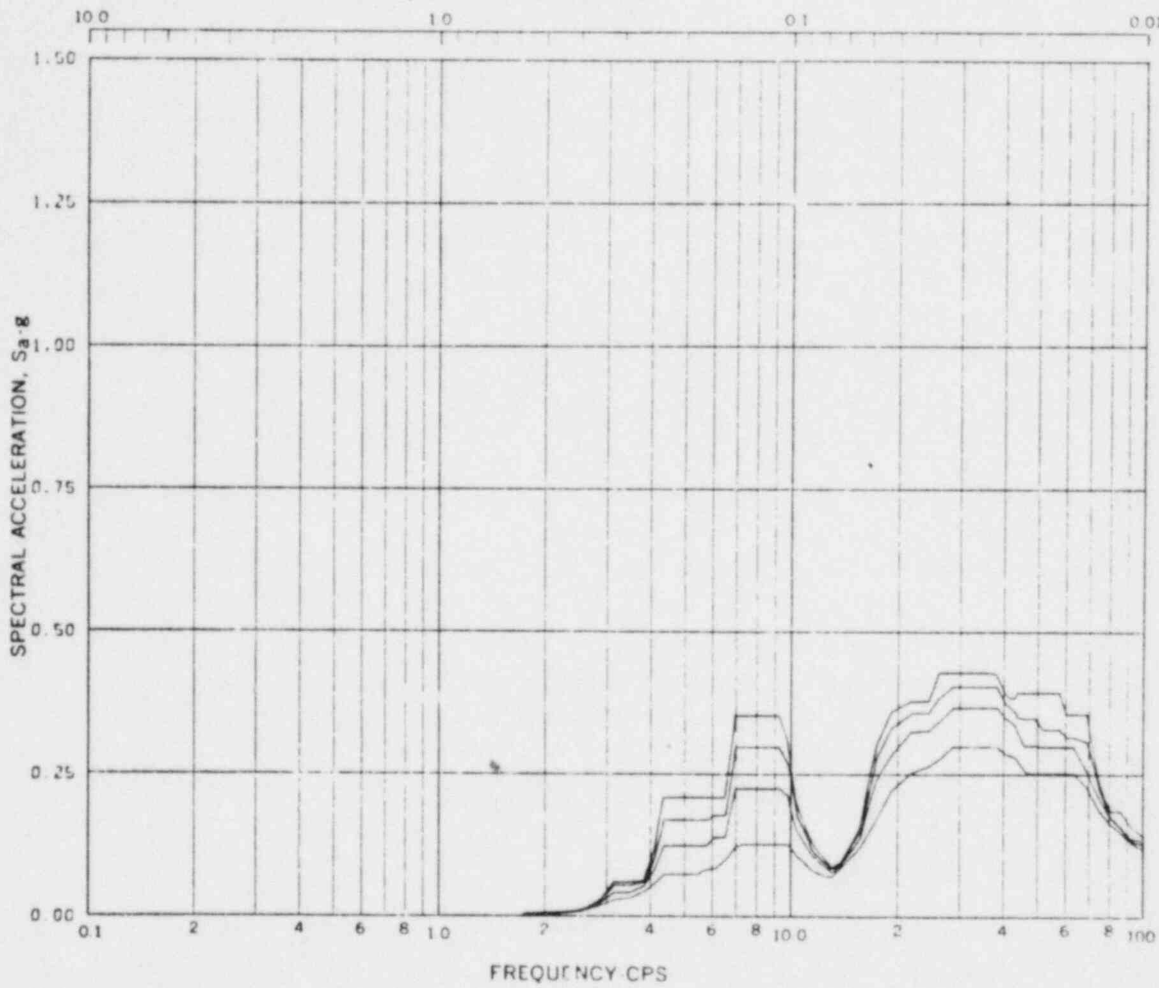
Node: 131 Direction: HORIZ Elev: 205'-11" Angle: 0°

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
SRV AXISYMMETRIC
DIRECTION X

FIGURE A.2-17



Acceleration Spectra for WETWELL WALL

Load Case: SRV - ASYMMETRIC

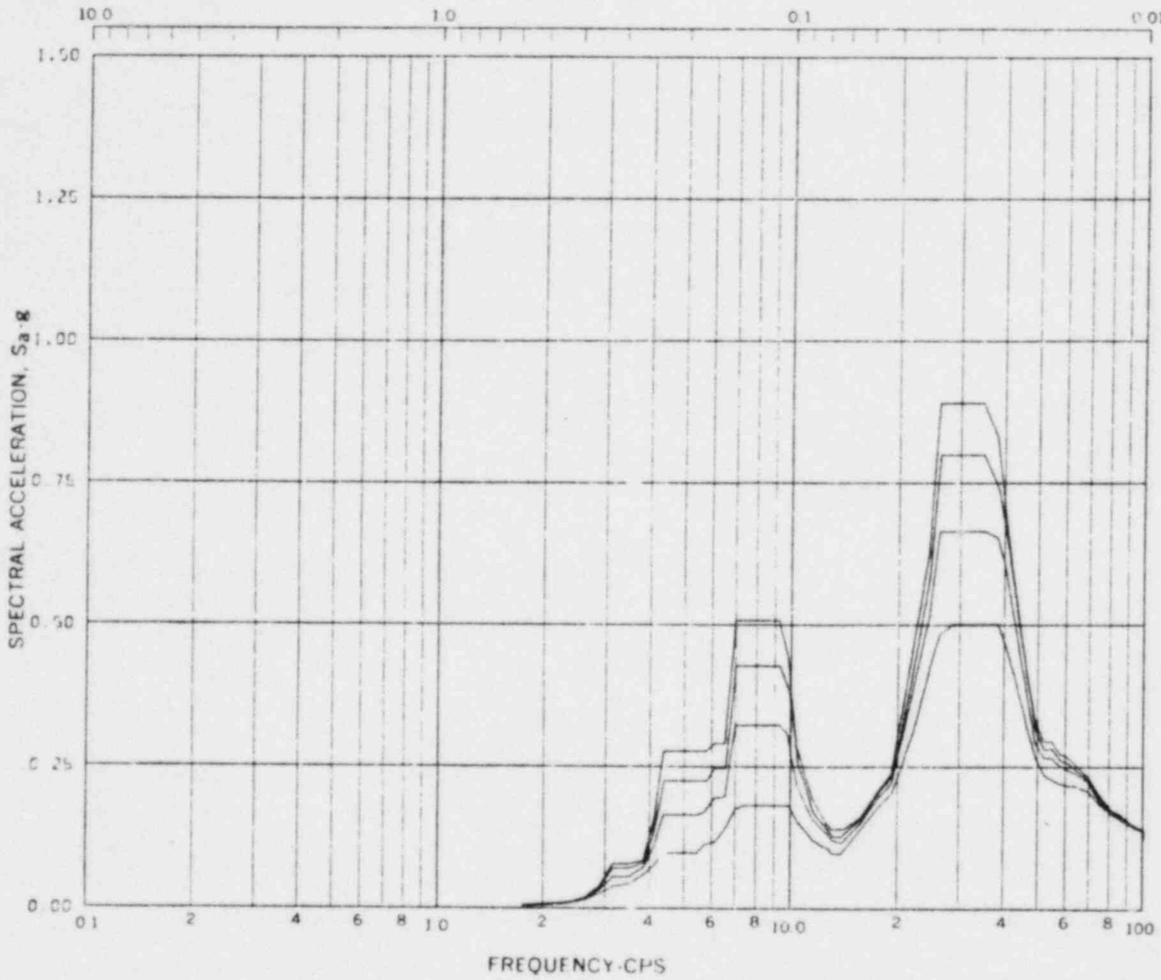
Node: 291 Direction: HORIZ Elev: 236'-2" Angle: 0°

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
SRV ASYMMETRIC
DIRECTION X

FIGURE A.2-18



Acceleration Spectra for DRYWELL WALL

Load Case: SRV - ASYMMETRIC

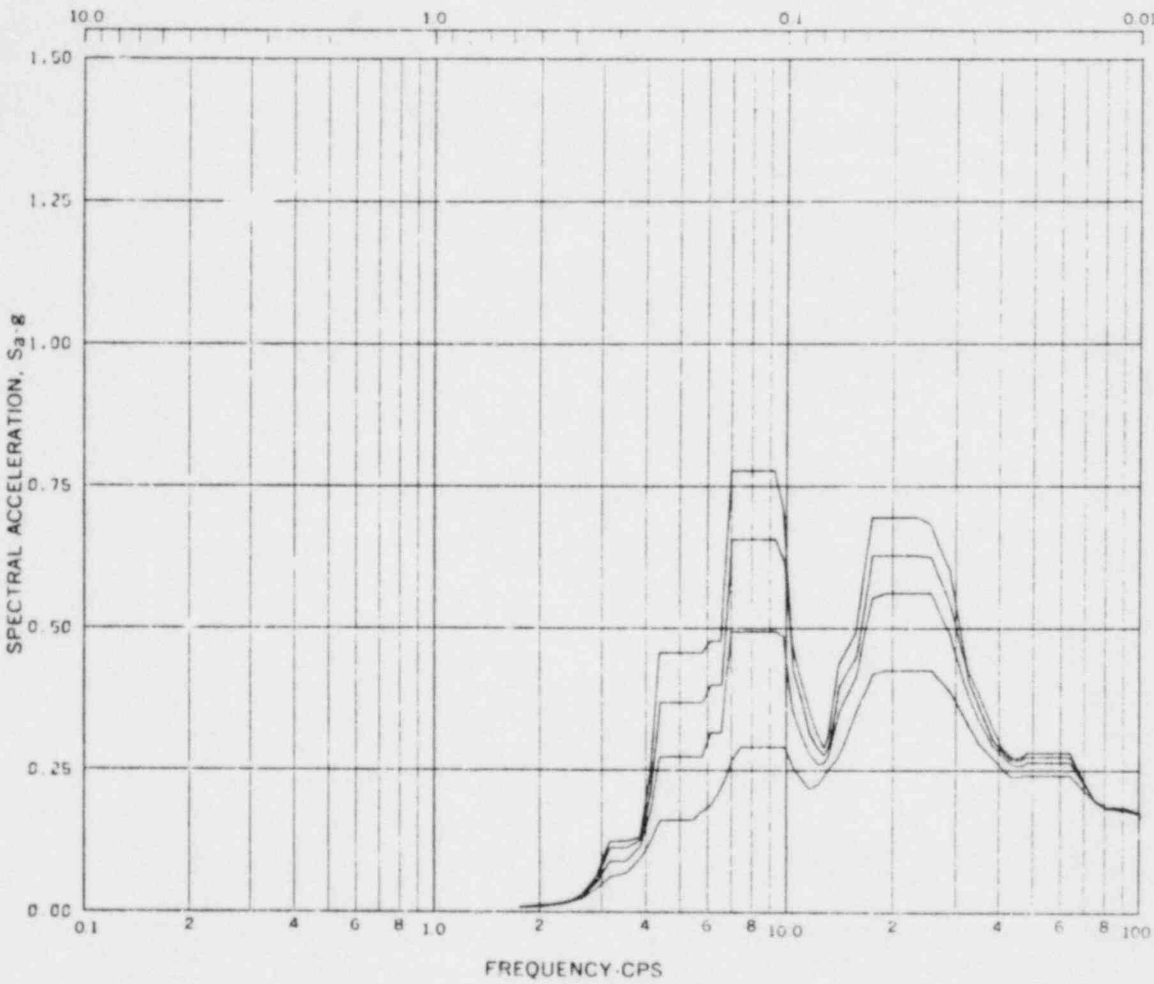
Node: 331 Direction: HORIZ Elev: 264'-6" Angle: 0°

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
SRV ASYMMETRIC
DIRECTION X

FIGURE A.2-19



Acceleration Spectra for DRYWELL WALL

Load Case: SRV - ASYMMETRIC

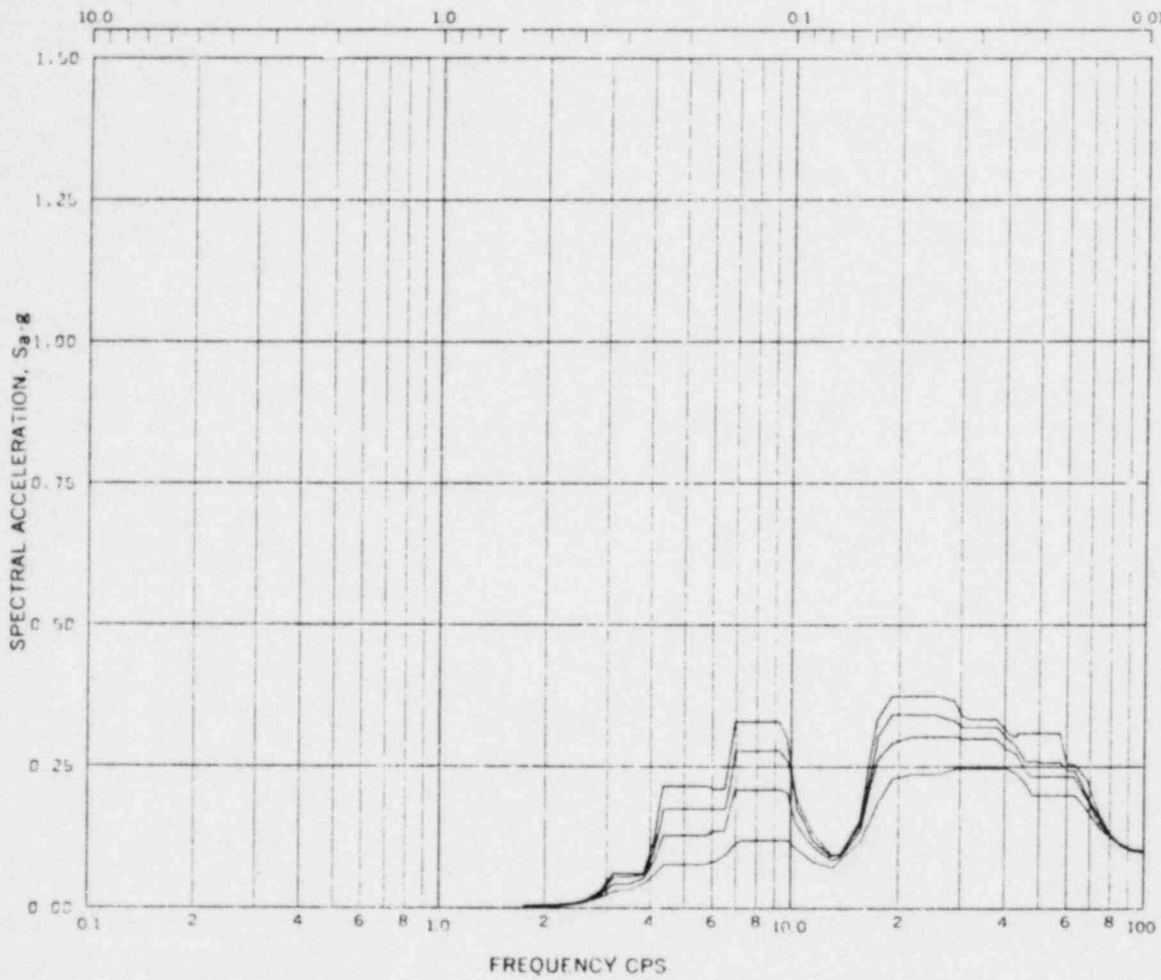
Node: 431 Direction: HORIZ Elev: 325'-8" Angle: 0°

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
SRV ASYMMETRIC
DIRECTION X

FIGURE A.2-20



Acceleration Spectra for PEDESTAL

Load Case: SRV - ASYMMETRIC

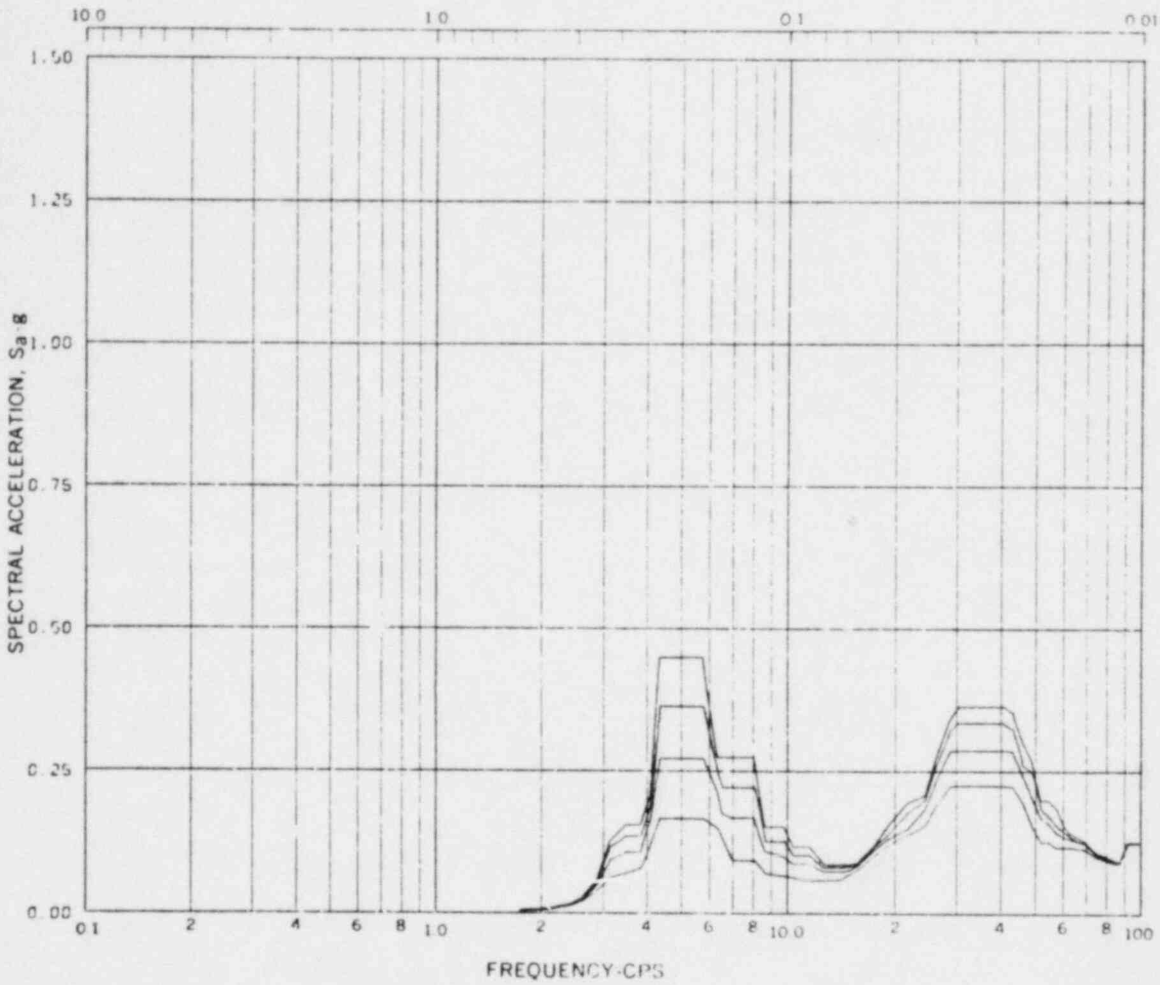
Node: 211 Direction: HORIZ Elev: 236'-2" Angle: 0°

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
SRV ASYMMETRIC
DIRECTION X

FIGURE A.2-21



Acceleration Spectra for PEDESTAL

Load Case: SRV - ASYMMETRIC

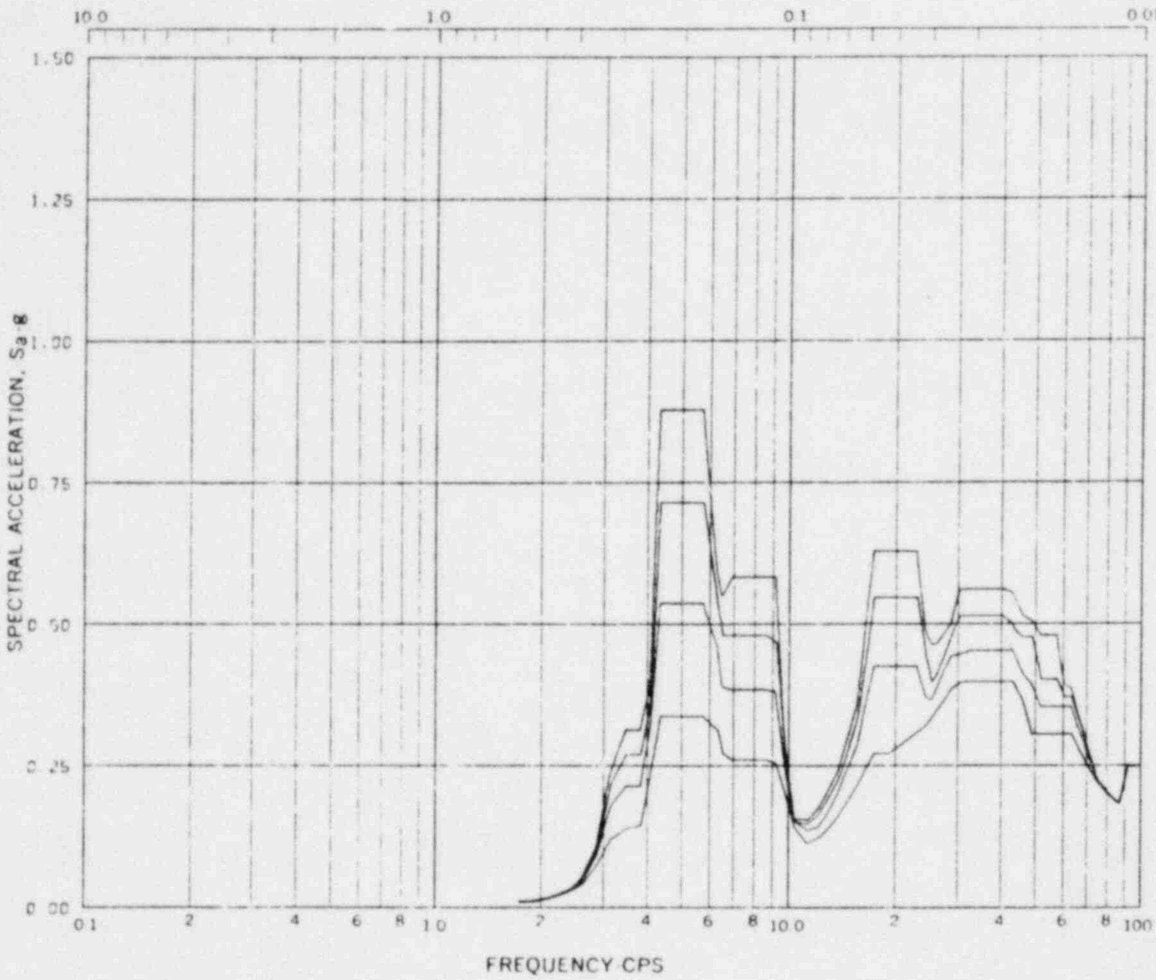
Node: 531 Direction: HORIZ Elev: 263'-8 5/8" Angle: 0°

Damping: 0.005, 0.01, 0.02, 0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
SRV ASYMMETRIC
DIRECTION X

FIGURE A.2-22



Acceleration Spectra for SHIELD WALL

Load Case: SRV - ASYMMETRIC

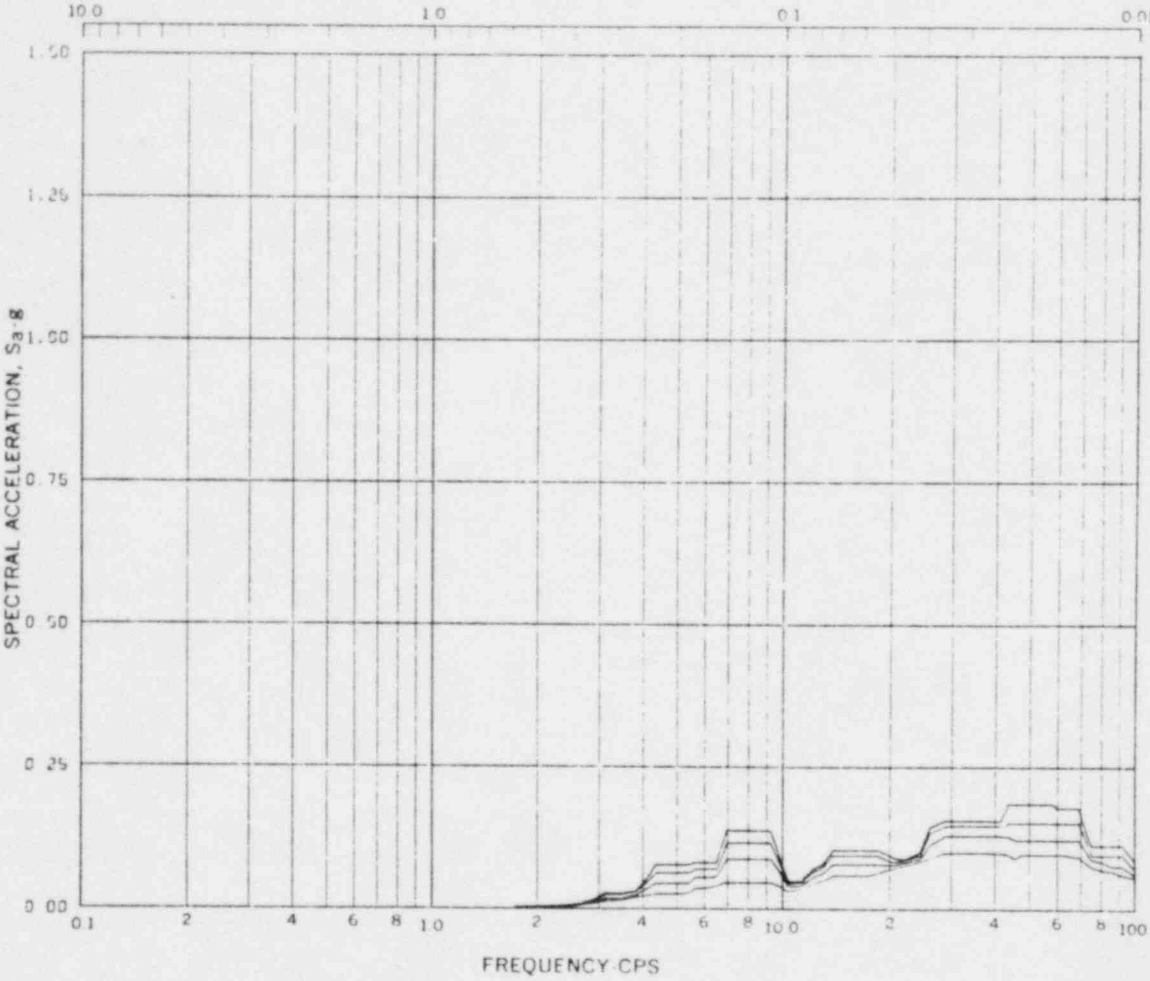
Node: 841 Direction: HORIZ Elev: 312'-8" Angle: 0°

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
SRV ASYMMETRIC
DIRECTION X

FIGURE A.2-23



Acceleration Spectra for WETWELL WALL

Load Case: SRV - ASYMMETRIC

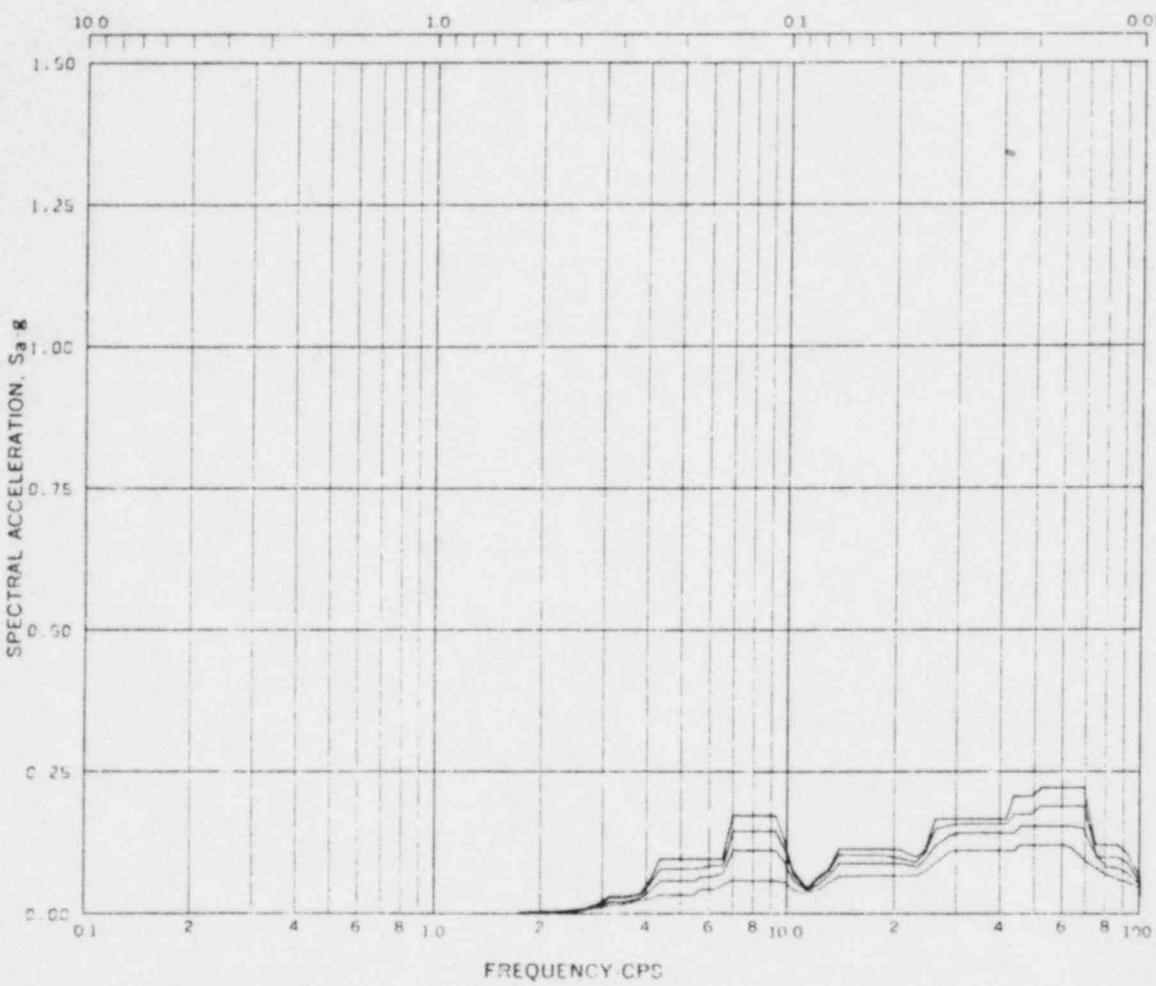
Node: 131 Direction: VERT Elev: 205'-11" Angle: 0°

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
SRV ASYMMETRIC
DIRECTION Z

FIGURE A.2-24



Acceleration Spectra for WETWELL WALL

Load Case: SRV - ASYMMETRIC

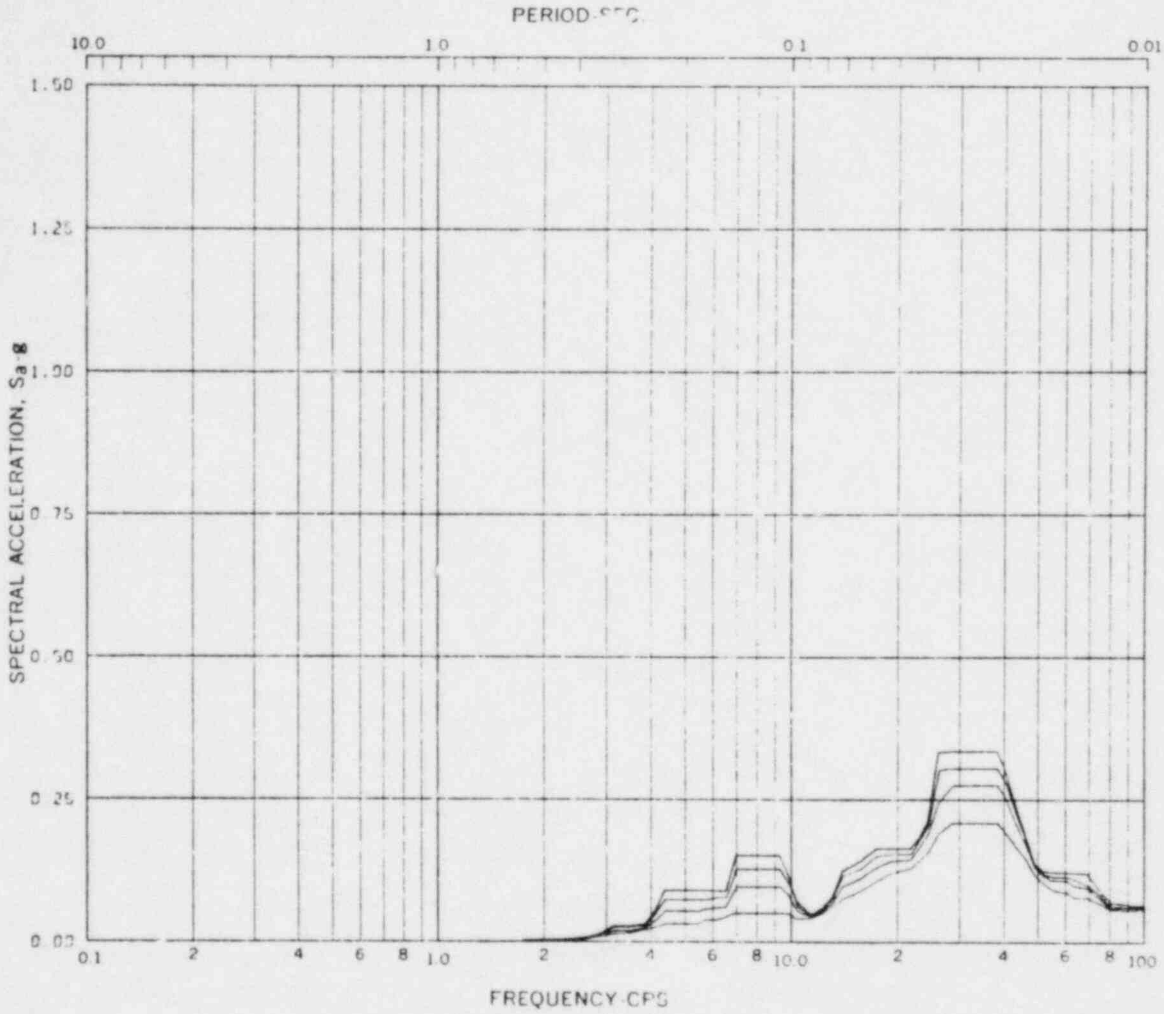
Node: 291 Direction: VERT Elev: 236'-2" Angle: 0°

Damping: 0.005, 0.01, 0.02, 0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
SRV ASYMMETRIC
DIRECTION Z

FIGURE A.2-25



Acceleration Spectra for DRYWELL WALL

Load Case: SRV - ASYMMETRIC

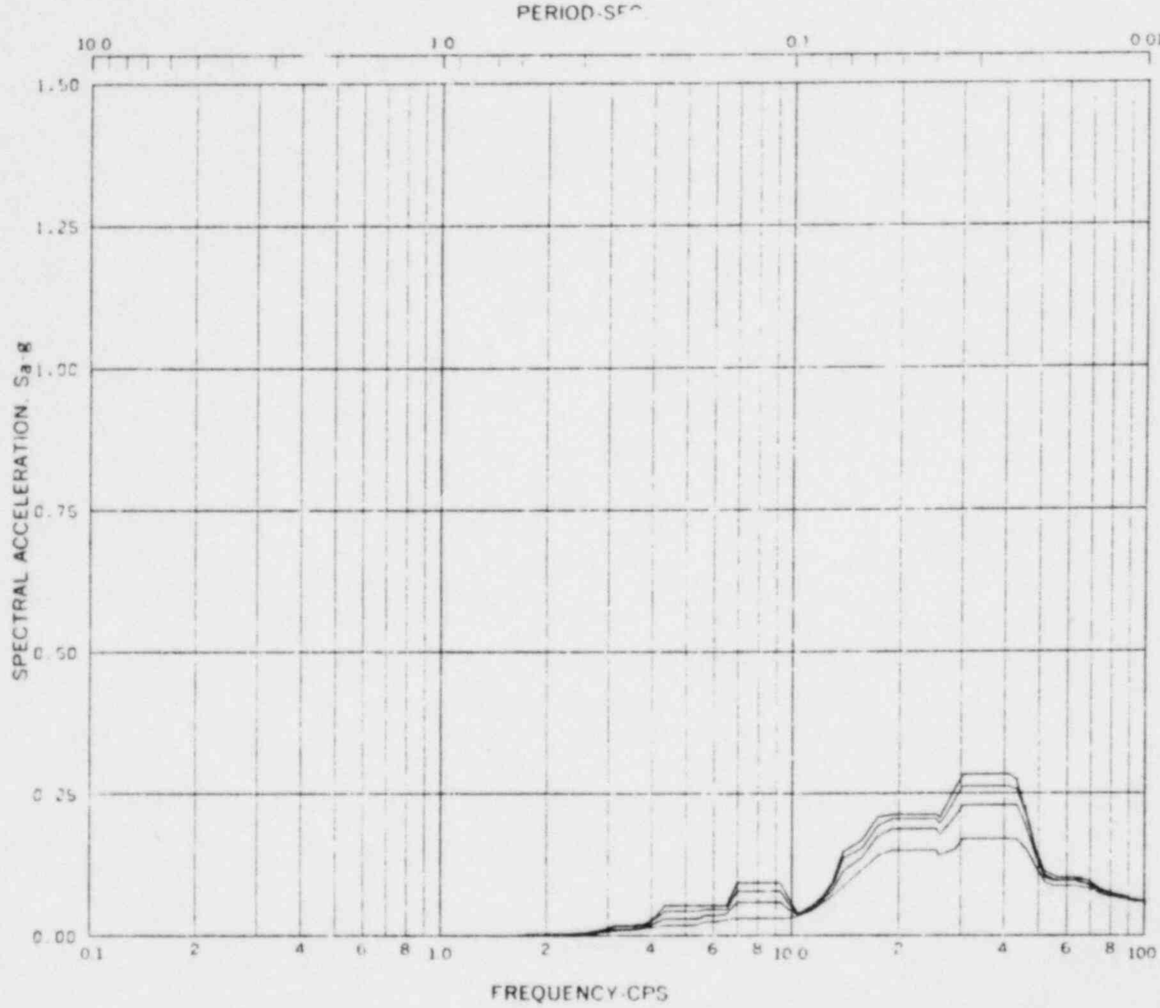
Node: 331 Direction: VERT Elev: 264'-6" Angle: 0°

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
SRV ASYMMETRIC
DIRECTION Z

FIGURE A.2-26



Acceleration Spectra for DRYWELL WALL

Load Case: SRV - ASYMMETRIC

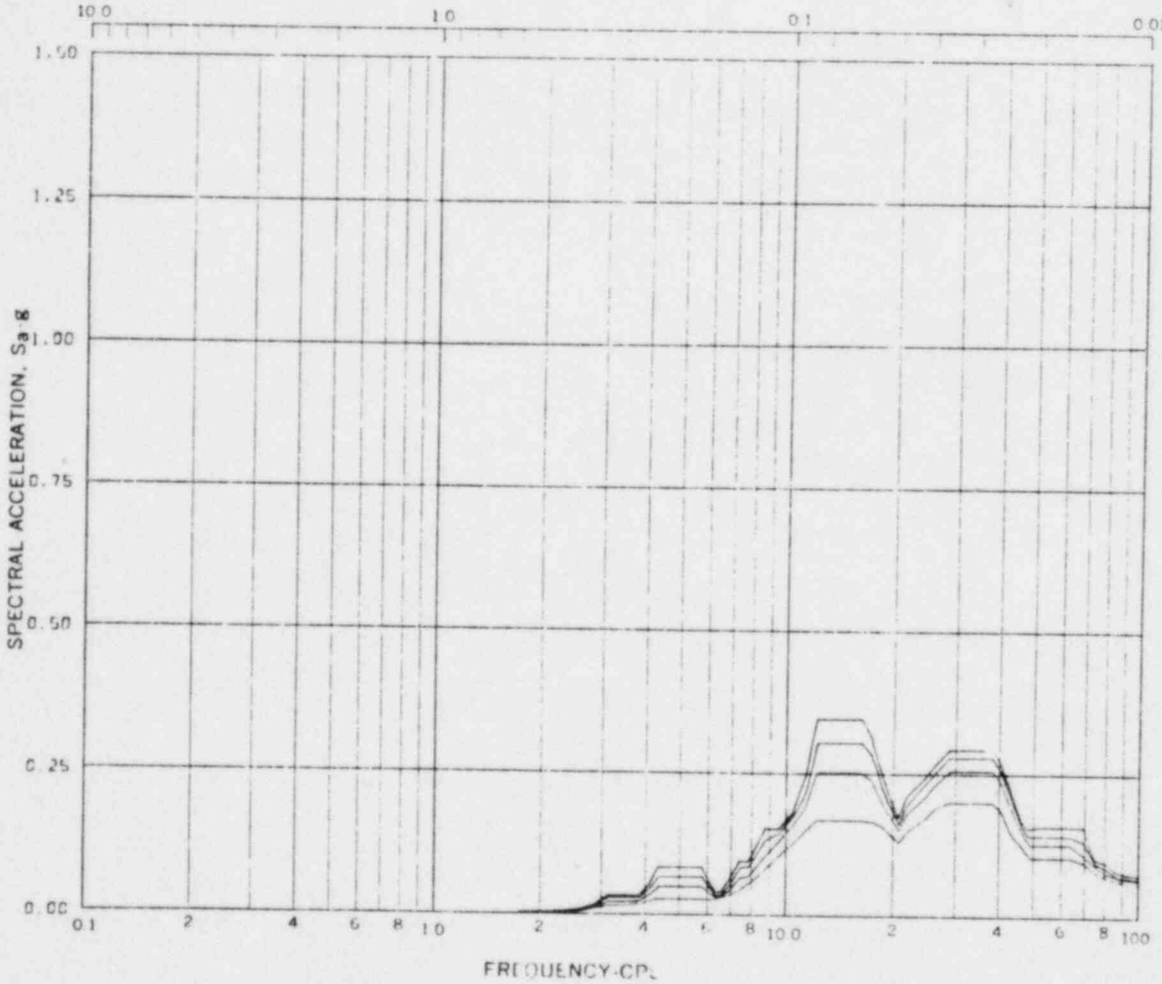
Node: 431 Direction: VERT Elev: 325'-8" Angle: 0°

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
SRV ASYMMETRIC
DIRECTION Z

FIGURE A.2-27



Acceleration Spectra for PEDESTAL

Load Case: SRV - ASYMMETRIC

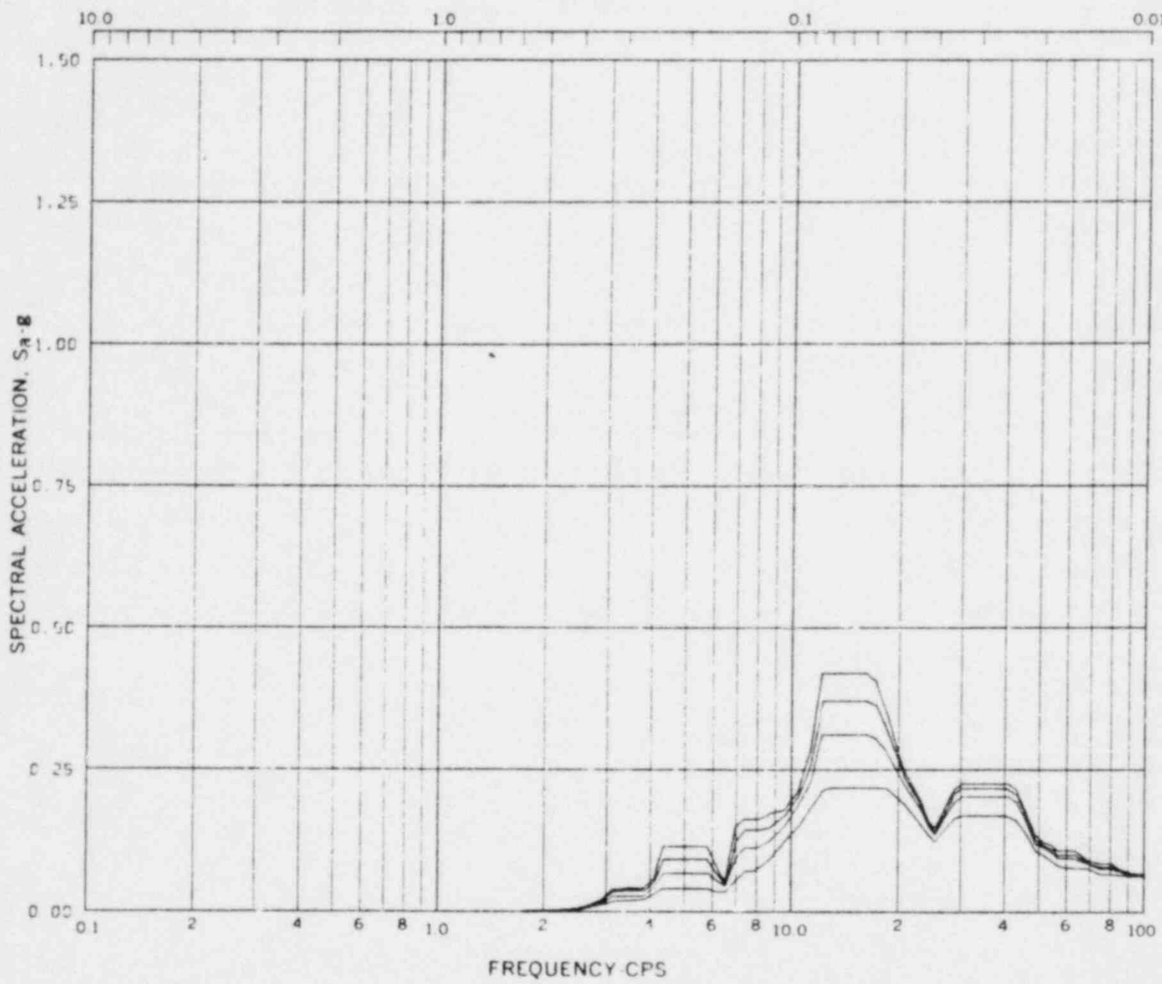
Node: 211 Direction: VERT Elev: 236'-2" Angle: 0°

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
SRV ASYMMETRIC
DIRECTION Z

FIGURE A.2-28



Acceleration Spectra for PEDESTAL

Load Case: SRV - ASYMMETRIC

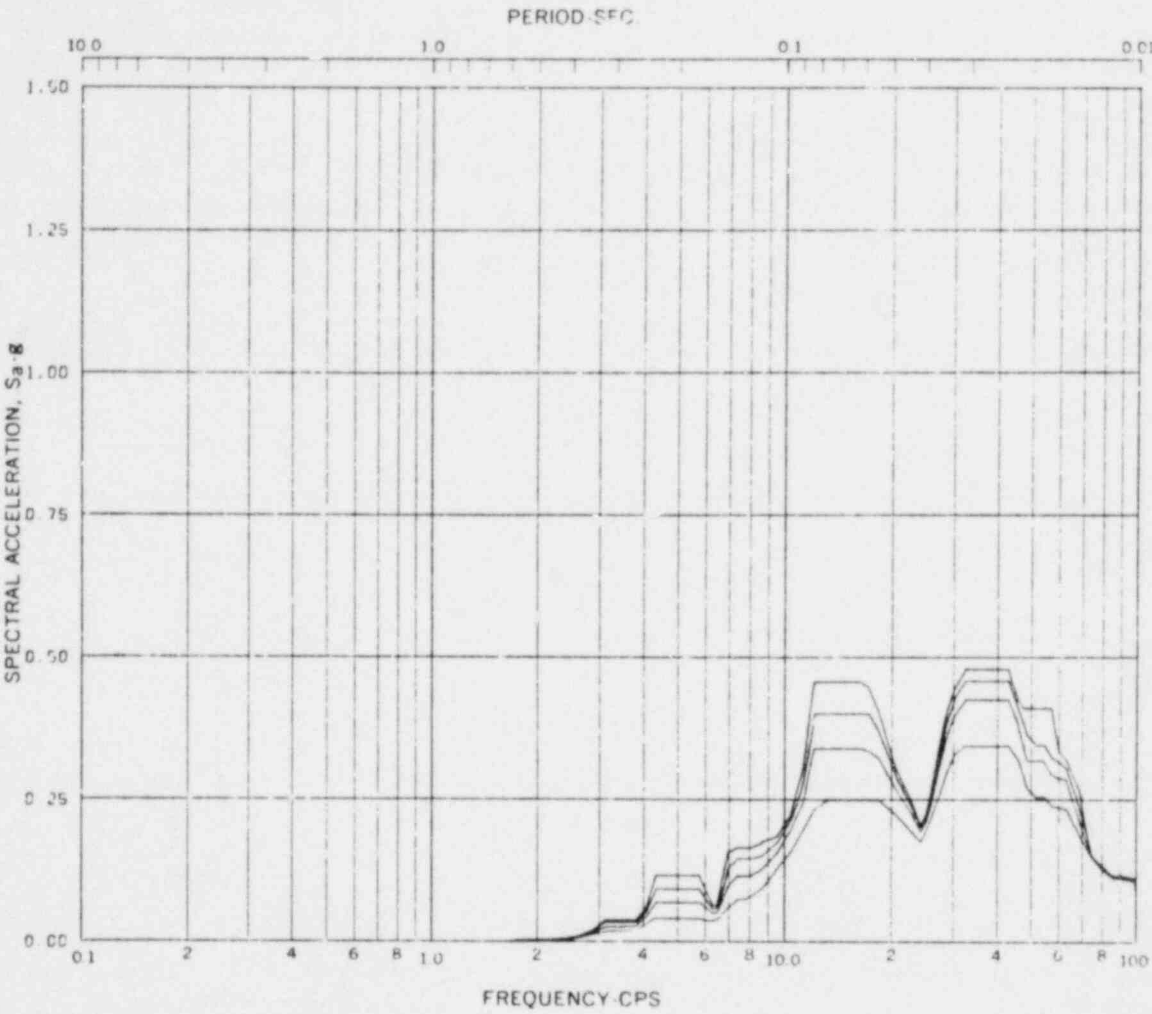
Node: 531 Direction: VERT Elev: 263'-8 5/8" Angle: 0°

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
SRV ASYMMETRIC
DIRECTION Z

FIGURE A.2-29



Acceleration Spectra for SHIELD WALL

Load Case: SRV - ASYMMETRIC

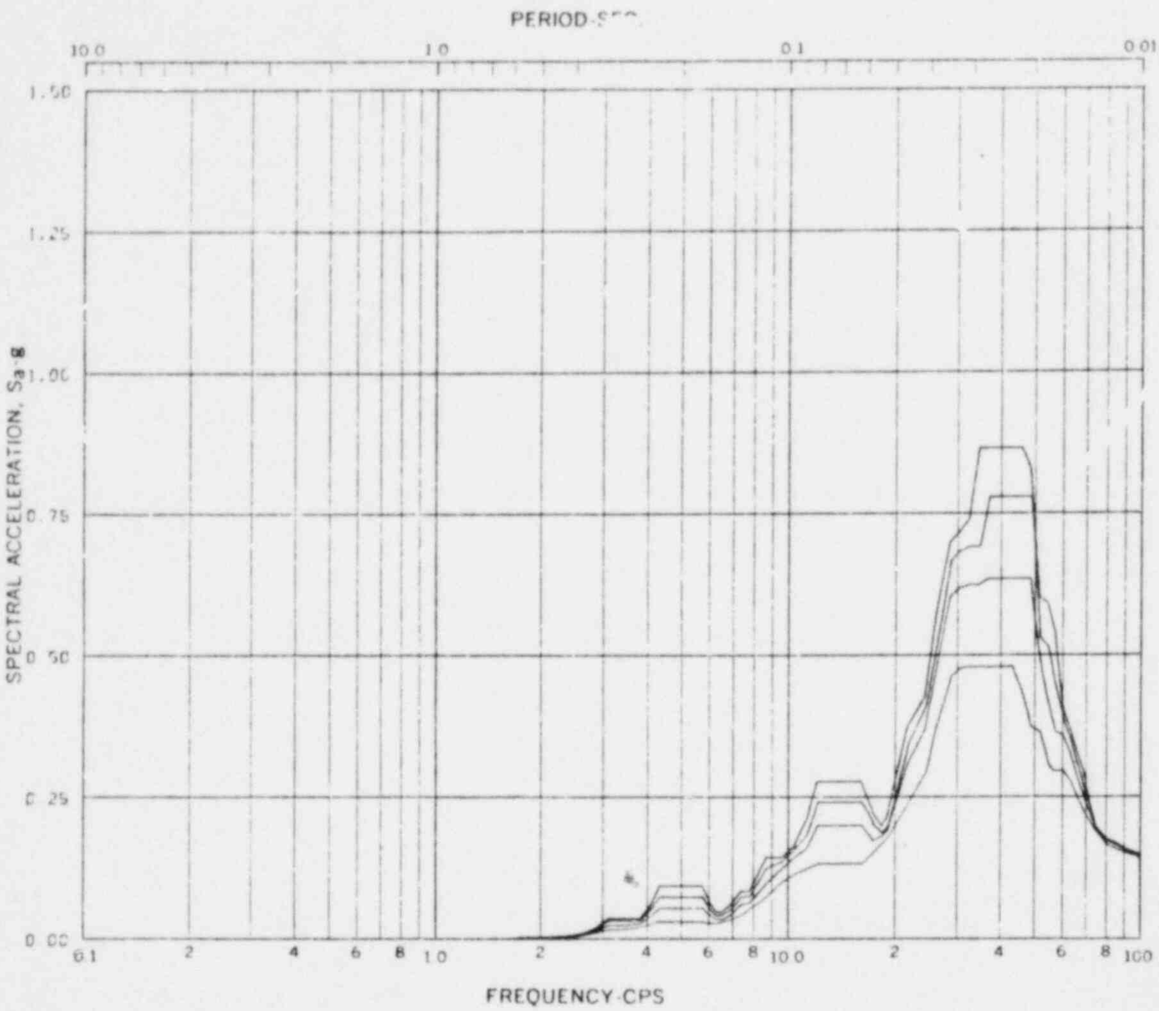
Node: 841 Direction: VERT Elev: 312'-8" Angle: 0°

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
SRV ASYMMETRIC
DIRECTION Z

FIGURE A.2-30



Acceleration Spectra for DIAPHRAGM SLAB

Load Case: SRV - ASYMMETRIC

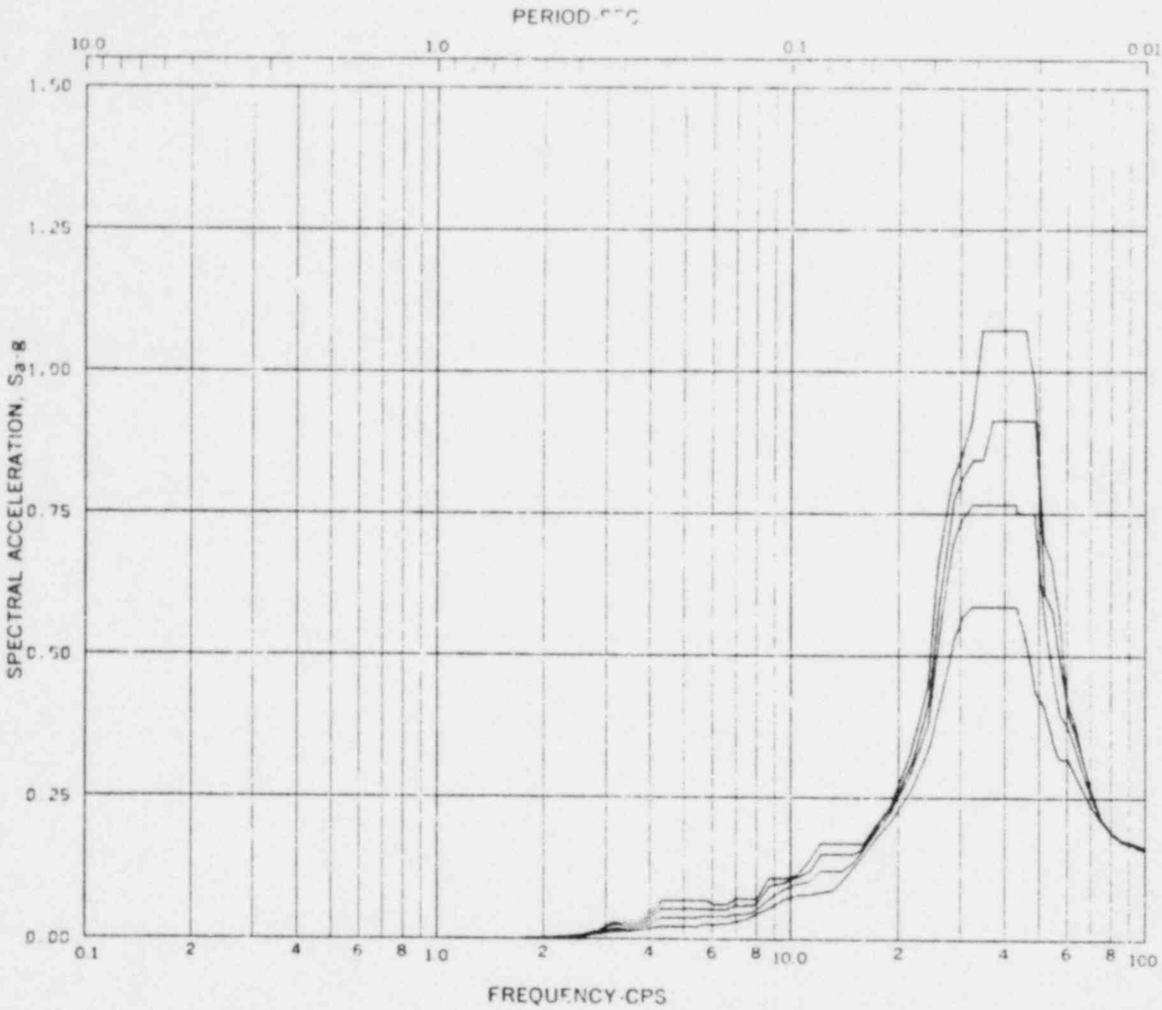
Node: 231 Direction: VERT Elev: 236'-2" Angle: 0°

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
SRV ASYMMETRIC
DIRECTION Z

FIGURE A.2-31



Acceleration Spectra for DIAPHRAGM SLAB

Load Case: SRV - ASYMMETRIC

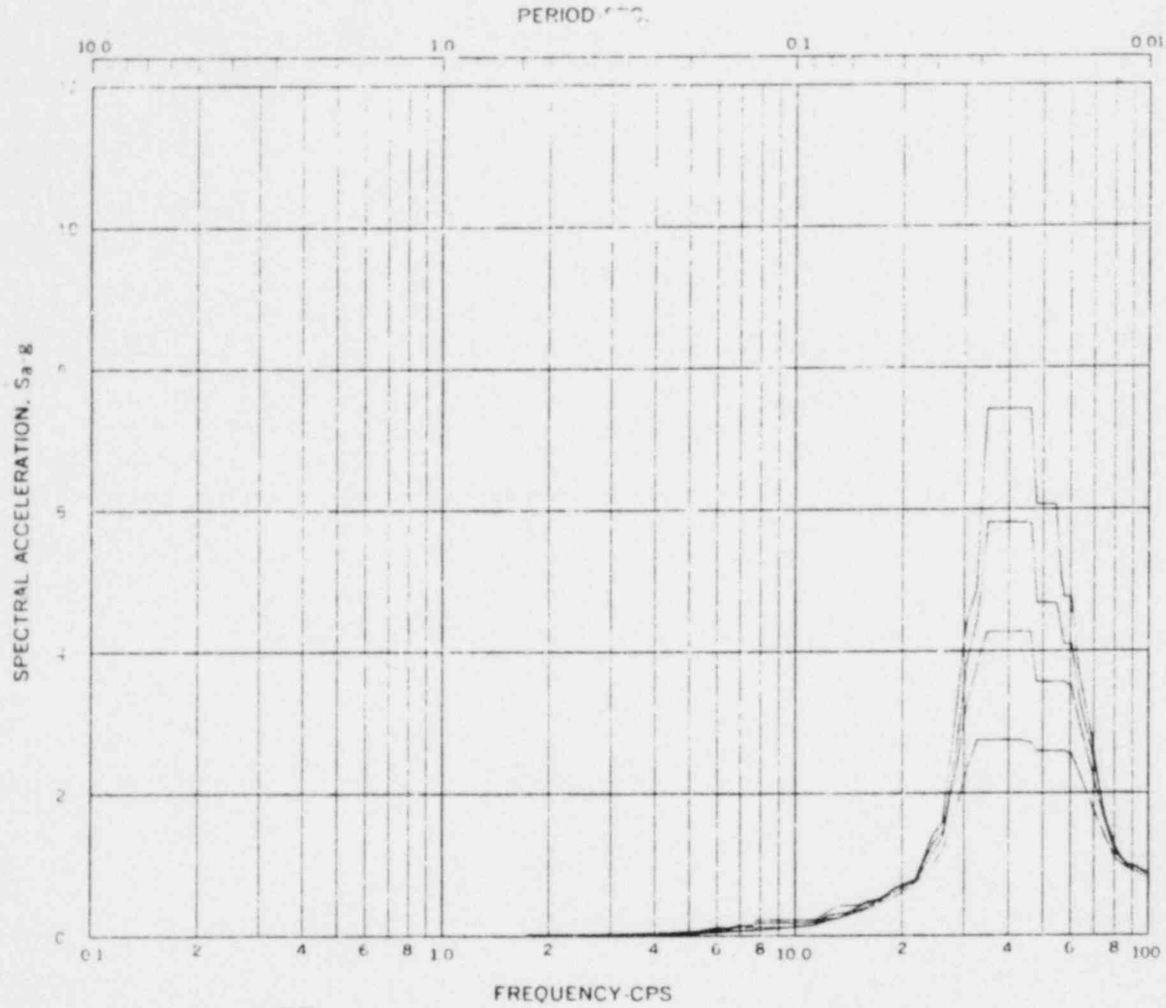
Node: 252 Direction: VERT Elev: 236'-2" Angle: 22°-30'

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
SRV ASYMMETRIC
DIRECTION Z

FIGURE A.2-32



Acceleration Spectra for WETWELL WALL

Load Case: C04B

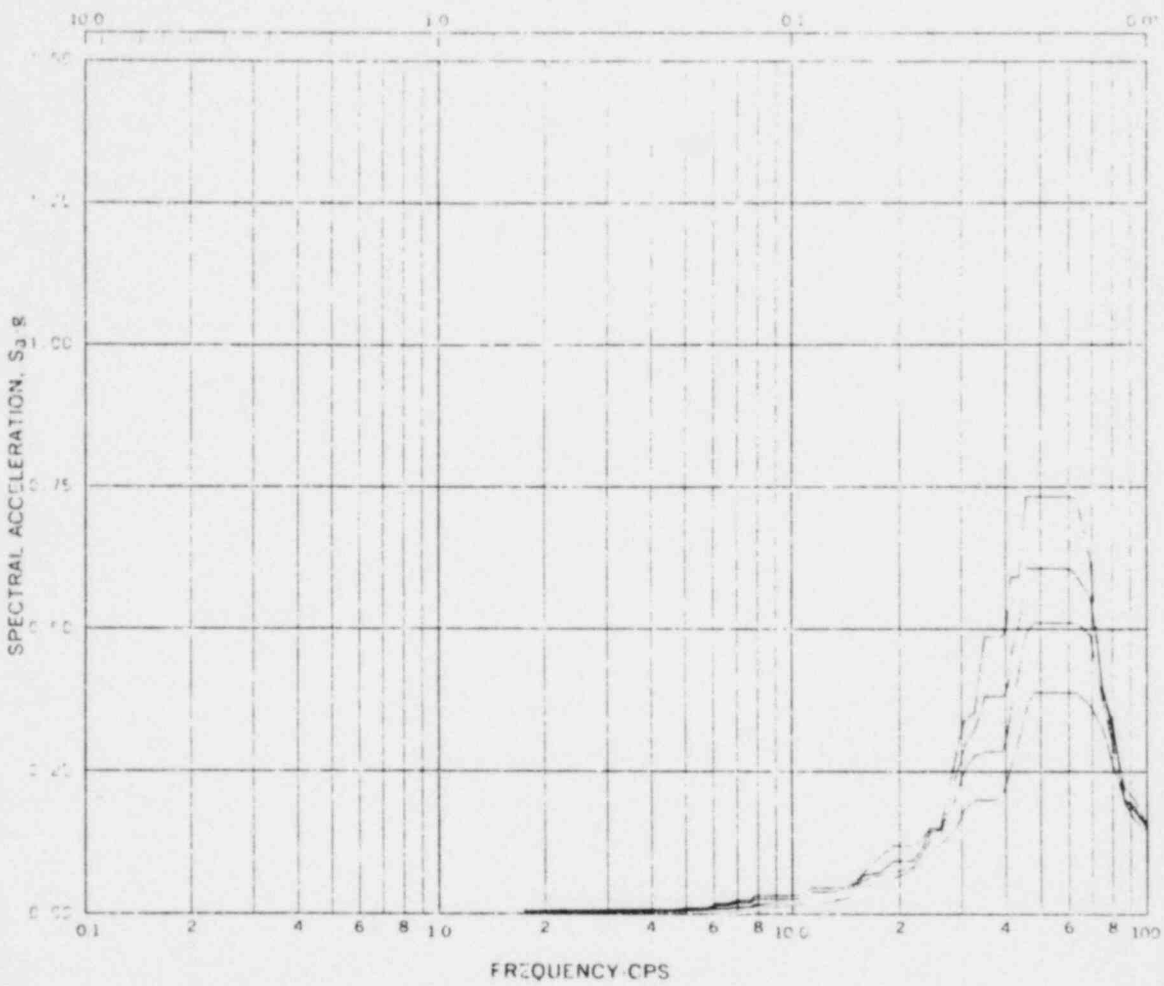
Node: 131 Direction: HORIZ Elev: 205'-11" Angle: 0°

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
CONDENSATION OSCILLATION
DIRECTION X

FIGURE A.2-33



Acceleration Spectra for WETWELL WALL

Load Case: CO4B

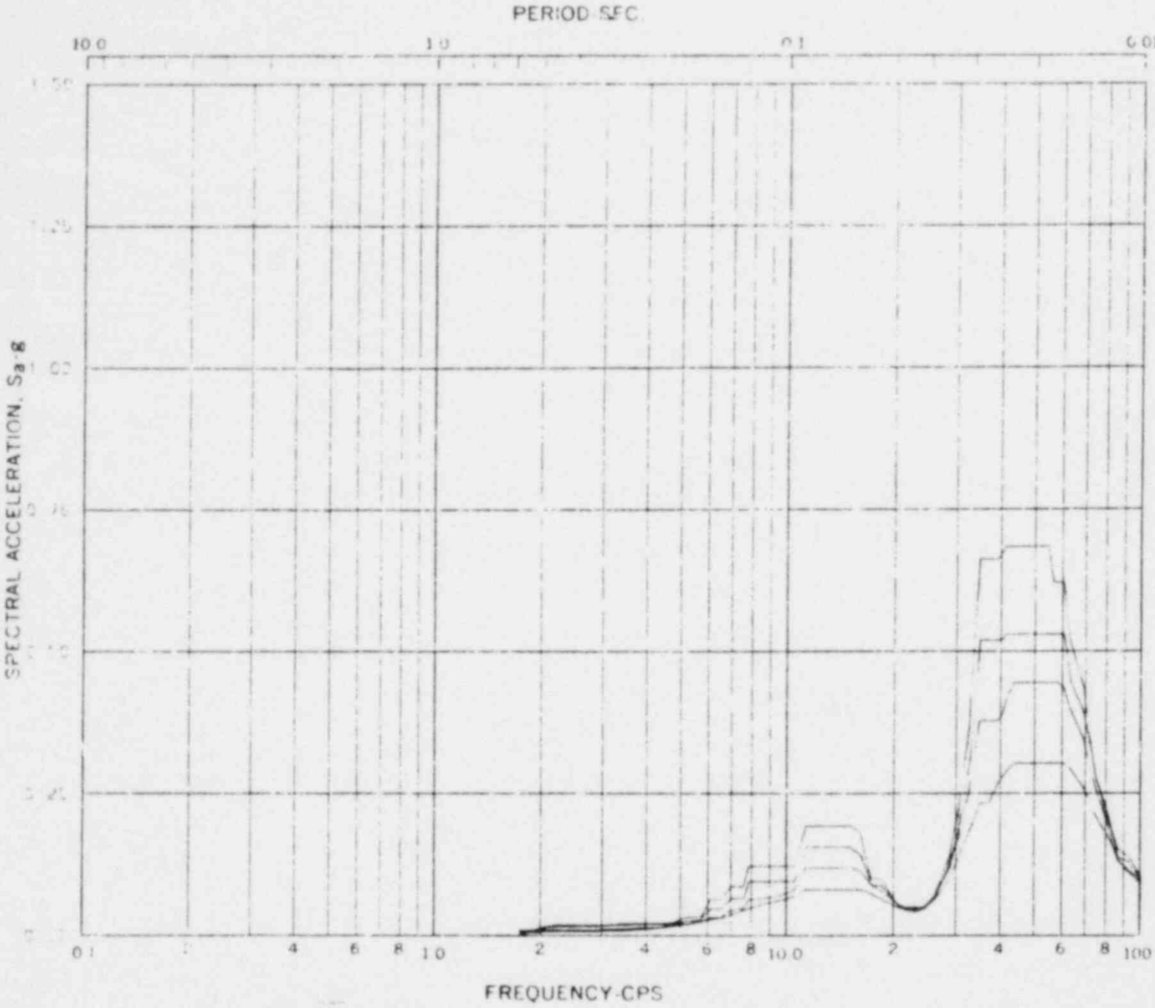
Node: 291 Direction: HORIZ Elev: 236'-2" Angle: 0°

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
CONDENSATION OSCILLATION
DIRECTION X

FIGURE A.2-34



Acceleration Spectra for DRYWELL WALL

Load Case: CO4B

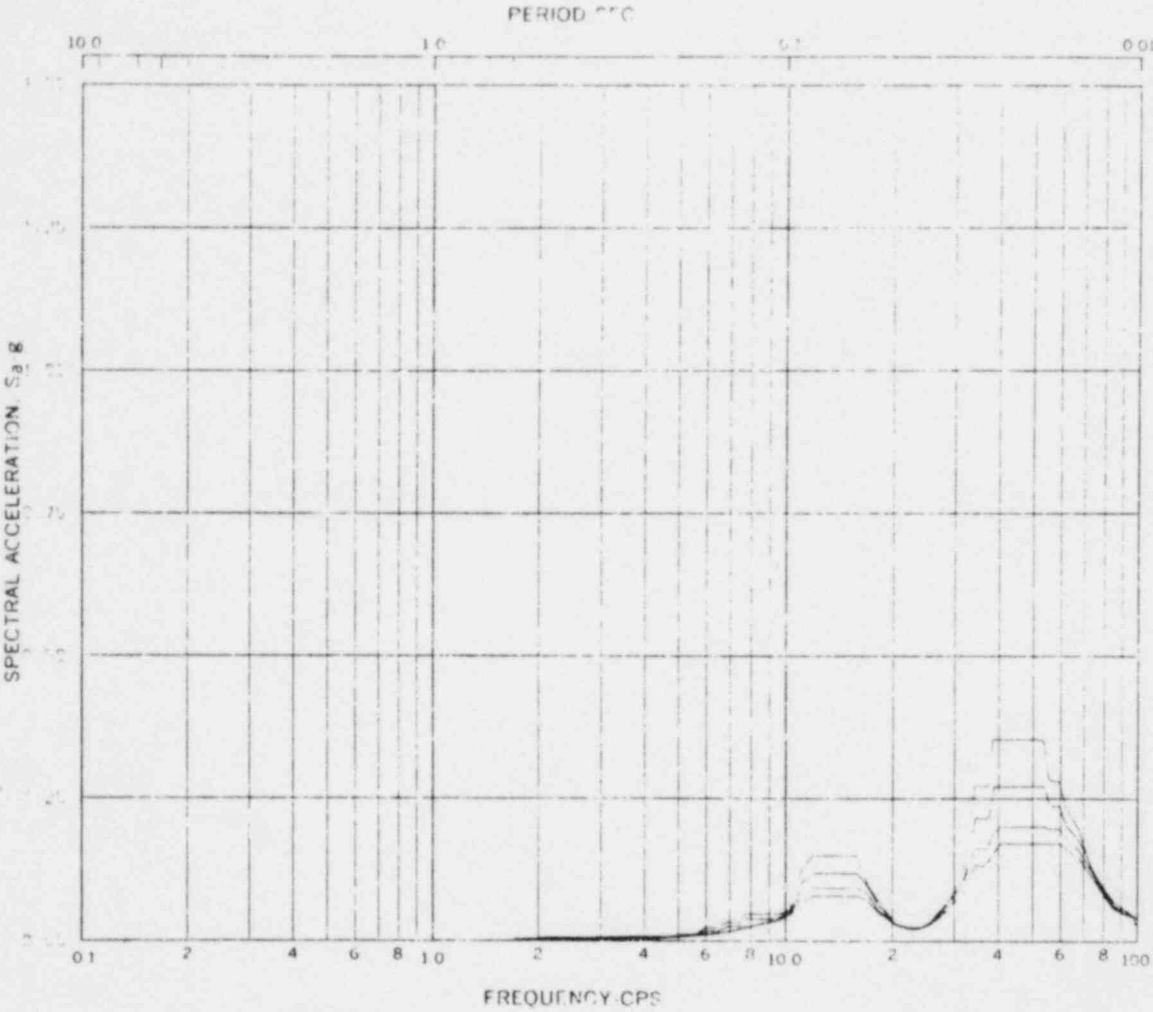
Node: 331 Direction: HORIZ Elev: 264'-6" Angle: 0°

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
CONDENSATION OSCILLATION
DIRECTION X

FIGURE A.2-35



Acceleration Spectra for DRYWELL WALL

Load Case: CO4B

Node: 431 Direction: HORIZ Elev: 325'-8" Angle: 0°

Damping: 0.005,0.01,0.02,0.03

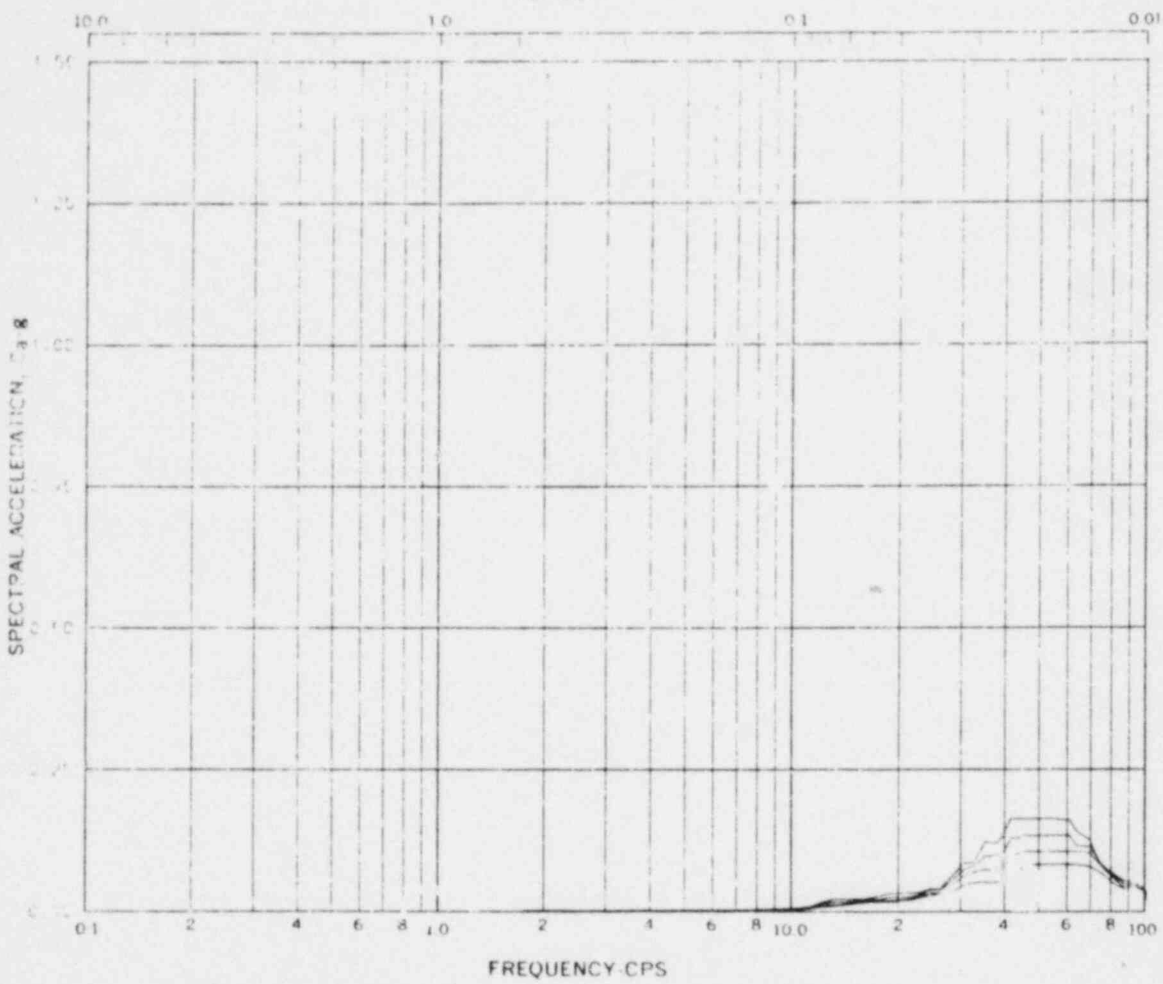
NOTE:

1. 0.05 DAMPING NOT INCLUDED.

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
CONDENSATION OSCILLATION
DIRECTION X

FIGURE A.2-36



Acceleration Spectra for PEDESTAL

Load Case: C04B

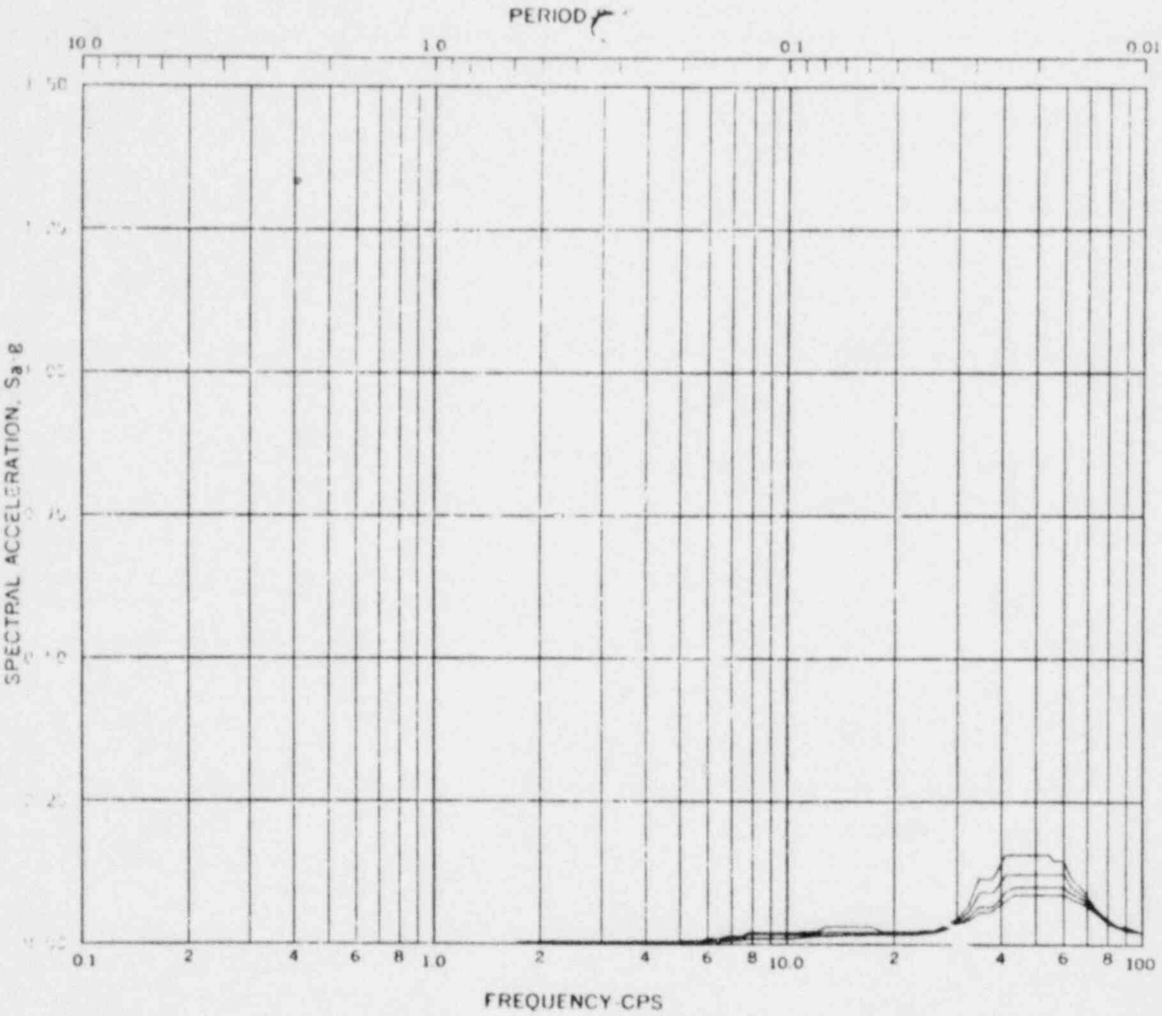
Node: 211 Direction: HORIZ Elev: 236'-2" Angle: 0°

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
CONDENSATION OSCILLATION
DIRECTION X

FIGURE A.2-37



Acceleration Spectra for PEDESTAL

Load Case: CO4B

Node: 531 Direction: HORIZ Elev: 263'-8 5/8" Angle: 0°

Damping: 0.005, 0.01, 0.02, 0.03

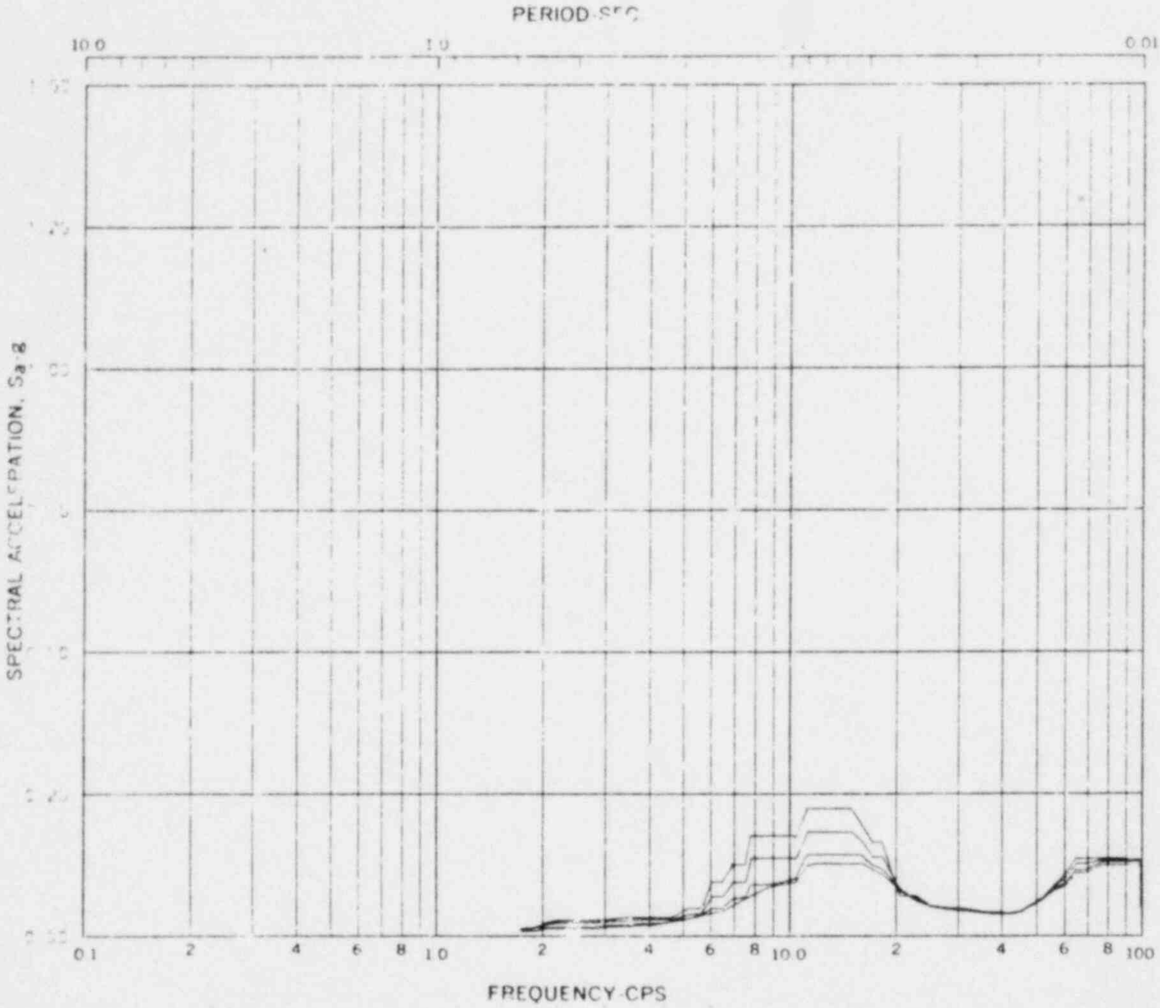
NOTE:

1. 0.05 DAMPING NOT INCLUDED.

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
CONDENSATION OSCILLATION
DIRECTION X

FIGURE A.2-38



Acceleration Spectra for SHIELD WALL

Load Case: C04B

Node: 841 Direction: HORIZ Elev: 312'-8" Angle: 0°

Damping: 0.005,0.01,0.02,0.03

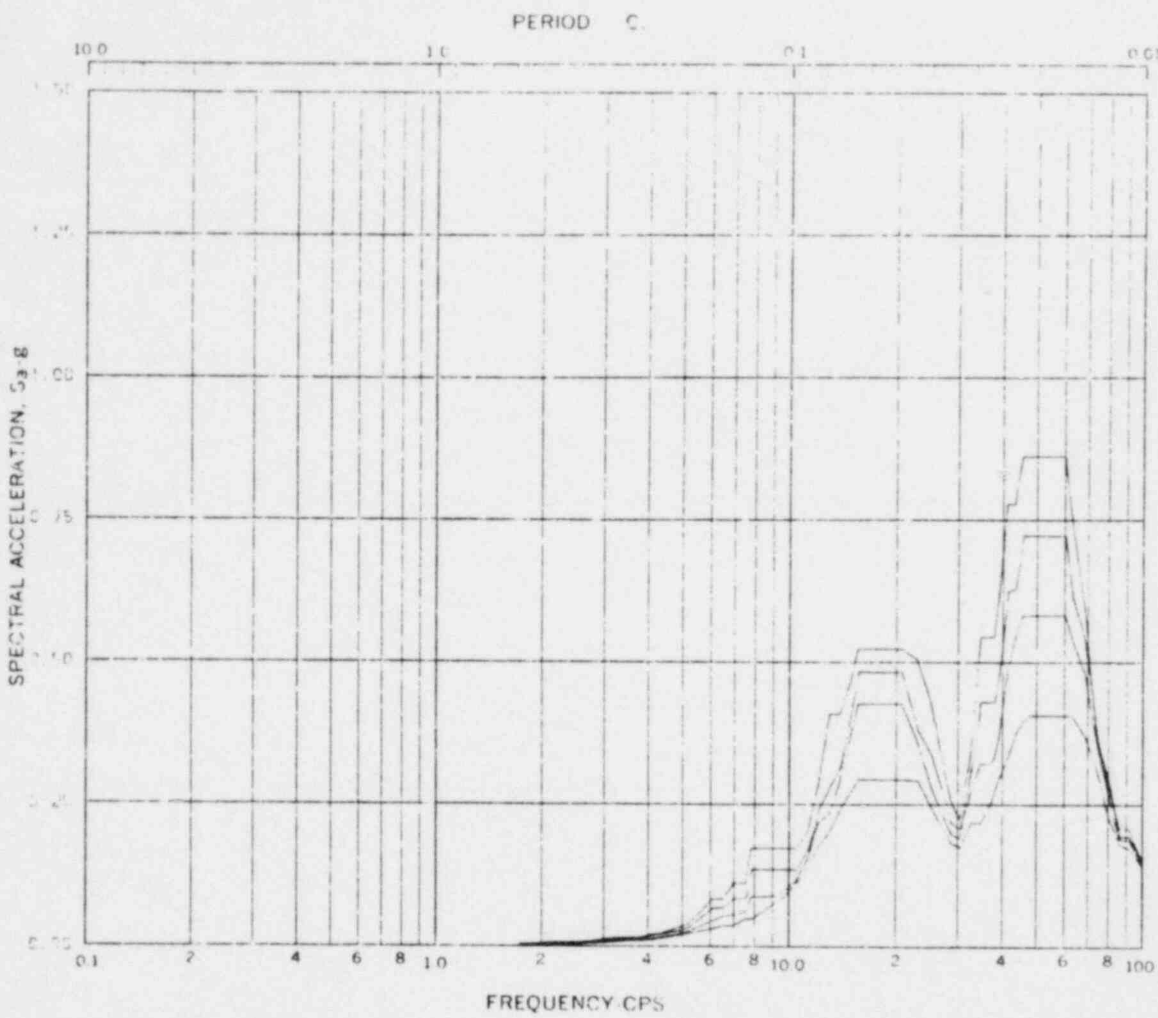
NOTE:

1. 0.05 DAMPING NOT INCLUDED.

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
CONDENSATION OSCILLATION
DIRECTION X

FIGURE A.2-39



Acceleration Spectra for WETWELL WALL

Load Case: CO4B

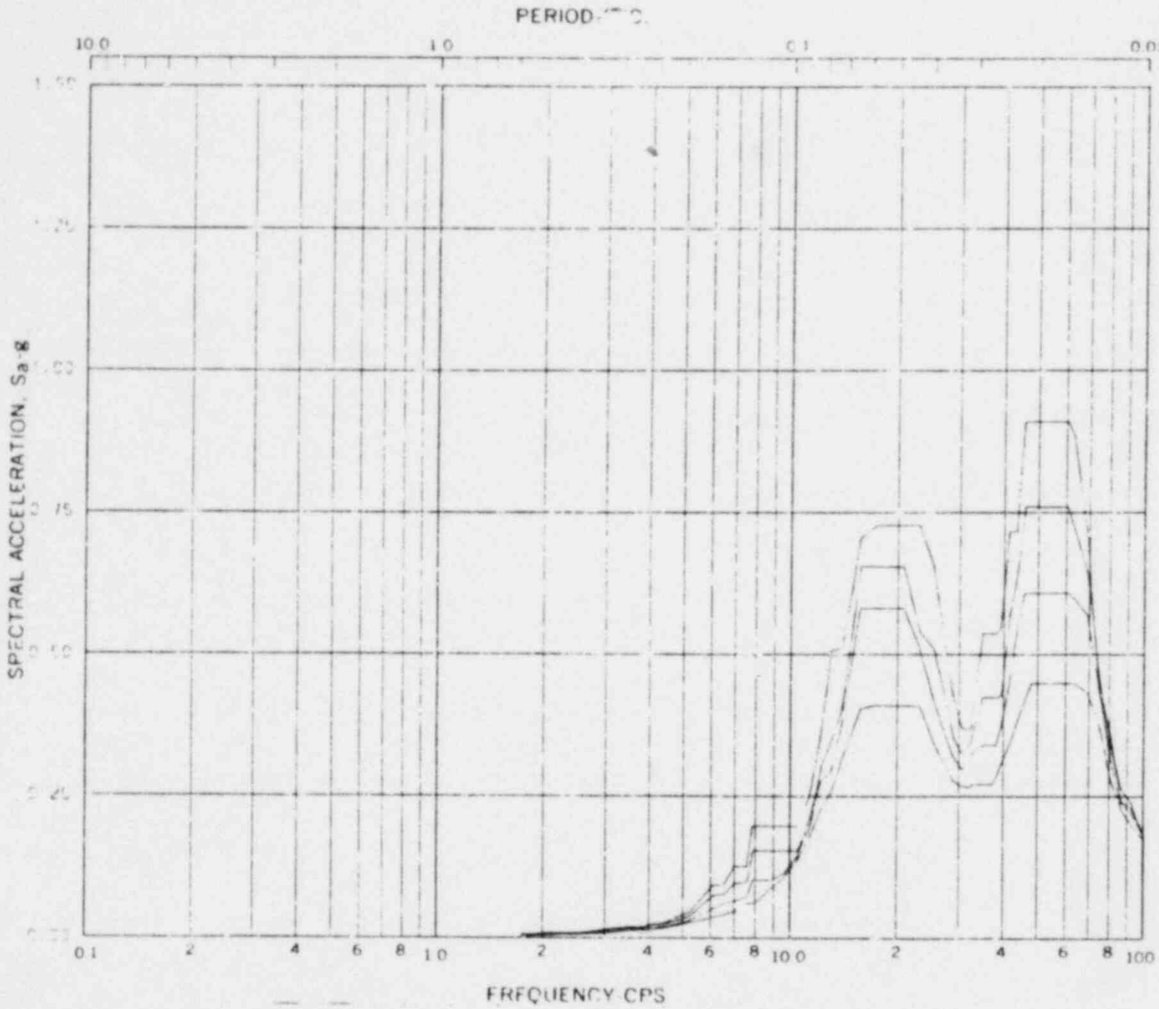
Node: 131 Direction: VERT Elev: 205'-11" Angle: 0°

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
CONDENSATION OSCILLATION
DIRECTION Z

FIGURE A.2-40



Acceleration Spectra for WETWELL WALL

Load Case: CO4B

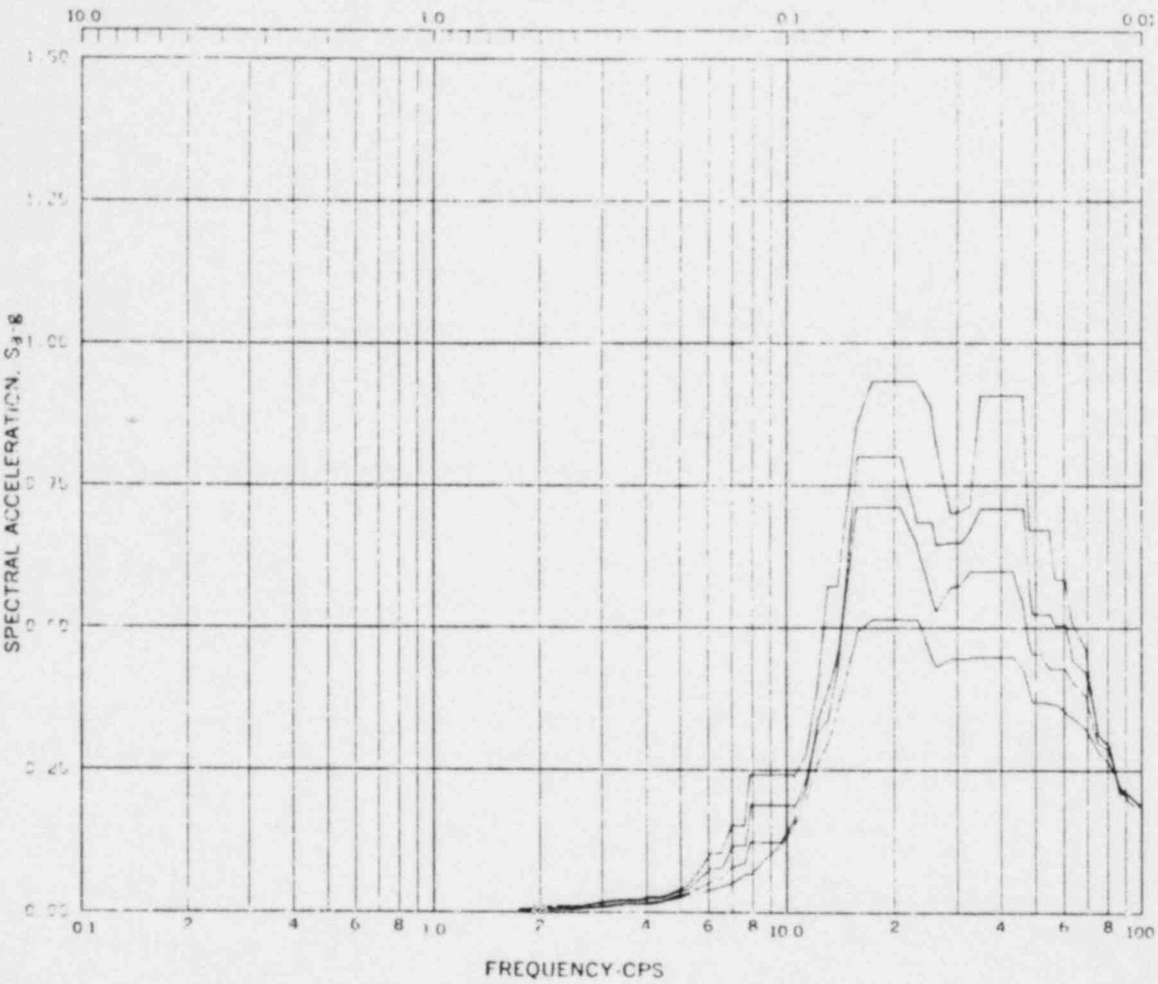
Node: 291 Direction: VERT Elev: 236'-2" Angle: 0°

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
CONDENSATION OSCILLATION
DIRECTION Z

FIGURE A.2-41



Acceleration Spectra for DRYWELL WALL

Load Case: C04B

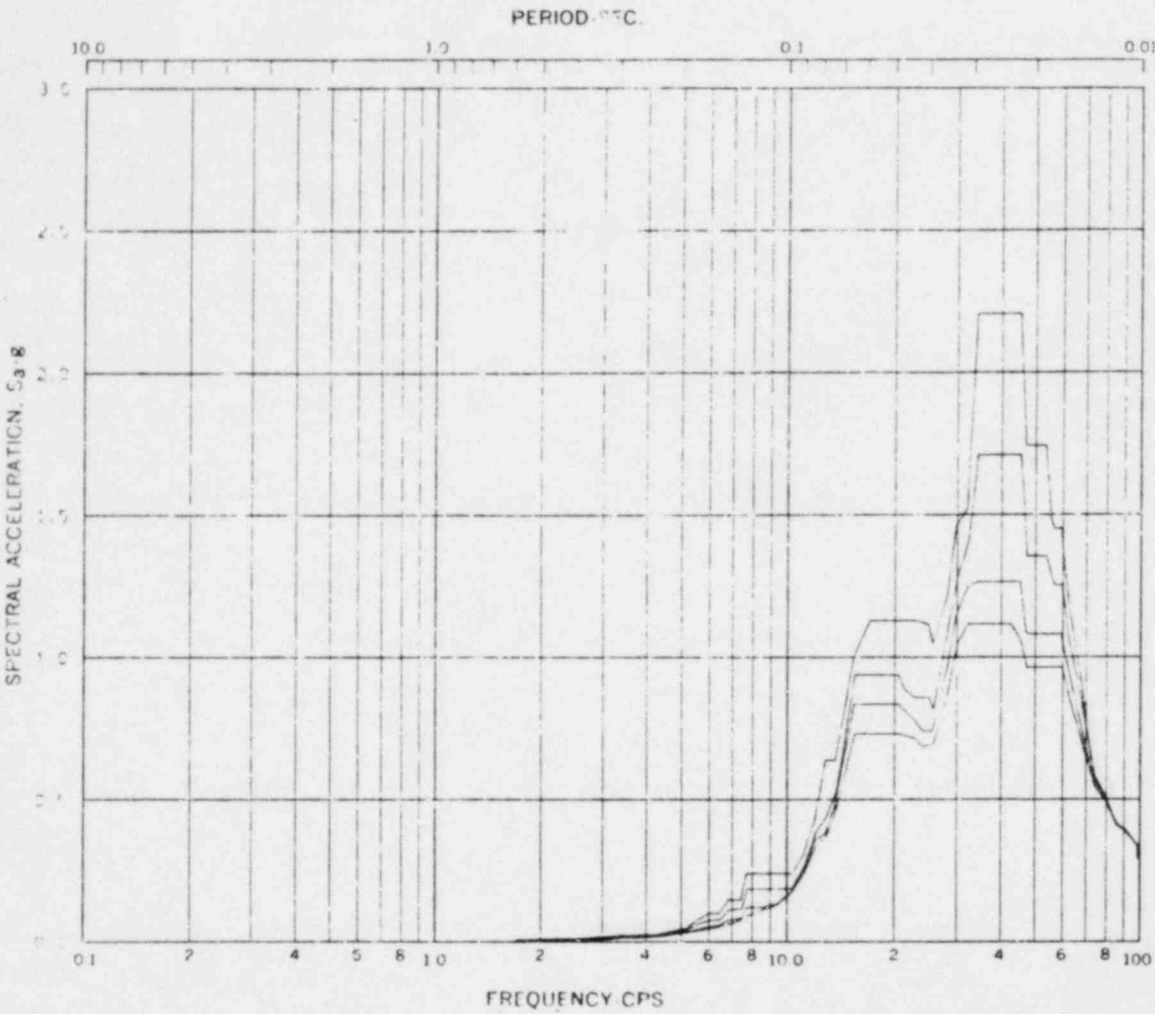
Node: 331 Direction: VERT Elev: 264'-6" Angle: 0°

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
CONDENSATION OSCILLATION
DIRECTION Z

FIGURE A.2-42



Acceleration Spectra for DRYWELL WALL

Load Case: C04B

Node: 431 Direction: VERT Elev: 325'-8" Angle: 0°

Damping: 0.005,0.01,0.02,0.03

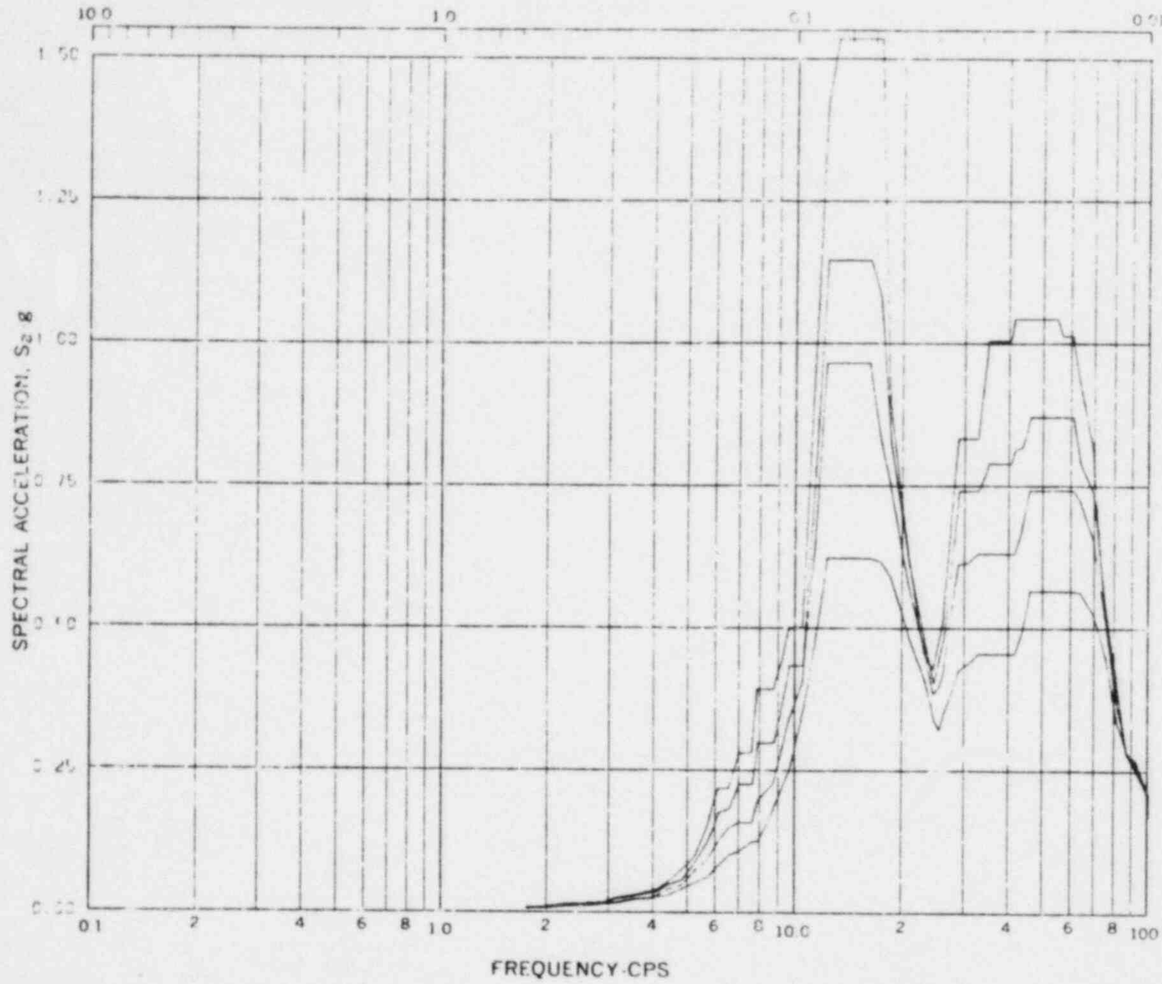
NOTE:

1. 0.05 DAMPING NOT INCLUDED.

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
CONDENSATION OSCILLATION
DIRECTION Z

FIGURE A.2-43



Acceleration Spectra for PEDESTAL

Load Case: C04B

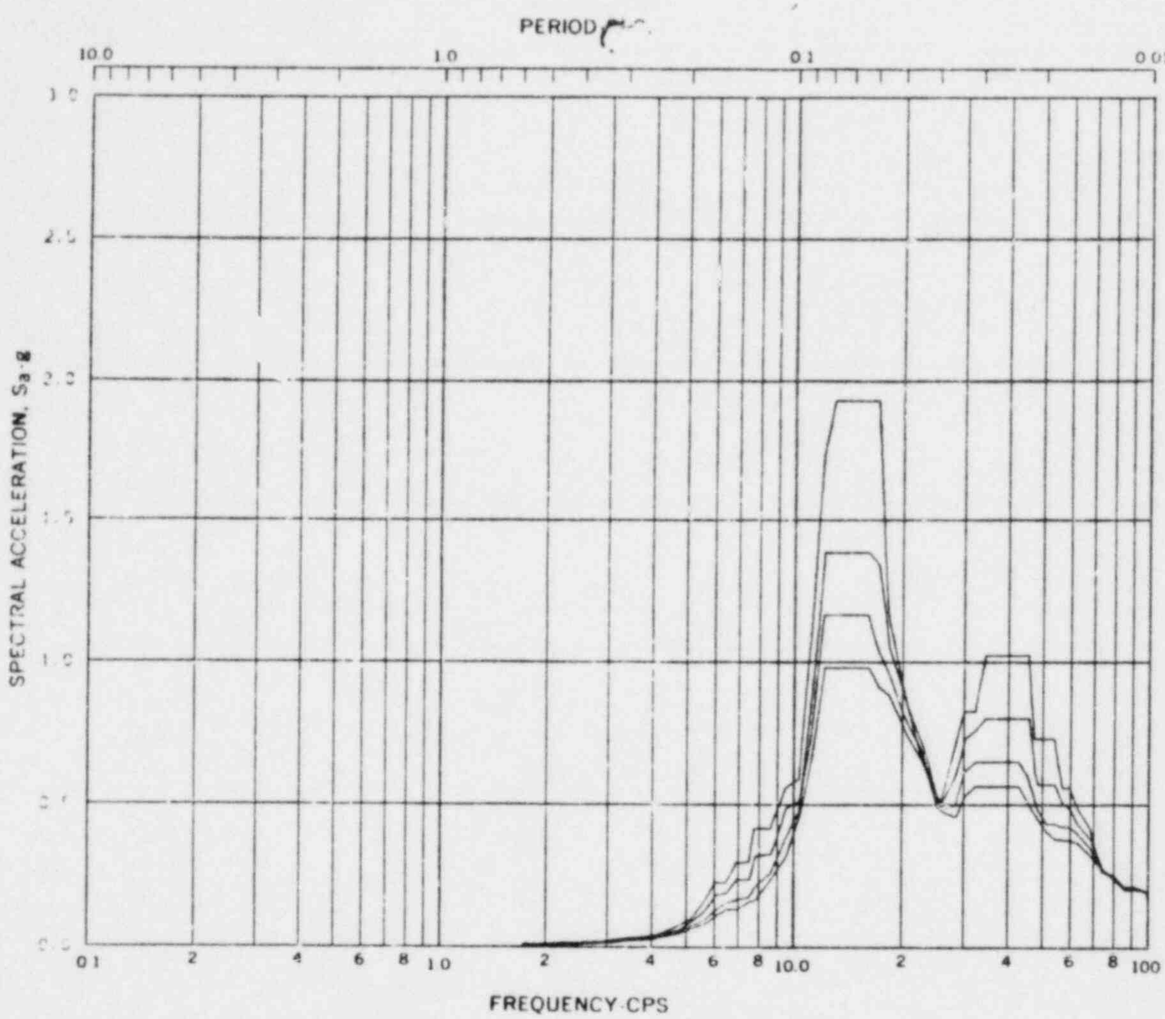
Node: 211 Direction: VERT Elev: 236'-2" Angle: 0°

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
CONDENSATION OSCILLATION
DIRECTION Z

FIGURE A.2-44



Acceleration Spectra for PEDESTAL

Load Case: CO4B

Node: 531 Direction: VERT Elev: 263'-8 5/8" Angle: 0°

Damping: 0.005,0.01,0.02,0.03

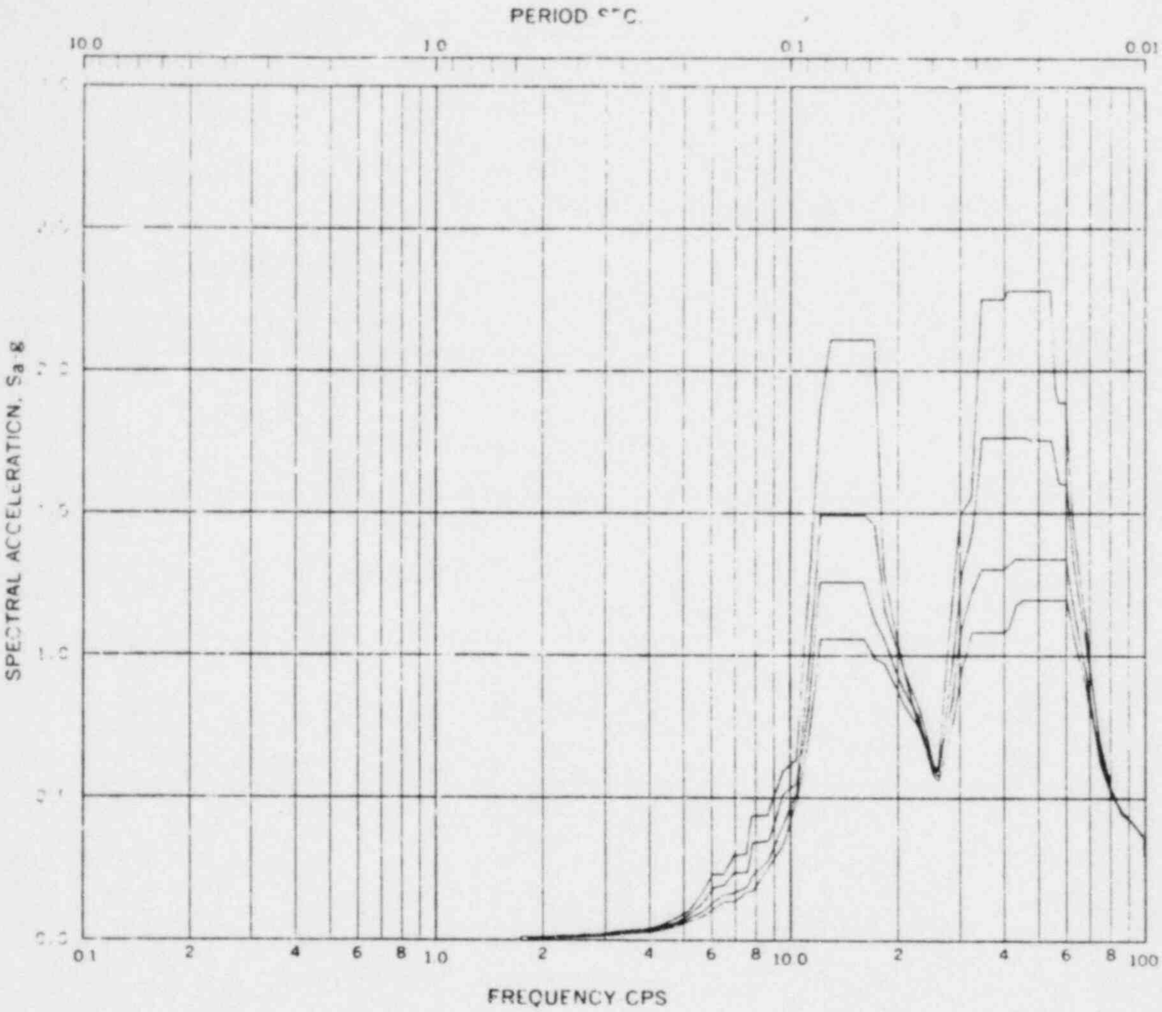
NOTE:

1. 0.05 DAMPING NOT INCLUDED.

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
CONDENSATION OSCILLATION
DIRECTION Z

FIGURE A.2-45



Acceleration Spectra for SHIELD WALL

Load Case: C04B

Node: 841 Direction: VERT Elev: 312'-8" Angle: 0°

Damping: 0.005,0.01,0.02,0.03

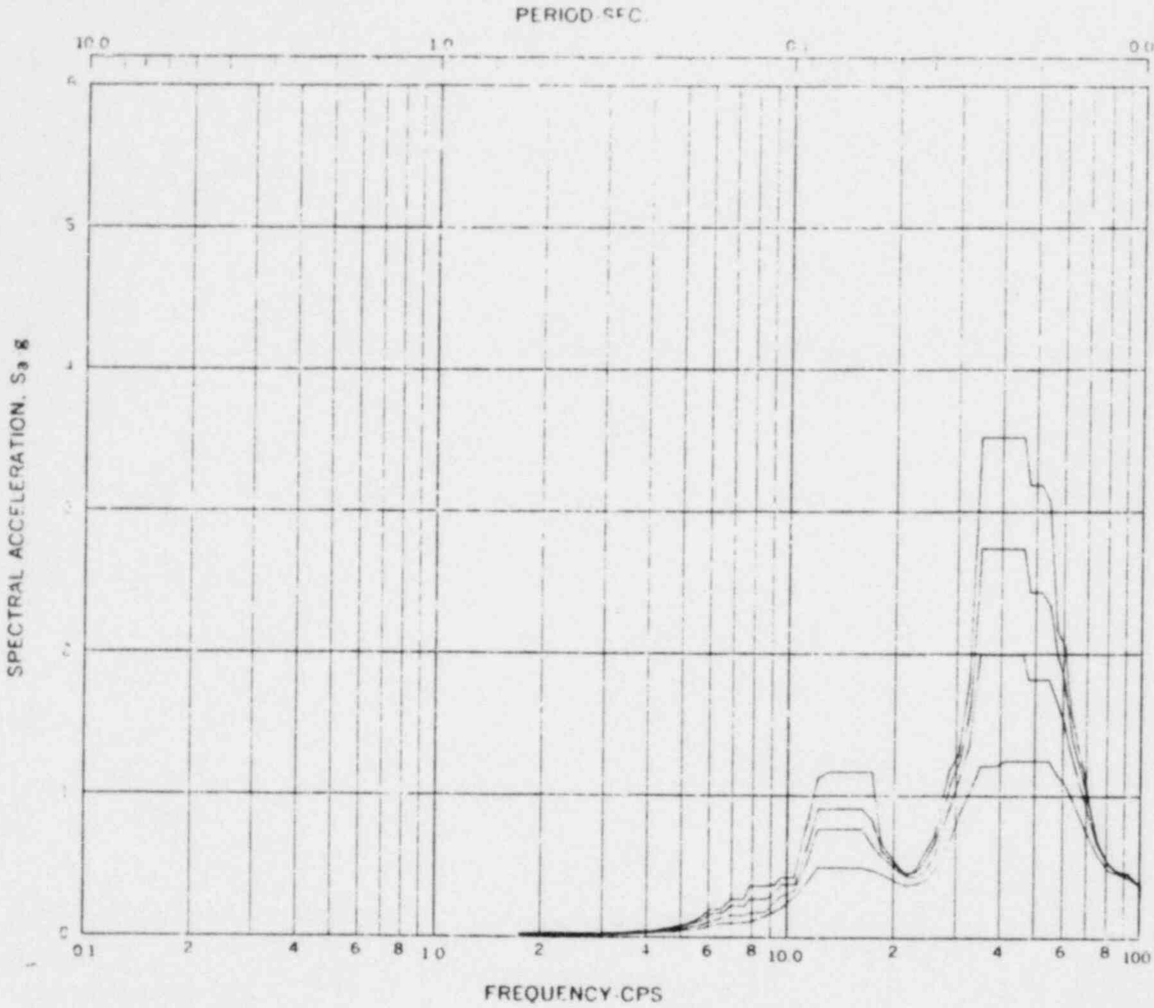
NOTE

1. 0.05 DAMPING NOT INCLUDED.

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
CONDENSATION OSCILLATION
DIRECTION Z

FIGURE A.2-46



Acceleration Spectra for DIAPHRAGM SLAB

Load Case: C04B

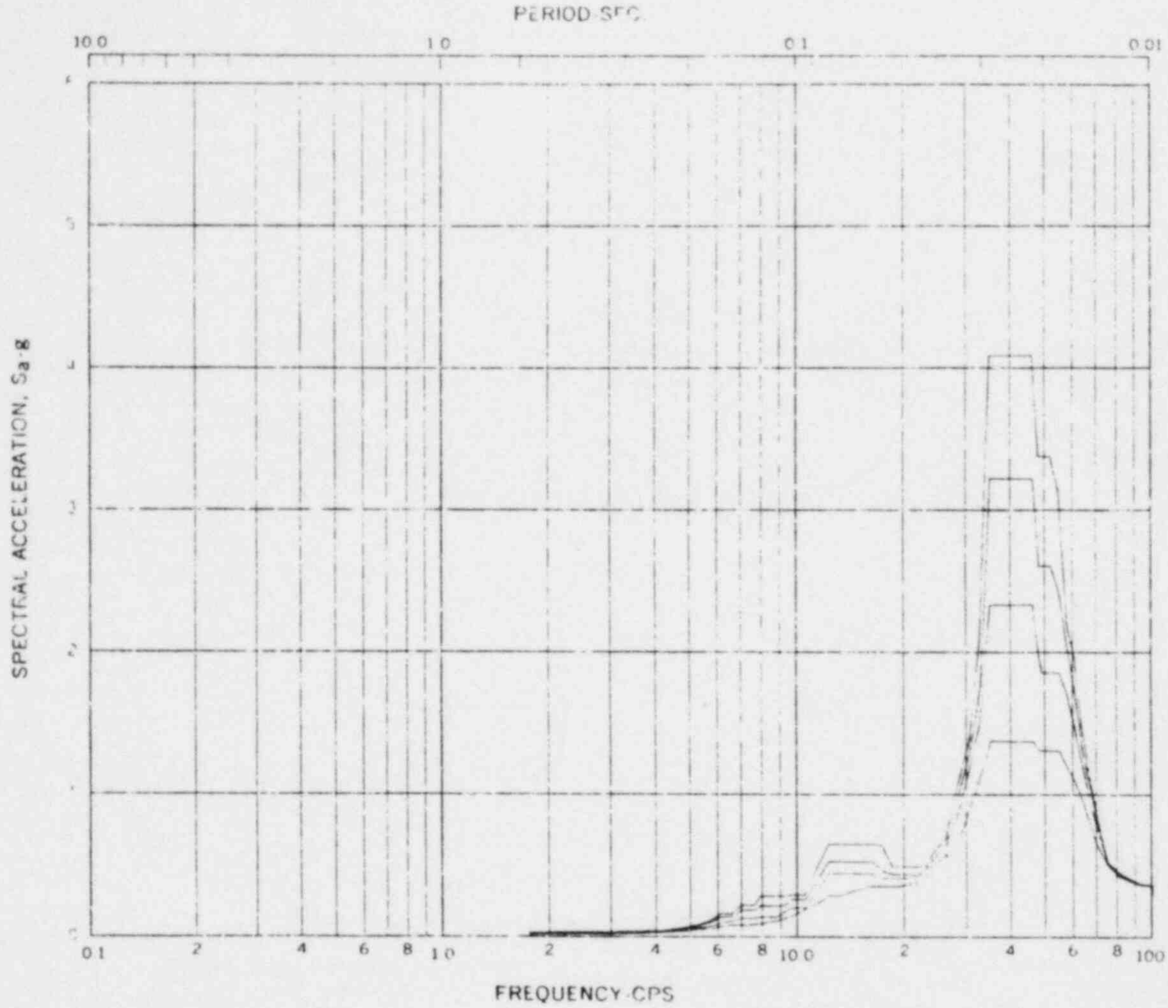
Node: 231 Direction: VERT Elev: 236'-2" Angle: 0°

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
CONDENSATION OSCILLATION
DIRECTION Z

FIGURE A.2-47



Acceleration Spectra for DIAPHRAGM SLAB

Load Case: CO4B

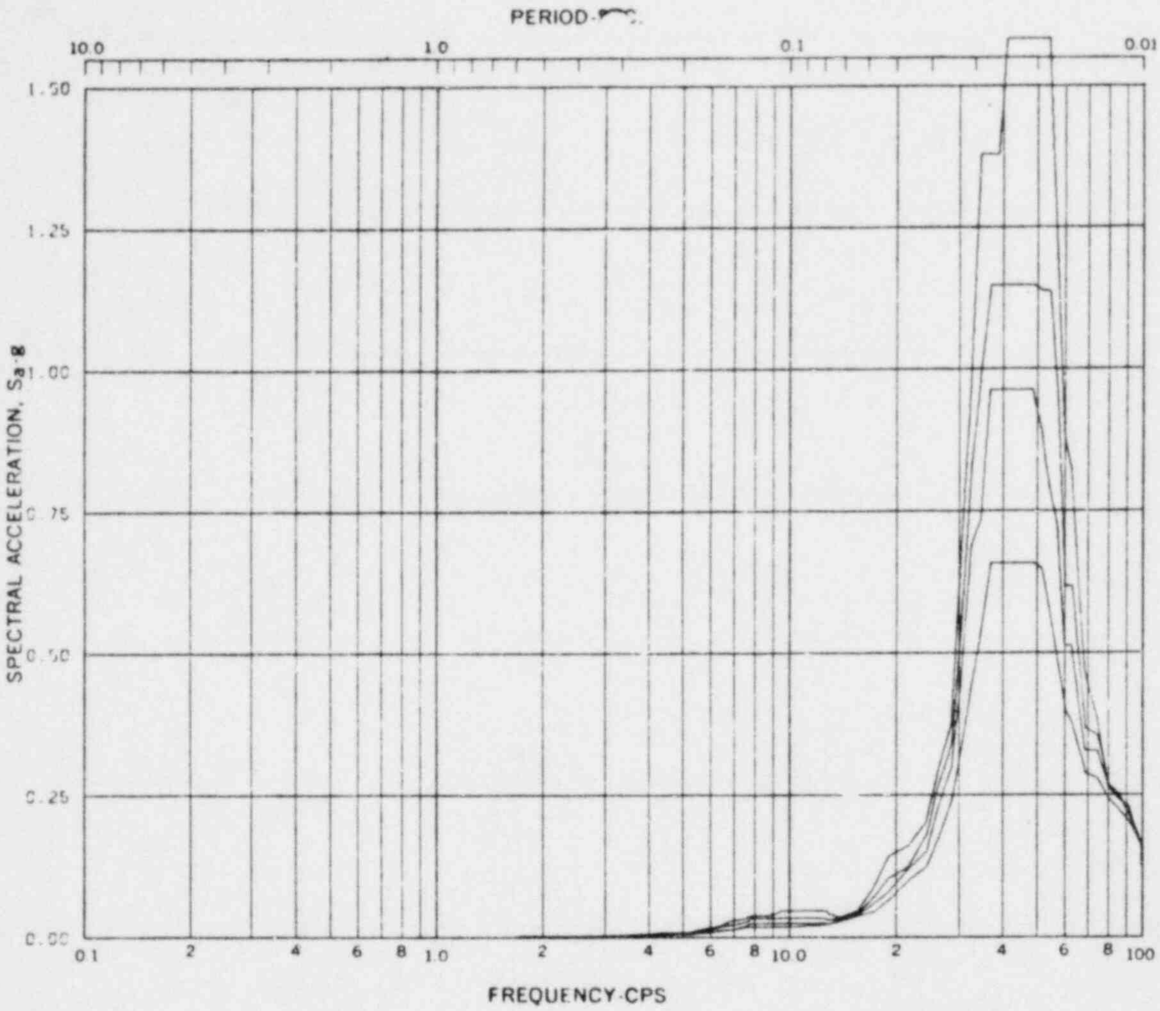
Node: 252 Direction: VERT Elev: 236'-2" Angle: 22°30'

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
CONDENSATION OSCILLATION
DIRECTION Z

FIGURE A.2-48



Acceleration Spectra for WETWELL WALL

Load Case: CO FOR COMBINATION WITH ADS

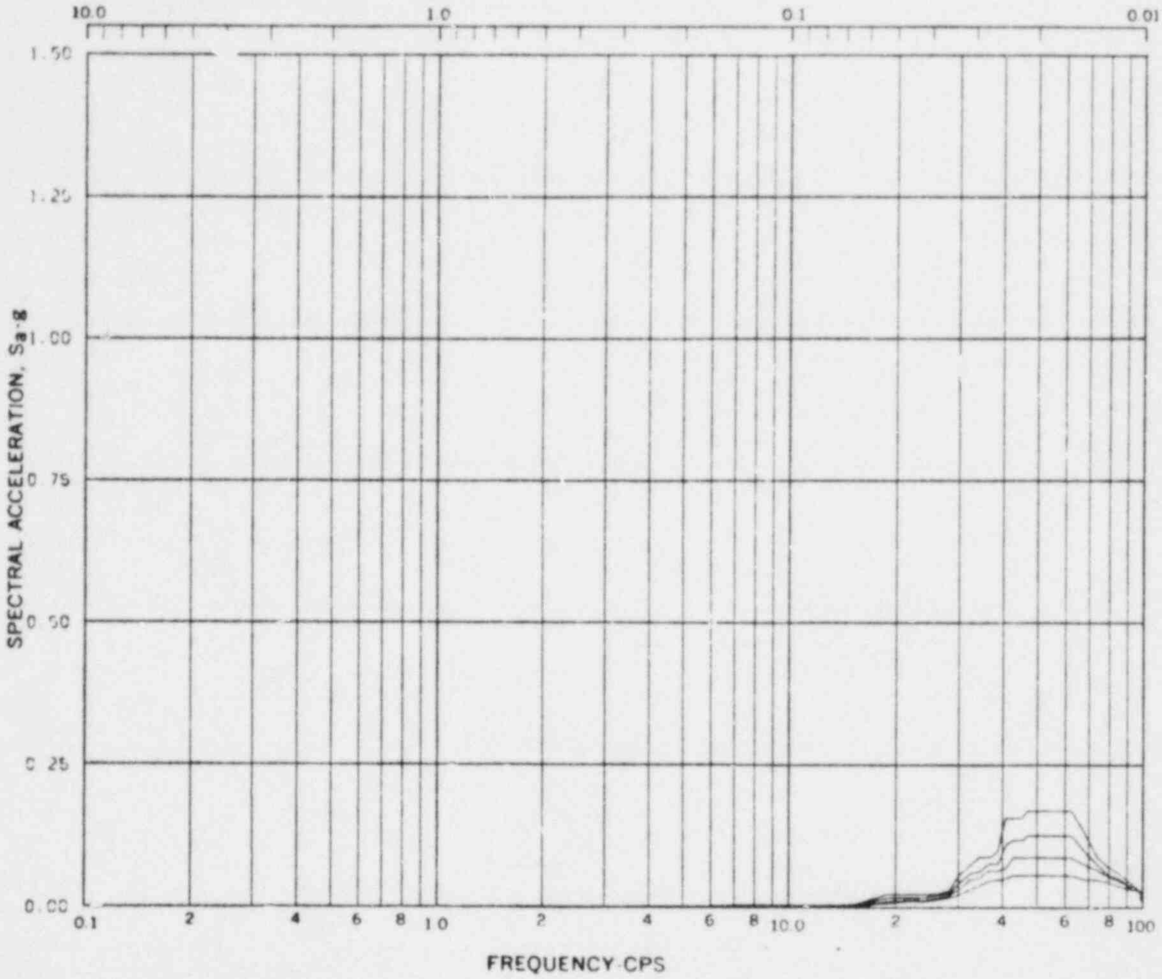
Node: 131 Direction: HORIZ Elev: 205'-11" Angle: 0°

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
CONDENSATION OSCILLATION
WITH ADS
DIRECTION X

FIGURE A.2-49



Acceleration Spectra for WETWELL WALL

Load Case: CO FOR COMBINATION WITH ADS

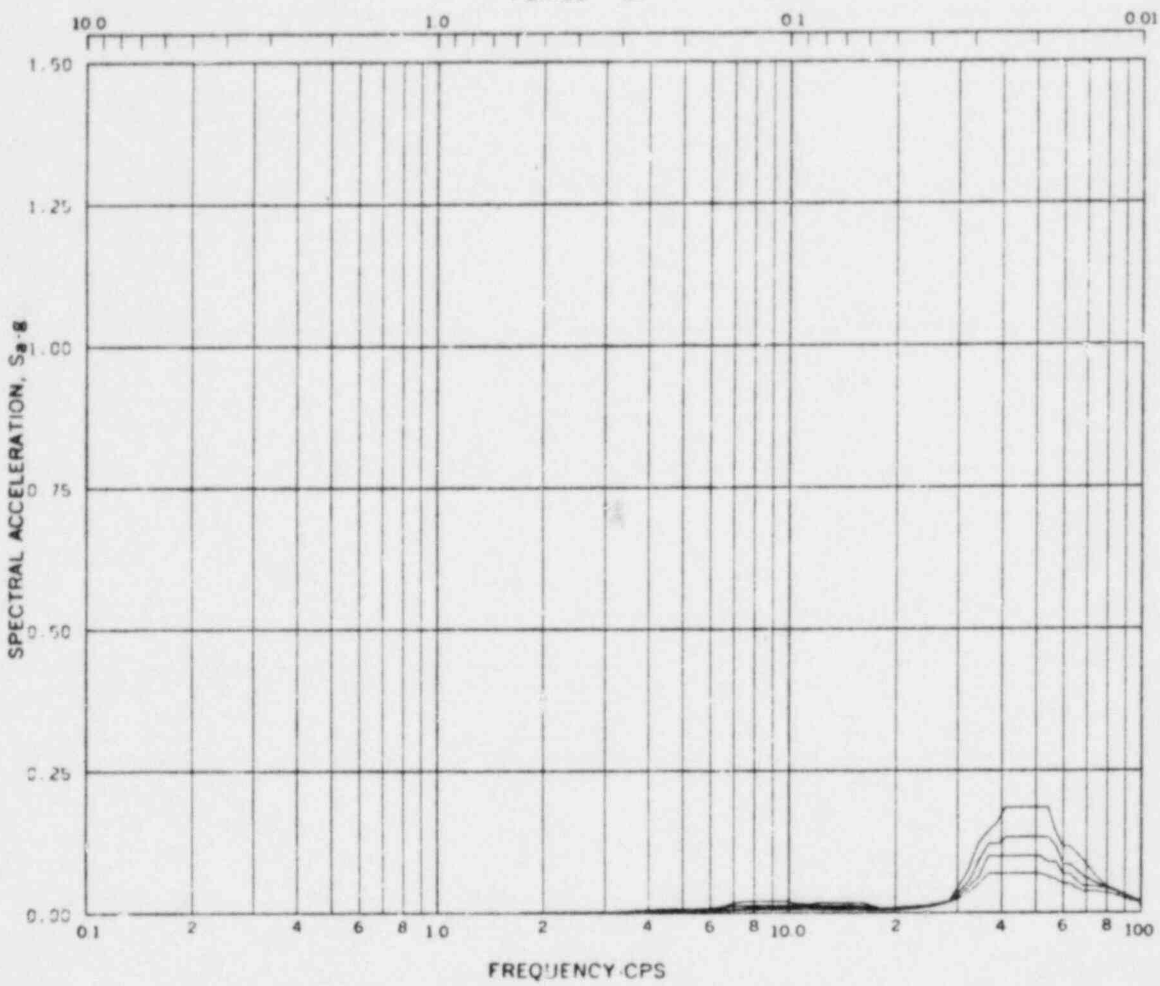
Node: 291 Direction: HORIZ Elev: 236'-2" Angle: 0°

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
CONDENSATION OSCILLATION
WITH ADS
DIRECTION X

FIGURE A.2-50



Acceleration Spectra for DRYWELL WALL

Load Case: CO FOR COMBINATION WITH ADS

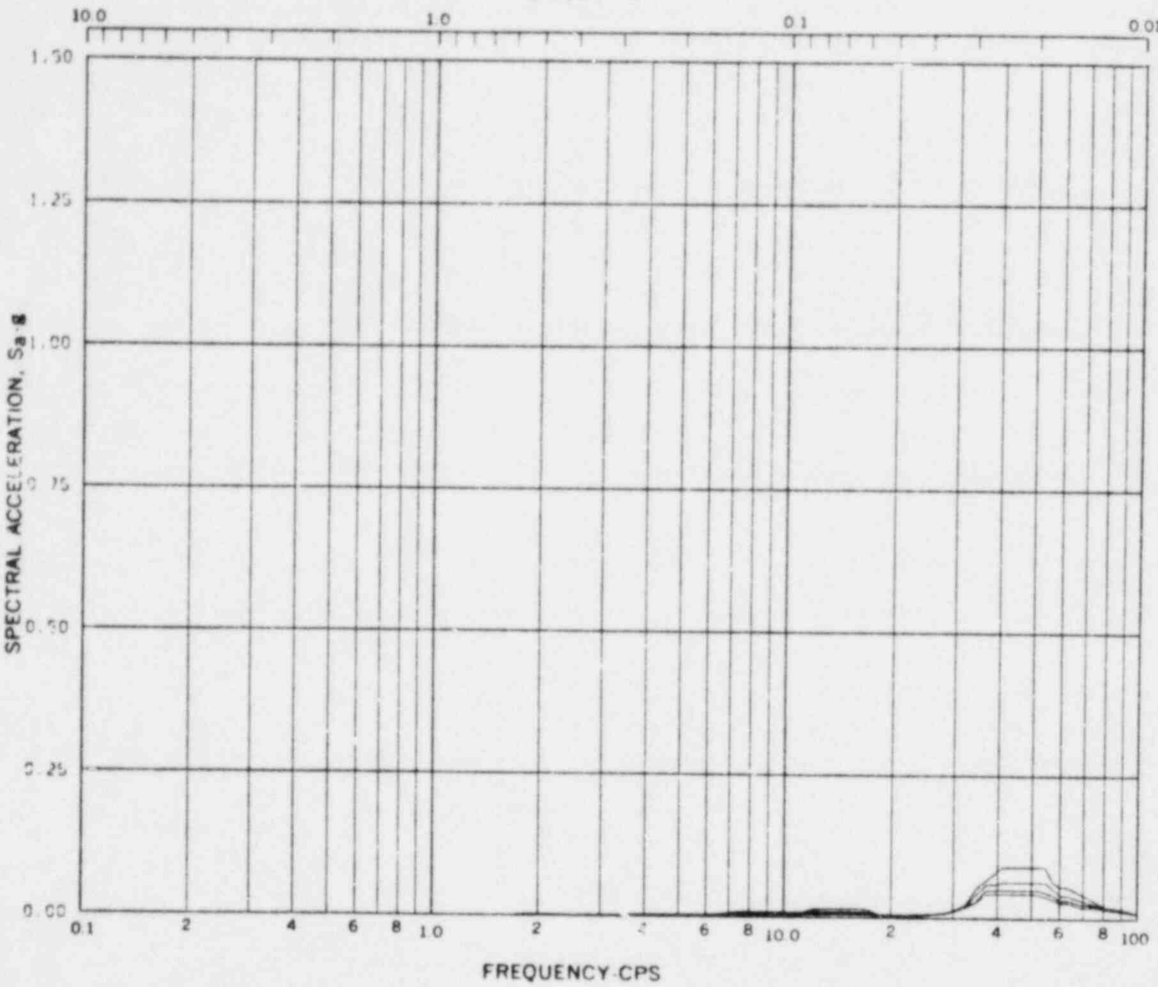
Node: 331 Direction: HORIZ Elev: 264'-6" Angle: 0°

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
CONDENSATION OSCILLATION
WITH ADS
DIRECTION X

FIGURE A.2-51



Acceleration Spectra for DRYWELL WALL

Load Case: CO FOR COMBINATION WITH ADS

Node: 431 Direction: HORIZ Elev: 325'-8" Angle: 0°

Damping: 0.005,0.01,0.02,0.03

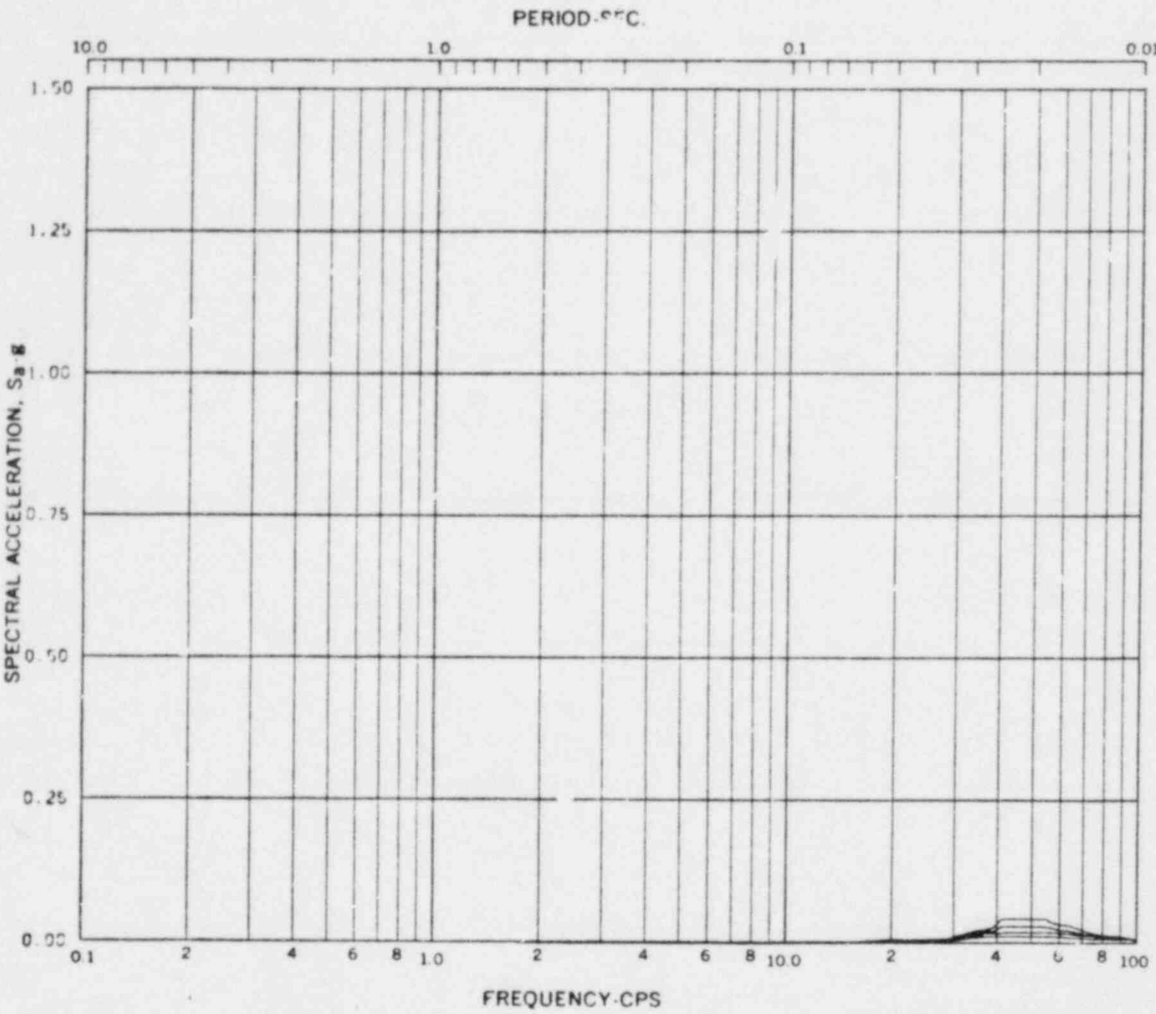
NOTE:

1. 0.05 DAMPING NOT INCLUDED.

