INFORMATION SUMMARY

Attachment No.	Description
1.	Response to Item Part A, (b), RRC Bench Board
2.	Response to Item Part A, (d), Bailey Alarm
3.	G.E. Document No. 328X227TU, Rev. 24
4.	Required Response Spectra (SSE) for Zimmer Auxiliary Building at the Control Room Level
5.	Transmissibility Plots for Zimmer Panel No. H13-P612
6.	Accelerometer Locations on Panel H13-P612
7.	Supporting Calculation for the Qualification of Bailey Alarm
8.	Assessment Report of a Spent Fuel Storage Rack for Wm. H. Zimmer Power Station, Revision 1, NUTECH Engineers File 33.803.0962
9.	Spent Fuel Storage Rack Calculations, Revision 0, NUTECH Engineers File No. 33.803.0551
10.	Stress Analysis - Spent Fuel Storage Rack - Conc. 2, by General Electric, Dated 10/21/77 (Reference 1)
11.	Caorso, Assurance of Function, DRF 139F16-E002-BBL, by General Electric, Dated 01/20/77 (Reference 2)
12.	Spent Fuel Storage Racks Horizontal Seismic Response Study, by Sargent & Lundy Engineers, Dated 03/13/78 (Reference 3)
13.	STARDYNE Computer Output, Run No. MPV06JP, Dated 10/12/81, NUTECH Engineers File No. 33.803.0551 (Reference 5)
14.	R. G. Dong, Effective Mass and Damping of Submerged Structures, Lawrence Livermore Laboratories UCRL-52342, Dated 4/1/78, (Reference 5)
15.	General Electric Drawing 762E210, Spent Fuel Storage Rack, Revision 6, Dated 06/20/79 (Reference 6)
16.	General Electric Drawing 829E422, Fuel Bundle, Revision 1, Dated 04/26/82 (Reference 7)
17.	Sargent & Lundy Engineers Drawing S-421, Reactor Building Pool Liner. Revision K, Dated 01/2/80 (Reference 9)

Attachment 1

ZIMMER NSSS SQRT AUDIT QUESTIONS

Part A, (b) GE REACTOR CORE COOLING BENCHBOARD

1. GE test report 22A4315 for the H13-P603 panel, a bench board panel structurally similar to the H13-P601, states that non-class 1E recorders and the full core display module experienced severe vibration. The essential function of the tested panel was in no way impaired. The devices for which anomalies were observed were all non-essential, and there was no indication of any type of structural failure.

The P601 panel contains only a third as many recorders and does not contain the full core display module, which is unique to the H13-P601 panel. Not having the large cut-out for the display module, the P601 would not have the flexing observed for the P603. Also, the test vibration to a level of 0.75g at 13 Hz front-to-rear is much more severe than the required ZPA for the Zimmer control room.

The class 1E devices in the P601 are either already qualified to very high acceleration levels or scheduled for requalification. Most of these devices are switches on the bench section. They are located in such a way that even a gross structural failure of the recorders in the vertical section of the panel would not affect the operability of the essential devices. The analysis contained in Sargent and Lundy file EMD-021333 stated that the "g" levels calculated for all points, where safety related devices were mounted, were less than 1.5g in all directions for panels H13-P601, P602, and P603.

Analysis and test data demonstrate a high seismic capability for the Zimmer H13-P601 panel and all the essential devices mounted on it. Table 1 lists the essential devices, seismic capability or test limit, and qualification status. Table 2 lists the non-essential devices, manufacturer, identification and model numbers.

nutech
San Jose, California

Project: Wm. H. Zimmer Nuclear Power Station — File No. 135.2401.0200
Owner: Cincinnati Gas and Electric Co.
Client: Cincinnati Gas and Electric Co.

Attachment 1

Table 1

SUBJECT: Zimmer H13-P601 Class 1E

Item#[1]	Name	Identification	Status		Demonstrated Seismic Capability (g) S-S	F/B	V
002	Square Root Converter	159C4486	Qualified by test	(1)	8	10	10
005-011, 031,051, 054	Switch (Type CR2940)	145C3040	"	(2)	20	20	20
013	Controller	163C1392	"	(3)	20	8.5	7.5
014 & 015	Switch (Pushbutton)	145C3230	Qualified by Zimmer test	(6)	1.7	1.6	1.85
034	Switch (SBM Control)	234A9329	Qualified by test	(4)	25	25	25
036	Switch (Series 40)	249A1892	"	(5)	10	10	10
038	Switch (SBM Control)	262A6023	"	(4)	25	25	25
049	Switch (SBM Control)	262A7721	"	(4)	25	25	25
050	Switch	163C1420	"	(5)	10	10	10

(1) GE Report No. C61-P001
(2) GE Report No. 225A6280
(3) GE/MAC Report No. 502
(4) Ogden Testing Lab. Report No.70709-2
(5) Acton Corp. Report No. 2020-01
(6) Wyle Laboratories Report No. 58685

Note 1: Per GE Document No. 328X227TU, Rev. 24

Revision	0	Page 1.2 of 1.3
Prepared By/Date	DBH/12-3-82	
Checked By/Date	SC/12-3-82	

Project: Wm. H. Zimmer Nuclear Power Station File No. 135.2401.02.00
Owner: Cincinnati Gas and Electric Co.
Client: Cincinnati Gas and Electric Co.

Attachment 1

Table 2

Response to Zimmer SQRT Audit Specific Open Item Part A (b). A list of non-essential devices on the Reactor Core Cooling Benchboard (H13-P601) are as follows:

Item#[1]	Name	Manufacturer	Identification (PPD#)	Model#
004	Fuse Cartridge	Bussman	145C3039	MIN-1,2,3,5,10 15,20,25,30
016	Resistor	*	145C3232	*
045	Switch	General Electric	-	CR-2940
001,17, 019-30 047,58	Meter, Panel (Ammeter, Voltmeter)	General Electric	157C4545 & 163C1746	Type 180 Vertical Edge-wise Meter
044 & 018	Recorder	Bailey	193B1484	732232BBAA1WAB
039	Resistor	Ohmite	234A9775	0777
041-043	Controller	Bailey	248A9393	701002AAAA1

The non-essentiality of these devices were established by the non-essential classification shown in GE Electrical Device List (EDL) for Reactor Core Cooling System Benchboard (H13-P601) (Document No. 328X227TU, Rev. 24) for Zimmer.

*to meet Military Standard QPL-18546-25 by various manufacturers.

Note 1: Per GE Document No. 328X227TU, Rev. 24

Revision	0					Page 1.3 of 1.3
Prepared By/Date	DBH/12-3-82					
Checked By/Date	SRC/12-3-82					

Attachment 2

ZIMMER NSSS SQRT AUDIT QUESTIONS

Part A, (d) Bailey Alarm

1. Provide floor response spectra and an evaluation of the expected g level at the device location.

Attachment 4 gives the SSE horizontal and vertical RRS at 2% damping for the Zimmer Auxiliary Building at the control room level.

Using results of the H13-P612 test the following is the expected g levels at the device location:

Accelerometer #6

Axis	Transmiss-ability*	Zimmer* ZPA	Accel. G
X Front to Rear	8.6	.45	3.87
Y Vertical	6.6	.45	2.97
Z Side to Side	6.1	.45	2.75

*References

1) Attachment 5 are the transmissability plots

2) Attachment 6 is the location of the accelerometers

3) Attachment 4 is the floor spectra for Zimmer control room

This location represents the highest location these devices are mounted at Zimmer, whether essential or non-essential.

The required g levels are below the demonstrated device capability.

2. Document conducting of resonance search test prior to malfunction limit test.

Test Report #526 did not specifically state the order of testing in the report itself. It does, however, reference Seismic Test Specification 225A5766 which addresses the order and type of

Attachment 2

ZIMMER NSSS SQRT AUDIT QUESTIONS

Part A, (d) Bailey Alarm (Cont'd)

testing in Section 4. Also, it is standard seismic testing laboratory practice to run the resonance search testing prior to other tests.

3. Discussion of correct function in side-to-side direction.

   A. Due to the printed circuit card connection method, the alarm units are most sensitive to severe vibration in the front to rear direction. In this mode there was no malfunction and the mounting was normal.

   B. The test run on the same device indicated no malfunction up to and including the 9 g[1] limit of the shaker.

   C. The attached calculation shows that the expected g level at the rack location, evaluated above, would result in accelerations of the alarm device conservatively less than the 9 g level. Also, the sine dwell at resonance tends to excite a response in that mode greater than that expected from random, multifrequency excitation at the same g level.

Note 1: Per G.E. Test Report #468.

EIS IDENT RX CORE COOLING SYS

REVISION STATUS SHEET

GENERAL ELECTRIC

NUCLEAR ENERGY DIVISION

DOCUMENT NO. 328X227TU REV. 24

APPLICATION ZIMMER 1 (H13-P601)

FCF: 328X501TUG1

☐ SPECIFICATION ☒ DRAWING ☐ OTHER ______ TYPE EDL

DOCUMENT TITLE REACTOR CORE COOLING SYSTEM

LEGEND:

REVISIONS			C
21	CHG PER ECN NE79654 a - FDI - TUBA b - FDI - TUAY c - FDI - TUAZ d - FDI - TUBB J.J.D J.J.D 1-21-77		
22	E. Hendon E. HENDON NOV 15 1977 RJV		
	NE86633 FDI-TUBQ chk'd by A. Huntener AHUNTENER		
23	E. Hendon E. HENDON 3-7-1978 R.J.V.		94 50 PR 47
	NJ01346 FDI-TUCJ CHK'D BY: E. Hendon		
24	J. Pappas J. PAPPAS APR 17 1978 RJV		
	NJ02202 FDI-TUCH CHKD BY E. Hendon	DESCRIPTION OF GROUPS	PRINTS TO

MADE BY H. HOLM 9-21-73	APPROVALS R.P. ORNELLIS 9-21-73	NEPD DEPT.	328X227TU
ISSUED P. TYLE 9-21-73		SAN JOSE LOCATION	CONT. ON SHEET 2 SH. NO. 1

GENERAL ELECTRIC

NUCLEAR ENERGY DIVISION, SAN JOSE, CA

TITLE EDL
RX CRE COOLING SYS

PL 328X227TU | SECT A | REV. 24

ITEM NO.	ALT	DOCUMENT TYPE	DESCRIPTION: NAME	DESCRIPTION: IDENTIFICATION	DOC STA	E C	C C	GROUP NUMBER AND QUANTITY: 0001	U/M	SRC	SPA	ACT.
001			METER, PANEL	163C1746P161108		N		1				
			E51 R606					X				
002			SQUARE ROOT CONVERTER	159C4466P001 ✓	[illegible]	A		1				
			E51 K601					X				
004			FUSE CARTRIDGE	145C3039P005		N		29			B	
			E12A-F13					X				
			E12A-F14AB					X				
			E12A-F27AB					X				
			E12A-F28AB					X				
			E12A-F29AC					X				
			E12A-F30AB					X				
			E21A-F04					X				
			E22A-F03					X				
			E22A-F04					X				
			E22A-F05					X				
			E51A-F09					X				
			E51A-F10					X				
			E51A-F11					X				
			E51A-F12					X				
			E51A-F17					X				
			E51A-F18					X				
			E51A-F19					X				
			E51A-F20					X				
			E51A-F27					X				
			E51A-F28					X				

MADE BY EDP | DATE MO. 04 DAY 20 YR 78 | CONT ON SHEET 3 | SH NO 2 | 328X227TU | SECT A | REV. 24

GENERAL ELECTRIC

NUCLEAR ENERGY DIVISION, SAN JOSE, CA

TITLE EDL
RX CRE COOLING SYS

PL 328X227TU | SECT A | REV. 24

ITEM NO.	ALT	DOCUMENT TYPE	DESCRIPTION: NAME	DESCRIPTION: IDENTIFICATION	DOC STA	EC	CC	GROUP NUMBER AND QUANTITY: 0001	U/M	SRC	SPA	ACT.
004			(CONTINUED)									
			E51A-F29					X				
			E51A-F30					X				
			E51A-F33					X				
005			SWITCH (TYPE CR2940)	145C3040P001	[illegible]	M		16			B	
			B21H-S26AB					X				
			E12A-S15AB					X				
			E12A-S20AC					X				
			E12A-S56					X				
			E21A-S03					X				
			E21A-S06					X				
			E22A-S05					X				
			E22A-S06					X				
			E22A-S07					X				
			E51A-S17					X				
			E51A-S18					X				
			E51A-S19					X				
			E51A-S23					X				
			E51A-S32					X				
006			SWITCH (TYPE CR2940)	145C3040P002	[illegible]	M		6			B	
			B21C-S10AB					X				
			B21C-S11AB					X				
			B21H-S32					X				
			B21H-S33					X				
007			SWITCH (TYPE CR2940)	145C3040P003	[illegible]	M		30			B	

MADE BY EDP | DATE MO. 04 DAY 20 YR 78 | CONT ON SHEET 4 | SH NO 3 | PL 328X227TU | SECT A | REV 24

GENERAL ELECTRIC

NUCLEAR ENERGY DIVISION, SAN JOSE, CA

TITLE EDL
RX CRE COOLING SYS

PL 328X227TU | SECT A | REV. 24

ITEM NO.	ALT	DOCUMENT TYPE	DESCRIPTION NAME	IDENTIFICATION	DOC STA	EC	CC	GROUP NUMBER AND QUANTITY 0001	U/M	SRC	SPA	ACT.
007			(CONTINUED)									
			B21C-S01					X				
			B21C-S02					X				
			B21C-S03					X				
			B21C-S04					X				
			B21C-S05					X				
			B21C-S06					X				
			B21C-S07					X				
			B21C-S08					X				
			B21C-S09					X				
			B21C-S20					X				
			B21C-S21					X				
			B21C-S22					X				
			B21C-S23					X				
			B21H-S17					X				
			B21H-S18					X				
			B21H-S69					X				
			B21H-S70					X				
			E12A-S06AB					X				
			E12A-S41AB					X				
			E12A-S63AB					X				
			E21A-S10					X				
			E51A-S11					X				
			E51A-S12					X				
			E51A-S13					X				

MADE BY EDP | DATE MO. 04 DAY 20 YR 78 | CONT ON SHEET 5 | SH NO 4 | PL 328X227TU | SECT A | REV. 24

GENERAL ELECTRIC

NUCLEAR ENERGY DIVISION, SAN JOSE, CA

TITLE EDL
RX CRE COOLING SYS

PL 328X227TU — SECT A — REV. 24

ITEM NO.	ALT	DOCUMENT TYPE	NAME	IDENTIFICATION	DOC STA	EC	CC	0001	U/M	SRC	SPA	ACT.
007			(CONTINUED)									
			E51A-S27					X				
			E51A-S28					X				
008			SWITCH (TYPE CR2940)	145C3040P005	[illegible]			6			B	
			E12A-S02AB					X				
			E12A-S40AB					X				
			E12A-S54AB					X				
009			SWITCH (TYPE CR2940)	145C3040P007	[illegible]			11			B	
			E12A-S04AC					X				
			E12A-S34AB					X				
			E21A-S01					X				
			E51A-S01					X				
			E51A-S18					X				
			E51A-S25					X				
			E51A-S35					X				
			E51A-S38					X				
010			SWITCH (TYPE CR2940)	145C3040P010	[illegible]			16			B	CHG
			CONTACT BLOCK									
			B21H-S74-1					X				ADD
			B21H-S75-1					X				ADD
			B21H-S76-1					X				ADD
			B21H-S77-1					X				ADD
			E12A-S04AC-1					X				
			E12A-S34AB-1					X				
			E12A-S71AB-1					X				

MADE BY EDP — DATE MO. 04 DAY 20 YR 78 — CONT ON SHEET 6 — SH NO 5 — PL 328X227TU — SECT A — REV. 24

GENERAL ELECTRIC

NUCLEAR ENERGY DIVISION, SAN JOSE, CA

TITLE EDL
RX CRE COOLING SYS

PL 328X227TU | SECT A | REV. 24

ITEM NO.	ALT	DOCUMENT TYPE	DESCRIPTION NAME	IDENTIFICATION	DOC STA	EC	CC	GROUP NUMBER AND QUANTITY 3001	U/M	SRC	SPA	ACT.
011			(CONTINUED)									
			E22A-S23					X				
			E51A-S03					X				
			E51A-S04					X				
			E51A-S05					X				
			E51A-S06					X				
			E51A-S07					X				
			E51A-S08					X				
			E51A-S09					X				
			E51A-S10					X				
			E51A-S20					X				
			E51A-S21					X				
			E51A-S22					X				
			E51A-S24					X				
			E51A-S26					X				
0:3			CONTROLLER (RCIC TURBINE	163C1392P000	[illegible]	A		1			NO	
			E51 R600 PUMP FLOW CONTROL)					X				
J14			SWITCH (PUSHBUTTON)	145C3230P003	[illegible]	H		4				
			B21H-S25AD					X				
015			SWITCH (PUSHBUTTON)	145C3230P004	[illegible]	H		6				
			B21C-S12AB					X				
			E12A-S61					X				
			E21A-S09					X				
			E22A-S02					X				
			E51A-S39					X				

MADE BY EDP | DATE MO. 04 DAY 20 YR 78 | CONT ON SHEET 8 | SH NO 7 | PL 328X227TU | SECT A | REV. 24

GENERAL ELECTRIC

NUCLEAR ENERGY DIVISION, SAN JOSE, CA

TITLE EDL
RX CRE COOLING SYS

PL 328X227TU | SECT A | REV. 24

ITEM NO.	ALT	DOCUMENT TYPE	NAME	IDENTIFICATION	DOC STA	EC	CC	0001	U/M	SRC	[illegible]
010			(CONTINUED)								
			E21A-S01-1					X			
			E21A-S11-1					X			
			E22A-S14-1					X			
			E51A-S40-1					X			
			E51A-S41-1					X			
011			SWITCH (TYPE CR2940)	145C3040P013	[illegible]	H		43			B
			E12A-S09AB					X			
			E12A-S1[illegible]					X			
			E12A-S12AB					X			
			E12A-S13AB					X			
			E12A-S14AB					X			
			E12A-S16AC					X			
			E12A-S35AB					X			
			E12A-S36AB					X			
			E12A-S37AB					X			
			E12A-S39AB					X			
			E12A-S66AB					X			
			E21A-S04					X			
			E21A-S05					X			
			E22A-S01					X			
			E22A-S10					X			
			E22A-S11					X			
			E22A-S12					X			
			E22A-S16					X			

MADE BY EDP | DATE MO. 04 DAY 20 YR 78 | CONT ON SHEET 7 | SH NO 6 | PL 328X227TU | SECT A | REV. 24

GENERAL ELECTRIC

NUCLEAR ENERGY DIVISION, SAN JOSE, CA

TITLE EDL
RX CRE COOLING SYS

PL 328X227TU | SECT A | REV. 24

ITEM NO.	ALT	DOCUMENT TYPE	DESCRIPTION NAME	IDENTIFICATION	DOC STA	EC	CC	0001	U/M	SRC	SPA	ACT.
016			RESISTOR	145C3232P60B2500		N		4			B	
			E12A-R04					X				
			E12A-R05AB					X				
			E12A-R06					X				
017			METER, PANEL RHR	163C1746P145049		N		1				
			B21 R610 RPV Level					X				
018			RECORDER (TYPE 731 & 732)	193B1484G004 NS4		N		2				
			B21 R623 AB (POST LOCA RPV LVL & PRESS)					X				
019			METER, PANEL	163C1746P137030		N		1				
			E51 R603 RCIC TURB EXH. PRESS					X				
020			METER, PANEL	163C1746P139012		N		1				
			E51 R602 RCIC TURB. STM. INLET PRESS.					X				
021			METER, PANEL	163C1746P142044		N		1				
			E51 R604 RCIC PUMP SUCTION PRESS.					X				
022			METER VALVE POSITION	157C4545AP81626		N		6				
		RHR-Hx	E12 R608 AB F073A.B. VENT (OUTBD)					X				
		" "	E12 R609 AB F074A.B VENT (INBD)					X				
		HPCS to CST	E22 R604 F011, RETURN (OUTBD)					X				
		" "	E22 R606 F010, RETURN (INBD)					X				
023			METER, PANEL	163C1746P138028		N		1				
			E22 R601 HPCS PUMP DISCH. PRESS.					X				
024			METER, PANEL	163C1746P161079		N		1				
			E12 R607 RHR HEAD SPRAY FLOW IND.					X				
025			METER, PANEL	163C1746P162078		N		2				
			E12 R602AB RHR-Hx SERVICE WTR FLOW					X				

MADE BY EDP | DATE MO. 04 DAY 20 YR 78 | CONT ON SHEET 9 | SH NO 8 | PL 328X227TU | SECT A | REV. 24

GENERAL ELECTRIC

NUCLEAR ENERGY DIVISION, SAN JOSE, CA1

TITLE EDL
RX CRE COOLINO SYS

PL 328X227TU | SECT A | REV. 24

ITEM NO.	ALT	DOCUMENT TYPE	DESCRIPTION: NAME	DESCRIPTION: IDENTIFICATION	DOC STA	EC	CC	GROUP NUMBER AND QUANTITY: 0001	U/M	SRC	SPA	ACT.
026			METER, PANEL	163C1746P162079		N		4				
			E12 R603 AC LPCI Flow					X				
			E22 R603 HPCS Flow					X				
027			METER, PANEL	163C1746P162080		N		1				
			E21 R600 LPCS PUMP DISCH. Flow					X				
028			METER, PANEL	163C1716P216026		N		2				
			E12 R604AB-1 RHR-Hx Lvl (STM COND)					X				
029			METER, PANEL	163C1746P237030		N		1				
			E12 R605 001 RHR/RCIC STM INLET PRESS.					X				
030			METER, PANEL	163C1746P237038		N		2				
			E12 R606 1A RHR-Hx, INLET STM PRESS					X				
			E12 R606 1B " " " "					X				
031			SWITCH (TYPE CR29.	146C3040P018	[illegible]	N		4			B	
			CONTACT BLOCK									
			E51A-S01-1					X				
			E51A-S02-1					X				
			E51A-S35-1					X				
			E51A-S36-1					X				
034			SWITCH, SBM CONTROL	234A9329P003	[illegible]	H		2			B	
			B21H-S07					X				
			B21H-S08					X				
036			SWITCH (SERIES 40)	249A1892P001	[illegible]	H		16				
			B21H-S05					X				
			B21H-S06					X				
			B21H-S09					X				

MADE BY EDP | DATE MO. 04 DAY 20 YR 78 | CONT'D ON SHEET 10 | SH NO 5 | PL 328X227TU | SECT A | REV. 24

GENERAL ELECTRIC

NUCLEAR ENERGY DIVISION, SAN JOSE, CA

TITLE EDL
RX CRE COOLING SYS

PL 328X227TU | SECT A | REV. 24

ITEM NO.	ALT	DOCUMENT TYPE	DESCRIPTION NAME	DESCRIPTION IDENTIFICATION	DOC STA	EC	CC	GROUP NUMBER AND QUANTITY 0001								U/M	SRC	SPA	ACT.
036			(CONTINUED)																
			B21H-S10					X											
			B21H-S12					X											
			B21H-S13					X											
			B21H-S14					X											
			B21H-S15					X											
			B21H-S16					X											
			B21H-?22					X											
			B21H-S23					X											
			B21H-S35					X											
			B21H-S36					X											
			B21H-S37					X											
			B21H-S38					X											
			B21H-S73					X											
038			SWITCH, SBM CONTROL	282A6023P002	[illegible]	N		8											
			B21H-S01AD					X											
			B21H-S02AD					X											
039			RESISTOR	234A9775P003		N		6										B	
			E12A-R02AB					X											
			E12A-R03AB					X											
			E22A-R01					X											
			E22A-R02					X											
041			CONTROLLER	248A9393G005		N		2											
			E12 N604 AB RHR-Hx LIC					X											
042			CONTROLLER	248A9393G006		N		1											

MADE BY EDP | DATE MO. 04 DAY 20 YR 78 | CONT ON SHEET 11 | SH NO 10 | PL 328X227TU | SECT A | REV. 24

GENERAL ELECTRIC

NUCLEAR ENERGY DIVISION, SAN JOSE, CA

TITLE EDL
RX CRE COOLING SYS

PL 328X227TU | SECT A | REV. 24

ITEM NO.	ALT	DOCUMENT TYPE	DESCRIPTION NAME	DESCRIPTION IDENTIFICATION	DOC STA	E C	C C	GROUP NUMBER AND QUANTITY 0001	U/M	SRC	SPA	ACT.
042			(CONTINUED)									
			E12 R605 RHR/RCIC STM LN PIC					X				
043			CONTROLLER	248A9393G007		N		2				
			E12 R606 AB RHR-HX STM INLET PRESS.					X				
044			RECORDER (TYPE 731 & 732)	193B1484G042		N		1				
			B21 R615 RPV LVL					X				
045			SWITCH	CR2940US203E		N		3				
			B21H-S03AD					X				
			B21H-S04AD					X				
047			METER, PANEL	163C1746P113010		N		2				
			E12 R611 AB RHR-HX EXIT CONDUCTIVITY					X				
049			SWITCH, SBM CONTROL	262A7721P001	[illegible]	N		11				
			E12A-S03AC					X				
			E12A-S57					X				
			E21A-S06					X				
			E21A-S07					X				
			E22A-S03					X				
			E22A-S13					X				
			E51A-S14					X				
			E51A-S15					X				
			E51A-S33					X				
050			SWITCH	163C1420P004	[illegible]	N		10				
			E12A-S10AC					X				
			E12A-S58AB					X				
			E12A-S59AB					X				

MADE BY EDP | DATE MO. 04 DAY 20 YR 78 | CONT'D ON SHEET 12 | SH NO 11 | PL 328X227TU | SECT A | REV. 24

GENERAL ELECTRIC

NUCLEAR ENERGY DIVISION, SAN JOSE, CA

TITLE EDL
RX CRE COOLING SYS

PL 328X227TU | SECT A | REV. 24

ITEM NO.	ALT	DOCUMENT TYPE	DESCRIPTION NAME	DESCRIPTION IDENTIFICATION	DOC STA	E C	C C	GROUP NUMBER AND QUANTITY 0001								U/M	SRC	SPA	ACT.
050			(CONTINUED)																
			E21A-S02					X											
			E22A-S04					X											
			E51A-S34					X											
051			SWITCH (TYPE CR2940)	146C3040P004	[illegible]	H		5										B	
			E12A-S62AB					X											
			E22A-S08					X											
			E51A-S37					X											
			E51A-S38					X											
054			SWITCH (TYPE CR2940)	146C3040P006	[illegible]	H		10										E	CHG
			B21H-S74					X											ADD
			B21H-S75					X											ADD
			B21H-S76					X											ADD
			B21H-S77					X											ADD
			E12A-S71AB					X											
			E21A-S11					X											
			E22A-S14					X											
			E51A-S40					X											
			E51A-S41					X											
056			SWITCH (TYPE CR2940)	146C3040P049		N		1										B	
			E51A-S02					X											
057			SWITCH (TYPE CR2940)	146C3040P009		N		2										B	
			CONTACT BLOCK																
			E51A-S16-1					X											
			E51A-S25-1					X											

MADE BY EDP | DATE MO. 04 DAY 20 YR 78 | CONT ON SHEET 13 | SH NO 12 | PL 328X227TU | SECT A | REV. 24

GENERAL ELECTRIC

NUCLEAR ENERGY DIVISION, SAN JOSE, CA

TITLE EDL
RX CRE COOLING SYS

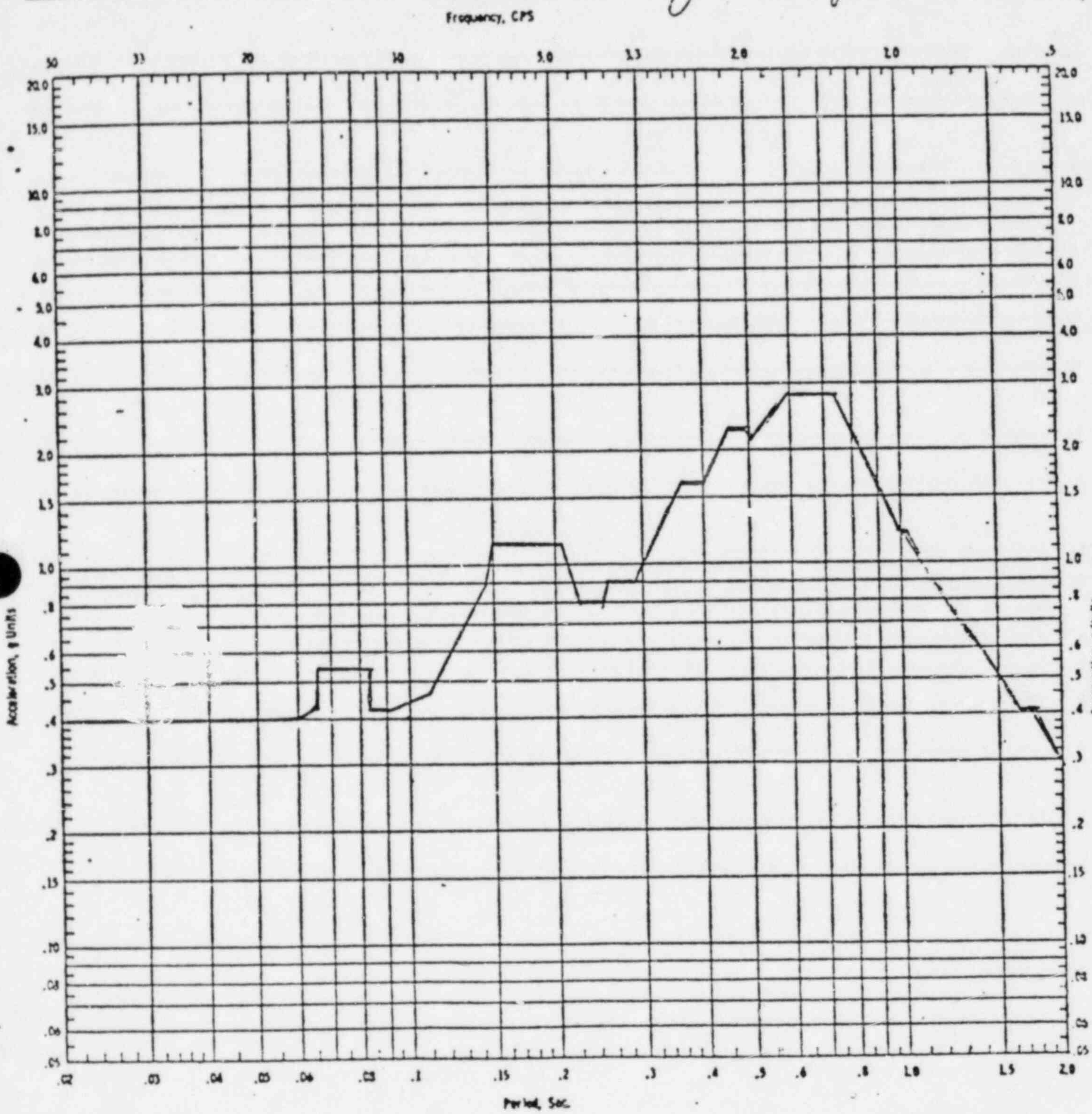
PL 329×227TU | SECT A | REV. 24

ITEM NO.	ALT	DOCUMENT TYPE	DESCRIPTION NAME	IDENTIFICATION	DOC STA	EC	CC	GROUP NUMBER AND QUANTITY 0001	U/M	SRC	SPA	ACT.
058			METER, PANEL	163C1746P139013				1				
			E51 R601 RCIC PUMP DISCH PRESS.					X				

MADE BY EDP | DATE MO. 04 DAY 20 YR 78 | LAST ITEM NO. USED - 058 | FINAL SECTION | FINAL | 13 | PL 328X227TU | SECT A | REV. 24

ARGONNE NATIONAL ENGINEERS CHICAGO	Attachment 4	Rev. 00 Date 3/5/81
[X] Safety-Related	Non-Safety-Related	Page 3 of 4

Client CINGRP & CECo	Prepared by CF Lee	Date 3/5/81
Project Zimmer-1 & LaSalle County 1 2 2	Reviewed by Jon Papadopoulos	Date 3-5-81
Proj. No. 4130-00/6093-00 Equip. No. Several	Approved by [illegible]	Date 3-5-81



EXCITATION SSE – Horizontal NS & EW (2% Damping) LOCATION: Auxiliary Building

SPECTRA NO 3 ELEVATION: Zimmer: Envelop of 546'6" & 52[illegible]

LaSalle: Envelop of 768' & 731'

SARGENT & LUNDY
ENGINEERS
CHICAGO

FOR Main Control Board

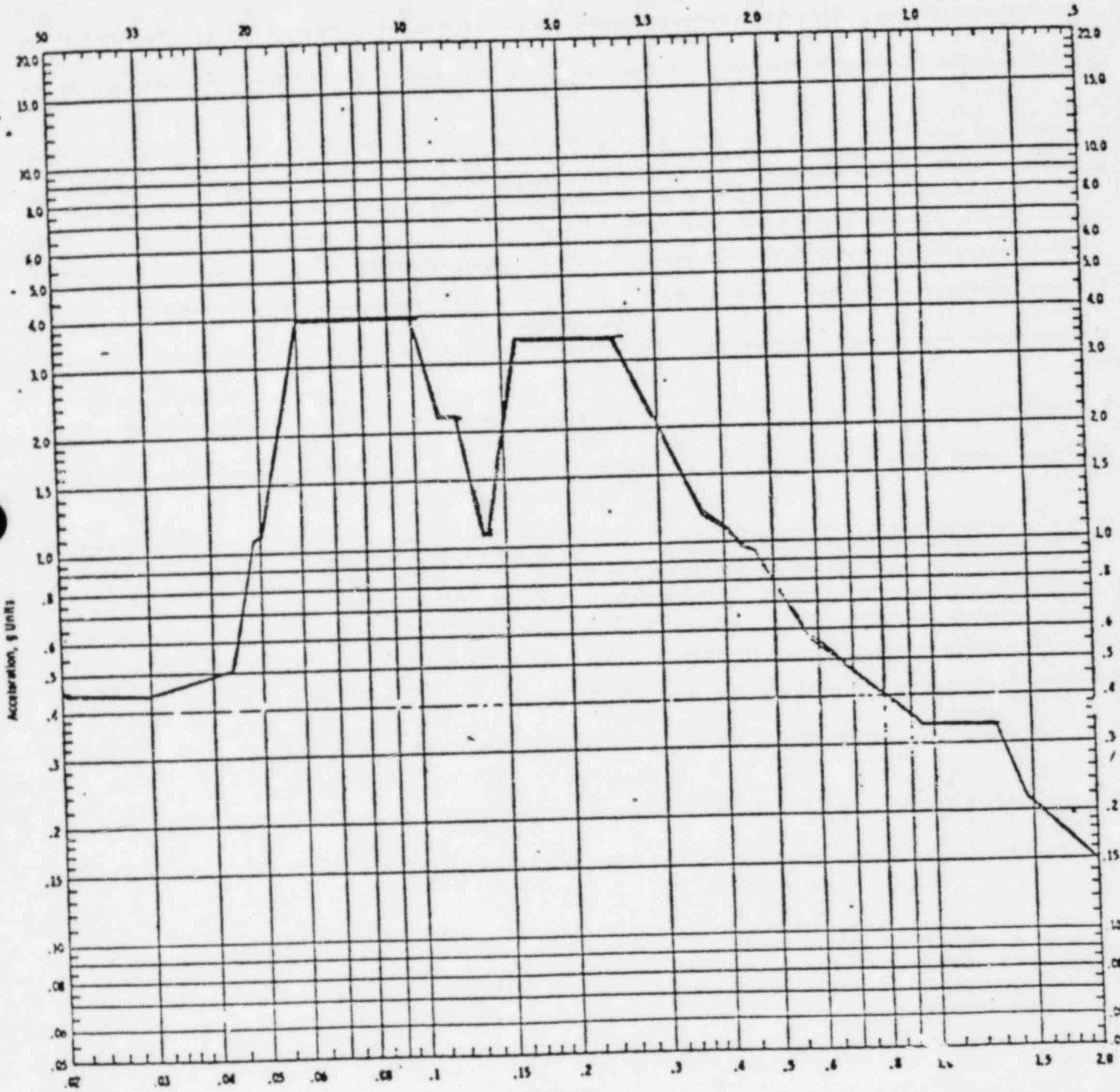
Attachment 4

☒ Safety-Related ☐ Non-Safety-Related

Rev. 00 Date 3/5/81

Page 4 of 4

Client CINGRP & CECo		Prepared by C F Lee	Date 3/5/81
Project Zimmer-1 & LaSalle County 1 & 2		Reviewed by Jon Papadopoulos	Date 3-5-81
Proj. No. 4130-00/6093-00	Equip. No. Several	Approved by [illegible]	Date 3-5-81



EXCITATION SSE - Vertical VS (2% Damping) LOCATION: Auxiliary Building

ELEVATION: Zimmer: Envelop of 546'6" &

SPECTRA NO 4

LaSalle: Envelop of 763' & 7-

WYLE LABORATORIES Attachment 5 Report No. 58626

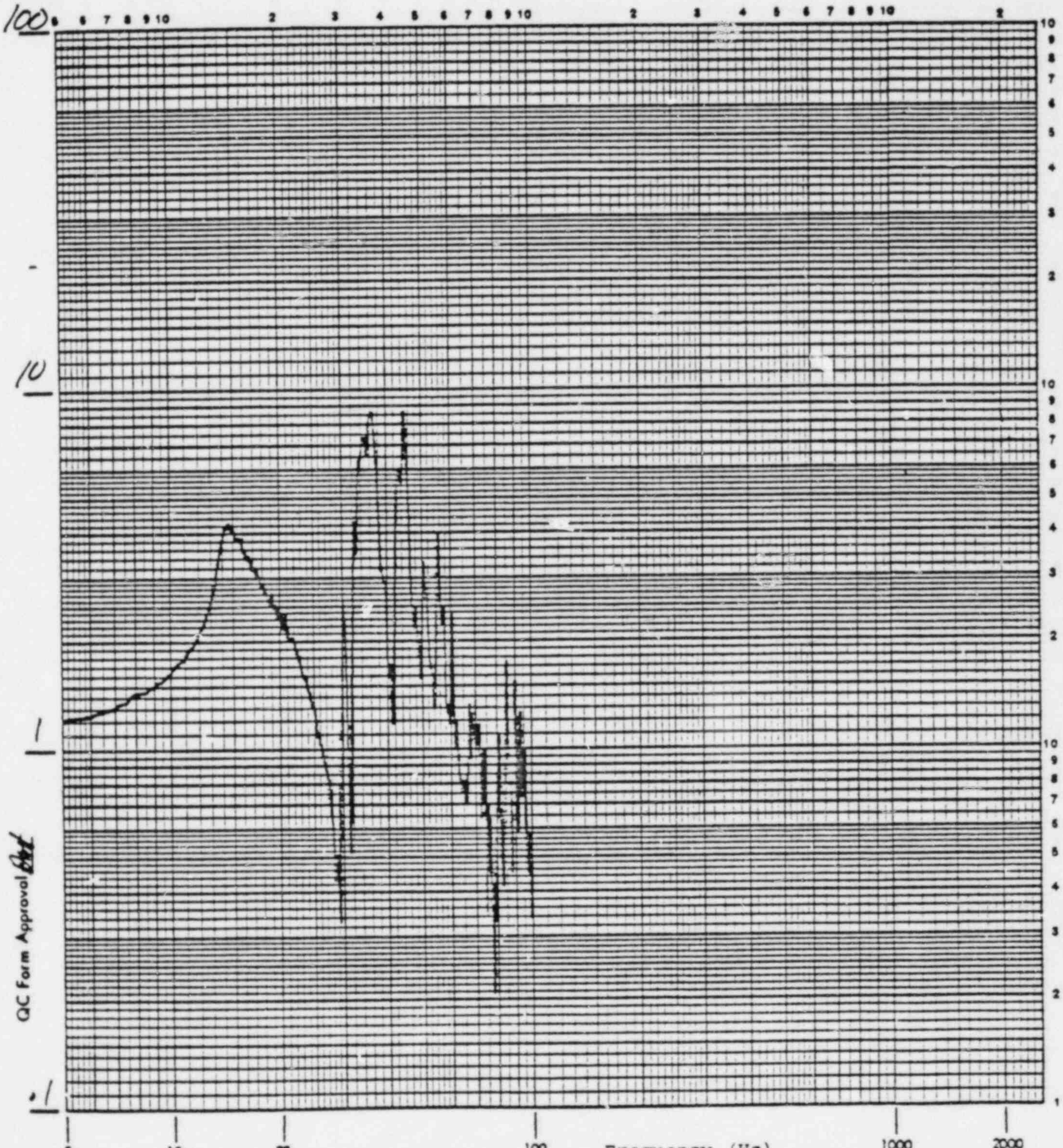
CUSTOMER Nutech Job No. 58626 Page No. 341

Full Scale 100 g Accel. No. 1+6 Control (X) Response (X)

Operator Ellis Specimen H13-P612

Date 3-10-81 Axis of Test X

TRANSMISSIBILITY



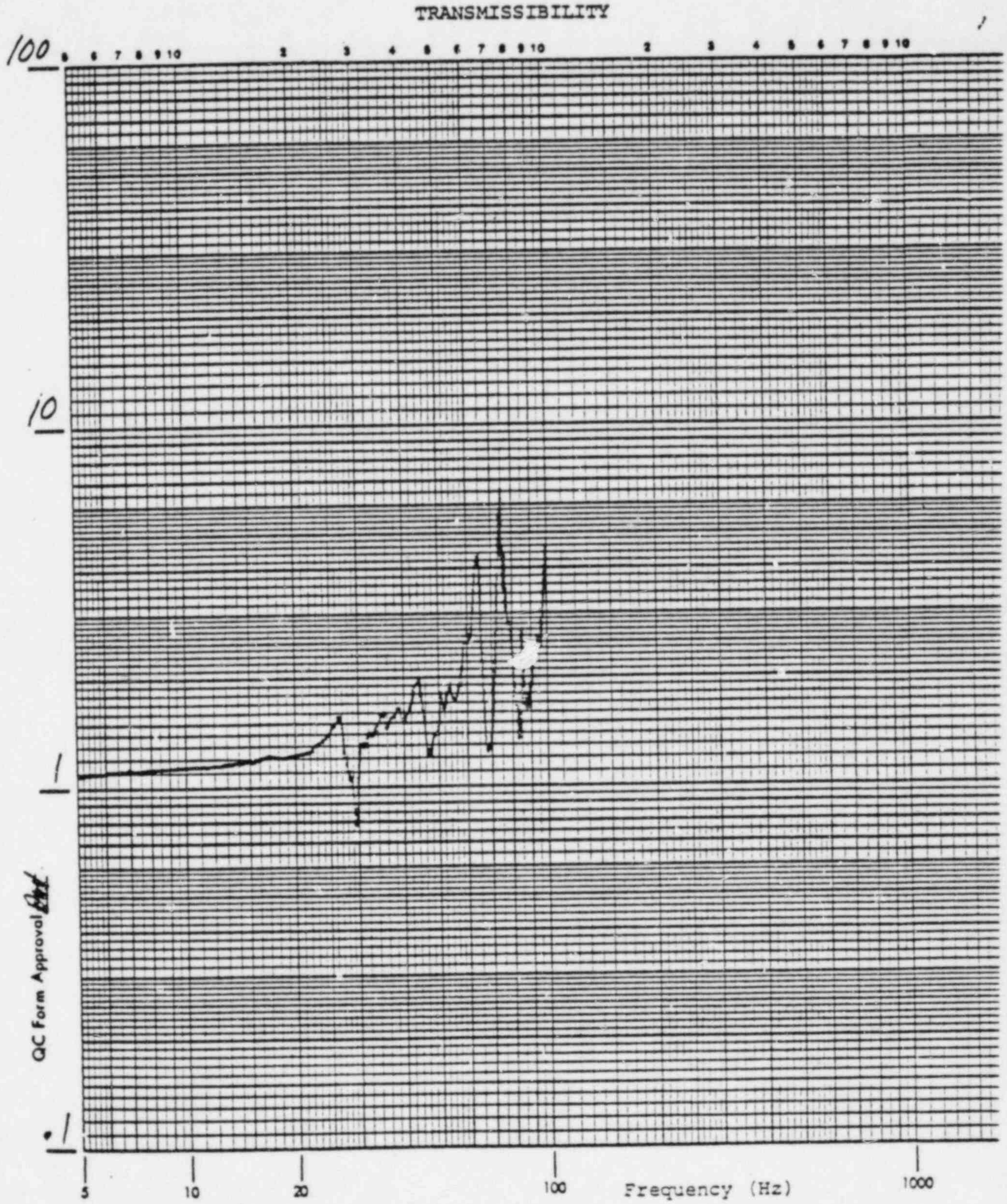
WYLE LABORATORIES Attachment 5 Report No. 586__

CUSTOMER Nutech Job No. 58626 Page No. 352

Full Scale 100 g Accel. No. 2+6 Control (X) Response

Operator Ellis Specimen H13-P612

Date 3-10-81 Axis of Test Y



Attachment 6

WYLE LABORATORIES

DATA SHEET

Report No. 58626

Page No. 28

CUSTOMER NUTECH

Test Title: SEISMIC

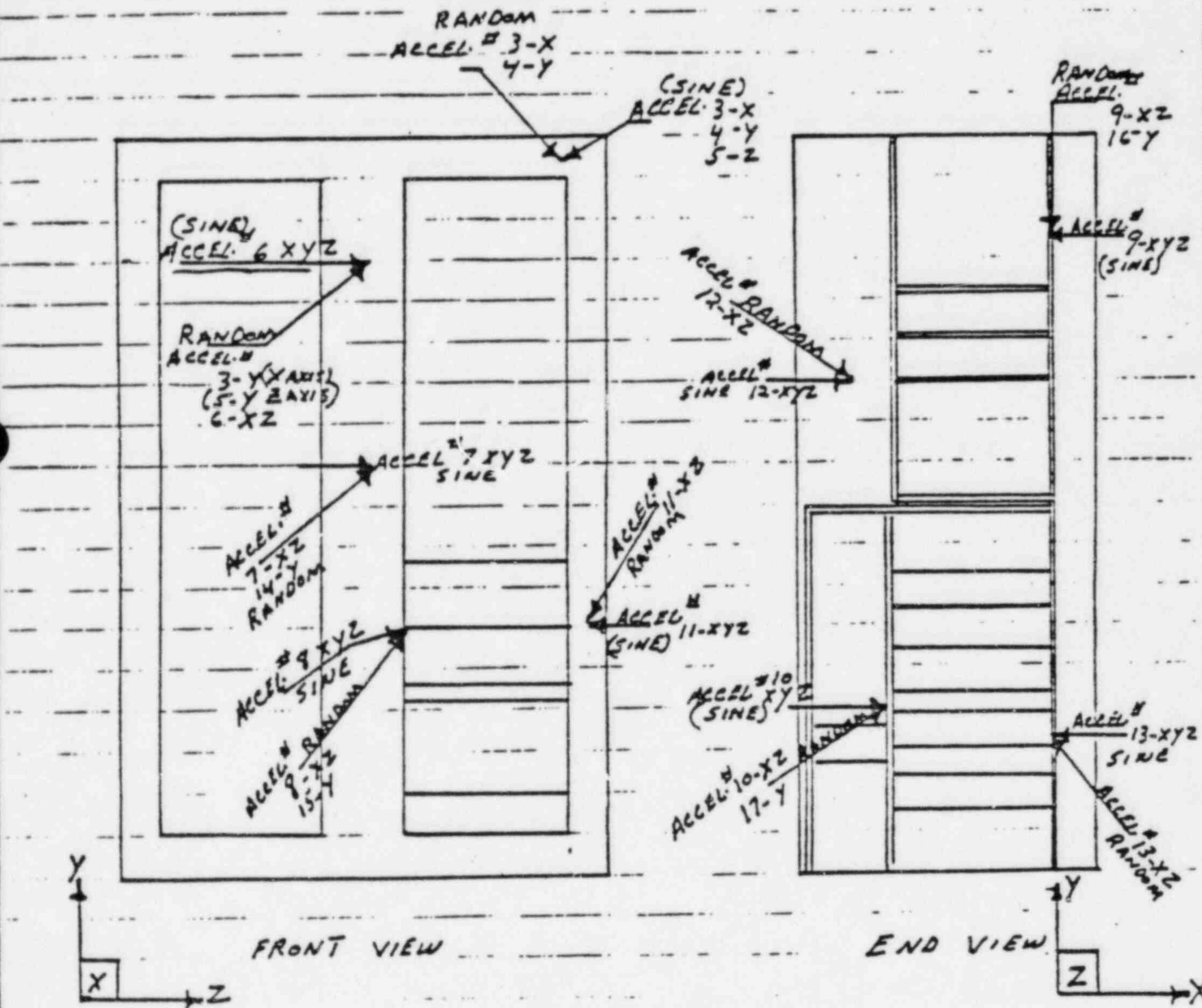
Specimen PANEL H13-P612

Job No. 58626

S/N SEE REC INSP

Part No. SEE REC INSP

Date 3-10-81



PANEL H13-P612

QC Form Approval

Attachment 7

Bailey Alarm (745) in Rack (7610) Accelerations

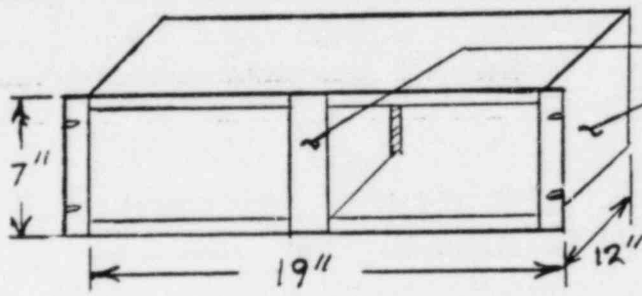


Fig. 1

H13-P612 PL382X512TU, Rev. 4, item 168
Model 761200AAAA1 is the same as the 761000AAAA1 (Type 7610) mechanically, per the Bailey Catalog.

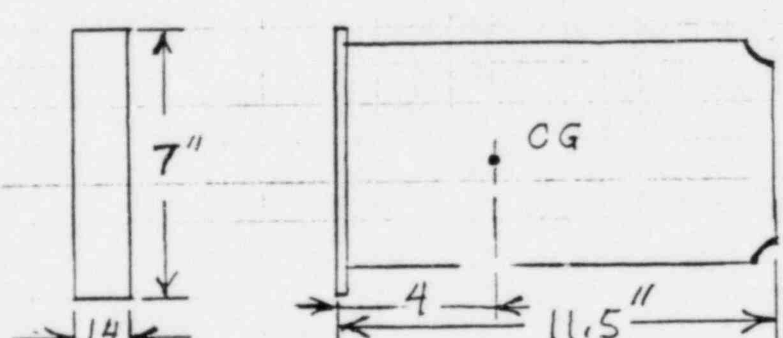
Assumptions:

1. The rack or card cage drives the alarm unit card with the front fixed by the adjacent filler modules, the top and bottom fixed by guide slots, and the rear restrained by the electrical plug-in connection.

2. In the side to side vibration mode the rack flexes at the bolted joints but hte rack sides and the inserted units remain parallel.

3. The bolted aluminum structure with cards installed has a damping value for an SSE that is as great as that for bolted steel structures. IEEE 344 1975, Table 1 recommends 7%.

4. The center of gravity for the alarm unit card with aluminum plate on the front is assumed to be located 1/3 D behind the front face of the unit (Fig. 2).



Alarm Weight = 1.0 lb

W = 1.4
H = 7
D = 11.5

Fig. 2

Revision	0				Page 7.1
Prepared By/Date	DBH/12-3-82				of 7.3
Checked By/Date	[illegible]/12-3-82				

Attachment 7

Analysis

1. Seismic Amplification for the Rack:

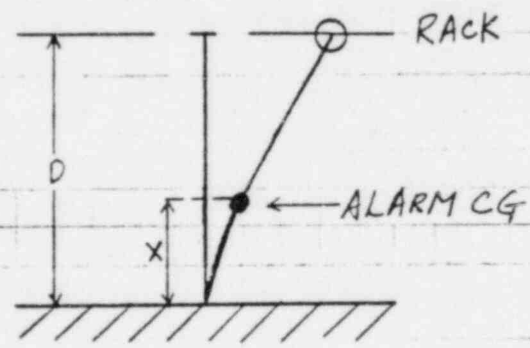
   G.E. Report #526 reports that the rack has a side-to-side resonance at 18 Hz. Using β from assumption 3, obtain the magnification factor Q_R:

   $$Q_R = \frac{1}{2\beta} = \frac{1}{2(.07)} = 7.14 \quad \text{(for the rack)}$$

2. Adjust to the Alarm Unit CG:

   Justification of reduction ratio:

   The magnification factor of the rack (Q_R) is conservatively estimated as a single degree of freedom system with center of gravity at the rear. The alarm is mounted within the rack, and has a center of gravity (CG) more toward the front. Thus, conservatively estimating the alarm center of gravity (CG) at one third (1/3) the depth of the rack, means that the alarm experiences a factor of three less magnification of acceleration. (see Figure below)



$$Q_{CG} \cong \frac{X}{D} Q_R$$

AMPLICATION FACTOR

Attachment 7

Analysis (Cont'd)

$$\frac{Q_{CG}}{Q_R} = \frac{4"}{12"} = \frac{1}{3} \qquad Q_{CG} = \frac{Q_R}{3} = 2.38$$

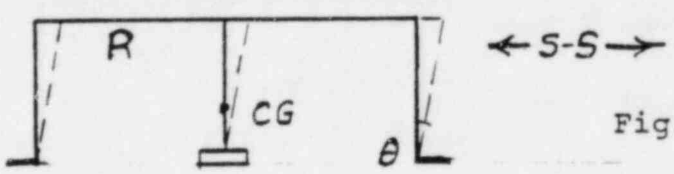


Fig. 3 Plan View of Rack & Unit

Front Face of Unit

3. Calculate CG Acceleration:

From Accelerometer #6 of H13-P612 test side-to-side motion, one has:

Transmissibility	Zimmer-ZPA	Panel Accel.	Q_{CG} Ampli.	Alarm Accel
6.1	0.45g	2.75	2.38	6.53

4. Deflection at resonance assuming harmonic motion:

$$d = \frac{a\ (386.09)}{4\pi^2 f^2} = \frac{6.53}{(0.1023)(18Hz)^2} = 0.198 \text{ in.}$$

Where: a = accel. (g)
f = freq (Hz)

$$\theta = \tan^{-1} \frac{.197}{4} = 2.82^\circ \approx 3^\circ$$

Attachment 8

FOR INFORMATION ONLY

CGE-03-218
33.803.0962
Revision 1

Assessment Report
Spent Fuel Storage Rack
For
Wm. H. Zimmer
Nuclear Power Station

Prepared by:
NUTECH Engineers
San Jose, CA

Prepared by:

Mark Voutyras 6/8/82

Mark Voutyras
Engineering Analyst

Approved by:

G. P. Chew

G. P. Chew
Engineering Manager

Checked by:

A. Javid 6/8/82

A. Javid
Project Engineer

Issued by:

V. J. Brocato

V. J. Brocato, P.E.
Project Manager

REVISION CONTROL SHEET

SUBJECT: Assessment Report
Spent Fuel Storage Rack
for Wm. H. Zimmer Nuclear
Power Station

REPORT NUMBER: CGE-03-218

M. Voutyras/Engineering Analyst — MPV
NAME/TITLE — INITIAL

A. Javid/Chief Consultant — AJ
NAME/TITLE — INITIAL

G. Chew/Engineering Manager — GC
NAME/TITLE — INITIAL

V. Brocato/Project Manager — VJB
NAME/TITLE — INITIAL

EFFEC-TIVE PAGE(S)	REV	PRE-PARED	ACCURACY CHECK	CRITERIA CHECK	EFFEC-TIVE PAGE(S)	REV	PRE-PARED	ACCURACY CHECK	CRITERIA CHECK
All	0	MPV *	AJ *	AJ *					
4, i, ii	1	MPV	AJ	AJ					

QEP-001.1-00

*Revision 0 issued without revision control sheets. Accuracy and criteria checks were performed before Revision 0 issued.

REVISION CONTROL SHEET

REPORT NUMBER: CGE-03-218

FILE NUMBER: 33.803.0962

SUBJECT: Assessment Report
Spent Fuel Storage Rack for
William H. Zimmer Nuclear Power Station

This page is a record of all revisions of this document.

REVISION	DATE	PREPARED BY	CHECKED BY	PAGES	REMARKS
0	6/8/82	MPV*	[illegible] *	All	
1	6/8/82	MPV	[illegible]	4, i, ii	

*Revision 0 issued with revision control sheets. Accuracy and criteria checks were performed before Revision 0 issued.

INTRODUCTION

Seismic analysis of the Spent Fuel Storage Rack was performed for the purpose of SORT requalification. The two NRC concerns were 1) that the overturning moments in the E-W direction, and 2) that the seismic restraints were not considered in the original analysis. In addition to these concerns, NUTECH has also addressed the effect of added hydrodynamic mass of the water surrounding the racks.

METHOD OF ANALYSIS

Analysis of Spent Fuel Storage Rack was composed of two parts. In the first part a dynamic analysis was performed. The modal superposition method using acceleration response spectra, was utilized and the dynamic loads on the system (shears and moments) were calculated using the computer program STARDYNE. In the second phase, the calculated loads were utilized to obtain the stresses at the critical parts of the assembly.

The rack was modeled as a finite element model as shown in Figure 1. The simple components of the rack justified the use of only a beam element with six static degrees of freedom and three dynamic degrees (translations only). A sufficient number of nodes was included in the model to obtain an accurate representation of the system and to extract all applicable frequencies. Seismic supports were modeled by springs at the appropriate nodal point. The effect of the surrounding water and other racks was simulated by adding a uniformly distributed mass in both horizontal directions. This added mass was conservatively estimated by assuming that only one rack is free dynamically while all surrounding racks remain stationary. In actuality the added mass will be closer to that of an in-phase multi-member arrangement.

RESULTS AND CONCLUSIONS

Results from the modal extraction, along with the response spectrum used in the dynamic analysis, are shown in Appendix A. Resulting dynamic loads (also Appendix A) were used to calculate stresses in five critical areas, as summarized in Table 1. The only critically stressed area was found to be the bolt pad of the base supports. It is shown to be 1.6% overstressed. However, it is considered acceptable because of the amount of conservatism that was used in calculating the water mass which is directly proportional to this stress. An additional stress calculation was made on the cross bracing members ~~numbers~~ to validate the assumption that the vertical columns act together, enabling the rack to be modeled using a simple stick model. This stress is shown to be well within the allowable.

By using a six degree of freedom model and the appropriate restraints NUTECH has considered both NRC concerns mentioned

above. In addition, NUTECH has considered additional loading due to the hydrodynamic mass of water surrounding the racks. Dynamic analysis was performed using the appropriate response spectra. All stresses were calculated to be within acceptable limits. This analysis demonstrates that the Spent Fuel Storage Racks for the Zimmer Nuclear Power Station will maintain their functional integrity if subjected to seismic events.

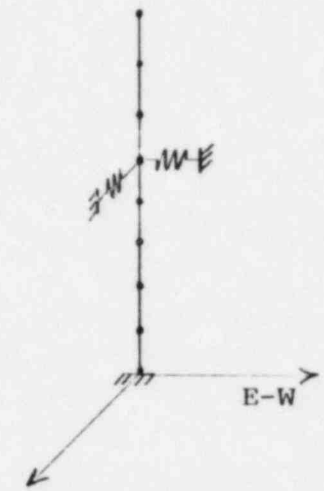


Figure 1. Finite Element Model

Table 1. Summary of Stresses

Component (Stress Type)	Maximum Stress (PSI)	Allowable Stress (PSI)
Column and End Channel		
(Combined Bending & Axial)	3179	31000
(Shear)	256	31000
Column-base Weld		
(Combined Bending)	6438	20000
(Shear)	767	20000
Column-div'der Weld		
(Combined Bending)	4141	20000
(Shear)	875	20000
Bolt Pad (Bearing)	16262	16000
Base (Compression)	5354	21000
Cross Bracing (Shear)	2035	14000

REFERENCES

1. Stress Analysis-Spent Fuel Storage Rack-Conc. 2, by General Electric, dated 10/21/77.

2. Caorso, Assurance of Function, DRF # 139F16-E002-RB1, by GE, dated 1/20/77.

3. Spent Fuel Storage Racks Horizontal Seismic Response Study, Project No. 4130 by Sargent & Lundy, dated 3/13/78.

4. CGE Spent Fuel Storage Rack Analysis, NUTECH File No. 33.803.0551, 10/20/81. Rev. 1

5. CGE Spent Fuel Storage Rack Computer Output, NUTECH File No. 33.803.0551, 10/12/81.

6. Effective Mass and Damping of Submerged Structures, R.G. Dong, Lawrence Livermore Laboratory, UCRL-52342, April 1, 1978.