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
CONDENSATION OSCILLATION
WITH ADS
DIRECTION X

FIGURE A.2-52



Acceleration Spectra for PEDESTAL

Load Case: CO FOR COMBINATION WITH ADS

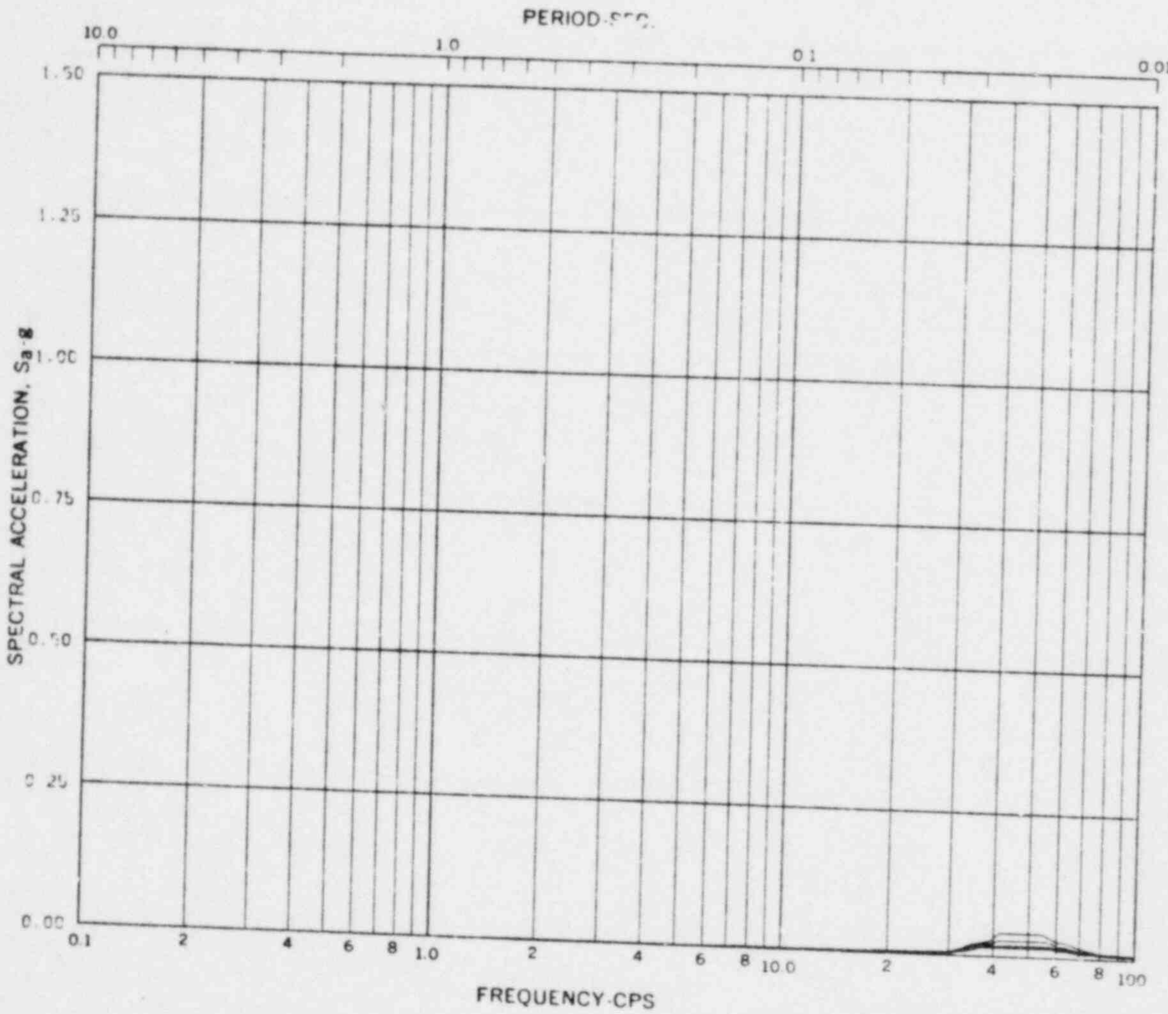
Node: 211 Direction: HORIZ Elev: 236'-2" Angle: 0°

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
CONDENSATION OSCILLATION
WITH ADS
DIRECTION X

FIGURE A.2-53



Acceleration Spectra for PEDESTAL

Load Case: CO FOR COMBINATION WITH ADS

Node: 531 Direction: HORIZ Elev: 263'-8 5/8" Angle: 0°

Damping: 0.005,0.01,0.02,0.03

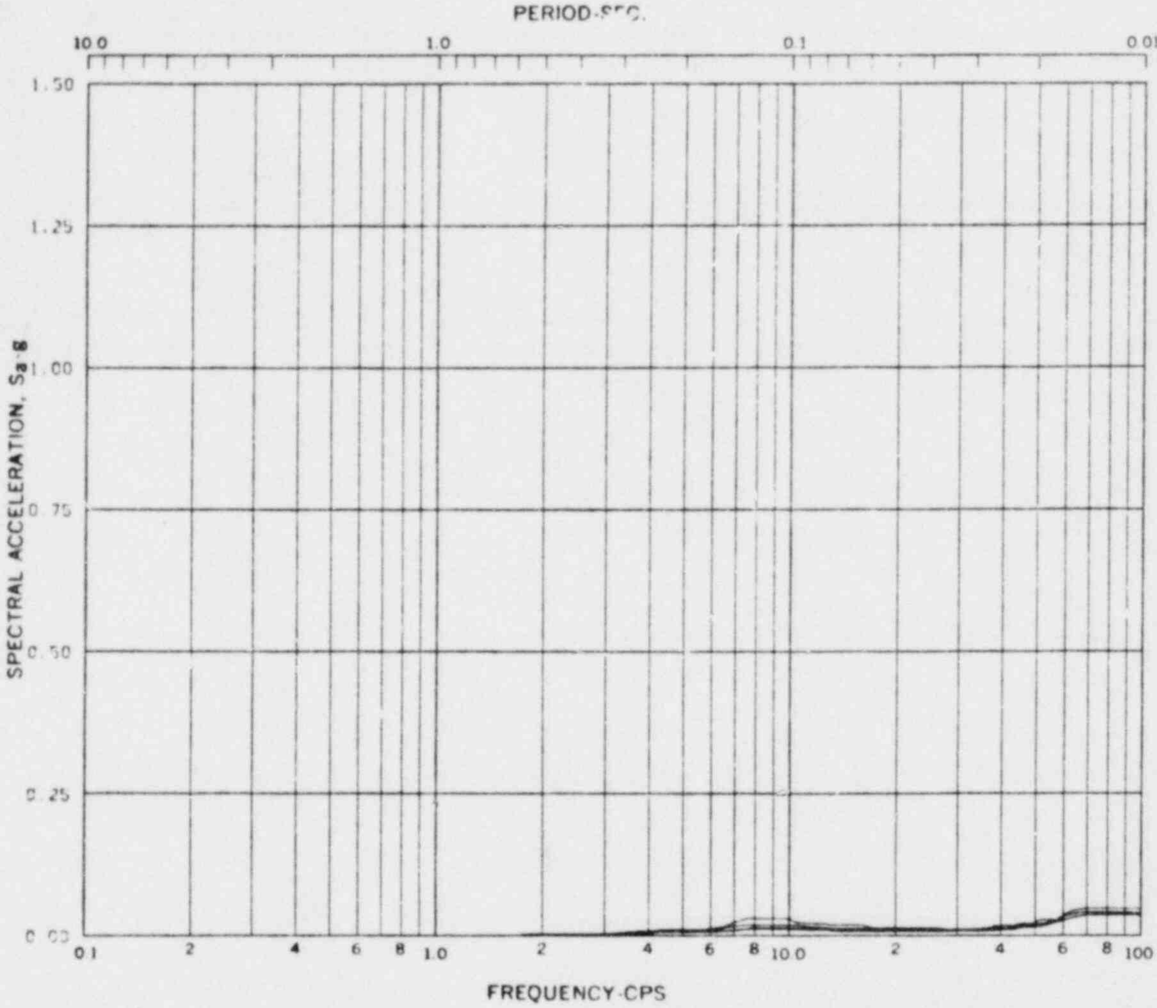
NOTE:

1. 0.05 DAMPING NOT INCLUDED.

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
CONDENSATION OSCILLATION
WITH ADS
DIRECTION X

FIGURE A.2-54



Acceleration Spectra for SHIELD WALL

Load Case: CO FOR COMBINATION WITH ADS

Node: 841 Direction: HORIZ Elev: 312'-8" Angle: 0°

Damping: 0.005,0.01,0.02,0.03

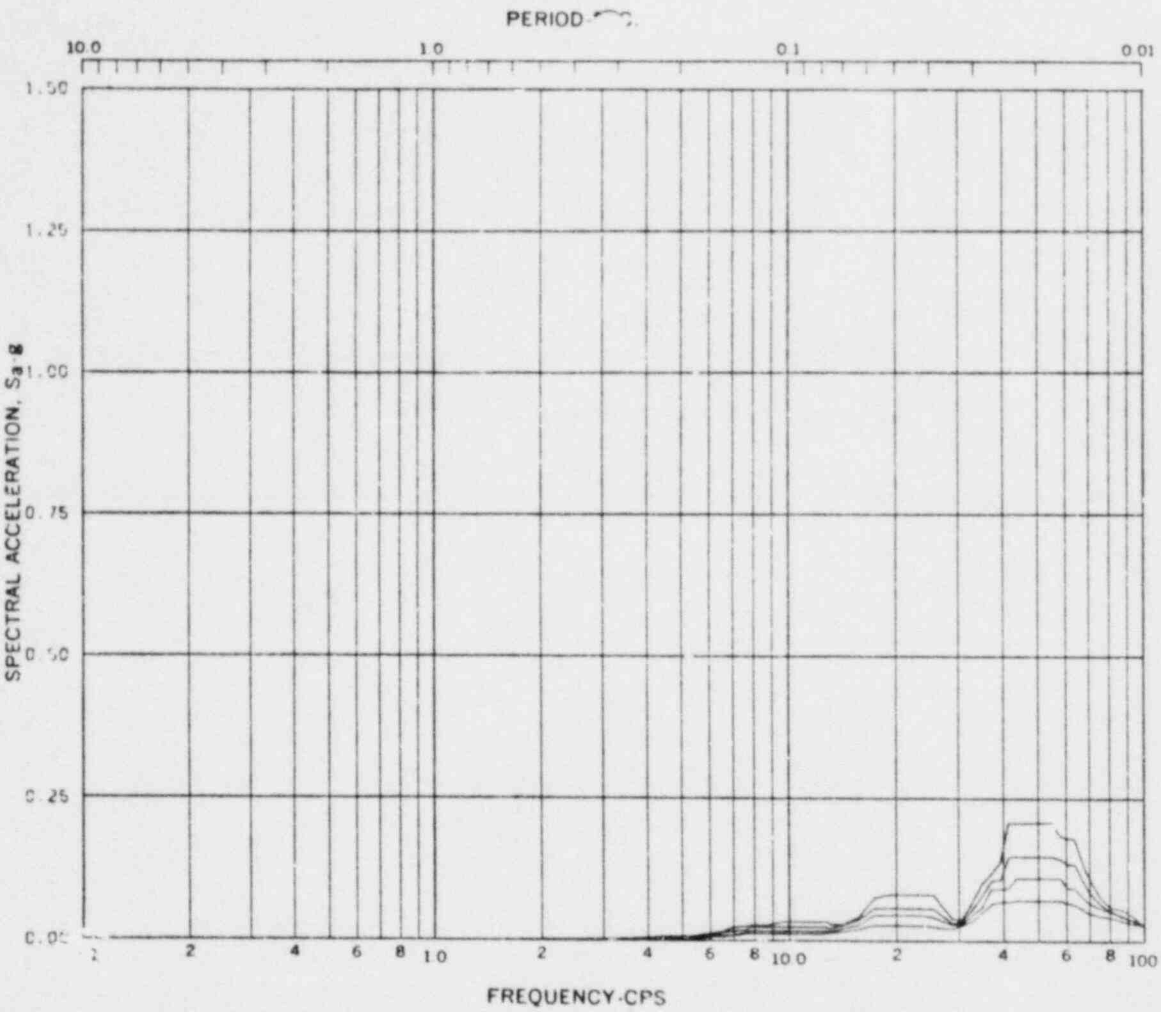
NOTE:

1. 0.05 DAMPING NOT INCLUDED.

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
CONDENSATION OSCILLATION
WITH ADS
DIRECTION X

FIGURE A.2-55



Acceleration Spectra for WETWELL WALL

Load Case: CO FOR COMBINATION WITH ADS

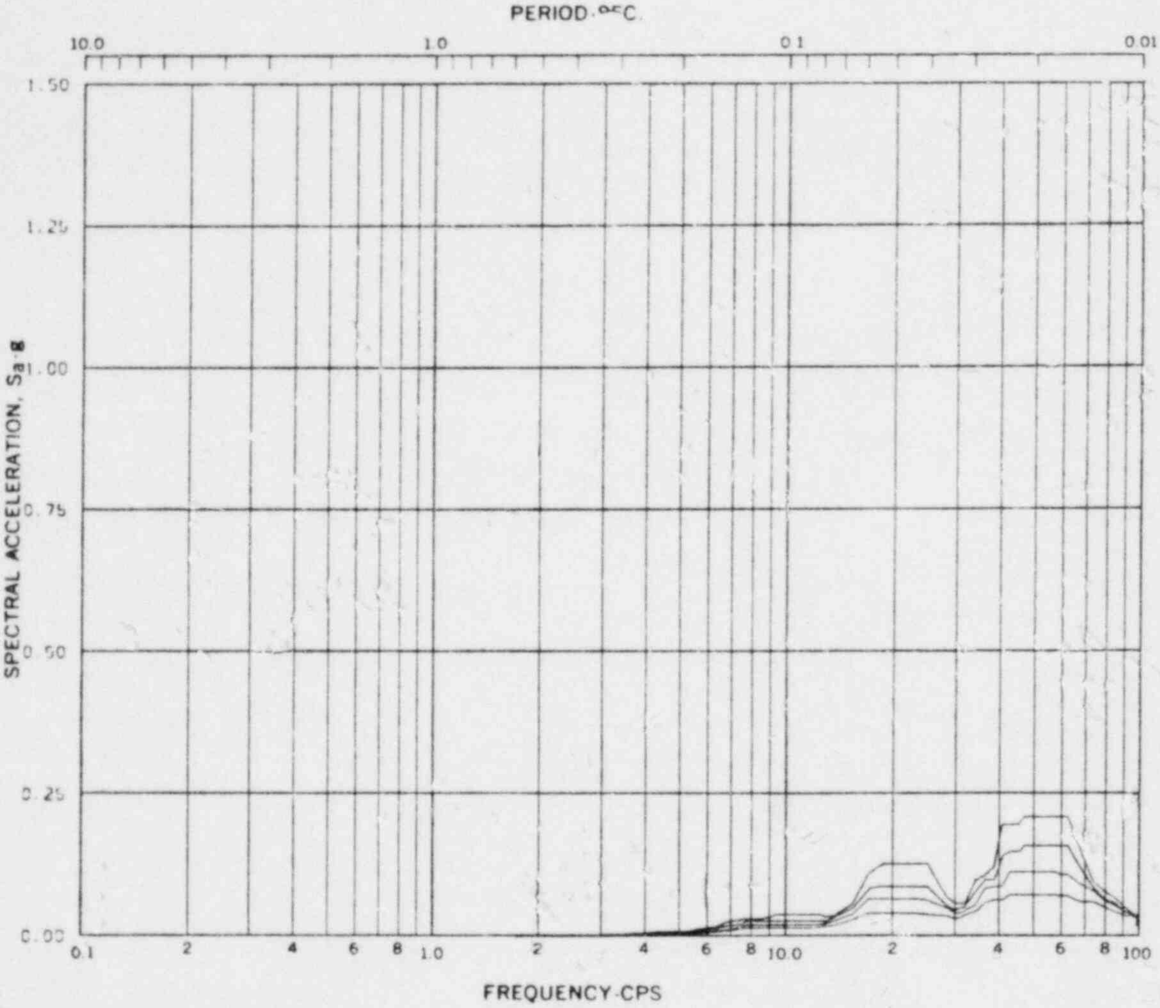
Node: 131 Direction: VERT Elev: 205'-11" Angle: 0°

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
CONDENSATION OSCILLATION
WITH ADS
DIRECTION Z

FIGURE A.2-56



Acceleration Spectra for WETWELL WALL

Load Case: CO FOR COMBINATION WITH ADS

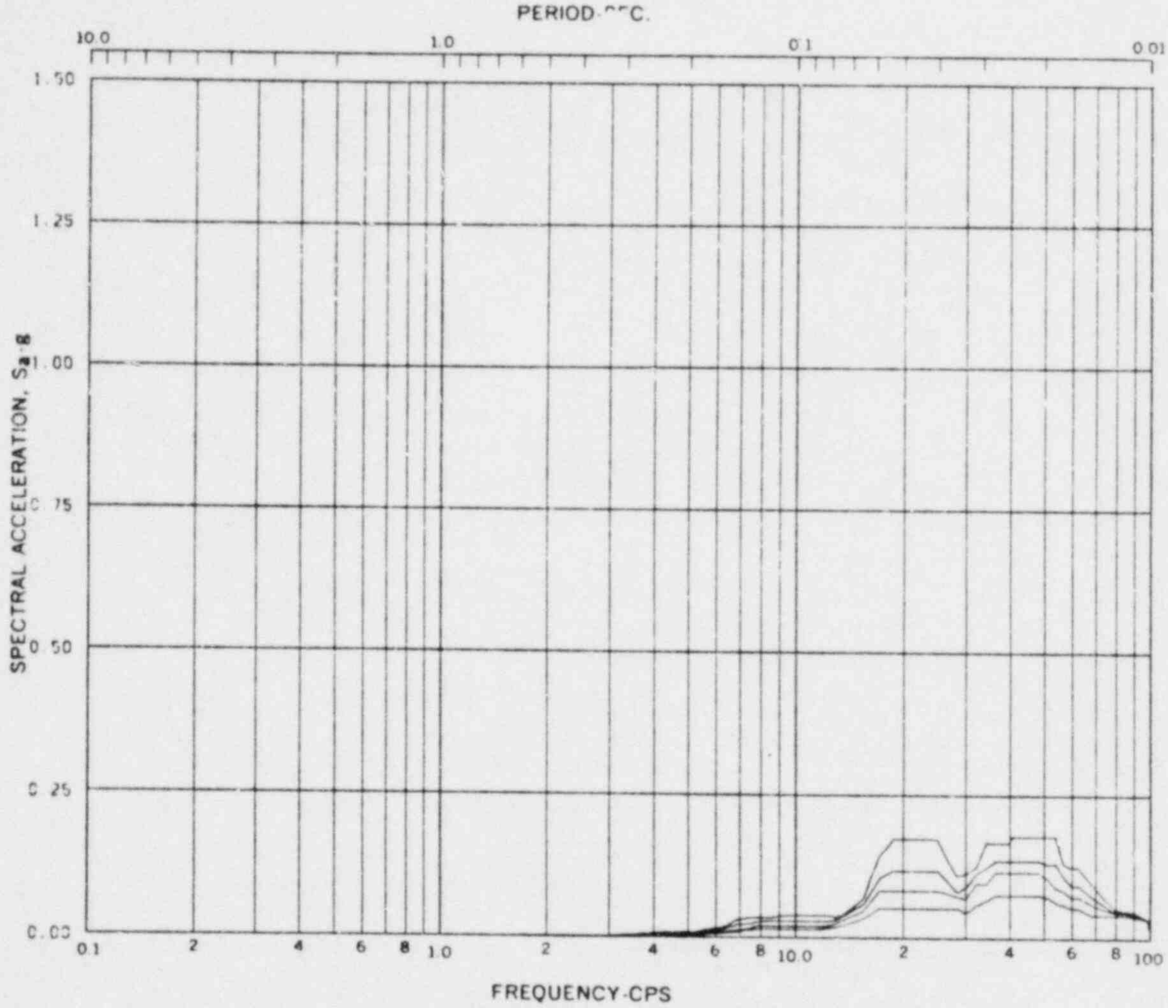
Node: 291 Direction: VERT Elev: 236'-2" Angle: 0°

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
CONDENSATION OSCILLATION
WITH ADS
DIRECTION Z

FIGURE A.2-57



Acceleration Spectra for DRYWELL

Load Case: CO FOR COMBINATION WITH ADS

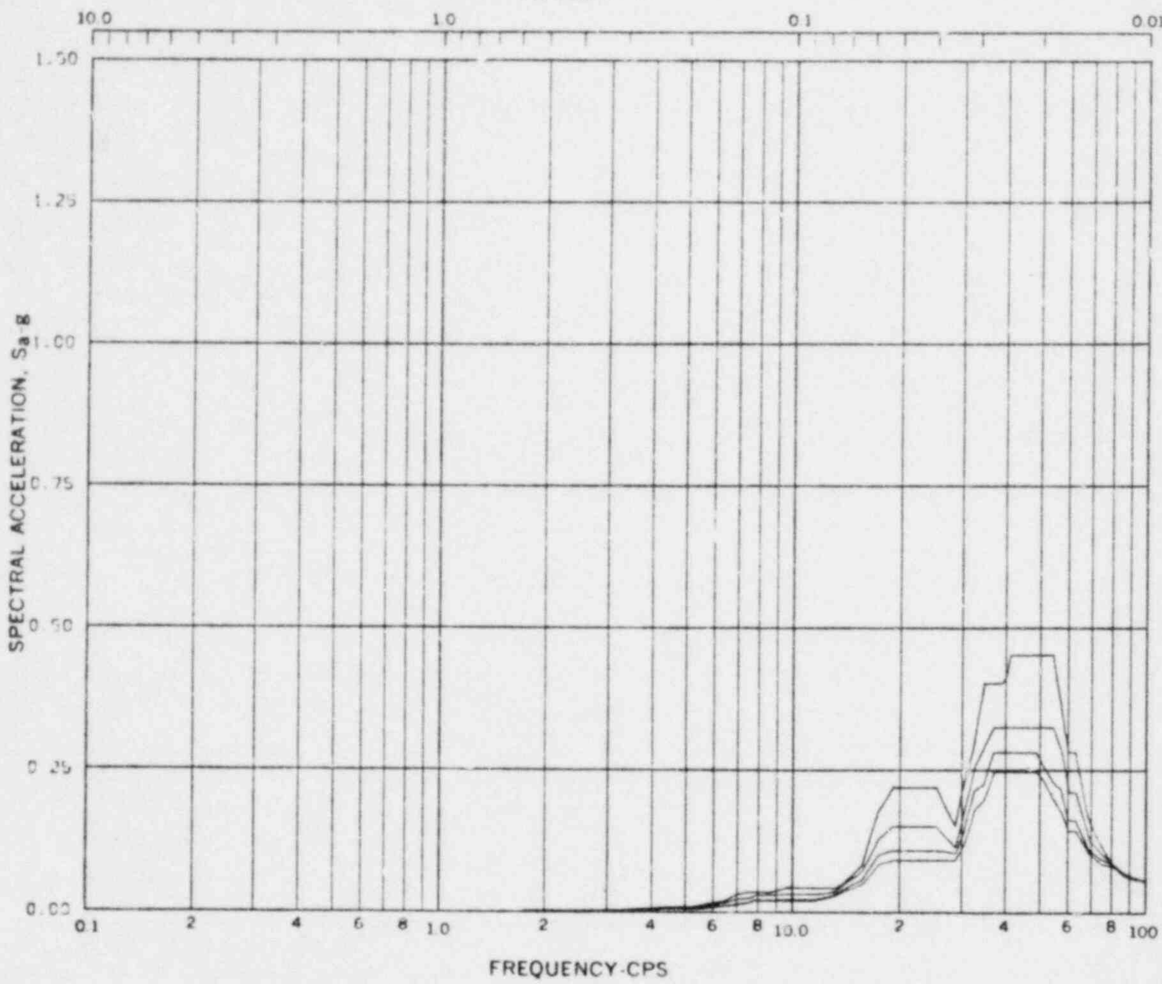
Node: 331 Direction: VERT Elev: 264'-6" Angle: 0°

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
CONDENSATION OSCILLATION
WITH ADS
DIRECTION Z

FIGURE A.2-58



Acceleration Spectra for DRYWELL

Load Case: CO FOR COMBINATION WITH ADS

Node: 431 Direction: VERT Elev: 3?5'-8" Angle: 0°

Damping: 0.005,0.01,0.02,0.03

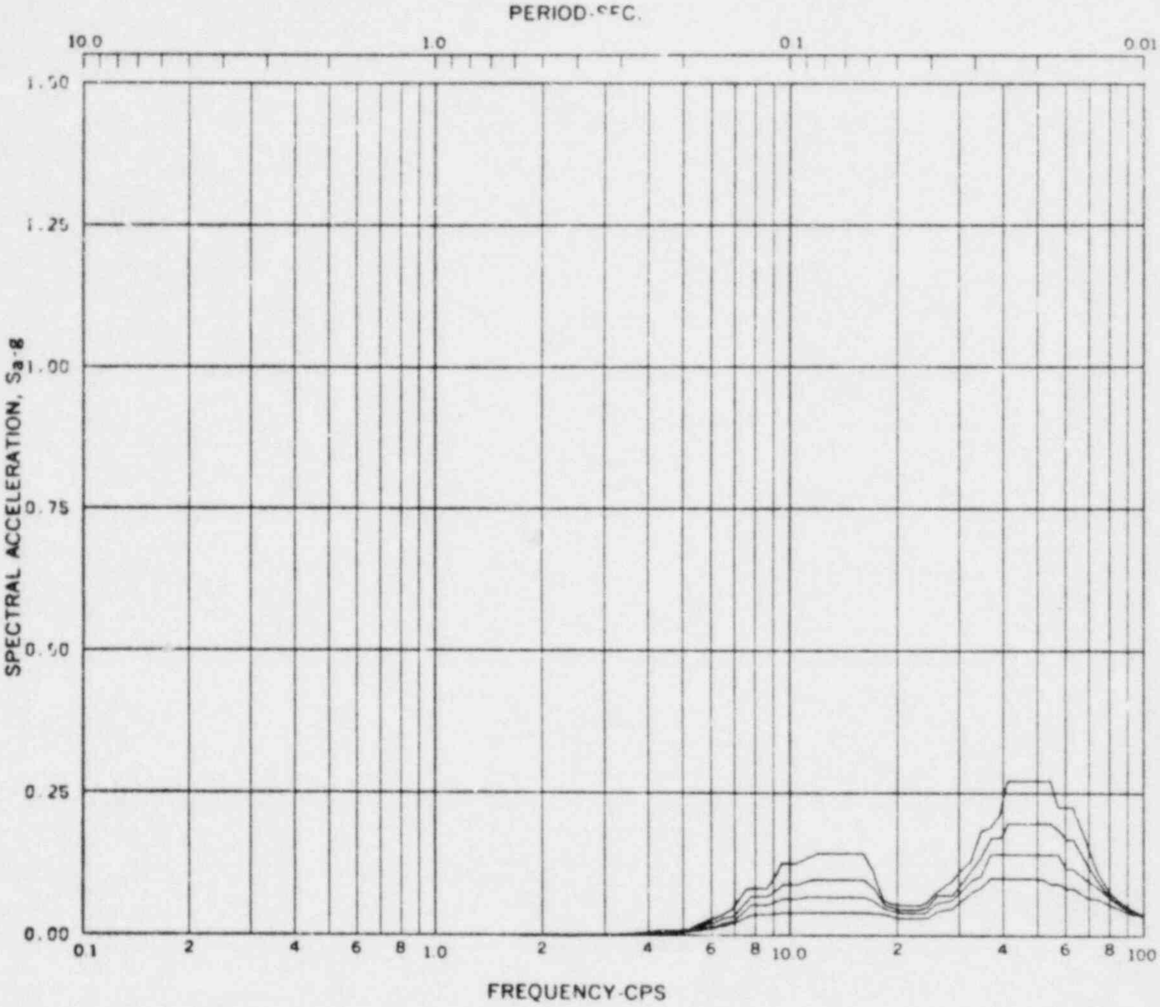
NOTE:

1. 0.05 DAMPING NOT INCLUDED.

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
CONDENSATION OSCILLATION
WITH ADS
DIRECTION Z

FIGURE A.2-59



Acceleration Spectra for PEDESTAL

Load Case: CO FOR COMBINATION WITH ADS

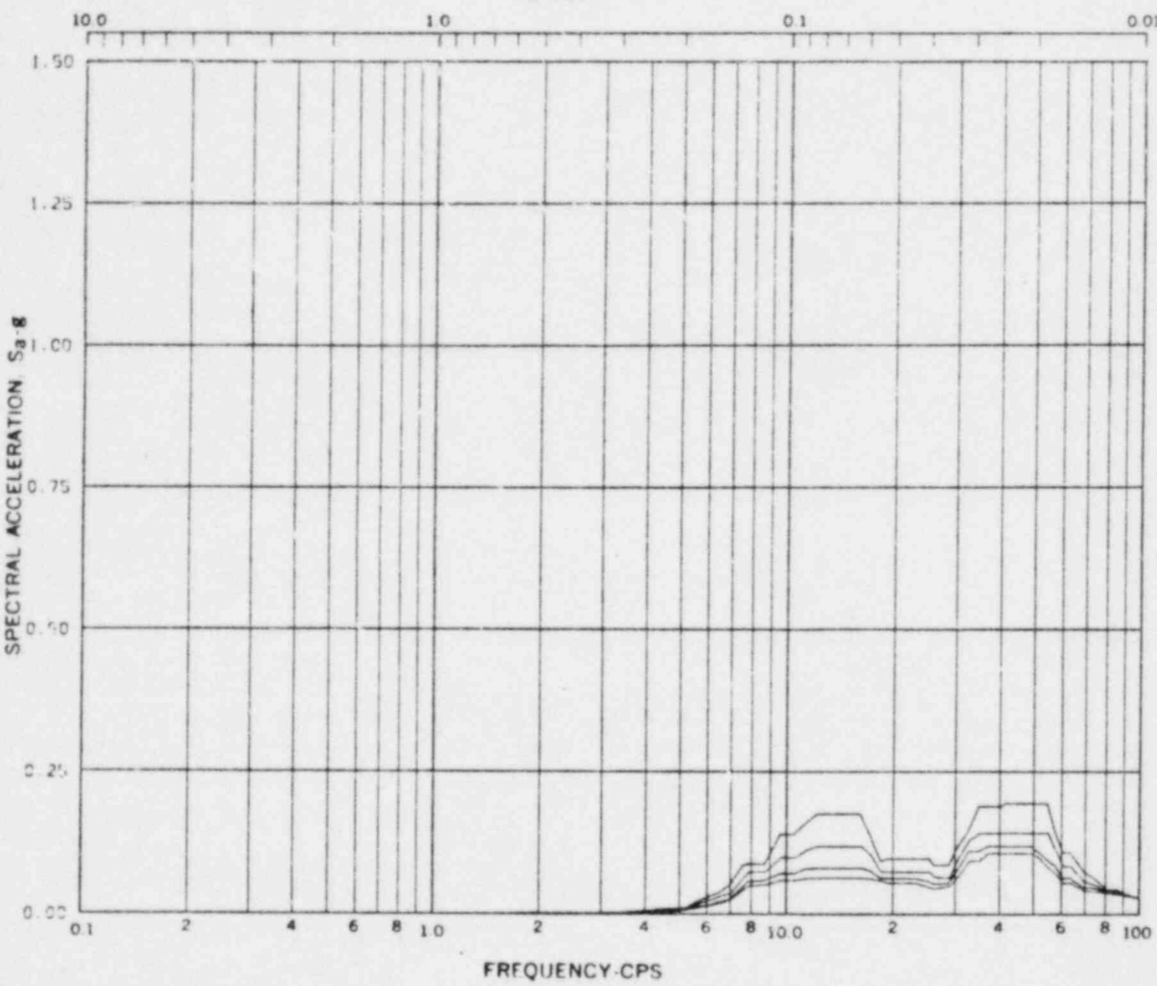
Node: 211 Direction: VERT Elev: 236'-2" Angle: 0°

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
CONDENSATION OSCILLATION
WITH ADS
DIRECTION Z

FIGURE A.2-60



Acceleration Spectra for ___ DESTAL

Load Case: CO FOR COMBINATION WITH ADS

Node: 531 Direction: VERT Elev: 263'-8 5/8" Angle: 0°

Damping: 0.005,0.01,0.02,0.03

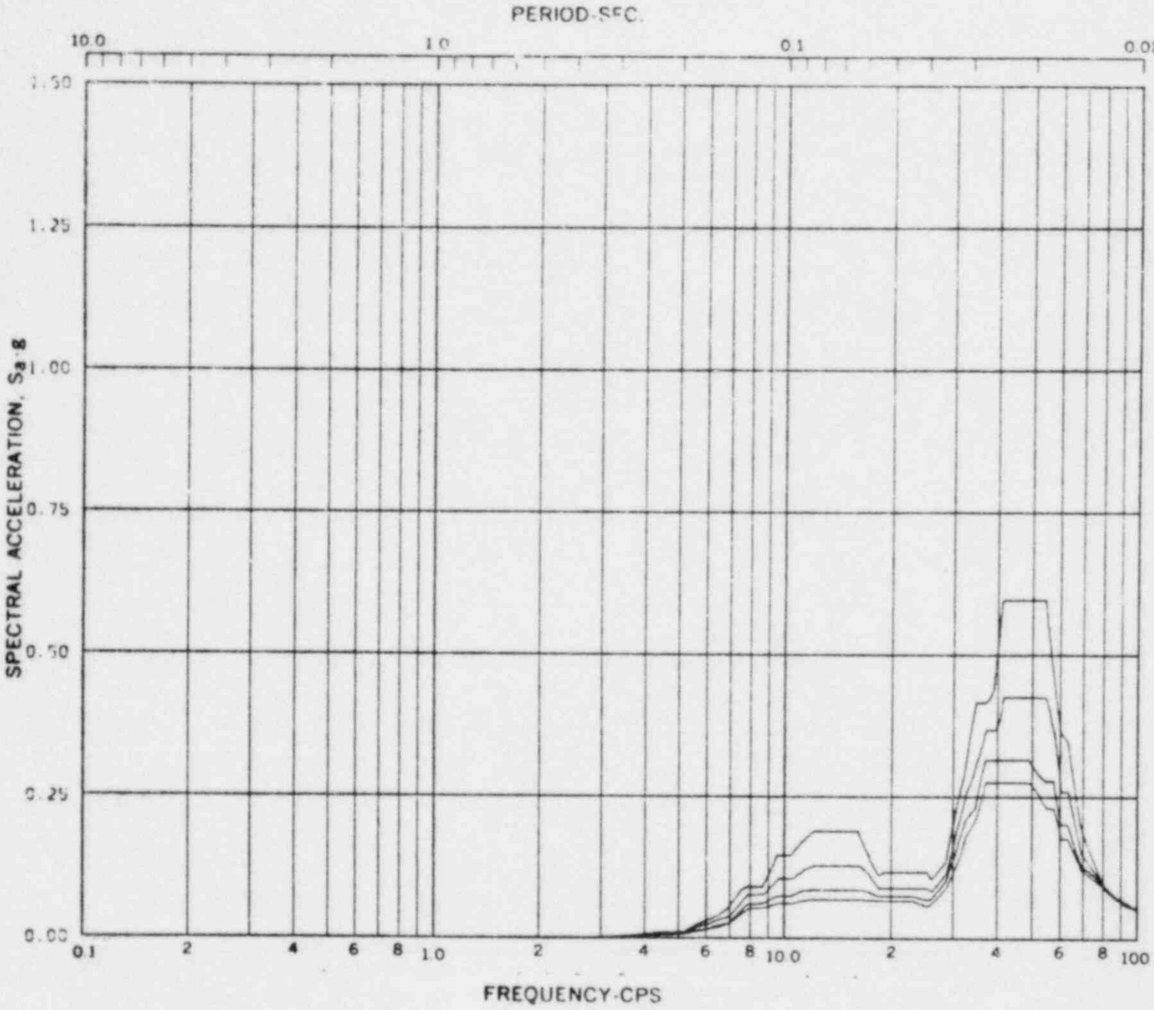
NOTE:

1. 0.05 DAMPING NOT INCLUDED.

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
CONDENSATION OSCILLATION
WITH ADS
DIRECTION Z

FIGURE A.2-61



Acceleration Spectra for SHIELD WALL

Load Case: CO FOR COMBINATION WITH ADS

Node: 841 Direction: VERT Elev: 312'-8" Angle: 0°

Damping: 0.005,0.01,0.02,0.03

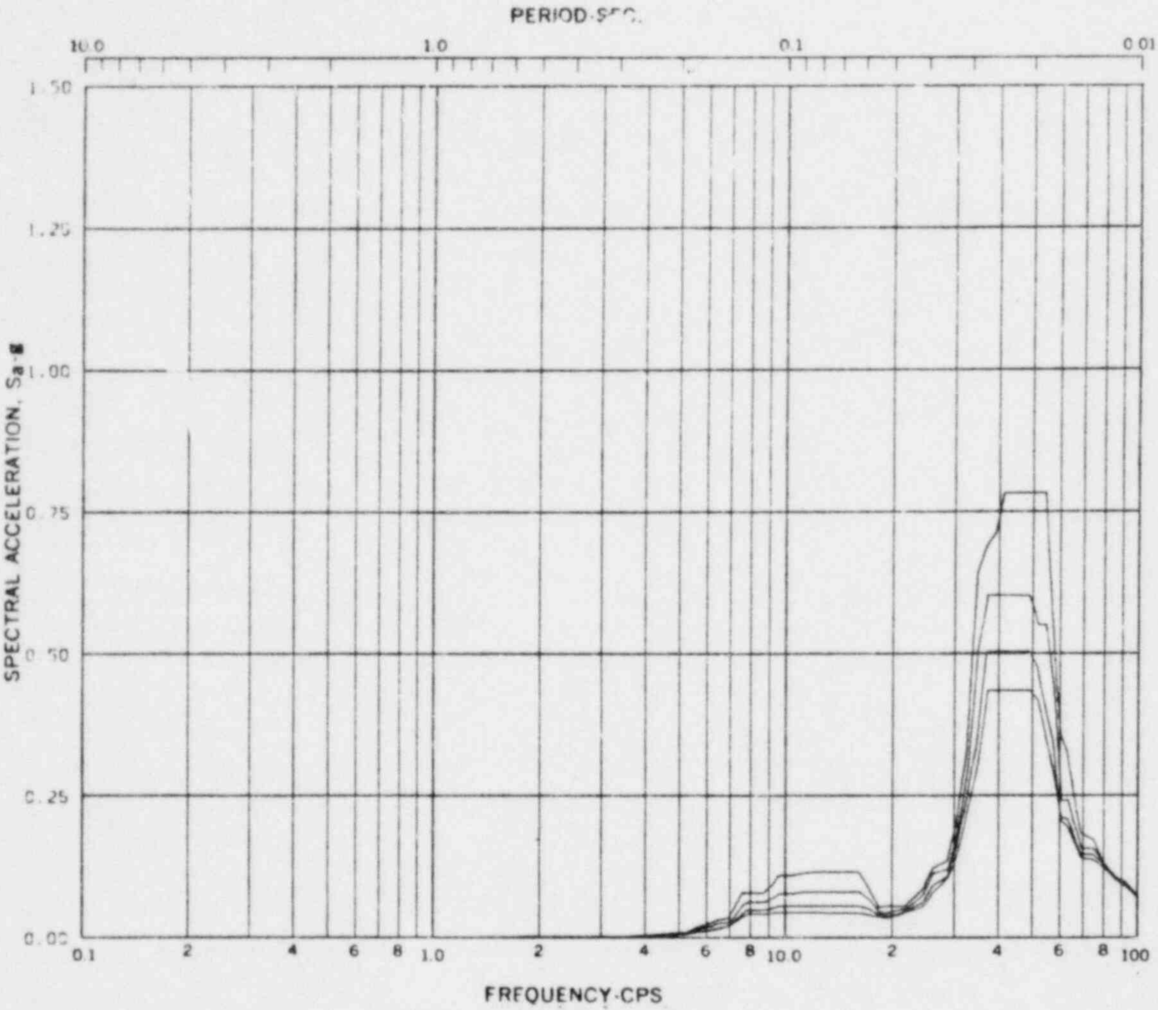
NOTE:

1. 0.05 DAMPING NOT INCLUDED.

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
CONDENSATION OSCILLATION
WITH ADS
DIRECTION Z

FIGURE A.2-62



Acceleration Spectra for DIAPHRAGM SLAB

Load Case: CO FOR COMBINATION WITH ADS

Node: 231 Direction: VERT Elev: 236'-2" Angle: 0°

Damping: 0.005,0.01,0.02,0.03

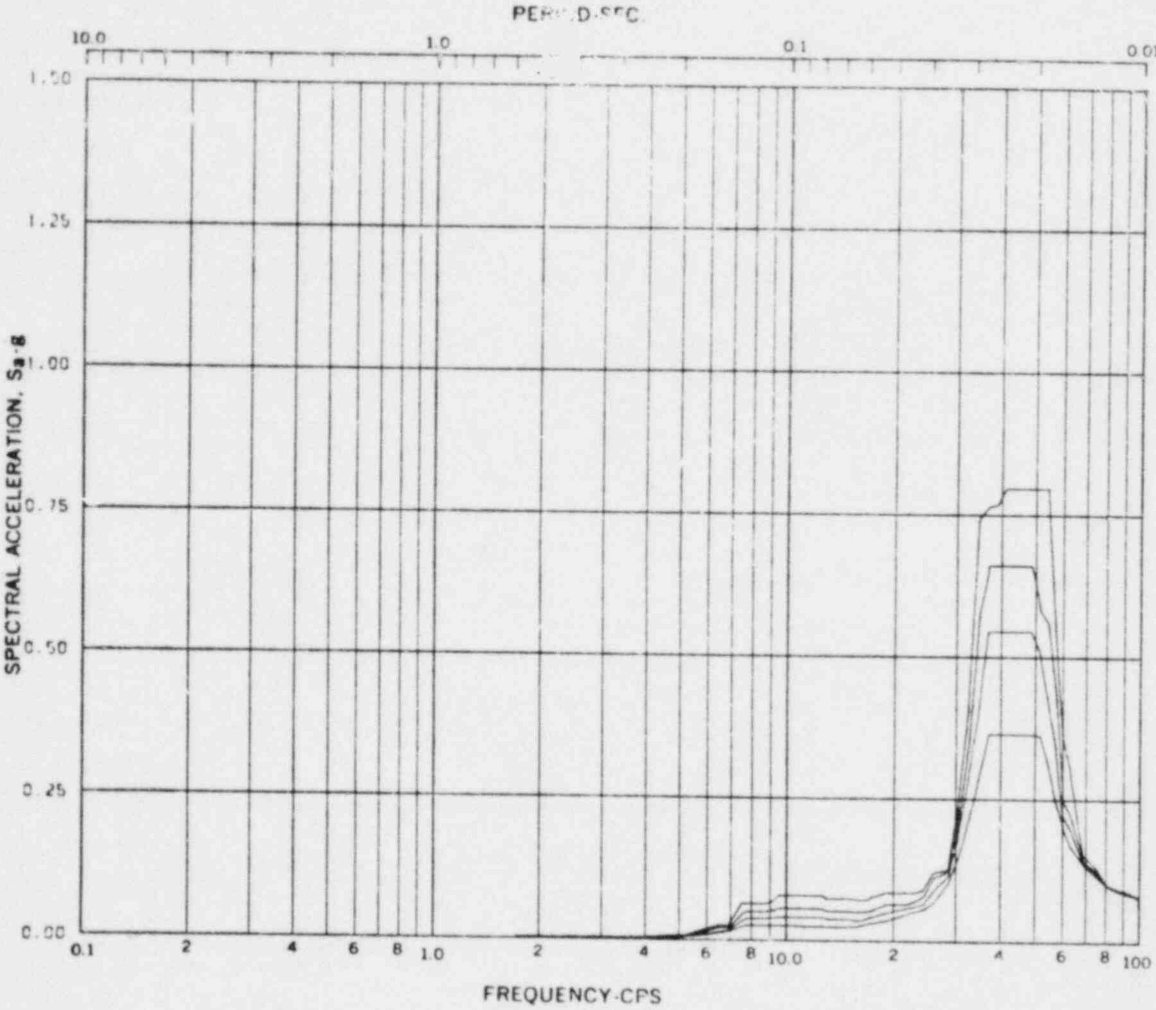
NOTE:

1. 0.05 DAMPING NOT INCLUDED.

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
CONDENSATION OSCILLATION
WITH ADS
DIRECTION Z

FIGURE A.2-63



Acceleration Spectra for DIAPHRAGM SLAB

Load Case: CO FOR COMBINATION WITH ADS

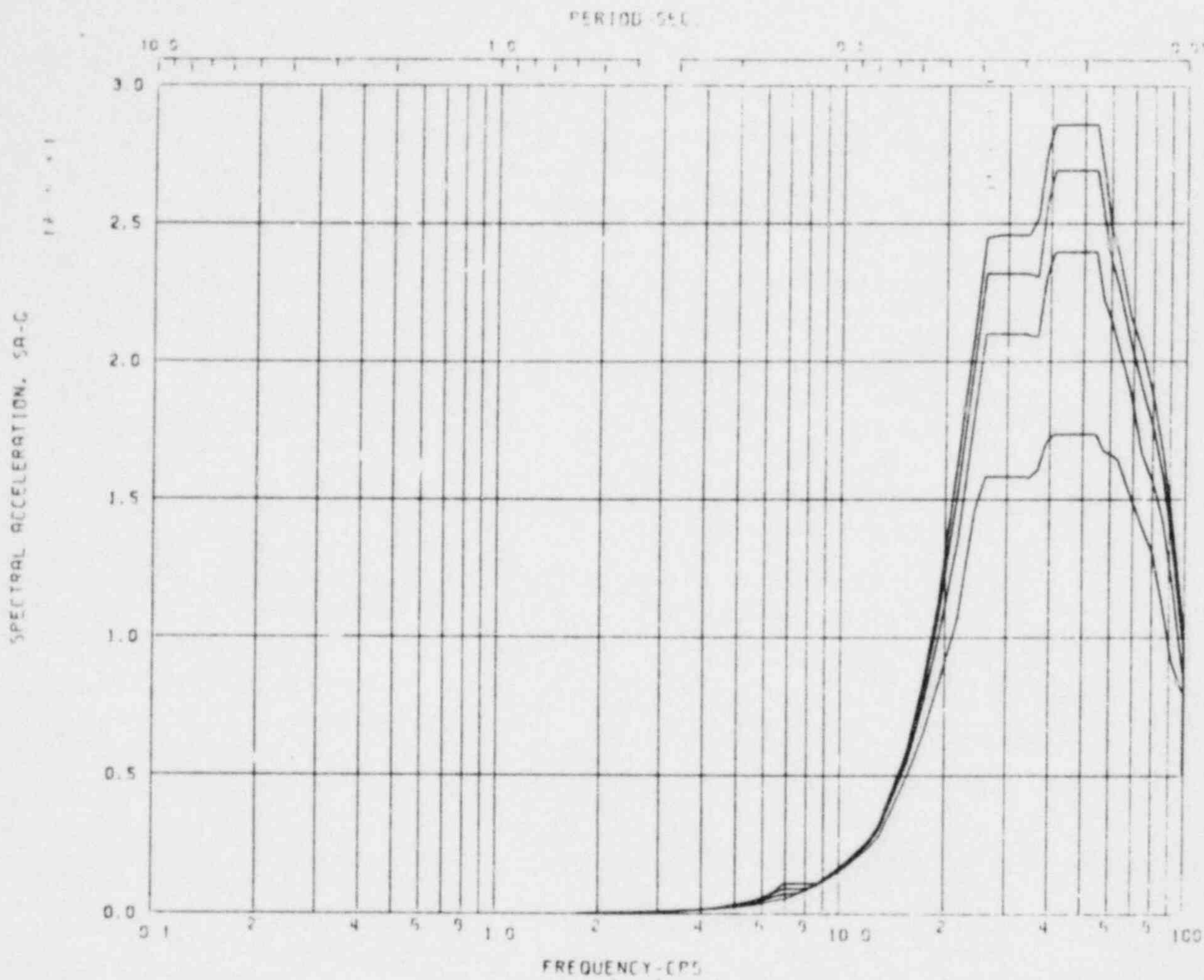
Node: 252 Direction: VERT Elev: 236'-2" Angle: 22°30'

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
CONDENSATION OSCILLATION
WITH ADS
DIRECTION Z

FIGURE A.2-64



Acceleration Spectra for WETWELL WALL

Load Case: CHUG 700 SYM/700A ASYM

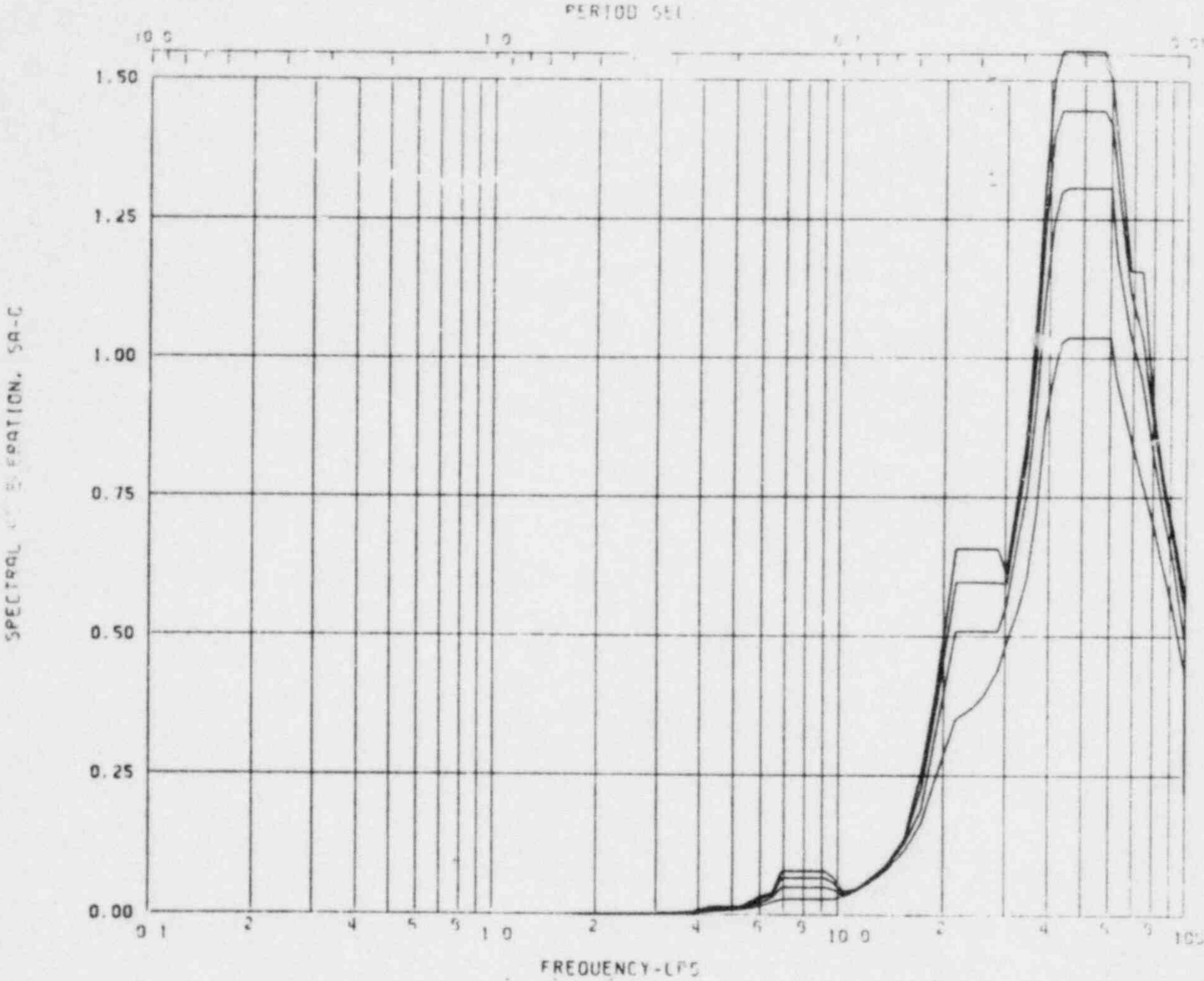
Node: 131 Direction: HORIZ Elev: 205'-11" Angle: -

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
CHUGGING
DIRECTION X

FIGURE A.2-65



Acceleration Spectra for WETWELL WALL

Load Case: CHUG 700 SYM/700A ASYM

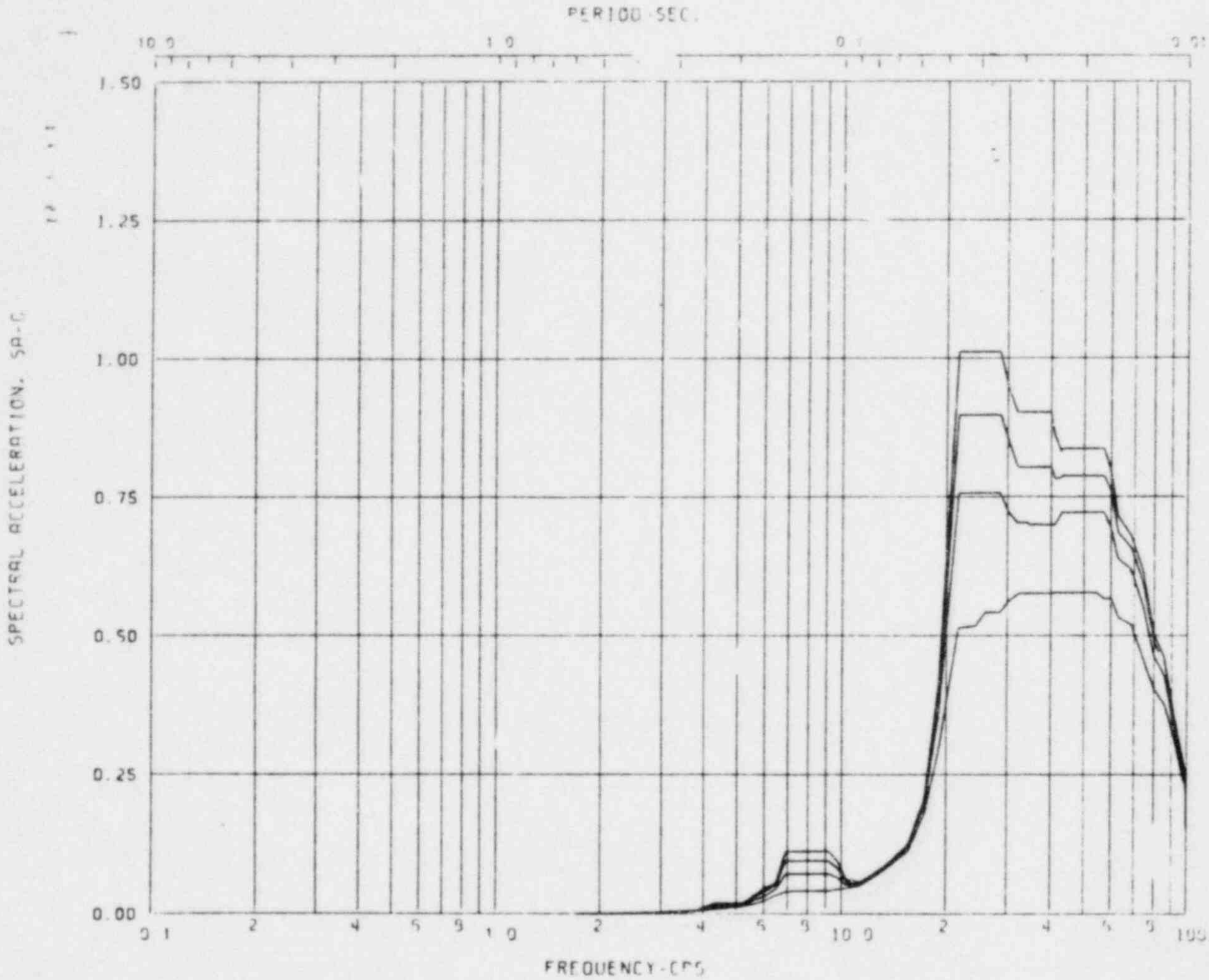
Node: 291 Direction: HORIZ Elev: 236'-2" Angle: -

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
CHUGGING
DIRECTION X

FIGURE A.2-66



Acceleration Spectra for DRYWELL WALL

Load Case: CHUG 700 SYM/700A ASYM

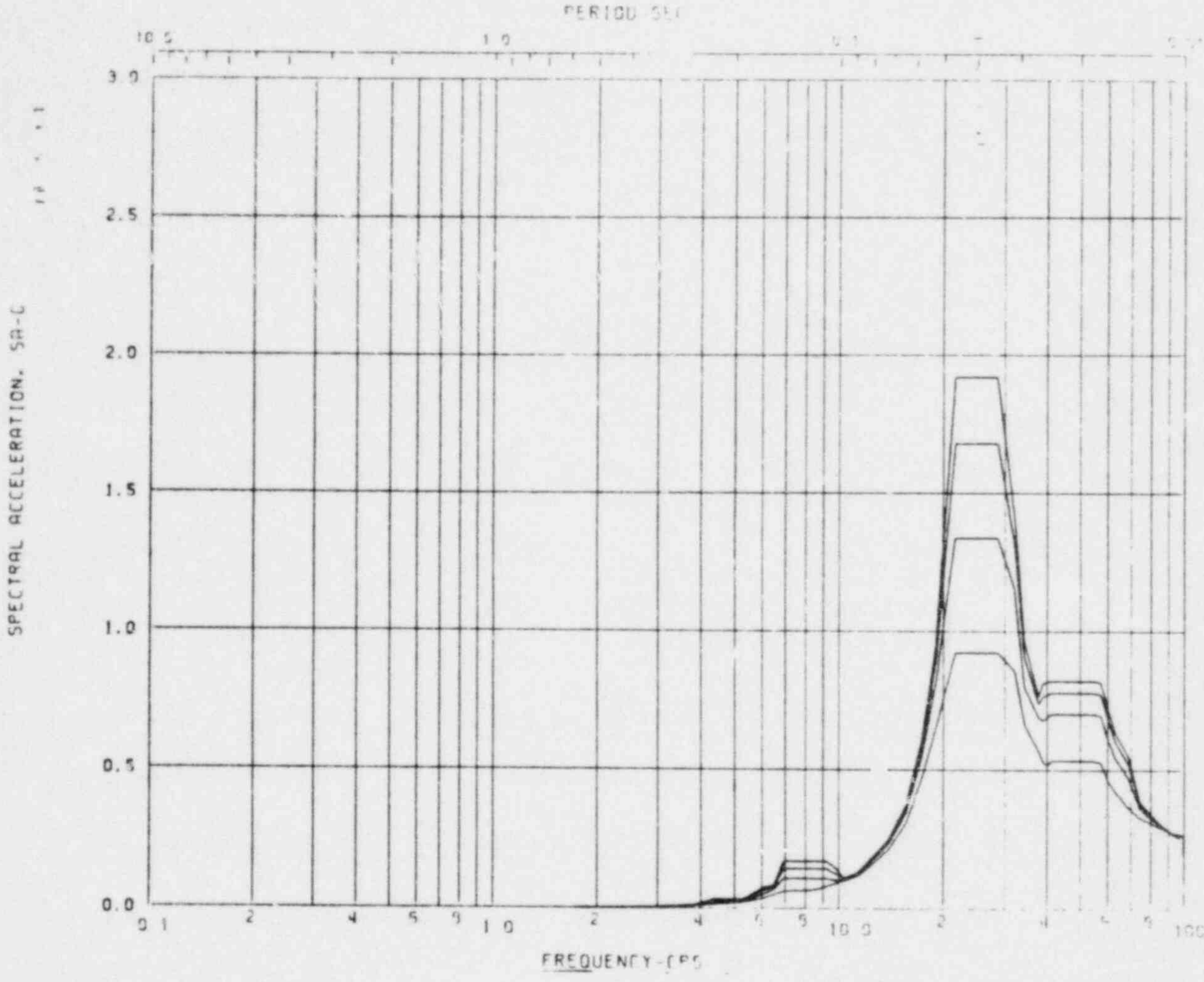
Node: 331 Direction: HORIZ Elev: 264'-6" Angle: -

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
CHUGGING
DIRECTION X

FIGURE A.2-67



Acceleration Spectra for DRYWELL WALL

Load Case: CHUG 700 SYM/700A ASYM

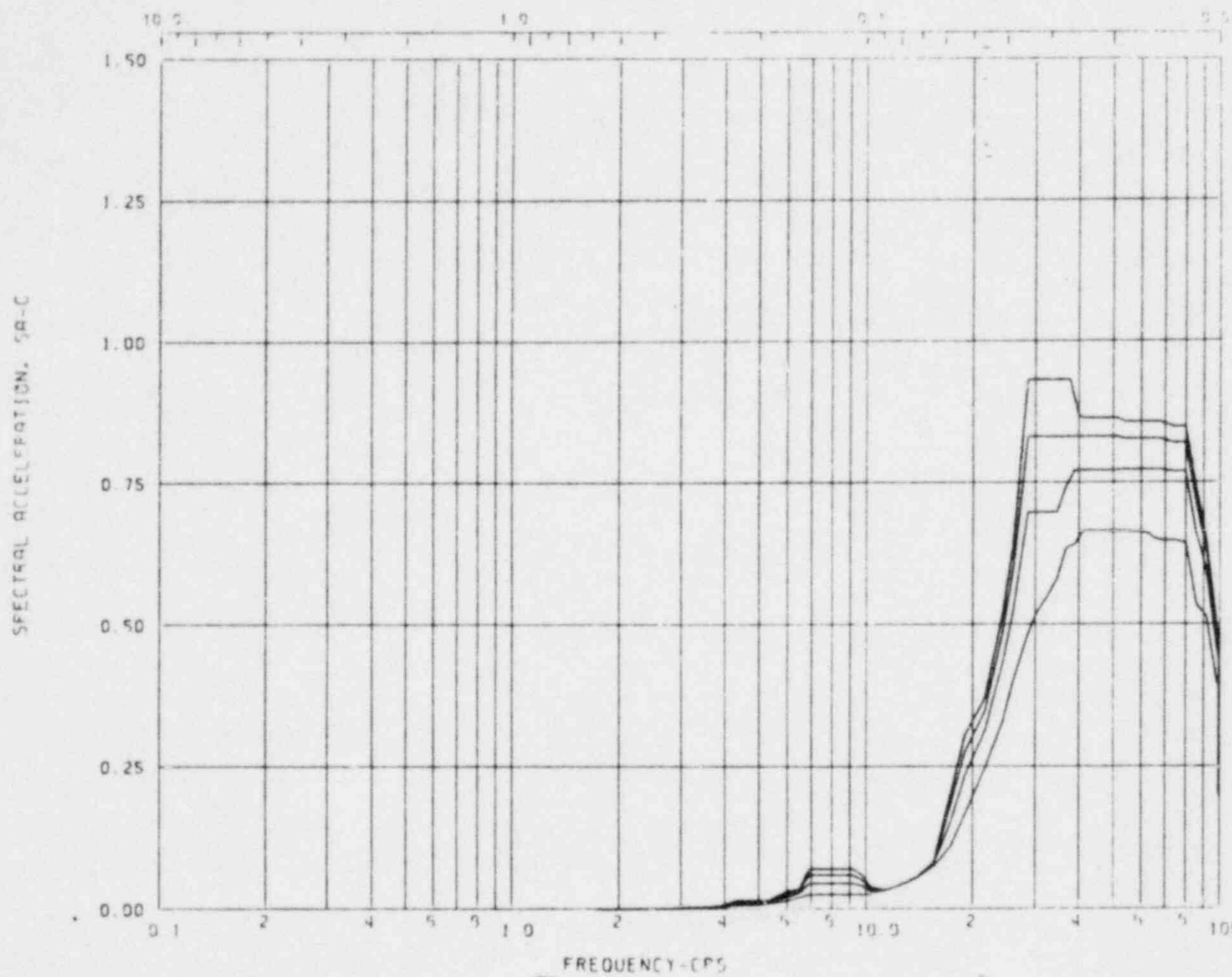
Node: 431 Direction: HORIZ Elev: 325'-8" Angle: -°

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
CHUGGING
DIRECTION X

FIGURE A.2-68



Acceleration Spectra for PEDESTAL

Load Case: CHUG 700 SYM/700A ASYM

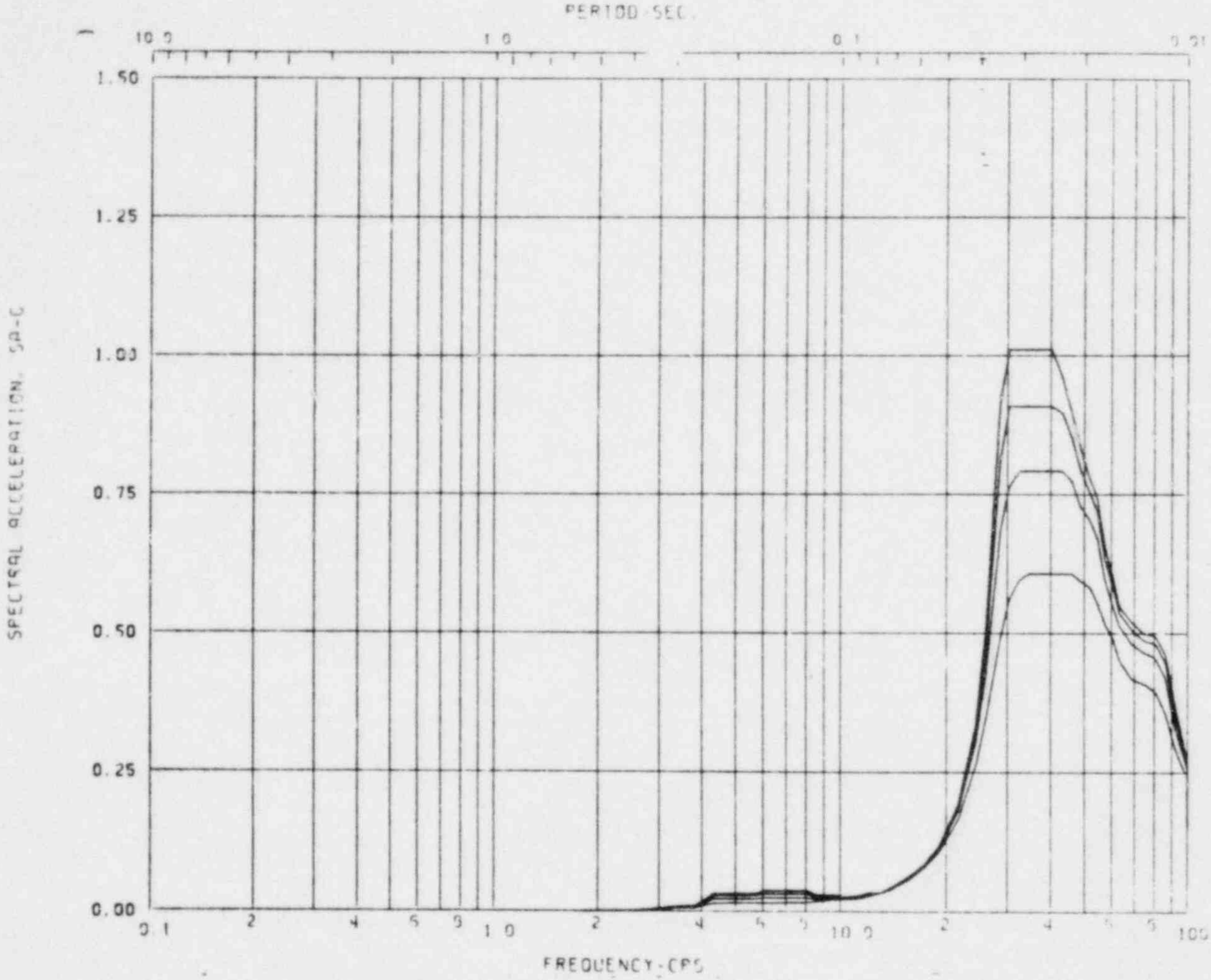
Node: 211 Direction: HORIZ Elev: 236'-2" Angle: -

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
CHUGGING
DIRECTION X

FIGURE A.2-69



Acceleration Spectra for PEDESTAL

Load Case: CHUG 700 SYM/700A ASYM

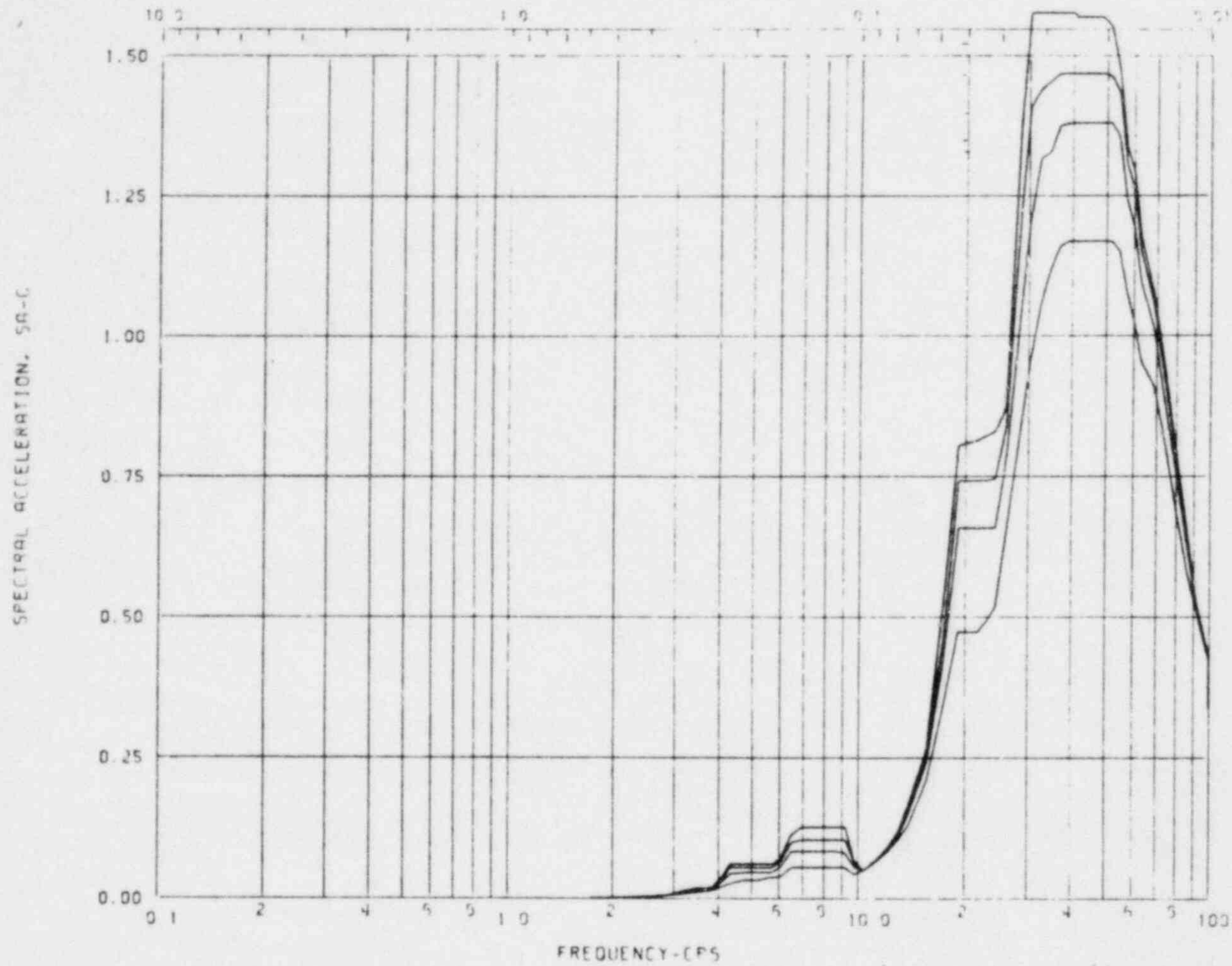
Node: 531 Direction: HORIZ Elev: 263'-8 5/8" Angle: -

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
CHUGGING
DIRECTION X

FIGURE A.2-70



Acceleration Spectra for SHIELD WALL

Load Case: CHUG 700 SYM/700A ASYM

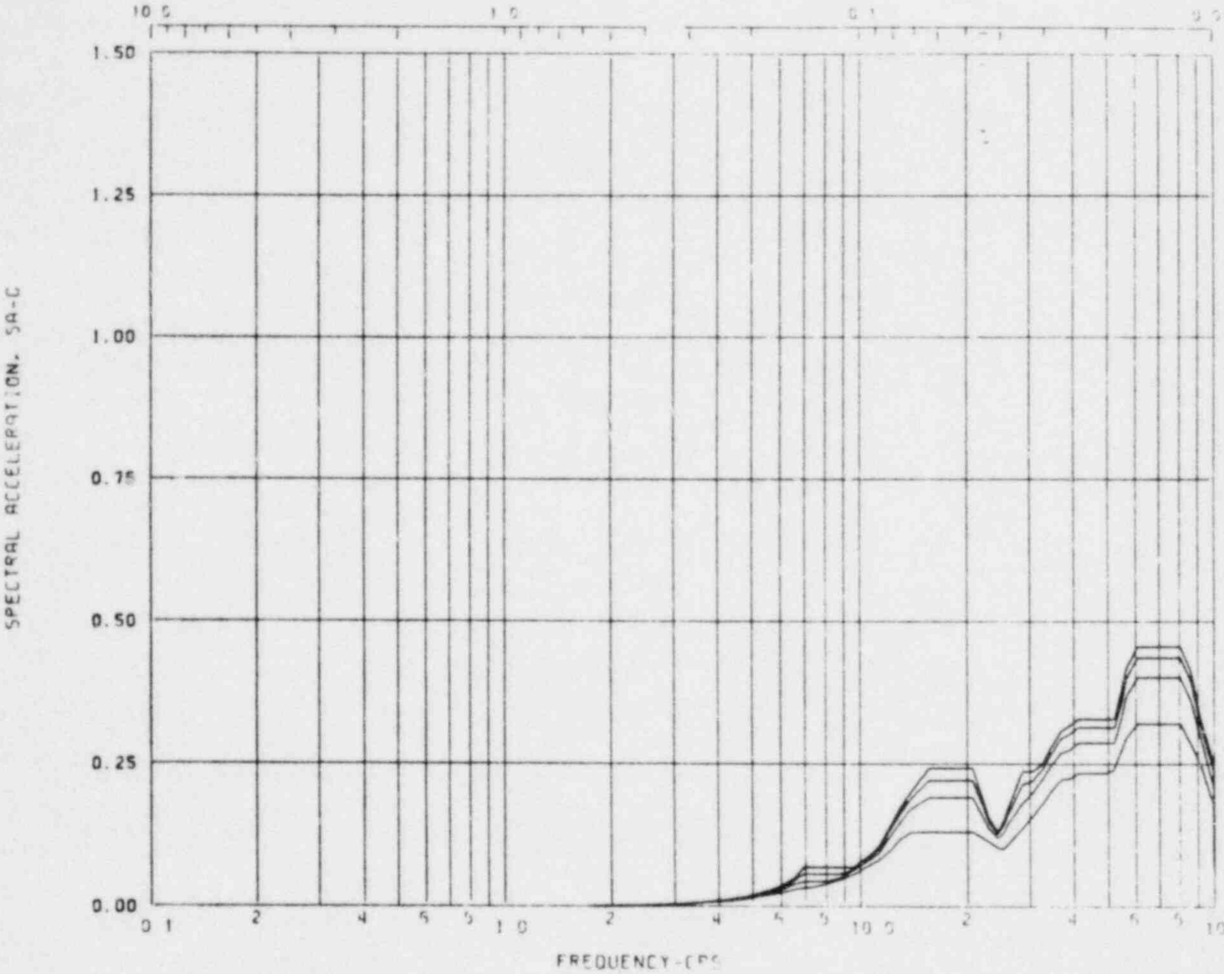
Node: 841 Direction: HORIZ Elev: 312'-8" Angle: -

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
CHUGGING
DIRECTION X

FIGURE A.2-71



Acceleration Spectra for WETWELL WALL

Load Case: CHUG 700 SYM/700A ASYM

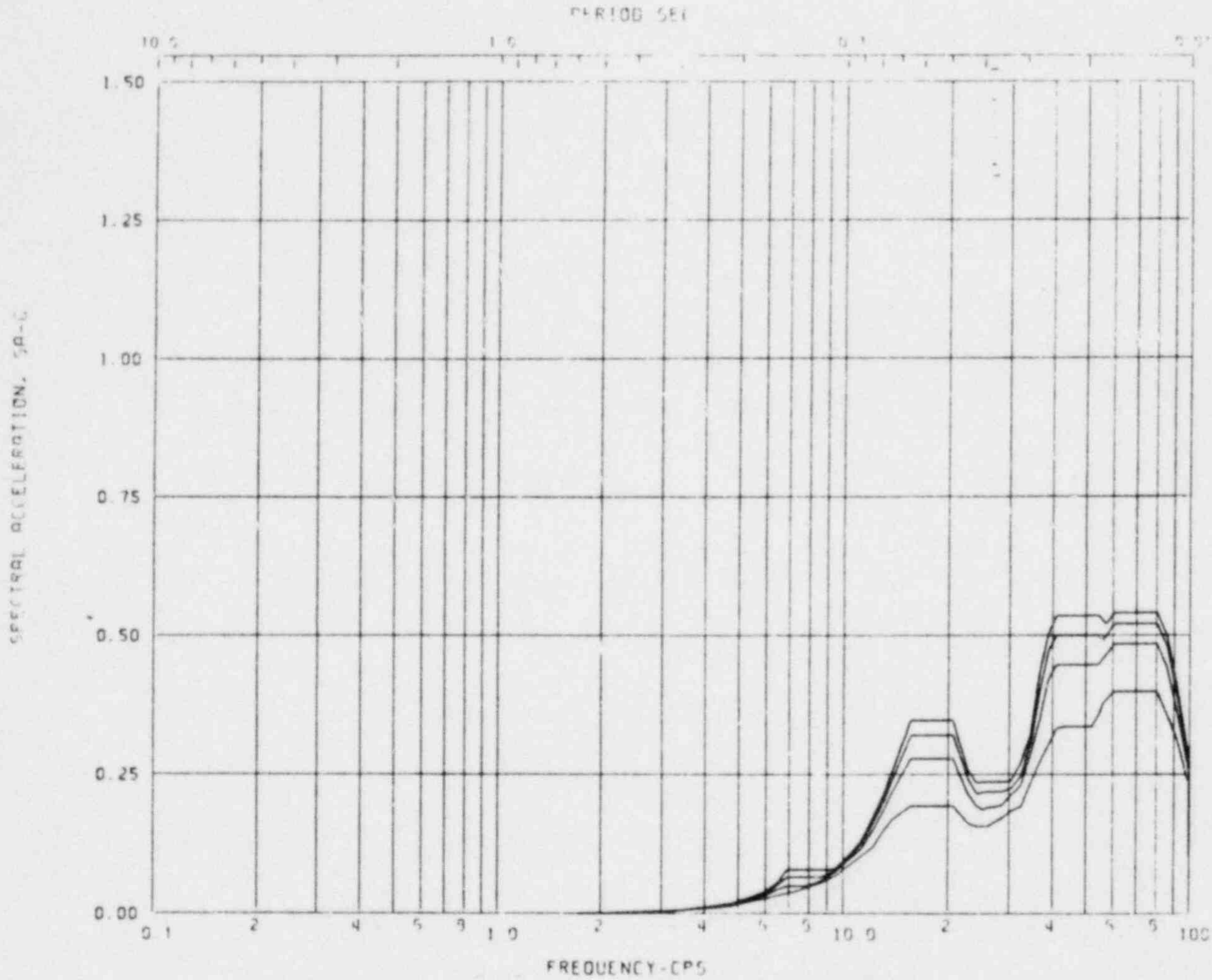
Node: 131 Direction: VERT Elev: 205'-11" Angle: -

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
CHUGGING
DIRECTION Z

FIGURE A.2-72



Acceleration Spectra for WETWELL WALL

Load Case: CHUG 700 SYM/700A ASYM

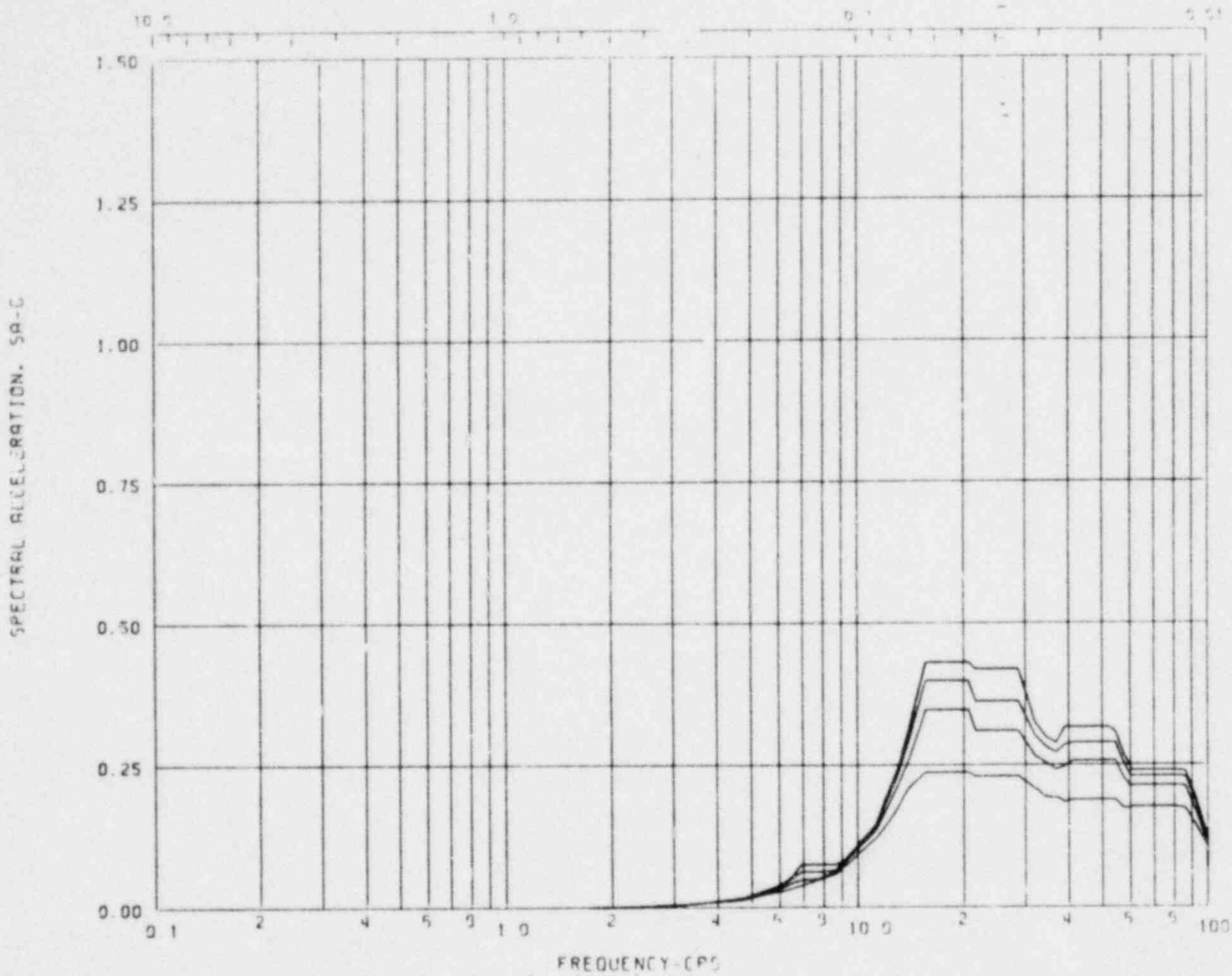
Node: 291 Direction: VERT Elev: 236'-2" Angle: -

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
CHUGGING
DIRECTION Z

FIGURE A.2-73



Acceleration Spectra for DRYWELL WALL

Load Case: CHUG 700 SYM/700A ASYM

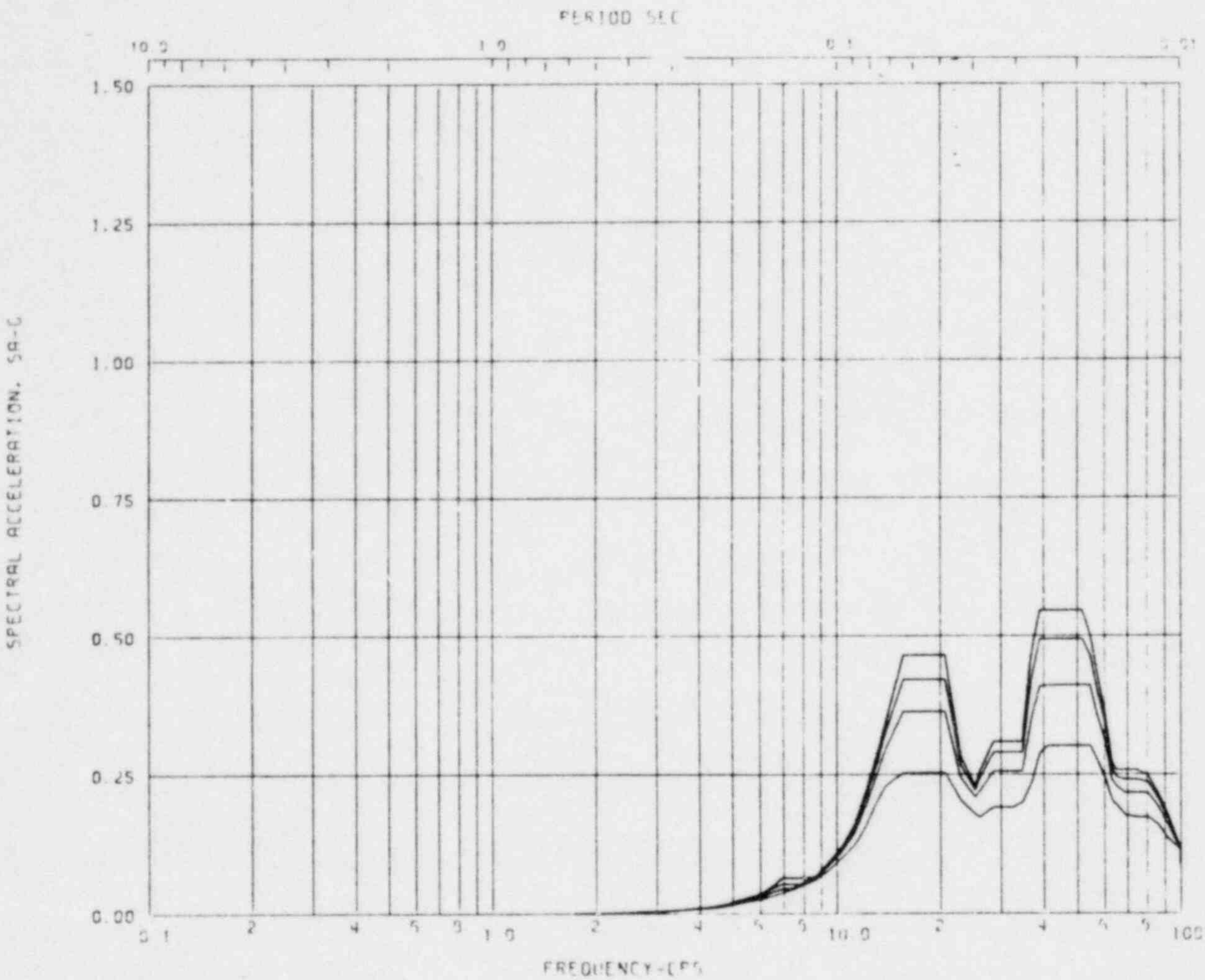
Node: 331 Direction: VERT Elev: 264'-6" Angle: -

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
CHUGGING
DIRECTION Z

FIGURE A.2-74



Acceleration Spectra for DRYWELL WALL

Load Case: CHUG 700 SYM/700A ASYM

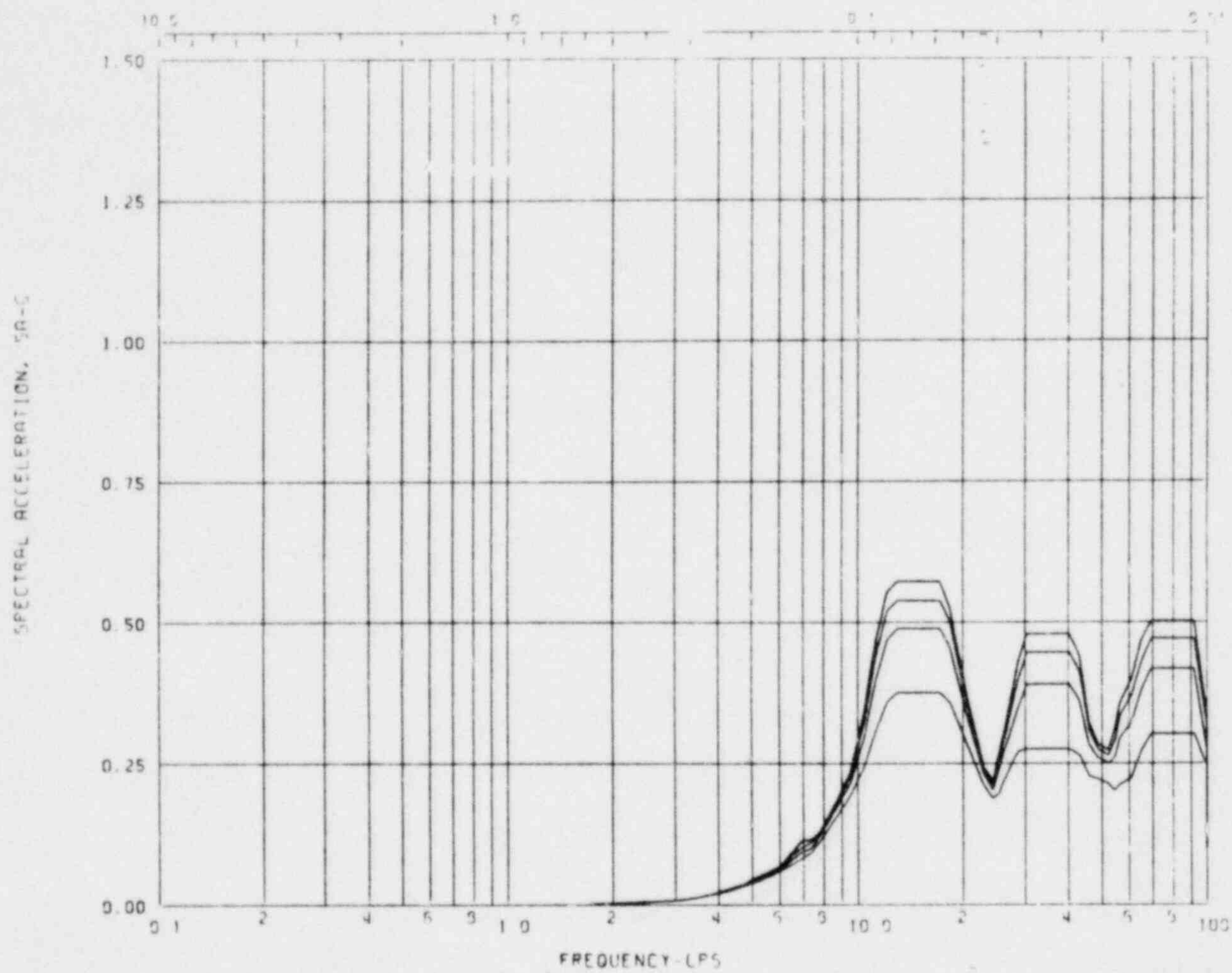
Node: 431 Direction: VERT Elev: 325'-8" Angle: -

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
CHUGGING
DIRECTION Z

FIGURE A.2-75



Acceleration Spectra for PEDESTAL

Load Case: CHUG 700 SYM/700A ASYM

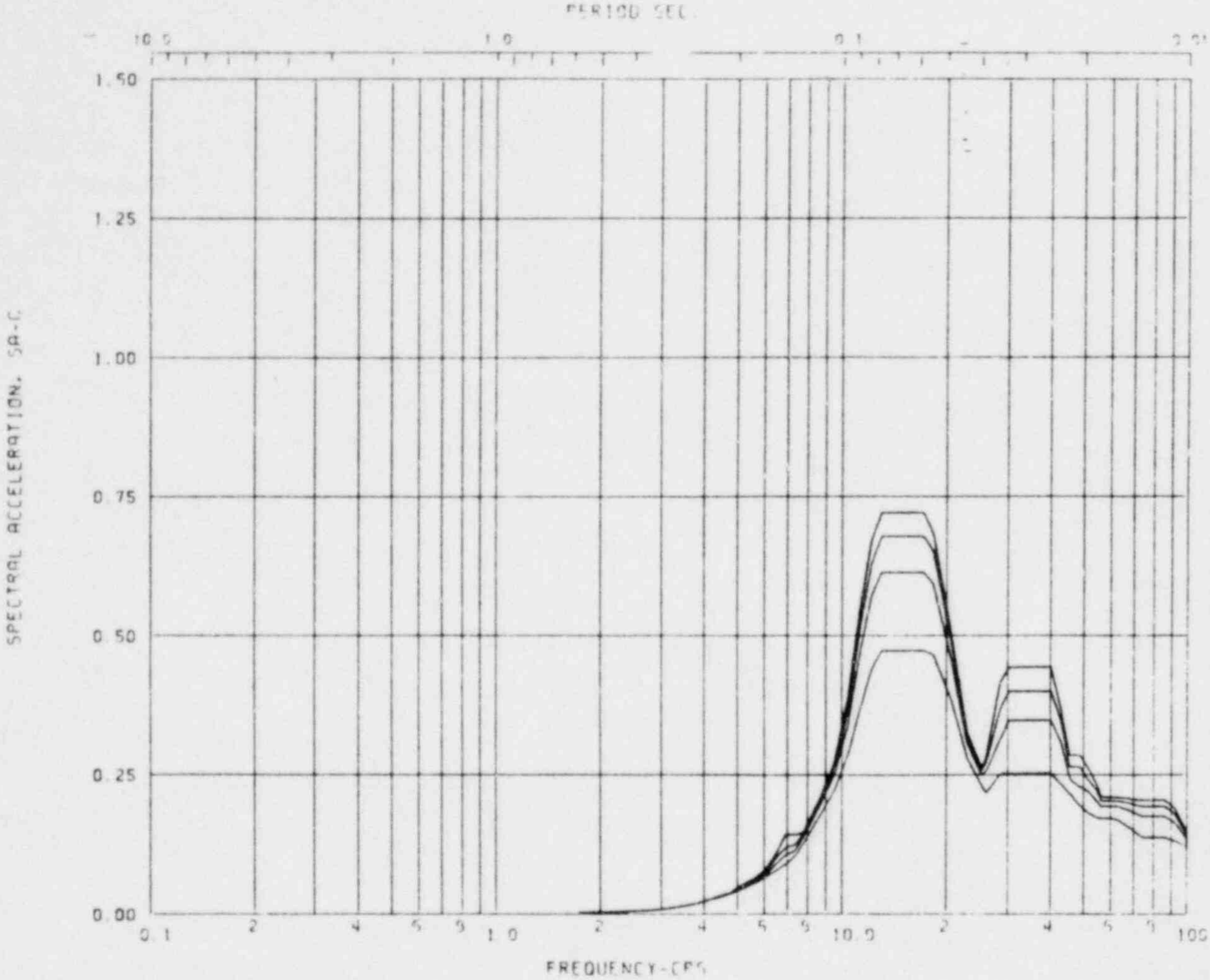
Node: 211 Direction: VERT Elev: 236'-2" Angle: -

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
CHUGGING
DIRECTION Z

FIGURE A.2-76



Acceleration Spectra for PEDESTAL

Load Case: CHUG 700 SYM/700A ASYM

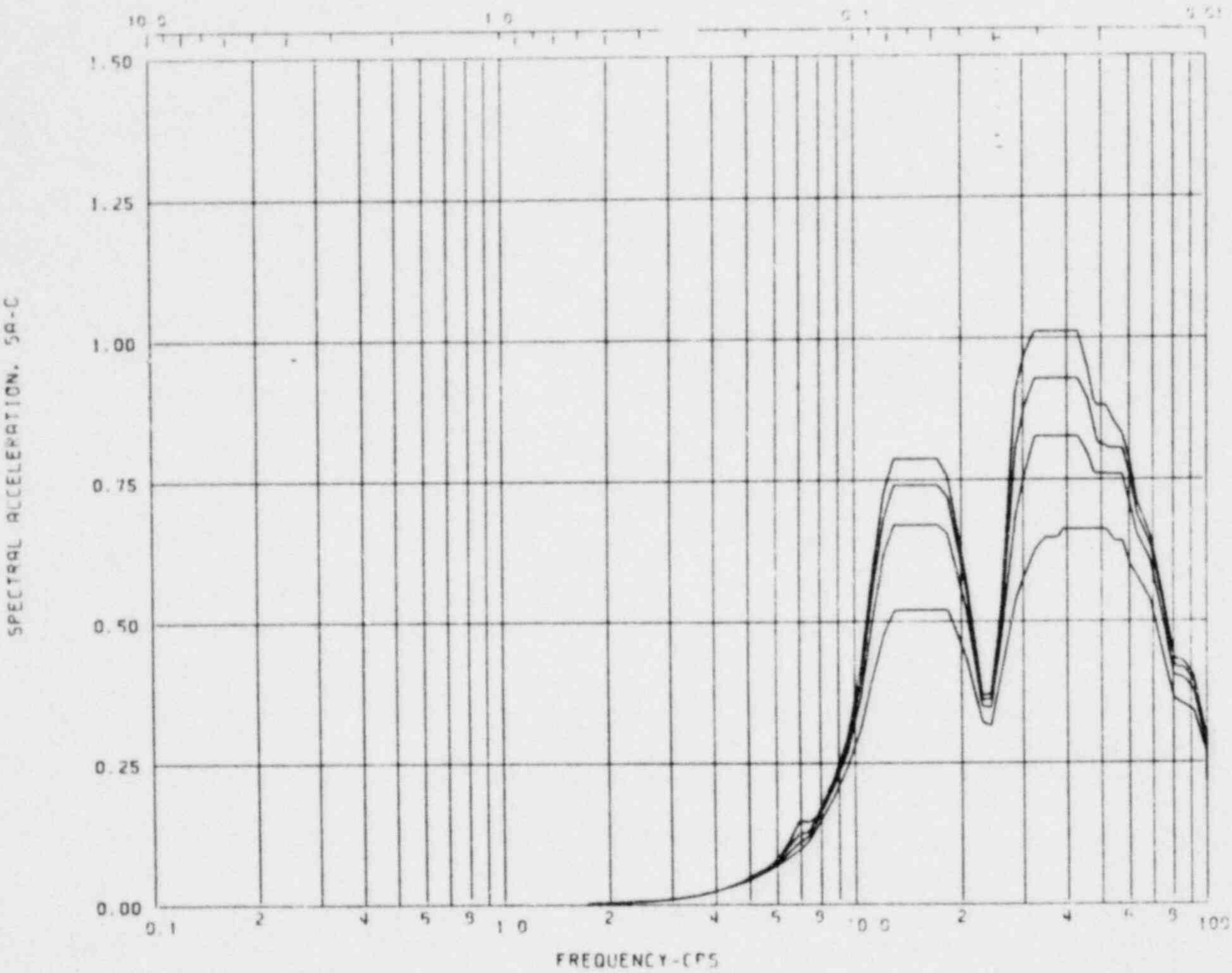
Node: 531 Direction: VERT Elev: 263'-8 5/8" Angle: -

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
CHUGGING
DIRECTION Z

FIGURE A.2-77



Acceleration Spectra for SHIELD WALL

Load Case: CHUG 700 SYM/700A ASYM

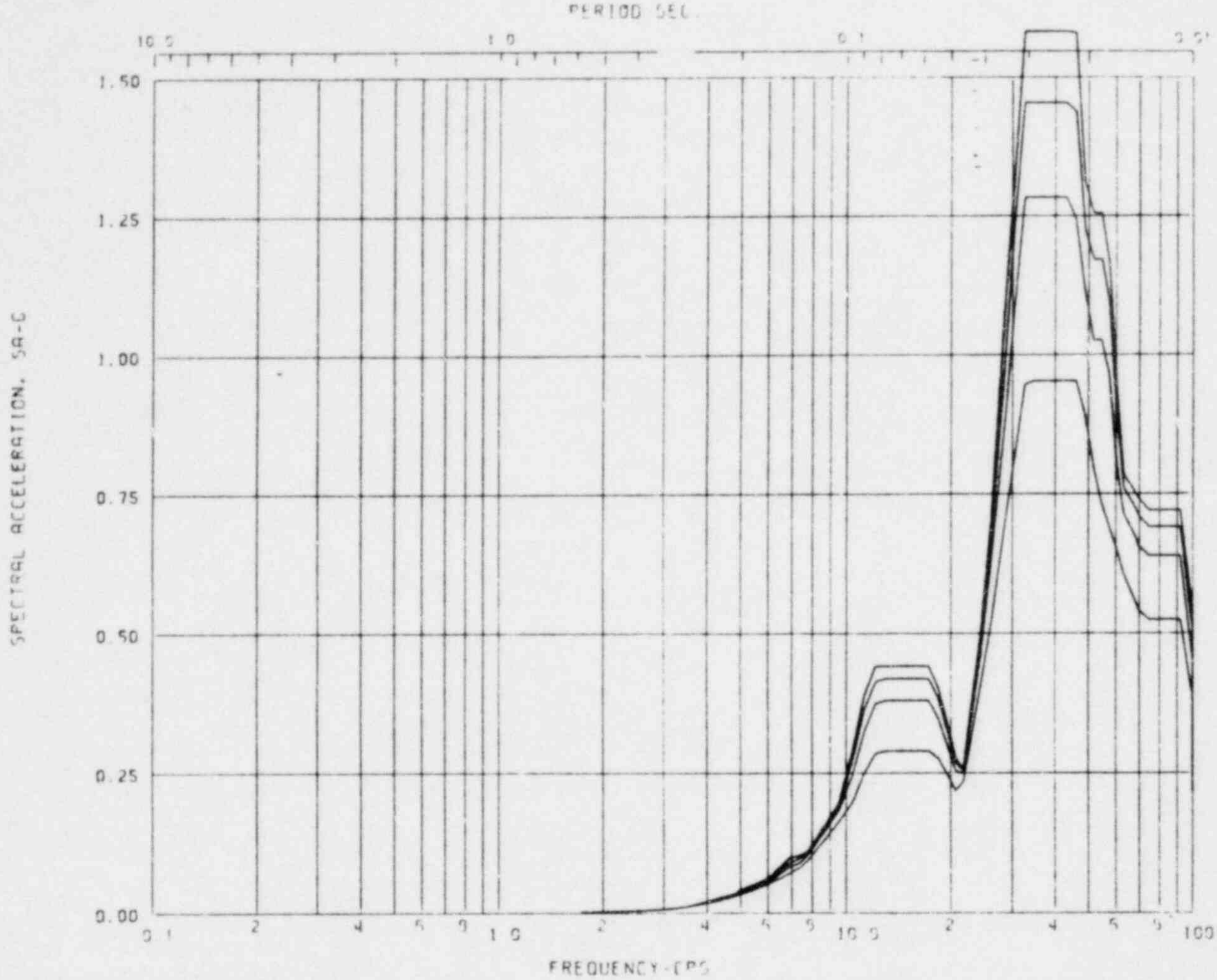
Node: 841 Direction: VERT Elev: 312'-8" Angle: -

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
CHUGGING
DIRECTION Z

FIGURE A.2-78



Acceleration Spectra for DIAPHRAGM SLAB

Load Case: CHUG 700 SYM/700A ASYM

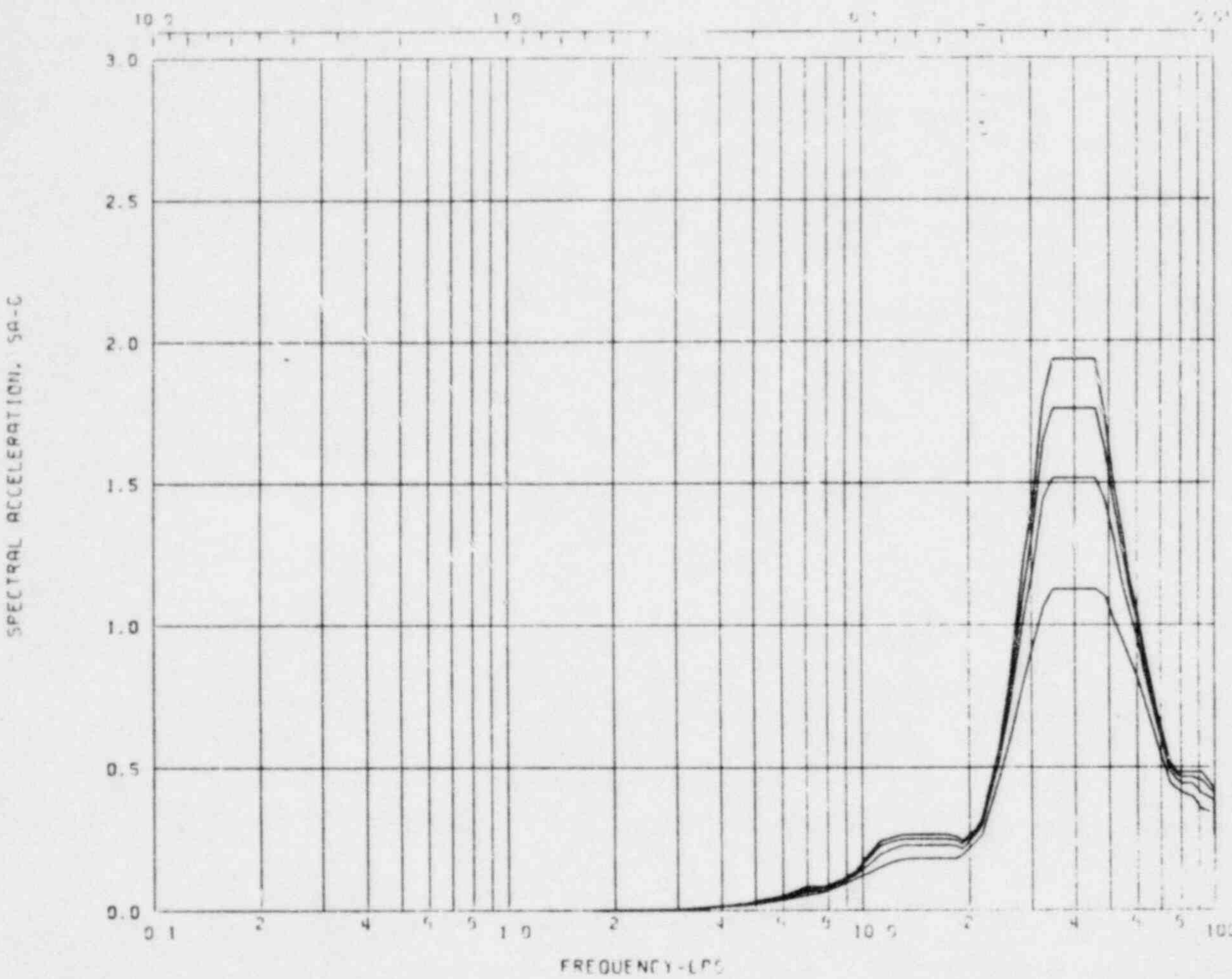
Node: 231 Direction: VERT Elev: 236'-2" Angle: -

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
CHUGGING
DIRECTION Z

FIGURE A.2-79



Acceleration Spectra for DIAPHRAGM SLAB

Load Case: CHUG 700 SYM/700A ASYM

Node: 252 Direction: VERT Elev: 236'-2" Angle: -

Damping: 0.005,0.01,0.02,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTAINMENT RESPONSE SPECTRA
CHUGGING
DIRECTION Z

FIGURE A.2-80

APPENDIX B

REACTOR BUILDING AND CONTROL STRUCTURE

MODE SHAPES AND HYDRODYNAMIC RESPONSE SPECTRA

TABLE OF CONTENTS

APPENDIX B

FIGURES

APPENDIX B

FIGURES (Cont'd)

B.1 REACTOR BUILDING AND CONTROL STRUCTURE MODE SHAPES

The reactor building and control structure horizontal mathematical stick model (for north-south and east-west directions) is shown in Figure 7.1-5. Mode frequencies and participation factors are shown in Figure B.1-1. Representative vibration mode shapes that have significant participation are plotted in Figures B.1-2 and B.1-3.

The reactor building and control structure vertical mathematical decoupled stick model is shown in Figure 7.1-4. Mode frequencies and participation factors are shown in Figure B.1-4. Representative vibration mode shapes that have significant participation are plotted in Figures B.1-5 to B.1-13.

The control structure floor vertical "half model" is shown in Figure 7.1-6. Mode frequencies and participation factors for a typical local floor model at elevation 269 feet in the control structure are shown in Figure B.1-14. Representative vibration mode shapes that have significant participation are plotted in Figures B.1-15 to B.1-18.

B.2 REACTOR BUILDING AND CONTROL STRUCTURE HYDRODYNAMIC ACCELERATION RESPONSE SPECTRA

This appendix shows representative examples of the horizontal and vertical response spectra curves of the structure due to LOCA and SRV loading. Five special damping values, i.e., 0.005, 0.01, 0.02, 0.03 and 0.05, are shown on each group of curves. The response spectra presented in this appendix are at representative locations of the building models (Figures 7.1-3 to 7.1-5).

The SRV loads are defined by KWU from measured pressure traces. Figures B.2-1 to B.2-58 show broadened response spectra for the SRV loads, considering both asymmetric and axisymmetric cases.

The LOCA loads consist of chugging and condensation oscillation. The chug loads were generated from the improved Mark II chugging load definition based on GE 700 series design sources. The source data were based on 4TCO test data. Figures B.2-59 to B.2-116 show broadened response spectra curves for chugging, considering both asymmetric and axisymmetric cases. The CO loads were generated from GE's generic 4TCO test data. Figures B.2-117 to B.2-184 show broadened response spectra curves for CO-Basic and CO-ADS (axisymmetric only).

The seismic loads are described in FSAR Section 3.7.

HORIZONTAL EAST-WEST DIRECTION

MODE No.	FREQUENCY (Hz.)	PARTICIPATION FACTOR
1	3.96	-89.98
2	12.50	-32.68
3	18.77	-22.52
4	24.20	15.29
5	31.63	-12.80
6	44.39	4.77
7	58.78	15.41
8	76.17	10.67
9	90.00	0.0003
10	133.78	-0.008
11	139.92	0.002
12	148.41	-0.0003

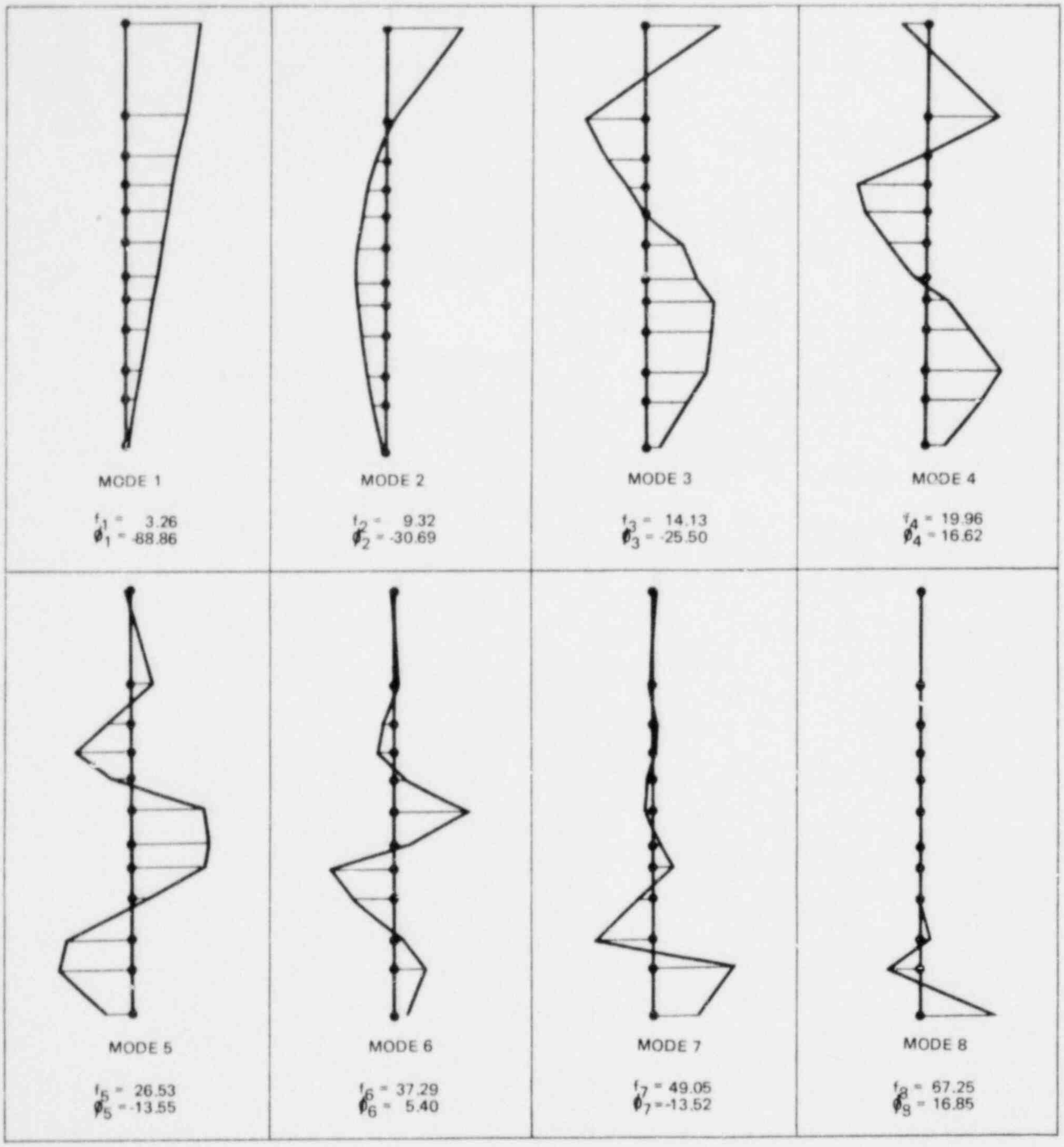
HORIZONTAL NORTH-SOUTH DIRECTION

MODE No.	FREQUENCY (Hz.)	PARTICIPATION FACTOR
1	3.26	-88.86
2	9.32	-30.69
3	14.13	-25.50
4	19.96	16.62
5	26.53	-13.55
6	37.29	5.40
7	49.05	-13.52
8	67.25	16.85
9	76.13	0.0003
10	114.47	-0.007
11	118.02	-0.002
12	120.51	0.0007

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND CONTROL STRUCTURE MODE FREQUENCIES AND PARTICIPATION FACTORS (HORIZONTAL STICK MODEL)

FIGURE B.1-1



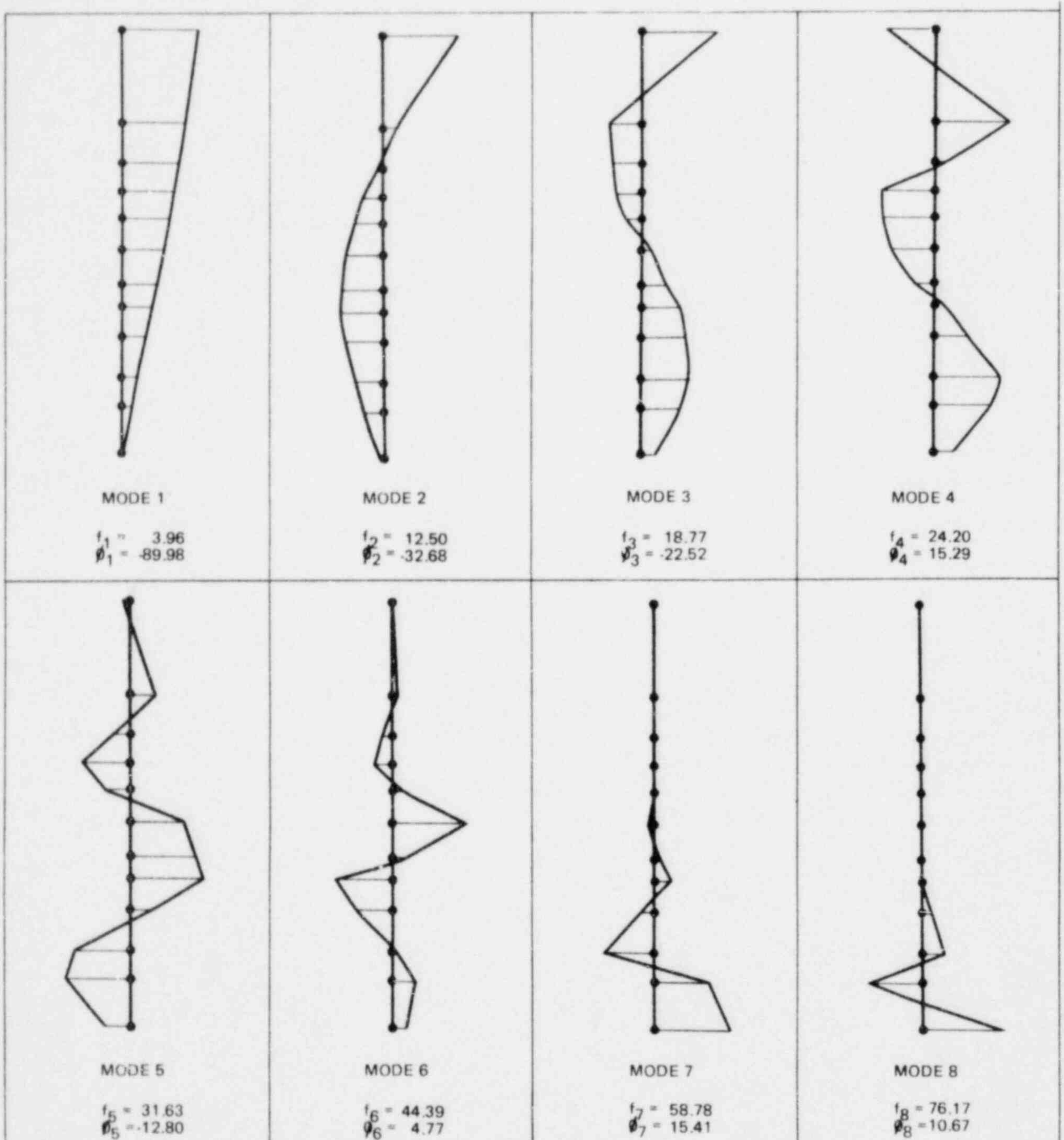
NOTE:

f = FREQUENCY (Hz)
ø = PARTICIPATION FACTOR

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND
CONTROL STRUCTURE
HORIZONTAL N-S
MODE SHAPES

FIGURE B.1-2



NOTE:

f = FREQUENCY Hz
ϕ = PARTICIPATION FACTOR

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND CONTROL STRUCTURE HORIZONTAL E-W MODE SHAPES

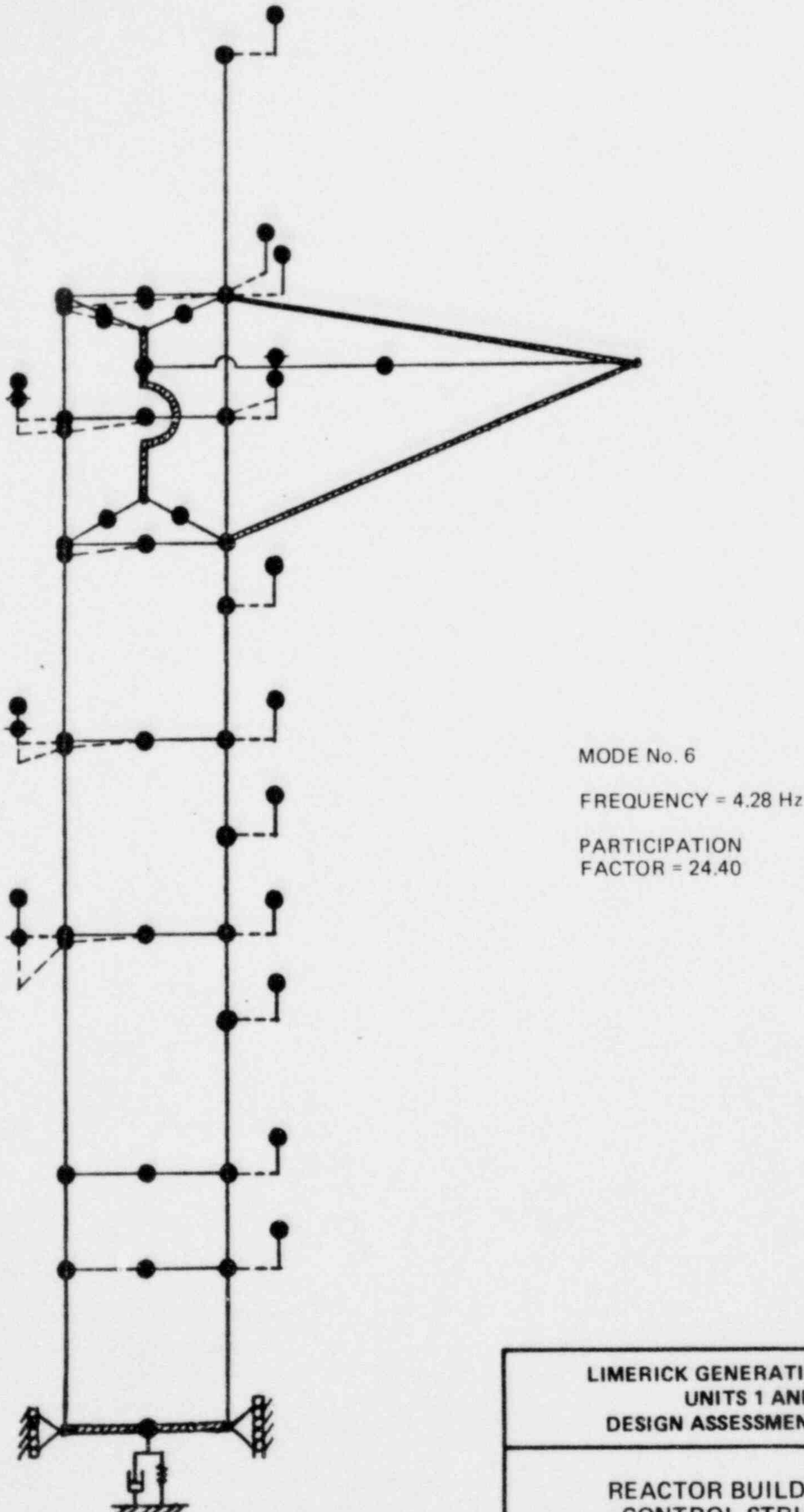
FIGURE B.1-3

MODE No.	FREQUENCY (Hz.)	PARTICIPATION FACTOR
1	2.00	20.14
2	3.01	11.16
3	3.28	-10.05
4	4.07	-13.13
5	4.25	-27.59
6	4.28	-24.40
7	4.32	-5.29
8	4.57	-11.99
9	4.58	-9.33
10	4.64	9.27
11	4.89	-8.56
12	5.91	17.06
13	7.82	-59.71
14	9.23	-38.78
15	10.42	-5.16
16	11.29	-18.72
17	11.72	-14.46
18	11.81	2.31
19	12.03	0.75
20	12.24	[illegible].85
21	12.34	9.61
22	12.54	-0.26
23	13.58	10.44
24	13.94	-14.85
25	15.37	-14.46
26	15.50	5.37
27	18.39	27.28
28	20.22	5.36
29	29.86	-10.40
30	38.20	-23.12
31	47.54	7.00
32	51.75	-4.61
33	59.14	-0.63
34	74.39	7.82
35	103.48	3.19
36	114.33	4.43
37	121.98	0.07
38	128.79	-1.78
39	136.47	-0.24
40	171.12	-0.91
41	241.59	-0.0001
42	252.96	0.00004
43	334.43	-0.002
44	372.81	-0.00008
45	399.96	-0.0003

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND CONTROL STRUCTURE MODE FREQUENCIES AND PARTICIPATION FACTORS (VERTICAL STICK MODEL)

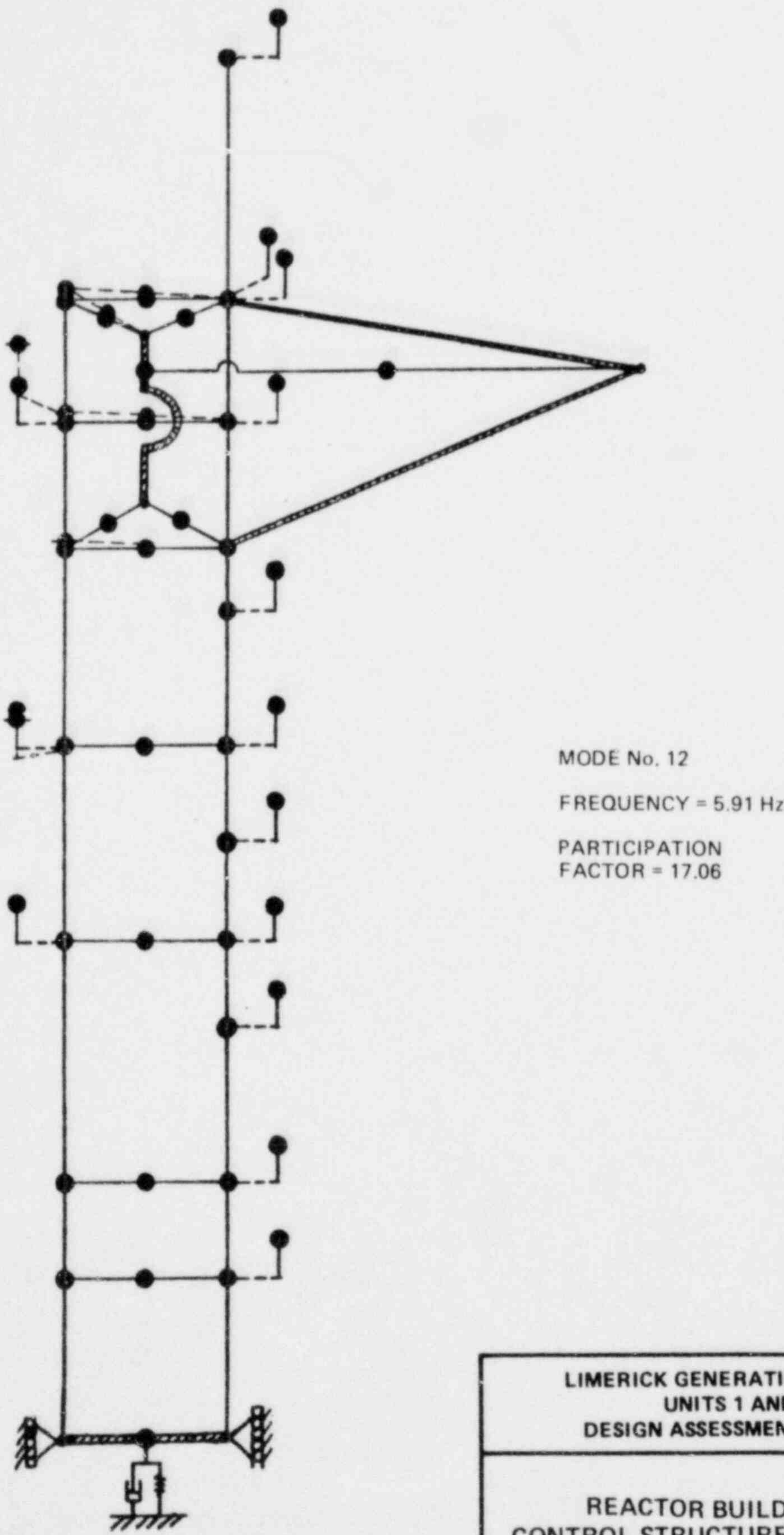
FIGURE B.1-4



LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND
CONTROL STRUCTURE
VERTICAL MODE SHAPES

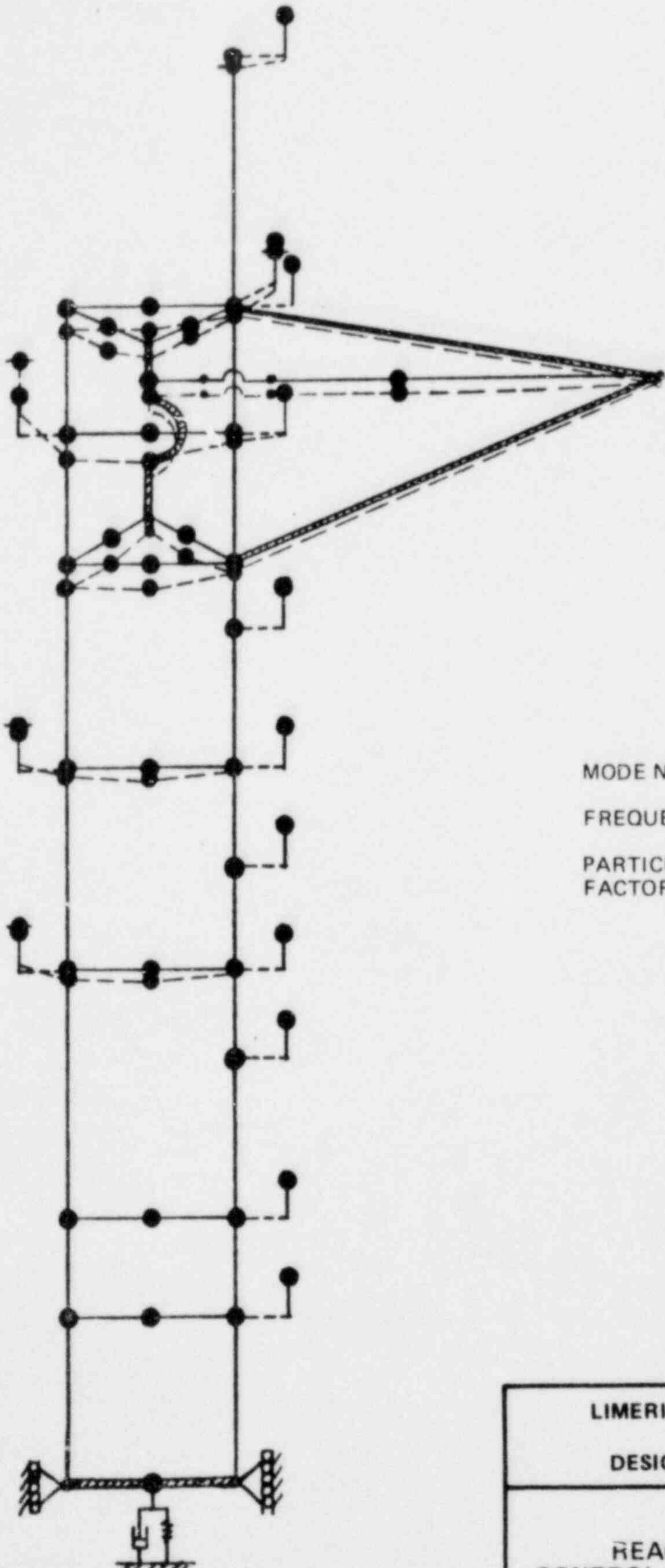
FIGURE B.1-5



LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND CONTROL STRUCTURE MODE SHAPES

FIGURE B.1-6



MODE No. 13

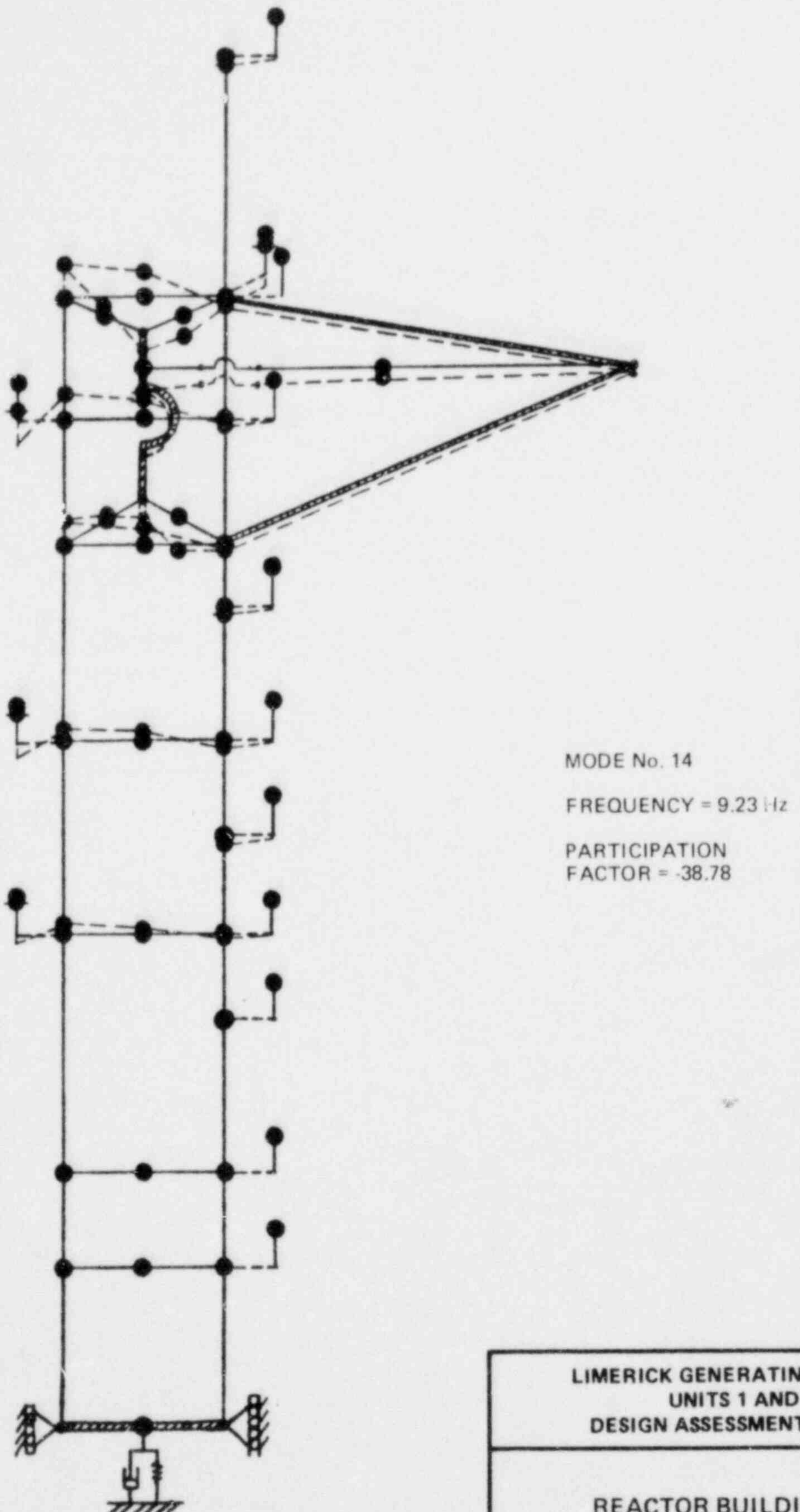
FREQUENCY = 7.82 Hz

PARTICIPATION
FACTOR = -59.71

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND
CONTROL STRUCTURE MODE SHAPES

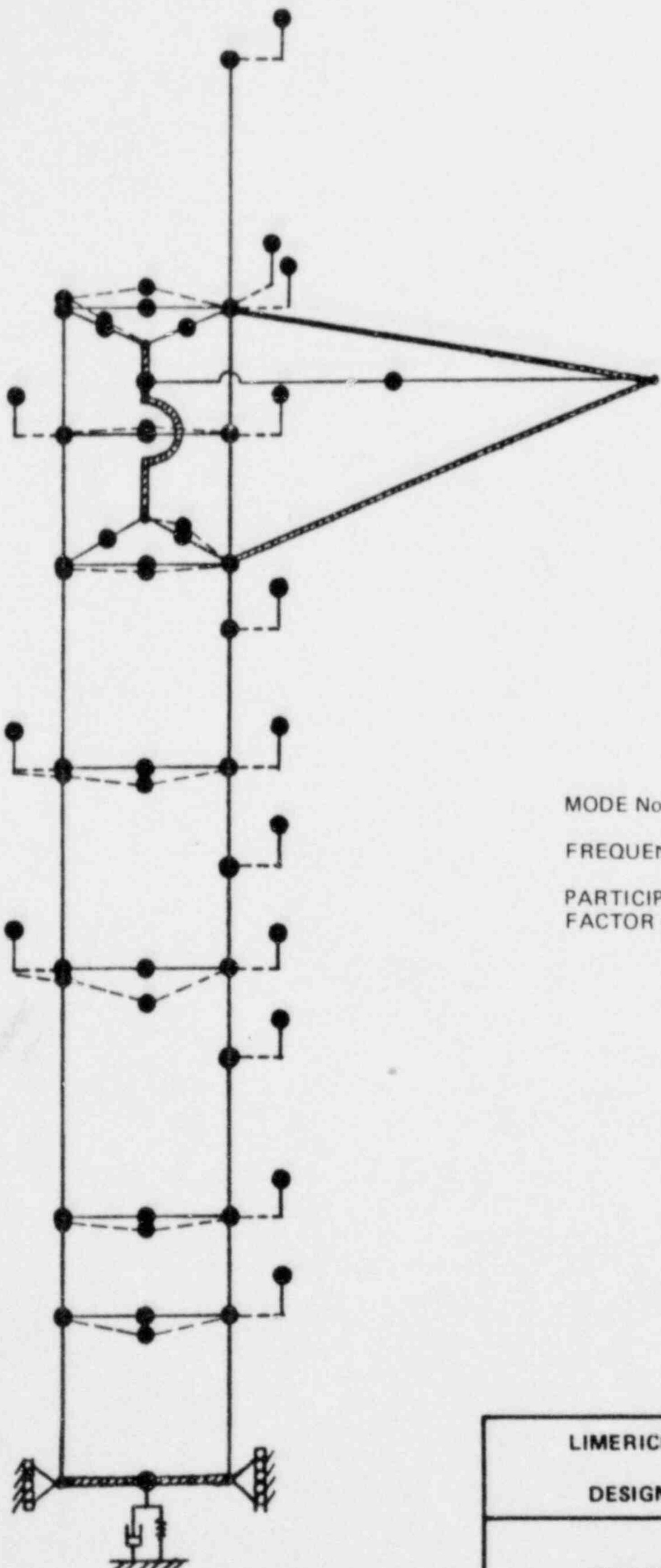
FIGURE B.1-7



LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND
CONTROL STRUCTURE MODE SHAPES

FIGURE B.1-8



MODE No. 16

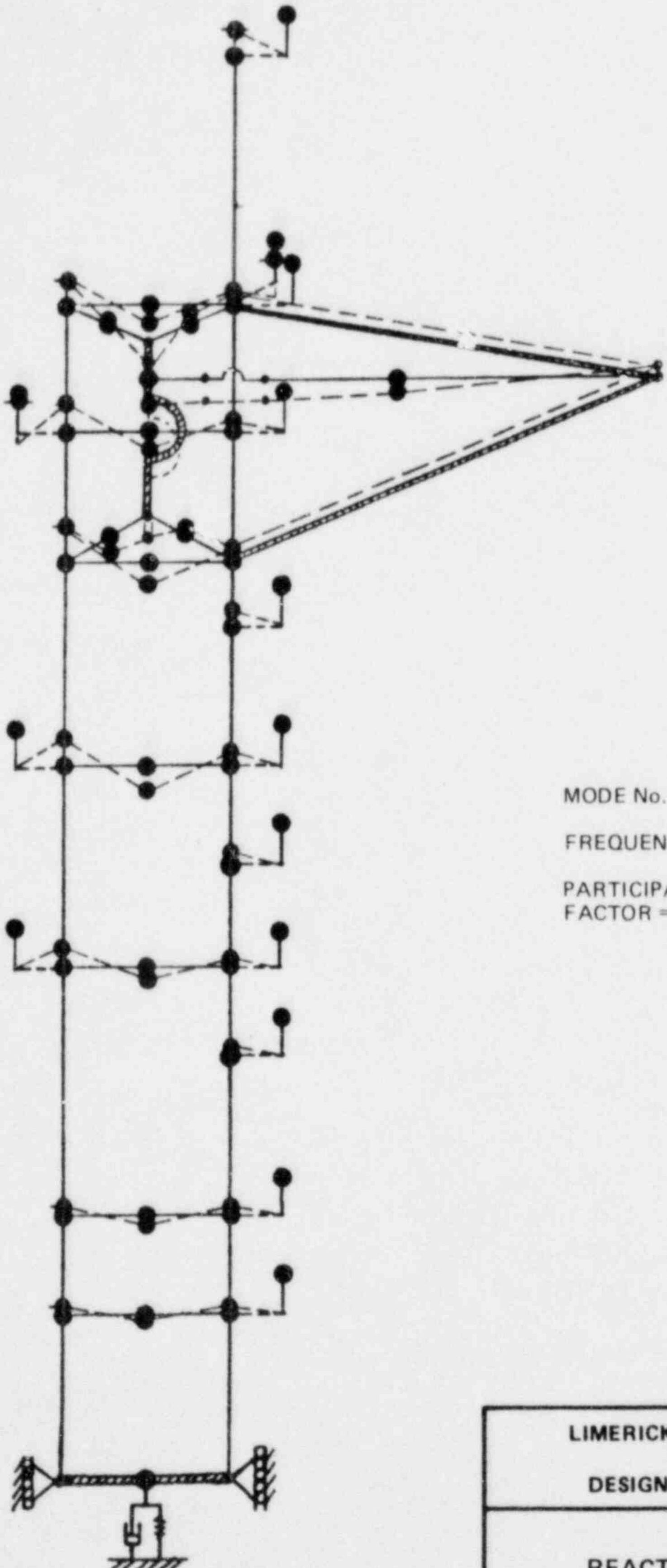
FREQUENCY = 11.29 Hz

PARTICIPATION
FACTOR = -18.72

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND
CONTROL STRUCTURE MODE SHAPES

FIGURE B.1-9



MODE No. 27

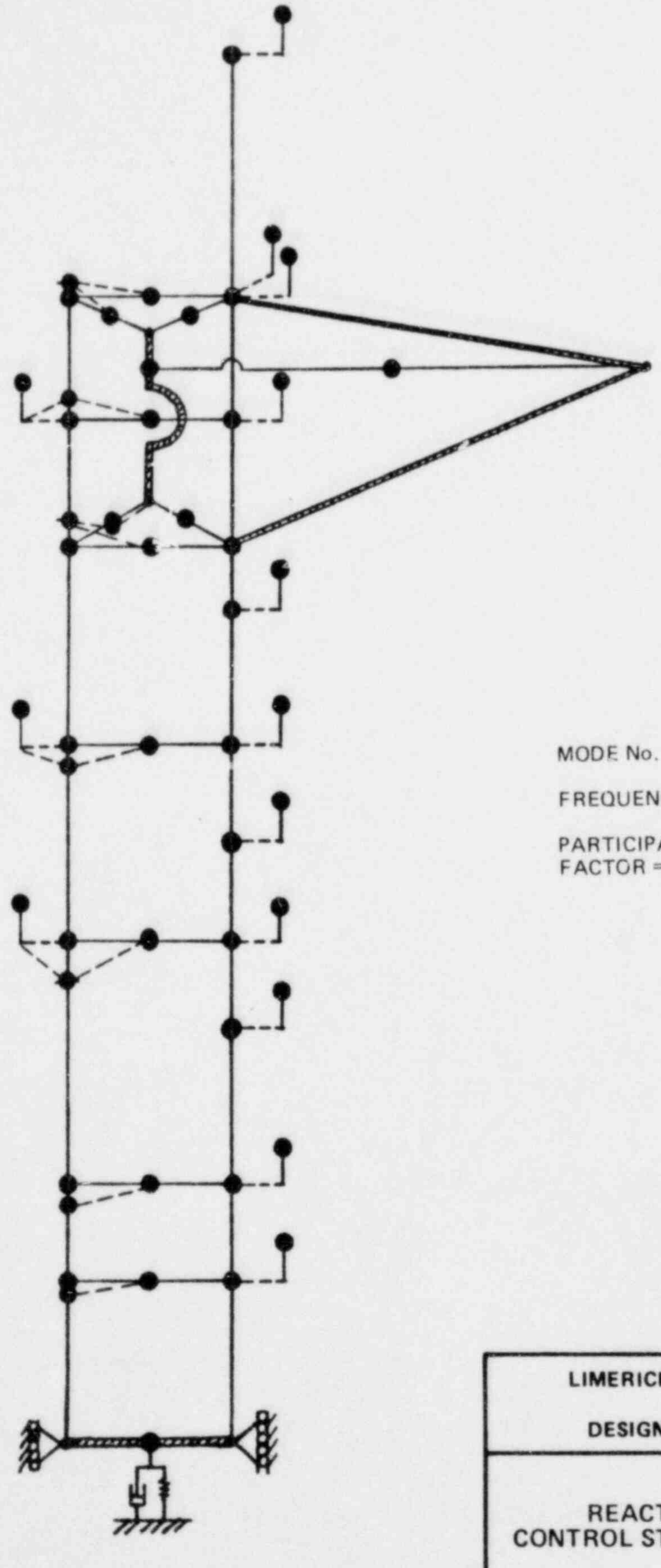
FREQUENCY = 18.39 Hz

PARTICIPATION
FACTOR = 27.28

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND
CONTROL STRUCTURE MODE SHAPES

FIGURE B.1-10



MODE No. 29

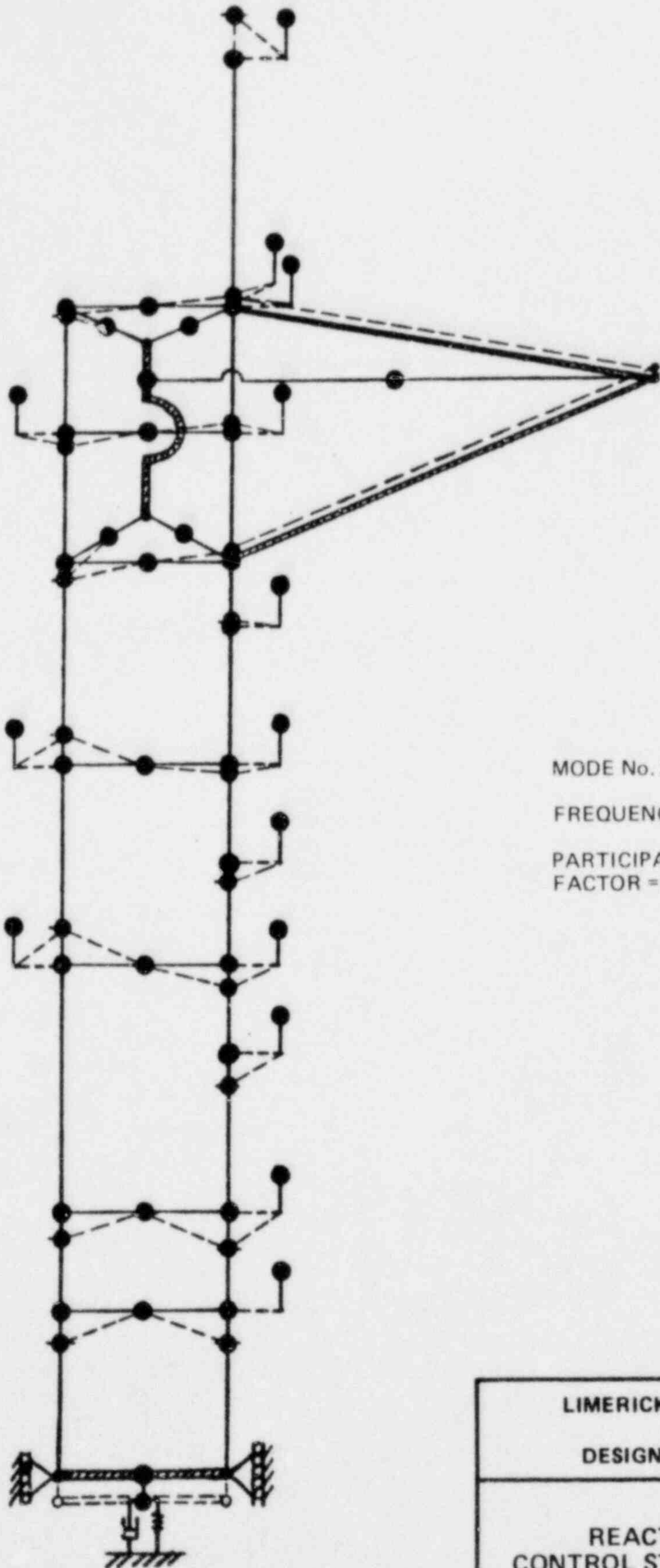
FREQUENCY = 29.86 Hz

PARTICIPATION
FACTOR = -10.40

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND
CONTROL STRUCTURE MODE SHAPES