MODE NO	EIGENVALUE (OMEGA**2)	NATURAL FREQUENCY	PERIOD	GENERALIZED WEIGHT	MAX TRANSLATION NODE-DOF	MAX TRANSLATION VALUE	--- MODAL WEIGHTS --- (GEN. WGT. * PARTICIPATION FACTORS**2) X1	X2	X3	
1	8820.15	14.947	.0669	6825.53	9-2	1.0000	.00000	6565.12449	.00000	12.0
2	8837.39	14.962	.0668	6340.75	9-1	1.0000	14831.28763	.00000	.00000	12.0
3	47805.1	34.798	.0287	17276.3	4-2	1.0000	.00000	36642.61128	.00000	12.0
4	186357.	68.706	.0146	8446.12	9-1	1.0000	4806.51923	.00000	.00000	12.0
5	194497.	70.190	.0142	23539.1	9-2	1.0000	.00000	931.33245	.00000	12.0
6	246179.	78.967	.0127	8437.10	9-3	1.0000	.00000	.00000	13564.99925	12.0
7	349504.	94.091	.0106	20645.5	9-2	1.0000	.00000	2075.00085	.00000	12.0
8	794952.	141.904	.0070	19040.3	2-2	1.0000	.00000	1750.37960	.00000	12.0
9	836652.	145.577	.0069	9142.45	9-1	1.0000	1141.19699	.00000	.00000	12.0
10	.122854E+07	176.407	.0057	24744.0	6-2	1.0000	.00000	20.10587	.00000	12.0
11	.160345E+07	201.534	.0050	22995.8	3-2	1.0000	.00000	179.36620	.00000	12.0
12	.181756E+07	214.568	.0047	11350.3	2-1	1.0000	447.90462	.00000	.00000	12.0
13	.210807E+07	231.080	.0043	17404.6	7-2	1.0000	.00000	67.15890	.00000	11.0
14	.215627E+07	233.707	.0043	8537.67	9-3	1.0000	.00000	.00000	1433.34153	11.3
15	.304532E+07	277.738	.0036	9975.44	2-1	1.0000	184.30817	.00000	.00000	10.3
16	.415850E+07	324.555	.0031	10174.2	6-1	1.0000	49.95701	.00000	.00000	8.8
17	.489534E+07	352.137	.0028	9417.29	4-1	1.0000	22.86859	.00000	.00000	7.6
18	.574123E+07	381.351	.0026	8414.37	9-3	1.0000	.00000	.00000	451.56575	7.4
19	.629637E+07	399.361	.0025	7021.53	8-1	1.0000	.01882	.00000	.00000	7.1
20	.101322E+08	506.608	.0020	4615.17	9-3	1.0000	.00000	.00000	180.88156	7.8

THE FOLLOWING ARE APPROX. EIGENVALUES FOR WHICH MODES WERE NOT REQUESTED.

MODE NO	EIGENVALUE (OMEGA**2)	NATURAL FREQUENCY	
21	.152075E+08	620.656	6.4
22	.202003E+08	715.318	6.1
23	.224376E+08	753.891	5.5
24	.303283E+08	876.485	6.7

LANCZOS REDUCED MATRIX SIZE (DOF) = 24
APPROX. MAXIMUM EIGENVALUE(OMEGA**2)= .303283E+04

NOTE THE LAST COLUMN IN THE TABLE ABOVE IS RELATED TO EIGENVALUE ACCURACY BOUNDS.

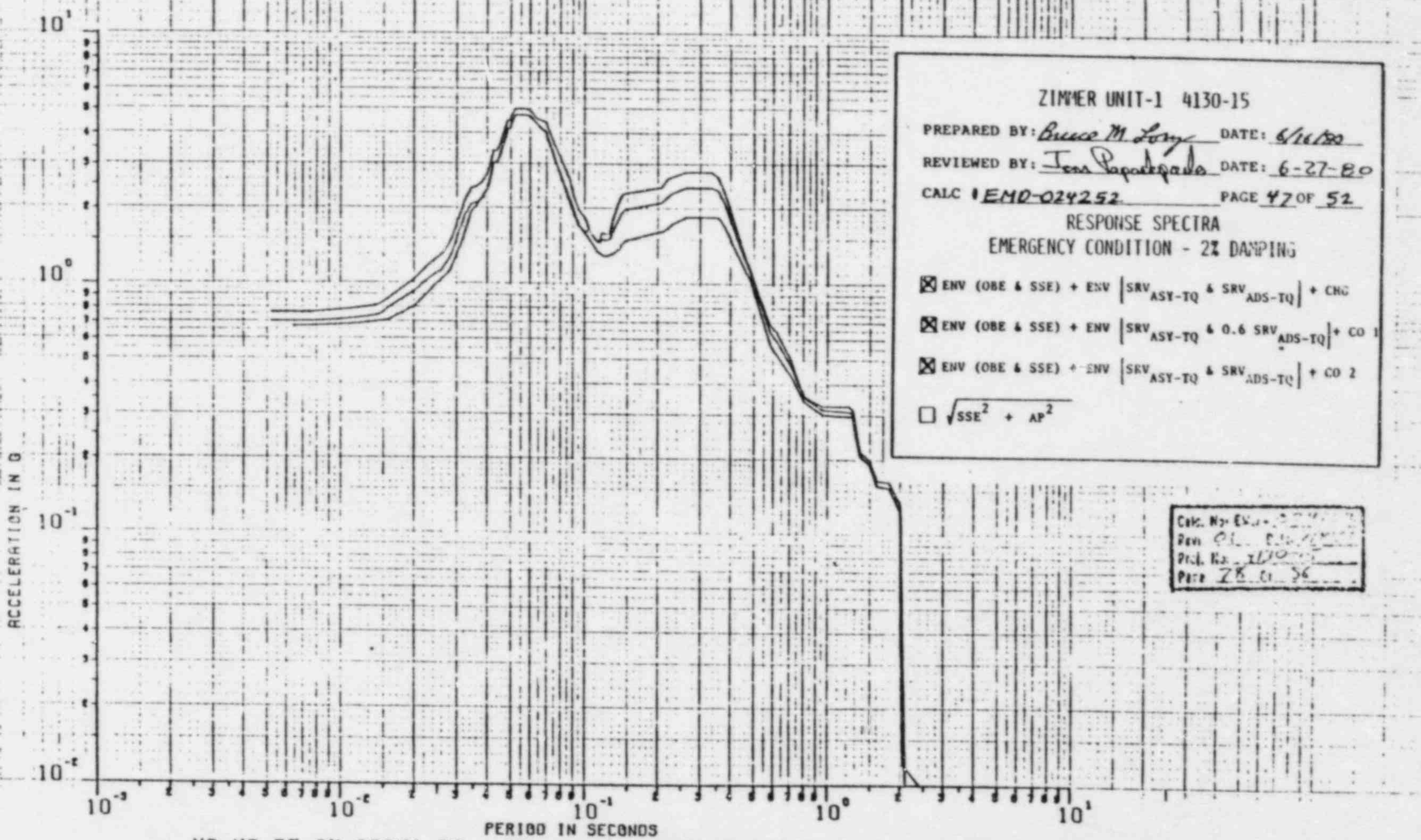
****** [illegible] ******

ERSS - 1)   BEAM END LOADS (NODAL)

NO	NODES		FX1	FX2	FX3	MX1	MX2	MX3
1	JA	1	7.8702E+03	8.6149E+03	1.1242E+04	2.5454E+05	9.7627E+05	0.
	JB	2	7.8702E+03	8.6149E+03	1.1242E+04	5.6457E+04	7.9972E+05	0.
2	JA	2	7.6984E+03	5.6326E+03	1.0771E+04	5.6457E+04	7.9972E+05	0.
	JB	3	7.6884E+03	5.5324E+03	1.0771E+04	1.03[illegible]E+05	6.2547E+05	0.
3	JA	3	7.2619E+03	3.1210E+03	9.8480E+03	1.03[illegible]E+05	6.2587E+05	0.
	JB	4	7.2619E+03	3.1210E+03	9.8480E+03	1.6955E+05	4.6111E+05	0.
4	JA	4	6.5923E+03	3.6849E+03	8.5121E+03	1.6959E+05	4.6111E+05	0.
	JB	5	6.5923E+03	3.6849E+03	8.5121E+03	1.4731E+05	3.1032E+05	0.
5	JA	5	5.6499E+03	7.4701E+03	6.7556E+03	1.4731E+05	3.1032E+05	0.
	JB	6	5.6499E+03	7.4701E+03	6.7556E+03	1.9778E+05	1.7016E+05	0.
6	JA	6	4.4298E+03	4.9577E+03	4.6226E+03	1.9778E+05	1.7016E+05	0.
	JB	7	4.4298E+03	4.9577E+03	4.6226E+03	1.0077E+05	8.1655E+04	0.
7	JA	7	2.9702E+03	3.5470E+03	2.9546E+03	1.0577E+05	8.1855E+04	0.
	JB	8	2.9702E+03	3.5470E+03	2.9546E+03	3.0812E+04	2.2512E+04	0.
8	JA	8	1.1256E+03	1.5406E+03	9.9521E+02	3.0812E+04	2.2512E+04	0.
	JB	9	1.1256E+03	1.5406E+03	9.9521E+02	2.5391E-09	4.9617E-08	0.

MAXIMUM RESPONSES FOR THE 12 VALUES PRINTED FOR EACH ELEMENT OF THIS TYPE...

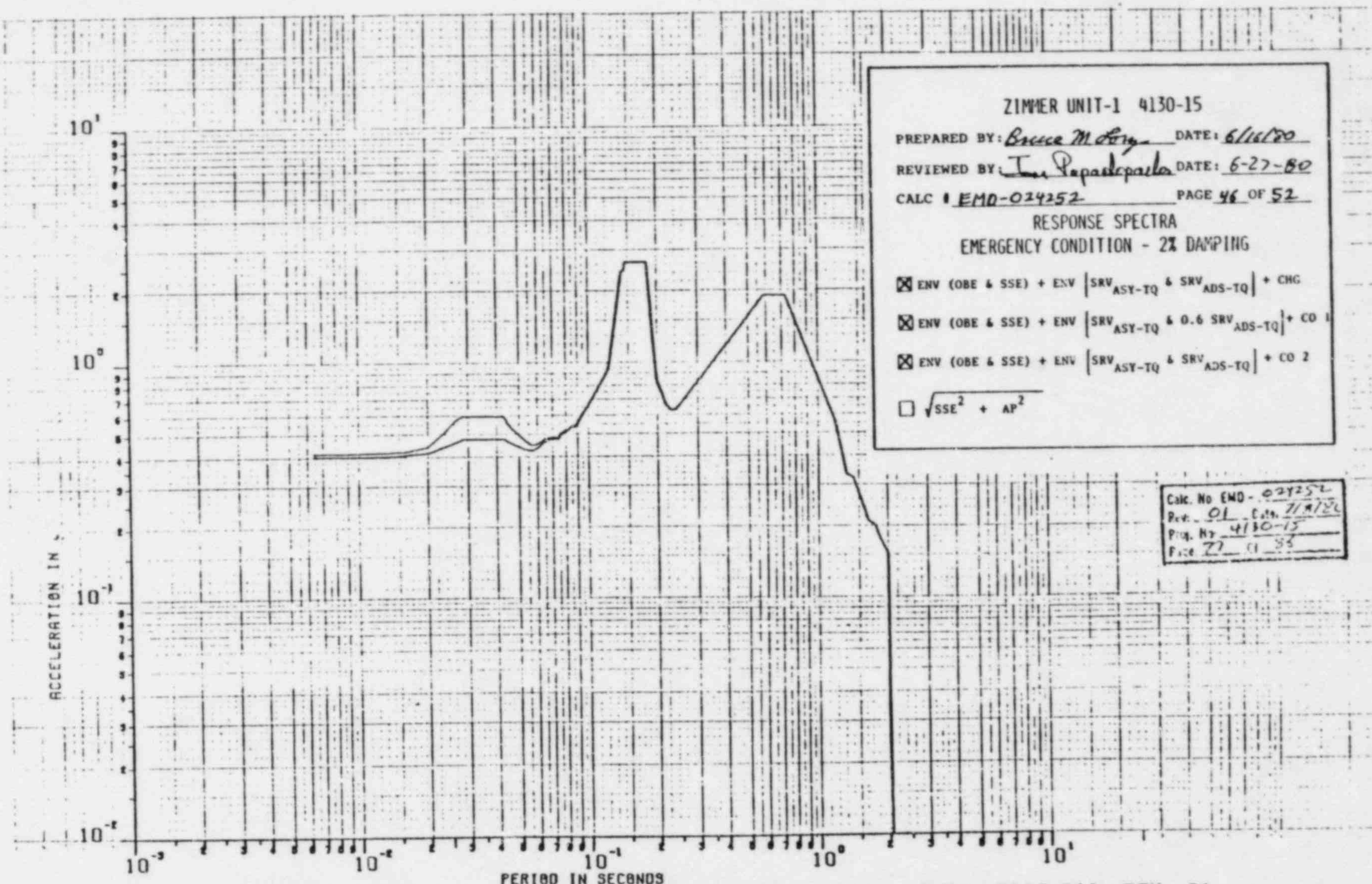
1 =	7870.17369 AT ELEMENT NO	1
2 =	8614.89920 AT ELEMENT NO	1
3 =	11242.44617 AT ELEMENT NO	1
4 =	254544.46644 AT ELEMENT NO	1
5 =	976265.04551 AT ELEMENT NO	1
6 =	0.00000 AT ELEMENT NO	1
7 =	7870.17369 AT ELEMENT NO	1
8 =	8614.89920 AT ELEMENT NO	1
9 =	11242.44617 AT ELEMENT NO	1
10 =	197778.22715 AT ELEMENT NO	5
11 =	799720.31667 AT ELEMENT NO	1
12 =	0.00000 AT ELEMENT NO	1



VS-VS DF-2% ABSV(C2 + C3 +C4) ZIMMER REACTOR BLDG. ELEV. 593'-6'' REV. 01

K-E KEUFFEL & ESSER CO.

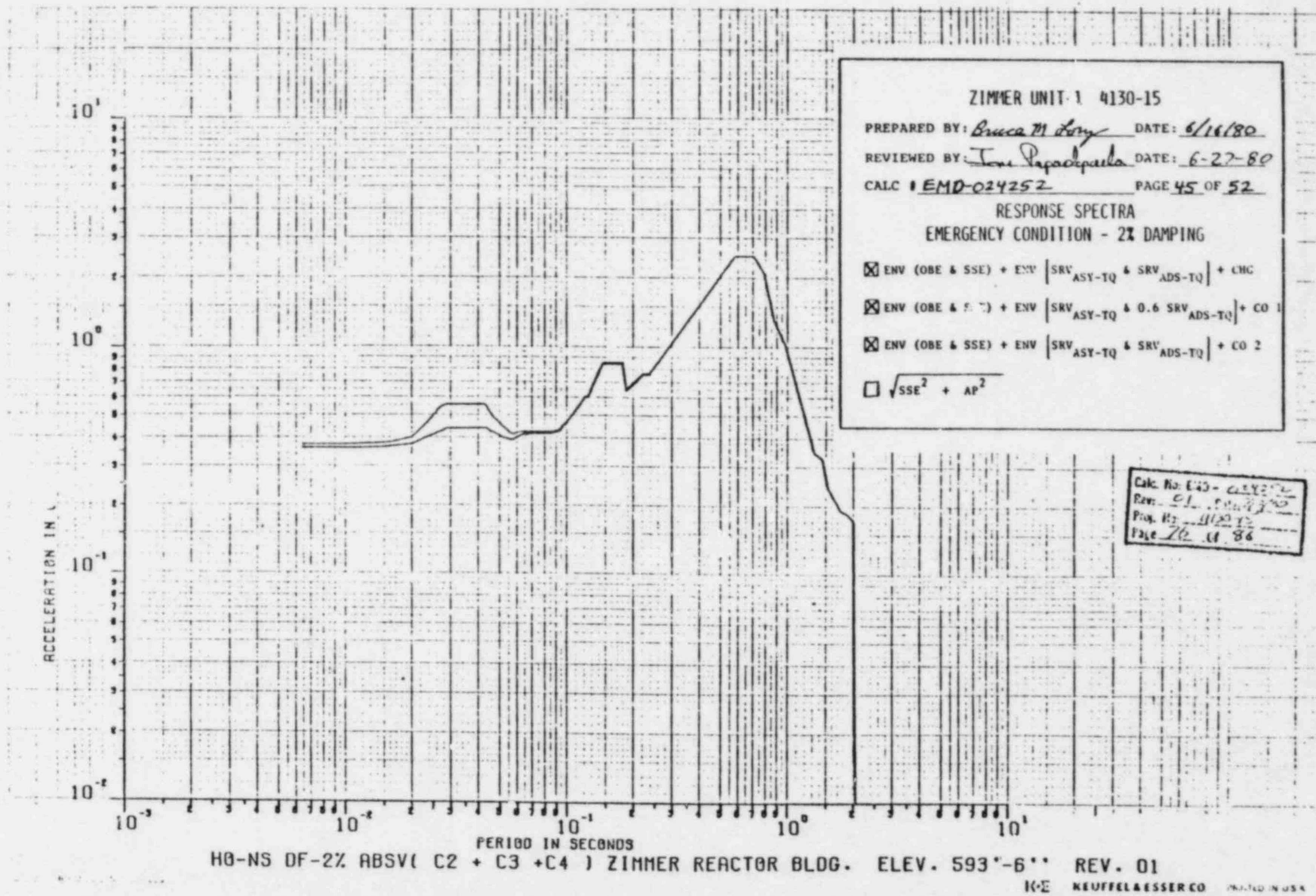
Run I.D. BML 6/16/80



HO-EW OF-2% ABSV(C2 + C3 +C4) ZIMMER REACTOR BLDG. ELEV. 593'-6" REV. 01

K&E KEUFFEL & ESSER CO.

Run I.D. BML 6/16/80



Run I.D. BML 6/16/80

Attachment 9

The following is a step by step summary of the attached calculation package which is used to address NRC concerns mentioned in assessment report of a spent fuel storage rack for Wm. H. Zimmer Nuclear Power Station, NUTECH File 33.803.0962 Rev. 1:

1) Moment of Inertia Calculation pp. 1 to 4 - This is a repeat of calculations used in the original report (Reference 1).

2) Effective Mass Calculation pp. 5 to 10 - This calculation addresses the total effective mass of the rack. The effective hydrodynamic mass is calculated by using two factors, one to account for a single rectangular member submerged in a fluid and another to account for a multimember arrangement. Both factors are calculated per recommendations of Reference 8. It should be noted that any factor used for multiple member arrangement is expected to be conservative because it assumes that one member moves while the others remain stationary.

3) Seismic Restraint Spring Constant Evaluation pp. 11 to 12 - The seismic restraints are modeled as springs having equivalent beam stiffnesses.

4) Stress Calculations pp. 18 to 26 - Simplified stress calculations are made using responses from STARDYNE run (Reference 5), allowables from previous reports (References 1 & 2) and weld geometry specified on GE Dwg. No. 762E210 Rev. 6. Please note that for the most critical component, the base casting lug bearing, the actual yield and ultimate strength for the ASTM B108 SG70A-T6 material are 22000 psi and 33000 psi, respectively. For the upset condition (N + OBE + SRV + LOCA) the allowable is $0.88\ F_y = 19360$ psi. For the faulted condition (N + SSE + SRV + LOCA) the allowable is $0.7\ F_u = 23100$ psi. The loads evaluated in this analysis are for the faulted condition.

nutech
ENGINEERS

nutech
San Jose, California

Project Wm. H. Zimmer Nuclear Power Station File No. 33.803.0551
Owner Cincinnati Gas and Electric Co.
Client Cincinnati Gas and Electric Co.

1) REFERENCES:

① STRESS ANALYSIS - SPENT FUEL STORAGE RACK - CONC. 2, BY GENERAL ELECTRIC, DATED 10-21-77. FILE 33.803.0551

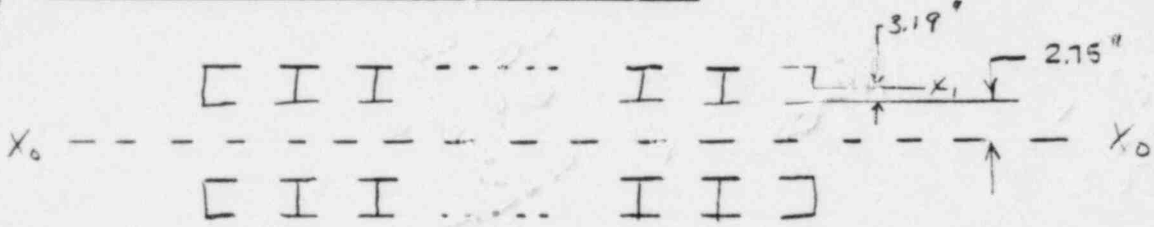
② CAORSO, ASSURANCE OF FUNCTION, DRF # 139F16-6000-B31 BY GE, DATED 1-20-77, FILE 33.803.0551

③ SPENT FUEL STORAGE RACKS HORIZONTAL SEISMIC RESPONSE STUDY, BY SARGENT & LUNDY, DATED 3-13-78., FILE 33.803.0551

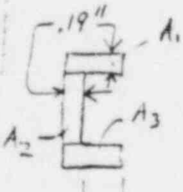
④ FORMULAS FOR STRESS & STRAIN, ROARK, 5th ED.

⑤ STARDYNE Computer Output, RUN NO. MPV06SP, DATED 10-12-81, FILE 33.803.0551

2) MOMENT OF INERTIA CALC:



NINE COLUMNS & TWO END CHANNELS ON EACH ROW OF FUEL CELLS



END CHANNEL

MATL: 6063-T5 AL. EXTRUSION
ρ = 0.099 lbs/cu in
l = 168 ins.

Ref ⑥ p.4

⑥ GE Dwg. 762E210, SPENT FUEL STORAGE RACK, REV. 6, 6-20-79
⑦ GE Dwg. 829E422, FUEL BUNDLE, REV. 4, 4-20-79
⑧ R.G. DONG, EFFECTIVE MASS AND DAMPING OF SUBMERGED STRUCTURES, APRIL, 1978, LAWRENCE LIVERMORE LAB UCRL-52342
⑨ S&L Dwg. S-421, REACTOR BUILDING POOL LINER, REV. K, DATED 1-2-80

NUTECH FILE NO. 33.303.0551

Revision	C					
Prepared By/Date	MPV 10-16-81					
Checked By/Date	[illegible] 10/20/81					

Page 1 of 26

nutech
San Jose, California

Project Wm. H. Zimmer Nuclear Power Station File No. 33.803.0551
Owner Cincinnati Gas and Electric Co.
Client Cincinnati Gas and Electric Co.

SPENT FUEL STORAGE RACK CALCULATIONS

TABLE OF CONTENTS:

Revision	0	
Prepared By/Date	MPV 12-6-82	
Checked By/Date	PWB 12-8-82	

END CHANNEL (cont)

$A_1 = 2.19(.19) = .416$

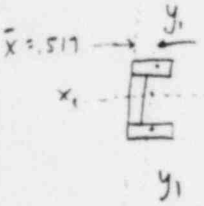
$A_3 = A_1 = .416$

$A_2 = 6(.19) = 1.14$

$A_{Total} = 1.97$ sq. in.

Weight = 1.97(.099) 168 = 32.7 lbs

$$I_{x_1} = 2\left[\frac{(.19)^3 2.19}{12} + .416(3.095)^2\right] + \frac{.19(6)^3}{12} = 11.392 \text{ in}^4$$



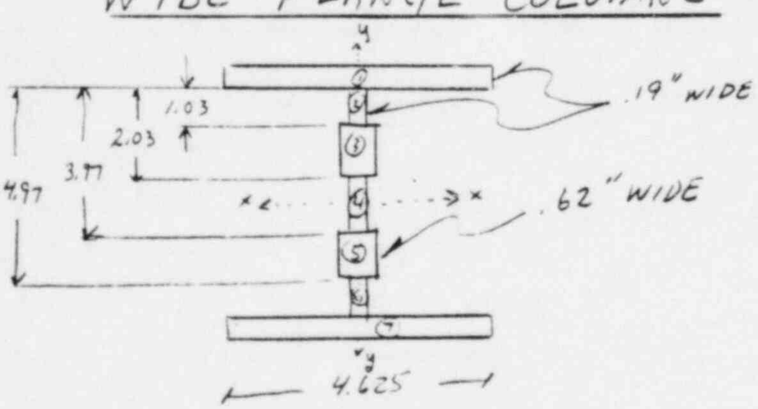
$$\bar{x} = \frac{\Sigma A x}{\Sigma A} = \frac{2(1.095).416 + .095(1.14)}{1.97} = .517 \text{ in}$$

$$I_{y_1} = \frac{6(.19)^3}{12} + 1.14(.517 - .095)^2 + 2\left[\frac{.19(2.19)^3}{12} + .416(1.095 - .517)^2\right]$$

(annotations above terms: .003, .20, .61)

$= 0.817 \text{ in}^4$

WIDE FLANGE COLUMNS Ref ① p. 6



MAT'L: 6063-T5 Alum
ρ = .099 lbs/cu in
ℓ = 169 ins.

WIDE FLANGE COLUMNS (cont.)

$A_1 = 4.625(.19) = .879$
$A_2 = 1.03(.19) = .196$
$A_3 = 1(.62) = .62$
$A_4 = 1.94(.19) = .369$
$A_5 = A_3 = .62$
$A_6 = A_2 = .196$
$A_7 = A_1 = .879$

$A_{Total} = 3.758$

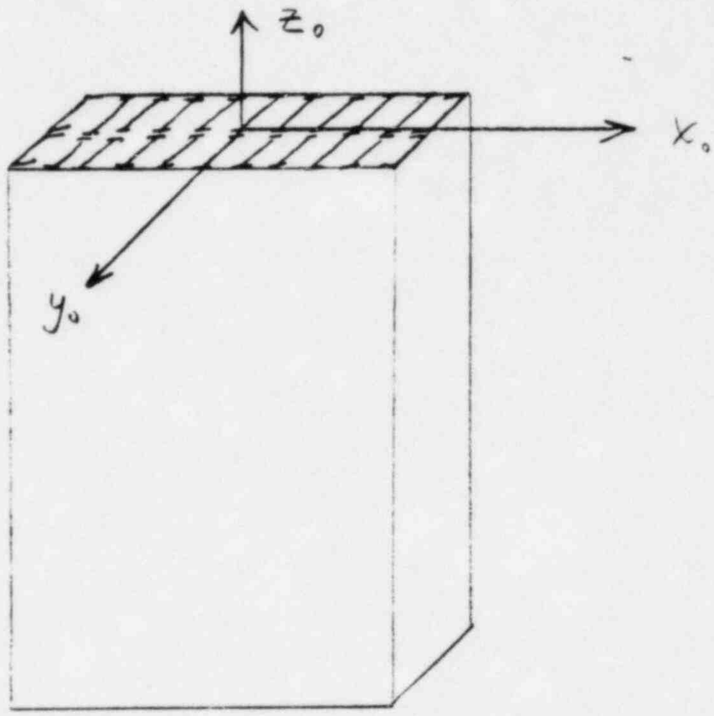
Weight $= 3.758$ ([illegible]) $168 = 62.5$ lb

$$I_{x_1} = 2\left[\frac{4.625(.19)^3}{12} + .879(3.19 - .095)^2 + \frac{.19(1.03)^3}{12} + .196(3.19 - .705)^2 + \frac{.62(1)^3}{12} + .62(3.19 - 1.72)^2\right] + \frac{.19(1.94)^3}{12}$$

$$= 21.690 \text{ in}^4$$

$$I_{y_1} = 2\left[\frac{.19(4.625)^3}{12} + \frac{1.03(.19)^3}{12} + \frac{1(.62)^3}{12}\right] + \frac{1.94(.19)^3}{12} = 3.174 \text{ in}^4$$

MOMENT OF INERTIA OF RACK



$$I_{x_0} = \Sigma I_{x_1} + \Sigma A d_{x_{1-0}}^2$$

$$= \left[9(21.690) + 9(3.758)(2.75+3.19)^2 + 2(11.392) + 2(1.97)(2.75+3.19)^2\right] 2$$

$$= 3101 \ in^4$$

$$I_{y_0} = 18(3.174) + 4(3.758)\left[(6.625)^2+(13.25)^2+(19.875)^2+(26.5)^2\right] + 4(.817) + 4(1.97)(33-.517)^2$$

$$= 28168 \ in^4$$

3.) EFFECTIVE MASS

EFFECTIVE MASS ARE ① MASS OF RACK, ② MASS OF WATER INSIDE RACK, ③ EFFECTIVE MASS OF WATER OUTSIDE RACK

① MASS OF RACK = 645 (20) + 2020 = 14920 lbs

- 645: @ FUEL ELEMENT (REF ⑦)
- 2020: EMPTY RACK WGT (REF ② p 2)

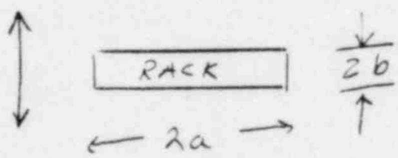
② MASS OF WATER INSIDE RACK:

$$m_w = \left[(5.226)^2 - \frac{.493^2}{4} \pi (64) \right] (20)\, 178\, \rho \qquad \text{Ref ⑦}$$

$$= 53735\ in^3 \ \frac{62.4\ lb}{12^3\ in^3} = 1[illegible]40\ lbs$$

EFFECTIVE MASS (Cont.)

(3) ADDED HYDRODYNAMIC MASS



$2b \cong 18''$
$2a \cong 66''$

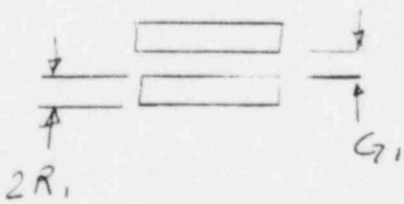
$a/b = 3.67$

FROM FIGURE 2 $m_h = 1.26\,\pi\rho a^2$ Ref (8)

m_h = Mass of fluid displaced for single rectangular member

FOR MULTIPLE CYLINDIRICAL MEMBERS SEE FIGURE 3.

USING DIMENSIONS FROM FIGURE 1



@ $G_1/R_1 = \frac{6.55}{9.14} = 0.72$ $C \cong 1.25$ Ref (8)

CONSIDERING BOTH FIGURES 2 & 3
M_y = EFFECTIVE ADDED MASS WHEN MULTI MEMBER ARRANGEMENT

$M_y = 1.26(1.25)\,\pi\rho a^2 \ell$ = 34,635 lbs

Revision	0					Page 6 of 26
Prepared By/Date	MPV 10/20/81					
Checked By/Date	[illegible] 10/20/81					

EFFECTIVE MASS: (Cont.)

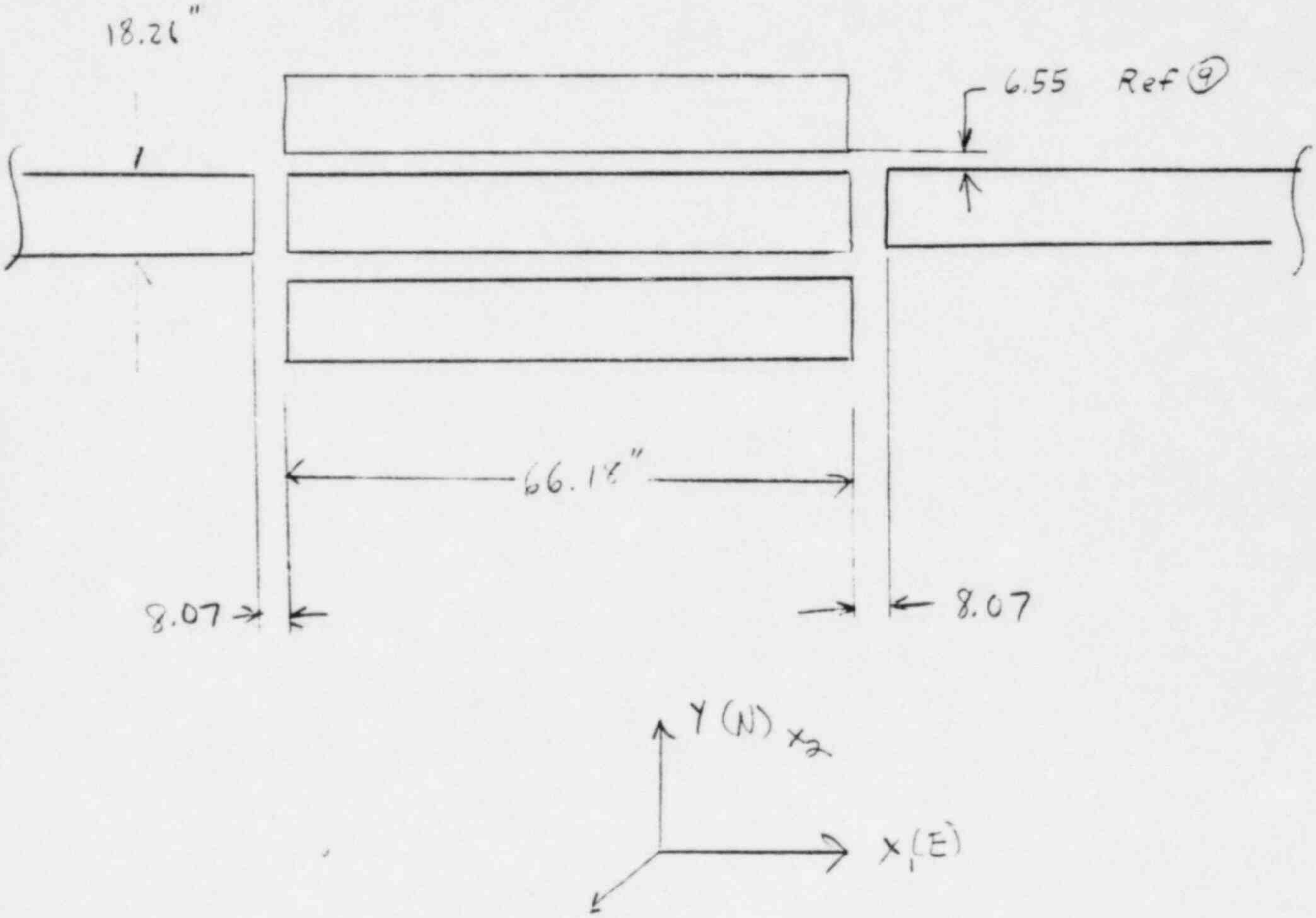


FIGURE 1 : SPENT FUEL RACK SPACING

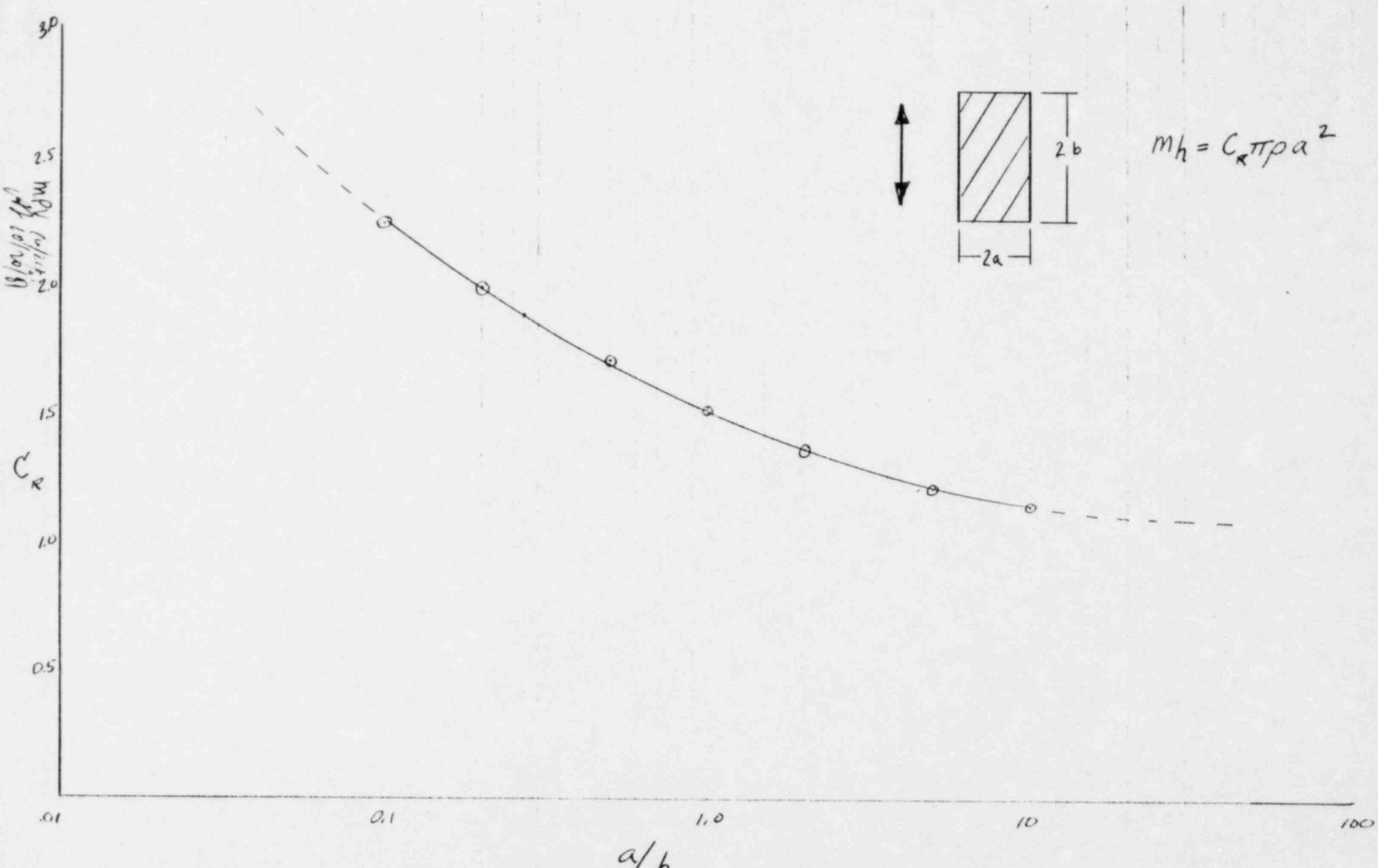


FIGURE 2 ADDED HYDRODYNAMIC MASS COEFFICIENTS FOR SINGLE RECTANGULAR MEMBER (REF 8)

EFFECTIVE MASS (cont.)

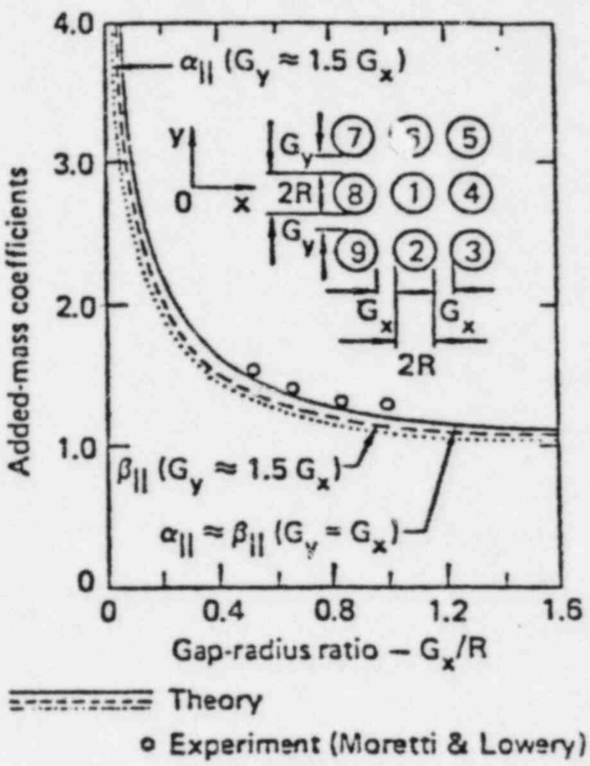


FIGURE 3. ADD HYDRODYNAMIC MASS COEF. FOR MULTIPLE CYLINDRICAL MEMBERS.

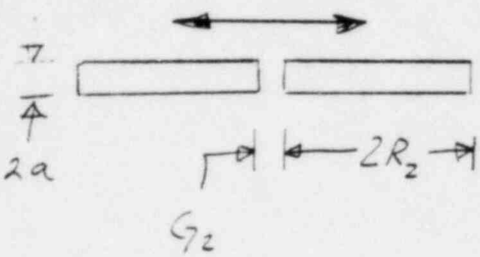
REFERENCE FOR FIGURES 2 & 3

REF ⑧: R.G DONG, EFFECTIVE MASS AND DAMPING OF SUBMERGED STRUCTURES APR 1, 1978 LAWRENCE LIVERMORE LAB, UCRL-52342

Revision	0						Page 9
Prepared By/Date	MPV 10/20/81						of 26
Checked By/Date	[illegible] 10/20/81						

EFFECTIVE MASS (Cont.)

CALCULATING M_x



$b = R_2 = 33''$

$a = 9''$

$a/b = .273$

$G_2/R_2 = \frac{7.56}{33.34}$

$= .23$

$$M_x = C C_R \pi \rho a^2 l$$

$$= 2.0\,(1.88)\,\pi \rho a^2 l$$

$$= \underline{\underline{6150 \text{ lbs}}}$$

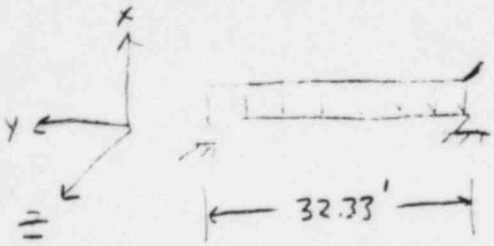
Revision	0					Page 10 of 26
Prepared By/Date	MPV 10-20-81					
Checked By/Date	[illegible] 10/20/81					

nutech
San Jose, California

Project: Wm. H. Zimmer Nuclear Power Station — File No. 33.803.0551
Owner: Cincinnati Gas and Electric Co.
Client: Cincinnati Gas and Electric Co.

SEISMIC RESTRAINT SPRING CONSTANT EVALUATION:

STIFFNESS APPROXIMATED BY ASSUMING } ① SIMPLE SUPPORTS, UNIFORM LOAD. ② LONGEST LENGTH OF BEAM



w lb/in = 45 lb/ft / 12 = 3.75 lbf/in

$$f_n = \frac{K_n}{2\pi}\sqrt{\frac{EIg}{w\,l^4}}$$

1ST MODE $K_n = 9.87$

Ref ④ p. 575

$$f_n = \frac{1}{2\pi}\sqrt{\frac{K_1}{m}}$$

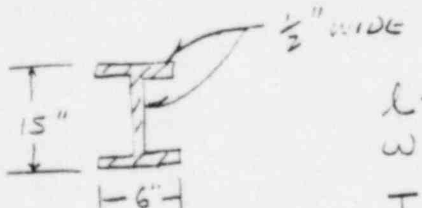
K_1 = SPRING CONSTANT

$m = \frac{wl}{g}$ $w = mg$

$$K_1 = \frac{(K_n)^2 EIg}{\frac{g}{l}\, l^4} = \frac{K_n^2 EI}{l^3}$$

$$= \frac{(9.87)^2\, 29(10)^6(18.14)}{[32.33(12)]^3} = 877.4 \text{ lbf/in}$$

IN X DIRECTION



$l = 32.33'$
$w = 45$ #/ft
$I_{zz} = 18.14$ in⁴
$E = 29\ 10^6$ psi

} Ref ③ p 9

Revision	0					Page 11 of 26
Prepared By/Date	MPV 10/20/81					
Checked By/Date	[illegible] 10/20/81					

Project: Wm. H. Zimmer Nuclear Power Station — File No. 33.803.0551
Owner: Cincinnati Gas and Electric Co.
Client: Cincinnati Gas and Electric Co.

SEISMIC RESTRAINT
SPRING CONSTANT EVALUATION (cont):

X-DIRECTION

$$K_2 = \frac{AE}{l} = \frac{75.52\ 29(10)^6}{32.33(12)} = 5.64E6$$

Revision	0					Page 12 of 26
Prepared By/Date	MPV 10/20/81					
Checked By/Date	[illegible] 10/20/81					

MODEL PROPERTIES

MAT'L : ALUM 6063-T5

$E = 10.3 \times 10^6$

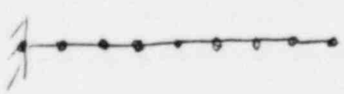
POISSON'S RATIO = .334

WEIGHT DENSITY = 16860 / 178" (1.97(4) - 3.758(1.8))

= 16860 / 178 (75.524)

= 1.254 lb/in³

EXTRA NODE WEIGHTS:



Y-DIRECTION –

34,635/8 = 4330/ELEMENT

NODES 2 thru 8 = 4330 lbs

NODES 1 & 9 = 2165 lbs

X-DIRECTION –

6150/8 = 769

NODES 2 thru 8 = 769

NODES 1 & 9 = 385

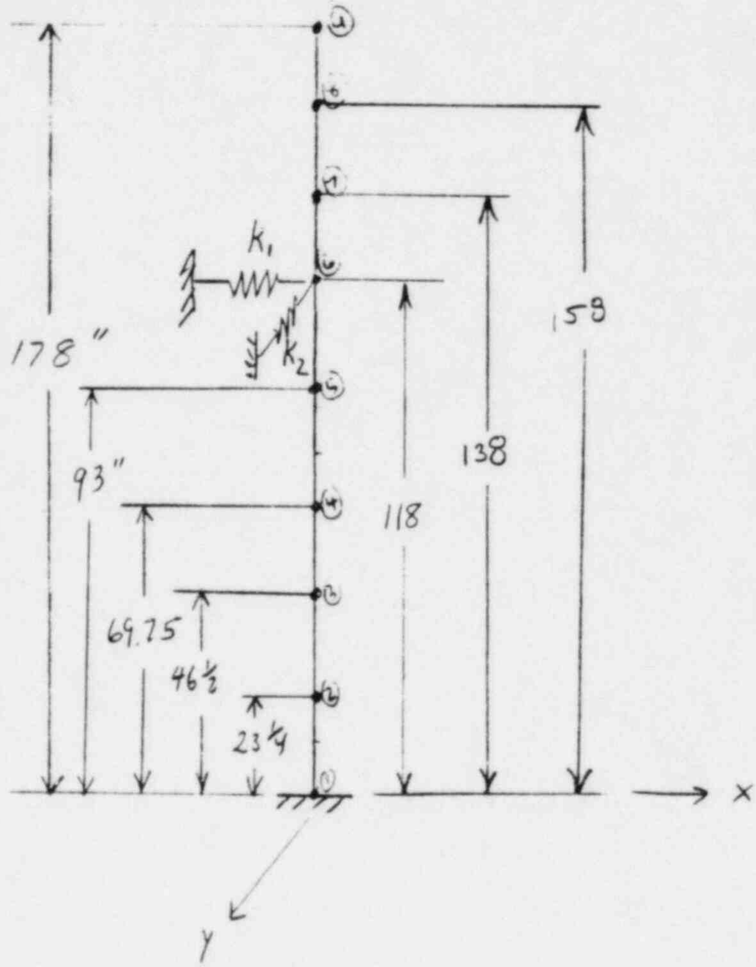
nutech
San Jose, California

Project: Wm. H. Zimmer Nuclear Power Station — File No. 33.803.0551

Owner: Cincinnati Gas and Electric Co.

Client: Cincinnati Gas and Electric Co.

MODEL AND PROPERTIES:



NUMBER of NODES = 9

AREA = 75.52 "

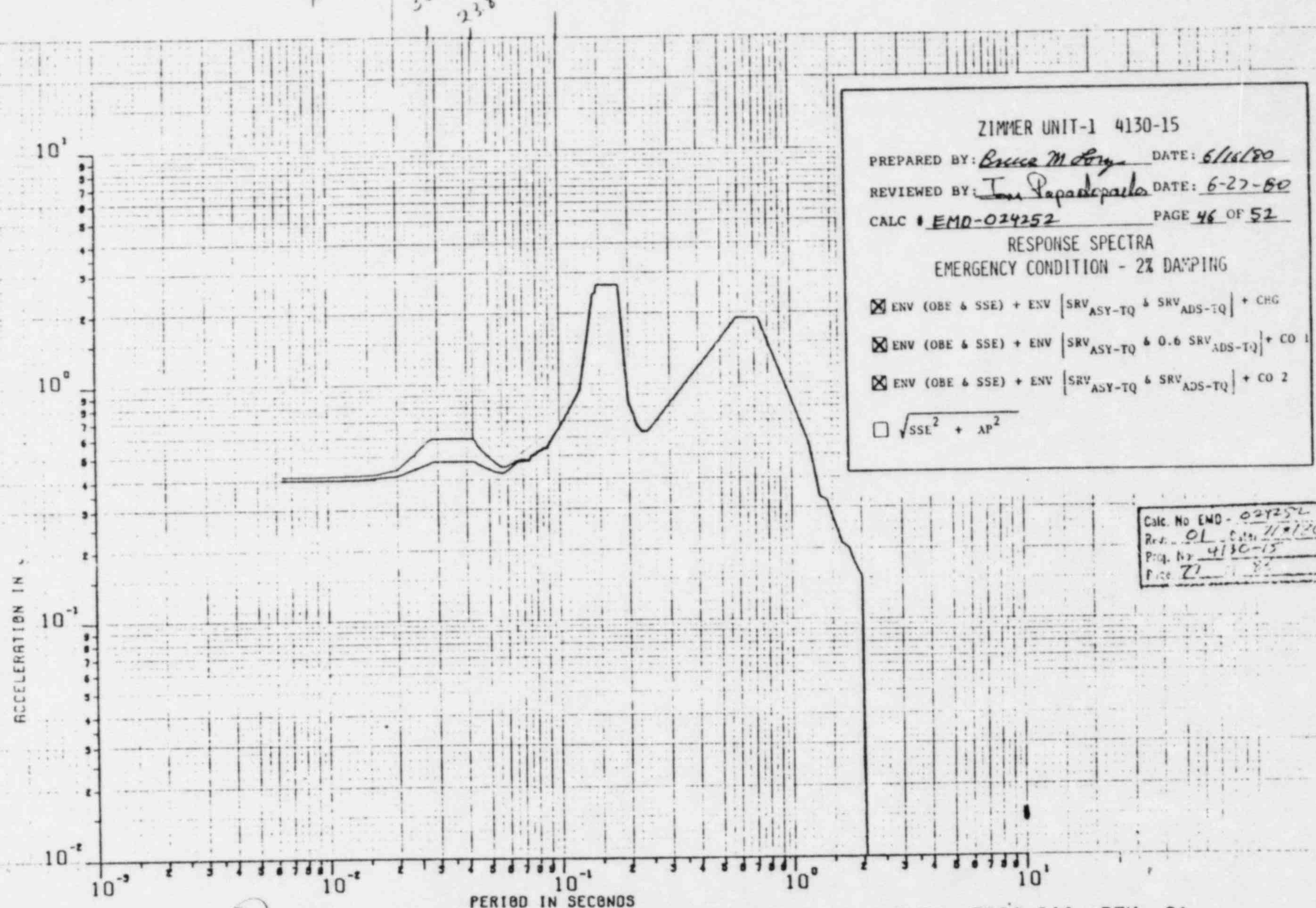
I_x = 3101 in^4

I_y = 28168 in^4

NOTE: LENGTH IS 10" LONGER THAN INDIVIDUAL CHANNELS (REF 6)

Revision	0					Page 14 of 26
Prepared By/Date	MPV 10/20/81					
Checked By/Date	[illegible] 10/20/81					

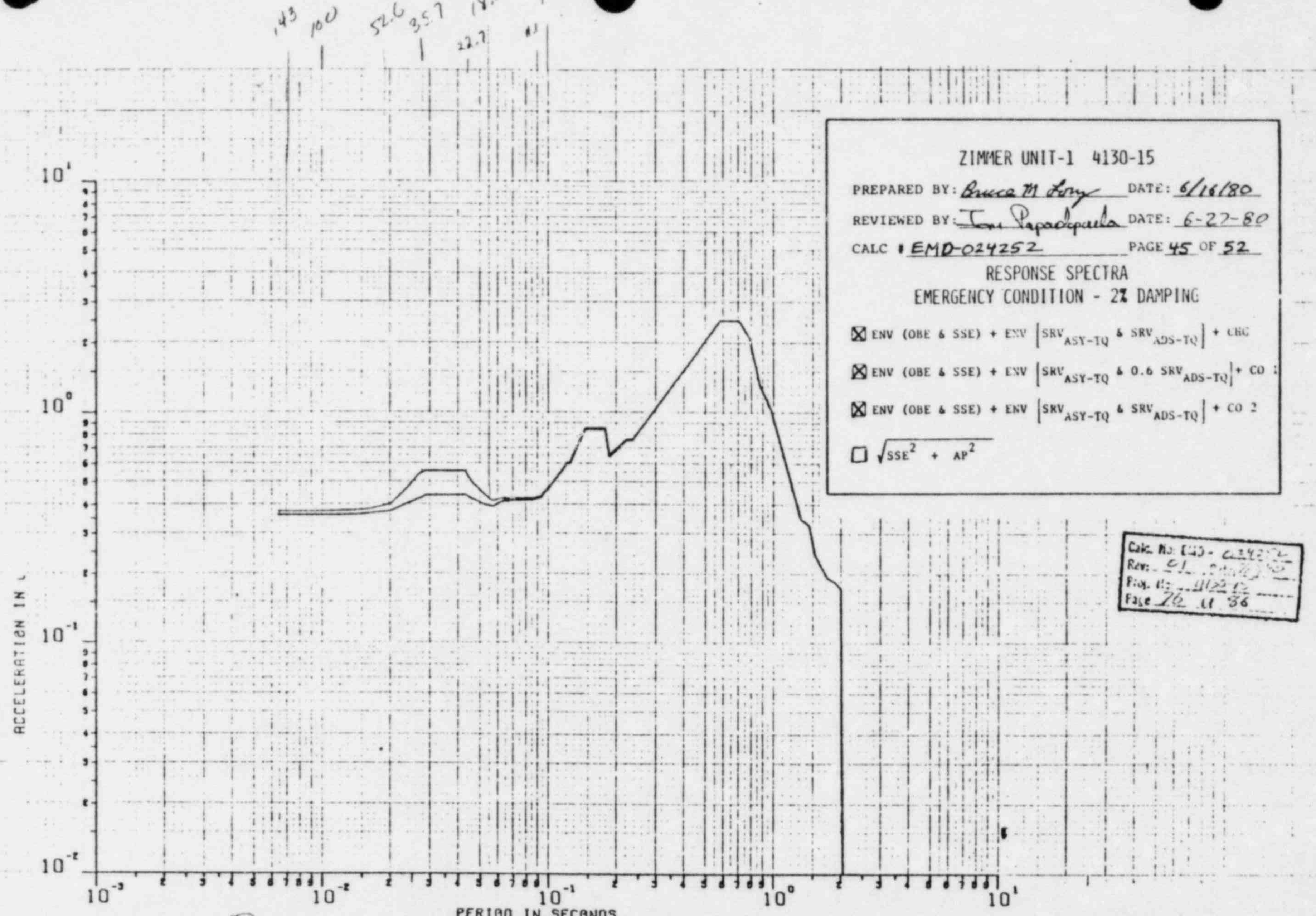
33.803.0551



HO-EW DF-2% ABSV(C2 + C3 +C4) ZIMMER REACTOR BLDG. ELEV. 593'-6" REV. 01

(X1) RUN ID 899 BML 06/11/80

15/26



HO-NS DF-2% ABSV(C2 + C3 +C4) ZIMMER REACTOR BLDG. ELEV. 593'-6" REV. 01

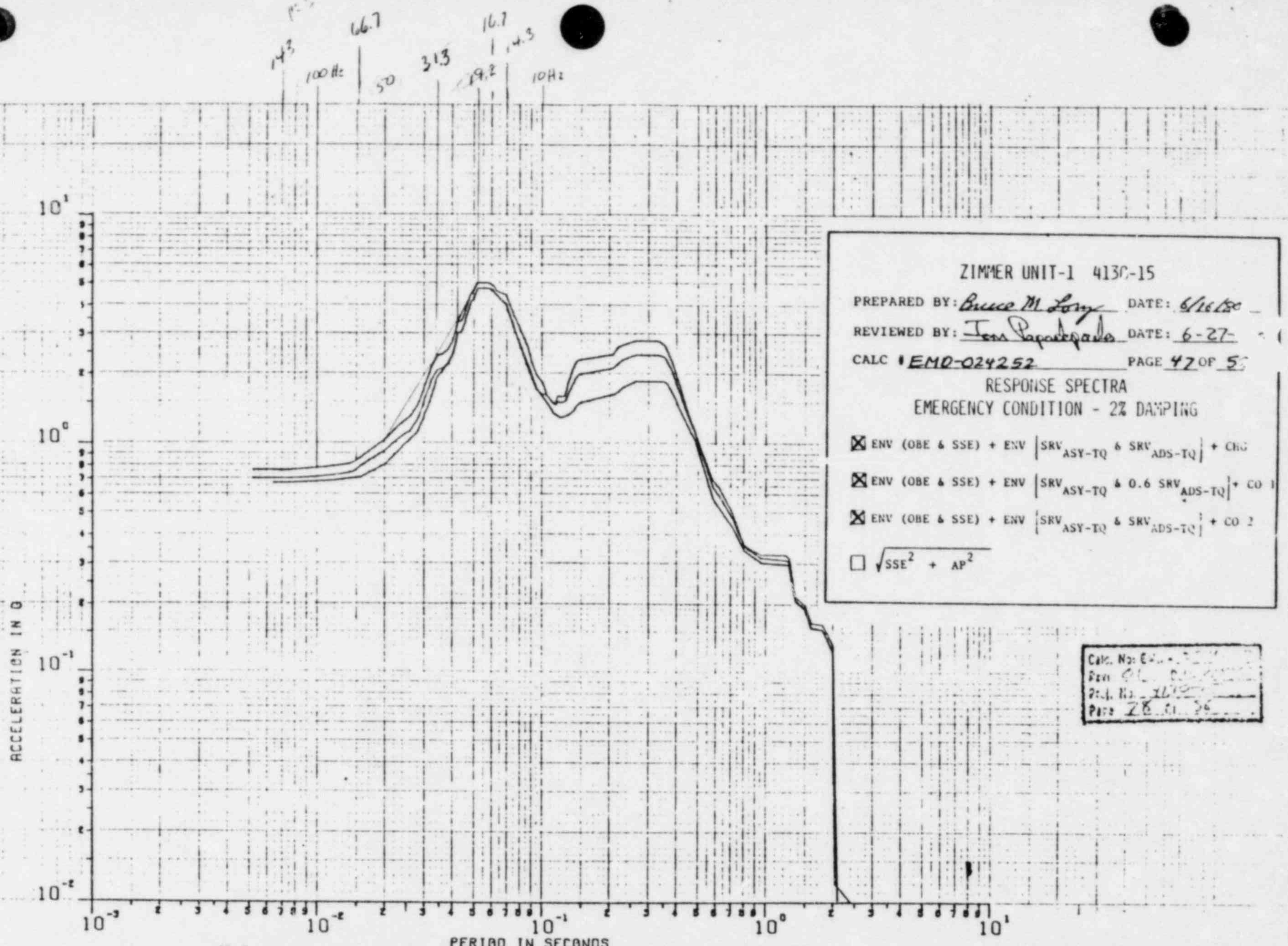
K+E KEUFFEL & ESSER CO.

RUN 1D 895 BML 06/15/80

(X2)

53.803.0551

16/26



VS-(VS) DF-2% ABSV(C2 + C3 +C4) ZIMMER REACTOR BLDG. ELEV. 593'-6'' REV. 01

K-E KEUFFEL&ESSER CO.

(X3) RUN ID 899 BML 06/16/80

17/26

STRESS CALCULATIONS
MAXIMUM STRESS IN COLUMNS

$P/A = 149$ psi
$V_2/KA = 122$ psi
$V_3/KA = 134$ psi
$M_2/I = 82$ psi
$M_3/I = 35$ psi

} AT BASE REF. ⑤

$$\frac{M_2 C}{I} = 82(33) = 2706 \text{ psi}$$

$$\frac{M_3 C}{I} = 35(9.13) = 320 \text{ psi}$$

COMBINED BENDING AND AXIAL

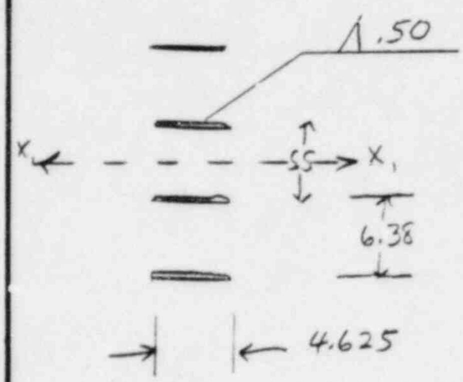
$2706 + 320 + 149 = 3179$ psi

COMBINED SHEAR

$122 + 134 = 256$ psi

YIELD = 31 KSI

WELDS AT BASE (NODE 1)

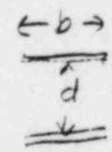


REACTIONS AT NODE 1

F_1	7.87	$(10)^3$ lbs	REF ③
F_2	8.62	"	
F_3	11.2	"	
M_1	2.55	10^5 in·lbs	
M_2	9.78	"	

ABOUT $X_1 - X_1$

$$I_u = \frac{bd^2}{2}$$ FOR TWO INSIDE OR OUTSIDE



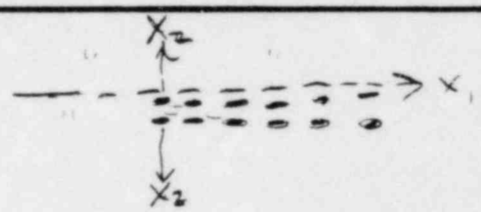
$$I_{u_1} + I_{u_2} = 4/2\left((5.5)^2 + (18.26)^2\right)$$ REF ① p. 17 (Dwg has larger values)

$$= 727 \ in^3$$

$$I_{u_{TOTAL}} = .707(.19)\,727 = 97.7$$

$$\sigma_{x_1} = \frac{Mc}{I} \quad \frac{2.55(10)^5/10\ (9.13)}{97.7} = 2383 \ psi$$

WELDS AT BASE (cont)



$$I_{x_2} \cong 8\left[5\frac{hd^3}{12} + A\left[6.625^2 + 13.25^2 + 19.9^2 + 26.5^2 + \frac{1}{2}32.5^2\right]\right]$$

$$= 5\left[\frac{.707(.19)(4)^3}{12}\right] + .707(.19)4\left[6.625^2 + 13.25^2 + 19.9^2 + 26.5^2 + \frac{1}{2}32.5^2\right]\Big]$$

$$= 8\left[5(.716) + .537[1846]\right]$$

$$= 7958 \text{ in}^4$$

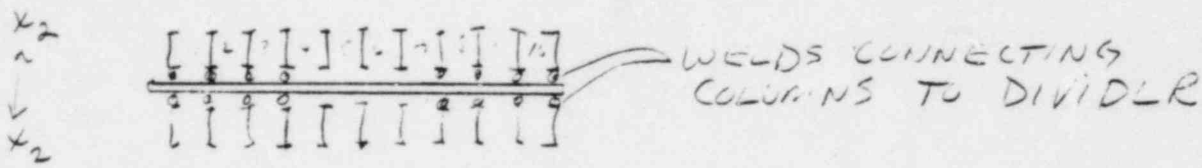
$$\sigma_{x_2} = \frac{9.78(10)^5(33)}{7958} = 4055 \text{ psi}$$

$$\tau_1 + \tau_2 = \frac{1370 + 8620}{40(4).707(.19)} = 767 \text{ psi} \quad \text{OK}$$

$$\sigma_{x_1} + \sigma_{x_2} = 4055 + 2383 = 6438 \text{ psi} \quad \text{OK}$$

... YIELD = 20,000 ... ref (2) p 17

WELDS AT DIVIDER (AT NODE 6)



$A_w = 22.7 \ in^2$ (Ref 2 p.13)

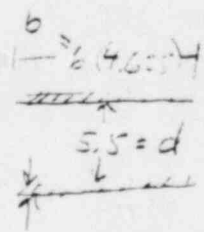
YIELD STRENGTH = 20,000 psi (Ref 2 p.13)

TOTAL FORCES = $F_{x_1} + F_{x_2} + F_{x_3}$ (CONSERVATIVE)

$7.47 + 6.75 + 5.65 = 19.87$ Kips (Element 5 Ref (3). Not spring loads, Spring loads not given by Dyna 4)

SHEAR STRESS = $\frac{19870}{22.7} = 875$ psi O.K. ✓

THESE WELDS DO NOT TAKE BENDING, HOWEVER THE BENDING STRESSES ARE CONSERVATIVELY INCLUDED HERE AS IF THESE WELDS HELD UPPER AND LOWER HALF OF RACK TOGETHER.



$\sigma_{x_1} = \frac{Mc}{I} = \frac{M}{2bdh(.707)}$ where

h = .25

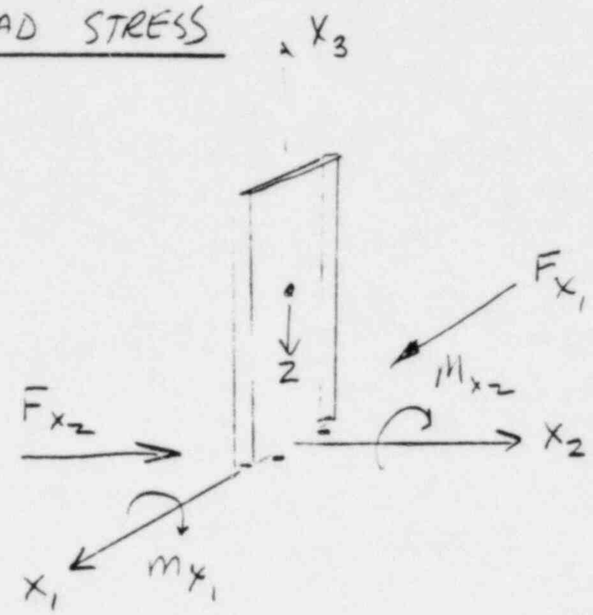
M = 1.98(10)^5

$= \frac{1.98(10)^5}{2(4.625)(6)(5.5)(.25)(.707)}$

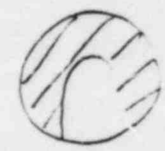
$= 3666$ psi

Revision	0					Page 21 of 26
Prepared By/Date	mpv 10/20/81					
Checked By/Date	[illegible] 10/20/81					

BOLT PAD STRESS



BOLT PAD



Area = 1.29 sq in
Ref ② p 20

RESULTANT FORCE ON ONE BOLT (TENSION):

$$R = \left[M_{x_2}/2r_2 + M_{x_1}/2r_1 \right] \frac{1}{2} + \left[\overbrace{F_3 - mg}^{-Z} \right] \frac{1}{4} + \text{Pretorque}$$

Where
$M_{x_2} = 9.783\,(10)^5$ in-lb
$M_{x_2} = 2.546\,(10)^5$
$r_2 \cong 21''$ (min) — Ref ⑥ dwg 762E210
$r_1 = 10.75''$ — Ref ② p 10
$F_3 = 1.124\ 10^4$ lbs
$mg = 1.68\ 10^4$
Pretorque = 4800 lbs — ref ② 20

$$R = [(9.783/21) + (2.546/10.75)]\,10^5(.25) + (1.124 - 1.68)\,10^4(.25) + 4800 = 2.0977(10)^4 \text{ lbs}$$

nutech
San Jose, California

Project: Wm. H. Zimmer Nuclear Power Station — File No. 33.803.055
Owner: Cincinnati Gas and Electric Co.
Client: Cincinnati Gas and Electric Co.

WELDS AT DIVIDER (cont)

$A_w = .707\, h\, d = .707(.25)\, 4.625$ Ref 1. 13

ABOUT X_2 AXIS

$$I_{x_2} \cong 8\left[3\tfrac{1}{2}\frac{hd^3}{12} + .707hd\left[13.25^2 + 19.9^2 + 26.5^2 + \tfrac{1}{2}\,32.5^2\right]\right]$$

$$= 8\left[\frac{3.5(.707).25(4.625)^3}{12} + .707(.25)\,4.625\left[1802\right]\right]$$

$$= 11825$$

$$\sigma_{x_2} = \frac{Mc}{I} = \frac{1.7(10)^5\, 32}{11525} = 475 \text{ psi}$$

$$\sigma_{x_1} + \sigma_{x_2} = 475 + 3666 = 4141 \text{ psi}$$

ALLOWABLE - 20,000 psi ref(2) p13

Revision	0					Page 22 of 26
Prepared By/Date	MPV 10/22/...					
Checked By/Date	... 10/20/81					

BOLT PAD STRESS (cont)

$$\sigma = R/A$$

$$= 20977/1.29 = 16{,}262 \text{ psi}$$ ✓

$\sigma_{min\ tensile} = 23{,}000$ } Ref ② p 20

$\sigma_{min\ yield} = 16\,000$

Revision	0					Page 24 of 26
Prepared By/Date	MPV 10/20/81					
Checked By/Date	[illegible] 10/20/81					

COMPRESSION OF BASE CASTING AT SUPPORTS

[illegible] MAX [illegible] FORCE [illegible] BASE EQUAL TO FORCE CALCULATED [illegible] PR[illegible] [illegible] CALC

$$R = [M_2/r_2 + M_1/r_1]\tfrac{1}{4} + [F_3 + mg]\tfrac{1}{4} + \text{PRETORQUE}$$

AREA OF SUPPORT = 5.485 in² [illegible] p35

$$R = \left[\frac{9.783(10)^5}{2(21)} + \frac{2.546(10)^5}{2(10.75)}\right]\frac{1}{2} + \frac{1}{4}(1.08 - 1.12)10^4 + 4800$$

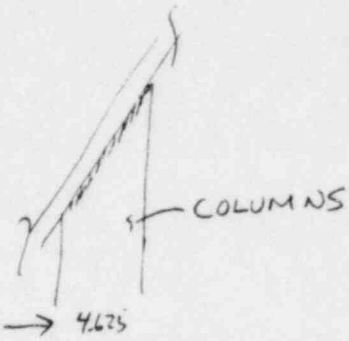
$$= 2.937(10)^4$$

$$\sigma = R/A = \frac{2.937(10)^4}{5.485} = 5{,}354 \text{ psi}$$

Allowable = 21,000 psi Ref ② p35

Revision	0					Page 25
Prepared By/Date	MPV 10/20/81					of 26
Checked By/Date	[illegible] 10/20/81					

WELDS ON DIAGONAL BRACING



ASSUME 2.5" LENGTH WELD BOTH SIDES OF BRACE

2 PAIRS OF OUTER CROSS BRACING

5 WELDS / BRACE @ SIDE

4 BRACES BETWEEN ROWS OF FUEL CELLS

4 WELDS / BRACE @ SIDE

NUMBER OF WELDS BETWEEN NODES 1-5

$= [4(5) + 4(4)]\, 2 = 72$ WELDS

$AREA/WELD = .707(.25)\, 2.5 = .44\ in^2$

$TOTAL\ AREA = .44(72) = 31.815\ in^2$

$P = \Sigma F_{x_1} + \Sigma F_{x_2} = 35050 + 29710 = 64760$

$\tau_{avg} = \frac{64760}{31.815} = 2035\ psi$

$\tau_{allowable} = 5600\ psi$ Ref ① p18

Revision	0				
Prepared By/Date	MPV 10/20/81				
Checked By/Date	[illegible] 10/20/81				

Attachment 10

33.303...

Z I -

GENERAL ELECTRIC

DESIGN RECORD FILE

ASSIGNMENT SHEET

1.0 IDENTIFICATION

DRF FILE NO. ______ ASSIGNMENT DATE ______

SUBJECT Stress Analysis - Spent Fuel Storage Rack - Conc. 2

2.0 ASSIGNMENT RESPONSIBILITY

RESPONSIBLE ENGINEER E. B. Farr COMPONENT NO. 139

3.0 RECORDS STORAGE

MICROFILM DATE ______

DESIGN ABSTRACT

SD-005 (3/76)

GENERAL ELECTRIC

DESIGN RECORD FILE

TABLE OF CONTENTS

SUBJECT	INDEX NO	DATE ENTERED	AUTHOR	REMARKS

SD-006 (3/76)

GENERAL ELECTRIC CO.
Nuclear Energy Division
ENGINEERING CALCULATION SHEET

ZIH

DATE 21 OCTOBER 1977

SHOP ORDER NO. STRESS ANALYSIS — ZIMMER FSAR

SUBJECT DESIGN VERIFICATION NOTES COVER SHEET BY ROBERT B. FARR SHEET 1 OF F

1. Design of: SPENT FUEL STORAGE RACKS MPL# F16/F22 - E002
System, Equipment, Component

2. Input to: ☒ Initial Design ☐ Design Change

SPENT FUEL STORAGE RACK-762E210 REV.#5 ECN# NONE
Title, Number and Current Reivison Number of Document

ERM# NONE

☐ Specification ☐ Drawing Type: ___________

3. Product Line: ☒ 67, ☒ 69, ☐ BWR 6, ☒ Other as applicable

4. Identification of specific design and engineering data sources.
PER CALCULATION SHEETS

5. Assumptions made for this design:
PER CALCULATION SHEETS

6. Qaulity, safety, functional requirements on this design:
PER CALCULATION SHEETS

7. Acceptance criteria specified in:
PER CALCULATION SHEETS

8. Interfacing design units within NED:
N/A

9. Does this change require new or revised calculations ☒ Yes ☐ No

Organization responsible for calculations: REACTOR SERVICING AND INSTRUMENTATION EQUIPT DESIGN UNIT #139

10. Manager's designation of verification method(s), and evidence of verification:

Design Review by: 21 Oct. 1977 [signature] 139
Date Reviewing Engr.Sig. Unit #

11. Responsible Design Engineer: Robt B. Farr 10-21-77

Manager's Acceptance: [signature] 10-24-77

FORM NO. NED-67

ZIMMER
Stress Analysis
Spent Fuel Storage Racks

I.) GENERAL

1.) This analysis is for the spent fuel r ks for Zimmer.

2.) Various loads to be considered are:

a) Horizontal seismic and SRV.

b) Vertical seismic, SRV, and chugging.

(Note: Horizontal "chugging", vent clearing and vertical vent clearing are not applicable. See # 386HA625 and letter Farr/Zemer October 22, 1977, see Appendix # 6).

II.) APPLICABLE DOCUMENTS

1.) Load combination and acceptance criteria # 386HA625.

2.) Sargent and Lundy calculation No. SDD - EMD - 030 dated August 16, 1976, for Project 4130-15.

3.) Aluminum standards and data 1972-1973.

4.) Kaiser Aluminum Welding 1st Edition.

5.) DRF - 139 - F16 - E002 -B81.

6.) Roark 5th Edition.

7.) G. E. Drawings:

a) End channel # 117C2001

b) Tube # 117C2000

c) Guide # 729E475

d) Column # 919D992

e) Divider # 112C3600

f) Base # 922D255

g) Arrangement # 761E957 Rev. 3

h) Spent fuel rack # 762E210

III.) BASIC DATA AND ASSUMPTIONS

1.) Upon examination of the racks in a 'free standing' condition it becomes evident that the weakest section presented is that section which resists a horizontally applied load directly transverse to the width of the rack.

2.) Racks will be laterally supported by a continuous structural member extending the full width of the rack at an elevation 9'10" from the base of the rack.

3.) Loads applied in any tri-axial direction are considered maximum, and are the resolved loads of ANY SRSS loads.

4.) Allowable stresses for 6061-T6 will be in accordance with 386HA625.

5.) All loads are to be considered as static "g" load equivalents acting thru a point that will provide the most conservative results.

IV.) CALCULATIONS

1.) Spent fuel racks will be considered as a large fabricated beam with horizontal loading on a ~~cantelubra~~ CANTILEVER beam with ~~a~~ AN OUTBOARD support, AS SHOWN IN FIG. 1-4- BELOW.

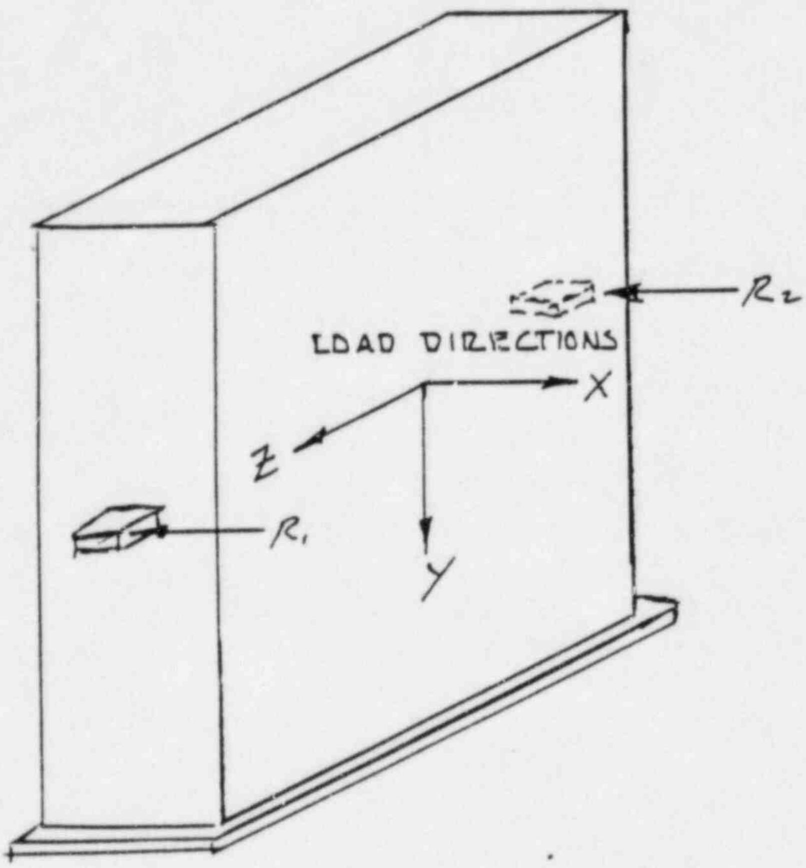


FIG. 1

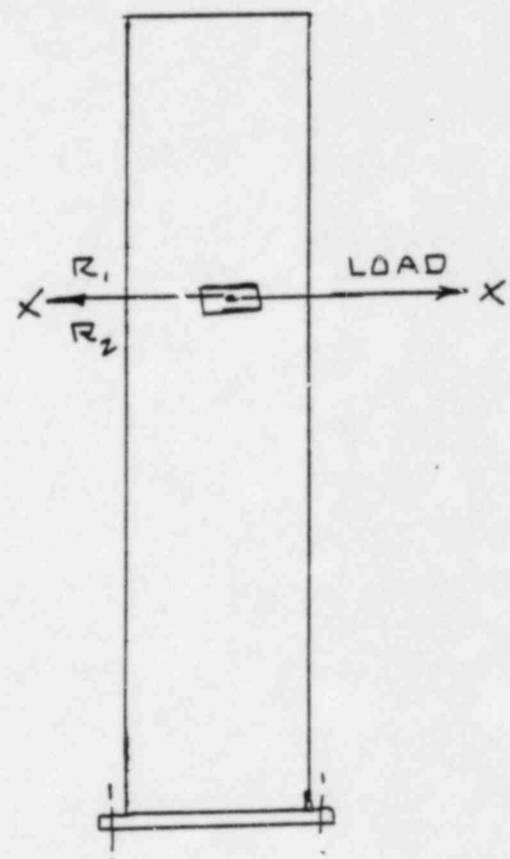


FIG. 2 (X-Y Plane)

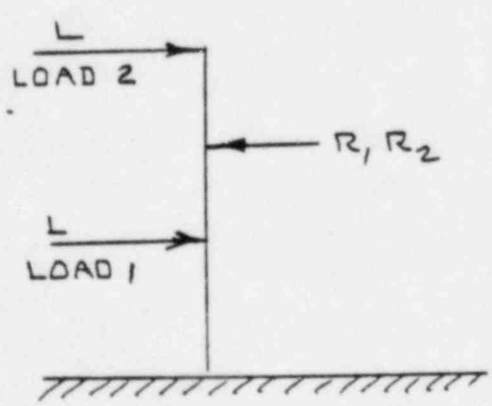


FIG. 3

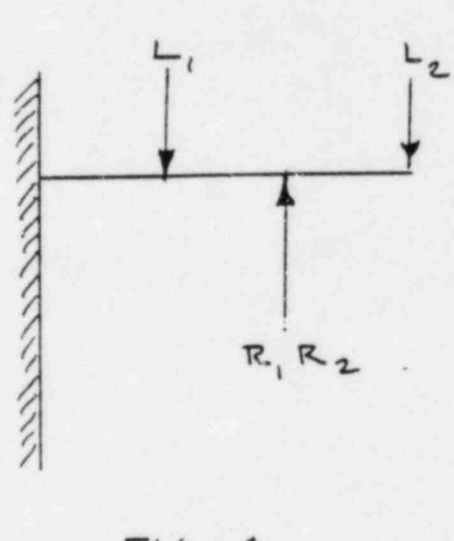
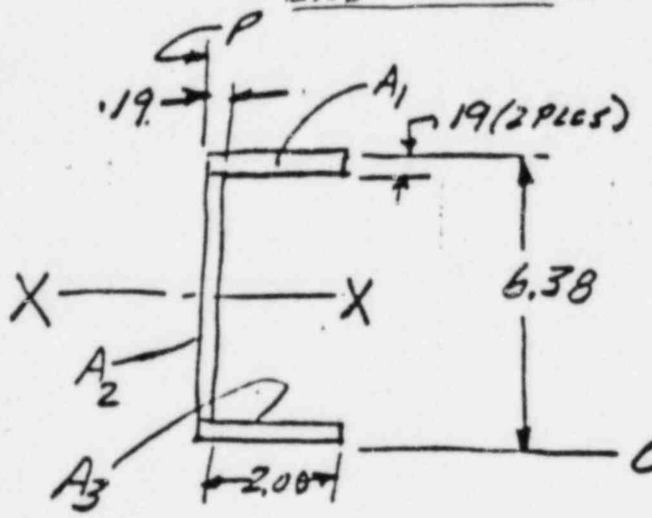


FIG. 4
(FIG 3 ROTATED 90° CW)

2.) The problem can be resolved into two separate beam considerations 1. beam, with one end fixed and other end support is a simple support and, 2. cantilever beam. It is believed that this is a simple but conservative approach. This is especially so when the loads are considered concentrated at the mid-point, L_1, in the one case, and at the end of the beam, L_2, in the case of the cantilever beam analysis.

3.) BEAM SECTION ANALYSIS (SIMULATED BEAM) END CHANNEL:



Mat'l: 6063 -T5 Al. Extrusion

Density: .099 lbs/cu.in.

Length = 168.00 inches

Areas:

A_{1+3} = (2.19)(.19)(2) = .83 sq.in. A_1 = .415

A_2 = (6)(.19) = 1.14 sq.in. A_3 = .415

Total - 1.97 sq.in.

Weight, (1.97)(168)(.099) = 32.76 lbs.

$\therefore\ \bar{y}$ = Neutral axis = EMo

$1.97\,\bar{y} = \frac{(.83)}{(2)}(6.285) + (1.14)(3.19) + \frac{(.83)}{(2)}(.095) = 2.608 + 3.636 + .039$

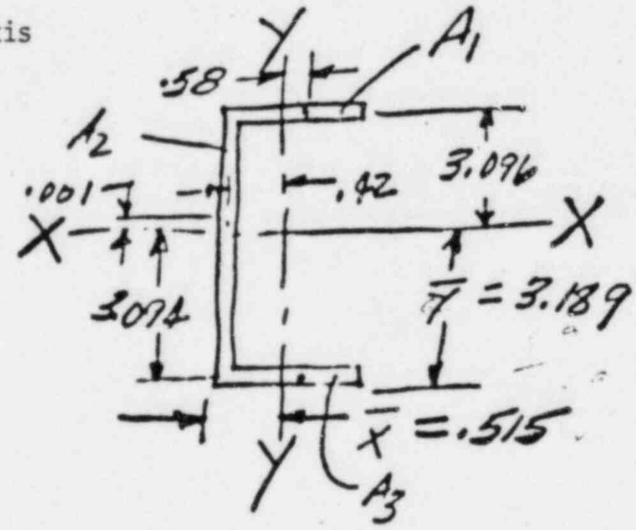
$1.97\,\bar{y} = 6.283 \quad \therefore\ \bar{y} = \underline{\underline{3.189}}$

$\therefore\ \bar{x}$ = Neutral axis = EMp

$1.97\,\bar{x} = \frac{(.83)}{(2)}(1.095) + (1.14)(.095) + \frac{(.83)}{(2)}(1.095) = .454 + .108 + .454$

$1.97\,\bar{x} = 1.016 \quad \therefore\ \bar{x} = \underline{\underline{.515}}$

. = Element N_1 Axis



Moment of inertia (Ix) = Ic +Ad^2 = Transfer formula

Note: Symbols defined on page 3.

$\therefore\ I_{x_{A_1}} = \frac{(2.19)(.19)^3}{12} + (.83)(3.096)^2 = .00125 + 7.955 = 7.956$ (handwritten corrections: (.83) → .415; 7.955 → 3.978; 7.956 → 3.979)

$I_{x_{A_2}} = \frac{(.19)(6)^3}{12} + (1.14)(.001)^2 = 3.42 + 0 = 3.420$

$I_{x_{A_3}} = \frac{(2.19)(.19)^3}{12} + (.83)(3.094)^2 = .00125 + 7.945 = 7.946$ (handwritten corrections: (.83) → .415; 7.945 → 3.978; 7.946 → 3.979)

$EI_x = 19.322\ in^4$ (handwritten correction: 11.378)

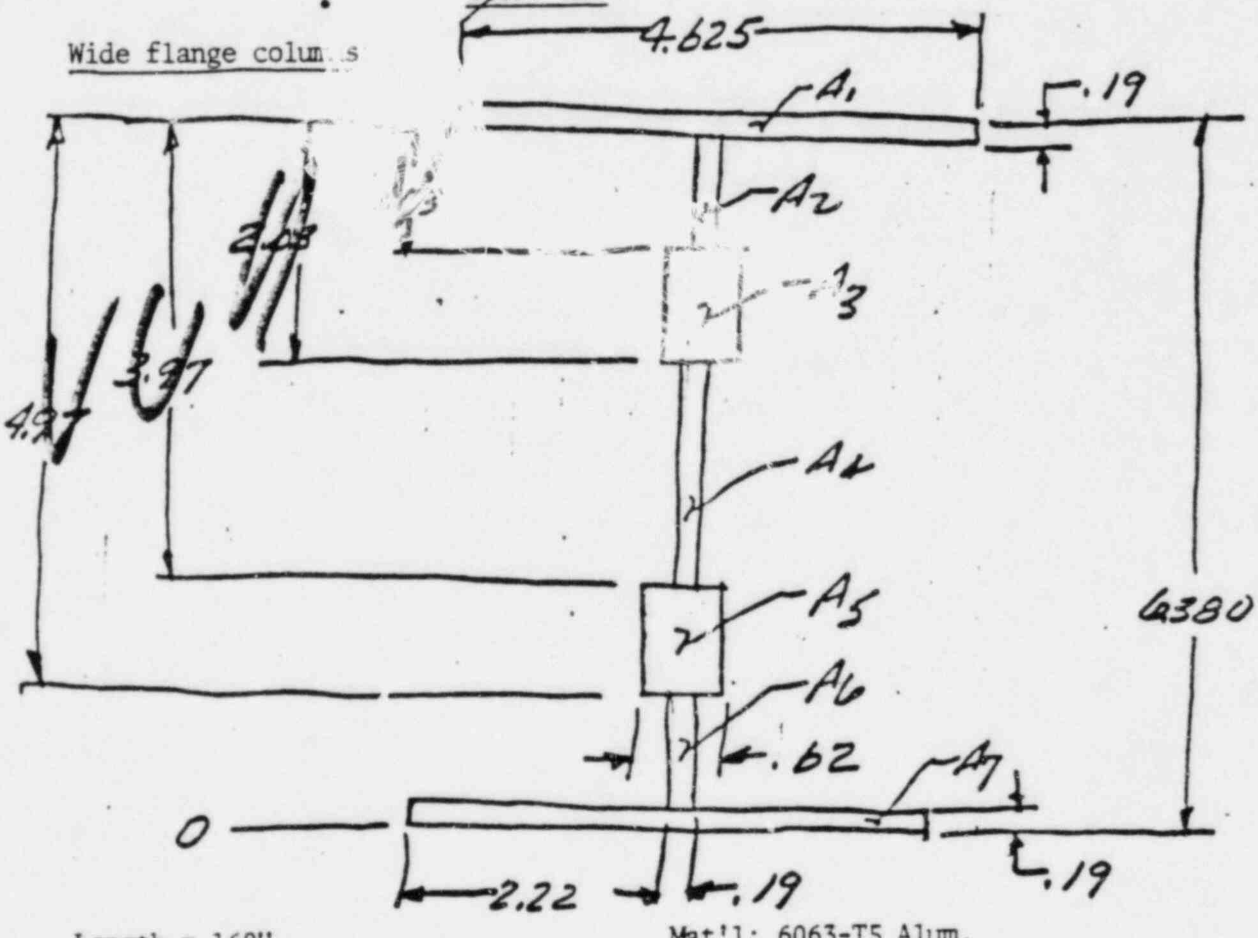
$I_{y_{A_1}} = \frac{(.19)(2.19)^3}{12} + (.83)(.58)^2 = .166 + .279 = .445$ (handwritten: .416; .31 mev)

$I_{y_{A_2}} = \frac{(6)(.19)^3}{12} + (1.14)(.42)^2 = .00343 + .201 = .204$

$I_{y_{A_3}} = I_{y_{A_1}} = .445$ (handwritten: .31)

$\therefore = 1.094 \text{ in}^4$ (handwritten: .817 in⁴ mev)

Wide flange columns



Length = 168"

Mat'l: 6063-T5 Alum.

Density = .099 lbs/cu.in.

<u>Areas</u>:

A_1 = (4.625)(.19) = . .878 sq. in.

A_2 = (1.03)(.19) = .196

A_3 = (1.00)(.62) = .620

A_4 = (1.94)(.19) = .368

A_5 = (1.00)(.62) = .620

A_6 = (1.03)(.19) = .196

A_7 = (4.625)(.19) = .878

Total = 3.756 sq. in.

Weight = (3.756)(168)(.099) = 62.4[illegible]9 lbs.

$\therefore \bar{y}$ = Neutral axis = ΣMo

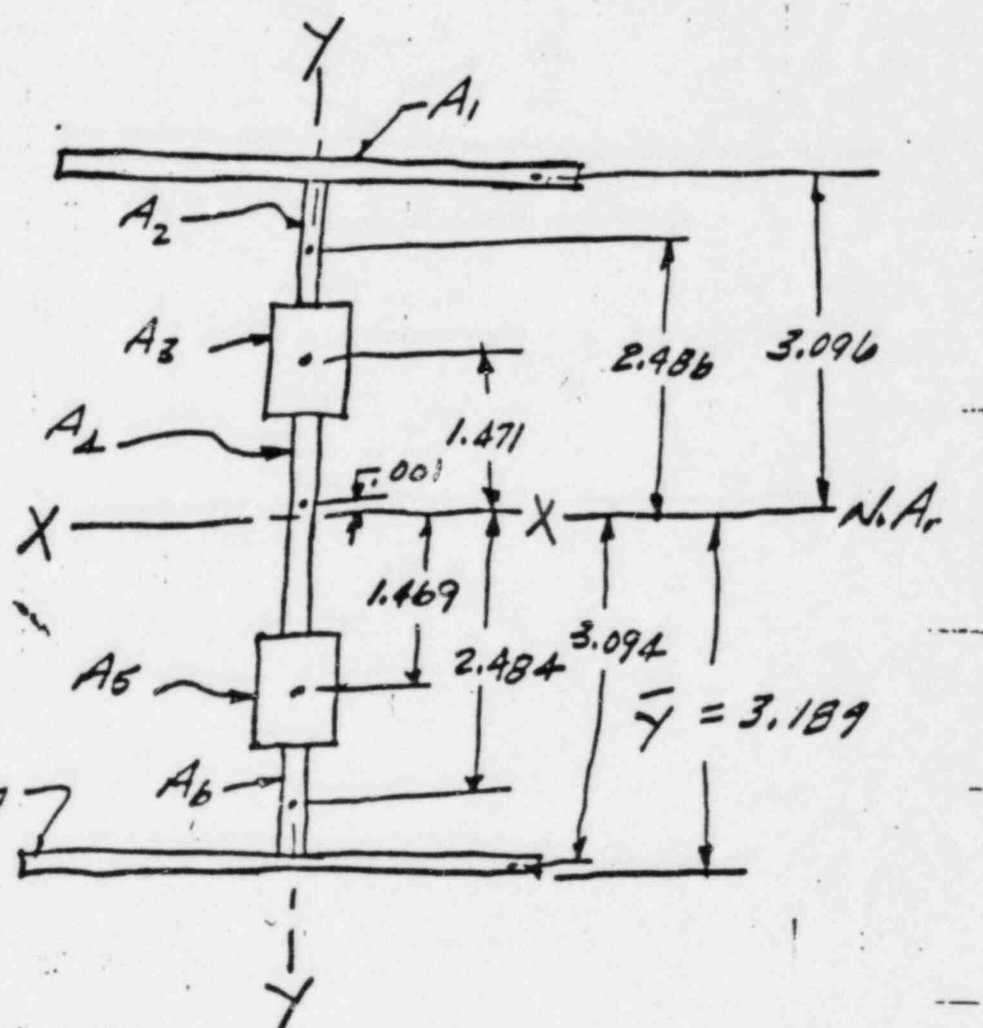
$3.756\ \bar{y} = (.878)(6.285) + (.196)(5.675) + (.62)(4.66) + (.368)(3.19)$

$+ (.62)(1.72) + (.196)(.705) + (.878)(.095)$

$3.756\ \bar{y} = 5.518 + 1.112 + 2.889 + 1.173 + 1.066 + .138 + .083$

$3.756\ \bar{y} = 11.979 \qquad \therefore \bar{y} = \frac{11.979}{3.756} = \underline{\underline{3.189''}}$

. = Element N. Axis



Moment of inertia (I_x)

Using transfer formula = $I_x = I_c + A_d^2$

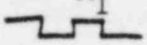
Composite I_x = E of $I_x 0$ + All areas:

$I_c = I_x$ of area in which $I_x = \frac{bh^3}{12}$

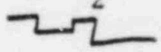
A = Area

d = ⊥ Distance between the parallel axes.

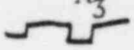
$$I_{x_{A_1}} = \frac{(4.625)(.19)^3}{12} + (.878)(3.096)^2 = .0026 + 8.416 = \underline{8.418}$$



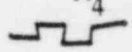
$$I_{x_{A_2}} = \frac{(.19)(1.03)^3}{12} + (.196)(2.486)^2 = .017 + 1.211 = \underline{1.228}$$



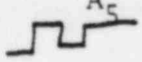
$$I_{x_{A_3}} = \frac{(.62)(1)^3}{12} + (.62)(1.471)^2 = .052 + 1.341 = \underline{1.393}$$



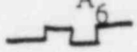
$$I_{x_{A_4}} = \frac{(.19)(1.94)^3}{12} + (.368)(.001)^2 = .116 + 0 = \underline{.116}$$



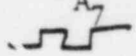
$$I_{x_{A_5}} = \frac{(.62)(1)^3}{12} + (.62)(1.469)^2 = .052 + 1.338 = \underline{1.390}$$



$$I_{x_{A_6}} = \frac{(.19)(1.03)^3}{12} + (.196)(2.484)^2 = .017 + 1.209 = \underline{1.226}$$

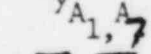


$$I_{x_{A_7}} = \frac{(4.625)(.19)^3}{12} + (.878)(3.094)^2 = .0026 + 8.405 = \underline{8.407}$$



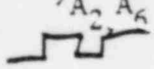
$$EI_x = \underline{22.18 \text{ in}^4}$$

$$I_{y_{A_1, A_7}} = (4) \quad \frac{(.19)(2.312)^3}{12} + (.19)(2.312)(1.156)^2 \quad = (4) \quad .196 + .587$$



$$= \underline{3.132}$$

$$I_{y_{A_2, A_6}} = (4) \quad \frac{(1.03)(.095)^3}{12} + (.095)(1.03)(.047)^2 \quad = (4) \quad .000074 + 0$$



= neglect

$$I_{y_{A_1,A_7}} = (4)\left[\frac{(.19)(2.312)^3}{12} + (.19)(2.312)(1.156)^2\right] = (4)\left[.196 + .587\right] = \underline{3.132}$$

DUPLICATION OF PREVIOUS PAGE

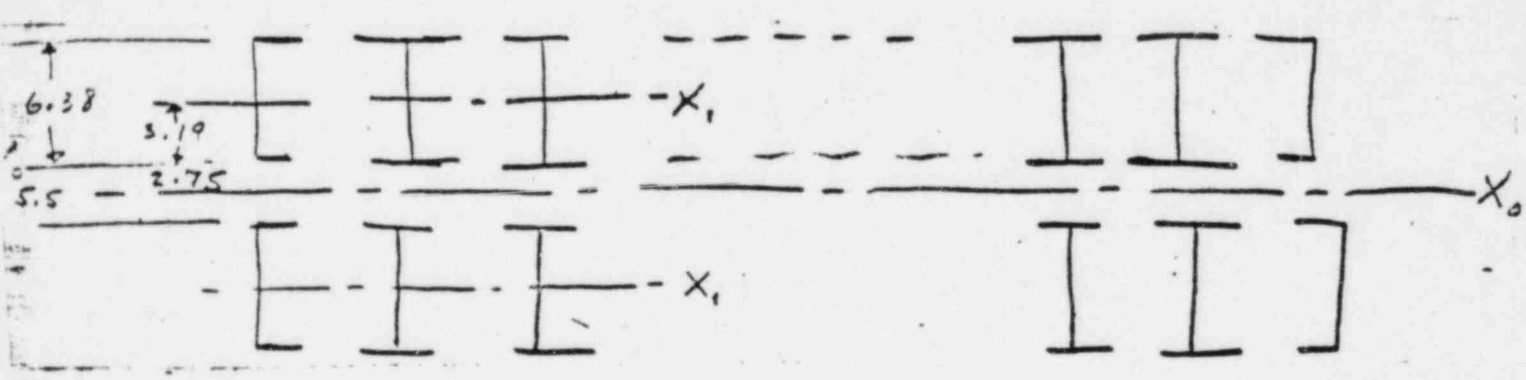
$$I_{y_{A_2,A_6}} = (4)\left[\frac{(1.03)(.095)^3}{12} + (.095)(1.03)(.047)^2\right] = (4)\left[.00074\right] = \text{Neglect}$$

DUPLICATION OF PREVIOUS PAGE

$$I_{y_{A_3,A_5}} = (4)\left[\frac{(1)(.31)^3}{12} + (.31)(1)(.155)^2\right] = (4)\left[.0025 + .007\right] = \underline{.038}$$

$$I_{y_{A_4}} = (2)\left[\frac{(1.94)(.095)^3}{12} + (.095)(1.94)(.047)^2\right] = (2)\left[.00014 + 00041\right] = \underline{.0011}$$

$$I_y = \underline{\underline{3.17}}\ \text{in}^4$$



End channels

$Ix_1 = \sout{19.322}$ 11.378 d = 3.19 + 2.75 = 5.94"

$\Sigma x_o = Ix_1 + Ad^2$

$$Ix_1 = \left[\sout{19.322}\ 11.378 + 1.97\ (5.94)^2\right] \times 2 = \sout{177.66}\ 161.77 \text{ (1 pair)}$$

Wide flange column

$Ix_j = 22.18$

$Ix_o = Ix_j + Ad^2$

$Ix_o = \left[22.18 + 3.756\ (5.94)^2\right] \times 2 = \underline{\underline{309.41}}$

Total Ix_o

$Ix_o = 2\ Ix_1 + 9\ Ix_2$ — 2 pairs end channels

$Ix_o = 2(\sout{177.66}\ 161.77) + 9\ (309.41)$ — 9 ~~each~~ PAIRS W.F. columns

$Ix_o = \sout{355}\ 323.5 + 2785$

$Ix_o = \underline{\underline{\sout{3,140}\ 3108\ in^4}}$

Note: Exterior and interior box beams are not considered in the analysis, thus the results are very conservative.

4.) Applied loadings

Determine approximate elevation of C.G. of spent fuel with reference to refueling floor and relate this to the Seismic, SRV, and LOCA curves provided by Sargent and Lundy. Appropriate "g" accelerations can be obtained by assuming those values at elevations very close to C.G. of spent fuel, or, by interpolation.

Seismic (See appendices # 1 and 2)

Refueling floor	= 627'9"
Floor of pool	= 588'0"
Height of C.G.	+ 8'0"
Elevation @ rack C.G.	= 596'0"

Mode at elevation 593'6" is closest to rack C.G.

First natural frequency of rack = 258.1 Hz (see Reference # 5)

Seismic "g" acceleration @ 258.1 Hz and N-S = .34 (Racks are oriented in rows extending N-S)

Seismic "g" acceleration @ 258.1 Hz and E-W = .36

Hydrodynamic weight of fuel element = 840#

Hydrodynamic weight of rack = 2020# (see Reference # 5)

HIGHEST ~~Height~~ "g" loading is in the E-W direction and is .36 g horizontally

Load generated Seismically = .36 (~~840 x 2020~~) = 6775# ✓ — (840x20 + 2020) OMF

SRV Loading (see Appendix # 3)

Refueling floor = 627'9"

Floor or pool = 588'

+ 8' (PROX. ~~prior~~ to C.G. rack)

596

Node 601'7" is closest to C.G. rack elevation. SRV at this elevation

(At first natural frequency = 258.1 Hz

"g" load this point = .05 "g"

load generated = .05 x (840 x 20 + 2020) = 941#

LOCA loads do not apply to spent fuel storage racks for Zimmer per CONVERSATION Farr/de la Fuente 10/14/77 (see Appendix # 6).

5.) Total loading (horizontal maximum)

$$= 0 + \sqrt{(\text{scram})^2 + (\text{SRV})^2}$$

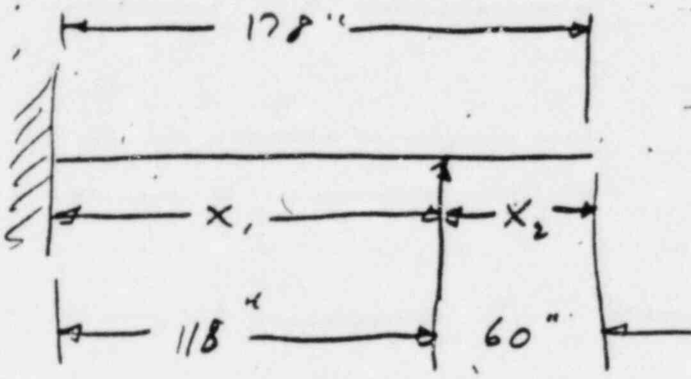
$$= \sqrt{(6775)^2 + (941)^2}$$

$$= \sqrt{45{,}900{,}625 + 885{,}481}$$

$$= \sqrt{46{,}786{,}106}$$

$$= 6840\#$$

6.) Application of load to simulated beam



Load per inch = $\frac{6840}{178}$ = 38.426#/in

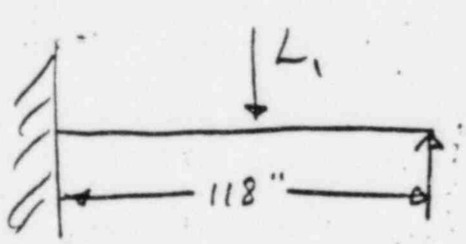
Load beam X_1 = 38.426 x 118 = 4534.268#

Load beam X_2 = 38.426 x 60 = 2305.56#

6839.828

Use 6840#

7.) MOMENTS of both simulated beams



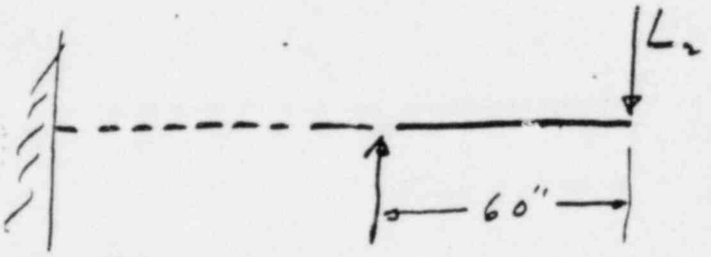
L_1 = 4534#

Beam X_1

Load assumed conservative in the interest of conservatism.

$$M = \frac{FL}{4} = \frac{4534 \times 118}{4} = \frac{535012}{4}$$

M = <u>133,753</u> lbs. in.



L_2 = ~~941~~ 2305 ?

BEAM X2

Load assumed concentrated at the end in the interest of conservatism.

$M = FL = $ ~~941~~ 2305 x 60 = ~~56460~~ 138300

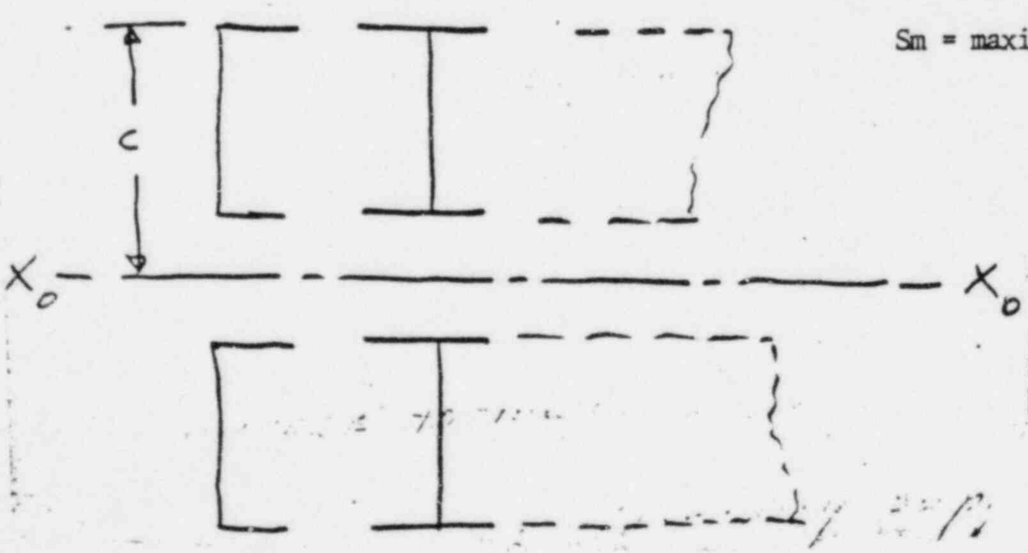
M = ~~56460~~ 138300 lbs. in.

8.) <u>Stresses (maximum outer fiber) both simulated beams</u>

Ix_o = ~~3140~~ 3108

C = 6.38 + 2.75 = 9.13

Sm = maximum stress



For beam X_1

$S_m = \frac{MC}{I} = \frac{133,753 \times 9.13}{3140 \text{ (struck; } 3108)} = \frac{1,221,165}{3140 \text{ (struck; } 3108)}$

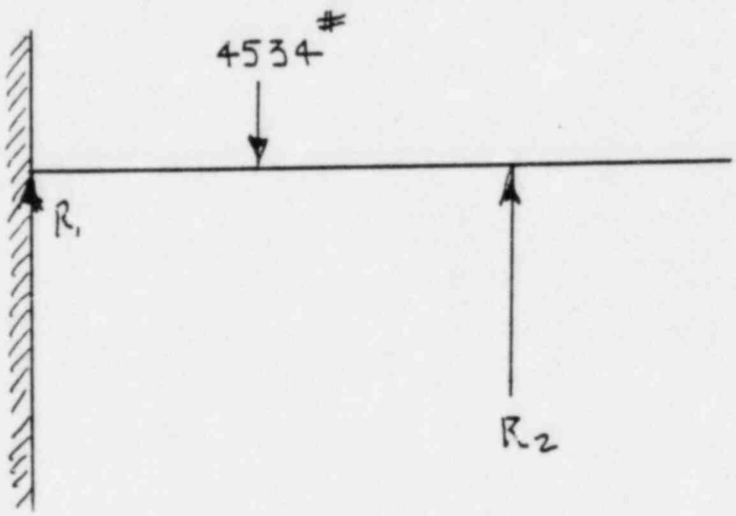
$S_m = 389\#/in^2$ (corrected: 392)

For beam ~~X2~~ X_2

$S_m = \frac{MC}{I} = \frac{56,460 \text{ (struck; } 138300) \times 9.13}{3140 \text{ (struck; } 3108)} = \frac{515,480 \text{ (struck; } 1262679)}{3140 \text{ (struck; } 3108)}$ ~~~

$S_m = 164\#/in^2$ (struck; 166, 406)

9.) Base weld in shear (HORIZ)

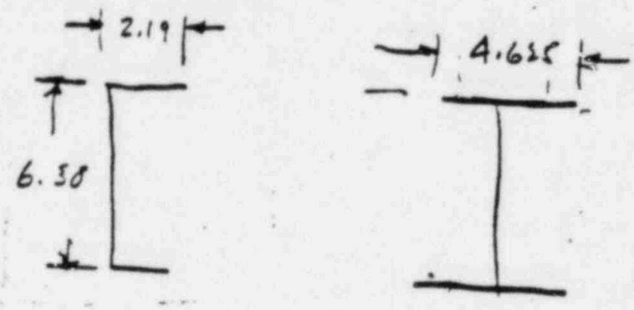


$R_1 = \frac{4534}{2} = 2267\#$

1/4" welds

Weld [= 4(2.19 + 2.19 + 6.58)

= 43.04"



Weld I = 18(4.625 + 4.625)

= 166.5"

Total 1/4" weld = 166.5 + 43 = 209.5"

Weld shear area = .25 x .707 x 209.5 = 37.029 in^2

Stress applied = $\frac{2267}{37.029}$ = 61.22#/in^2

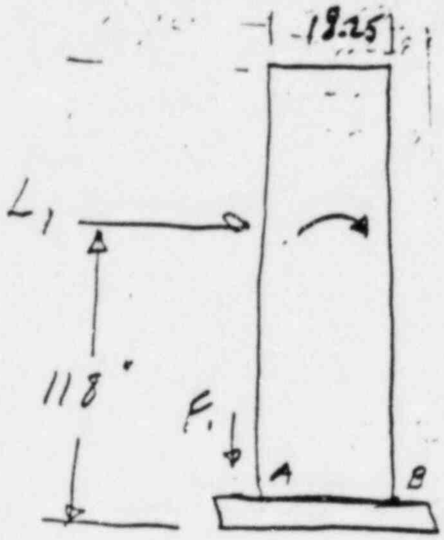
10) Base welds in vertical shear

Note upward vertical seismic will not be considered due to the low magnitude of the vertical upward "g" response. VERTICAL SEISMIC = .41"g" (LESS THAN 1"g"). Upward vertical SRV will not be considered due to low magnitude (Reference Sargent and Lundy, page 73) = .07"g" (less THAN .1 g)

Assume that rack is not restrained by seismic bracing and is IN A FREE standing condition.

A-B = 6.375 + 6.375 + 5.5 = 18.25"

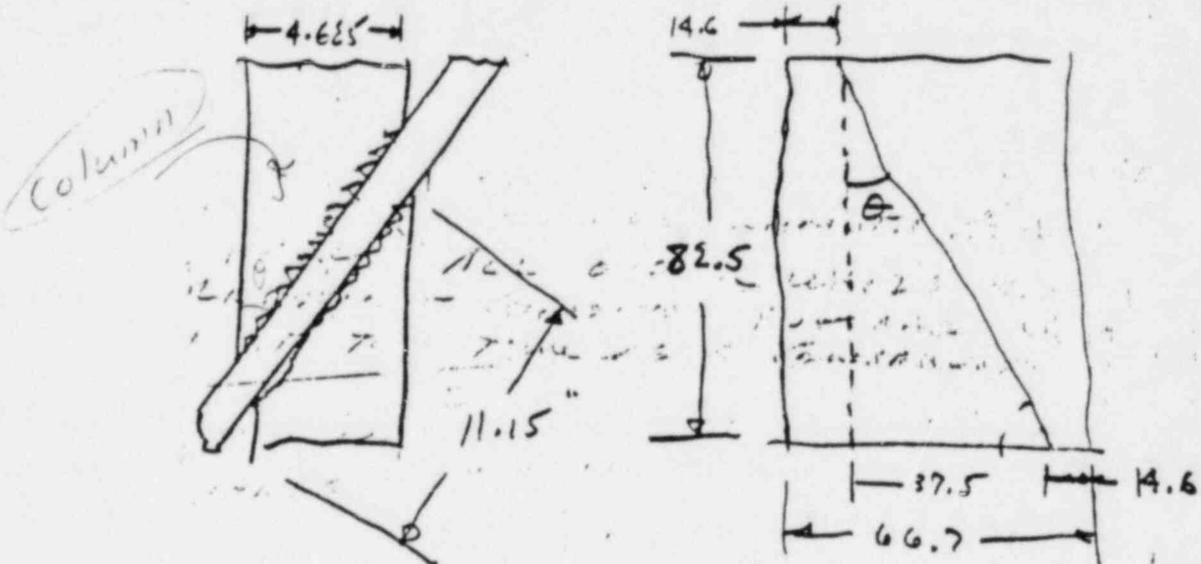
L = 6840#



~~Also assume that~~ THE load WHICH ~~extends~~ EXERTS its force thru the point at which the seismic bracing would normally contact THE ~~entire~~ rack, will tend to rotate THE ENTIRE about point "B" with ~~entire~~ ~~restraining force considered TO BE applied at point~~ "A" for full length horizontal along the base. All other WELDS enter into the restraint condition but are not considered at this time as a conservative approach.

11.) Welds on diagonal bracing

Consider one side only and only the full length bracing.



$\tan \theta = \frac{37.5}{82.5} = .454545$

$\theta = 24 \frac{1}{2}°$ prox

$\sin \theta = \frac{\text{side opp.}}{\text{Hyp.}}$

$\text{Hyp.} = \frac{4.625}{.41469} = 11.15''$

Examination of Dwg. indicates that this weld occurs on 5 columns.

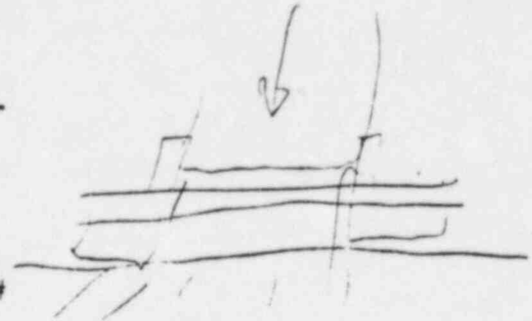
Length of weld = (11.15 x 2) x 5 = 111.5"

Area of weld = .707 x .25 x 111.5 = 19.7 in^2

Applied stress = $389\#/\text{in}^2$

Weld allowable F_5 = prox. .40 Sy = $5600\ \#\text{in}^2$

Weld is adequate.



$$L_1 = \frac{6840 \times 118}{18.25} = \frac{807120}{18.25} = 44{,}226\#$$

Length of weld = (2 x 2.19) + 9 (4.625)

= 4.38 + 41.625

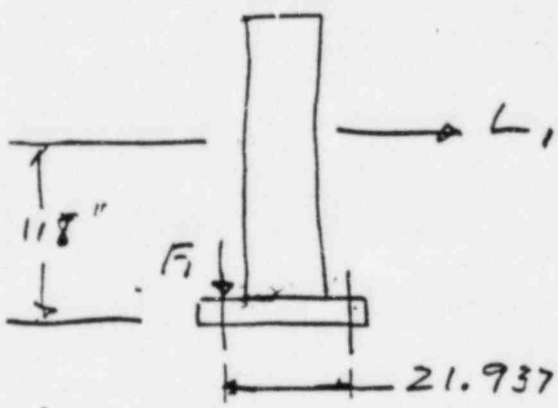
= 46"

Shear area of weld = .25 x .707 x 46 = 8.131 in^2

$$\text{Stress applied} = \frac{44{,}226}{8.131} = \underline{\underline{5439\#/in^2}}$$

When it is considered that seismic braces are in effect the rack is very safe.

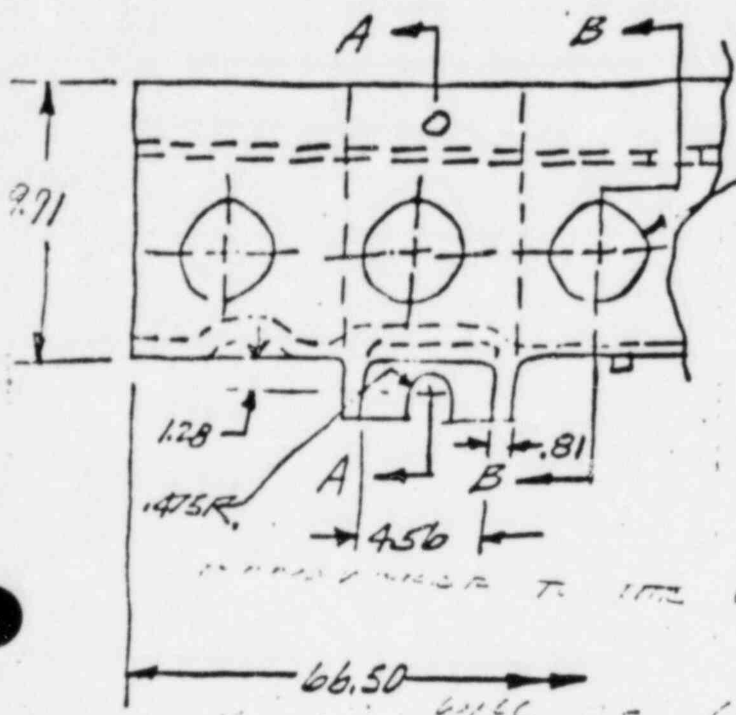
12.) Floor bolt lugs

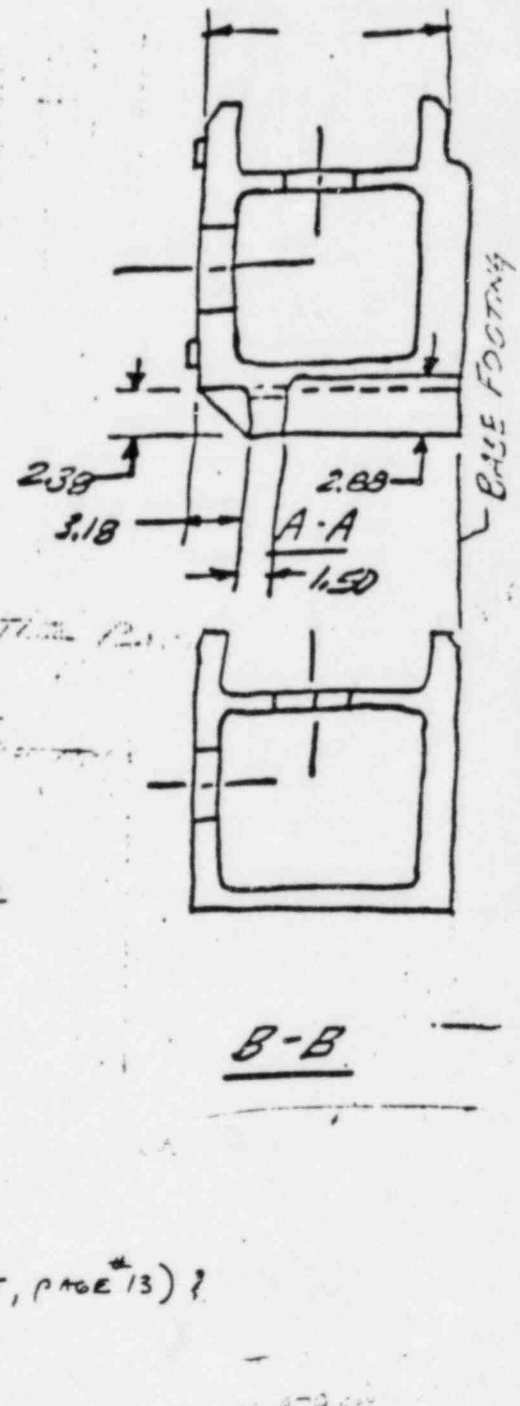


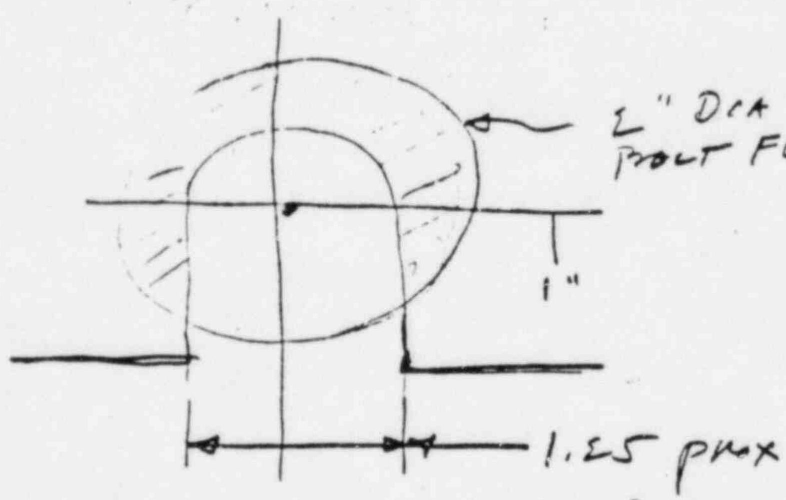
L_1 = 6840

$$F_1 = \frac{6840 \times 118}{21.937} = \frac{807120}{21.937} = \underline{\underline{36{,}793\#}}$$

Each of (2) bolts has $\frac{36{,}793}{2}$ = 18,396# APPLIED LOAD.







Area = approximately 1.29 in^2 (see Ref. #5, page #13)

Bearing

$F_a = \frac{18,396}{1.29} = 14,260\#/in^2$

Allowable = 35,000 x .6 = 21,000#

Lug in shear

Area of shear =(circ. of 2" circle - Gap) x thickness of lug

Area = (6.2832 - 1.25) x 1.5 = 7.5498 in^2

$S_s = \frac{18,396}{7.5498} = 2,437\#/in^2$

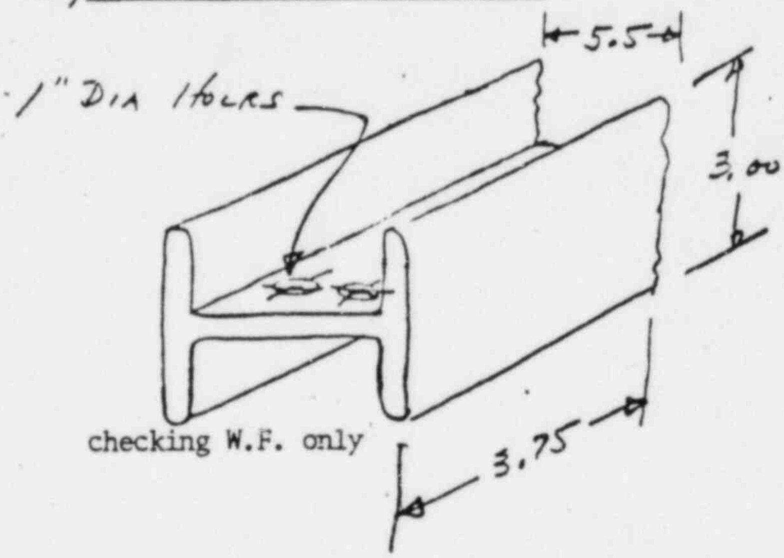
$F_s = .40 \times S_y$

$= .40 \times 30,000\#/in^2$

$= 12,000\#/in^2$ allowable

Note: When it is considered that lateral seismic bracing is in use, the lugs are very safe.