FIGURE B.1-11



MODE No. 30

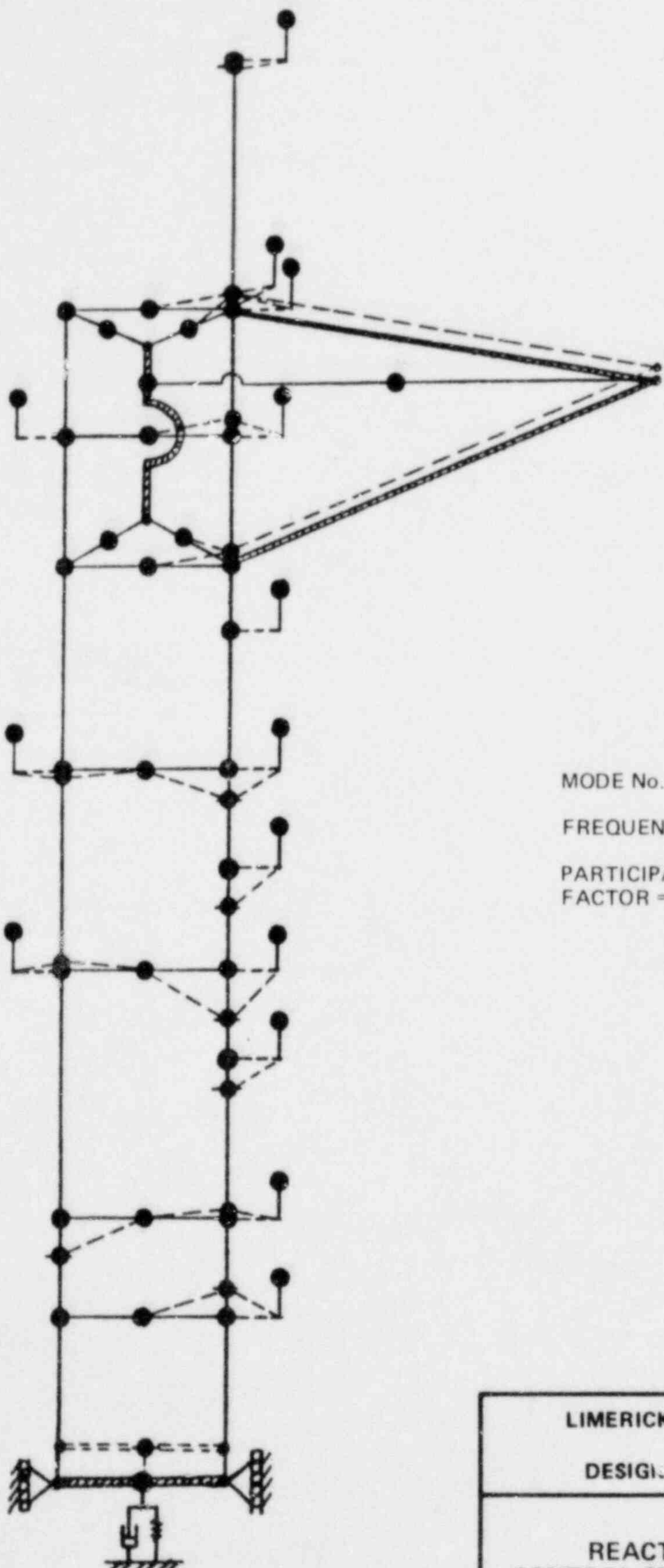
FREQUENCY = 38.20 Hz

PARTICIPATION
FACTOR = -23.12

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND
CONTROL STRUCTURE MODE SHAPES

FIGURE B.1-12



MODE No. 34

FREQUENCY = 74.39 Hz

PARTICIPATION
FACTOR = 7.82

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND
CONTROL STRUCTURE MODE SHAPES

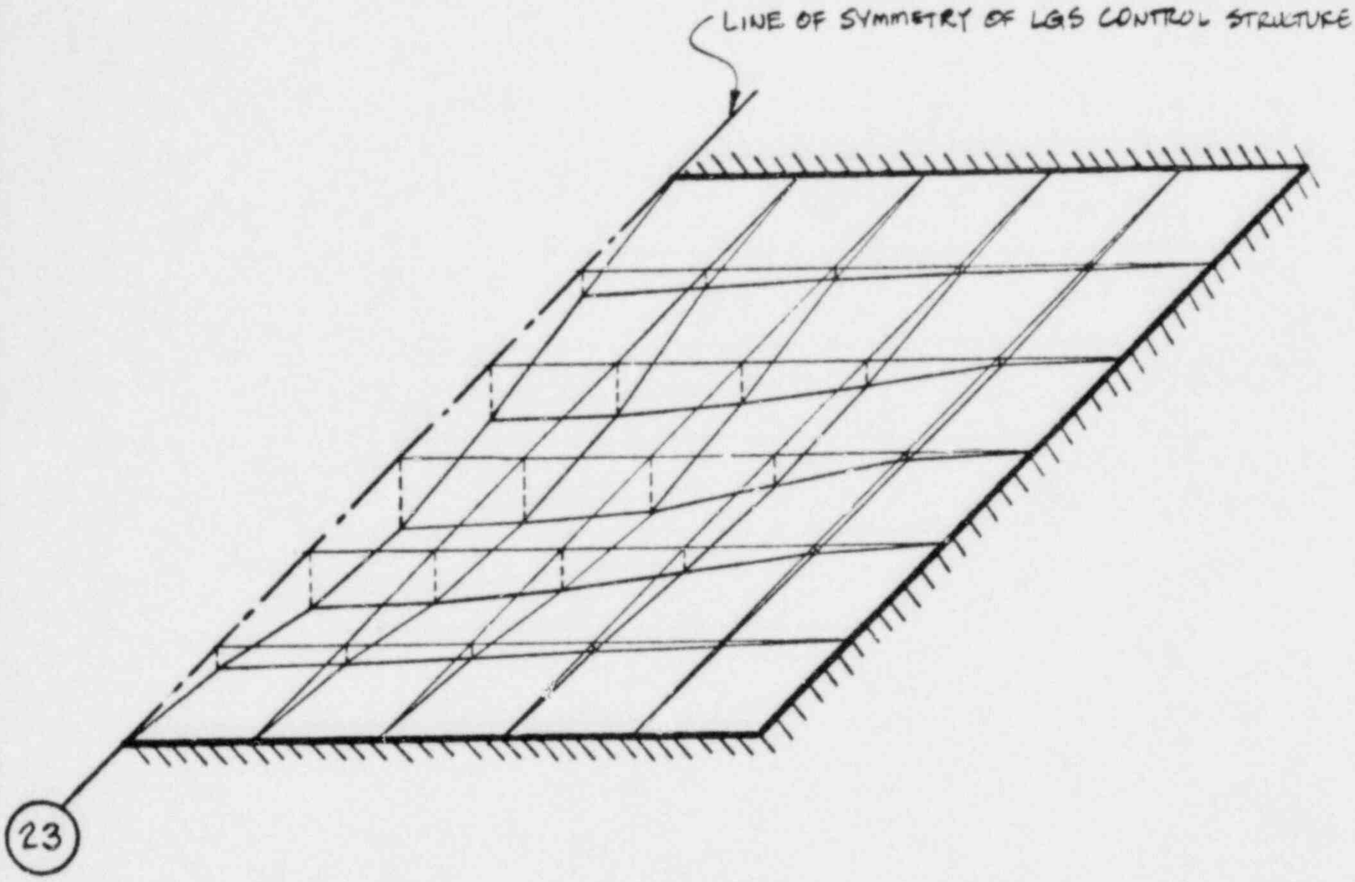
FIGURE B.1-13

MODE No.	FREQUENCY (Hz.)	PARTICIPATION FACTOR
1	14.20	-4.04
2	24.75	1.59
3	37.67	-0.0003
4	47.39	-1.04
5	48.03	-0.0001
6	68.63	-0.00005
7	73.01	1.77
8	78.53	0.71
9	82.70	0.59
10	94.42	-0.00007
11	99.84	-0.31

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTROL STRUCTURE MODE FREQUENCIES AND PARTICIPATION FACTORS (VERTICAL LOCAL FLOOR MODEL AT EL. 269'-0")

FIGURE B.1-14



MODE No. 1

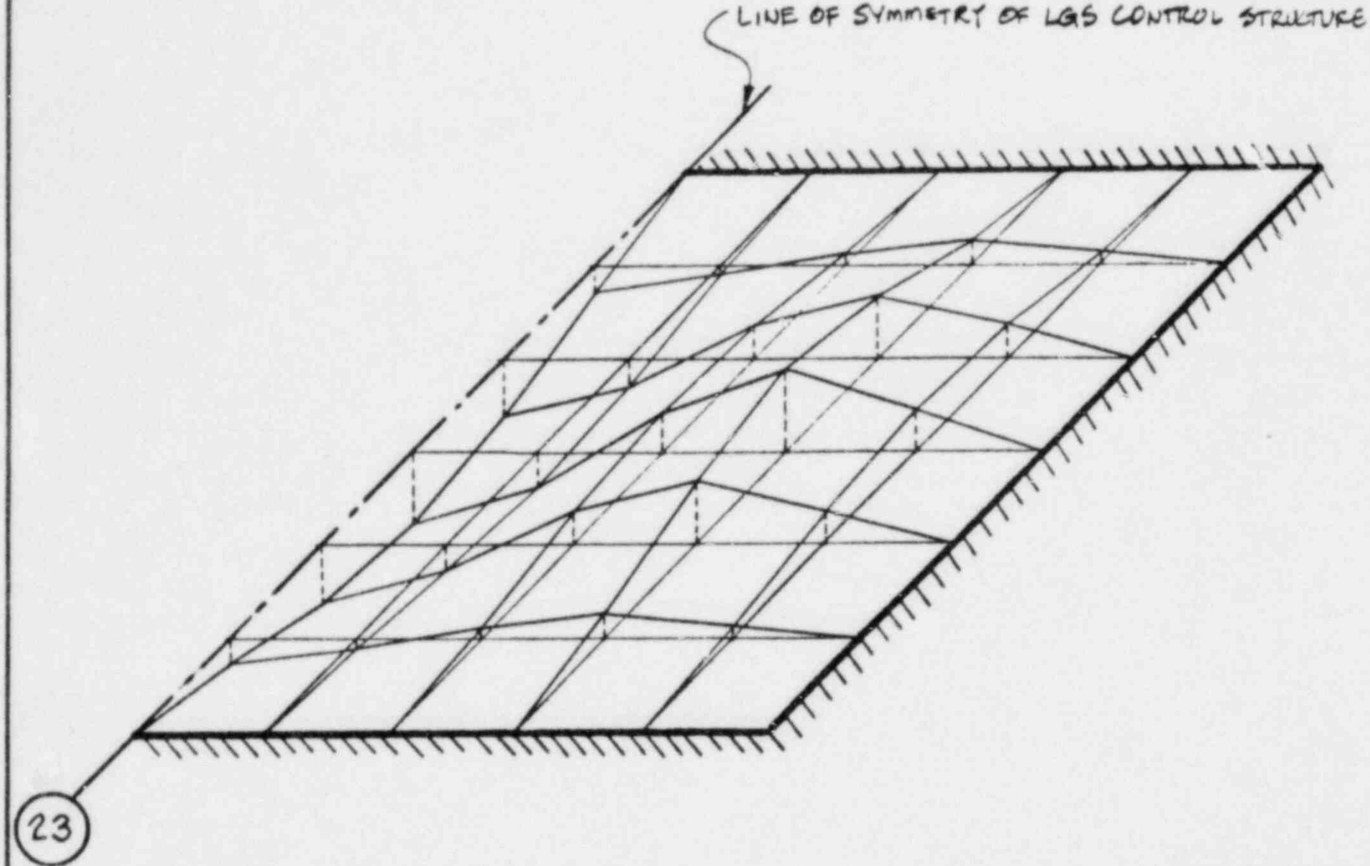
FREQUENCY = 14.20 Hz

PARTICIPATION
FACTOR = -4.04

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTROL STRUCTURE
VERTICAL LOCAL FLOOR MODEL
MODE SHAPES (EL. 269'-0")

FIGURE B.1-15



MODE No. 2

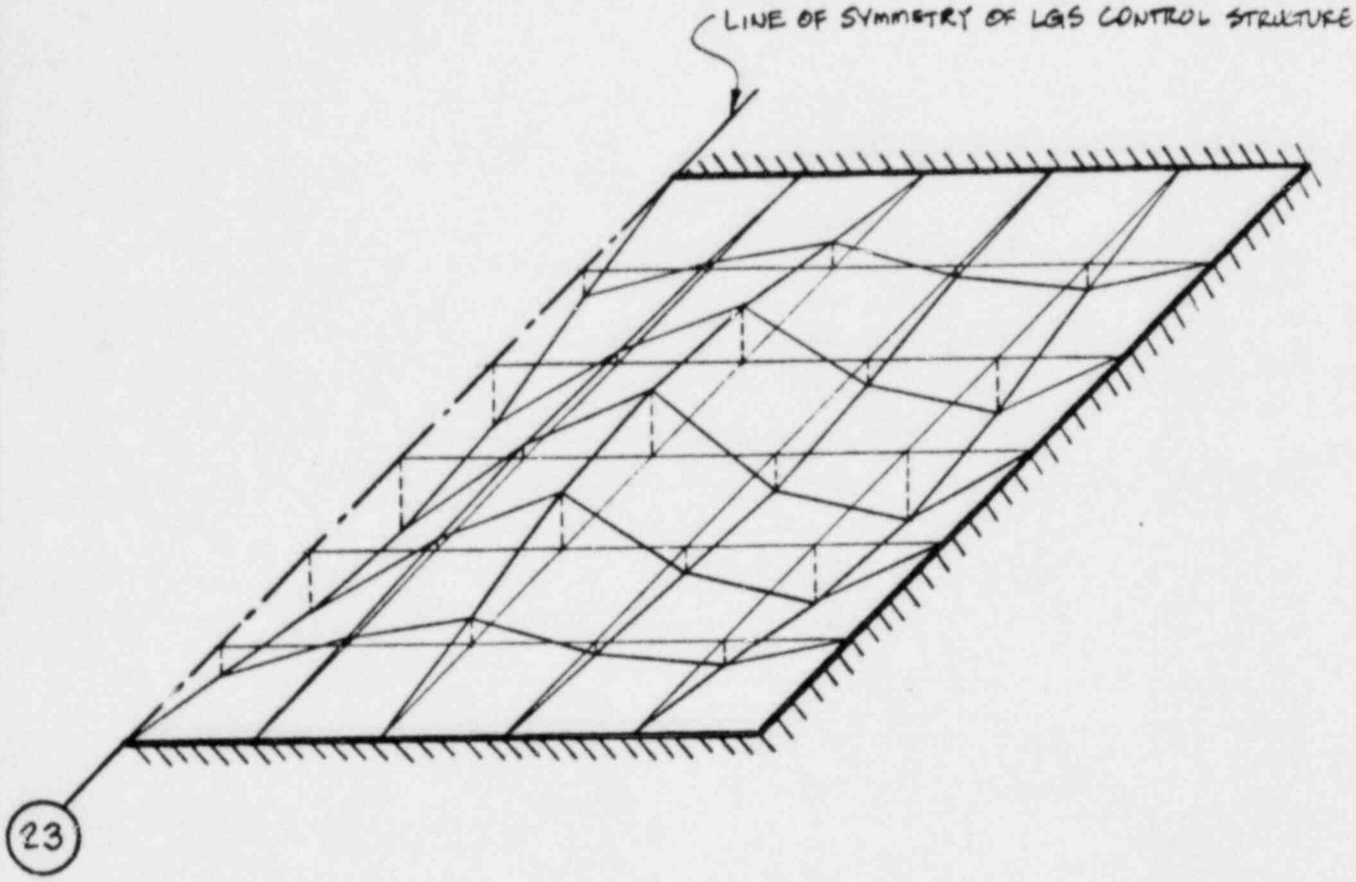
FREQUENCY = 24.75 Hz

PARTICIPATION
FACTOR = 1.59

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTROL STRUCTURE
VERTICAL LOCAL FLOOR
MODEL MODE SHAPES
(EL. 269'-0")

FIGURE B.1-16



MODE No. 4

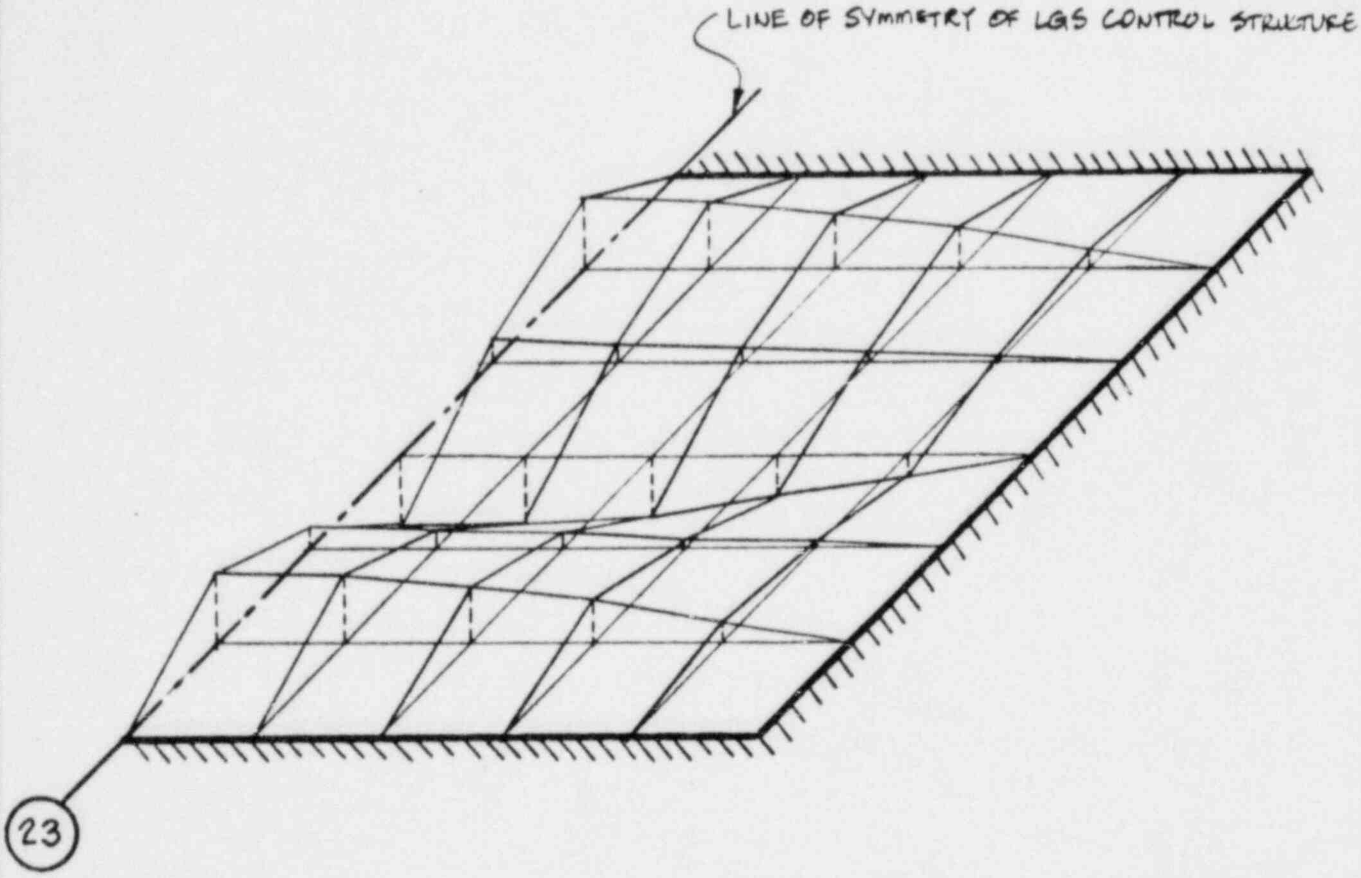
FREQUENCY = 47.39 Hz

PARTICIPATION
FACTOR = -1.04

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTROL STRUCTURE
VERTICAL LOCAL FLOOR
MODEL MODE SHAPES
(EL. 269'-0")

FIGURE B.1-17



MODE No. 7

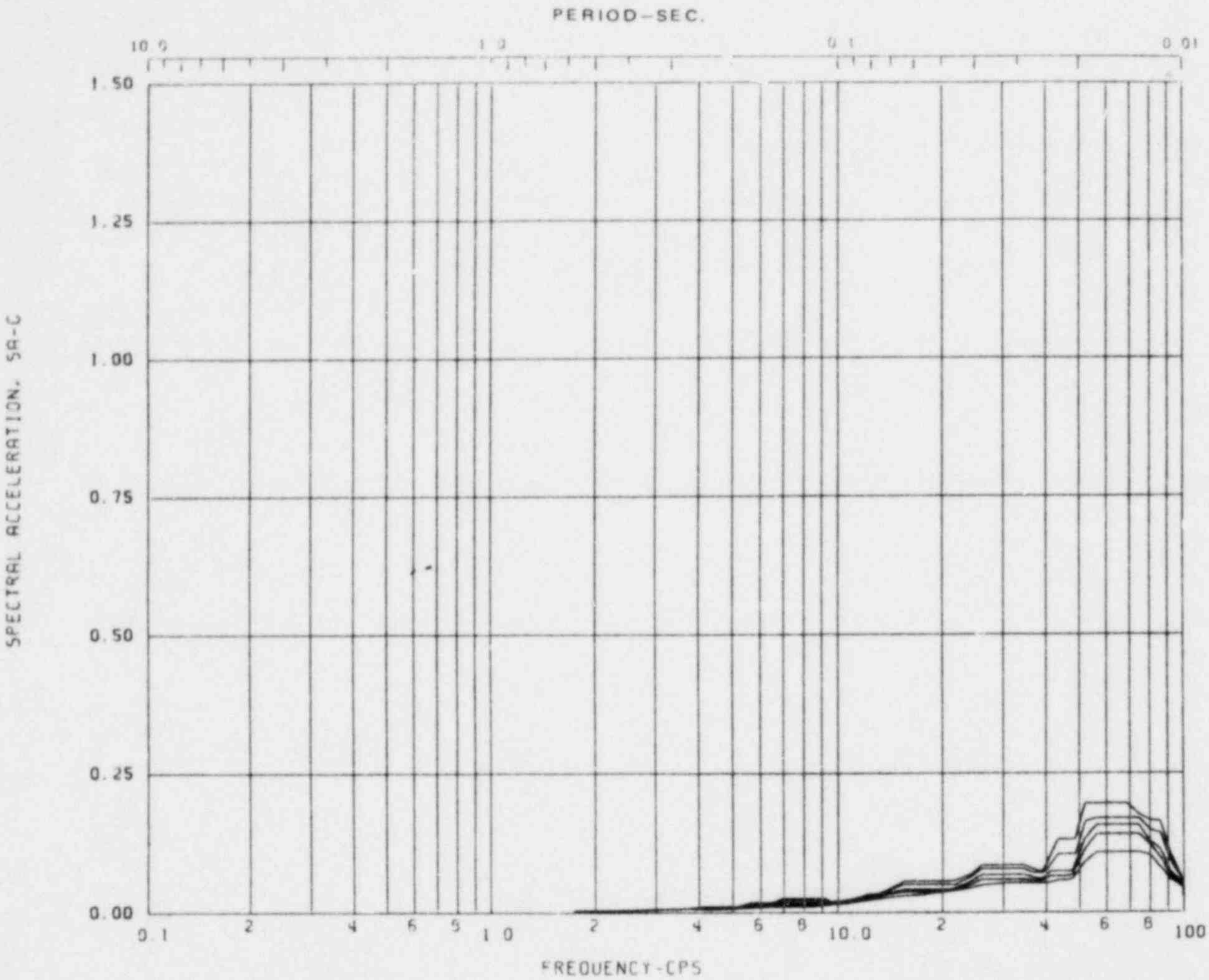
FREQUENCY = 73.01 Hz

PARTICIPATION
FACTOR = 1.77

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTROL STRUCTURE
VERTICAL LOCAL FLOOR
MODEL MODE SHAPES
(EL. 269'-0")

FIGURE B.1-18



Acceleration Spectra for REACTOR BLDG., CONTROL STRUCTURE

Load Case: KWU SRV ASYMMETRIC ENVELOPE (WIDENED - 15%)

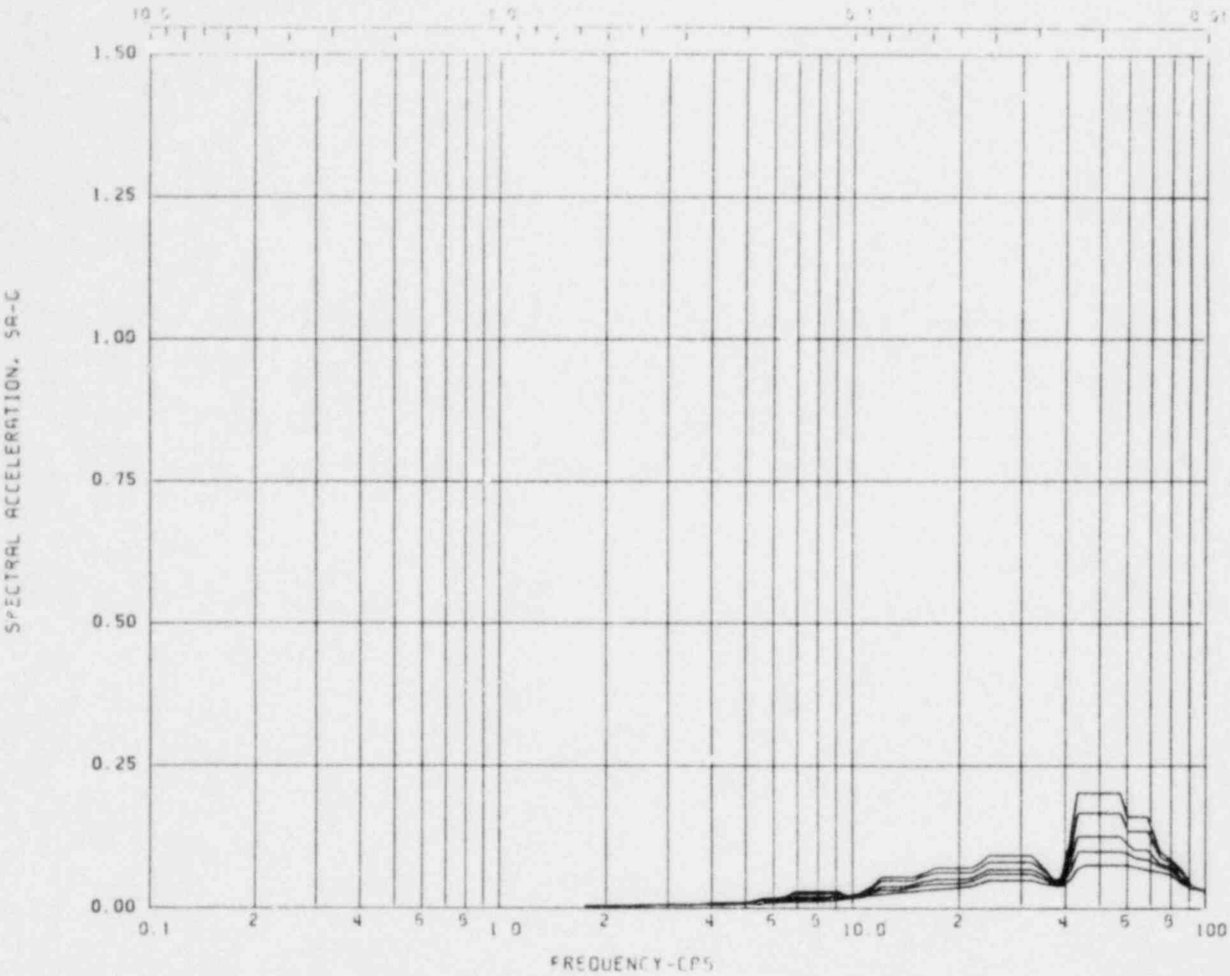
Node: 1 Direction: N-S HORIZ Elev: 177'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND CONTROL STRUCTURE GLOBAL RESPONSE SPECTRA, N-S HORIZONTAL, SRV ASYMMETRIC

FIGURE B.2-1



Acceleration Spectra for REACTOR BLDG., CONTROL STRUCTURE

Load Case: KWU SRV ASYMMETRIC ENVELOPE (WIDENED - 15%)

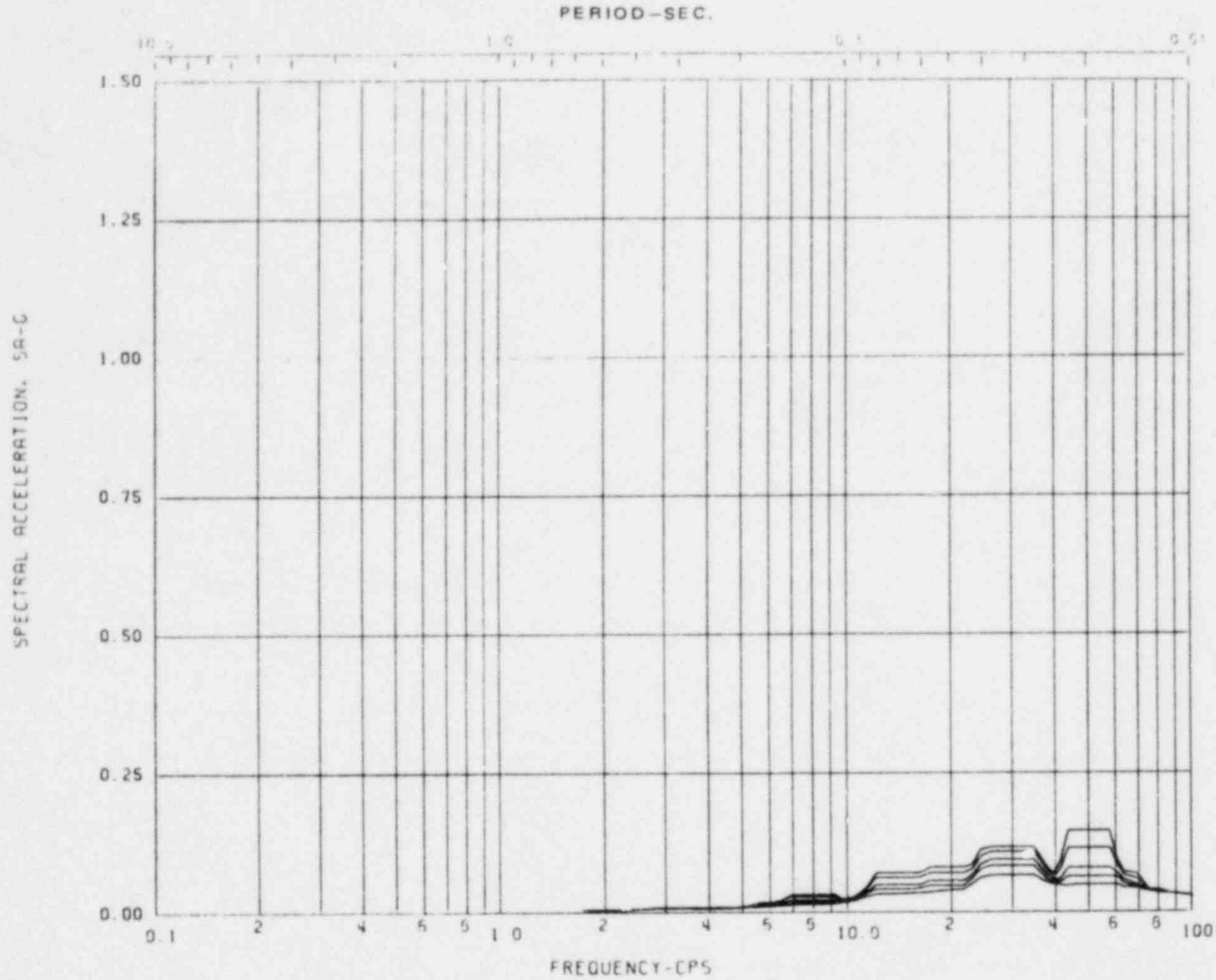
Node: 2 Direction: N-S HORIZ Elev: 201'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND CONTROL STRUCTURE GLOBAL RESPONSE SPECTRA, N-S HORIZONTAL, SRV ASYMMETRIC

FIGURE B.2-2



Acceleration Spectra for REACTOR BLDG., CONTROL STRUCTURE

Load Case: KWU SRV ASYMMETRIC ENVELOPE (WIDENED - 15%)

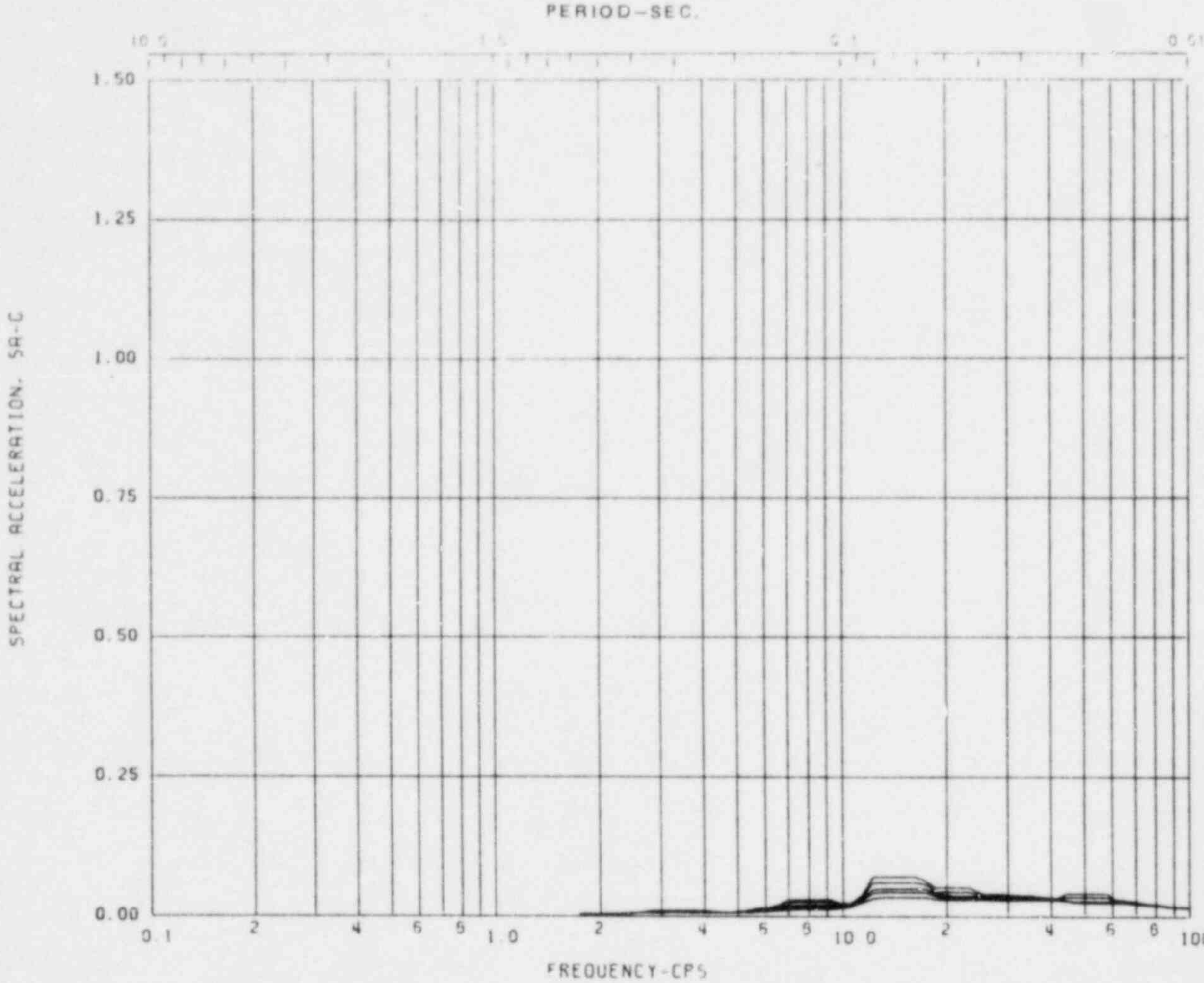
Node: 3 Direction: N-S HORIZ Elev: 217'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND CONTROL STRUCTURE GLOBAL RESPONSE SPECTRA, N-S HORIZONTAL, SRV ASYMMETRIC

FIGURE B.2-3



Acceleration Spectra for REACTOR BLDG., CONTROL STRUCTURE

Load Case: KWU SRV ASYMMETRIC ENVELOPE (WIDENED - 15%)

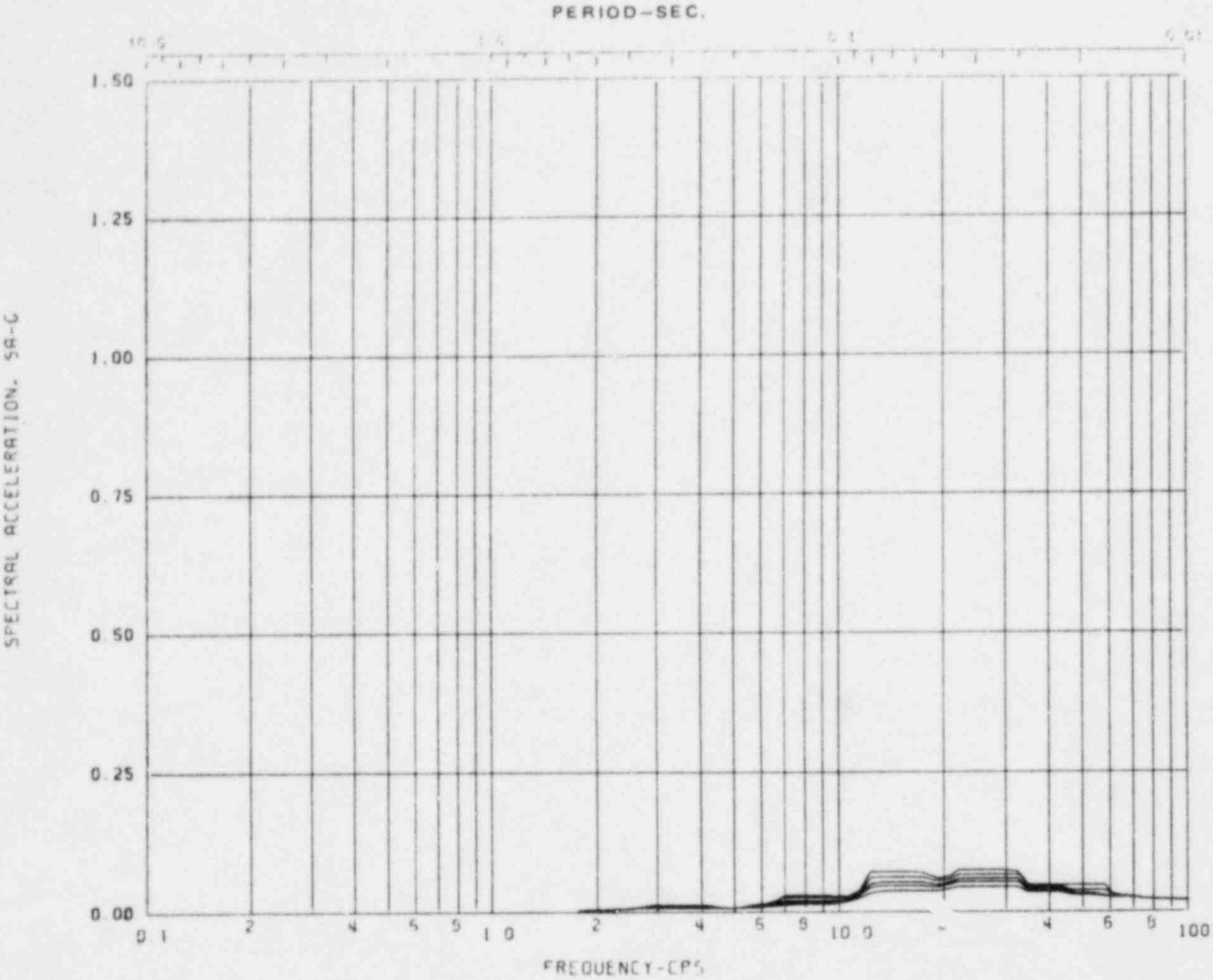
Node: 4 Direction: N-S HORIZ Elev: 239'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND CONTROL STRUCTURE GLOBAL RESPONSE SPECTRA, N-S HORIZONTAL, SRV ASYMMETRIC

FIGURE B.2-4



Acceleration Spectra for REACTOR BLDG., CONTROL STRUCTURE

Load Case: KWU SRV ASYMMETRIC ENVELOPE (WIDENED - 15%)

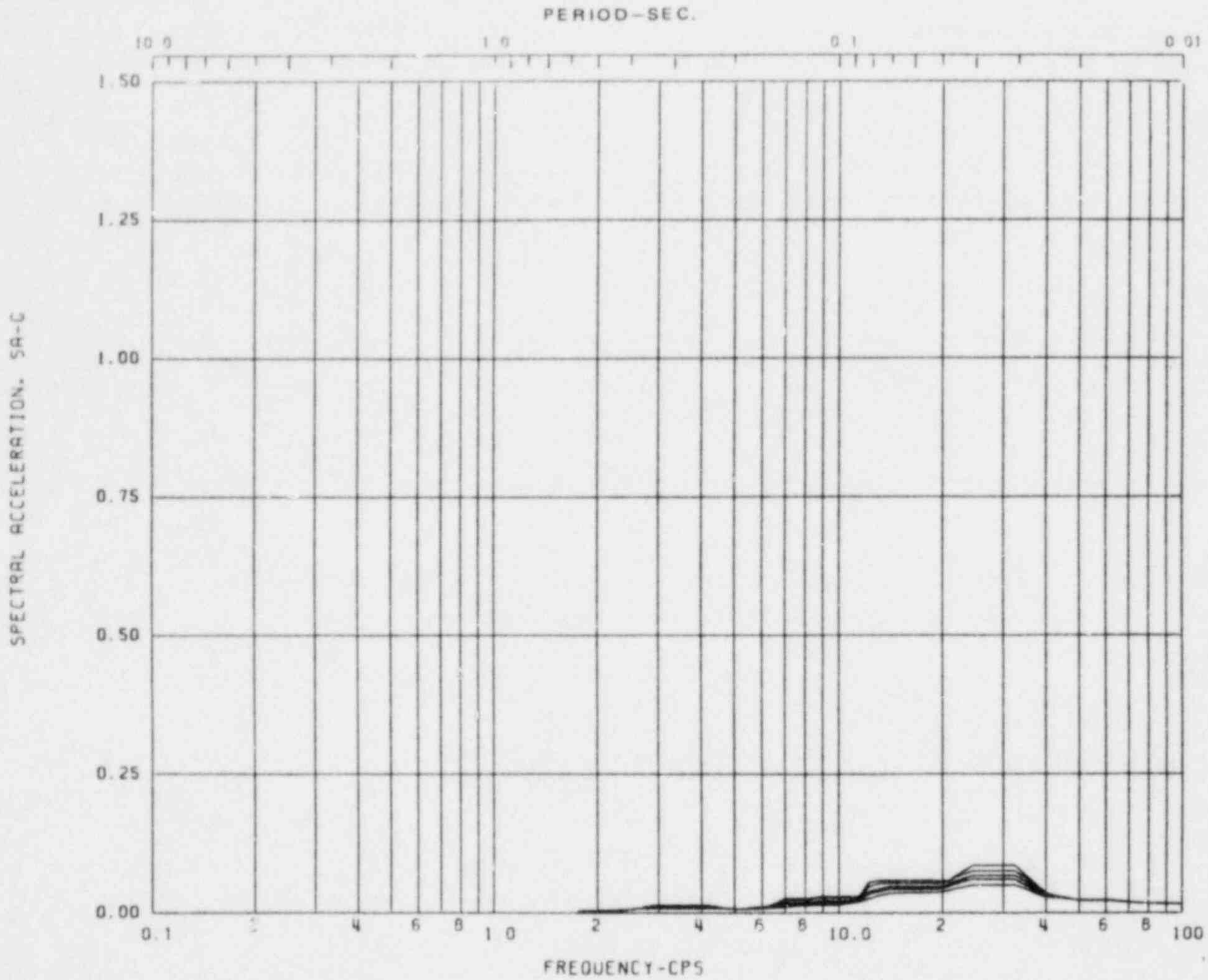
Node: 5 Direction: N-S HORIZ Elev: 253'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND CONTROL STRUCTURE GLOBAL RESPONSE SPECTRA, N-S HORIZONTAL, SRV ASYMMETRIC

FIGURE B.2-5



Acceleration Spectra for REACTOR BLDG., CONTROL STRUCTURE

Load Case: KWU SRV ASYMMETRIC ENVELOPE (WIDENED - 15%)

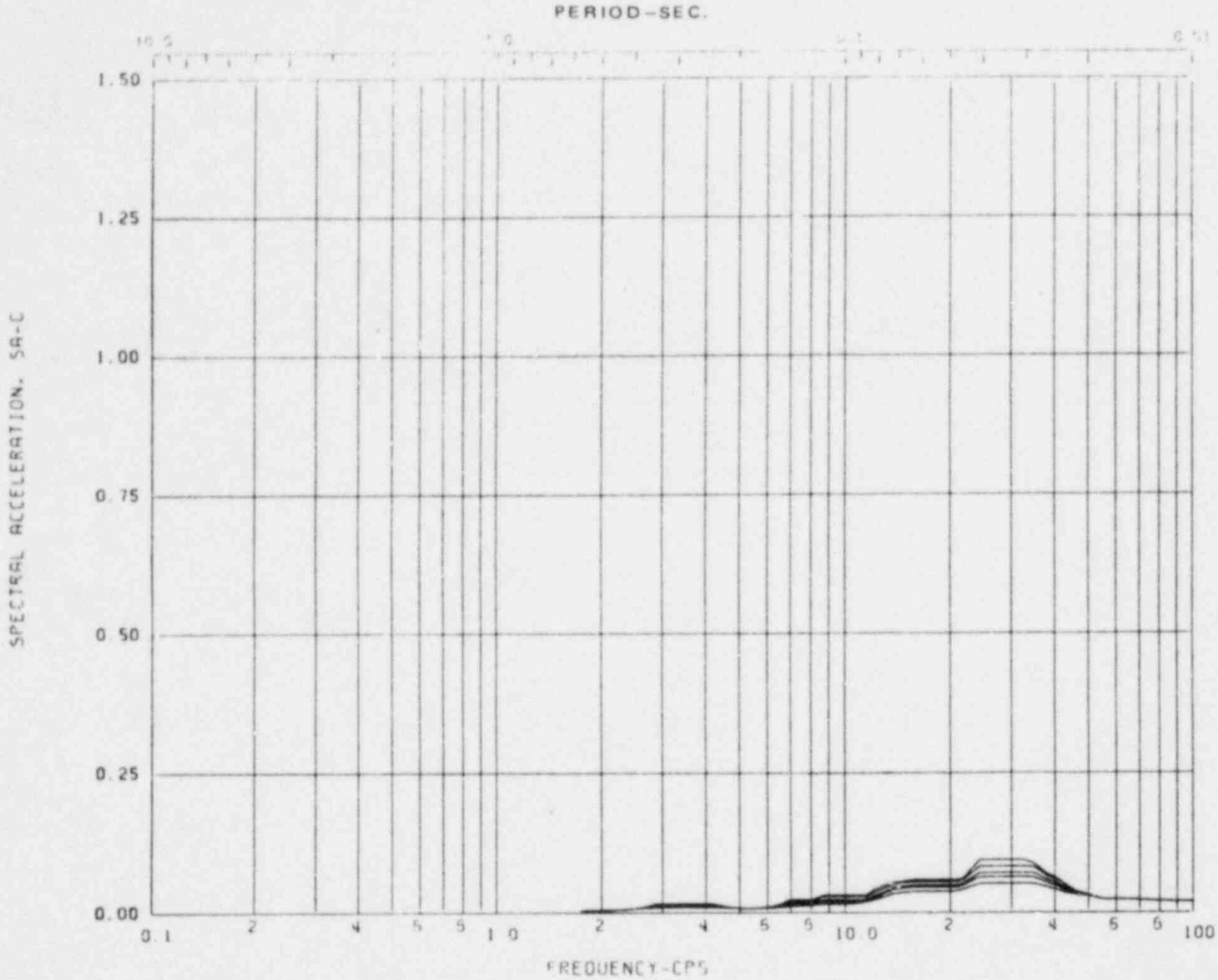
Node: 6 Direction: N-S HORIZ Elev: 269'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND CONTROL STRUCTURE GL^BAL RESPONSE SPECTRA, N-S ORIZONTAL, SRV ASYMMETRIC

FIGURE B.2-6



Acceleration Spectra for REACTOR BLDG., CONTROL STRUCTURE

Load Case: KWU SRV ASYMMETRIC ENVELOPE (WIDENED - 15%)

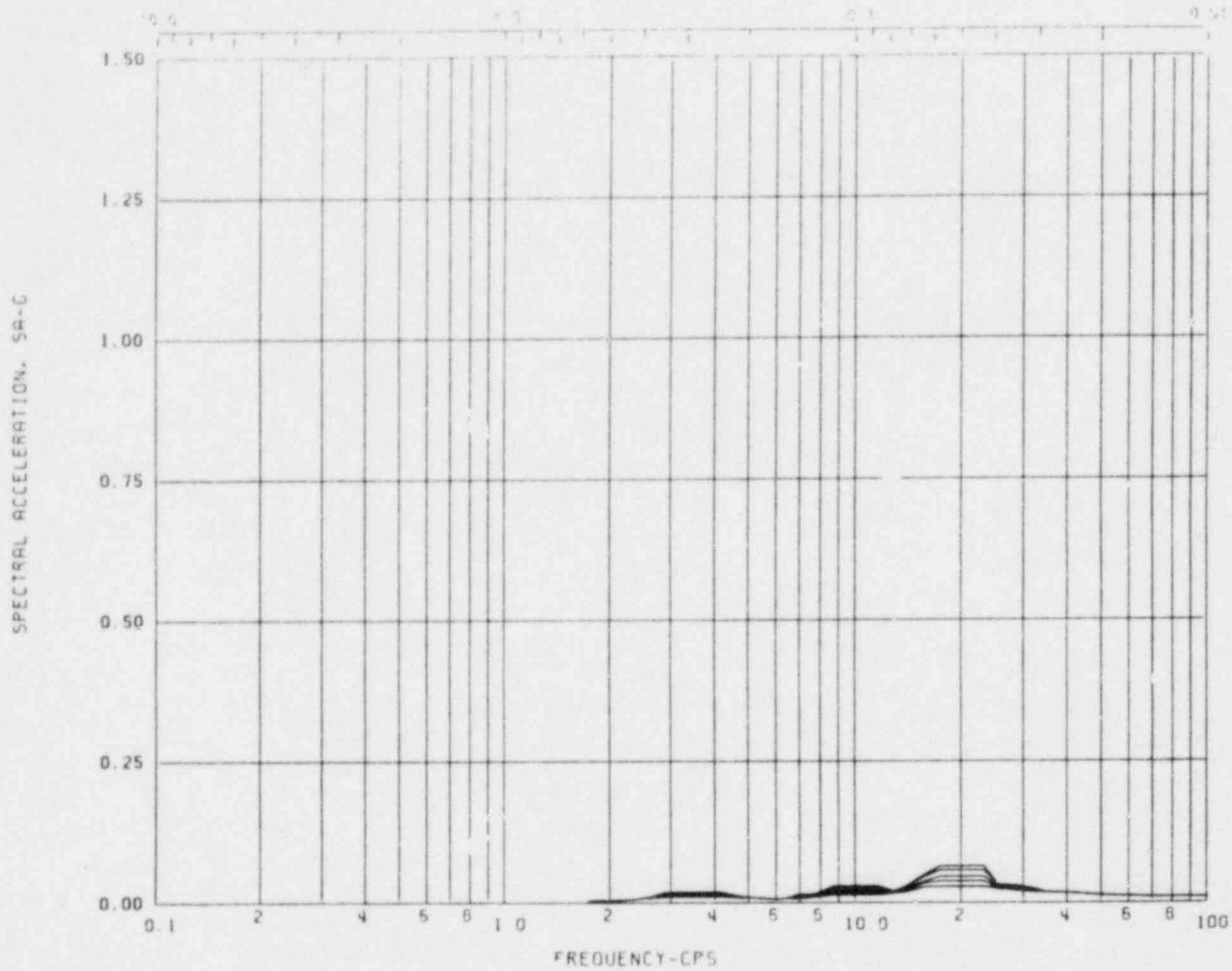
Node: 7 Direction: N-S HORIZ Elev: 283'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND CONTROL STRUCTURE GLOBAL RESPONSE SPECTRA, N-S HORIZONTAL, SRV ASYMMETRIC

FIGURE B.2-7



Acceleration Spectra for REACTOR BLDG., CONTROL STRUCTURE

Load Case: KWU SRV ASYMMETRIC ENVELOPE (WIDENED - 15%)

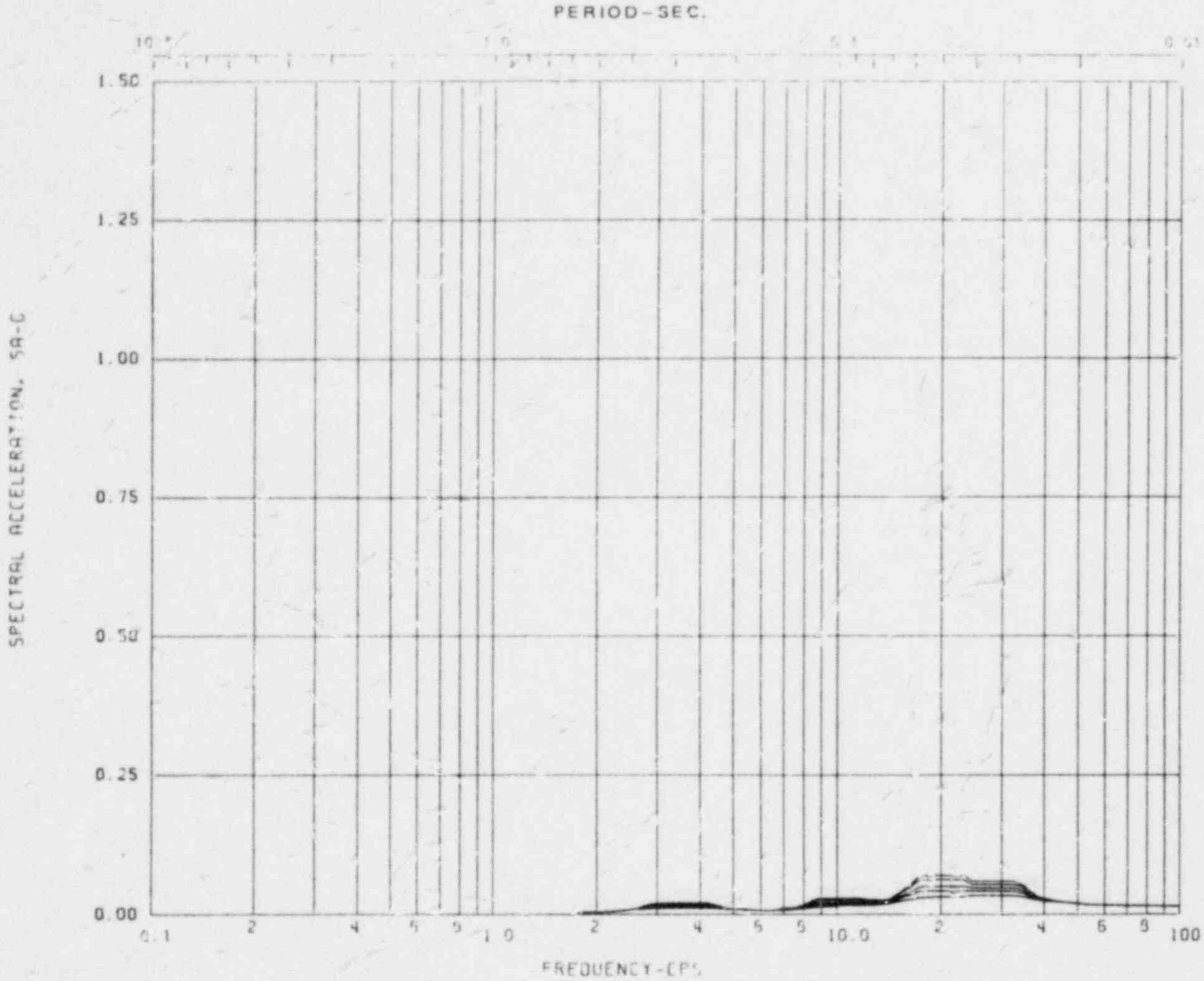
Node: 8 Direction: N-S HORIZ Elev: 304'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND CONTROL STRUCTURE GLOBAL RESPONSE SPECTRA, N-S HORIZONTAL, SRV ASYMMETRIC

FIGURE B.2-8



Acceleration Spectra for REACTOR BLDG., CONTROL STRUCTURE

Load Case: KWU SRV ASYMMETRIC ENVELOPE (WIDENED - 15%)

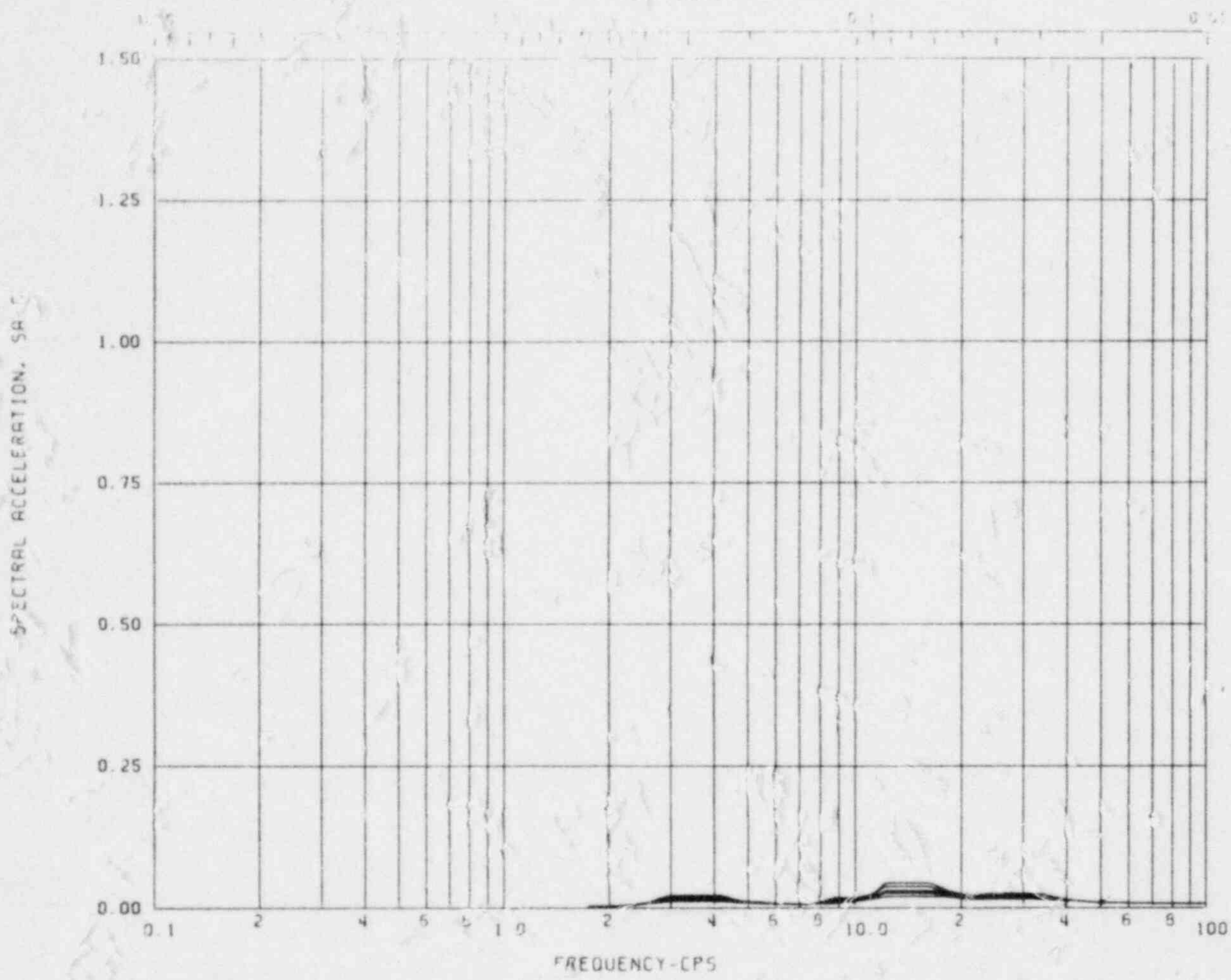
Node: 9 Direction: N-S HORIZ Elev: 313'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND CONTROL STRUCTURE GLOBAL RESPONSE SPECTRA, N-S HORIZONTAL, SRV ASYMMETRIC

FIGURE B.2-9



Acceleration Spectra for REACTOR BLDG., CONTROL STRUCTURE

Load Case: KWU SRV ASYMMETRIC ENVELOPE (WIDENED - 15%)

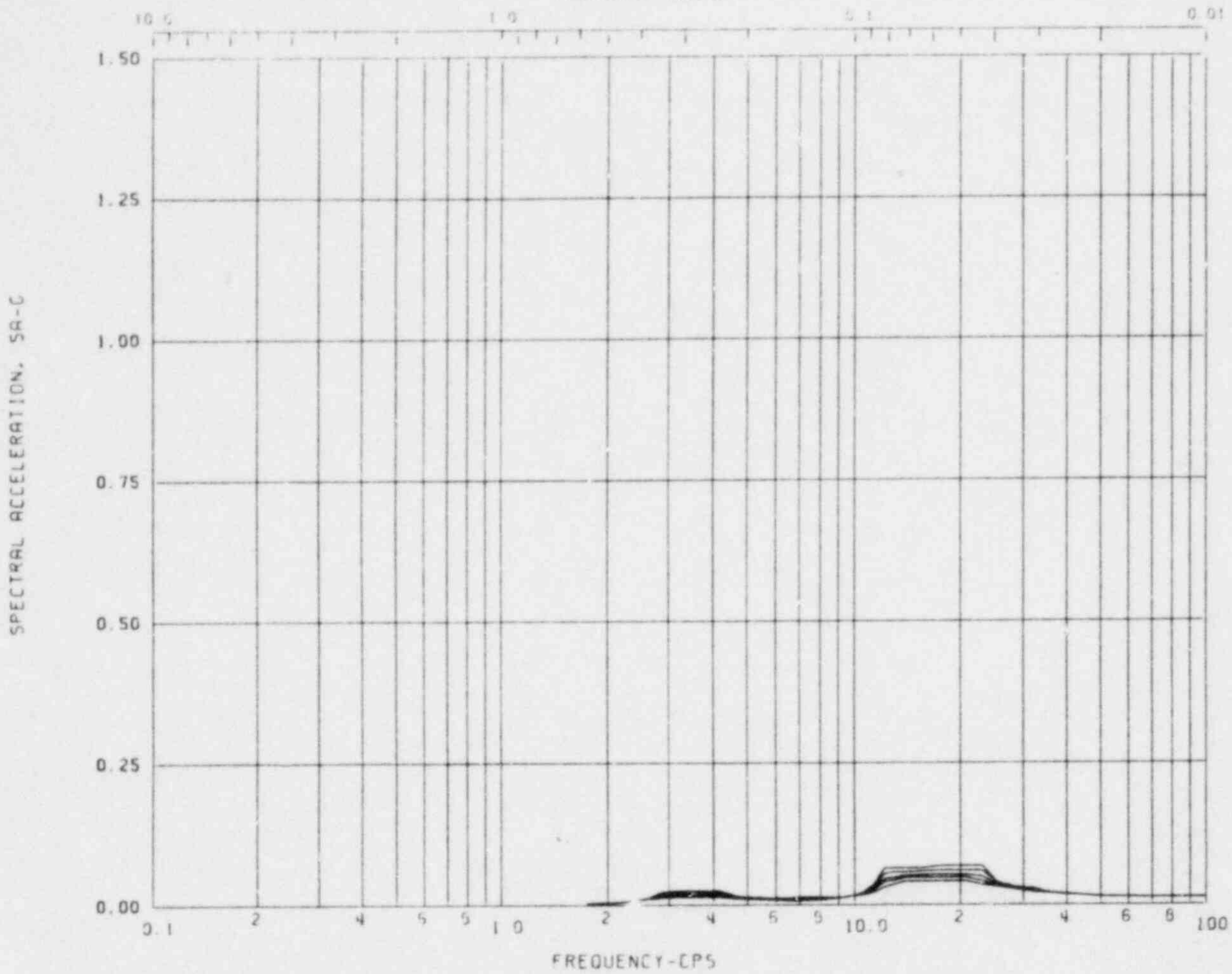
Node: 10 Direction: N-S HORIZ Elev: 332'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND CONTROL STRUCTURE GLOBAL RESPONSE SPECTRA, N-S HORIZONTAL, SRV ASYMMETRIC

FIGURE B.2-10



Acceleration Spectra for REACTOR BLDG., CONTROL STRUCTURE

Load Case: KWU SRV ASYMMETRIC ENVELOPE (WIDENED - 15%)

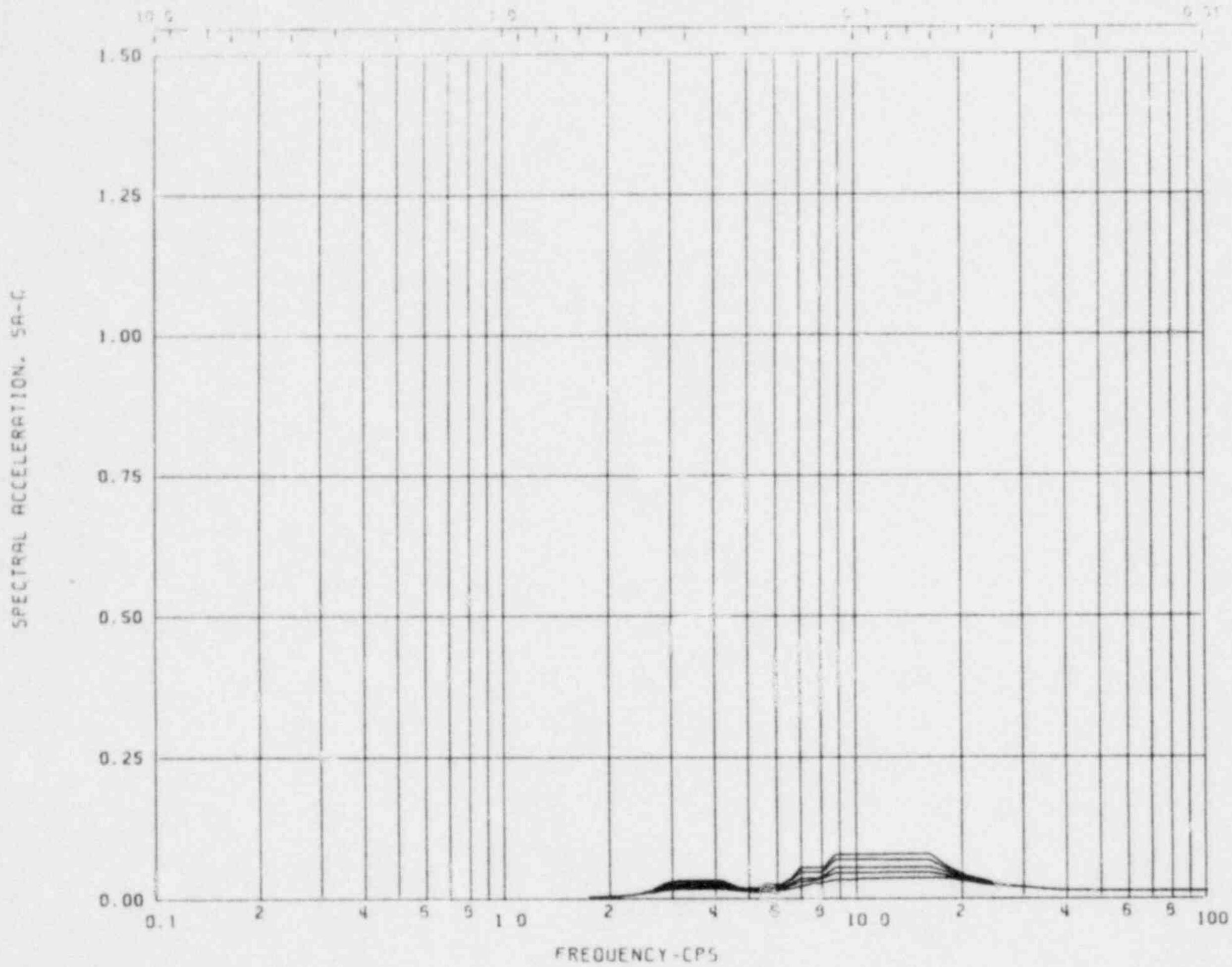
Node: 11 Direction: N-S HORIZ Elev: 352'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND CONTROL STRUCTURE GLOBAL RESPONSE SPECTRA, N-S HORIZONTAL, SRV ASYMMETRIC

FIGURE B.2-11



Acceleration Spectra for REACTOR BLDG., CONTROL STRUCTURE

Load Case: KWU SRV ASYMMETRIC ENVELOPE (WIDENED - 15%)

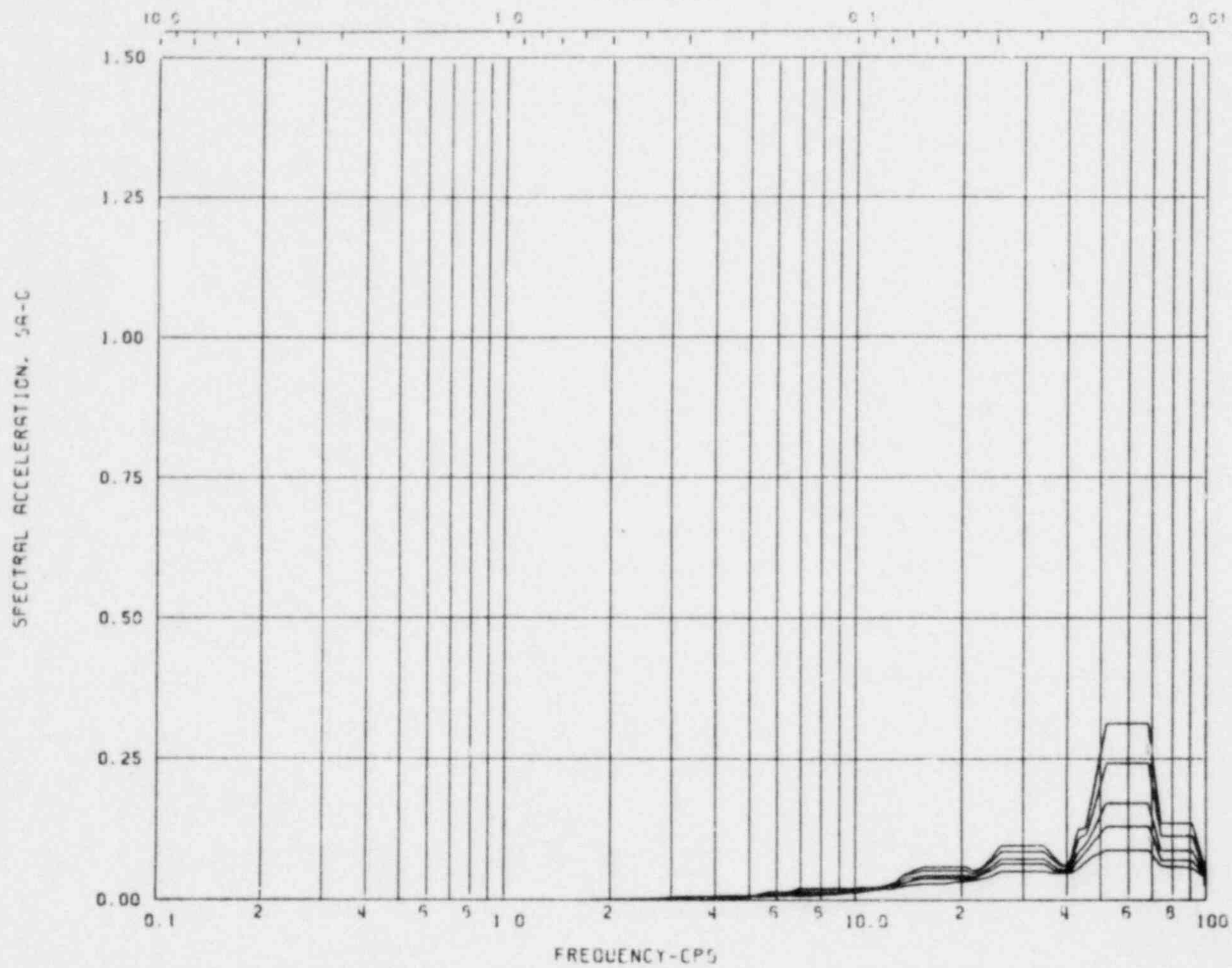
Node: 12 Direction: N-S HORIZ Elev: 410'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND CONTROL STRUCTURE GLOBAL RESPONSE SPECTRA, N-S HORIZONTAL, SRV ASYMMETRIC

FIGURE B.2-12



Acceleration Spectra for REACTOR BLDG., CONTROL STRUCTURE

Load Case: KWU SRV ASYMMETRIC ENVELOPE (WIDENED - 15%)

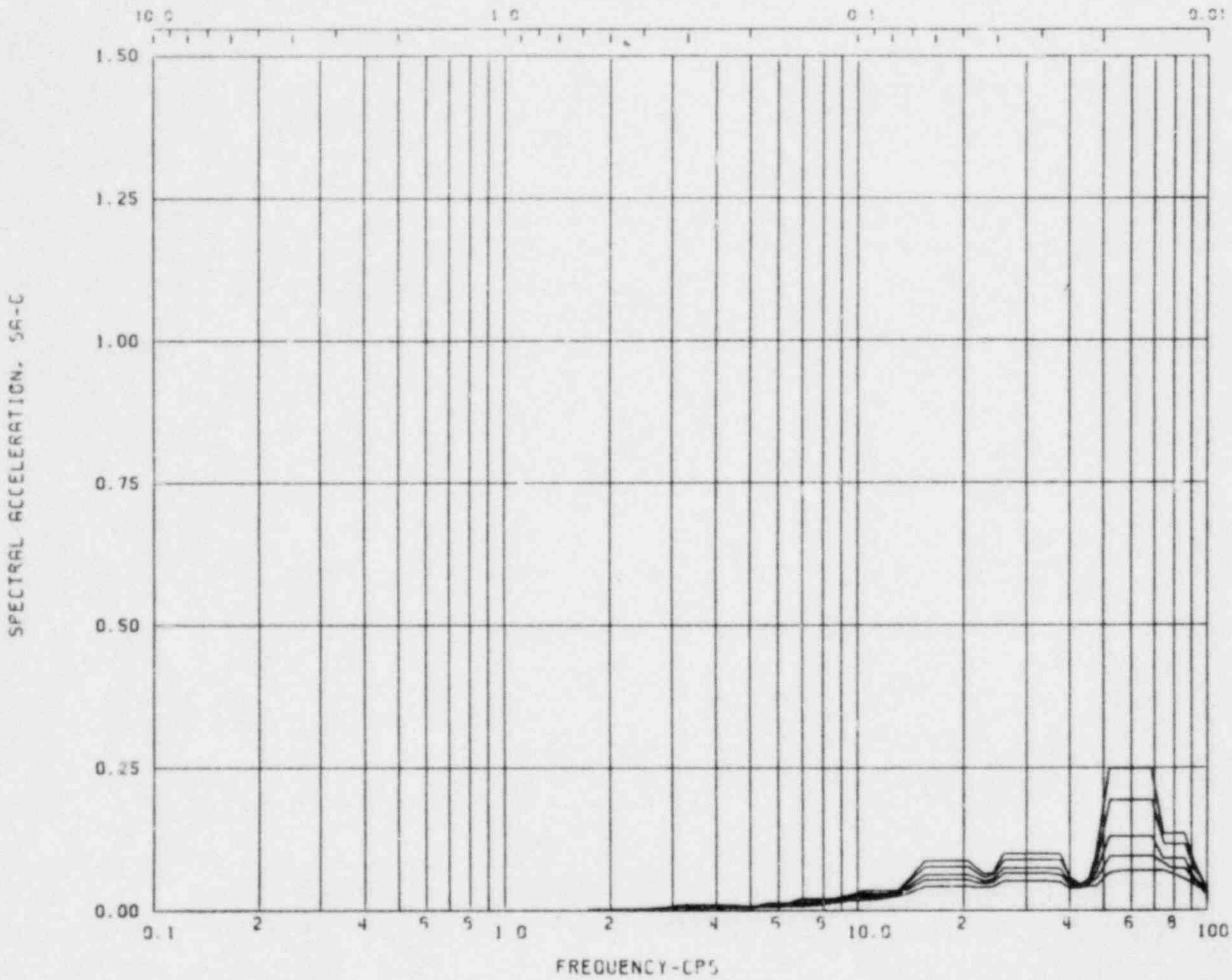
Node: 1 Direction: E-W HORIZ Elev: 177'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND CONTROL STRUCTURE GLOBAL RESPONSE SPECTRA, E-W HORIZONTAL, SRV ASYMMETRIC

FIGURE B.2-13



Acceleration Spectra for REACTOR BLDG., CONTROL STRUCTURE

Load Case: KWU SRV ASYMMETRIC ENVELOPE (WIDENED - 15%)

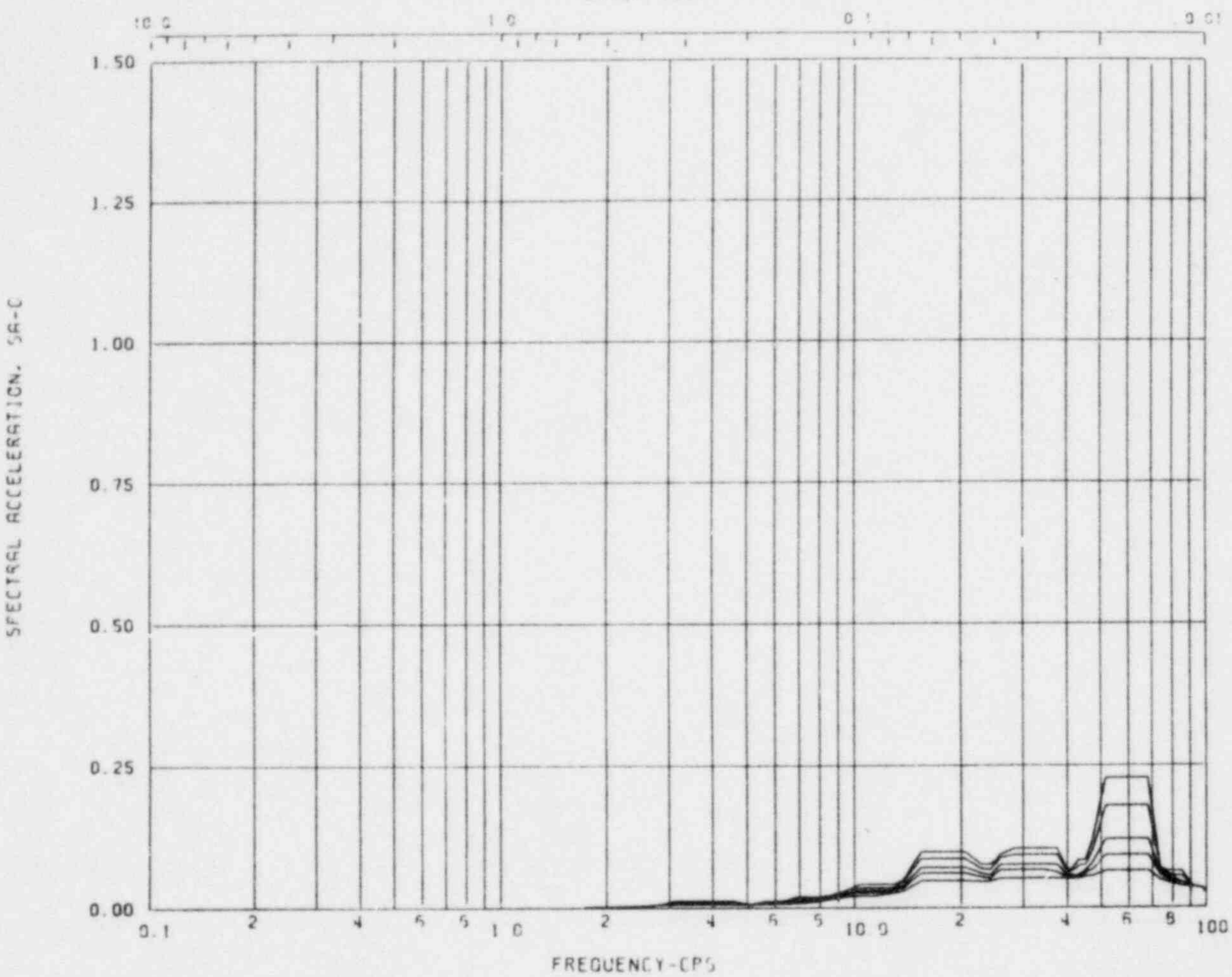
Node: 2 Direction: E-W HORIZ Elev: 201'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND CONTROL STRUCTURE GLOBAL RESPONSE SPECTRA, E-W HORIZONTAL, SRV ASYMMETRIC

FIGURE B.2-14



Acceleration Spectra for REACTOR BLDG., CONTROL STRUCTURE

Load Case: KWU SRV ASYMMETRIC ENVELOPE (WIDENED - 15%)

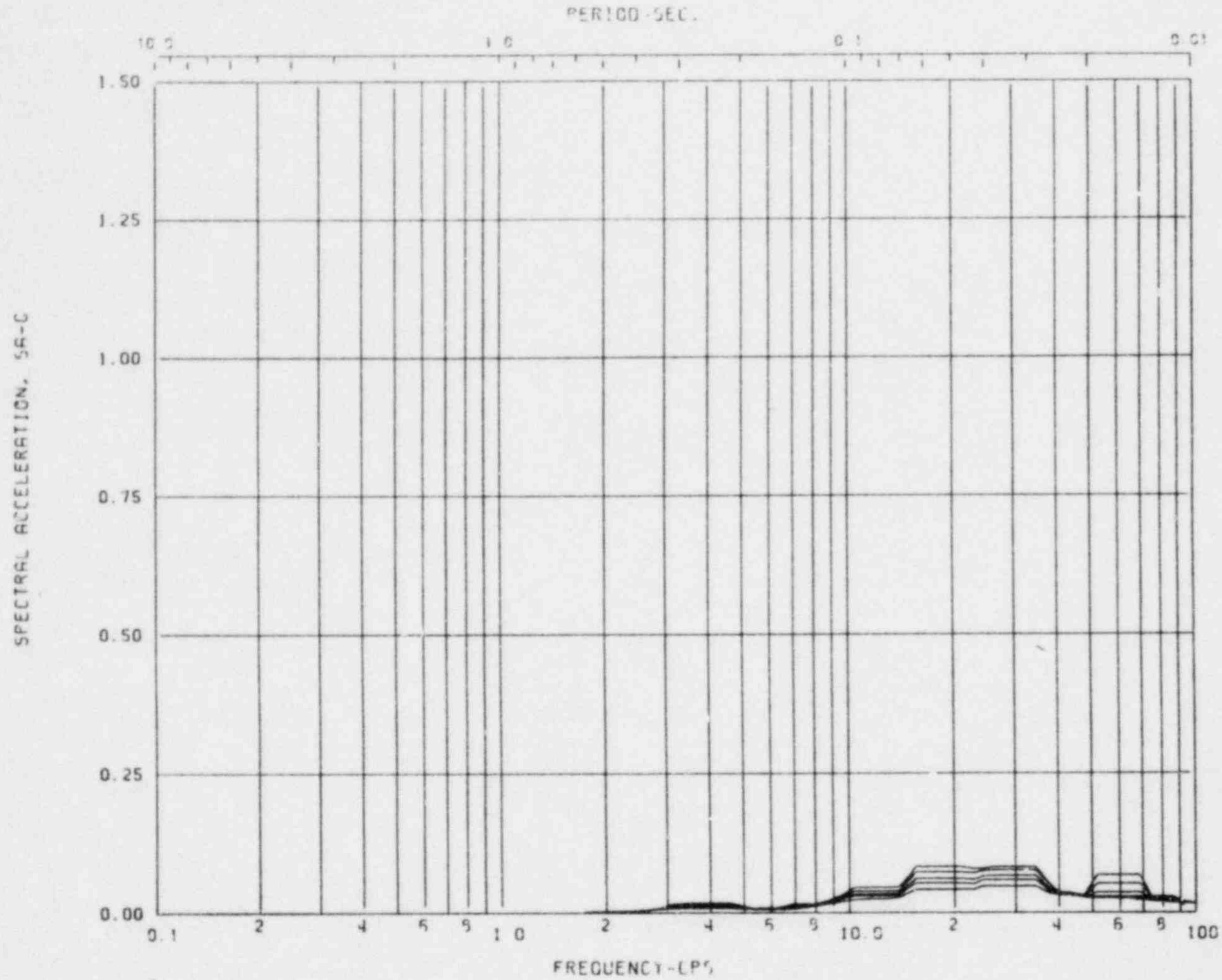
Node: 3 Direction: E-W HORIZ Elev: 217'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND CONTROL STRUCTURE GLOBAL RESPONSE SPECTRA, E-W HORIZONTAL, SRV ASYMMETRIC

FIGURE B.2-15



Acceleration Spectra for REACTOR BLDG., CONTROL STRUCTURE

Load Case: KWU SRV ASYMMETRIC ENVELOPE (WIDENED - 15%)

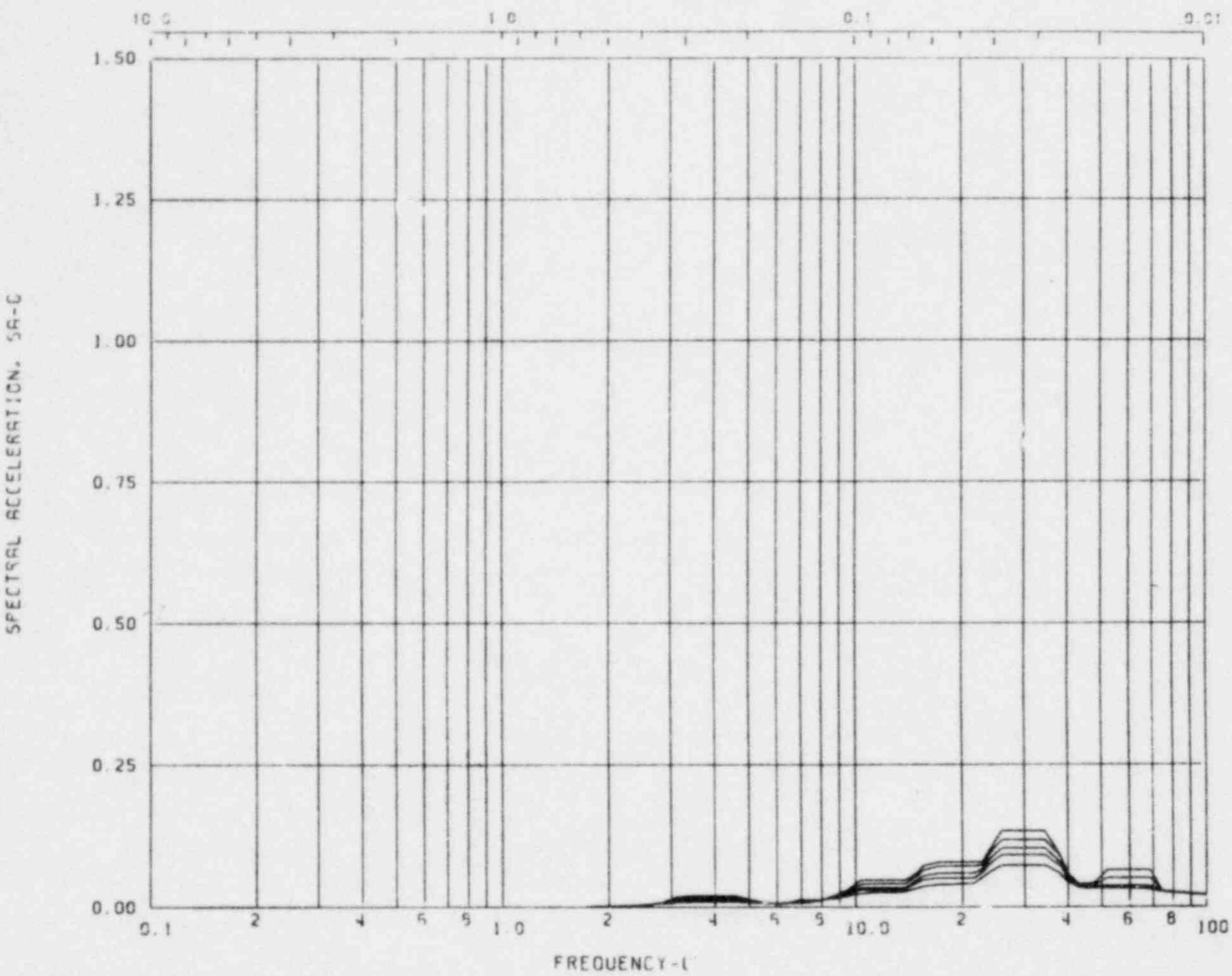
Node: 4 Direction: E-W HORIZ Elev: 239'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND CONTROL STRUCTURE GLOBAL RESPONSE SPECTRA, E-W HORIZONTAL, SRV ASYMMETRIC

FIGURE B.2-16



Acceleration Spectra for REACTOR BLDG., CONTROL STRUCTURE

Load Case: KWU SRV ASYMMETRIC ENVELOPE (WIDENED - 15%)

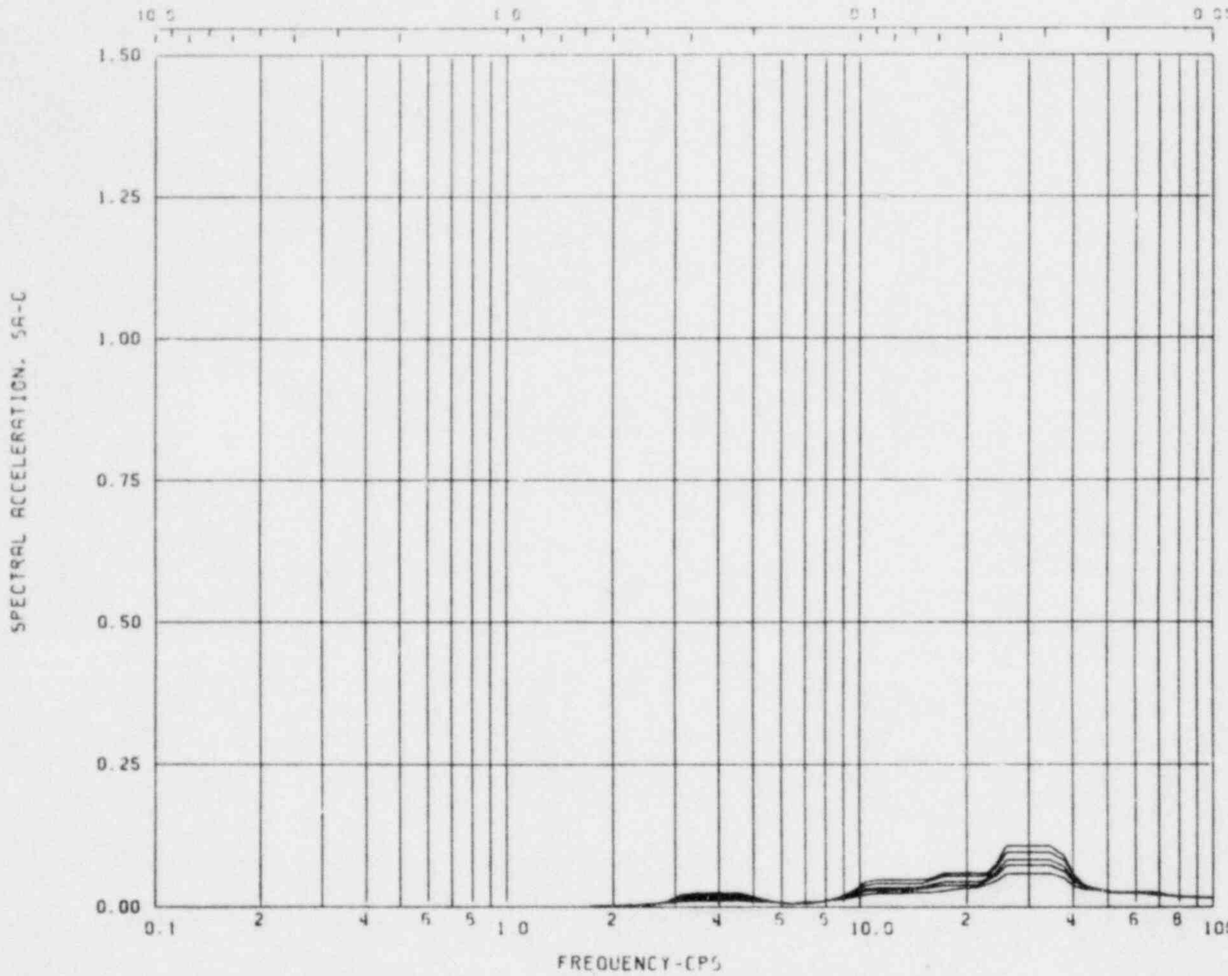
Node: 5 Direction: E-W HORIZ Elev: 253'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND CONTROL STRUCTURE GLOBAL RESPONSE SPECTRA, E-W HORIZONTAL, SRV ASYMMETRIC

FIGURE B.2-17



Acceleration Spectra for REACTOR BLDG., CONTROL STRUCTURE

Load Case: KWU SRV ASYMMETRIC ENVELOPE (WIDENED - 15%)

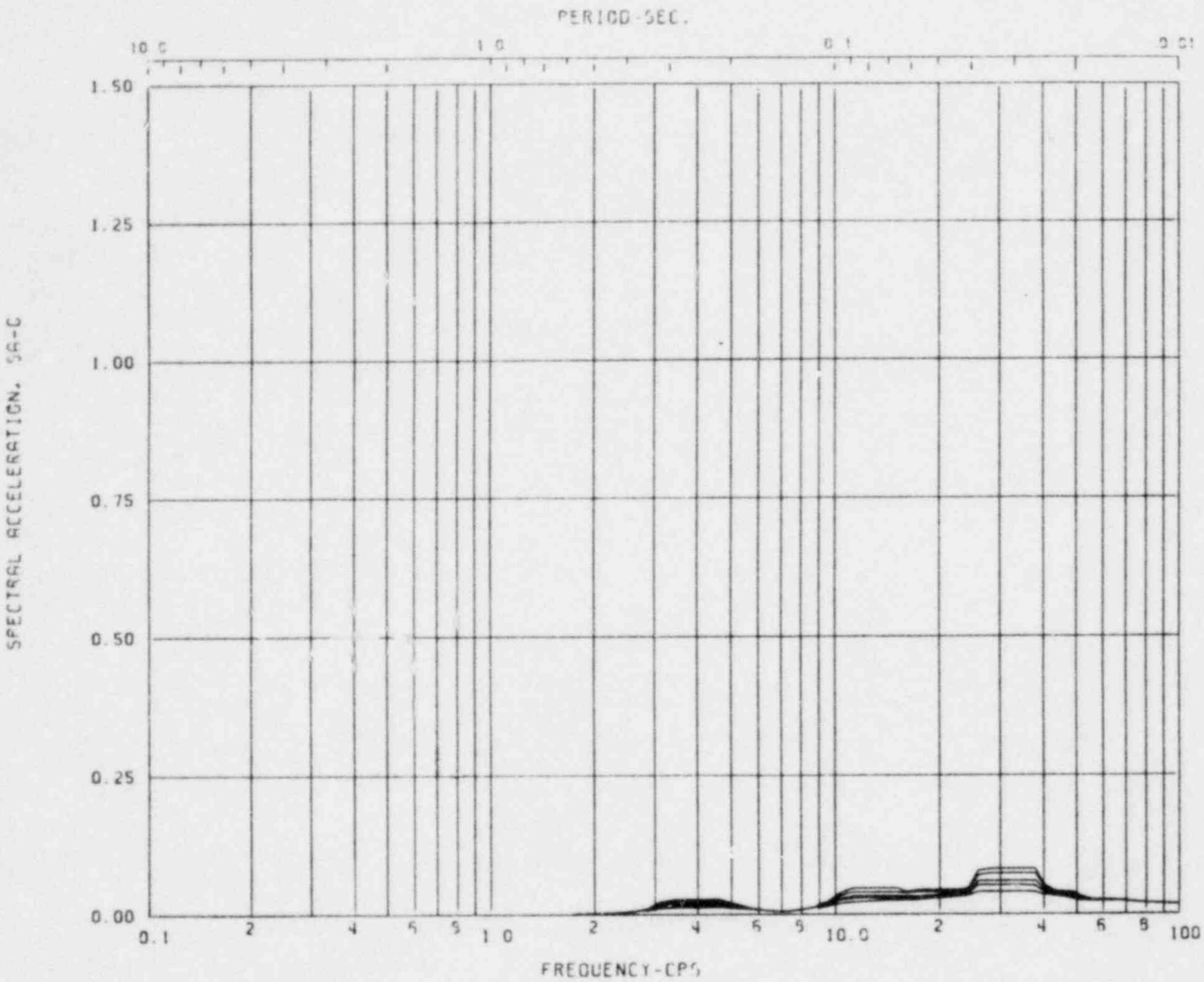
Node: 6 Direction: E-W HORIZ Elev: 269'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND CONTROL STRUCTURE GLOBAL RESPONSE SPECTRA, E-W HORIZONTAL, SRV ASYMMETRIC

FIGURE B.2-18



Acceleration Spectra for REACTOR BLDG., CONTROL STRUCTURE

Load Case: KWU SRV ASYMMETRIC ENVELOPE (WIDENED - 15%)

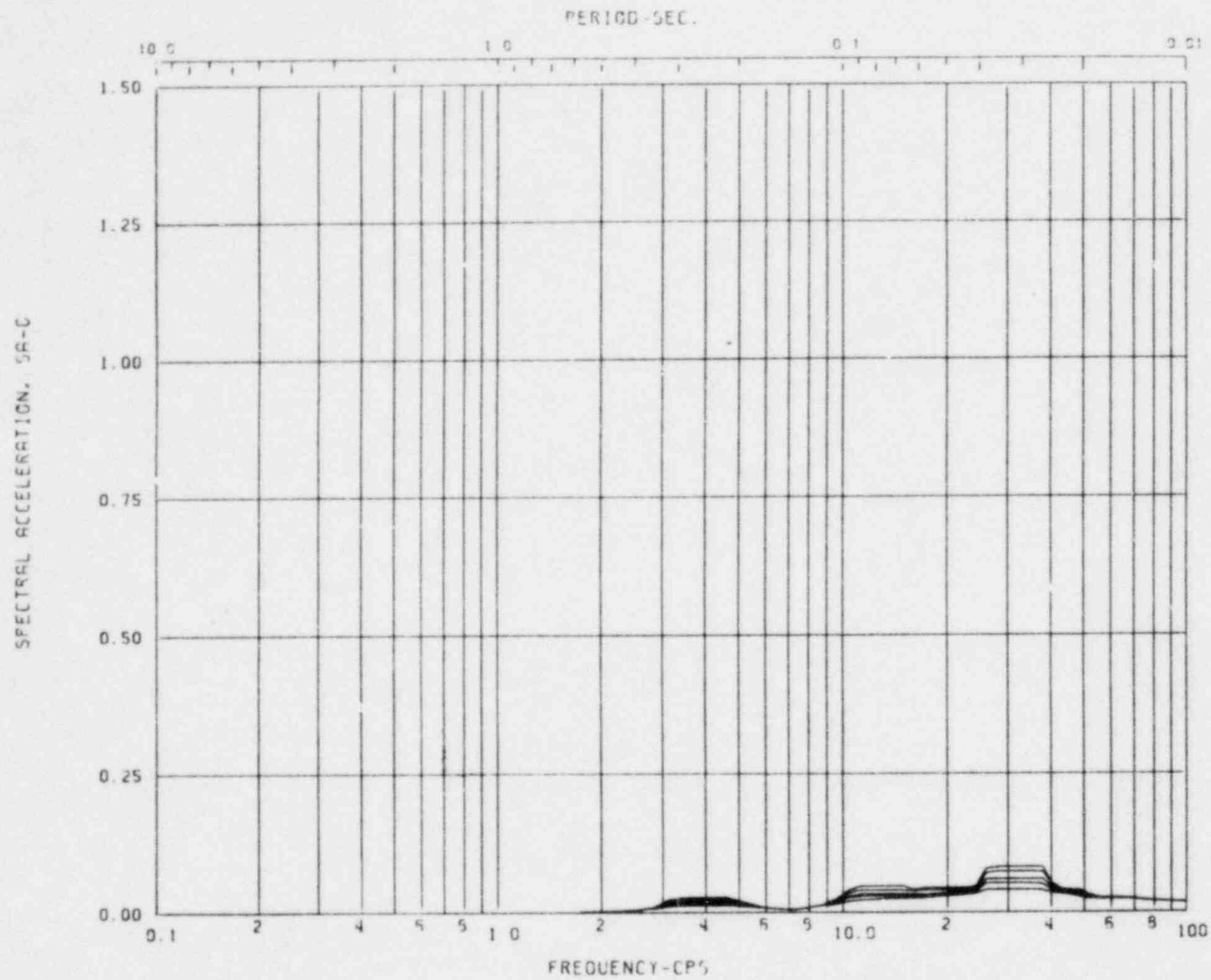
Node: 7 Direction: E-W HORIZ Elev: 283'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND CONTROL STRUCTURE GLOBAL RESPONSE SPECTRA, E-W HORIZONTAL, SRV ASYMMETRIC

FIGURE B.2-19



Acceleration Spectra for REACTOR BLDG., CONTROL STRUCTURE

Load Case: KWU SRV ASYMMETRIC ENVELOPE (WIDENED - 15%)

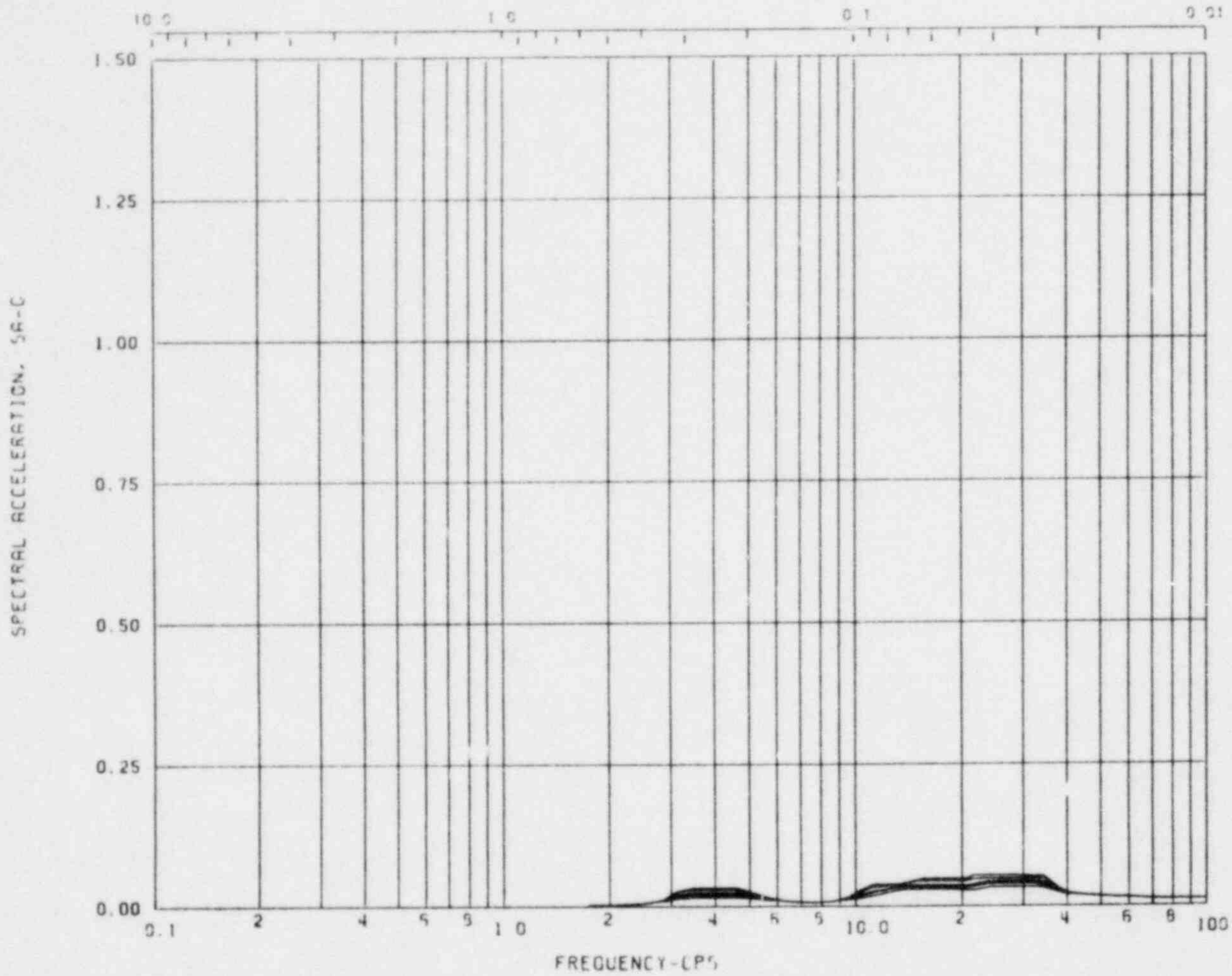
Node: 7 Direction: E-W HORIZ Elev: 283'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND CONTROL STRUCTURE GLOBAL RESPONSE SPECTRA, E-W HORIZONTAL, SRV ASYMMETRIC

FIGURE B.2-19



Acceleration Spectra for REACTOR BLDG., CONTROL STRUCTURE

Load Case: KWU SRV ASYMMETRIC ENVELOPE (WIDENED - 15%)

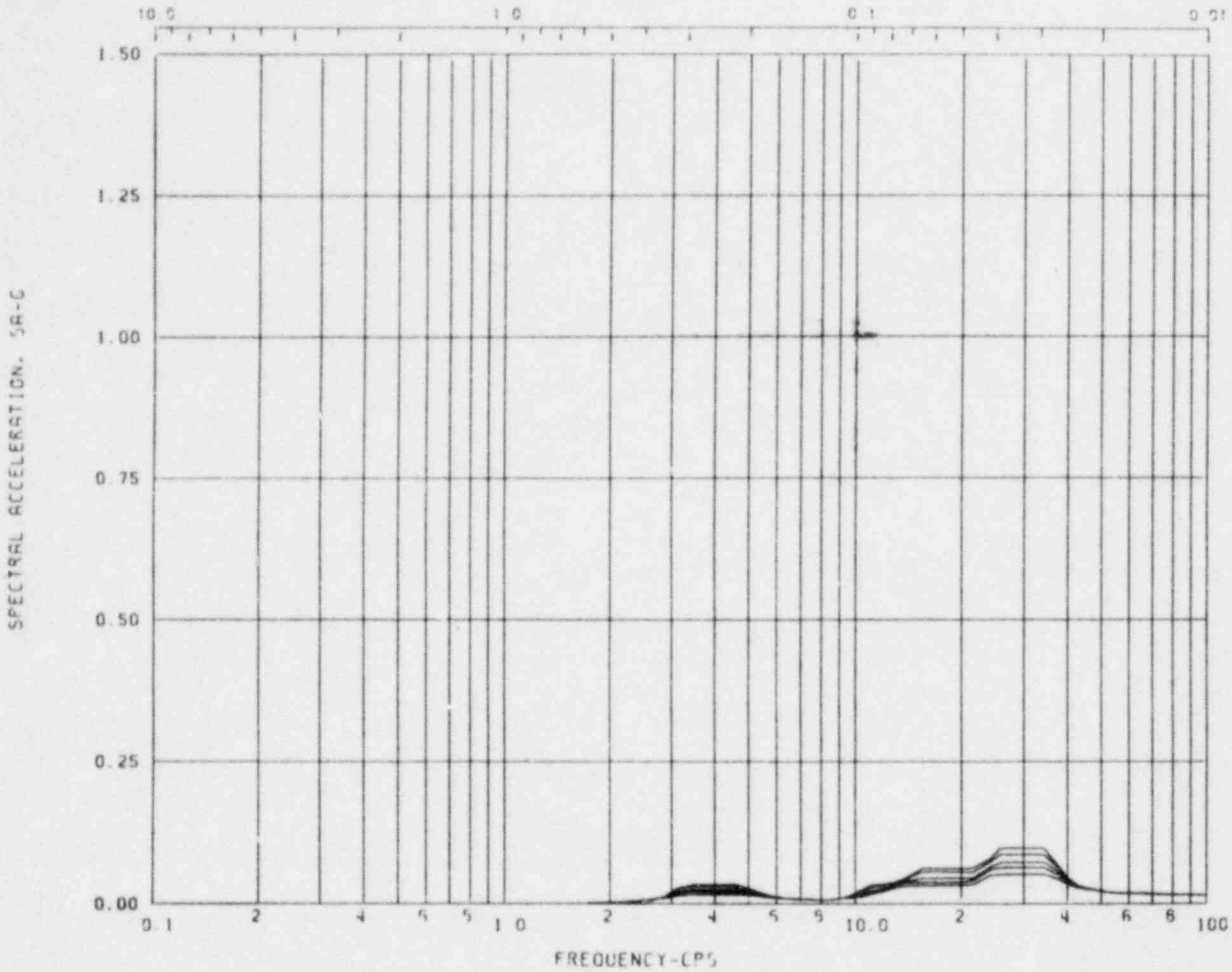
Node: 8 Direction: E-W HORIZ Elev: 304'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND CONTROL STRUCTURE GLOBAL RESPONSE SPECTRA, E-W HORIZONTAL, SRV ASYMMETRIC

FIGURE B.2-20



Acceleration Spectra for REACTOR BLDG., CONTROL STRUCTURE

Load Case: KWU SRV ASYMMETRIC ENVELOPE (WIDENED - 15%)

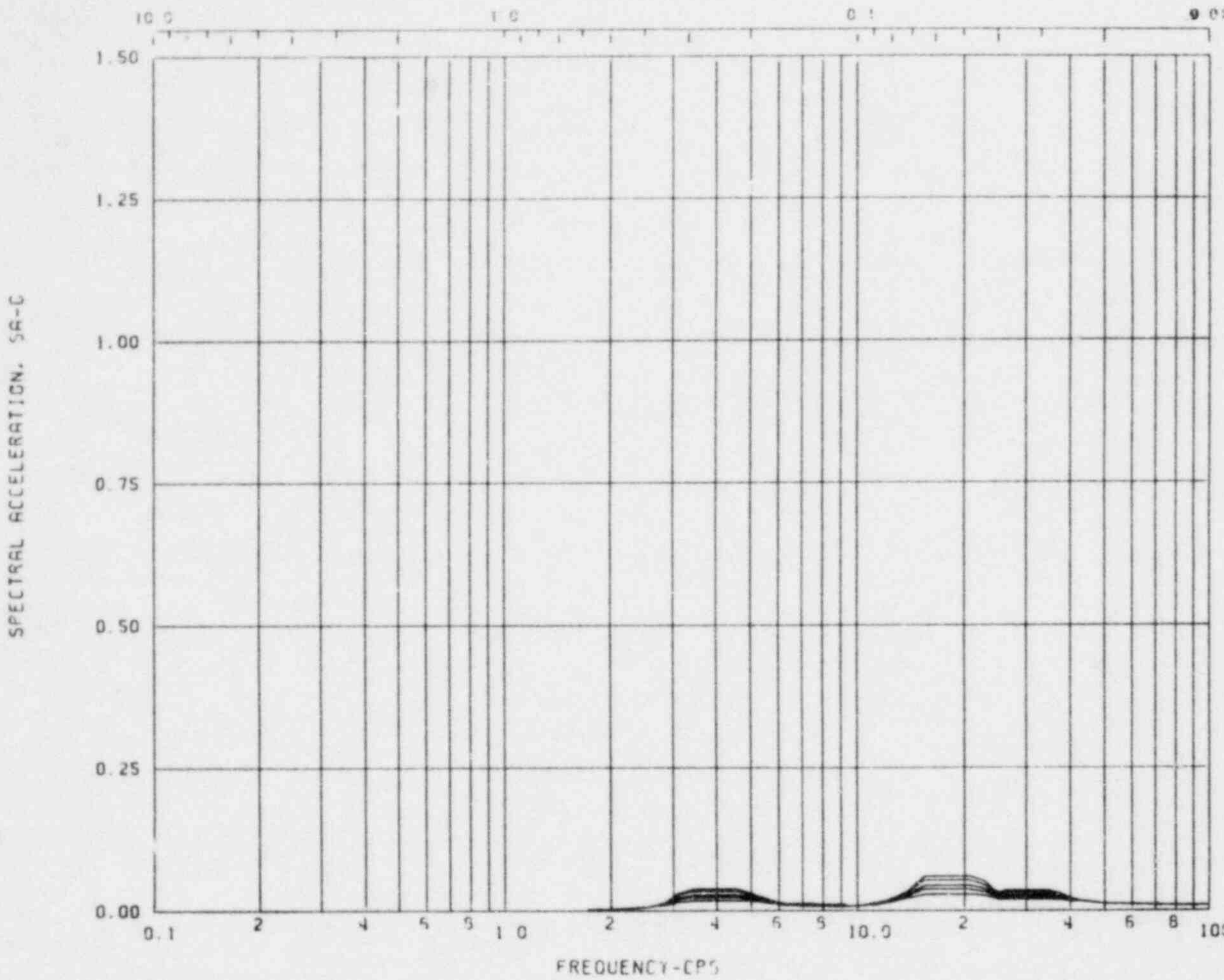
Node: 9 Direction: E-W HORIZ Elev: 313'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND CONTROL STRUCTURE GLOBAL RESPONSE SPECTRA, E-W HORIZONTAL, SRV ASYMMETRIC

FIGURE B.2-21



Acceleration Spectra for REACTOR BLDG., CONTROL STRUCTURE

Load Case: KWU SRV ASYMMETRIC ENVELOPE (WIDENED - 15%)

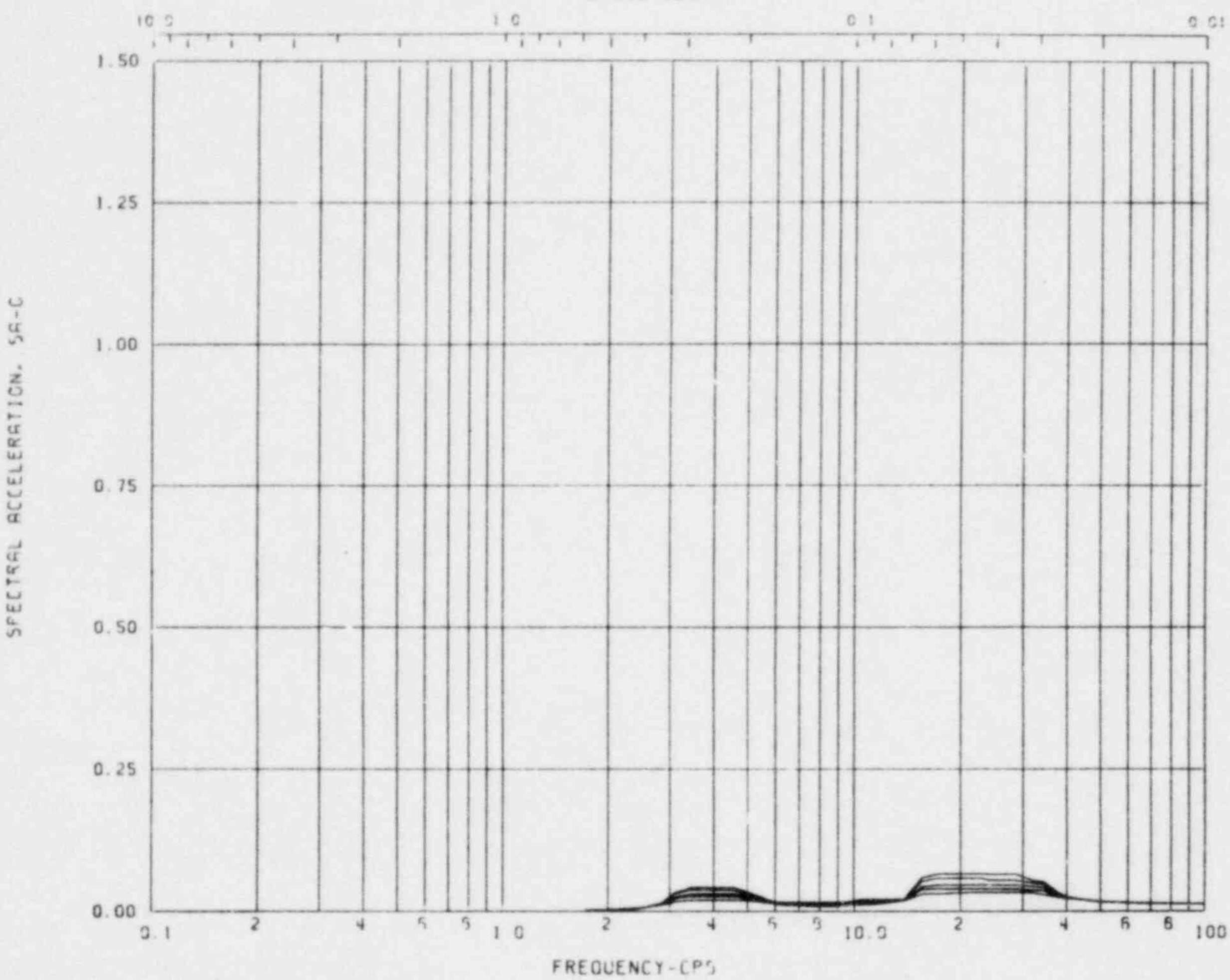
Node: 10 Direction: E-W HORIZ Elev: 332'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND CONTROL STRUCTURE GLOBAL RESPONSE SPECTRA, E-W HORIZONTAL, SRV ASYMMETRIC

FIGURE B.2-22



Acceleration Spectra for REACTOR BLDG., CONTROL STRUCTURE

Load Case: KWU SRV ASYMMETRIC ENVELOPE (WIDENED - 15%)

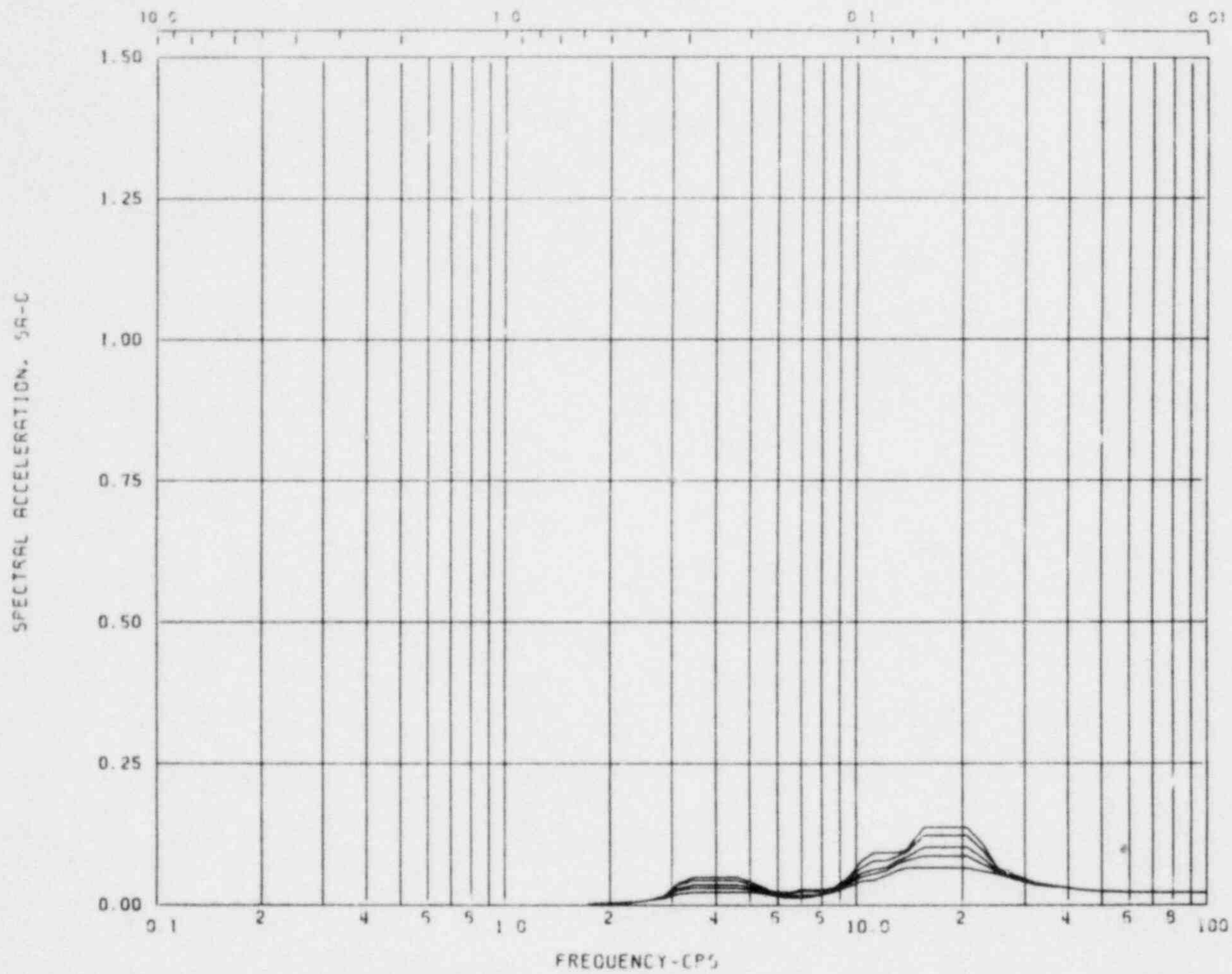
Node: 11 Direction: E-W HORIZ Elev: 352'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND CONTROL STRUCTURE GLOBAL RESPONSE SPECTRA, E-W HORIZONTAL, SRV ASYMMETRIC

FIGURE B.2-23



Acceleration Spectra for REACTOR BLDG., CONTROL STRUCTURE

Load Case: KWU SRV ASYMMETRIC ENVELOPE (WIDENED - 15%)

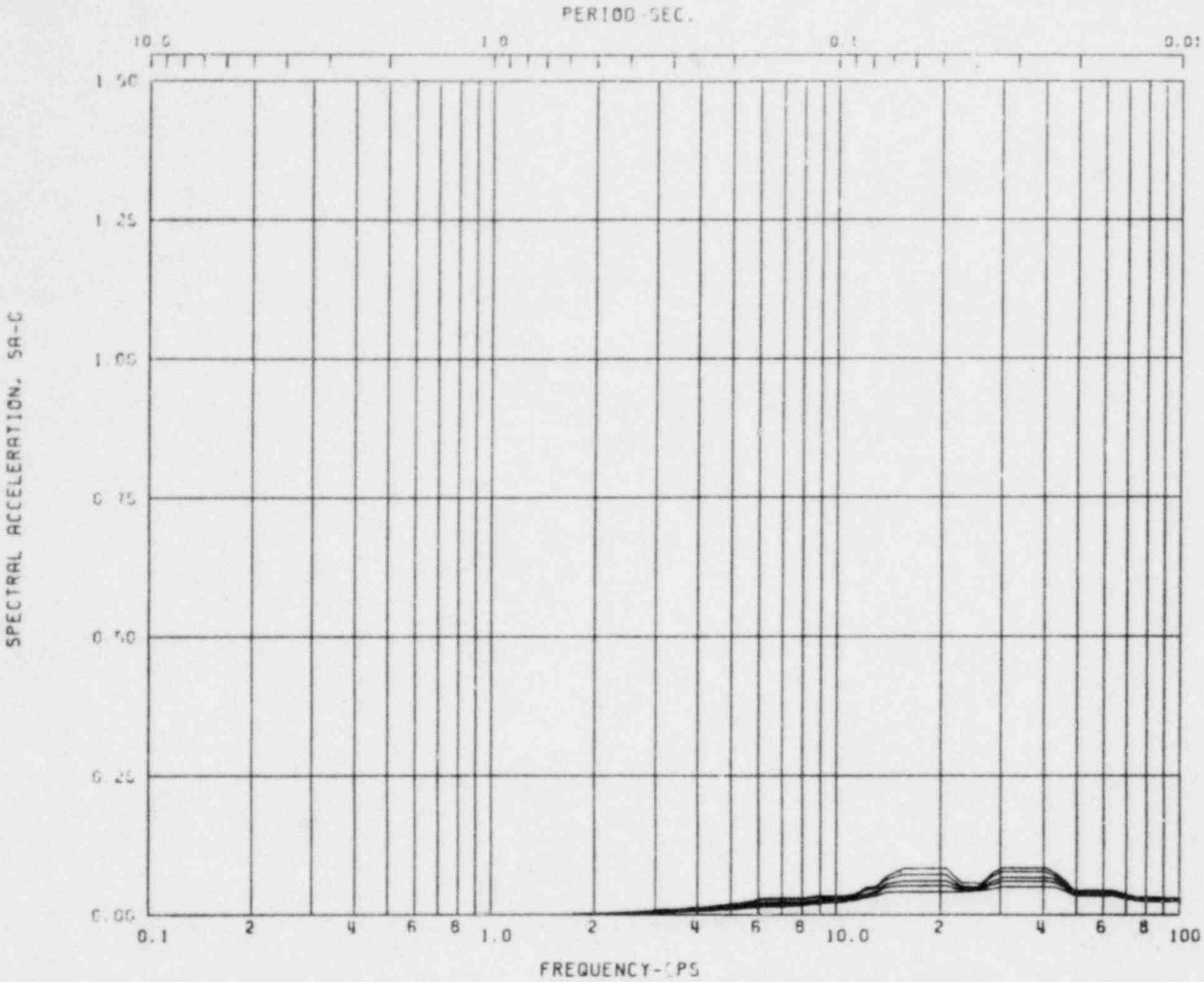
Node: 12 Direction: E-W HORIZ Elev: 410'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND CONTROL STRUCTURE GLOBAL RESPONSE SPECTRA, E-W HORIZONTAL, SRV ASYMMETRIC

FIGURE 8.2-24



Acceleration Spectra for REACTOR BLDG.

Load Case: KWU SRV AXISYMMETRIC ENVELOPE (WIDENED - 15%)

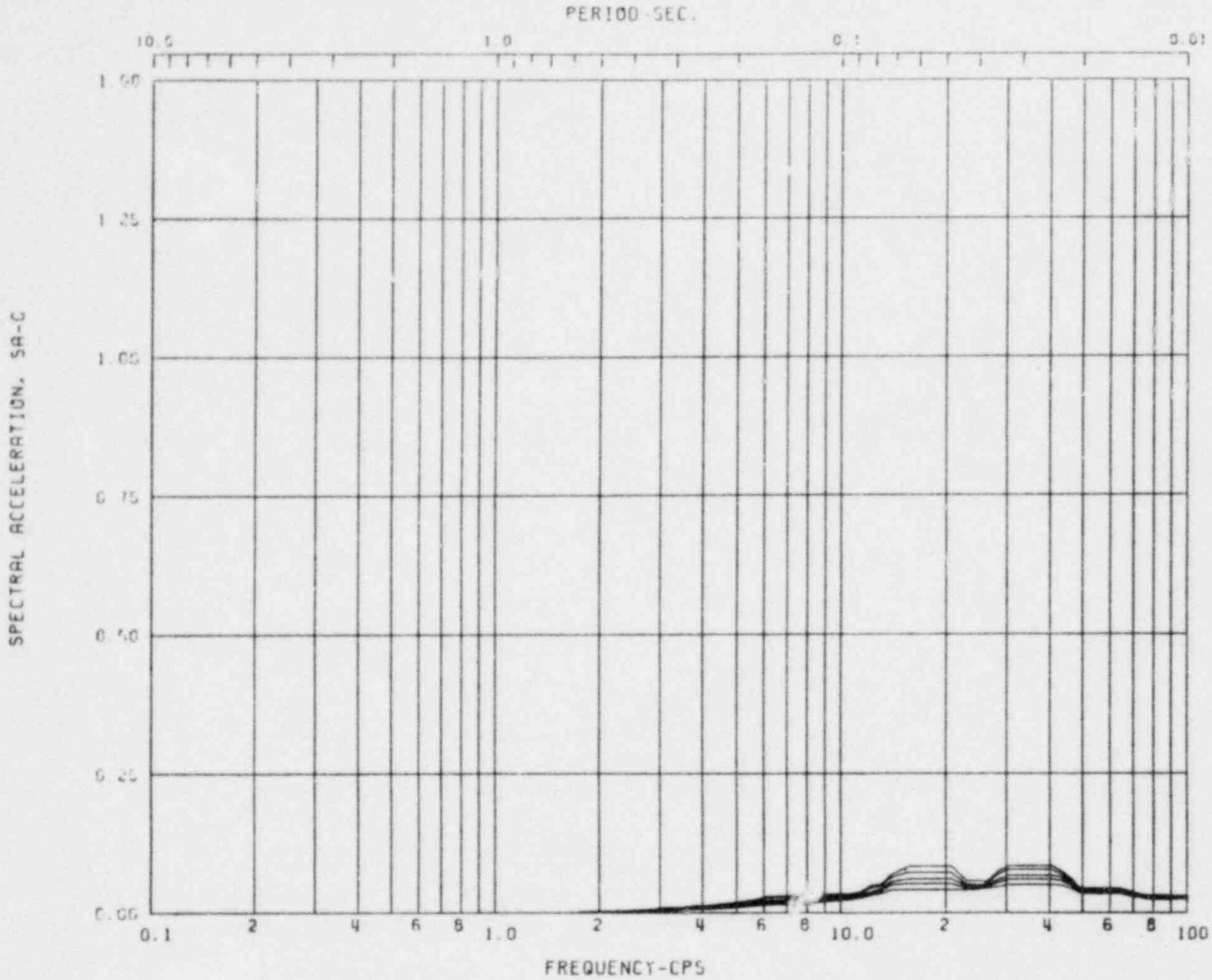
Node: 159 Direction: VERTICAL Elev: 177'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING
GLOBAL RESPONSE SPECTRA
VERTICAL, SRV AXISYMMETRIC

FIGURE B.2-25



Acceleration Spectra for REACTOR BLDG.

Load Case: KWU SRV AXISYMMETRIC ENVELOPE (WIDENED - 15%)

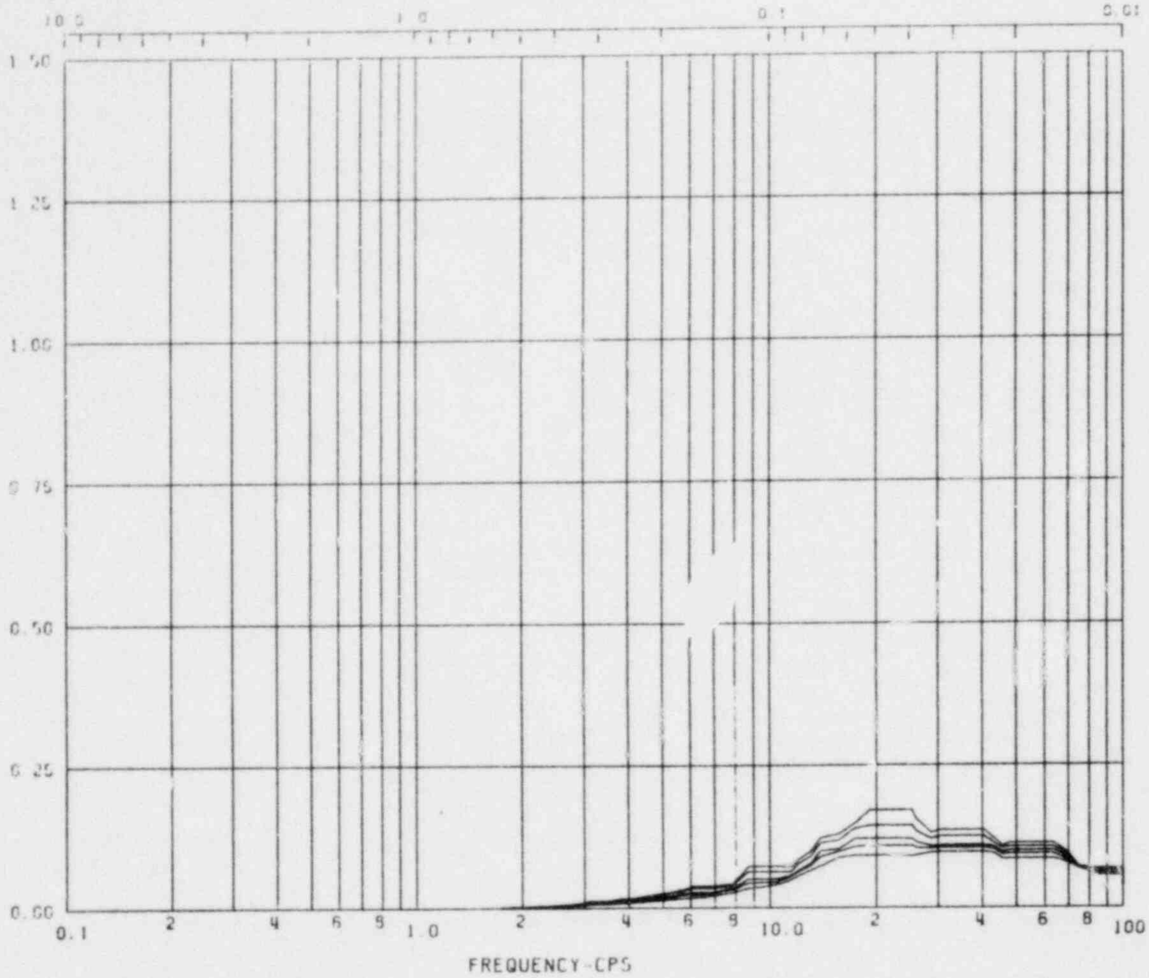
Node: 159 Direction: VERTICAL Elev: 177'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING
GLOBAL RESPONSE SPECTRA
VERTICAL, SRV AXISYMMETRIC

FIGURE B.2-25



Acceleration Spectra for REACTOR BLDG.

Load Case: KWU SRV AXISYMMETRIC ENVELOPE (WIDENED - 15%)

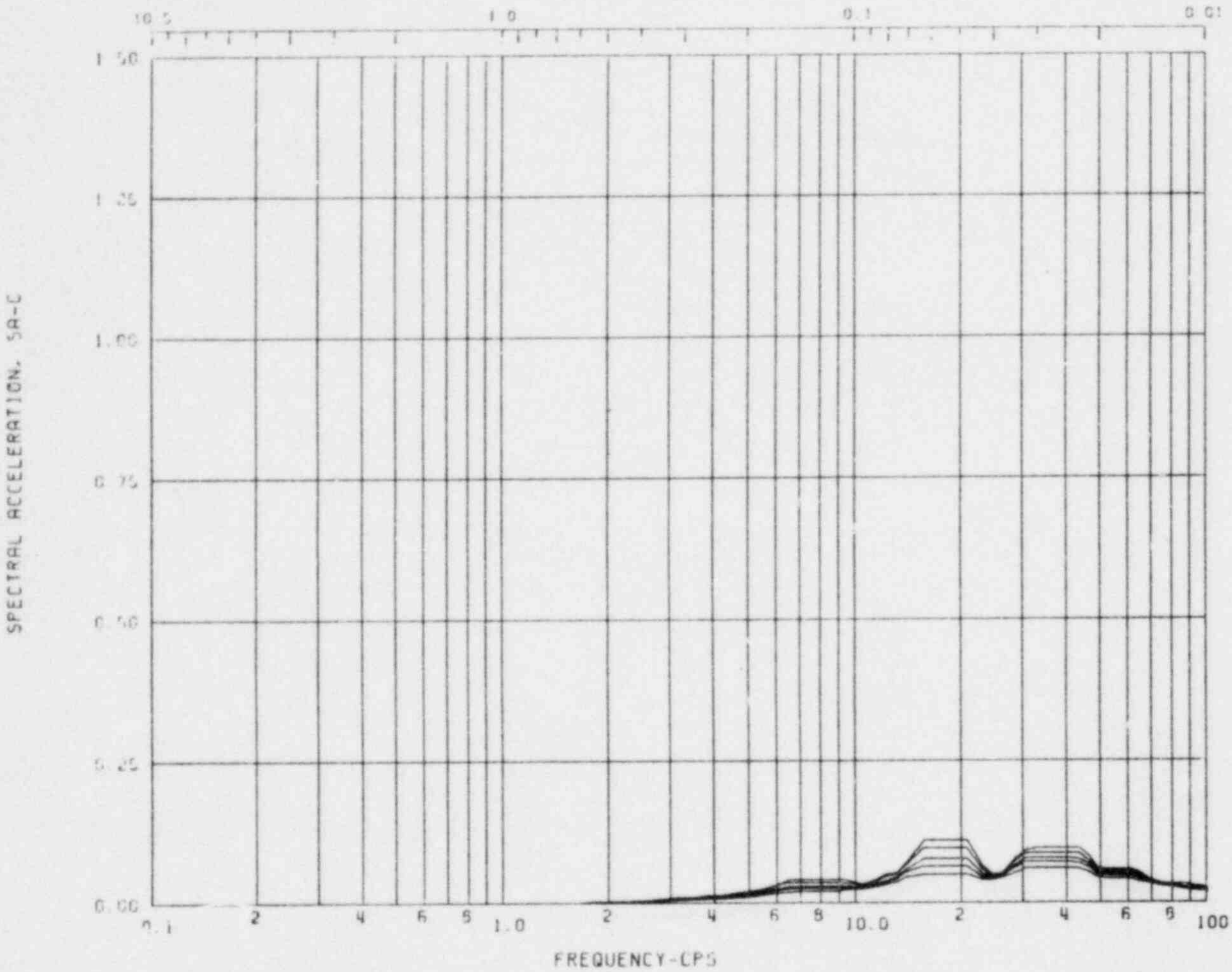
Node: 154 Direction: VERTICAL Elev: 177'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING
GLOBAL RESPONSE SPECTRA
VERTICAL, SRV AXISYMMETRIC

FIGURE B.2-26



Acceleration Spectra for REACTOR BLDG.

Load Case: KWU SRV AXISYMMETRIC ENVELOPE (WIDENED - 15%)

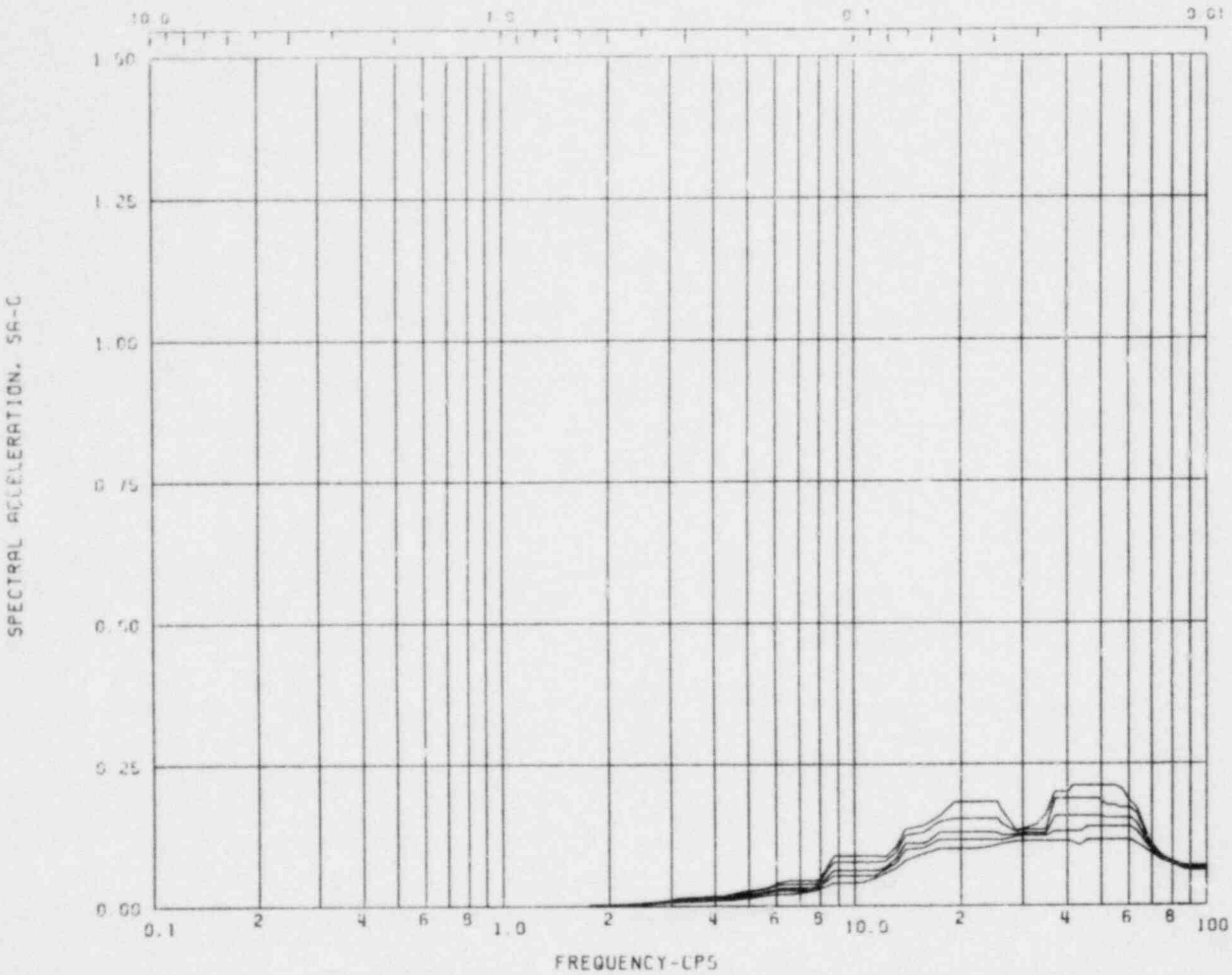
Node: 128 Direction: VERTICAL Elev: 201'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING
GLOBAL RESPONSE SPECTRA
VERTICAL, SRV AXISYMMETRIC

FIGURE B.2-27



Acceleration Spectra for REACTOR BLDG.

Load Case: KWU SRV AXISYMMETRIC ENVELOPE (WIDENED - 15%)

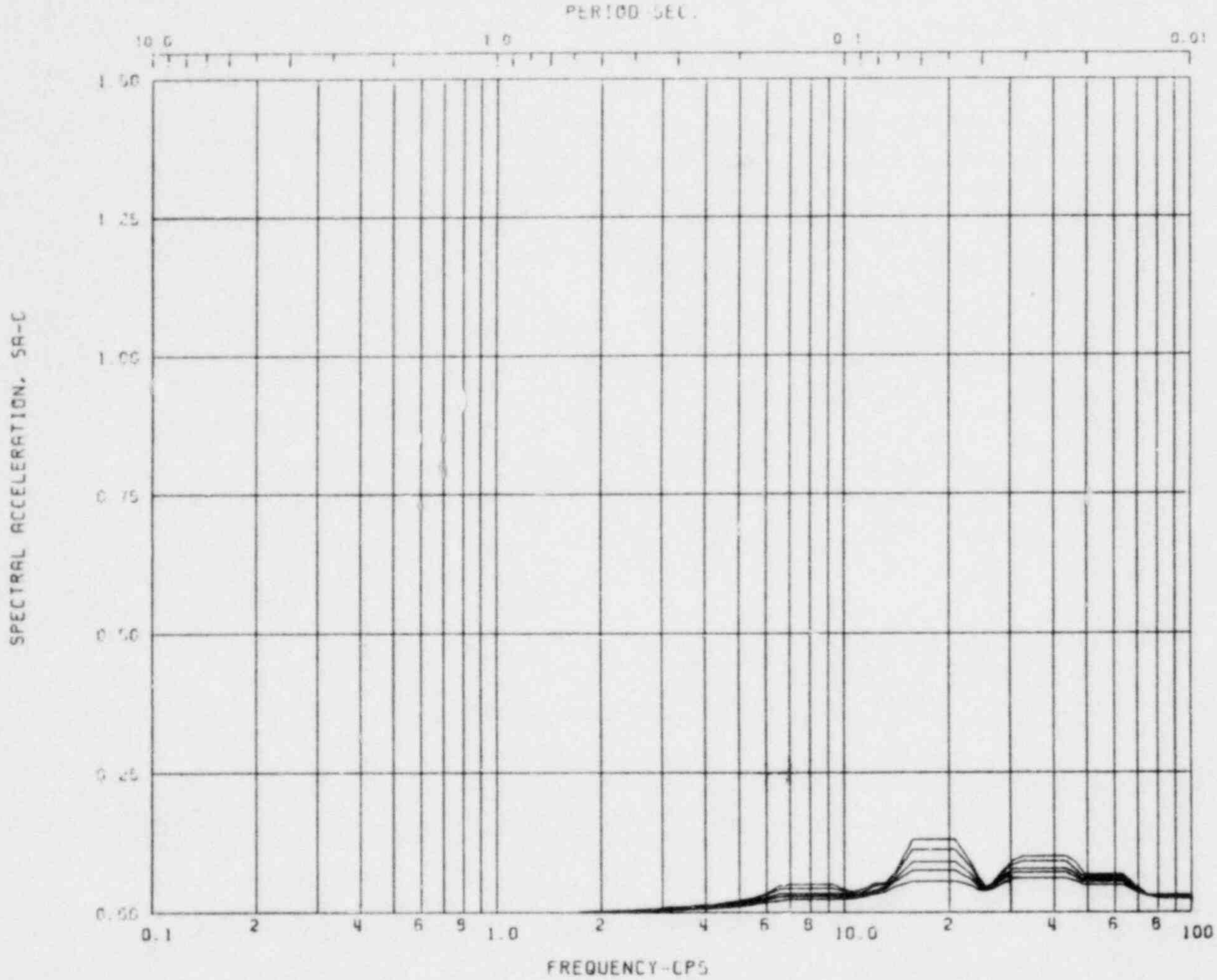
Node: 130 Direction: VERTICAL Elev: 201'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING
GLOBAL RESPONSE SPECTRA
VERTICAL, SRV AXISYMMETRIC

FIGURE B.2-28



Acceleration Spectra for REACTOR BLDG.