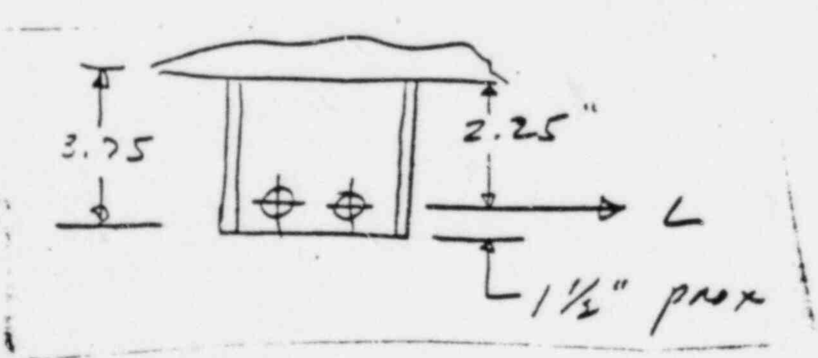
13.) Strength of seismic restraints (WF for bracing)



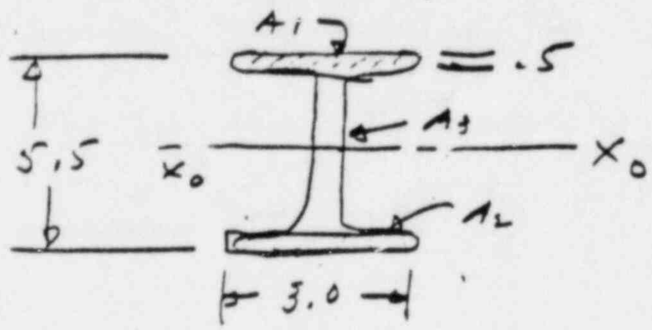
Flange thick. = .50"

Web thick. = .50"

checking W.F. only



AS A CANTILEVER BEAM;



$A_1 = A_2 = .5 \times 3.00 = 1.5\ in^2$

$A_3 = 4.5 \times .5 = 2.25\ in^2$

$Ix_1 = \frac{bd^3}{12} = \frac{3 \times (.5)^3}{12} = \frac{.375}{12} = \underline{\underline{.03125}}$

$Ix_2 = Ix_1$

$Ix_3 = \frac{bd^3}{12} = \frac{.5 \times (4.5)^3}{12} = \frac{45.5625}{12} = \underline{\underline{3.7968}}$

Transferring Ia_1 and Ia_3 to Xo

$Ix_0 = \left[(x_1 + A_1 (2.50)^2\right] + \left[Ix_2 + A_2 (2.50)^2\right] + \left[Ix_3 + A_3 (0)^2\right]$

$Ix_o = \left[.03125 + 1.5 (6.25)\right] + \left[.03125 + 1.5 (6.25)\right] + \left[3.7968\right]$

$Ix_o = 9.40625 + 9.40625 + 3.7968$

$Ix_o = \underline{\underline{22.6093\ in^4}}$

Load applied = ~~3208# (see sheet 9)~~ 6840 ÷ 2 = 3420# (SEE SHEET #12) USING FULL LOAD IS VERY CONSERVATIVE.

Lad as applied is equally divided between the (2) ends and ~~1604#~~ = 1710#.

$M = \frac{FL}{2} = \frac{\sout{1604}\ 1710 \times 2.25}{2} = \sout{1804.5\#}\ 1923.75\#$

$S = \frac{MC}{I} = \frac{\sout{1804}\ 1924 \times 2.75}{22.6093} = \sout{219\#/in^2}\ 234\#/in^2$

Bearing loads at bolt ~~hooks~~ HOLES

Assume ONE bolt holding INSTEAD OF TWO.

$A = 1.00$ dia. x .5 thickness = .5 in^2

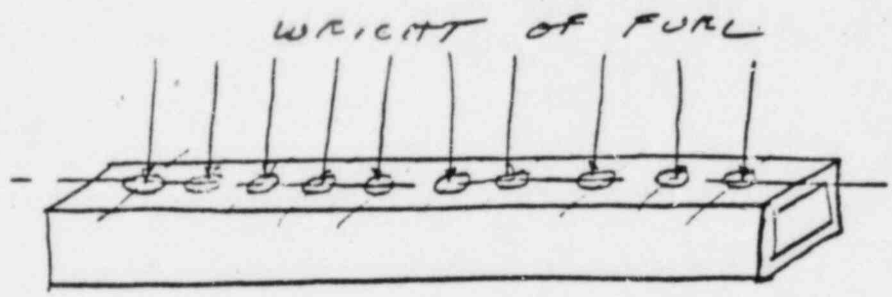
$S = \frac{L}{A} = \frac{1710}{.5} = 3420\#/in^2$ (typed values ~~1604~~, ~~3208~~ struck out)

$Fa = .6 \times 30{,}000\# = 18{,}000\#/in^2$

$F.S. = \frac{18{,}000\#}{3420\#} = 5.26$ (typed values ~~3208#~~, ~~5.61~~ struck out)

14.) Strength of lower casting as a flat plate

Strength of top surface of casting can be considered as a rectangular flat plate support on the two long sides and uniformely loaded. (Reference ~~Poxak~~ ROARK 5th Edition, page 26, (ASE6).



Hydrodynamic weight of fuel = 840

Ten fuel bundles - 10 x 840 = 8400#

Vertical columns are not considered as ~~the~~ THEIR support is vested in the vertical sides of the casting. The weight of flat plate portion of casting is not computed as the results are ~~nigligible~~ NEGLIGIBLE - only the weight of the fuel need be considered. First natural frequency OF THE WELDED RACK ASSEMBLY IN THE VERTICAL DIRECTION IS 1441 HZ, (see Reference # 5). pg. 22 [illegible]

TOTAL LOADING WILL BE OBTAINED BY SRSS METHOD USING NORMAL LOAD, (STATIC WEIGHT), PLUS SEISMIC "g" LOAD, PLUS SRV "g" LOAD. LOCA LOADING DOES NOT APPLY TO ZIMMER FUEL STORAGE POOLS. (REF: APPEND. #4 & #5). ABOVE DATA WILL BE USED PER 386HA625 AS FOLLOWS:

$\Sigma \text{ LOAD} = \text{STATIC WGHT} + \sqrt{(\text{SEISMIC})^2 + (\text{SRV})^2}$

Normal static weight = 8400#

Seismic = .4 x 8400 = 3360#

SRV = .125 x 8400 = 1050#

Note: LOCA is not considered as the first natural frequency is so high that corresponding "g" accelerations are negligible. (340#)

Vertical upward load is not considered as the sum of seismic and SRV = 0.4 + 0.125 = .525 "g" $<$ 1 "g".

Vertical downward load:

$$L = \text{Normal} + \sqrt{(\text{seismic})^2 + (\text{SRV})^2}$$

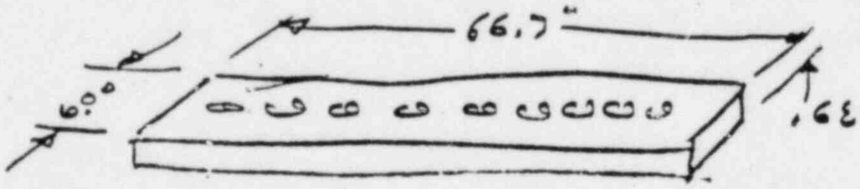
$$L = 8400 + \sqrt{(3360)^2 + (1050)^2}$$

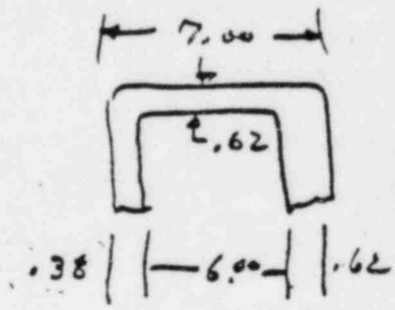
$$L = 8400 + \sqrt{11{,}289{,}600 + 1{,}102{,}500}$$

$$L = 8400 + 3520$$

$$L = \underline{\underline{11920\#}}$$

Stress on top of casting (see Reference # 6, page





$$\text{Surface } \sout{\text{laod}}\ \text{LOAD} = \frac{11920}{6 \times 66.7} = \underline{\underline{29.78\#\text{in}^2}}$$

Allowable stress = $F_b = .66 \times S_y$

$F_b = .66 \times 30{,}000 \ \#/in^2$

$F_b = 20{,}000 \ \#/in^2$

~~NOTE: SHOULD A FAILURE OCCUR IN THE CASTING AS DESCRIBED ABOVE, A CRITICAL ARRAY WILL NOT OCCUR AS THE FUEL ELEMENTS WILL FALL LESS THAN 1" BUT WILL REMAIN UPRIGHT AND WITHIN THE SAME GEOMETRIC ARRAY PRESENTED BY THE RACK COLUMNS.~~

$$S = \frac{\beta q b^2}{t^2}$$

$$S = \frac{.5\,(29.78)\,(6.00)^2}{(.62)^2}$$

$S = 13945 \ \#/in^2$ (~~41,528~~)

$\beta = .5$

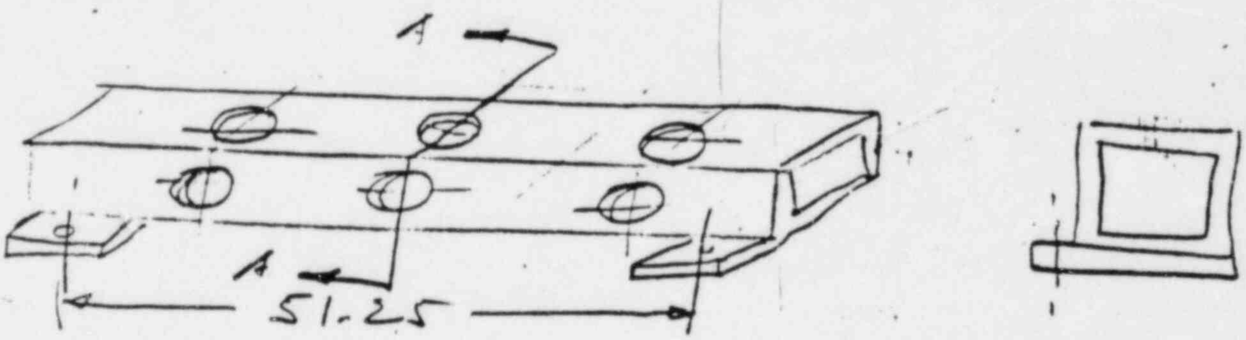
q = Surface load = $29.78\#/in^2$

$b = 6.00$

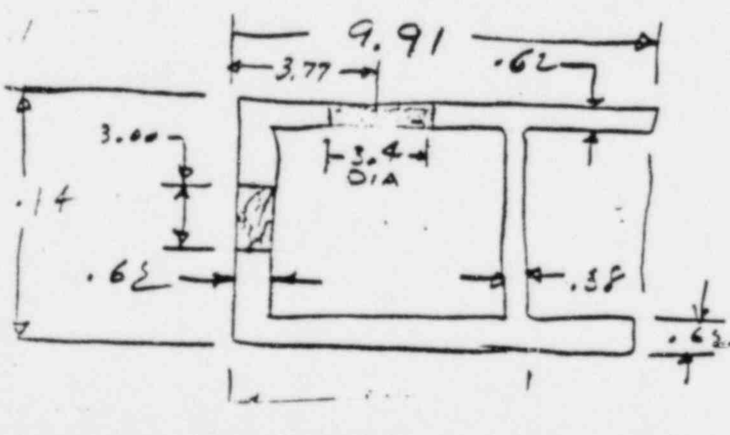
$t = .62$

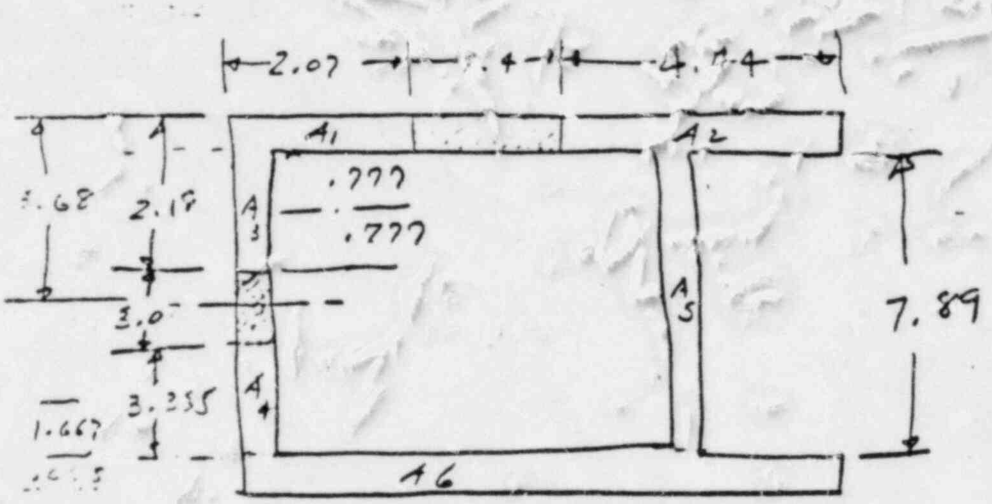
15.) Casting as a beam (load in —"Y" direction)

In this analysis the casting will be considered as a ~~uniformally loaded beam, simply supported~~ simply supported beam with a concentrated load. No consideration will be given for the beneficial effects of the superstructure comprising the columns and end channels which are welded to, and form a part of, the lower casting. ~~Casual~~ observation reveals that only slight effects may be gained as the columns and end channels are not welded together to form a relatively homogeneous structure.



Areas of section





A_1 = .625 x 2.07 = 1.293 in²

A_2 = .625 x (9.91 - 2.07 - 3.4) = 2.775

A_3 = .625 x (2.18 -.625) = .972

A_4 = .625 x (9.14 - .625 - 2.18 - 3.0) = 2.084

A_5 = .625 (9.14 - .625 - .625) = 4.931

A_6 = .625 x 9.91 = 6.194

18.249 in²

Determine neutral axis

18.249 = 1.293 (8.827) + 2.775 (8.827) + .972 (7.738) + 2.084 (2.292) + 4.931 (4.57) + 6.194 (.3125)

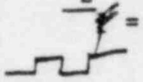
18.249 = 11.413 + 24.494 + 7.521 + 4.776 + 22.53 + 1.935

18.249 = 72.669

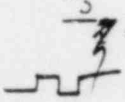
= 3.982"

Determine moment of inertia

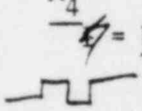
$$A_1 = \frac{bd^3}{12} = \frac{2.07\ (.625)^3}{12} = .042\ in^4$$



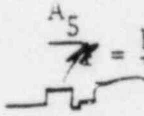
$$A_2 = \frac{bd^3}{12} = \frac{4.44\ (.625)^3}{12} = .090\ in^4$$



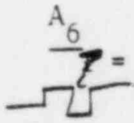
$$A_3 = \frac{bd^3}{12} = \frac{.625\ (1.555)^3}{12} = .195\ in^4$$



$$A_4 = \frac{bd^3}{12} = \frac{.625\ (3.335)^3}{12} = 1.932\ in^4$$

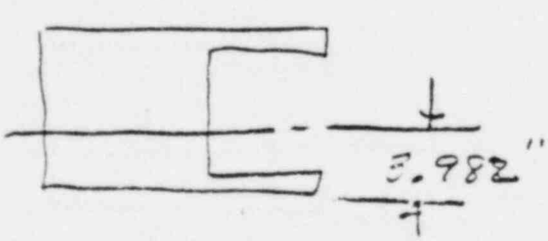


$$A_5 = \frac{bd^3}{12} = \frac{.625\ (7.89)^3}{12} = 25.581\ in^4$$



$$A_6 = \frac{bd^3}{12} = \frac{9.91\ (.625)^3}{12} = .201\ in^4$$

$$28.041\ in^4$$



ΣI About neutral axis

$$Ix_o = [Ix_1 + A_1\ (4.533)^2] + [Ix_2 + A_2\ (4.533)^2] + [Ix_3 + A_3 + (3.756)^2] + [Ix_4 + A_4\ (1.69)^2] + [Ix_5 + A_5\ (.68)^2] + [Ix_6 + A_6\ (3.669)^2]$$

$$Ix_o = 26.61 + 57.11 + 13.91 + 7.88 + 27.86 + 83.58$$

$$Ix_o = 216.95\ in^4$$

Maximum load = ~~9108~~ 11920 + weight of columns + top casting

= ~~9108~~ 11920 + 562# + 85#

= ~~9755#~~ 12567

$$M = \frac{FL}{4} = \text{~~9755~~ } 12567 \times \frac{51.25}{4}$$

M = ~~124,986~~ 161015 lbs. in.

Maximum stress (outer fiber)

$$S = \frac{MC}{I} = \frac{\text{~~124,986~~ } 161015 \times 3.982}{216.95}$$

S = ~~2294~~ 2955 $\#/in^2$

17. Casting as a beam (load in "X" direction)

In this case it becomes obvious that the section modulus will be greater in the vertical axis and with lighter loads (see page 9) it becomes unnecessary to calculate stresses in this direction.

V. MISCELLANEOUS LOAD CONSIDERATIONS

1. Load in "Z" direction are not considered as the relative strength of the rack in the "Z" direction is much greater than in the "X" direction.
2. Loads in the +"Y" direction are much less than in the -"Y" direction due to the fact that the fuel elements are not restrained by the rack.

VI. SUMMARY

1. The spent fuel rack is adequate with regard to its capacity to withstand all external loads that would present a critical array of the fuel elements.

2. Points considered and maximum stresses

    a) Vertical columns = 392 ~~389#~~/in²

    b) End channels= 392 ~~389#~~/in²

    c) Welds (base to columns)= 61#/in²

    d) Welds (diagonal bracing)= 389#/in²

    e) Base (top surface) 1394.5 ~~41,528#~~/in²

    f) Base (maximum flexural stress) = 2,955 ~~3,294#~~/in²

    g) Lugs (shear) = 2,437#/in²

    Lugs (Bearing) = 14,250#/in²

    h) Lateral beam (flexural) = 219#/in²

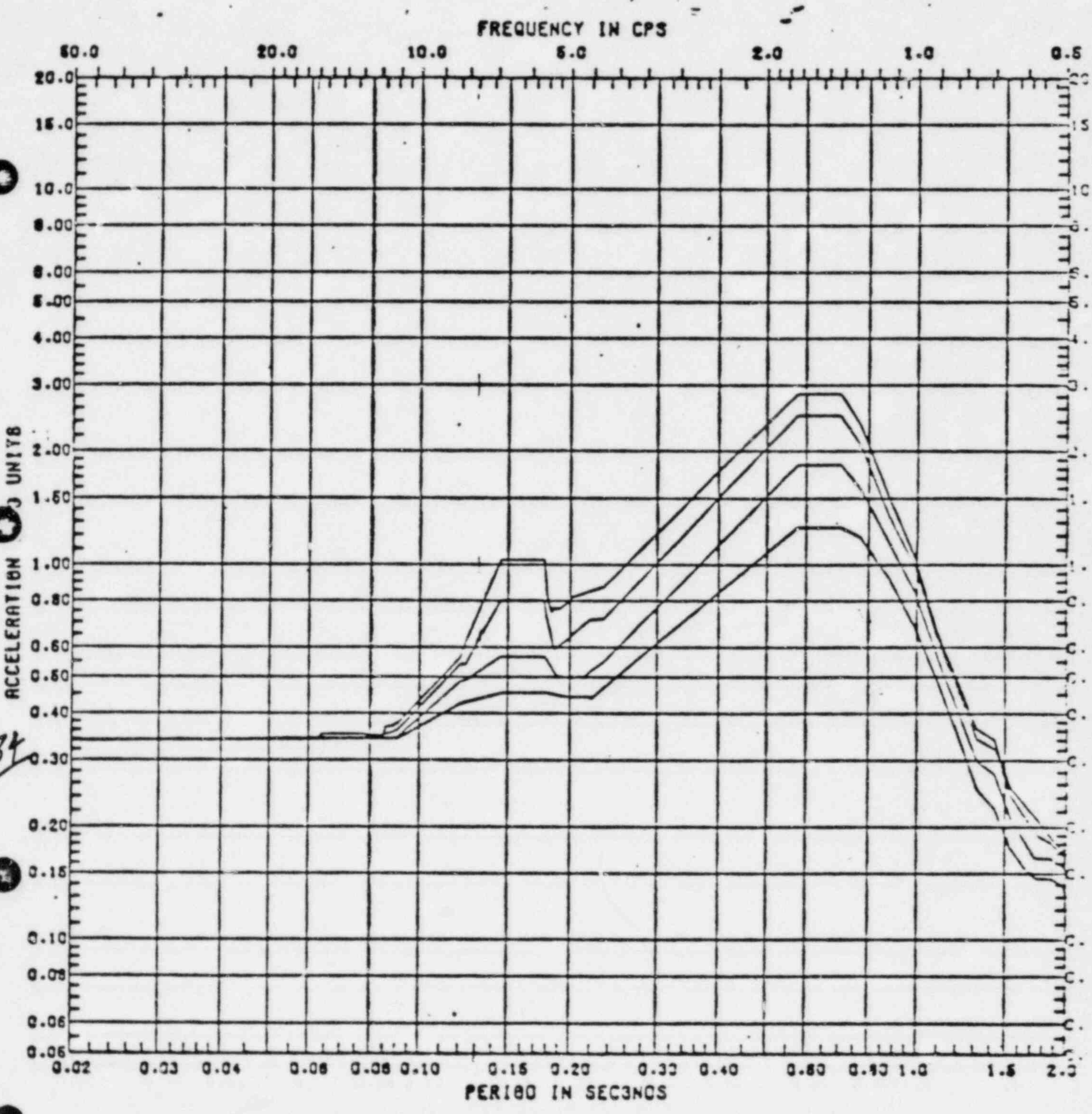
~~3. It is to be specifically noted that a failure of the top surface of base casting, a critical array will not be effected.~~

SARGENT & LUNDY
ENGINEERS

28 JUL 76
8290EL

ZIMMER.413 5.SOIL-STRUCT.HORIZ.OBE
DESIGNER O.L. Icv CHECKER B.P. Jain
DESIGN SPECTRA AT JOINT/SLAB 5 X-COMP
PEAKS WIDENED BY 10% ON EACH SIDE
DAMPING 0.010 0.020 0.050 0.100
PAGE 40 OF 125

Appendix #1



O.B.E. Horiz. Response Spectra N-S Component SPECTRA NO. 5-C

ELEVATION 593'-6"

LOCATION Reactor Building Slab REVISION NO. 0

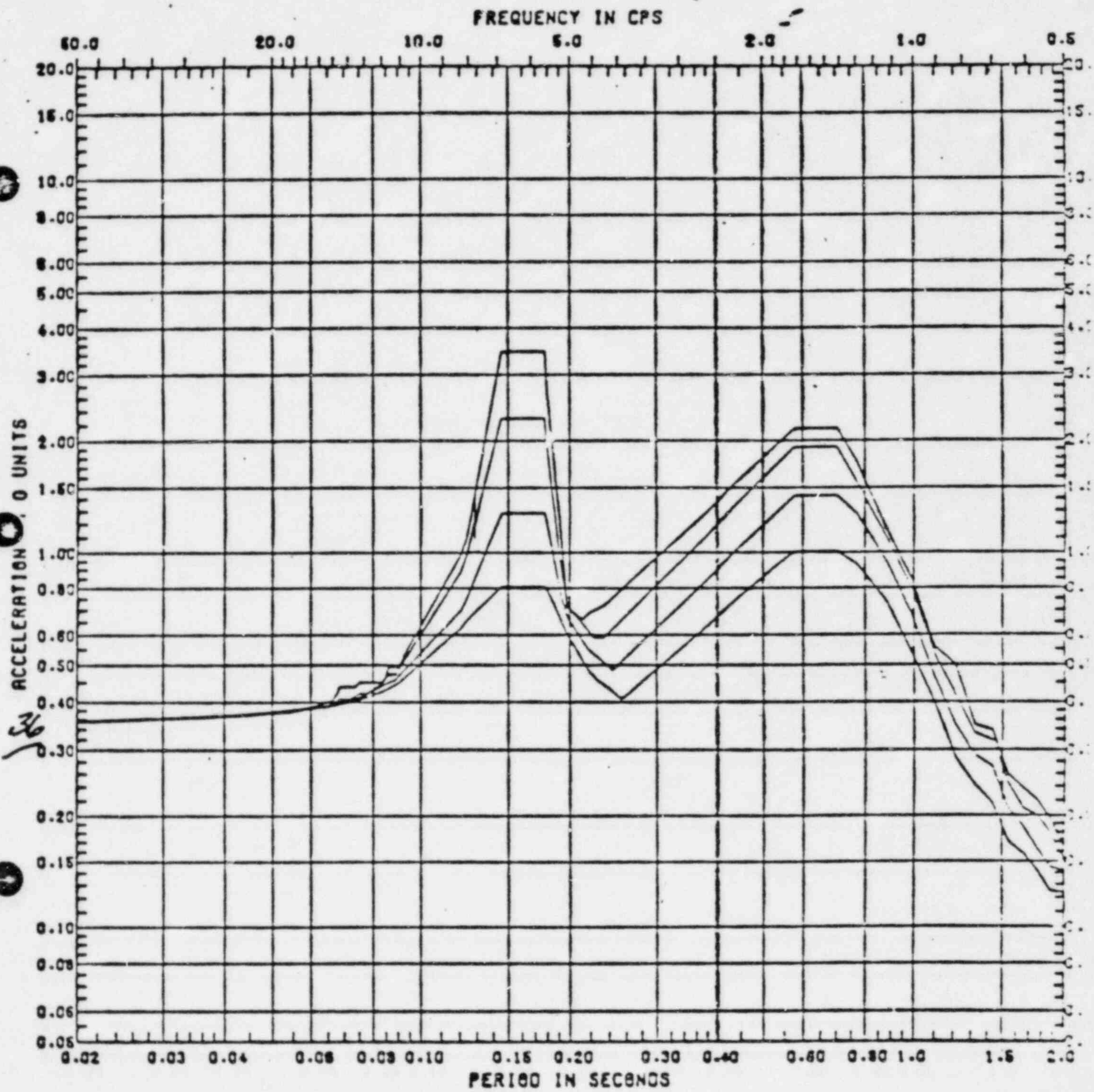
SARGENT & LUNDY ENGINEERS

28 JUL 76
8290EL

ZIMMER.413015.SOIL-STRUCT.HORIZ.OBE
DESIGNER O. Lav CHECKER B.P. Jain
DESIGN SPECTRA AT JOINT/SLAB 5 Y-COMP
PEAKS WIDENED BY 10% ON EACH SIDE
DAMPING 0.010 0.020 0.050 0.100
PAGE 41 OF 125

10

Appendix # 2



.5% Horiz. Response Spectra E-W Component SPECTRA NO. 5-D

ELEVATION 593'-6" SSE

LOCATION Reactor Building Slab REVISION NO. 0

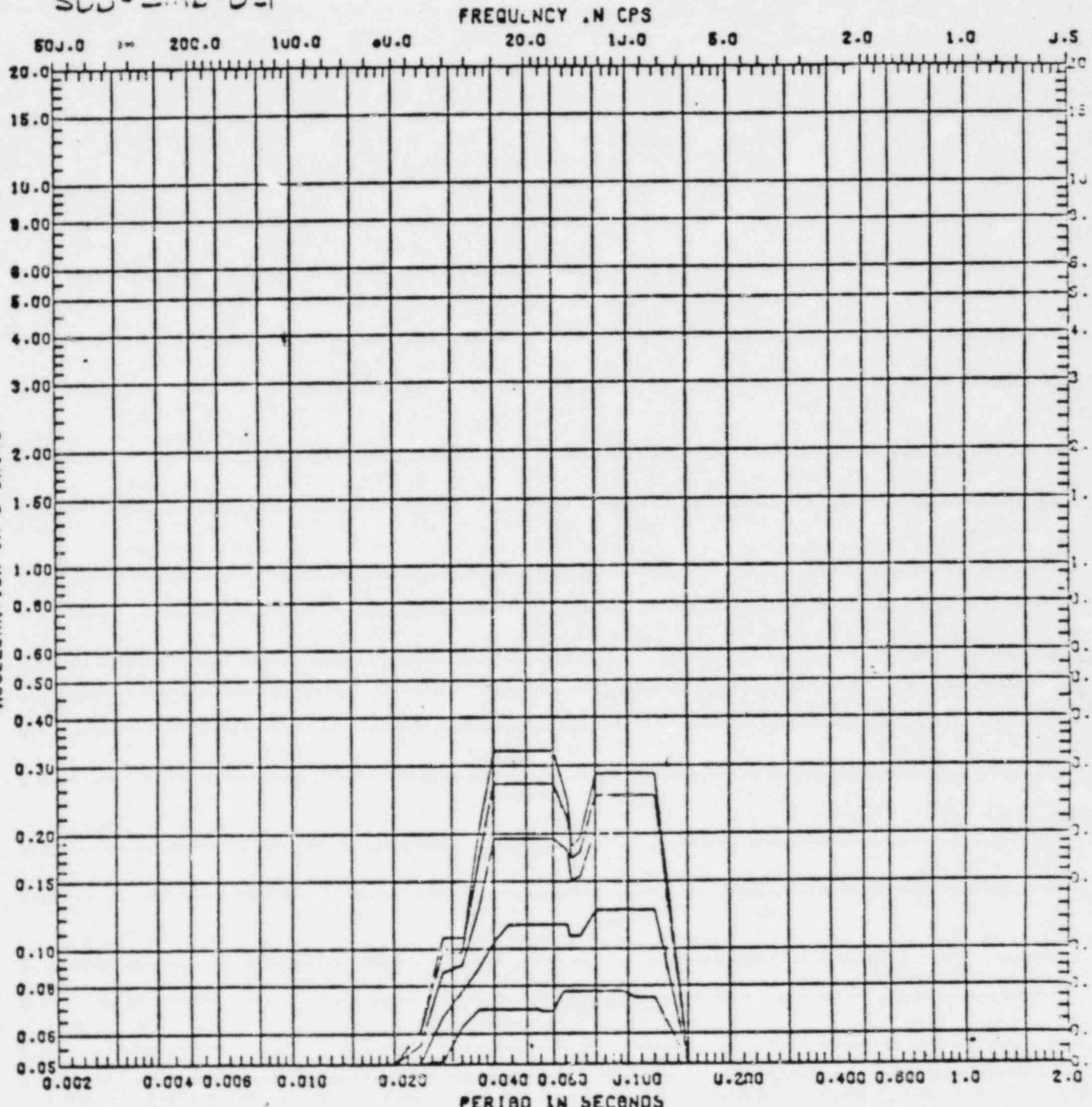
SARGENT & LUNDY ENGINEERS

10/01/7
191SWC

4130-15
SDD-[illegible]-021

ZIMMER SEQ-SRV-RSO-ENV-NH222
DESIGNER [illegible] CHECKER [illegible]
DESIGN SPECTRA AT JOINT/SLAB
PEAKS WIDENED BY 20% ON EACH SIDE
DAMPING 0.005 0.010 0.020 0.050 0.100

Appendix #3



KS303-4 insignificant

HORIZ RESPONSE SPECTRA SPECTRA NO. S303-H

ELEVATION 549'-4"

LOCATION REACTOR BUILDING REVISION NO. 2

SARGENT & LUNDY ENGINEERS

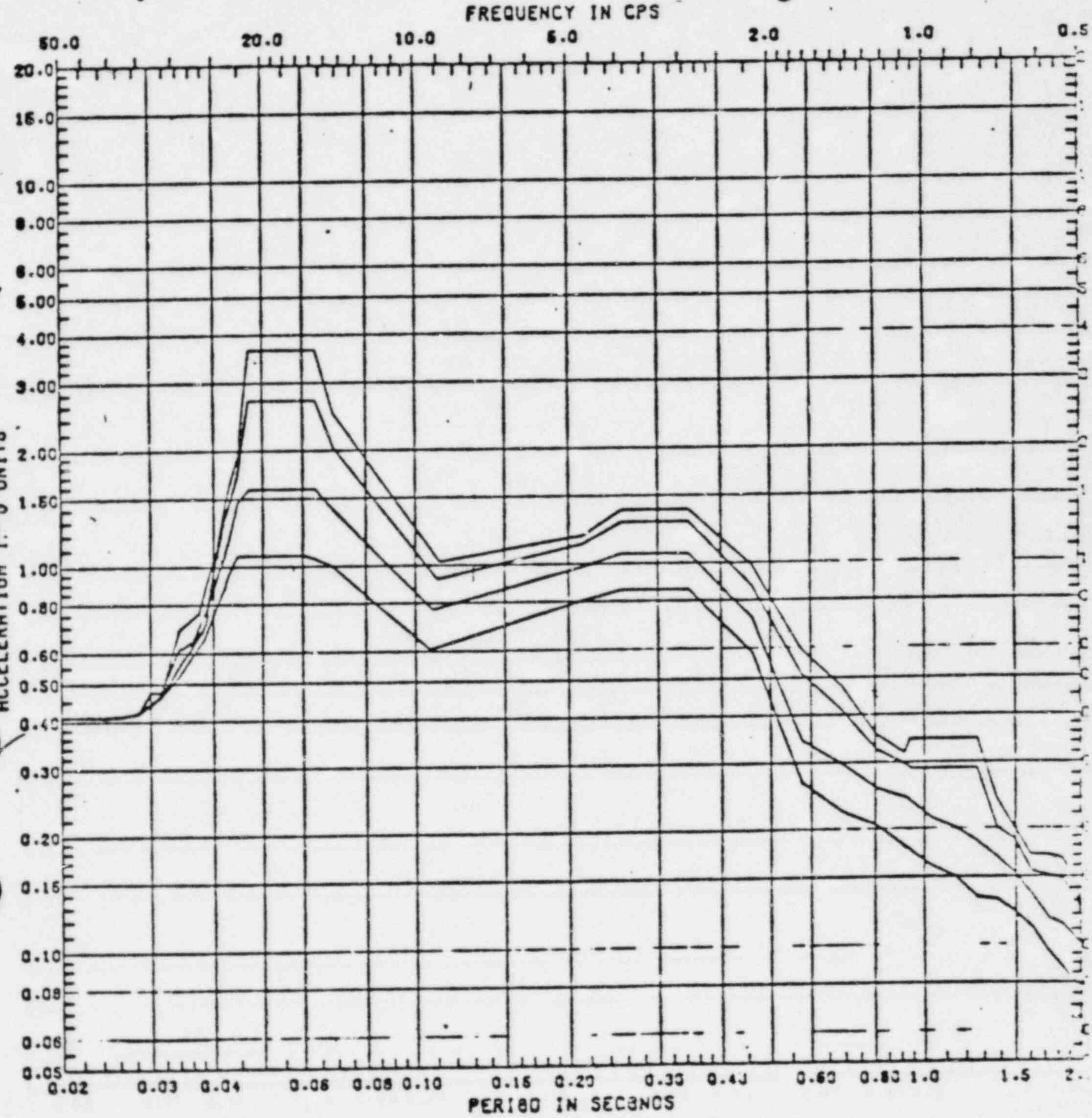
01 AUG 76

6740EL

ZIMMER1.4' DIS.SOIL-STRUCT.V.S S.OBE
DESIGNER . Low CHECKER B.P. Jain
DESIGN SPECTRA AT JOINT/SLAB 27 X-COMP
PEAKS WIDENED BY 15% ON EACH SIDE
DAMPING 0.010 0.020 0.050 0.100
PAGE 48 OF 125

9

Appendix #4



D.B.E. VERT RESPONSE SPECTRA

ELEVATION 593'-6", 570'-6"

LOCATION Reactor Bldg. Slab

SPECTRA NO. 4-F, 5-F

REVISION NO. 0

Attachment 11

81

33,803,0551

139F16-E002-BB1

ISSUED BY PD
DATE 1-21-77

DESIGN RECORD FILE

ASSIGNMENT SHEET

1.0 IDENTIFICATION

DRF FILE NO. 139-F16E002-BB1 ASSIGNMENT DATE 1-20-77

SUBJECT CAORSO, ASSURANCE OF FUNCTION

PRODUCT SEGMENT SPENT FUEL STORAGE RACKS

COMPONENT/SUBCOMPONENT

PROJECT/PRODUCT LINE CAORSO

2.0 ASSIGNMENT RESPONSIBILITY

DRF CUSTODIAN D. VICKERMAN COMP. 139 EXT. 5-6850

3.0 RECORDS STORAGE

MICROFILM DATE

DESIGN ABSTRACT

THIS FILE CONTAINS THE SEISMIC, NATURAL FREQUENCY AND STRESS CALCULATIONS TO DETERMINE IF THE SPENT FUEL STORAGE RACKS RETAIN THEIR FUNCTIONAL INTEGRITY DURING A SEISMIC EVENT WITH THE NEW LOADS COMBINED.

APPROVED BY: [signature]
1-20-77

GENERAL ELECTRIC CO.
Nuclear Energy Division
ENGINEERING CALCULATION SHEET

2

DATE JAN 7-77

SHOP ORDER NO. CACRSC ASSURANCE OF FUNCTION ...

SUBJECT DESIGN VERIFICATION NOTES COVER SHEET BY ______ SHEET 1 OF 1

1. Design of: SPENT FUEL STORAGE RACK MPL# F16 E002
System, Equipment, Component

2. Input to: [X] Initial Design [ ] Design Change

ASSEM DWG 762E210 G001
Title, Number and Current Reivison Number of Document

ECN# ______

ERM# ______

[ ] Specification [ ] Drawing Type: STRESS ANALYSIS

3. Product Line: [X] 67, [ ] 69, [ ] BWR 6, [ ] Other as applicable

4. Identification of specific cesign and engineering data sources.
"LOADING COMBINATION AND ACCEPTANCE CRITERIA" 22A4677 (Review copy)
LETTER TO J. GANJEZ FROM JOHN CUNLIFFE DATED DEC 21-1976

5. ~~Assumptions made for this design:~~
SEE THE ANALYSIS

Per P.D. ... 785HA758 ... Replaces 22A4677 (Review copy) without affecting this analysis. ... 1-12-77

6. Qaulity, safety, functional requirements on this design:
PER 762E210

7. Acceptance criteria specified in:
PER 762E210

8. Interfacing design units within NED:
N/A

9. Does this change require new or revised calculations [X] Yes [ ] No

Organization responsible for calculations: REACTOR STRUCTURES EQUIPMENT ... DESIGN

10. Manager's designation of verification method(s), and evidence of verification:
Review &/or alternate calculations. Design Review by: 11-JAN-77 * INTERIM E. C. Ueberman 134
Date Reviewing Engr.Sig. Unit
* OVER FOR COMMENTS

11. Responsible Design Engineer: JAVAD GANJEZ J. Ganjez JAN 7-77

Manager's Acceptance: ... 1-12-77

①

Page C.2

VERIFICATION COMMENTS

IN THE HORIZ DIRECTION THE NATURAL FREQUENCY IS BELOW 33 CPS. FROM THIS, USING SRSS COMBINATION OF THE G LOADING OBTAINED FROM SPEC 22A4677, THE G LOADING IS LESS THAN 1. WITH THE USAGE OF 1G LOAD THE ONLY PART OF THE RACKS IN QUESTION IS THE BOLT PADS. THESE PADS SEEM TO BE THE WEAKEST PART. VERTICAL ANALYSIS WAS NOT CONDUCTED BECAUSE THE NATURAL FREQ IS GREATER THAN 33 CPS. (IE RIGID BODY). THIS IS AN INTERIM VERIFICATION BECAUSE THE INPUT DATA IS NOT VERIFIED AND THE ANALYSIS IS NOT COMPLETE TO PROOF THAT THE RACKS WOULD NOT HAVE A LOSS OF FUNCTION. IF ANALYSIS IS INCLUDED ON THE EFFECTS OF THE DIVIDER (P/N 22) ON THE OVERTURNING MOMENT AND WITH THE INPUT DATA (SPEC 22A 4677) VERIFIED I FEEL THAT THE RACKS WILL BE ADEQUATE FOR RETAINING THEIR FUNCTIONAL INTEGRITY.

D. C. Vickerman 11 JAN 77

DESIGN RECORD FILE

TABLE OF CONTENTS

SUBJECT	NO.	DATE ENTERED	AUTHOR	REMARKS
ASSURANCE OF FUNCTION CALCULATIONS	1	7 JAN 77	J. GANJEI	
VERIFICATION CALCULATIONS	2	13 JAN 77	D. VICKERMAN	
CONFIRMATION LETTER	3	13 JAN 77	J. GANJEI	

GENERAL ELECTRIC CO.
Nuclear Energy Division
ENGINEERING CALCULATION SHEET

NUMBER ______ DATE JAN 7-77
SUBJECT [illegible] ASSURANCE OF FUNCTION BY T. G. [illegible] SHEET 0.1 OF ______

INTRODUCTION

IN ADDITION TO SEISMIC. THE CAORSO RACKS WERE TO BE ANALYZED FOR CHUGGING AND SRVD LOADS. THE COMBINED EFFECT OF THESE THREE LOADS = 0.644743 g HOWEVER ~~THE ENTIRE ANALYSIS, FOR SAKE OF CONSERVATISM, WAS BASED ON 1.0 g.~~

THE RACK IS QUITE STRONG IN HORIZONTAL DIRECTION. IN VERTICAL DIRECTION THE NATURAL FREQUENCY IS 1444 HZ. WHICH INDICATES THAT THE RACK IS EVEN ~~MORE~~ STRONGER THAN THE HORIZONTAL DIRECTION.

27 3HZ [illegible]

GENERAL ELECTRIC CO.
Nuclear Energy Division
ENGINEERING CALCULATION SHEET

NUMBER EWA NO. 7392J-25 REV. 1 DATE DEC 18 [illegible]
SUBJECT CAORSO LOSS OF FUNCTION ASSESSMENT BY D. GANJEI SHEET 1 OF

THE PURPOSE OF THIS ANALYSIS IS TO ASSESS THE STRUCTURAL INTEGRITY OF CAORSO'S SPENT FUEL STORAGE RACKS WHEN SUBJECTED TO "THE NEW LOADS".

ORIGINAL ANALYSIS FOR CAORSO RACKS WITH ASSEMBLY DRAWING NO. 762E 210 G001 WAS NOT AT HAND. THEREFORE A COMPLETE ANALYSIS FOR SEISMIC AS WELL AS FOR THE "NEW LOADS" WILL BE DONE. THE FINAL LOAD FOR STRUCTURAL ANALYSIS OF RACK WILL BE THE COMBINATION (BY SRSS METHOD) OF ALL THE LOADS.

THE FOLLOWING RESPONSE SPECTRA WERE FURNISHED BY THE AUTHOR OF EWA NO. 7992J-25 REV. 1.

HORIZ. RESPONSE SPECTRUM FOR SSE (FOR 36.4m ELEV.)
" " " " OBE (FOR 36.4m ELEV.)
VERTICAL " " " " (FOR ALL LOCATIONS)

GENERAL ELECTRIC CO.
Nuclear Energy Division
ENGINEERING CALCULATION SHEET

NUMBER ______ DATE JAN. 7-77
SUBJECT ASSURANCE OF FUNCTION FOR SPCRS BY J GANJEI SHEET 1A OF ______

REFERENCES:

1) LOADING COMBINATIONS AND ACCEPTANCE CRITERIA FOR BWR 4 & 5 MARK II (22A4677)

2) STRUCTURAL ALUMINUM DESIGN. REYNOLDS ALUMINUM.

3) ENGINEERING DATA FOR ALUMINUM STRUCTURES. THE ALUMINUM ASSOCIATION

4) DESIGN OF WELDED STRUCTURES. BY BLODGETT

5) STRESS ANALYSIS OF CONCEPT 2 RACK FOR FUKUSHIMA 6 AND TOKAI 2 BY: J. GANJEI

6) FORMULAS FOR STRESS AND STRAIN BY: ROARK

7) LETTER TO J. GANJEI FROM JOHN CUNLIFFE DATED DEC 21-1976

GENERAL ELECTRIC CO.
Nuclear Energy Division
ENGINEERING CALCULATION SHEET

NUMBER ______ DATE DEC 15-76
SUBJECT CARRSC LOSS OF FUNCTION ASSESMENT BY J GANTEI SHEET 2 OF ____

NATURAL FREQUENCY CALCULATION

- $\omega_n = 2\pi f_n \longrightarrow f_n = \frac{\omega_n}{2\pi}$

- $\omega_n = \frac{3.52}{l^2}\sqrt{\frac{EI}{m}}$

RACK LENGTH = 178 IN.

where m = mass / LENGTH

total mass = $\frac{1}{g}$ (RACK WT. + FUEL WT.)

$= \frac{1}{386.4}(2020 + 20 \times 650) = 38.87$ #-sec²/IN

$m = \frac{38.87}{178} = .21835$ #-sec²/IN²

TOTAL $I = \Sigma\left[I_i + A_i d_i^2\right]$

$I_1 = 21.3$ IN⁴, $A_1 = 3.76$ IN², $d_1 = 5.34$ IN — FOR I-BEAMS (20)

$I = 1.556$ IN⁴, $A = 1.734$ IN², $d = 10.375$ IN — FOR SQ. TUBE (4)

FOR I $= 20\left[21.3 + 3.76(5.34)^2\right]$

$= 3080$ IN⁴

FOR ▭ $= 4\left(1.556 + 1.734(10.375)^2\right)$

$= 755$ IN⁴

TOTAL $= 3835$ IN⁴

$\omega_n = \frac{3.52 \times 10^3}{(178)^2}\sqrt{\frac{10 \times 3835}{.21835}} = 46.54$ RAD/SEC

$f_n = \frac{\omega_n}{2\pi} = \frac{46.54}{6.28} = 7.4$ cycles/sec

$T = \frac{1}{f_n} = \frac{1}{7.4} = .135$ SEC. (PERIOD)

GENERAL ELECTRIC CO.
Nuclear Energy Division
ENGINEERING CALCULATION SHEET

NUMBER ______ DATE Dec. 23 - 76
SUBJECT [illegible] Loss of Function Assessment BY J. GANTET SHEET 3 OF ____

FOR PERIOD T = .135 SEC THE MAX RESPONSE (HORIZONTAL) ACCELERATION IS .46g (DUE TO SEISMIC FOR SSE)

NOW WE ATTEMPT TO CALCULATE RESPONSE ACCELERATION (HORIZ) DUE TO CHUGGING. TO FIND THIS, WE USE SPECTRA IN SECTION 4B (REF. 1) FOR NODE 44 TIMES A FACTOR OF 2.0. THIS ACCELERATION IS .02g. FOR OUR USE 2 X .02g = .04g

NEXT. WE FIND HORIZ. RESPONSE SPECTRA DUE TO SRVD. TO DO THIS WE USE SPECTRA ~~FOR~~ IN SECTION 3B FOR NODE 44 TIMES A FACTOR OF 1.5 THIS ACCELERATION IS .3g FOR OUR USE .3g X 1.5 = .45g

THE MAX EFFECT ON RACK IS EXPECTED TO BE:

SEISMIC + CHUGGING + SRVD

WE NOW COMBINE THE EFFECTS BY SRSS METHOD:

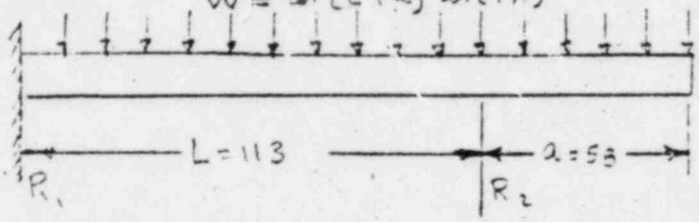
$$G = \sqrt{g_{seis}^2 + g_{chug}^2 + g_{SRVD}^2} = \sqrt{(.46)^2 + (.04)^2 + (.45)^2} = .644748$$

GENERAL ELECTRIC CO.
Nuclear Energy Division
ENGINEERING CALCULATION SHEET

NUMBER ______ DATE JAN 12-77
SUBJECT CACRS - LEGS OF FUNCTION BY J. GANJEI SHEET 1 OF ____

DIVIDER (P/N 22) IS A SEISMIC RESTRAINT WHICH PREVENTS RACK FROM OVERTURNING, THEREFORE IT OFFERS SUPPORT TO EACH ROW OF COLUMNS

$W = w(L+a)\; w(171'')$



$16522 \div 2 = 8261$ LBS LOAD PER ROW (10 BUNDLES/ROW)

$w = 8261 \div 171 = 48.3 \frac{LBS}{IN}$ LOAD PER LENGTH

__REACTION__

$R_2 = \frac{w}{8L}(6a^2 + 8aL + 3L^2)$ REF. 2 STRUCTURAL ALUMIN. DES. REYNOLDS

$R_2 = \frac{48.3}{8(113)}\left(6(58)^2 + 8(58)(113) + 3(113)^2\right) = 5926$ LBS PER ROW

$R_1 = w(L+a) - R_2$

$= 48.3(113+58) - 5926 = 2333$ LBS PER ROW

__BENDING MOMENTS__

$M_{R_2} = -\frac{wa^2}{2} = -\frac{(48.3)(58)^2}{2} = 81240$ IN-LBS PER ROW

$M_{R_1} = -\frac{w(a+L)^2}{2} + R_2 L$

$= -\frac{48.3(171)^2}{2} + 5926(113) = -36532$ IN-LBS PER ROW

THE REACTIONS AND MOMENTS FOR 2 ROWS (1 RACK) ARE:

$R_2 = 11852$ LBS	$R_2 = 592$ LBS (PER COLUMN)
$R_1 = 4666$ LBS	$R_1 = 233$ LBS (")
$M_2 = 162480$ IN-LBS	$M_2 = 8124$ IN-LBS (")
$M_1 = -73065$ IN-LBS	$M_1 = -3653$ IN-LBS (")

GENERAL ELECTRIC CO.
Nuclear Energy Division
ENGINEERING CALCULATION SHEET

NUMBER ______ DATE JAN 12-77
SUBJECT CASE 5A LOSS OF FUNCTION BY J GANTE? SHEET 5 OF ______

AT DIVIDER $\begin{cases} R_2 = 11852 \text{ LBS} \\ M_2 = 162480 \text{ IN-LBS} \end{cases}$

AT BELT $\begin{cases} R_1 - 4666 \text{ LBS} \\ M_1 = -73065 \text{ IN-LBS} \end{cases}$

WEIGHT OF LOADED RACK = 15020 #

HYDRODYNAMIC MASS = 10% OF 15020 #

TOTAL - 16.522

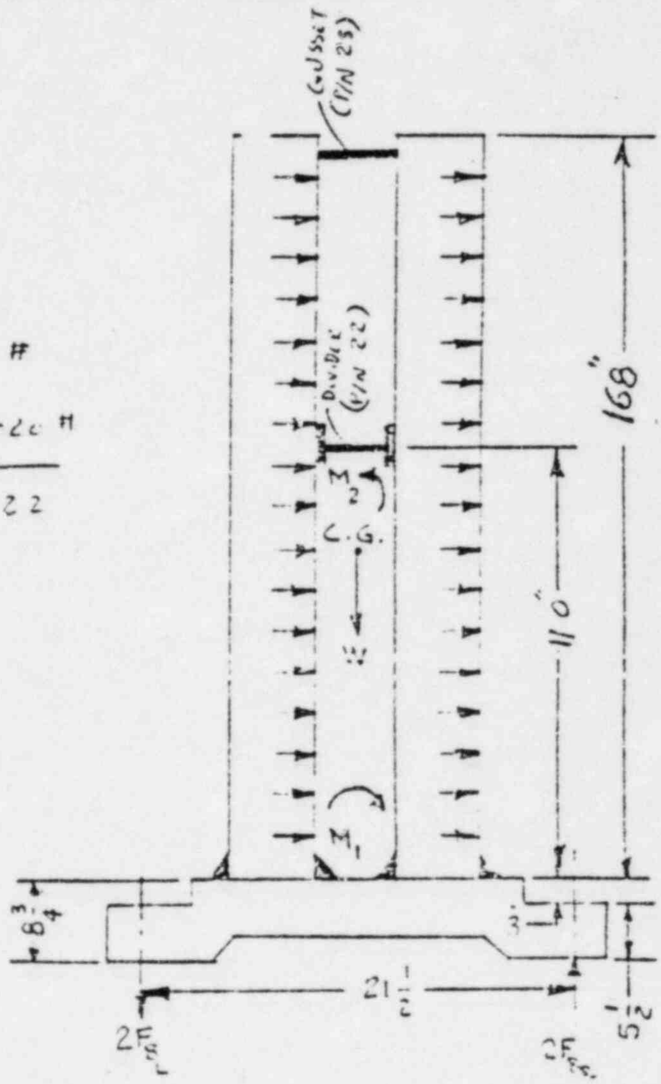
TAKING MOMENTS ABOUT F_{R_L}

$\Sigma M_{F_{R_L}} = 0$

$M_2 + M_1 + W\left(\frac{21.5}{2}\right) = 2F_{B_L}(21.5)$

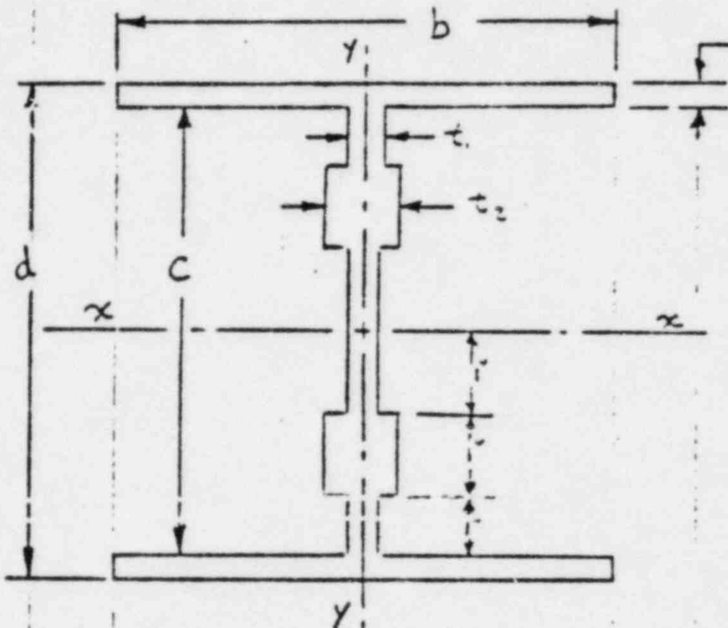
$162480 - 73065 - 16522(10.75) = 43 F_{B_L}$

$F_{R_L} = -2051$ LBS (IN COMPRESS RACK)



SECTION MODULUS, $Z = \frac{I}{C}$

REF 5



$b = 4.625$
$d = 6.375$
$t_1 = .1875$
$t_2 = .625$
$m = .1875$
$C = 6.00$

SECTION AREA $= 2bm + 4''(t_1) + 2''(t_2)$

$= 2(4.625)(.1875) + 4(.1875) + 2(.625)$

$= 3.76\ IN^2$

MOMENT OF INERTIA

$$I_{x\cdot x} = \frac{b(d^3 - c^3)}{12} + \frac{t_1 c^3}{12} + 2\left[\frac{(t_2 - t_1)^3}{12} + (t_2 - t_1)(1)(1.5)^2\right]$$

$$= \frac{1}{12}\left[(4.625)\left[(6.375)^3 - (6.00)^3\right] + \frac{(.4375)^3}{6} + 2(.4375)(1.5)^2\right.$$

$$= \frac{1}{12}\left[4.625(260 - 216) + .1875(216)\right] + \frac{.08}{6} + 1.0$$

$$= \frac{1}{12}\left[203 + 40.5\right] = \frac{1}{12}(243.5) + 1 = 21.3\ IN^4$$

12

GENERAL ELECTRIC CO.
Nuclear Energy Division
ENGINEERING CALCULATION SHEET

NUMBER ________ DATE Dec. 23. 76
SUBJECT Cable Rack Analysis for Loss of Function BY J. Gantei SHEET 6 OF ____

$I_{xx} = 21.3 \ IN^4$

$A_1 = 3.76 \ IN^2$

$c = 3.13 \ IN.$

Bend. Stress $= \frac{Mc}{I} = \frac{3653 \times 3.13}{21.3} = 547$ PSI (At the base, Point #1)

Shear Stress $= \frac{R_2}{A} = \frac{592}{3.76} = 157$ PSI (At divider, Point #2)

Bend. Stress $= \frac{Mc}{I} = \frac{8124 \times 3.19}{21.3} = 1217$ PSI (At divider, Point #2)

Shear Stress $= \frac{R_1}{A} = \frac{233}{3.76} = 62$ PSI (At base, Point #1)

Resultant Stresses.

For Point #1 $= \sqrt{(547)^2 + (62)^2} = 550$ PSI

For Point #2 $= \sqrt{(1217)^2 + (157)^2} = 1226$ PSI

GENERAL ELECTRIC CO.
Nuclear Energy Division
ENGINEERING CALCULATION SHEET

NUMBER ______________________ DATE JAN 3 · 77
SUBJECT [illegible] BY [illegible] GANTEZ SHEET 7 OF ____

WELD CALCULATION ON COLUMN - DIVIDER - COLUMN (DWG NO. 762E210)

IN THIS ANALYSIS THE WORST CONDITION IS CONSIDERED FOR SAKE OF CONSERVATISM. ASSUME THAT THE TWO ROWS OF COLUMNS ARE PULLING APART.

BY LOOKING AT DWG 762E210 AND READING NOTE 3, WE CAN SAY THAT ONLY $3\frac{1}{2}$ PAIRS OF COLUMNS ARE WELDED FROM EACH END TO THE DIVIDER (PART NO. 22). THE REMAINDER 3 PAIRS IN MIDDLE ARE NOT WELDED TO THE DIVIDER.

SINCE THE TWO ROWS ARE COMPLETELY CONNECTED TO EACH OTHER, (BY GUSSET, P/N 23) ALL THE PULLING FORCE IS TRANSMITTED TO THE DIVIDER.

F = ma WHERE a = 1 g = 32.2 $\frac{ft}{sec^2}$ = 386.4 $\frac{in}{sec^2}$

m = $\frac{W}{g}$, AND W = 16 522 LBS (LOADED RACK)

F = $\frac{W}{g}$ · g = W = 16 522 LB

WELD AREA A_w

A_w = [illegible] (4)(·) + ([illegible])([illegible])(2 [illegible])(4)(2) = 22.712 in^2

FOR 6 COLUMNS   FOR 2 END CHANNELS

WELD STRESS, $T_w = \frac{F}{A} = \frac{16\,522}{22.712} = 727$ PSI

FOR FILLER ALLOY ER-5356 YIELD STRENGTH = 20 000 PSI (REF. WELDING BY KISER ALUMINUM TABLE [illegible] 3-[illegible]); SAFETY FACTOR = $\frac{20\,000}{727}$ = 27

WELD CALCULATION

COLUMN - GUSSET - COLUMN (PART NOS. 17, 3, AND 16)

WELD AREA, A_w:

$$A_w = (.707)(.1875)(4)(7)(6) + (.707)(.1875)(2)(2)(2.[illegible]) = 23.66 \text{ SQ.IN.}$$

STRESS ON WELD $\sigma_w = \frac{F}{A} = \frac{16522}{23.66} = 698$ PSI

SAFETY FACTOR $= \frac{[illegible]}{698} = 28$

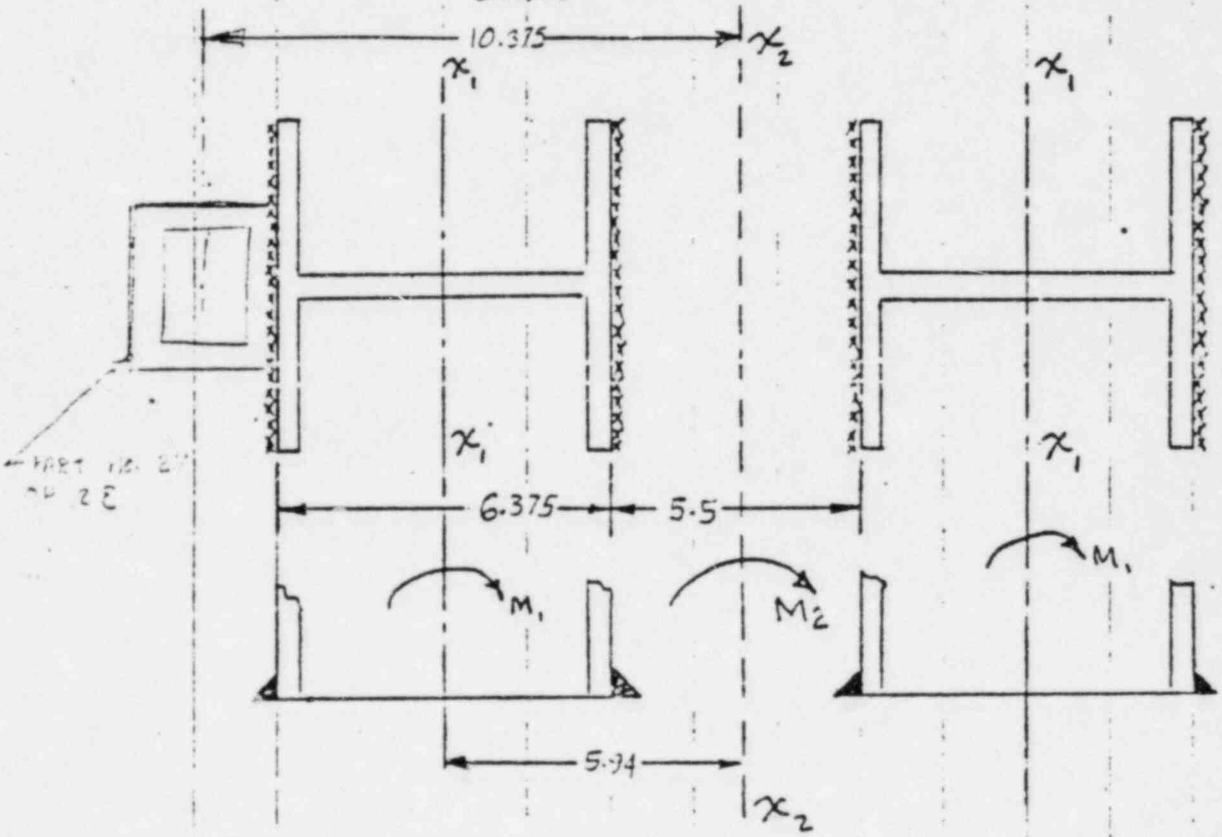
IN REALITY, THE FORCE THAT PULLS GUSSET APART FROM COLUMNS IS FAR LESS THAN 16522 LBS.