Load Case: KWU SRV AXISYMMETRIC ENVELOPE (WIDENED - 15%)

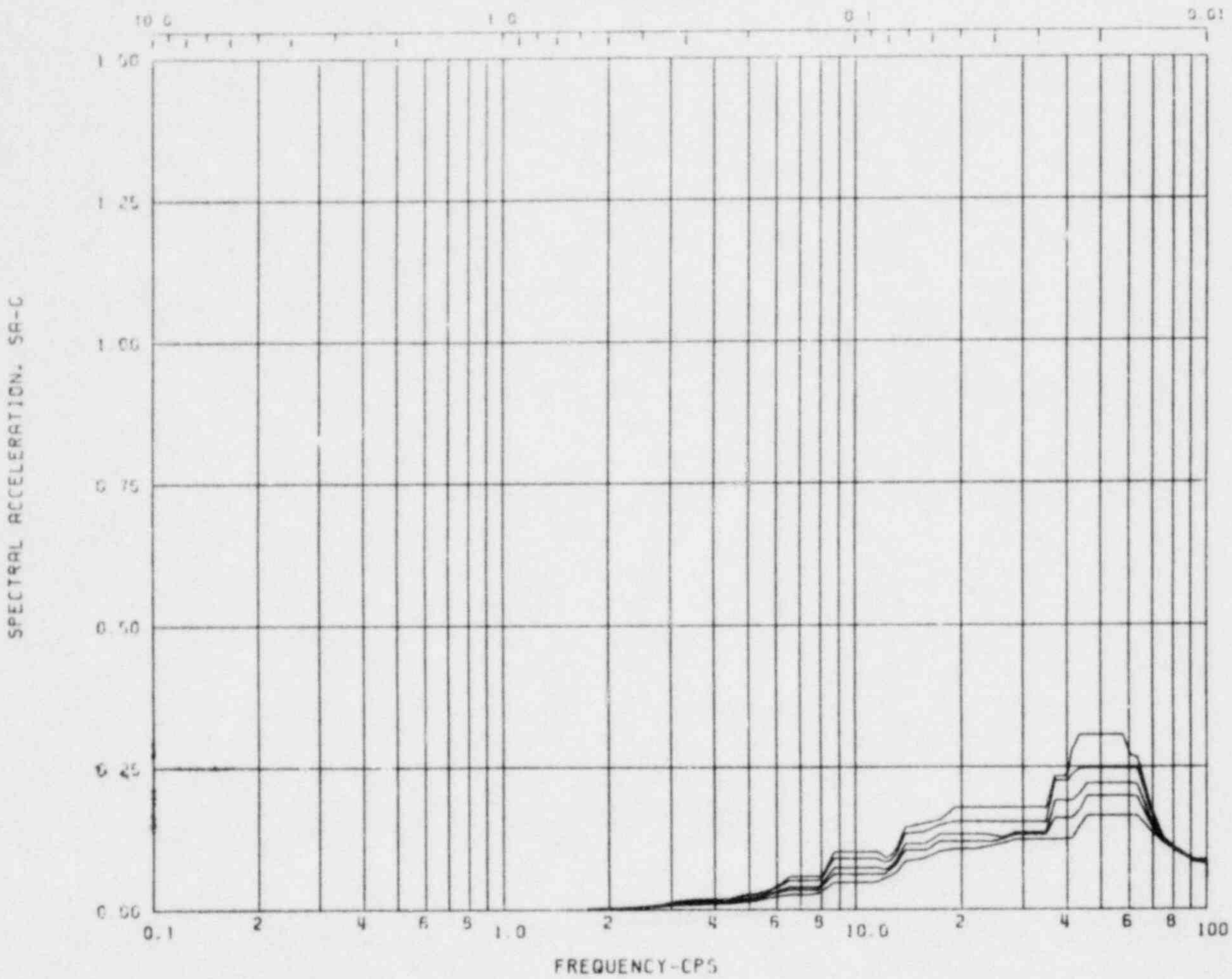
Node: 106 Direction: VERTICAL Elev: 217'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING
GLOBAL RESPONSE SPECTRA
VERTICAL, SRV AXISYMMETRIC

FIGURE B.2-29



Acceleration Spectra for REACTOR BLDG.

Load Case: KWU SRV AXISYMMETRIC ENVELOPE (WIDENED - 15%)

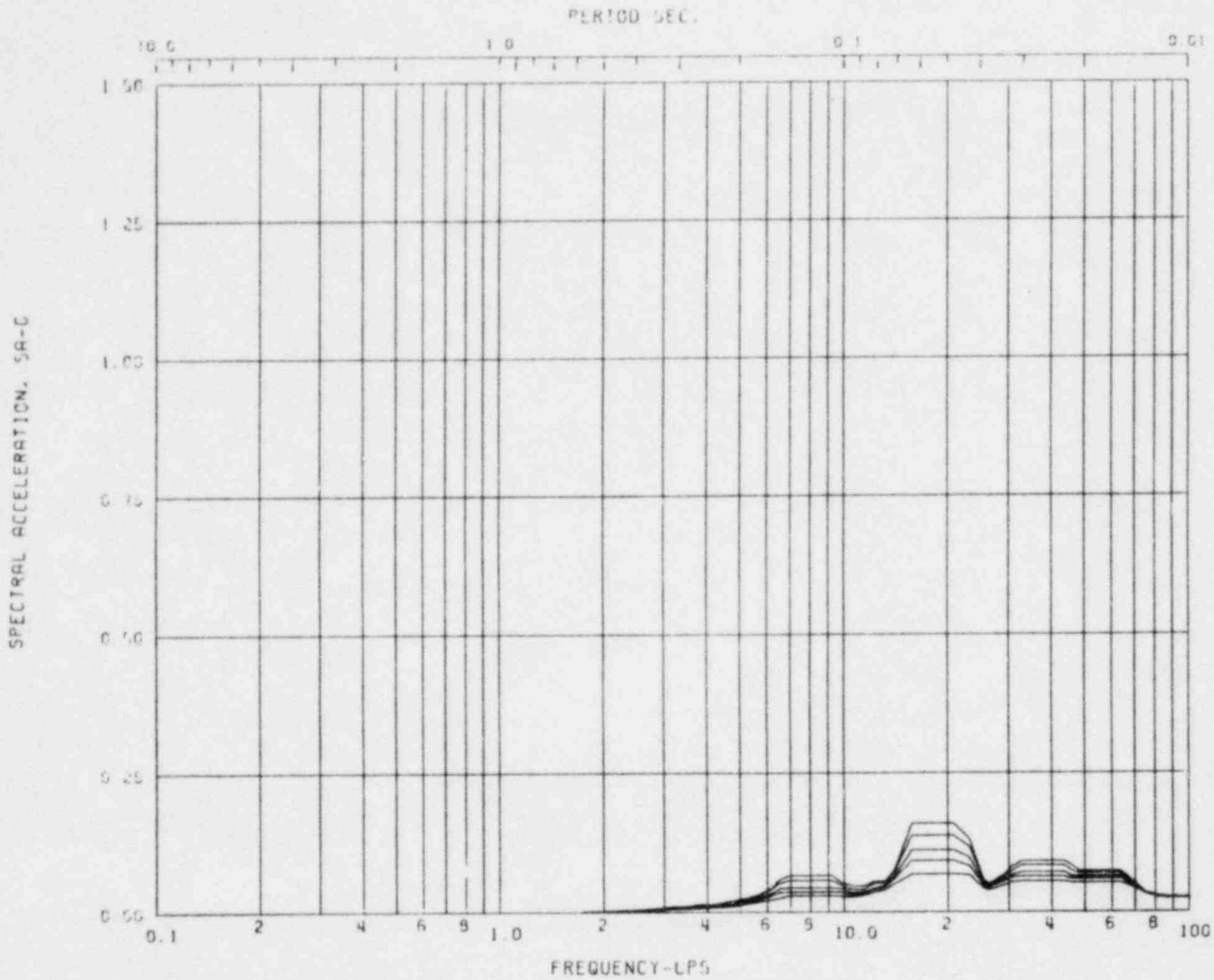
Node: 108 Direction: VERTICAL Elev: 217'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING
GLOBAL RESPONSE SPECTRA
VERTICAL, SRV AXISYMMETRIC

FIGURE B.2-30



Acceleration Spectra for REACTOR BLDG.

Load Case: KWU SRV AXISYMMETRIC ENVELOPE (WIDENED - 15%)

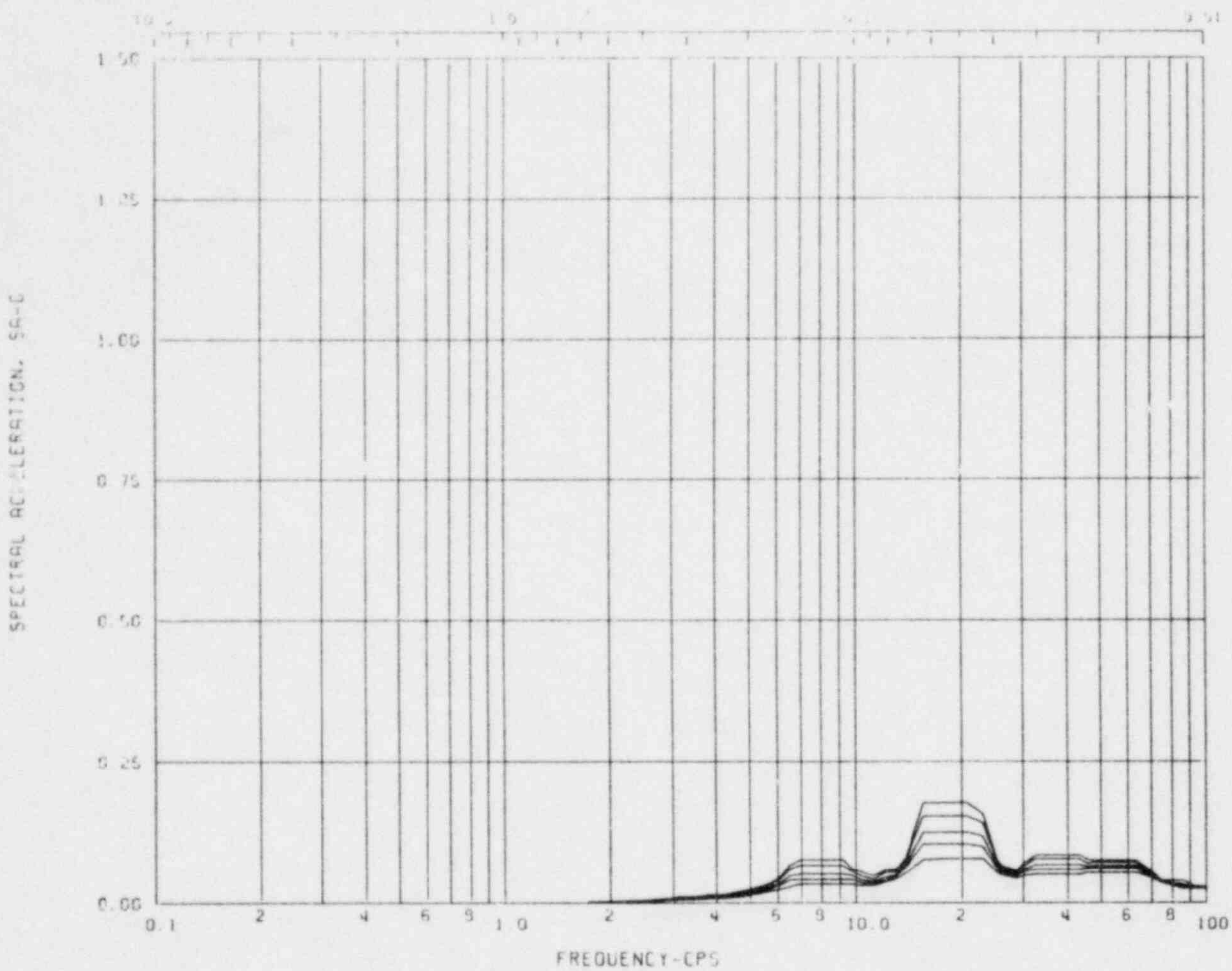
Node: 104 Direction: VERTICAL Elev: 239'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING
GLOBAL RESPONSE SPECTRA
VERTICAL, SRV AXISYMMETRIC

FIGURE B.2-31



Acceleration Spectra for REACTOR BLDG.

Load Case: KWU SRV AXISYMMETRIC ENVELOPE (WIDENED - 15%)

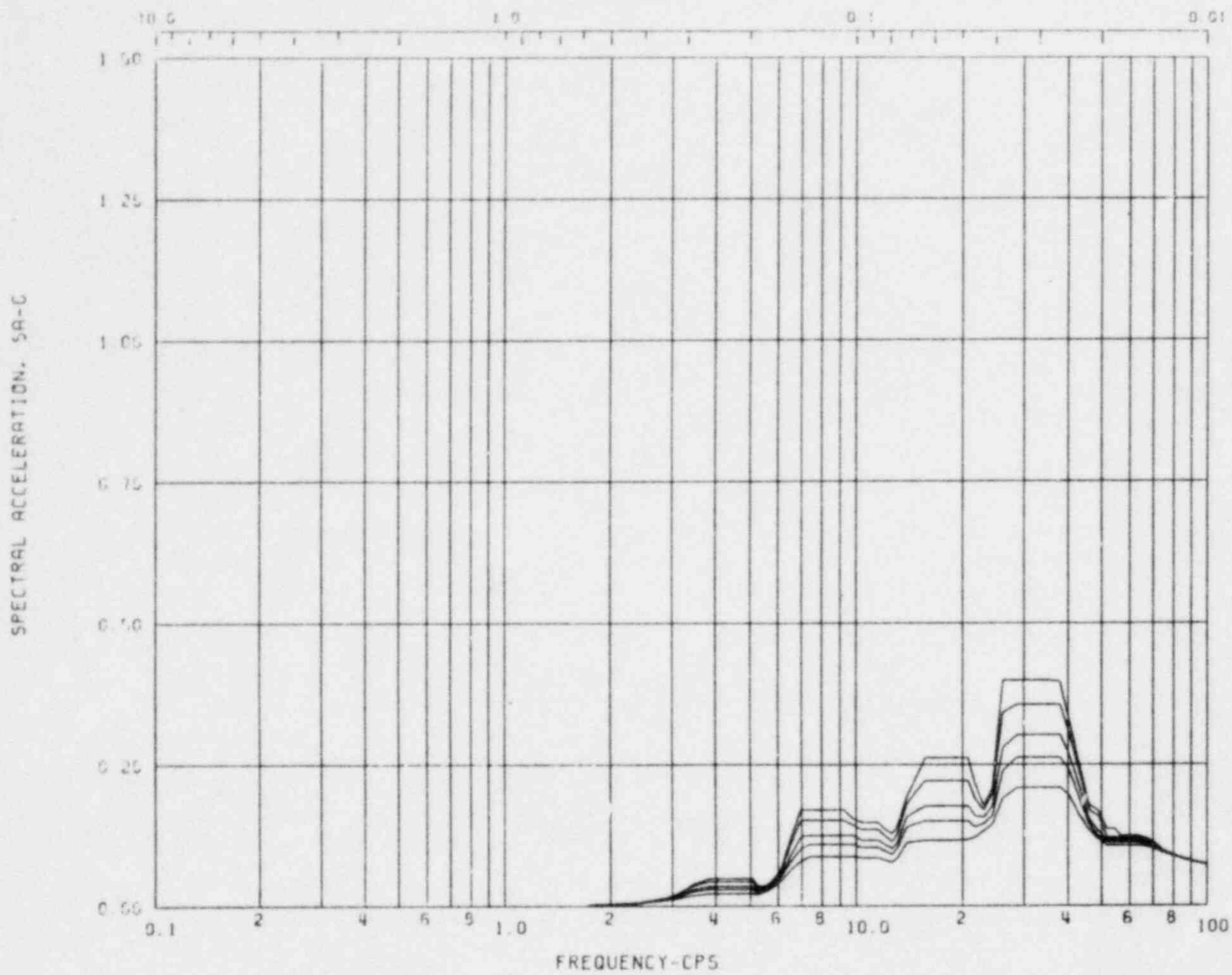
Node: 79 Direction: VERTICAL Elev: 253'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING
GLOBAL RESPONSE SPECTRA
VERTICAL, SRV AXISYMMETRIC

FIGURE B.2-32



Acceleration Spectra for REACTOR BLDG.

Load Case: KWU SRV AXISYMMETRIC ENVELOPE (WIDENED - 15%)

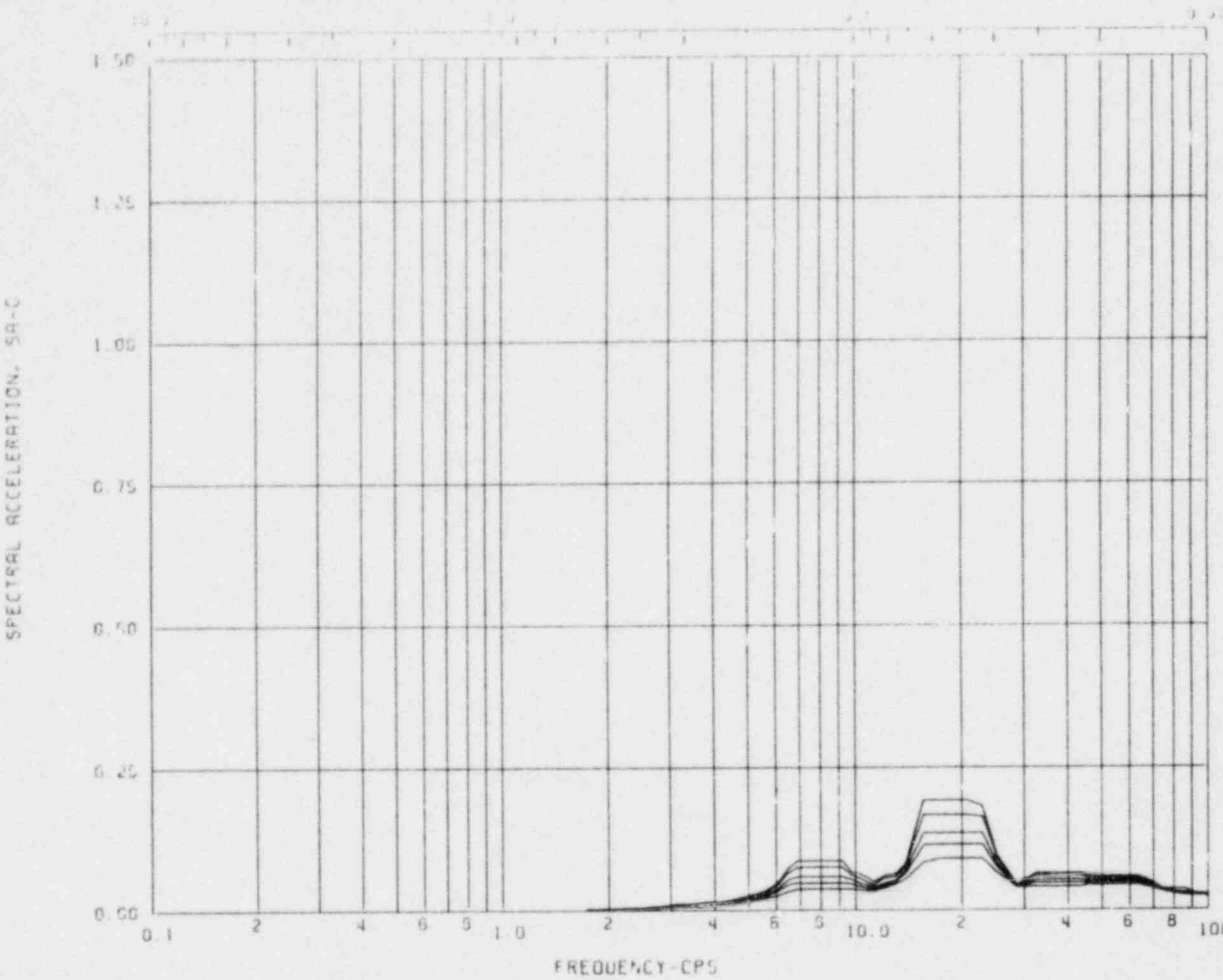
Node: 81 Direction: VERTICAL Elev: 253'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING
GLOBAL RESPONSE SPECTRA
VERTICAL, SRV AXISYMMETRIC

FIGURE B.2-33



Acceleration Spectra for REACTOR BLDG.

Load Case: KWU SRV AXISYMMETRIC ENVELOPE (WIDENED - 15%)

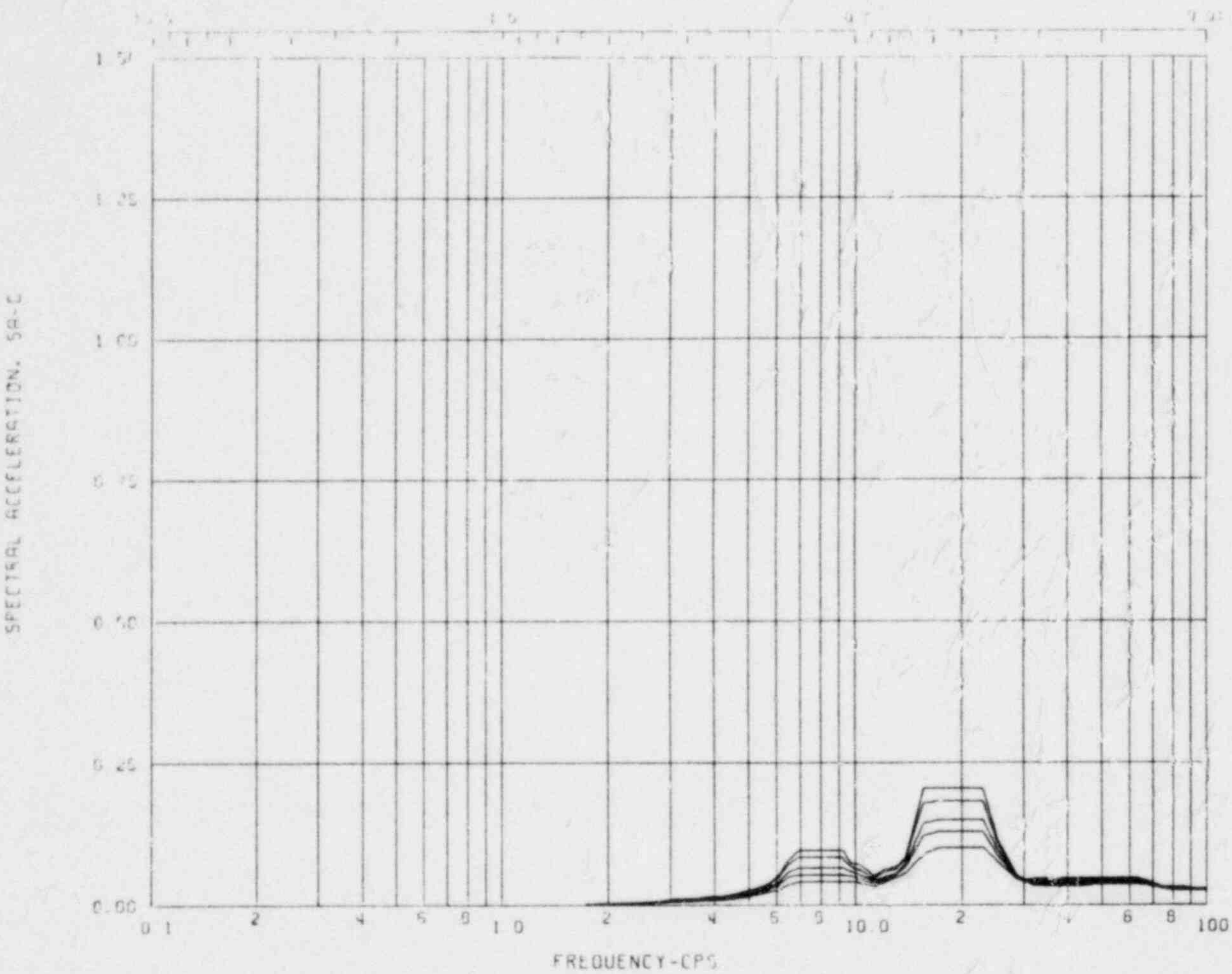
Node: 77 Direction: VERTICAL Elev: 269'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING
GLOBAL RESPONSE SPECTRA
VERTICAL, SRV AXISYMMETRIC

FIGURE B.2-34



Acceleration Spectra for REACTOR BLDG.

Load Case: KWU SRV AXISYMMETRIC ENVELOPE (WIDENED - 15%)

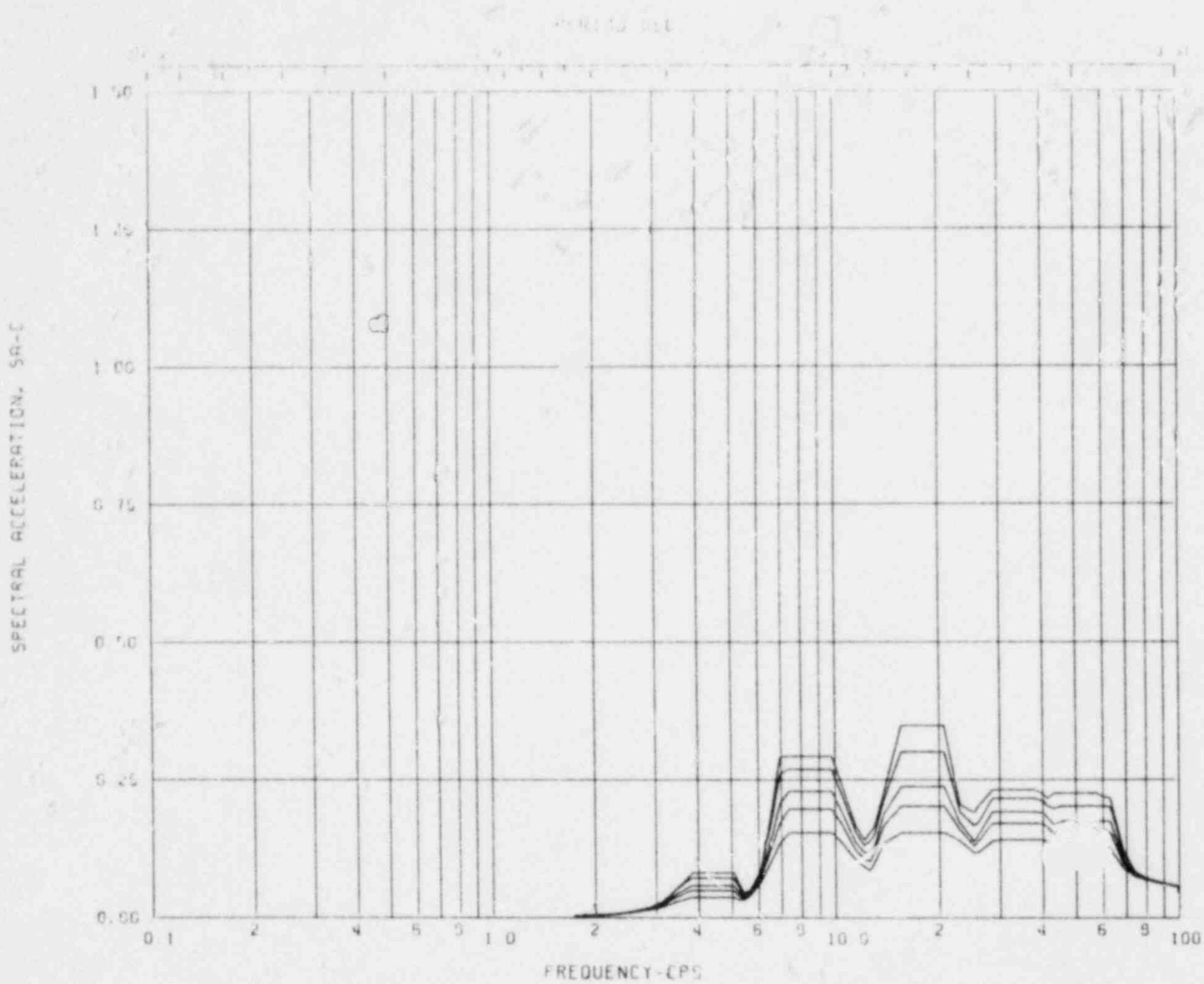
Node: 58 Direction: VERTICAL Elev: 283'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING
GLOBAL RESPONSE SPECTRA
VERTICAL, SRV AXISYMMETRIC

FIGURE B.2-35



Acceleration Spectra for REACTOR BLDG.

Load Case: KWU SRV AXISYMMETRIC ENVELOPE (WIDENED - 15%)

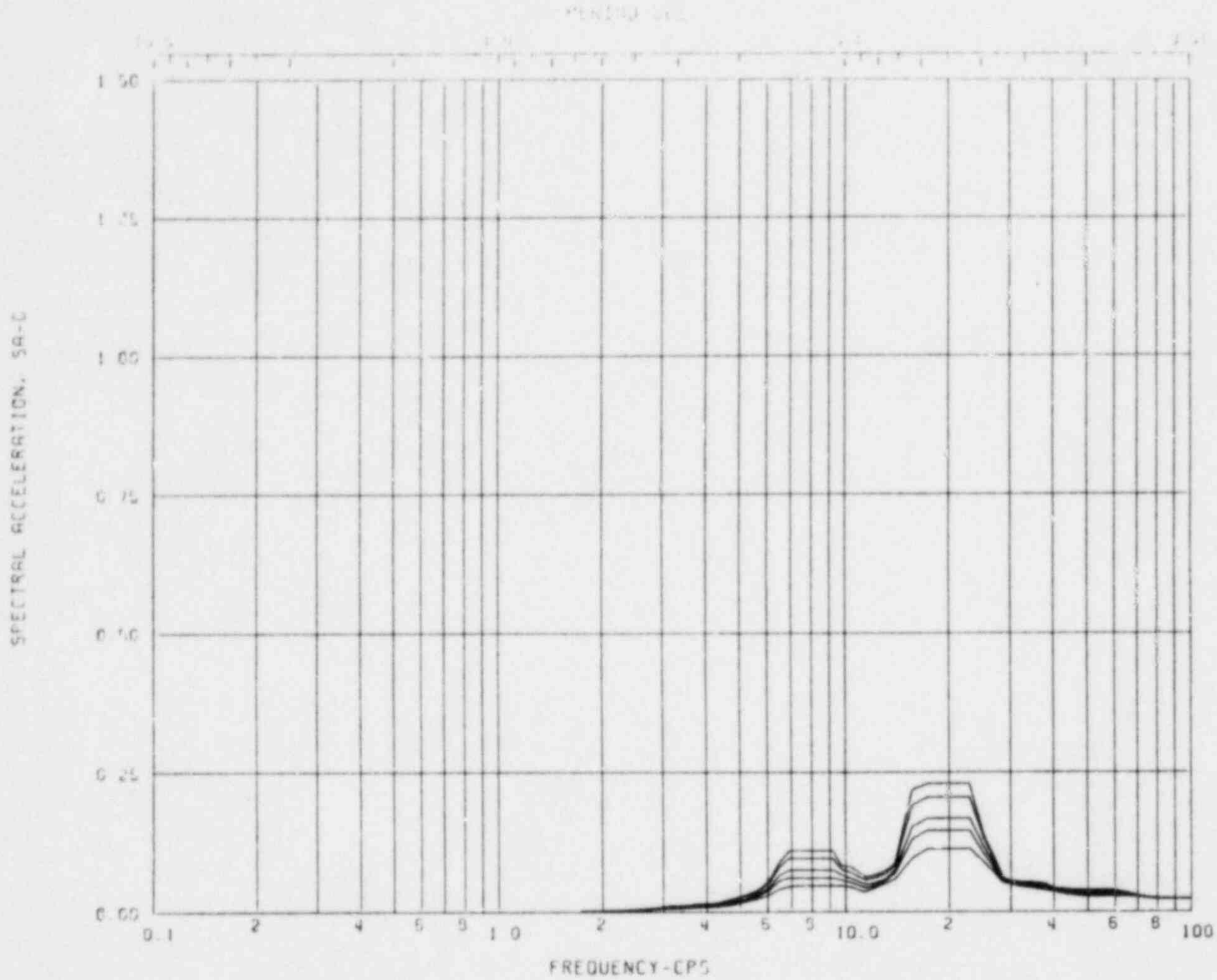
Node: 60 Direction: VERTICAL Elev: 283'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING
GLOBAL RESPONSE SPECTRA
VERTICAL, SRV AXISYMMETRIC

FIGURE B.2-36



Acceleration Spectra for REACTOR BLDG.

Load Case: KWU SRV AXISYMMETRIC ENVELOPE (WIDENED - 15%)

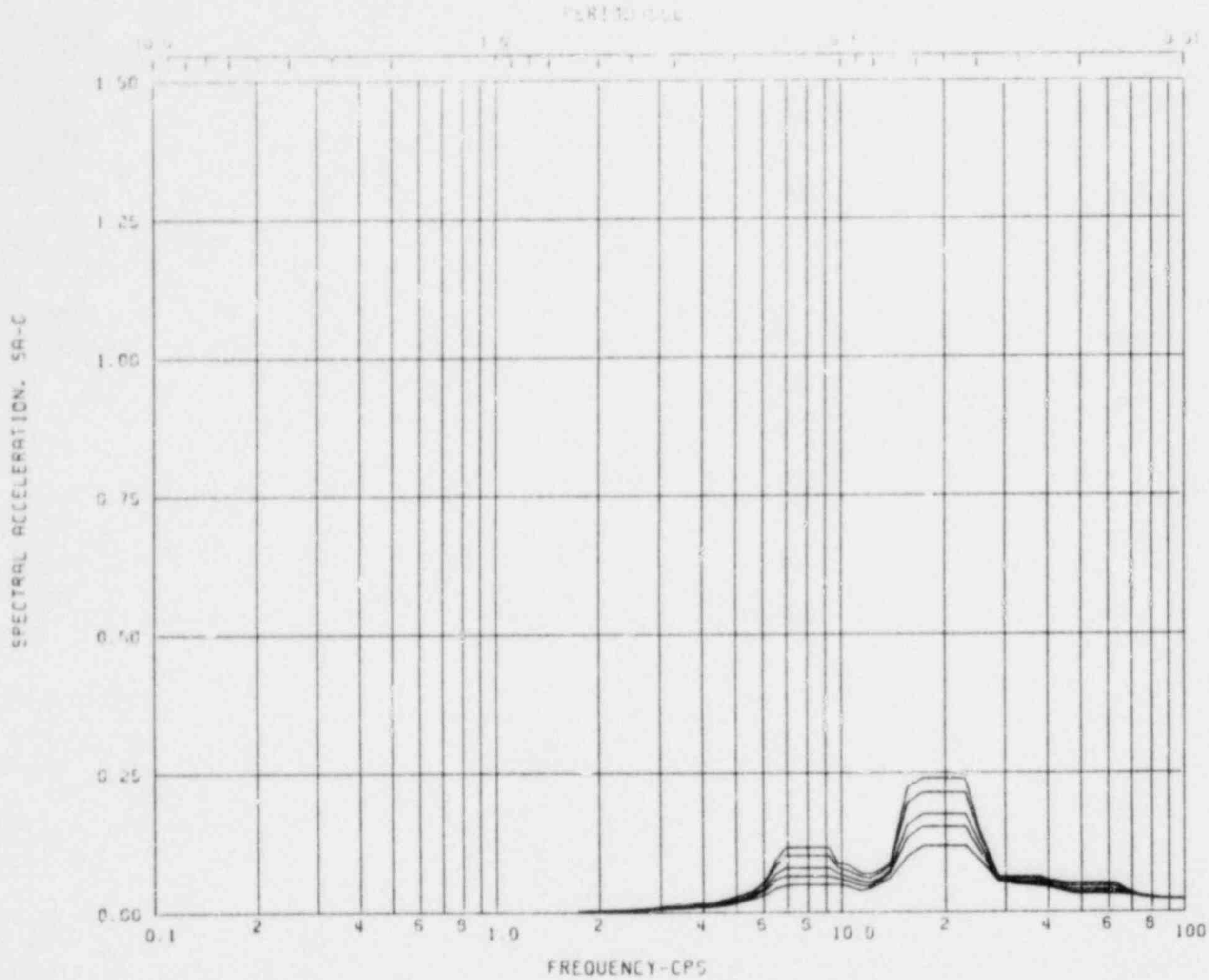
Node: 56 Direction: VERTICAL Elev: 304'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING
GLOBAL RESPONSE SPECTRA
VERTICAL, SRV AXISYMMETRIC

FIGURE B.2-37



Acceleration Spectra for REACTOR BLDG.

Load Case: KWU SRV AXISYMMETRIC ENVELOPE (WIDENED - 15%)

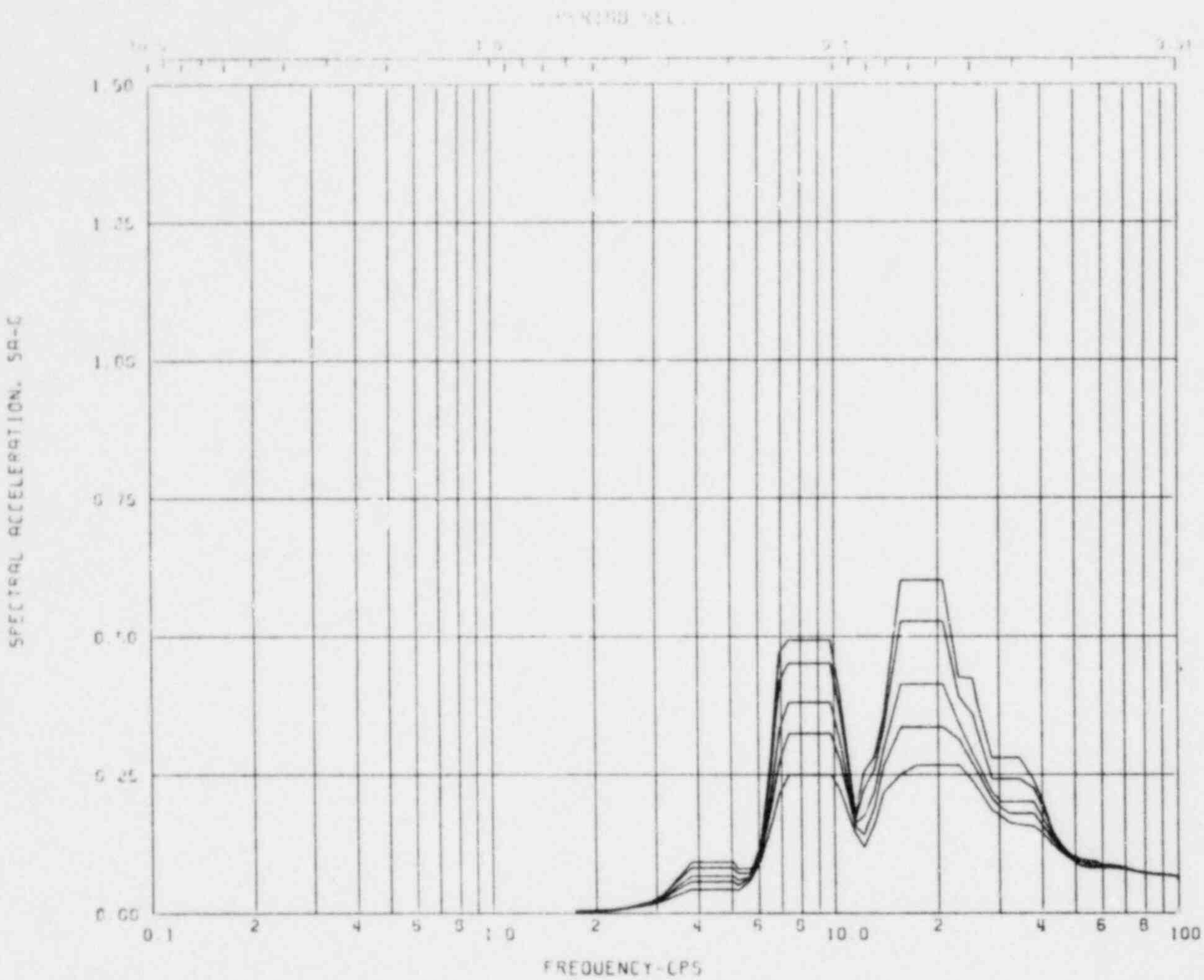
Node: 35 Direction: VERTICAL Elev: 313'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING
GLOBAL RESPONSE SPECTRA
VERTICAL, SRV AXISYMMETRIC

FIGURE B.2-38



Acceleration Spectra for REACTOR BLDG.

Load Case: KWU SRV AXISYMMETRIC ENVELOPE (WIDENED - 15%)

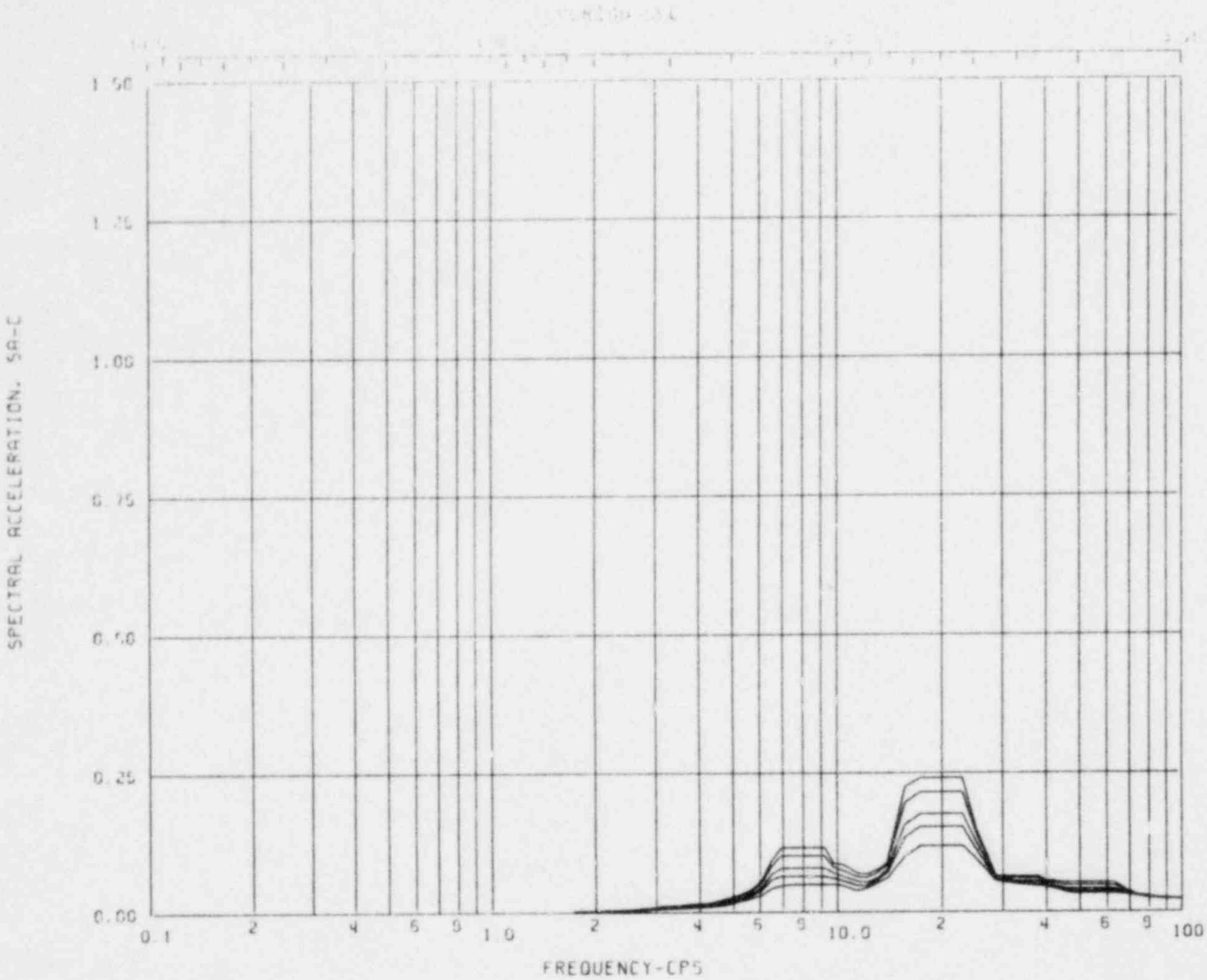
Node: 43 Direction: VERTICAL Elev: 313'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING
GLOBAL RESPONSE SPECTRA
VERTICAL, SRV AXISYMMETRIC

FIGURE B.2-39



Acceleration Spectra for REACTOR BLDG.

Load Case: KWU SRV AXISYMMETRIC ENVELOPE (WIDENED - 15%)

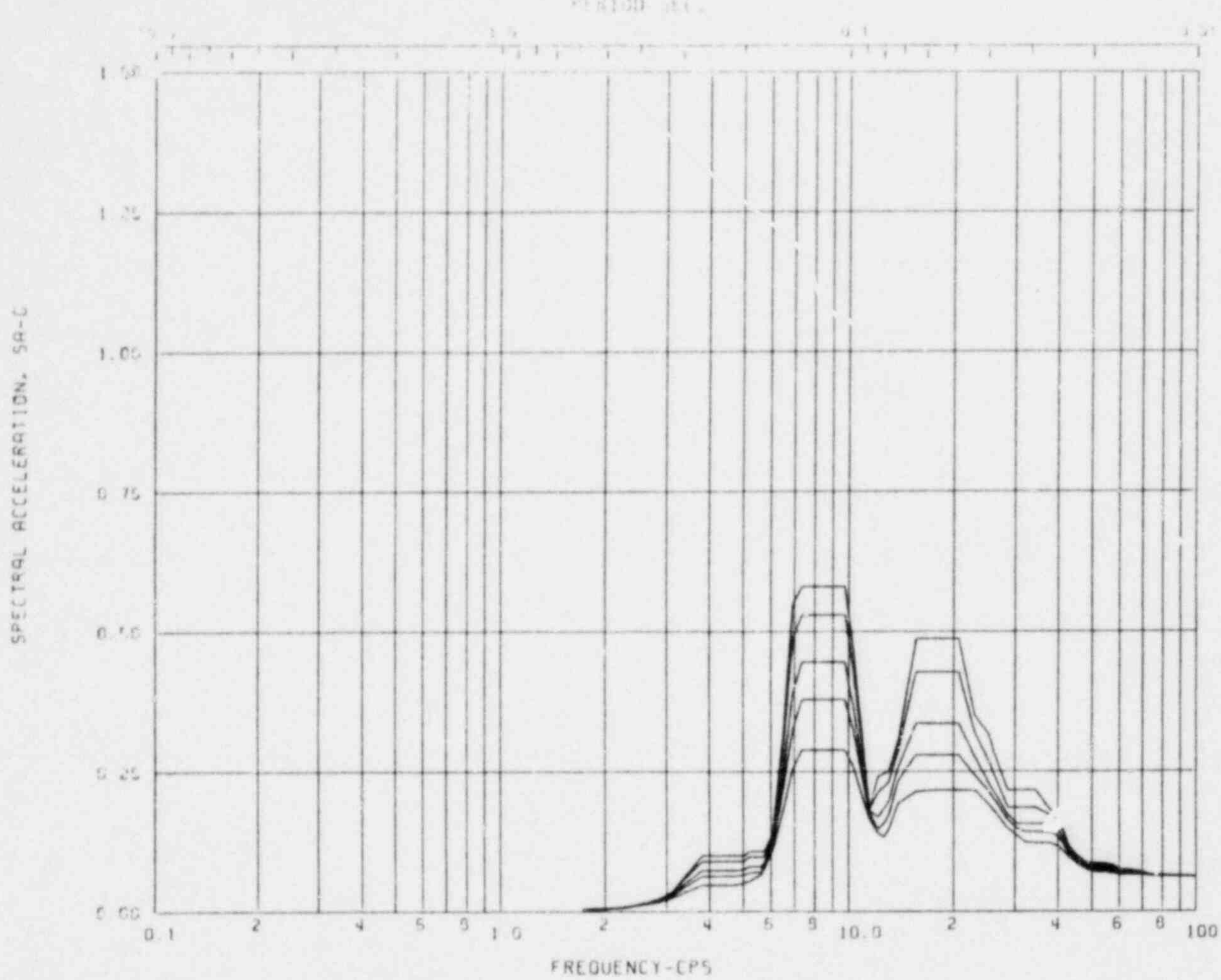
Node: 21 Direction: VERTICAL Elev: 333'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING
GLOBAL RESPONSE SPECTRA
VERTICAL, SRV AXISYMMETRIC

FIGURE B.2-40



Acceleration Spectra for REACTOR BLDG.

Load Case: KWU SRV AXISYMMETRIC ENVELOPE (WIDENED - 15%)

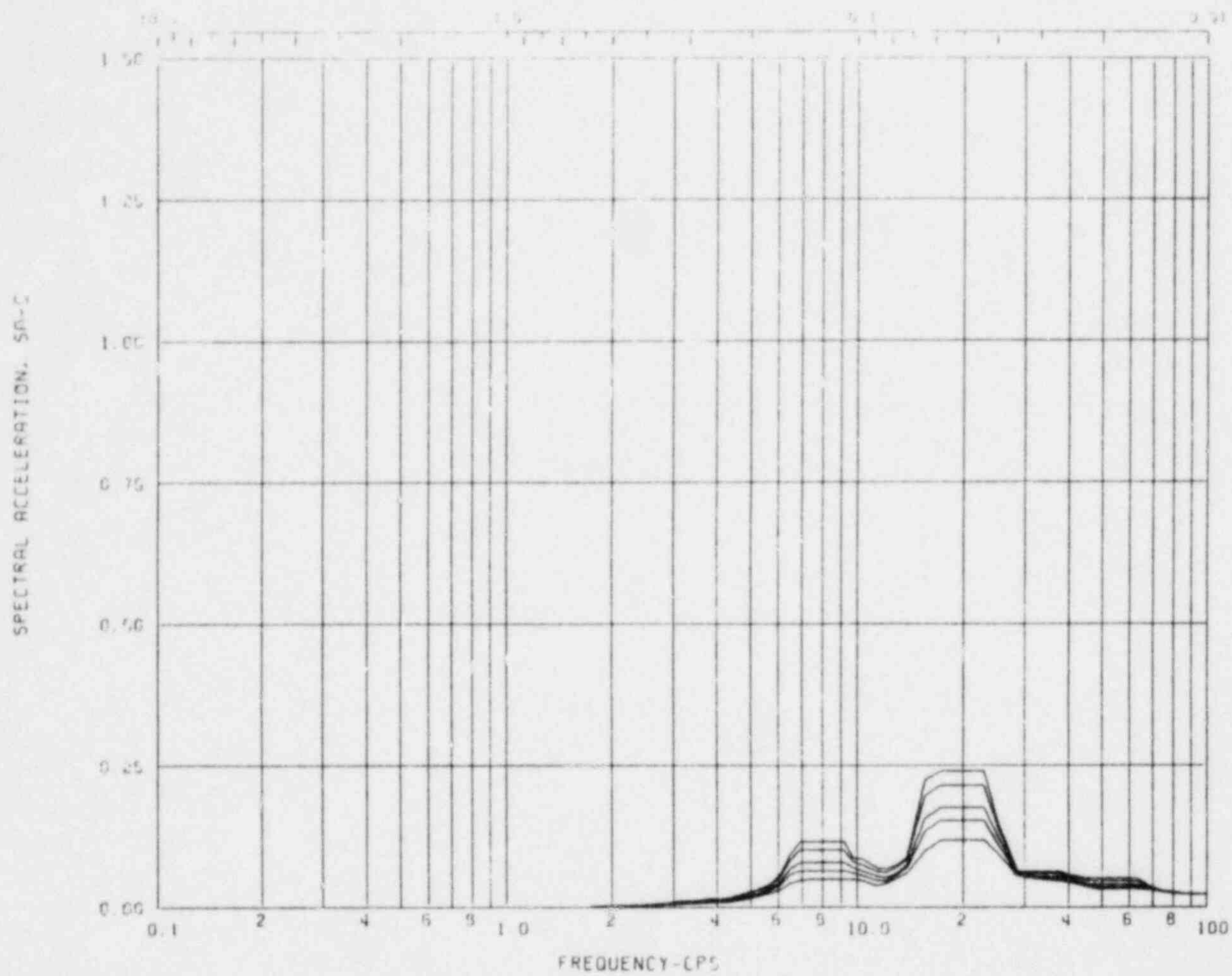
Node: 33 Direction: VERTICAL Elev: 333'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING
GLOBAL RESPONSE SPECTRA
VERTICAL, SRV AXISYMMETRIC

FIGURE B.2-41



Acceleration Spectra for REACTOR BLDG.

Load Case: KWU SRV AXISYMMETRIC ENVELOPE (WIDENED - 15%)

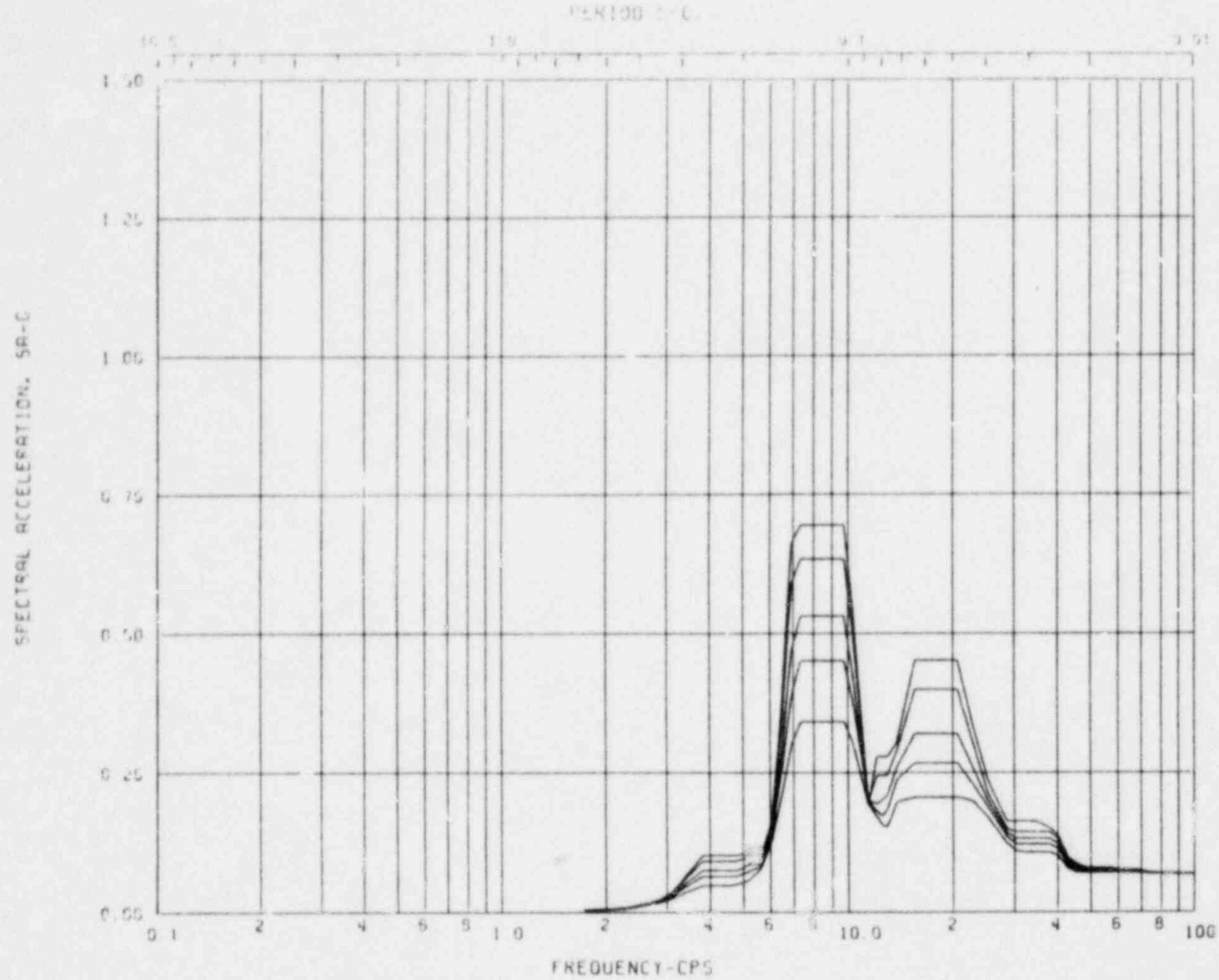
Node: 9 Direction: VERTICAL Elev: 352'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING
GLOBAL RESPONSE SPECTRA
VERTICAL, SRV AXISYMMETRIC

FIGURE B.2-42



Acceleration Spectra for REACTOR BLDG.

Load Case: KWU SRV AXISYMMETRIC ENVELOPE (WIDENED - 15%)

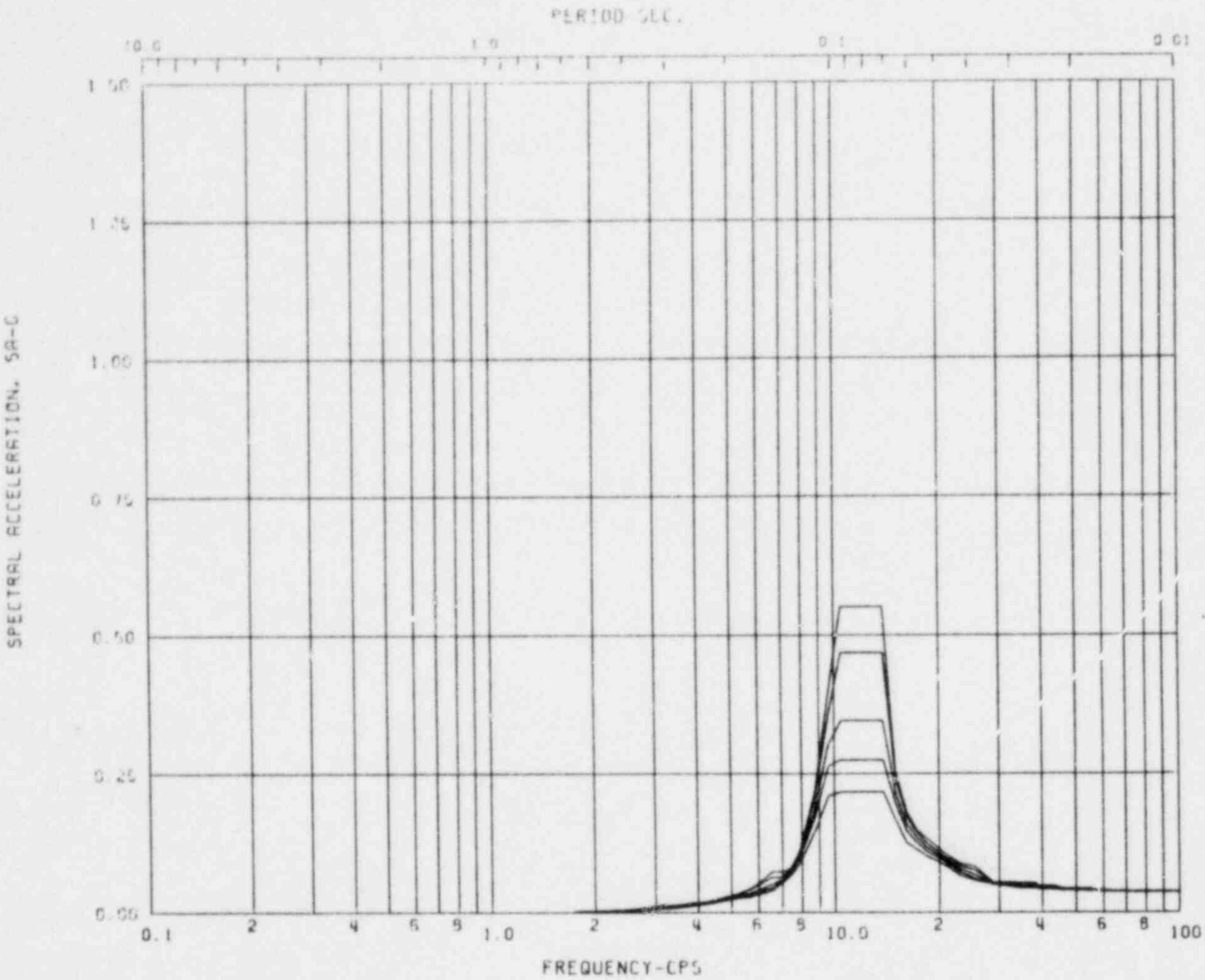
Node: 13 Direction: VERTICAL Elev: 352'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING
GLOBAL RESPONSE SPECTRA
VERTICAL, SRV AXISYMMETRIC

FIGURE B.2-43



Acceleration Spectra for REACTOR BLDG.

Load Case: KWU SRV AXISYMMETRIC ENVELOPE (WIDENED - 15%)

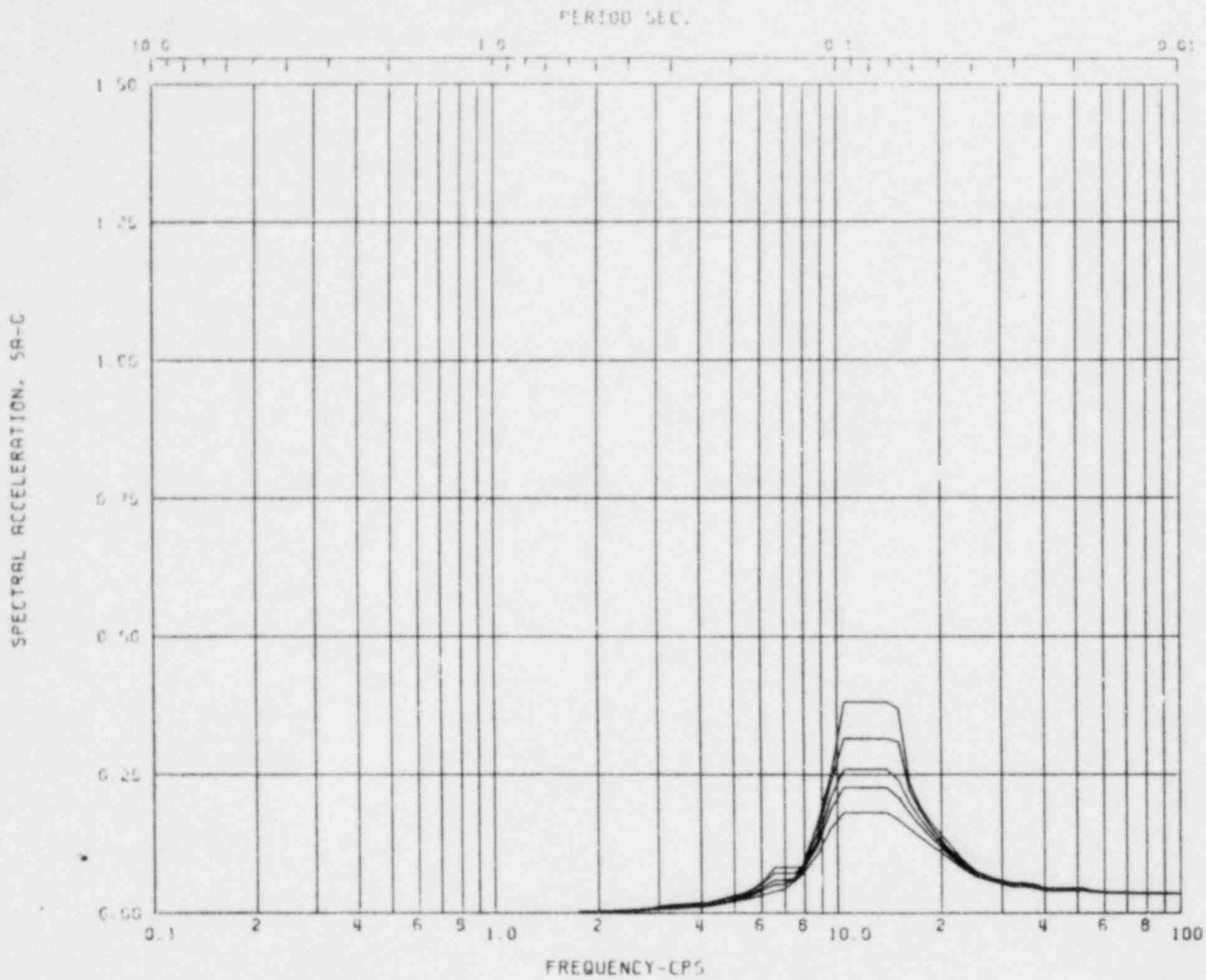
Node: 129 Direction: VERTICAL Elev: 201'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING
GLOBAL RESPONSE SPECTRA
VERTICAL, SRV AXISYMMETRIC

FIGURE B.2-44



Acceleration Spectra for REACTOR BLDG.

Load Case: KWU SRV AXISYMMETRIC ENVELOPE (WIDENED - 15%)

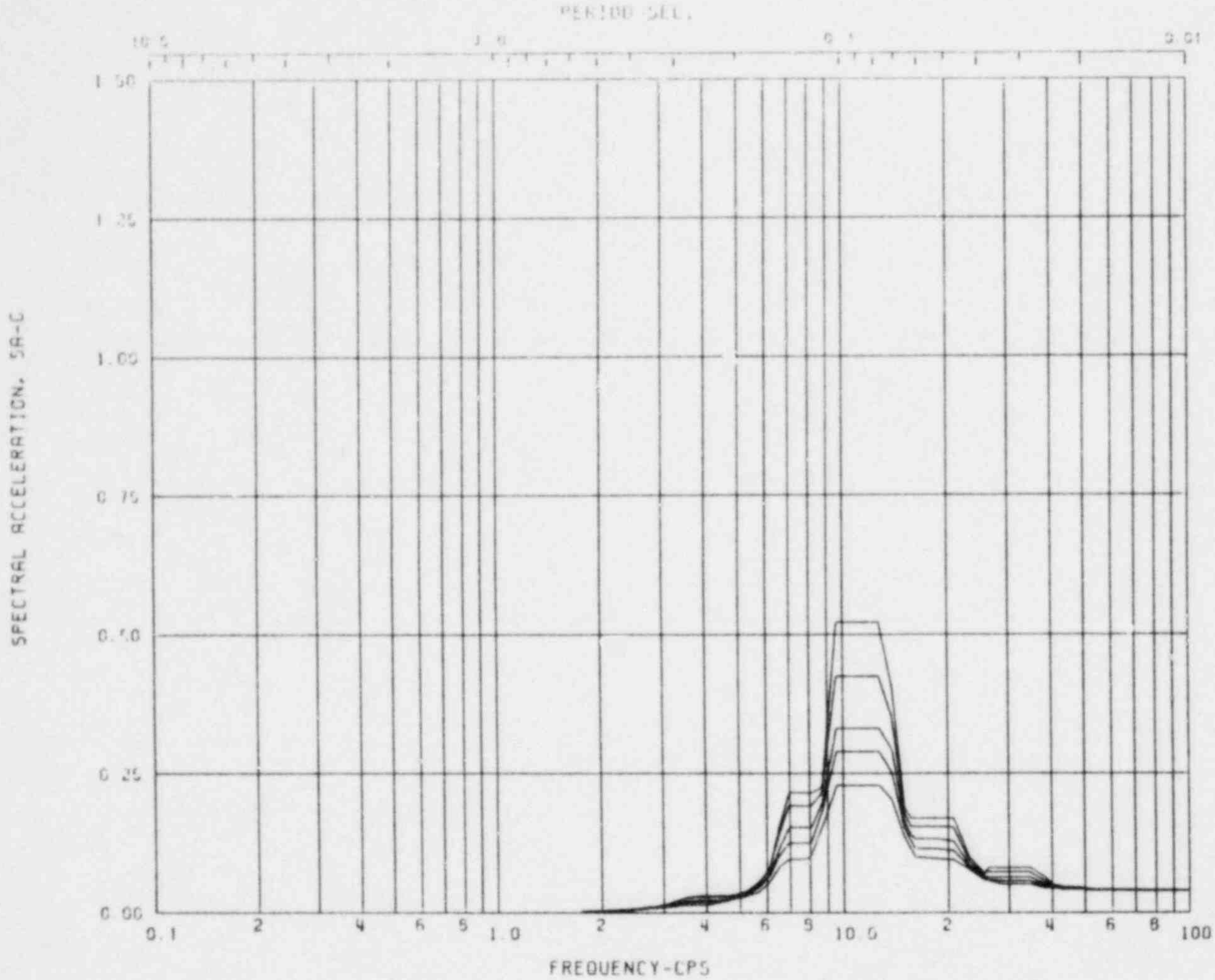
Node: 107 Direction: VERTICAL Elev: 217'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING
GLOBAL RESPONSE SPECTRA
VERTICAL, SRV AXISYMMETRIC

FIGURE B.2-45



Acceleration Spectra for REACTOR BLDG.

Load Case: KWU SRV AXISYMMETRIC ENVELOPE (WIDENED - 15%)

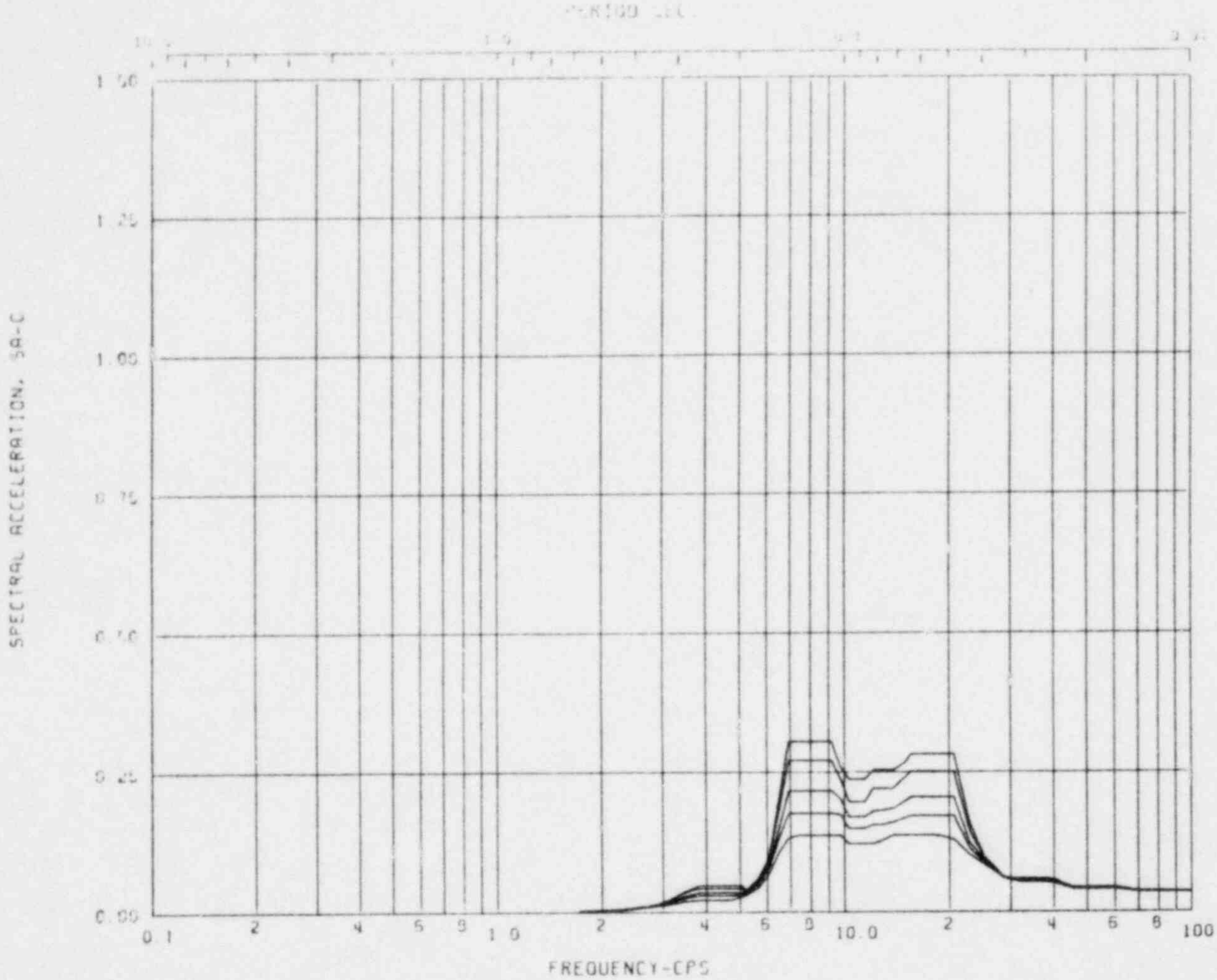
Node: 80 Direction: VERTICAL Elev: 253'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING
GLOBAL RESPONSE SPECTRA
VERTICAL, SRV AXISYMMETRIC

FIGURE B.2-46



Acceleration Spectra for REACTOR BLDG.

Load Case: KWU SRV AXISYMMETRIC ENVELOPE (WIDENED - 15%)

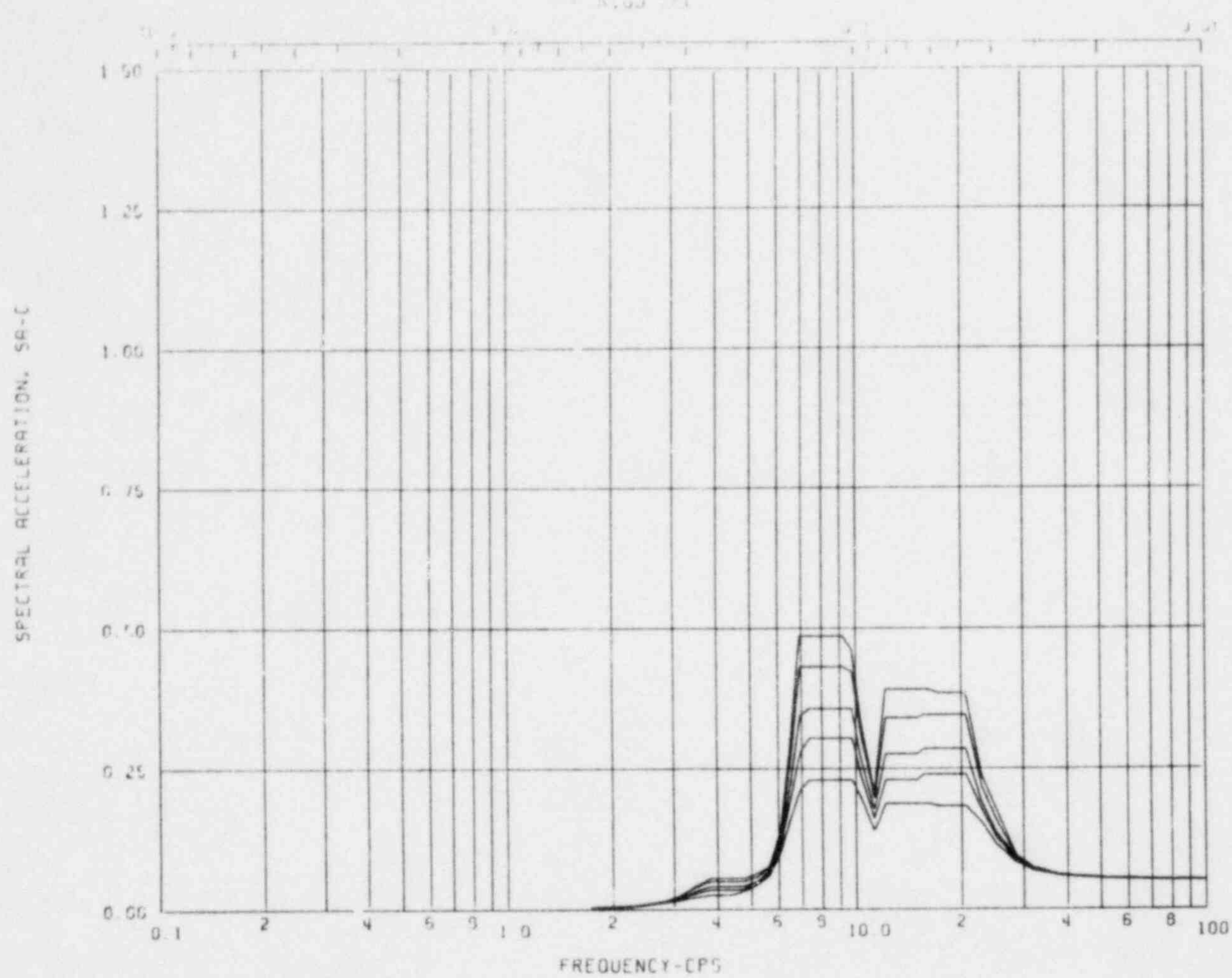
Node: 59 Direction: VERTICAL Elev: 283'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING
GLOBAL RESPONSE SPECTRA
VERTICAL, SRV AXISYMMETRIC

FIGURE B.2-47



Acceleration Spectra for REACTOR BLDG.

Load Case: KWU SRV AXISYMMETRIC ENVELOPE (WIDENED - 15%)

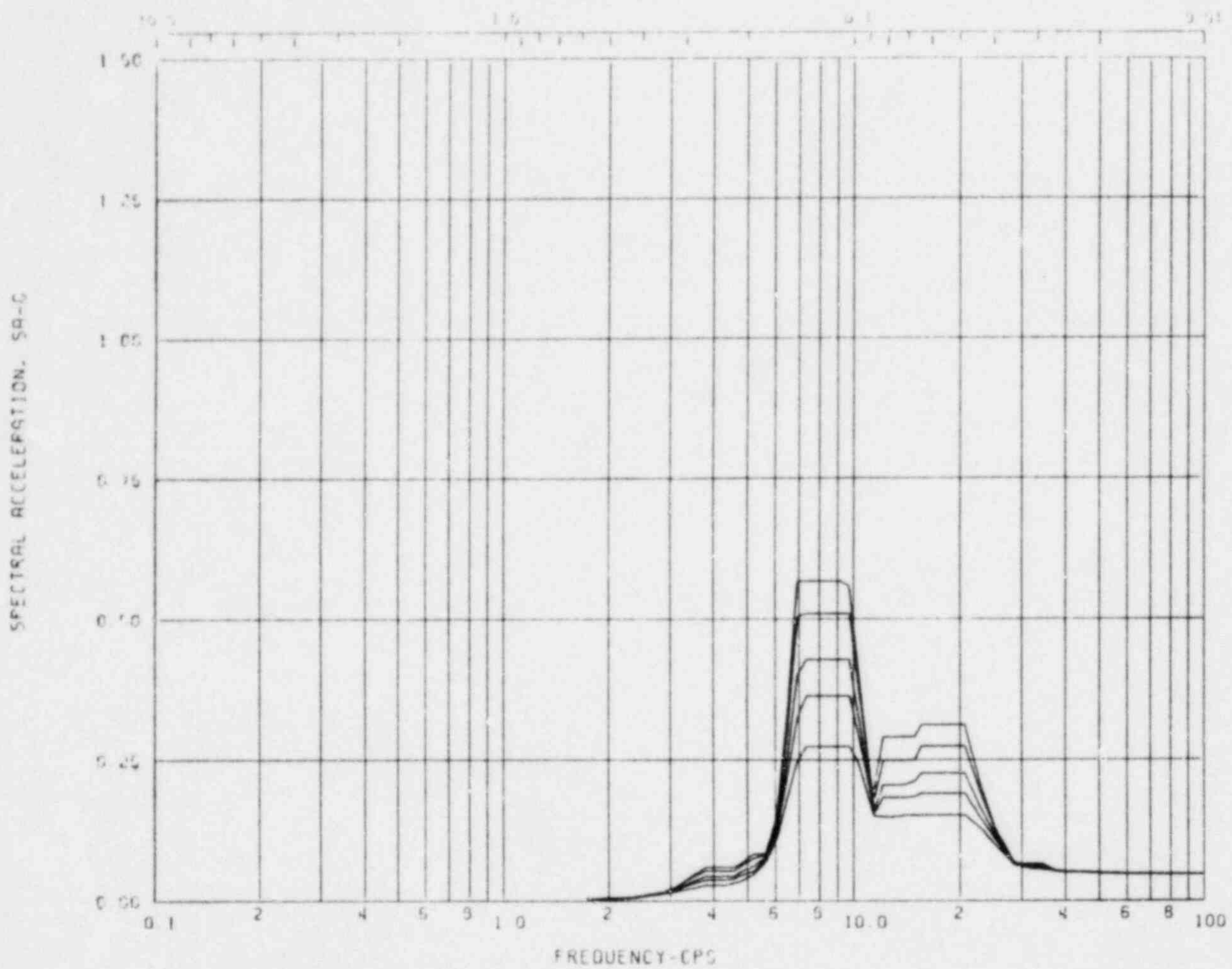
Node: 54 Direction: VERTICAL Elev: 313'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING
GLOBAL RESPONSE SPECTRA
VERTICAL, SRV AXISYMMETRIC

FIGURE B.2-48



Acceleration Spectra for REACTOR BLDG.

Load Case: KWU SRV AXISYMMETRIC ENVELOPE (WIDENED - 15%)

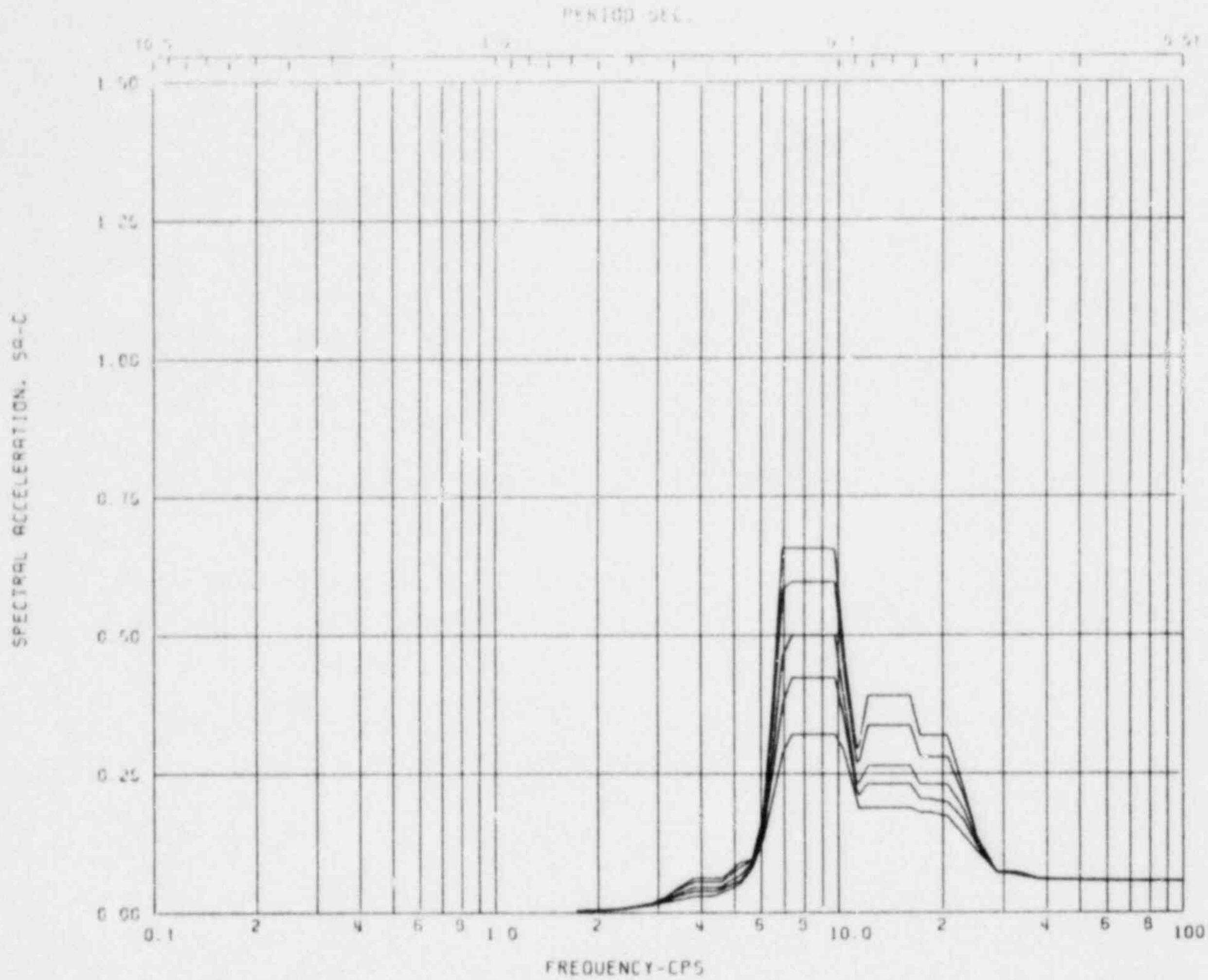
Node: 32 Direction: VERTICAL Elev: 333'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING
GLOBAL RESPONSE SPECTRA
VERTICAL, SRV AXISYMMETRIC

FIGURE B.2-49



Acceleration Spectra for REACTOR BLDG.

Load Case: KWU SRV AXISYMMETRIC ENVELOPE (WIDENED - 15%)

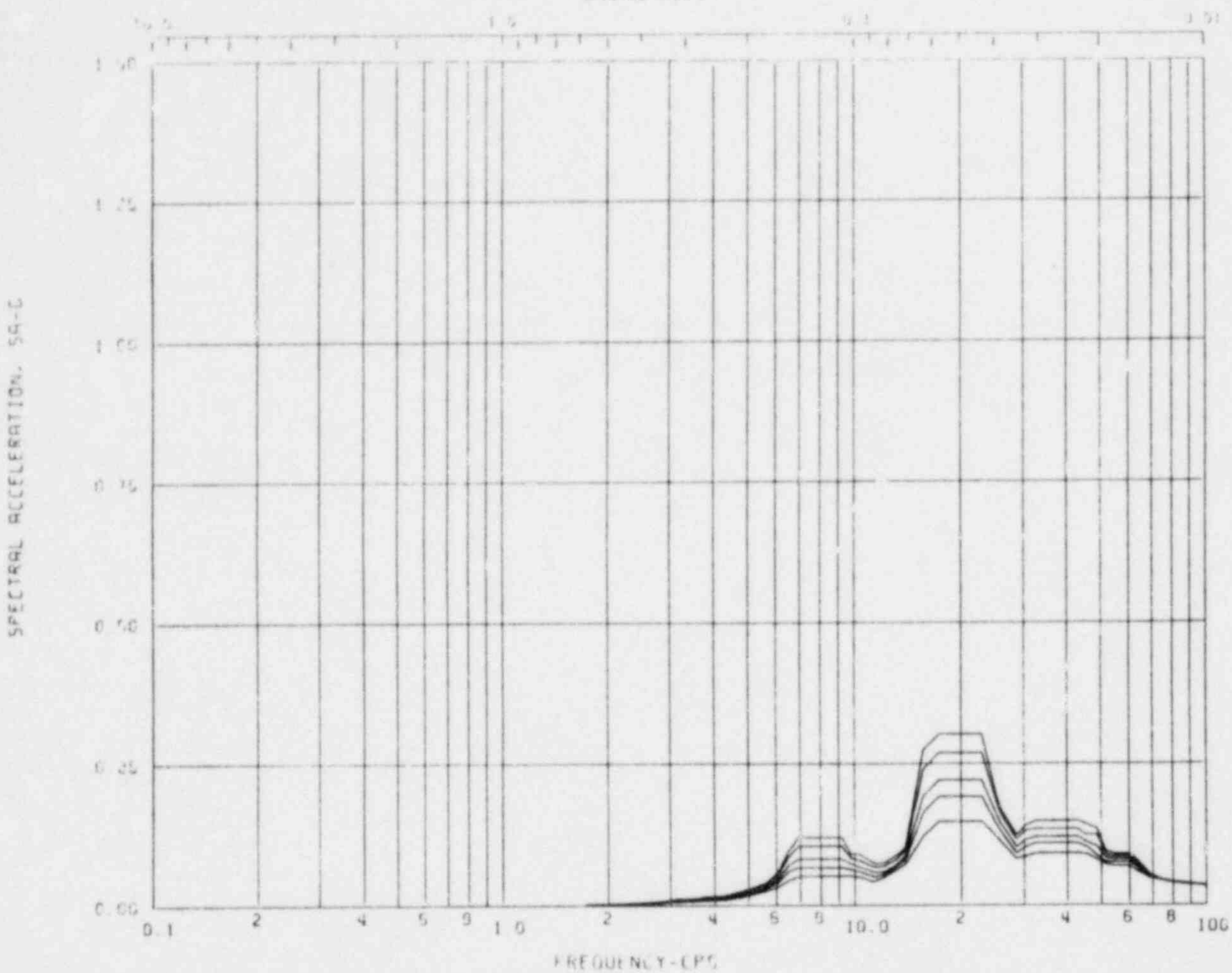
Node: 12 Direction: VERTICAL Elev: 352'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING
GLOBAL RESPONSE SPECTRA
VERTICAL, SRV AXISYMMETRIC

FIGURE B.2-50



Acceleration Spectra for REACTOR BLDG.

Load Case: KWU SRV AXISYMMETRIC ENVELOPE (WIDENED - 15%)

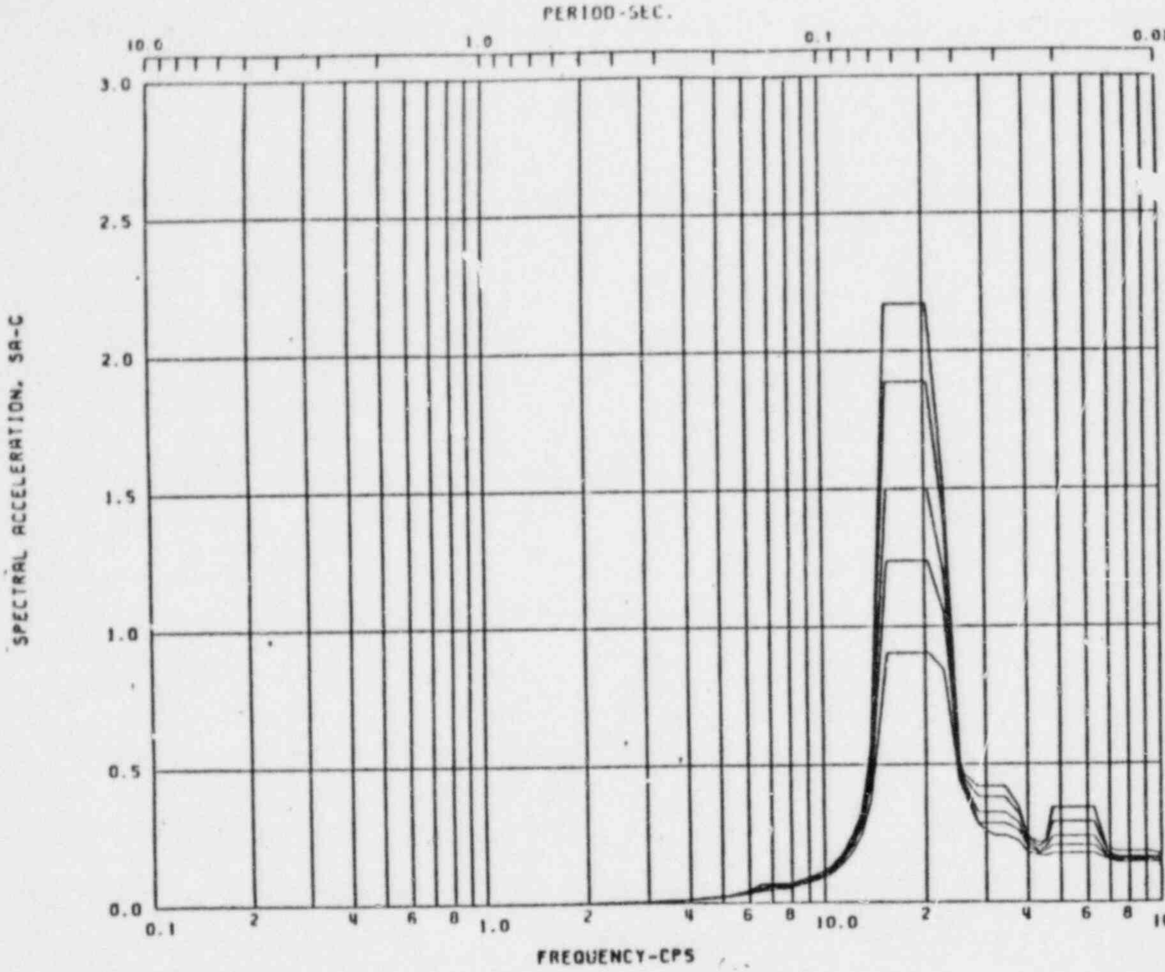
Node: 6 Direction: VERTICAL Elev: 410'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING
GLOBAL RESPONSE SPECTRA
VERTICAL, SRV AXISYMMETRIC

FIGURE B.2-51



Acceleration Spectra for CONTROL STRUCTURE

Load Case: KWU SRV AXISYMMETRIC ENVELOPE (WIDENED - 15%)

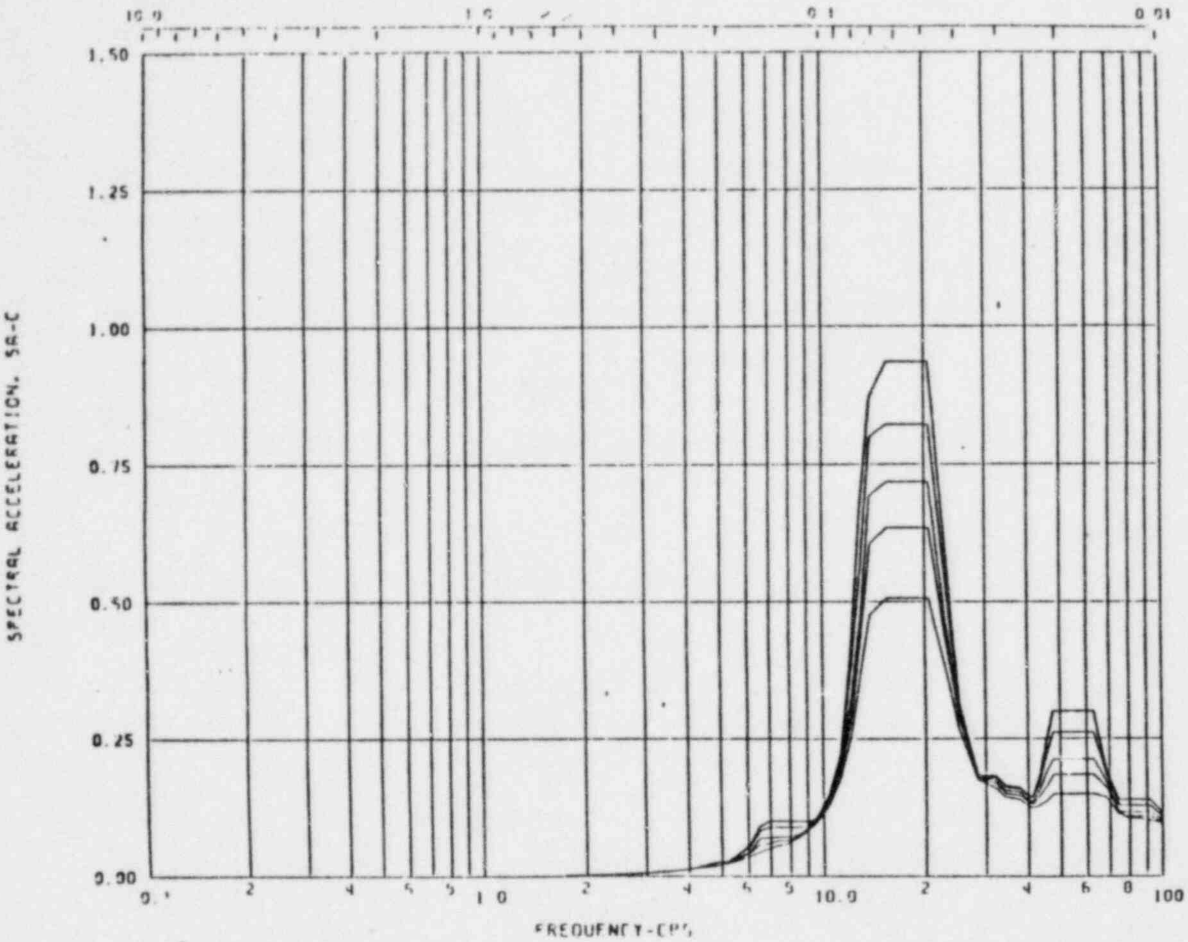
Node: 19 Direction: VERTICAL Elev: 217'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTROL STRUCTURE
LOCAL RESPONSE SPECTRA,
VERTICAL, SRV AXISYMMETRIC

FIGURE B.2-52



Acceleration Spectra for CONTROL STRUCTURE

Load Case: KWU SRV AXISYMMETRIC ENVELOPE (WIDENED - 15%)

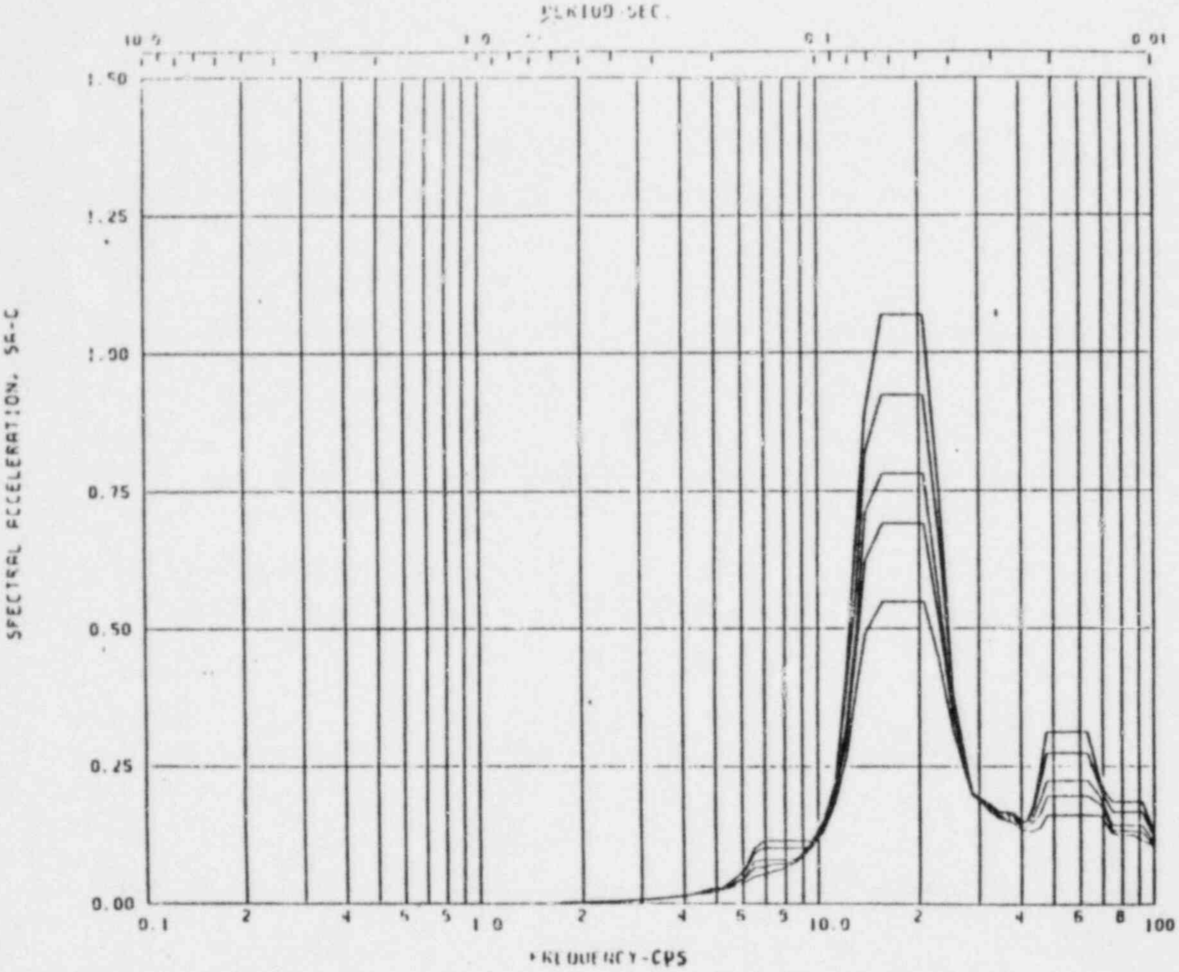
Node: 19 Direction: VERTICAL Elev: 239'

Damping: 0.005, 0.01, 0.02, 0.03, 0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTROL STRUCTURE
LOCAL RESPONSE SPECTRA,
VERTICAL, SRV AXISYMMETRIC

FIGURE B.2-53



Acceleration Spectra for CONTROL STRUCTURE

Load Case: KWU SRV AXISYMMETRIC ENVELOPE (WIDENED - 15%)

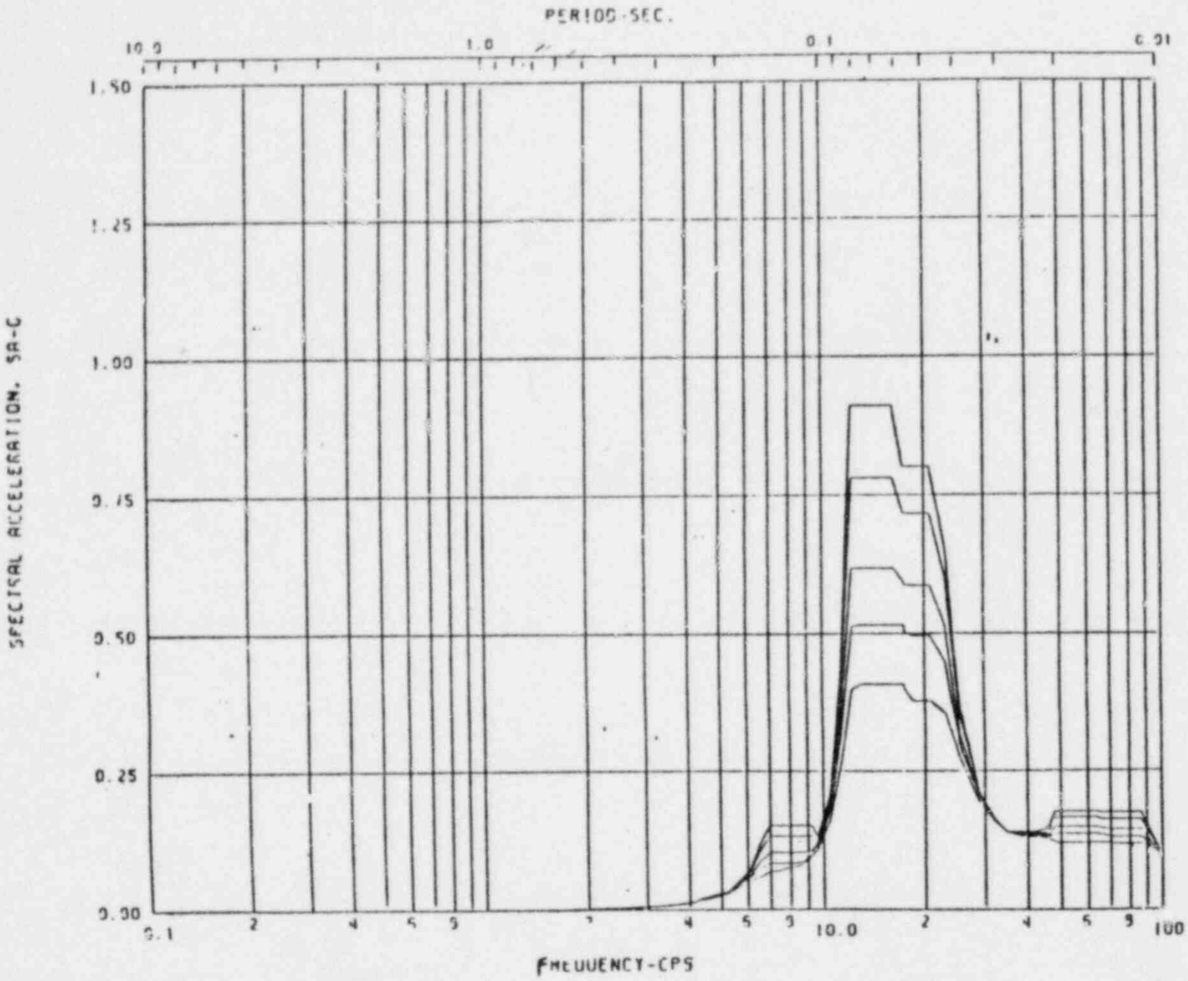
Node: 19 Direction: VERTICAL Elev: 254'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTROL STRUCTURE
LOCAL RESPONSE SPECTRA,
VERTICAL, SRV AXISYMMETRIC

FIGURE B.2-54



Acceleration Spectra for CONTROL STRUCTURE

Load Case: KWU SRV AXISYMMETRIC ENVELOPE (WIDENED - 15%)

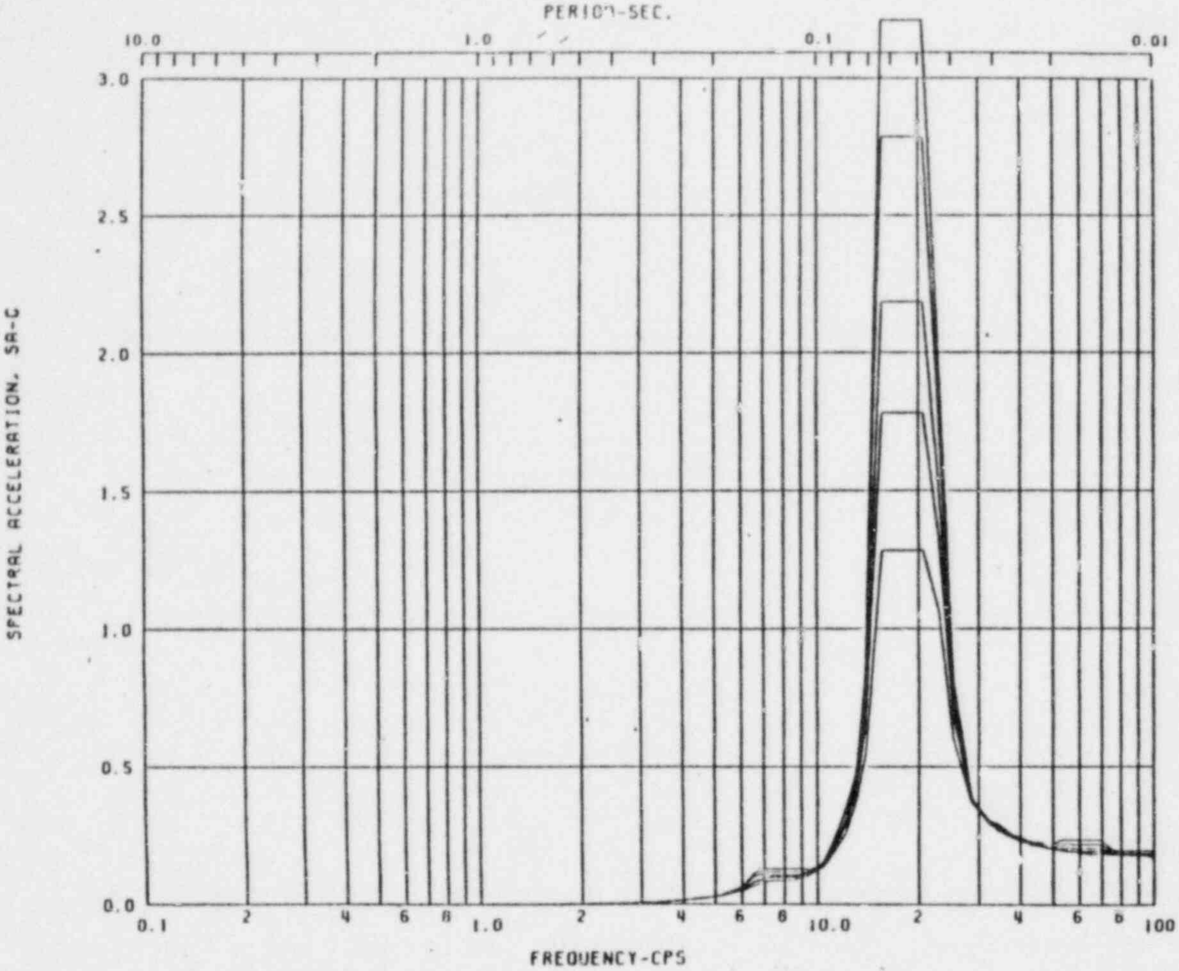
Node: 19 Direction: VERTICAL Elev: 269'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTROL STRUCTURE
LOCAL RESPONSE SPECTRA,
VERTICAL, SRV AXISYMMETRIC

FIGURE B.2-55



Acceleration Spectra for CONTROL STRUCTURE

Load Case: KWU SRV AXISYMMETRIC ENVELOPE (WIDENED - 15%)

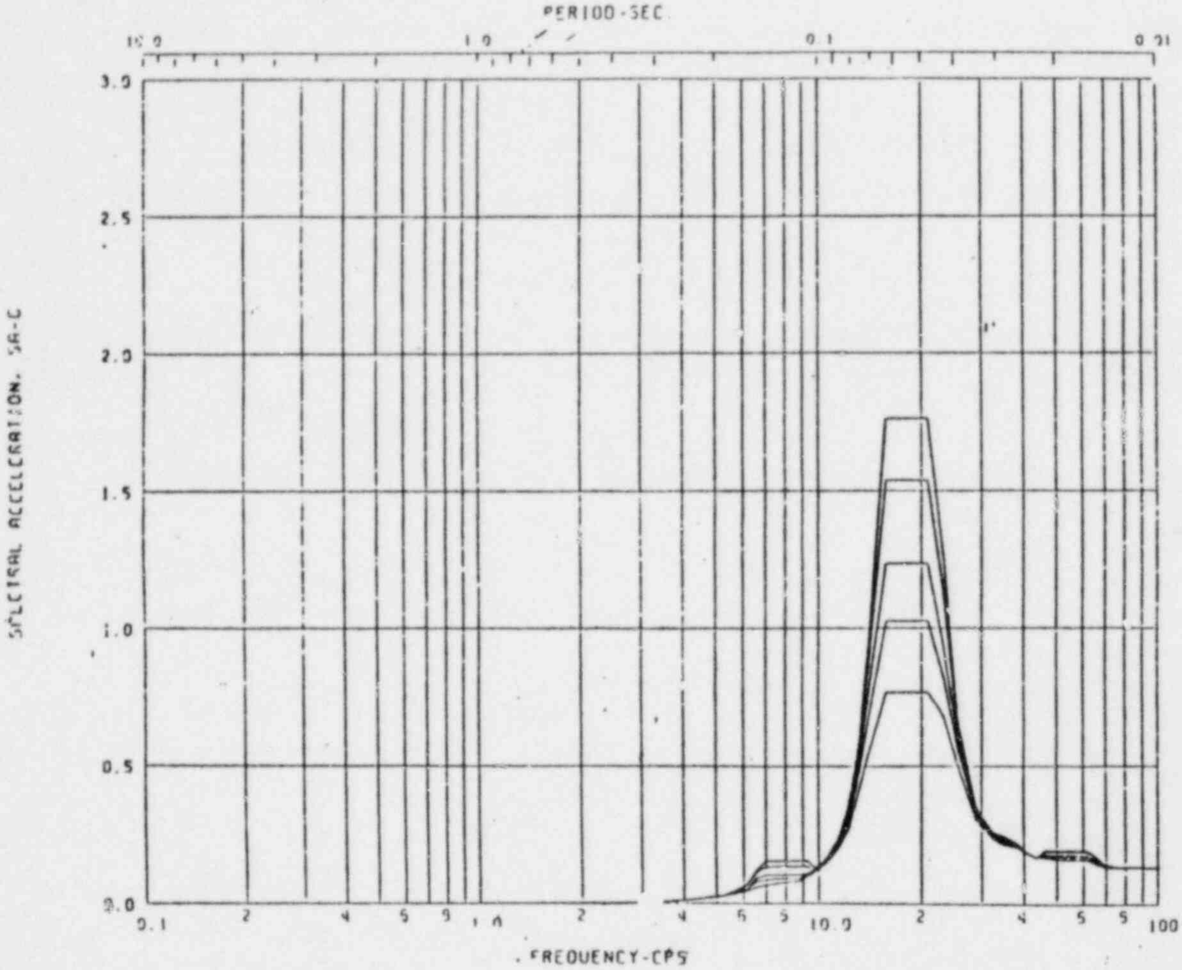
Node: 19 Direction: VERTICAL Elev: 289'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTROL STRUCTURE
LOCAL RESPONSE SPECTRA,
VERTICAL, SRV AXISYMMETRIC

FIGURE B.2-56



Acceleration Spectra for CONTROL STRUCTURE

Load Case: KWU-SRV AXISYMMETRIC ENVELOPE (WIDENED - 15%)

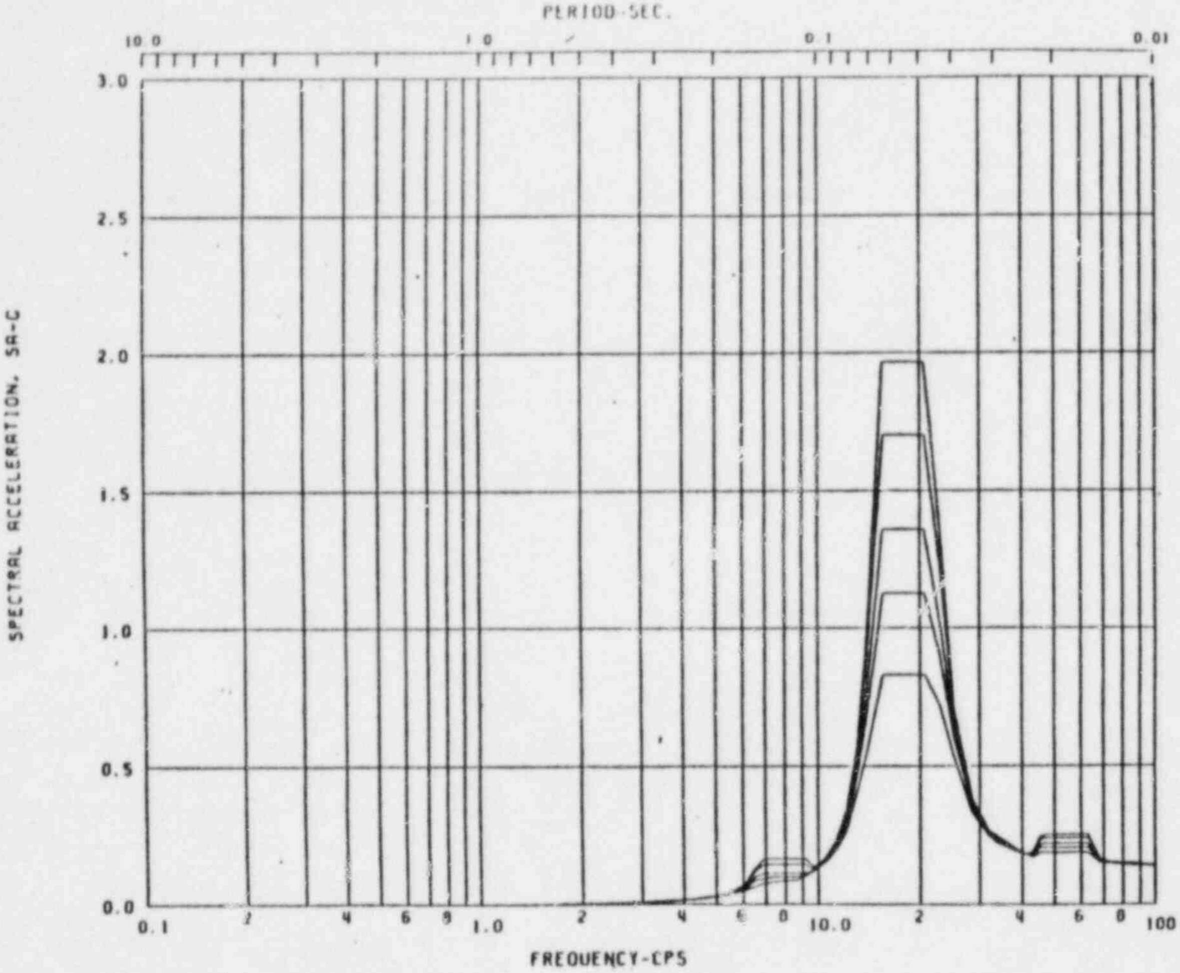
Node: 19 Direction: VERTICAL Elev: 304'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTROL STRUCTURE
LOCAL RESPONSE SPECTRA,
VERTICAL, SRV AXISYMMETRIC

FIGURE B.2-57



Acceleration Spectra for CONTROL STRUCTURE

Load Case: KWU-SRV AXISYMMETRIC ENVELOPE (WIDENED - 15%)

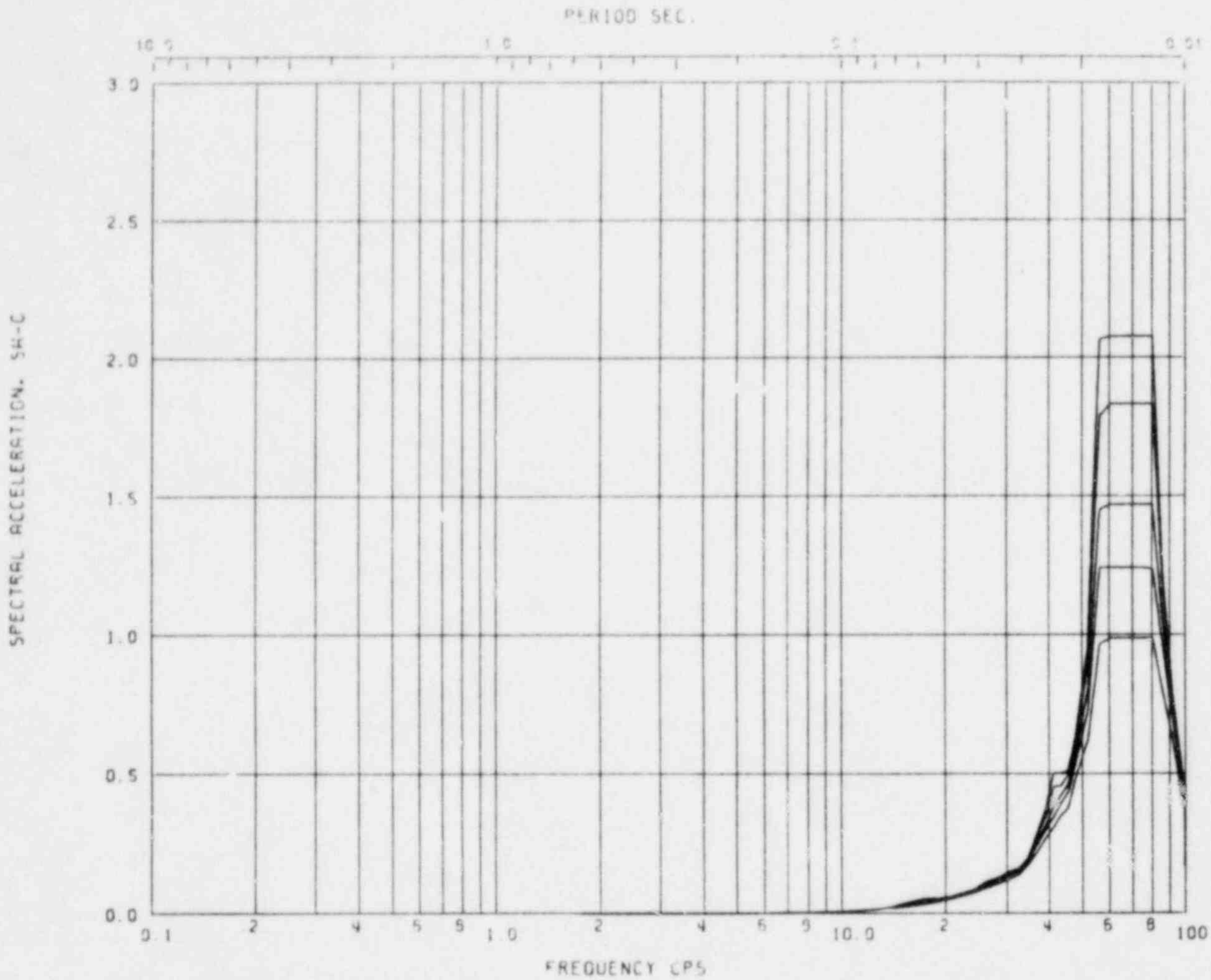
Node: 19 Direction: VERTICAL Elev: 332'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTROL STRUCTURE
LOCAL RESPONSE SPECTRA,
VERTICAL, SRV AXISYMMETRIC

FIGURE B.2-58



Acceleration Spectra for REACTOR BLDG., CONTROL STRUCTURE

Load Case: CHUGGING GE700 SERIES ASYMMETRIC ENVELOPE (WIDENED - 15%)

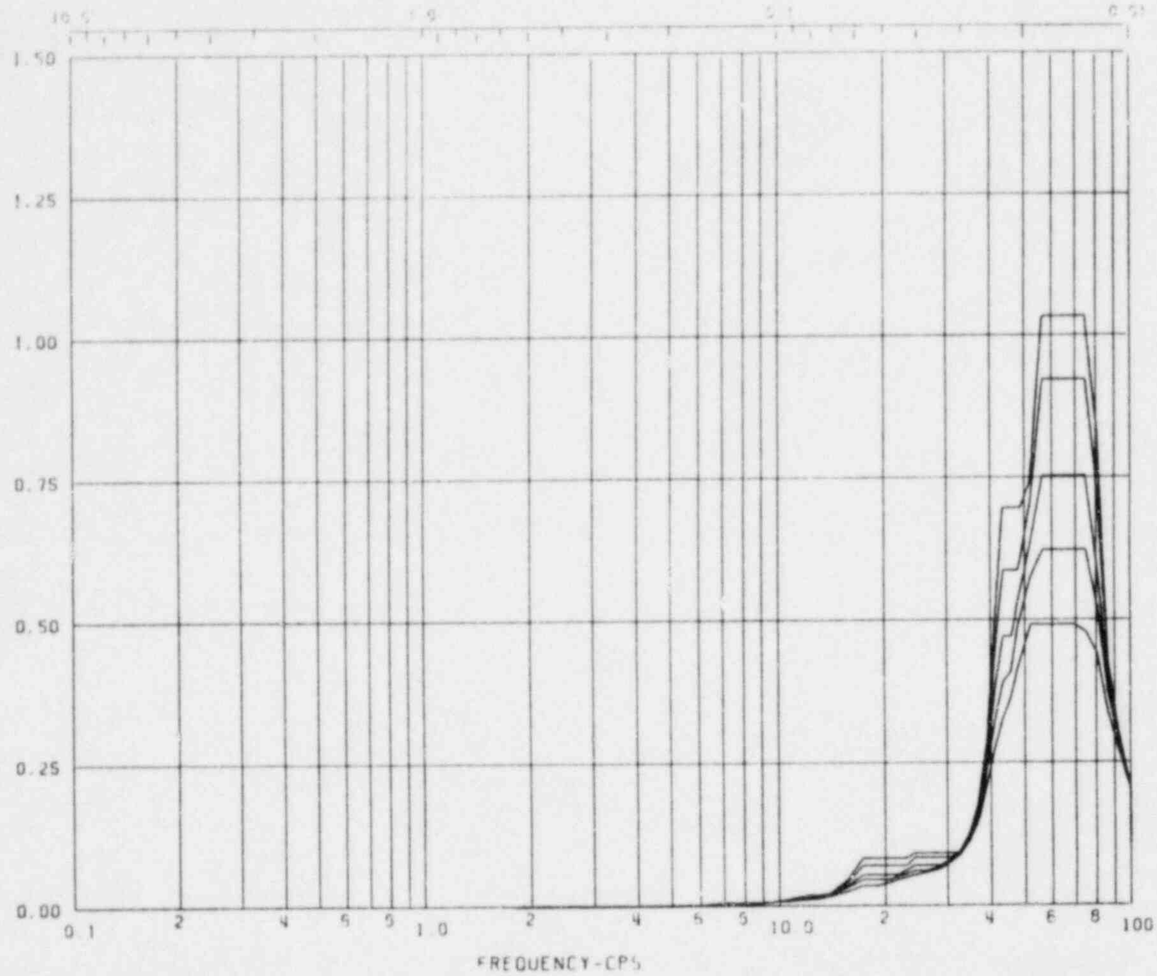
Node: 1 Direction: HORIZ N-S Elev: 177'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND CONTROL STRUCTURE GLOBAL RESPONSE SPECTRA, N-S HORIZONTAL, CHUG ASYMMETRIC

FIGURE B.2-59



Acceleration Spectra for REACTOR BLDG., CONTROL STRUCTURE

Load Case: CHUGGING GE700 SERIES ASYMMETRIC ENVELOPE (WIDENED - 15%)

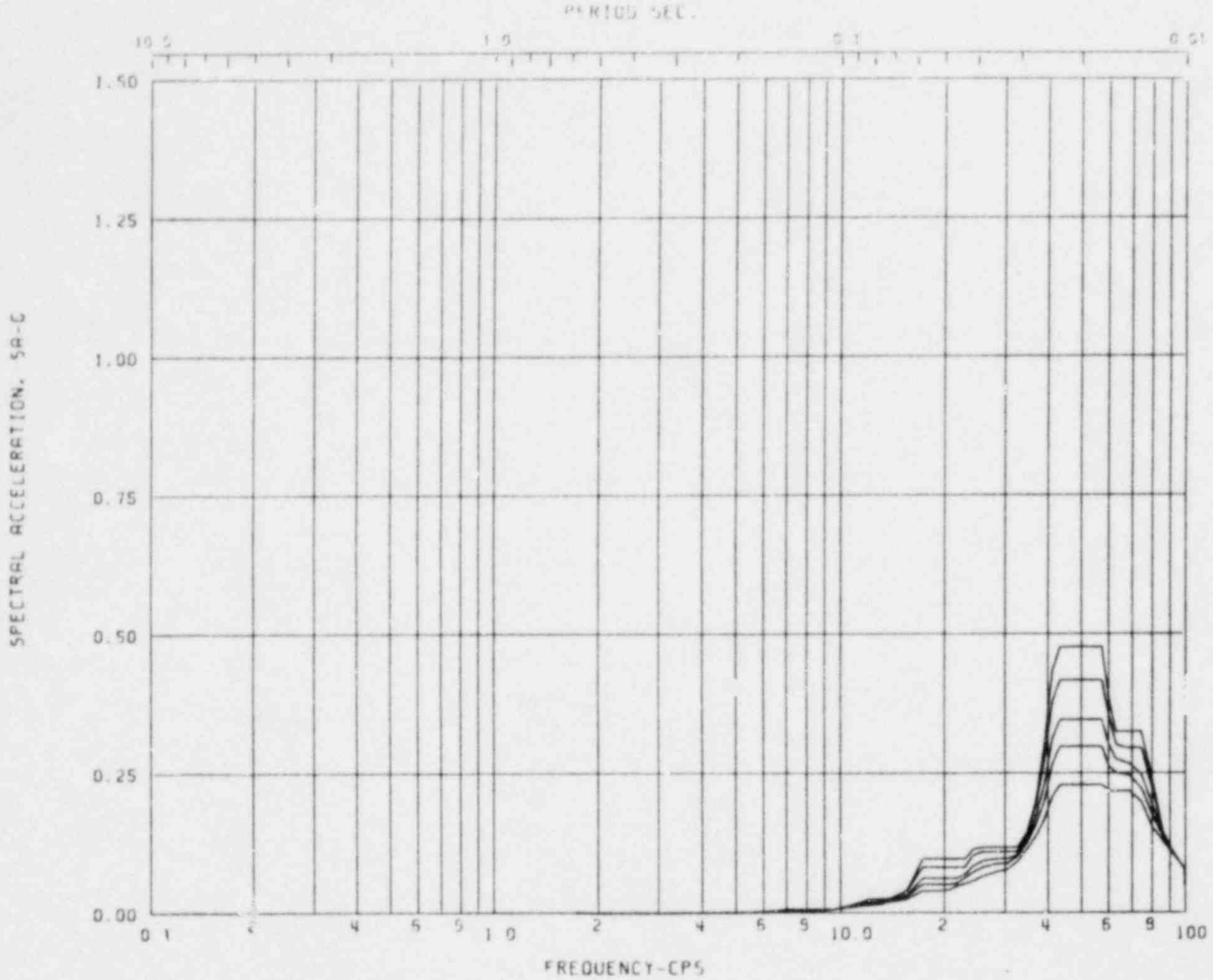
Node: 2 Direction: HORIZ N-S Elev: 201'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND CONTROL STRUCTURE GLOBAL RESPONSE SPECTRA, N-S HORIZONTAL, CHUG ASYMMETRIC

FIGURE B.2-60



Acceleration Spectra for REACTOR BLDG., CONTROL STRUCTURE

Load Case: CHUGGING GE700 SERIES ASYMMETRIC ENVELOPE (WIDENED - 15%)

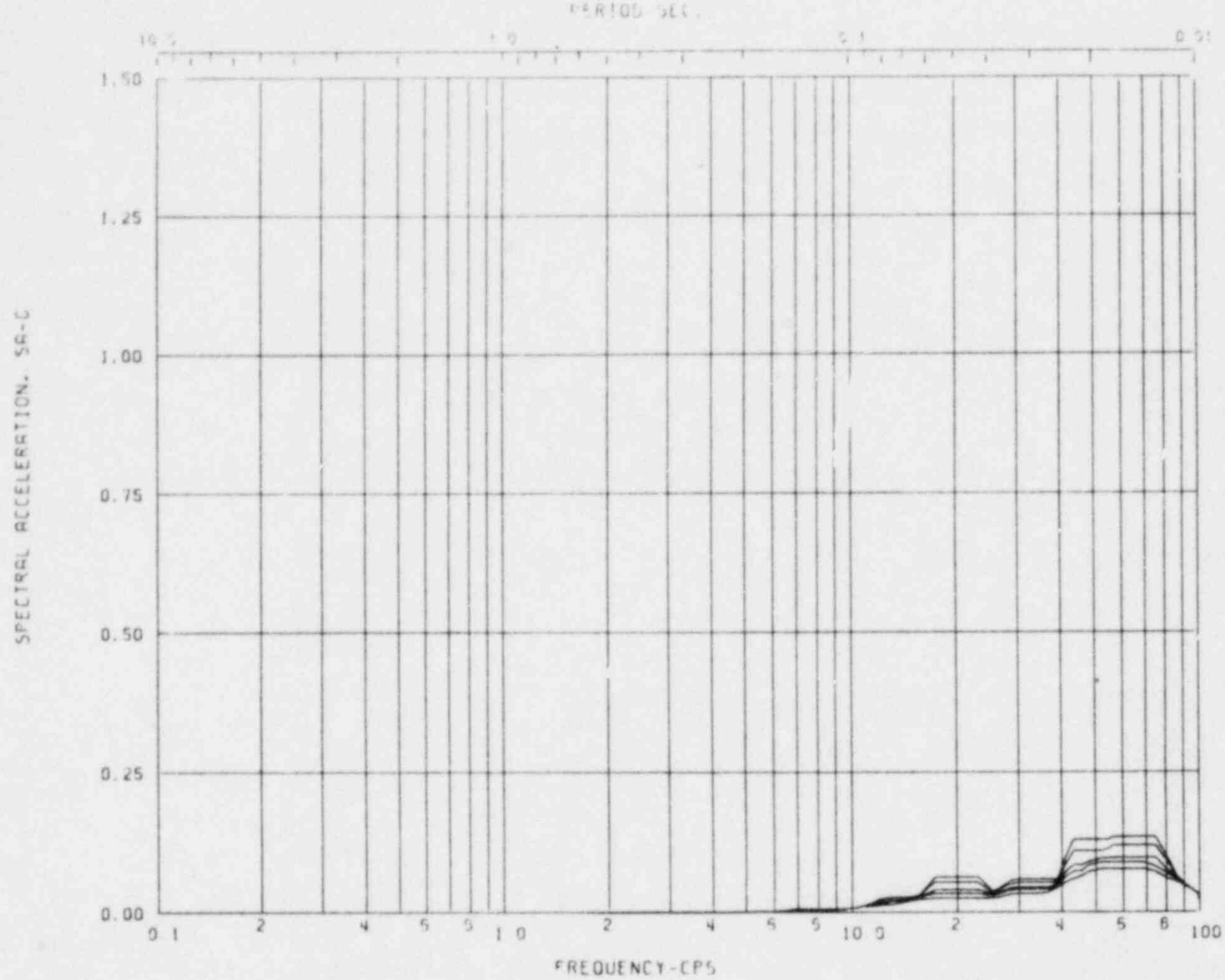
Node: 3 Direction: HORIZ N-S Elev: 217'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND CONTROL STRUCTURE GLOBAL RESPONSE SPECTRA, N-S HORIZONTAL, CHUG ASYMMETRIC

FIGURE B.2-61



Acceleration Spectra for REACTOR BLDG., CONTROL STRUCTURE

Load Case: CHUGGING GE700 SERIES ASYMMETRIC ENVELOPE (WIDENED - 15%)

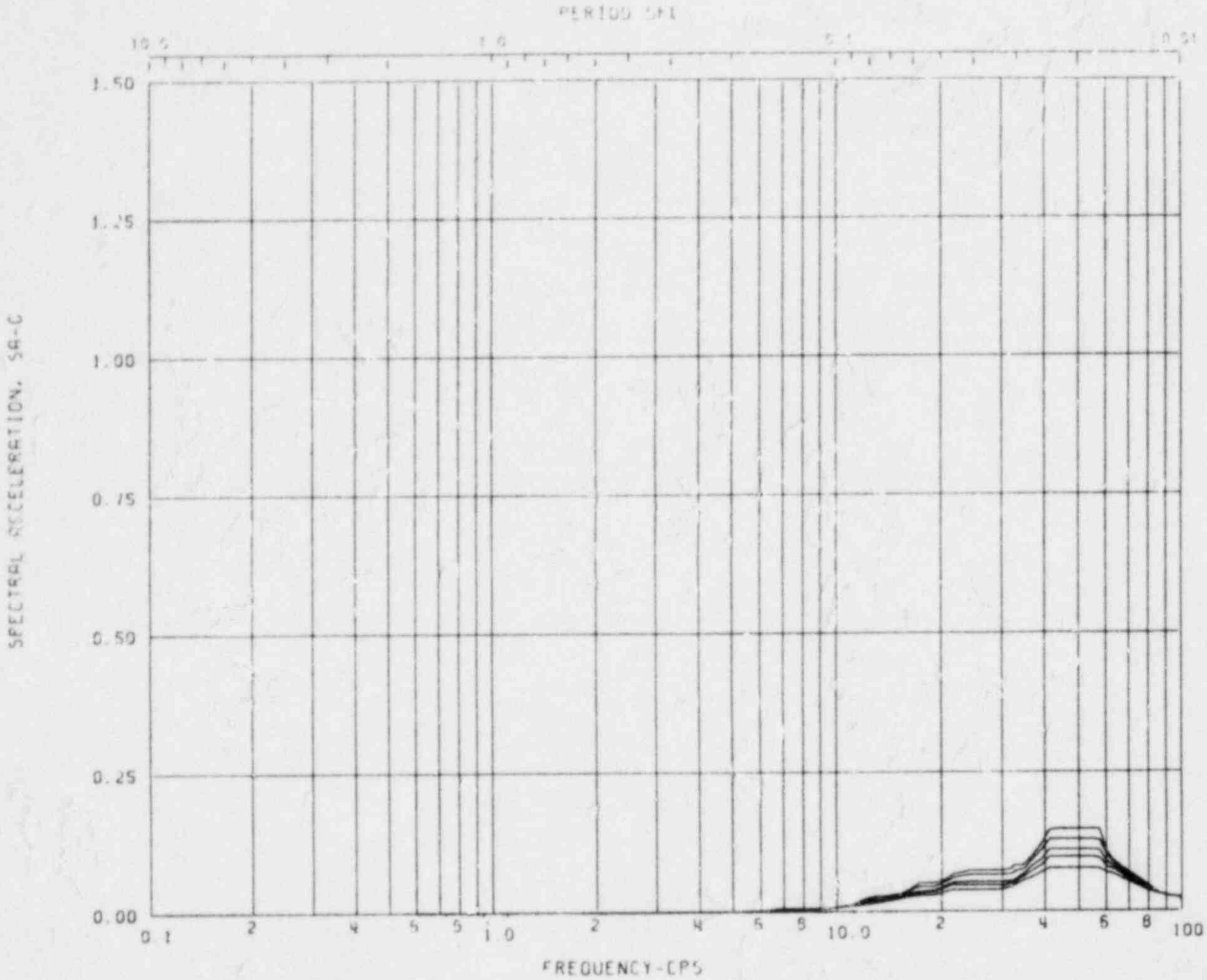
Node: 4 Direction: HORIZ N-S Elev: 239'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND CONTROL STRUCTURE GLOBAL RESPONSE SPECTRA, N-S HORIZONTAL, CHUG ASYMMETRIC

FIGURE B.2-62



Acceleration Spectra for REACTOR BLDG., CONTROL STRUCTURE

Load Case: CHUGGING GE700 SERIES ASYMMETRIC ENVELOPE (WIDENED - 15%)

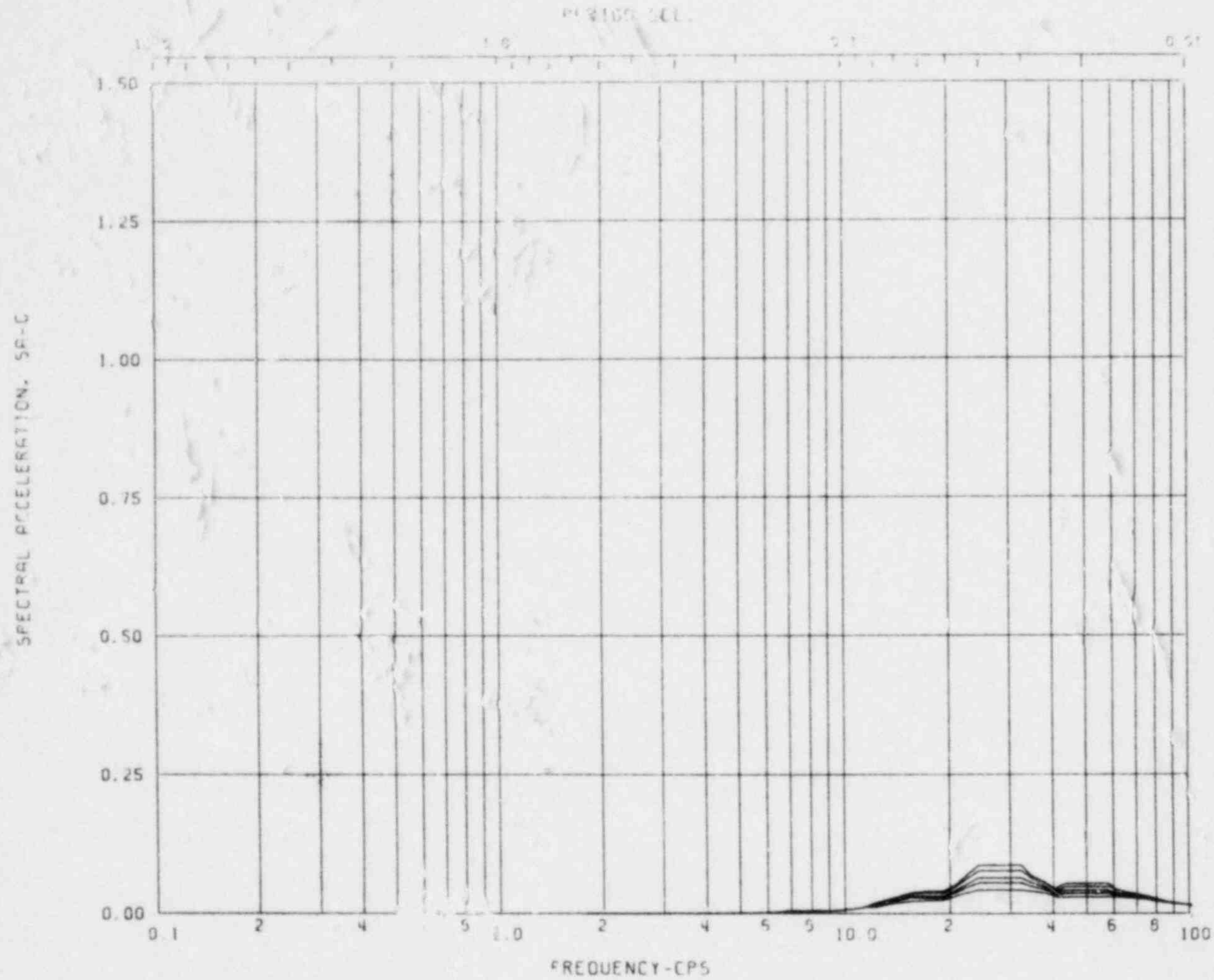
Node: 5 Direction: HORIZ N-S Elev: 253'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND CONTROL STRUCTURE GLOBAL RESPONSE SPECTRA, N-S HORIZONTAL, CHUG ASYMMETRIC

FIGURE B.2-63



Acceleration Spectra for REACTOR BLDG., CONTROL STRUCTURE

Load Case: CHUGGING GE700 SERIES ASYMMETRIC ENVELOPE (WIDENED - 15%)

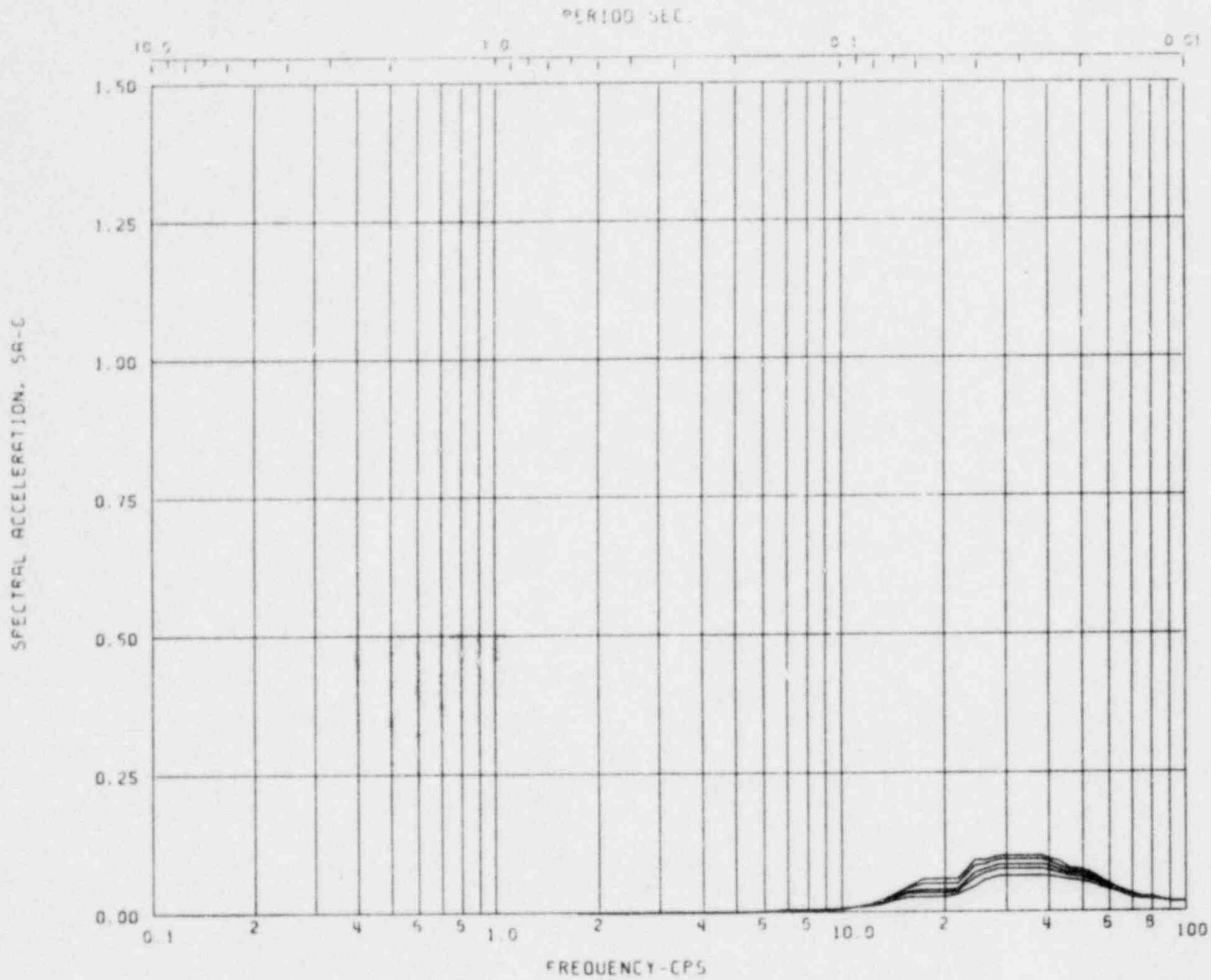
Node: 6 Direction: HORIZ N-S Elev: 269'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND CONTROL STRUCTURE GLOBAL RESPONSE SPECTRA, N-S HORIZONTAL, CHUG ASYMMETRIC

FIGURE B.2-64



Acceleration Spectra for REACTOR BLDG., CONTROL STRUCTURE

Load Case: CHUGGING GE700 SERIES ASYMMETRIC ENVELOPE (WIDENED - 15%)

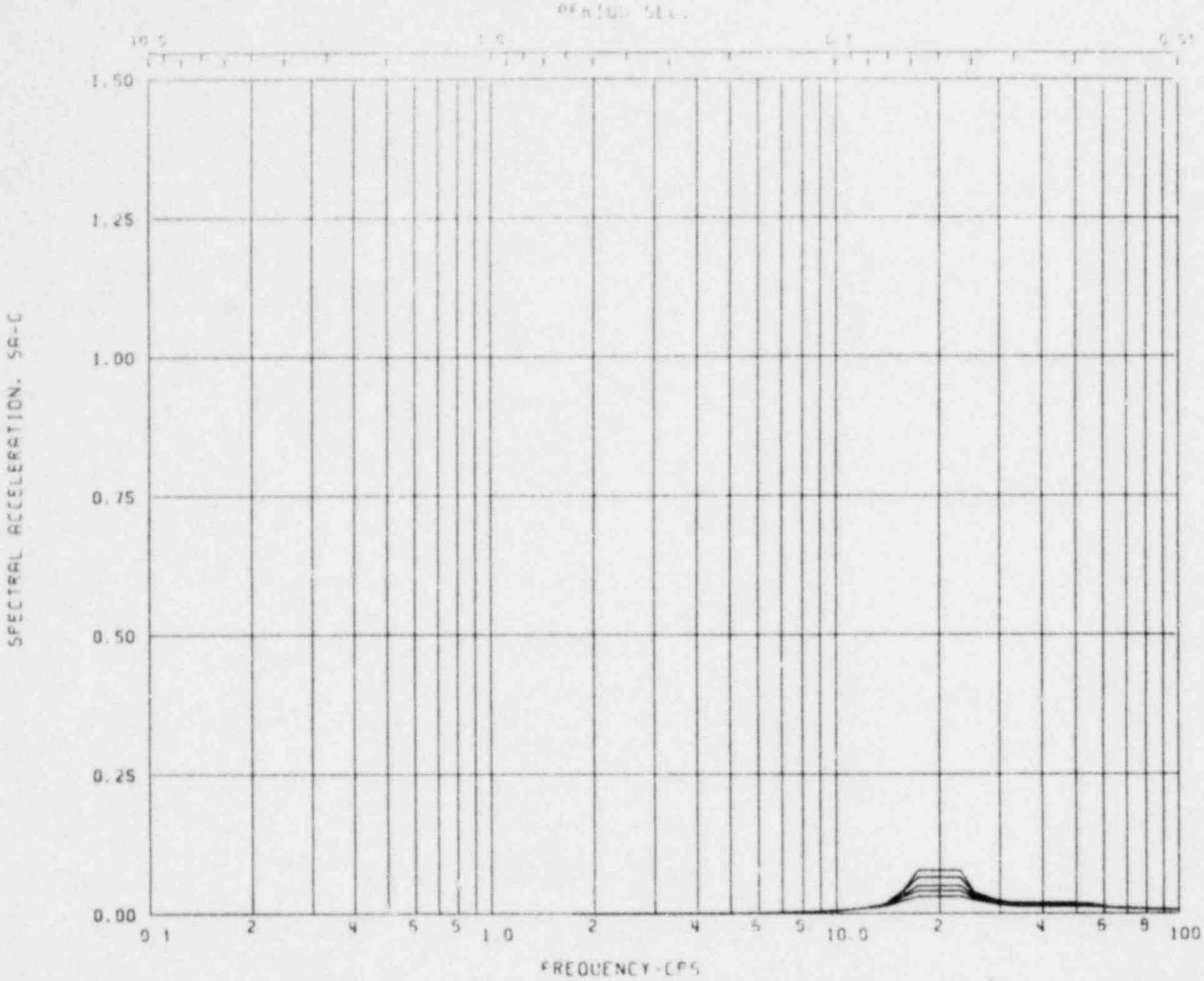
Node: 7 Direction: HORIZ N-S Elev: 283'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND CONTROL STRUCTURE GLOBAL RESPONSE SPECTRA, N-S HORIZONTAL, CHUG ASYMMETRIC

FIGURE B.2-65



Acceleration Spectra for REACTOR BLDG., CONTROL STRUCTURE

Load Case: CHUGGING GE700 SERIES ASYMMETRIC ENVELOPE (WIDENED - 15%)

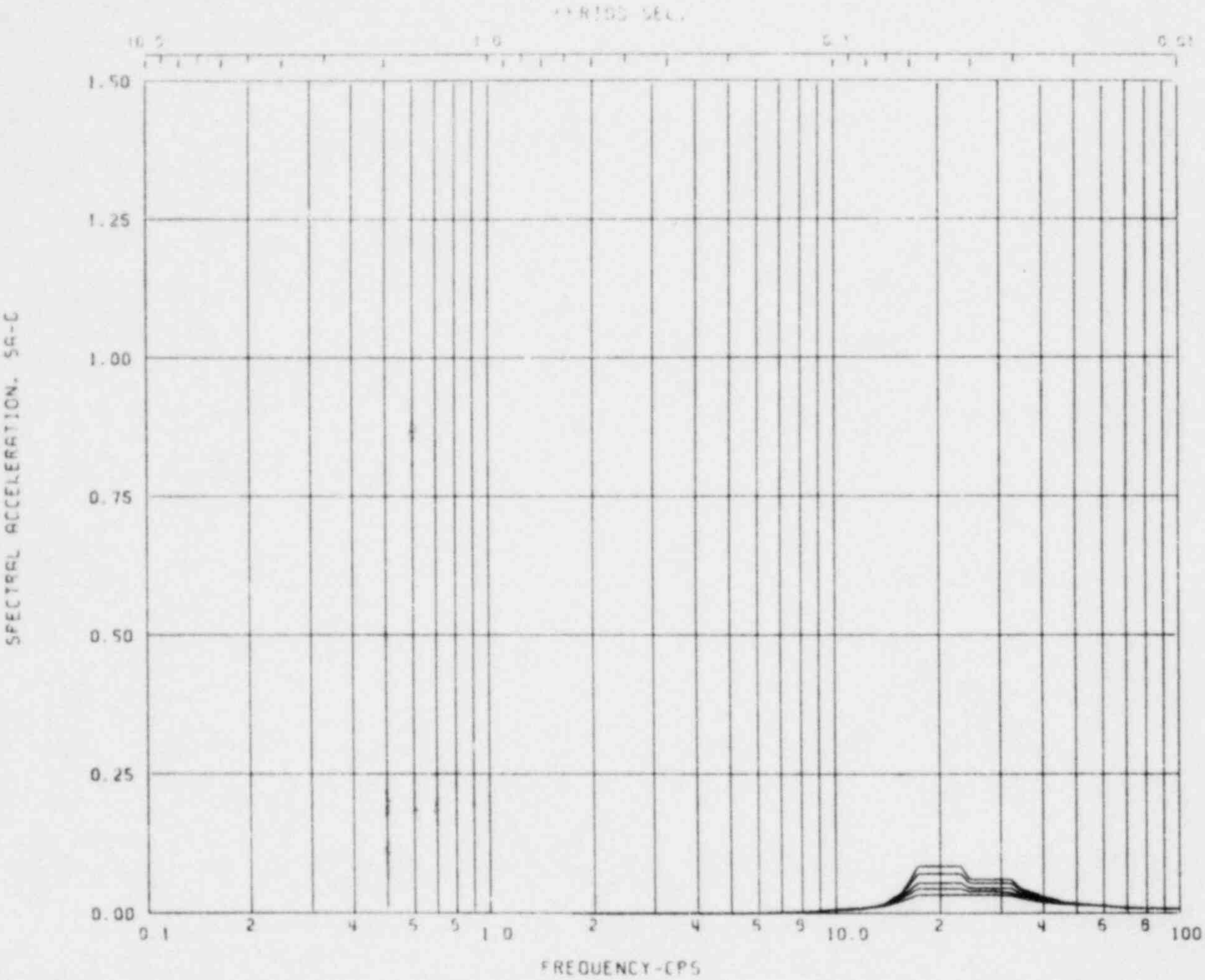
Node: 8 Direction: HORIZ N-S Elev: 304'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND CONTROL STRUCTURE GLOBAL RESPONSE SPECTRA, N-S HORIZONTAL, CHUG ASYMMETRIC

FIGURE B.2-66



Acceleration Spectra for REACTOR BLDG., CONTROL STRUCTURE

Load Case: CHUGGING GE700 SERIES ASYMMETRIC ENVELOPE (WIDENED - 15%)

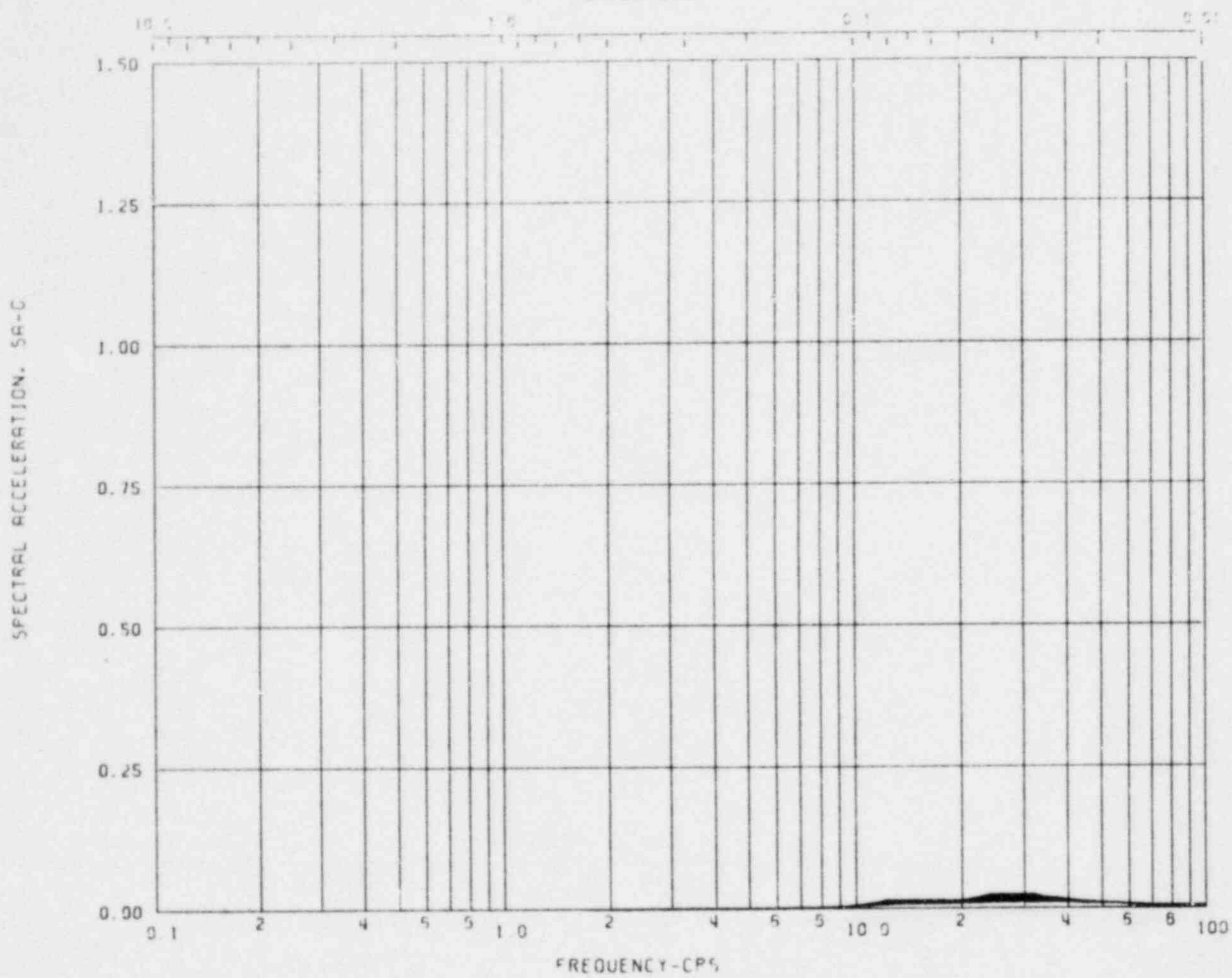
Node: 9 Direction: HORIZ N-S Elev: 313'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND CONTROL STRUCTURE GLOBAL RESPONSE SPECTRA, N-S HORIZONTAL, CHUG ASYMMETRIC

FIGURE B.2-67



Acceleration Spectra for REACTOR BLDG., CONTROL STRUCTURE

Load Case: CHUGGING GE700 SERIES ASYMMETRIC ENVELOPE (WIDENED - 15%)

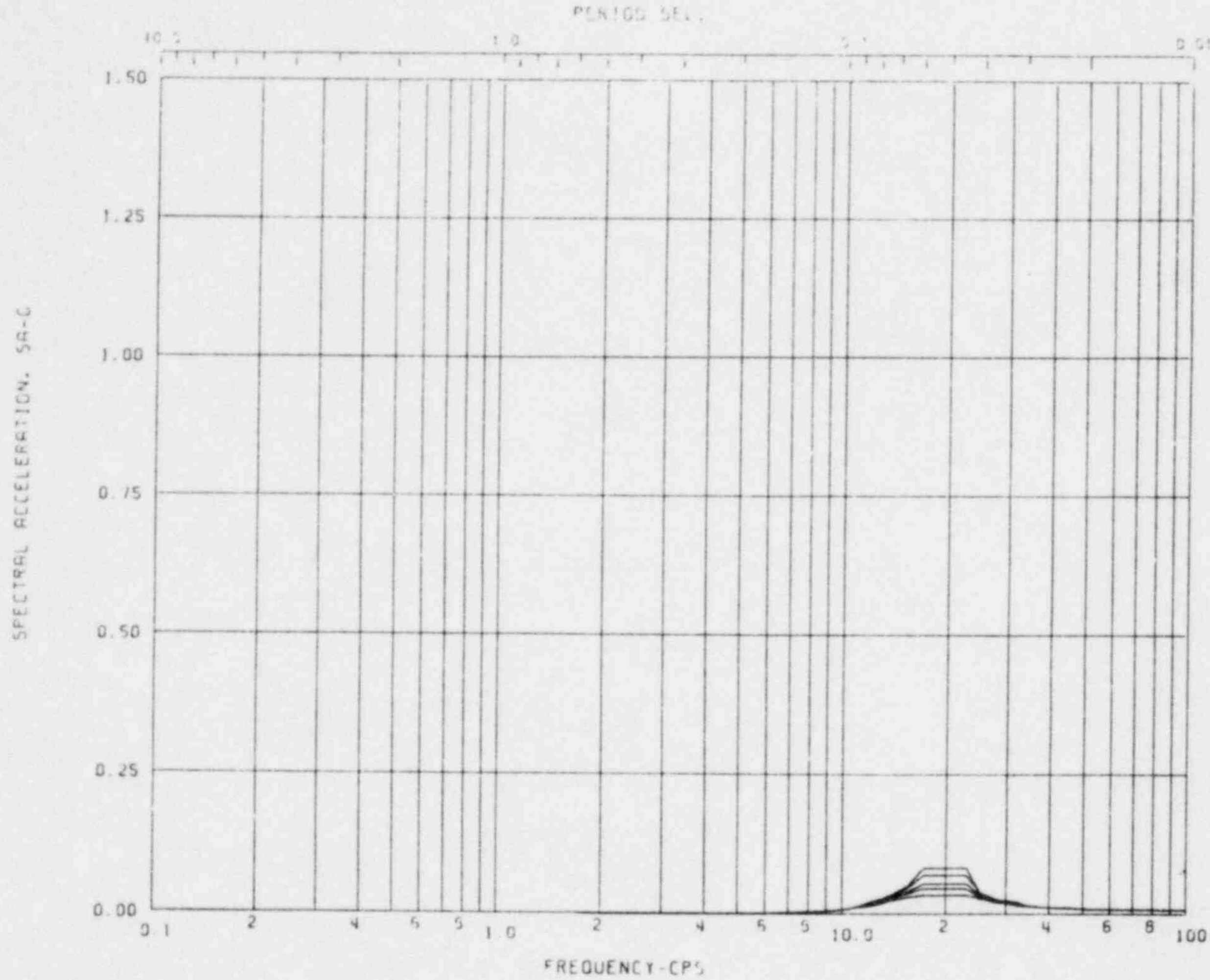
Node: 10 Direction: HORIZ N-S Elev: 332'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND CONTROL STRUCTURE GLOBAL RESPONSE SPECTRA, N-S HORIZONTAL, CHUG ASYMMETRIC

FIGURE B.2-68



Acceleration Spectra for REACTOR BLDG., CONTROL STRUCTURE

Load Case: CHUGGING GE700 SERIES ASYMMETRIC ENVELOPE (WIDENED - 15%)

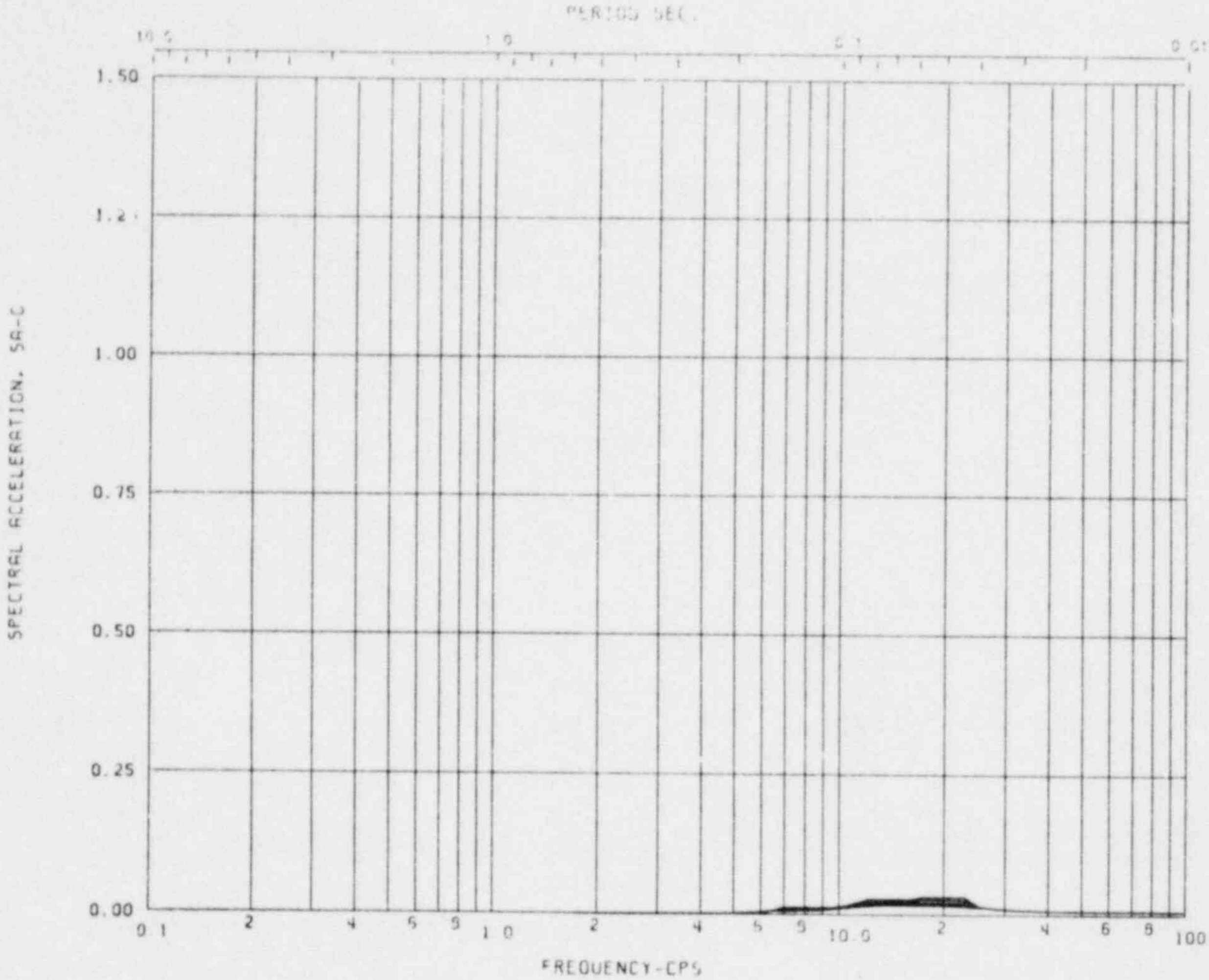
Node: 11 Direction: HORIZ N-S Elev: 352'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND CONTROL STRUCTURE GLOBAL RESPONSE SPECTRA, N-S HORIZONTAL, CHUG ASYMMETRIC

FIGURE B.2-69



Acceleration Spectra for REACTOR BLDG., CONTROL STRUCTURE

Load Case: CHUGGING GE700 SERIES ASYMMETRIC ENVELOPE (WIDENED - 15%)

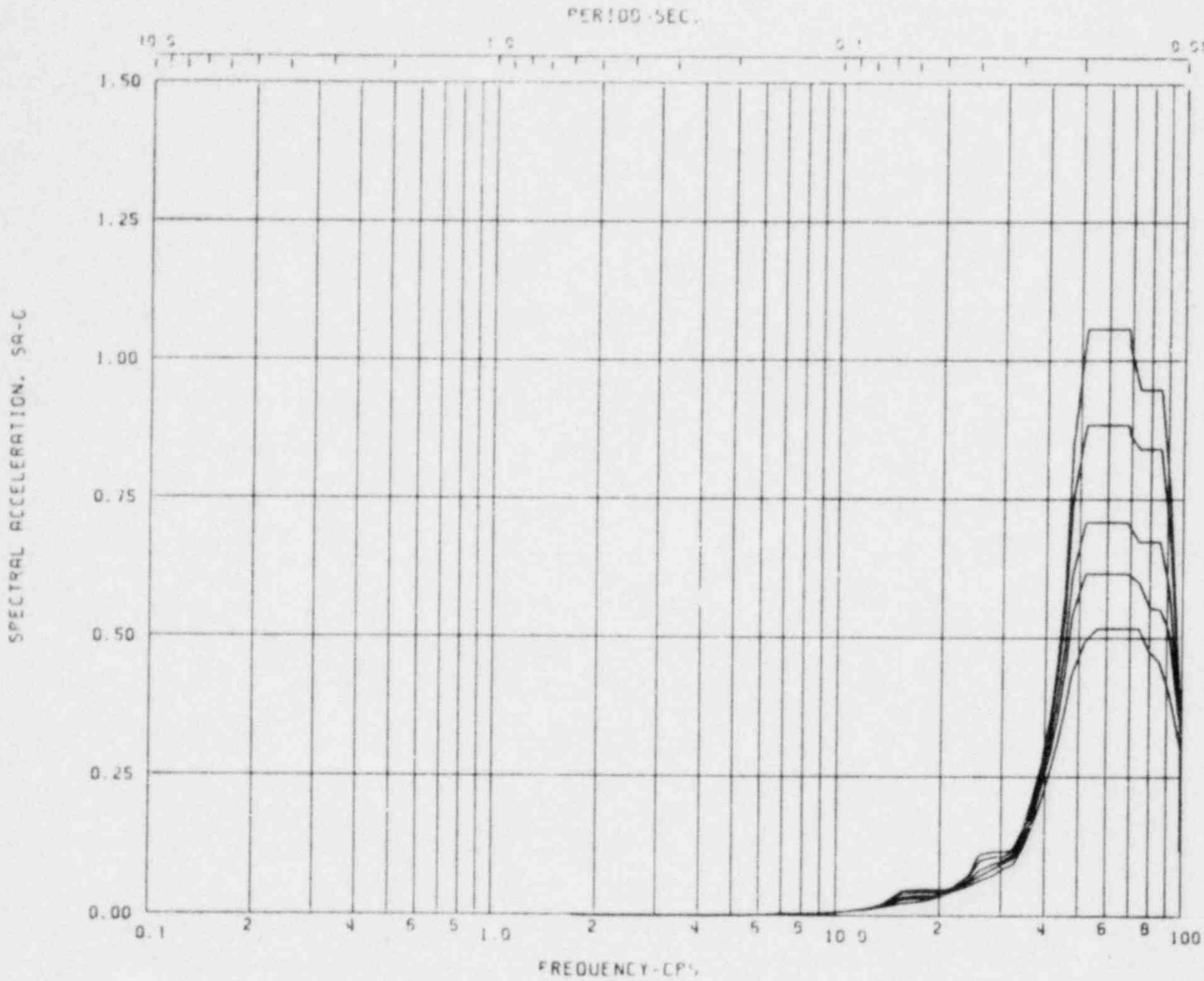
Node: 12 Direction: HORIZ N-S Elev: 410'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND CONTROL STRUCTURE GLOBAL RESPONSE SPECTRA, N-S HORIZONTAL, CHUG ASYMMETRIC

FIGURE B.2-70



Acceleration Spectra for REACTOR BLDG., CONTROL STRUCTURE

Load Case: ASYMMETRIC CHUGGING GE 700 SERIES ENVELOPE (WIDENED - 15%)

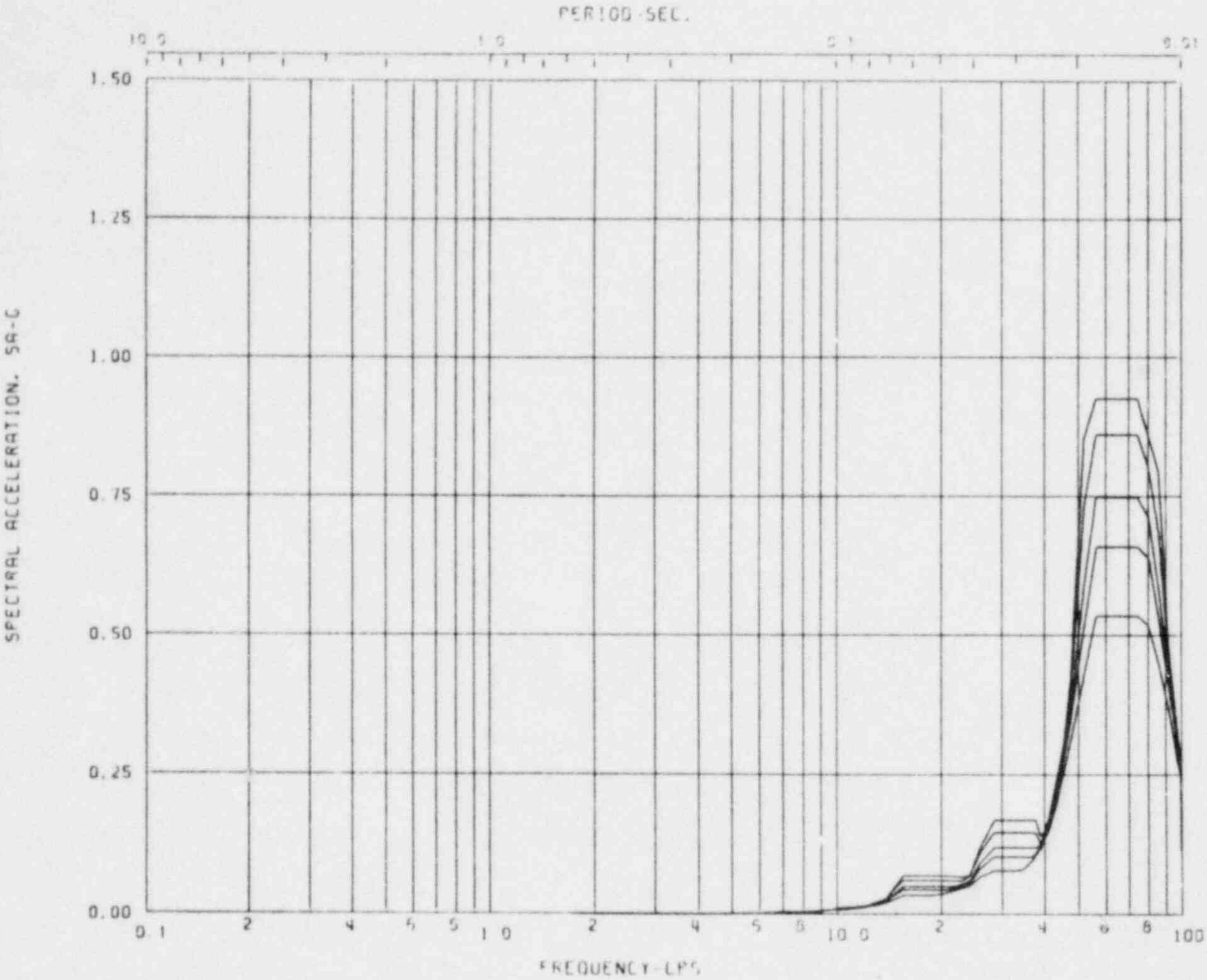
Node: 1 Direction: HORIZ N-S Elev: 177'-0

Dampi 1g: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND CONTROL STRUCTURE GLOBAL RESPONSE SPECTRA, E-W HORIZONTAL, CHUG ASYMMETRIC

FIGURE B.2-71



Acceleration Spectra for REACTOR BLDG., CONTROL STRUCTURE

Load Case: ASYMMETRIC CHUGGING GE 700 SERIES ENVELOPE (WIDENED - 15%)

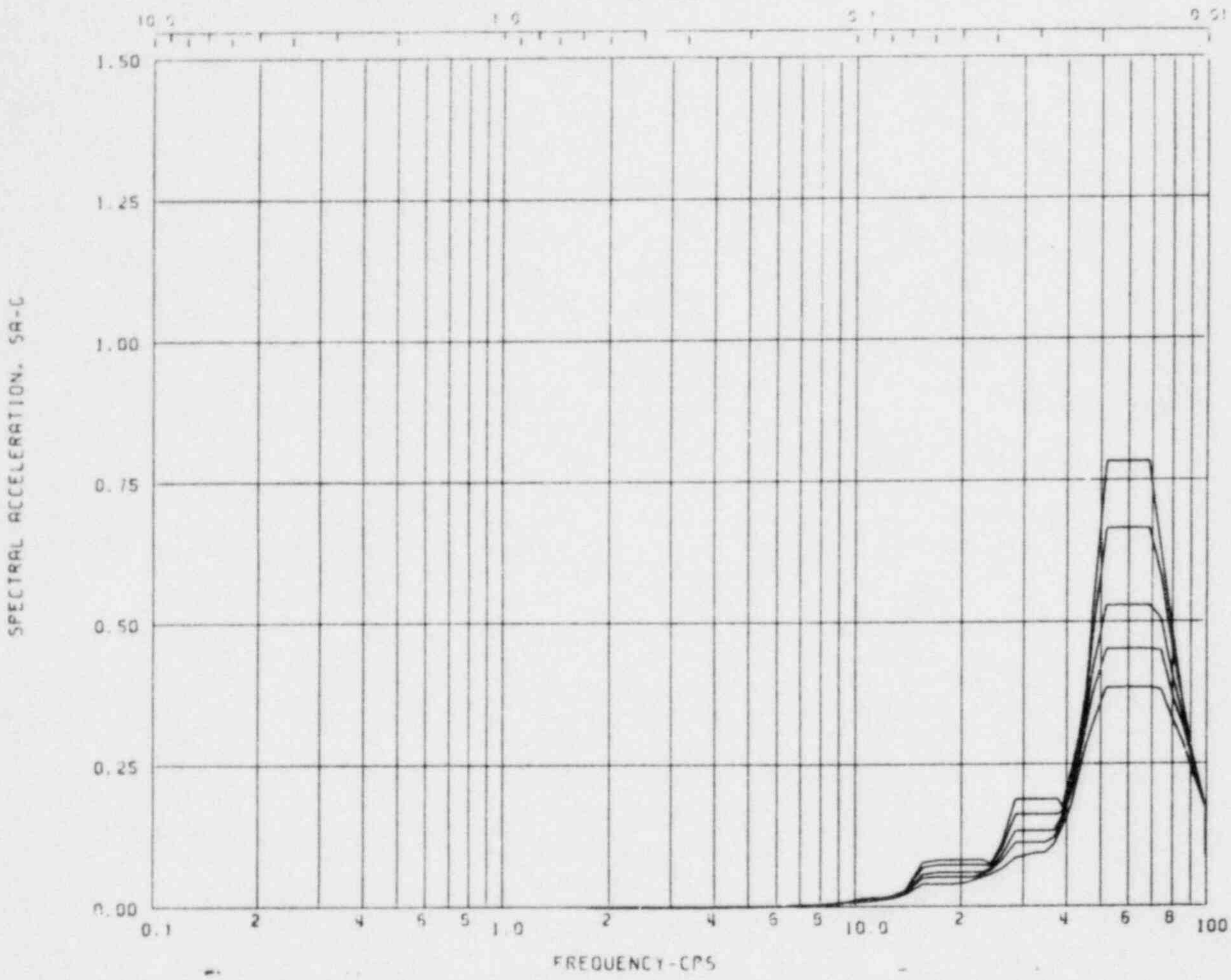
Node: 2 Direction: HORIZ N-S Elev: 201'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND CONTROL STRUCTURE GLOBAL RESPONSE SPECTRA, E-W HORIZONTAL, CHUG ASYMMETRIC

FIGURE B.2-72



Acceleration Spectra for REACTOR BLDG., CONTROL STRUCTURE

Load Case: ASYMMETRIC CHUGGING GE 700 SERIES ENVELOPE (WIDENED - 15%)

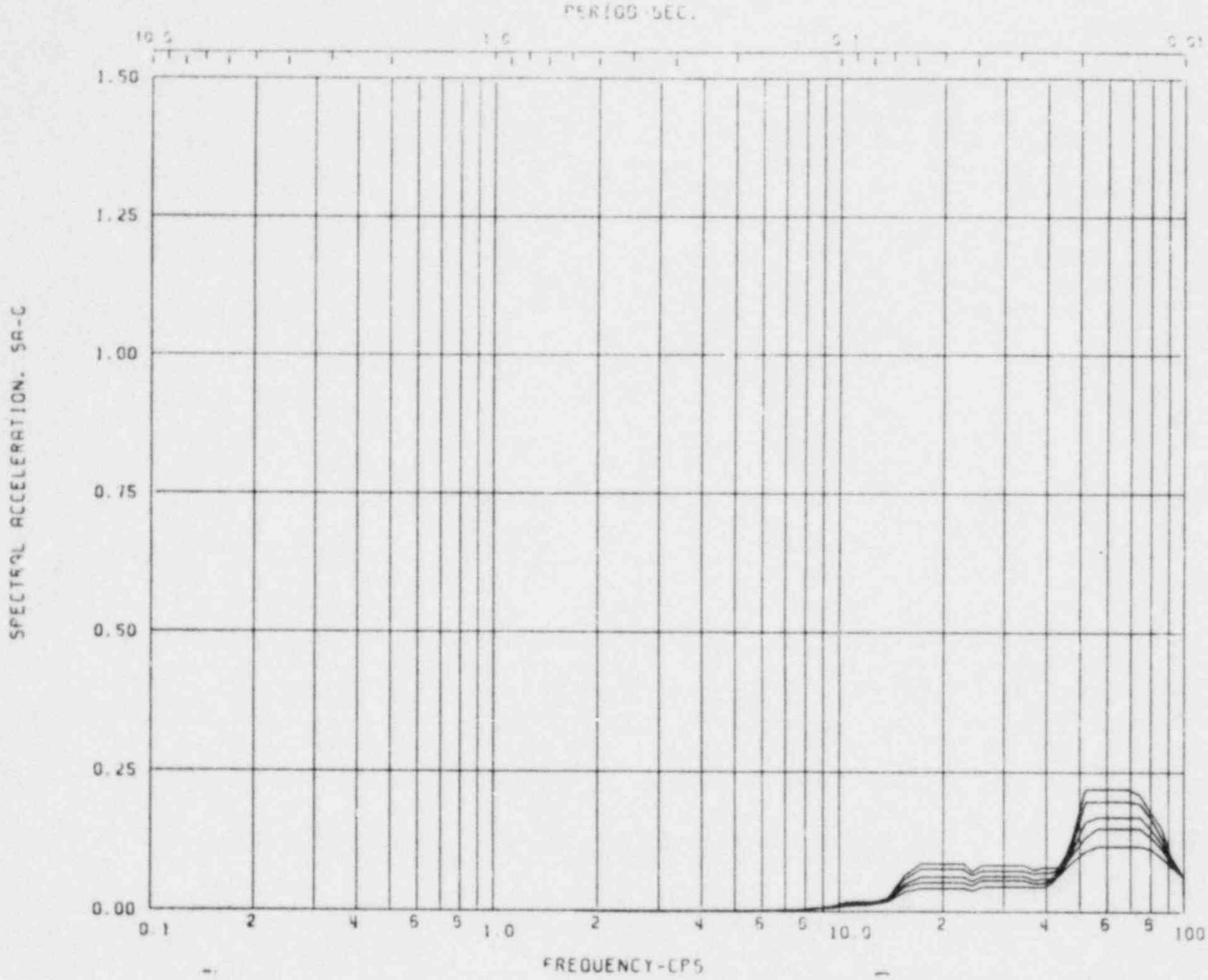
Node: 3 Direction: HORIZ N-S Elev: 217'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND CONTROL STRUCTURE GLOBAL RESPONSE SPECTRA, E-W HORIZONTAL, CHUG ASYMMETRIC

FIGURE B.2-73



Acceleration Spectra for REACTOR BLDG., CONTROL STRUCTURE

Load Case: ASYMMETRIC CHUGGING GE 700 SERIES ENVELOPE (WIDENED - 15%)

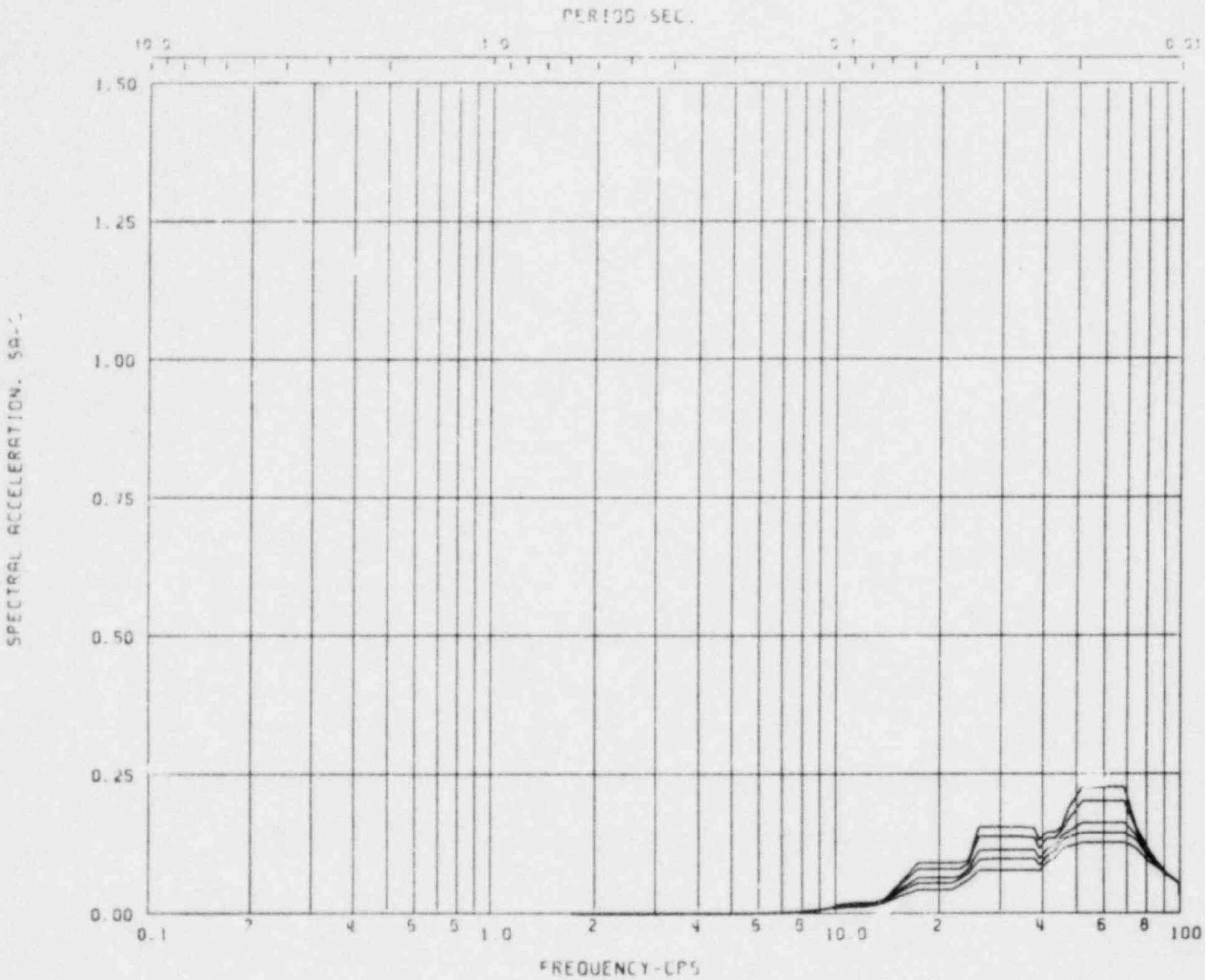
Node: 4 Direction: HORIZ N-S Elev: 239'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND CONTROL STRUCTURE GLOBAL RESPONSE SPECTRA, E-W HORIZONTAL, CHUG ASYMMETRIC

FIGURE B.2-74



Acceleration Spectra for REACTOR BLDG., CONTROL STRUCTURE

Load Case: ASYMMETRIC CHUGGING GE 700 SERIES ENVELOPE (WIDENED - 15%)

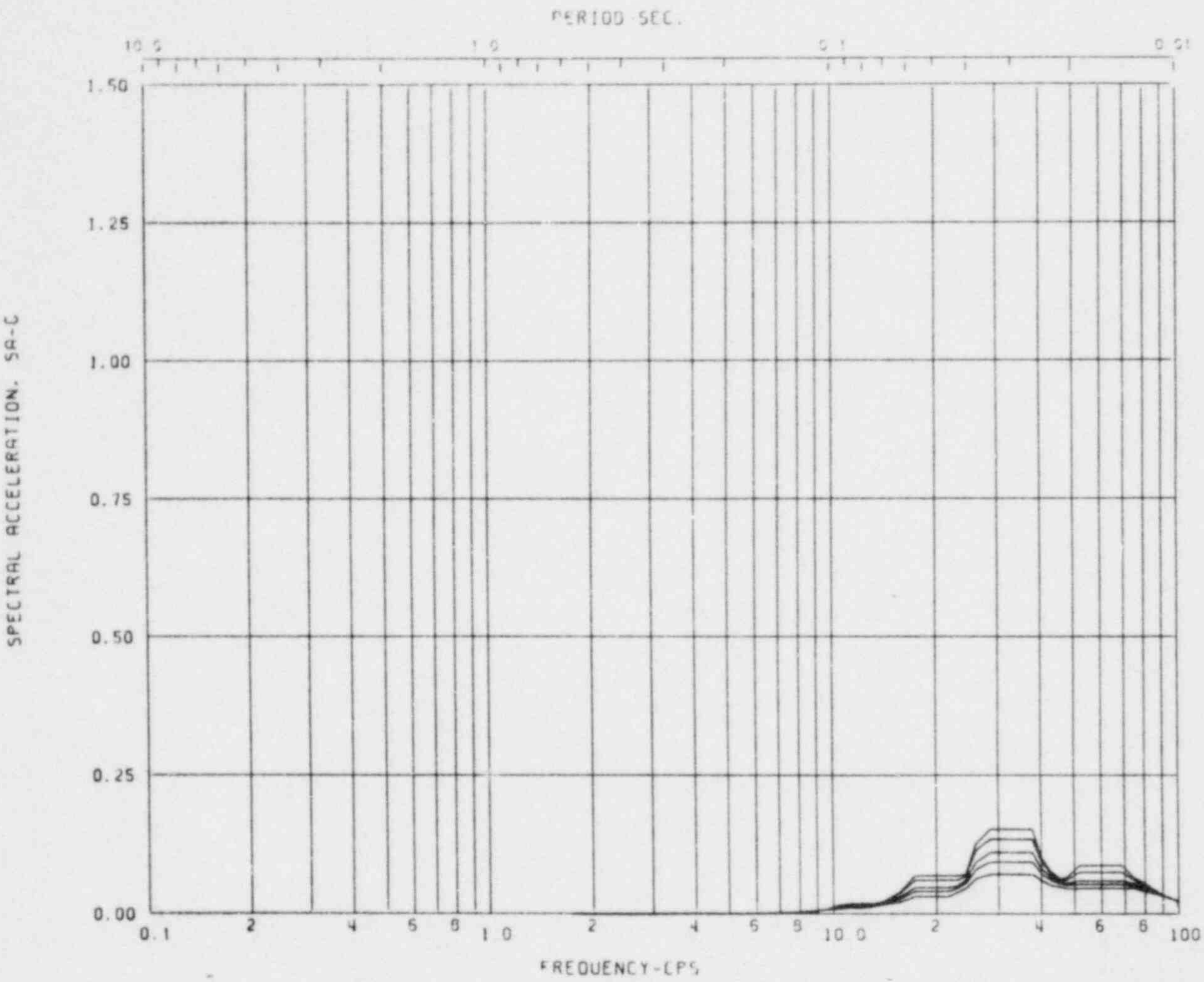
Node: 5 Direction: HORIZ N-S Elev: 253'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND CONTROL STRUCTURE GLOBAL RESPONSE SPECTRA, E-W HORIZONTAL, CHUG ASYMMETRIC

FIGURE B.2-75



Acceleration Spectra for REACTOR BLDG., CONTROL STRUCTURE

Load Case: ASYMMETRIC CHUGGING GE 700 SERIES ENVELOPE (WIDENED - 15%)

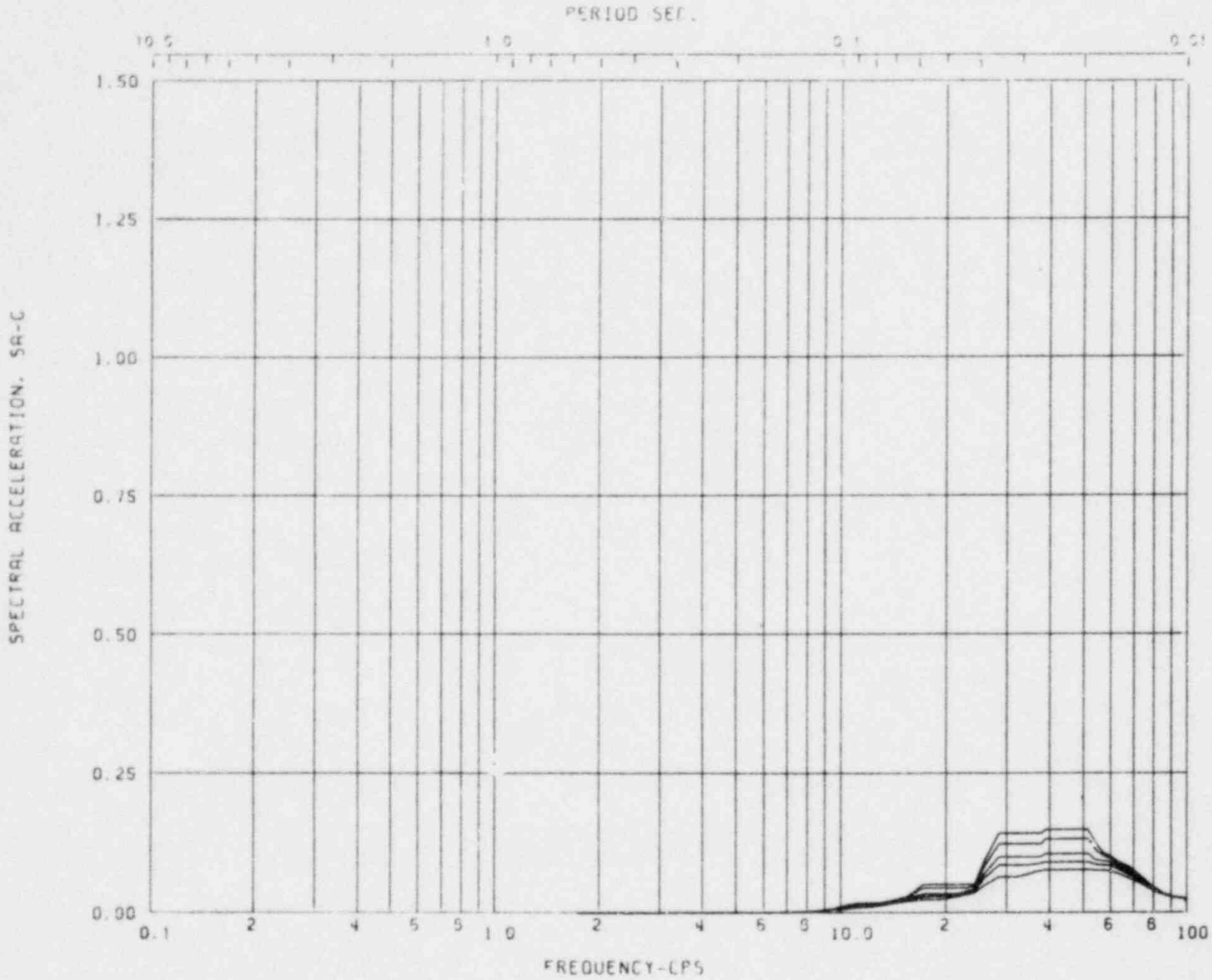
Node: 6 Direction: HORIZ N-S Elev: 269'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND CONTROL STRUCTURE GLOBAL RESPONSE SPECTRA, E-W HORIZONTAL, CHUG ASYMMETRIC

FIGURE B.2-76



Acceleration Spectra for REACTOR BLDG., CONTROL STRUCTURE

Load Case: ASYMMETRIC CHUGGING GE 700 SERIES ENVELOPE (WIDENED - 15%)

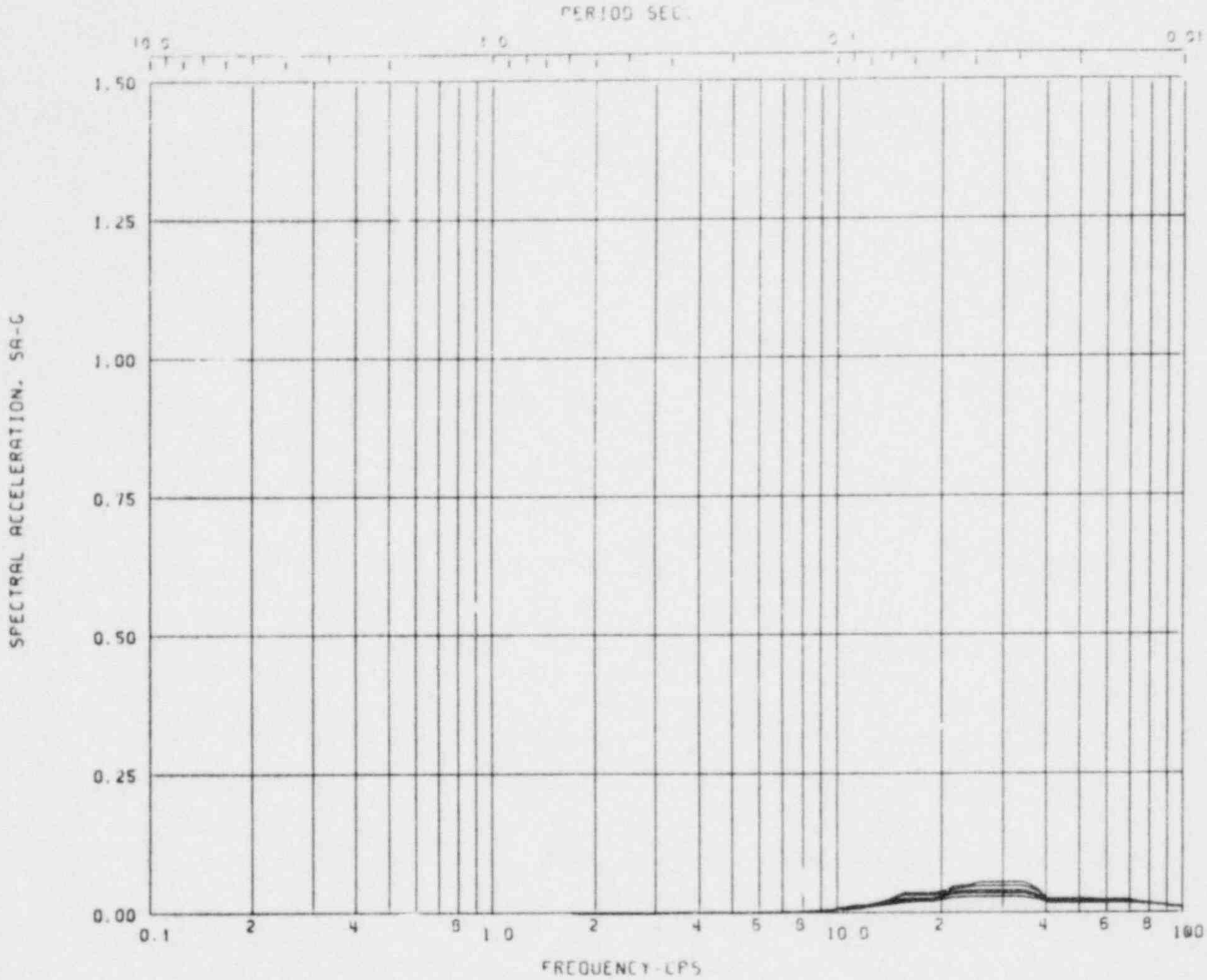
Node: 7 Direction: HORIZ N-S Elev: 283'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND CONTROL STRUCTURE GLOBAL RESPONSE SPECTRA, E-W HORIZONTAL, CHUG ASYMMETRIC

FIGURE B.2-77



Acceleration Spectra for REACTOR BLDG., CONTROL STRUCTURE

Load Case: ASYMMETRIC CHUGGING GE 700 SERIES ENVELOPE (WIDENED - 15%)

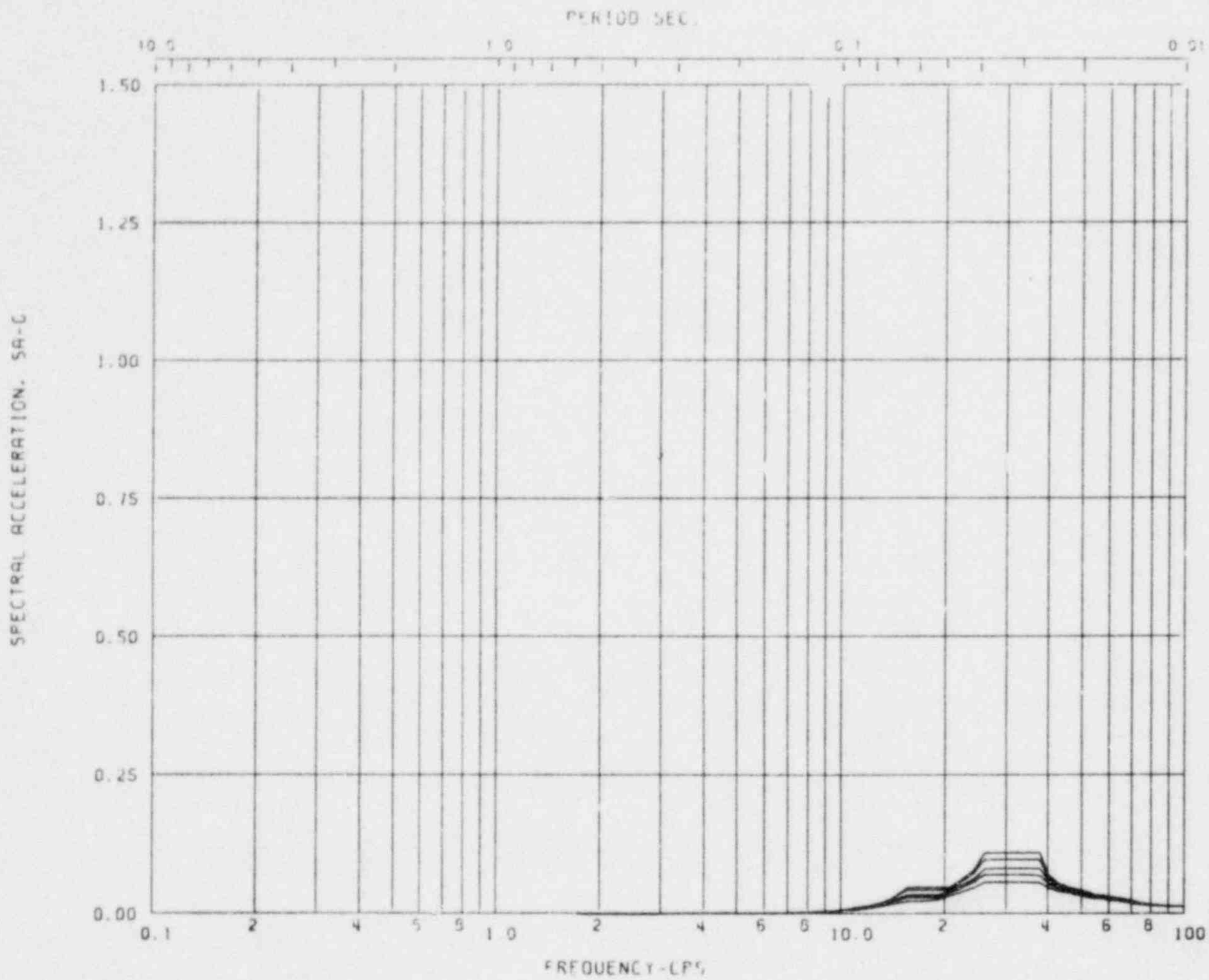
Node: 8 Direction: HORIZ N-S Elev: 304'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND CONTROL STRUCTURE GLOBAL RESPONSE SPECTRA, E-W HORIZONTAL, CHUG ASYMMETRIC

FIGURE B.2-78



Acceleration Spectra for REACTOR BLDG., CONTROL STRUCTURE

Load Case: ASYMMETRIC CHUGGING GE 700 SERIES ENVELOPE (WIDENED - 15%)

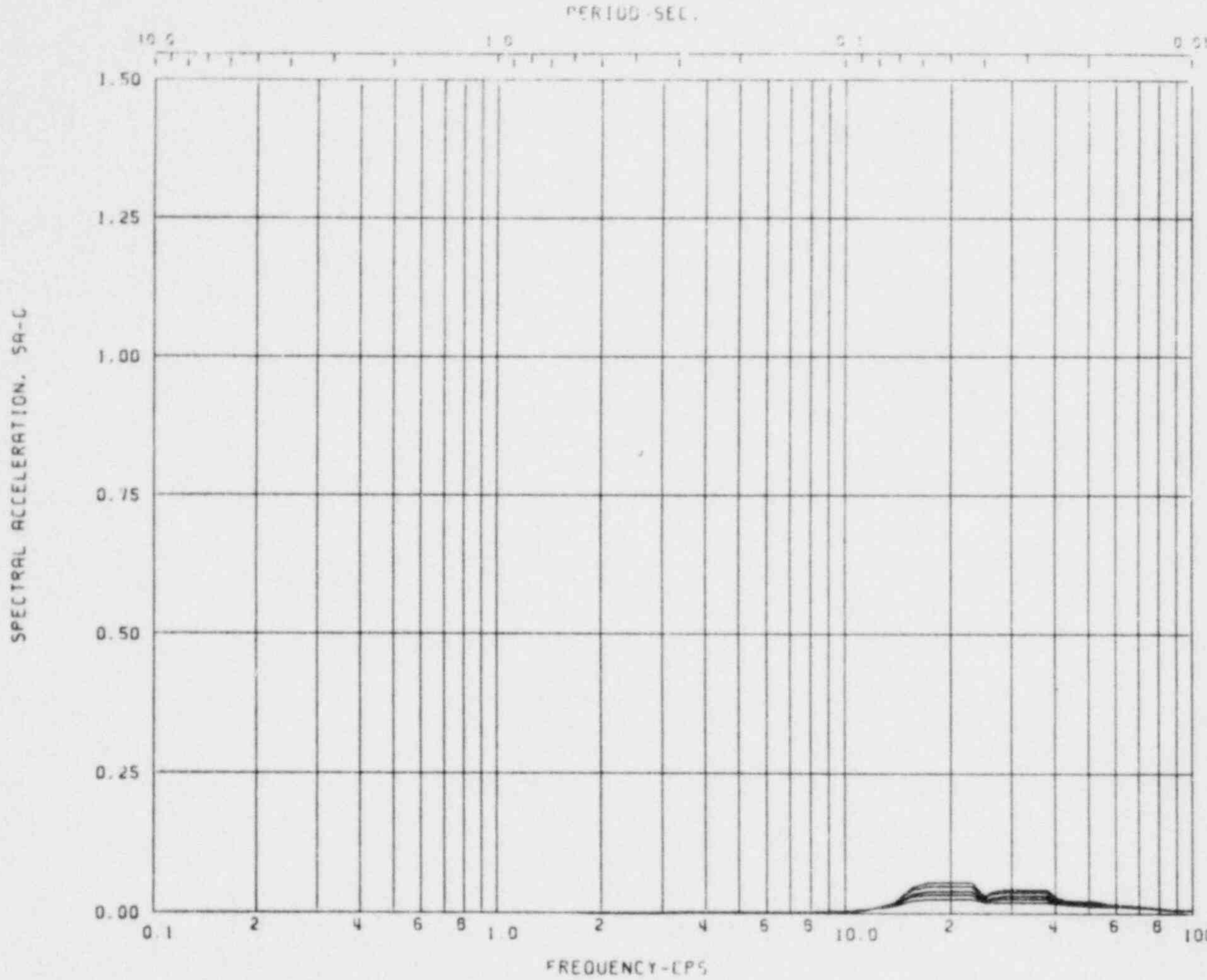
Node: 9 Direction: HORIZ N-S Elev: 313'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND CONTROL STRUCTURE GLOBAL RESPONSE SPECTRA, E-W HORIZONTAL, CHUG ASYMMETRIC

FIGURE B.2-79



Acceleration Spectra for REACTOR BLDG., CONTROL STRUCTURE

Load Case: ASYMMETRIC CHUGGING GE 700 SERIES ENVELOPE (WIDENED - 15%)

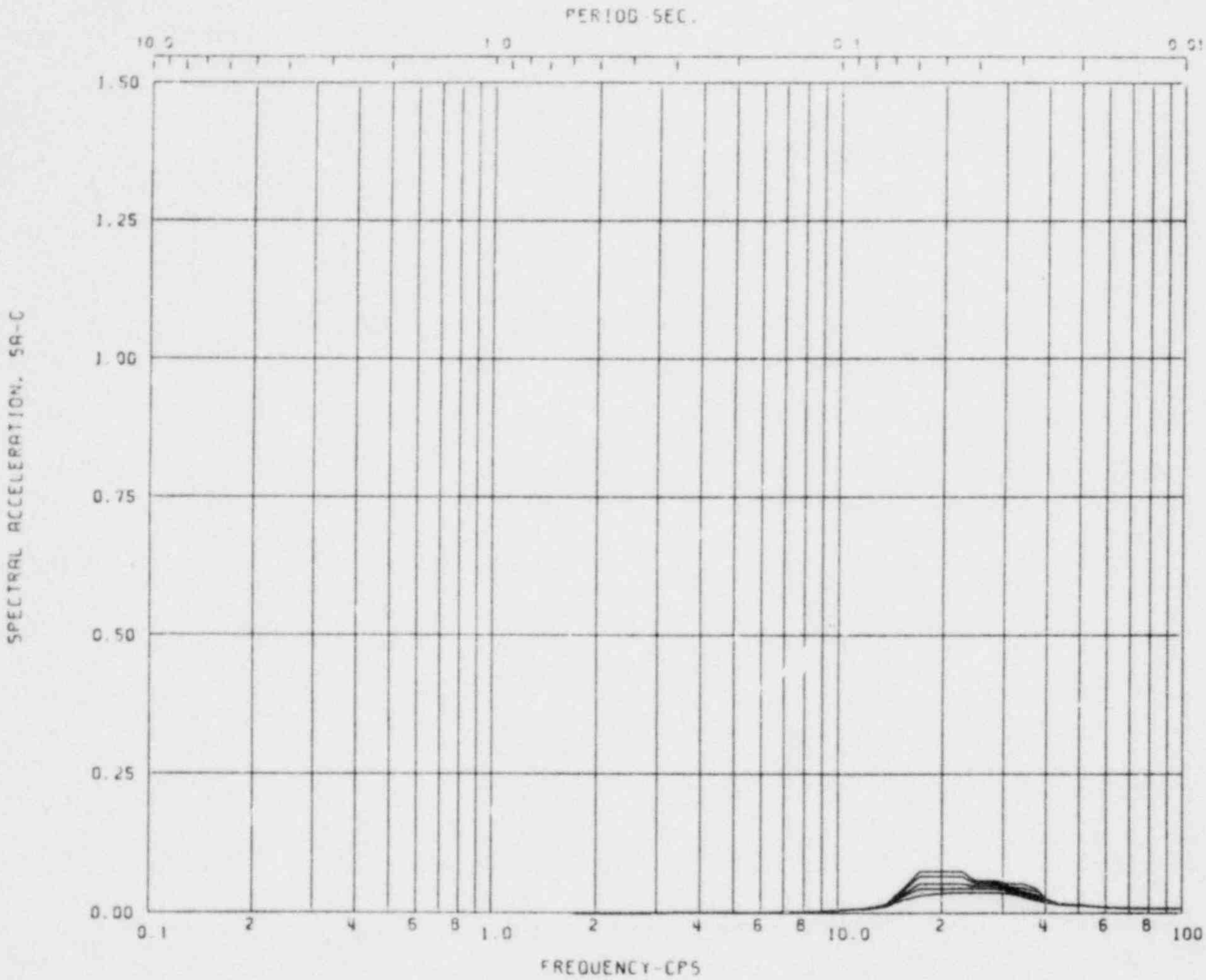
Node: 10 Direction: HORIZ N-S Elev: 332'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND CONTROL STRUCTURE GLOBAL RESPONSE SPECTRA, E-W HORIZONTAL, CHUG ASYMMETRIC

FIGURE B.2-80



Acceleration Spectra for REACTOR BLDG., CONTROL STRUCTURE

Load Case: ASYMMETRIC CHUGGING GE 700 SERIES ENVELOPE (WIDENED - 15%)

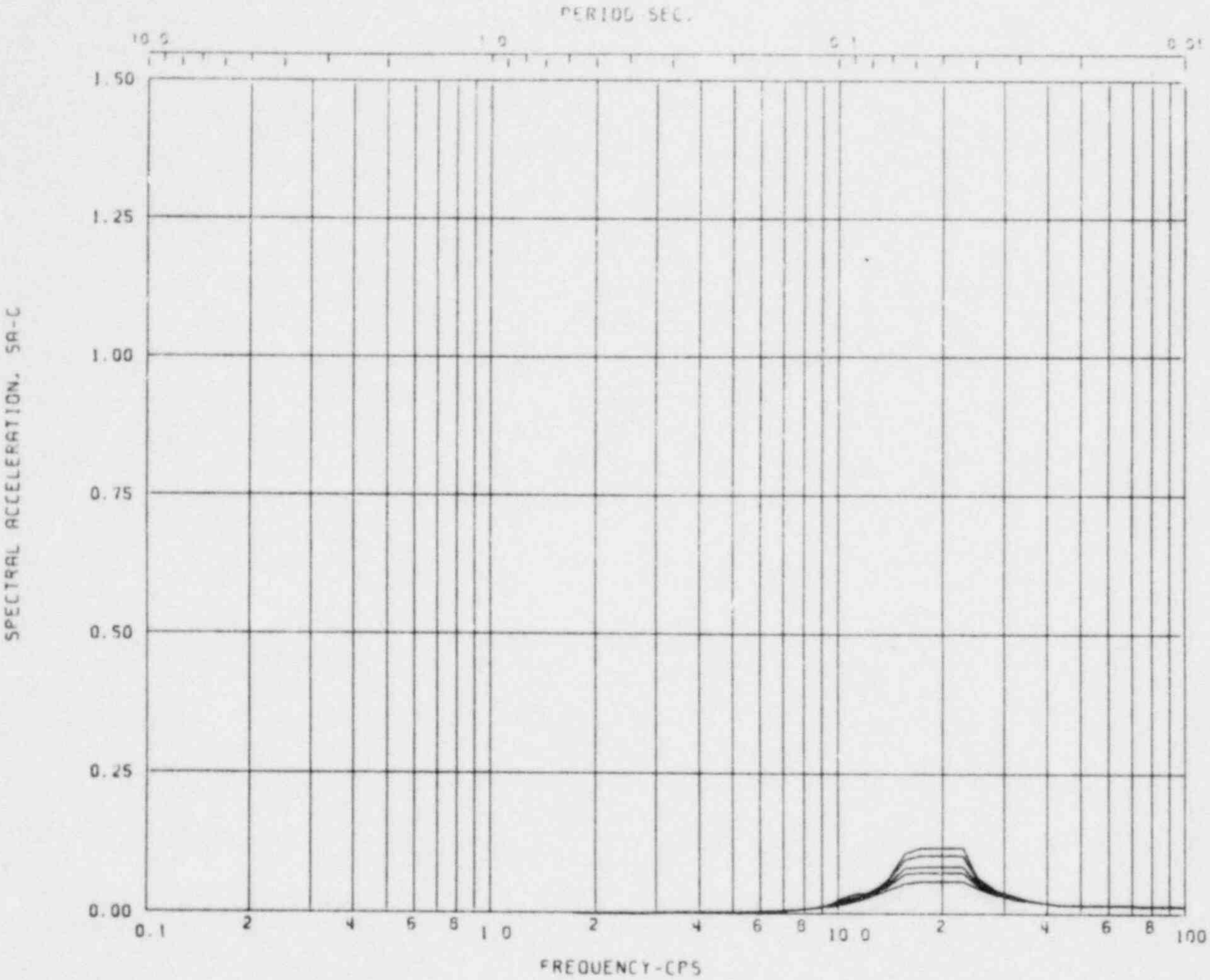
Node: 11 Direction: HORIZ N-S Elev: 352'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND CONTROL STRUCTURE GLOBAL RESPONSE SPECTRA, E-W HORIZONTAL, CHUG ASYMMETRIC

FIGURE B.2-81



Acceleration Spectra for REACTOR BLDG., CONTROL STRUCTURE

Load Case: ASYMMETRIC CHUGGING GE 700 SERIES ENVELOPE (WIDENED - 15%)

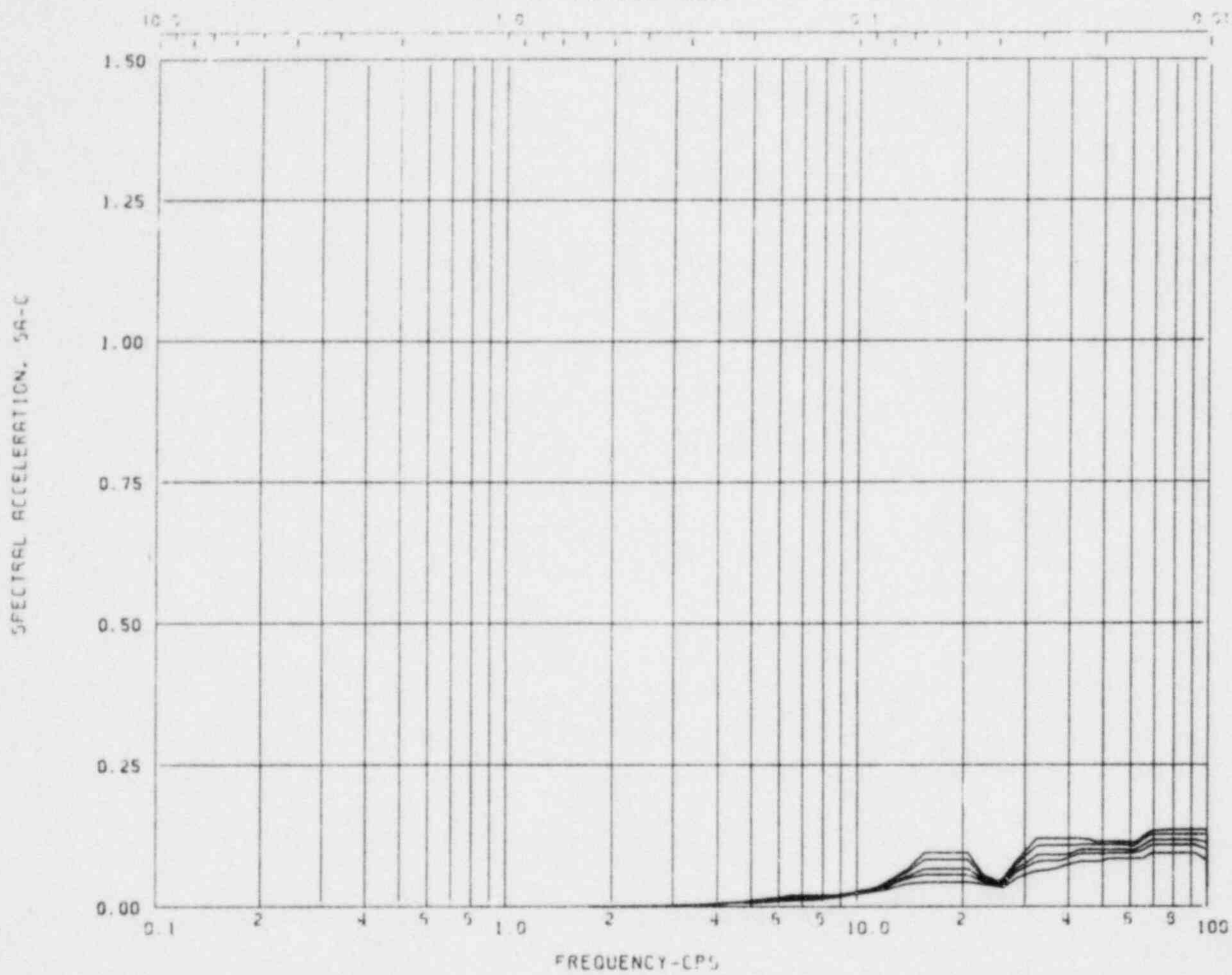
Node: 12 Direction: HORIZ N-S Elev: 410'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING AND CONTROL STRUCTURE GLOBAL RESPONSE SPECTRA, E-W HORIZONTAL, CHUG ASYMMETRIC

FIGURE B.2-82



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC CHUGGING GE700 SERIES ENVELOPE (WIDENED - 15%)

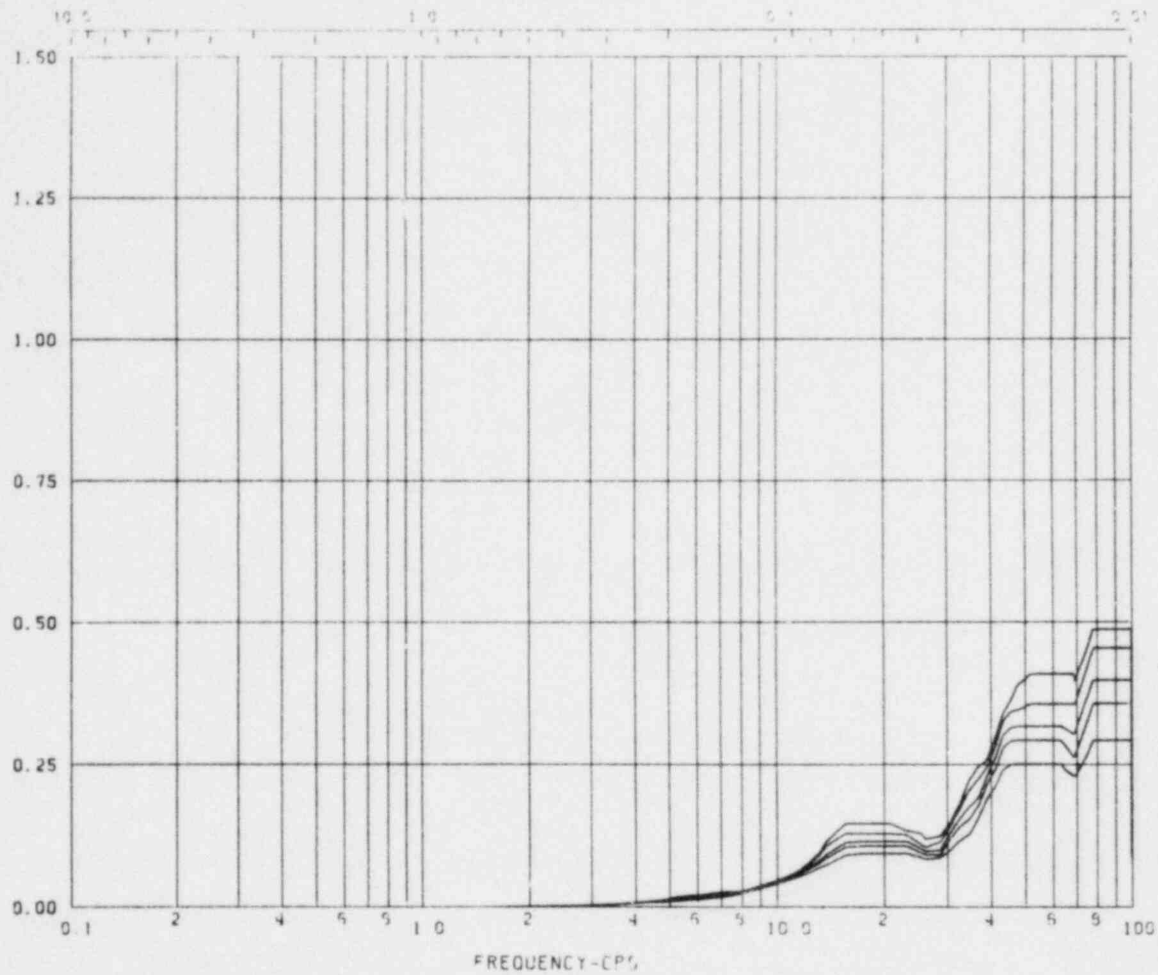
Node: 159 Direction: VERTICAL Elev: 177'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL RESPONSE SPECTRA, VERTICAL, CHUG AXISYMMETRIC

FIGURE B.2-83



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC CHUGGING GE700 SERIES ENVELOPE (WIDENED - 15%)

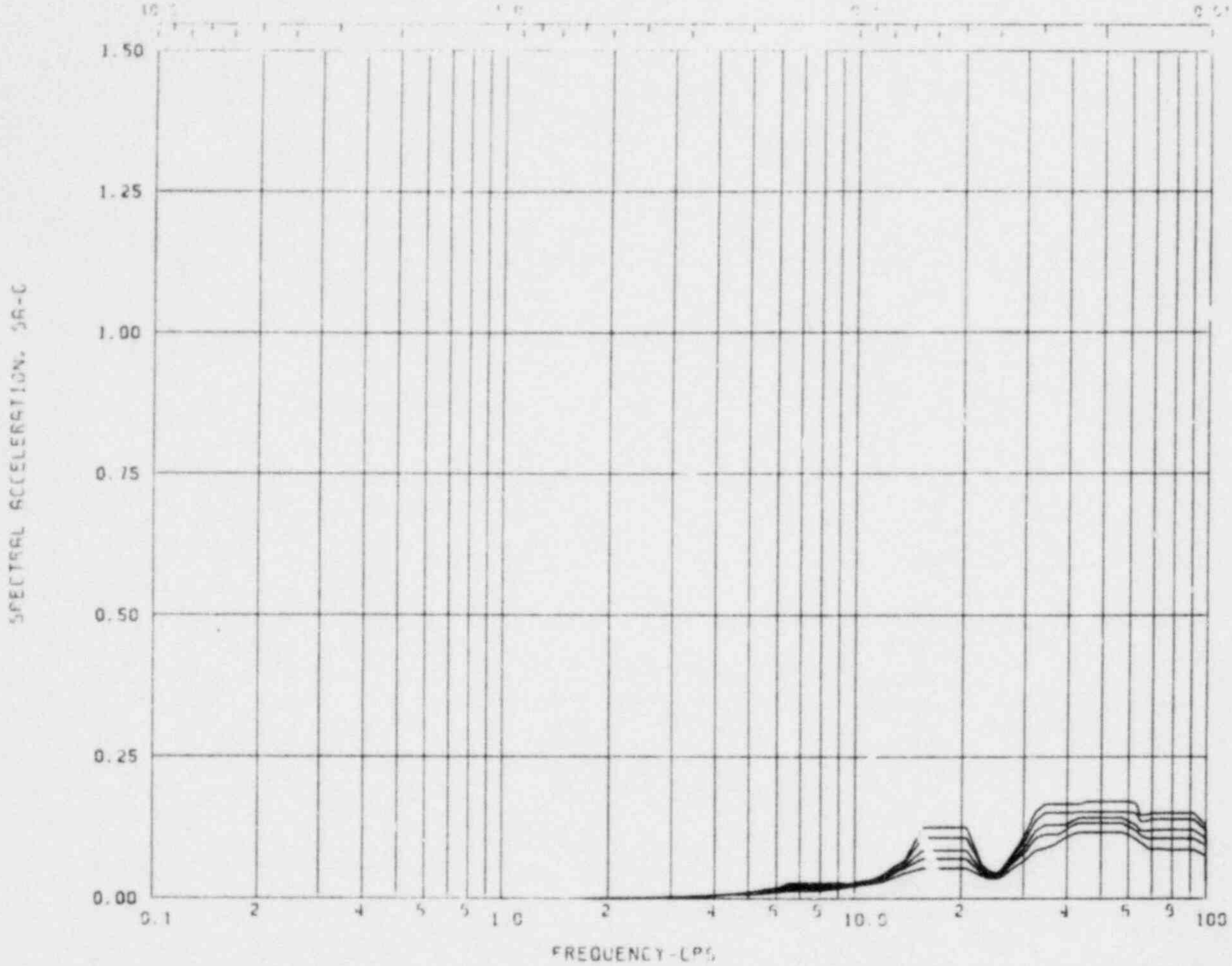
Node: 154 Direction: VERTICAL Elev: 177'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL RESPONSE SPECTRA, VERTICAL, CHUG AXISYMMETRIC

FIGURE B.2-84



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC CHUGGING GE700 SERIES ENVELOPE (WIDENED - 15%)

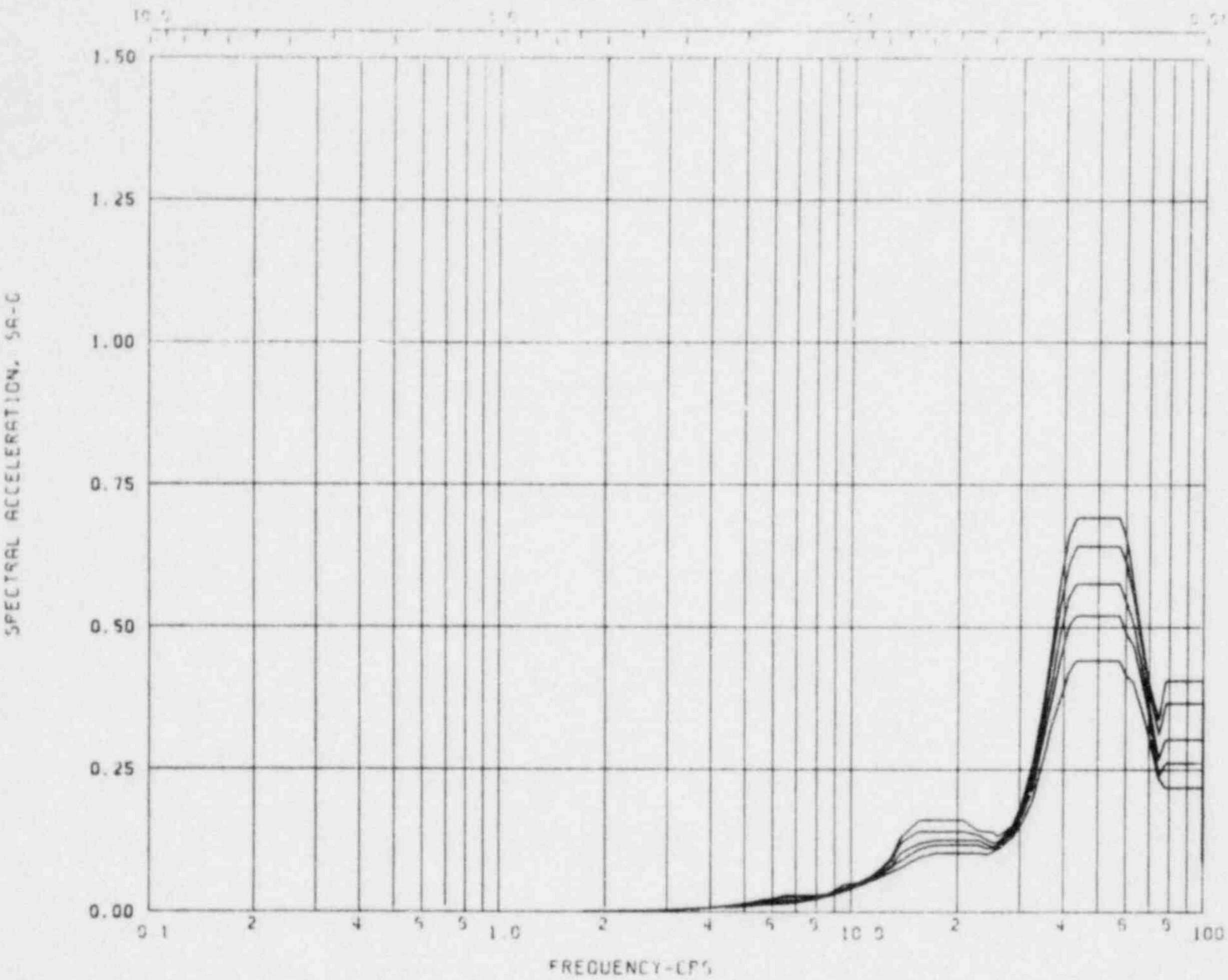
Node: 128 Direction: VERTICAL Elev: 201'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL
RESPONSE SPECTRA, VERTICAL,
CHUG AXISYMMETRIC

FIGURE B.2-85



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC CHUGGING GE700 S[illegible] IFS ENVELOPE (WIDENED - 15%)

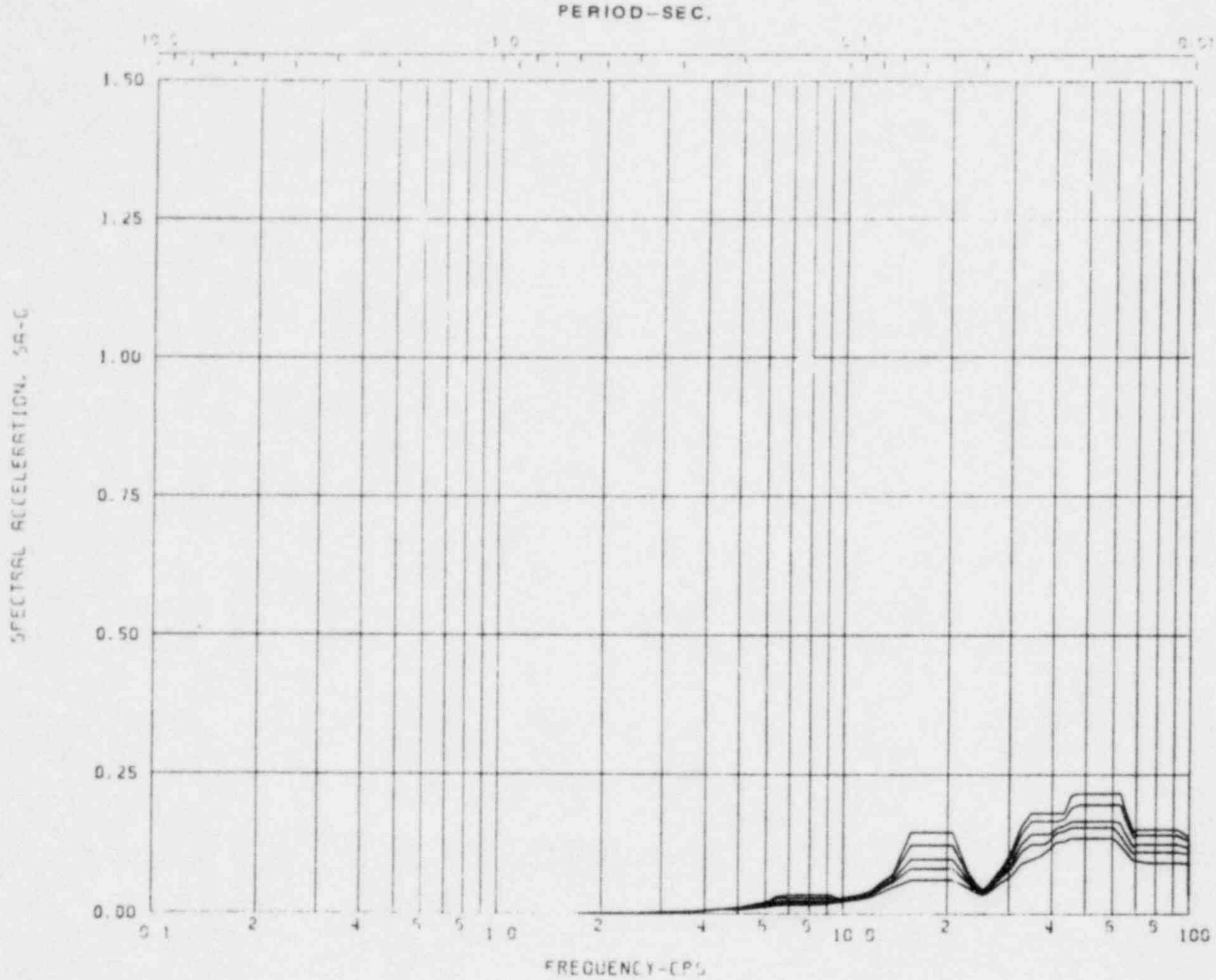
Node: 130 Direction: VERTICAL Elev: 201'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL RESPONSE SPECTRA, VERTICAL, CHUG AXISYMMETRIC

FIGURE B.2-86



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC CHUGGING GE700 SERIES ENVELOPE (WIDENED - 15%)

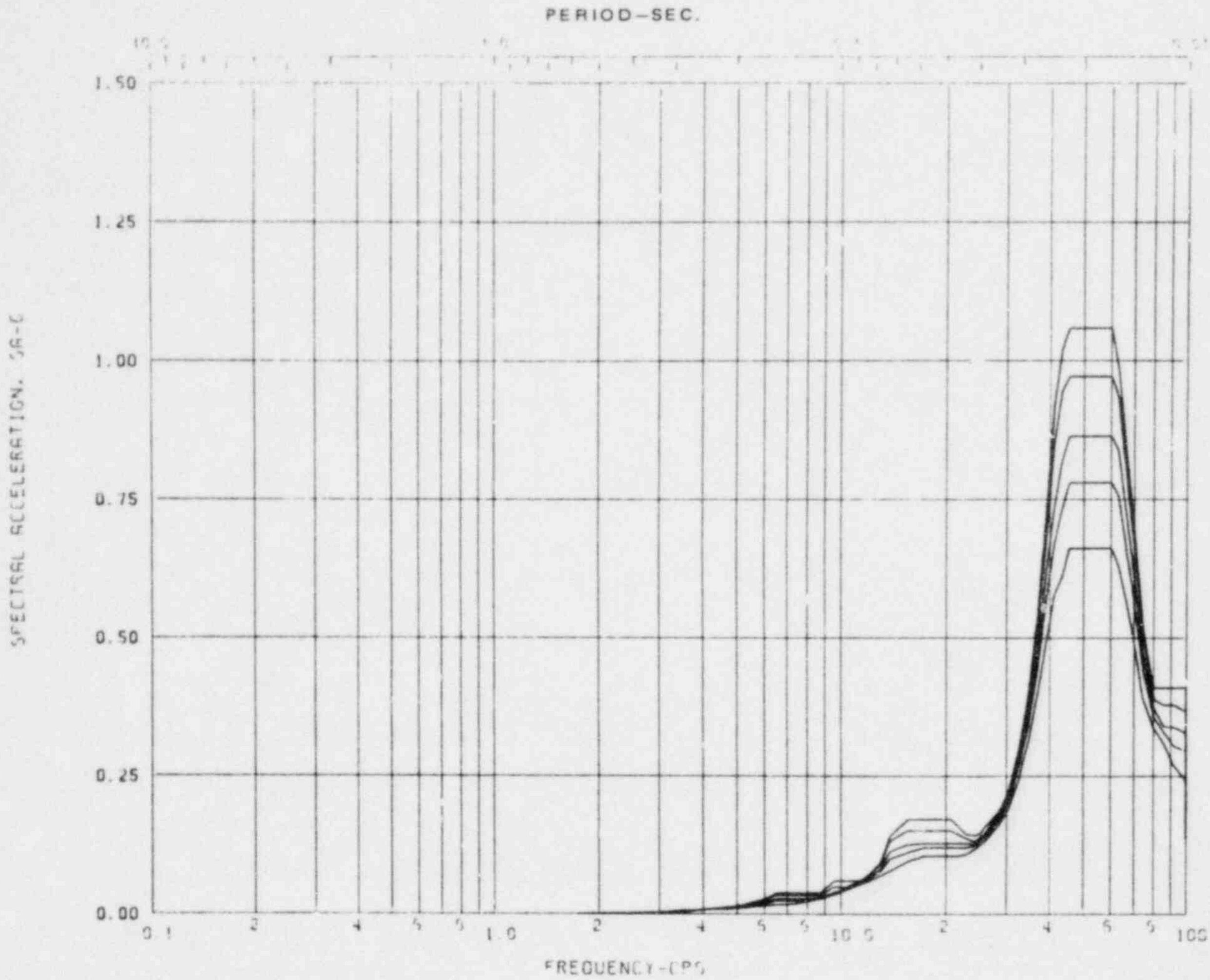
Node: 106 Direction: VERTICAL Elev: 217'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL RESPONSE SPECTRA, VERTICAL, CHUG AXISYMMETRIC

FIGURE B.2-87



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC CHUGGING GE700 SERIES ENVELOPE (WIDENED - 15%)

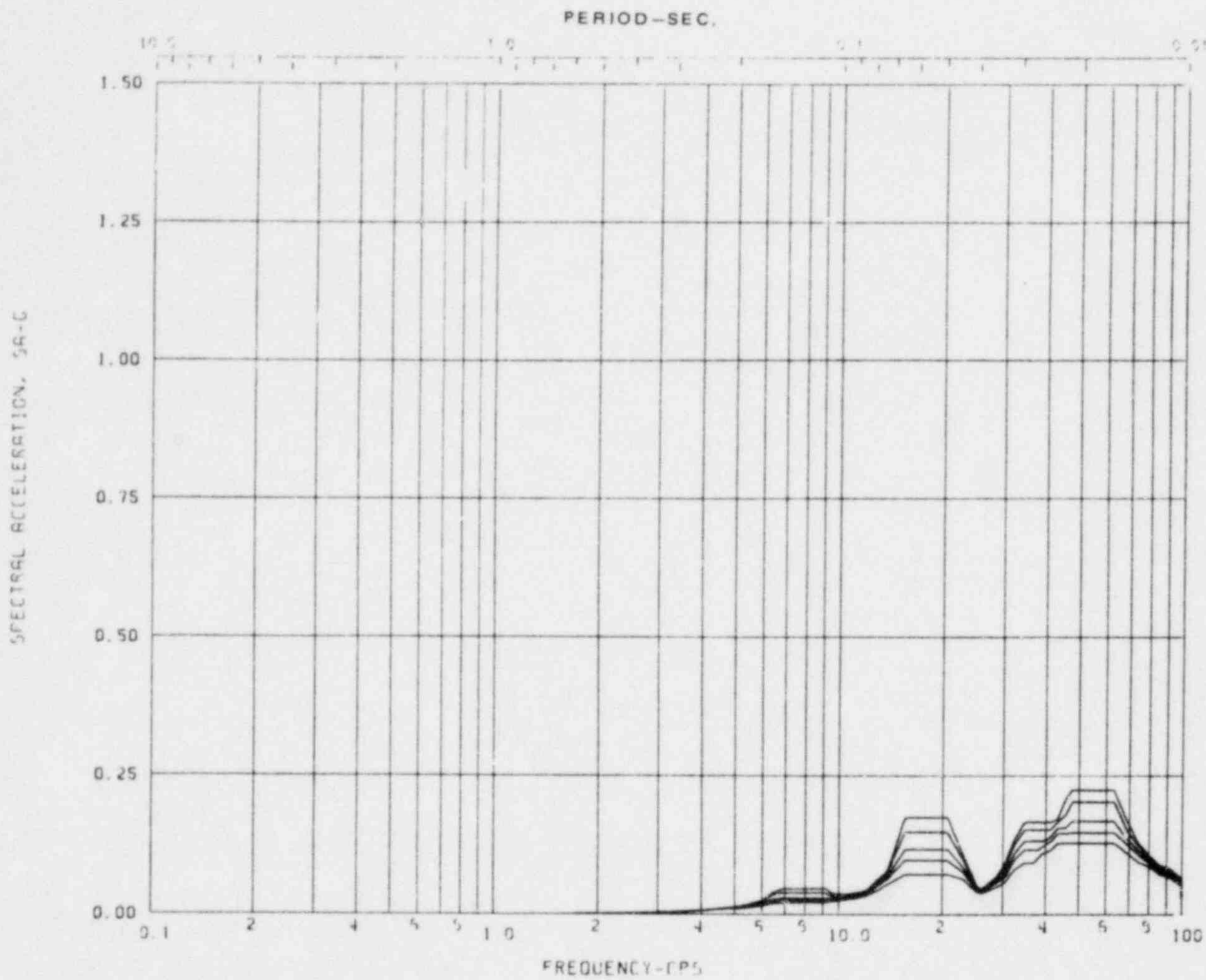
Node: 108 Direction: VERTICAL Elev: 217'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL RESPONSE SPECTRA, VERTICAL, CHUG AXISYMMETRIC

FIGURE B.2-88



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC CHUGGING GE700 SERIES ENVELOPE (WIDENED - 15%)

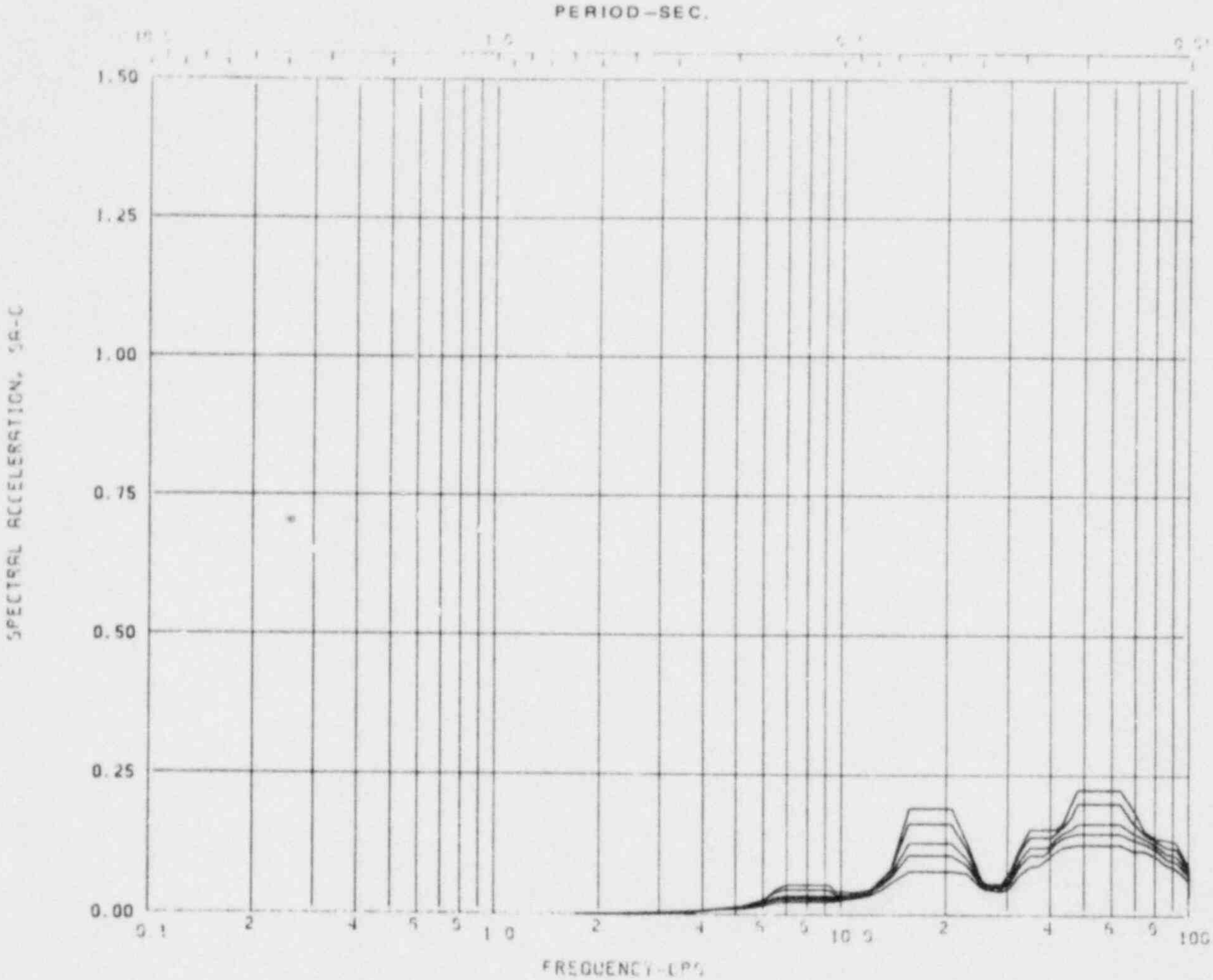
Node: 104 Direction: VERTICAL Elev: 239'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL
RESPONSE SPECTRA, VERTICAL,
CHUG AXISYMMETRIC

FIGURE B.2-89



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC CHUGGING GE700 SERIES ENVELOPE (WIDENED - 15%)

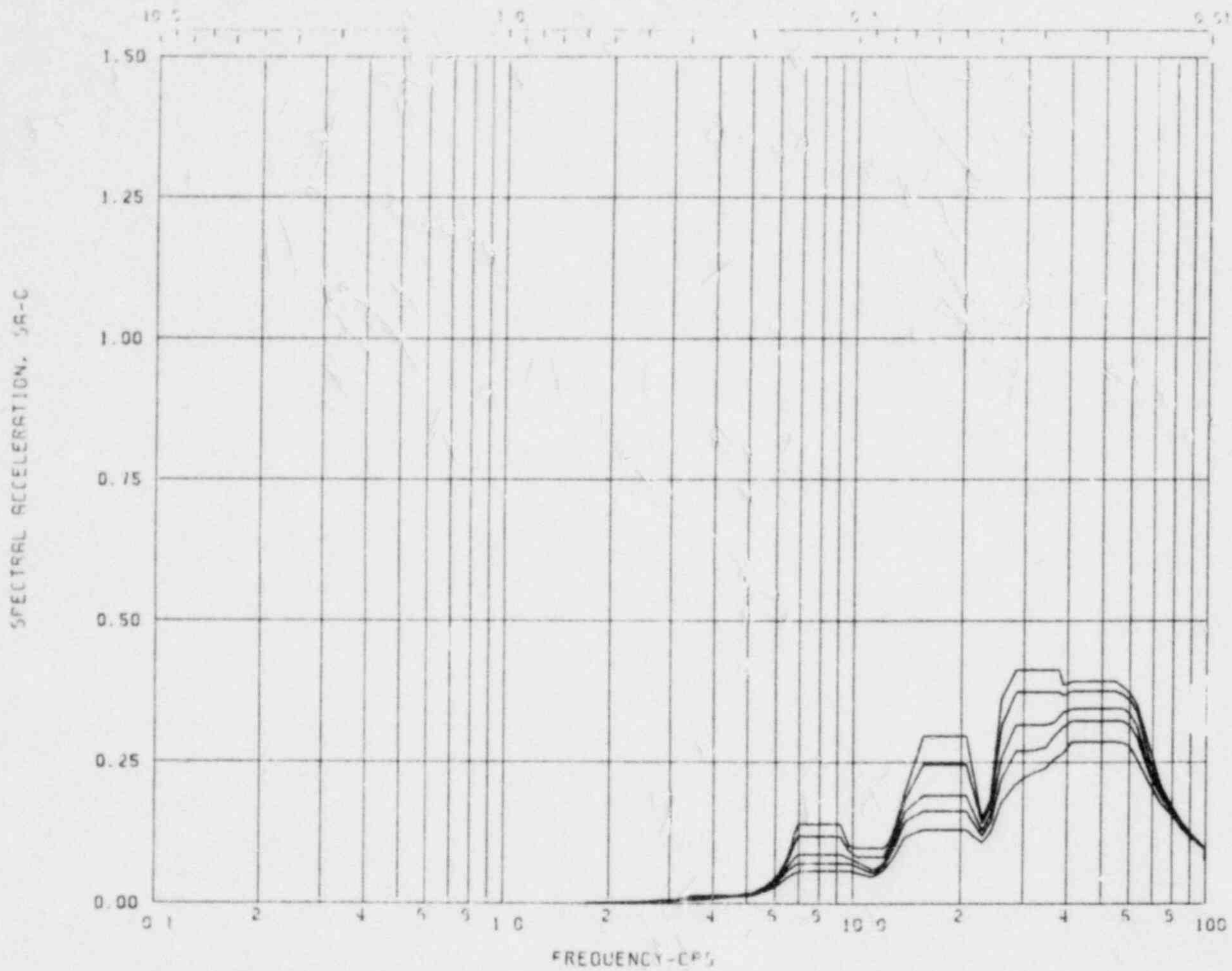
Node: 79 Direction: VERTICAL Elev: 253'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL RESPONSE SPECTRA, VERTICAL, CHUG AXISYMMETRIC

FIGURE B.2-90



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC CHUGGING GE700 SERIES ENVELOPE (WIDENED - 15%)

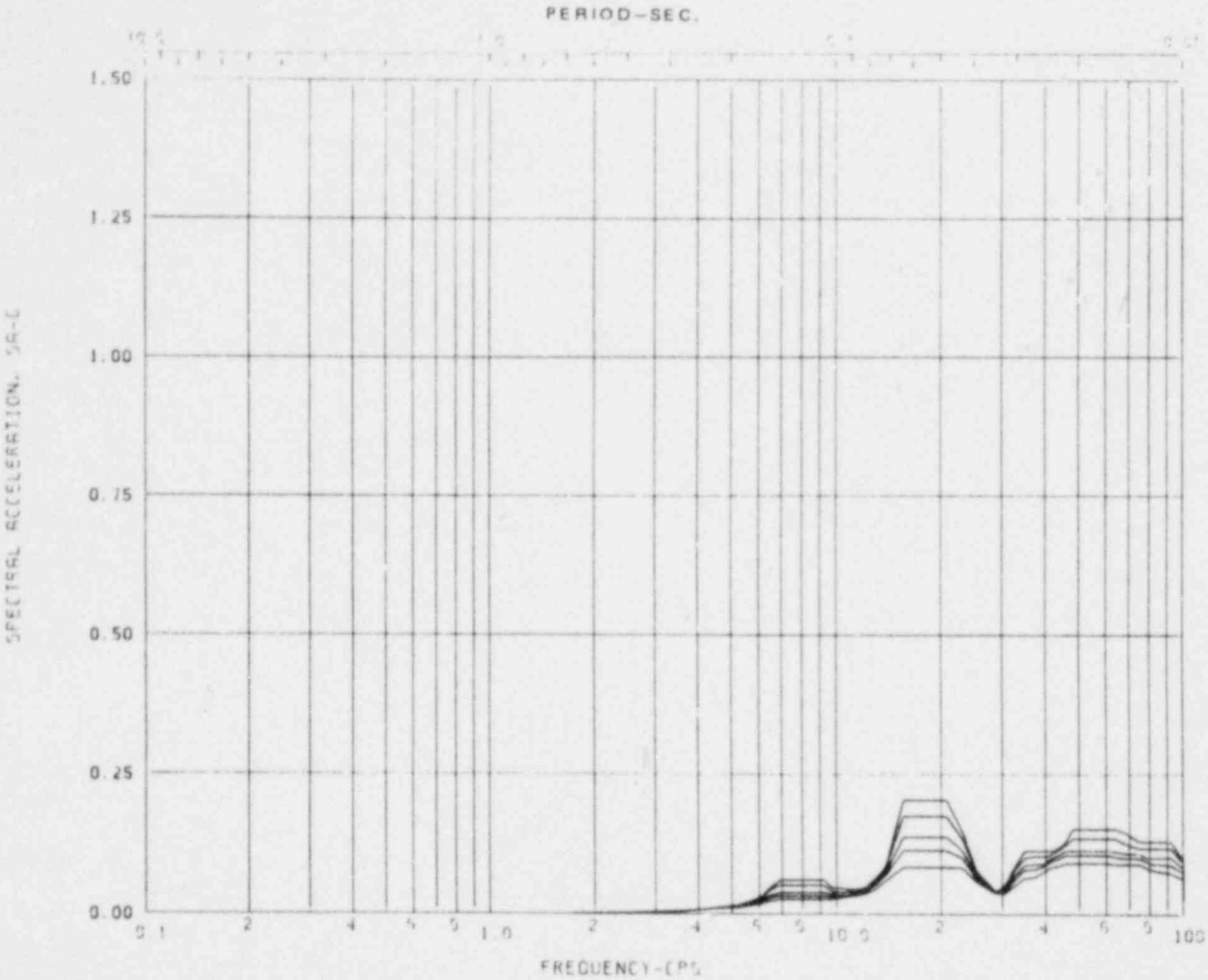
Node: 81 Direction: VERTICAL Elev: 253'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL RESPONSE SPECTRA, VERTICAL, CHUG AXISYMMETRIC

FIGURE B.2-91



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC CHUGGING GE700 SERIES ENVELOPE (WIDENED - 15%)

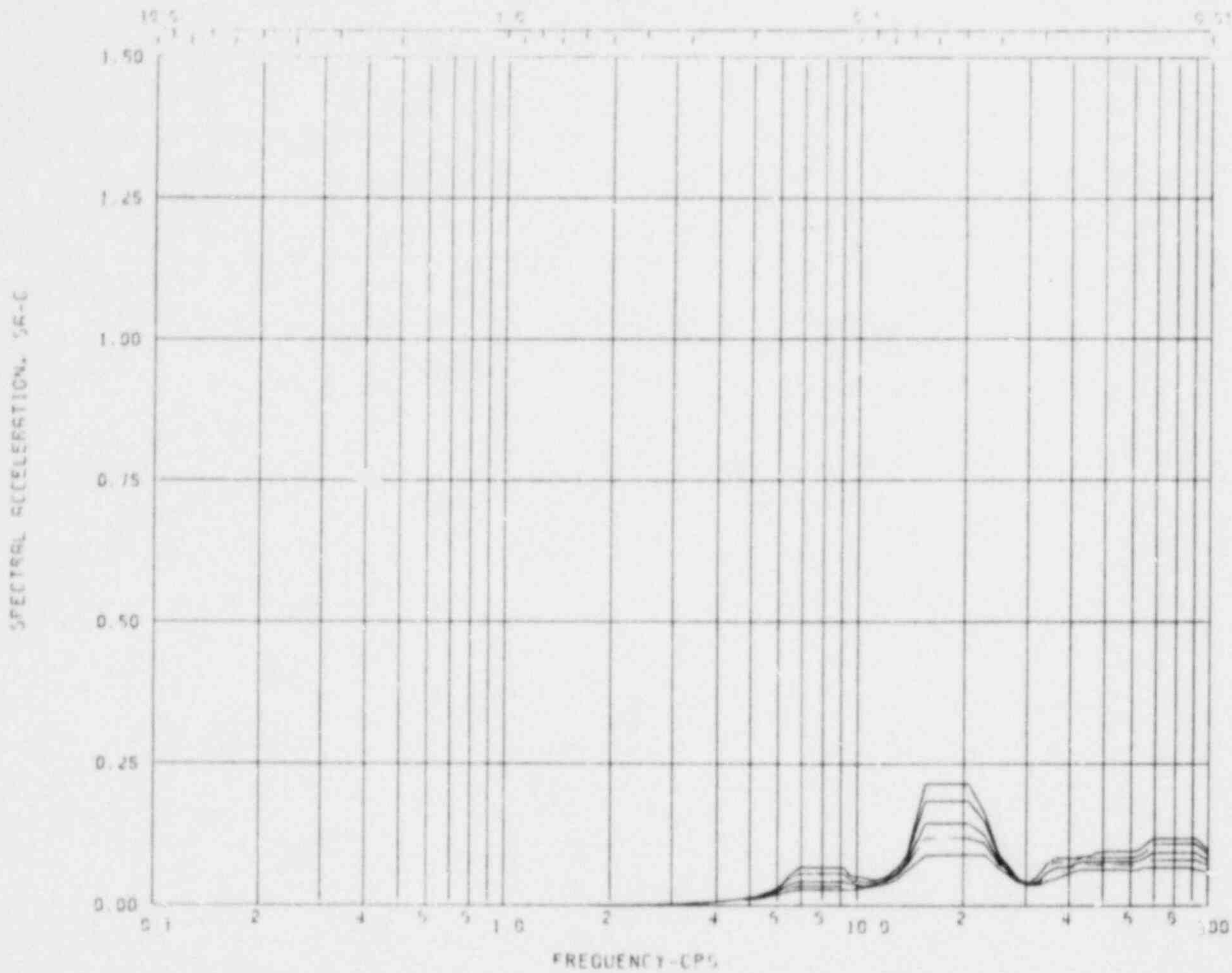
Node: 77 Direction: VERTICAL Elev: 269'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL RESPONSE SPECTRA, VERTICAL, CHUG AXISYMMETRIC

FIGURE B.2-92



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC CHUGGING GE700 SERIES ENVELOPE (WIDENED - 15%)

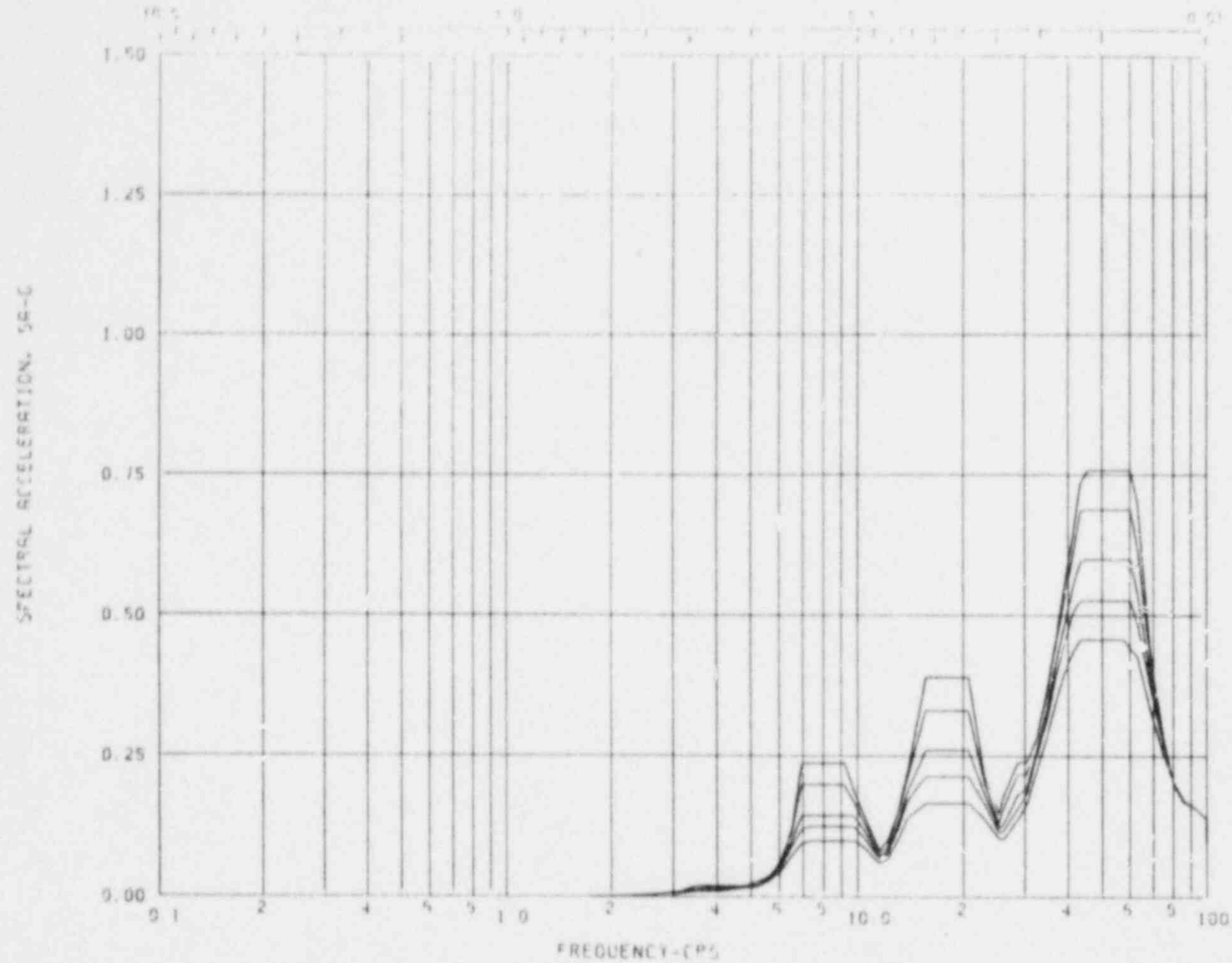
Node: 58 Direction: VERTICAL Elev: 283'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL RESPONSE SPECTRA, VERTICAL, CHUG AXISYMMETRIC

FIGURE B.2-93



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC CHUGGING GE700 SERIES ENVELOPE (WIDENED - 15%)

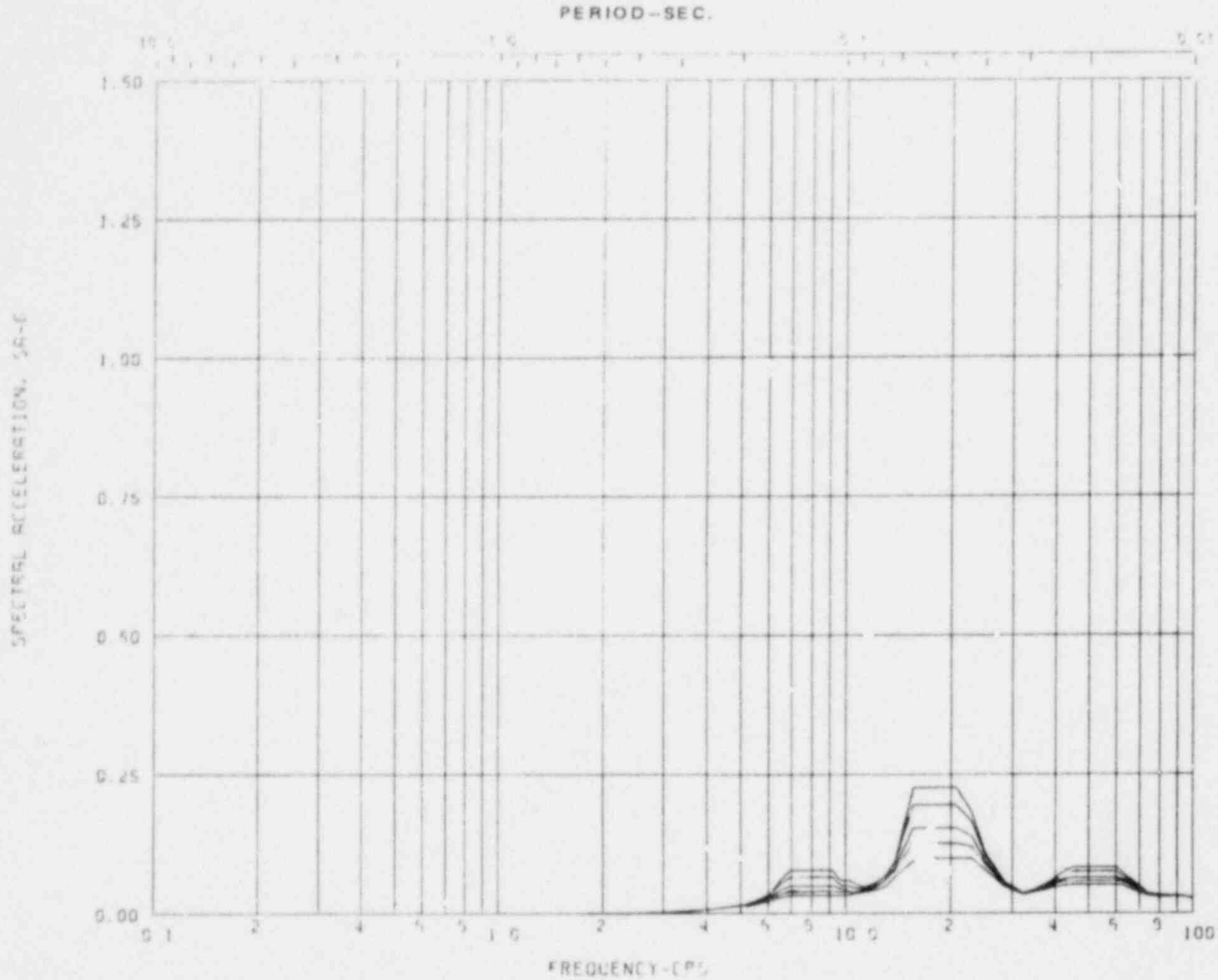
Node: 60 Direction: VERTICAL Elev: 283'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL
RESPONSE SPECTRA, VERTICAL,
CHUG AXISYMMETRIC

FIGURE B.2-94



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC CHUGGING GE700 SERIES ENVELOPE (WIDENED - 15%)

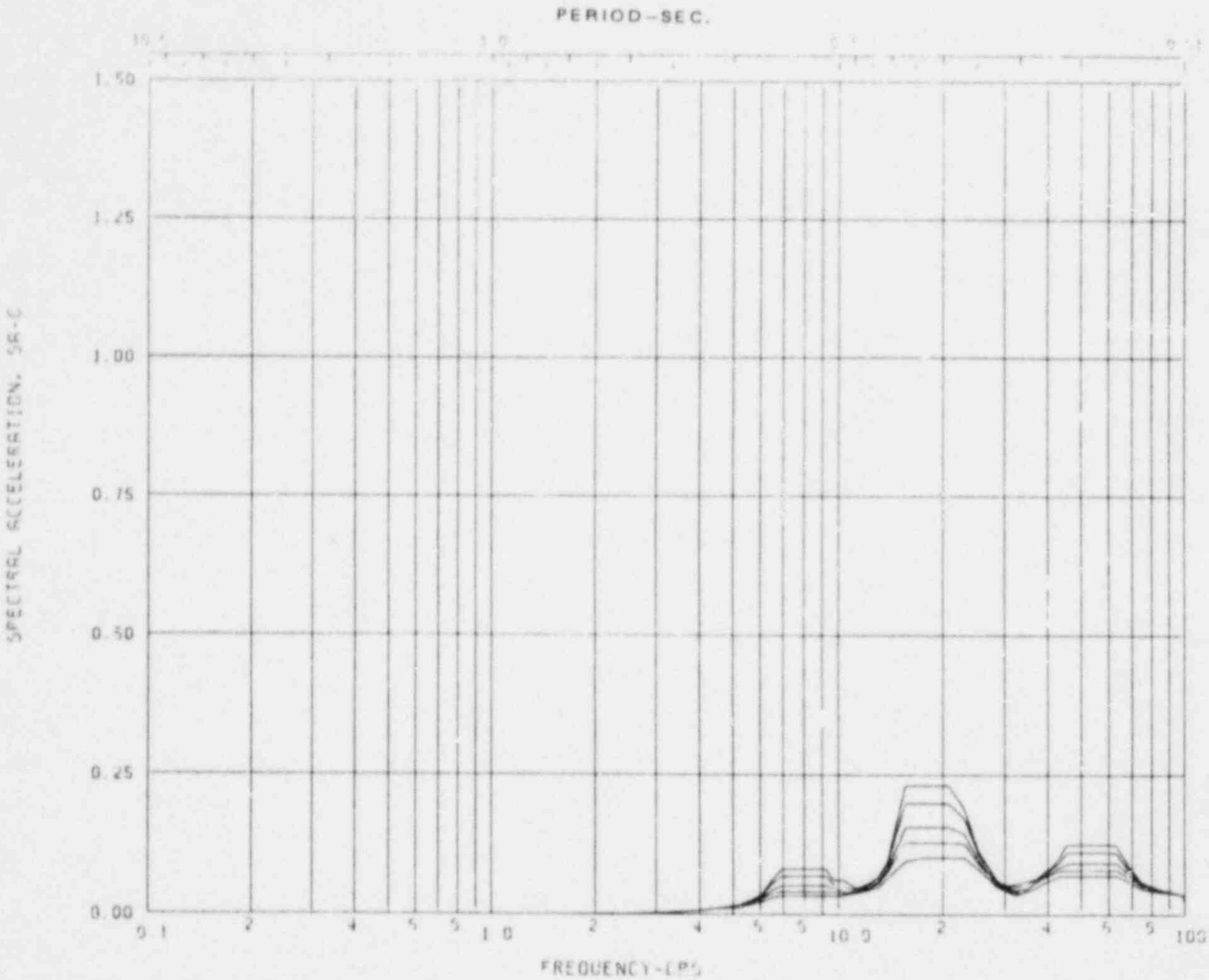
Node: 56 Direction: VERTICAL Elev: 304'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL RESPONSE SPECTRA, VERTICAL, CHUG AXISYMMETRIC

FIGURE B.2-95



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC CHUGGING GE700 SERIES ENVELOPE (WIDENED - 15%)

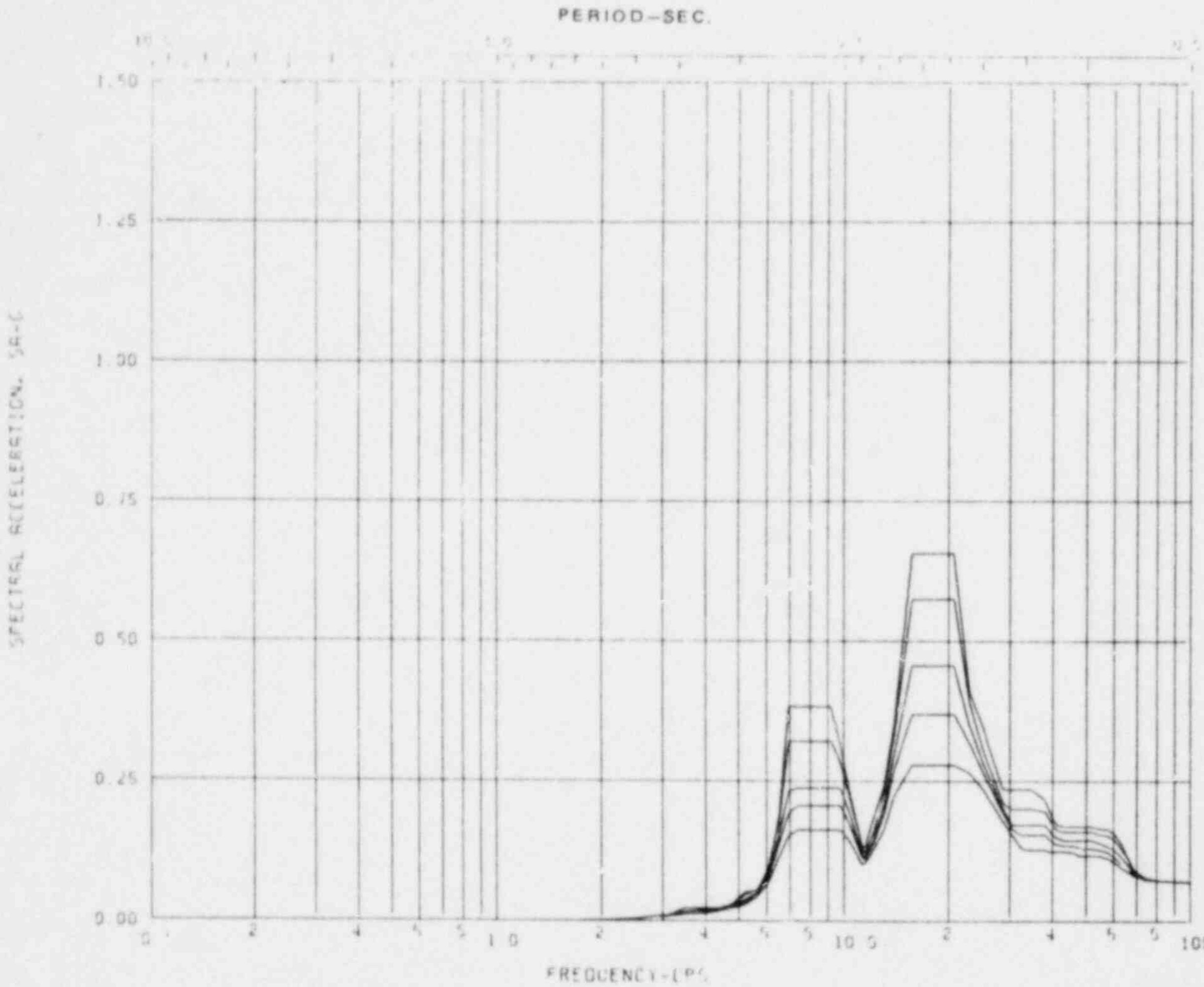
Node: 35 Direction: VERTICAL Elev: 313'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL RESPONSE SPECTRA, VERTICAL, CHUG AXISYMMETRIC

FIGURE B.2-9C



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC CHUGGING GE700 SERIES ENVELOPE (WIDENED - 15%)

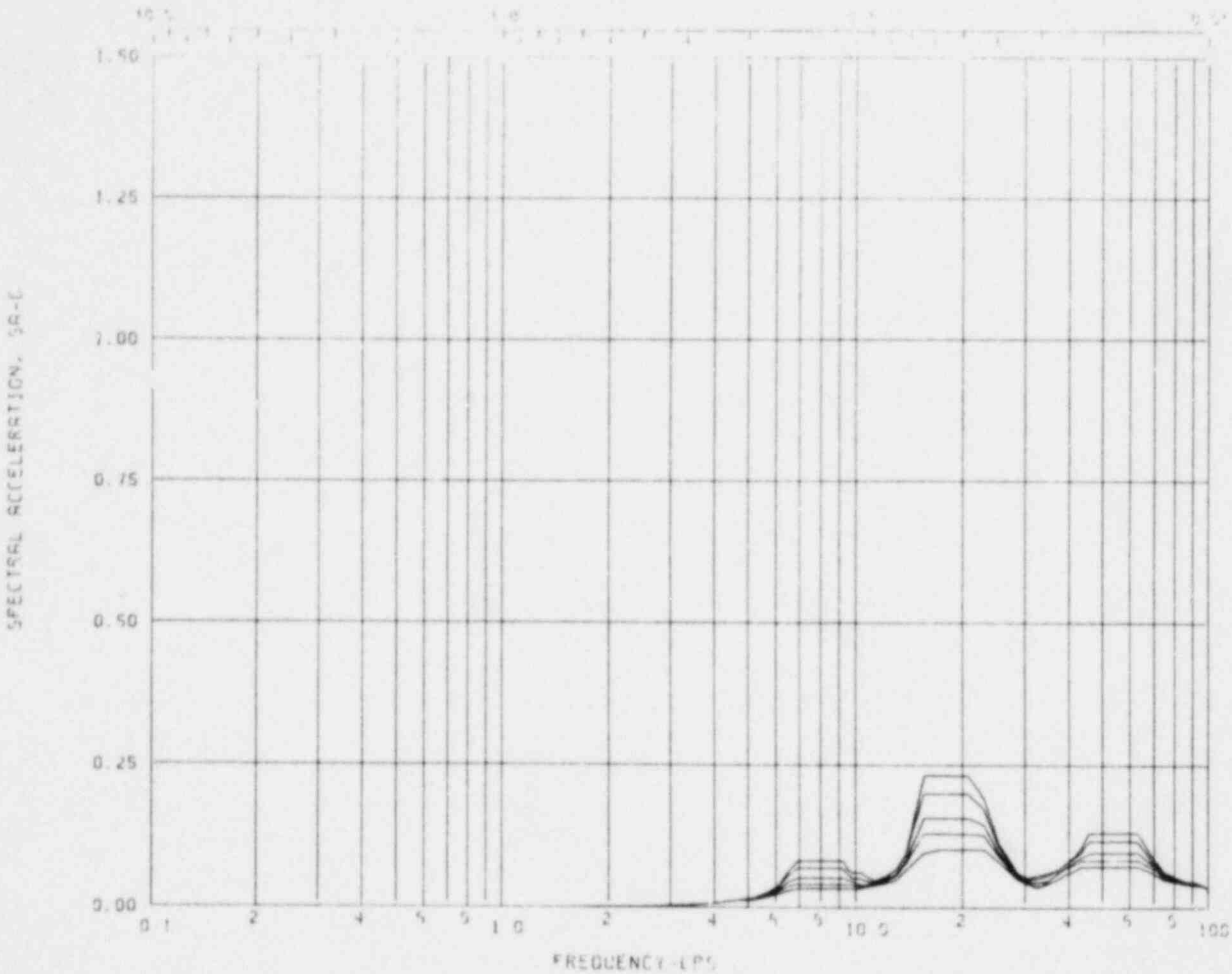
Node: 43 Direction: VERTICAL Elev: 313'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL RESPONSE SPECTRA, VERTICAL, CHUG AXISYMMETRIC

FIGURE B.2-97



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC CHUGGING GE700 SERIES ENVELOPE (WIDENED - 15%)

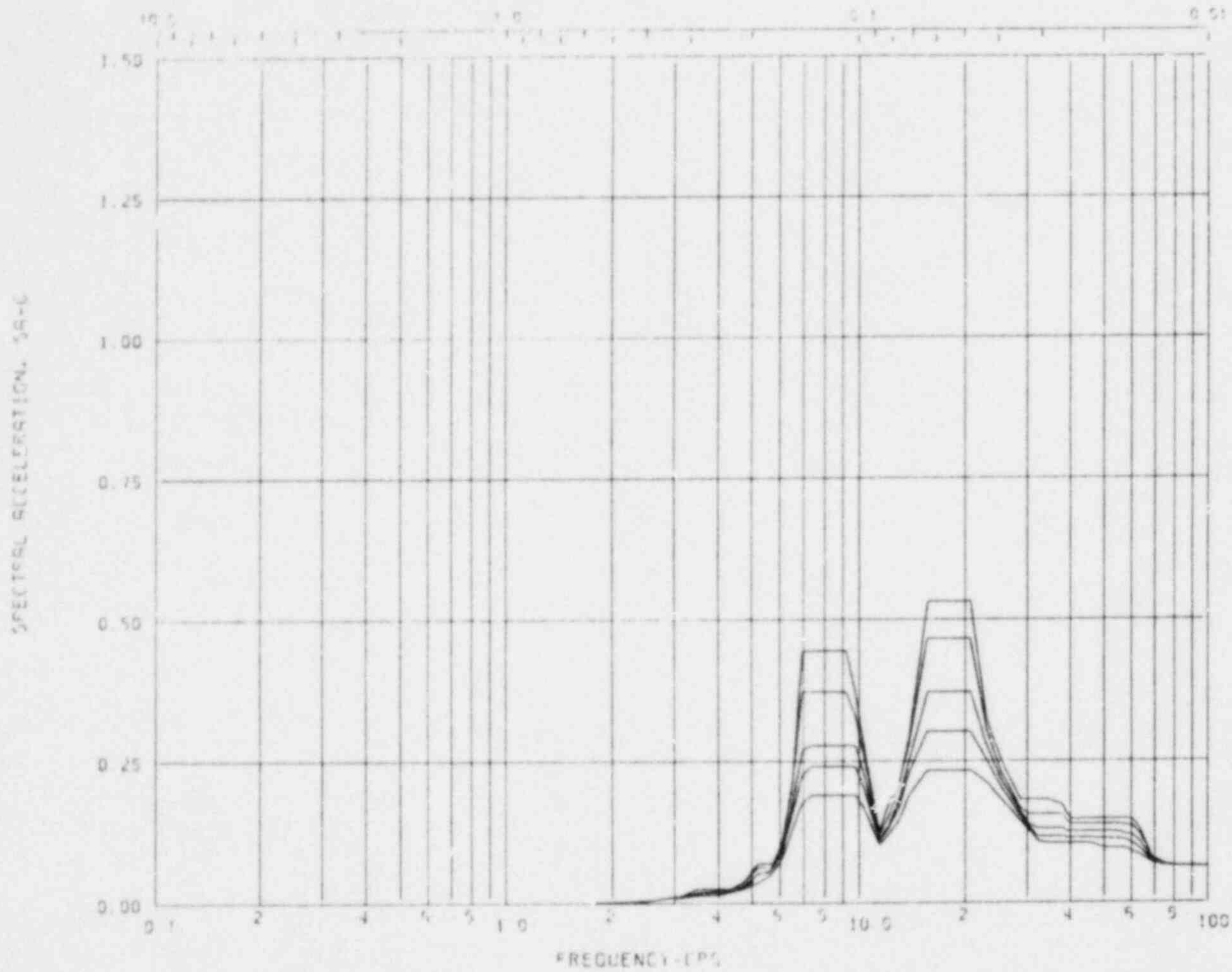
Node: 21 Direction: VERTICAL Elev: 333'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL RESPONSE SPECTRA, VERTICAL, CHUG AXISYMMETRIC

FIGURE B.2-98



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC CHUGGING GE700 SERIES ENVELOPE (WIDENED - 15%)

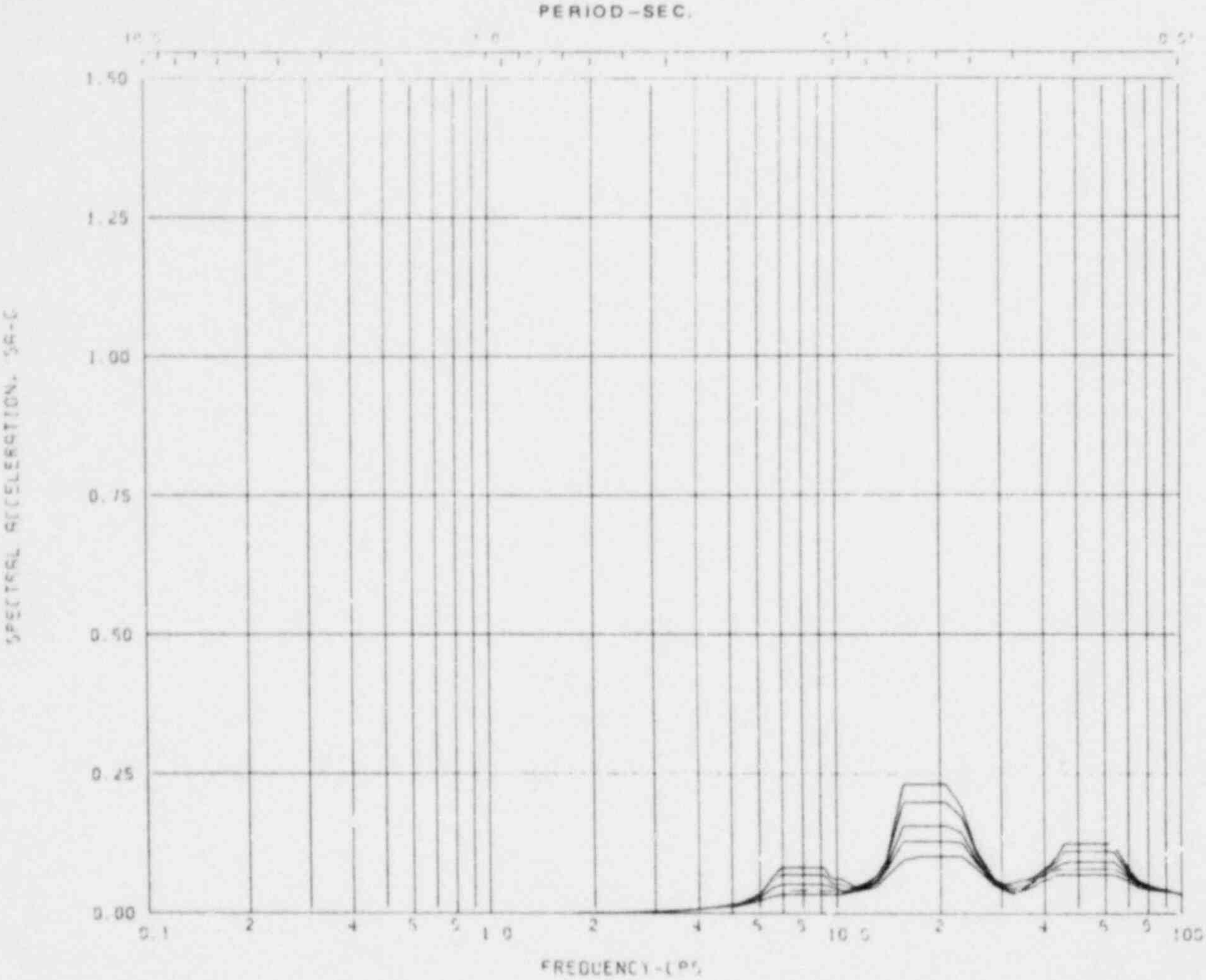
Node: 33 Direction: VERTICAL Elev: 333'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL RESPONSE SPECTRA, VERTICAL, CHUG AXISYMMETRIC

FIGURE B.2-99



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC CHUGGING GE700 SERIES ENVELOPE (WIDENED - 15%)

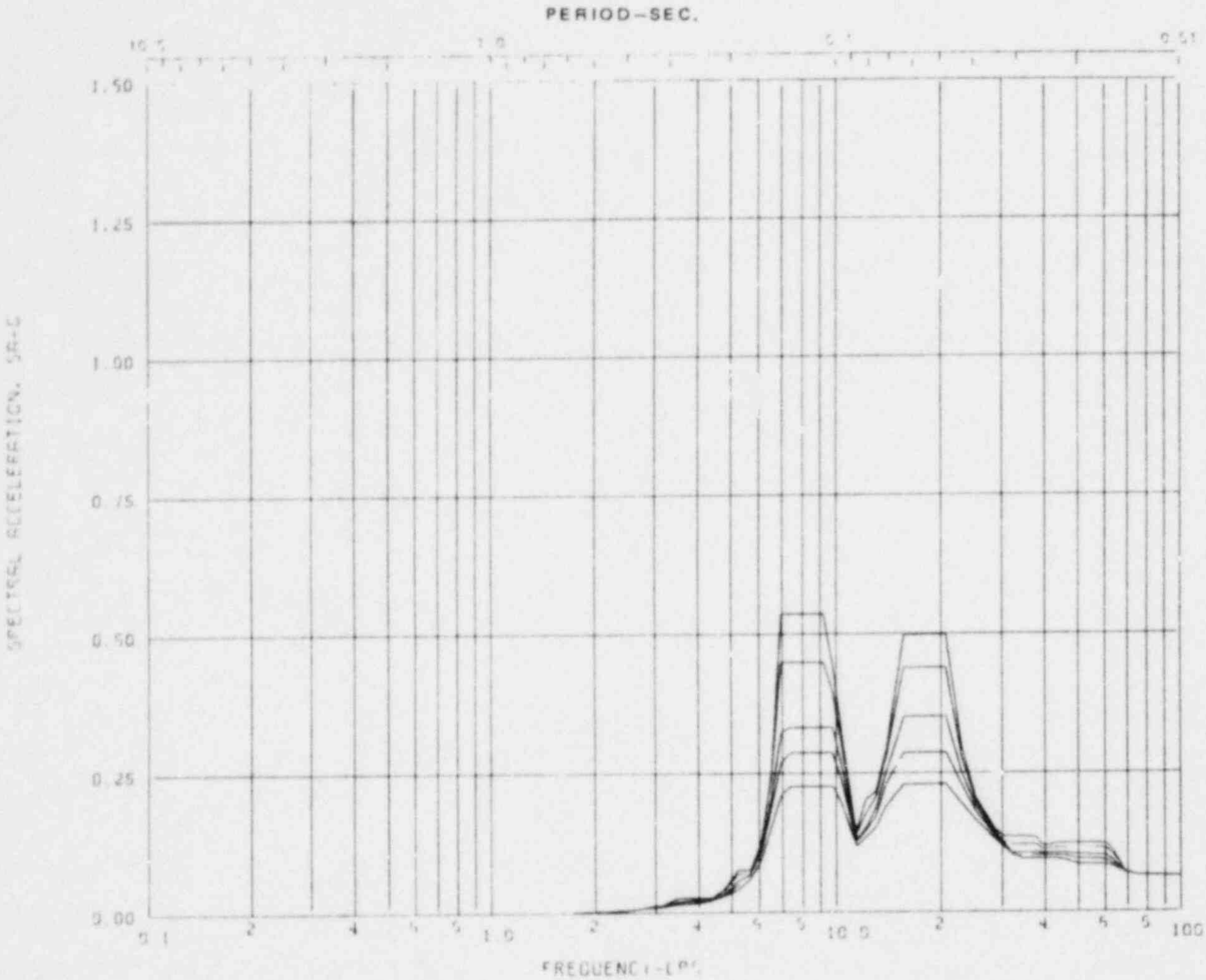
Node: 9 Direction: VERTICAL Elev: 352'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL RESPONSE SPECTRA, VERTICAL, CHUG AXISYMMETRIC