IN ABOVE ANALYSIS, THE STIFFENER GUSSET (PART NO 25) IS NOT EVEN CONSIDERED

WELD STRESSES ON COLUMN-BASE JOINT

CASE 1) ASSUMING EACH COLUMN CARRIES ITS OWN MOM. AND SHEAR

CASE 2) ASSUMING BOTH COLUMNS ACT AS A SINGLE BEAM



FOR THE COLUMN

$$I_{x_1x_1} = 21.3 \text{ IN}^4$$

$$A_1 = 3.76 \text{ IN}^2$$

$$c_1 = 3.19 \text{ IN}$$

FOR THE TWO COLUMNS:

$$I_{x_2x_2} = 2I_{x_1x_1} + (5.94)^2(2A_1)$$
$$= 2(21.3) + (5.94)^2(2)(3.76) = 308 \text{ in}^4$$

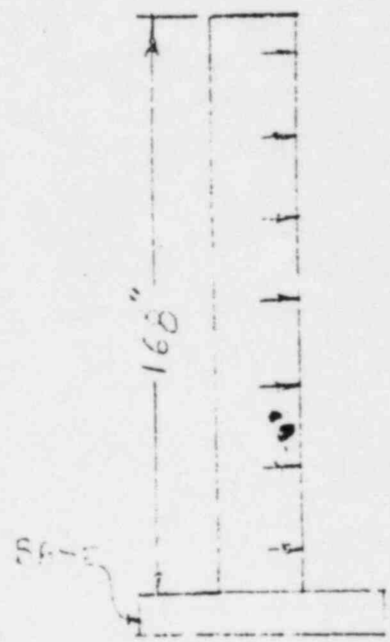
GENERAL ELECTRIC CO.
Nuclear Energy Division
ENGINEERING CALCULATION SHEET

NUMBER ______ DATE JAN 12 - 77
SUBJECT CANKSO LOSS OF FUNCTION BY J GANJET SHEET 9A OF ______

IN NEXT PAGE THE ENTIRE RACK, FOR SAKE OF CONSERVATISM, IS CONSIDERED AS A CANTILEVER BEAM WHICH IS UNIFORMLY LOADED ~~AND~~ WITH LENGTH OF 168 IN.

MOMENT AT BASE IS:

$$M = -\frac{WL}{2} = -\frac{(16562)(168)}{2} = 1470458 \text{ IN. LBS}$$

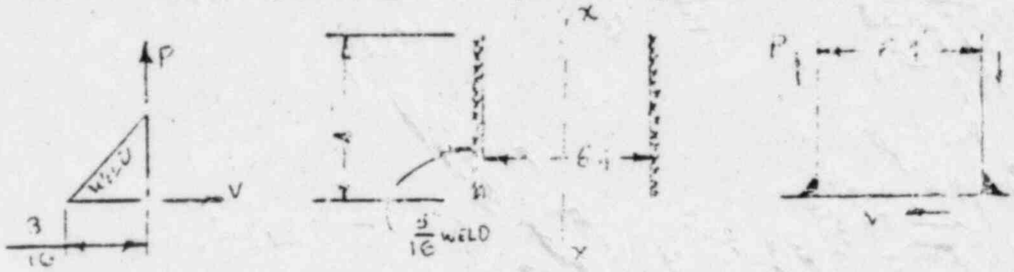


GENERAL ELECTRIC CO.
Nuclear Energy Division
ENGINEERING CALCULATION SHEET

NUMBER ______ DATE ______
SUBJECT CACRS ASSURANCE OF FUNCTION BY J. GANJEI SHEET 10 OF ______

WELD ANALYSIS – CASE I

CONSIDER A SINGLE COLUMN (P/N 16) WHICH IS FIXED AT BASE AND SUBJECTED TO BENDING MOMENT



MOMENT PER COLUMN = 1470458 ÷ 20 = 73523 IN-LBS

$P = \frac{M}{6.4} = \frac{73523}{6.4} = 11488$ LBS

$V = \frac{15,020}{20} = 751$ LBS (SHEAR PER COLUMN)

RESULTANT = $\sqrt{(11488)^2 + (751)^2}$ = 11,513 LBS

STRESS = $\frac{F}{A_w}$

$A_w = 2(.707)(.19)(4\quad) = 1.07$ SQ IN

STRESS = $\frac{11513}{1.07} = 10700$ PSI < YIELD

Y.S. FOR ER 5356 = 20,000 PSI

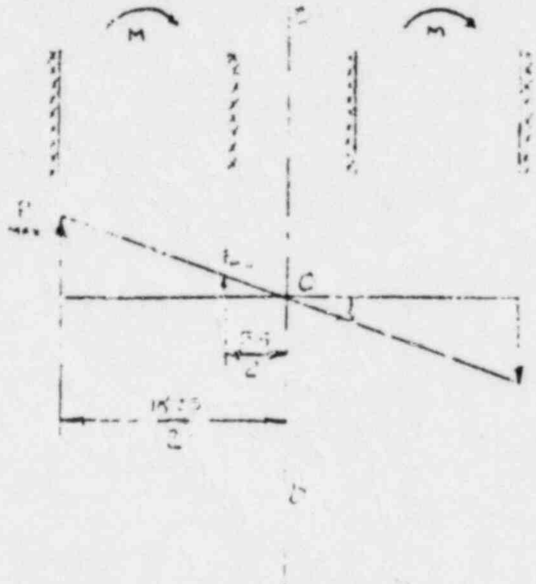
Y.S. FOR ER 5356-T6 = 30,000 PSI

NOTE:
IN ABOVE CALCULATION THE SUPPORT FROM THE DIVIDER (P/N 22) WAS IGNORED. IF WE CONSIDER THE DIVIDER, THE MOMENT AND SHEAR VALUES FOR THIS CALCULATION WOULD BE: M = 3653 IN-LBS, AND V = 233 LBS RESPECTIVELY (SEE PAGE 5) WHICH WOULD RESULT IN LOT HIGHER SAFETY FACTOR.

GENERAL ELECTRIC CO.
Nuclear Energy Division
ENGINEERING CALCULATION SHEET

NUMBER ______ DATE JAN 5 77
SUBJECT SEISMIC ASSURANCE OF FUNCTION BY J. GARJEJ SHEET 11 OF ____

WELD ANALYSIS (CONTINUED) CASE II



ASSUMING THAT B-B AXIS IS THE NEUTRAL AXIS FOR THE TWO I-BEAMS. THE WELD STRESSES INCREASE LINEARLY FROM B-B AXIS.

$\sum M_B = 0$

$2M = 2P_{max}\left(\frac{18.25}{2}\right) + 2P_{min}\left(\frac{5.5}{2}\right)$

IN TWO SIMILAR TRIANGLES, WE HAVE: $\frac{P_{min}}{5.5} = \frac{P_{max}}{18.5}$, $P_{min} = \frac{P_{max}(5.5)}{18.5}$

$P_{min} = .3P_{max}$

MOMENT FOR COLUMN = 73523 IN-LB.

$73523 = 9.125P_{max} + 2.75(.3P_{max})$

P_{max} = 7[illegible]0 LBS

SHEAR FOR COLUMN = 751 LBS

RESULTANT, $R = \sqrt{P_{max}^2 + V^2} = \sqrt{(5.40)^{10} + (5.64)^5} = 7427$ LBS

$A_w = 1.07\ in^2$ (SEE PG 10)

$s = \frac{7427}{1.07} = 6941$ PSI COMPARE THIS WITH YIELD STRENGTH OF WELD ON PAGE 10

AGAIN, NO CREDIT WAS TAKEN FOR EXISTANCE OF THE DIVIDER (P/N 22) CONSIDERING THE DIVIDER WOULD RESULT IN LOT LESSER STRESSES.

GENERAL ELECTRIC CO
Nuclear Energy Division

ENGINEERING CALCULATION SHEET

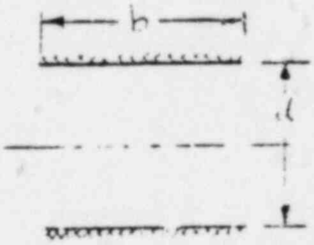
NUMBER ______ DATE Jan 4 - 77
SUBJECT CAGS: [illegible] of [illegible] BY J. Gandet SHEET 12 OF ______

ALTERNATE WELD ANALYSIS

BASED ON PROPERTIES OF WELD TREATED AS A LINE.

(SEE PAGE 7.4-7 TABLES OF REF 4)

WE USE SECTION MODULUS OF WELD, S_w FOR WELDS SUBJECTED TO BENDING LOADS.



$S_w = bd$

$b = 4$

$d = 6.4$

$S_w = (4)(6.4) = 25.6$ in²

$f_B = \frac{M}{S_w} = \frac{73523}{25.6} = 2872 \ \frac{LBS}{IN}$

SHEAR $= 751$

SHEAR/IN. $= \frac{751}{2(4)} = 94 \ \frac{LBS}{IN}$

f = RESULTANT $= \sqrt{(2434)^2 + (94)^2} = 2486 \ \frac{LBS}{IN}$ THIS SHOULD BE THE WELD STRENGTH

f = (ALLOWABLE WELD STRESS)(WELD SIZE ω)

KNOWING THAT Y.S OF WELD = 20,000 PSI, WE CAN SAY THAT ITS ALLOWABLE IS AT LEAST 15,000 PSI

$\therefore \quad 2486 \frac{LB}{IN} = (15{,}000 \frac{LB}{IN^2})(\omega) \longrightarrow \omega = .1657''$

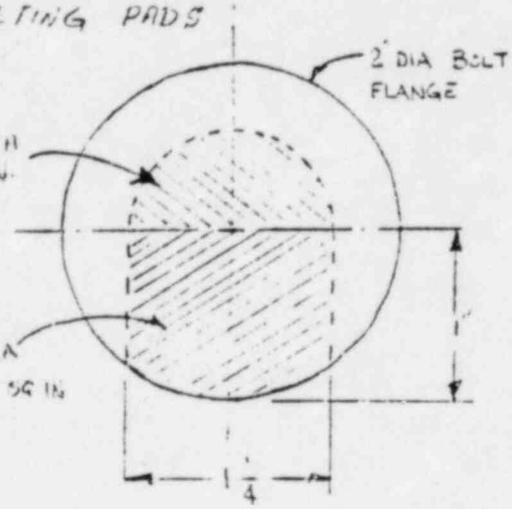
THE WELD SIZE USED IS: $\frac{3}{16}$ WHICH RESULTS IN SAFETY FACTOR OF: $\frac{.19}{.1657} = 1.15$ (SEE NOTE ON PAGE 10)

GENERAL ELECTRIC CO.
Nuclear Energy Division
ENGINEERING CALCULATION SHEET

NUMBER ______ DATE JAN 6 - 77

SUBJECT RACKS ... ASSURANCE OF FUNCTION BY J GANIEZ SHEET 13 OF ____

STRESS ANALYSIS OF RACK'S BOLTING PADS



BOLT FLANGE AREA

$A_B = \frac{\pi D^2}{4} = 3.14$ SQ IN.

NET STRESS AREA

$A_N = 3.14 - (.6 + 1.29) = 1.29\ IN^2$

TIGHTENING TORQUE AS SHOWN ON ARRANGEMENT DWG = 80 FT-LBS

$(80\ FT\text{-}LB)(12\ \frac{IN}{FT}) = 960\ IN\text{-}LBS$

APPROXIMATE RELATION BETWEEN TORQUE AND TENSILE FORCE ON BOLT IS:

$T = \mu D F$ WHERE.

$960 = (.2)(1) F$

$F = 4800$ LBS

T = TORQUE, IN-LBS

D = NOMINAL BOLT DIA, IN

F = TENSILE FORCE ON BOLT, LBS

μ = COEFFICIENT OF FRICTION ≈ .2

LOAD ON BOLT AS A RESULT OF OVERTURNING = 2051 LBS (FROM P15)

TOTAL LOAD = 2051 + 4800 = 6851 LBS

STRESS ON BOLTING PAD = $\frac{6851}{1.29}$ = 5310. PSI OK

MATERIAL OF CASTING: ASTM B-108 TYPE 3G70A-T6

MIN TENSILE STRENGTH = 23000 PSI

MIN YIELD (AT 0.2% OFFSET) = 16.000 PSI

GENERAL ELECTRIC CO.
Nuclear Energy Division
ENGINEERING CALCULATION SHEET

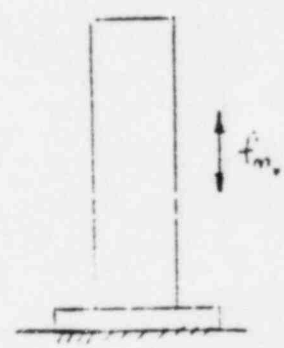
NUMBER ______ DATE JAN 7 - 77
SUBJECT CPERS: ASSURANCE OF FUNCTIONAL BY J GANSEI SHEET 14 OF ______

CALCULATION OF NATURAL FREQUENCY IN VERTICAL DIRECTION

$$f_{n_v} = 3.13\sqrt{\frac{k}{W + \frac{1}{3}w\ell}} \qquad \text{(REF. G PG 303 CASE 11)}$$

THE ABOVE IS THE FORMULA FOR LONGITUDINAL VIBRATION OF UNIFORM BAR OR SPRING, WITH END LOAD W, AND ITS OWN WEIGHT, $w\ell$, AND SPRING CONSTANT k = TENSION REQUIRED PER INCH OF STRETCH.

IN THIS EQUATION W IS ZERO SINCE WE HAVE NO LOAD APPLIED TO THE END OF RACK. ALSO THE WEIGHT OF FUEL BUNDLES DOES NOT CONTRIBUTE TO VERTICAL VIBRATION. THEREFORE IT IS EXCLUDE.



$$\therefore f_{n_v} = 3.13\sqrt{\frac{3k}{w\ell}}$$

WHERE:
$w\ell$ = WEIGHT OF EMPTY RACK, LBS
E = MODULUS OF ELASTICITY, PSI
A = CROSS SECTIONAL AREA, IN^2
ℓ = LENGTH OF RACK, 168 IN

$$k = \frac{F}{x} = \frac{EA}{\ell}$$

$$E = \frac{Stress}{Strain} = \frac{F/A}{\epsilon} = \frac{F}{\epsilon A}$$

$$\epsilon = \frac{\Delta\ell}{\ell}$$

$$\therefore E = \frac{F\ell}{A(\Delta\ell)} \longrightarrow \Delta\ell = \frac{F\ell}{AE}$$

$$k = \frac{F}{x = \Delta\ell} = \frac{FEA}{F\ell} = \frac{EA}{\ell}$$

$$\therefore f_{n_v} = 3.13\sqrt{\frac{3EA}{w\ell^2}} = \frac{3.13(\sqrt{3})}{\ell}\sqrt{\frac{EA}{w}}$$

GENERAL ELECTRIC CO.
Nuclear Energy Division
ENGINEERING CALCULATION SHEET

NUMBER ______ DATE JAN 7-77
SUBJECT [illegible] BY J GANTER SHEET 13 OF ______

$A = 20(3.76) + 8(1.734)$ SEE Pg 2

$A = 89$ SQ IN.

$w = \frac{2020}{168} = 12 \ \frac{LBS}{IN.}$

$f_{m_v} = \frac{\overset{5.42}{\sout{28.17}}}{168} \sqrt{\frac{10 \times 10^6 \times 89}{12}} = \frac{(28.17)(1000)(\overset{9.61}{\sout{8.46}})}{168} = 277.? \ Hz$

$f_{m_v} = 1444$ CYCLES/SEC.

BY REFERING TO CORRESPONDING CURVES (SEE REF. 7).

THIS HIGH NATURAL FREQUENCY IN VERTICAL DIRECTION INDICATES THAT THE RACK IS QUITE RIGID IN THIS DIRECTION AND SEISMIC LOADS ARE NOT SIGNIFICANT.

23

GENERAL ELECTRIC CO.
Nuclear Energy Division
ENGINEERING CALCULATION SHEET

DATE 13 JAN 77

SHOP ORDER NO. EWA 7992I-28 VERIFICATION CALCULATIONS.

SUBJECT SPENT FUEL RACKS, CAORSO LOSS OF FUNCTION ASSESSMENT BY J.C. Vickerman SHEET 1 OF 15

REFERENCES

1) DWGS.; SPENT FUEL RACK, TOP DWG 762E210

OUTL	105D4781
COLUMN	919D992
TUBE	117C2000
END CHANNEL	117C2001
GUSSET	209A7282
BASE CASTING	922D246
DIVIDER	112C3600
FUEL, FIELD ASSY	159C5242
BUNDLE OUTL	814E929
CHANNEL OUTL	829E165

2) SPECS; LOADING COMBINATIONS AND ACCEPTANCE CRITERIA 22A4677

3) LETTER; LOADS FOR CAORSO LOSS OF FUNCTION ASSESSMENT, DEC. 21, 1976, FROM JOHN CUNLIFFE

4) TEXT; VIBRATION THEORY & APPLICATIONS, W. F. THOMSON, © 1965, pg 274-275

GENERAL ELECTRIC CO.
Nuclear Energy Division
ENGINEERING CALCULATION SHEET

DATE 13 JAN 77

SHOP ORDER NO.

SUBJECT BY SHEET 2 OF 15

PURPOSE

THE PURPOSE OF THESE CALCULATIONS IS TO VERIFY THE CALCULATIONS BY J. GANJEI, 7 JAN 77, FOR ANALYSIS OF THE SPENT FUEL RACKS LOSS OF FUNCTION ASSESSMENT FOR THE CAORSO PLANT.

CALCULATIONS

WEIGHT OF FUEL BUNDLE & CHANNEL

645 + 99 = 744 Lbs

APPROX BUOYANT FORCE ON FUEL ASSEMBLY IN WATER, F_B/FUEL ASSY.

VOL. DISPL BY FUEL BUNDLE 1.1049 ft^3
CHANNEL .2417 ft^3

ASSUME $\rho_{WATER} = 62.4$ lb/ft

F_B/FUEL ASSY $= (1.1049 + .2417)(62.4) = 84.032$ Lbs

WEIGHT OF THE RACK = 2020 Lbs

BUOYANT FORCE ON RACK IN WATER.

VOL DISPL = 11.928 ft^3

F_B/RACK $= (11.928)(62.4) = 744.307$ Lbs.

TOTAL WT OF RACK AND FUEL, 20 BUNDLES, W_a.

$W_a = 20(744) + 2020 = 16,900$ Lbs.

GENERAL ELECTRIC CO.
Nuclear Energy Division
ENGINEERING CALCULATION SHEET

DATE 13 JAN 77

SHOP ORDER NO. ______

SUBJECT ______ BY ______ SHEET 3 OF 15

WET WEIGHT OF FULL RACK, W_B

$W_B = 16,900 - 20(84.032) - 744.307$

$= 14,475$ Lbs

THE EQ FOR THE NATURAL FREQUENCY OF THE RACK IS:

$$\omega_N = n^2 \sqrt{gEI/w} \quad , \; w = \text{WT/UNIT LENGTH}$$

ASSUME THAT THE EFFECTIVE LENGTH IS FROM THE CENTER OF THE DIVIDER TO THE TOP OF THE BASE.

$$\ell = 110.79 \text{ in.}$$

ASSUMING THAT THE END CONDITIONS ARE CLAMPED AND HINGED, THE VALUE FOR $(n\ell)^2$ IN THE FUNDAMENTAL MODE IS:

$$(n\ell)^2 = 15.4$$

SOLVING FOR FREQ, f_N

$$f = \frac{\omega}{2\pi}$$

$$\therefore f_N = \frac{15.4}{2\pi \ell^2} \sqrt{gEI/w}$$

$g = 386.07$ in/sec²

$E = 1 \times 10^7$ PSI, ALUM.

GENERAL ELECTRIC CO.
Nuclear Energy Division
ENGINEERING CALCULATION SHEET

DATE 13 JAN 77

SHOP ORDER NO.

SUBJECT ______ BY ______ SHEET 4 OF 15

MOMENT OF INERTIA ABOUT THE CENTER OF THE RACK

I FOR BOX CHANNEL, USING I OF X-SECT IF CHANNEL WAS STRAIGHT UP & DOWN.

$$I_{\square} = \frac{2.500^4 - 2.125^4}{12} = 1.556 \text{ IN}^4$$

I_I FOR COLUMN,
DUE TO SCHEDULE, THE VALUE OF MOMENT OF INERTIA FOR THE COLUMN WAS COMPARED TO STANDARD I BEAMS AND FOUND TO BE ACCURATE

$$I_I = 21.3 \text{ IN}^4$$

$$I = \Sigma\left[I_n + A_n d_n^2\right]$$

FOR COLUMNS $A = 3.76 \text{ IN}^2$

$$d = \frac{6.38}{2} + \frac{5.60}{2} = 5.99 \text{ IN}$$

FOR BOX CHANNEL $A = 1.73 \text{ IN}^2$

$$d_1 = \frac{2.5}{2} + 6.38 - \frac{5.6}{2} = 10.43 \text{ IN}$$

$$d_2 = \frac{5.6}{2} - \frac{2.5}{2} = 1.55 \text{ IN}$$

I_{TOTAL} FOR COLUMNS

$$I = 20\left[21.3 + (3.76)(5.99)^2\right]$$

$$= 3124 \text{ IN}^4$$

GENERAL ELECTRIC CO.
Nuclear Energy Division
ENGINEERING CALCULATION SHEET

DATE 13 JAN 77

SHOP ORDER NO. ______

SUBJECT ______ BY ______ SHEET 5 OF 15

I_{TOTAL} FOR BOX CHANNEL

$$I_1 = 4\left[1.556 + (1.73)(10.43)^2\right]$$

$$= 759 \text{ IN}^4$$

$$I_2 = 4\left[1.556 + (1.73)(1.55)^2\right]$$

$$= 22.85 \text{ IN}^4$$

$$I = I_1 + I_2 = 759 + 23 = 782 \text{ IN}^4$$

I FOR THE RACK

$$I = 782 + 3124 = 3906 \text{ IN}^4$$

WEIGHT PER UNIT LENGTH, W

1st THE WEIGHT FOR THIS VALUE IS CONSIDERED TO BE THE WT OF COLUMNS, TUBES (BOX CHANNEL) & PLATES (ITEM 12) OVER A LENGTH EQUAL TO THE LENGTH OF THE COLUMNS

WT_I OF COLUMNS, $A = 3.76 \text{ in}^2$, $L = 168$ in., $\rho = .098$ #/in³

$$WT = (3.76)(168)(.098)(20) = 1238 \text{ LBS.}$$

$WT_{\square}$ OF TUBES, $A = 1.734$, $L_{COMB} = 1630.24$ in.

$$WT = (1.734)(1630.24)(.098) = 277 \text{ LBS.}$$

WT OF PLATES, $A = .625$, $L = 13.75$ in

$$WT = (.625)(13.75)(4)(.098) = 3.37 \text{ LBS}$$

TOTAL EFFECTIVE WEIGHT PER UNIT LENGTH

$$W = \frac{1238 + 277 + 3}{168} = 9.0357 \text{ Lb/IN}$$

THEREFORE THE ANALYTIC NATURAL FREQUENCY IS;

$$f_N = \frac{15.4}{2\pi(110.79)^2}\sqrt{\frac{(386.07)(10^7)(3906)}{9.0357}}$$

$$\boxed{f_N = 258.1 \text{ CPS}}$$

257.7 HZ

2ND THE WEIGHT PER UNIT LENGTH, W, IS CALCULATED CONSIDERING THE WEIGHT OF THE FUEL AS AN INTERGRAL PART OF THE RACK.

TOTAL DRY WEIGHT = 16,900 Lbs.
LENGTH = 176.75 IN

95.615 Lbs/IN

$$\therefore f_N = \frac{15.4}{2\pi(110.79)^2}\sqrt{\frac{(386.07)(10^7)(3906)}{95.615}}$$

$$\boxed{f_N = 79.3 \text{ CPS}}$$

$$\boxed{T = .0126 \text{ SEC}}$$

GENERAL ELECTRIC CO.
Nuclear Energy Division
ENGINEERING CALCULATION SHEET

DATE 13 JAN 77

SHOP ORDER NO.

SUBJECT BY SHEET 7 OF 15

BOTH OF THE FREQUENCIES OBTAINED ARE HIGHER THAN THE DATA AVAILABLE. FAROUK HUSSAIN STATED THAT IN THIS CASE THE VALUES OF G AT THE END OF THE SCALE SHOULD BE USED. THE DAMPENING FACTOR USED IN THE FOLLOWING DATA IS 4.0 %, 2 % FOR COMBINED LOADS PLUS 2 % FOR SUBMERGENCE IN WATER. THE FOLLOWING IS THE DATA FROM THE RESPONSE SPECTRA FURNISHED BY THE AE, HORZ.

SSE $G = .375$

SRVD $G = .6 \times 1.5 = .9$ @ 36 CPS

CHUGGING $= .425 \times 2.0 = .850$ @ 49 CPS

THE MULTIPLING FACTORS ARE FROM JOHN CUNLIFFES LETTER OF 24 SEP 76 TO J.P. HOFFMAN. USING SRSS FOR COMBINING THE G'S YIELDS THE FOLLOWING.

$$G_{COMB} = (.375^2 + .9^2 + .850^2)^{1/2}$$

$$\boxed{G_{\underset{HORZ.}{COMB}} = 1.293}$$

GENERAL ELECTRIC CO.
Nuclear Energy Division
ENGINEERING CALCULATION SHEET

DATE 13 JAN 77

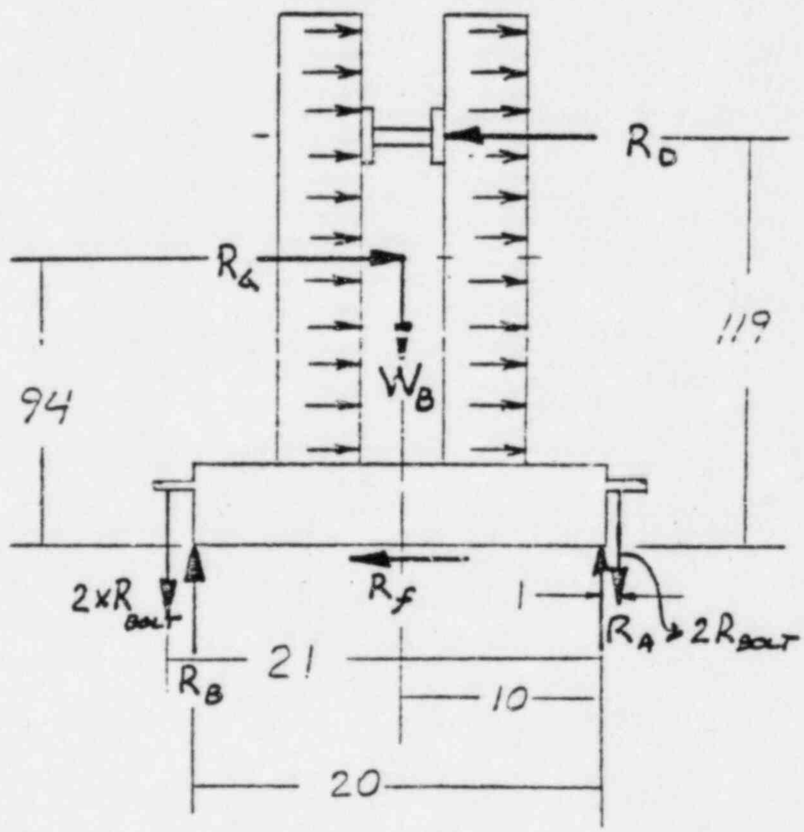
SHOP ORDER NO.

SUBJECT

BY

SHEET 8 OF 15

ASSUMING THAT THE FUEL LOAD IS UNIFORMLY DISTRIBUTED AGAINST THE SIDE OF THE RACK AND THAT THEIR RESULTANT G LOAD AND THE TOTAL WEIGHT ACT THROUGH THE GEOMETRIC CENTER OF THE RACK.



W_B IS THE WET WEIGHT OF FUEL & RACK

R_G IS THE HORZ. G LOAD

R_D IS THE REACTION AT THE DIVIDER

R_f IS THE FRICTION FORCE

R_{BOLT} IS THE LOAD FROM THE BOLT TORQUE

W_B = DRY WEIGHT − BUOYANT FORCE

DISPLACED VOLUMES OF WATER

RACK = 11.928 ft^3

FUEL = 20.097 ft^3

F. CHANNEL = 4.835 ft^3

TOTAL DISPLACEMENT = 38.86 ft^3

BUOYANT FORCE = $(38.86\ ft^3)(62.4\ Lb/ft^3\ H_2O)$

= 2424.864 Lbs

$\therefore W_B = 16{,}900 - 2425 =$ **14,475 Lbs**

R_G = G LOAD × (DRY WEIGHT + HYDRODYNAMIC)

= 1.293 (16,900 + 10% DRY WT)

R_G = **24037 Lbs.**

$R_f = \mu(W_B + 4R_{BOLT})$ ASSUMING $\mu = .2$

$R_{BOLT} = \dfrac{TORQUE}{K \times BOLT\ DIA}$, K = .193 FOR 1"-8NC BOLT

$R_{BOLT} = \dfrac{(80\ ft\text{-}Lb)(12\ \frac{IN}{FT})}{(.193)(1\ IN)} =$ **4974 Lbs**

GENERAL ELECTRIC CO.
Nuclear Energy Division
ENGINEERING CALCULATION SHEET

DATE 13 JAN 77

SHOP ORDER NO. ____________________

SUBJECT ____________________ BY ____________________

$$R_f = .2\left(14{,}475 + 4(4974)\right) = \boxed{6874 \text{ Lbs}}$$

SOLVING FOR R_D

$$\Sigma F_x = R_G - R_D - R_f$$

$$R_D = 24037 - 6874$$

$$R_D = \boxed{17163 \text{ Lbs}}$$

SOLVING FOR THE FLOOR REACTIONS R_A & R_B.

$$\Sigma M_A = R_B(20) - 2R_{BOLT}(21) - W_B(10) + R_G(94) - R_D(119) + 2R_{BOLT}(1)$$

$$R_B = \frac{208908 + 144750 - 2259478 + 2042397 - 9948}{20}$$

$$R_B = 6331.45 \approx \boxed{6331 \text{ Lbs}}$$

$$\Sigma F_y = R_B + R_A - 4R_{BOLT} - W_B$$

$$R_A = -6331 + 4(4974) + 14{,}475$$

$$R_A = \boxed{28040 \text{ Lbs}}$$

GENERAL ELECTRIC CO.
Nuclear Energy Division
ENGINEERING CALCULATION SHEET

DATE 13 JAN 77

SHOP ORDER NO.

SUBJECT ______ BY ______ SHEET 11 OF 15

LOAD ON DIVIDER WELDS IN TENSION FROM 1/2 OF THE RACK.

LOAD = 17,163 / 2 = 8581.5

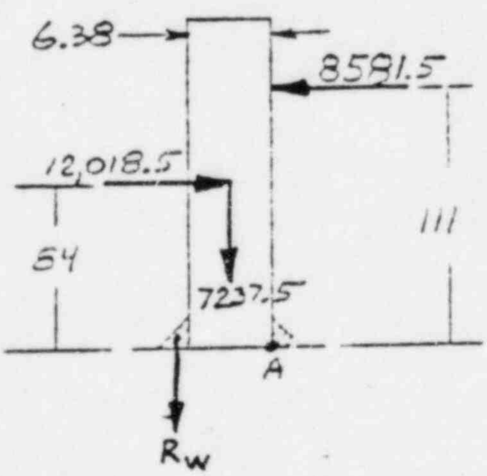
TOTAL LENGTH OF WELD
3 COLS. BOTH ENDS TIMES WIDTH
$3 \times 2 \times 4.62 = 27.72$ IN
2 END CHANNELS TIMES WIDTH
$2 \times 2.19 = 4.38$ IN

AREA OF WELD, .25 FILLET

$$A_W = (.25)(.707)(27.72 + 4.38) = 5.674 \text{ IN}^2$$

$$\sigma_W = \frac{8581.5}{5.674} = \boxed{1512 \text{ PSI}}$$

WELD STRESSES IN BASE



AREA OF WELD
COL FILLET WIDTH
$9 \times .50 \times .707 \times 4.62 = 14.7$
ENDS
$2 \times .50 \times .707 \times 2.19 = 1.55$

TOTAL AREA = 16.25 IN^2

$$\Sigma M_A = 12{,}018.5(84) - R_W(6.38) - 7237.5(6.38/2) - 8581.5(111)$$

$$R_W = 5316.59$$

$$\sigma_W = \boxed{327 \text{ PSI}}$$

WELD AT BOTTOM OF COL IN SHEAR

WELD AREA = 16.25 X 2 = 32.50 IN^2

F_S = 12,018.5 − 8581.5 = 3437. Lb

$\tau_W = \frac{3437}{32.5} = \boxed{105.75}$ PSI

STRESS IN BOLT FLANGE

ASSUME THAT THE LOAD FROM TORQUING THE BOLTS IS NOT RELIEVED BY COMPRESSION OF THE BASE.

ANALYZING FOR SHEAR OUT OF FLANGE

SHEAR CIRCUMFERENCE = (2" DIA) π − 1.25
= 5.03 IN

SHEAR AREA = (5.03)(1.5)

A_S = 7.5497 IN^2

$\tau_{FLANGE} = \frac{4974}{7.5497} = \boxed{658.83 \text{ PSI}}$

GENERAL ELECTRIC CO.
Nuclear Energy Division
ENGINEERING CALCULATION SHEET

DATE 13 JAN 77

SHOP ORDER NO.

SUBJECT BY SHEET 13 OF 15

COMPESSION OF BASE CASTING AT SUPPORTS.

X-SECT AREA OF WEBS IN COMPRESSION IS ASSUMED TO BE THE AREA BETWEEN LIGHTENING HOLE SPACING.

THICK WEB AREA = (.62)(6.625) = 4.1075 IN^2

THIN WEB AREA MINUS HOLE AREA =

(.38)(6.625) - (.38)(3.00) = 1.3775 IN^2

TOTAL A_x = 5.485 IN^2

MAX COMPRESSIVE LOAD PER SUPPORT

LOAD = 28040/2 = 14020 LBS.

COMPRESSIVE STRESS, σ_c

$$\sigma_c = \frac{14020 \text{ LBS}}{5.485 \text{ IN}^2} = \boxed{2556 \text{ PSI}}$$

THIS STRESS IS THE MOST CRITICAL STRESS IN THE RACK. WHEN COMPARED TO THE COMPRESSIVE YLD STR OF 21,000 PSI THE F.S. IS:

$$F.S. = \frac{21,000}{2556} = 8.22 \quad \text{(HORZ.)}$$

GENERAL ELECTRIC CO.
Nuclear Energy Division
ENGINEERING CALCULATION SHEET

DATE 13 JAN 77

SHOP ORDER NO. ______

SUBJECT ______ BY ______ SHEET 14 OF 15

ANALYSIS IN THE VERTICAL DIRECTION.

THE LOAD IN THE VERTICAL DIRECTION IS THE RACKS OWN WEIGHT.

THE EQUATION FOR THE NATURAL FREQ IS:

$$f_N = 3.13\sqrt{\frac{3k}{w\ell}} \quad , k = \frac{F}{\Delta x} \quad , E = \frac{F/A}{\Delta x/\ell}$$

$$= 3.13\sqrt{\frac{3EA}{(w\ell)\ell}} \quad , w\ell = \text{OWN WEIGHT}$$

$A = 20(3.76) + 8(1.734)$, REF PG. 4

$A = 89 \text{ in}^2$

$$f_N = 3.13\sqrt{\frac{3(10^7)(89)}{2020(168)}} = \boxed{277.7 \text{ CPS}}$$

$$T = \frac{1}{f_N} = \boxed{.0036 \text{ SEC}}$$

FROM VERTICAL RESPONSE SPECTRA

SSE = .15G

$(SRVD - 20\%)1.1 = \left(\frac{200}{386.07} - 20\%\right)1.1 = .45585G$

CHUGGING × 1.5 = (.215)1.5 = .3225G

COMBINING, SSE + SRVD + CHUG, FOR COMBINED LOAD

$$\text{LOAD COMBO} = (.15^2 + .45585^2 + .3225^2)^{1/2} = .5782G$$

DRF-439-# 16 2507-331 (FINAL)
35

GENERAL ELECTRIC

) JOHN CUNLIFFE
RYWELL ARR. CONT.
MC 767

PLACE
DATE JAN-13-77
CC: J.M. SAGER

BJECT CAORSO RACKS · ASSURANCE OF FUNCTION.

THE SUBJECT RACK HAS BEEN ANALIZED FOR STRUCTURAL STABILITY WHEN SUBJECTED TO COMBINED LOADS = SEISMIC, CHUGGING, AND SRVD LOADS. BASIS FOR THIS ANALYSIS VAS YOUR LETTER TO ME (DATED 12-21-76) AND DOCUMENT 22A4677 FOR BWR 4&5 FOR MARK II.

RACK IS STRONG AND WILL MAINTAIN ITS FUNCTION WHEN UBJECTED TO THE COMBINED ABOVE LOADS. THIS ANALYSIS IAS BEEN VERIFIED BY DAVE VICKERMAN WHO IS NOW RESPONSIBLE NGINEER FOR THESE RACKS (CONCEPT #2).

DESIGN RECORD FILE NO. IS "DV 762E210"

Gangli | REATOR SERVICING | 1850-283 | 5-1873

IN YOUR NAME PLAINLY — COMPONENT — BLDG & ROOM — PHONE DIAL COMM

-316 A (8-68) Rev.

GENERAL ELECTRIC CO.
Nuclear Energy Division
ENGINEERING CALCULATION SHEET

DATE 13 JAN 77

SHOP ORDER NO.

SUBJECT ____ BY ____ SHEET 15 OF 15

∴ THE MAX LOAD WILL BE

$$\text{MAX LOAD} = 1G + .5782G = 1.5782G$$

USING THE LOAD THE MAX VERTICAL LOAD ON THE BASE IS:

$$(16,900)(1.5782) = 26,672 \text{ Lbs.}$$

THE STRESS IN THE BASE WEB OVER ONE OF THE SUPPORTS IS.

$$\sigma_c = \frac{26,672}{4} / 5.485 = \boxed{1216 \text{ PSI}}$$

SUMMARY

FROM THE PRECEDING ANALYSIS, THE SPENT FUEL STORAGE RACK, LOSS OF FUNCTION CALCULATIONS BY JAVAD GANJEI CONFIRM THAT THE RACKS RETAIN THEIR FUNCTIONAL INTEGRITY UNDER THE NEW COMBINED LOADS.

D. C. Vickerman
13 JAN 77

Attachment 12

SARGENT & LUNDY ENGINEERS CHICAGO	Calcs. For SPENT FUEL STORAGE RACKS HORIZ. SEISMIC RESPONSE STUDY	Calc. No. 72
	X Safety-Related / Non-Safety-Related	Rev. / Date
		Page 1 of 17

Client CG&E	Prepared by [signature] Date 3/10/78
Project ZIMMER-1	Reviewed by [signature] Date 3/13/78
Proj. No. 4130 Equip. No.	Approved by Date

NUTECH FILE NO. 33.803.0551

STRUCTURE DESCRIPTION: SPENT FUEL POOL OF THE REACTOR BUILDING @ EL. 627'-9". THE SPENT FUEL STORAGE RACKS AND THE DIVIDER BEAM (BY G.E.) SPAN BETWEEN I-SECTIONS WITH BUMPER GUSSETT PLATES (BY S&L) AS A STRUCTURAL SYSTEM TO TRANSFER ALL HORIZONTAL SEISMIC FORCES TO THE POOL WALLS.

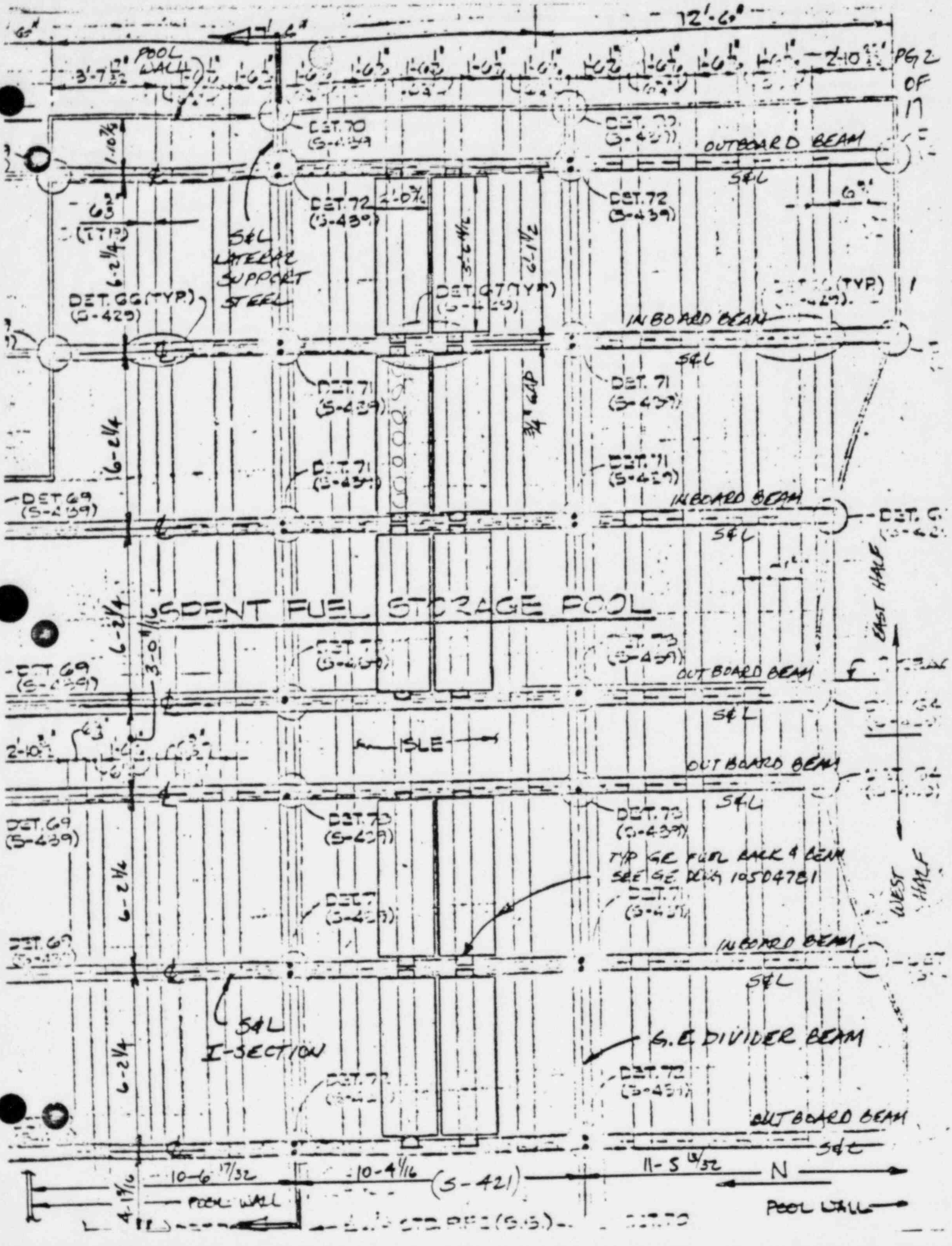
PROCEDURES FOR ANALYSIS FOR DESIGN: TWO APPROACHES FOR SEISMIC ANALYSIS WERE CONSIDERED.

PGS 1-16 (1) CONSIDER THE HORIZONTAL (EAST-WEST) SEISMIC RESPONSE OF S&L I-SECTIONS TO BE TRANSFERRED TO THE POOL WALL THRU THE G.E. DIVIDER BEAMS OF THE SPENT FUEL STORAGE RACKS. THE GE DIVIDER BEAMS USED AS LATERAL SUPPORTS ARE LOCATED AT APPROXIMATE THIRD SPANS OF THE S&L I-SECTIONS. THE CONNECTION BETWEEN THE LAST I-SECTION AND POOL WALL IS PROVIDED BY S&L. (REF. S-421)

PGS 16-17 (2) CONSIDER THE HORIZONTAL (EAST-WEST) SEISMIC RESPONSE OF S&L I-SECTIONS TO BE TRANSFERRED TO THE BASE OF THE SPENT FUEL POOL THRU CROSS BRACING OF THE STORAGE RACKS AND THRU SWING BOLTS @ BASE OF RACKS.

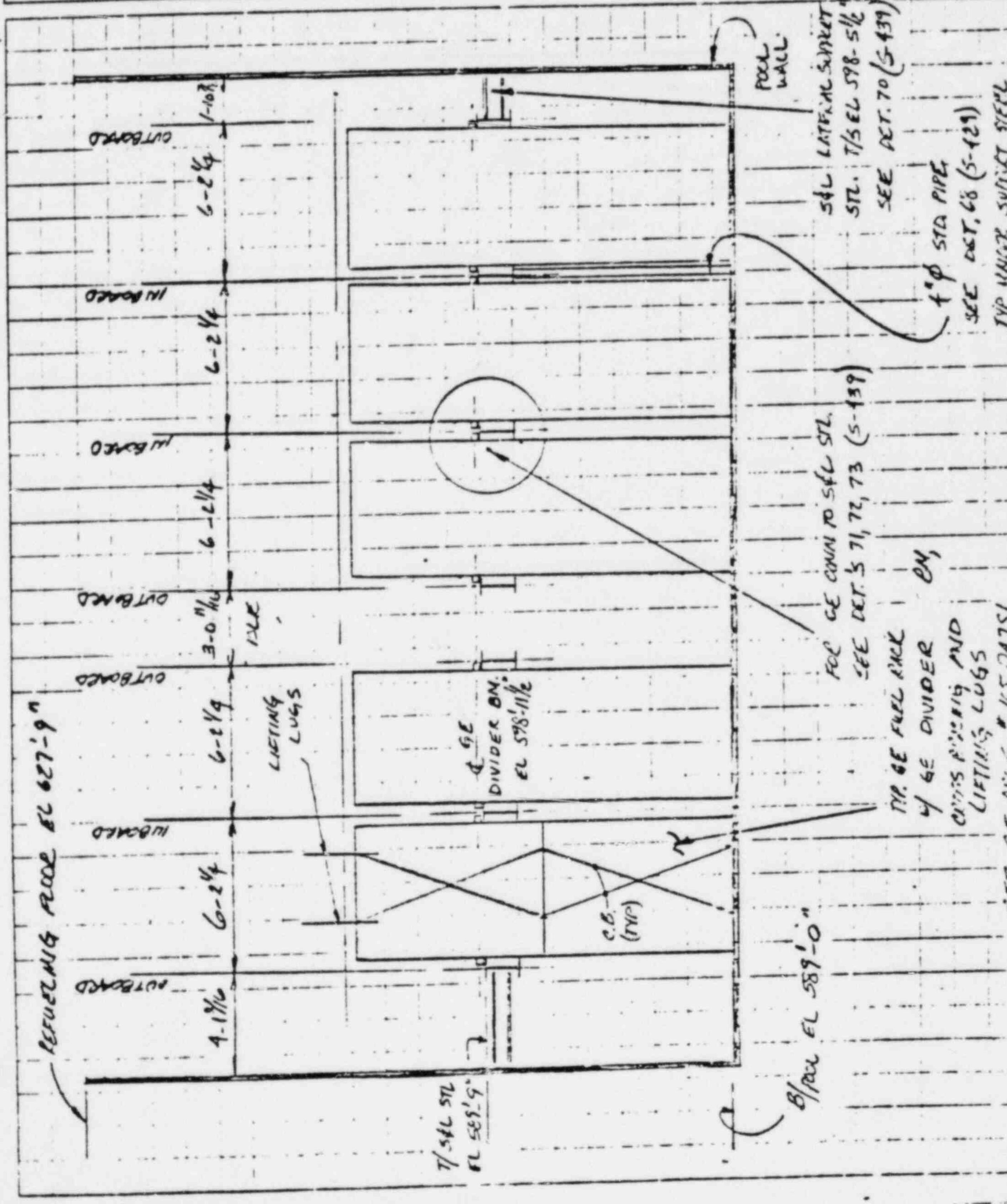
DESIGN METHODS & CODES, REFERENCES AND CRITERIA
MATERIALS
LOADS AND LOAD COMBINATIONS
} SEE INDIVIDUAL CALCULATION SHEETS

Form GQ 3.08.1 Rev. 2


PG 2 OF 17
12'-6"
POOL WALL
DET. 70 (S-439)
OUTBOARD BEAM
S&L
DET. 72 (S-439)
S&L LATERAL SUPPORT STEEL
DET. 66 (TYP.) (S-429)
DET. 67 (TYP.)
IN BOARD BEAM
DET. 71 (S-439)
3/4" GAP
DET. 69 (S-439)
INBOARD BEAM
SPENT FUEL STORAGE POOL
EAST HALF
OUT BOARD BEAM
ISLE
TYP GE FUEL RACK & BEAM SEE GE DWG 10504781
WEST HALF
S&L I-SECTION
G.E. DIVIDER BEAM
10-6 17/32
10-4 1/16
(S-421)
11-5 13/32
N
POOL WALL

SARGENT & LUNDY ENGINEERS CHICAGO	Calcs. For SPENT FUEL STORAGE RACKS ZIMMER SEISMIC RESPONSE STUDY	Calc. No. 72
	X Safety-Related / Non-Safety-Related	Rev. / Date
		Page 3 of 17

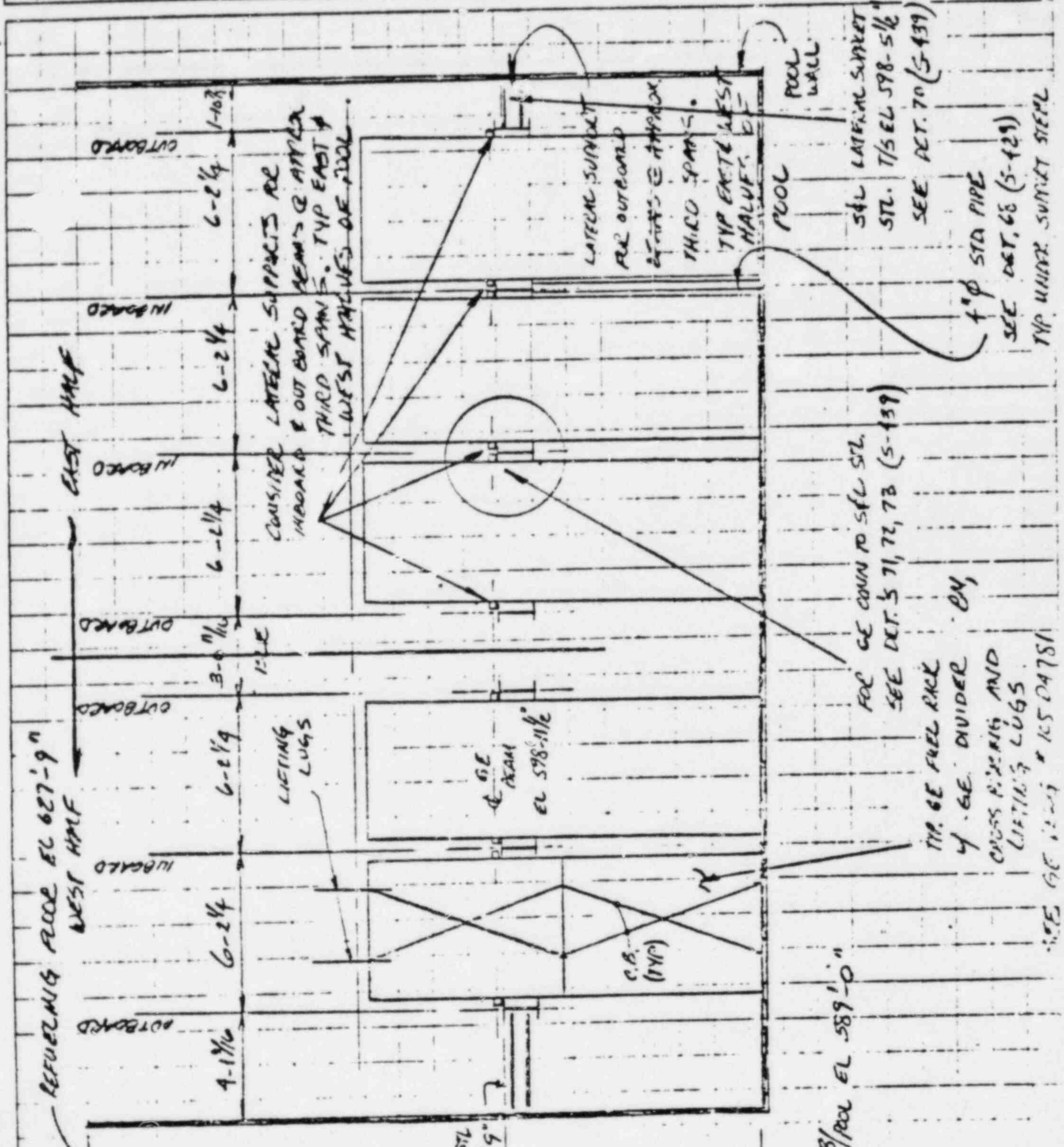
Client CG&E	Prepared by [signature]	Date 3/10/78
Project ZIMMER-1	Reviewed by [signature]	Date 3/10/78
Proj. No. 4130-00 Equip. No.	Approved by	Date



Form GQ 3.08.1 Rev. 2

SARGENT & LUNDY ENGINEERS CHICAGO	Calcs. For SPENT FUEL STORAGE RACKS — NOTE SEISMIC RESPONSE STUDY	Calc. No. 72
	X Safety-Related / Non-Safety-Related	Rev. / Date
		Page 4 of 17

Client CG&E	Prepared by James D. Ridge — Date 3/10/78
Project ZIMMER-1	Reviewed by Robert S. Natalie — Date 3/13/78
Proj. No. 4120-00 Equip. No.	Approved by — Date

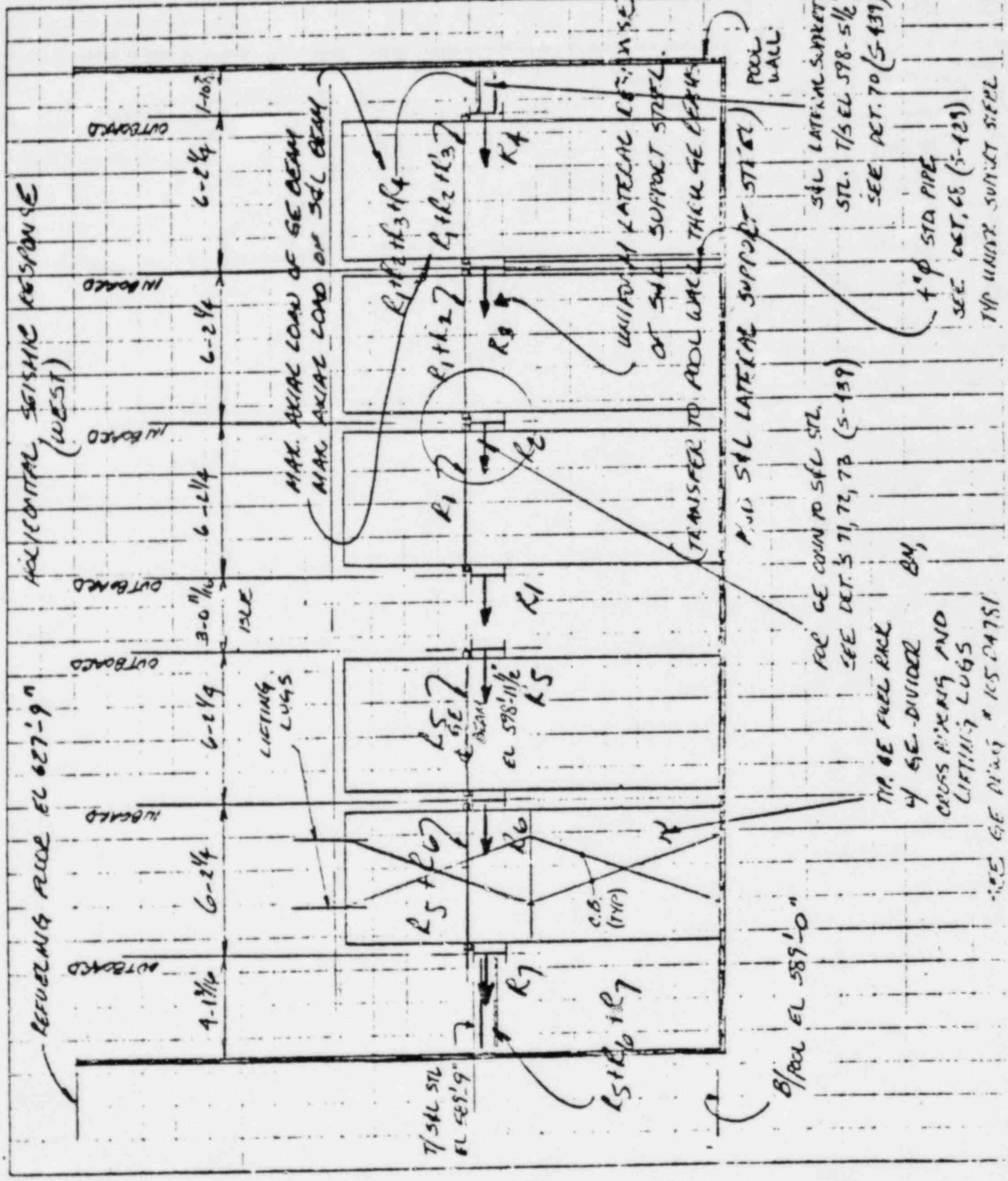


Form GQ 3.08.1 Rev. 2

SARGENT & LUNDY
ENGINEERS
CHICAGO

Calcs. For SPENT FUEL STORAGE RACKS		Calc. No. 72	
[illegible] SEISMIC RESPONSE [illegible]UDY		Rev.	Date
X Safety-Related	Non-Safety-Related	Page 5	of 17

Client CG&E		Prepared by [illegible]	Date 3/10/78
Project ZIMMER-1		Reviewed by [illegible]	Date 3/13/78
Proj. No. 4130-00	Equip. No.	Approved by	Date

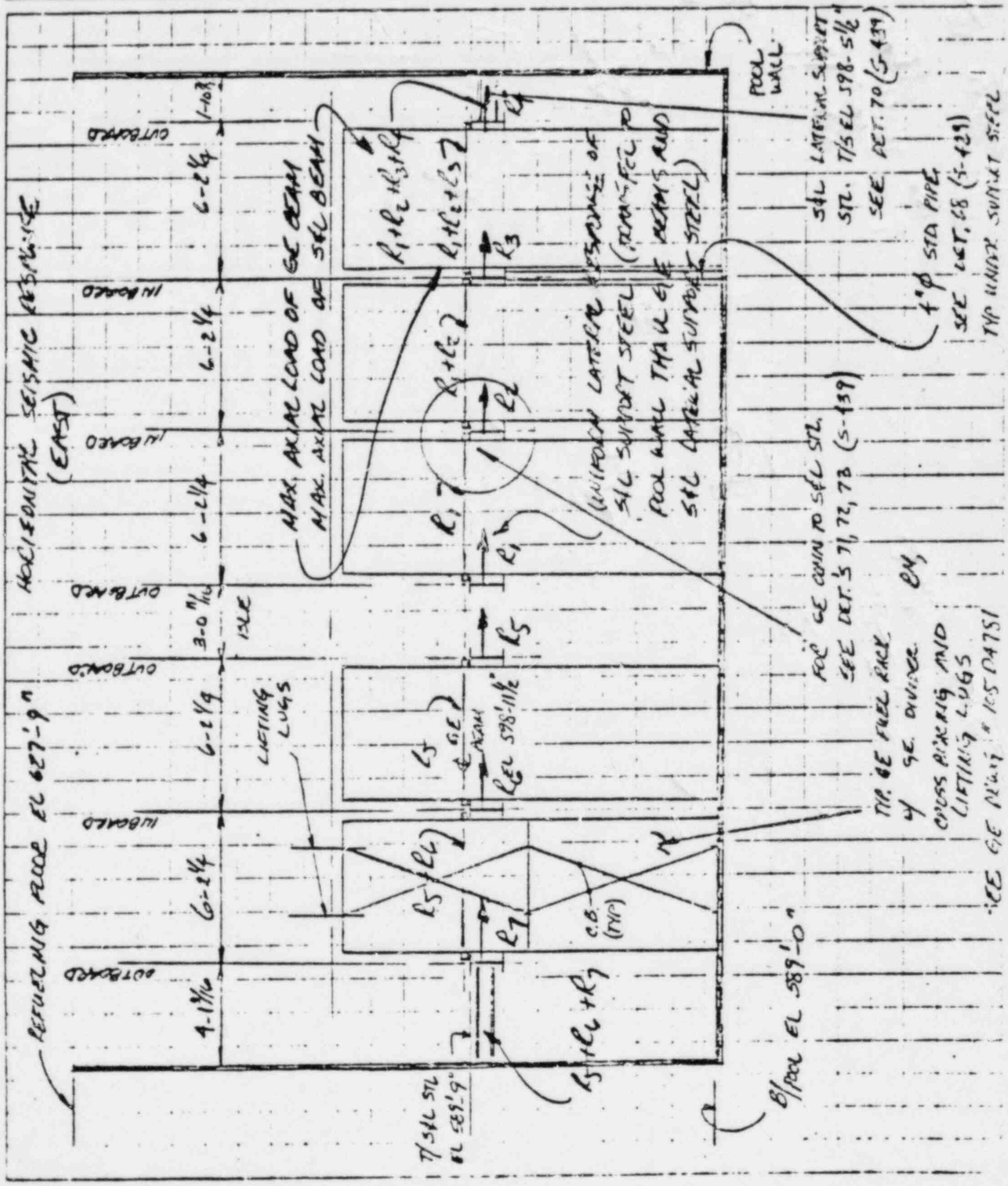


Form GO 3.08.1 Rev. 2

SARGENT & LUNDY ENGINEERS CHICAGO

Calcs. For SPENT FUEL STORAGE RACKS (HORIZ. SEISMIC RESPONSE) STUDY		Calc. No. 72	
X Safety–Related	Non–Safety–Related	Rev.	Date
		Page 6	of 17

Client CG&E	Prepared by [signature]	Date 3/10/78	
Project ZIMMER-1	Reviewed by Robert S. [signature]	Date 3/13/78	
Proj. No. 4170-00	Equip. No.	Approved by	Date

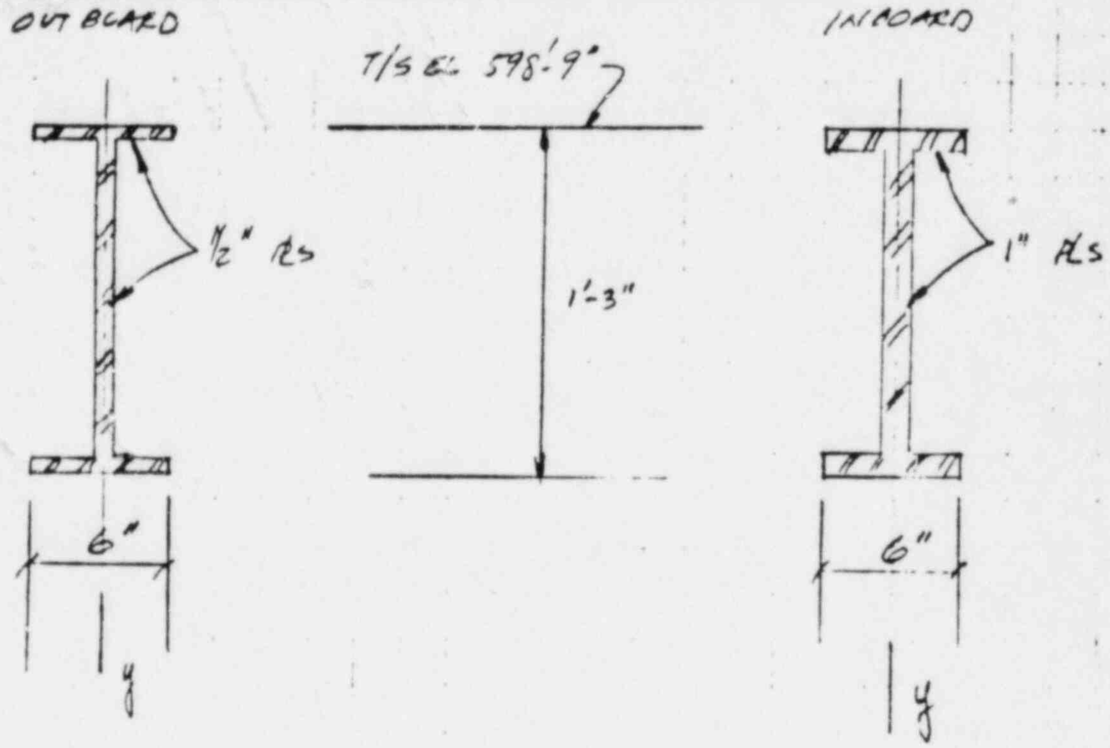


SARGENT & LUNDY ENGINEERS CHICAGO	Calcs. For SPENT FUEL STORAGE RACKS HORIZ. SEISMIC RESPONSE STUDY	Calc. No. 72
	☒ Safety-Related ☐ Non-Safety-Related	Rev. Date
		Page 7 of 17

Client CG&E	Prepared by [signature]	Date 3/10/78
Project ZIMMER-1	Reviewed by [signature]	Date 3/13/78
Proj. No. 4190-00 Equip. No.	Approved by	Date

DETERMINE OUTBOARD & INBOARD BEAM FREQUENCIES FOR UNIFORM LATERAL RESPONSE OF SEISMIC OCCURANCE.

SEC-I- SECTIONS OF THE SPENT FUEL POOL.



WEIGHT PER FOOT (ASSUME STAINLESS STEEL = 500 #/ft³)

OUTBOARD $\left[\left(2 \times \frac{6}{12} \times \frac{0.5}{12}\right) + \left(\frac{14}{12} \times \frac{0.5}{12}\right)\right] 500\ \#/ft^3 = 45\ \#/ft$

INBOARD $\left[\left(2 \times \frac{6}{12} \times \frac{1}{12}\right) + \left(\frac{13}{12} \times \frac{1}{12}\right)\right] 500\ \#/ft^3 = 87\ \#/ft$

Form GQ 3.08.1 Rev. 2

SECTION PROPERTIES

OUTBOARD

$$AREA = (2\times 6\times \tfrac{1}{2}) + (14\times \tfrac{1}{2}) = 13\ in^2$$

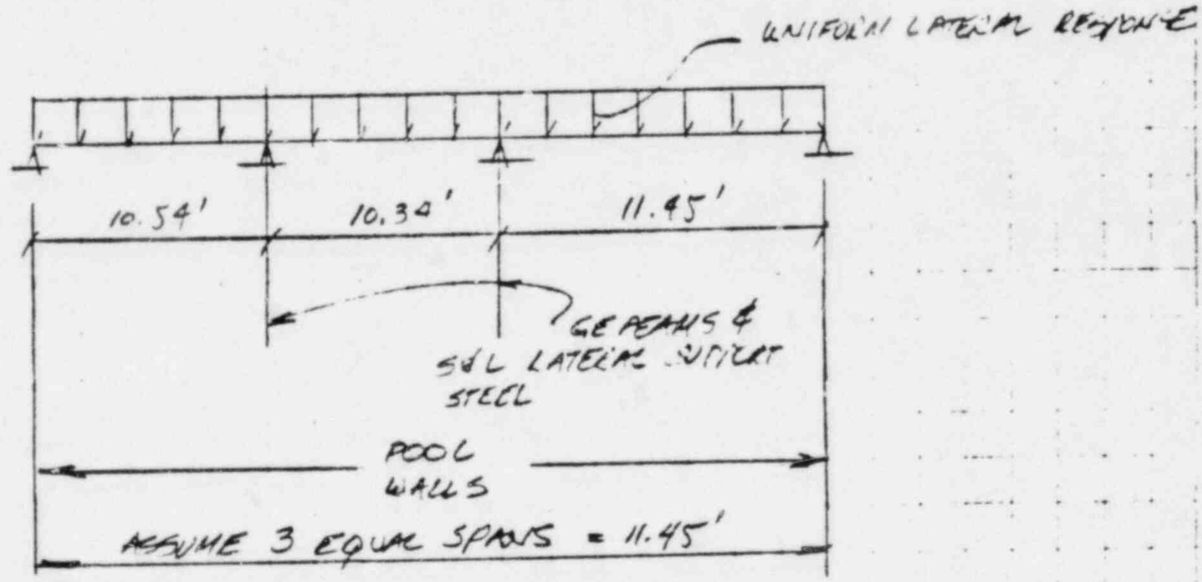
$$I_{yy} = bh^3/12 = \left(2\times \frac{0.5\times 6^3}{12}\right) + \frac{14\times 0.5^3}{12} = 18.14\ in^4$$

INBOARD

$$AREA = (2\times 6\times 1) + (13\times 1) = 25\ in^2$$

$$I_{yy} = bh^3/12 = \left(2\times \frac{1\times 6^3}{12}\right) + \frac{13\times 1^3}{12} = 37.08\ in^4$$

BEAM SPAN & BOUNDARY CONDITIONS (SELECT LARGEST LENGTH)



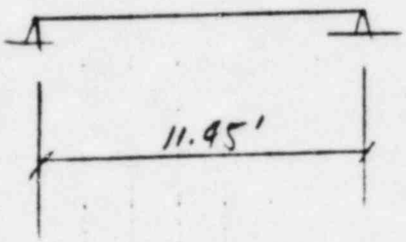
BY APPROXIMATE ANALYSIS TO DETERMINE THE FUNDAMENTAL FREQUENCY OF THE CONTINUOUS BEAM ABOVE, SELECT NATURAL MODE SHAPES OF A SIMPLY-SUPPORTED SINGLE SPAN AND A SIMPLE-FIXED END, SINGLE SPAN. THE FREQUENCIES OF THESE 2 CASES WILL PROVIDE A CONSERVATIVE RANGE OF VALUES IN WHICH TO SELECT CORRESPONDING HORIZ RESPONSES OF SEISMIC OCCURANCE FOR THE S&L I-SECTIONS.

SARGENT & LUNDY ENGINEERS CHICAGO	Calc. For SPENT FUEL STORAGE RACKS HORIZ. SEISMIC RESPONSE STUDY	Calc. No. 72
	X Safety-Related / Non-Safety-Related	Rev. / Date
		Page 9 of 17

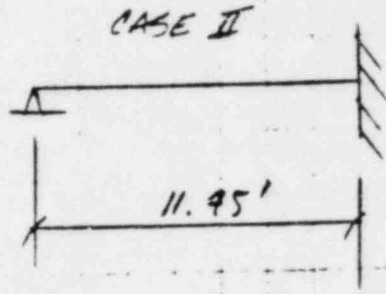
Client	CG&E	Prepared by	[signature] Date 3/10/78
Project	ZIMMER-1	Reviewed by	Robert S. Walter Date 3/13/78
Proj. No.	4190-00 Equip. No.	Approved by	Date

SELECT LARGEST SINGLE SPAN

CASE I



CASE II



Case I:

$$2\pi f_1 = \omega$$

$$\omega = \frac{n^2\pi^2}{l^2}\left(\frac{EI}{m}\right)^{1/2}$$

Case II:

$$2\pi f = \omega$$

$$\omega \cong \frac{(n+1/4)^2\pi^2}{l^2}\left(\frac{EI}{m}\right)^{1/2}$$

FOR BOTH CASES ABOVE, CONSIDER THE FIRST MODE SHAPE ($n=1$), AND CALCULATE THE FREQUENCIES FOR INBOARD AND OUTBOARD BEAMS.

$$\omega = \frac{\pi^2}{l^2}\left(\frac{EI}{m}\right)^{1/2} \qquad \omega \cong \frac{(1.25)^2\pi^2}{l^2}\left(\frac{EI}{m}\right)^{1/2}$$

WHERE $m = W/g$

$$\omega = \frac{\pi^2}{l^2}\left(\frac{EIg}{W}\right)^{1/2} \qquad \omega \cong \frac{(1.25)^2\pi^2}{l^2}\left(\frac{EIg}{W}\right)^{1/2}$$

OR $\omega = \pi^2\left(\frac{EIg}{Wl^4}\right)^{1/2}$ OR $\omega \cong (1.25)^2\pi^2\left(\frac{EIg}{Wl^4}\right)^{1/2}$

THEN $f = \frac{\omega}{2\pi} = \frac{\pi}{2}\left(\frac{EIg}{Wl^4}\right)^{1/2}$ THEN $f = \frac{\omega}{2\pi} \cong (1.25)^2\frac{\pi}{2}\left(\frac{EIg}{Wl^4}\right)^{1/2}$

WHERE $E = 29 \times 10^6$ psi $\qquad W = \#/in$

$I = in^4$

$g = 32.1739$ ft/sec/sec OR 386 in/sec/sec $\qquad l = in = (11.45)12 = 137.4''$

SARGENT & LUNDY ENGINEERS	For SPENT FUEL STORAGE RACKS HORIZ. SEISMIC RESPONSE STUDY	Calc. No. 72
	X Safety-Related / Non-Safety-Related	Rev. / Date
		Page 10 of 17

Client CG&E	Prepared by James Q Cidic	Date 3/10/78
Project ZIMMER-1	Reviewed by Robert S Wattick	Date 3/13/78
Proj. No. 4130-00 Equip. No.	Approved by	Date

FOR CASE I

OUTBOARD $f_{I_o} = \pi/2 \sqrt{\dfrac{29\times10^6 (12.14)(386)}{3.75 (137.4)^4}} = 19.36$ cps

INBOARD $f_{I_i} = \pi/2 \sqrt{\dfrac{29\times10^6 (37.03)\, 386}{7.25 (137.4)^4}} = 19.91$ cps

FOR CASE II

OUTBOARD $1.25^2 f_{I_o} = 30.25$ cps

INBOARD $1.25^2 f_{I_i} = 31.11$ cps

OBTAIN THE HORIZONTAL RESPONSE FOR OUTBOARD & INBOARD BEAMS FROM THE RESPONSE SPECTRA PLOTS USING A FREQUENCY RANGE OF 19 — 30 cps. REFERENCE SOIL-STRUCTURE INTERACTION (SSI) SEISMIC RESPONSE SPECTRA AND SAFETY RELIEF VALVE (SRV) RESPONSE SPECTRA. CONSERVATIVELY SELECT READINGS FROM THE REACTOR BUILDING SLABS @ EL. 627'-9" IN EAST & WEST DIRECTION ONLY. FOR SRV, HIGHEST ELEV. OF RESPONSE GIVEN IS EL 601'-7".

A. WORKING LOADS (SERVICE CONDITION) SSI + SRV (= OBE + SRV)

B. YIELD LOADS (ACCIDENT CONDITION) SSI (= DBE)

Form GQ 3.08.1 Rev. 2

SARGENT & LUNDY ENGINEERS CHICAGO	Calc. For SPENT FUEL STORAGE RACKS HORIZ. SEISMIC RESPONSE STUDY	Calc. No. 72
	X Safety-Related / Non-Safety-Related	Rev. / Date
		Page 11 of 17
Client C.G.&E.	Prepared by [signature]	Date 3/10/78
Project ZIMMER-1	Reviewed by Robert S. Walter [signature]	Date 3/13/78
Proj. No. 4190-00 Equip. No.	Approved by	Date

LOAD A
(FOR WORKING LOADS)

$SSI = 0.34\,g$
$SRV = 0.095\,g$
$SSI + SRV = 0.435\,g$ ← (GOVERNS REF. PG 12 & 14)

LOAD B
(FOR YEILD LOADS)

$SSI = 0.20\,g$ ← (REF. PG 13)

THE ABOVE g VALUES CORRESPOND TO THE % OF CRITICAL DAMPING AS FOLLOWS

STRUCTURE	OBE	DBE
H.S. BOLTED STL. FRAMED STRUCTURE	5%	10%

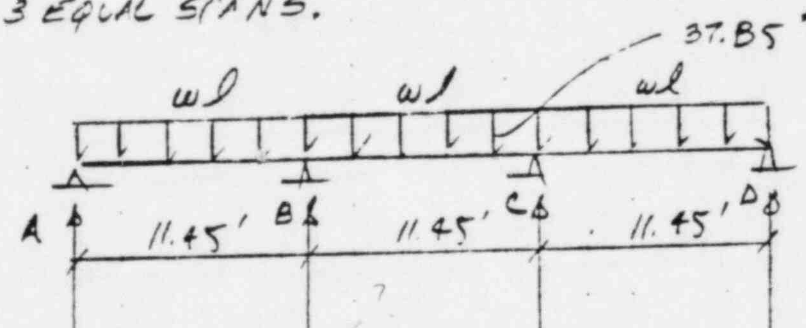
REF. S&L DESIGN CRITERIA FOR ZIMMER-1 PROJECT

RESPONSES

O[illegible] $45\,\#/ft\,(0.435) = 19.58\,\#/ft$

INBOARD $87\,\#/ft\,(0.435) = 37.85\,\#/ft$

DETERMINE THE RESPONSES @ LATERAL SUPPORT PTS.
REF. AISC PG 2-210 #36. CONSIDER INBOARD BEAM FIRST.
ASSUME 3 EQUAL SPANS.



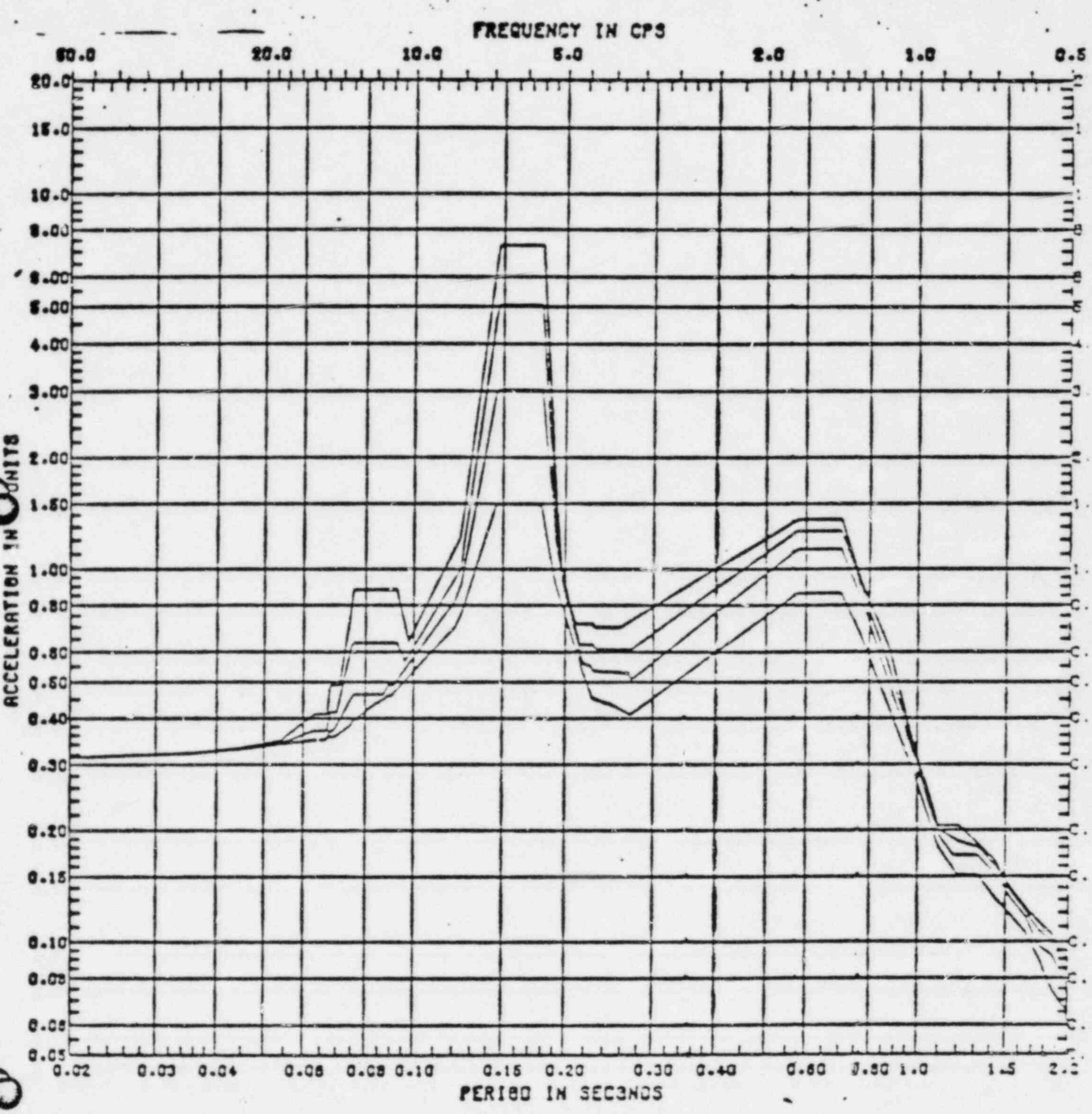
$R_A = 0.4wl$ $R_B = 1.1wl$ $R_C = 1.1wl$ $R_D = 0.4wl$
$R_A = 173\#$ $R_B = 476\#$ $R_C = 476\#$ $R_D = 173\#$

Form GQ 3.08.1 Rev. 2

SARGENT & LUNDY ENGINEERS

14 JUL 76
SL180

ZIMMER1 SS -STRUCT.HBR.885.SLAB 6 Y
DESIGNER O.E. Lev CHECKER B. P. Jain
DESIGN SPECTRA AT JOINT/SLAB
PEAKS WIDENED BY 10% ON EACH SIDE
DAMPING 0.005 0.010 0.020 0.050
PAGE 12 OF 17



O.B.E. Horiz. Response Spectra E-W Component SPECTRA NO. 6-B

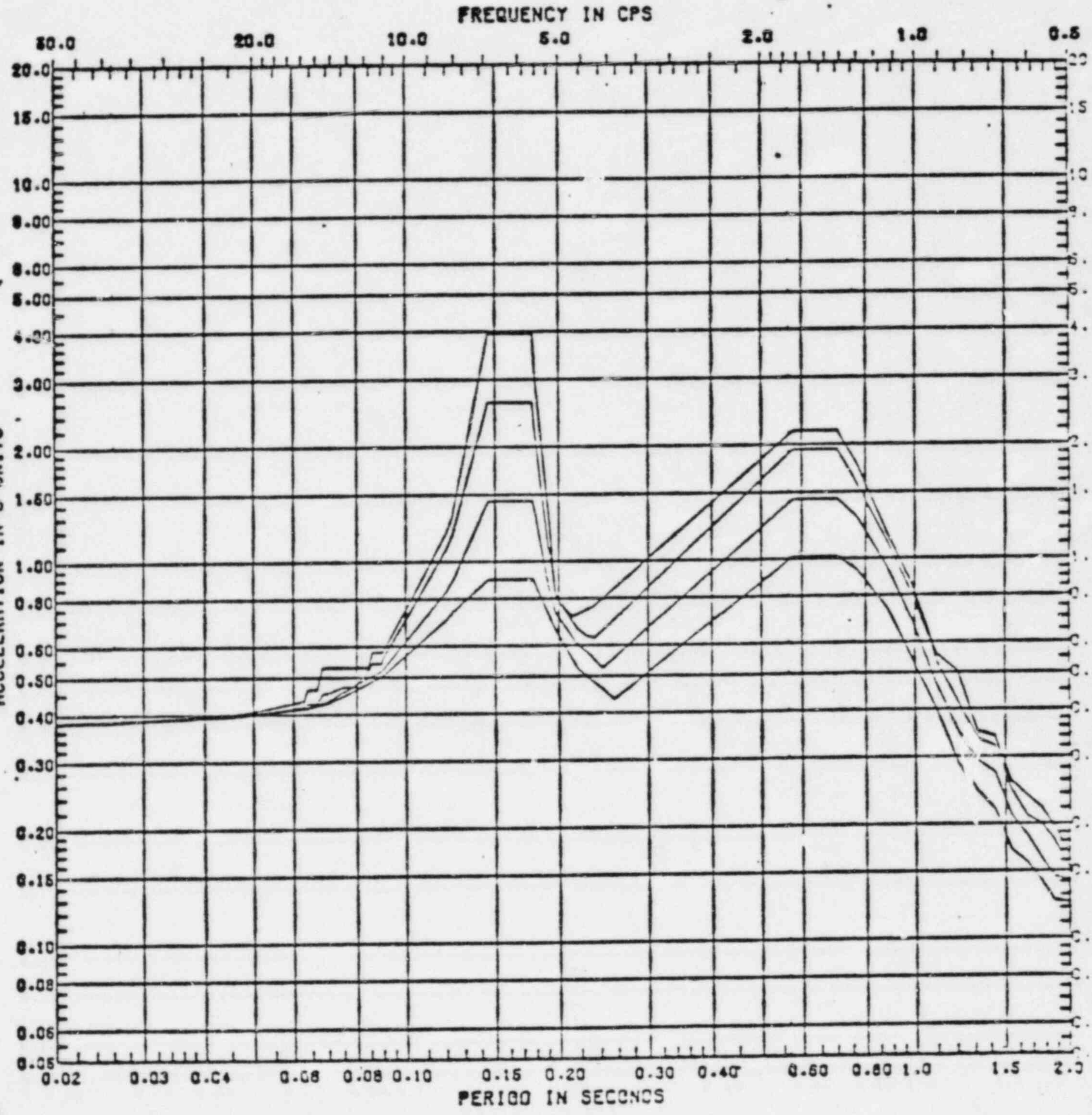
ELEVATION 627'-9"

LOCATION Reactor Building Slab REVISION NO. 0

SARGENT & LUNDY
ENGINEERS

28 JUL 76
8290EL

ZIMMER.4130'6.SOIL-STRUCT.HORIZ.DBE
DESIGNER [illegible] Lov CHECKER B.P. Jain
DESIGN SPECTRA AT JOINT/SLAB 6 Y-COMP
PEAKS WIDENED BY 10% ON EACH SIDE
DAMPING 0.010 0.020 0.050 0.100
PAGE 13 OF 17



D.B.E. Horiz. Response Spectra E-W Component

SPECTRA NO. 6-D

ELEVATION 627'-9"

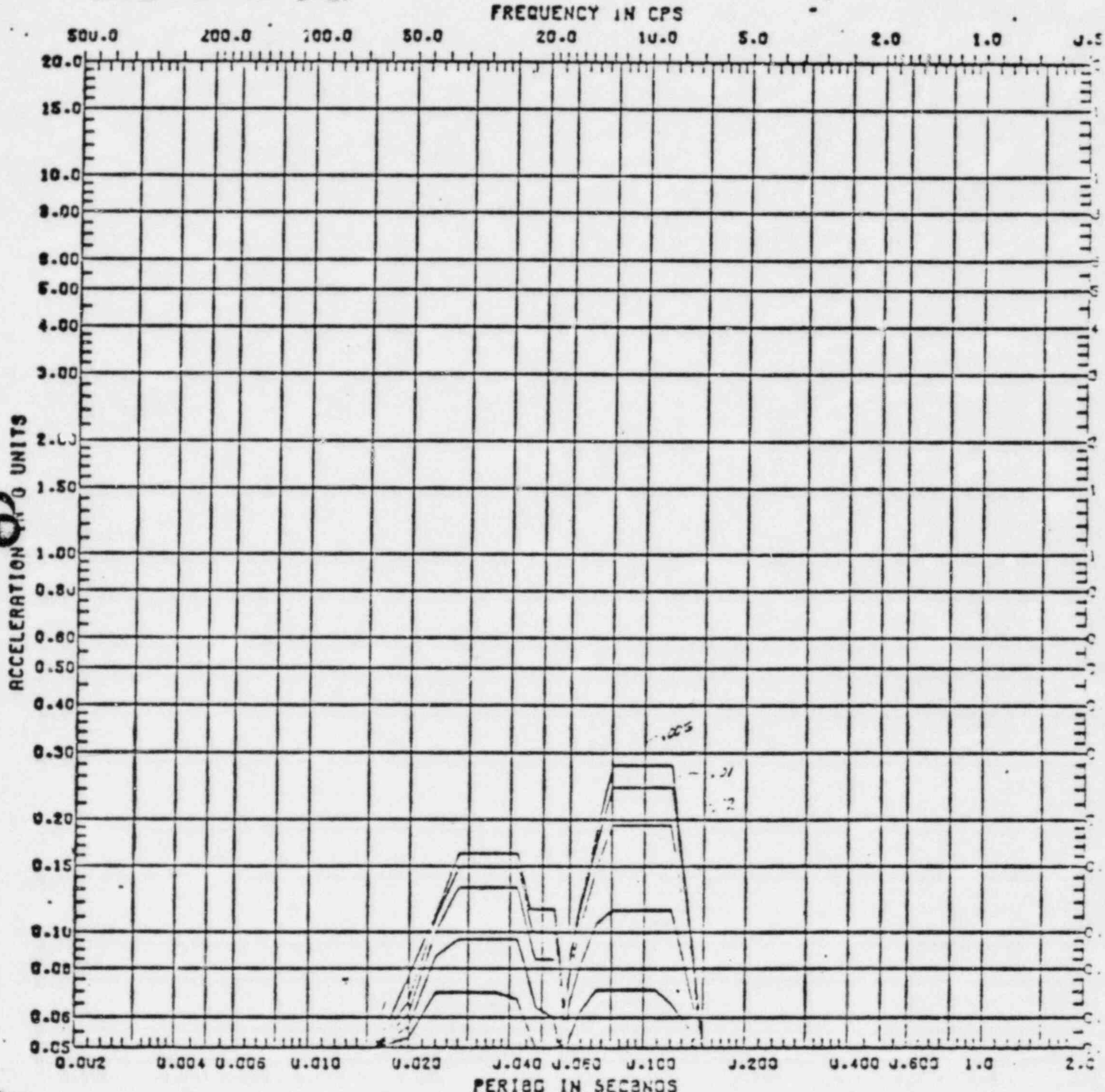
LOCATION Reactor Building Slab

REVISION NO. 0

SARGENT & LUNDY
ENGINEERS

10/01/7
191SWC
4130-15
SDD-EMD-021

ZIMMER SEQ-SRV-RSO-ENV-HM242
DESIGNER [illegible] CHECKER [illegible]
DESIGN SPECTRA AT JOINT, SLAB
PEAKS WIDENED BY 20% ON EACH SIDE
DAMPING 0.005 0.010 0.020 0.050 0.100
PAGE 14 OF 17



HORIZ RESPONSE SPECTRA
ELEVATION 601'-7"
LOCATION REACTOR BUILDING

SPECTRA NO. S304-H
REVISION NO. 2

SARGENT & LUNDY ENGINEERS	Calc. For SPENT FUEL STORAGE RACKS HOPE SEISMIC RESPONSE STUDY	Calc. No. 72
	✗ Safety-Related / Non-Safety-Related	Rev. / Date / Page 15 of 17
Client CG & E	Prepared by [signature]	Date 3/?/78
Project ZIMMER-1	Reviewed by [signature]	Date 3/13/78
Proj. No. 4130-00 Equip. No.	Approved by	Date

NOW CONSIDER OUTBOARD BEAM

$$R_A = R_D = 173\left(\frac{19.58}{37.85}\right) = 90^{\#}$$

$$R_B = R_C = 476\left(\frac{19.58}{37.85}\right) = 246^{\#}$$

DESIGN PROCEDURE #1

MAX. AXIAL LOAD OF GE DIVIDER BEAM (REF. PGS 5 & 6) $= R_1 + R_2 + R_3$

WHERE R_1 = INTERIOR SUPPORT RESPONSE OF OUTBOARD BM
$R_2 = R_3$ = " " " " INBOARD "

$R_1 = 246^{\#}$
$R_2 = R_3 = 476^{\#}$
$R_1 + R_2 + R_3 = 1198^{\#}$

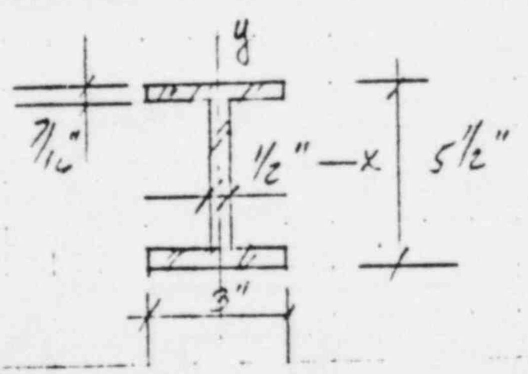
MAX. AXIAL OF S&L BEAM @ POOL WALL (REF PGS 5 & 6) $= R_1 + R_2 + R_3 + R_4$

WHERE $R_4 = R_1$

$R_1 + R_2 + R_3 + R_4 = 1444^{\#}$

SECTION PROPERTIES OF GE DIVIDER BEAM

REF. GE DRWG # 105D4781 & FIELD DATA PER TELEPHONE CONVERSATION BETWEEN J. RIGGIE (S&L) & L. KRAMITZ (KEI), 3/10/78.



$$AREA = (2 \times 3 \times 7/16) + (4\,5/8 \times 1/2) = 4.94 \text{ in}^2$$

$$I_x = 2\left[\frac{3(7/16)^3}{12} + 1.3125(2.53)^2\right] + \frac{0.5(4\,5/8)^3}{12}$$

$$I_x = 20.97 \text{ in}^4$$

Form GQ 3.08.1 Rev. 2

$$S_x = 20.97/2.75 = 7.63 \text{ in}^3$$

$$I_y = 2 \times \frac{7/16\,(3)^3}{12} + \frac{4\,5/8\,(0.5)^3}{12} = 2.02 \text{ in}^4$$

$$S_y = 2.02/1.5 = 1.34 \text{ in}^3$$

MAX. AXIAL STRESS OF GE DIVIDER BEAM

$$f_a = 1.198^k / 4.96\text{ in}^2 = 0.24 \text{ ksi}$$

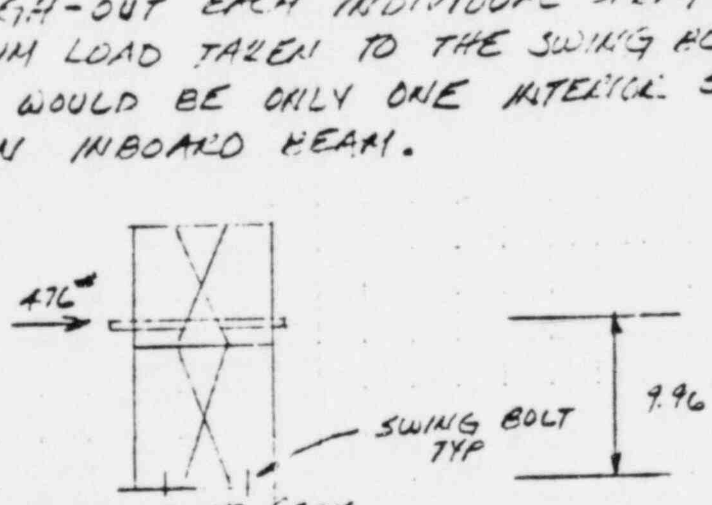
MAX. AXIAL STRESS OF S&L BEAM @ POOL WALL (REF DET. 70 S-439)

$$AREA = (2 \times 1/2 \times 4) + (1/2 \times 7) = 7.5 \text{ in}^2$$

$$f_a = 1.444^k / 7.5\text{ in}^2 = 0.19 \text{ ksi}$$

DESIGN PROCEDURE #2

ASSUMING THE LATERAL RESPONSES OF S&L SUPPORT STEEL TO TRANSFER INTO THE GE BEAM AND THEN DISSIPATE THROUGH-OUT EACH INDIVIDUAL SPENT FUEL RACK, THE MAXIMUM LOAD TAKEN TO THE SWING BOLTS AT THE RACK BASE WOULD BE ONLY ONE INTERIOR SUPPORT RESPONSE OF AN INBOARD BEAM.



ELEV. OF TYP. RACK

SARGENT & LUNDY ENGINEERS CHICAGO	For SPENT FUEL STORAGE RACKS HORIZ. SEISMIC RESPONSE STUDY	Calc. No. 72
	✓ Safety–Related / Non–Safety–Related	Rev. / Date
		Page 17 of 17

Client CG&E	Prepared by [signature]	Date 3/12/79
Project ZIMMER-1	Reviewed by [signature]	Date 3/12/79
Proj. No. 4130-00 Equip. No.	Approved by	Date

OVERTURNING MOMENT FOR SWING BOLT TENSION

$$M = Pe = 0.476(9.96) = 4.74^{1k}$$

FORCE COUPLE OF OVERTURNING MOMENT

$Fd = M$ WHERE d = C-C SPACING OF SWING BOLTS ON EACH RACK

$d = 4'3\frac{1}{4}" = 51.25" = 4.27'$

REF. PLAN S-421

$$F = M/d = 4.74^{1k}/4.27' = 1.11^{k} \text{ TENSION}$$

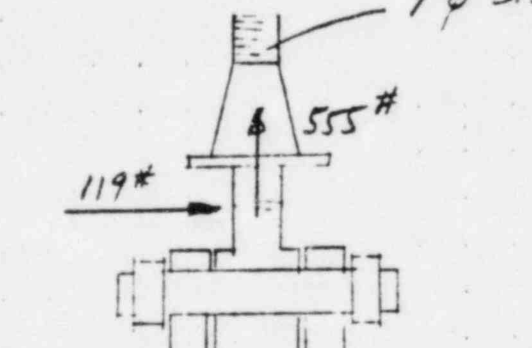
SWING BOLT LOADING (4 BOLTS/RACK 2 EA. SIDE)

REF. DET. 25 S-426

1"ϕ S.S. BOLT 8-UNC-2A

SHEAR = 476/4 = 119#

TENSION = 1.11/2 = 555# } PER BOLT



LOADS ARE TOO SMALL TO CONSIDER ANY APPRECIABLE STRESSING.

Form GQ 3.08.1 Rev. 2

Attachment 13

MPV06JP
MPV06JP
MPV06JP
MPV06JP
MPV06JP
MPV06JP
MPV06JP
MPV06JP
MPV06JP

NUTECH Engineers

San Jose, Ca.

Zimmer Spent Fuel Storage Rack Analysis

CLIENT	=	CINCINNATI GAS & ELECTRIC Co.
PROJECT NAME	=	SEISMIC REQUALIFICATION ANALYSIS
JOB NUMBER	=	CGE-0311
FILE NUMBER	=	33.083.0551
COMPUTER CODE	=	STARDYNE
RUN NUMBER	=	MPVO6JP
MICROFICHE NUMBER	=	NONE
REPORT NUMBER	=	CGE-03-218

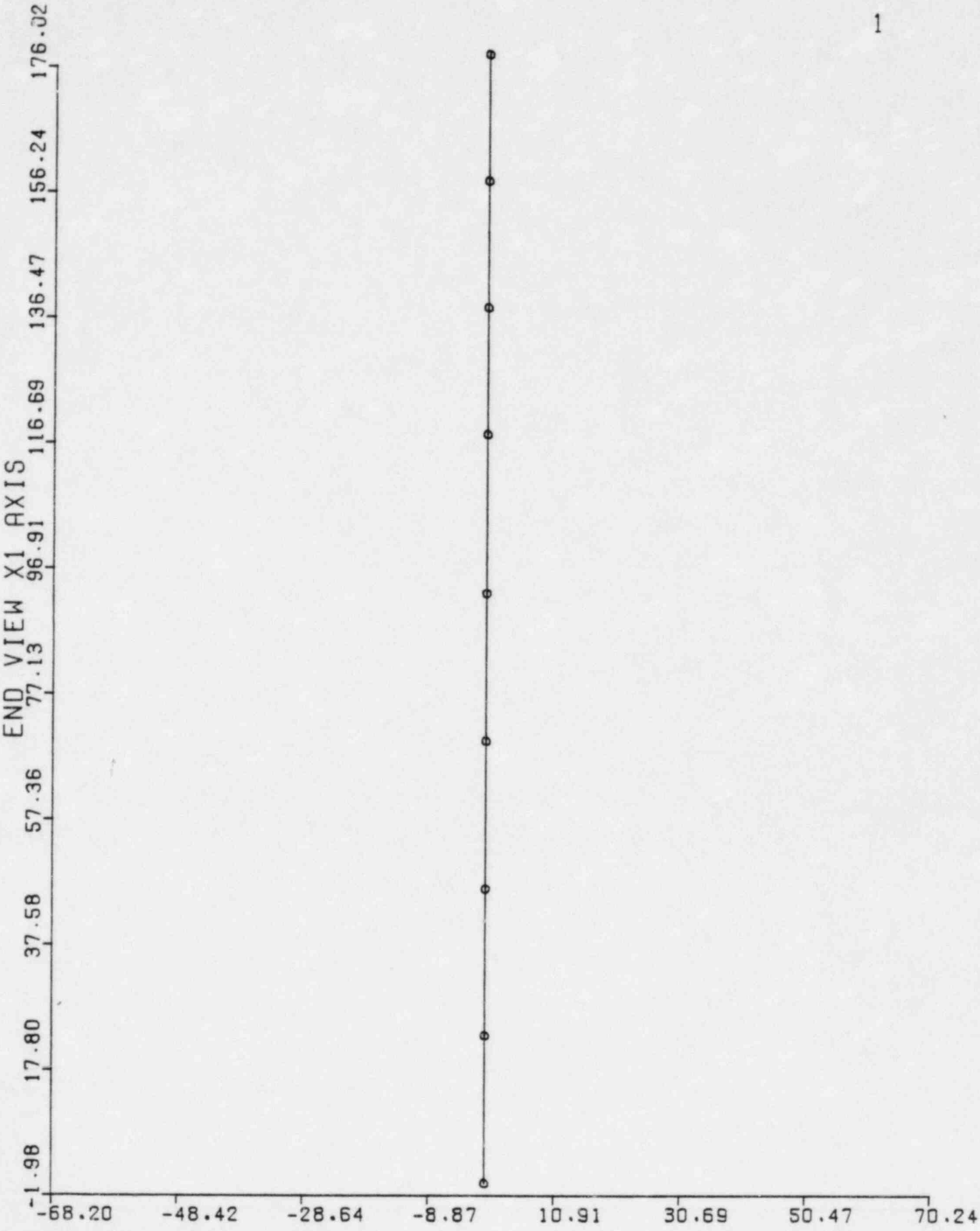
PREPARED BY/DATE: Mark Voutyras 10/12/81
Mark Voutyras

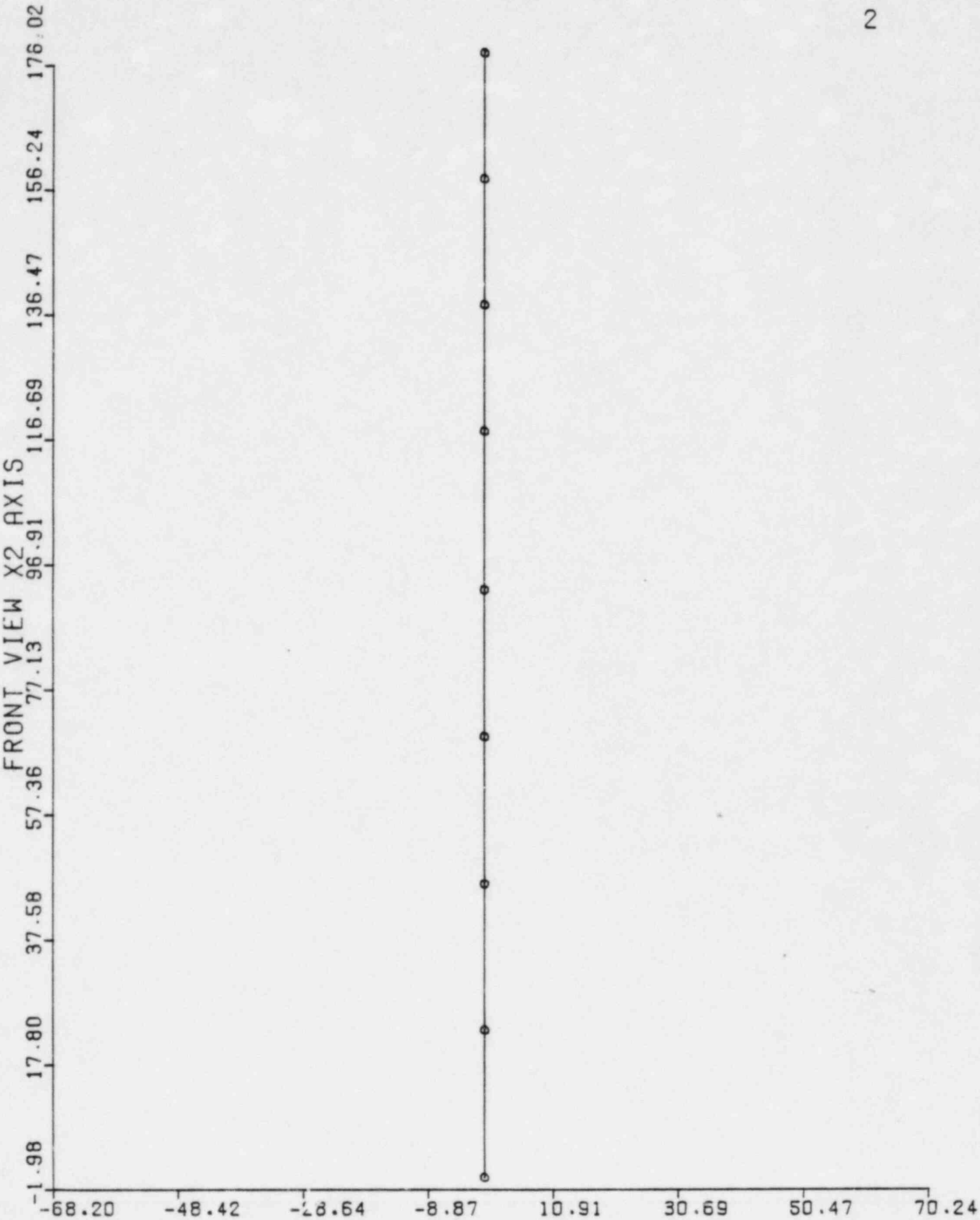
CHECKED BY/DATE: A. Javid 10/12/81
Ahmad Javid

Start

$$$$$$$$

```
**************************************************************************
   ATTENTION : USERS OF THE NEW CALCOMP 1051 PLOTTER AT THE
               LOS ANGELES DATA CENTER.
**************************************************************************

 SCOPE 3.4 USERS, PLEASE REFER TO "EXPLAIN,LAPLOTS" IF LOGGED IN
 NOS, OR "SYSBULL,46" IF LOGGING IN SCOPE 3.4, (VIA A BATCH TER-
 MINAL) FOR INSTRUCTIONS NEEDED TO DRAW SCOPE ORIGIN PLOTS.

**************************************************************************


        OVER THE COUNTER PROCESSING AT W.C.C.
        -------------------------------------
ON MONDAY, SEPTEMBER 14, 1981, THE TERMINAL OPERATIONS OF THE
WESTERN CYBERNET CENTER (CENTRAL SITE) WILL MOVE TO A NEW
LOCATION AT 1190 BORREGAS, IN SUNNYVALE. (RIGHT BEHIND THE
CURRENT CYBERNET CENTER AT 215 MOFFETT PARK DRIVE)
ANY JOBS DIVERTED TO  UN=C (CENTRAL SITE) WILL COME OUT AT THE
NEW BUILDING.

PLEASE NOTE THE NEW HOURS OF TERMINAL OPERATION OVER-THE-COUNTER

             MONDAY - FRIDAY      0800 - 2000
                    SATURDAY      0800 - 1700
                      SUNDAY      CLOSED

FOR ADDITIONAL INFORMATION, PLEASE CONTACT THE CYBERNET SUPPORT
GROUP OR YOUR MARKETING REPRESENTATIVE.
**************************************************************************


*************************************************************************
*** ENTERING PHASE    1 *** RUN DATE = 10/12/81  TIME OF DAY 14.41.29 ***
*************************************************************************


          **** GEOMETRY READ, PRINT AND CHECK LINK ****
```


1
END VIEW X1 AXIS
176.02
156.24
136.47
116.69
96.91
77.13
57.36
37.58
17.80
-1.98
-68.20
-48.42
-28.64
-8.87
10.91
30.69
50.47
70.24


FRONT VIEW X2 AXIS
176.02
156.24
136.47
116.69
96.91
77.13
57.36
37.58
17.80
-1.98
-68.20
-48.42
-28.64
-8.87
10.91
30.69
50.47
70.24

```
            SSSSSSSS   SSSSSSSSSS   SSSSSSSS   SSSSSSSSS
           SSSSSSSSSS  SSSSSSSSSS  SSSSSSSSSS  SSSSSSSSSS
           SS       S      SS      SS      SS  SS      SS
 S     S   SS              SS      SS      SS  SS      SS          S     S
  S   S    SSSSSSSSS       SS      SS      SS  SSSSSSSSSS           S   S
SSSSSSSSSS  SSSSSSSSS      SS      SSSSSSSSSS  SSSSSSSSS          SSSSSSSSSS
  S   S            SS      SS      SSSSSSSSSS  SS   SS              S   S
 S     S   S       SS      SS      SS      SS  SS    SS            S     S
           SSSSSSSSSS      SS      SS      SS  SS     SS
            SSSSSSSS       SS      SS      SS  SS      SS

************************************************************
*                   ** STAR       (R)  **                  *
*                   ** STARDYNE-3 (R)  **                  *
*                   ** SEP01/81 C LEVEL**                  *
************************************************************
*   LATEST USER MANUAL  SEPT 1979                          *
*                                                          *
*                                                          *
*   RUN DATE      MONDAY    , OCT. 12, 1981                *
*                 10/12/81   DAY 285 OF 1981               *
*   RUN TIME      14.41.36.                                *
*                                                          *
*    CYBERNET            SCOPE  3.4      +4338             *
*                                                          *
*   (R) 1968 STARDYNE    SYSTEM  BY MECHANICS RESEARCH INC *
*   (R) 1971 STARDYNE-2 SYSTEM  BY MECHANICS RESEARCH INC *
*   (R) 1974 STARDYNE-3 SYSTEM  BY MECHANICS RESEARCH INC *
*   (R) 1977 STARDYNE-3 SYSTEM  BY SYSTEM DEVELOPMENT CORP*
************************************************************


************************************************************
*           S T A R D Y N E   B U L L E T I N S            *
*                                                          *
*     A STARDYNE INFORMATION BULLETIN IS AVAILABLE         *
*   WHICH DESCRIBES IMPORTANT CHANGES CONCERNING THIS      *
*   RELEASE LEVEL OF THE PROGRAM.  IN ORDER TO ACCESS      *
*   THIS BULLETIN - ENTER THE FOLLOWING CONTROL CARDS..    *
*    AT SCOPE 3.4              AT NOS 1                    *
*                                                          *
*    .                          .                          *
*   APPLIC(STARBUL)            ATTACH(STARBUL/UN=LIBRARY)  *
*   REWIND(STARBUL)            REWIND(STARBUL)             *
*   COPYBF(STARBUL,A)          COPYBF(STARBUL,A)           *
*   REWIND(A)                  REWIND(A)                   *
*   COPYSBF(A,OUTPUT)          COPYSBF(A,OUTPUT)           *
*    .                          .                          *
************************************************************
```

```
                                   *** STARDYNE 3.0     INPUT ***
              /--------------------------------- CARD  IMAGE  ---------------------------------/
              1  4   8  12  16  20  24  28  32  36  40  44  48  52  56  60  64  68  72  76  80
              *  *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *   *
 CARD NO      ********************************************************************************  CARD TYPE
       1      START       2                                                                      START
**NOTE** GEOMETRY INPUT WILL BE READ FROM TAPE 2
       2       TAPE2 CREATION DATE 10/02/81,TIME 15.18.06, STAR 3.0  LEVEL  SEP01/81             TAPE
       3       SPENT FUEL STORAGE RACK                                                            SPEN
       4      MATLG       16063-T5 AL     10.3E6  0.334   1.254                                  MATLG
       5      END                                                                                END
       6      NODEG       1   5   1   0.0     0.0       0.0       0.0     0.0      93.0          NODEG
       7      NODE   6         0.0         0.0               118.0                               NODE
       8      NODEG       7   9   1   0.0     0.0      138.0   0.0     0.0      178.0            NODEG
       9      NODE  10         2.0         0.0               0.0                                 NODE
      10      END                                                                                END
      11      RESTG       1         123456                                                       RESTG
      12      END                                                                                END
      13      WGHT        9     385.0   2165.0    0.0                                            WGHT
      14      WGHT        1     385.0   2165.0    0.0                                            WGHT
      15      WGHTG       2   8   1  769.0      4330.0    0.0                                    WGHTG
      16      END                                                                                END
      17      BEAMG       1   8   1   1   2   1  10   1   1                                      BEAMG
      18      END                                                                                END
      19      BPROP1      1  75.52   31269.0    3101.0    28168.0    0.85       0.85              BPROP
      20      END                                                                                END
      21      MADDX       6    1      877.4                           5.64E6                     MADDX
      22      END                                                                                END
      23      FIXED      10                                                                      FIXED
      24      END                                                                                END
      25      WASNOWX     9   5   3   8   4   4   6   9   5   2   7   7   8   3   2   6          WASNO
      26      WASNDAT1    2   1   2  12  12   6   2   48  24  24                                 WASNO
      27      END                                                                                END
      29       MODAL ANALYSIS OF SPENT FUEL STORAGE RACK                                          MODA
      30      DYNAMIC                 2                                                          DYNAM
      31      TAPE4G         1 9999                        1 11        1                         TAPE4
      32      ENDMODEL                                                                           ENDMO
```

TAPE2 CREATION DATE 10/02/81,TIME 15.18.06. STAR 3.0 LEVEL SEP01/81

SPENT FUEL STORAGE RACK

GEOMETRY PROCESSING OPTIONS---

GEOMETRY INPUT FILE	(NFILE) =	2
ACCELERATION OF GRAVITY	(G) =	.3860000E+03
DOF PER NODE	(JDOF) =	6
NODE REORDER	(IRENUM) =	0.0
GEOMETRY PLOTS	(IGEOMP) =	0
DEFORMED PLOTS	(IVECTP) =	0
PLOT VIEW SELECTOR	(IPVIEW) =	0
PLOTTER TYPE	(PLTYPE) =	SC420
PLOT SYMBOL	(IPSYM) =	0
CALCOMP PLOT SIZE	(PSIZE) =	1.0

****** M A T E R I A L   P R O P E R T Y   T A B L E ******

	---MATERIAL--- NUMBER	NAME	MODULUS OF ELASTICITY E1/E2	POISSONS RATIO PR1/PR2	SHEAR MODULUS G/GTSHR	DENSITY	COEFFICIENT OF THERMAL EXPANSION ALPH1/ALPH2	DAMPING COEFFICIENT
MATL	1	6063-T5 AL	1.030000E+07	3.340000E-01	3.860570E+06	1.254000E+00	0.	0.
			1.030000E+07	3.340000E-01	3.860570E+06		0.	

*** NODAL COORDINATE TABLE ***

	NODE	X1	X2	X3
NODES	1	0.	0.	0.
NODES	2	0.	0.	.2325000E+02
NODES	3	0.	0.	.4650000E+02
NODES	4	0.	0.	.6975000E+02
NODES	5	0.	0.	.9300000E+02
NODES	6	0.	0.	.1180000E+03
NODES	7	0.	0.	.1380000E+03
NODES	8	0.	0.	.1580000E+03
NODES	9	0.	0.	.1780000E+03
NODES	10	.2000000E+01	0.	0.

--- MAXIMUM ALLOWABLE NODE NUMBER BY ANALYSIS TYPE ---

	FOR CM277700		FOR CM377700
STAR STATIC	1700		4000
STAR LANCZOS	1500		4000
STAR HOR/GUYAN	1300		2500
STAR INV.ITER.	1000	1300	
STAR SUBSTRUCTURE	1700		3500
DYNRE 1		NO LIMIT	
DYNRE 2		NO LIMIT	
DYNRE 3		NO LIMIT	
DYNRE 4		NO LIMIT	
DYNRE 5		NO LIMIT	

LARGEST NODE NUMBER CODED IN THIS MODEL = 10

NEXT TABLE HEADER (RESTG

*** NODAL RESTRAINED DOF TABLE ***

	NODE	X1	X2	X3	X4	X5	X6
RESTS	1	1	1	1	1	1	1

NEXT TABLE HEADER (WGHT)

*** INPUT NODAL WEIGHT TABLE ***

	NODE	X W1	Y W2	Z W3	W4	W5	W6
WEIGHTS	9	.38500E+03	.21650E+04	0.	0.	0.	0.
WEIGHTS	1	.38500E+03	.21650E+04	0.	0.	0.	0.
WEIGHTS	2	.76900E+03	.43300E+04	0.	0.	0.	0.
WEIGHTS	3	.76900E+03	.43300E+04	0.	0.	0.	0.
WEIGHTS	4	.76900E+03	.43300E+04	0.	0.	0.	0.
WEIGHTS	5	.76900E+03	.43300E+04	0.	0.	0.	0.
WEIGHTS	6	.76900E+03	.43300E+04	0.	0.	0.	0.
WEIGHTS	7	.76900E+03	.43300E+04	0.	0.	0.	0.
WEIGHTS	8	.76900E+03	.43300E+04	0.	0.	0.	0.
SUMMATION		.61530E+04	.34640E+05	0.	0.	0.	0.

NEXT TABLE HEADER (BEAMG)

*** BEAM SECTION PROPERTY TABLE ***

NUMBER							
	BPROP1=	A	J	I2	I3	SF2	SF3
	BPROP2=	H2	H3	CTORS	SSF2	SSF3	DIST WGHT
	BPROP3=	OD	T	RADIUS	FLEX FLAG	LIQ DENS	DIST WGHT
	BPROP4=	XOFFA	YOFFA	ZOFFA	XOFFB	YOFFB	ZOFFB
	BPROP5=	SYA	SZA	SYB	SZB	SYC	SZC
1	BPROP1	7.552000E+01	3.126900E+04	3.101000E+03	2.816800E+04	8.500000E-01	8.500000E-01

*** BEAM CONNECTIVITY TABLE ***

	NO	JA	JB	JC	MATL NO	BPRP NO	FIN CODE	H2/ OD	H3/ T	LENGTH	AREA	J	I2	I3	SF2	SF3
BEAMG	1	1	2	10	1	1	000000	2.000E+00	2.000E+00	2.325E+01	7.552E+01	3.127E+04	3.101E+03	2.817E+04	.850	.850
BEAMG	2	2	3	10	1	1	000000	2.000E+00	2.000E+00	2.325E+01	7.552E+01	3.127E+04	3.101E+03	2.817E+04	.850	.850
BEAMG	3	3	4	10	1	1	000000	2.000E+00	2.000E+00	2.325E+01	7.552E+01	3.127E+04	3.101E+03	2.817E+04	.850	.850
BEAMG	4	4	5	10	1	1	000000	2.000E+00	2.000E+00	2.325E+01	7.552E+01	3.127E+04	3.101E+03	2.817E+04	.850	.850
BEAMG	5	5	6	10	1	1	000000	2.000E+00	2.000E+00	2.500E+01	7.552E+01	3.127E+04	3.101E+03	2.817E+04	.850	.850
BEAMG	6	6	7	10	1	1	000000	2.000E+00	2.000E+00	2.000E+01	7.552E+01	3.127E+04	3.101E+03	2.817E+04	.850	.850
BEAMG	7	7	8	10	1	1	000000	2.000E+00	2.000E+00	2.000E+01	7.552E+01	3.127E+04	3.101E+03	2.817E+04	.850	.850
BEAMG	8	8	9	10	1	1	000000	2.000E+00	2.000E+00	2.000E+01	7.552E+01	3.127E+04	3.101E+03	2.817E+04	.850	.850

NOTICE TO SUPPRESS PRINTING OF THE FOLLOWING TWO BEAM INPUT DATA TABLES (2 AND 3), ADD THIS CARD -

```
1         12
BEAMPRNT   1
```

ANYWHERE IN THE BEAM CONNECTIVITY TABLE.

B E A M   D A T A   T A B L E   2

	NO	WEIGHT	\CTORS	SSF2	SSF3	ELBOW RADIUS	FLEXIBILITY FACTOR	ELBOW ANGLE	BEAM X2-DIR.COSINES X1	X2	X3
BEAMG	1	2.202E+03	1.352E+00	1.176E+00	1.176E+00	0.	0.	0.	1.000E+00	0.	0.
BEAMG	2	2.202E+03	1.352E+00	1.176E+00	1.176E+00	0.	0.	0.	1.000E+00	0.	0.
BEAMG	3	2.202E+03	1.352E+00	1.176E+00	1.176E+00	0.	0.	0.	1.000E+00	0.	0.
BEAMG	4	2.202E+03	1.352E+00	1.176E+00	1.176E+00	0.	0.	0.	1.000E+00	0.	0.
BEAMG	5	2.368E+03	1.352E+00	1.176E+00	1.176E+00	0.	0.	0.	1.000E+00	0.	0.
BEAMG	6	1.894E+03	1.352E+00	1.176E+00	1.176E+00	0.	0.	0.	1.000E+00	0.	0.
BEAMG	7	1.894E+03	1.352E+00	1.176E+00	1.176E+00	0.	0.	0.	1.000E+00	0.	0.
BEAMG	8	1.894E+03	1.352E+00	1.176E+00	1.176E+00	0.	0.	0.	1.000E+00	0.	0.

NEXT TABLE HEADER (MADDX)

STIFFNESS

*** MATRIX ADDITION TABLE ***

	ROW	COLUMN	IR	IC	IR	IR+1	IR+2
MADD	6	0	1	0	8.7740000000E+02	5.6400000000E+06	0.

THE NUMBER OF MATRIX CARDS ENTERED IS 1

NEXT TABLE HEADER (FIXED)

XXXXXXXXXXXXXXXXXXX END OF GEOMETRY DATA XXXXXXXXXXXXXXXXXXX

*** FINAL WEIGHT SUMMARY ***
(INCLUDES ELEMENT AND NODAL WEIGHTS)

	NODE	W1	W2	W3	W4	W5	W6
WEIGHTS	1	.14859E+04	.32659E+04	.11009E+04	0.	0.	0.
WEIGHTS	2	.29708E+04	.65318E+04	.22018E+04	0.	0.	0.
WEIGHTS	3	.29708E+04	.65318E+04	.22018E+04	0.	0.	0.
WEIGHTS	4	.29708E+04	.65318E+04	.22018E+04	0.	0.	0.
WEIGHTS	5	.30537E+04	.66147E+04	.22847E+04	0.	0.	0.
WEIGHTS	6	.28998E+04	.64608E+04	.21308E+04	0.	0.	0.
WEIGHTS	7	.26630E+04	.62240E+04	.18940E+04	0.	0.	0.
WEIGHTS	8	.26630E+04	.62240E+04	.18940E+04	0.	0.	0.
WEIGHTS	9	.13320E+04	.31120E+04	.94702E+03	0.	0.	0.
SUMMATION		.23010E+05	.51497E+05	.16857E+05	0.	0.	0.