FIGURE B.2-100



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC CHUGGING GE700 SERIES ENVELOPE (WIDENED - 15%)

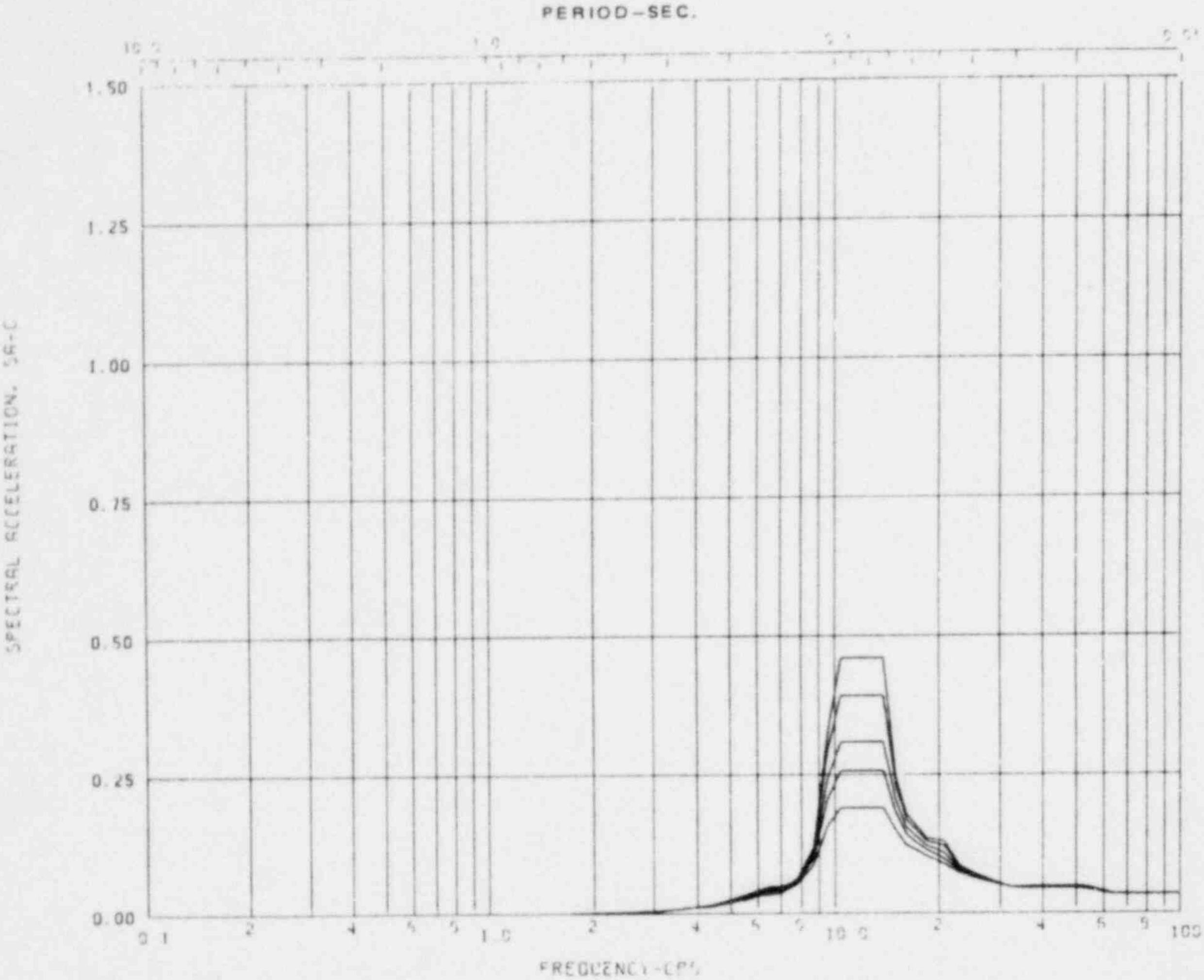
Node: 13 Direction: VERTICAL Elev: 352'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL RESPONSE SPECTRA, VERTICAL, CHUG AXISYMMETRIC

FIGURE B.2-101



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC CHUGGING GE700 SERIES ENVELOPE (WIDENED - 15%)

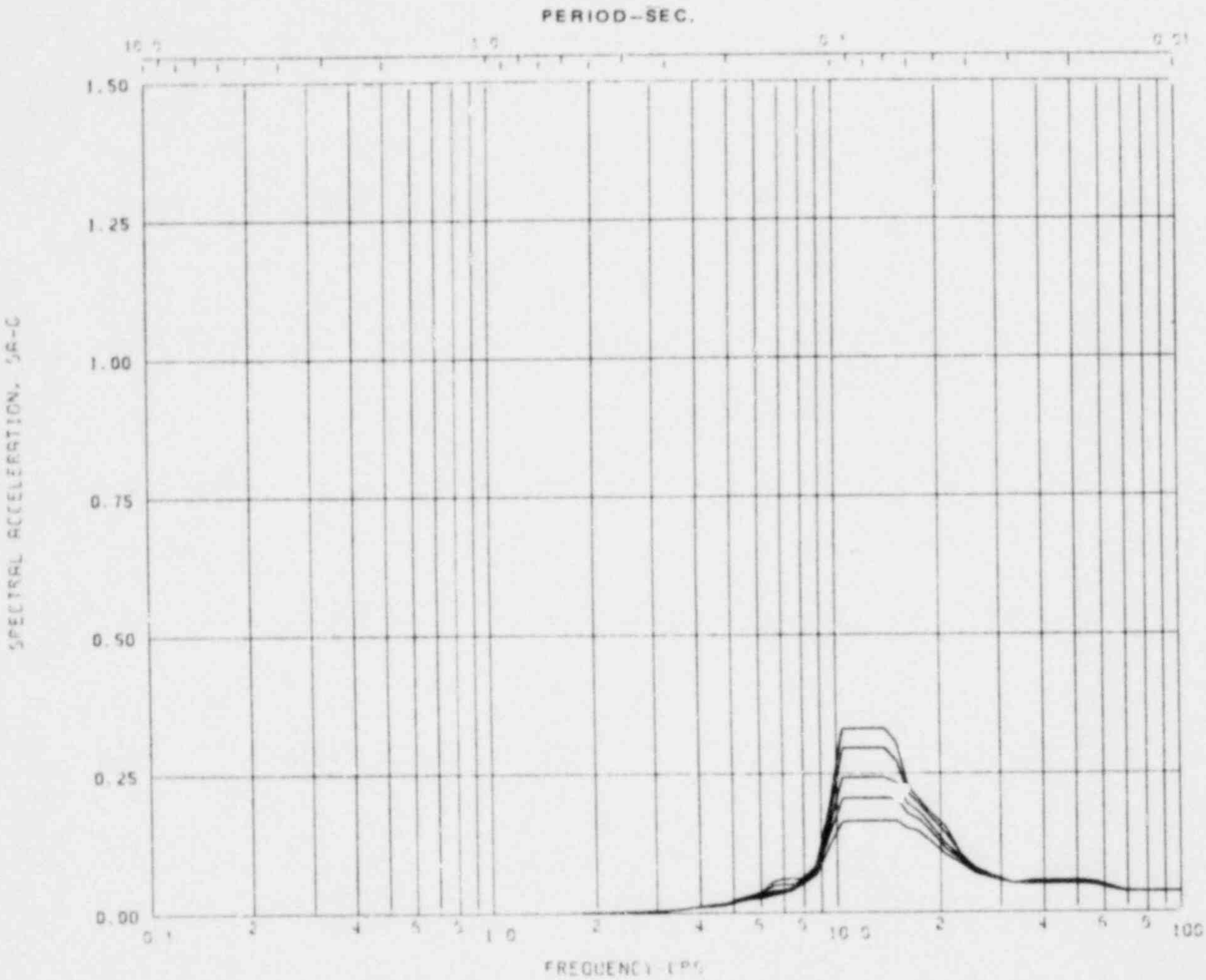
Node: 129 Direction: VERTICAL Elev: 2[illegible]

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL
RESPONSE SPECTRA, VERTICAL,
CHUG AXISYMMETRIC

FIGURE B.2-102



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC CHUGGING GE700 SERIES ENVELOPE (WIDENED - 15%)

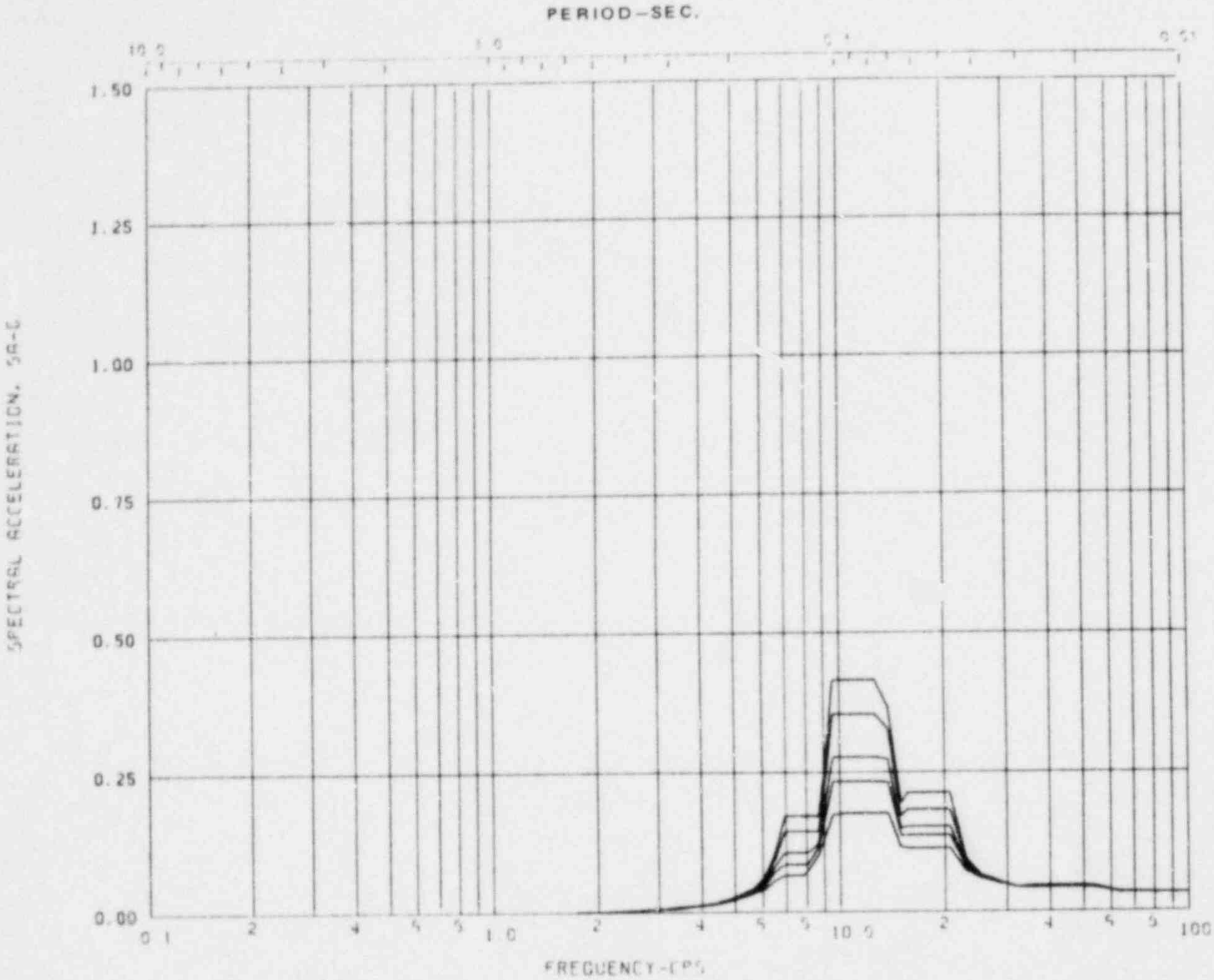
Node: 107 Direction: VERTICAL Elev: 217'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL
RESPONSE SPECTRA, VERTICAL,
CHUG AXISYMMETRIC

FIGURE B.2-103



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC CHUGGING GE700 SERIES ENVELOPE (WIDENED - 15%)

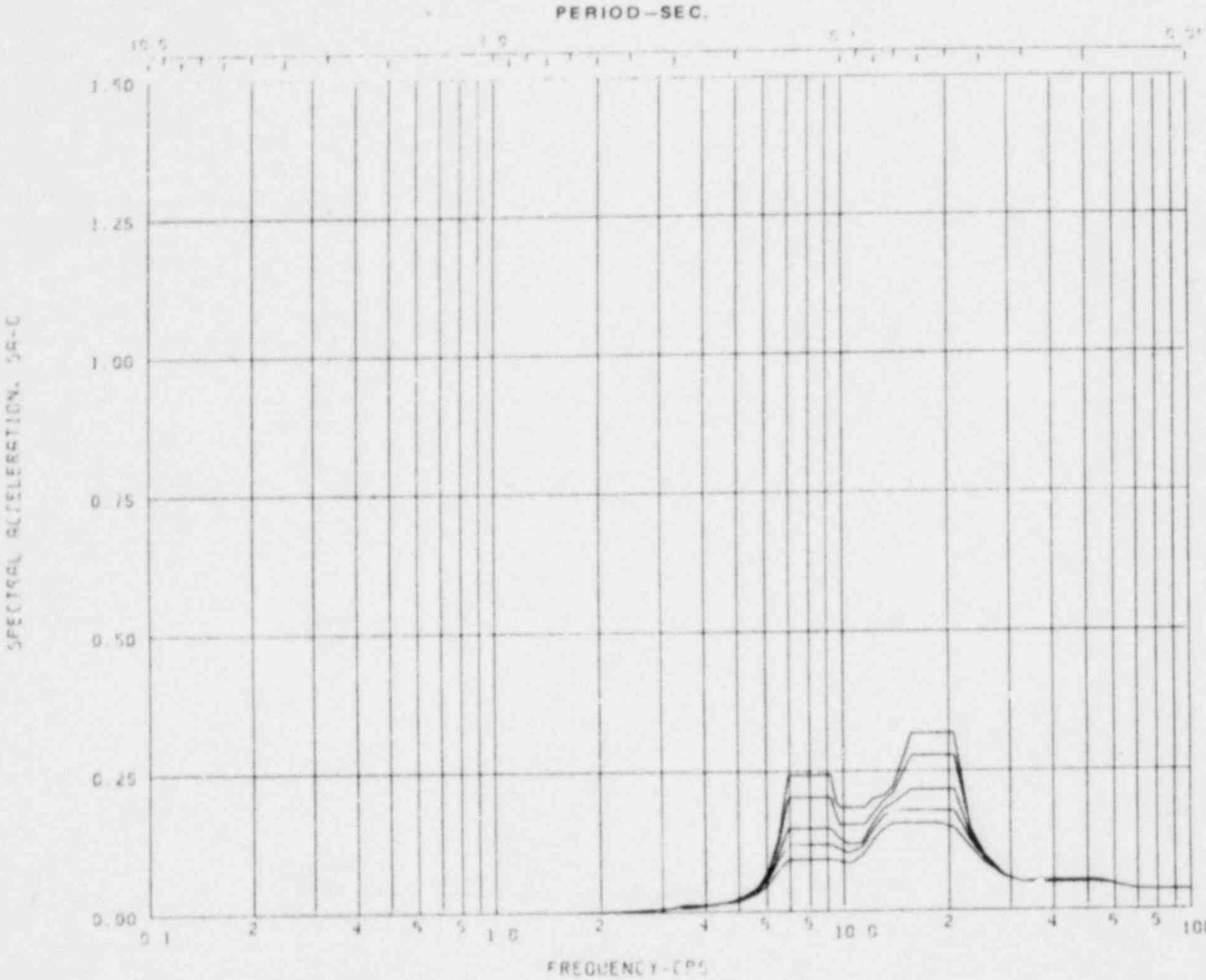
Node: 80 Direction: VERTICAL Elev: 253'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL RESPONSE SPECTRA, VERTICAL, CHUG AXISYMMETRIC

FIGURE B.2-104



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC CHUGGING GE700 SERIES ENVELOPE (WIDENED - 15%)

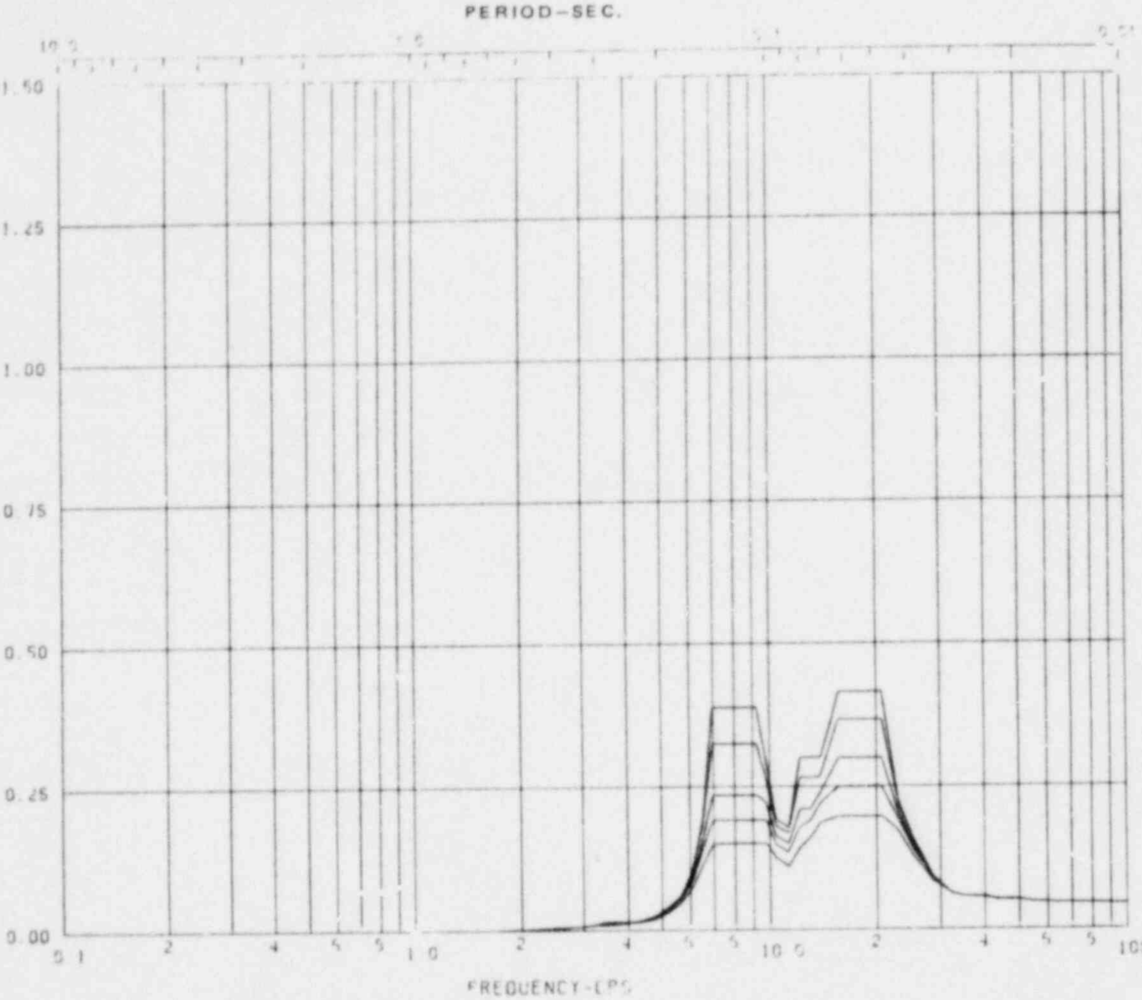
Node: 59 Direction: VERTICAL Elev: 283'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL RESPONSE SPECTRA, VERTICAL, CHUG AXISYMMETRIC

FIGURE B.2-105



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC CHUGGING GE700 SERIES ENVELOPE (WIDENED - 15%)

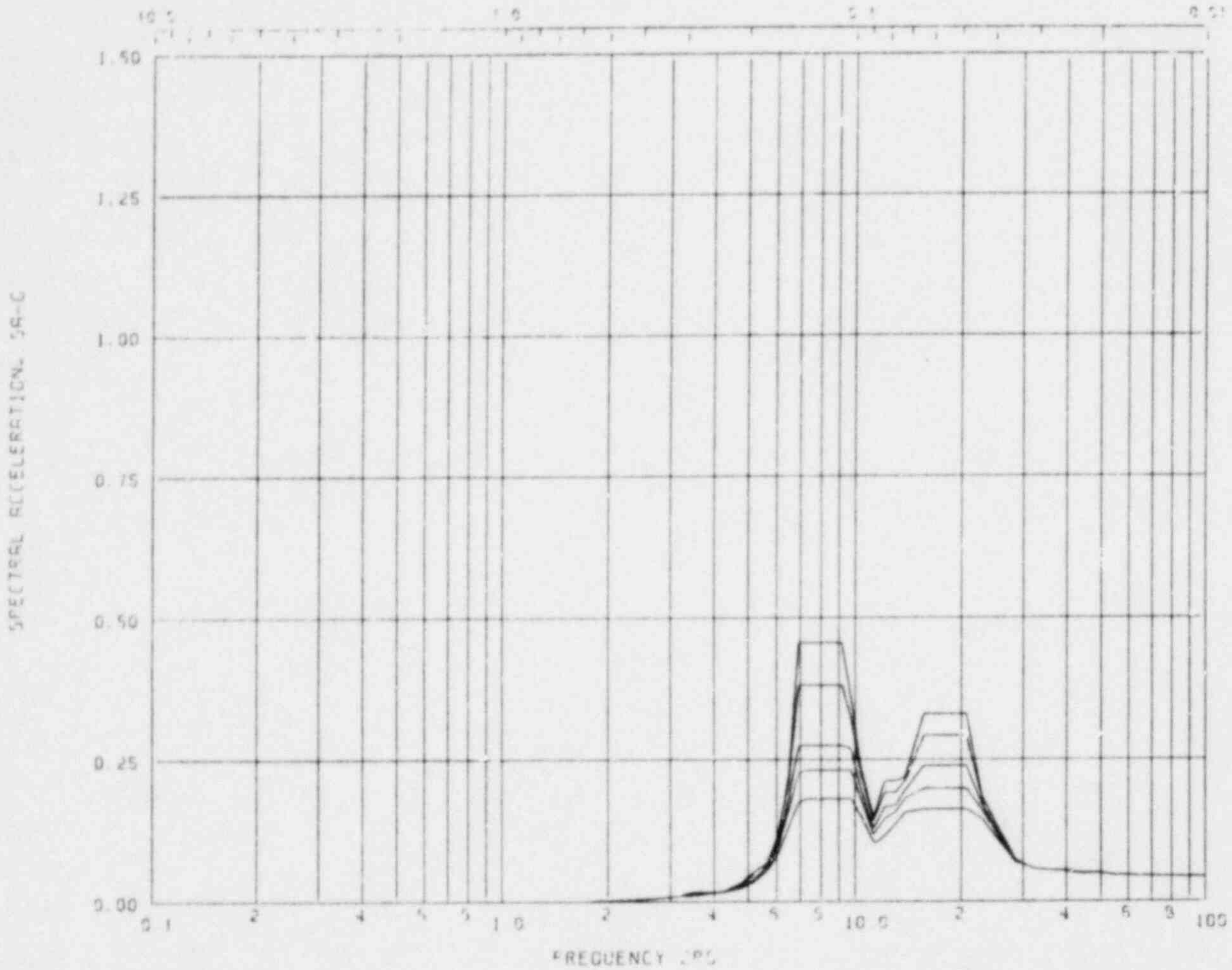
Node: 54 Direction: VERTICAL Elev: 313'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL RESPONSE SPECTRA, VERTICAL, CHUG AXISYMMETRIC

FIGURE B.2-106



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC CHUGGING GE700 SERIES ENVELOPE (WIDENED - 15%)

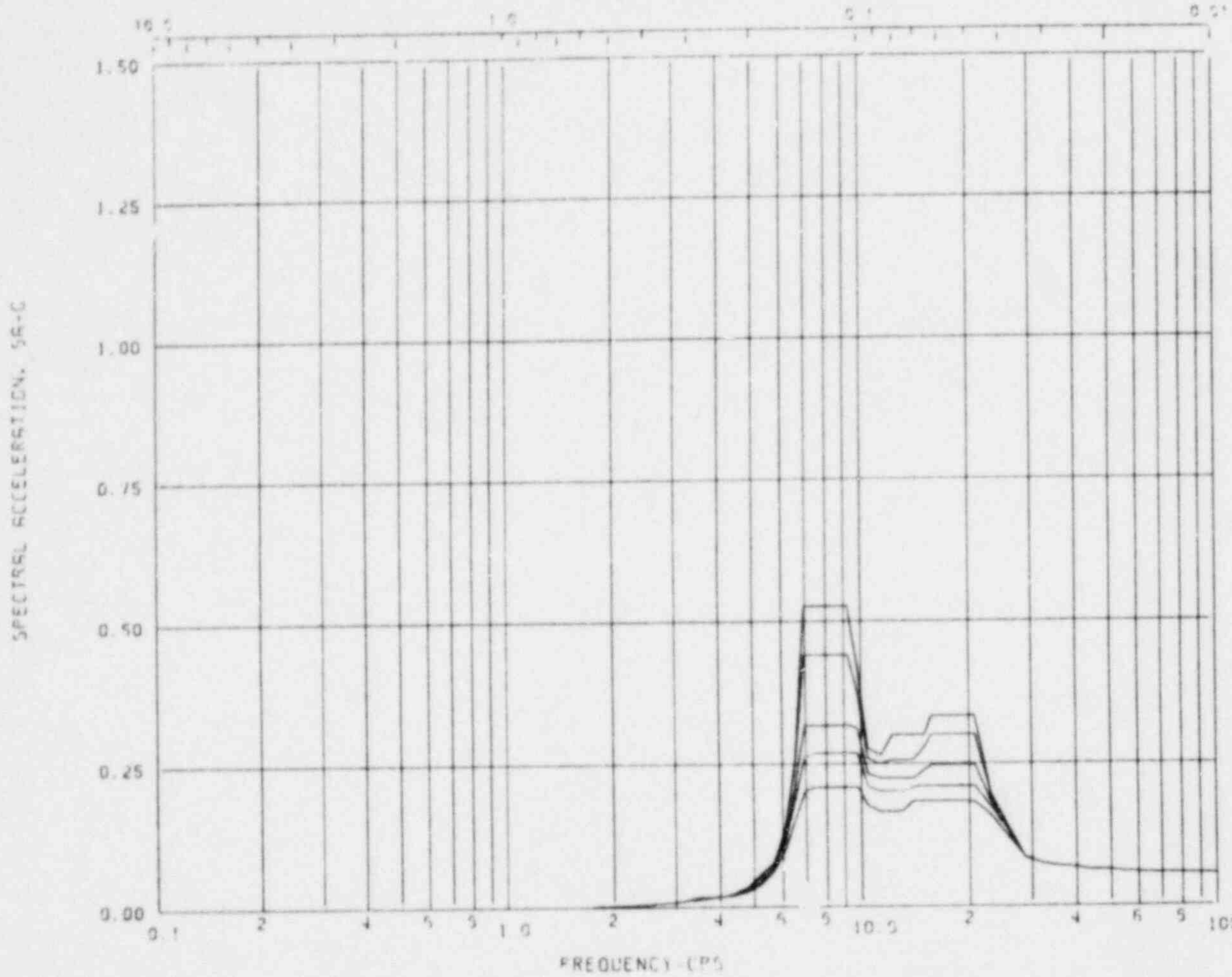
Node: 32 Direction: VERTICAL Elev: 333'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL RESPONSE SPECTRA, VERTICAL, CHUG AXISYMMETRIC

FIGURE B.2-107



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC CHUGGING GE700 SERIES ENVELOPE (WIDENED - 15%)

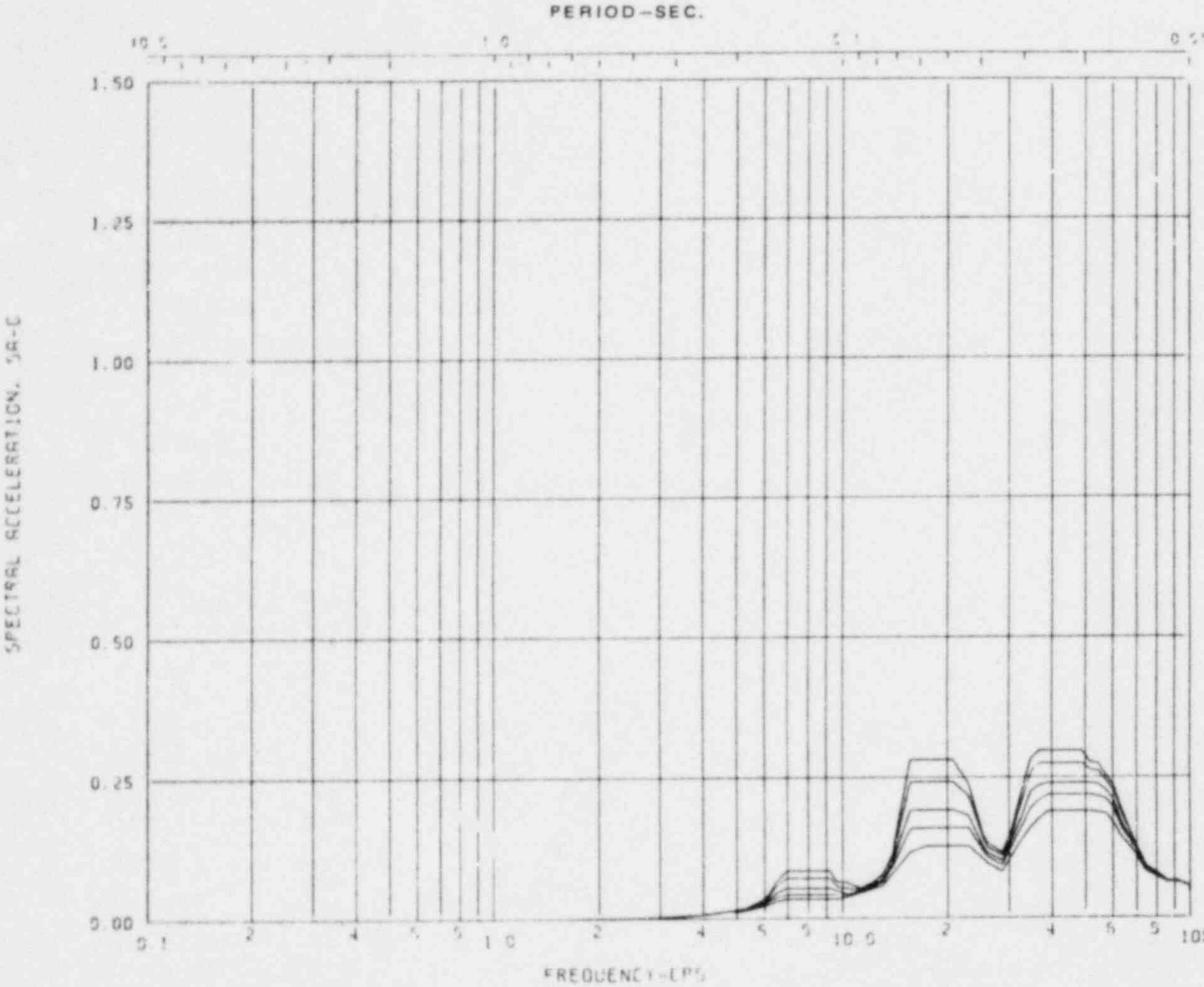
Node: 12 Direction: VERTICAL Elev: 352'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL
RESPONSE SPECTRA, VERTICAL,
CHUG AXISYMMETRIC

FIGURE B.2-108



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC CHUGGING GE700 SERIES ENVELOPE (WIDENED - 15%)

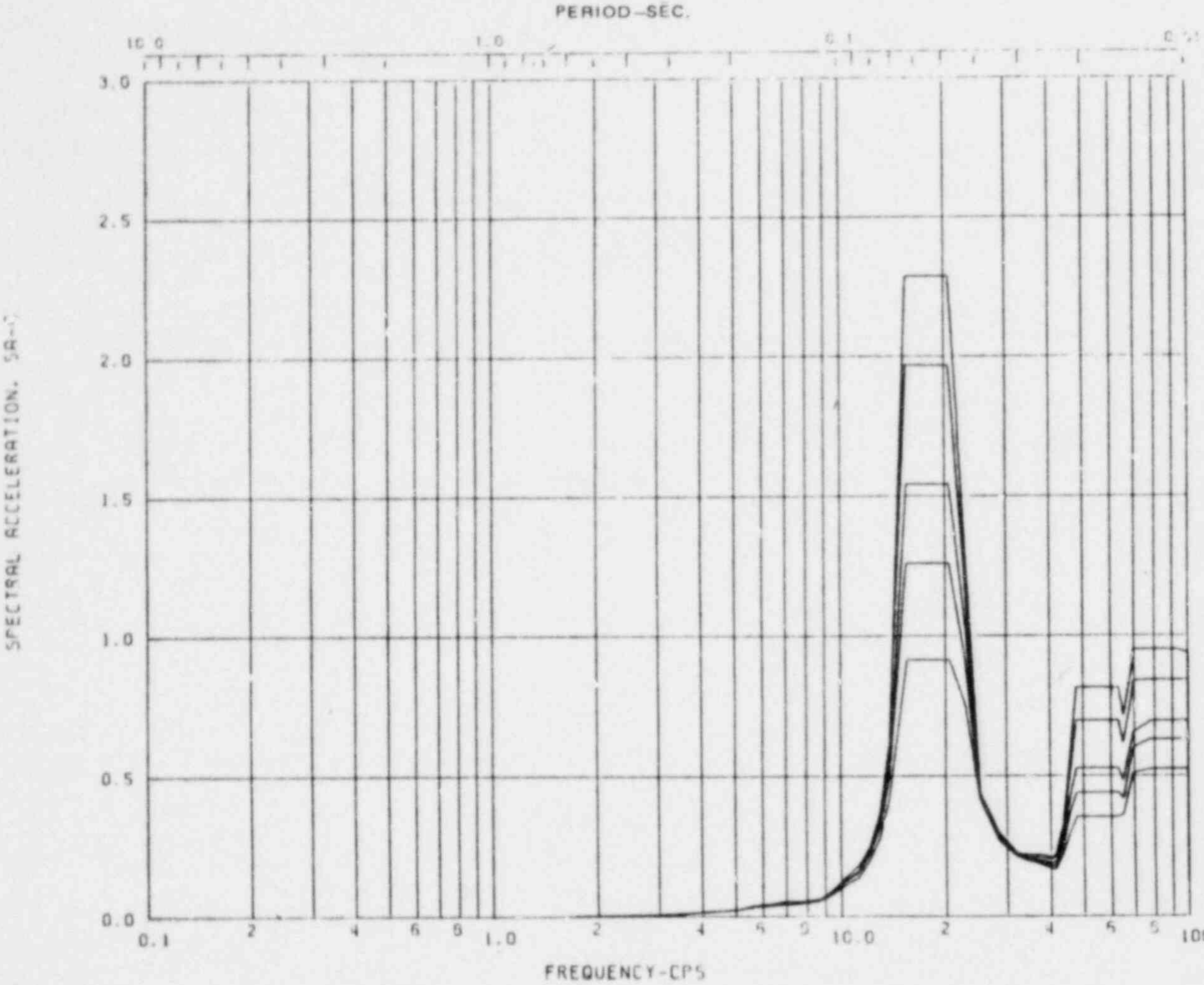
Node: 6 Direction: VERTICAL Elev: 410'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL RESPONSE SPECTRA, VERTICAL, CHUG AXISYMMETRIC

FIGURE B.2-109



Acceleration Spectra for CONTROL STRUCTURE

Load Case: AXISYMMETRIC CHUGGING GE 700 SERIES ENVELOPE (WIDENED - 15%)

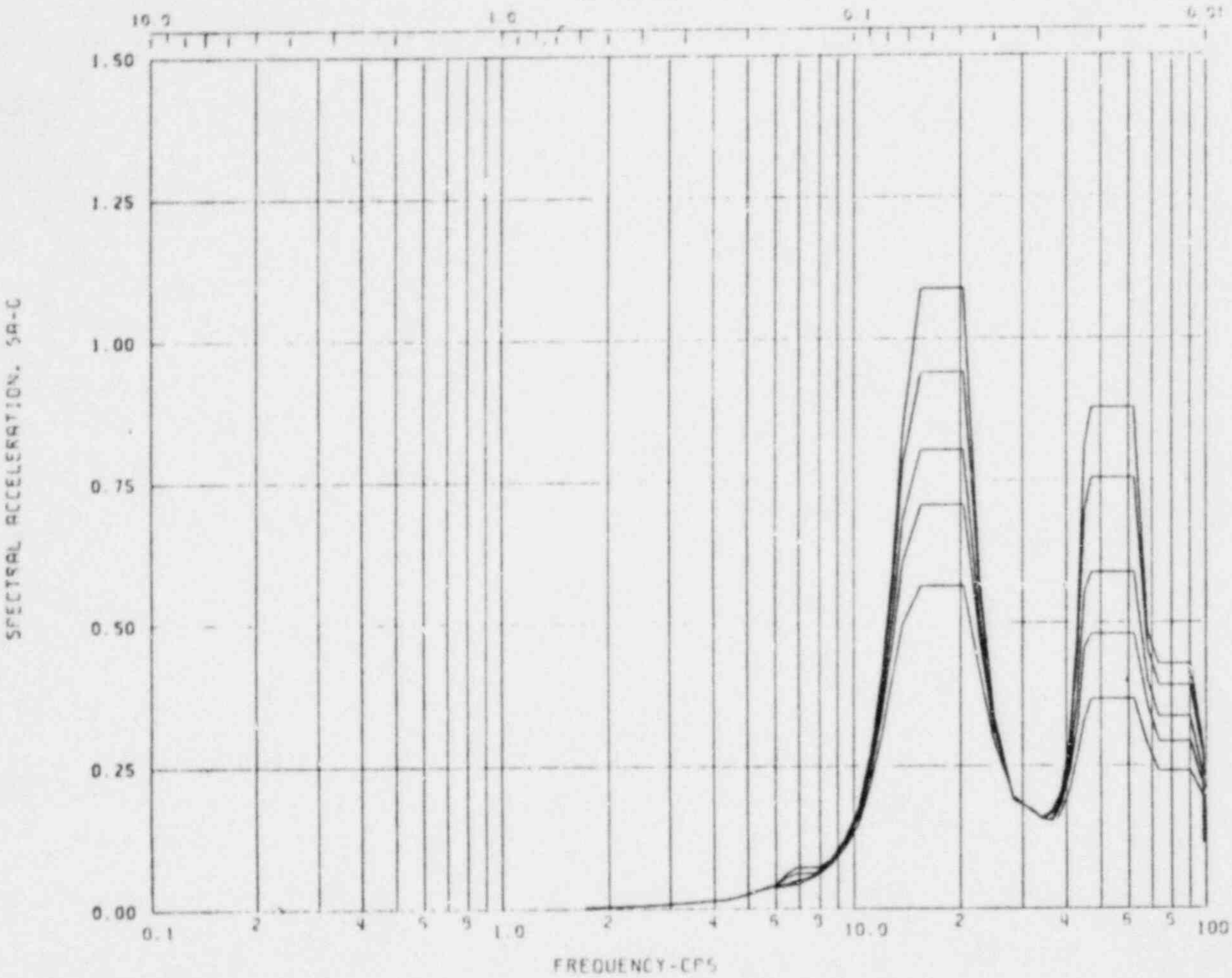
Node: 19 Direction: VERTICAL Elev: 217'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTROL STRUCTURE LOCAL RESPONSE SPECTRA, VERTICAL, CHUG AXISYMMETRIC

FIGURE B.2-110



Acceleration Spectra for CONTROL STRUCTURE

Load Case: AXISYMMETRIC CHUGGING GE 700 SERIES ENVELOPE (WIDENED - 15%)

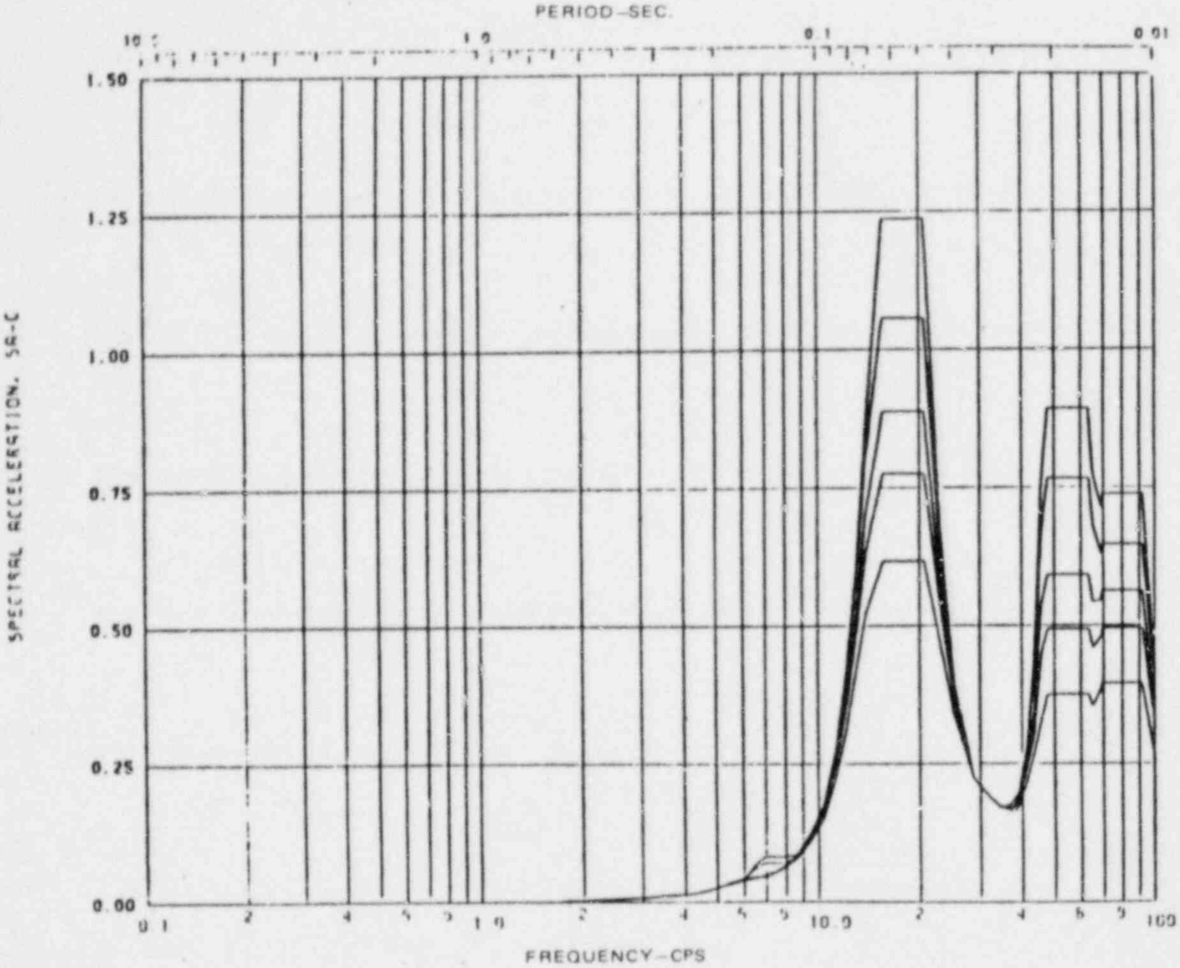
Node: 19 Direction: VERTICAL Elev: 239'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTROL STRUCTURE LOCAL RESPONSE SPECTRA, VERTICAL, CHUG AXISYMMETRIC

FIGURE B.2-111



Acceleration Spectra for CONTROL STRUCTURE

Load Case: AXISYMMETRIC CHUGGING GE 700 SERIES ENVELOPE (WIDENED - 15%)

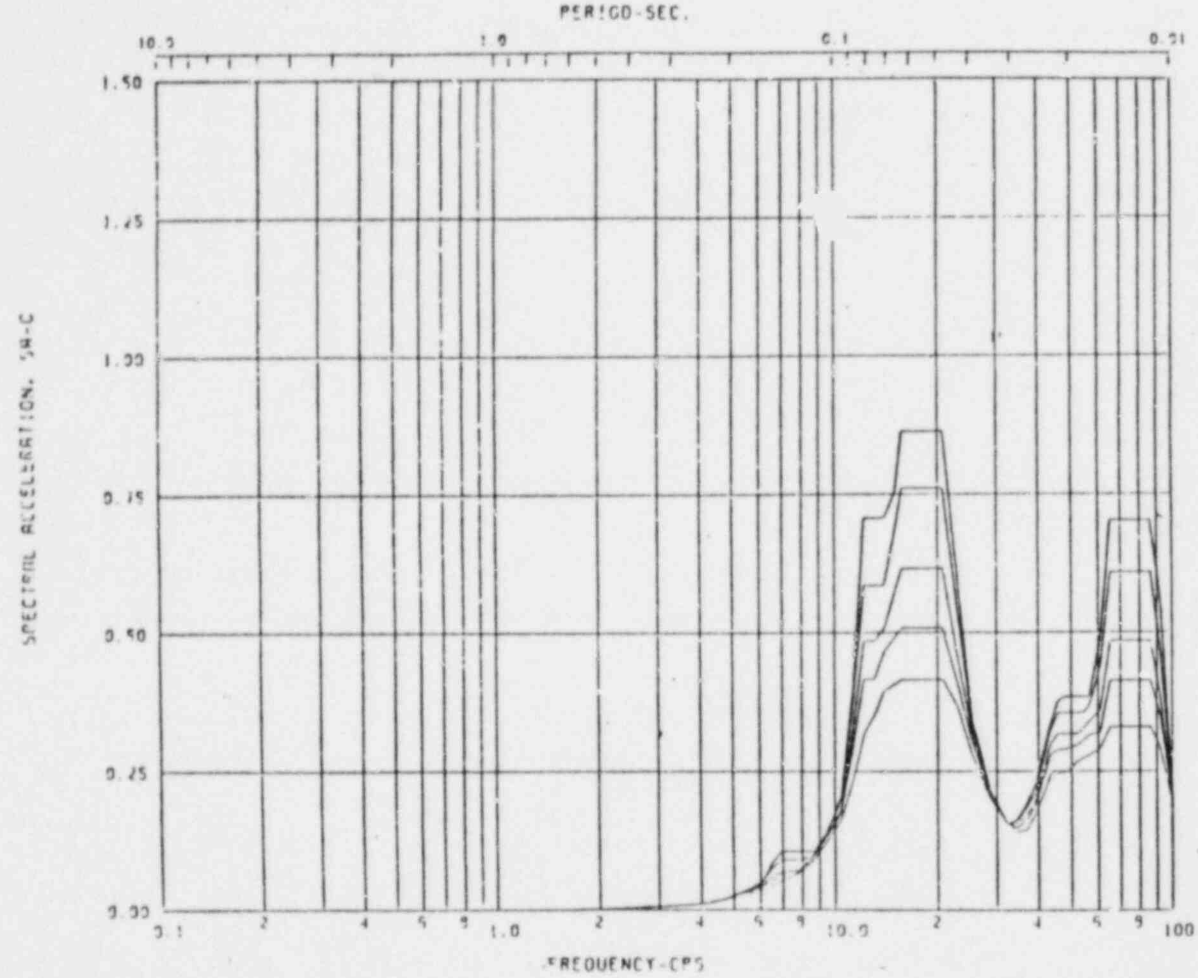
Node: 19 Direction: VERTICAL Elev: 254'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTROL STRUCTURE LOCAL RESPONSE SPECTRA, VERTICAL, CHUG AXISYMMETRIC

FIGURE B.2-112



Acceleration Spectra for CONTROL STRUCTURE

Load Case: AXISYMMETRIC CHUGGING GE 700 SERIES ENVELOPE (WIDENED - 15%)

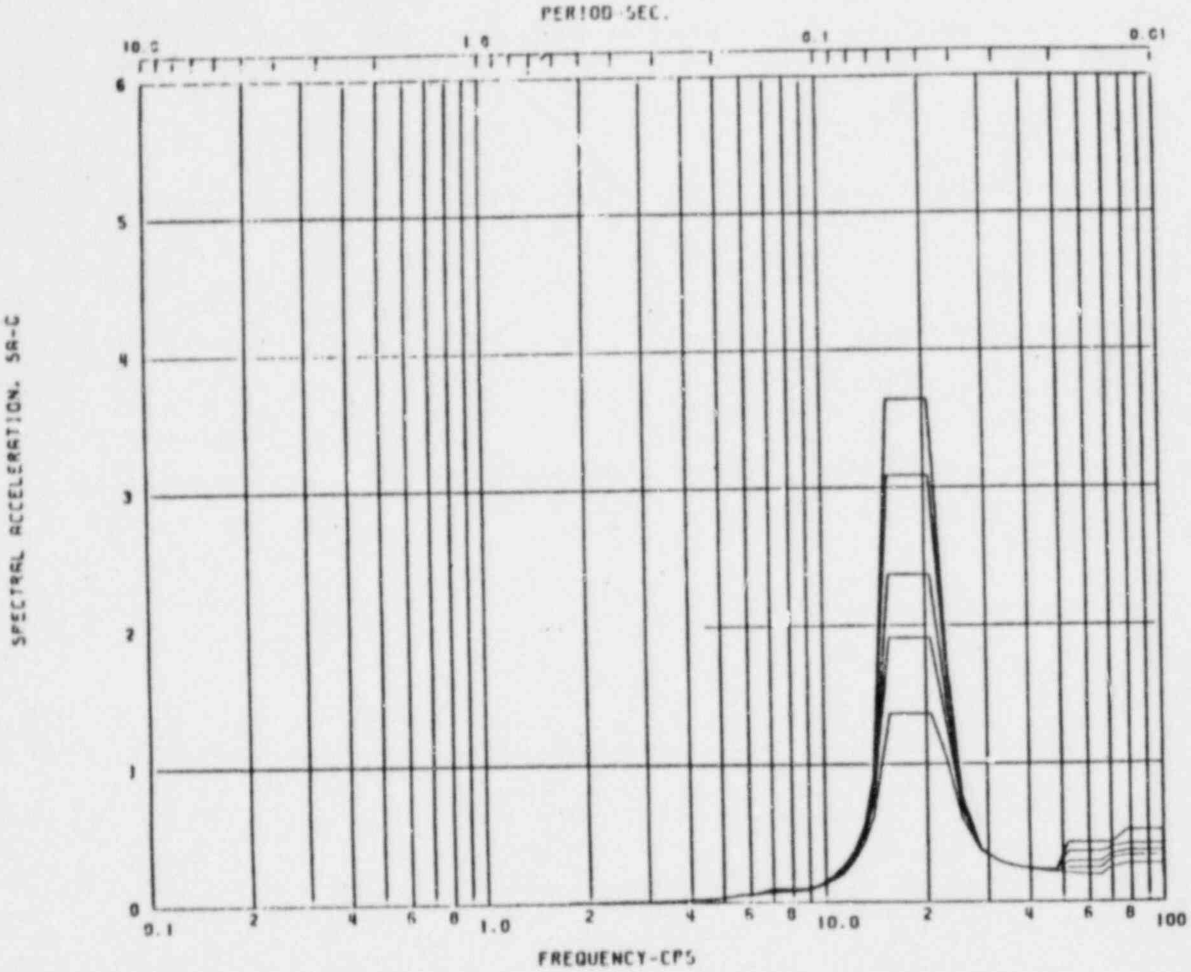
Node: 19 Direction: VERTICAL Elev: 269'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTROL STRUCTURE LOCAL RESPONSE SPECTRA, VERTICAL, CHUG AXISYMMETRIC

FIGURE B.2-113



Acceleration Spectra for CONTROL STRUCTURE

Load Case: AXISYMMETRIC CHUGGING GE 700 SERIES ENVELOPE (WIDENED - 15%)

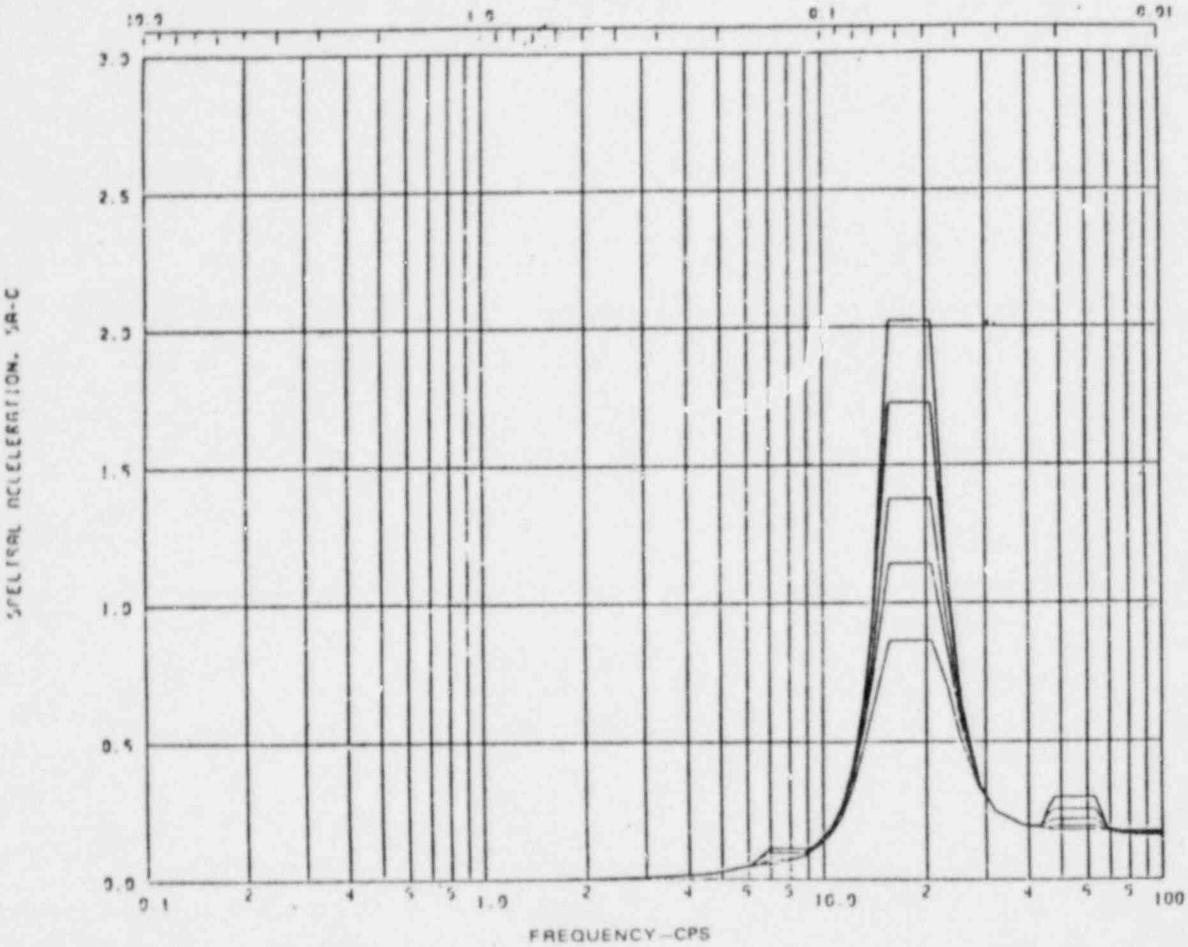
Node: 19 Direction: VERTICAL Elev: 289'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTROL STRUCTURE LOCAL RESPONSE SPECTRA, VERTICAL, CHUG AXISYMMETRIC

FIGURE B.2-114



Acceleration Spectra for CONTROL STRUCTURE

Load Case: AXISYMMETRIC CHUGGING GE 700 SERIES ENVELOPE (WIDENED - 15%)

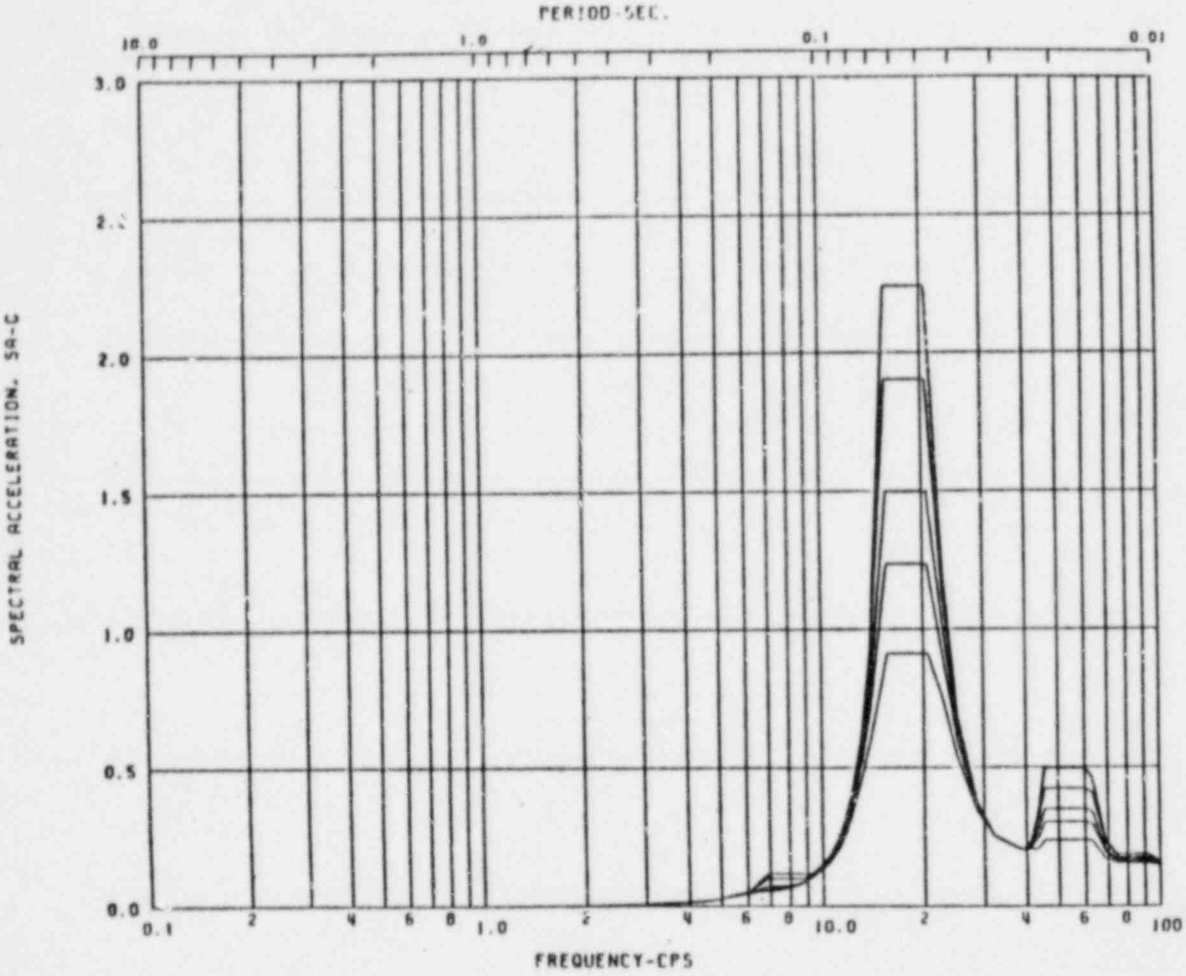
Node: 19 Direction: VERTICAL Elev: 304'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTROL STRUCTURE LOCAL RESPONSE SPECTRA, VERTICAL, CHUG AXISYMMETRIC

FIGURE B.2-115



Acceleration Spectra for CONTROL STRUCTURE

Load Case: AXISYMMETRIC CHUGGING GE 700 SERIES ENVELOPE (WIDENED - 15%)

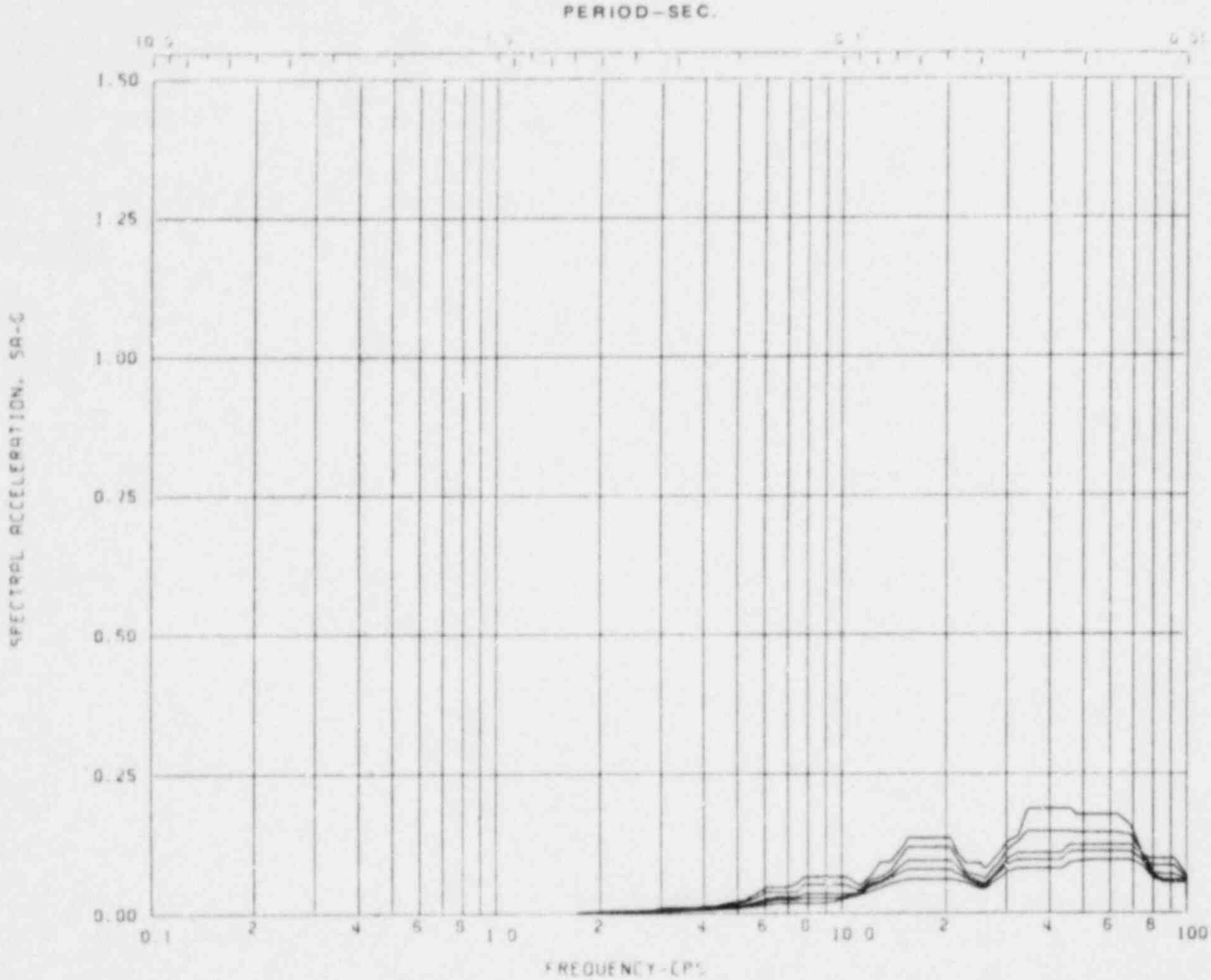
Node: 19 Direction: VERTICAL Elev: 332'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTROL STRUCTURE LOCAL RESPONSE SPECTRA, VERTICAL, CHUG AXISYMMETRIC

FIGURE B.2-116



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC GE CO-BASIC ENVELOPE (WIDENED - 15%)

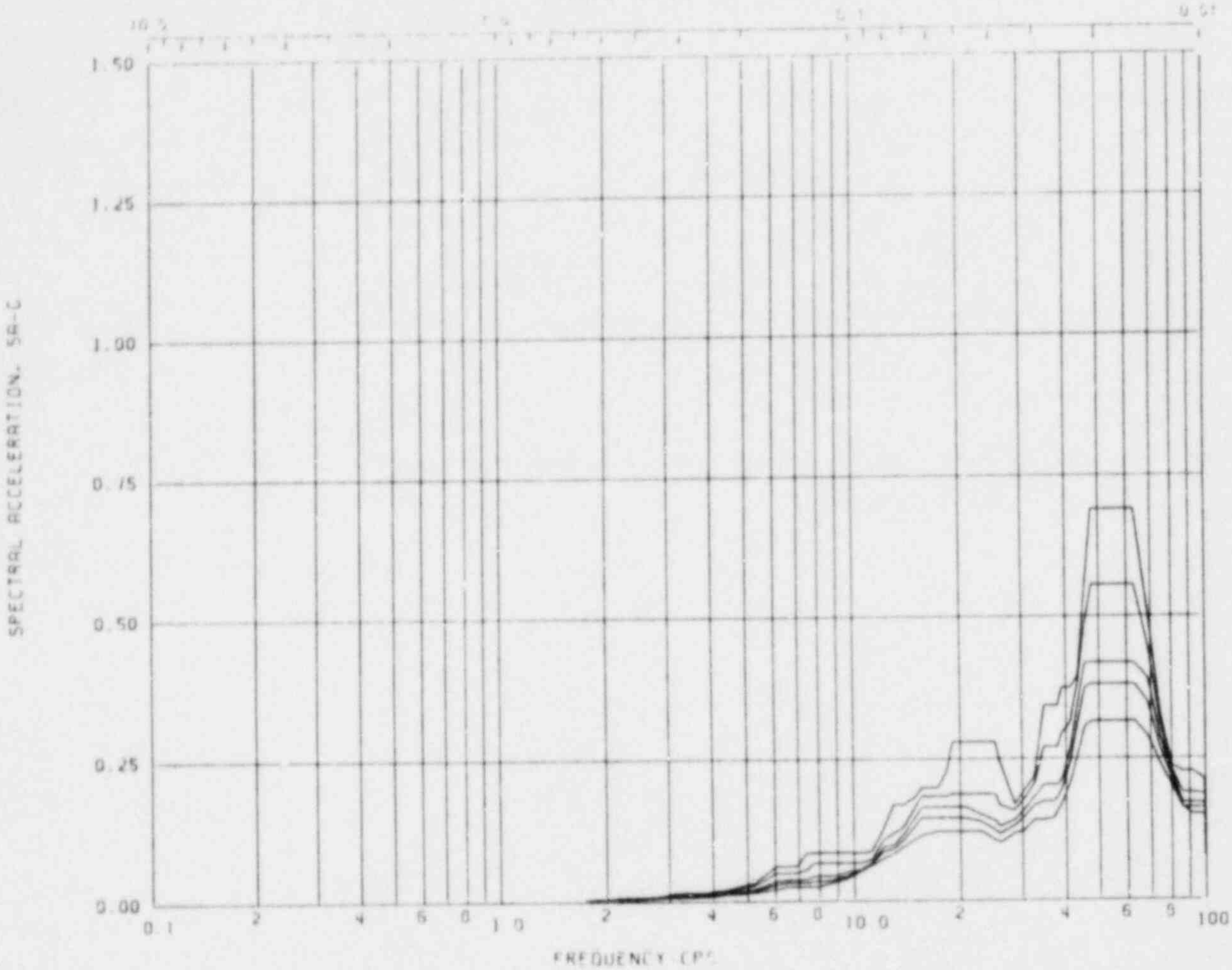
Node: 159 Direction: VERTICAL Elev: 177'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL RESPONSE SPECTRA, VERTICAL, CO – BASIC AXISYMMETRIC

FIGURE B.2-117



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC GE CO-BASIC ENVELOPE (WIDENED - 15%)

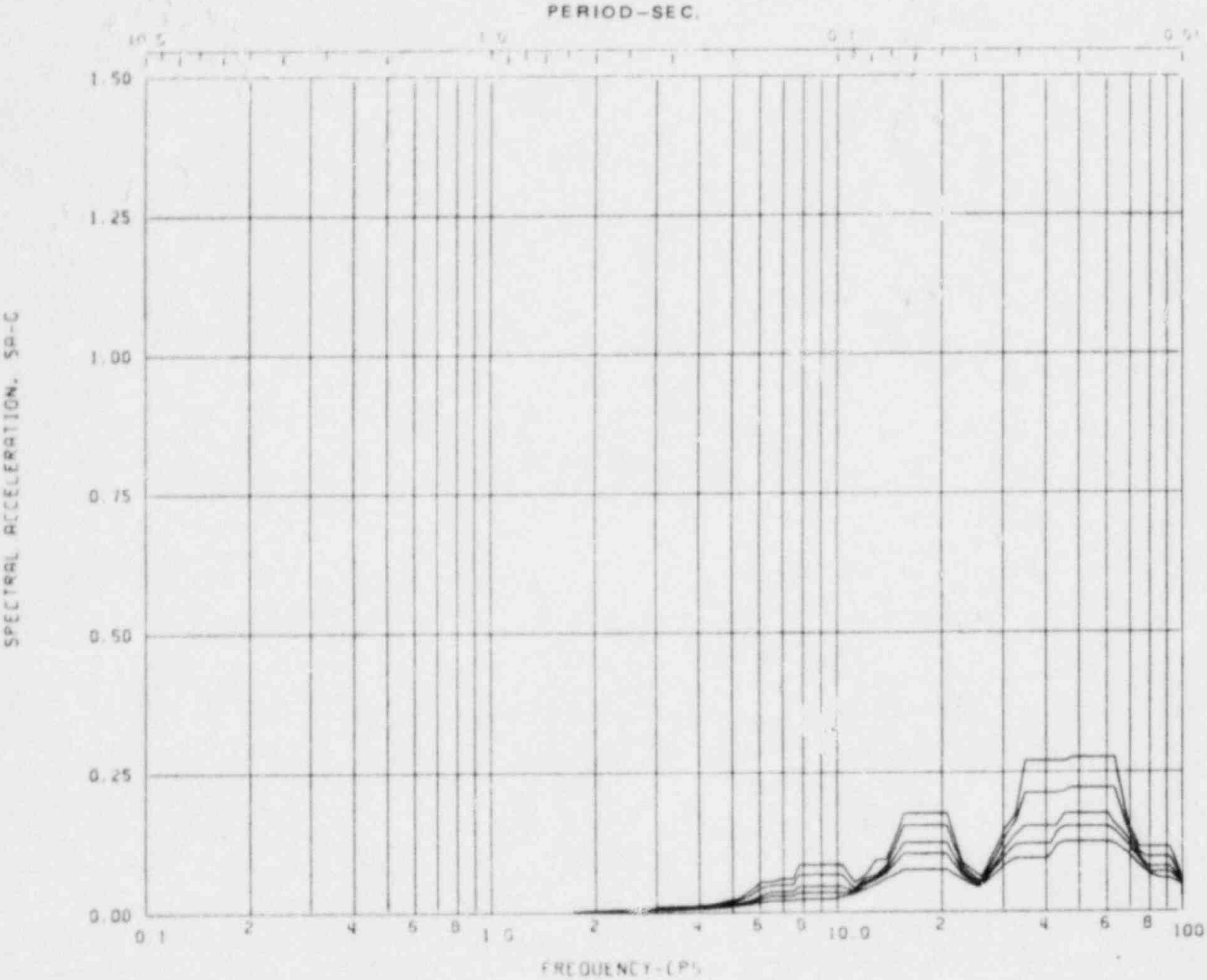
Node: 154 Direction: VERTICAL Elev: 177'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL RESPONSE SPECTRA, VERTICAL, CO – BASIC AXISYMMETRIC

FIGURE B.2-118



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC GE CO-BASIC ENVELOPE (WIDENED - 15%)

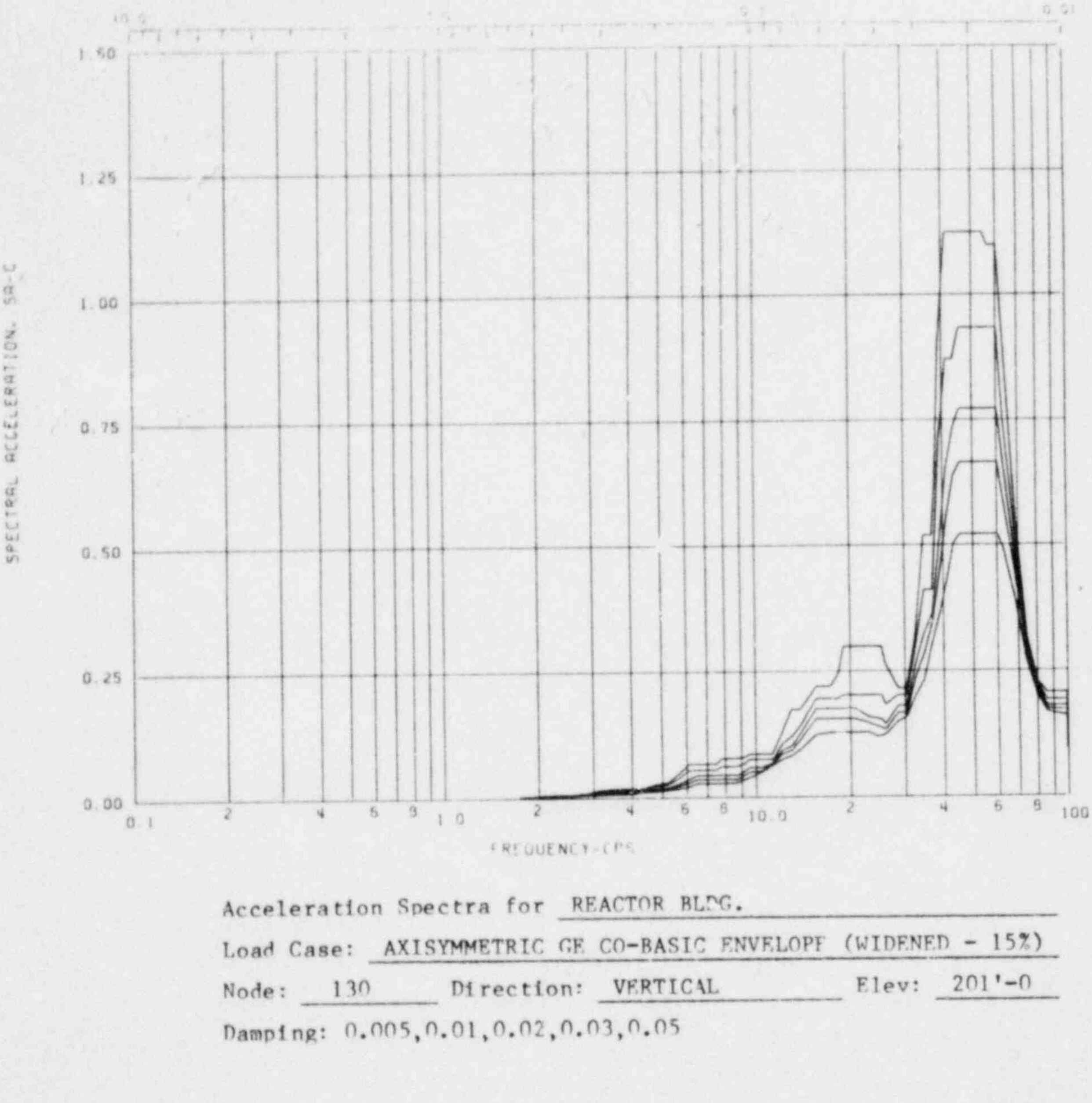
Node: 128 Direction: VERTICAL Elev: 201'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL RESPONSE SPECTRA, VERTICAL, CO – BASIC AXISYMMETRIC

FIGURE B.2-119



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC GE CO-BASIC ENVELOPE (WIDENED - 15%)

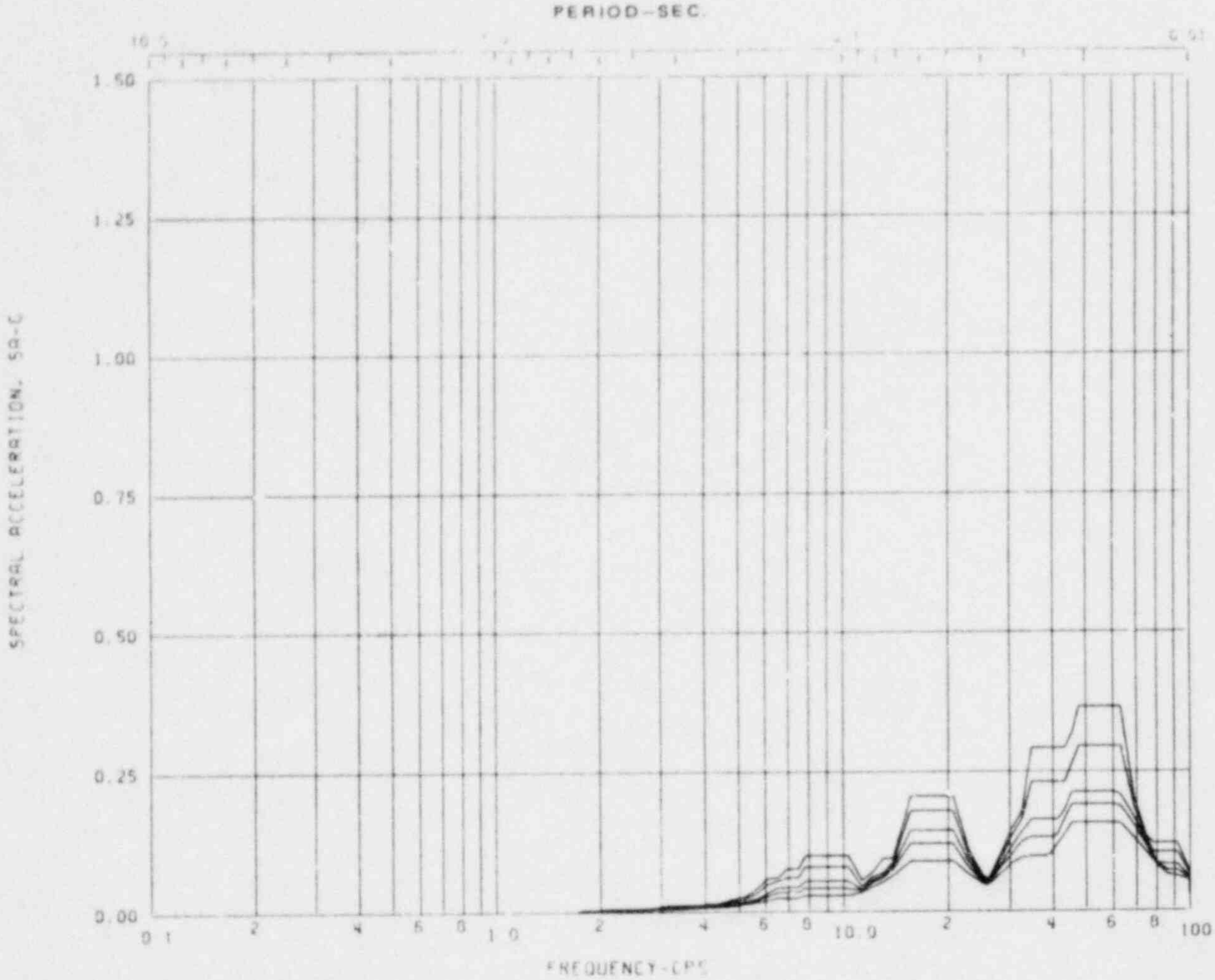
Node: 130 Direction: VERTICAL Elev: 201'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL
RESPONSE SPECTRA, VERTICAL,
CO – BASIC AXISYMMETRIC

FIGURE B.2-120



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC GE CO-BASIC ENVELOPE (WIDENED - 15%)

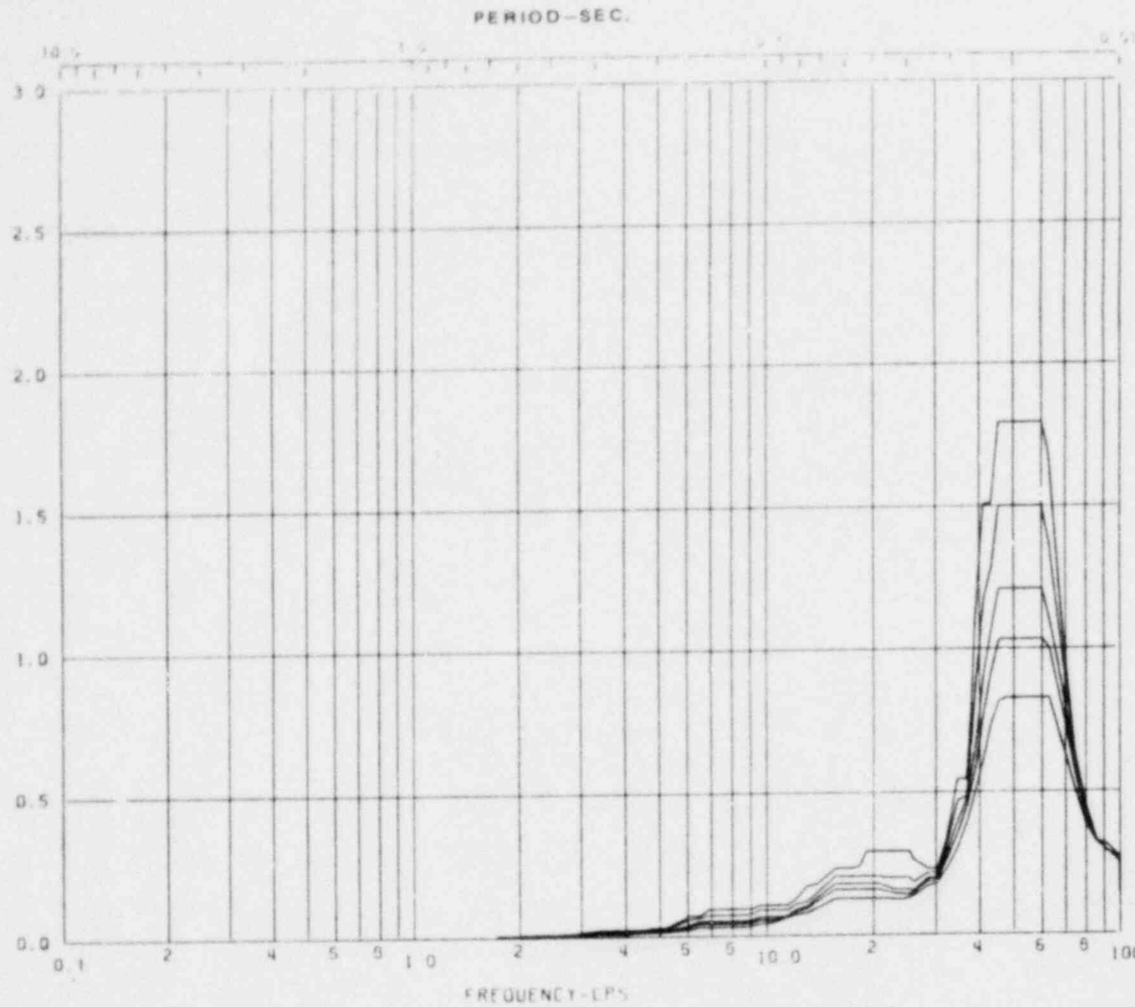
Node: 106 Direction: VERTICAL Elev: 217'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL
RESPONSE SPECTRA, VERTICAL,
CO – BASIC AXISYMMETRIC

FIGURE B.2-121



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC GE CO-BASIC ENVELOPE (WIDENED - 15%)

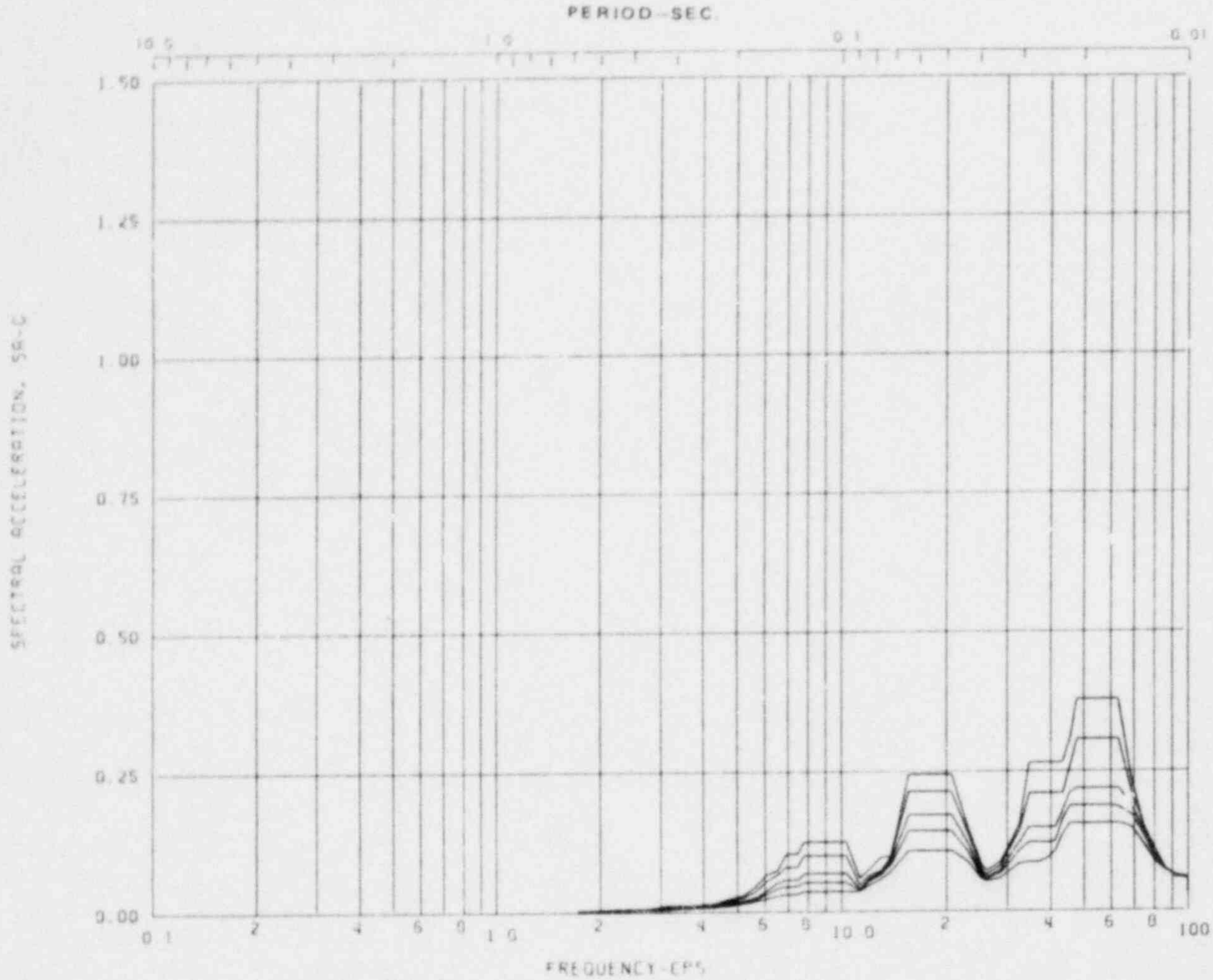
Node: 108 Direction: VERTICAL Elev: 217'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL RESPONSE SPECTRA, VERTICAL, CO – BASIC AXISYMMETRIC

FIGURE B.2-122



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC GE CO-BASIC ENVELOPE (WIDENED - 15%)

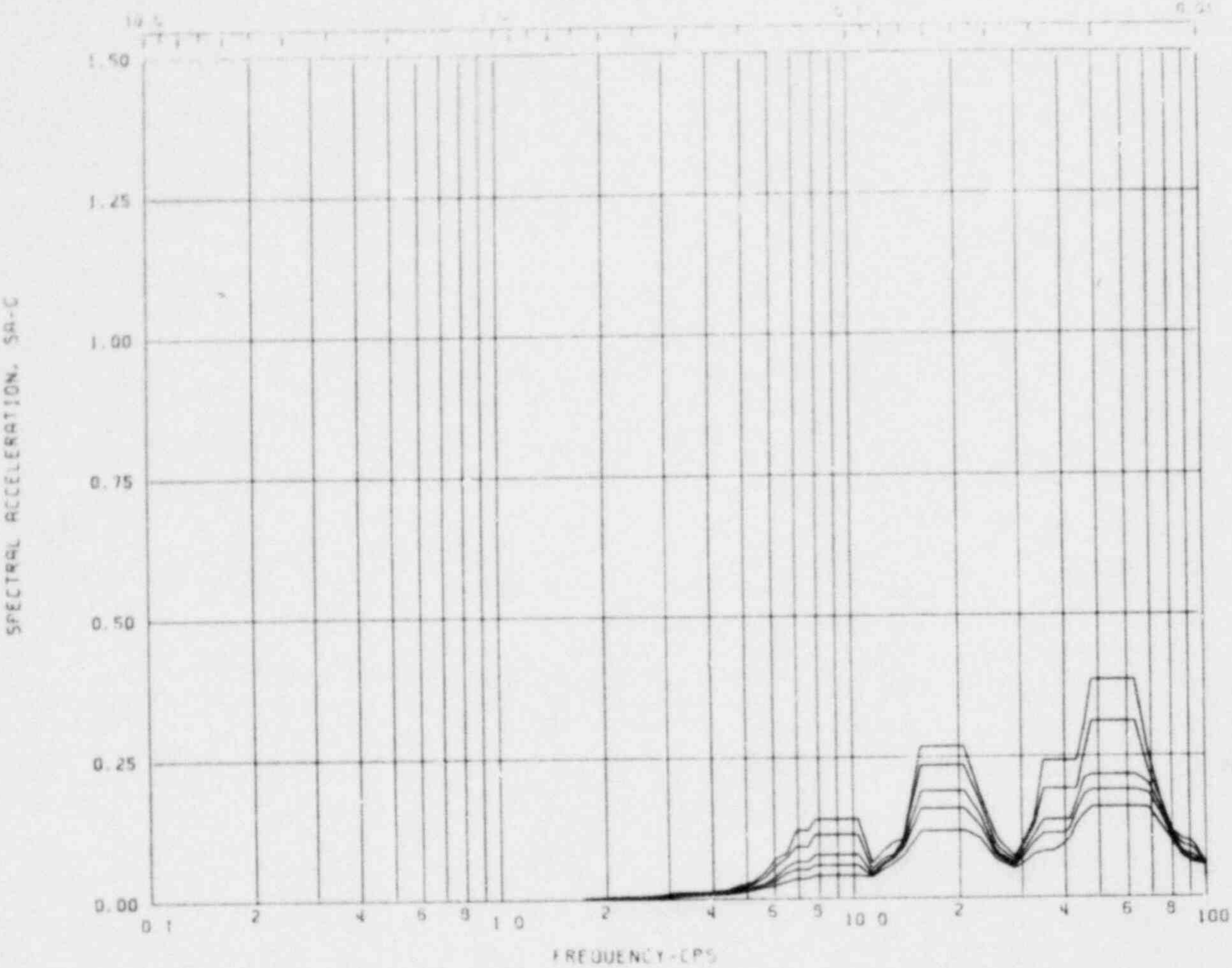
Node: 104 Direction: VERTICAL Elev: 239'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL
RESPONSE SPECTRA, VERTICAL,
CO – BASIC AXISYMMETRIC

FIGURE B.2-123



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC GE CO-BASIC ENVELOPE (WIDENED - 15%)

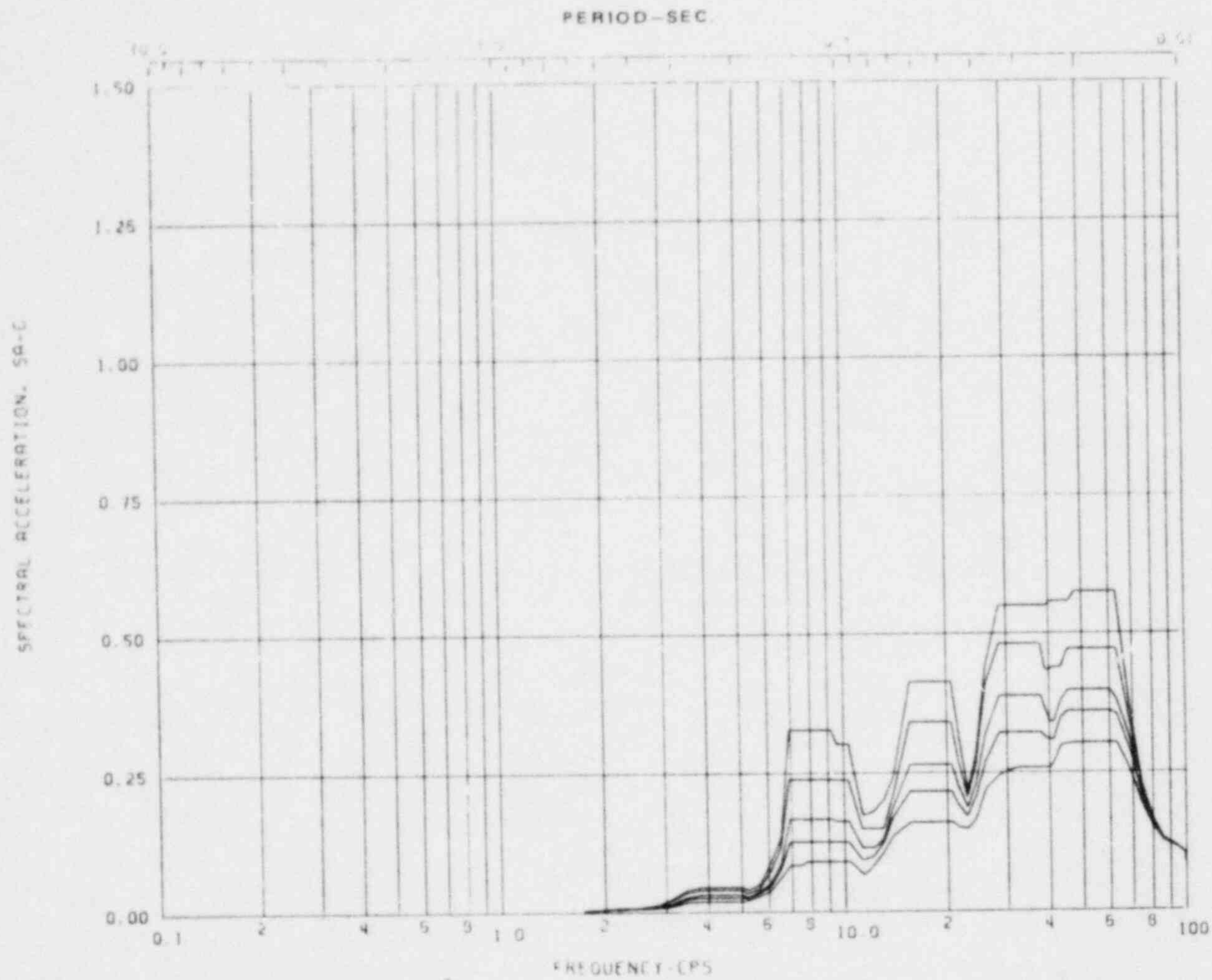
Node: 79 Direction: VERTICAL Elev: 253'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL RESPONSE SPECTRA, VERTICAL, CO – BASIC AXISYMMETRIC

FIGURE B.2-124



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC GE CO-BASIC ENVELOPE (WIDENED - 15%)

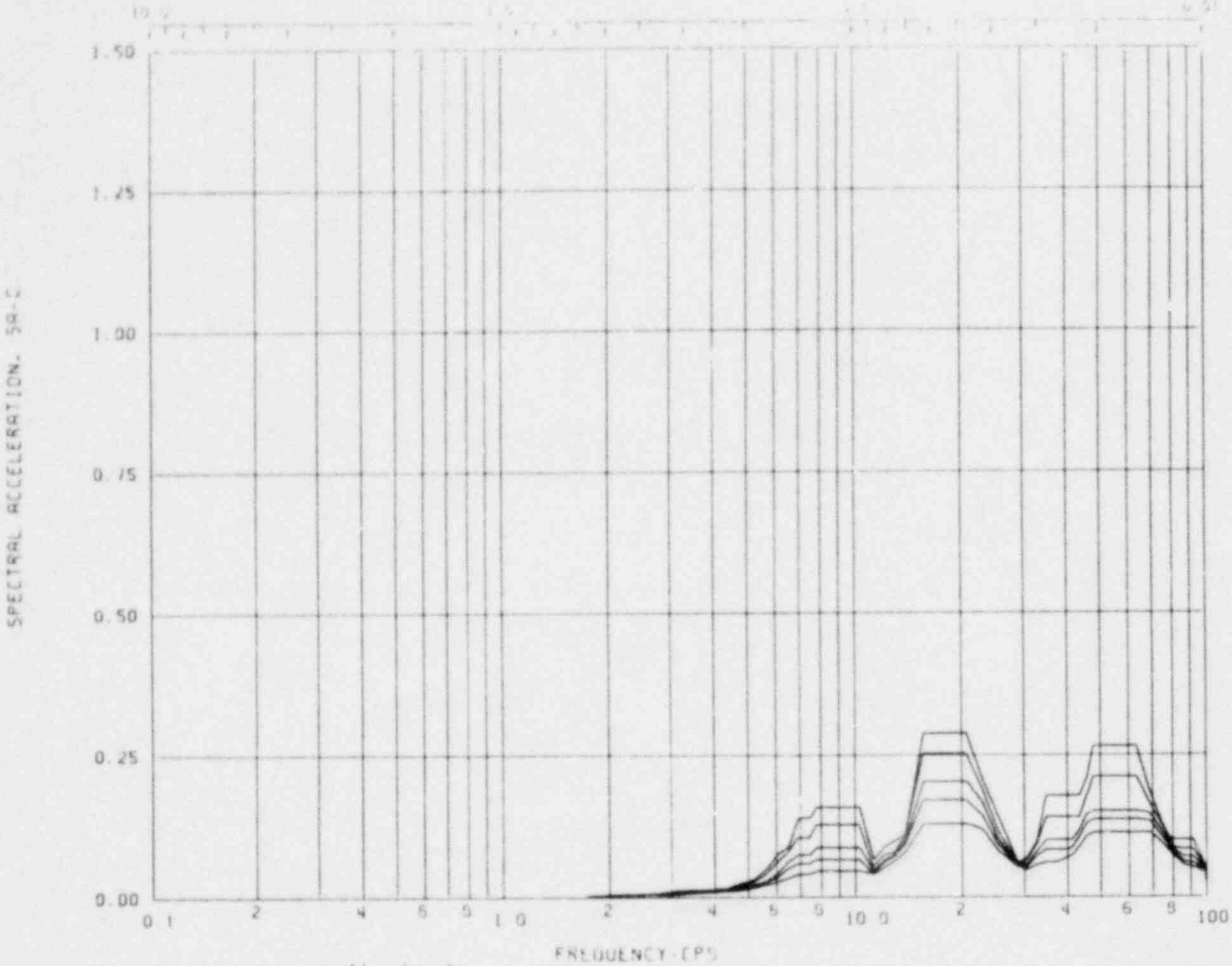
Node: 81 Direction: VERTICAL Elev: 253'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL RESPONSE SPECTRA, VERTICAL, CO – BASIC AXISYMMETRIC

FIGURE B.2-125



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC GE CO-BASIC ENVELOPE (WIDENED - 15%)

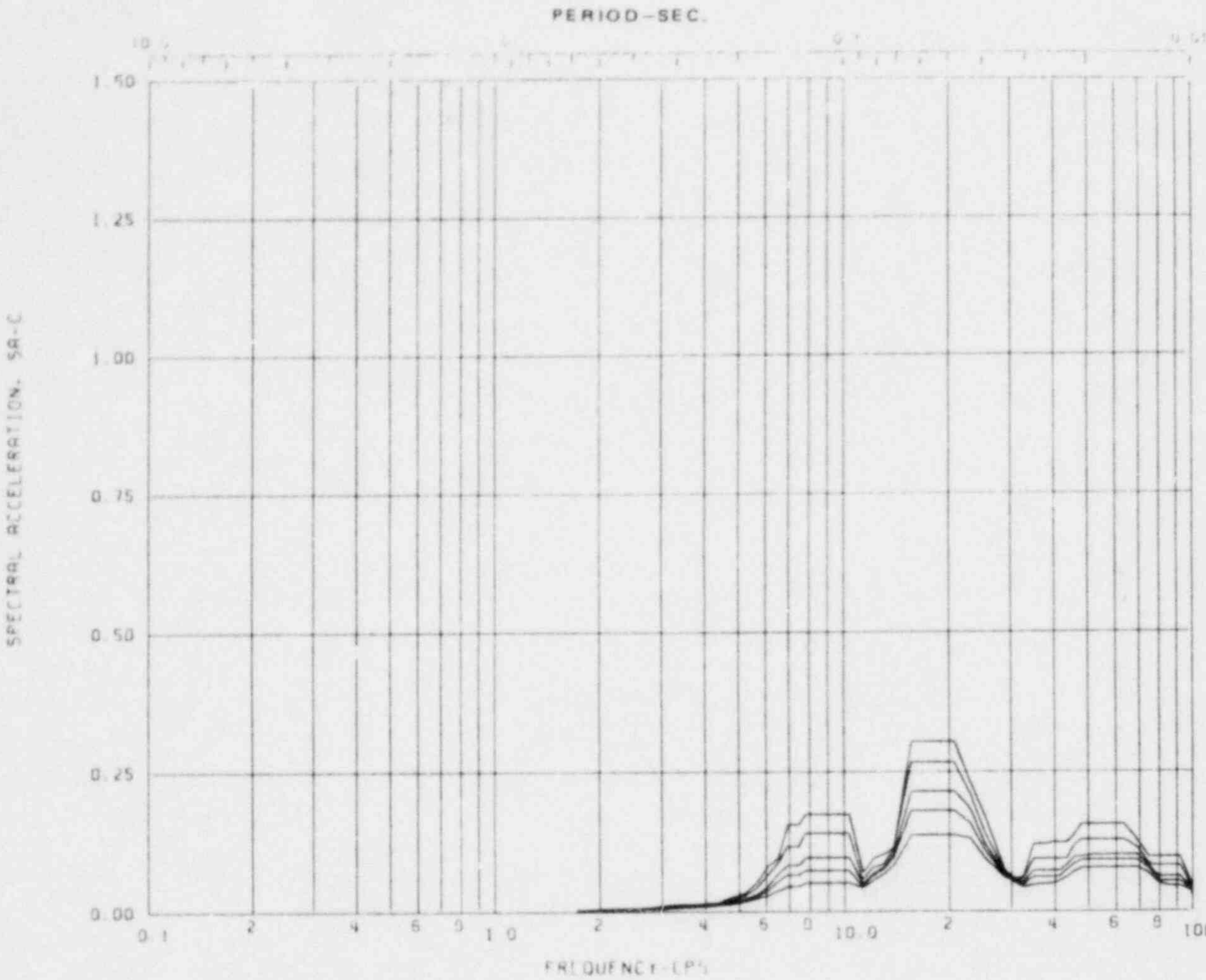
Node: 77 Direction: VERTICAL Elev: 269'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL RESPONSE SPECTRA, VERTICAL, CO – BASIC AXISYMMETRIC

FIGURE B.2-126



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC GE CO-BASIC ENVELOPE (WIDENED - 15%)

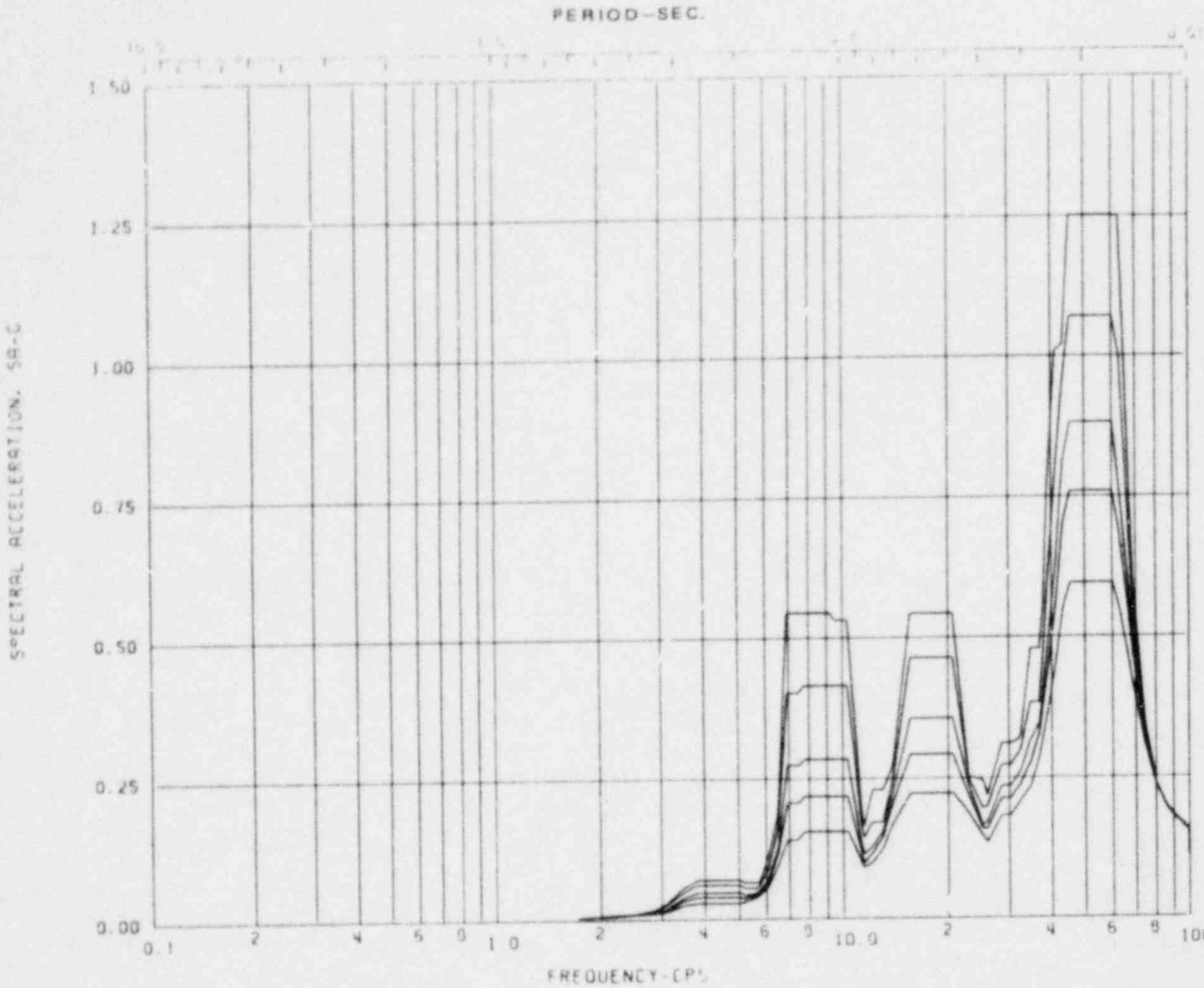
Node: 58 Direction: VERTICAL Elev: 283'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL
RESPONSE SPECTRA, VERTICAL,
CO – BASIC AXISYMMETRIC

FIGURE B.2-127



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC GE CO-BASIC ENVELOPE (WIDENED - 15%)

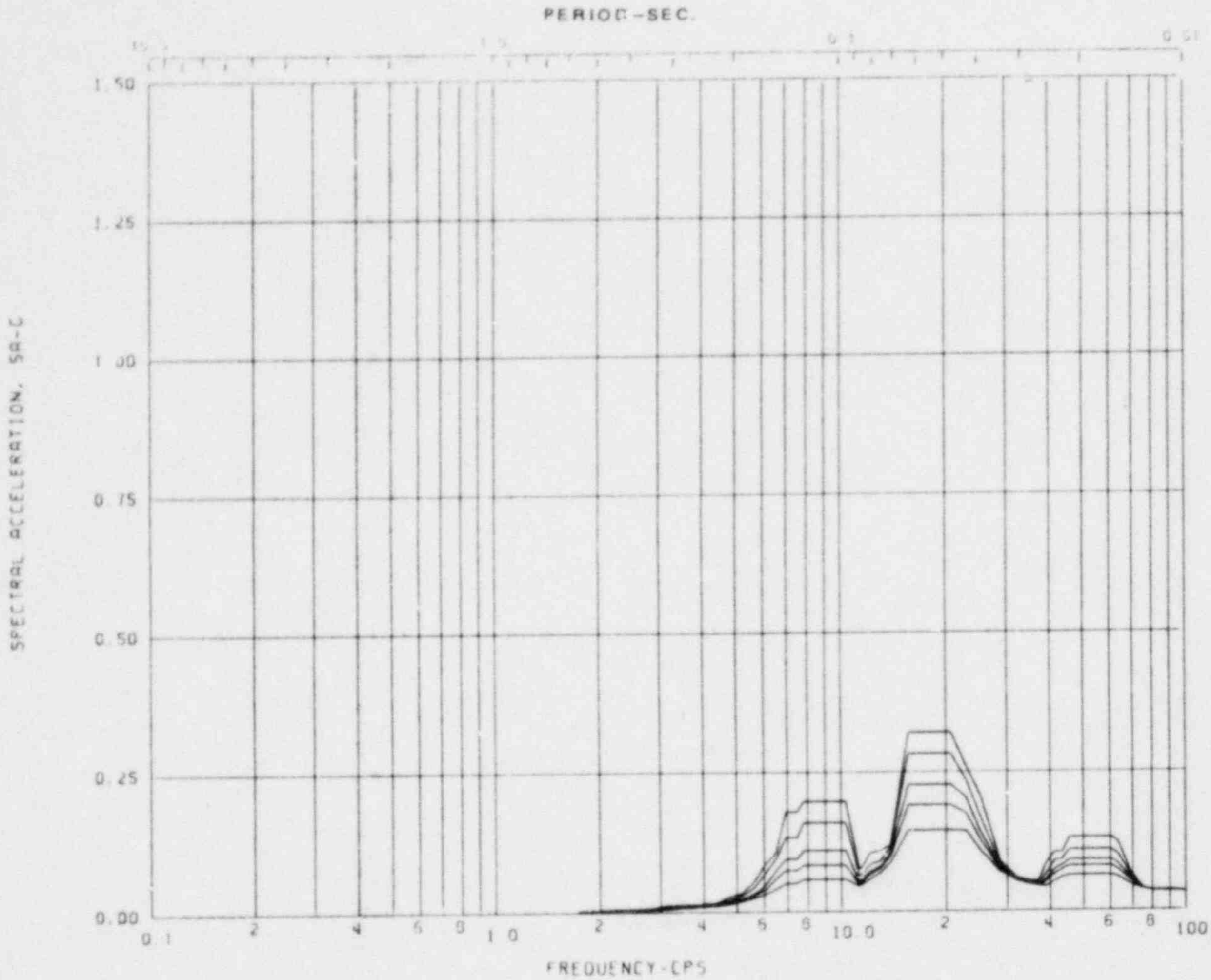
Node: 60 Direction: VERTICAL Elev: 283'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL
RESPONSE SPECTRA, VERTICAL,
CO – BASIC AXISYMMETRIC

FIGURE B.2-128



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC GE CO-BASIC ENVELOPE (WIDENED - 15%)

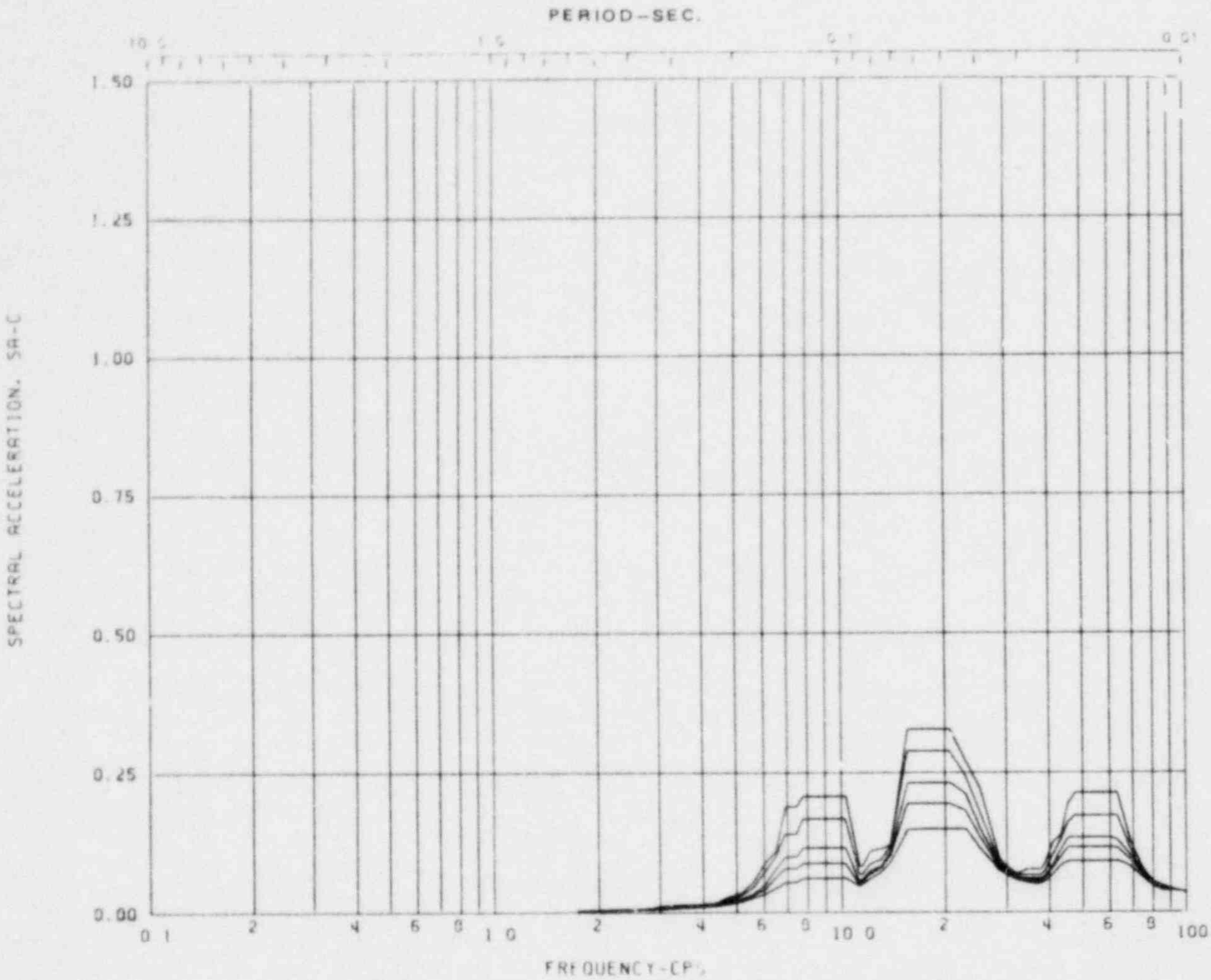
Node: 56 Direction: VERTICAL Elev: 304'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL RESPONSE SPECTRA, VERTICAL, CO – BASIC AXISYMMETRIC

FIGURE B.2-129



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC GE CO-BASIC ENVELOPE (WIDENED - 15%)

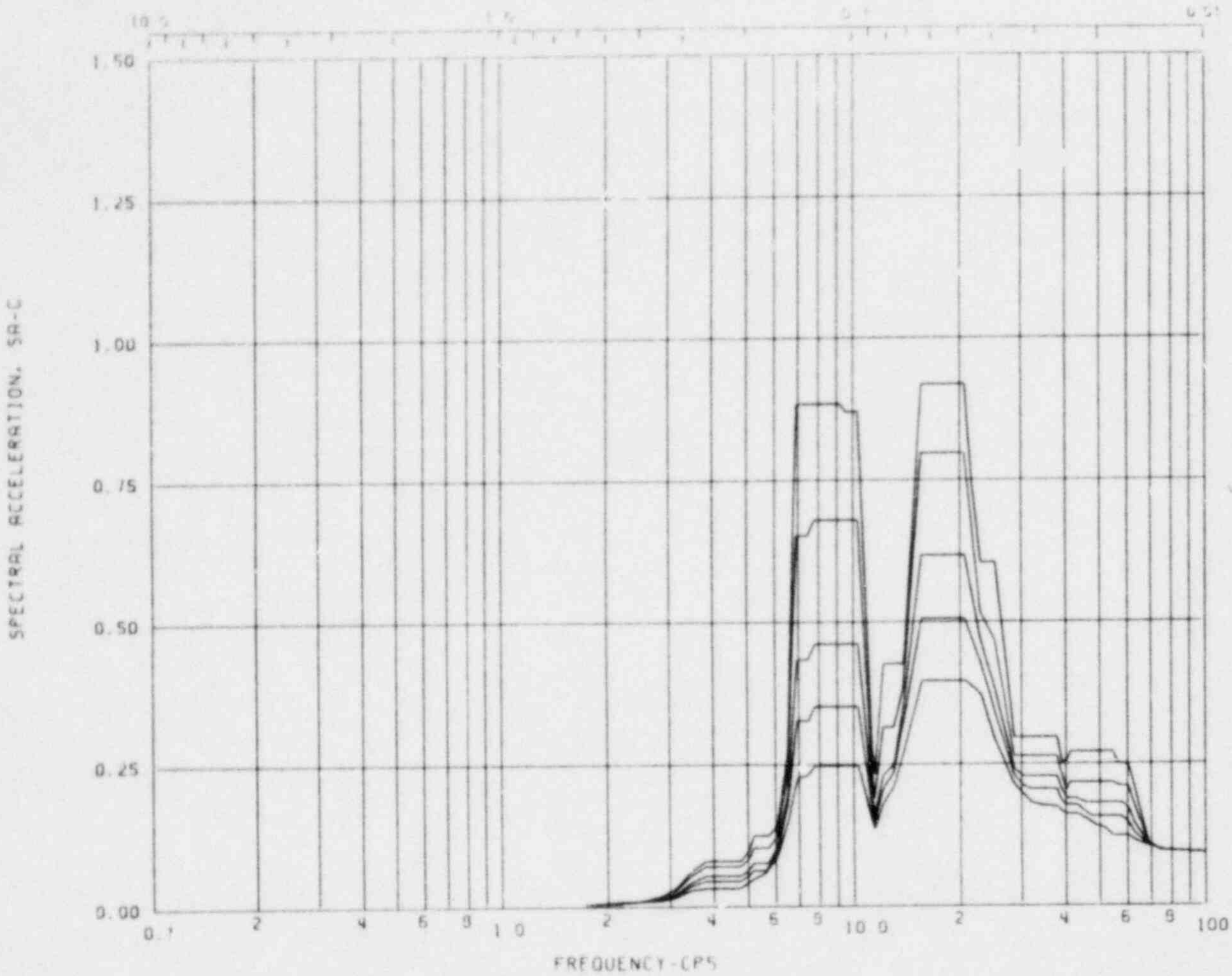
Node: 35 Direction: VERTICAL Elev: 313'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL RESPONSE SPECTRA, VERTICAL, CO – BASIC AXISYMMETRIC

FIGURE B.2-130



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC GE CO-BASIC ENVELOPE (WIDENED - 15%)

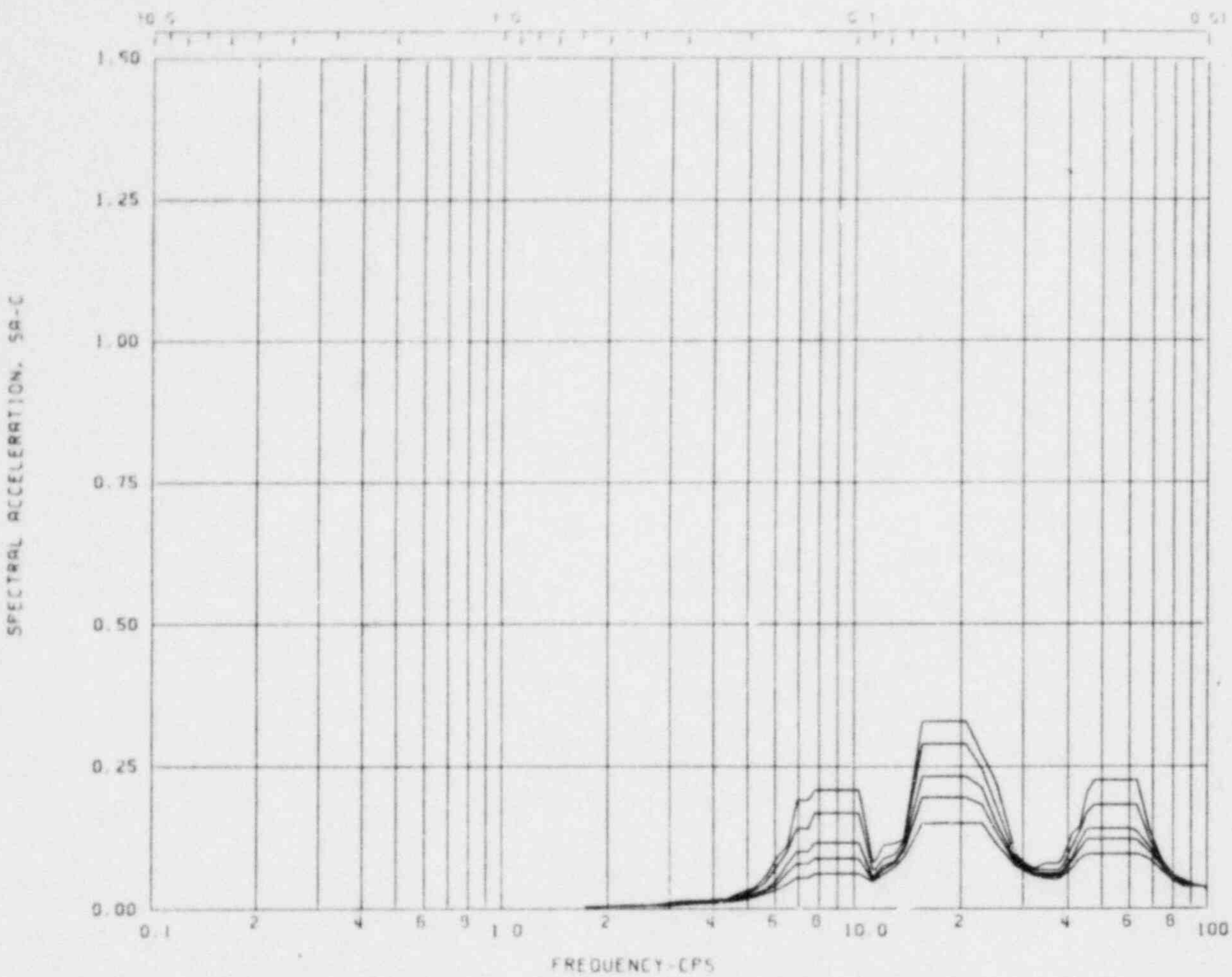
Node: 43 Direction: VERTICAL Elev: 313'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL
RESPONSE SPECTRA, VERTICAL,
CO – BASIC AXISYMMETRIC

FIGURE B.2-131



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC GE CO-BASIC ENVELOPE (WIDENED - 15%)

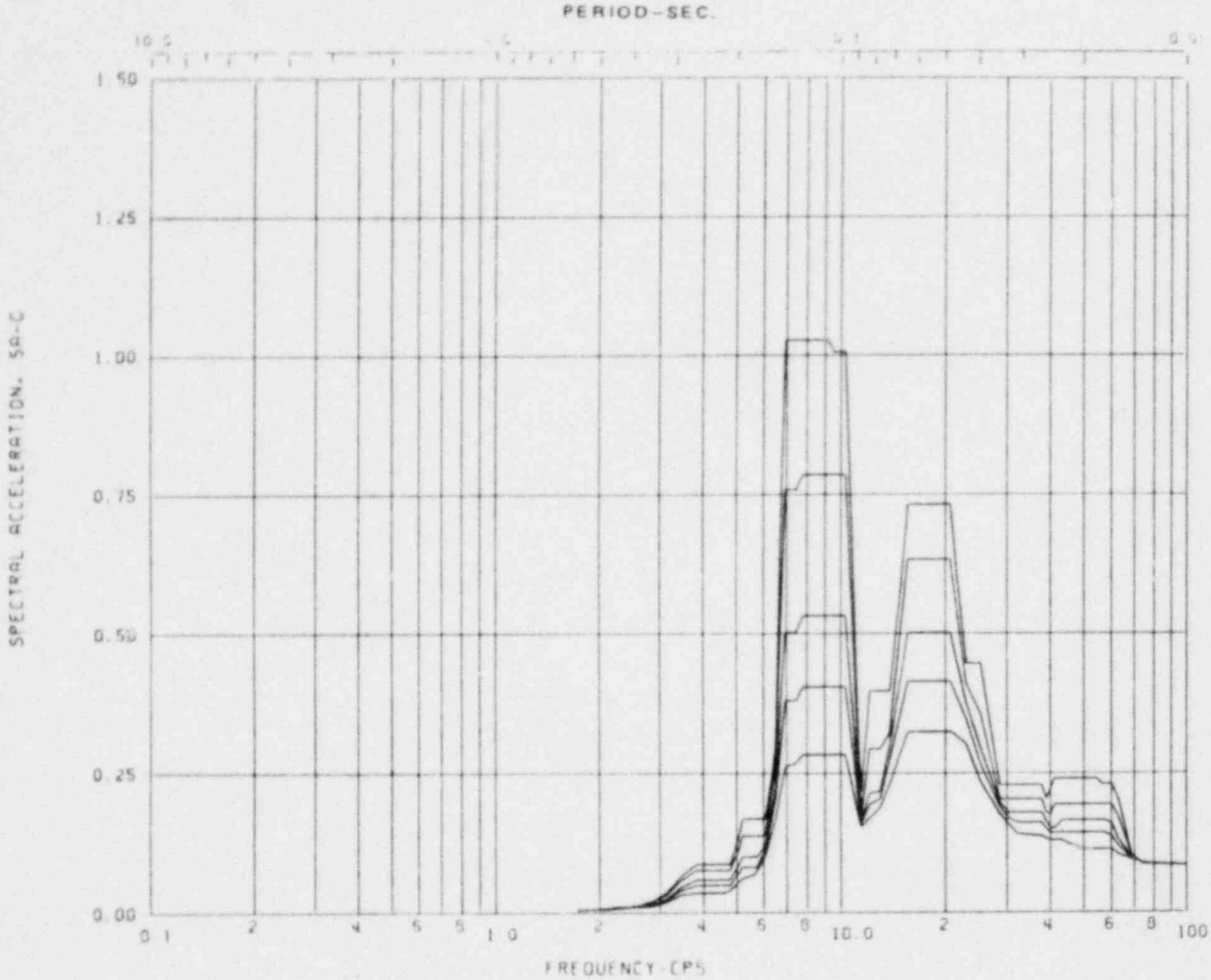
Node: 21 Direction: VERTICAL Elev: 333'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL RESPONSE SPECTRA, VERTICAL, CO – BASIC AXISYMMETRIC

FIGURE B.2-132



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC GE CO-BASIC ENVELOPE (WIDENED - 15%)

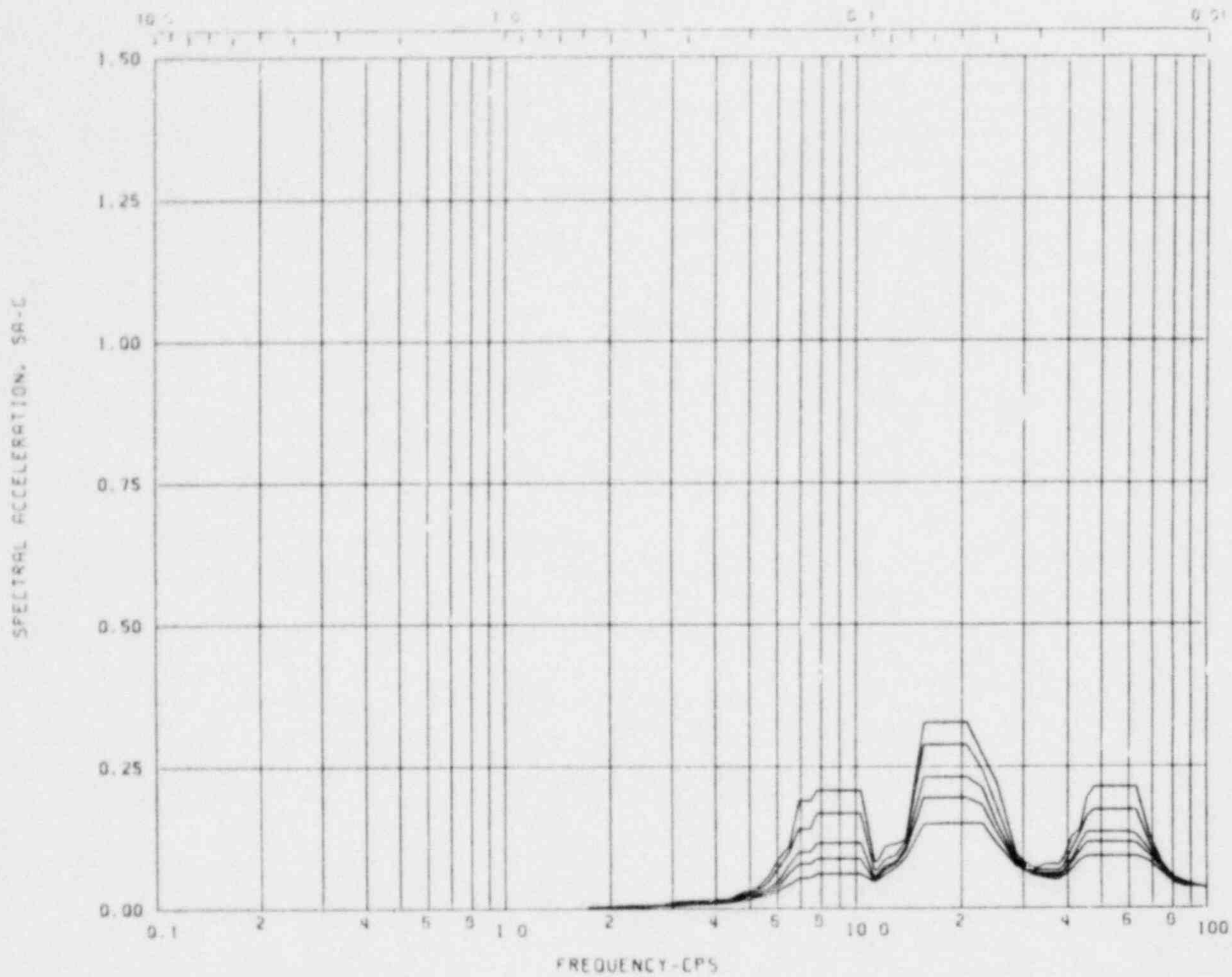
Node: 33 Direction: VERTICAL Elev: 333'-0

Damping: 0.005, 0.01, 0.02, 0.03, 0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL
RESPONSE SPECTRA, VERTICAL,
CO – BASIC AXISYMMETRIC

FIGURE B.2-133



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC GE CO-BASIC ENVELOPE (WIDENED - 15%)

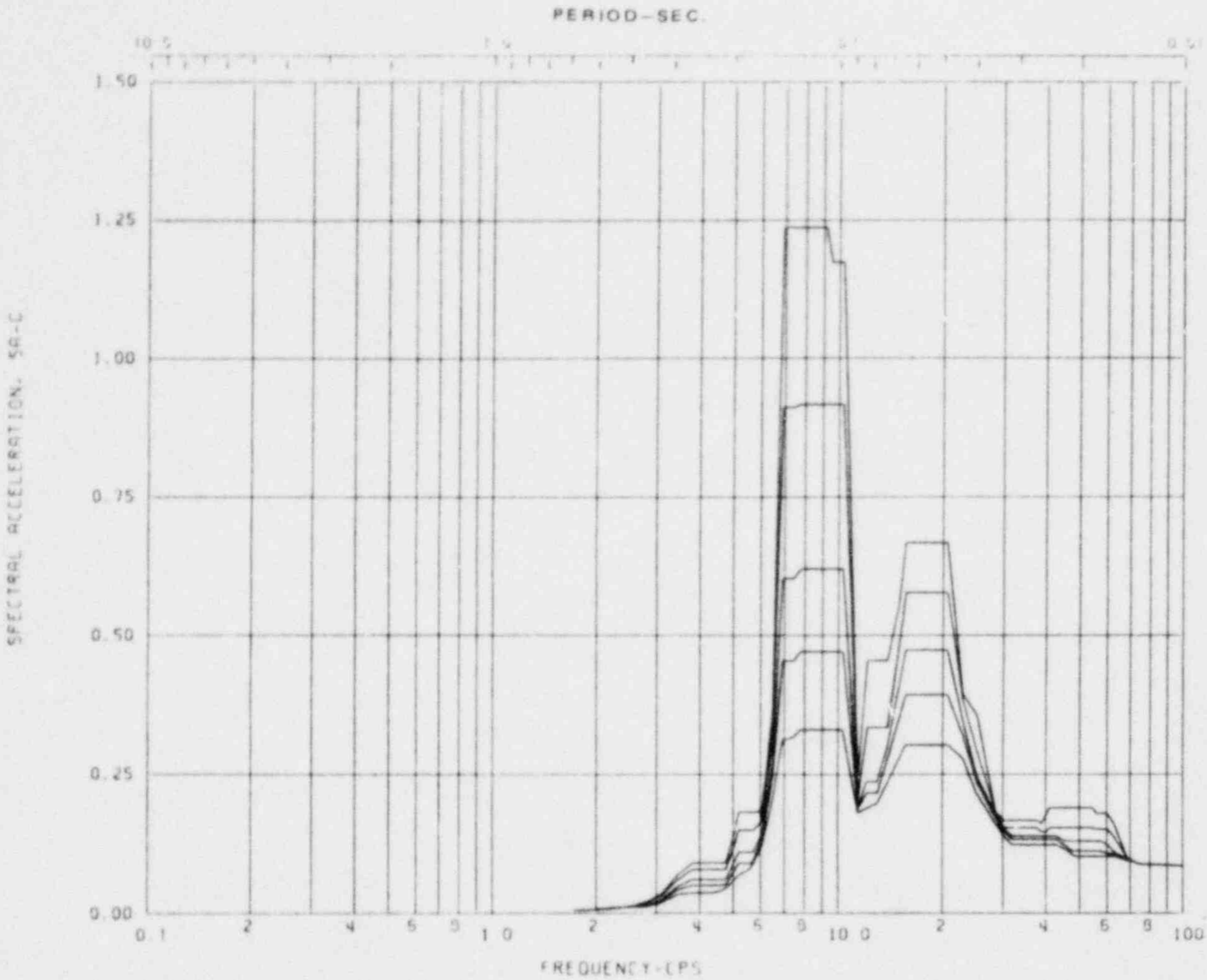
Node: 9 Direction: VERTICAL Elev: 352'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL
RESPONSE SPECTRA, VERTICAL,
CO – BASIC AXISYMMETRIC

FIGURE B.2-134



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC GE CO-BASIC ENVELOPE (WIDENED - 15%)

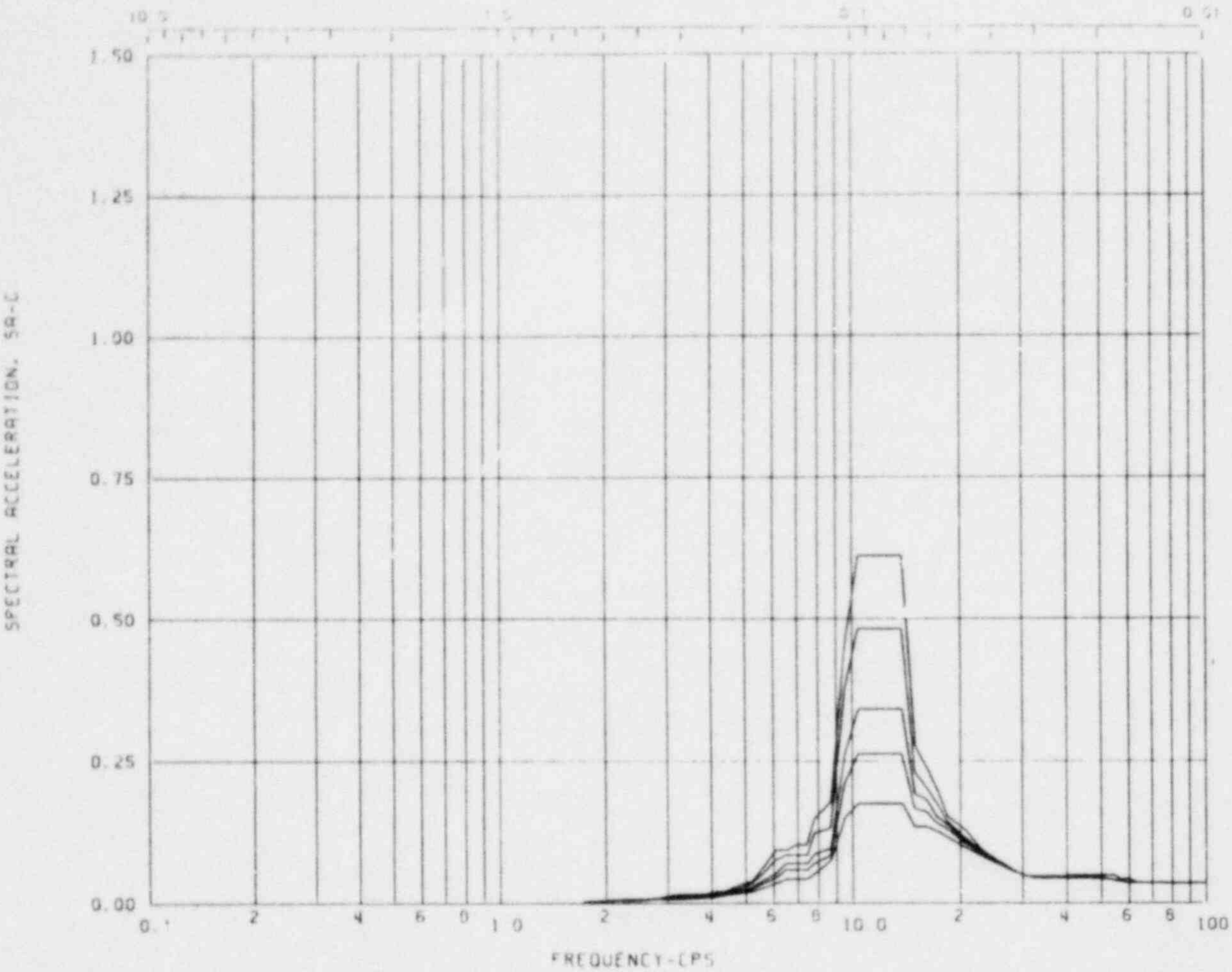
Node: 13 Direction: VERTICAL Elev: 352'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL
RESPONSE SPECTRA, VERTICAL,
CO – BASIC AXISYMMETRIC

FIGURE B.2-135



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC GE CO-BASIC ENVELOPE (WIDENED - 15%)

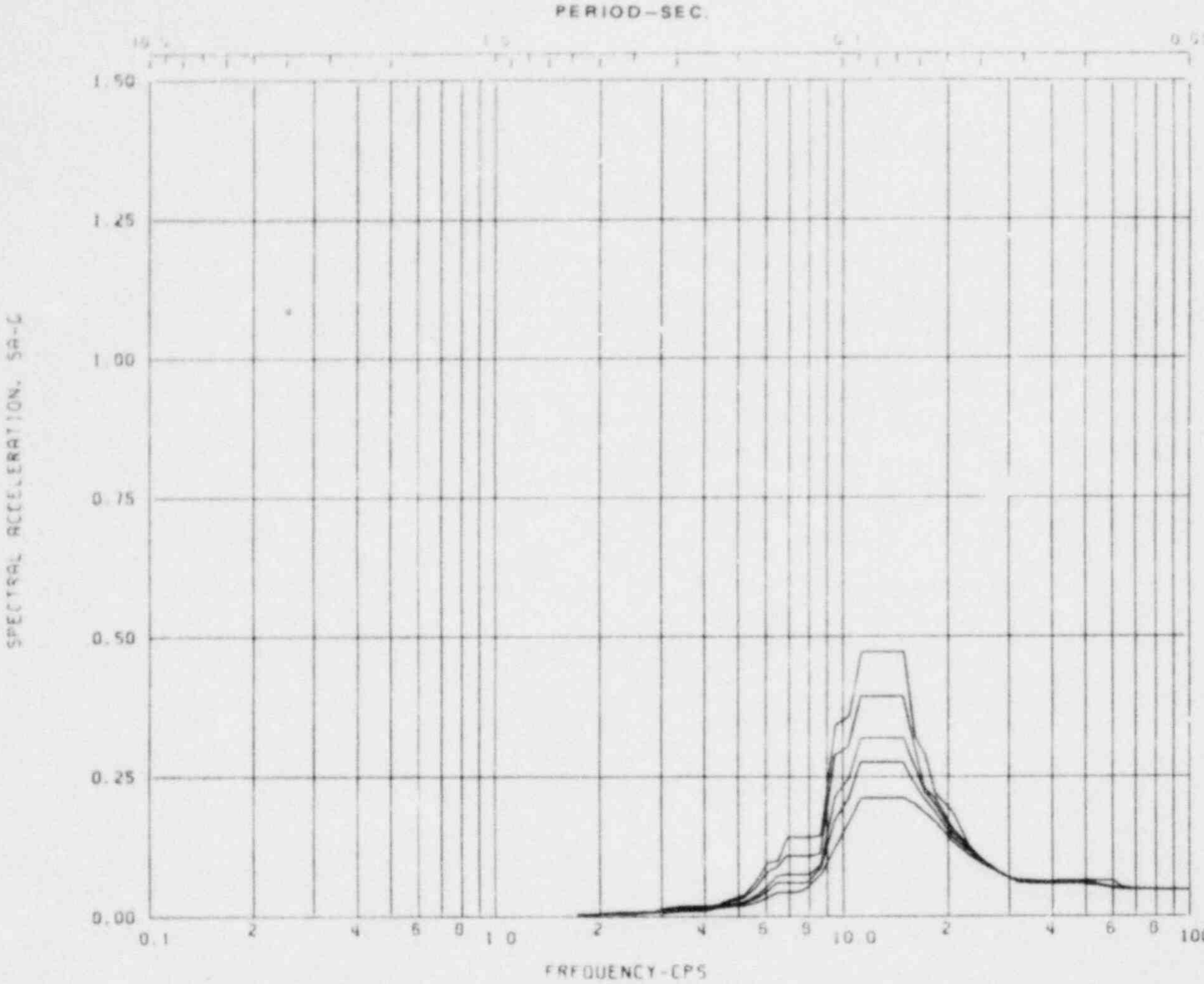
Node: 129 Direction: VERTICAL Elev: 201'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL RESPONSE SPECTRA, VERTICAL, CO – BASIC AXISYMMETRIC

FIGURE B.2-136



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC GE CO-BASIC ENVELOPE (WIDENED - 15%)

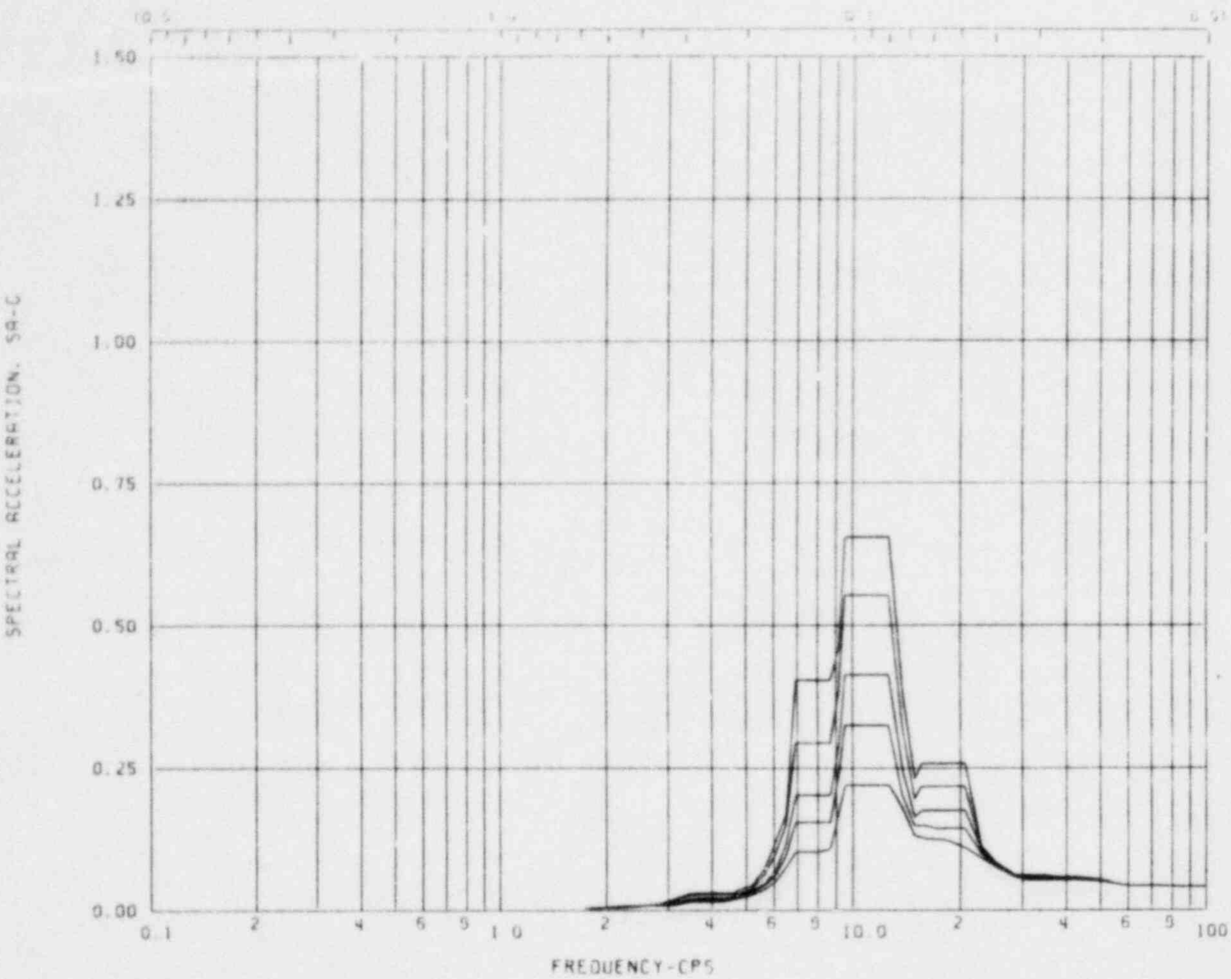
Node: 107 Direction: VERTICAL Elev: 217'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL
RESPONSE SPECTRA, VERTICAL,
CO – BASIC AXISYMMETRIC

FIGURE B.2-137



Acceleration Spectra for EACTOR BLDG.