CENTER OF GRAVITY BASED ON X1 WEIGHTS ONLY.
(WEIGHTS IN NON-GLOBAL DIRECTIONS WILL INVALIDATE RESULTS)

X1 = 0.
X2 = 0.
X3 = .897853769E+02

CENTER OF GRAVITY BASED ON X2 WEIGHTS ONLY.
(WEIGHTS IN NON-GLOBAL DIRECTIONS WILL INVALIDATE RESULTS)

X1 = 0.
X2 = 0.
X3 = .909759415E+02

CENTER OF GRAVITY BASED ON X3 WEIGHTS ONLY.
(WEIGHTS IN NON-GLOBAL DIRECTIONS WILL INVALIDATE RESULTS)

X1 = 0.
X2 = 0.
X3 = .890000000E+02

* PHASE I INPUT SUMMARY *

NOTE NODE 10 WAS FULLY RESTRAINED, SINCE IT IS NOT CONNECTED TO ANY ELEMENT OR MATRIX.

NODE NO	NO OF BEAMS	NO OF JTCS	NO OF T-PLATES	NO OF Q-PLATES	NO OF CUBES	NO OF TET-RAHEDRONS	MATRIX ADDITIONS	NO OF RESTRAINTS	NO OF WEIGHTS
1	1	0	0	0	0	0	0	6	3
2	2	0	0	0	0	0	0	0	3
3	2	0	0	0	0	0	0	0	3
4	2	0	0	0	0	0	0	0	3
5	2	0	0	0	0	0	0	0	3
6	2	0	0	0	0	0	1	0	3
7	2	0	0	0	0	0	0	0	3
8	2	0	0	0	0	0	0	0	3
9	1	0	0	0	0	0	0	0	3
10	0	8	0	0	0	0	0	6	0

```
*************************************************** BEGIN NODE REORDERING ***************************************************

BANDWIDTH OPTIMIZATION WAS BYPASSED.

     FINAL NODAL BAND =       2
     FINAL  DOF  BAND =      12

*************************************************** END  NODE REORDERING ***************************************************
```

TABL[illegible]. THIS IS THE DCF VERSUS NODE TABLE FOR DYNAMIC DEPE[illegible]NT MATRIX (THOSE DEGREES OF FREEDOM
OF THE FINAL MATRIX WHICH HAVE ZERO MASSES). THIS TABLE IS USED TO IDENTIFY THE DOF
ASSOCIATED WITH THE DECOMPOSED MATRIX OBTAINED DURING A HOUSEHOLDER-QP MODAL EXTRACTION.
(USE THIS TABLE TO FIND THE NODE NUMBER ASSOCIATED WITH A ROW/COLUMN NUMBER OF MATRICES OUTPUT BY -STAR-)

DOF	NODE-LDOF	DOF	NODE-LDOF	DOF	NODE-LDOF	DOF	NODE-LDOF
1	2-X4,X5,X6,	4	3-X4,X5,X6,	7	4-X4,X5,X6,	10	5-X4,X5,X6,
13	6-X4,X5,X6,	16	7-X4,X5,X6,	19	8-X4,X5,X6,	22	9-X4,X5,X6,

TABL[illegible]A. THIS IS THE DOF VERSUS NODE TABLE FOR THE INDEPENDE[illegible]ATRIX . THE ORDER OF THIS MATRIX IS EQUAL TO THE NUMBER OF DYNAMIC DEGREES OF FREEDOM (EIGENMODES) IN THE MODEL. (USE THIS TABLE TO FIND THE NODE NUMBER ASSOCIATED WITH A ROW/COLUMN NUMBER OF MATRICES OUTPUT BY -STAR-)

DOF	NODE-LDOF	DOF	NODE-LDOF	DOF	NODE-LDOF	DOF	NODE-LDOF
1	2-X1,X2,X3,	4	3-X1,X2,X3,	7	4-X1,X2,X3,	10	5-X1,X2,X3,
13	6-X1,X2,X3,	16	7-X1,X2,X3,	19	8-X1,X2,X3,	22	9-X1,X2,X3,

* T I M E   E S T I M A T E S   F O R   A   S T A T I C   A N A L Y S I S *

ESTIMATED TIME = 15.5 (DECIMAL) + 1.4 PER LOAD CASE (FULL PROCESSING)
-OR- + .7 PER LOAD CASE (DISP.VECTOR ONLY)

TOTAL TIME IF 1 LOAD CASE = 17.5 (DECIMAL) (FULL OUTPUT PROCESSING)
TOTAL TIME IF 5 LOAD CASE = 23.3 (DECIMAL) (FULL OUTPUT PROCESSING)
TOTAL TIME IF 10 LOAD CASE = 30.3 (DECIMAL) (FULL OUTPUT PROCESSING)

NOTE ADD 0.18 PER (THERMALLY OR PRESSURE LOADED) QUADRILATERAL TO GENERATE CONSISTENT LOAD VECTOR
NOTE ADD 0.06 PER (INTERMEDIATELY LOADED) BEAM TO GENERATE EQUIV. LOAD VECTOR AND STRESS DISTRIBUTION

STATIC MATRIX SIZE (DOF) = 48
STATIC MATRIX BAND (DOF) = 12

* T I M E   E S T I M A T E S   F O R   A   D Y N A M I C   A N A L Y S I S *

LANCZOS AND INVITR MATRIX SIZES ARE THE SAME AS STATIC.
HQR PARTITIONED MATRIX SIZES
DEPENDENT MATRIX SIZE (DEPDOF) = 24
DEPENDENT MATRIX BAND = 12
INDEPENDENT MATRIX SIZE (DDOF) = 24
WARNING INVERSE ITERATION TIME IS VERY PROBLEM DEPENDENT.

NUMBER OF EIGENVECTORS	TOTAL TIME (DECIMAL) IF EIGENVECTOR ONLY IS OUTPUT: LANCZOS	HQR/GUYAN	INVITR	ADDITIONAL TIME IF COMPOSITE DAMPING IS COMPUTED ALSO (ANY METHOD)	-OR- IF ALL POSSIBLE OUTPUT IS COMPUTED ALSO (ANY METHOD)
1	25.7	36.4	24.1	.5	.7
2	28.1	37.6	33.2	1.0	1.4
5	36.0	41.1	60.6	2.4	3.6
10	46.0	46.9	106.4	4.8	7.2

* T I M E   S A V E D   I F   R E S T A R T   F I L E S   E N T E R E D *

TAPE7	ANY METHOD	TIME SAVED =	3.3
TAPE9	STATIC,LANCZOS,INVITR	TIME SAVED =	2.1
TAPE9	HQR	TIME SAVED =	2.0
TAPE28	HQR	TIME SAVED =	3.9

NOTE IF TAPE9 IS SUPPLIED FOR STATIC OR LANCZOS, THEN INCLUDE THE TAPE7 TIME SAVED ALSO.

NOTE TIME ESTIMATES ASSUME THAT INPUT IS ON TAPE2 AND THAT MAXIMUM OUTPUT OPTIONS ARE REQUESTED.
NOTE ADD RENUMBERING AND/OR PLOT TIME TO ESTIMATES IF THEY ARE TO BE PERFORMED ON NEXT RUN.
NOTE BEFORE CODING TIME LIMIT , ADD 20 PERCENT TO TIME ESTIMATE.

** STRUCTURAL DATA INPUT TOTALS *****

NUMBER OF NODES	10
NUMBER OF ELASTIC BEAMS	8
NUMBER OF RIGID BEAMS	0
NUMBER OF RIGID SYSTEMS	0
NUMBER OF NODES WITH RESTRAINTS ..	2
NUMBER OF TRI-PLATES	0
NUMBER OF QUAD-PLATES	0
NUMBER OF CUBES	0
NUMBER OF TETRAHEDRONS	0
NUMBER OF MATRIX ADDITIONS	1
NUMBER OF NODES WITH WEIGHTS	9
NUMBER OF NODES WITH BOUNDARIES ..	0

```
********************************************************************************
*** ENTERING PHASE   2 *** RUN DATE = 10/12/81  TIME OF DAY 14.41.42 ***
********************************************************************************


**** RUN CONTROL, APPLIED LOADS     LINK ****

MODAL ANALYSIS OF SPENT FUEL STORAGE RACK

********************* CONTROLS FOR LANCZOS MODAL EXTRACTION ********************************

NOUT   (FINAL STIFFNESS MATRIX      ( TABLE 2) PRINT 0=NO,+-1=YES ,  -4 AND -5=CHECK RUN).... =        0

ISAVE  (USE PREVIOUSLY DECOMPOSED MATRIX ON TAPE9      0=NO, 2=YES )......................... =        2

IERDPT (STIFFNESS MATRIX DECOMPOSITION ERROR ANALYSIS.  -2 THRU +1, (1 IS NORMAL OPTION)).... =        0

NLOWM  (MAX NUMBER OF EIGENVALUES TO BE EXTRACTED,      0=20  )............................. =        0

SHIFTP (PERMITTED VALUES = 0.0 OR (FOR FREE-FREE)    -0.1 THROUGH -100000.)................. =     0.
          **NOTE** FOR POSITIVE SHIFTP, LANCZOS WILL COMPUTE THE NUMBER OF EIGENVALUES BELOW SHIFTP -ONLY-
                   (I.E. NO EIGENVALUES/VECTORS AND NO OFF-DIAGONAL MASS).

********************END OF DYNAMIC CONTROL CARD EVALUATION**************************************
```

```
***** O U T P U T   O P T I O N   C O N T R O L S *****

OPTION    STARTVP =  1      FIRST VECTOR PROCESSED.
          NPROCES = 20      LAST VECTOR        PROCESSED.
          IGOMTRY =  0      REPRINT NODAL GEOMETRY.
          ICUBE   =  0      CUBE STRESS COORD.SYSTEM (0=GLOBAL, 1=ELEMENT).
          FORMAT  =  0      FORMAT TYPE (0=E FORMAT, 1=F FORMAT).
          PAGE    =  0      LINES PER PAGE.

               ***** P R I N T I N G *****

          (2=PRINT, 1=NO PRINT, 0=DEFAULT)

           NODES  BEAMS    TPLTS      QPLT CUBE  T  M
                  I I I  I I I I I    I I  I I  E  A COMP
     FROM  I I I  0 0 0  0 0 0 0 0    0 0  0 0  T  D DAMP
     LOAD  0 0 0  B B B  P P P P P    Q Q  C C  R  D
     CASE  1 2 3  1 2 3  2 7 3 4 5    1 2  2 1  A  L

        1  2 2 1  1 1 1  1 1 1 1 1    1 1  1 1  1  1  0
       21  1 2 1  1 1 1  1 1 1 1 1    1 1  1 1  1  1  1

       ****** TAPE4 OPTIONS SPECIFIED ******

     FROM CASE-TO CASE      FROM CASE-TO CASE      FROM CASE-TO CASE
          1     9999              0       0              0       0

          WRITE ON TAPE4 = 1 , DO NOT WRITE ON TAPE4 = 0 .

   TAPE4     I041  =  1     APPLIED LOAD VECTORS WRITTEN.
             I042  =  1     DISPLACEMENT VECTORS WRITTEN.
             I043  =  1     BEAM END LOADS WRITTEN.
             I044  =  1     BEAM STRESSES  WRITTEN.
             I045  =  0     TRI-PLATE STRESSES  WRITTEN.
             I046  =  0     QUAD-PLATE STRESSES WRITTEN.
             I047  =  0     CUBE  STRESSES  WRITTEN.
             I048  =  0     TETRAHEDRA STRESSES WRITTEN.
             I049  =  0     TPLT GBL.CORNER FORCE WRITTEN.
            I0410  =  0     QPLT GBL.CORNER FORCE WRITTEN.
            I0411  =  0     CUBE GBL.CORNER FORCE WRITTEN.
            I0412  =  1     BEAM LOADS(GLOBAL) WRITTEN.
            I0413  =  0       ( UNUSED )
            I0414  =  0       ( UNUSED )
            I0415  =  0     MATRIX ELEMENT LOADS WRITTEN.
            I0416  =  0     EQUILIBRIUM CHECK VECTOR WRITTEN.

LIMIT ELEMENT STRESS PRINTING TO MINIMUM STRESS LEVEL OF --

                                         BEAM          0.
                                         TPLATE        0.
                                         QPLATE        0.
                                         CUBE+TETR     0.
```

```
*****************************************************************************************************************

                                    * COMPUTER TIME LIMIT CHECK SUMMARY *

                    MAXIMUM  TIME LIMIT ASSUMED        =    500.0 (DECIMAL)

                      TIME EXPENDED ALREADY            =     11.3 (DECIMAL)

                    1.2*PREDICTED TIME TO COMPLETION =      64.2 (DECIMAL)

          THERE IS   SUFFICIENT TIME REMAINING FOR THIS  LANCZOS   ANALYSIS.

*****************************************************************************************************************


                                                 *********************************************************************
                                                 *** ENTERING PHASE   3 *** RUN DATE = 10/12/81  TIME OF DAY 14.41.45 ***
                                                 *********************************************************************


                    **** STIFFNESS MATRIX FORMULATION   LINK ****


                                                 *********************************************************************
                                                 *** ENTERING PHASE  18 *** RUN DATE = 10/12/81  TIME OF DAY 14.41.46 ***
                                                 *********************************************************************


MASS DOF

              24
```

```
*************************************************************************************
*** ENTERING PHASE  17 *** RUN DATE = 10/12/81  TIME OF DAY 14.41.47 ***
*************************************************************************************
```

**** LANCZOS EIGENVALUE EXTRACTION LINK ****

M O D A L   E X T R A C T I O N   D A T A

MODE NO	EIGENVALUE (OMEGA**2)	NATURAL FREQUENCY	PERIOD	GENERALIZED WEIGHT	MAX TRANSLATION NODE-DOF	VALUE	--- MODAL WEIGHTS --- (GEN. WGT. * PARTICIPATION FACTORS**2) X1	X2	X3	
1	8820.15	14.947	.0669	6825.53	9-2	1.0000	.00000	6565.12449	.00000	12.0
2	8837.39	14.962	.0668	6386.75	9-1	1.0000	14831.28763	.00000	.00000	12.0
3	47805.1	34.798	.0287	17276.3	4-2	1.0000	.00000	36642.61128	.00000	12.0
4	186357.	68.706	.0146	8446.12	9-1	1.0000	4806.51923	.00000	.00000	12.0
5	194497.	70.190	.0142	20539.1	9-2	1.0000	.00000	931.33245	.00000	12.0
6	246179.	78.967	.0127	8437.30	9-3	1.0000	.00000	.00000	13564.99925	12.0
7	349504.	94.091	.0106	20645.5	9-2	1.0000	.00000	2075.00085	.00000	12.0
8	794962.	141.904	.0070	19080.3	2-2	1.0000	.00000	1750.37960	.00000	12.0
9	836652.	145.577	.0069	9142.95	9-1	1.0000	1181.19699	.00000	.00000	12.0
10	.122854E+07	176.407	.0057	24794.0	6-2	1.0000	.00000	20.10587	.00000	12.0
11	.160345E+07	201.534	.0050	22995.8	3-2	1.0000	.00000	179.36620	.00000	12.0
12	.181756E+07	214.568	.0047	11350.3	2-1	1.0000	447.90462	.00000	.00000	12.0
13	.210807E+07	231.080	.0043	17404.6	7-2	1.0000	.00000	67.15890	.00000	11.0
14	.215627E+07	233.707	.0043	8637.67	9-3	1.0000	.00000	.00000	1433.34163	11.3
15	.308932E+07	279.738	.0036	9978.44	2-1	1.0000	184.30817	.00000	.00000	10.3
16	.415850E+07	324.555	.0031	10194.2	6-1	1.0000	49.95701	.00000	.00000	8.8
17	.489534E+07	352.137	.0028	9817.29	4-1	1.0000	22.86859	.00000	.00000	7.6
18	.574128E+07	381.351	.0026	8439.37	9-3	1.0000	.00000	.00000	451.56575	7.4
19	.629637E+07	399.361	.0025	7023.63	8-1	1.0000	.01882	.00000	.00000	7.1
20	.101322E+08	506.608	.0020	8615.19	9-3	1.0000	.00000	.00000	180.88156	7.8

THE FOLLOWING ARE APPROX. EIGENVALUES FOR WHICH MODES WERE NOT REQUESTED.

MODE NO	EIGENVALUE (OMEGA**2)	NATURAL FREQUENCY	
21	.152076E+08	620.656	6.4
22	.202003E+08	715.318	6.1
23	.224376E+08	753.891	5.5
24	.303283E+08	876.485	6.7

LANCZOS REDUCED MATRIX SIZE (DOF) = 24
APPROX. MAXIMUM EIGENVALUE(OMEGA**2)= .303283E+08

NOTE THE LAST COLUMN IN THE TABLE ABOVE IS RELATED TO EIGENVALUE ACCURACY BOUNDS.

```
*** EIGENVALUE SEARCH HAS BEEN COMPLETED ******

THE NUMBER OF EIGENVALUES EXTRACTED  =   20


** TIME SUMMARY FOR LANCZOS EIGENSOLUTION **

                            SBUCP     SBUIO
   TIME FOR   DECOMP          .02       .32
   TIME FOR   PREVEC          .02       .26
   TIME FOR   TRIDIAG        1.93     18.23
   TIME FOR   EIGVAL          .01       .32
   TIME FOR   EIGVEC          .12       .16
   TIME FOR   EXPAND          .26      4.20
   TIME FOR   OUTPUT          .39      4.37
   TOTAL LANCZOS TIME        2.77     27.86     30.63


*************************************************************************************
*** ENTERING PHASE   7 *** RUN DATE - 10/12/81  TIME OF DAY 14.42.18 ***
*************************************************************************************


**** POST-PROCESS FOR ELEMENT LOADS LINK ****
```

* * * * * * * * * * * * * * * * * *

N O D A L   P O I N T   A P P L I E D   F O R C E S   FOR OUTPUT VECTOR   1

NODE	X1	X2	X3	X4	X5	X6
2	-.175752E-07	-.679989E+04	.107545E-11	0.	0.	0.
3	-.516691E-07	-.173464E+05	0.	0.	0.	0.
4	-.985324E-07	-.234028E+05	.860359E-11	0.	0.	0.
5	-.158532E-06	-.179940E+05	0.	0.	0.	0.
6	-.215242E-06	.782472E+04	0.	0.	0.	0.
7	-.246492E-06	.463022E+05	-.555070E-11	0.	0.	0.
8	-.295857E-06	.931816E+05	-.277535E-11	0.	0.	0.
9	-.171843E-06	.710365E+05	.462559E-12	0.	0.	0.

MODE SHAPE (EIGENVECTOR)

MODE NUMBER 1 , FREQUENCY = 14.947141 , GENERALIZED WEIGHT = 6825.5330

*MAXIMUM ROTATION IS AT NODE 9 *DOF = 4 VALUE = -.170681E-01

*MAXIMUM TRANSLATION IS AT NODE 9 *DOF = 2 VALUE = .100000E+01

	*********** TRANSLATIONS	***********		********** ROTATIONS (RADIANS) **********		
NODE	X1	X2	X3	X4	X5	X6
2	-.000000000	-.045606689	.000000000	.002328254	-.000000000	0.000000000
3	-.000000000	-.116342103	0.000000000	.002235669	-.000000000	0.000000000
4	-.000000000	-.156961791	.000000000	-.000073424	-.000000000	0.000000000
5	-.000000000	-.119173684	0.000000000	-.004254204	-.000000000	0.000000000
6	-.000000000	.053057128	0.000000000	-.010440967	-.000000000	0.000000000
7	-.000000000	.325904334	-.000000000	-.014705357	-.000000000	0.000000000
8	-.000000000	.655871182	-.000000000	-.016623254	-.000000000	0.000000000
9	-.000000000	1.000000000	.000000000	-.017068062	-.000000000	0.000000000

MODAL PARTICIPATION FACTOR (X1) = -8.0598186E-12 GEN.WT. TIMES MODAL PART. FACT. (X1) = -5.5012558E-08

MODAL PARTICIPATION FACTOR (X2) = 9.8073844E-01 GEN.WT. TIMES MODAL PART. FACT. (X2) = 6.6940626E+03

MODAL PARTICIPATION FACTOR (X3) = 1.1652818E-17 GEN.WT. TIMES MODAL PART. FACT. (X3) = 7.9536692E-14

N O D A L   P O I N T   A P P L I E D   F O R C E S   FOR OUTPUT VECTOR 2

NODE	X1	X2	X3	X4	X5	X6
2	.311140E+04	-.333165E-07	.521679E-12	0.	0.	0.
3	.916002E+04	-.849811E-07	-.521679E-12	0.	0.	0.
4	.174657E+05	-.114348E-06	.521679E-12	0.	0.	0.
5	.281253E+05	-.881656E-07	-.324787E-11	0.	0.	0.
6	.381355E+05	.386486E-07	-.504851E-12	0.	0.	0.
7	.437223E+05	.227594E-06	-.841418E-12	0.	0.	0.
8	.524104E+05	.457075E-06	-.673134E-12	0.	0.	0.
9	.304648E+05	.348918E-06	.560945E-12	0.	0.	0.

* * * * * * * * * * * * * * * * * *

MODE SHAPE (EIGENVECTOR)

MODE NUMBER 2 , FREQUENCY = 14.961744 , GENERALIZED WEIGHT = 6386.7461

*MAXIMUM ROTATION IS AT NODE 9 *DOF = 5 VALUE = .685891E-02

*MAXIMUM TRANSLATION IS AT NODE 9 *DOF = 1 VALUE = .100000E+01

	*********** TRANSLATIONS	***********		*********** ROTATIONS (RADIANS)	***********	
NODE	X1	X2	X3	X4	X5	X6
2	.045792282	-.000000000	.000000000	.000000000	.002077782	0.000000000
3	.134813200	-.000000000	-.000000000	.000000000	.003744669	0.000000000
4	.257053037	-.000000000	.000000000	-.000000000	.005012093	0.000000000
5	.402703411	-.000000000	-.000000000	-.000000000	.005904858	0.000000000
6	.575009267	.000000000	-.000000000	-.000000000	.006495249	0.000000000
7	.717857427	.000000000	-.000000000	-.000000000	.006738779	0.000000000
8	.860503147	.000000000	-.000000000	-.000000000	.006837910	0.000000000
9	1.000000000	.000000000	.000000000	-.000000000	.006858911	0.000000000

MODAL PARTICIPATION FACTOR (X1) = 1.5238759E+00 GEN.WT. TIMES MODAL PART. FACT. (X1) = 9.7326085E+03
MODAL PARTICIPATION FACTOR (X2) = 5.1442063E-12 GEN.WT. TIMES MODAL PART. FACT. (X2) = 3.2854739E-08
MODAL PARTICIPATION FACTOR (X3) = -2.8647896E-17 GEN.WT. TIMES MODAL PART. FACT. (X3) = -1.8296684E-13

* * * * * * * * * * * * * * * * * *

N O D A L   P O I N T   A P P L I E D   F O R C E S   FOR OUTPUT VECTOR 3

NODE	X1	X2	X3	X4	X5	X6
2	.139823E-08	.279503E+06	-.431791E-10	0.	0.	0.
3	.302950E-08	.655164E+06	-.539739E-10	0.	0.	0.
4	.699116E-08	.808112E+06	-.863582E-10	0.	0.	0.
5	.670708E-08	.640916E+06	-.134412E-09	0.	0.	0.
6	.545921E-08	.263251E+06	-.835725E-10	0.	0.	0.
7	.167116E-08	.184748E+06	-.928583E-10	0.	0.	0.
8	.501349E-08	.183419E+06	-.167145E-09	0.	0.	0.
9	0.	.977166E+05	-.742867E-10	0.	0.	0.

MODE SHAPE (EIGENVECTOR)

MODE NUMBER 3 , FREQUENCY = 34.798235 , GENERALIZED WEIGHT = 17276.280

*MAXIMUM ROTATION IS AT NODE 2 *DOF = 4 VALUE = -.160802E-01

*MAXIMUM TRANSLATION IS AT NODE 4 *DOF = 2 VALUE = .100000E+01

	*********** TRANSLATIONS	***********		********** ROTATIONS (RADIANS)	**********	
NODE	X1	X2	X3	X4	X5	X6
2	.000000000	.345871126	-.000000000	-.016080216	.000000000	0.000000000
3	.000000000	.810734026	-.000000000	-.013279954	.000000000	0.000000000
4	.000000000	1.000000000	-.000000000	.000491563	.000000000	0.000000000
5	.000000000	.783167533	-.000000000	.012851981	-.000000000	0.000000000
6	.000000000	.329341263	-.000000000	.010667949	-.000000000	0.000000000
7	.000000000	.239922477	-.000000000	.003006228	-.000000000	0.000000000
8	.000000000	.238195978	-.000000000	.000022106	-.000000000	0.000000000
9	0.000000000	.253798305	-.000000000	-.000589765	-.000000000	0.000000000

MODAL PARTICIPATION FACTOR (X1) = 1.4161942E-14 GEN.WT. TIMES MODAL PART. FACT. (X1) = 2.4466567E-10

MODAL PARTICIPATION FACTOR (X2) = 1.4563578E+00 GEN.WT. TIMES MODAL PART. FACT. (X2) = 2.5160445E+04

MODAL PARTICIPATION FACTOR (X3) = -3.4424241E-16 GEN.WT. TIMES MODAL PART. FACT. (X3) = -5.9472281E-12

* * * * * * * * * * * * * * * * * *

N O D A L   P O I N T   A P P L I E D   F O R C E S   FOR OUTPUT VECTOR   4

NODE	X1	X2	X3	X4	X5	X6
2	-.500232E+06	.775304E-05	-.385737E-07	0.	0.	0.
3	-.985673E+06	.181325E-04	-.864423E-07	0.	0.	0.
4	-.123643E+07	.219376E-04	-.135589E-06	0.	0.	0.
5	-.115424E+07	.162222E-04	-.187107E-06	0.	0.	0.
6	-.574673E+06	.332721E-05	-.215881E-06	0.	0.	0.
7	.476462E+05	-.221922E-05	-.214282E-06	0.	0.	0.
8	.688266E+06	-.549136E-05	-.229473E-06	0.	0.	0.
9	.642420E+06	-.383738E-05	-.118735E-06	0.	0.	0.

MODE SHAPE (EIGENVECTOR)

MODE NUMBER 4 , FREQUENCY = 68.705678 , GENERALIZED WEIGHT = 8446.1189

*MAXIMUM ROTATION IS AT NODE 9 *DOF = 5 VALUE = .207611E-01

*MAXIMUM TRANSLATION IS AT NODE 9 *DOF = 1 VALUE = .100000E+01

	************ TRANSLATIONS	************		************ ROTATIONS (RADIANS) ************		
NODE	X1	X2	X3	X4	X5	X6
2	-.349129627	.000000000	-.000000000	-.000000000	-.004281571	0.000000000
3	-.687936348	.000000000	-.000000000	-.000000000	-.003304441	0.000000000
4	-.862951228	.000000000	-.000000000	.000000000	.001547143	0.000000000
5	-.783726578	.000000000	-.000000000	.000000000	.008203099	0.000000000
6	-.410908922	.000000000	-.000000000	.000000000	.014844851	0.000000000
7	.037097278	-.000000000	-.000000000	.000000000	.018515299	0.000000000
8	.535883210	-.000000000	-.000000000	.000000000	.020318299	0.000000000
9	1.000000000	-.000000000	-.000000000	.000000000	.020761148	0.000000000

MODAL PARTICIPATION FACTOR (X1) = -7.5437406E-01 GEN.WT. TIMES MODAL PART. FACT. (X1) = -6.3715330E+03
MODAL PARTICIPATION FACTOR (X2) = 1.3827404E-11 GEN.WT. TIMES MODAL PART. FACT. (X2) = 1.1678790E-07
MODAL PARTICIPATION FACTOR (X3) = -3.0099183E-13 GEN.WT. TIMES MODAL PART. FACT. (X3) = -2.5422127E-09

* * * * * * * * * * * * * * * * * *

N O D A L   P O I N T   A P P L I E D   F O R C E S   FOR OUTPUT VECTOR 5

NODE	X1	X2	X3	X4	X5	X6
2	.127407E-05	.161165E+07	-.251910E-06	0.	0.	C.
3	.244544E-05	.227932E+07	-.554048E-06	0.	0.	C.
4	.333218E-05	.512688E+06	-.872413E-06	0.	0.	C.
5	.376592E-05	-.202920E+07	-.121013E-05	0.	0.	0.
6	.328305E-05	-.283532E+07	-.138774E-05	0.	0.	0.
7	.245985E-05	-.281946E+07	-.139394E-05	0.	0.	0.
8	.179255E-05	-.487628E+06	-.149431E-05	0.	0.	C.
9	.580601E-06	.156646E+07	-.766083E-06	0.	0.	C.

MODE SHAPE (EIGENVECTOR)

MODE NUMBER 5 , FREQUENCY = 70.190252 , GENERALIZED WEIGHT = 20539.093

*MAXIMUM ROTATION IS AT NODE 9 *DOF = 4 VALUE = -.547309E-01

*MAXIMUM TRANSLATION IS AT NODE 9 *DOF = 2 VALUE = .100000E+01

	*********** TRANSLATIONS	***********		********** ROTATIONS (RADIANS) **********		
NODE	X1	X2	X3	X4	X5	X6
2	.000000000	.490183469	-.000000000	-.012589148	.000000000	0.000000000
3	.000000000	.693257654	-.000000000	.007144916	.000000000	0.000000000
4	.000000000	.155934542	-.000000000	.026276535	.000000000	0.000000000
5	.000000000	-.509451999	-.000000000	.021179518	.000000000	0.000000000
6	.000000000	-.871846094	-.000000000	.003679042	-.000000000	0.000000000
7	.000000000	-.899948629	-.000000000	-.018549583	-.000000000	0.000000000
8	.000000000	-.155646598	-.000000000	-.044922208	-.000000000	0.000000000
9	.000000000	1.000000000	-.000000000	-.054730873	-.000000000	0.000000000

MODAL PARTICIPATION FACTOR (X1) = 1.8313757E-12 GEN.WT. TIMES MODAL PART. FACT. (X1) = 3.7614796E-08

MODAL PARTICIPATION FACTOR (X2) = -2.1294220E-01 GEN.WT. TIMES MODAL PART. FACT. (X2) = -4.3736397E+03

MODAL PARTICIPATION FACTOR (X3) = -7.6515641E-13 GEN.WT. TIMES MODAL PART. FACT. (X3) = -1.5715619E-08

N O D A L   P O I N T   A P P L I E D   F O R C E S   FOR OUTPUT VE   6

NODE	X1	X2	X3	X4	X5	X6
2	-.864973E-06	.150191E-04	.285788E+06	0.	0.	0.
3	-.186507E-05	.313072E-04	.559594E+06	0.	C.	C.
4	-.306023E-05	.343199E-04	.809936E+06	0.	0.	0.
5	-.441958E-05	.242899E-04	.106494E+07	0.	0.	C.
6	-.541337E-05	.648969E-05	.117191E+07	0.	0.	C.
7	-.578172E-05	-.203296E-05	.113241E+07	0.	0.	C.
8	-.655005E-05	-.938419E-05	.118799E+07	0.	C.	C.
9	-.363677E-05	-.887145E-05	.603355E+06	0.	0.	C.

* * * * * * * * * * * * * * * * * *

MODE SHAPE (EIGENVECTOR)

MODE NUMBER 6 , FREQUENCY = 79.966929 , GENERALIZED WEIGHT = 8437.3037

*MAXIMUM ROTATION IS AT NODE 2 *DOF = 4 VALUE = -.147352E-12

*MAXIMUM TRANSLATION IS AT NODE 9 *DOF = 3 VALUE = .100000E+01

	*********** TRANSLATIONS		***********	********** ROTATIONS (RADIANS) **********		
NODE	X1	X2	X3	X4	X5	X6
2	-.000000000	.000000000	.203727002	-.000000000	-.000000000	0.000000000
3	-.000000000	.000000000	.398911831	-.000000000	-.000000000	0.000000000
4	-.000000000	.000000000	.577370485	.000000000	-.000000000	0.000000000
5	-.000000000	.000000000	.731620280	.000000000	-.000000000	0.000000000
6	-.000000000	.000000000	.863253428	.000000000	-.000000000	0.000000000
7	-.000000000	-.000000000	.933428176	.000000000	-.000000000	0.000000000
8	-.000000000	-.000000000	.984486713	.000000000	-.000000000	0.000000000
9	-.000000000	-.000000000	1.000000000	.000000000	-.000000000	0.000000000

MODAL PARTICIPATION FACTOR (X1) = -5.8770193E-12 GEN.WT. TIMES MODAL PART. FACT. (X1) = -4.9586197E-08

MODAL PARTICIPATION FACTOR (X2) = 1.6861263E-11 GEN.WT. TIMES MODAL PART. FACT. (X2) = 1.4226360E-07

MODAL PARTICIPATION FACTOR (X3) = 1.2679673E+00 GEN.WT. TIMES MODAL PART. FACT. (X3) = 1.0698225E+04

• • • • • • • • • • • • • • • • • •

N O D A L   P O I N T   A P P L I E D   F O R C E S   FOR OUTPUT VECTOR   7

NODE	X1	X2	X3	X4	X5	X6
2	-.294603E-06	-.465209E+07	.119667E-05	0.	0.	0.
3	-.381725E-05	-.424430E+07	.222171E-05	0.	0.	0.
4	-.107524E-04	.222280E+07	.312775E-05	0.	0.	0.
5	-.221602E-04	.493253E+07	.407425E-05	0.	0.	0.
6	-.361686E-04	-.838176E+06	.447887E-05	0.	0.	0.
7	-.459457E-04	-.453921E+07	.431192E-05	0.	0.	0.
8	-.590189E-04	-.161660E+07	.448851E-05	0.	0.	0.
9	-.358564E-04	.281486E+07	.225870E-05	0.	0.	0.

MODE SHAPE (EIGENVECTOR)

MODE NUMBER 7 , FREQUENCY = 94.090563 , GENERALIZED WEIGHT = 20645.456

*MAXIMUM ROTATION IS AT NODE 9 *DOF = 4 VALUE = -.588743E-01

*MAXIMUM TRANSLATION IS AT NODE 9 *DOF = 2 VALUE = .100000E+01

	*********** TRANSLATIONS	***********		********** ROTATIONS (RADIANS)	**********	
NODE	X1	X2	X3	X4	X5	X6
2	-.000000000	-.787406331	.000000000	.012066398	-.000000000	0.000000000
3	-.000000000	-.718384731	.000000000	-.023004634	-.000000000	0.000000000
4	-.000000000	.376227245	.000000000	-.029931119	-.000000000	0.000000000
5	-.000000000	.324413522	.000000000	.008393093	-.000000000	0.000000000
6	-.000000000	-.143428041	.000000000	.030844120	-.000000000	0.000000000
7	-.000000000	-.806293616	.000000000	.001506175	-.000000000	0.000000000
8	-.000000000	-.287153768	.000000000	-.041248557	-.000000000	0.000000000
9	-.000000000	1.000000000	.000000000	-.058874341	-.000000000	0.000000000

MODAL PARTICIPATION FACTOR (X1) = -1.1460489E-11 GEN.WT. TIMES MODAL PART. FACT. (X1) = -2.3660702E-07

MODAL PARTICIPATION FACTOR (X2) = -3.1702747E-01 GEN.WT. TIMES MODAL PART. FACT. (X2) = -6.5451767E+03

MODAL PARTICIPATION FACTOR (X3) = 1.4002493E-12 GEN.WT. TIMES MODAL PART. FACT. (X3) = 2.8908786E-08

* * * * * * * * * * * * * * * * * *

N O D A L   P O I N T   A P P L I E D   F O R C E S   FOR OUTPUT VECTOR   8

NODE	X1	X2	X3	X4	X5	X6
2	.549499E-05	.134383E+08	.114501E-04	0.	0.	0.
3	-.198625E-04	-.131440E+07	.139149E-04	0.	0.	C.
4	-.341532E-04	-.112976E+08	.107208E-04	0.	0.	C.
5	-.511438E-04	.778646E+07	.619434E-05	0.	0.	C.
6	-.828676E-04	.854548E+07	.470507E-06	0.	0.	C.
7	-.113929E-03	-.364487E+07	-.388284E-05	0.	0.	C.
8	-.156402E-03	-.573273E+07	-.821964E-05	0.	0.	C.
9	-.101656E-03	.410901E+07	-.542373E-05	0.	0.	C.

MODE SHAPE (EIGENVECTOR)

MODE NUMBER 8 , FREQUENCY = 141.90357 , GENERALIZED WEIGHT = 19080.256

*MAXIMUM ROTATION IS AT NODE 9 *DOF = 4 VALUE = -.464692E-01

*MAXIMUM TRANSLATION IS AT NODE 2 *DOF = 2 VALUE = .100000E+01

	************ TRANSLATIONS	************		************ ROTATIONS (RADIANS)	************	
NODE	X1	X2	X3	X4	X5	X6
2	.000000000	1.000000000	.000000000	.003979319	-.000000000	0.000000000
3	-.000000000	-.097809846	.000000000	.034098496	-.000000000	0.000000000
4	-.000000000	-.840704461	.000000000	-.012235744	-.000000000	0.000000000
5	-.000000000	.572164619	.000000000	-.028299495	-.000000000	0.000000000
6	-.000000000	.542896092	.000000000	.018685692	-.000000000	0.000000000
7	-.000000000	-.284643041	-.000000000	.020551610	-.000000000	0.000000000
8	-.000000000	-.447691998	-.000000000	-.020739876	-.000000000	0.000000000
9	-.000000000	.541779113	-.000000000	-.046469210	-.000000000	0.000000000

MODAL PARTICIPATION FACTOR (X1) = -1.4126135E-11 GEN.WT. TIMES MODAL PART. FACT. (X1) = -2.6953027E-07
MODAL PARTICIPATION FACTOR (X2) = 3.0288239E-01 GEN.WT. TIMES MODAL PART. FACT. (X2) = 5.7790736E+03
MODAL PARTICIPATION FACTOR (X3) = 6.4003307E-13 GEN.WT. TIMES MODAL PART. FACT. (X3) = 1.2211995E-08

* * * * * * * * * * * * * * * * * * *

NODAL POINT APPLIED FORCES FOR OUTPUT VECTOR 9

NODE	X1	X2	X3	X4	X5	X6
2	.460686E+07	-.729022E-03	-.223016E-04	0.	0.	0.
3	.594980E+07	-.168614E-02	-.453103E-04	0.	0.	0.
4	.258148E+07	-.223612E-02	-.683858E-04	0.	0.	0.
5	-.273741E+07	-.190494E-02	-.924406E-04	0.	0.	0.
6	-.512838E+07	-.717666E-03	-.103549E-03	0.	0.	0.
7	-.270682E+07	-.228826E-03	-.101193E-03	0.	0.	0.
8	.166593E+07	.381199E-03	-.107073E-03	0.	0.	0.
9	.288416E+07	.626409E-03	-.544533E-04	0.	0.	0.

* * * * * * * * * * * * * * * * * *

MODE SHAPE (EIGENVECTOR)

MODE NUMBER 9 , FREQUENCY = 145.57594 , GENERALIZED WEIGHT = 9142.9528

*MAXIMUM ROTATION IS AT NODE 9 *DOF = 5 VALUE = .245787E-01

*MAXIMUM TRANSLATION IS AT NODE 9 *DOF = 1 VALUE = .100000E+01

	*********** TRANSLATIONS	***********		********** ROTATIONS (RADIANS)	**********	
NODE	X1	X2	X3	X4	X5	X6
2	.716176430	-.000000000	-.000000000	.000000000	.001964792	0.000000000
3	.924949138	-.000000000	-.000000000	.000000000	-.005037670	0.000000000
4	.401313052	-.000000000	-.000000000	.000000000	-.011172957	0.000000000
5	-.414006722	-.000000000	-.000000000	-.000000000	-.008493454	0.000000000
6	-.816779018	-.000000000	-.000000000	-.000000000	.003957433	0.000000000
7	-.469433466	-.000000000	-.000000000	-.000000000	.015477600	0.000000000
8	.288915720	.000000000	-.000000000	-.000000000	.022590541	0.000000000
9	1.000000000	.000000000	-.000000000	-.000000000	.024578720	0.000000000

MODAL PARTICIPATION FACTOR (X1) = 3.5943298E-01 GEN.WT. TIMES MODAL PART. FACT. (X1) = 3.2862788E+03

MODAL PARTICIPATION FACTOR (X2) = -3.2818991E-10 GEN.WT. TIMES MODAL PART. FACT. (X2) = -3.0006249E-06

MODAL PARTICIPATION FACTOR (X3) = -3.0040565E-11 GEN.WT. TIMES MODAL PART. FACT. (X3) = -2.7465947E-07

N O D A L   P O I N T   A P P L I E D   F O R C E S   FOR OUTPUT VECTOR   10

NODE	X1	X2	X3	X4	X5	X6
2	-.800297E-04	-.173574E+08	.130454E-03	0.	0.	0.
3	-.190328E-03	.144308E+08	.216660E-03	0.	0.	0.
4	-.148156E-03	-.684926E+06	.272230E-03	0.	0.	0.
5	-.115894E-05	-.134912E+08	.316599E-03	0.	0.	0.
6	.103592E-03	.205419E+08	.308708E-03	0.	0.	0.
7	.592063E-04	.366881E+07	.271949E-03	0.	0.	0.
8	-.501428E-04	-.181306E+08	.262210E-03	0.	0.	0.
9	-.868534E-04	.877773E+07	.126097E-03	0.	0.	0.

* * * * * * * * * * * * * * * * * * *

MODE SHAPE (EIGENVECTOR)

MODE NUMBER 10 , FREQUENCY = 176.40688 , GENERALIZED WEIGHT = 24794.035

*MAXIMUM ROTATION IS AT NODE 9 *DOF = 4 VALUE = -.730668E-01

*MAXIMUM TRANSLATION IS AT NODE 6 *DOF = 2 VALUE = .100000E+01

NODE	************ TRANSLATIONS*** X1	X2	X3 ***********	********** ROTATIONS (RADIANS) X4	X5	X6 **********
2	-.000000000	-.835788951	.000000000	-.013979264	-.000000000	0.000000000
3	-.000000000	.594868906	.000000000	-.014523332	-.000000000	0.000000000
4	-.000000000	-.032980336	.000000000	.023132773	.000000000	0.000000000
5	-.000000000	-.641486402	.000000000	-.017329792	.000000000	0.000000000
6	.000000000	1.000000000	.000000000	-.009534774	-.000000000	0.000000000
7	.000000000	.185395590	.000000000	.033258852	-.000000000	0.000000000
8	-.000000000	-.916188495	.000000000	-.018103434	-.000000000	0.000000000
9	-.000000000	.987127228	.000000000	-.073066792	-.000000000	0.000000000

MODAL PARTICIPATION FACTOR (X1) = -4.9963376E-12 GEN.WT. TIMES MODAL PART. FACT. (X1) = -1.2387937E-07

MODAL PARTICIPATION FACTOR (X2) = -2.8476578E-02 GEN.WT. TIMES MODAL PART. FACT. (X2) = -7.0604928E+02

MODAL PARTICIPATION FACTOR (X3) = 2.4164235E-11 GEN.WT. TIMES MODAL PART. FACT. (X3) = 5.9912889E-07

* * * * * * * * * * * * * * * * * *

N O D A L   P O I N T   A P P L I E D   F O R C E S   FOR OUTPUT VECTOR   11

NODE	X1	X2	X3	X4	X5	X6
2	-.692831E-04	-.198199E+08	.122053E-03	0.	0.	0.
3	-.370359E-03	.271052E+08	.268249E-03	0.	0.	0.
4	-.314893E-03	-.267647E+08	.243662E-03	0.	0.	C.
5	-.390386E-03	.174896E+08	.480978E-04	0.	0.	C.
6	-.736173E-03	-.451081E+07	-.252181E-03	0.	0.	C.
7	-.742548E-03	-.109132E+08	-.408153E-03	0.	0.	C.
8	-.695253E-03	.146956E+08	-.509911E-03	0.	0.	0.
9	-.341952E-03	-.570964E+07	-.254389E-03	0.	0.	C.

* * * * * * * * * * * * * * * * * *

MODE SHAPE (EIGENVECTOR)

MODE NUMBER 11 , FREQUENCY = 201.53388 , GENERALIZED WEIGHT = 22995.811

*MAXIMUM ROTATION IS AT NODE 9 *DOF = 4 VALUE = .394330E-01

*MAXIMUM TRANSLATION IS AT NODE 3 *DOF = 2 VALUE = .100000E+01

	*********** TRANSLATIONS	***********		********** ROTATIONS (RADIANS) **********		
NODE	X1	X2	X3	X4	X5	X6
2	-.000000000	-.731219985	.000000000	-.018552749	-.000000000	0.000000000
3	-.000000000	1.000000000	.000000000	.004038519	-.000000000	0.000000000
4	-.000000000	-.987436670	.000000000	.006124621	-.000000000	0.000000000
5	-.000000000	.637163674	.000000000	-.015176050	-.000000000	0.000000000
6	-.000000000	-.158247899	-.000000000	.017408174	-.000000000	0.000000000
7	-.000000000	-.422532434	-.000000000	-.011555426	-.000000000	0.000000000
8	-.000000000	.564980271	-.000000000	.003681045	-.000000000	0.000000000
9	-.000000000	-.442127558	-.000000000	.039433021	-.000000000	0.000000000

MODAL PARTICIPATION FACTOR (X1) = -3.8363127E-11 GEN.WT. TIMES MODAL PART. FACT. (X1) = -8.8219122E-07

MODAL PARTICIPATION FACTOR (X2) = -8.8317332E-02 GEN.WT. TIMES MODAL PART. FACT. (X2) = -2.0309287E+03

MODAL PARTICIPATION FACTOR (X3) = -7.7816433E-12 GEN.WT. TIMES MODAL PART. FACT. (X3) = -1.7894520E-07

* * * * * * * * * * * * * * * * * *

NODAL POINT APPLIED FORCES FOR OUTPUT VECTOR 12

NODE	X1	X2	X3	X4	X5	X6
2	.139743E+08	.135539E-02	.486142E-04	0.	0.	0.
3	.689736E+07	.286191E-02	.862923E-04	0.	0.	0.
4	-.106272E+08	.402974E-02	.539720E-04	0.	0.	0.
5	-.114891E+08	.332572E-02	.126003E-05	0.	0.	0.
6	.715135E+07	.111326E-03	-.404000E-04	0.	0.	0.
7	.105539E+03	-.218491E-02	-.577980E-04	0.	0.	0.
8	.322669E+06	-.459429E-02	-.675804E-04	0.	0.	0.
9	-.617726E+07	-.388587E-02	-.254697E-04	0.	0.	0.

* * * * * * * * * * * * * * * * * *

MODE SHAPE (EIGENVECTOR)

MODE NUMBER 12 , FREQUENCY = 214.56788 , GENERALIZED WEIGHT = 11350.307

*MAXIMUM ROTATION IS AT NODE 9 *DOF = 5 VALUE = -.270757E-01

*MAXIMUM TRANSLATION IS AT NODE 2 *DOF = 1 VALUE = .100000E+01

	*********** TRANSLATIONS	***********		********** ROTATIONS (RADIANS)	**********	
NODE	X1	X2	X3	X4	X5	X6
2	1.000000000	.000000000	.000000000	-.000000000	-.002862068	0.000000000
3	.493575612	.000000000	.000000000	-.000000000	-.012466912	0.000000000
4	-.760486805	.000000000	.000000000	-.000000000	-.009369037	0.000000000
5	-.799854820	.000000000	.000000000	.000000000	.002956248	0.000000000
6	.524285985	.000000000	-.000000000	.000000000	.003083622	0.000000000
7	.842528378	-.000000000	-.000000000	.000000000	-.010265088	0.000000000
8	.025758849	-.000000000	-.000000000	.000000000	-.022817443	0.000000000
9	-.985899063	-.000000000	-.000000000	.000000000	-.027075704	0.000000000

MODAL PARTICIPATION FACTOR (X1) = 1.9865018E-01 GEN.WT. TIMES MODAL PART. FACT. (X1) = 2.2547405E+03

MODAL PARTICIPATION FACTOR (X2) = 1.9086286E-11 GEN.WT. TIMES MODAL PART. FACT. (X2) = 2.1663520E-07

MODAL PARTICIPATION FACTOR (X3) = -2.0782120E-14 GEN.WT. TIMES MODAL PART. FACT. (X3) = -2.3586344E-10

N O D A L   P O I N T   A P P L I E D   F O R C E S   FOR OUTPUT VECTOR 13

NODE	X1	X2	X3	X4	X5	X6
2	.194727E-02	-.258451E+07	-.320220E-03	0.	0.	0.
3	.800965E-03	.516984E+07	-.621610E-03	0.	0.	0.
4	-.102271E-02	-.949291E+07	-.886967E-03	0.	0.	0.
5	-.519441E-03	.159201E+08	-.114554E-02	0.	0.	0.
6	.306201E-03	-.318319E+08	-.124000E-02	0.	0.	0.
7	-.251749E-03	.339563E+08	-.118579E-02	0.	0.	0.
8	-.107566E-02	-.248409E+08	-.124512E-02	0.	0.	0.
9	-.837647E-03	.780564E+07	-.623703E-03	0.	0.	0.

MODE SHAPE (EIGENVECTOR)

MODE NUMBER 13 , FREQUENCY = 231.07996 , GENERALIZED WEIGHT = 17404.619

*MAXIMUM ROTATION IS AT NODE 9 *DOF = 4 VALUE = -.443597E-01

*MAXIMUM TRANSLATION IS AT NODE 7 *DOF = 2 VALUE = .100000E+01

	*********** TRANSLATIONS	***********		********** ROTATIONS (RADIANS) **********		
NODE	X1	X2	X3	X4	X5	X6
2	.000000000	-.072526487	-.000000000	-.002528070	-.000000000	0.000000000
3	.000000000	.145075784	-.000000000	.003190965	-.000000000	0.000000000
4	-.000000000	-.266389893	-.000000000	-.004720106	-.000000000	0.000000000
5	-.000000000	.441151721	-.000000000	.010320938	-.000000000	0.000000000
6	.000000000	-.703085399	-.000000000	-.014030522	-.000000000	0.000000000
7	-.000000000	1.000000000	-.000000000	-.004399469	-.000000000	0.000000000
8	-.000000000	-.731554344	-.000000000	.004516743	-.000000000	0.000000000
9	-.000000000	.459746685	-.000000000	-.044359688	-.000000000	0.000000000

MODAL PARTICIPATION FACTOR (X1) = -6.8746584E-12 GEN.WT. TIMES MODAL PART. FACT. (X1) = -1.1965081E-07

MODAL PARTICIPATION FACTOR (X2) = -6.2118295E-02 GEN.WT. TIMES MODAL PART. FACT. (X2) = -1.0811452E+03

MODAL PARTICIPATION FACTOR (X3) = -7.6605259E-11 GEN.WT. TIMES MODAL PART. FACT. (X3) = -1.3332853E-06

* * * * * * * * * * * * * * * * * *

N O D A L   P O I N T   A P P L I E D   F O R C E S   FOR OUTPUT VECTOR   14

NODE	X1	X2	X3	X4	X5	X6
2	-.117803E-03	.168101E-02	-.721128E+07	0.	0.	0.
3	-.277037E-03	.242140E-02	-.117742E+08	0.	0.	0.
4	-.164176E-03	.225327E-02	-.120129E+08	0.	0.	0.
5	-.553931E-03	.286935E-02	-.813476E+07	0.	0.	0.
6	-.102850E-02	.937491E-03	-.135525E+06	0.	0.	0.
7	-.101775E-02	.341866E-03	.521507E+07	0.	0.	0.
8	-.105151E-02	-.236964E-02	.913335E+07	0.	0.	0.
9	-.626427E-03	-.200066E-02	.528477E+07	0.	0.	0.

* * * * * * * * * * * * * * * * * * *

MODE SHAPE (EIGENVECTOR)

MODE NUMBER 14 , FREQUENCY = 233.70708 , GENERALIZED WEIGHT = 8637.6682

*MAXIMUM ROTATION IS AT NODE 8 *DOF = 4 VALUE = .295015E-11

*MAXIMUM TRANSLATION IS AT NODE 9 *DOF = 3 VALUE = .100000E+01

	************ TRANSLATIONS	************		*********** ROTATIONS (RADIANS)	***********	
NODE	X1	X2	X3	X4	X5	X6
2	-.000000000	.000000000	-.586898791	-.000000000	-.000000000	0.000000000
3	-.000000000	.000000000	-.958253462	-.000000000	-.000000000	0.000000000
4	-.000000000	.000000000	-.977680504	-.000000000	-.000000000	0.000000000
5	-.000000000	.000000000	-.638045151	.000000000	-.000000000	0.000000000
6	-.000000000	.000000000	-.011397560	.000000000	-.000000000	0.000000000
7	-.000000000	.000000000	.493405101	.000000000	-.000000000	0.000000000
8	-.000000000	-.000000000	.864119523	.000000000	-.000000000	0.000000000
9	-.000000000	-.000000000	1.000000000	.000000000	-.000000000	0.000000000

MODAL PARTICIPATION FACTOR (X1) = -1.0035181E-10 GEN.WT. TIMES MODAL PART. FACT. (X1) = -8.6680565E-07

MODAL PARTICIPATION FACTOR (X2) = 1.2725865E-10 GEN.WT. TIMES MODAL PART. FACT. (X2) = 1.0992180E-06

MODAL PARTICIPATION FACTOR (X3) = -4.0735833E-01 GEN.WT. TIMES MODAL PART. FACT. (X3) = -3.5186261E+03

* * * * * * * * * * * * * * * * * *

N O D A L   P O I N T   A P P L I E D   F O R C E S   FOR OUTPUT VECTOR 15

NODE	X1	X2	X3	X4	X5	X6
2	.237521E+08	-.388718E-02	.591833E-03	0.	0.	0.
3	-.960620E+07	-.106732E-01	.103261E-02	0.	0.	0.
4	-.181766E+08	-.122864E-01	.139984E-02	0.	0.	0.
5	.196007E+08	-.664565E-02	.172581E-02	0.	0.	0.
6	.803502E+07	.324722E-02	.179055E-02	0.	0.	0.
7	-.148994E+08	.119481E-01	.167828E-02	0.	0.	0.
8	-.663162E+07	.187924E-01	.173045E-02	0.	0.	0.
9	.876839E+07	.110866E-01	.848483E-03	0.	0.	0.

* * * * * * * * * * * * * * * * * *

MODE SHAPE (EIGENVECTOR)

MODE NUMBER 15 , FREQUENCY = 279.73805 , GENERALIZED WEIGHT = 9978.4419

*MAXIMUM ROTATION IS AT NODE 9 *DOF = 5 VALUE = .233733E-01

*MAXIMUM TRANSLATION IS AT NODE 2 *DOF = 1 VALUE = .100000E+01

	************ TRANSLATIONS	************		************ ROTATIONS (RADIANS) ************		
NODE	X1	X2	X3	X4	X5	X6
2	1.000000000	-.000000000	.000000000	.000000000	-.004846676	0.000000000
3	-.404435242	-.000000000	.000000000	.000000000	-.007767074	0.000000000
4	-.765259824	-.000000000	.000000000	-.000000000	.004416951	0.000000000
5	.802825468	-.000000000	.000000000	-.000000000	.005823393	0.000000000
6	.346572051	.000000000	.000000000	-.000000000	-.002470059	0.000000000
7	-.699784071	.000000000	.000000000	-.000000000	.003766943	0.000000000
8	-.311469880	.000000000	.000000000	-.000000000	.017328809	0.000000000
9	.823347359	.000000000	.000000000	-.000000000	.023373256	0.000000000

MODAL PARTICIPATION FACTOR (X1) = 1.3590672E-01 GEN.WT. TIMES MODAL PART. FACT. (X1) = 1.3561373E+03
MODAL PARTICIPATION FACTOR (X2) = 1.4517366E-10 GEN.WT. TIMES MODAL PART. FACT. (X2) = 1.4486069E-06
MODAL PARTICIPATION FACTOR (X3) = 1.3534710E-10 GEN.WT. TIMES MODAL PART. FACT. (X3) = 1.3505532E-06

* * * * * * * * * * * * * * * * * *

N O D A L   P O I N T   A P P L I E D   F O R C E S   FOR OUTPUT VECTOR   16

NODE	X1	X2	X3	X4	X5	X6
2	-.2220 7E+08	-.101208E-02	-.541679E-03	0.	0.	0.
3	.258376E+08	.990943E-03	-.211970E-02	0.	0.	0.
4	-.900[illegible]32E+07	.274459E-03	-.340285E-02	0.	0.	0.
5	-.149846E+08	-.158260E-02	-.430047E-02	0.	0.	0.
6	.312081E+08	.226782E-03	-.431754E-02	0.	0.	0.
7	-.135333E+08	.108527E-01	-.402906E-02	0.	0.	0.
8	-.190590E+08	.264481E-01	-.425422E-02	0.	0.	0.
9	.140518E+08	.206874E-01	-.238594E-02	0.	0.	C.

MODE SHAPE (EIGENVECTOR)

MODE NUMBER 16 , FREQUENCY = 324.55512 , GENERALIZED WEIGHT = 10194.248

*MAXIMUM ROTATION IS AT NODE 9 *DOF = 5 VALUE = .287874E-01

*MAXIMUM TRANSLATION IS AT NODE 6 *DOF = 1 VALUE = .100000E+01

NODE	*********** TRANSLATIONS		***********	*********** ROTATIONS (RADIANS)	***********	
	X1	X2	X3	X4	X5	X6
2	-.694367662	-.000000000	-.000000000	-.000000000	.004644805	0.000000000
3	.808183778	.000000000	-.000000000	-.000000000	.002919051	0.000000000
4	-.281564524	.000000000	-.000000000	.000000000	-.001787237	0.000000000
5	-.455954252	-.000000000	-.000000000	-.000000000	.006211349	0.000000000
6	1.000000000	.000000000	-.000000000	-.000000000	.003490271	0.000000000
7	-.472198924	.000000000	-.000000000	-.000000000	.003179378	0.000000000
8	-.664999890	.000000000	-.000000000	-.000000000	.019100856	0.000000000
9	.980216911	.000000001	-.000000000	-.000000000	.028787416	0.000000000

MODAL PARTICIPATION FACTOR (X1) = -7.0003638E-02 GEN.WT. TIMES MODAL PART. FACT. (X1) = -7.1363447E+02

MODAL PARTICIPATION FACTOR (X2) = 5.1849908E-10 GEN.WT. TIMES MODAL PART. FACT. (X2) = 5.2857084E-06

MODAL PARTICIPATION FACTOR (X3) = -2.3107244E-10 GEN.WT. TIMES MODAL PART. FACT. (X3) = -2.3556099E-06

N O D A L   P O I N T   A P P L I E D   F O R C E S   FOR OUTPUT VECTOR 17

NODE	X1	X2	X3	X4	X5	X6
2	.204606E+08	-.187712E-02	-.276277E-03	0.	0.	0.
3	-.337618E+08	.643665E-02	-.249749E-03	0.	0.	0.
4	.376377E+08	-.844004E-04	-.115489E-03	0.	0.	0.
5	-.303565E+08	.507583E-03	-.315793E-03	0.	0.	0.
6	.192305E+03	-.892874E-03	-.566016E-03	0.	0.	0.
7	-.645414E+06	-.990860E-02	-.673252E-03	0.	0.	0.
8	-.152844E+08	-.147176E-01	-.756915E-05	0.	0.	0.
9	.872228E+07	-.106676E-01	-.181660E-03	0.	0.	C.

MODE SHAPE (EIGENVECTOR)

MODE NUMBER 17 , FREQUENCY = 352.13698 , GENERALIZED WEIGHT = 9817.2902

*MAXIMUM ROTATION IS AT NODE 9 *DOF = 5 VALUE = .153023E-01

*MAXIMUM TRANSLATION IS AT NODE 4 *DOF = 1 VALUE = .100000E+01

NODE	*********** TRANSLATIONS		***********	*********** ROTATIONS	(RADIANS)	***********
	X1	X2	X3	X4	X5	X6
2	.543620546	-.000000000	-.000000000	-.000000000	-.003543293	0.000000000
3	-.897021849	.000000000	-.000000000	-.000000000	.000790643	0.000000000
4	1.000000000	-.000000000	-.000000000	.000000000	.000610602	0.000000000
5	-.784660488	.000000000	-.000000000	-.000000000	-.000472725	0.000000000
6	.523453296	-.000000000	-.000000000	.000000000	.003778211	0.000000000
7	-.019129991	-.000000000	-.000000000	-.000000000	.001787875	0.000000000
8	-.453028307	-.000000000	-.000000000	-.000000000	.009289620	0.000000000
9	.516860386	-.000000000	-.000000000	-.000000000	.015302284	0.000000000

MODAL PARTICIPATION FACTOR (X1) = 4.8264060E-02 GEN.WT. TIMES MODAL PART. FACT. (X1) = 4.7382228E+02

MODAL PARTICIPATION FACTOR (X2) = -2.5088363E-10 GEN.WT. TIMES MODAL PART. FACT. (X2) = -2.4629974E-06

MODAL PARTICIPATION FACTOR (X3) = -1.9182163E-11 GEN.WT. TIMES MODAL PART. FACT. (X3) = -1.8831686E-07

N O D A L   P O I N T   A P P L I E D   F O R C E S   FOR OUTPUT VECTOR   18

NODE	X1	X2	X3	X4	X5	X6
2	.114284E-02	.198379E-02	.283622E+08	0.	0.	0.
3	-.122032E-02	.276155E-02	.289900E+08	0.	0.	0.
4	-.327803E-02	.263642E-02	.126955E+07	0.	0.	0.
5	-.278106E-02	-.981750E-03	-.287346E+08	0.	0.	0.
6	-.745716E-02	-.856807E-02	-.276976E+08	0.	0.	0.
7	-.916759E-02	-.126744E-01	-.521729E+07	0.	0.	0.
8	-.103667E-01	-.140517E-01	.179606E+08	0.	0.	0.
9	-.554473E-02	-.615540E-02	.140712E+08	0.	0.	0.