Load Case: AXISYMMETRIC GE CO-BASIC ENVELOPE (WIDENED - 15%)

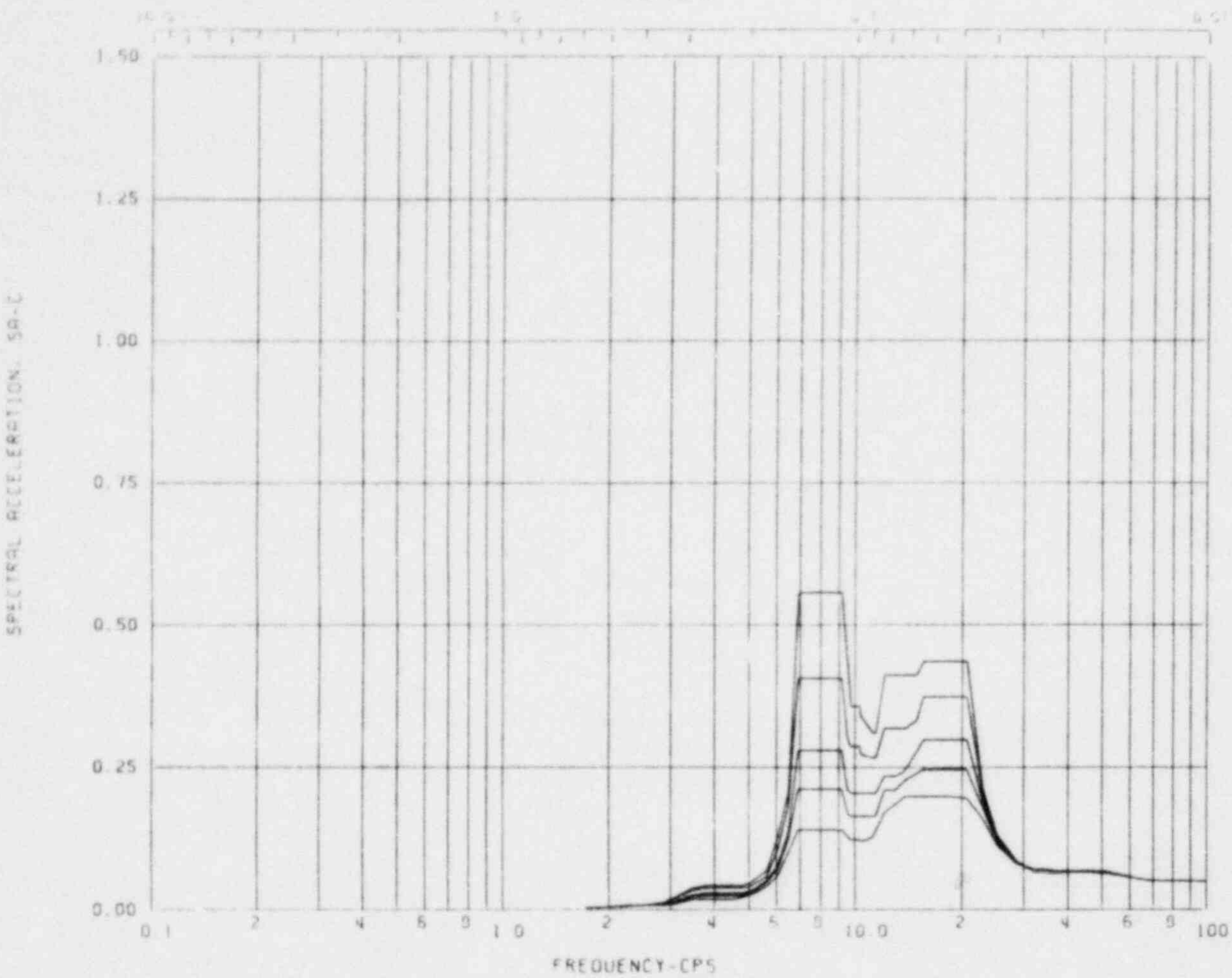
Node: 80 Direction: VERTICAL Elev: 253'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL
RESPONSE SPECTRA, VERTICAL,
CO – BASIC AXISYMMETRIC

FIGURE B.2-138



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC GE CO-BASIC ENVELOPE (WIDENED - 15%)

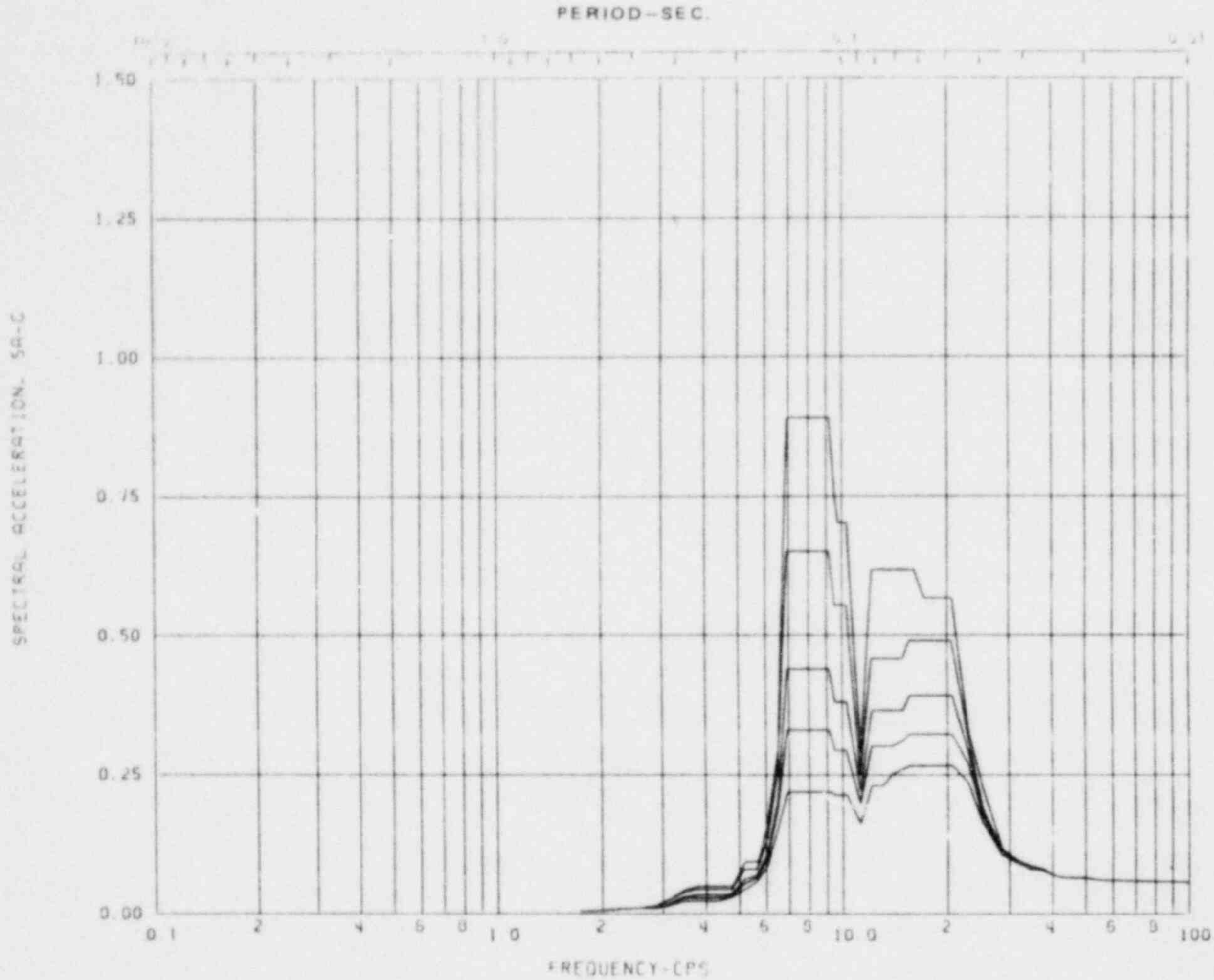
Node: 59 Direction: VERTICAL Elev: 283'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL RESPONSE SPECTRA, VERTICAL, CO – BASIC AXISYMMETRIC

FIGURE B.2-139



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC GE CO-BASIC ENVELOPE (WIDENED - 15%)

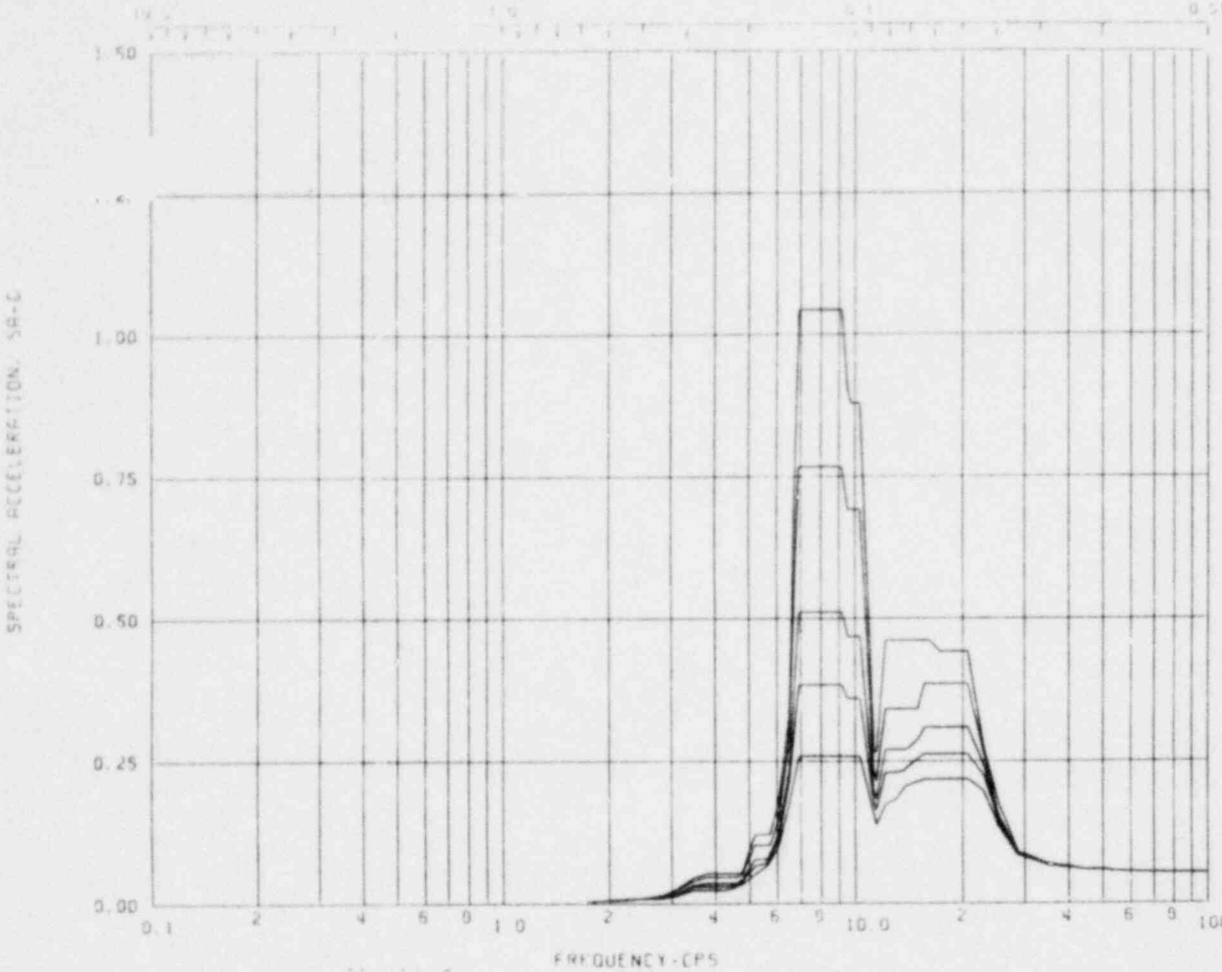
Node: 54 Direction: VERTICAL Elev: 313'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL
RESPONSE SPECTRA, VERTICAL,
CO – BASIC AXISYMMETRIC

FIGURE B.2-140



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC GE CO-BASIC ENVELOPE (WIDENED - 15%)

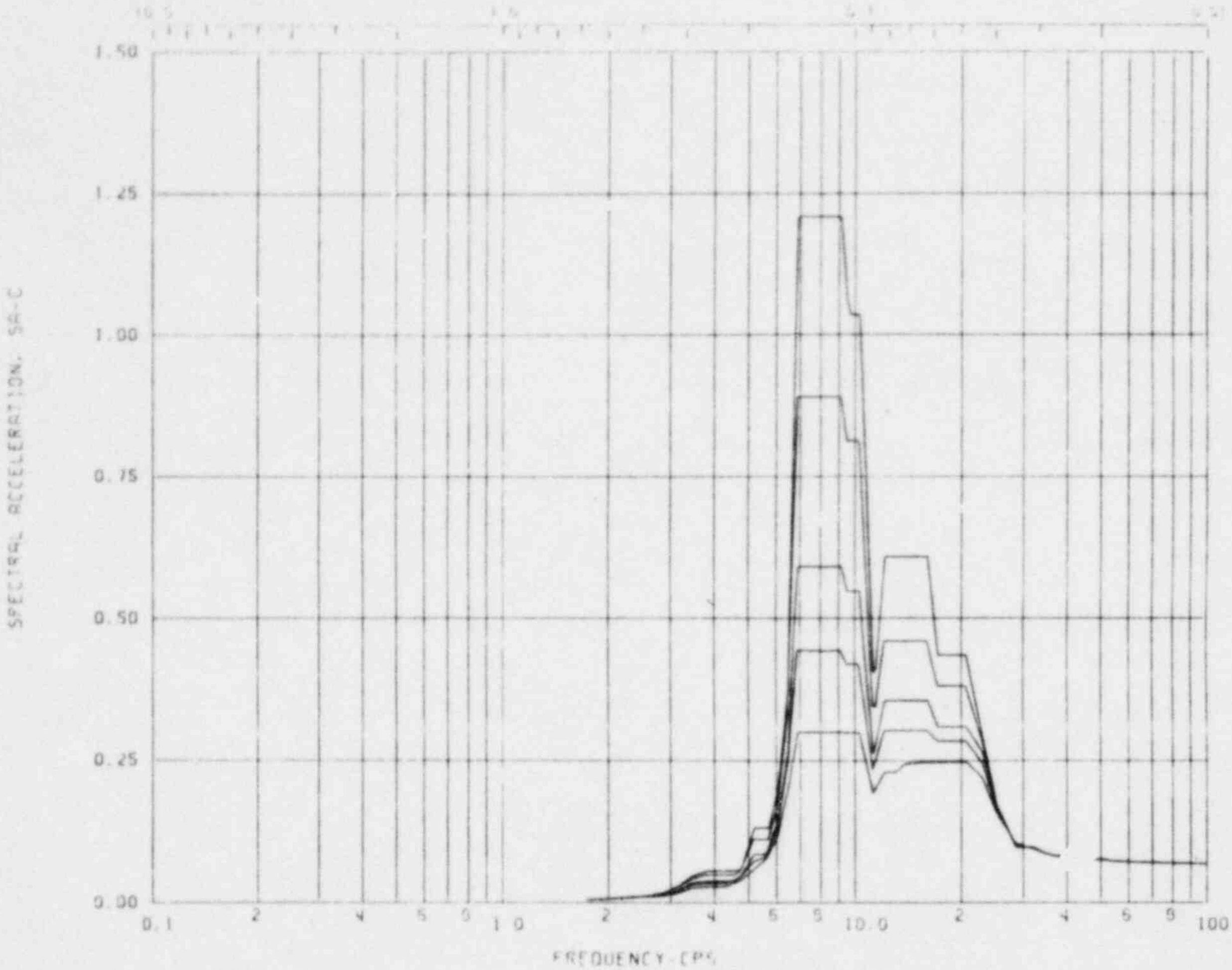
Node: 32 Direction: VERTICAL Elev: 333'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL RESPONSE SPECTRA, VERTICAL, CO – BASIC AXISYMMETRIC

FIGURE B.2-141



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC GE CO-BASIC ENVELOPE (WIDENED - 15%)

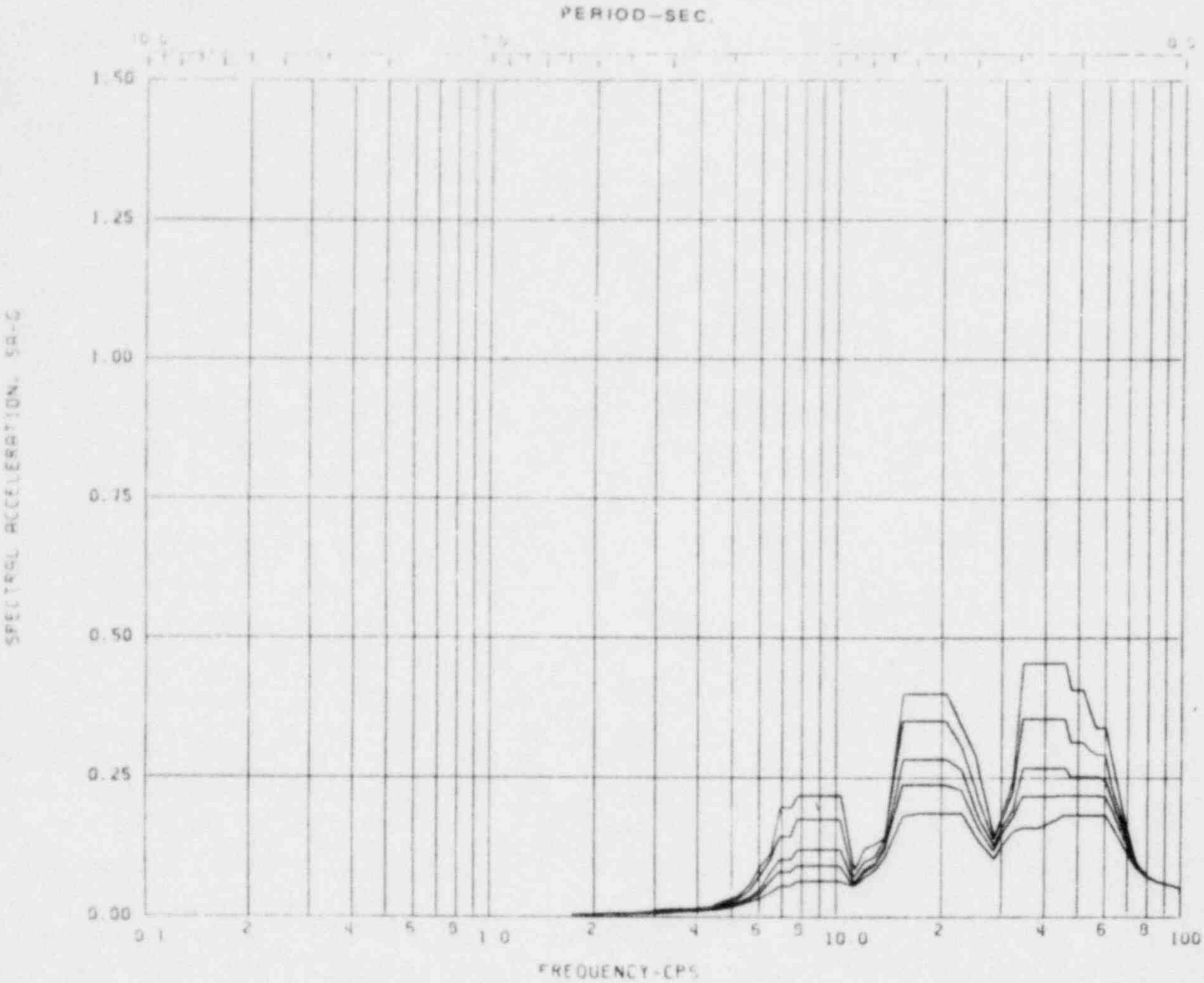
Node: 12 Direction: VERTICAL Elev: 352'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL RESPONSE SPECTRA, VERTICAL, CO – BASIC AXISYMMETRIC

FIGURE B.2-142



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC GE CO-BASIC ENVELOPE (WIDENED - 15%)

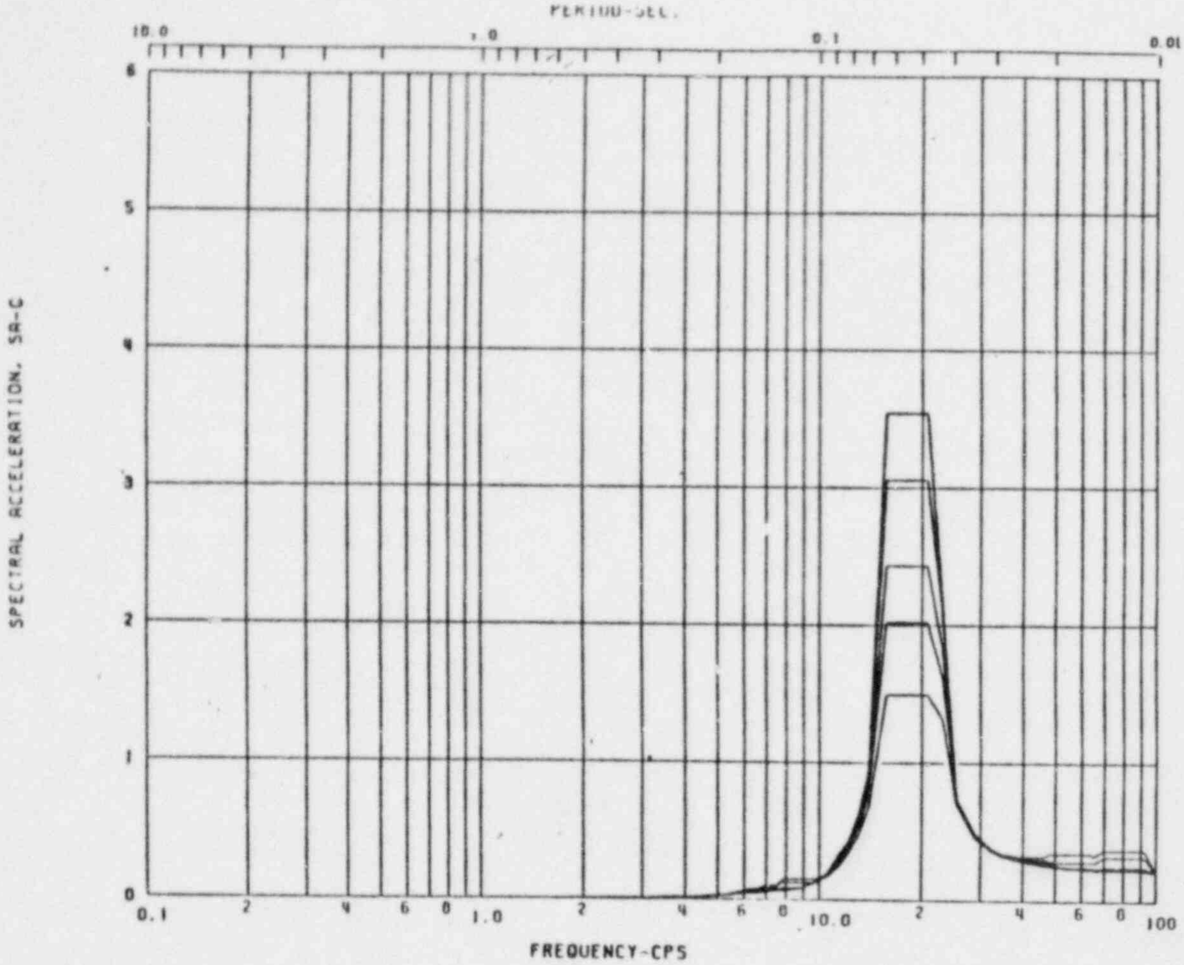
Node: 6 Direction: VERTICAL Elev: 410'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL
RESPONSE SPECTRA, VERTICAL,
CO – BASIC AXISYMMETRIC

FIGURE B.2-143



Acceleration Spectra for CONTROL STRUCTURE

Load Case: AXISYMMETRIC GE CO-BASIC ENVELOPE (WIDENED - 15%)

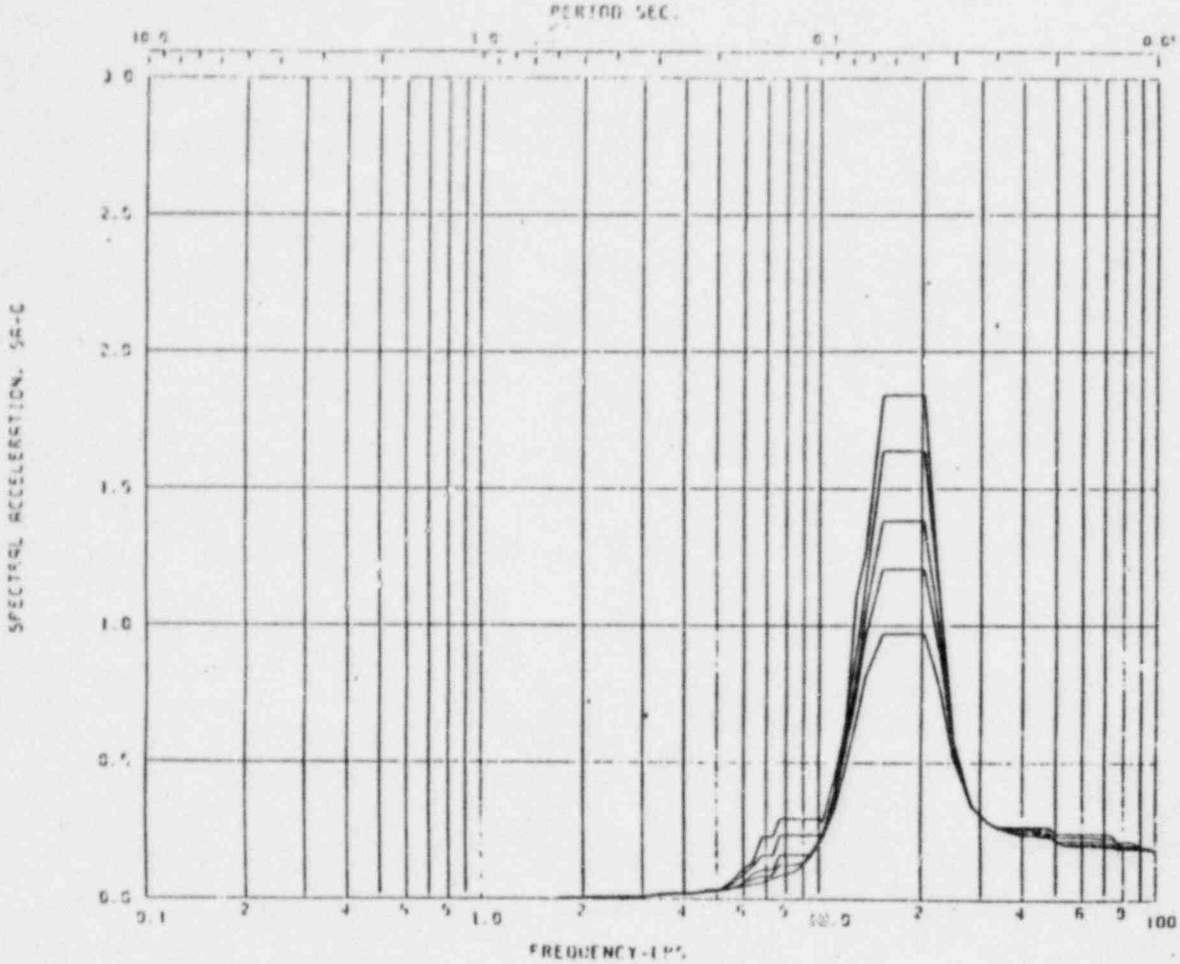
Node: 7 Direction: VERTICAL Elev: 217'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTROL STRUCTURE
LOCAL RESPONSE SPECTRA, VERTICAL,
CO – BASIC AXISYMMETRIC

FIGURE B.2-144



Acceleration Spectra for CONTROL STRUCTURE

Load Case: AXISYMMETRIC GE CO-BASIC ENVELOPE (WIDENED - 15%)

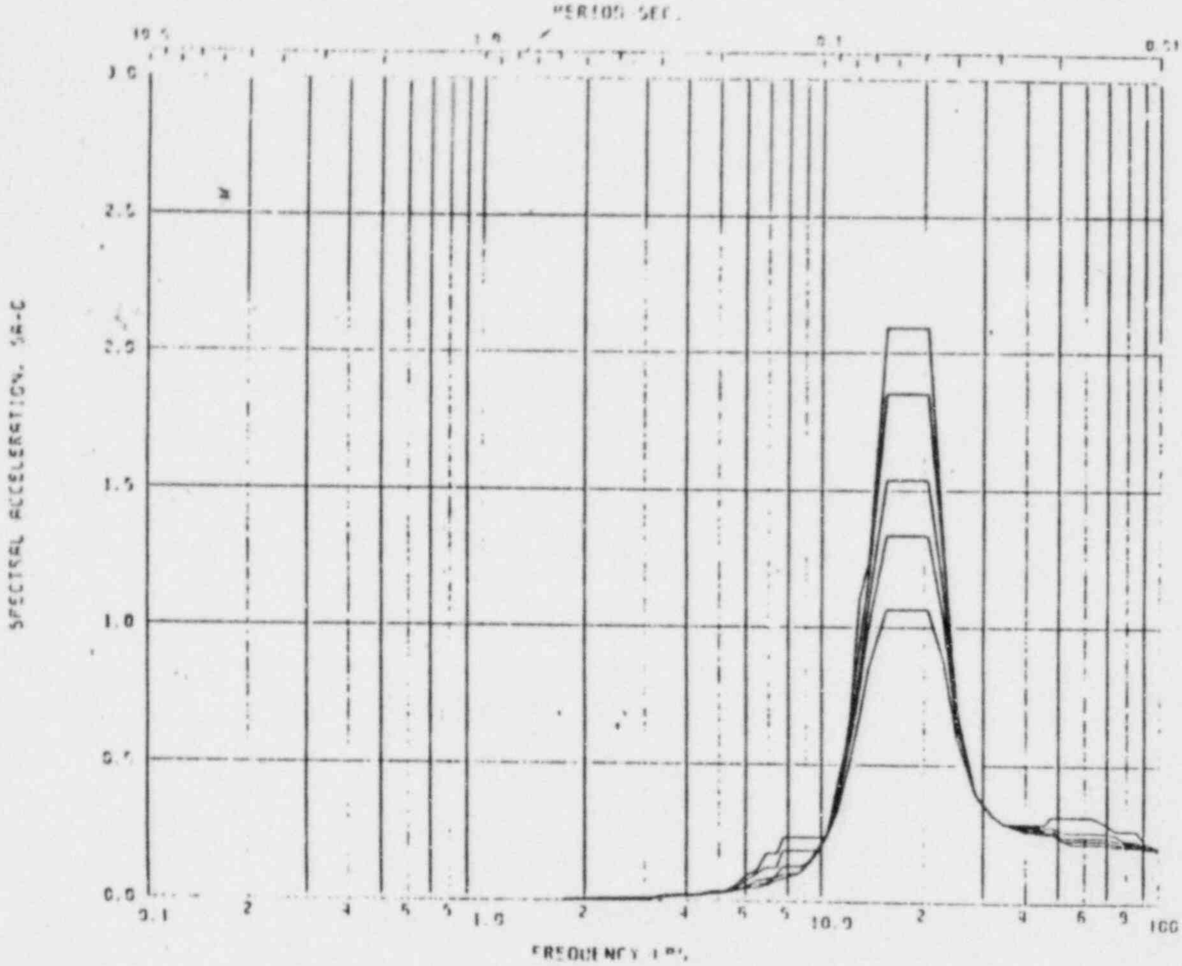
Node: 7 Direction: VERTICAL Elev: 239'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTROL STRUCTURE
LOCAL RESPONSE SPECTRA, VERTICAL,
CO – BASIC AXISYMMETRIC

FIGURE B.2-145



Acceleration Spectra for CONTROL STRUCTURE

Load Case: AXISYMMETRIC GE CO-BASIC ENVELOPE (WIDENED - 15%)

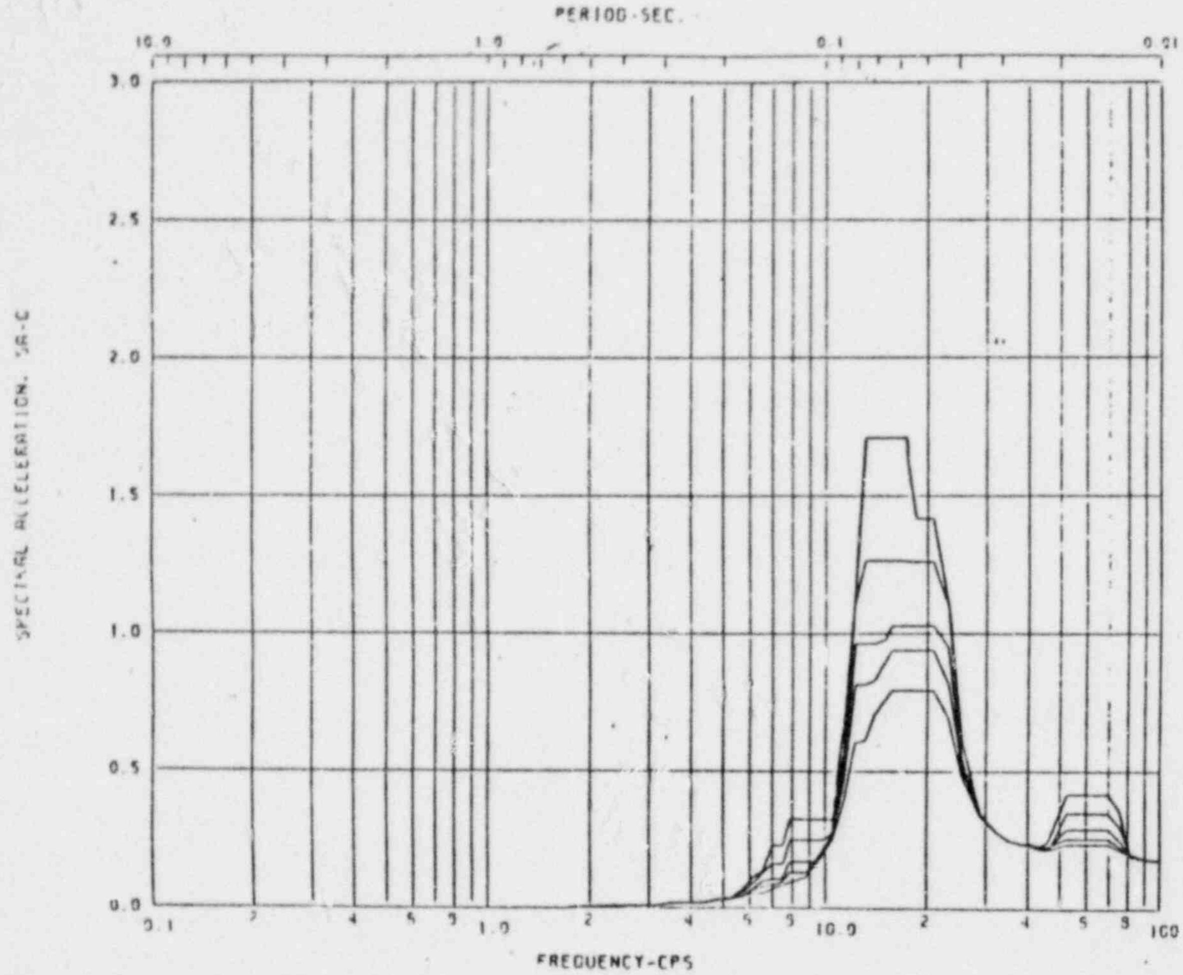
Node: 7 Direction: VERTICAL Elev: 254'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTROL STRUCTURE
LOCAL RESPONSE SPECTRA, VERTICAL,
CO – BASIC AXISYMMETRIC

FIGURE B.2-146



Acceleration Spectra for CONTROL STRUCTURE

Load Case: AXISYMMETRIC GE CO-BASIC ENVELOPE (WIDENED - 15%)

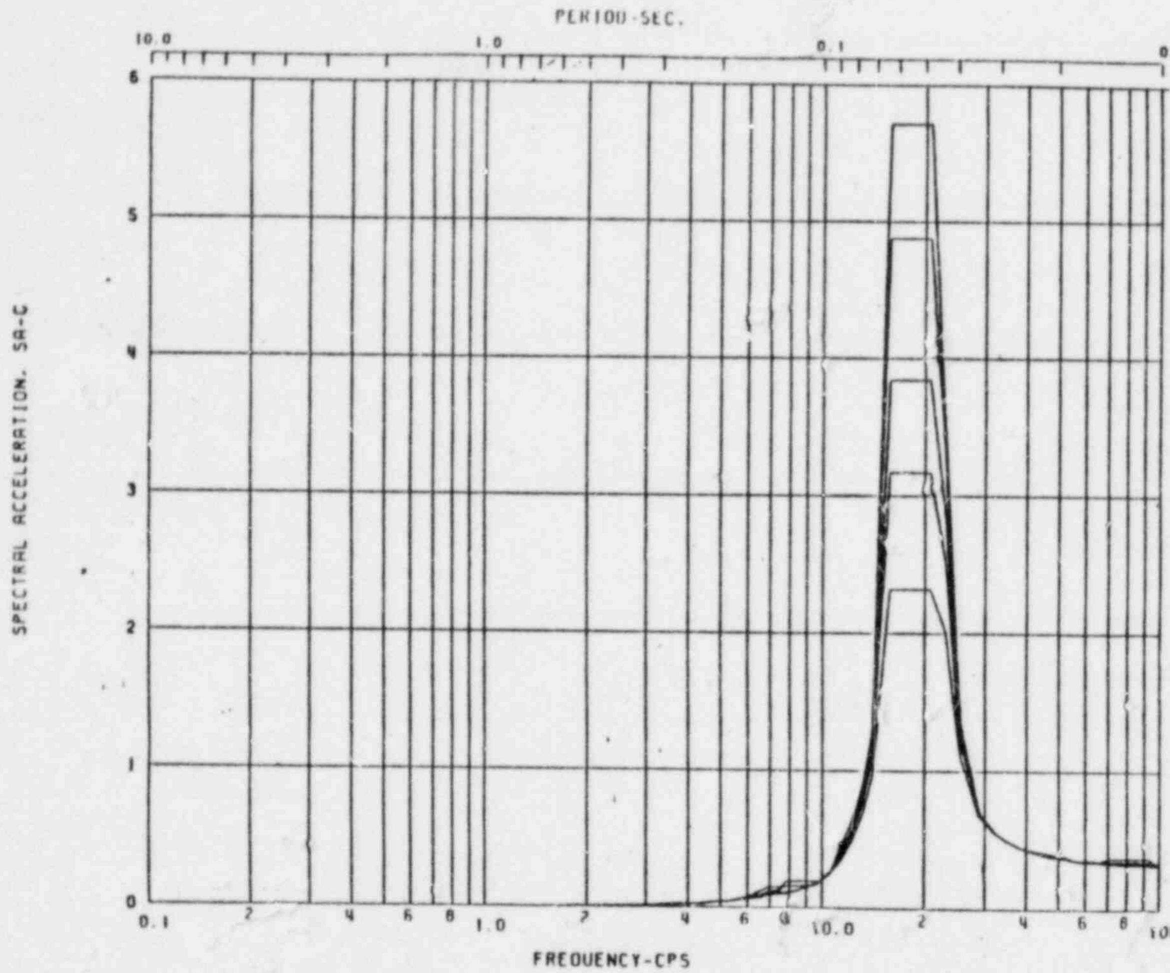
Node: 7 Direction: VERTICAL Elev: 269'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTROL STRUCTURE
LOCAL RESPONSE SPECTRA, VERTICAL,
CO – BASIC AXISYMMETRIC

FIGURE B.2-147



Acceleration Spectra for CONTROL STRUCTURE

Load Case: AXISYMMETRIC GE CO-BASIC ENVELOPE (WIDENED - 15%)

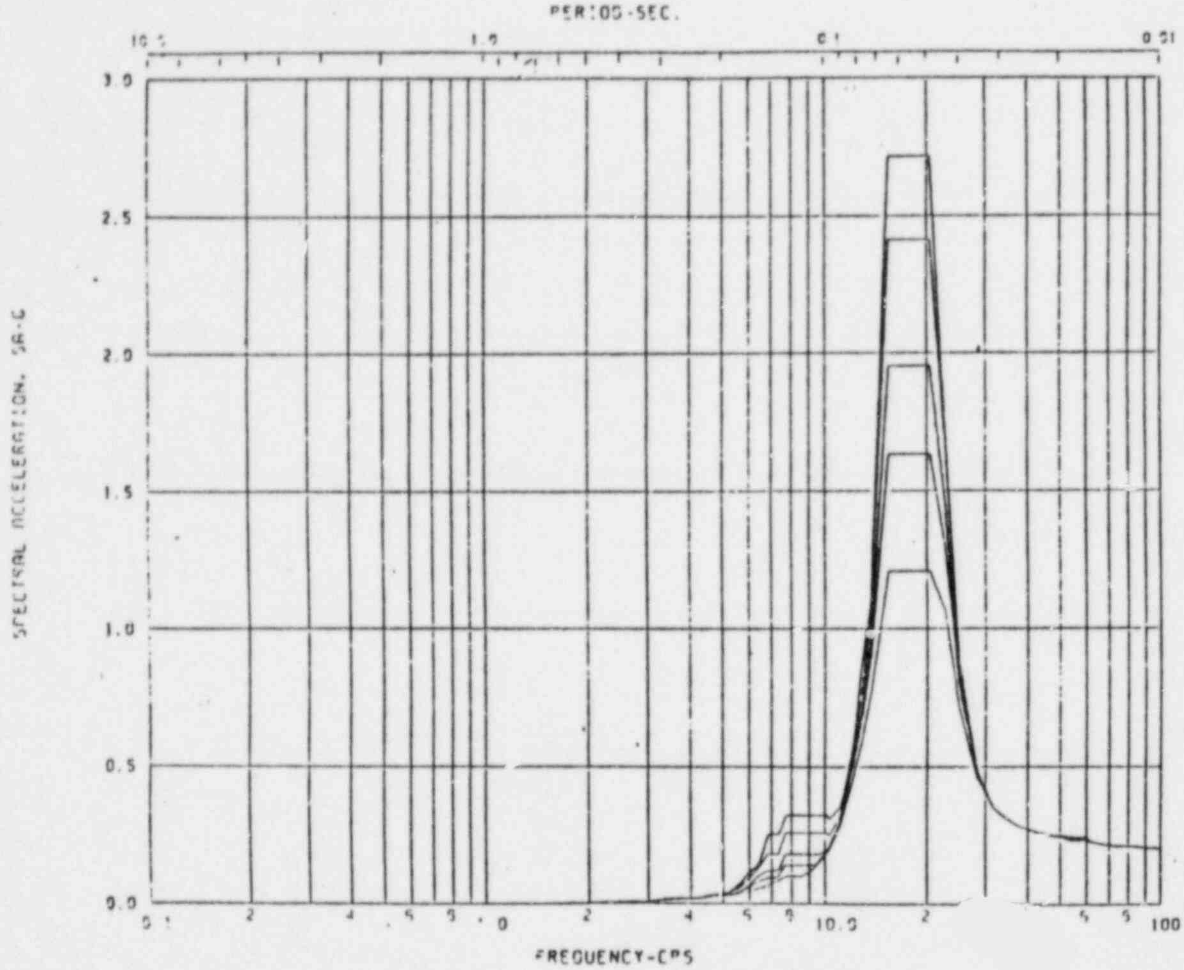
Node: 7 Direction: VERTICAL Elev: 289'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTROL STRUCTURE
LOCAL RESPONSE SPECTRA, VERTICAL,
CO – BASIC AXISYMMETRIC

FIGURE B.2-148



Acceleration Spectra for CONTROL STRUCTURE

Load Case: AXISYMMETRIC GE CO-BASIC ENVELOPE (WIDENED - 15%)

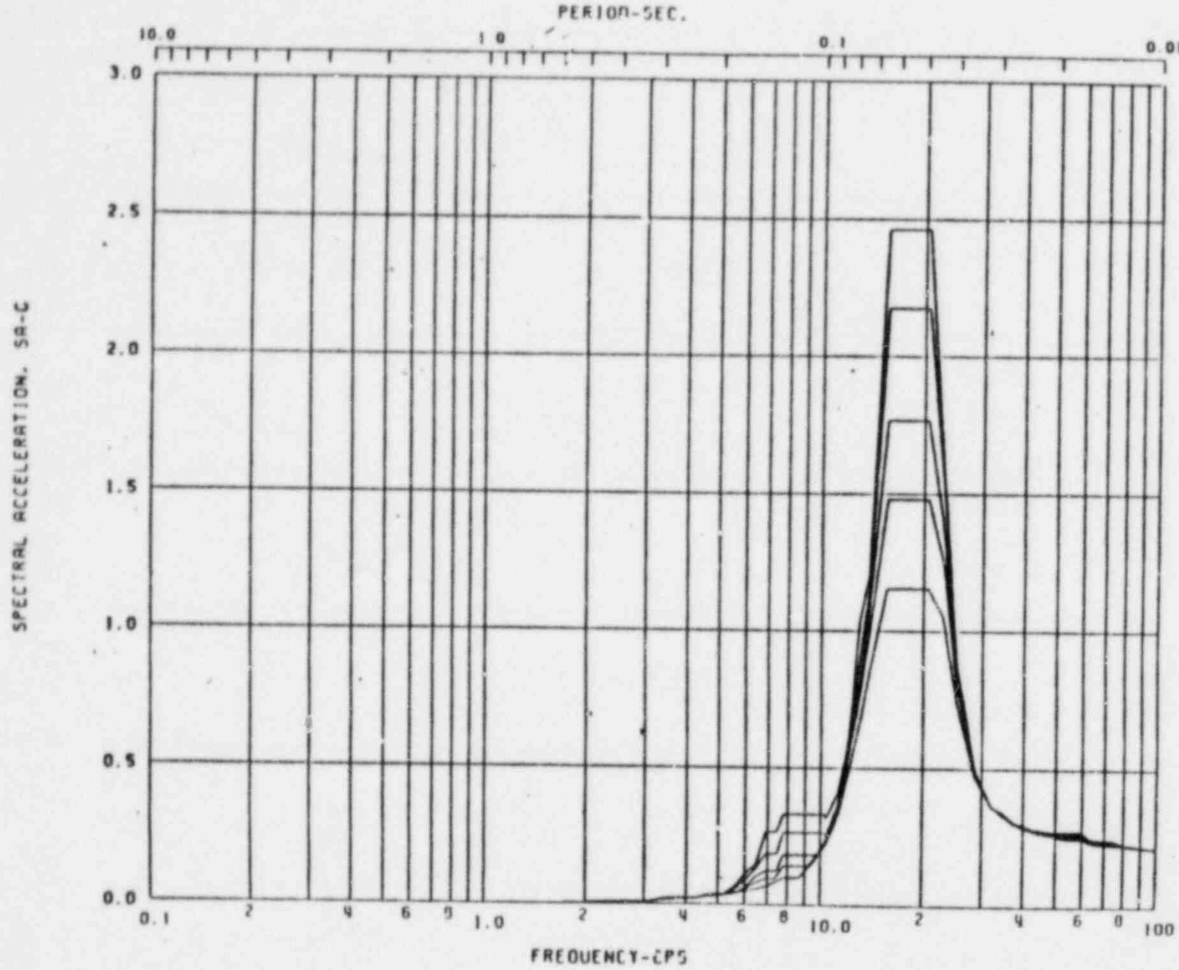
Node: 7 Direction: VERTICAL Elev: 304'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTROL STRUCTURE
LOCAL RESPONSE SPECTRA, VERTICAL,
CO – BASIC AXISYMMETRIC

FIGURE B.2-149



Acceleration Spectra for CONTROL STRUCTURE

Load Case: AXISYMMETRIC GE CO-BASIC ENVELOPE (WIDENED - 15%)

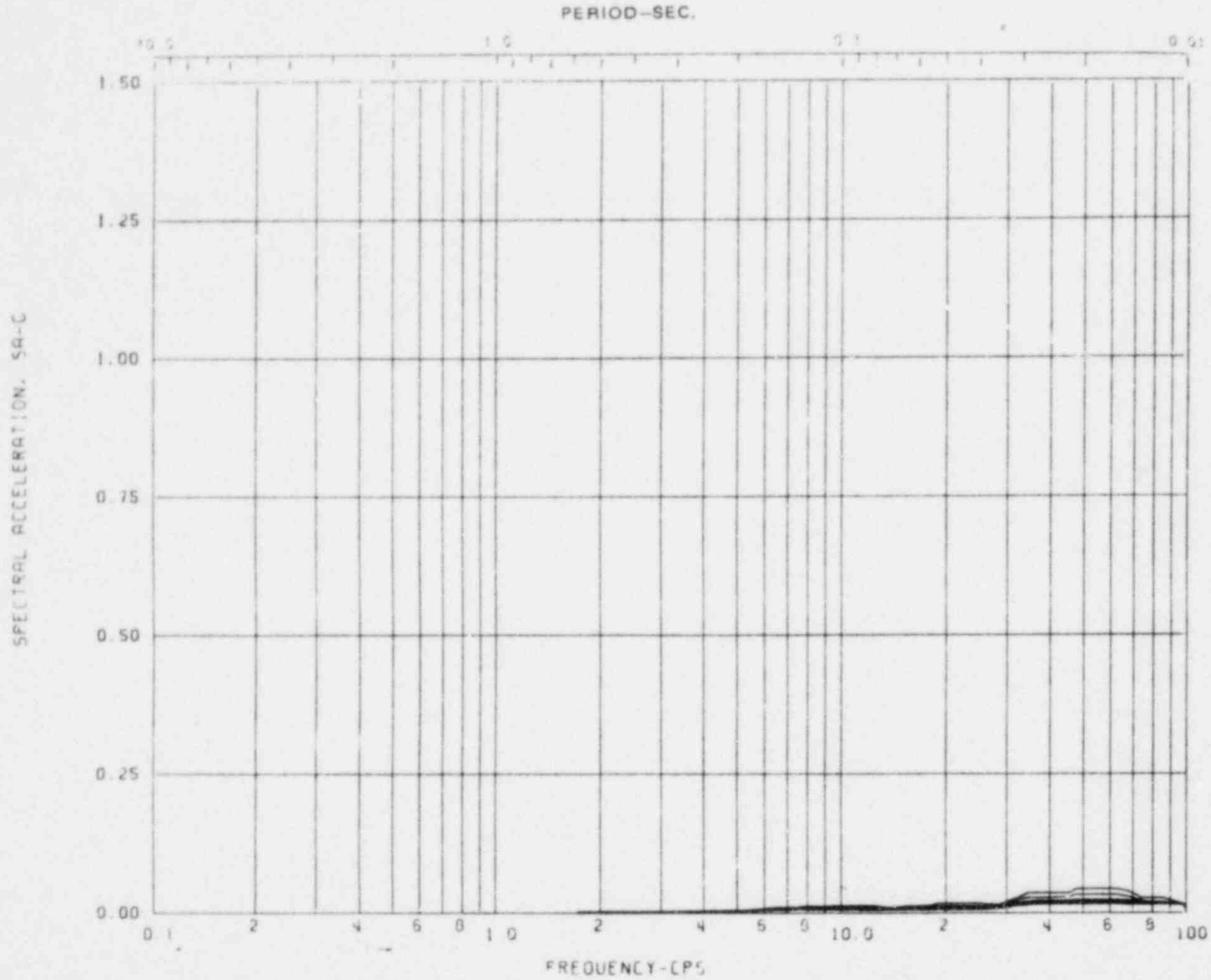
Node: 7 Direction: VERTICAL Elev: 332'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTROL STRUCTURE
LOCAL RESPONSE SPECTRA, VERTICAL,
CO – BASIC AXISYMMETRIC

FIGURE B.2-150



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC GE CO-ADS ENVELOPE (WIDENED - 15%)

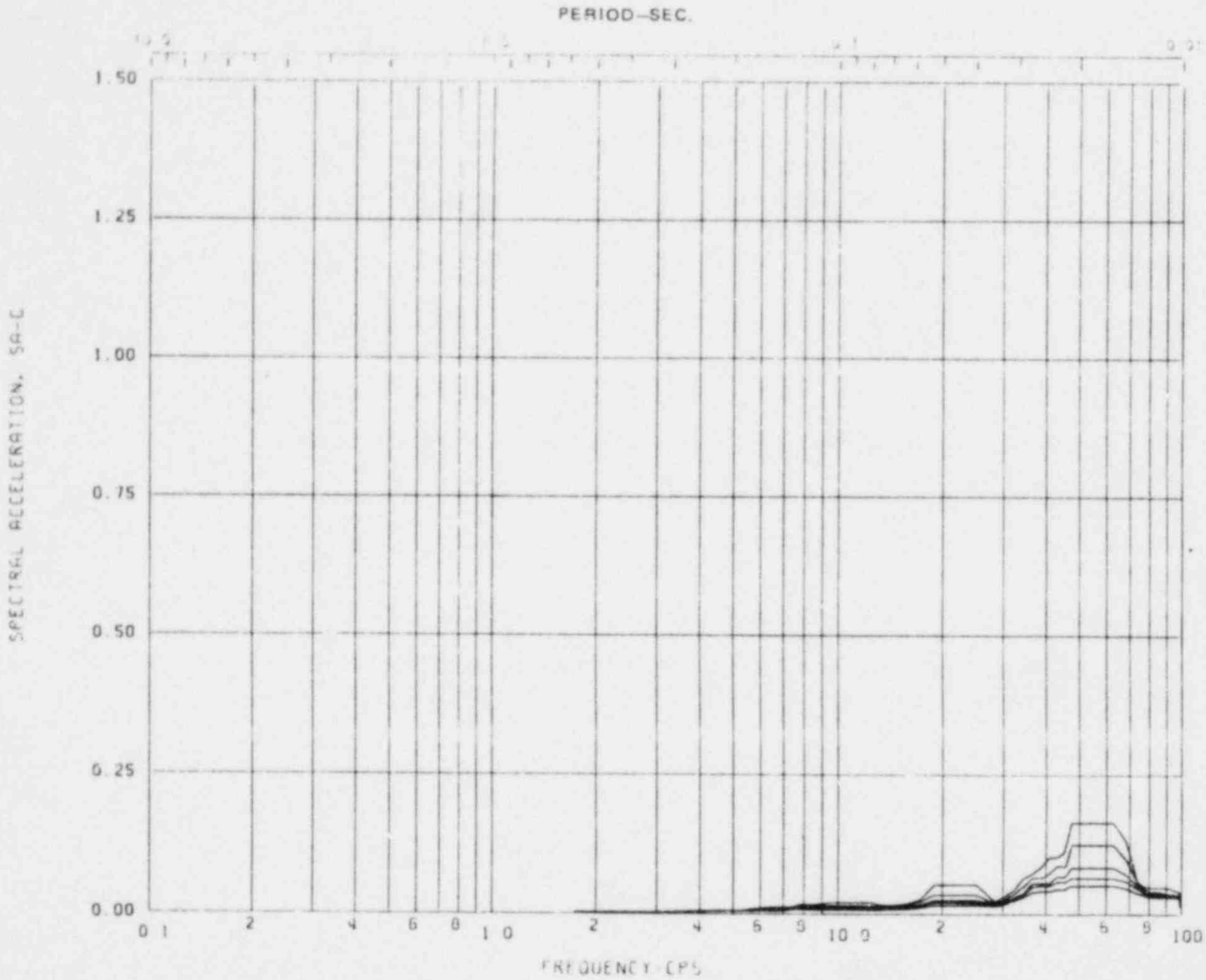
Node: 159 Direction: VERTICAL Elev: 177'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL RESPONSE SPECTRA, VERTICAL, CO – ADS AXISYMMETRIC

FIGURE B.2-151



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC GE CO-ADS ENVELOPE (WIDENED - 15%)

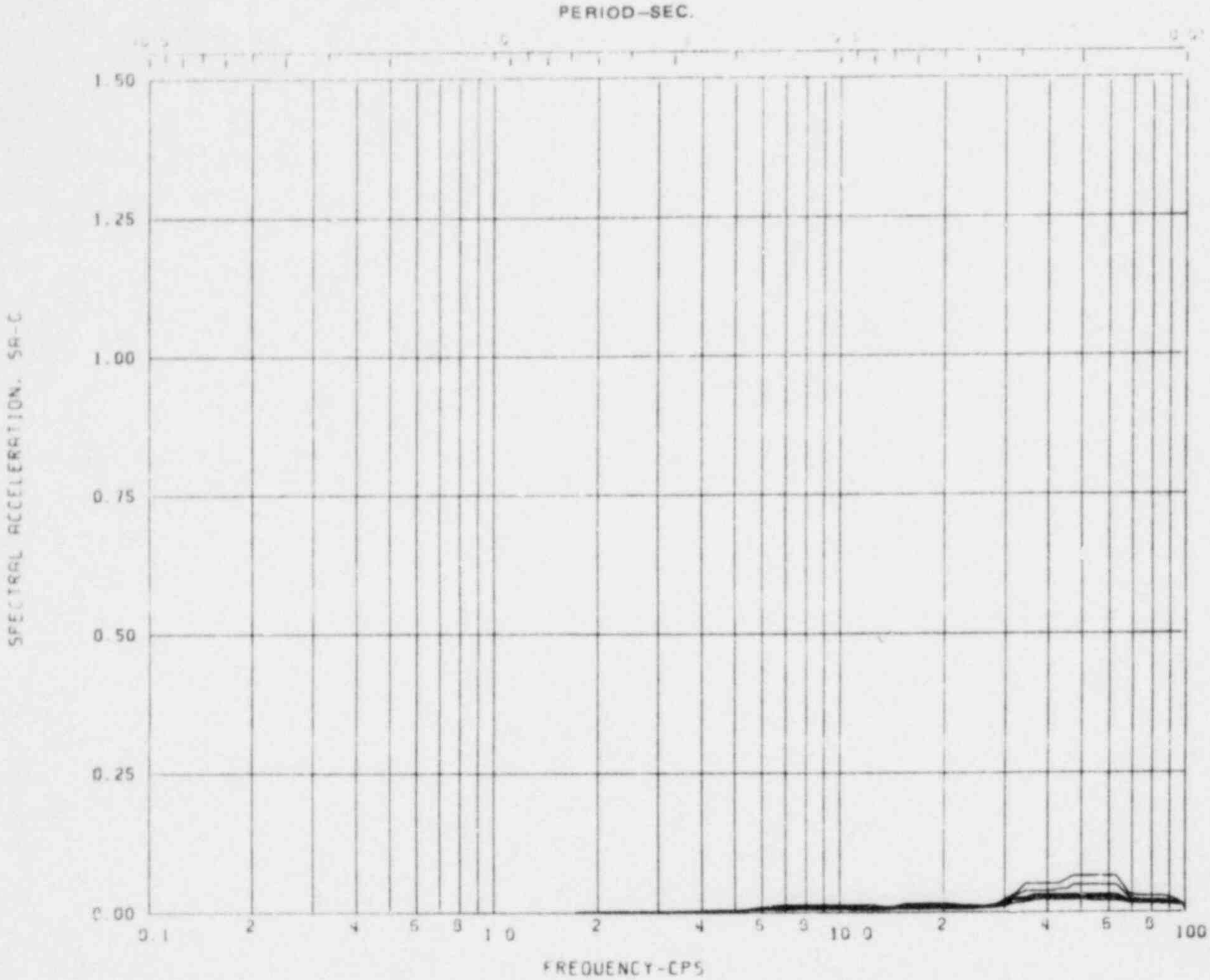
Node: 154 Direction: VERTICAL Elev: 177'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL RESPONSE SPECTRA, VERTICAL, CO – ADS AXISYMMETRIC

FIGURE B.2-152



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC GE CO-ADS ENVELOPE (WIDENED - 15%)

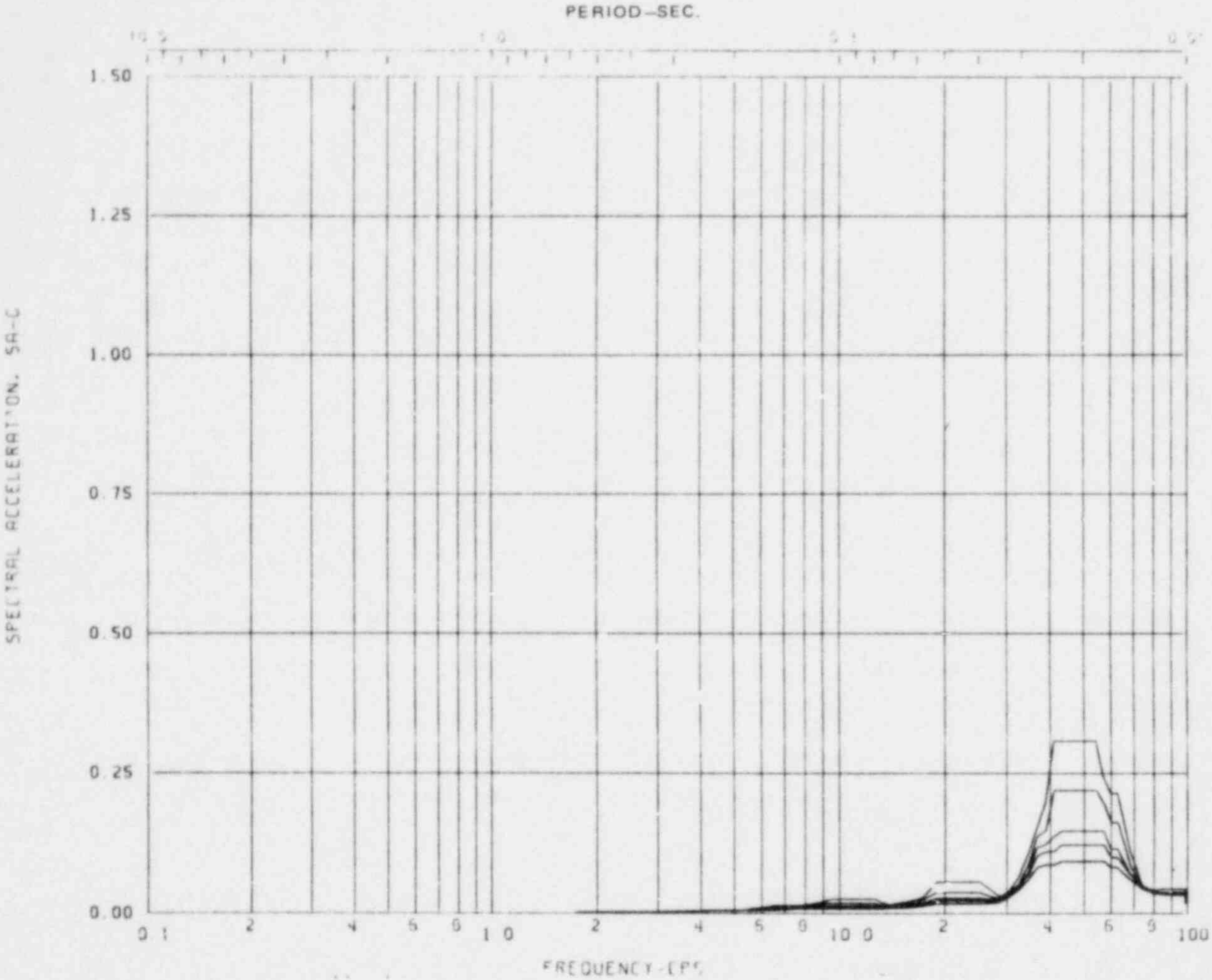
Node: 128 Direction: VERTICAL Elev: 201'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL
RESPONSE SPECTRA, VERTICAL,
CO – ADS AXISYMMETRIC

FIGURE B.2-153



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC GE CO-ADS ENVELOPE (WIDENED - 15%)

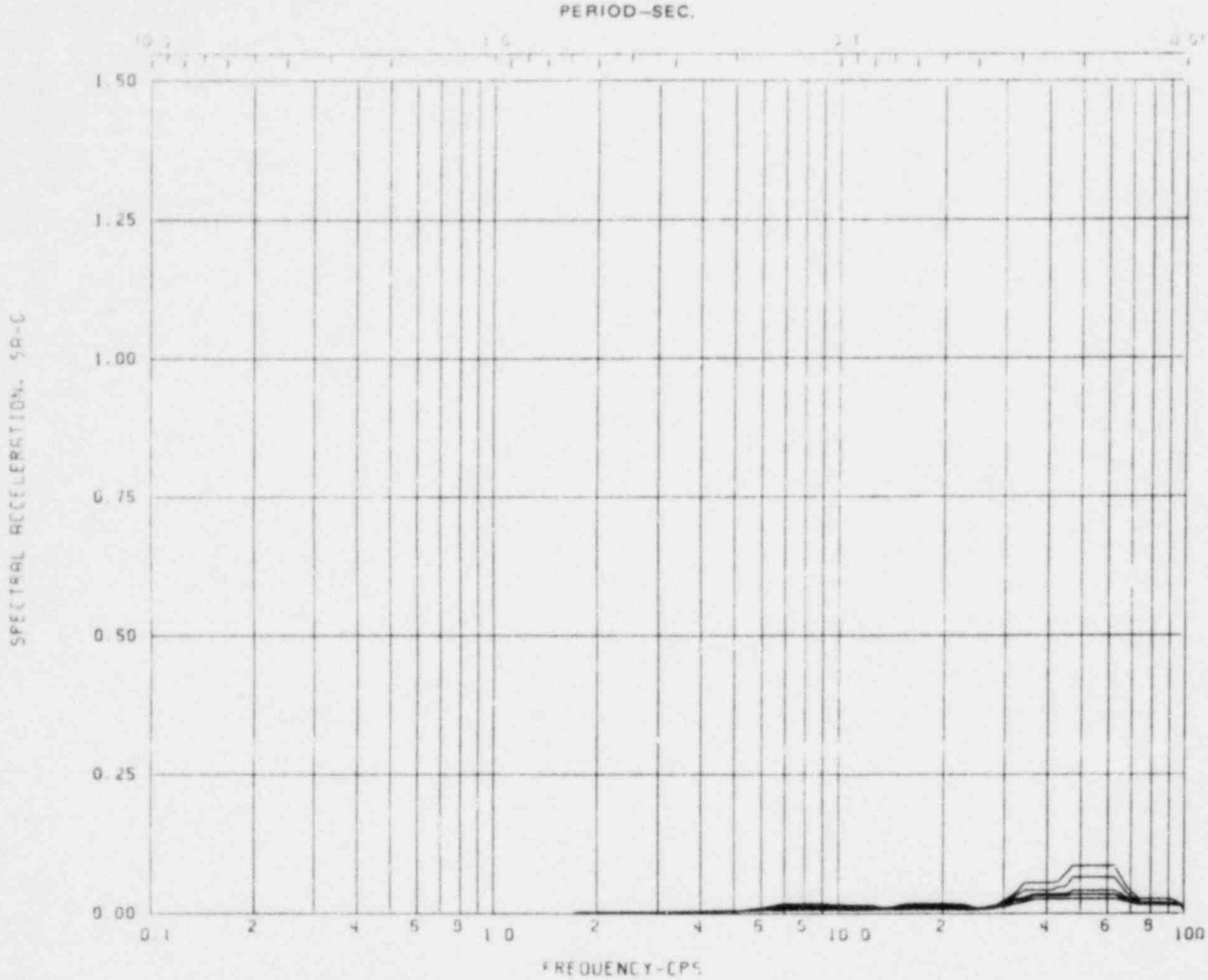
Node: 130 Direction: VERTICAL Elev: 201'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL RESPONSE SPECTRA, VERTICAL, CO – ADS AXISYMMETRIC

FIGURE B.2-154



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC GE CO-ADS ENVELOPE (WIDENED - 15%)

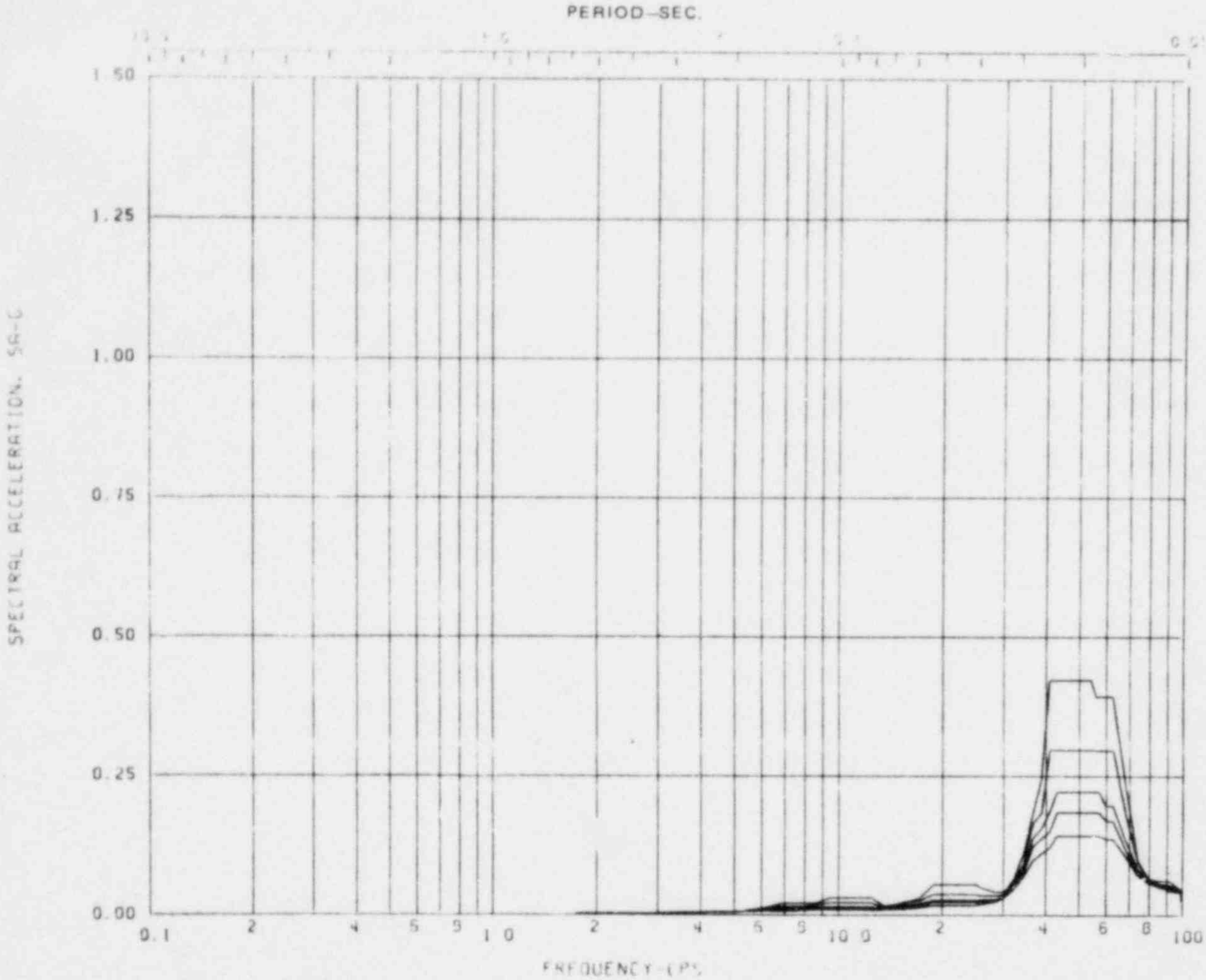
Node: 106 Direction: VERTICAL Elev: 217'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL RESPONSE SPECTRA, VERTICAL, CO – ADS AXISYMMETRIC

FIGURE B.2-155



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC GE CO-ADS ENVELOPE (WIDENED - 15%)

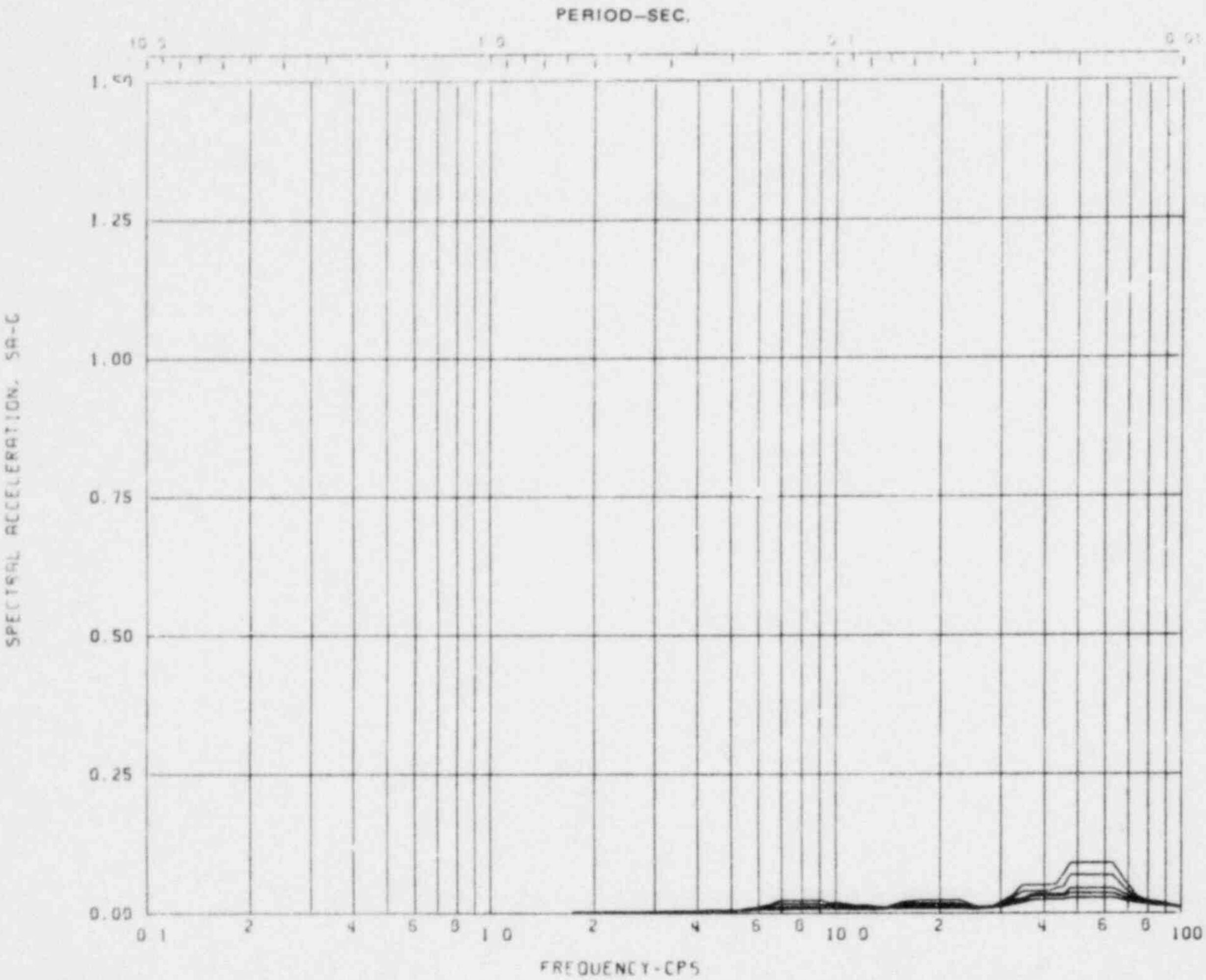
Node: 108 Direction: VERTICAL Elev: 217'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL RESPONSE SPECTRA, VERTICAL, CO – ADS AXISYMMETRIC

FIGURE B.2-156



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC GE CO-ADS ENVELOPE (WIDENED - 15%)

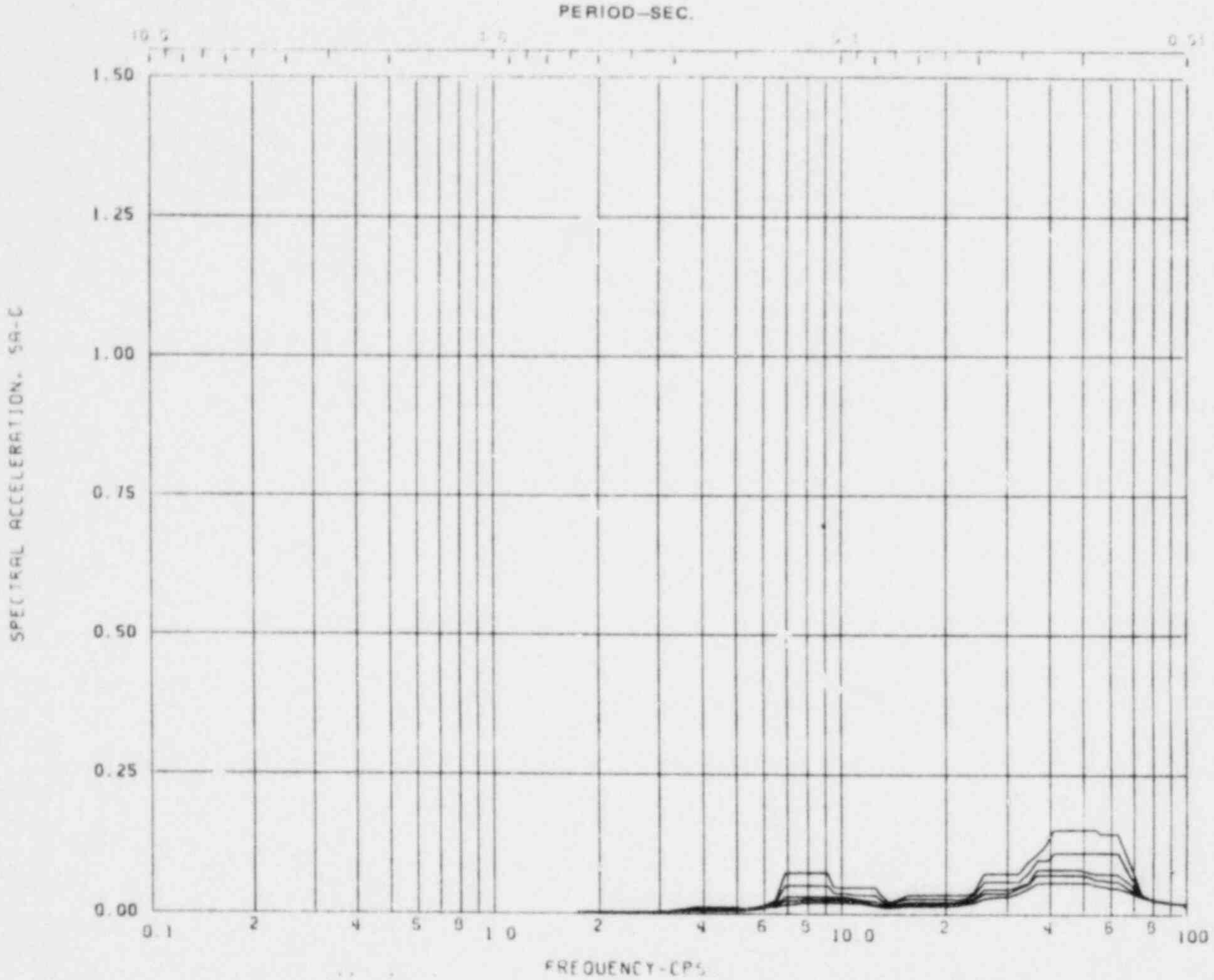
Node: 104 Direction: VERTICAL Elev: 239'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL
RESPONSE SPECTRA, VERTICAL,
CO – ADS AXISYMMETRIC

FIGURE B.2-157



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC GE CO-ADS ENVELOPE (WIDENED - 15%)

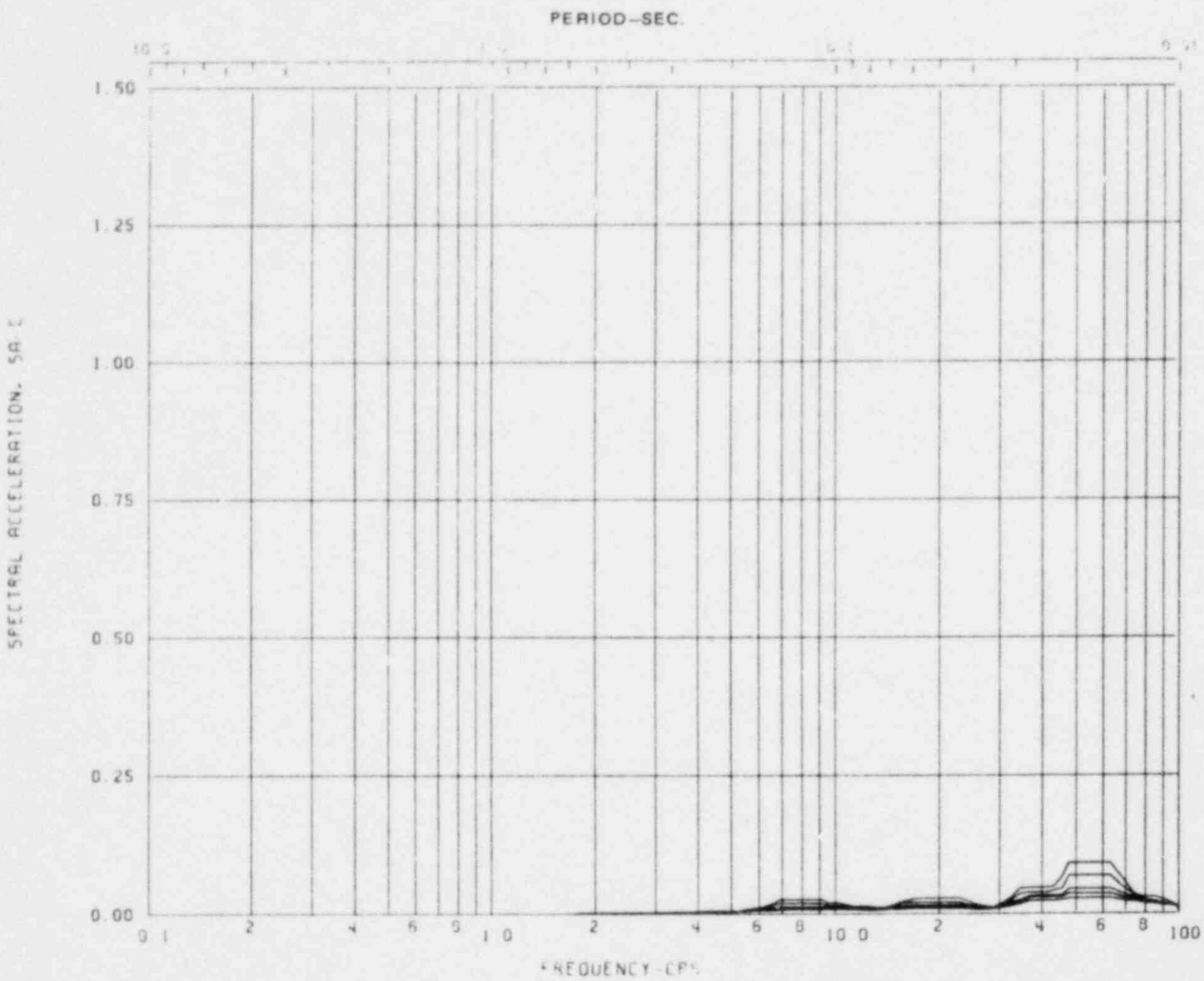
Node: 81 Direction: VERTICAL Elev: 253'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL
RESPONSE SPECTRA, VERTICAL,
CO – ADS AXISYMMETRIC

FIGURE B.2-158



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC GE CO-ADS ENVELOPE (WIDENED - 15%)

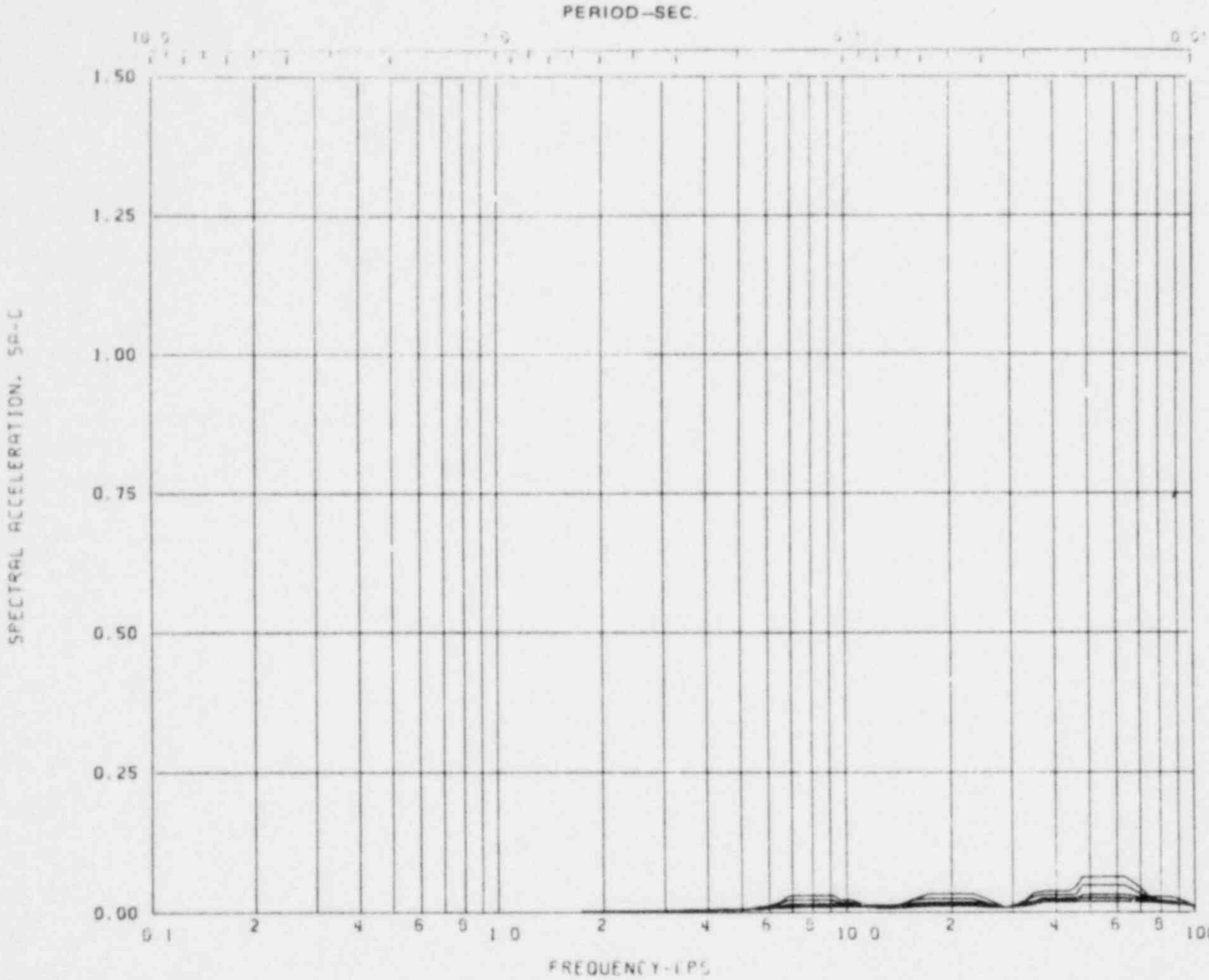
Node: 19 Direction: VERTICAL Elev: 253'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL RESPONSE SPECTRA, VERTICAL, CO – ADS AXISYMMETRIC

FIGURE B.2-159



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC GE CO-ADS ENVELOPE (WIDENED - 15%)

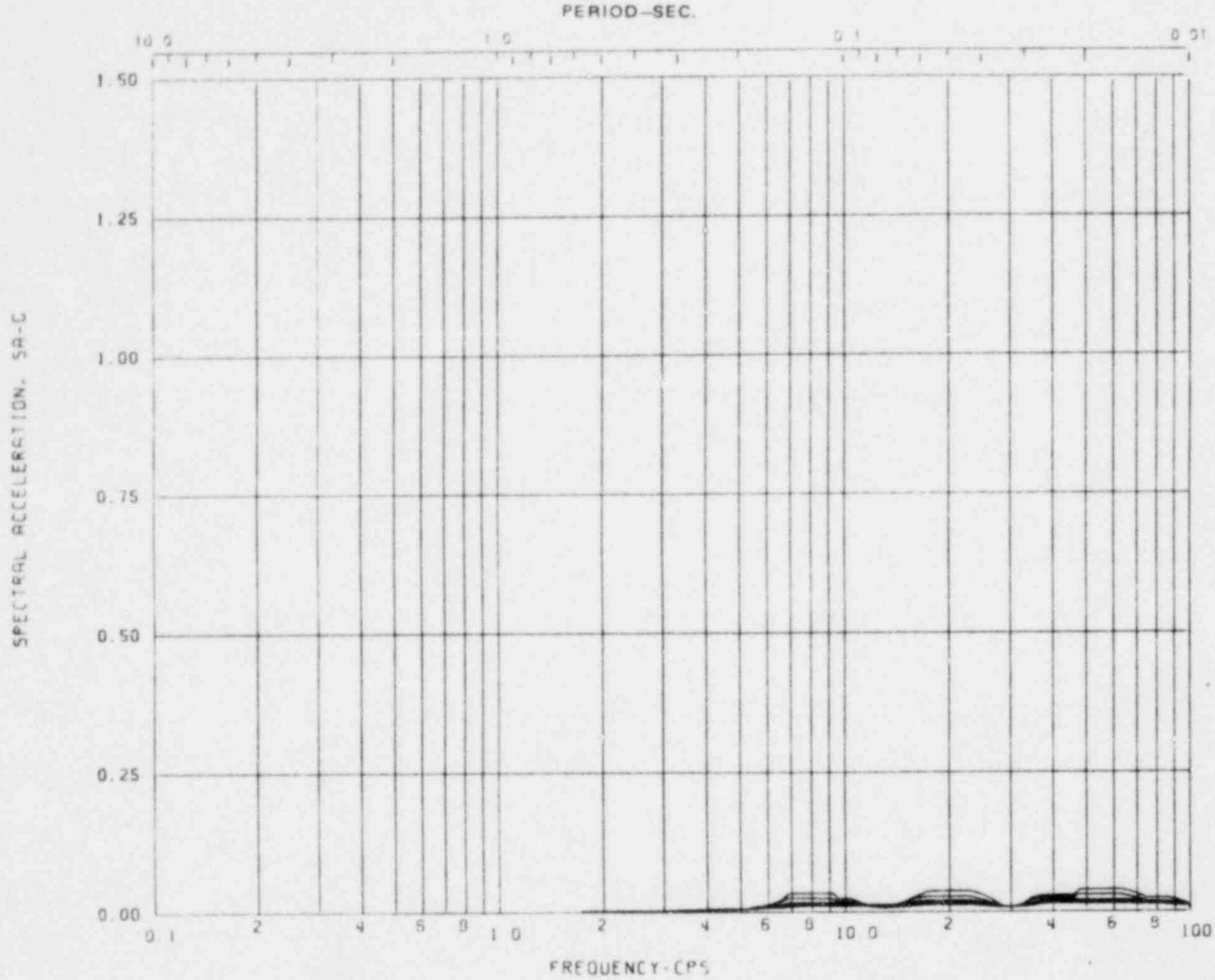
Node: 77 Direction: VERTICAL Elev: 269'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL RESPONSE SPECTRA, VERTICAL, CO – ADS AXISYMMETRIC

FIGURE B.2-160



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC GE CO-ADS ENVELOPE (WIDENED - 15%)

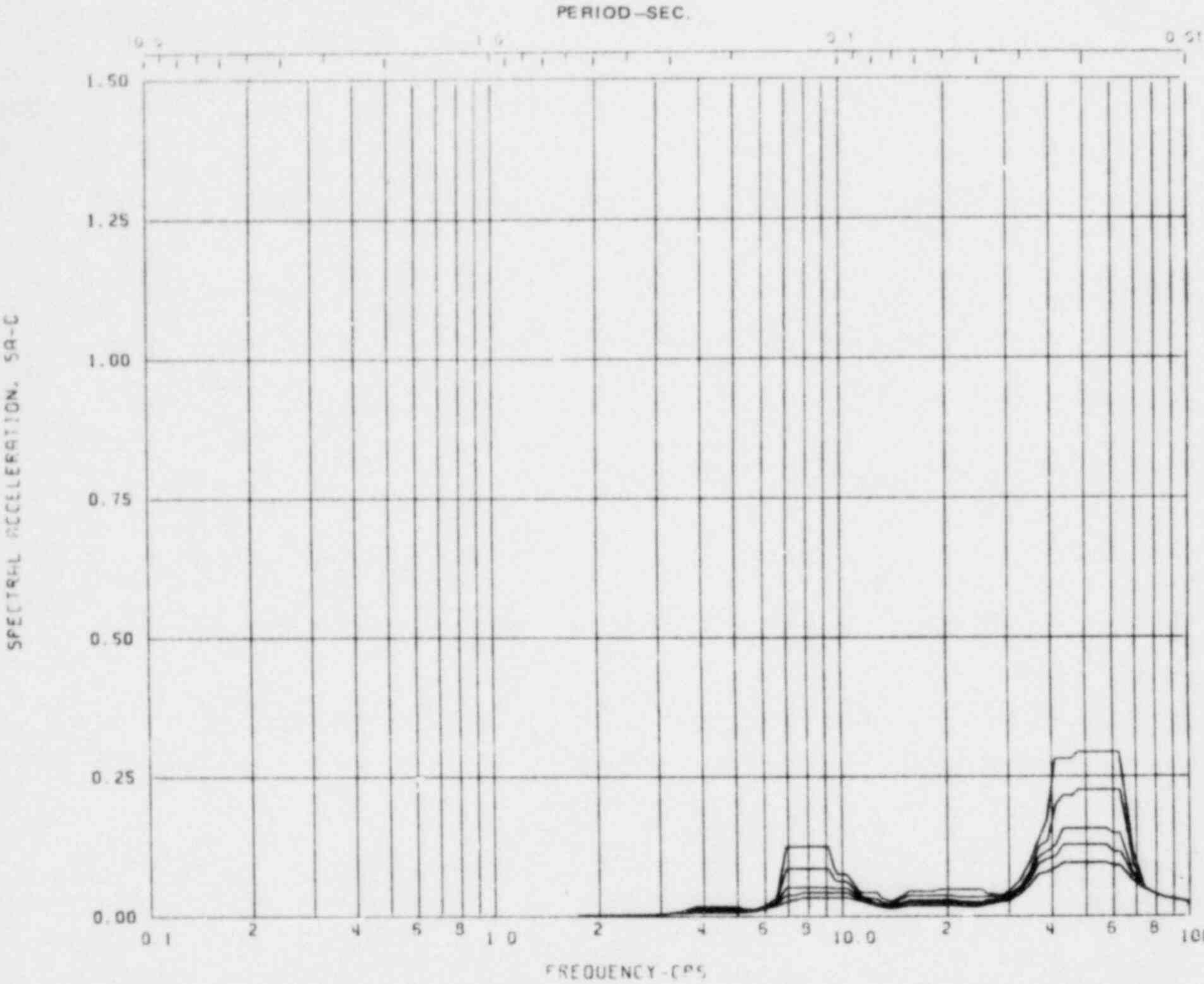
Node: 58 Direction: VERTICAL Elev: 283'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL
RESPONSE SPECTRA, VERTICAL,
CO – ADS AXISYMMETRIC

FIGURE B.2-161



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC GE CO-ADS ENVELOPE (WIDENED - 15%)

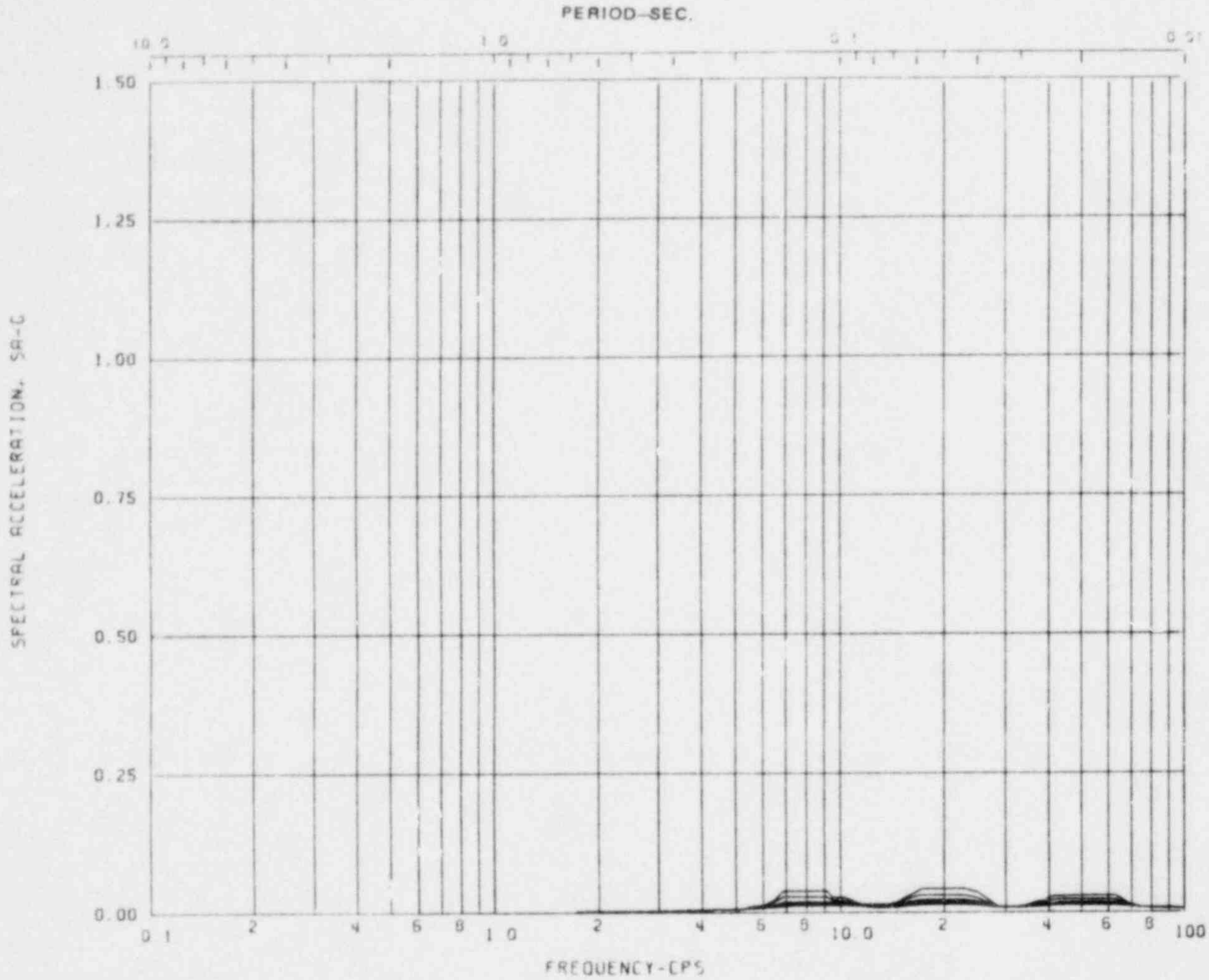
Node: 60 Direction: VERTICAL Elev: 283'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL
RESPONSE SPECTRA, VERTICAL,
CO – ADS AXISYMMETRIC

FIGURE B.2-162



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC GE CO-ADS ENVELOPE (WIDENED - 15%)

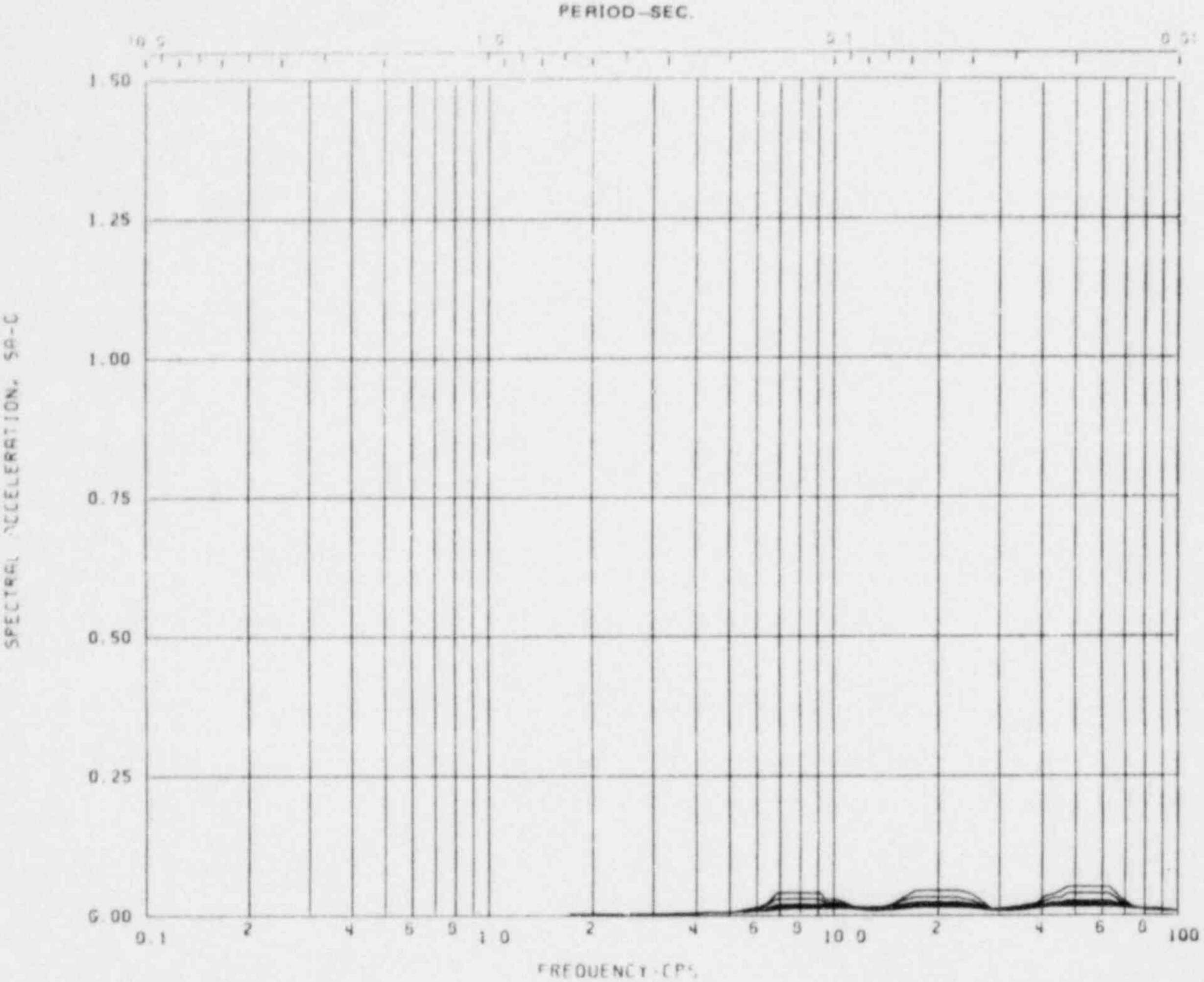
Node: 56 Direction: VERTICAL Elev: 304'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL RESPONSE SPECTRA, VERTICAL, CO – ADS AXISYMMETRIC

FIGURE B.2-163



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC GE CO-ADS ENVELOPE (WIDENED - 15%)

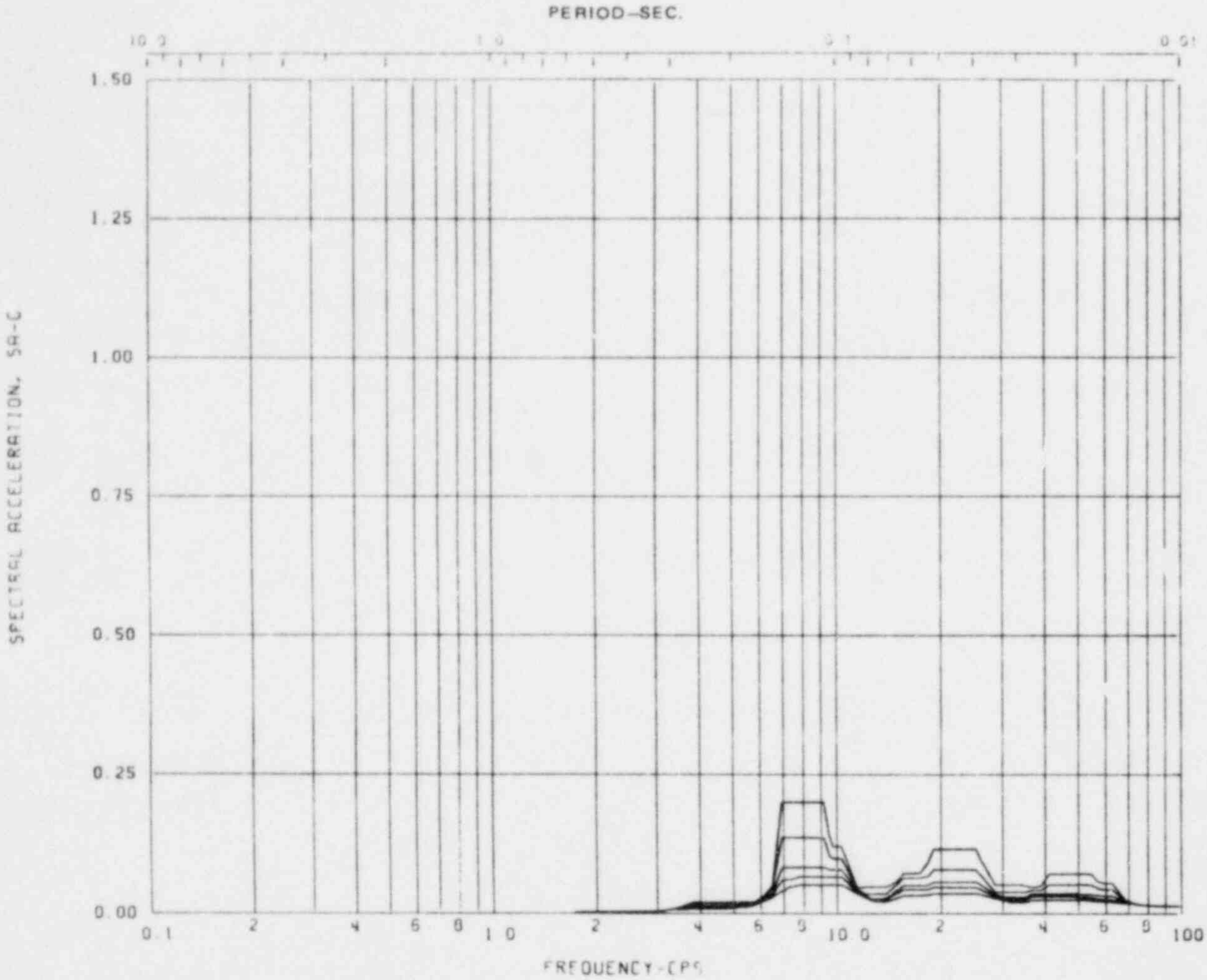
Node: 35 Direction: VERTICAL Elev: 313'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL
RESPONSE SPECTRA, VERTICAL,
CO – ADS AXISYMMETRIC

FIGURE B.2-164



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC GE CO-ADS ENVELOPE (WIDENED - 15%)

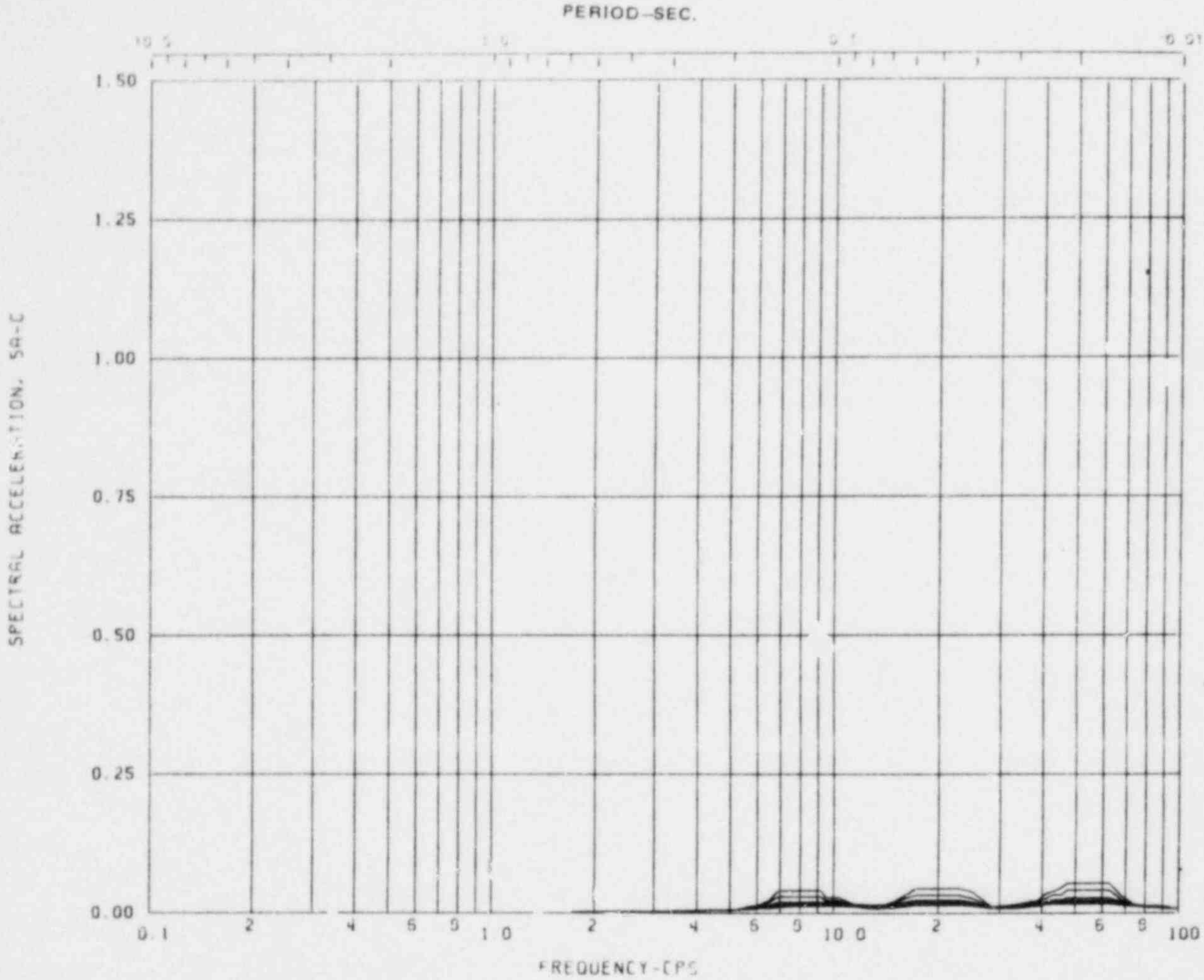
Node: 43 Direction: VERTICAL Elev: 313'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL RESPONSE SPECTRA, VERTICAL, CO – ADS AXISYMMETRIC

FIGURE B.2-165



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC GE CO-ADS ENVELOPE (WIDENED - 15%)

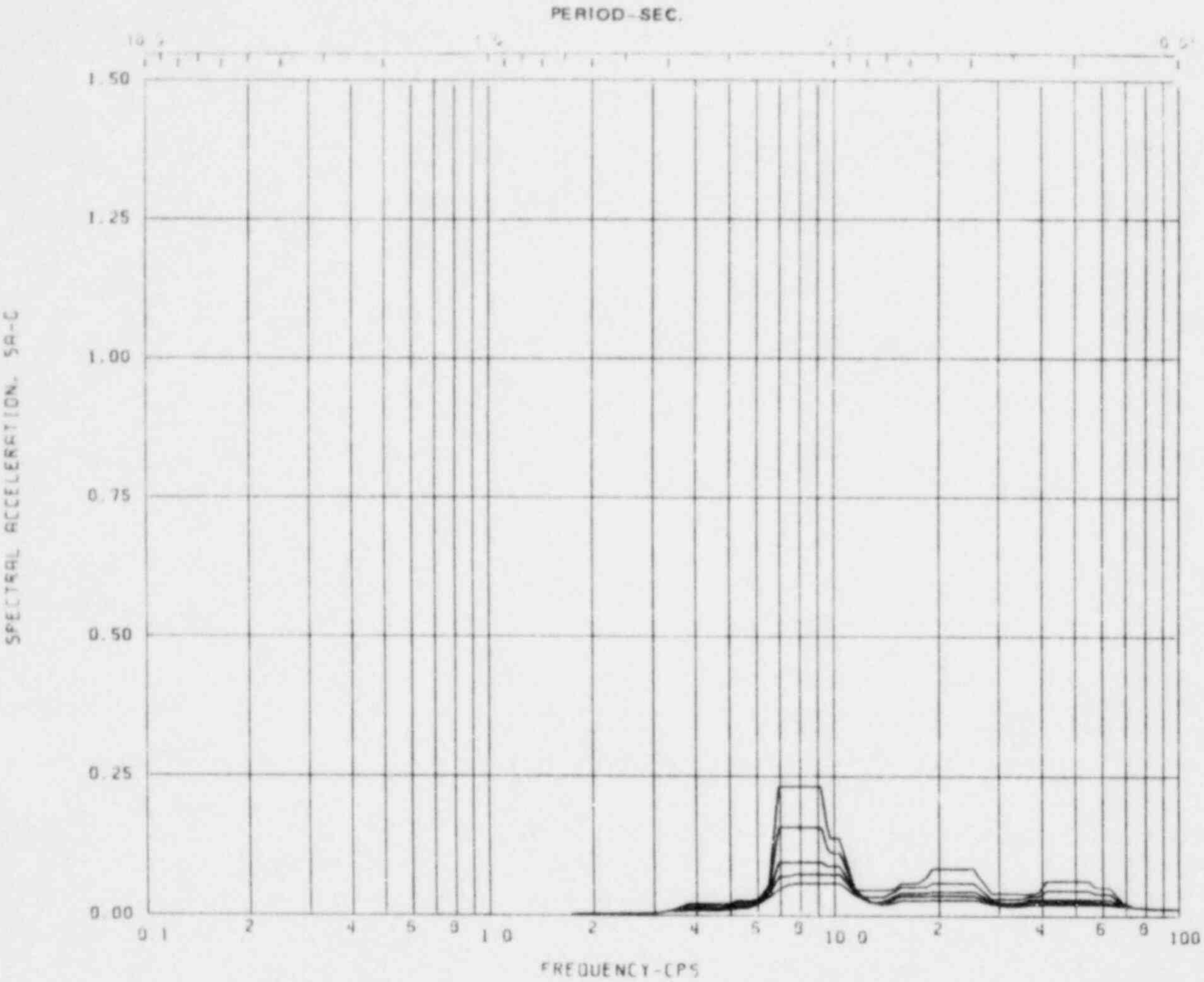
Node: 21 Direction: VERTICAL Elev: 333'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL RESPONSE SPECTRA, VERTICAL, CO – ADS AXISYMMETRIC

FIGURE B.2-166



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC GE CO-ADS ENVELOPE (WIDENED - 15%)

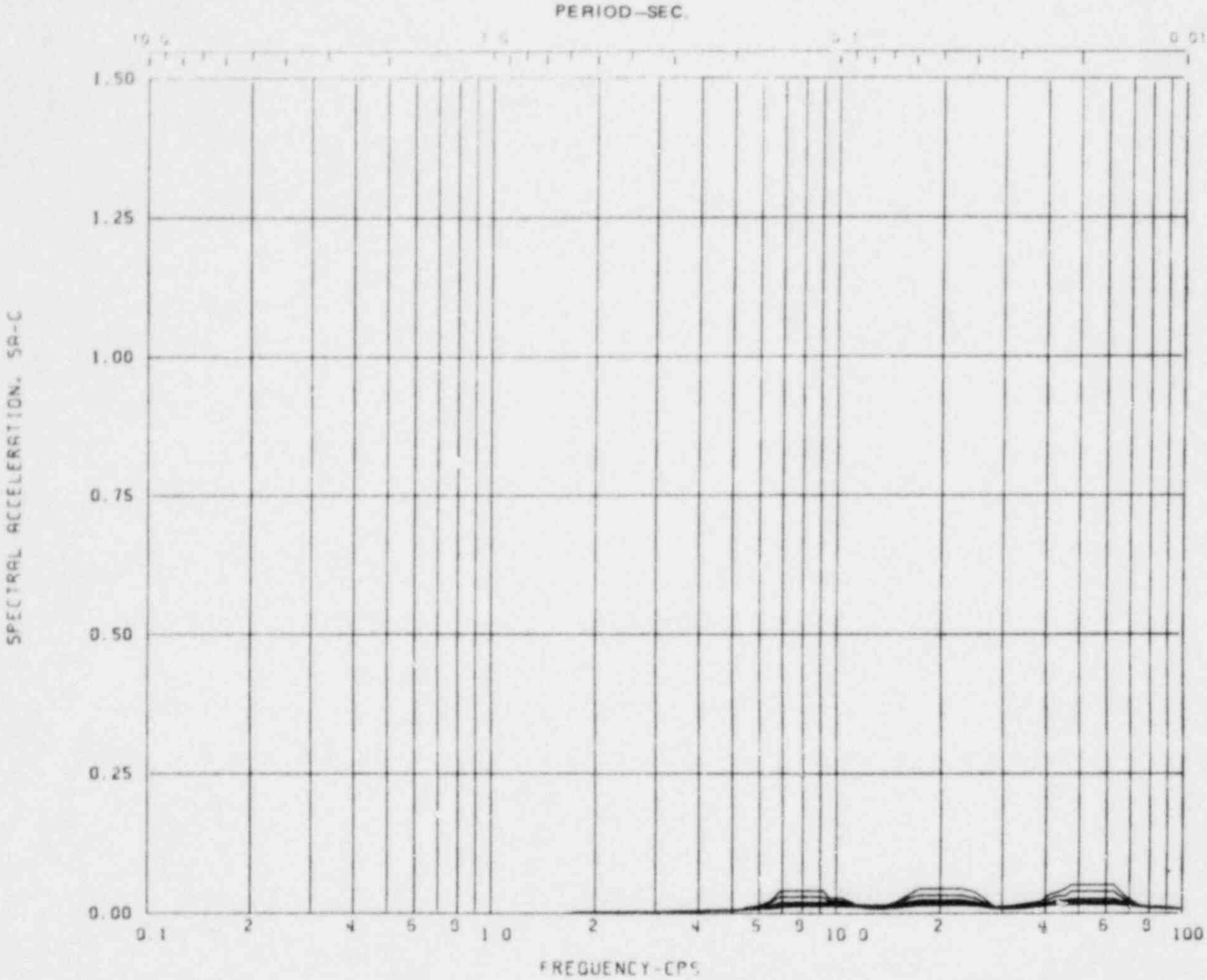
Node: 33 Direction: VERTICAL Elev: 333'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL RESPONSE SPECTRA, VERTICAL, CO – ADS AXISYMMETRIC

FIGURE B.2-167



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC GE CO-ADS ENVELOPE (WIDENED - 15%)

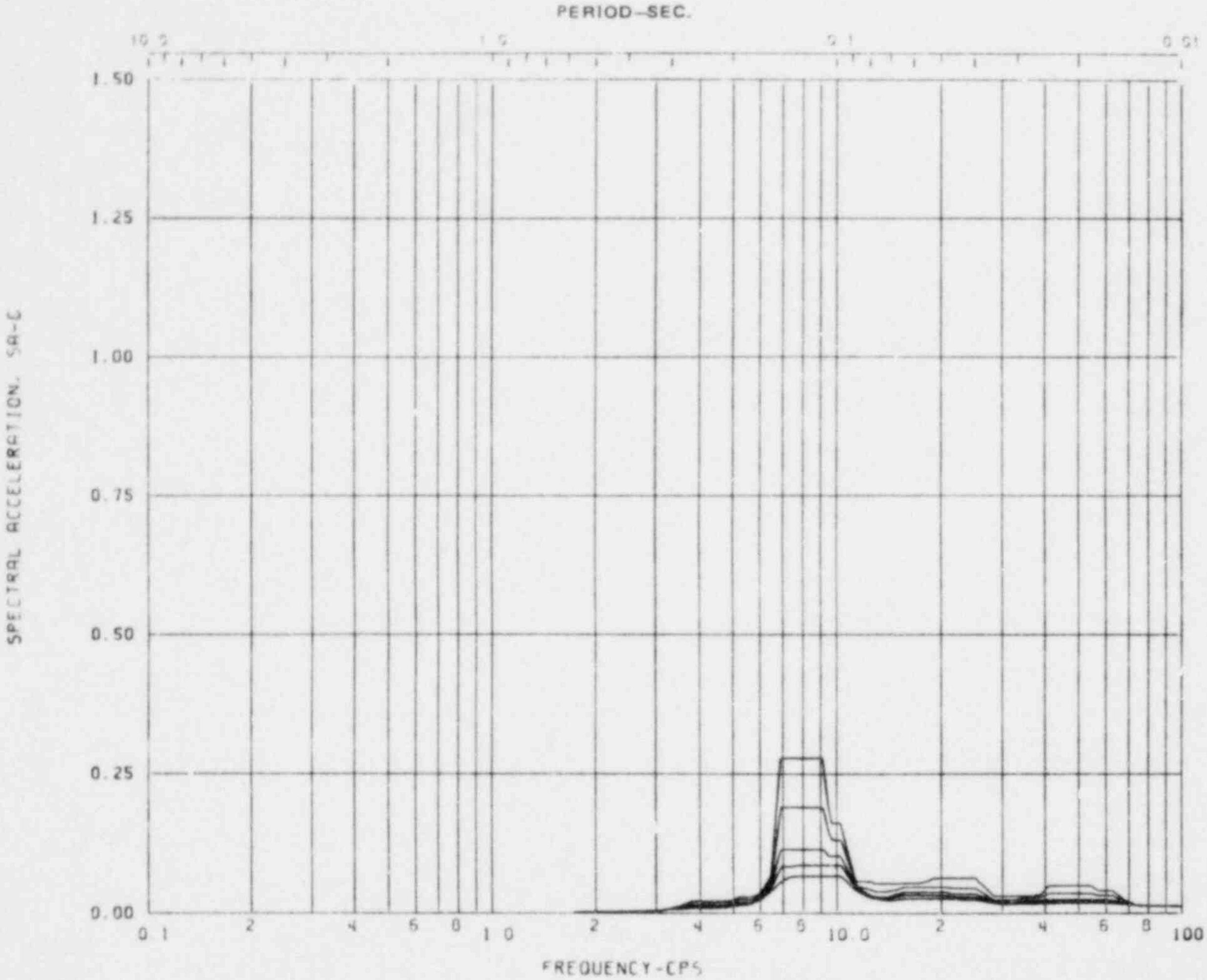
Node: 9 Direction: VERTICAL Elev: 352'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL RESPONSE SPECTRA, VERTICAL, CO – ADS AXISYMMETRIC

FIGURE B.2-168



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC GE CO-ADS ENVELOPE (WIDENED - 15%)

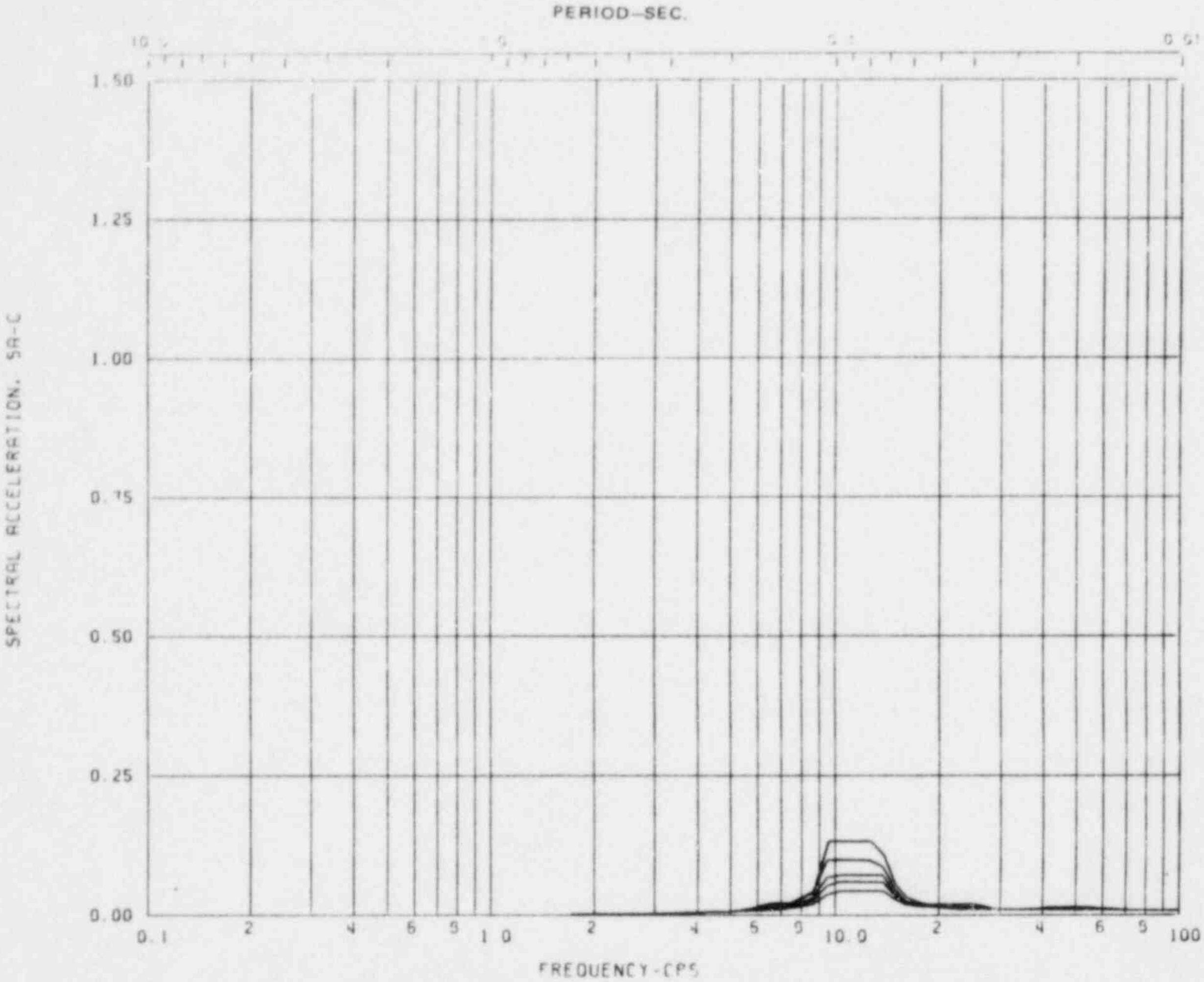
Node: 13 Direction: VERTICAL Elev: 352'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL RESPONSE SPECTRA, VERTICAL, CO – ADS AXISYMMETRIC

FIGURE B.2-169



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC GE CO-ADS ENVELOPE (WIDENED - 15%)

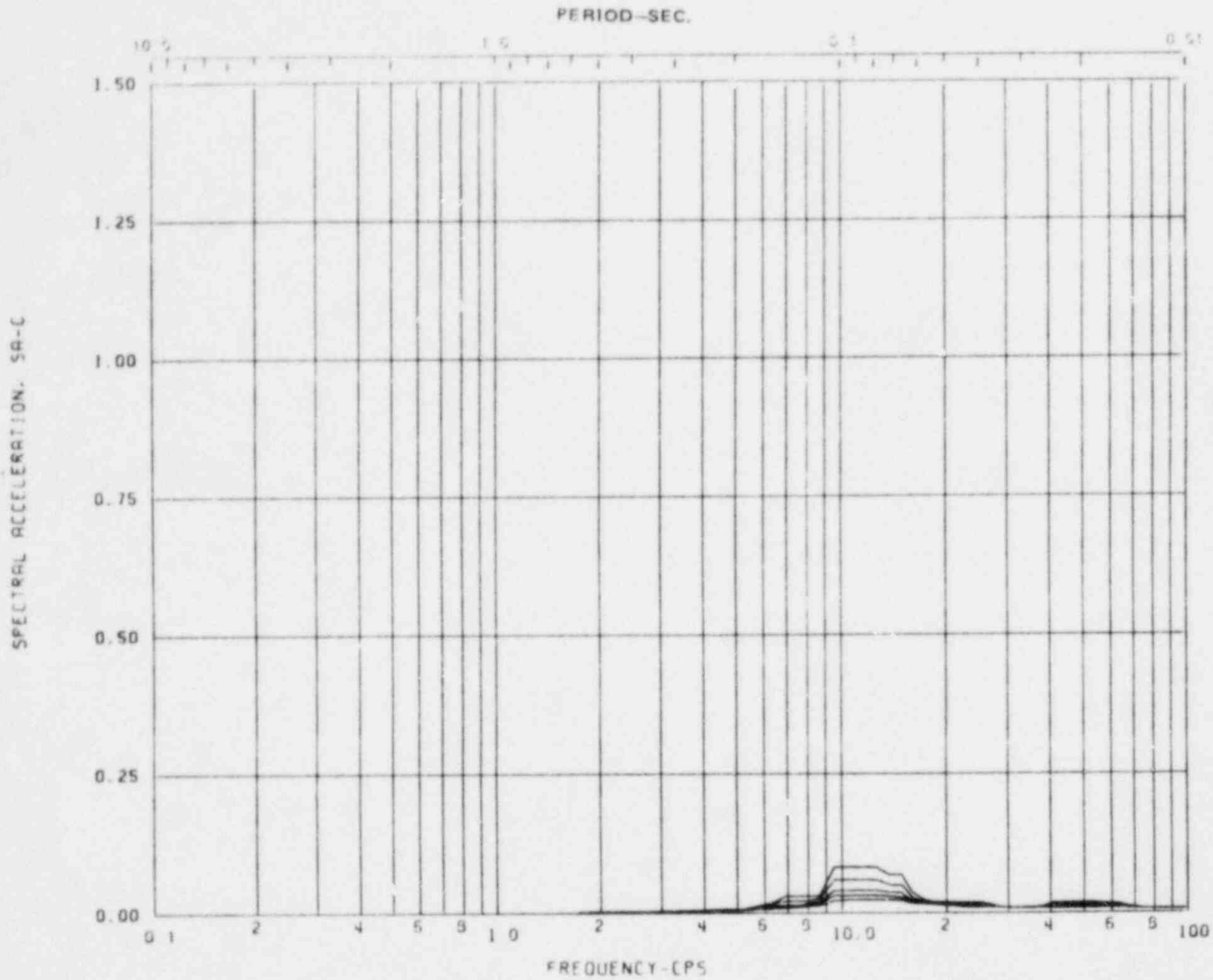
Node: 129 Direction: VERTICAL Elev: 201'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL RESPONSE SPECTRA, VERTICAL, CO – ADS AXISYMMETRIC

FIGURE B.2-170



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC GE CO-ADS ENVELOPE (WIDENED - 15%)

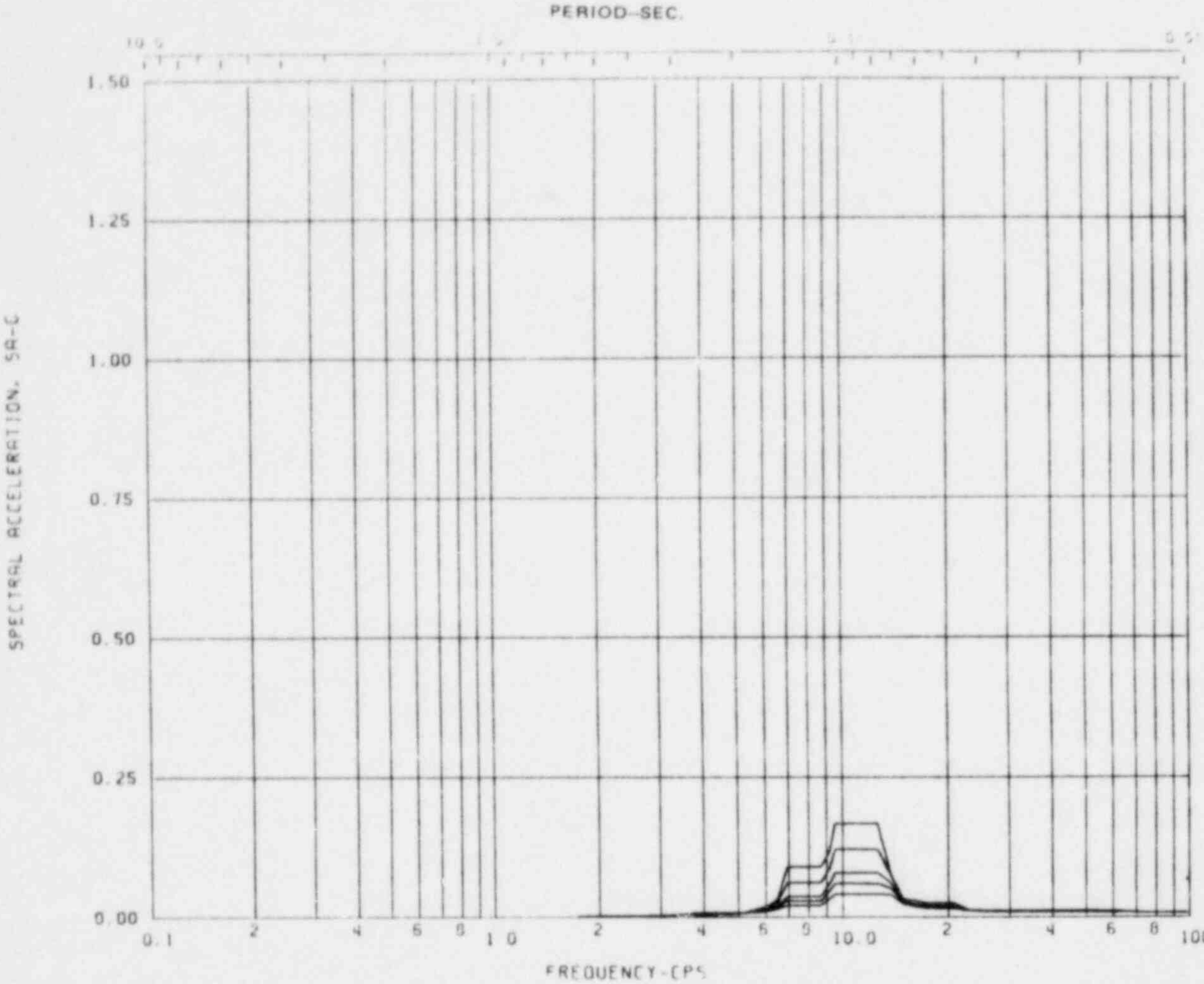
Node: 107 Direction: VERTICAL Elev: 217'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL
RESPONSE SPECTRA, VERTICAL,
CO – ADS AXISYMMETRIC

FIGURE B.2-171



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC GE CO-ADS ENVELOPE (WIDENED - 15%)

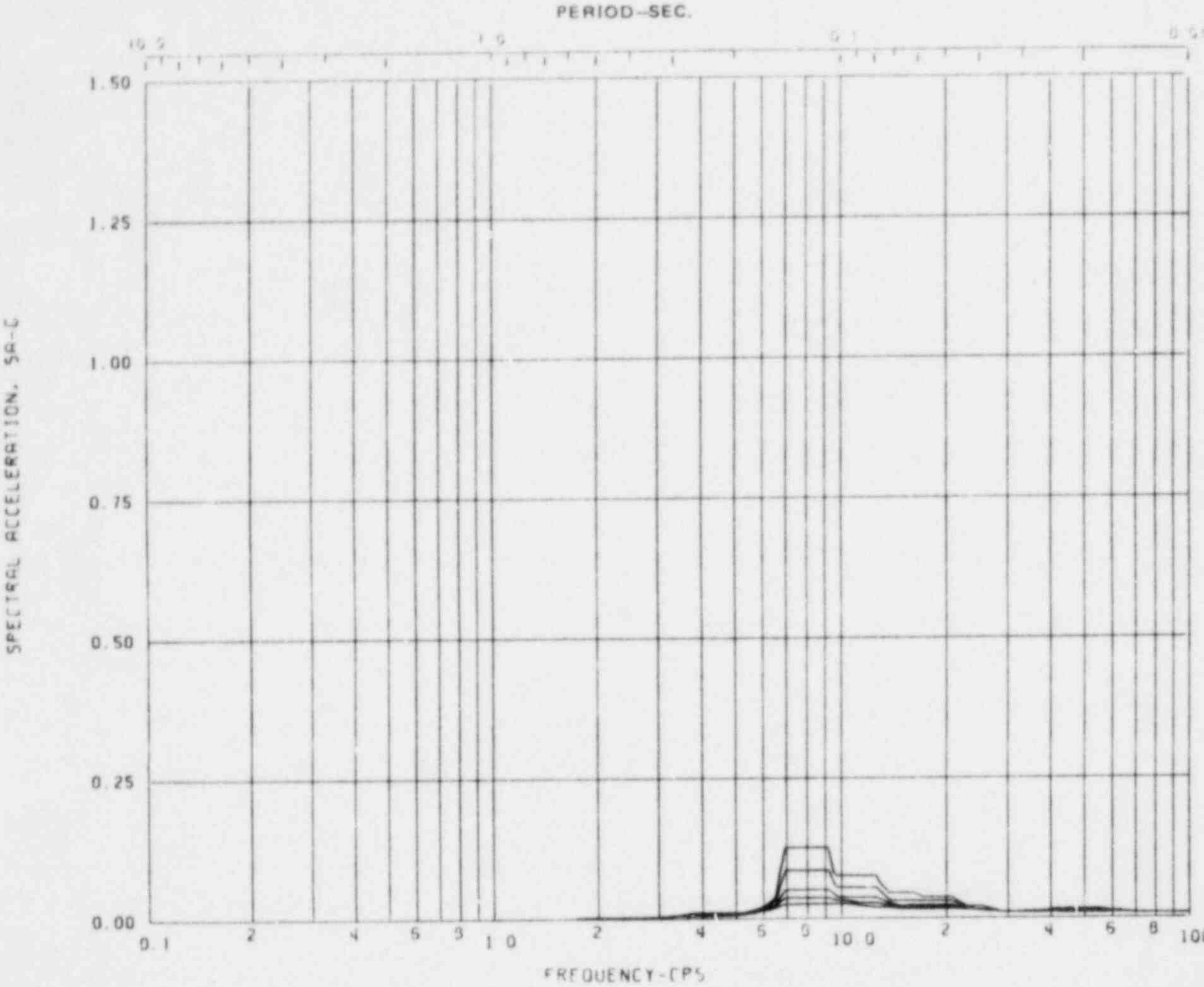
Node: 80 Direction: VERTICAL Elev: 253'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL RESPONSE SPECTRA, VERTICAL, CO – ADS AXISYMMETRIC

FIGURE B.2-172



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC GE CO-ADS ENVELOPE (WIDENED - 15%)

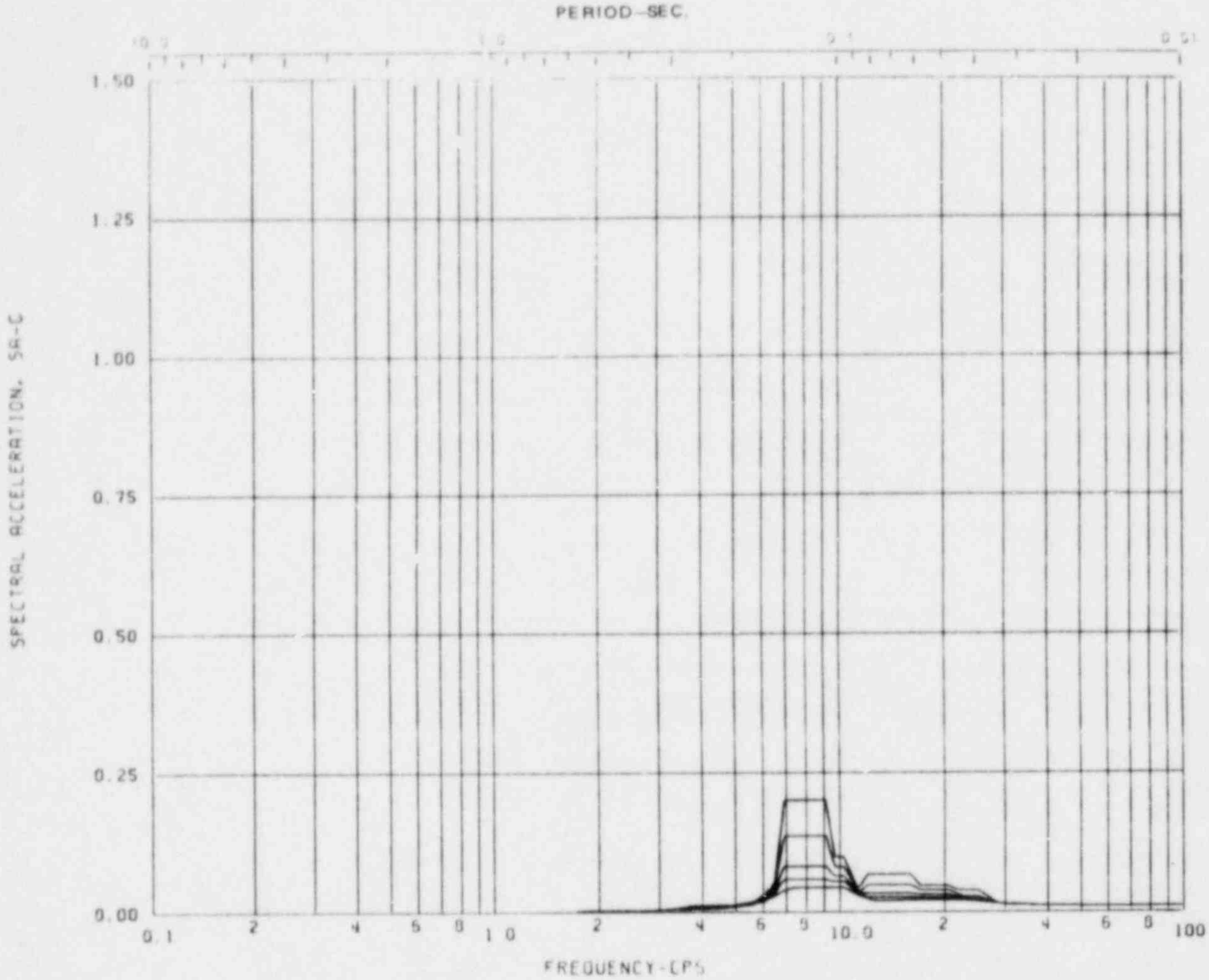
Node: 59 Direction: VERTICAL Elev: 283'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL RESPONSE SPECTRA, VERTICAL, CO – ADS AXISYMMETRIC

FIGURE B.2-173



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC GE CO-ADS ENVELOPE (WIDENED - 15%)

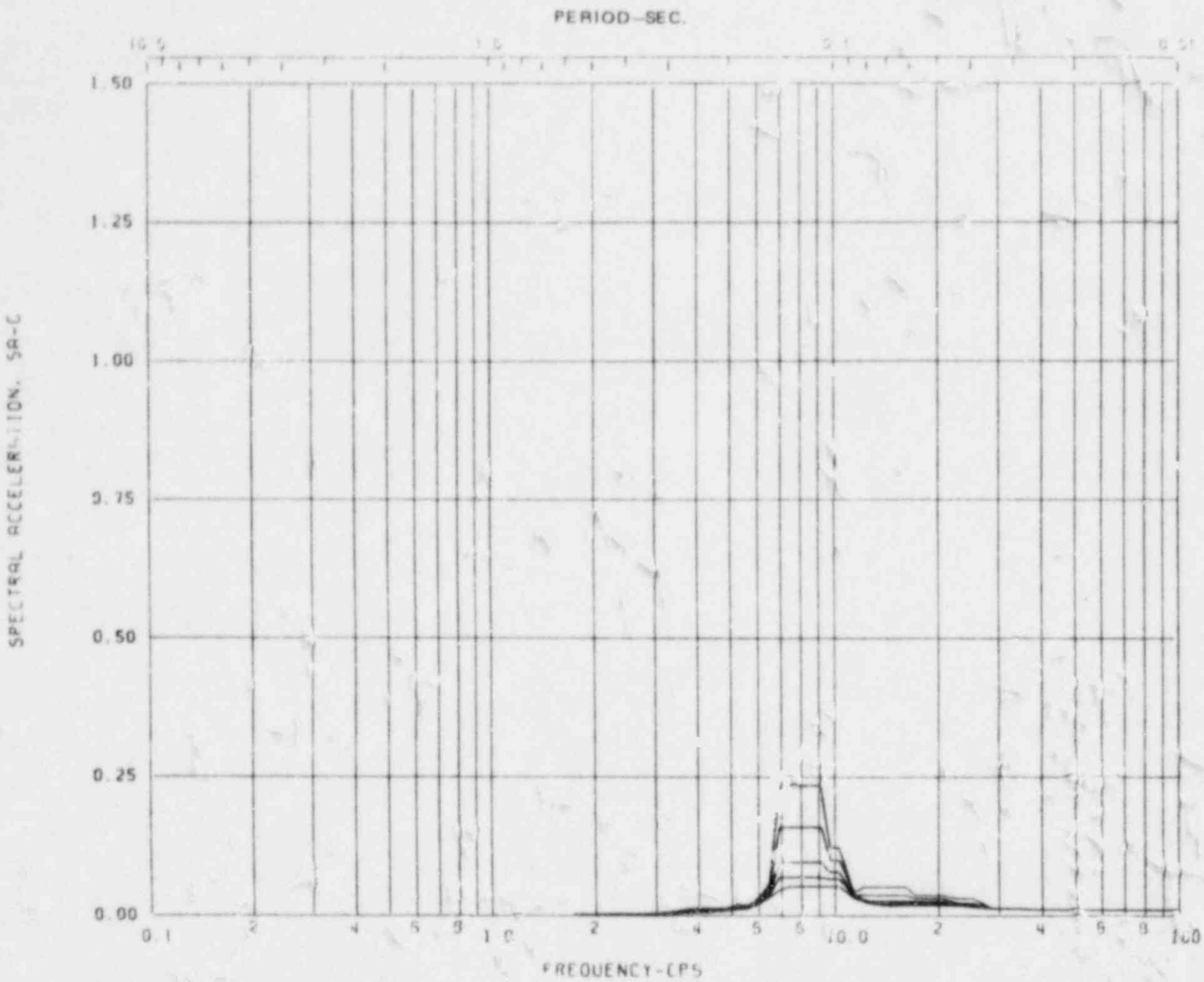
Node: 54 Direction: VERTICAL Elev: 313'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL
RESPONSE SPECTRA, VERTICAL,
CO – ADS AXISYMMETRIC

FIGURE B.2-174



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC GE CO-ADS ENVELOPE (WIDENED - 15%)

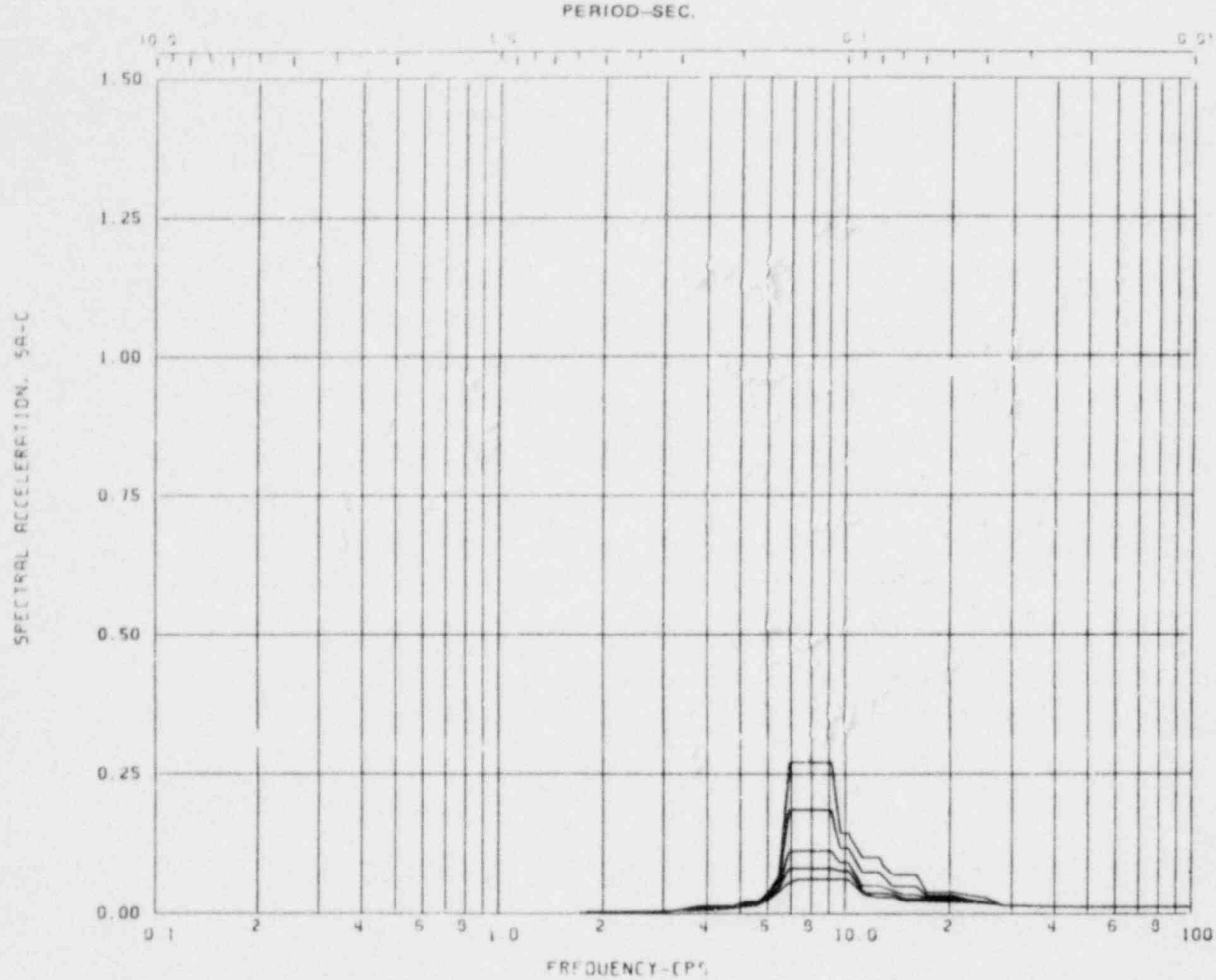
Node: 32 Direction: VERTICAL Elev: 333'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION UNITS 1 AND 2 DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL RESPONSE SPECTRA, VERTICAL, CO – ADS AXISYMMETRIC

FIGURE B.2-175



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC GE CO-ADS ENVELOPE (WIDENED - 15%)

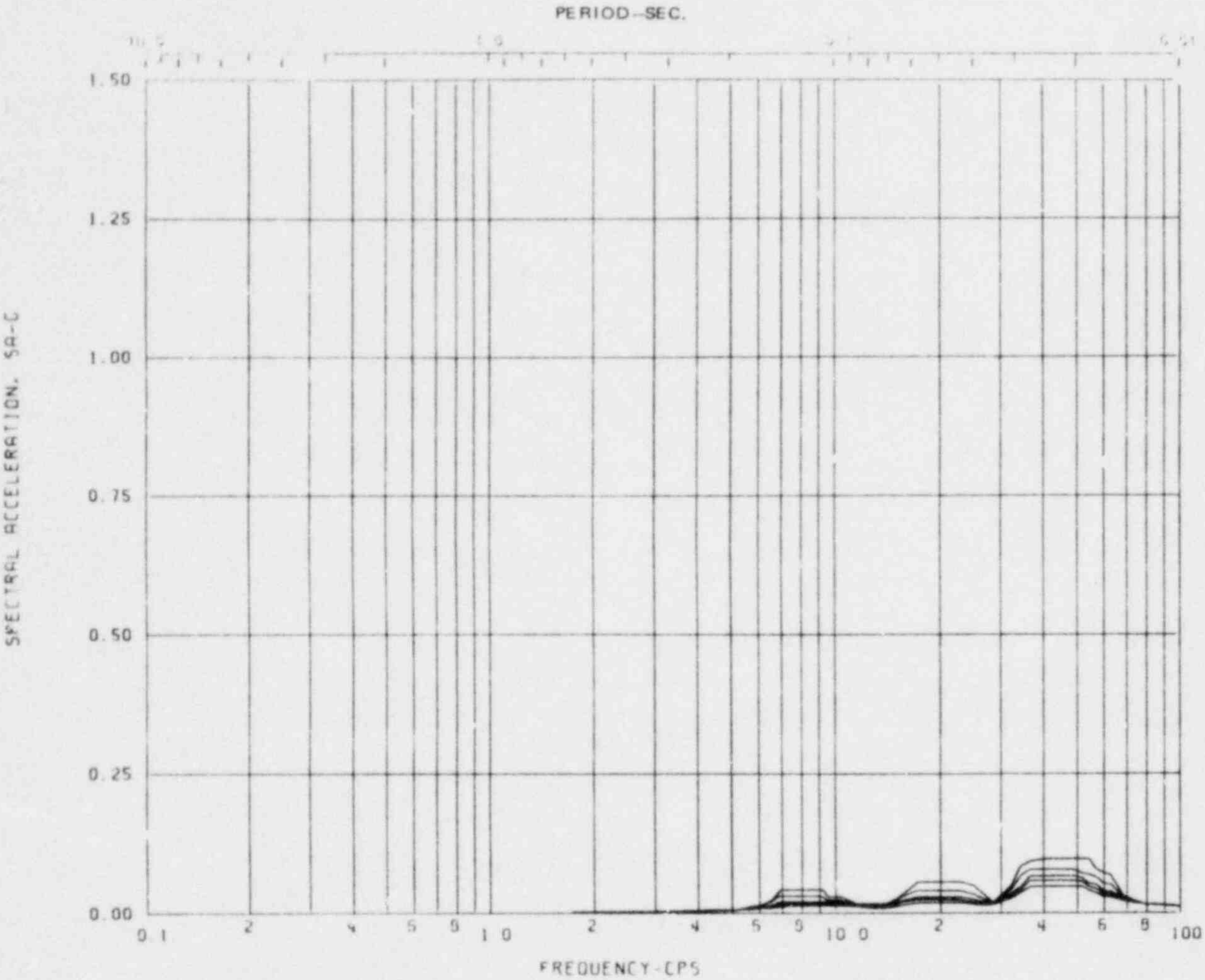
Node: 12 Direction: VERTICAL Elev: 352'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL RESPONSE SPECTRA, VERTICAL, CO – ADS AXISYMMETRIC

FIGURE B.2-176



Acceleration Spectra for REACTOR BLDG.

Load Case: AXISYMMETRIC GE CO-ADS ENVELOPE (WIDENED - 15%)

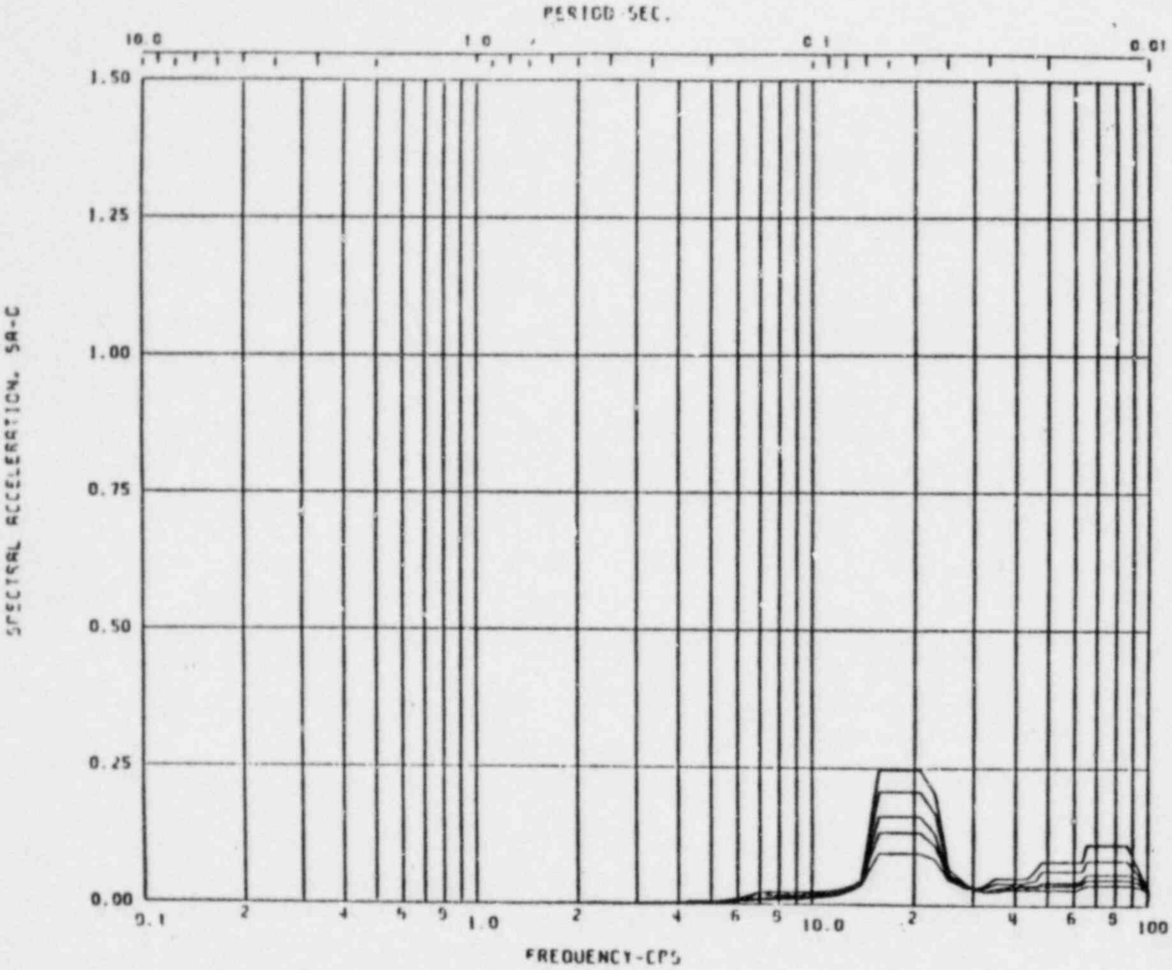
Node: 6 Direction: VERTICAL Elev: 410'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

REACTOR BUILDING GLOBAL RESPONSE SPECTRA, VERTICAL, CO-ADS AXISYMMETRIC

FIGURE B.2-177



Acceleration Spectra for CONTROL STRUCTURE

Load Case: AXISYMMETRIC GE CO-ADS ENVELOPE (WIDENED - 15%)

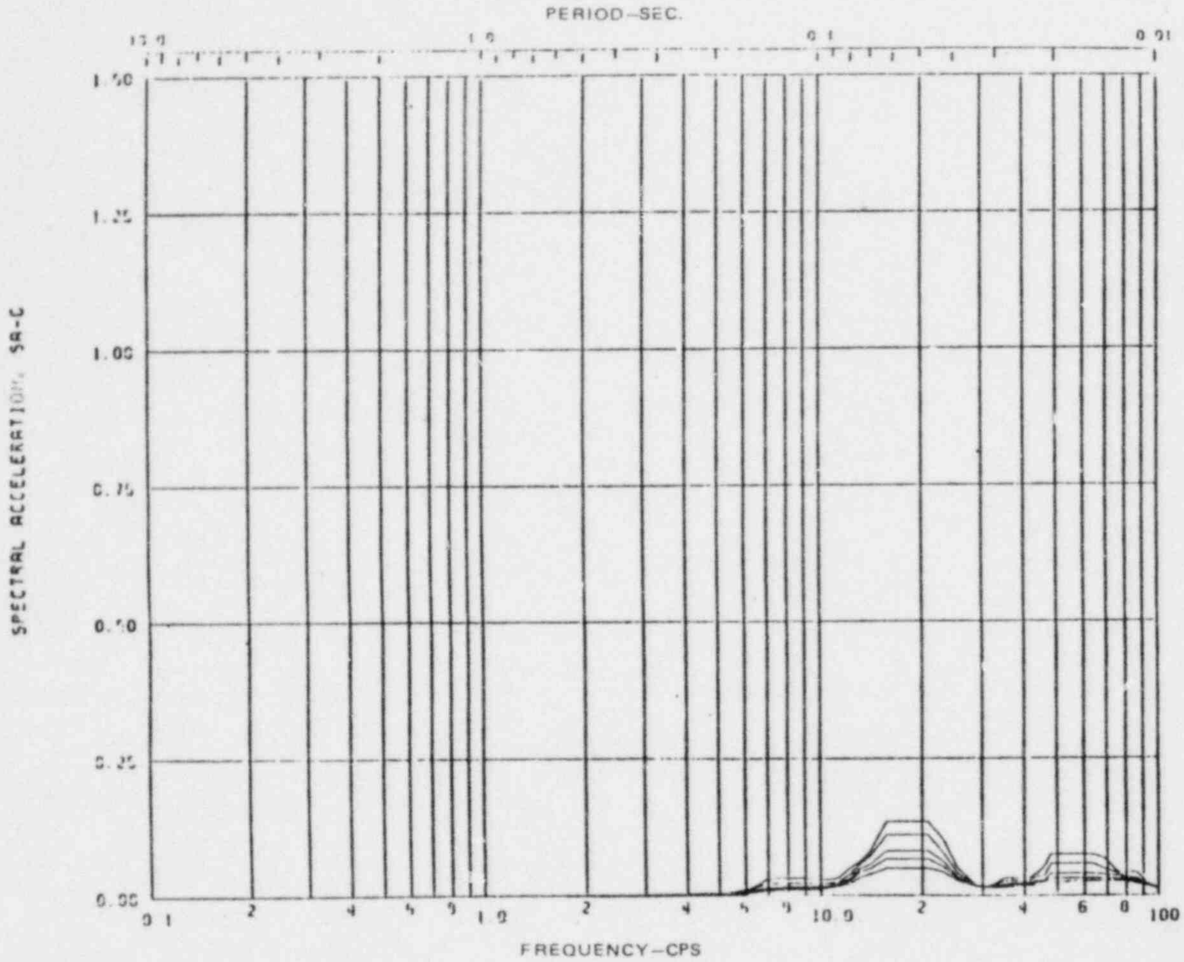
Node: 7 Direction: VERTICAL Elev: 217'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTROL STRUCTURE
LOCAL RESPONSE SPECTRA, VERTICAL,
CO – ADS AXISYMMETRIC

FIGURE B.2-178



Acceleration Spectra for CONTROL STRUCTURE

Load Case: AXISYMMETRIC GE CO-ADS ENVELOPE (WIDENED - 15%)

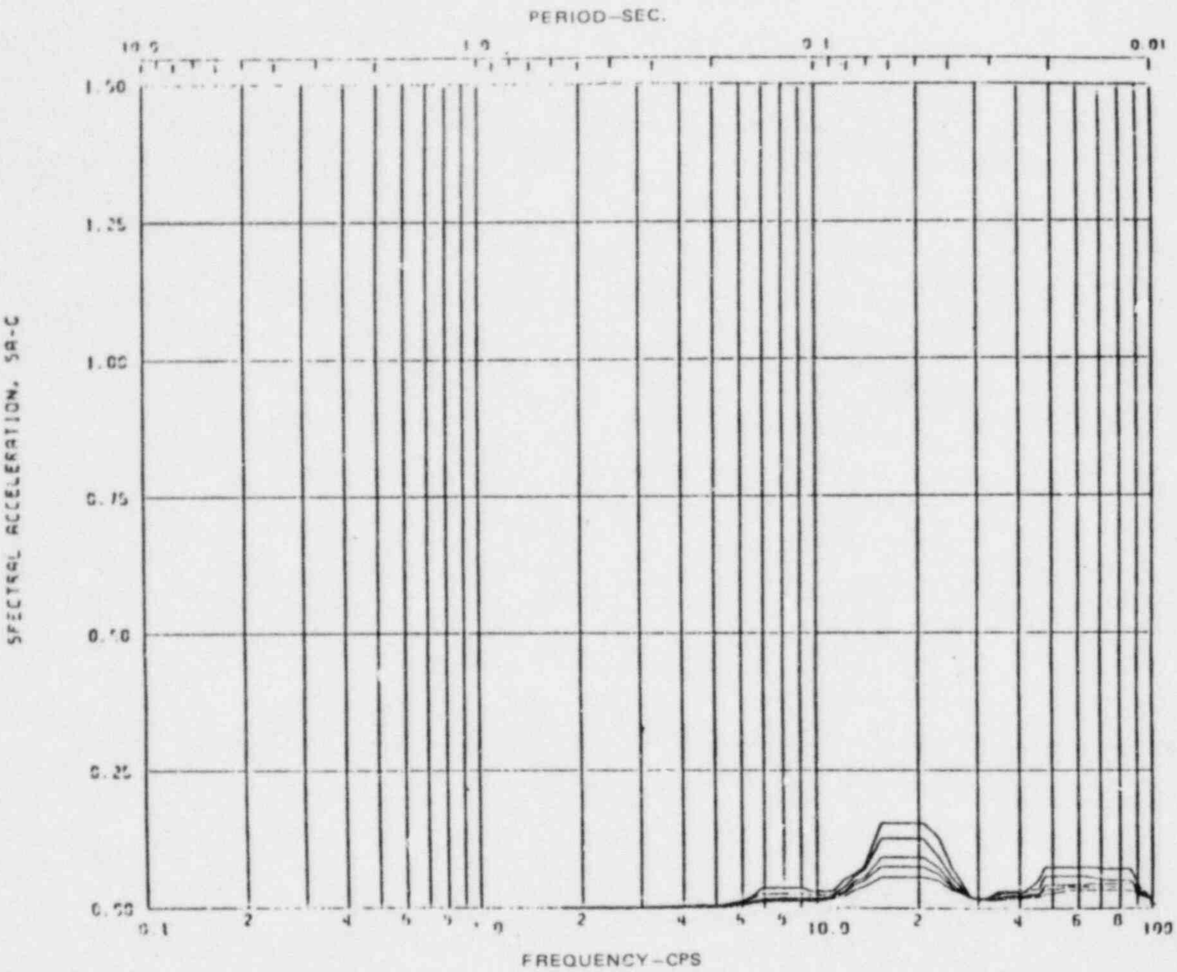
Node: 7 Direction: VERTICAL Elev: 239'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTROL STRUCTURE
LOCAL RESPONSE SPECTRA, VERTICAL,
CO – ADS AXISYMMETRIC

FIGURE B.2-179



Acceleration Spectra for CONTROL STRUCTURE

Load Case: AXISYMMETRIC GE CO-ADS ENVELOPE (WIDENED - 15%)

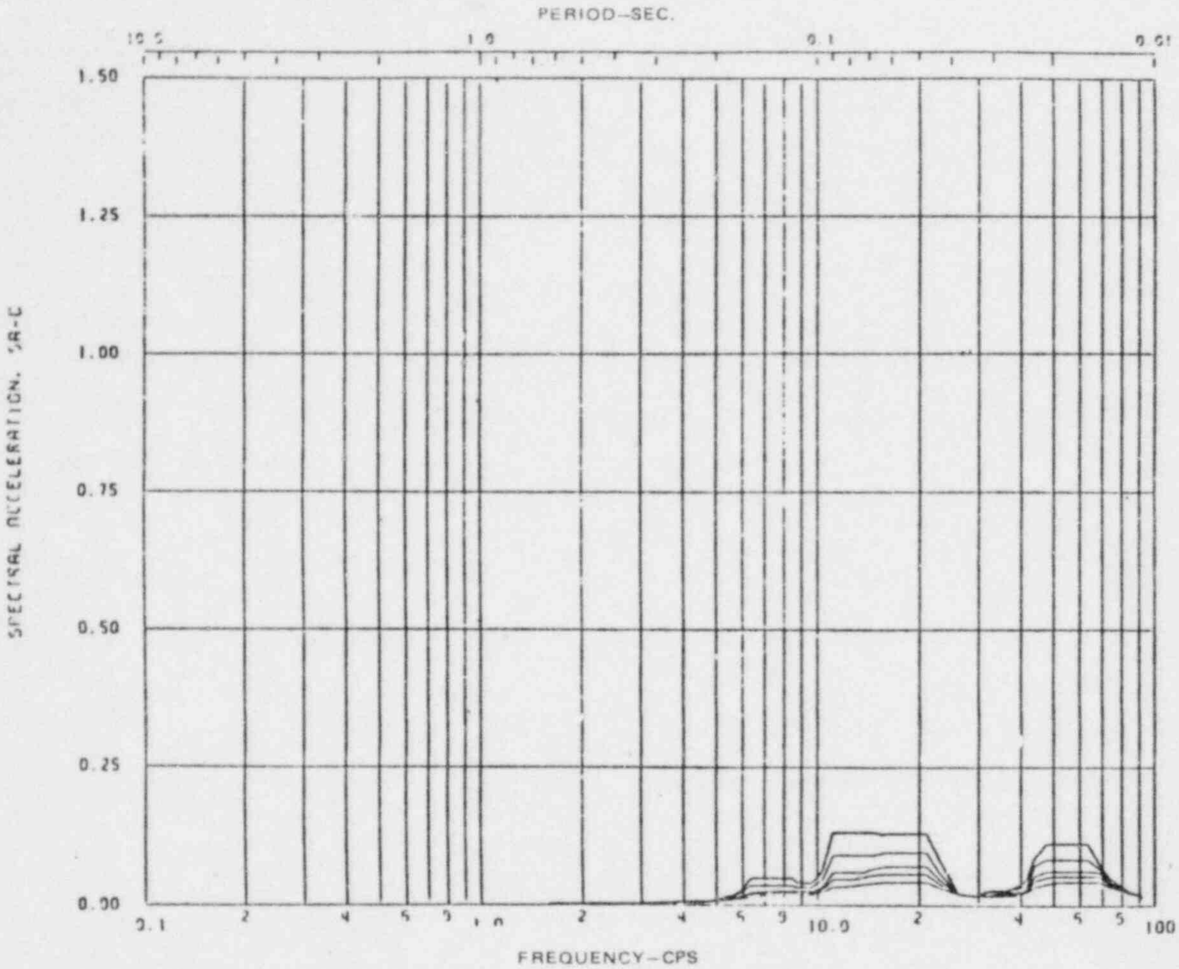
Node: 7 Direction: VERTICAL Elev: 254'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTROL STRUCTURE
LOCAL RESPONSE SPECTRA, VERTICAL,
CO – ADS AXISYMMETRIC

FIGURE B.2-180



Acceleration Spectra for CONTROL STRUCTURE

Load Case: AXISYMMETRIC GE CO-ADS ENVELOPE (WIDENED - 15%)

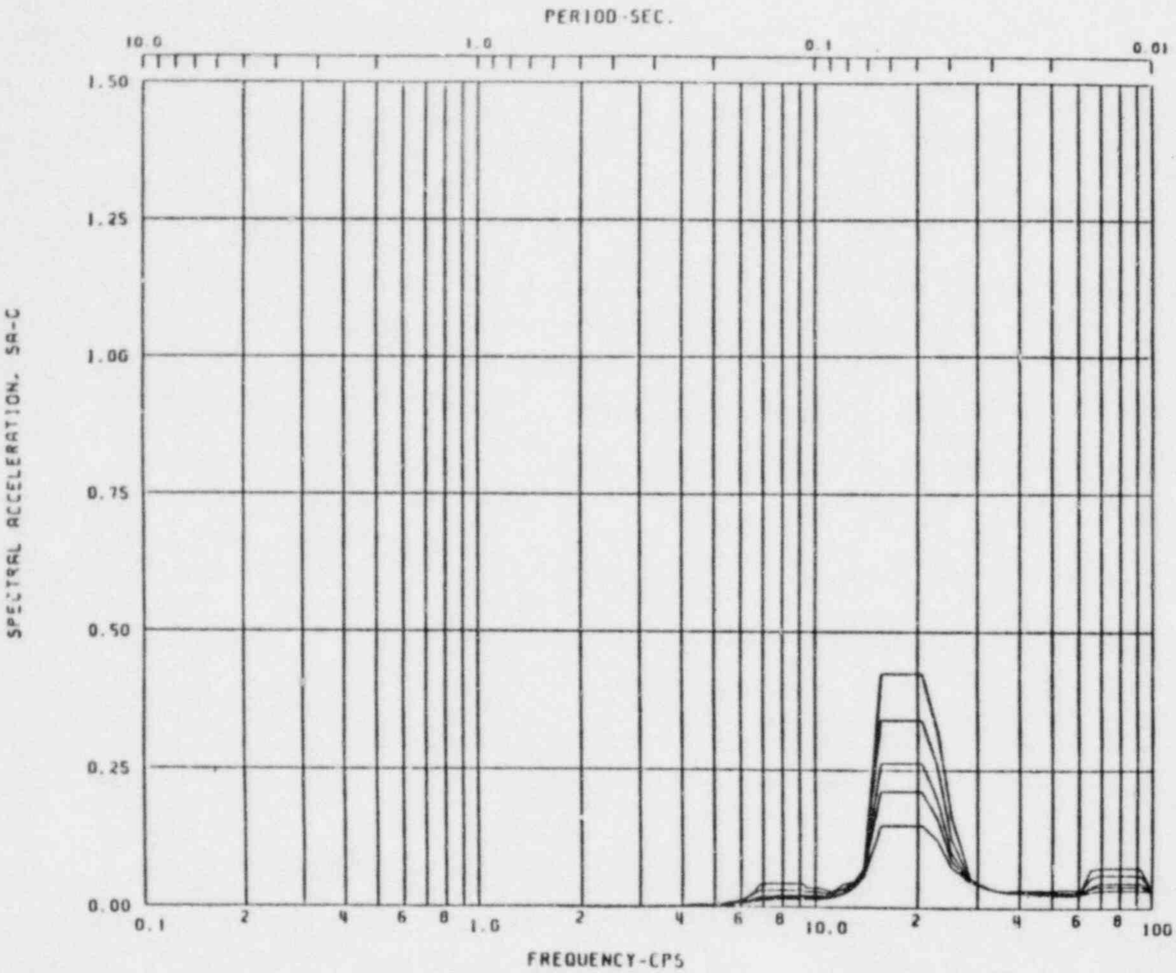
Node: 7 Direction: VERTICAL Elev: 269'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTROL STRUCTURE
LOCAL RESPONSE SPECTRA, VERTICAL,
CO – ADS AXISYMMETRIC

FIGURE B.2-181



Acceleration Spectra for CONTROL STRUCTURE

Load Case: AXISYMMETRIC GE CO-ADS ENVELOPE (WIDENED - 15%)

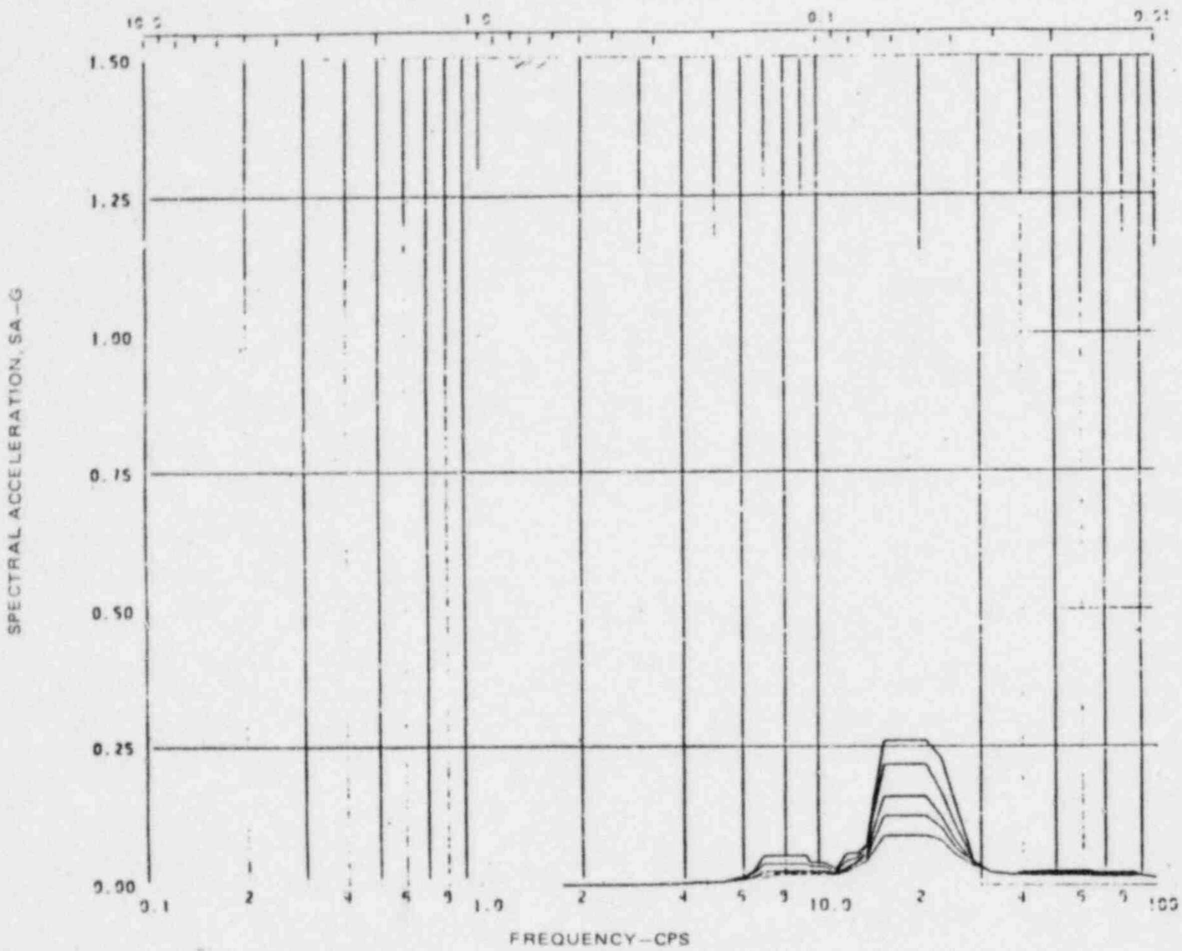
Node: 7 Direction: VERTICAL Elev: 289'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTROL STRUCTURE
LOCAL RESPONSE SPECTRA, VERTICAL,
CO – ADS AXISYMMETRIC

FIGURE B.2-182



Acceleration Spectra for CONTROL STRUCTURE

Load Case: AXISYMMETRIC GE CO-ADS ENVELOPE (WIDENED - 15%)

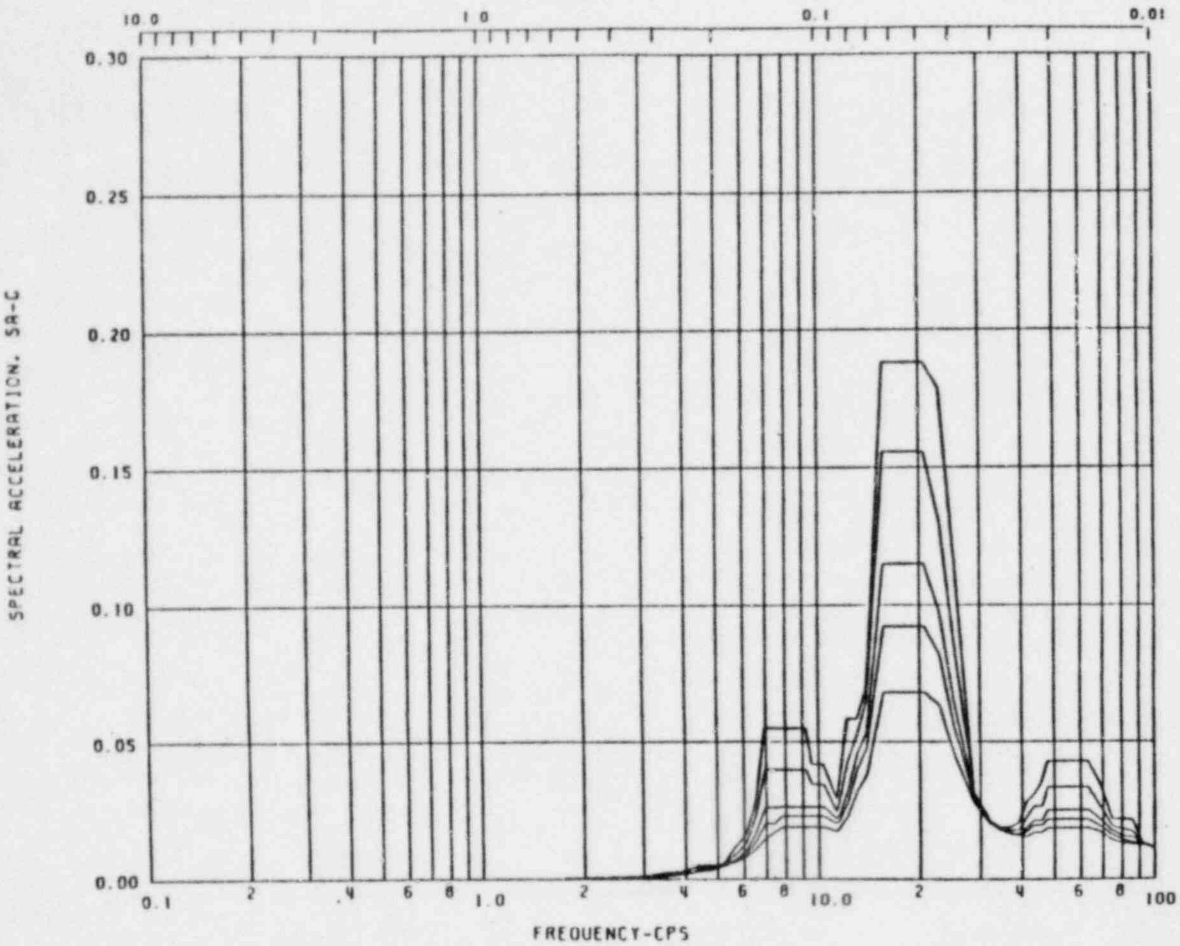
Node: 7 Direction: VERTICAL Elev: 304'-0

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTROL STRUCTURE
LOCAL RESPONSE SPECTRA, VERTICAL,
CO – ADS AXISYMMETRIC

FIGURE B.2-183



Acceleration Spectra for CONTROL STRUCTURE

Load Case: AXISYMMETRIC GE CO-ADS ENVELOPE (WIDENED - 15%)

Node: 7 Direction: VERTICAL Elev: 332'

Damping: 0.005,0.01,0.02,0.03,0.05

LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CONTROL STRUCTURE
LOCAL RESPONSE SPECTRA, VERTICAL,
CO – ADS AXISYMMETRIC

FIGURE B.2-184

APPENDIX C

SUBMERGED STRUCTURE METHODOLOGY

TABLE OF CONTENTS

APPENDIX C

TABLE OF CONTENTS (CONT'D)

APPENDIX C

FIGURES

Fig. No	Title
C.2-1	LOCA Air Clearing Velocity (4 sheets)
C.2-2	LOCA Air Clearing Acceleration (4 sheets)
C.2-3	Top View of 36 Degree Sector of a Typical Mark II Suppression Pool
C.2-4	Schematic View of Section A-A of Typical Mark II Suppression Pool
C.3-1	Model/Data Comparisons (4 sheets)
C.4-1	Cylinder Locations
C.4-2	Interference on Standard Drag: Three Cylinder Arrangment
C.4-3	Interference on Standard Drag: Three Cylinder Side-By-Side Arrangement
C.4-4	Flow Around Unequal Cylinders

SUBMERGED STRUCTURE METHODOLOGY

C.1 INTRODUCTION

The Mark II suppression pool is expected to experience fluid motion as a result of safety relief valve (SRV) actuation and postulated loss-of-coolant accident (LOCA). The velocity and acceleration fields will cause drag loads on structures submerged in the pool. These loads have been calculated in the past by assuming the existence of a uniform flow field and applying steady-state standard and acceleration drag coefficients. The NRC Lead Plant Acceptance Criteria (NUREG-0487, Reference 1.3-2) pointed out that this method might not be conservative under certain flow conditions and for certain structure geometries. This appendix explains the methods used by the lead plants and Limerick Generating Station to ensure that the design loads are conservative.

Section C.2 presents a method of evaluating the correction to both standard and acceleration drag coefficients in unsteady flow and a method to evaluate the transverse (lift) force in this flow. Sections C.3 and C.4 describe the effect of neighboring structures on the submerged structure drag loads. This method provides modified drag coefficients for the range of geometries existing in Mark II plants.

Section C.5 presents the results of sensitivity studies that verify the adequacy of the nodalization used in predicting loads. These studies show that increasing the number of points at which loads are calculated will not make significant changes in the result.

All of the drag coefficients used for submerged structure load calculations for each particular accident condition were determined directly from the data that are presented in the references listed at the end of each section. In addition, all modifications made to the drag coefficients describing the effects of neighboring structures and unsteady flow were based on actual data listed in these references. The theory provided in this section is used as background information and provides support to the load calculations performed on this plant. The theory presented also addresses the concerns raised in NUREG-0487.

C.2 DRAG AND LIFT COEFFICIENTS FOR UNSTEADY FLOW

C.2.1 GENERAL CONSIDERATIONS

Drag and lift loads on submerged structures in the suppression pool due to the LOCA charging air bubble, poolswell, fallback, and the SRV air bubble are considered. In calculating these loads on submerged structures, acceleration and standard drag and lift coefficients are used whenever they are applicable to a specific situation. The effects of unsteady flow on the above mentioned coefficients are treated in this section, and interference effects, if present, are addressed in Sections C.3 and C.4. The steady-state drag coefficients are corrected appropriately to include the effects of unsteady flow.

Because the majority of the available data for unsteady flow have been developed for a cylinder, the discussion provided herein is in terms of a cylinder. The structures in the Limerick suppression pool are all analyzed as cylinders. If differently shaped structures were present, a cylinder with an equivalent diameter would be used for calculations. This approach is conservative for drag load calculations, with the possible exception of the prediction of initiation of vortex shedding. Lift forces due to vortex shedding on sharp-edged structures are calculated conservatively based on available data.

Possible shapes of submerged structures in a Mark II suppression pool include circular cylinders, box beams, and I-beams. Equivalent diameters can easily be determined for these structures.

First, to determine the unsteady effects on a submerged structure, a circular cylinder with an equivalent diameter is considered. Then, from the appropriate literature, the drag coefficients due to unsteady flow for cylinders are determined, and a drag coefficient multiplier is calculated as the ratio of the unsteady drag coefficients to the steady-state drag coefficients. Finally these multipliers are applied to the steady-state drag coefficients of the particular submerged structure of interest. However, in computing the loads, the actual dimensions of the structure are used in order to properly determine the loads.

An equivalent diameter is determined by circumscribing a circle about any structure (Reference C.2-1, pg. 4-14). For a cylinder, the equivalent diameter is equal to the diameter of the cylinder.

If a box beam is considered, its equivalent diameter is:

$$D_{EQ} = \sqrt{a^2 + b^2} \qquad (C.2-1)$$

where:

a = height of box beam
b = width of box beam

For an I-beam, the equivalent diameter is:

$$D_{EQ} = \sqrt{a^2 + b^2} \qquad (C.2-2)$$

where:

a = depth of I-beam flange
b = width of I-beam flange

The nondimensional numbers on which drag coefficients depend are based on the equivalent diameter. They are:

$$\text{Reynolds number - Re} = \frac{U_m D_{EQ}}{\nu} \qquad (C.2-3)$$

$$\text{Period parameter - K} = \frac{U_m T}{D_{EQ}} \qquad (C.2-4)$$

$$\text{Strouhal number - S} = \frac{f D_{EQ}}{U_m} \qquad (C.2-5)$$

where:

U_m = maximum velocity at the location of the loaded structure during the transient

D_{EQ} = equivalent diameter

T = period of flow oscillation

f = vortex shedding frequency

ν = kinematic viscosity.

To properly determine the effect of unsteady flow, a drag coefficient multiplier is defined as the ratio of the unsteady to steady-state drag coefficients:

$$f_d = \frac{C_{D1}}{C_D} \qquad (C.2-6)$$

$$f_m = \frac{C_{M1}}{C_M} \qquad (C.2-7)$$

where:

C_D = steady-state standard drag coefficient

C_{D1} = unsteady standard drag coefficient

C_M = steady-state acceleration drag coefficient

C_{M1} = unsteady acceleration drag coefficient

f_d = standard drag coefficient multiplier

f_m = acceleration drag coefficient multiplier.

These factors are based on drag coefficients for circular cylinders. Once they are determined for cylinders using the

appropriate data, the factors are applied to the steady-state drag coefficients for the particular structure of interest. These steady-state drag coefficients are described in Reference C.2-1. The factors are applied in the following manner:

$$C_{D3} = f_d C_{D2} \quad (C.2\text{-}8)$$

$$C_{M3} = f_m C_{M2} \quad (C.2\text{-}9)$$

where:

C_{D2} = steady-state standard drag coefficient for the particular submerged structure

C_{D3} = corrected unsteady standard drag coefficient

C_{M2} = steady-state acceleration drag coefficient for the particular submerged structure

C_{M3} = corrected unsteady acceleration drag coefficient.

The lift coefficients are determined using the actual lift data for the specific structure analyzed for the applicable transient conditions.

However, if submerged structures of unique shapes are encountered in the suppression pool, they need to be considered on a plant-unique basis.

Finally, when all the coefficients are determined, the standard and acceleration drag forces are calculated based on the corrected drag coefficients and the actual structure dimensions. The sum of these forces is the in-line force.

The transverse force consists only of lift. The following equations present the contributions of the standard and acceleration drag forces to the in-line force:

$$F_S = \frac{C_{D3} A}{} \frac{\rho U(t)|U(t)|}{2 g_c} \qquad (C.2\text{-}10)$$

$$F_A = \frac{C_{M3} V_S \rho \dot{U}(t)}{g_c} \qquad (C.2\text{-}11)$$

$$F_{IN\text{-}LINE} = F_S + F_A \qquad (C.2\text{-}12)$$

where:

F_S = standard drag force

F_A = acceleration drag force

$F_{IN\text{-}LINE}$ = total in-line force

C_{D3} = corrected unsteady standard drag coefficient

C_{M3} = corrected unsteady acceleration drag coefficient

A = projected area of submerged structure

V_S = volume of submerged structure

ρ = fluid density

$U(t)$ = velocity in the in-line direction

$\dot{U}(t)$ = acceleration in the in-line direction.

g_c = gravitational acceleration

The determination of the lift force is considered separately in each of the following sections.

C.2.2 LOCA CHARGING AIR BUBBLE

The LOCA charging air bubble is considered to be a non-oscillatory accelerating flow. It is readily observed from the velocity and acceleration time histories of the transient (Figures C.2-1 and C.2-2) that the transient exhibited an increasing velocity and high positive values of acceleration. In addition, the fluid flow never reverses and the acceleration is nearly constant. This is true for all locations in the suppression pool. Comparing typical velocity time histories (Figure C.2-1) to acceleration time histories (Figure C.2-2), one can observe that the acceleration is the major contributor to the drag load because the velocity is small. The velocity and acceleration time histories were generated using the LOCA charging air bubble model described in Reference C.2-1.

The geometric configuration that was used to determine the LOCA charging air bubble transient on a submerged structure is shown in Figures C.2-3 and C.2-4. A 36 degree segment of a typical Mark II suppression pool was used, which contained 10 downcomers. The LOCA charging air bubbles were used at these downcomer locations to determine the velocity and acceleration time histories on a vertical submerged structure in the pool.

For this transient, Reference C.2-2 is used in determining the standard and acceleration drag coefficients, which are conservatively taken as 1.2 and 2.0, respectively.

Due to the low velocities and small duration of this transient, lift due to vortex shedding is not present. In Reference C.2-2, the author indicates that for unsteady flow, no lift force due to vortex shedding is present for small-period parameters. In addition, the author states that for a fluid starting from rest, a certain finite time is required for separation to occur if vortex shedding is to be present.

With the information in Reference C.2-2, it was determined that the time required for separation to occur was longer than the duration of the LOCA charging air bubble transient. Therefore, lift due to unsteady flow effects is not considered for this transient.

C.2.2.1 Lift Due to Vortex Shedding

According to Reference C.2-2, the separation necessary for vortex shedding to be present does not occur until a fluid has moved a distance:

$$S = 0.293D \qquad (C.2\text{-}13)$$

where:

S = traveled distance

D = cylinder diameter.

The authors also state in Reference C.2-2 that:

$$S = \frac{1}{2} Vt \qquad (C.2\text{-}14)$$

where:

V = velocity

t = time for separation to occur.

Assuming a representative case for LOCA charging air bubble velocity in a Mark II suppression pool, the maximum pipe diameter required for separation to occur can be determined. A linear velocity increase from 0.0 to 3.0 ft/sec was assumed to closely resemble the actual transient velocity with a transient duration of 60 msec. Integrating the velocity, a traveled distance S of 0.09 foot was determined. Using the above mentioned equations, the traveled distance translates to a maximum pipe diameter of 3-1/2 inches. In other words, for a pipe with a diameter of 3-1/2 inches that experienced a velocity transient increasing linearly from 0.0 to 3.0 ft/sec, separation would occur at 60 msec. This is the time when the LOCA charging air bubble transient has ended.

Following this procedure for other piping within the suppression pool experiencing the LOCA charging air bubble transient, it can

be concluded that lift due to vortex shedding is not present and does not need to be considered for Mark II pool geometries.

C.2.3 POOLSWELL

Poolswell is regarded as being an oscillatory flow, with the poolswell duration considered to be the half period of the flow field. This flow is exhibited by experimental data, namely, the EPRI and 4T tests. For Reynolds numbers in the subcritical region, the drag coefficients are determined from Reference C.2-3. These drag coefficients are dependent only on the period parameter. However, if the Reynolds number is in the supercritical region ($>4x10^5$), the steady-state standard drag coefficient reduces from 1.2 to 0.71 (Reference C.2-4). To determine the unsteady standard and acceleration drag coefficients for flow at the supercritical Reynolds numbers, Reference C.2-5 is used, which correlates the Reynolds number, period parameter, and the pipe roughness to both the standard and acceleration drag coefficients. The correlations for smooth pipes are used because these correlations best represent the structures within the Mark II suppression pool.

In addition, lift due to vortex shedding is considered. Reference C.2-6 provides the necessary information to determine lift loads. As before, the lift coefficient is based on the period parameter and the Reynolds number where both are evaluated at the maximum velocity observed in the transient. Moreover, the vortex shedding frequency must also be defined. Reference C.2-5 provides a correlation of f_r, the relative frequency, to the period parameter and the Reynolds number evaluated at the maximum velocity.

$$f_r = \frac{f_v}{f_w} \qquad \text{(C.2-15)}$$

where:

f_r = relative frequency

f_v = vortex shedding frequency

f_w = oscillating fluid frequency.

However, if the relative frequency falls out of the range shown in Figure 21 of Reference C.2-5, Reference C.2-6 indicates that a Strouhal number of 0.3 should be used at high Reynolds numbers.

When determining the lift force due to vortex shedding, the maximum amplitude is based on the maximum velocity that the structure sees (Reference C.2-6):

$$F_L = C_L \frac{A \rho U_m^2 \sin 2 \pi f_v t}{2g_c} \qquad \text{(C.2-16)}$$

Where:

F_L = lift force (transverse to flow direction)

C_L = lift coefficient

A = projected area of structure

g_c = gravitational acceleration

ρ = fluid density

U_m = maximum in-line velocity the structure observes

f_v = vortex shedding frequency

t = time.

The vortex shedding frequency is specified from the correlation mentioned previously. With the maximum amplitude and frequency, the lift force is defined. The lift force varies with time and is sinusoidal in nature for viscous lift.

In this case, the acceleration drag force considers the effect of gravity and is determined in the following manner:

$$F_A = \frac{V_S \rho C_{M3} \dot{U}(t)}{g_c} \qquad (C.2-17)$$

where:

F_A = acceleration drag force

V_S = volume of submerged structure

C_{M3} = corrected unsteady acceleration drag coefficient

$\dot{U}(t)$ = acceleration in the in-line direction.

C.2.4 FALLBACK

Fallback is considered to be a constantly accelerating flow. It is assumed that fallback behaves as a falling water slug. For this case, the standard and acceleration drag coefficients are determined from Reference C.2-2. As with poolswell, the lift coefficients due to vortex shedding are also determined. The lift coefficient is given by Reference C.2-7 as CL = 1.0 for Karman vortices. To determine the vortex shedding frequency, Reference C.2-7 indicates that a Strouhal number of 0.22 should be used. This is also substantiated by Reference C.2-8. The force is then determined as:

$$F_L = \frac{C_L \Delta\rho U_m^2 \sin 2 \pi f t}{2g_c} \qquad (C.2-18)$$

In this case, the acceleration drag force is determined in the following manner:

$$F_A = \frac{C_H g V_S \rho}{g_c} \qquad (C.2-19)$$

where:

C_H = hydrodynamic mass coefficient ($C_H = C_M - 1$).

C.2.5 SRV AIR BUBBLES

SRV air bubbles are considered to be of oscillatory nature. Reference C.2-3 is used to determine the unsteady standard and acceleration drag coefficients. These drag coefficients are based on the period parameter evaluated at the maximum velocity. However, if the unsteady drag coefficients are less than the steady-state drag coefficients, then the steady-state coefficients are used for load determination. If any lift is present, Reference C.2-3 is used, which also bases the lift coefficients on the period parameter. This reference mentions that no lift is present for period parameters less than 5. The drag loads are determined as described in Section C.2.1.

C.2-6 REFERENCES

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C.2-2 T. Sarpkaya and C. J. Garrison, "Vortex Formation and Resistance in Unsteady Flow," Journal of Applied Mechanics, pp. 16-24, March 1963.

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C.2-4 G. K. Batchelor, An Introduction to Fluid Dynamics, pg. 341, Cambridge, England, 1967.

C.2-5 T. Sarpkaya, "In-Line and Transverse Forces on Cylinders in Oscillatory Flow at High Reynolds Numbers," Journal of Ship Research, Vol. 21, No. 4, pp. 200-216, December 1977.

C.2-6 T. Sarpkaya, "Vortex Shedding and Resistance in Harmonic Flow About Smooth and Rough Circular Cylinders at High Reynolds Numbers," NPS-59SL76021, February 1976.

C.2-7 J. P. Den Hartog, Mechanical Vibrations, Fourth edition, pp. 305-306, McGraw-Hill Book Co., Inc., New York, 1956.

C.2-8 J. A. Roberson and C. T. Crowe, Engineering Fluid Mechanics, pp. 338-340, Houghton Mifflin Co., Illinois, 1975.

C.3 INTERFERENCE EFFECTS ON ACCELERATION DRAG

When submerged structures are closely located in a flow field, they can interfere with one another, affecting the acceleration drag. The proximity effect can be accounted for by either (a) using actual data that is presented in References C.3-4, C.3-6, and C.3-7, (b) performing a detailed analysis, or (c) applying a conservative factor of 4 on the acceleration drag. For the Limerick plant, actual data that are presented in References C.3-4, C.3-6, and C.3-7 were used to determine the interference effects on acceleration drag.

A detailed method is presented in the following sections for determining interference effects of nearby cylinders and/or a boundary on the acceleration drag for circular cylinders and is based on References C.3-1 through C.3-6.

According to the method, the interference effect between any two stationary cylinders can be completely determined by six force coefficients that are functions solely of the radius ratio and the relative spacing. For the case of more than two cylinders, the total proximity effect on a given cylinder may be approximately obtained simply by superimposing each interference effect between cylinder pairs.

C.3.1 METHOD OF ANALYSIS

The following assumptions are considered in the method:

a. Two-dimensional potential flow without separations and wakes is considered.

b. The velocity and acceleration in the flow field are the same as those seen locally by the submerged structure (cylinder).

c. The containment and pedestal walls are considered as plane boundaries.

d. Coordinate system

+x : radially outward from reactor pressure vessel centerline.

+y : vertically upward.

+z : by right-hand rule parallel to the plane boundary.

Origin: at the center of cylinder in question.

C.3.2 TWO STATIONARY CYLINDERS (REAL CYLINDERS)

If the p-th cylinder is isolated in a free stream, the hydrodynamic (acceleration drag) force per unit length of the cylinder is:

$$F_{po} = 2 \rho \pi A_p^2 \dot{U}_{\infty n} \qquad \text{(C.3-1)}$$

where:

F_{po} = acceleration drag force per unit length

ρ = fluid density

A_p = radius of p-th cylinder

$\dot{U}_{\infty n}$ = acceleration normal (in-line) to p-th cylinder

When the n-th cylinder is in the vicinity of the p-th cylinder, the change in the force of the p-th cylinder, ΔF_{pn}, is:

$$\Delta F_{pn} = \rho \pi A_p^2 |\dot{U}_{\infty n}| \left\{(C_1-1)\exp(i\alpha_1)-C_2\exp[i(2\beta_{pn}-\alpha_1)]\right\}$$

$$+ \rho A_p |U_{\infty n}|^2 \left\{(C_3+C_4)\exp(i\beta_{pn})-C_5\exp[i(3\beta_{pn}-2\alpha_2)]\right.$$

$$\left.-C_6\exp[i(2\alpha_2-\beta_{pn})]\right\} \qquad \text{(C.3-2)}$$

where:

$U_{\infty n}$ = velocity normal (in-line) to the p-th cylinder

α_1 = angle of acceleration with respect to z-axis

α_2 = angle of velocity with respect to z-axis

β_{pn} = angle between the line through centers of cylinders and the z-axis.

$$C_1 = 1+2\sum_{j=1}^{\infty} b_{1,2j+1}$$

$$C_2 = 2\left(\frac{A_n}{A_p}\right)^2 \sum_{j=1}^{\infty} b_{1,2j+1}$$

$$C_3 = 4\pi\sum_{k=1}^{\infty}\sum_{j=1}^{\infty}\frac{b_{1,2k-1}\, b_{2,2j}}{\left(\frac{L_{pn}}{A_p} - q_{1,2k-1} - \frac{A_n}{A_p} q_{2,2j}\right)^3}$$

$$C_4 = 4\pi\left(\frac{A_n}{A_p}\right)^4\sum_{k=1}^{\infty}\sum_{j=1}^{\infty}\frac{b_{1,2k-1}\, b_{2,2j-1}}{\left(\frac{L_{pn}}{A_p} - q_{1,2k} - \frac{A_n}{A_p} q_{2,2j-1}\right)^3}$$

$$C_5 = 4\left(\frac{A_n}{A_p}\right)^2 \sum_{k=1}^{\infty} \sum_{j=1}^{\infty} \frac{b_{1,2k-1}\, b_{2,2j-1}}{\left(\frac{L_{pn}}{A_p} - q_{1,2k-1} - \frac{A_n}{A_p}\, q_{2,2j-1}\right)^3}$$

$$C_6 = 4\left(\;{}^{\prime\prime}{}_{p}\right) \sum_{j=1}^{\infty} \sum_{k=1}^{\infty} \frac{b_{1,2k}\, b_{2,2j}}{\left(\frac{L_{pn}}{A_p} - q_{1,2k} - \frac{A_n}{A_p}\, q_{2,2j}\right)^3}$$

where:

$b_{1,1} = 1$

$b_{2,1} = 1$

$b_{1,m} = b_{2,m-1}\, q_{1,m}^2$ for $m \geq 2$

$b_{2,m} = b_{1,m-1}\, q_{2,m}^2$ for $m \geq 2$

in which:

$q_{1,1} = 0$,

$q_{2,1} = 0$,

$$q_{1,j} = \frac{A_p}{L_{pn} - A_n q_{2,j-1}} \qquad \text{for } j \geq 2,$$

$$q_{2,j} = \frac{A_n}{L_{pn} - A_p q_{1,j-1}} \qquad \text{for } j \geq 2,$$

A_n = radius of the n-th cylinder

L_{pn} = distance between the centers of cylinders.

C.3.3 STATIONARY CYLINDERS NEAR A PLANE BOUNDARY (REAL AND IMAGINARY CYLINDERS)

A single stationary cylinder in a uniform stream, $U_{\infty n}$, is hydrodynamically equivalent to a cylinder moving at a speed $-U_{\infty n}$ in a still fluid, except that the former cylinder experiences an extra force, $\rho \pi A_p^2 \dot{U}_{\infty n}$, from the pressure field that has been created to provide the fluid acceleration, $\dot{U}_{\infty n}$. This is also true for any number of cylinders if the cylinders move together.

When a cylinder is moving in an arbitrary direction (on a line or on a curve) with respect to the plane boundary, it can be considered as two equal cylinders moving symmetrically with respect to the plane boundary because the plane acts as a perfect reflector (mirror) of the hydrodynamic pressure. A similar argument can be applied to multiple cylinders.

Based on the above discussion, the plane boundary can be removed and replaced by an imaginary cylinder of the same size as the original (real) cylinder and located at twice the distance between the real cylinder and the plane boundary away from the original cylinder. Similarly, multiple imaginary cylinders can be obtained by reflecting those multiple real cylinders near the plane boundary.

Now if the n-th imaginary cylinder is in the proximity of the p-th cylinder, the change in the hydrodynamic force of the p-th cylinder, ΔF_{pn}, can be derived from Reference C.3-1 and is:

$$\Delta F_{pn} = \rho \pi A_p^2 \,|\dot{U}_{\infty n}|\, \left\{(C_1-1)\exp(i\alpha_1) - C_2\exp[i(\alpha_1+2\beta_{pn})]\right\}$$
$$+ \rho A_p |U_{\infty n}|^2 \left\{(C_3+C_4)\exp(i\beta_{pn}) - C_5\exp(i3\beta_{pn}) - C_6\exp(-i\beta_{pn})\right\} \qquad (C.3\text{-}3)$$

where:

C_1 through C_6 are the same as described earlier.

C.3.4 TOTAL ACCELERATION DRAG FORCE

Summing up each effect from all the surrounding N real and imaginary cylinders, the force on the p-th cylinder is approximately given as:

$$F_p = F_{po} + \sum_{\substack{n=1 \\ n\neq p}}^{n} \Delta F_{pn} = 2\rho\pi A_p^2 \dot{U}_{\infty n} + \sum_{\substack{n=1 \\ n\neq p}}^{n} \Delta F_{pn} \qquad (C.3\text{-}4)$$

or:

$$F_p = C_m \rho\pi A_p^2 \,|\dot{U}_{\infty n}| + C_{v\rho} A_p |U_{\infty n}|^2 \qquad (C.3\text{-}5)$$

where:

C_m = acceleration drag coefficient

C_v = convective force coefficient.

C.3.5 PRACTICAL APPLICATION

When the increase in force on the p-th cylinder arising from inerference effects is calculated, only those real and imaginary cylinders that have a significant contribution should be considered. Significant contributions to the summation equations presented in Section C.3.4 arise only from those cylinder pairs within a gap distance of 3D, where D is the larger diameter of the pair being considered.

If the flow is omnidirectional during a specific transient, a magnification factor K_M may be obtained from the maximum $|C_m|$ that is determined in the range of $0° \leq \alpha_1 \leq 180°$. This is performed to account for the interference effect on the acceleration drag. Similarly, to account for the lift force, the maximum $|C_v|$ can be determined by varying α_2 in the range of $0° \leq \alpha_2 \leq 180°$. Then the maximum lift coefficient is combined with the standard drag coefficient, C_D, by the square root of the sum of the squares to include the lift force due to the proximity effect.

The acceleration and drag forces are determined as follows:

$$|F_{Ap}| = \frac{2K_M \rho \pi A^2_p |\dot{U}_{\infty n}|}{g_c} \qquad (C.3-6)$$

$$|F_{sp}| = \sqrt{C_D^2 + |C_L|^2} \; \frac{\rho A_p |U_{\infty n}| U_{\infty n}}{2g_c} \qquad (C.3-7)$$

where:

F_{Ap} = acceleration drag per unit length on p-th cylinder

K_M = $|C_m|/2$ magnification factor and $|C_m|$ is the maximum acceleration drag coefficient

ρ = fluid density

A_p = radius of p-th cylinder

$\dot{U}_{\infty n}$ = acceleration in the normal (in-line) direction to the cylinder

$U_{\infty n}$ = velocity in the normal (in-line) direction to the cylinder

C_D = standard drag coefficient

$|C_L|$ = maximum lift coefficient

F_{sp} = standard drag per unit length on p-th cylinder.

The directions of the acceleration and standard drags are the same as those without the interference effect.

However, if the flow field is well defined and the direction of flow known, then the actual acceleration drag and lift coefficients are used. In this case, the lift force is applied in the transverse direction. The equations used are then:

$$F_{Ap} = \frac{2 C_m \rho \pi A_p^2 \dot{U}_{\infty n}}{g_c} \qquad (C.3\text{-}8)$$

$$F_{Lp} = \frac{C_L \rho A_p |U_{\infty n}| U_{\infty n}}{2g_c} \qquad (C.3\text{-}9)$$

where:

C_m = acceleration drag coefficient determined through the analysis

C_L = lift coefficient determined through the analysis

F_{Lp} = lift force in the transverse direction.

C.3.6 MODEL/DATA COMPARISONS

The method has been tested numerically as well as experimentally, and the results (Figure C.3-1) indicate excellent agreement with both known numerical values (References C.3-1, C.3-2, C.3-4) and experimental data (References C.3-3, C.3-5).

C.3.7 REFERENCES

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C.3-7 T. Sarpkaya, "In-Line and Transverse Forces on Cylinders Near a Wall in Oscillatory Flow at High Reynolds Numbers," Paper No. OTC 2898, presented at the Offshore Technology Conference, Houston, Texas, May 2-5, 1977.

C.4 INTERFERENCE EFFECTS ON STANDARD DRAG

When submerged structures are located closely together in a flow field, they can interfere with one another causing an effect on the standard drag. Actual data presented in the references can be used, a detailed analysis can be used, or a factor of four can be applied to the standard drag force. For the Limerick plant, actual data that are presented in Reference C.4-2 were used to determine the interference effects on standard drag.

This section deals with the detailed analysis to determine the interference effects on standard drag.

Three technical papers (References C.4-1, C.4-2, C.4-3) have described this phenomenon and presented experimental data on interference effects. Most of the data presented in these references are applicable to interference between two cylinders. Reference C.4-2 has presented some data for three cylinders whose axes are co-planar. Cylinder spacing, Reynolds number, and the angle between flow direction and the plane containing cylinder axes were varied in the above investigations. In many instances the data obtained from the above references can be applied directly to Mark II suppression pool conditions.

A procedure has been developed to use the above data for interference between more than two cylinders. The results have been compared with measured data of three cylinders and are found to be conservative.

C.4.1 INTERFERENCE BETWEEN TWO CYLINDERS OF EQUAL DIAMETER

As indicated by the data given in References C.4-1, C.4-2, and C.4-3, the interference between two parallel cylinders alters the flow direction drag and also induces a lift force normal to flow direction. For two cylinders of equal diameter, the interference effect on drag forces is small, and in most cases negative (i.e.,

the drag is reduced due to interference). The lift force, however, is not always insignificant.

The following bounding values for interference between two cylinders of equal diameter can be used without any further detailed analysis. A bounding value of C_D for a Reynolds number number greater than 8,000 and a S/d ratio greater than 0.2 is 1.4, and the bounding value for C_L is 1.0.

C.4.2 INTERFERENCE BETWEEN MORE THAN TWO CYLINDERS OF EQUAL DIAMETER

To evaluate the drag coefficient of a cylinder that is interfered by more than one cylinder, the maximum of C_{Do}, C_{Di}, and $D_{Di,j}$ should be used.

$$C_{Di} - C_{Do} = \sum_{\substack{j=1 \\ j \neq i}}^{n} (C_{Di,j} - C_{Do}) \qquad (C.4\text{-}1)$$

where:

C_{Di} = standard drag coefficient for the i-th cylinder

C_{Do} = standard drag coefficient for a single cylinder without any interference

$C_{Di,j}$ = drag coefficient of i-th cylinder when it is interfered by Cylinder j alone.

Figure C.4-1 illustrates an arrangement of cylinders. The standard drag coefficient of Cylinder 1 would be:

$$C_{D_1} = C_{D_0} + (C_{D_{1,2}} - C_{D_0}) + (C_{D_{1,3}} - C_{D_0}) + (C_{D_{1,4}} - C_{D_0})$$

From this, the maximum value of C_{D_1}, C_{D_0}, $C_{D_{1,2}}$, $C_{D_{1,3}}$, and $C_{D_{1,4}}$ would be used for the standard drag coefficient.

To evaluate the lift coefficient, the maximum of C_{Li} and $C_{Li,j}$ should be used:

$$C_{Li} = \sum_{\substack{j=1 \\ j \neq i}}^{n} C_{Li,j} \qquad (C.4-2)$$

where:

C_{Li} = lift coefficient of i-th cylinder

$C_{Li,j}$ = lift coefficient of i-th cylinder when it is interfered by Cylinder j alone.

From Figure C.4-1, the lift coefficient would be determined in the following manner:

$$C_{Li} = C_{L_{1,2}} + C_{L_{1,3}} + C_{L_{1,4}} \qquad (C.4-3)$$

The maximum value of C_{L_1}, $C_{L_{1,2}}$, $C_{L_{1,3}}$, and $C_{L_{1,4}}$ would be used for the lift coefficient.

The above described method yielding interference on standard drag between more than two cylinders of equal diameter (bounding procedure) is illustrated in the following examples:

Example 1

Consider the three cylinder arrangement shown in Figure C.4-2

$$\text{Let } \frac{S}{d} = 1,\ \theta = 60^\circ, \text{ and } Re = 2.78 \times 10^4.$$

For this arrangement.

$C_{D_{1,2}}$ = Drag coefficient of Cylinder 1 when interfered by Cylinder 2 only.

$= 1.01 \ (\frac{S}{d} = 1)$

$C_{D_{1,3}} = 1.02 \ (\frac{S}{d} = 3)$

C_{Do} = 1.16 [Reference C.2-4, pg. 341]

$$C_{Di} - C_{D_o} = (C_{D_{1,2}} - C_{D_o}) + (C_{D_{1,3}} - C_{D_1})$$

$$C_{Di} = 1.01 + 1.02 - 1.16$$

$$= 0.37$$

$\therefore$ Maximum of C_{Di} ; $C_{D_{1,2}}$; $C_{D_{1,3}}$; C_{D_o} is 1.16

$\therefore$ Use C_D = 1.16

From measurements (Reference C.4-2):

C_D = 0.97, which is less than the calculated drag coefficient.

Example 2

Consider the three cylinder side-by-side arrangement shown in Figure C.4-3.

Let $\frac{S}{d} = 1$ and $Re = 2.78 \times 10^4$.

$C_{D_{1/2}} = 1.03 \; (\frac{S}{d} = 1)$

$C_{D_{1/3}} = 1.05 \; (\frac{S}{d} = 3)$

$C_{D_0} = 1.16$

$\therefore C_{D_1} - 1.16 = 1.03 - 1.16 + 1.05 - 1.16$

or $C_{D_1} = 0.92$

Maximum of C_{D_0} ; C_{D_1} ; $C_{D_{1/2}}$; $C_{D_{1/3}}$ is 1.16

Use C_D = 1.16

The measured value is 0.98, which is less than the calculated value.

C.4.3 DRAG ON SMALL CYLINDER UPSTREAM OF LARGE CYLINDER

Figure C.4-4 presents the flow around cylinders of unequal diameters.

The coordinates of point A (center of smaller cylinder) are (-a,b). Let R and R_1 be the radii of larger and smaller cylinders, respectively. The velocity potential of flow around the larger cylinder in the absence of smaller cylinder is

$$\emptyset = ' \left(1 + \frac{R^2}{x^2 + y^2}\right)$$

where:

$\emptyset$ = velocity potential

U = free stream velocity

R = radius of large cylinder.

If u and v are the x and y components of velocity at point "A" (smaller cylinder absent) then,

$$u = U \left[1 + R^2 \left\{ \frac{b^2 - a^2}{(a^2 + b^2)^2} \right\} \right] \quad \text{(C.4-4)}$$

and

$$v = \frac{2ab\ R^2\ U}{(a^2 + b^2)^2} \quad \text{(C.4-5)}$$

where:

u = the velocity parallel to the free stream velocity at the centerline of the smaller cylinder

v = the velocity perpendicular to the free stream velocity at the centerline of the smaller cylinder.

To use the above velocity correction, it is more convenient to increase the standard drag coefficient and use the corrected standard drag coefficient with the free stream velocity. The standard drag force on the smaller cylinder with interference present is:

$$F_1 = \frac{C_D \rho A (u^2 + v^2)}{2g_c} \qquad (C.4-6)$$

where:

F_1 = standard drag force with interference

C_D = standard drag coefficient

ρ = fluid density

A = projected area of smaller cylinder.

The direction of flow is:

$$\beta = \tan^{-1} \left(\frac{v}{u}\right)$$

The standard drag force without interference is:

$$F = \frac{C_D \rho A U^2}{2g_c} \qquad (C.4-7)$$

where:

F = standard drag force without interference

U = free stream velocity.

The ratio of the two standard drag forces yields the following expression for the correction of the standard drag coefficients:

$$\frac{C_D\ (\text{interference})}{C_D\ (\text{without interference})} = m^2 + n^2 \qquad (C.4\text{-}8)$$

where:

$$m = 1 + R^2 \left\{ \frac{b^2 - a^2}{(a^2 + b^2)^2} \right\}, \text{ and}$$

$$n = \frac{2ab\ R^2}{(a^2 + b^2)^2}.$$

If the determined ratio of the standard drag coefficients is less than 1, then a ratio of 1 is used. However, if the determined ratio is greater than 1, then the determined ratio is used.

The standard drag force on the smaller cylinder is then determined by:

$$F_1 = \frac{C_D\ \rho\ A\ U\ |U|}{2g_c} \qquad (C.4\text{-}9)$$

Where:

F_1 = standard drag force on smaller cylinder

C_D = the corrected standard drag coefficient for interference

U = free stream velocity in the in-line direction.

The lift force on the smaller cylinder is determined in the same manner as was the standard drag force:

$$\frac{C_L\ (\text{interference})}{C_L\ (\text{without interference})} = m^2 + n^2 \qquad (C.4\text{-}10)$$

where m and n are the same as previously described. Once again, if the determined ratio is less than 1, then the ratio of 1 is

used. However, if the determined ratio is greater than 1, then the determined ratio is used. The lift force is then determined by:

$$F_L = \frac{C_L \rho A U |U|}{2g_c} \qquad (C.4-11)$$

where:

F_L = lift force

C_L = corrected lift coefficient for interference.

The lift force is applied in the transverse direction to the resultant flow.

C.4.4 STANDARD DRAG ON SMALLER CYLINDER DOWNSTREAM OF LARGE CYLINDER

If the smaller cylinder is located downstream of the larger cylinder, then the lift and standard drag coefficients are evaluated corresponding to S/d (where S is the distance between the cylinder surfaces and d is the diameter of the cylinders) ratios for both cylinders, assuming equal diameters. The coefficients are first determined by assuming both cylinders are equal to the diameter of the smaller cylinder, and then assuming both cylinders are equal to the diameter of the larger cylinder. When determining the coefficients, the centerline distance between the two submerged structures is maintained at the actual distance.

Afterwards, the larger coefficients are used for determining submerged structure loads. In addition, if the lift and standard drag coefficients are less than the coefficients without interference, then the coefficients without interference are used.

C.4.5 STANDARD DRAG ON THE LARGE CYLINDER

The method described in Section C.4.4 is used to determine the standard drag and lift on the large cylinder.

C.4.6 STRUCTURES OF NON-CIRCULAR CROSS-SECTION

The methodology of determining an equivalent diameter described in Section C.4.2 is used to determined the coefficients due to interference effects.

C.4.7 INTERFERENCE BETWEEN ON-PARALLEL CYLINDERS

To estimate the interference effects between non-parallel structures, the lift and standard drag coefficients are determined by assuming that the structures are parallel. The distance used between them would be the minimum distance between the two structures. In the same manner, the larger coefficients of either with or without interference effects are chosen for submerged structure load determination.

C.4.8 REFERENCES

C.4-1 E. I. Hori, "Experiments on Flow Around a Pair of Parallel Circular Cylinders," proceedings of the 9th Japan National Congress for Applied Mechanics, pp. 231-234, 1959.

C.4-2 C. Dalton and J. M. Szabo, "Drag on a Group of Cylinders," Transactions of the ASME, Journal of Pressure Vessel Technology, pp. 152-157, February 1977.

C.4-3 M. M. Zdravkovich, "Review of Flow Interference Between Two Circular Cylinders in Various Arrangements," Transactions of the ASME, Journal of Fluids Engineering, pp. 618-633, December 1977.

C.5 FLOW BLOCKAGE EFFECTS OF DOWNCOMER BRACING

The downcomer bracing is a flow restriction that increases the fluid velocity and acceleration during poolswell. As a result, the standard drag, acceleration drag, and lift loads on structures in the poolswell zone are higher than those which would exist if no downcomer bracing was present. Although the poolswell loads are not design-controlling criteria, the load calculations were adjusted for blockage effects by introducing a multiplicative factor to the fluid velocity and acceleration.

A method of correction has been developed based on References C.5-1 and C.5-2. A multiplicative factor has been determined based upon Maskell's paper (Reference C.5-2).

$$\frac{C_{Dm}}{C_{Df}} = 1 + n\, C_{Df} \frac{S}{C} \qquad (C.5\text{-}1)$$

where:

C_{Dm} = modified drag coefficient of structures in the poolswell zone

C_{Df} = steady flow, free steam drag coefficient

n = blockage factor

S = total blocked area

C = unrestricted flow area.

The value of the blockage factor, n, depends upon the structure's geometry. The blockage ratio varies from 0.96 to 2.77 for structures with aspect ratios, AR, from ∞ to 1.0, respectively. Maskell (Reference C.5-2) recommends a blockage factor of 2.5 for bluff bodies, and this value is considered conservative for the suppression pool bracing system.

The unrestricted flow area, C, is the pool surface area minus the area of the columns, downcomers and MSRV lines. The blocked area, S, includes all the flanges and members of the bracing system. The drag coefficient used on the right side of Equation C.5-1 is the steady flow, free stream drag coefficient of the particular structure being analyzed.

Equation C.5-1 can be rearranged to obtain

$$C_{Dm} = \left(1 + n\, C_{Df} \frac{S}{C}\right) C_{Df} \qquad (C.5\text{-}2)$$

$$= f\, C_{Df}$$

where f is defined as the blockage correction factor. Because f is proportional to the drag coefficients, and therefore to the square of the velocity, the fluid velocity and acceleration are multiplied by the square root of f. For consistency, the same multiplicative factor is used for the velocity and acceleration.

As a result, the poolswell loads are calculated by the following equations:

Standard Drag Load: $$F_X = \frac{1}{2} \rho (\sqrt{f} V)^2 C_D A \quad (C.5\text{-}3)$$

Acceleration Drag Load: $$F_A = \rho (\sqrt{f} a) C_m V_s \quad (C.5\text{-}4)$$

Lift Load: $$F_L = \frac{1}{2} \rho (\sqrt{f} V)^2 C_L A \quad (C.5\text{-}5)$$

where:

ρ = fluid density

f = blockage correction factor

V = fluid velocity

C_D = standard drag coefficient which accounts for any interference effects

A = projected cross-sectional area of the structure

C_L = lift coefficient

a = fluid acceleration

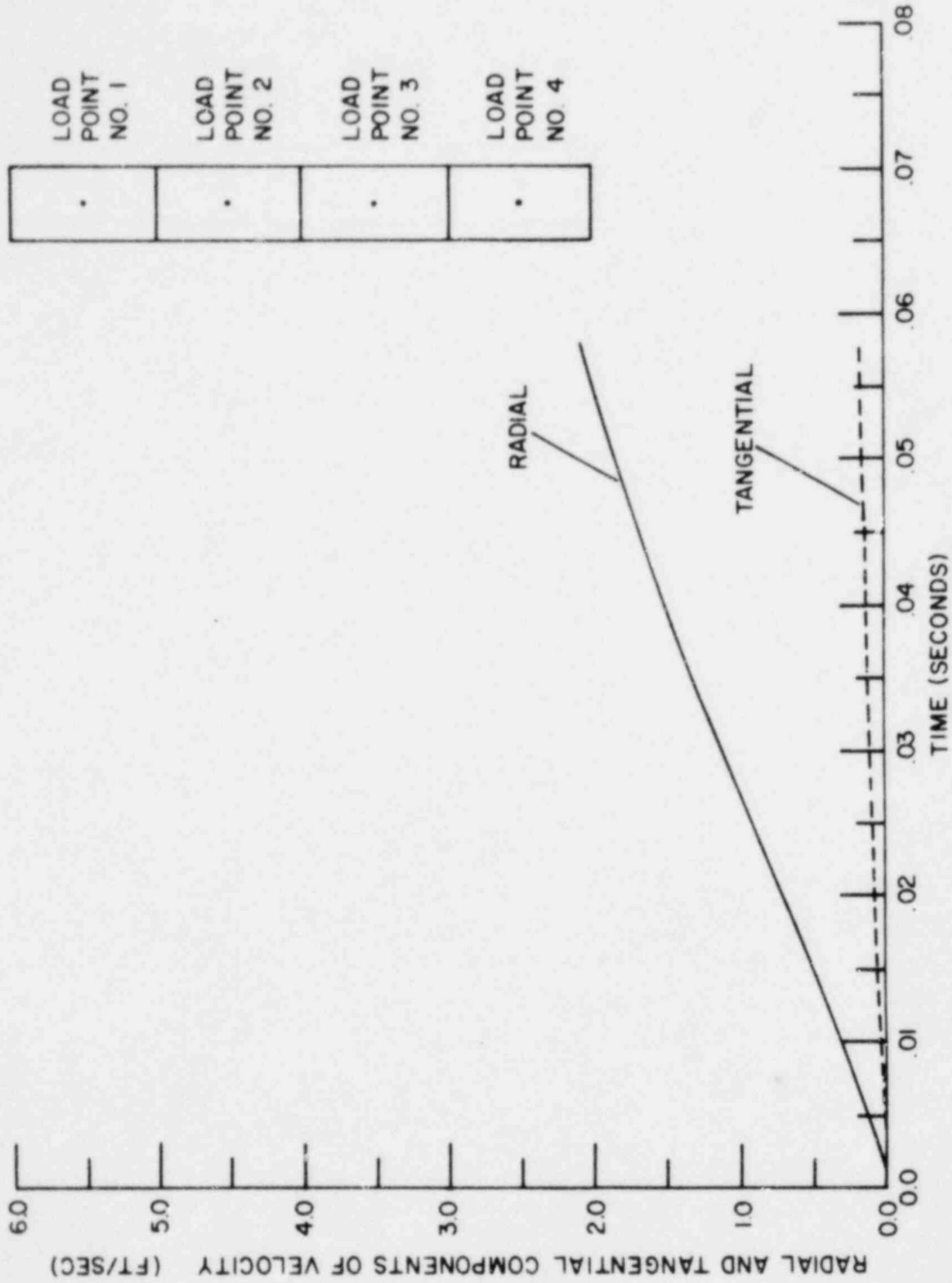
C_m = inertial coefficient

V_S = structure's volume.

C.5.1 REFERENCES

C.5-1 R. W. F. Gould, "Wake Blockage Corrections in a Closed Wind Tunnel One or Two Wall-Mounted Models Subject to Separated Flow," Aerodynamics Division, N.P.L., Reports and Memoranda 3649, February 1969.

C.5-2 E. C. Maskell, "A Theory of the Blockage Effects on Bluff Bodies and Stalled Wings in a Closed Wind Tunnel," British ARC, Reports and Memoranda 3400, November 1963.



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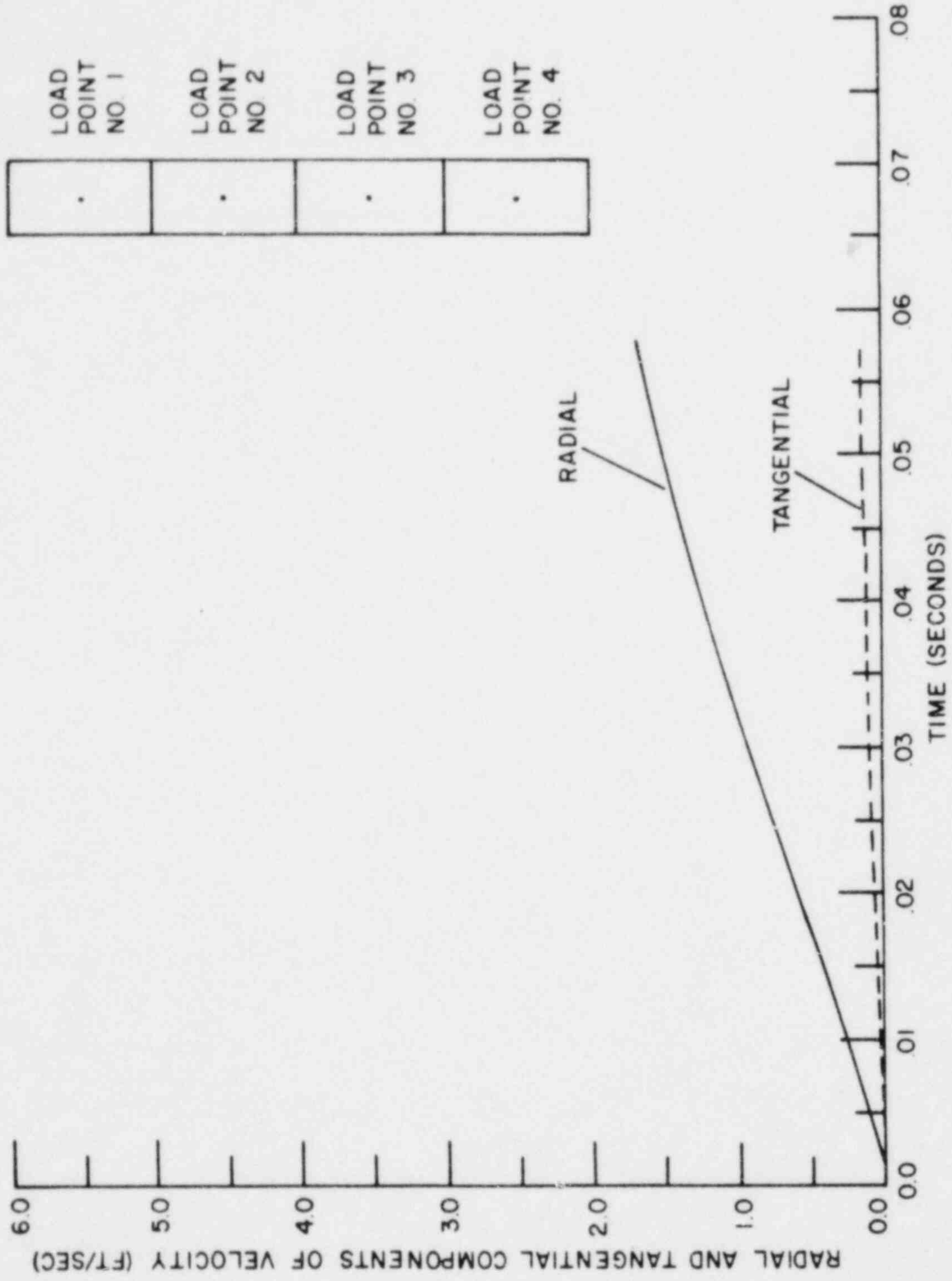
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

LOCA AIR CLEARING VELOCITY
SHEET 1 OF 4

FIGURE C.2-1



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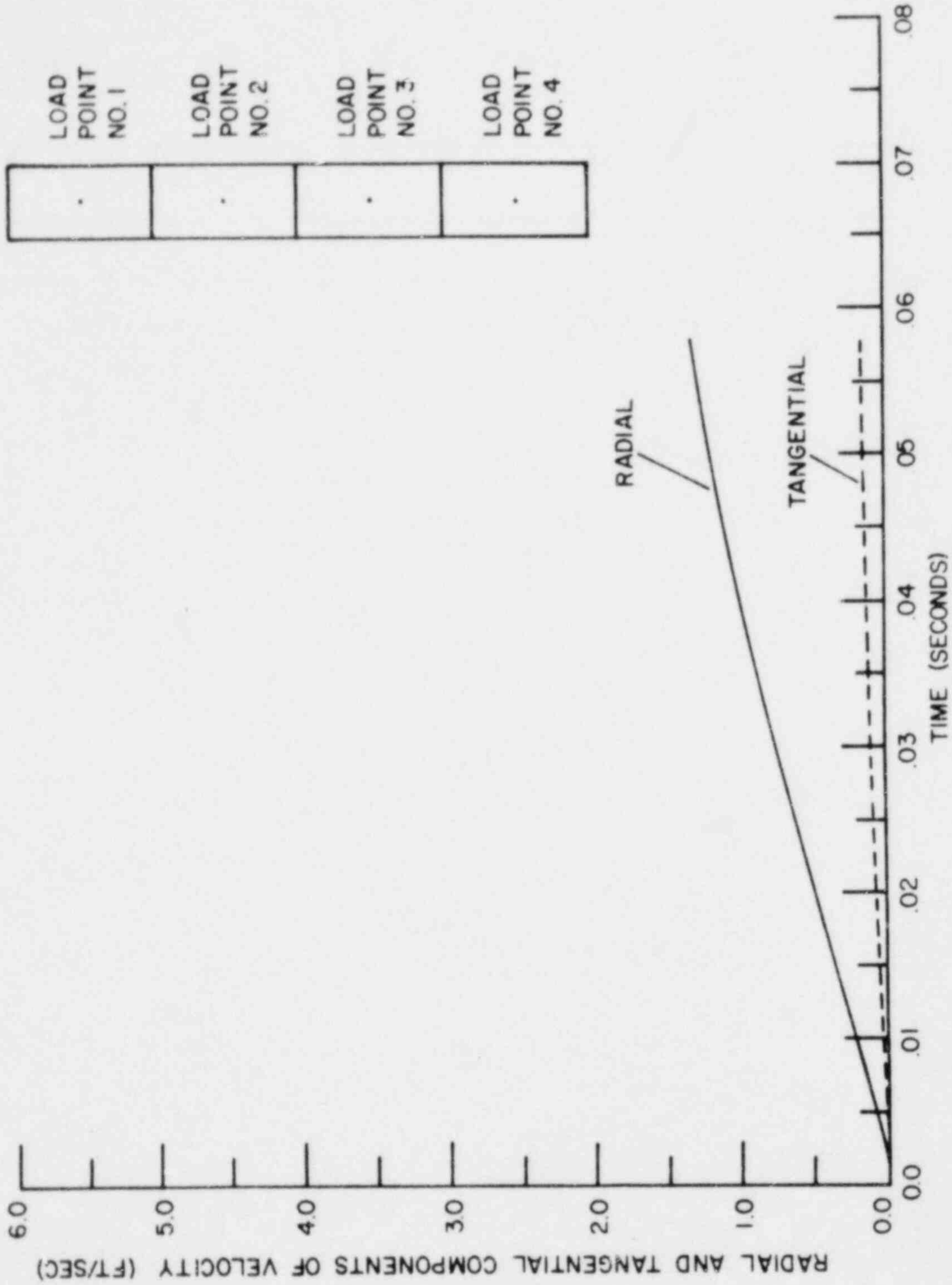
LIMERICK GENERATING STATION UNITS 1 AND 2 DESIGN ASSESSMENT REPORT
LOCA AIR CLEARING VELOCITY SHEET 2 OF 4
FIGURE C.2-1



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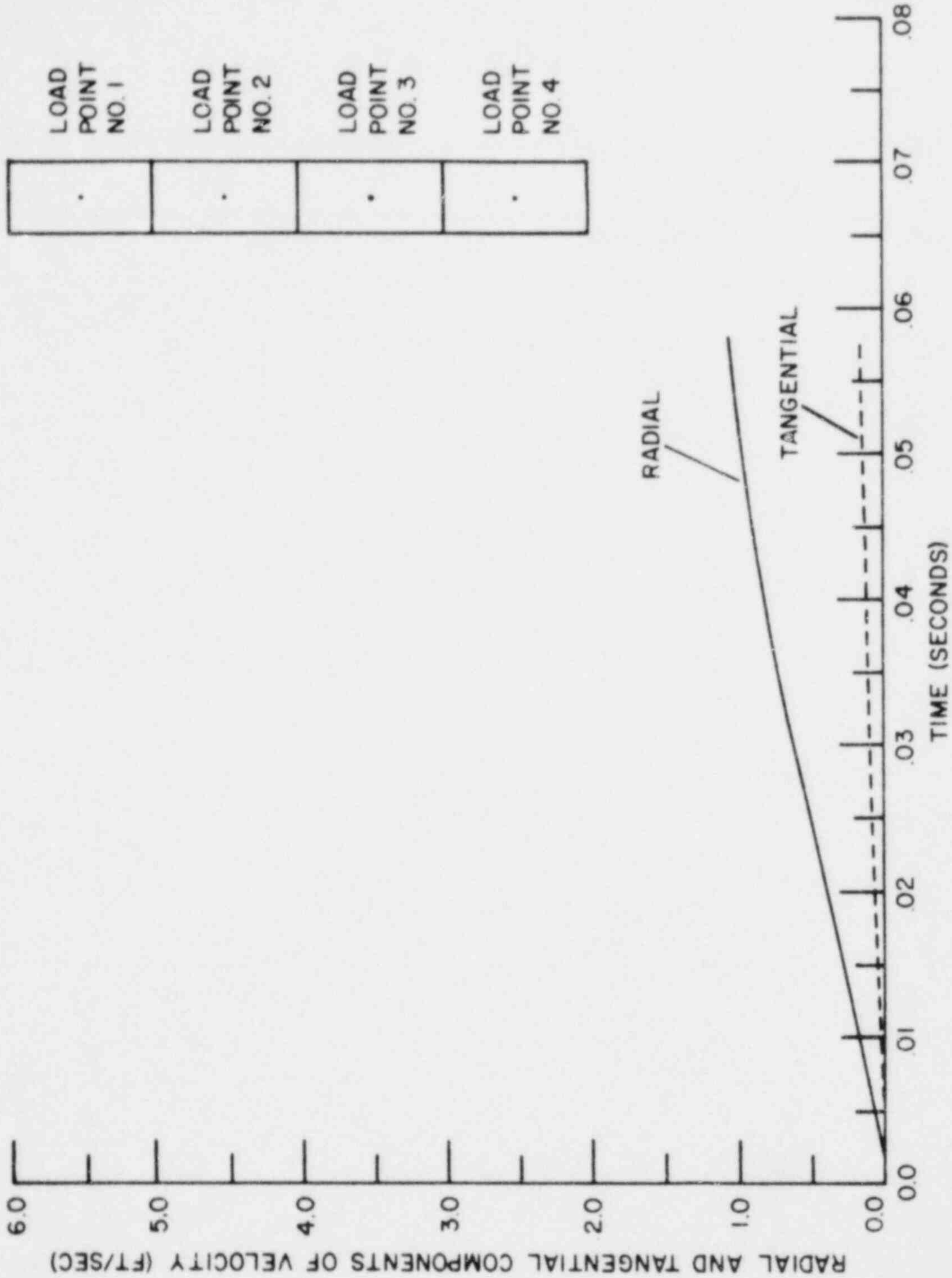
LOCA AIR CLEARING VELOCITY
SHEET 3 OF 4

FIGURE C.2-1



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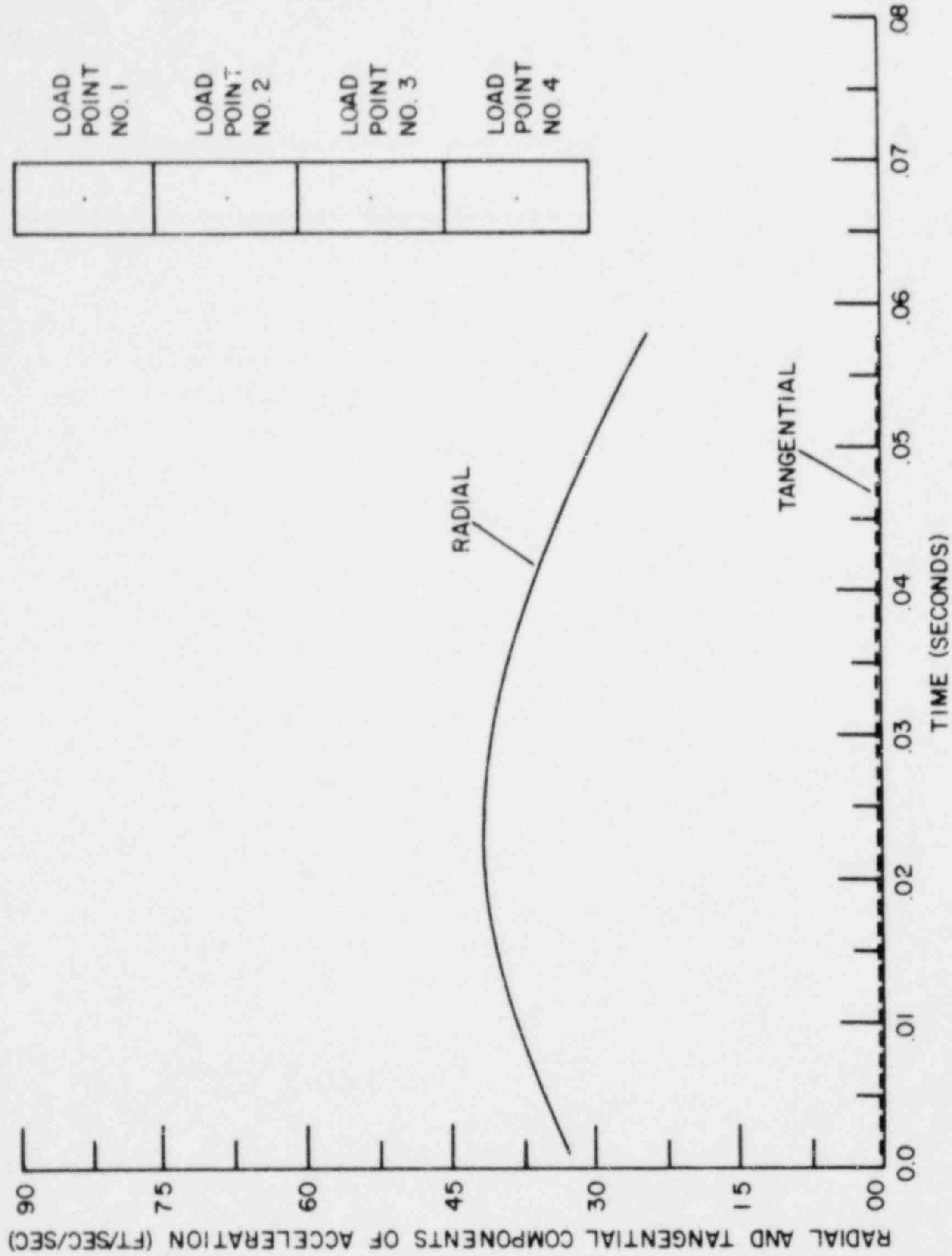
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

LOCA AIR CLEARING VELOCITY
SHEET 4 OF 4

FIGURE C.2-1



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UNITS 1 AND 2
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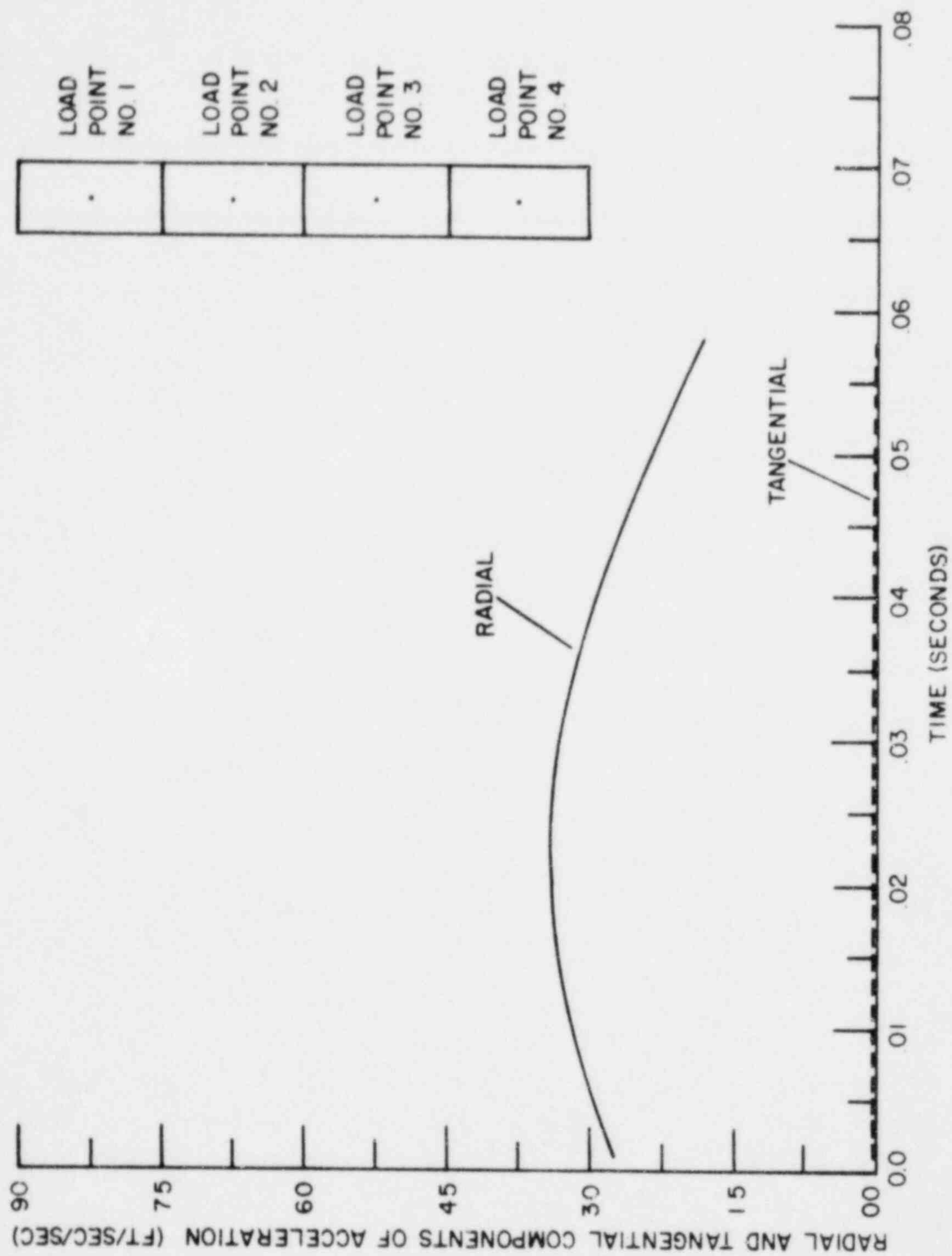
LOCA AIR CLEARING
ACCELERATION
SHEET 1 OF 4

FIGURE C.2-2



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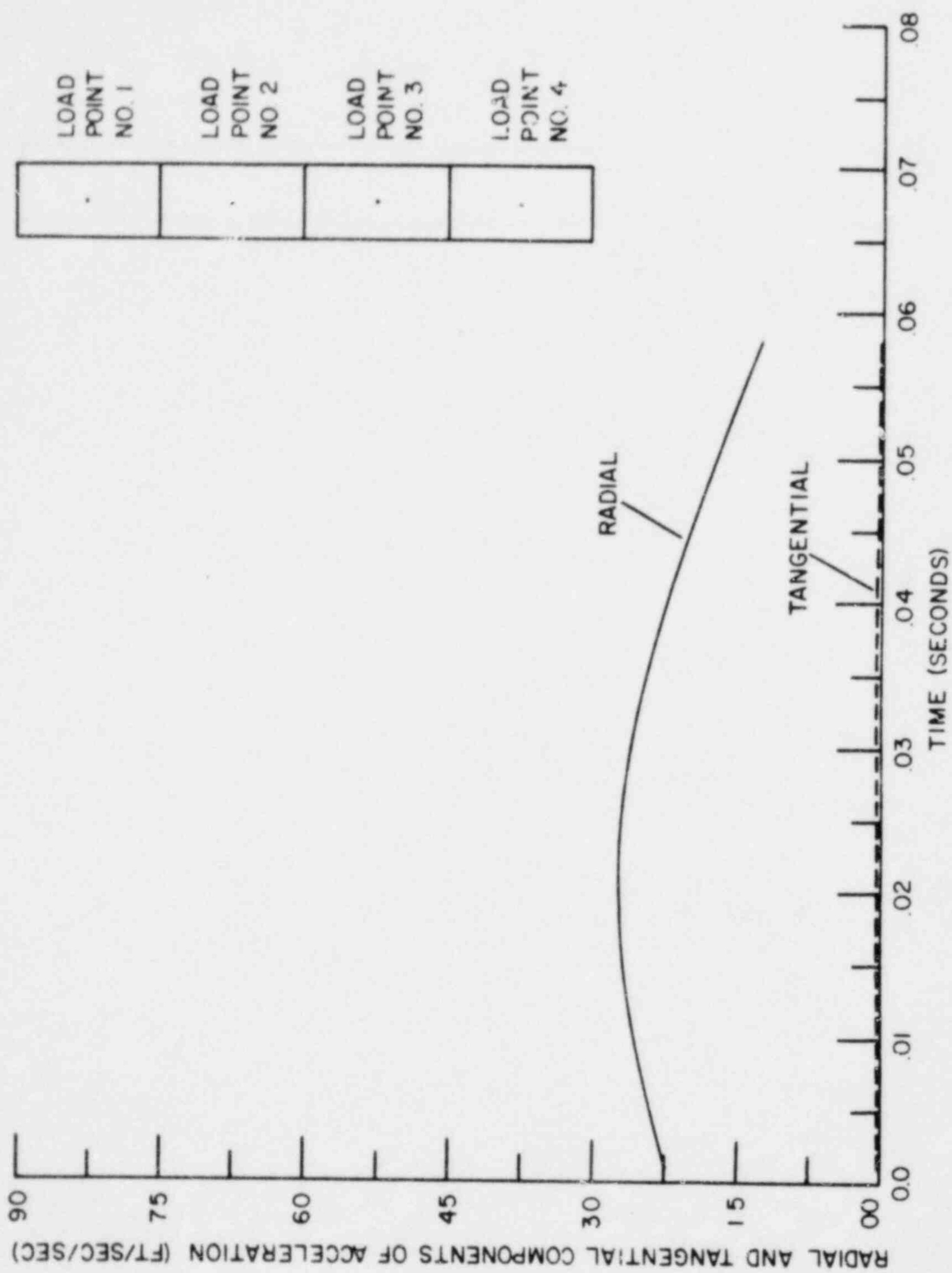
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

LOCA AIR CLEARING
ACCELERATION
SHEET 2 OF 4

FIGURE C.2-2



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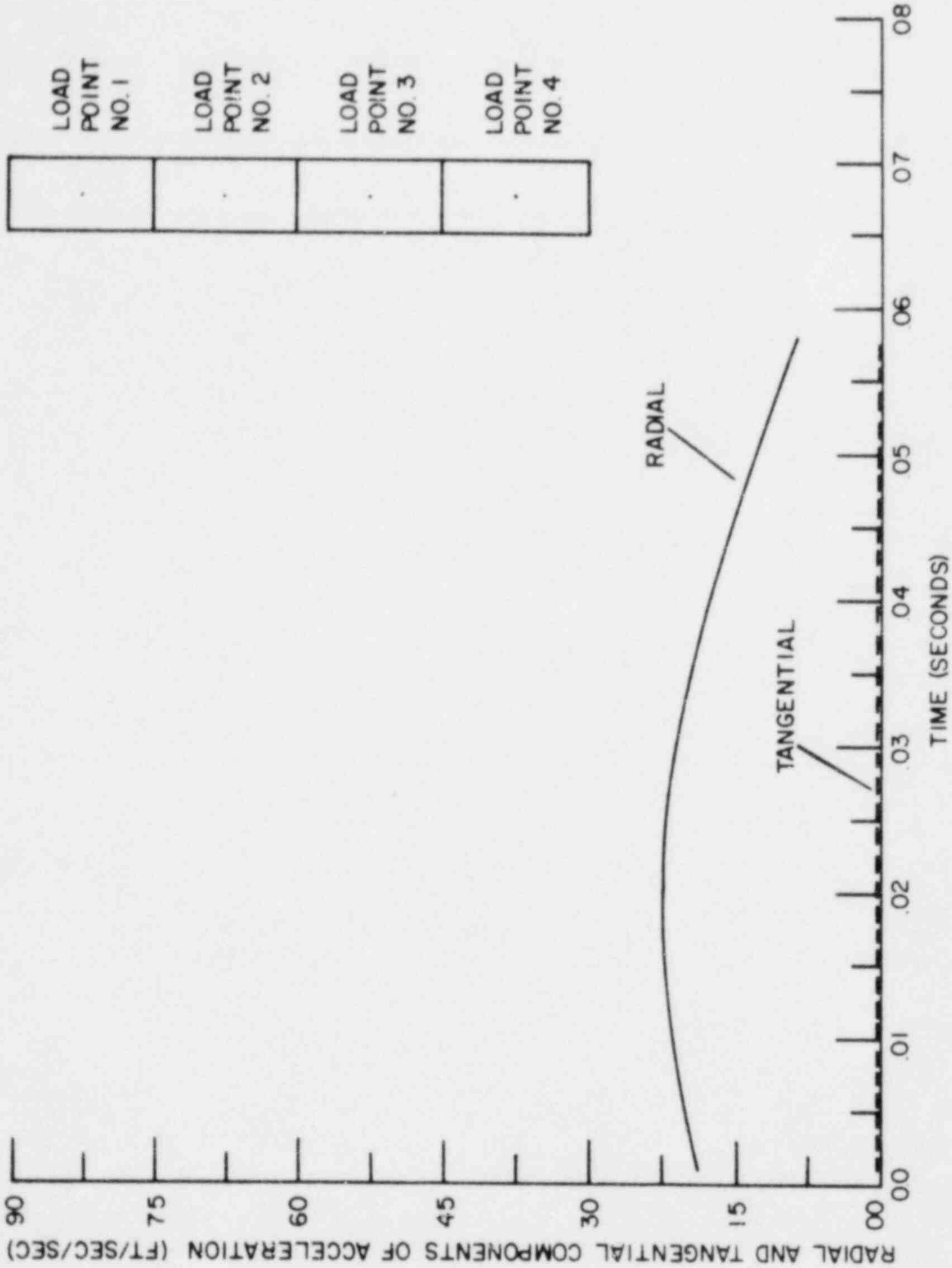
LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

LOCA AIR CLEARING
ACCELERATION
SHEET 3 OF 4

FIGURE C.2-2



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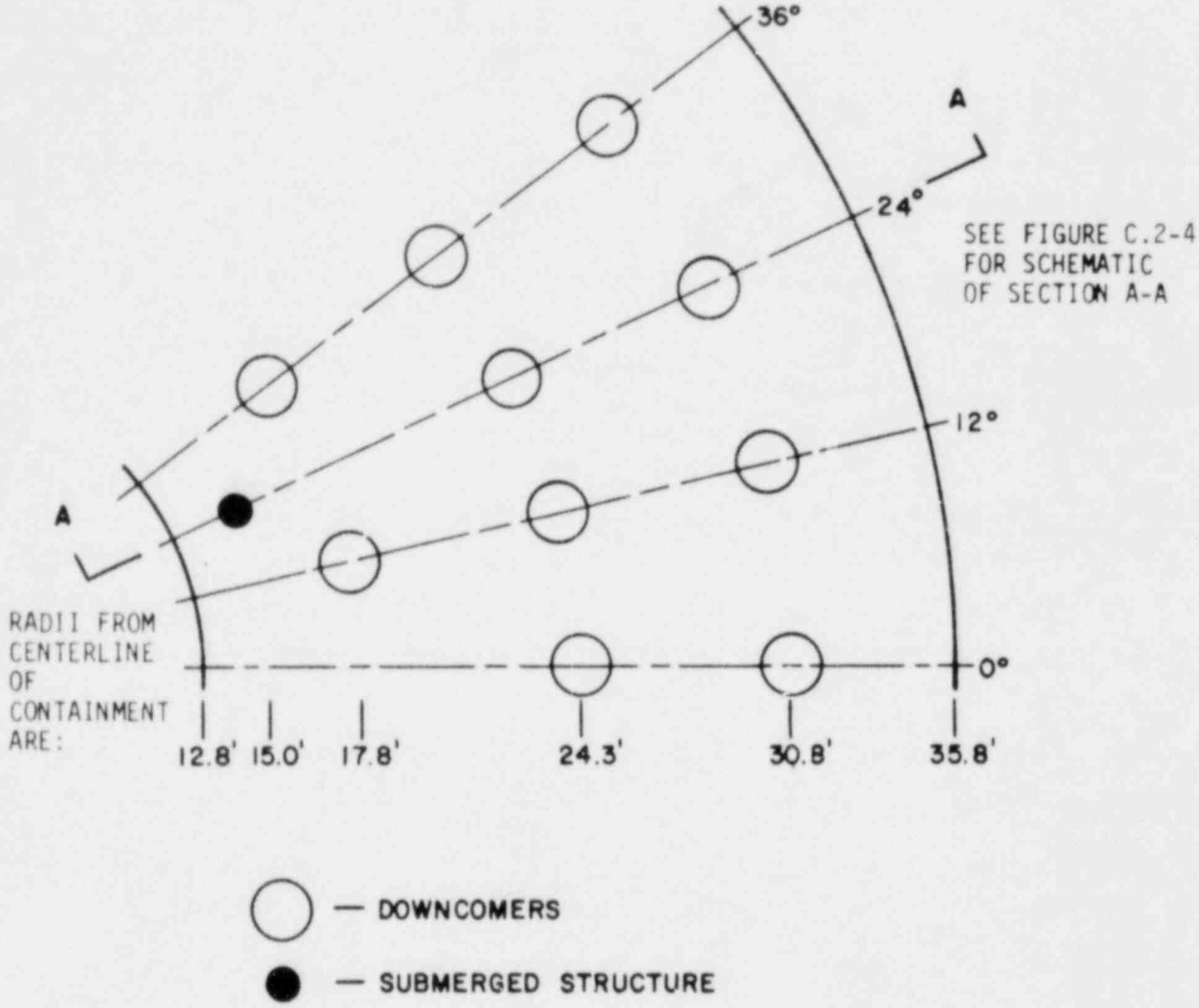
LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

LOCA AIR CLEARING
ACCELERATION
SHEET 4 OF 4

FIGURE C.2-2



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UNITS 1 AND 2
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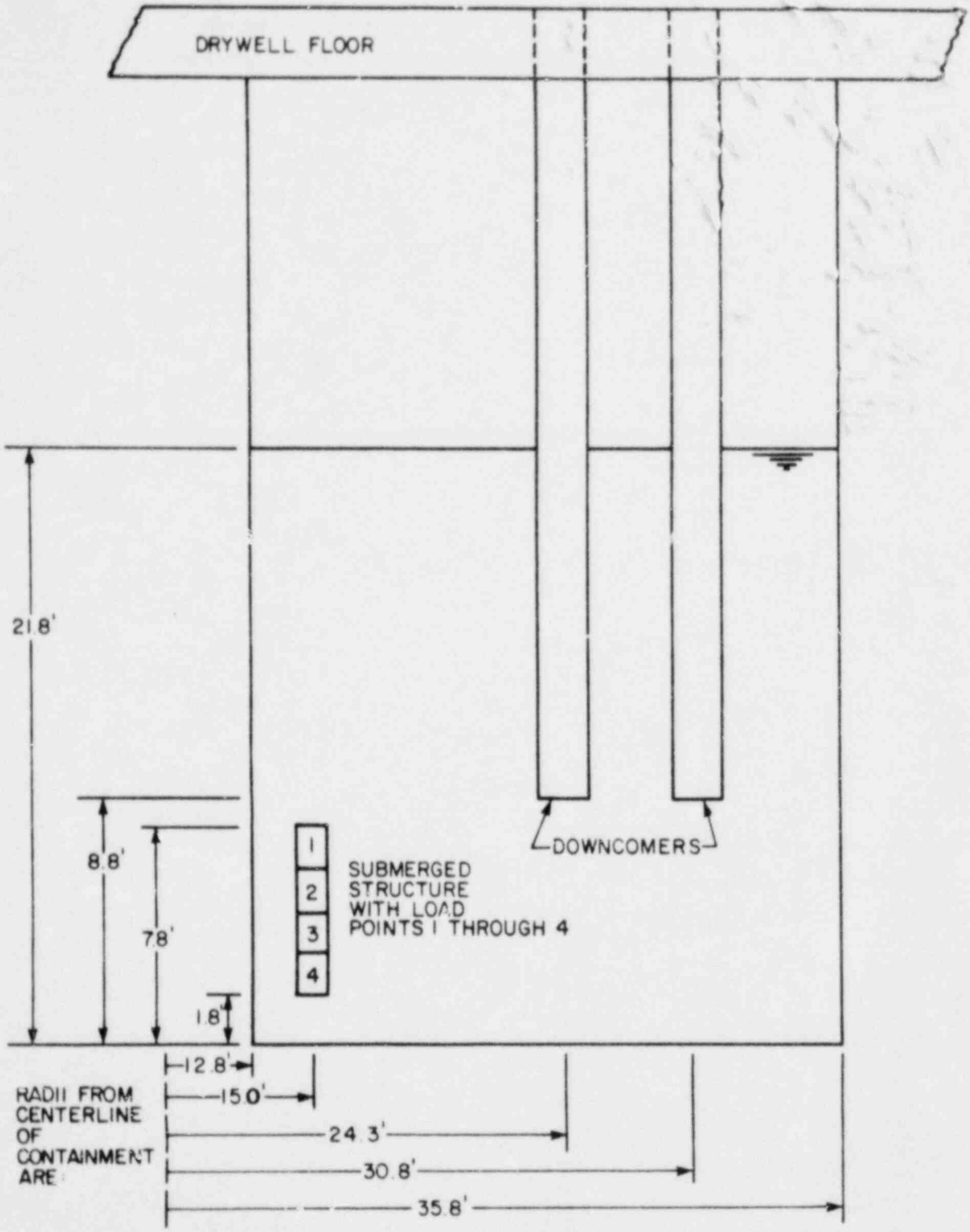
TOP VIEW OF 36° SECTOR OF A TYPICAL MARK II SUPPRESSION POOL

FIGURE C.2-3



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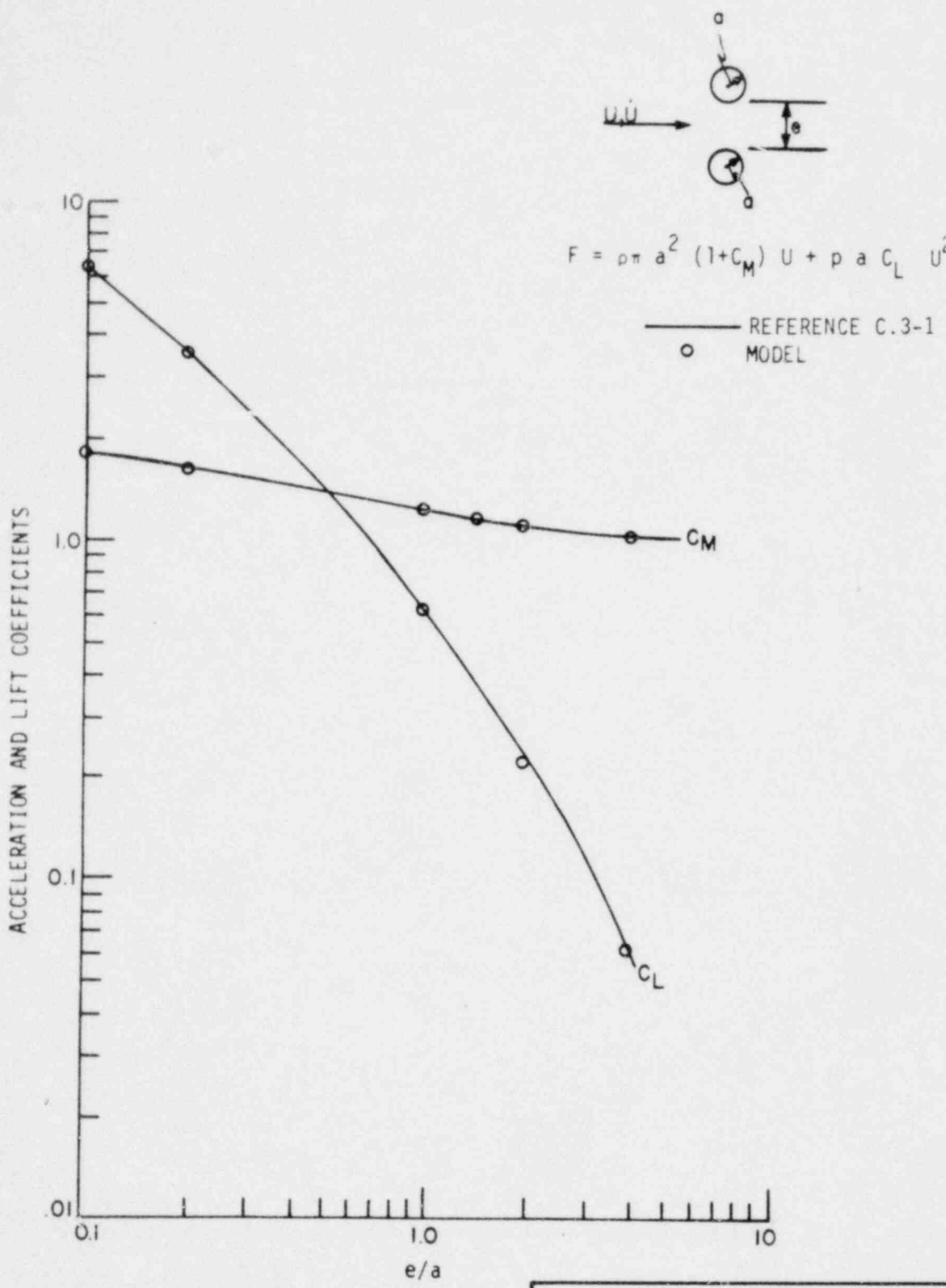
SCHEMATIC VIEW OF
SECTION A-A OF TYPICAL
MARK II SUPPRESSION POOL

FIGURE C.2-4



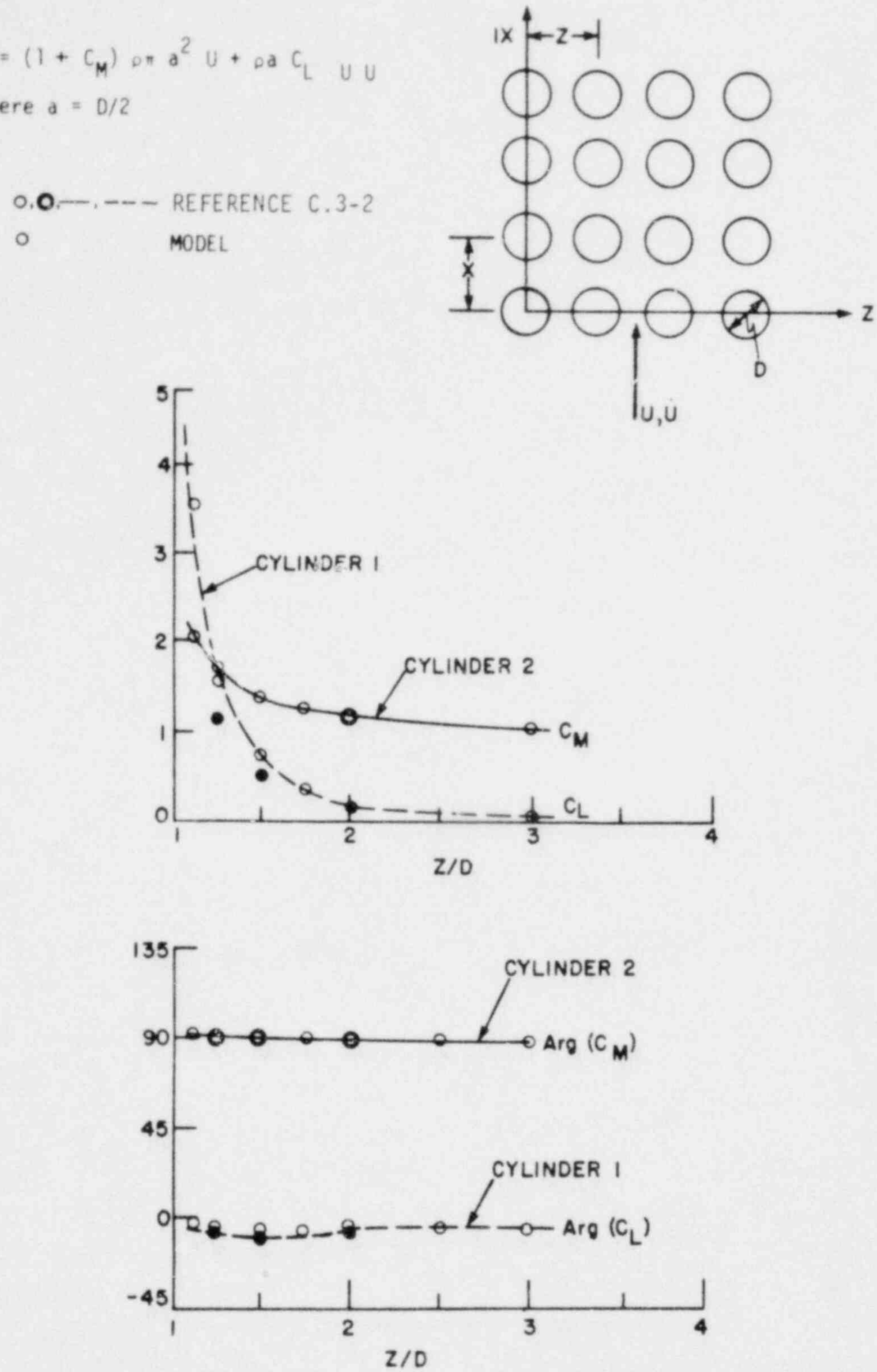
LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

MODEL/DATA COMPARISONS
SHEET 1 OF 4

FIGURE C.3-1

$F = (1 + C_M)\, \rho\pi\, a^2\, U + \rho a\, C_L\, U\, U$

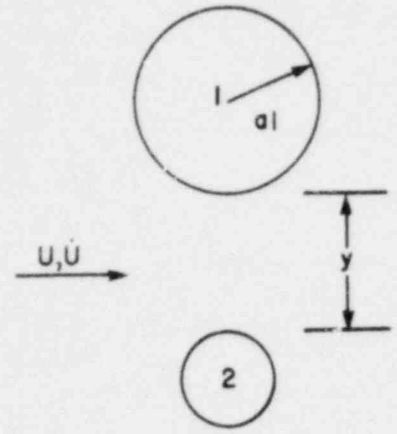
where $a = D/2$



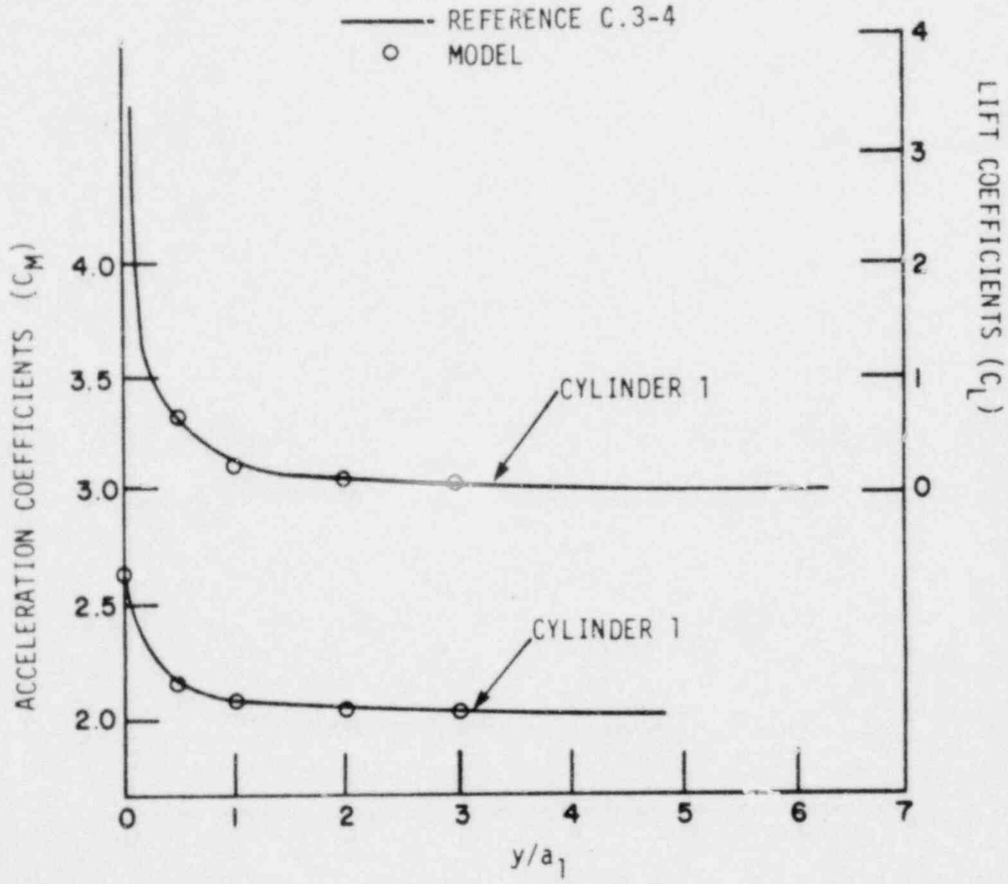
LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

MODEL/DATA COMPARISONS
SHEET 2 OF 4

FIGURE C.3-1



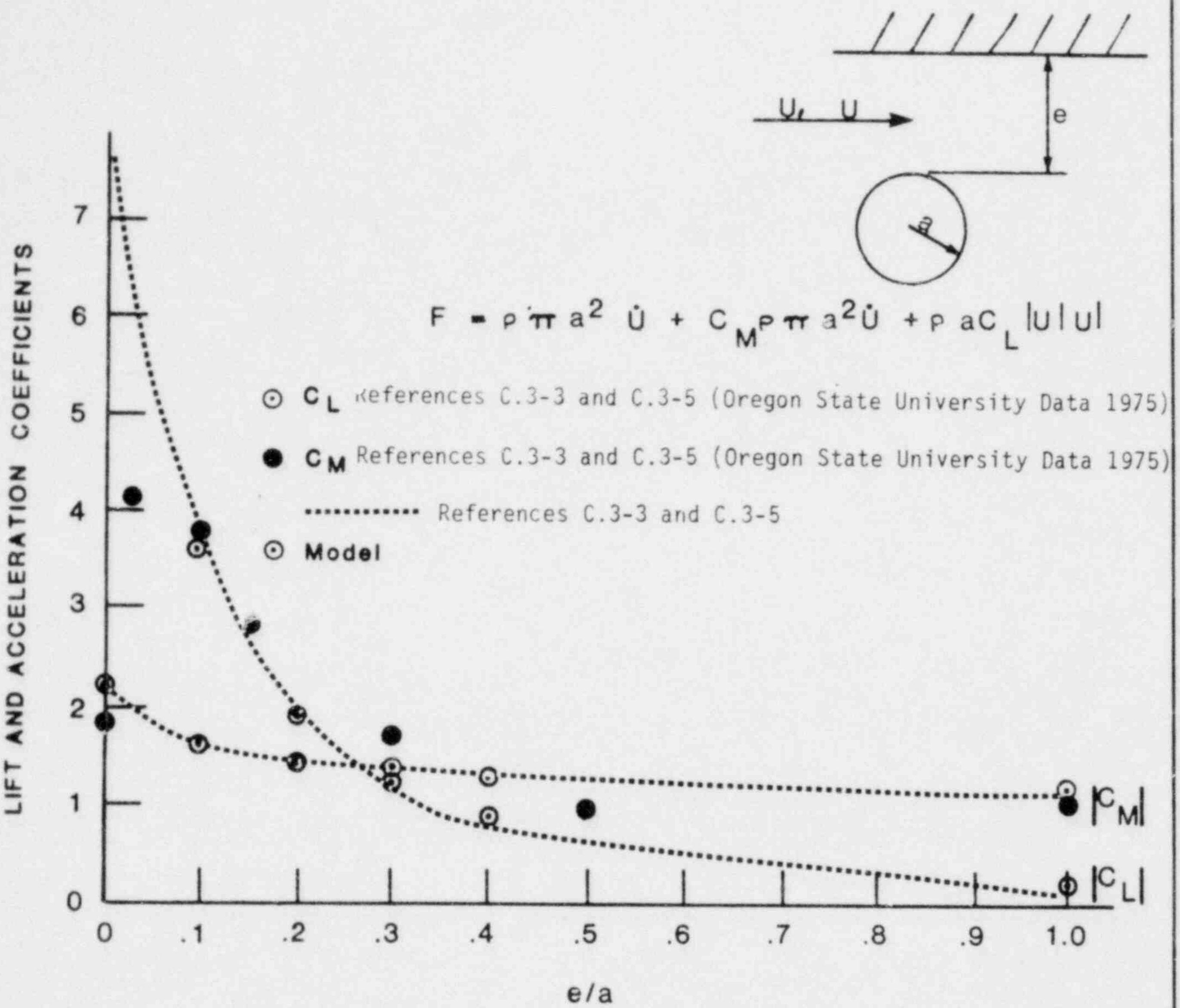
$$F = C_M \rho \pi a^2 \dot{U} + C_L \rho a U^2$$



LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

MODEL/DATA COMPARISONS
SHEET 3 OF 4

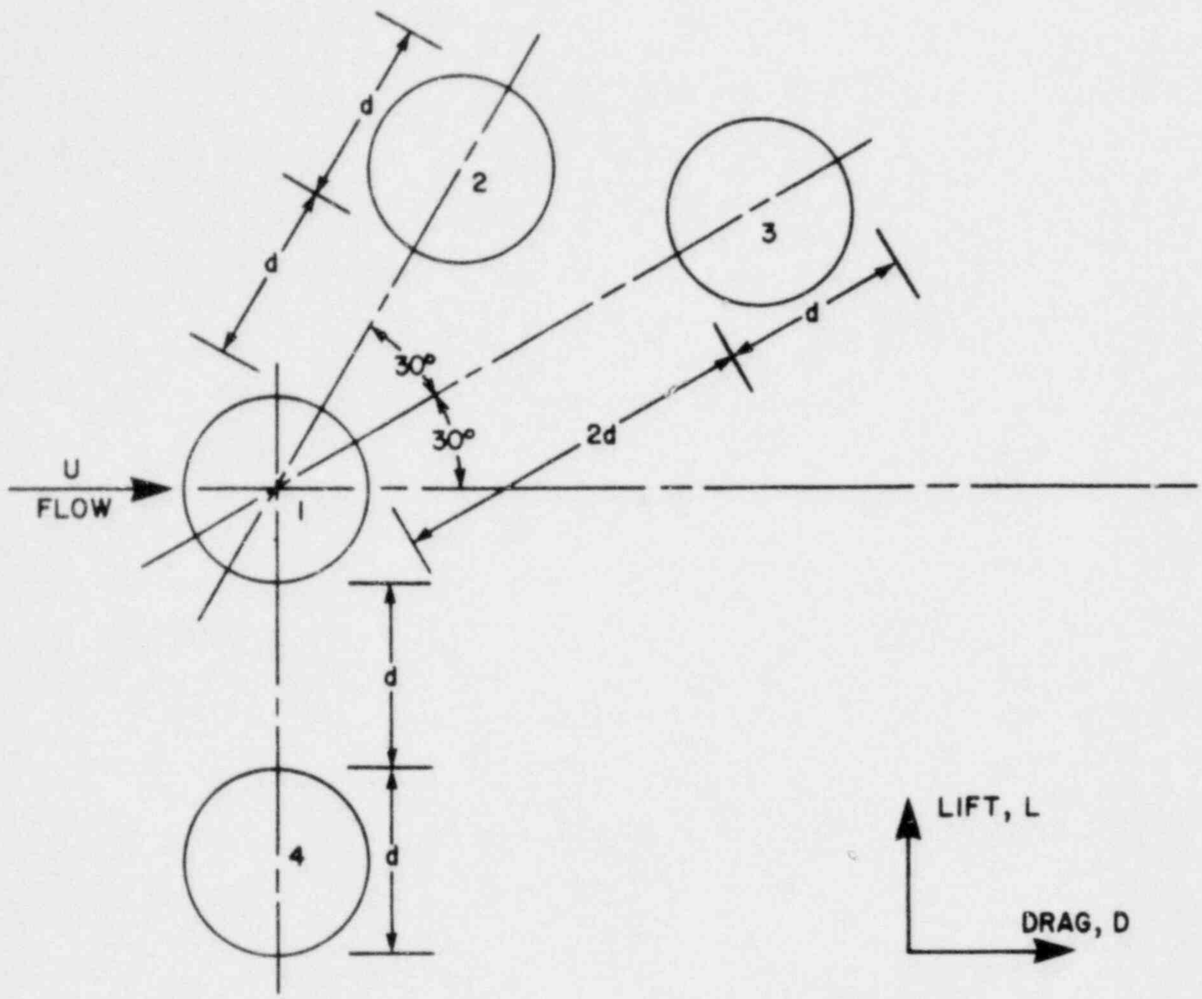
FIGURE C.3-1



LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

MODEL/DATA COMPARISONS
SHEET 4 OF 4

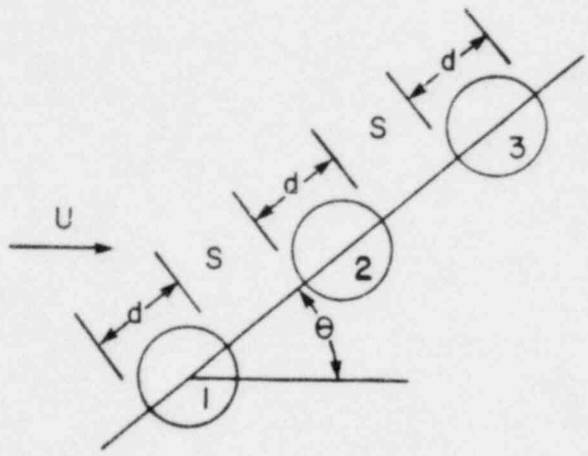
FIGURE C.3-1



LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

CYLINDER LOCATIONS

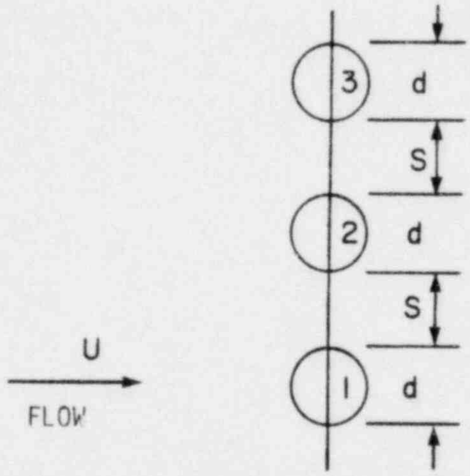
FIGURE C.4-1



LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

INTERFERENCE ON STANDARD DRAG: THREE CYLINDER ARRANGEMENT

FIGURE C.4-2



LIMERICK GENERATING STATION
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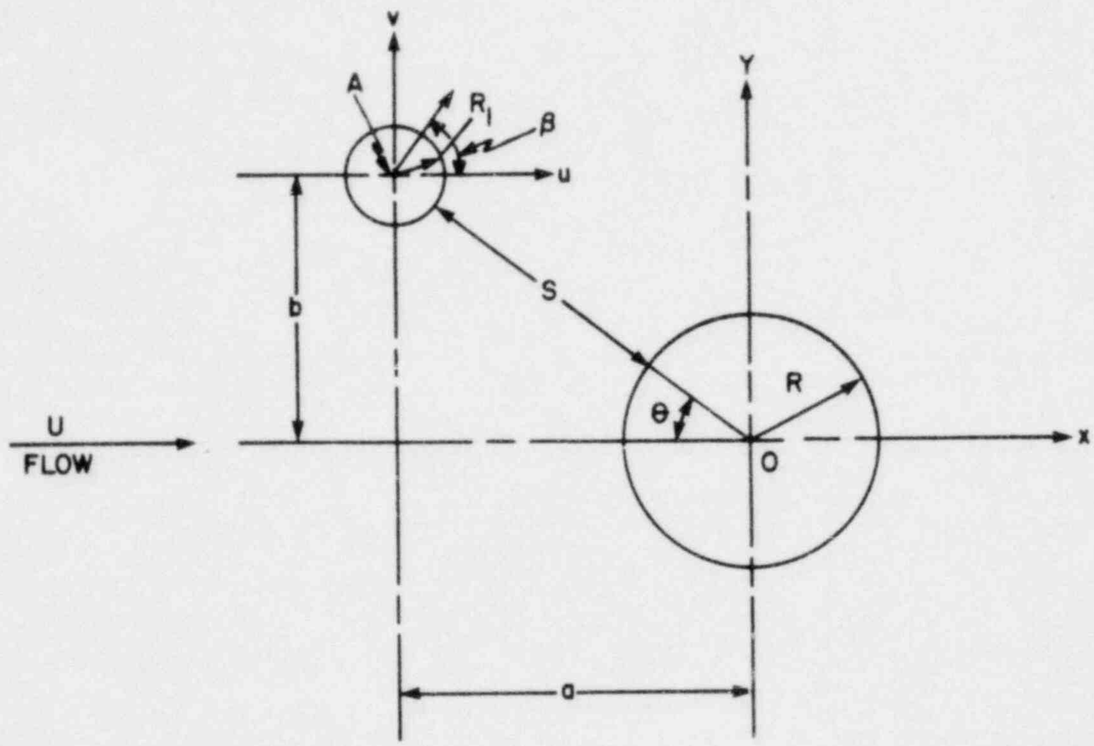
DESIGN ASSESSMENT REPORT

INTERFERENCE ON STANDARD DRAG: THREE CYLINDER SIDE-BY-SIDE ARRANGEMENT

FIGURE C.4-3



LIMERICK GENERATING STATION
UNITS 1 AND 2
DESIGN ASSESSMENT REPORT

FLOW AROUND UNEQUAL CYLINDERS

FIGURE C.4-4

APPENDIX D

CONTAINMENT AND SUBMERGED STRUCTURE STRUCTURAL DESIGN ASSESSMENT

TABLE OF CONTENTS

D.1 CONTAINMENT STRUCTURAL DESIGN ASSESSMENT

To be provided later.

D.2 SUBMERGED STRUCTURE DESIGN ASSESSMENT

To be provided later.

APPENDIX E

REACTOR BUILDING AND CONTROL STRUCTURE STRUCTURAL DES'GN ASSESSMENT

TABLE OF CONTENTS

FIGURES

Figures showing assessed sections and design margins will be provided later.

APPENDIX E

E.1 REACTOR BUILDING AND CONTROL STRUCTURE STRUCTURAL DESIGN ASSESSMENT

The selected elements and cross-sections of the reactor building and control structure where stresses are assessed are shown in this appendix. This appendix contains tabulations of the predicted stresses, allowable stresses, and design margins for critical loading combinations considered.

The critical load combinations are tabulated considering all the critical sections in the reactor building and control structure concrete mat, floor slabs, shear walls, blockwalls, refueling pool girders, floor structural steel, and superstructure steel. The emphasis is placed on the reinforcing bar stresses for concrete structures and bending stresses for steel structures. Generally, load combination equations 7a (Table 5.2-1) and 7 (Table 5.3-1) appear to be the most critical for concrete structures and steel structures, respectively.

Also contained are the axial forces, north-south shear forces, north-south moments, east-west shear forces and east-west moments in the reactor building and control structure for combined seismic and hydrodynamic loads.

APPENDIX F

PIPING DESIGN ASSESSMENT

TABLE OF CONTENTS

(To be provided later)

APPENDIX G

NSSS DESIGN ASSESSMENT

TABLE OF CONTENTS

(To be provided later)

APPENDIX H

EQUIPMENT DESIGN ASSESSMENT

TABLE OF CONTENTS

(To be provided later)

APPENDIX I

SUPPRESSION POOL DESIGN ASSESSMENT

TABLE OF CONTENTS

(To be provided later)