MODE SHAPE (EIGENVECTOR)

MODE NUMBER 18 , FREQUENCY = 381.35075 , GENERALIZED WEIGHT = 8438.3704

*MAXIMUM ROTATION IS AT NODE 9 *DOF = 5 VALUE = -.394630E-09

*MAXIMUM TRANSLATION IS AT NODE 9 *DOF = 3 VALUE = .100000E+01

	*********** TRANSLATIONS		***********	*********** ROTATIONS (RADIANS)		***********
NODE	X1	X2	X3	X4	X5	X6
2	.000000000	.000000000	.866932670	-.000000000	-.000000000	0.000000000
3	-.000000000	.000000000	.886123118	.000000000	-.000000000	0.000000000
4	-.000000000	.000000000	.038805691	-.000000000	-.000000000	0.000000000
5	-.000000000	-.000000000	-.846458423	.000000000	-.000000000	0.000000000
6	-.000000000	-.000000000	-.874837034	-.000000000	-.000000000	0.000000000
7	-.000000000	-.000000000	-.185388717	.000000000	-.000000000	0.000000000
8	-.000000000	-.000000000	.638205014	.000000000	-.000000000	0.000000000
9	-.000000000	-.000000000	1.000000000	.000000000	-.000000000	0.000000000

MODAL PARTICIPATION FACTOR (X1) = -3.0844283E-10 GEN.WT. TIMES MODAL PART. FACT. (X1) = -2.6027548E-06

MODAL PARTICIPATION FACTOR (X2) = -2.7954560E-10 GEN.WT. TIMES MODAL PART. FACT. (X2) = -2.3589093E-06

MODAL PARTICIPATION FACTOR (X3) = 2.3132960E-01 GEN.WT. TIMES MODAL PART. FACT. (X3) = 1.9520448E+03

* * * * * * * * * * * * * * * * * *

N O D A L   P O I N T   A P P L I E D   F O R C E S   FOR OUTPUT VECTOR   19

NODE	X1	X2	X3	X4	X5	X6
2	.709161E+06	.171317E-02	.514594E-03	0.	0.	0.
3	-.209527E+07	-.269241E-02	-.566052E-03	0.	0.	0.
4	.443869E+07	-.119281E-02	-.146700F-02	0.	0.	0.
5	-.106689E+08	-.737853E-02	-.140875E-02	0.	0.	0.
6	.243683E+08	-.359716E-02	-.156174E-02	0.	0.	0.
7	-.425721E+08	-.590869E-02	-.203163E-02	0.	0.	0.
8	.433941E+08	-.638715E-02	-.258949E-02	0.	0.	0.
9	-.173867E+09	-.377964E-02	-.129922E-02	0.	0.	C.

MODE SHAPE (EIGENVECTOR)

MODE NUMBER 19 , FREQUENCY = 399.36054 , GENERALIZED WEIGHT = 7023.6304

*MAXIMUM ROTATION IS AT NODE 9 *DOF = 5 VALUE = -.238879E-01

*MAXIMUM TRANSLATION IS AT NODE 8 *DOF = 1 VALUE = .100000E+01

NODE	********** TRANSLATIONS X1	X2	X3 **********	********** ROTATIONS (RADIANS) X4	X5	X6 **********
2	.014649237	.000000000	.000000000	-.000000000	-.000306234	0.000000000
3	-.043282313	-.000000000	-.000000000	-.000000000	-.000300047	0.000000000
4	.091690662	-.000000000	-.000000000	.000000000	-.001272717	0.000000000
5	-.214408295	-.000000000	-.000000000	-.000000001	-.001041151	0.000000000
6	.515709211	-.000000000	-.000000000	.000000000	-.006326433	0.000000000
7	-.981057234	-.000000000	-.000000000	-.000000000	-.005859772	0.000000000
8	1.000000000	-.000000000	-.000000000	-.000000000	-.011902468	0.000000000
9	-.801036175	-.000000000	-.000000000	-.000000001	-.023887877	0.000000000

MODAL PARTICIPATION FACTOR (X1) = 1.6369642E-03   GEN.WT. TIMES MODAL PART. FACT. (X1) = 1.1497431E+01

MODAL PARTICIPATION FACTOR (X2) = -2.5533688E-10   GEN.WT. TIMES MODAL PART. FACT. (X2) = -1.7933919E-06

MODAL PARTICIPATION FACTOR (X3) = -9.0950899E-11   GEN.WT. TIMES MODAL PART. FACT. (X3) = -6.3880549E-07

N O D A L   P O I N T   A P P L I E D   F O R C E S   FOR OUTPUT VECTOR   20

NODE	X1	X2	X3	X4	X5	X6
2	.205844E-02	-.708441E-02	-.564899E+08	0.	0.	0.
3	.166763E-02	-.380820E-02	-.154933E+08	0.	0.	0.
4	.323789E-02	.666979E-02	.522406E+08	0.	0.	0.
5	.506291E-04	.809983E-02	.309434E+08	0.	0.	0.
6	-.925568E-02	-.172852E-02	-.500374E+08	0.	0.	0.
7	-.157735E-01	-.733411E-02	-.366846E+08	0.	0.	0.
8	-.193806E-01	-.315141E-01	.179544E+08	0.	0.	0.
9	-.117948E-01	-.281683E-01	.248329E+08	0.	0.	0.

MODE SHAPE (EIGENVECTOR)

MODE NUMBER 20 , FREQUENCY = 506.60825 , GENERALIZED WEIGHT = 8615.1894

*MAXIMUM ROTATION IS AT NODE 9 *DOF = 5 VALUE = .210423E-09

*MAXIMUM TRANSLATION IS AT NODE 9 *DOF = 3 VALUE = .100000E+01

	*********** TRANSLATIONS	***********		*********** ROTATIONS (RADIANS)	***********	
NODE	X1	X2	X3	X4	X5	X6
2	.000000000	-.000000000	-.978409045	.000000000	.000000000	0.000000000
3	.000000000	-.000000000	-.268344715	-.000000000	.000000000	0.000000000
4	.000000000	.000000000	.904811112	.000000000	.000000000	0.000000000
5	.000000000	.000000000	.516503972	-.000000000	.000000000	0.000000000
6	-.000000000	-.000000000	-.895539884	.000000000	.000000000	0.000000000
7	-.000000000	-.000000000	-.738629025	-.000000000	.000000000	0.000000000
8	-.000000000	-.000000000	.361504476	-.000000000	.000000000	0.000000000
9	-.000000000	-.000000000	1.000000000	-.000000000	.000000000	0.000000000

MODAL PARTICIPATION FACTOR (X1) = -2.1774322E-10 GEN.WT. TIMES MODAL PART. FACT. (X1) = -1.8758990E-06

MODAL PARTICIPATION FACTOR (X2) = -2.8714349E-10 GEN.WT. TIMES MODAL PART. FACT. (X2) = -2.4737956E-06

MODAL PARTICIPATION FACTOR (X3) = -1.4489878E-01 GEN.WT. TIMES MODAL PART. FACT. (X3) = -1.2483305E+03

```
*****************************************************************************
*** ENTERING PHASE   1 *** RUN DATE - 10/12/81  TIME OF DAY 14.42.42 ***
*****************************************************************************


**** GEOMETRY READ, PRINT AND CHECK LINK ****


***      PROCESSING IS COMPLETE FOR THIS       MODEL -- BEGIN PROCESSING NEXT MODEL ***
```

```
                          SSSSSSSSS    SS      SS  SS      SS  SSSSSSSSS   SSSSSSSSSS       SSS
                          SSSSSSSSSS    SS    SS   SSS     SS  SSSSSSSSSS  SSSSSSSSSS      SSSS
                          SS      SS     SS  SS    SS S    SS  SS      SS  SS             SS SS
  S     S                 SS      SS      SSSS     SS SS   SS  SS      SS  SS            SS  SS      S     S
   S   S                  SS      SS       SS      SS  SS  SS  SSSSSSSSSS  SSSSSS       SS   SS       S   S
SSSSSSSSSS                SS      SS       SS      SS  SS  SS  SSSSSSSSS   SSSSSS      SSSSSSSSSS  SSSSSSSSSS
   S   S                  SS      SS       SS      SS   SS SS  SS   SS     SS          SSSSSSSSSS     S   S
  S     S                 SS      SS       SS      SS    S SS  SS    SS    SS                SS      S     S
                          SSSSSSSSSS       SS      SS      SSS SS     SS   SSSSSSSSSS        SS
                          SSSSSSSSS        SS      SS       SS SS      SS  SSSSSSSSSS        SS
```

```
**********************************************************
*                 **    DYNRE4  (R)  **                  *
*                 ** STARDYNE-3 (R)  **                  *
*                 ** SEP01/81 G LEVEL**                  *
**********************************************************
*   LATEST USER MANUAL  SEPT 1979                        *
*                                                        *
*                                                        *
*   RUN DATE      MONDAY   , OCT. 12, 1981               *
*                 10/12/81   DAY 285 OF 1981             *
*   RUN TIME      14.44.24.                              *
*                                                        *
*    CYBERNET            SCOPE  3.4     +433B            *
*                                                        *
*   (R) 1968 STARDYNE   SYSTEM  BY MECHANICS RESEARCH INC *
*   (R) 1971 STARDYNE-2 SYSTEM  BY MECHANICS RESEARCH INC *
*   (R) 1974 STARDYNE-3 SYSTEM  BY MECHANICS RESEARCH INC *
*   (R) 1977 STARDYNE-3 SYSTEM  BY SYSTEM DEVELOPMENT CORP*
**********************************************************
```

```
**********************************************************
*          S T A R D Y N E   B U L L E T I N S           *
*                                                        *
*     A STARDYNE INFORMATION BULLETIN IS AVAILABLE       *
*   WHICH DESCRIBES IMPORTANT CHANGES CONCERNING THIS    *
*   RELEASE LEVEL OF THE PROGRAM.  IN ORDER TO ACCESS    *
*   THIS BULLETIN - ENTER THE FOLLOWING CONTROL CARDS..  *
*    AT SCOPE 3.4             AT NOS 1                   *
*    .                        .                          *
*   APPLIC(STARBUL)           ATTACH(STARBUL/UN=LIBRARY) *
*   REWIND(STARBUL)           REWIND(STARBUL)            *
*   COPYBF(STARBUL,A)         COPYBF(STARBUL,A)          *
*   REWIND(A)                 REWIND(A)                  *
*   COPYSBF(A,OUTPUT)         COPYSBF(A,OUTPUT)          *
*    .                        .                          *
**********************************************************
```

```
**********************************************************
* A NEW SUMMATION PROCEDURE HAS BEEN INSTALLED IN DYNRE4. *
* THE CQC (COMPLETE QUADRATIC COMBINATION) METHOD HAS     *
* BEEN IMPLEMENTED AND MAY BE CHOSEN BY ENTERING RSS = 14 *
* ON THE OUTPUT CARD, PAGE F-60.  IN ADDITION, THE IRSSXI *
* DIRECTIONAL COMBINATION OPTIONS MAY BE USED WITH RSS=14.*
* IRSSXI = 0-8 CONTROLS THE COMBINATION OF THE UNSIGNED   *
* (ABSOLUTE VALUES) OF THE DIRECTIONAL MODAL RESPONSES.   *
```

```
* FOR CQC, IRSSXI = 9 HAS BEEN ADDED.  IT IS THE SAME AS  *
* IRSSXI = 0 (BUT WITH ALGEBRIAC DIRECTIONAL COMBINATION).*
* (IRSSXI IS ENTERED ON THE OUTPUT CARD AND DESCRIBED ON  *
*  PAGE F-135.                                            *
* FOR INFORMATION REGARDING THE CQC METHOD, SEE-(WILSON,  *
* DER KIUREGHIAN, AND BAYO - A REPLACEMENT FOR THE SRSS   *
* METHOD IN SEISMIC ANALYSIS, MARCH 1980).  COPIES OF     *
* THIS PAPER MAY BE OBTAINED FROM STARDYNE- (213)615-1536.*
***********************************************************

***********************************************************
* THE CQC METHOD INVOLVES THE CREATION OF A CROSS-MODE    *
* COEFFICIENT MATRIX (PIJ) OF ORDER NMODES, WHICH RELATES *
* MODAL DAMPING AND FREQUENCY RATIOS.  THREE ADDITIONAL   *
* ENTRIES MAY BE MADE ON THE OUTPUT CARD.  THEY ARE--     *
* *COL 8,  ENTER A 1 (ONE) IF PRINTOUT OF PIJ IS DESIRED. *
* *COL 73-76 (F4.0), ENTER THE CONSTANT PIJ MODAL DAMPING *
*       RATIO (ASSUMED THE SAME FOR ALL MODES).  IF BLANK, *
*       A VALUE OF .02 (2 PERCENT) WILL BE USED.          *
* *COL 77-80 (F4.0), A CUTOFF TOLERANCE TO PREVENT THE    *
*       COMPUTATION OF TRIVIAL PIJ TERMS.  SMALLER VALUES *
*       WILL BE NEGLECTED.  IF BLANK, A VALUE OF .001 WILL *
*       BE USED.  IF A VALUE OF 1.0 OR GREATER IS ENTERED *
*       TO ELEMINATE THE PIJ MATRIX, THE CQC METHOD       *
*       AND THE SRSS METHOD (RSS=1) SHOULD PRODUCE THE    *
*       SAME RESULTS.                                     *
***********************************************************
```

```
                                   ***** INPUT DATA CARD *****
          /------------------------------- CARD  IMAGE  --------------------------------/
           1    6    12   17   22   27   32   37   42   47   52   57   62   67   72       80
           *    *    *    *    *    *    *    *    *    *    *    *    *    *    *        *
CARD NO   ******************************************************************************
      1   DYNAMIC ANALYSIS
      2   STANDARD            1.0       1.0       1.0
      3   OUTPUT      0       1   1   1  -1   1         1 1 1
      4        1.04 0 3   RESPONSE SPECTRA GIVEN IN G VALUES
      5              -1         9
      6    6          1       0.7       0.45       0.6       0.6       0.45       0.42
      7    6         -7       0.42
      8    6          1      10.0      17.8       23.8      35.7      50.0       66.7
      9    6         -7     100.0
     10    6          1       0.48      0.43       0.43      0.55      0.55       0.40
     11    6         -7       0.37      0.37
     12    6          1      10.0      11.1       18.1      22.7      35.7       52.6
     13    6         -7     100.0     143.9
     14    6          1       1.9       4.5        5.0       5.0       1.0        0.85
     15    6         -7       0.80      0.76       0.76
     16    6          1      10.0      14.3       16.7      19.2      50.0       66.7
     17    6         -7     100.0     125.0      143.0
     18   ALL DONE

                    (END OF INPUT FOR MODEL NO.    1)
```

```
*** RESPONSE NUMBER   1, DYNAMIC ANALYSIS                                    ***

 STANDARD  ANALYSIS.

 MULTIPLIER X1       =     .10000000E+01

 MULTIPLIER X2       =     .10000000E+01

 MULTIPLIER X3       =     .10000000E+01

 MODE RESP PD (IMR) =     0

RESP TYPE (ABS)      =     0

RESP TYPE (RSS)      =     1

DISPLACEMENT(D)      =     1

    VELOCITY(V)      =     1

ACCELERATION(A)      =    -1

IRSSXI (RSS=1 OR 14)=      1

ACCEL OF GRAVITY(G) =     .38640000E+03


BAR LOADS (ELE.)           =     1
BAR LOADS (GLOBAL)         =     1
BAR STRESSES               =     1
TPLATE FORCES (GLOBAL) =         0
TPLATE STRESSES            =     0
QPLATE FORCES (GLOBAL) =         0
QPLATE STRESSES            =     0
CUBE FORCES (GLOBAL)       =     0
CUBE STRESSES              =     0
TETRA STRESSES             =     0
EQUILIBRIUM CHECK          =     0

     ***** RATIO     =        1.000000

     ***** ITYPE     =     4

     ***** ITAPE     =     0

     ***** IROW      =     3

     ***** DESC      =   RESPONSE SPECTRA GIVEN IN G VALUES


**THE FOLLOWING MODE NUMBERS WERE SELECTED FROM TAPE4
TAPE4 MODE    1 = DYNRE4 NO  1. DAMP/SPECTRA =  0.          , FACTOR =   .10000E+01, MPRINT =    0, IGROUP =         0
TAPE4 MODE    2 = DYNRE4 NO  2. DAMP/SPECTRA =  0.          , FACTOR =   .10000E+01, MPRINT =    0, IGROUP =         0
TAPE4 MODE    3 = DYNRE4 NO  3. DAMP/SPECTRA =  0.          , FACTOR =   .10000E+01, MPRINT =    0, IGROUP =         0
TAPE4 MODE    4 = DYNRE4 NO  4. DAMP/SPECTRA =  0.          , FACTOR =   .10000E+01, MPRINT =    0, IGROUP =         0
TAPE4 MODE    5 = DYNRE4 NO  5. DAMP/SPECTRA =  0.          , FACTOR =   .10000E+01, MPRINT =    0, IGROUP =         0
TAPE4 MODE    6 = DYNRE4 NO  6. DAMP/SPECTRA =  0.          , FACTOR =   .10000E+01, MPRINT =    0, IGROUP =         0
TAPE4 MODE    7 = DYNRE4 NO  7. DAMP/SPECTRA =  0.          , FACTOR =   .10000E+01, MPRINT =    0, IGROUP =         0
TAPE4 MODE    8 = DYNRE4 NO  8. DAMP/SPECTRA =  0.          , FACTOR =   .10000E+01, MPRINT =    0, IGROUP =         0
```

```
TAPE4 MODE  9 = DYNRE4 NO  9. DAMP/SPECTRA =  0.          , FAC  =  .1000E+01, MPRINT =   0, IGROUP =      0
    1 T4VERS = (10/12/8114.41.29SEP01/81)

TAPE4 HEADER=(ELELOADS    10     6    20     1     6 1 1 1 1 0 0 0 0 0 0 0 1 0 0 0 0)
```

GENERALIZED MODAL DATA

MODE NUMBER	FREQUENCY (CPS)	GENERALIZED WTS.	WEIGHT PARTICIPATION FACTORS GAMMA 1	GAMMA 2	GAMMA 3
1	.14947E+02	.68255E+04	-.80598E-11	.98074E+00	.11653E-16
2	.14962E+02	.63867E+04	.15239E+01	.51442E-11	-.28648E-16
3	.34798E+02	.17276E+05	.14162E-13	.14564E+01	-.34424E-15
4	.68706E+02	.84461E+04	-.75437E+00	.13827E-10	-.30099E-12
5	.70190E+02	.20539E+05	.18314E-11	-.21294E+00	-.76516E-12
6	.78967E+02	.84373E+04	-.58770E-11	.16861E-10	.12680E+01
7	.94091E+02	.20645E+05	-.11460E-10	-.31703E+00	.14002E-11
8	.14190E+03	.19080E+05	-.14126E-10	.30288E+00	.64003E-12
9	.1455[illegible]E+03	.91430E+04	.35943E+00	-.32819E-09	-.30041E-10

****** SHOCK SPECTRUM CHARACTERISTICS ******

*USER SPECTRUM - RESPONSE SPECTRA GIVEN IN G VALUES *

*USER SUPPLIED ACCEL. SPECTRA CURVE.

FOR DIRECTION X1

1	FREQ =	10.000000,	SPECTRA =	270.480000
2	FREQ =	17.800000,	SPECTRA =	173.880000
3	FREQ =	23.800000,	SPECTRA =	231.840000
4	FREQ =	35.700000,	SPECTRA =	231.840000
5	FREQ =	50.000000,	SPECTRA =	173.880000
6	FREQ =	66.700000,	SPECTRA =	162.288000
7	FREQ =	100.000000,	SPECTRA =	162.288000

*NATURAL FREQUENCY(.14190357E+03) IS OUTSIDE SPECTRA RANGE. IT WILL BE IGNORED.

*NATURAL FREQUENCY(.14557694E+03) IS OUTSIDE SPECTRA RANGE. IT WILL BE IGNORED.

*USER SUPPLIED ACCEL. SPECTRA CURVE.

FOR DIRECTION X2

1	FREQ =	10.000000,	SPECTRA =	185.472000
2	FREQ =	11.100000,	SPECTRA =	166.152000
3	FREQ =	18.100000,	SPECTRA =	166.152000
4	FREQ =	22.700000,	SPECTRA =	212.520000
5	FREQ =	35.700000,	SPECTRA =	212.520000
6	FREQ =	52.600000,	SPECTRA =	154.560000
7	FREQ =	100.000000,	SPECTRA =	142.968000
8	FREQ =	143.900000,	SPECTRA =	142.968000

*NATURAL FREQUENCY(.14557694E+03) IS OUTSIDE SPECTRA RANGE. IT WILL BE IGNORED.

*USER SUPPLIED ACCEL. SPECTRA CURVE.

FOR DIRECTION X3

1	FREQ =	10.000000,	SPECTRA =	734.160000
2	FREQ =	14.300000,	SPECTRA =	1738.800000
3	FREQ =	16.700000,	SPECTRA =	1932.000000
4	FREQ =	19.200000,	SPECTRA =	1932.000000
5	FREQ =	50.000000,	SPECTRA =	386.400000
6	FREQ =	66.700000,	SPECTRA =	328.440000
7	FREQ =	100.000000,	SPECTRA =	309.120000
8	FREQ =	125.000000,	SPECTRA =	293.664000
9	FREQ =	143.000000,	SPECTRA =	293.664000

*NATURAL FREQUENCY(.14557694E+03) IS OUTSIDE SPECTRA RANGE. IT WILL BE IGNORED.

MODE NUMBER	FREQUENCY (CPS)	VISCOUS MODAL DAMPING	X1 SPECTRUM VALUES DISPLACEMENT (UNITS)	VELOCITY (UNITS/SEC)	ACCELERATION (G UNITS)
1	14.947	0.000	.225374E-01	.211661E+01	.514449E+00
2	14.962	0.000	.224766E-01	.211296E+01	.514064E+00
3	34.798	0.000	.484969E-02	.106035E+01	.600000E+00
4	68.706	0.000	.870846E-03	.375936E+00	.420000E+00
5	70.190	0.000	.834398E-03	.367985E+00	.420000E+00
6	78.967	0.000	.659229E-03	.327086E+00	.420000E+00
7	94.091	0.000	.464338E-03	.274511E+00	.420000E+00
8	141.904	0.000	0.	0.	0.
9	145.577	0.000	0.	0.	0.

LINEAR PLOT OF DISPLACEMENT SPECTRA

```
     .2254E-01S         +         +         +         +         +         +         +         +         +         +
     .2156E-01
     .2058E-01
     .1960E-01
     .1862E-01
     .1764E-01
     .1666E-01+         +         +         +         +         +         +         +         +         +         +
     .1568E-01
     .1470E-01
     .1372E-01
D    .1274E-01
I    .1176E-01
S    .1078E-01+         +         +         +         +         +         +         +         +         +         +
P    .9799E-02
L    .8819E-02
A    .7839E-02
C    .6859E-02
E    .5879E-02
M    .4899E-02+         +    S    +         +         +         +         +         +         +         +         +
T    .3920E-02
     .2940E-02
     .1960E-02
     .9799E-03                                     SS        S
     .1110E-15                                                           S                                   S  S
              .         .         .         .         .         .         .         .         .         .         .
          14.95     28.01     41.07     54.14     67.20     80.26     93.33     106.4     119.5     132.5     145.6

                                                FREQUENCY
```

MODE NUMBER	FREQUENCY (CPS)	VISCOUS MODAL DAMPING	X2 SPECTRUM VALUES DISPLACEMENT (UNITS)	VELOCITY (UNITS/SEC)	ACCELERATION (G UNITS)
1	14.947	0.000	.188378E-01	.176916E+01	.430000E+00
2	14.962	0.000	.188010E-01	.176744E+01	.430000E+00

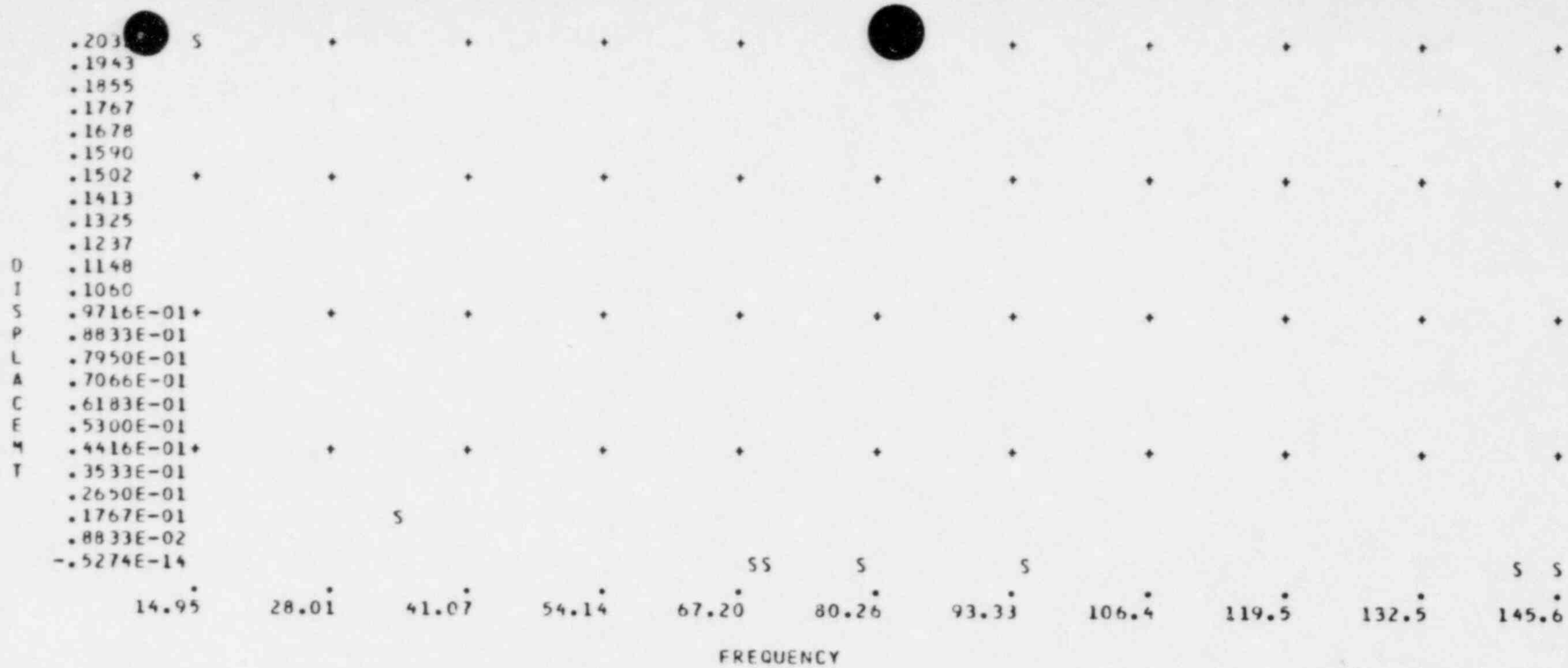
3	34.798	0.000	.444555E-02	.971992[illegible]	.550000E+00
4	68.706	0.000	.802925E-03	.346615[illegible]	.387242E+06
5	70.190	0.000	.767326E-03	.338405E+00	.386239E+00
6	78.967	0.000	.597632E-03	.296523E+00	.380756E+00
7	94.091	0.000	.412095E-03	.243626E+00	.372745E+00
8	141.904	0.000	.179843E-03	.160349E+00	.370000E+00
9	145.577	0.000	0.	0.	0.

LINEAR PLOT OF DISPLACEMENT SPECTRA

```
     .1884E-01S         +         +         +         +         +         +         +         +         +         +
     .1802E-01
     .1720E-01
     .1638E-01
     .1556E-01
     .1474E-01
     .1392E-01+         +         +         +         +         +         +         +         +         +         +
     .1310E-01
     .1229E-01
     .1147E-01
D    .1065E-01
I    .9828E-02
S    .9009E-02+         +         +         +         +         +         +         +         +         +         +
P    .8190E-02
L    .7371E-02
A    .6552E-02
C    .5733E-02
E    .4914E-02
M    .4095E-02+         +    S    +         +         +         +         +         +         +         +         +
T    .3276E-02
     .2457E-02
     .1638E-02
     .8190E-03                                         SS      S           S
    -.3851E-15
                                                                                                               S  S
              .         .         .         .         .         .         .         .         .         .         .
          14.95     28.01     41.07     54.14     67.20     80.26     93.33     106.4     119.5     132.5     145.6

                                                         FREQUENCY
```

MODE NUMBER	FREQUENCY (CPS)	VISCOUS MODAL DAMPING	X3 SPECTRUM VALUES DISPLACEMENT (UNITS)	VELOCITY (UNITS/SEC)	ACCELERATION (G UNITS)
1	14.947	0.000	.203155E+00	.190794E+02	.463731E+01
2	14.962	0.000	.202893E+00	.190734E+02	.464039E+01
3	34.798	0.000	.148683E-01	.325086E+01	.183949E+01
4	68.706	0.000	.175463E-02	.757456E+00	.846238E+00
5	70.190	0.000	.167582E-02	.739066E+00	.843535E+00
6	78.967	0.000	.130086E-02	.645438E+00	.828787E+00
7	94.091	0.000	.892556E-03	.527669E+00	.807328E+00
8	141.904	0.000	.369406E-03	.329365E+00	.760000E+00
9	145.577	0.000	0.	0.	0.

LINEAR PLOT OF DISPLACEMENT SPECTRA


DISPLACEMENT
.203
.1943
.1855
.1767
.1678
.1590
.1502
.1413
.1325
.1237
.1148
.1060
.9716E-01
.8833E-01
.7950E-01
.7066E-01
.6183E-01
.5300E-01
.4416E-01
.3533E-01
.2650E-01
.1767E-01
.8833E-02
-.5274E-14
14.95
28.01
41.07
54.14
67.20
80.26
93.33
106.4
119.5
132.5
145.6
FREQUENCY

*** GENERALIZED RESPONSES DUE TO X1 DIRECTION SHOCK MULTIPLIER ONLY. X1 = 1.000000 ***

MODE NUMBER	GENLZD FORCE	GENERALIZED DISPLACEMENT	GENERALIZED VELOCITY	GENERALIZED ACCELERATION
1	.283011E-07	.181647E-12	.170595E-10	.160215E-08
2	.500318E+04	.342515E-01	.321990E+01	.302694E+03
3	.146799E-09	.686811E-16	.150167E-13	.328330E-11
4	.267604E+04	.656944E-03	.283596E+00	.122426E+03
5	.157982E-07	.152810E-14	.673918E-12	.297210E-09
6	.208262E-07	.387430E-14	.192229E-11	.953770E-09
7	.993750E-07	.532154E-14	.314604E-11	.185990E-08
8	0.	0.	0.	0.
9	0.	0.	0.	0.

*** GENERALIZED RESPONSES DUE TO X2 DIRECTION SHOCK MULTIPLIER ONLY. X2 = 1.000000 ***

MODE NUMBER	GENLZD FORCE	GENERALIZED DISPLACEMENT	GENERALIZED VELOCITY	GENERALIZED ACCELERATION
1	.287845E+04	.184749E-01	.173509E+01	.162952E+03
2	.141275E-07	.967163E-13	.909205E-11	.854720E-09
3	.138382E+05	.647431E-02	.141557E+01	.309505E+03
4	.452252E-07	.111024E-13	.479278E-11	.206900E-08
5	.168927E+04	.163396E-03	.720606E-01	.317801E+02
6	.541677E-07	.100768E-13	.499976E-11	.248070E-08
7	.243968E+04	.130645E-03	.772360E-01	.456611E+02
8	.213826E+04	.544711E-04	.485668E-01	.433025E+02
9	0.	0.	0.	0.

*** ...NERALIZED RESPONSES DUE TO X3 DIRECTION SHOCK MULTIP... ONLY. X3 = 1.000000 ***

MODE NUMBER	GENLZD FORCE	GENERALIZED DISPLACEMENT	GENERALIZED VELOCITY	GENERALIZED ACCELERATION
1	.368836E-12	.236733E-17	.222329E-15	.208802E-13
2	.849037E-12	.581246E-17	.546414E-15	.513670E-13
3	.109399E-10	.511830E-17	.111908E-14	.244681E-12
4	.215132E-08	.528128E-15	.227988E-12	.984203E-10
5	.132567E-07	.128226E-14	.565501E-12	.249396E-09
6	.886654E+04	.164944E-02	.818395E+00	.40605[illegible]E+03
7	.233389E-07	.124980E-14	.738868E-12	.436810E-09
8	.928112E-08	.236432E-15	.210805E-12	.187955E-09
9	0.	0.	0.	0.

****** T SUM SQUARE (RSS) OF DIRECTIONAL GENERALIZED COORD E RESPONSES ******

MODE NUMBER	FREQUENCY (CPS)	GENERALIZED DISPLACEMENT	GENERALIZED VELOCITY	GENERALIZED ACCELERATION
1	.149471E+02	.184749E-01	.173509E+01	.162952E+03
2	.149617E+02	.342515E-01	.321990E+01	.302694E+03
3	.3479[illegible]E+02	.647431E-02	.141557E+01	.309505E+03
4	.687057E+02	.656944E-03	.283596E+00	.122426E+03
5	.701903E+02	.163396E-03	.720606E-01	.317801E+02
6	.789669E+02	.164944E-02	.818395E+00	.406058E+03
7	.940906E+02	.130645E-03	.772360E-01	.456611E+02
8	.141904E+03	.544711E-04	.485668E-01	.433025E+02
9	.145577E+03	0.	0.	0.

(RSS = 1) DISPLACMT.

NODE	X1	X2	X3	X4	X5	X6
2	1.58513576E-03	2.39672155E-03	3.36036305E-04	1.12674525E-04	7.12227245E-05	0.
3	4.63961879E-03	5.67389513E-03	6.57982773E-04	9.54576989E-05	1.28278926E-04	0.
4	8.82268645E-03	7.09444056E-03	9.52340350E-04	6.79247742E-06	1.71674752E-04	0.
5	1.38028046E-02	5.52989862E-03	1.20676677E-03	1.14527016E-04	2.02322084E-04	0.
6	1.96967838E-02	2.35143439E-03	1.42388829E-03	2.04931431E-04	2.22685702E-04	0.
7	2.45877108E-02	6.22084901E-03	1.54788484E-03	2.72395944E-04	2.31133607E-04	0.
8	2.94756320E-02	1.22150231E-02	1.62385582E-03	3.07250517E-04	2.34588775E-04	0.
9	3.42578066E-02	1.85490702E-02	1.64944412E-03	3.15585030E-04	2.35323603E-04	0.

MAXIMUM RESPONSES FOR THE 6 VALUES PRINTED FOR EACH NODE...

1 =	.03426	AT NODE	9
2 =	.01855	AT NODE	9
3 =	.00165	AT NODE	9
4 =	.00032	AT NODE	9
5 =	.00024	AT NODE	9
6 =	0.00000	AT NODE	1

(RSS = 1) VELOCITY

NODE	X1	X2	X3	X4	X5	X6
2	1.77605698E-01	5.03268482E-01	1.66729065E-01	2.31556959E-02	6.79953602E-03	0.
3	4.75911562E-01	1.16766650E+00	3.26467264E-01	1.93546469E-02	1.20938052E-02	0.
4	8.63106776E-01	1.44244306E+00	4.72516851E-01	3.12780380E-03	1.61443788E-02	0.
5	1.31557400E+00	1.13073704E+00	5.98754041E-01	1.97510462E-02	1.91548211E-02	0.
6	1.85513335E+00	4.80485885E-01	7.06481891E-01	2.37234884E-02	2.13335400E-02	0.
7	2.31144975E+00	6.65867469E-01	7.68004494E-01	2.59214874E-02	2.23244690E-02	0.
8	2.77489487E+00	1.18735381E+00	8.05693549E-01	2.92155630E-02	2.27588840E-02	0.
9	3.23236030E+00	1.77530953E+00	8.18394538E-01	3.03157259E-02	2.28563369E-02	0.

MAXIMUM RESPONSES FOR THE 6 VALUES PRINTED FOR EACH NODE...

1 =	3.23236	AT NODE	9
2 =	1.77531	AT NODE	9
3 =	.81839	AT NODE	9
4 =	.03032	AT NODE	9
5 =	.02286	AT NODE	9
6 =	0.00000	AT NODE	1

(RSS = 1) ACCEL.

NODE	X1	X2	X3	X4	X5	X6
2	1.16283397E-01	3.16171227E-01	2.14091445E-01	1.30448383E-02	2.11886069E-03	0.
3	2.42201104E-01	6.59317448E-01	4.19206142E-01	1.16780436E-02	3.11469615E-03	0.
4	3.39565366E-01	8.10552358E-01	6.06743733E-01	4.08371933E-03	3.95680281E-03	0.
5	4.01470089E-01	6.42000421E-01	7.68840859E-01	1.11026709E-02	5.30584758E-03	0.
→ 6	4.68881915E-01	2.84097940E-01	9.07170735E-01	1.04960059E-02	6.92903681E-03	0.
7	5.62470510E-01	2.67200571E-01	9.86169937E-01	7.20560792E-03	7.89184612E-03	0.
8	6.95145954E-01	3.41669817E-01	1.03457166E+00	9.58942890E-03	8.37471553E-03	0.
9	8.45016981E-01	4.95050168E-01	1.05087418E+00	1.21580433E-02	8.49344423E-03	0.

MAXIMUM RESPONSES FOR THE 6 VALUES PRINTED FOR EACH NODE...

1 =	.84502	AT NODE	9
2 =	.81055	AT NODE	4
3 =	1.05087	AT NODE	9
4 =	.01304	AT NODE	2
5 =	.00849	AT NODE	9
6 =	0.00000	AT NODE	1

(RSS - 1) BEAM END LOADS (ELEMENT). (LOCAL)

NO	NODES		AXIAL	V2	V3	M2	M3	TORSION
1	JA	1	1.1242E+04	7.8702E+03	8.6152E+03	2.5454E+05	9.7826E+05	0.
	JB	2	1.1242E+04	7.8702E+03	8.6152E+03	5.6458E+04	7.9973E+05	0.
2	JA	2	1.0771E+04	7.6884E+03	6.8328E+03	5.6458E+04	7.9973E+05	0.
	JB	3	1.0771E+04	7.6884E+03	6.8328E+03	1.0398E+05	6.2587E+05	0.
3	JA	3	9.8481E+03	7.2618E+03	3.1210E+03	1.0398E+05	6.2587E+05	0.
	JB	4	9.8481E+03	7.2618E+03	3.1210E+03	1.6959E+05	4.6110E+05	0.
4	JA	4	8.5121E+03	6.5924E+03	3.6850E+03	1.6959E+05	4.6110E+05	0.
	JB	5	8.5121E+03	6.5924E+03	3.6850E+03	1.4731E+05	3.1032E+05	0.
5	JA	5	6.7556E+03	5.6498E+03	7.4698E+03	1.4731E+05	3.1032E+05	0.
	JB	6	6.7556E+03	5.6498E+03	7.4698E+03	1.9778E+05	1.7016E+05	0.
6	JA	6	4.8226E+03	4.4297E+03	4.9577E+03	1.9778E+05	1.7016E+05	0.
	JB	7	4.8226E+03	4.4297E+03	4.9577E+03	1.0077E+05	8.1855E+04	0.
7	JA	7	2.9547E+03	2.9702E+03	3.5470E+03	1.0077E+05	8.1855E+04	0.
	JB	8	2.9547E+03	2.9702E+03	3.5470E+03	3.0812E+04	2.2512E+04	0.
8	JA	8	9.9520E+02	1.1256E+03	1.5406E+03	3.0812E+04	2.2512E+04	0.
	JB	9	9.9520E+02	1.1256E+03	1.5406E+03	2.6381E-08	4.9617E-08	0.

MAXIMUM RESPONSES FOR THE 12 VALUES PRINTED FOR EACH ELEMENT OF THIS TYPE...

1 =	11242.49565	AT ELEMENT NO	1
2 =	7870.19725	AT ELEMENT NO	1
3 =	8615.17598	AT ELEMENT NO	1
4 =	254544.32332	AT ELEMENT NO	1
5 =	✓978260.94703	AT ELEMENT NO	1
6 =	0.00000	AT ELEMENT NO	1
7 =	11242.49565	AT ELEMENT NO	1
8 =	7870.19725	AT ELEMENT NO	1
9 =	8615.17598	AT ELEMENT NO	1
10 =	197777.17809	AT ELEMENT NO	5
11 =	799729.56569	AT ELEMENT NO	1
12 =	0.00000	AT ELEMENT NO	1

NO	NODES		FX1	FX2	FX3	MX1	MX2	MX3
1	JA	1	7.8702E+03	8.6149E+03	1.1242E+04	2.5454E+05	9.7827E+05	0.
	JB	2	7.8702E+03	8.6149E+03	1.1242E+04	5.6457E+04	7.9972E+05	0.
2	JA	2	7.6884E+03	6.8328E+03	1.0771E+04	5.6457E+04	7.9972E+05	0.
	JB	3	7.6884E+03	6.8328E+03	1.0771E+04	1.0398E+05	6.2587E+05	0.
3	JA	3	7.2619E+03	3.1210E+03	9.8480E+03	1.0398E+05	6.2587E+05	0.
	JB	4	7.2619E+03	3.1210E+03	9.8480E+03	1.6959E+05	4.6111E+05	0.
4	JA	4	6.5923E+03	3.6849E+03	8.5121E+03	1.6959E+05	4.6111E+05	0.
	JB	5	6.5923E+03	3.6849E+03	8.5121E+03	1.4731E+05	3.1032E+05	0.
5	JA	5	5.6499E+03	7.4701E+03	6.7556E+03	1.4731E+05	3.1032E+05	0.
	JB	6	5.6499E+03	7.4701E+03	6.7556E+03	1.9778E+05	1.7016E+05	0.
6	JA	6	4.4298E+03	4.9577E+03	4.8226E+03	1.9778E+05	1.7016E+05	0.
	JB	7	4.4298E+03	4.9577E+03	4.8226E+03	1.0077E+05	8.1855E+04	0.
7	JA	7	2.9702E+03	3.5470E+03	2.9546E+03	1.0077E+05	8.1855E+04	0.
	JB	8	2.9702E+03	3.5470E+03	2.9546E+03	3.0812E+04	2.2512E+04	0.
8	JA	8	1.1256E+03	1.5406E+03	9.9521E+02	3.0812E+04	2.2512E+04	0.
	JB	9	1.1256E+03	1.5406E+03	9.9521E+02	2.6381E-08	4.9617E-08	0.

MAXIMUM RESPONSES FOR THE 12 VALUES PRINTED FOR EACH ELEMENT OF THIS TYPE...

1 =	7870.17369	AT ELEMENT NO	1
2 =	8614.89920	AT ELEMENT NO	1
3 =	11242.44617	AT ELEMENT NO	1
4 =	254544.46844	AT ELEMENT NO	1
5 =	978265.04551	AT ELEMENT NO	1
6 =	0.00000	AT ELEMENT NO	1
7 =	7870.17369	AT ELEMENT NO	1
8 =	8614.89920	AT ELEMENT NO	1
9 =	11242.44617	AT ELEMENT NO	1
10 =	197778.22715	AT ELEMENT NO	5
11 =	799720.31867	AT ELEMENT NO	1
12 =	0.00000	AT ELEMENT NO	1

(RSS = 1) BEAM STRESSES

for K= for K= for C=1 for C=1 LOCAL

NO	NODES		P/A	V2/KA	V3/KA	MC2/I	MC3/I	TC/J
1	JA	1	1.4887E+02	1.2260E+02	1.3421E+02	8.2085E+01	3.4730E+01	0.
	JB	2	1.4887E+02	1.2260E+02	1.3421E+02	1.8206E+01	2.8391E+01	0.
2	JA	2	1.4263E+02	1.1977E+02	1.0644E+02	1.8206E+01	2.8391E+01	0.
	JB	3	1.4263E+02	1.1977E+02	1.0644E+02	3.3531E+01	2.2219E+01	0.
3	JA	3	1.3040E+02	1.1313E+02	4.8620E+01	3.3531E+01	2.2219E+01	0.
	JB	4	1.3040E+02	1.1313E+02	4.8620E+01	5.4689E+01	1.6370E+01	0.
4	JA	4	1.1271E+02	1.0270E+02	5.7405E+01	5.4689E+01	1.6370E+01	0.
	JB	5	1.1271E+02	1.0270E+02	5.7405E+01	4.7504E+01	1.1017E+01	0.
5	JA	5	8.9454E+01	8.8014E+01	1.1637E+02	4.7504E+01	1.1017E+01	0.
	JB	6	8.9454E+01	8.8014E+01	1.1637E+02	6.3779E+01	6.0409E+00	0.
6	JA	6	6.3858E+01	6.9007E+01	7.7232E+01	6.3779E+01	6.0409E+00	0.
	JB	7	6.3858E+01	6.9007E+01	7.7232E+01	3.2496E+01	2.9060E+00	0.
7	JA	7	3.9125E+01	4.6270E+01	5.5256E+01	3.2496E+01	2.9060E+00	0.
	JB	8	3.9125E+01	4.6270E+01	5.5256E+01	9.9362E+00	7.9919E-01	0.
8	JA	8	1.3178E+01	1.7535E+01	2.4000E+01	9.9362E+00	7.9919E-01	0.
	JB	9	1.3178E+01	1.7535E+01	2.4000E+01	8.5073E-12	1.7615E-12	0.

MAXIMUM RESPONSES FOR THE 12 VALUES PRINTED FOR EACH ELEMENT OF THIS TYPE...

1 =	148.86777	AT ELEMENT NO	1
2 =	122.60406	AT ELEMENT NO	1
3 =	134.20951	AT ELEMENT NO	1
4 =	82.08456	AT ELEMENT NO	1
5 =	34.72951	AT ELEMENT NO	1
6 =	0.00000	AT ELEMENT NO	1
7 =	148.86777	AT ELEMENT NO	1
8 =	122.60406	AT ELEMENT NO	1
9 =	134.20951	AT ELEMENT NO	1
10 =	63.77851	AT ELEMENT NO	5
11 =	28.39142	AT ELEMENT NO	1
12 =	0.00000	AT ELEMENT NO	1

Attachment 14

UC-80

LAWRENCE LIVERMORE LABORATORY
University of California Livermore, California 94550

UCRL-52342

EFFECTIVE MASS AND DAMPING OF SUBMERGED STRUCTURES

R. G. Dong

MS. date: April 1, 1978

Contents

EFFECTIVE MASS AND DAMPING OF SUBMERGED STRUCTURES

ABSTRACT

Various structures important for safety in nuclear power plants must remain functioning in the event of an earthquake or other dynamic phenomenon. Some of these important structures, such as spent-fuel storage racks, main pressure-relief valve lines, and internal structures in the reactor vessel, are submerged in water. Dynamic analysis must include the force and damping effects of water. This report provides a technical basis for evaluating the wide variety of modeling assumptions currently used in design analysis. Current design analysis techniques and information in the literature form the basis of our conclusions and recommendations. We surveyed 32 industrial firms and reviewed 49 technical references. We compare various theories with published experimental results wherever possible. Our findings generally pertain to idealized structures, such as single isolated members, arrays of members, and coaxial cylinders. We relate these findings to the actual reactor structures through observations and recommendations. Whenever possible we recommend a definite way to evaluate the effect of hydrodynamic forces on these structures.

1. INTRODUCTION

To ensure that various structures important to the safety of nuclear power plants remain functioning during a severe earthquake or other dynamic phenomenon, detailed dynamic analyses must be performed. A number of structures, such as spent-fuel storage racks, main pressure-relief valve lines, and internals of the reactor vessel, are submerged in water. For these structures, the effect of the water in terms of forces and damping must be considered. A wide variety of modeling assumptions are being used in design analysis, and, at present, there are no uniform positions by which to judge the adequacy of the assumptions. The objective of this project is to provide a technical basis for evaluating the assumptions, and to recommend suitable methods to account for the effect of the water.

The methods investigated include the added mass and added damping concept, current design methods, and methods under development. Experimental results available in the literature form the basis of our evaluation whenever possible. Following a procedure agreed upon at the start of the project, we focus on two groups of idealized structures: single isolated members and multiple members. The second group includes two parallel cylinders, members near a boundary, an array of members, and coaxial cylinders. We relate our findings to spent-fuel storage racks, main pressure-relief valve lines, and the internals of the reactor vessel through observations and recommendations. Development of new methods and performing rigorous analyses were not major endeavors for the project.

An extensive survey of the literature and industrial firms was carried out. Forty-nine references (1-49), listed in the order reviewed, covered single isolated members and multiple members. Thirty-two industrial firms were contacted (see Table 1); this survey revealed that the design methods in current use are quite varied and that, in some instances, rather sophisticated developments are taking place.

Of special interest to the Nuclear Regulatory Committee (NRC) is a recommendation for added mass and damping values made by Newmark and Rosenblueth.[5] This recommendation forms the baseline for NRC's current position on the subject. We compared this recommendation with the theoretical and experimental results we reviewed.

The fluid–structure interaction for multiple members is significantly more complex than for single isolated members and is less well understood. Consequently, we find it advantageous to separate single isolated members from multiple members in our presentation.

Table 1. Industrial firms surveyed.

Argonne National Lab.
Argonne, Illinois
James Kennedy
Yao Chang
S. S. Chen

Babcock & Wilcox
Lynchburg, Virginia
Arthur F. J. Eckert

Bechtel
San Francisco, California
Sidney Ting
Ching Wu

Civil Engineering Lab.
Port Hueme, California
William Armstrong
Francis Liu
Dallas Meggitt

Combustion Engineering
Windsor, Connecticut
Bob Longo

EDAC
Irvine, California
Robert P. Kennedy

EDS
San Francisco, California
Majaraj Kaul

EPRI
Palo Alto, California
Conway Chan

Exxon Nuclear Co., Inc.
Richland, Washington
Denny Condotta
Charles A. Brown

Frederick R. Harris, Inc.
New York, New York
Herman Bomze

General Electric
San Jose, California
Lun-King Liu
Bob Buckles

Gilbert
Reading, Pennsylvania
Donald Croneberger

Los Alamos Scientific Laboratories
Los Alamos, New Mexico
Tony Hirt

Lockheed Corp.
Sunnyvale, California
Robert L. Waid

NASA
Huntsville, Alabama
Heinz Struck
Denny Kross

Naval Post Graduate School
Monterey, California
Targut Sarpkaya

Naval Research Laboratory
Washington, D.C.
Owen M. Griffin

Nuclear Energy Services Incorp.
Danbury, Connecticut
Iqbal Husain

Nuclear Services Corp.
Campbell, California
Henry Thailer

NUS Corporation
Boston, Massachusetts
Howard Eckert

Offshore Power Systems
Jacksonville, Florida
Richard Orr
Jeff Shulman

Oregon State University
Corvallis, Oregon
Tokuo Yamamoto

Physics International
San Leandro, California
Dennis Orphal

Program & Remote Systems
St. Paul, Minnisota
Donald F. Melton
Carl Newmeyer

Sargent & Lundy
Chicago, Illinois
Suren Singh
Norman Webber

Stone & Webster
Boston, Massachusetts
George Bushell

Southwest Research Institute
San Antonio, Texas
Frank Dodge

Universal Analytics
Los Angeles, California
Dave Herting

University of California
Berkeley, California
Anil K. Chopra
Ray Clough
John Wehausen

URS/John Blume
San Francisco, California
Roger Skjei
Roger Scholl

Wachter
Pittsburg, Pennsylvania
Mr. Wachter
Dave Secrist

Westinghouse
Pensacola, Florida
John Gormley
Tom C. Allen
George J. Bohm

2. STRUCTURES AND EXCITATIONS OF CONCERN

The nuclear power-plant structures and excitations of concern are shown in Table 2. Seismic loads are considered described by the response spectrum in the NRC's Regulatory Guide 1.60 (R.G. 1.60).[50] The horizontal spectrum is shown in Fig. 1. Time histories for the pressure-relief and blowdown loads were provided by NRC, and are shown in Figs. 2 and 3, respectively. The predominant frequencies are indicated. The structures of concern vary in dimension and arrangement depending on the design and the plant. A representative list of dimensions and/or natural frequencies are given in Table 3.

Table 2. Structures and excitations of concern.

Structures	Excitations
Spent-fuel storage racks	Seismic
Main steam-relief valve line	Pressure relief Blowdown-induced loads Seismic
Internals of reactor vessel	Blowdown-induced loads Seismic

Table 3. Representative sizes and natural frequencies of structures of concern.

Structure	Size	Natural frequency	Condition
Fuel elements	~ 0.5 in. D		
Fuel bundles, BWR	~ 5.5 x 5.5 in.	~3 Hz[a]	In water
Fuel bundles, PWR	~10 x 10 in.	~3 Hz[a]	In water
Fuel racks: firm (1)[b]		17 to 33 Hz	Full and in water
Fuel racks: firm (2)		10 to 20 Hz	Full and in water
Fuel racks: firm (3)		6 to 9 Hz	Full and in water
Fuel racks: firm (4)		~ 12 Hz	Full in air
Fuel racks: firm (4)		~ 10.5 Hz	Full in water
Fuel racks: firm (5)		~ 1.15 Hz	Full in water
Main steam-relief valve line[c]	8 in. D, 72 in. L	0.5 Hz	In air
	8 in. D, 72 in. L	1.2 Hz	In air
	8 in. D, 396 in. L	0.02 Hz	In air
	8 in. D, 396 in. L	0.04 Hz	In air
	12 in. D, 72 in. L	0.8 Hz	In air
	12 in. D, 72 in. L	1.8 Hz	In air
	12 in. D, 396 in. L	0.03 Hz	In air
	12 in. D, 396 in. L	0.06 Hz	In air
Reactor core barrel		40 Hz[a]	In air
		10 Hz[a]	In water

[a] Approximate frequency values provided by NRC.
[b] The industrial firms generally wished to remain anonymous.
[c] Range of diameters and lengths provided by NRC.

3. HYDRODYNAMIC THEORIES

Five variations of hydrodynamic theory seen in the literature are listed in Table 4, approximately in the order of increasing complexity. For the dynamic effect on submerged structures, the two simplest theories are used most. The incompressible invicid theory, sometimes referred to as potential theory, is used for nonflexible members; i.e., members that can be treated as translating rigid bodies. The compressible invicid theory is used for flexible members, such as flexible coaxial cylinders.

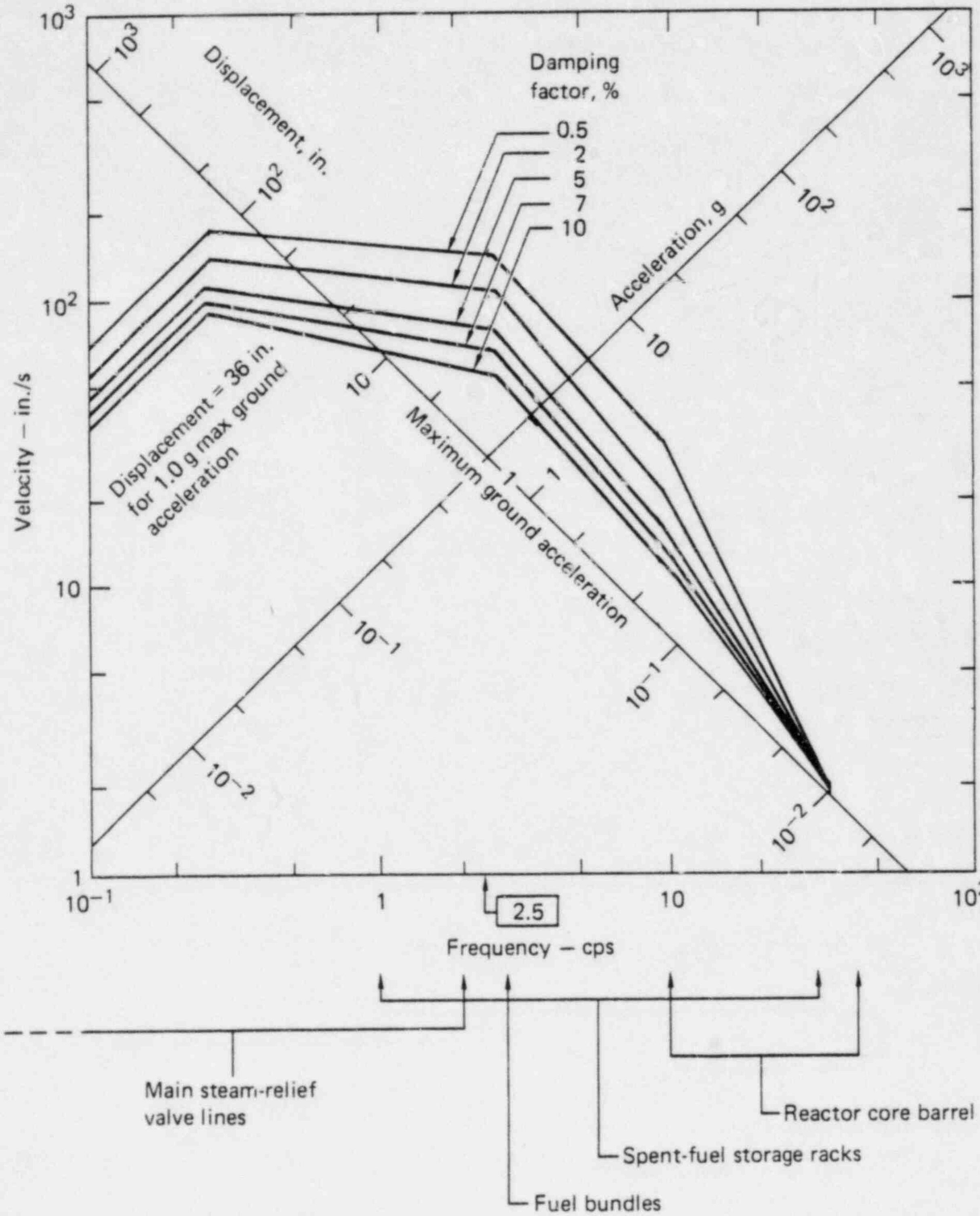


Fig. 1. Horizontal design response spectra, scaled to 1-g horizontal ground acceleration (from R. G. 1.60).[19]

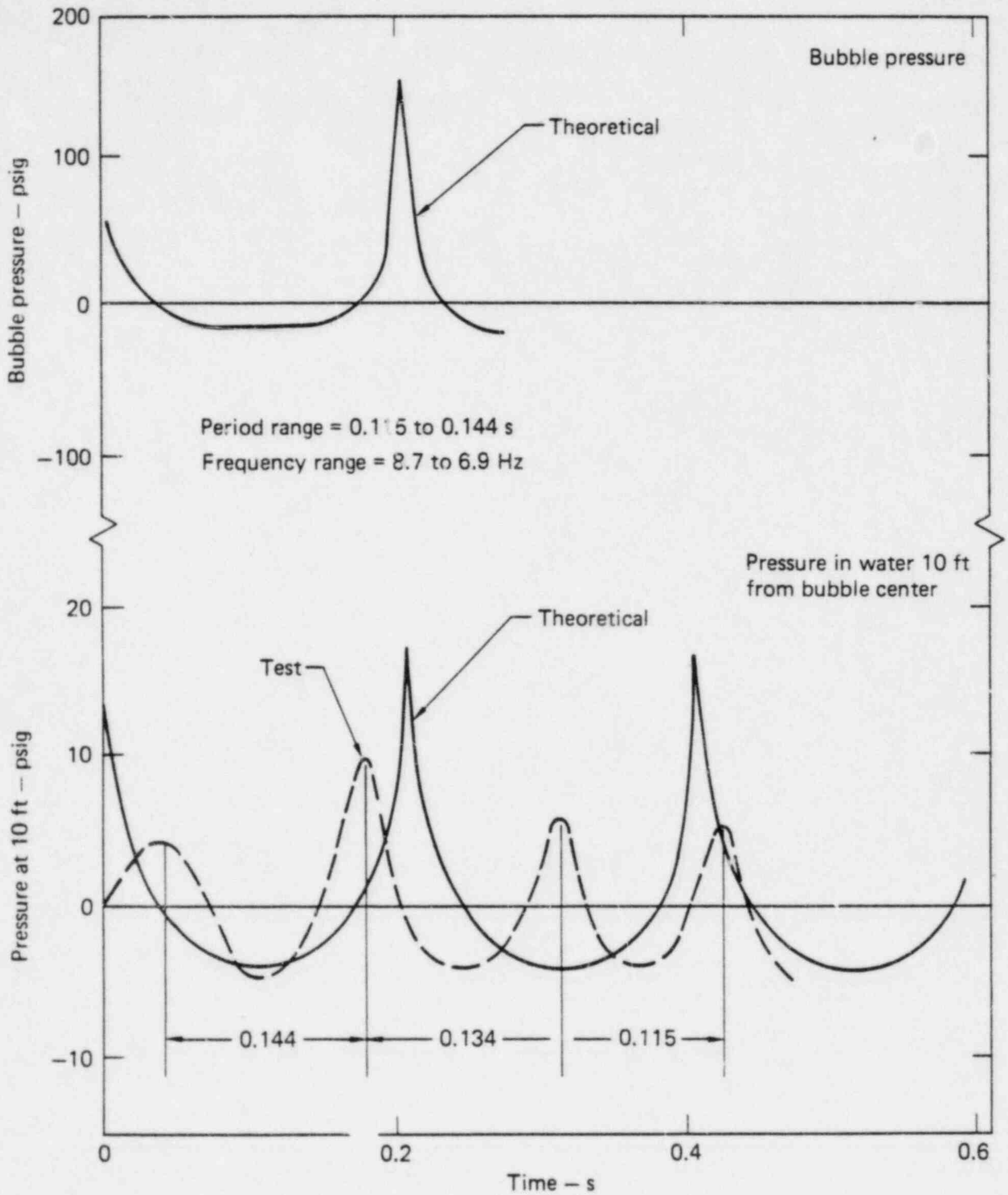


Fig. 2. Pressure in bubble and water, steam relief.

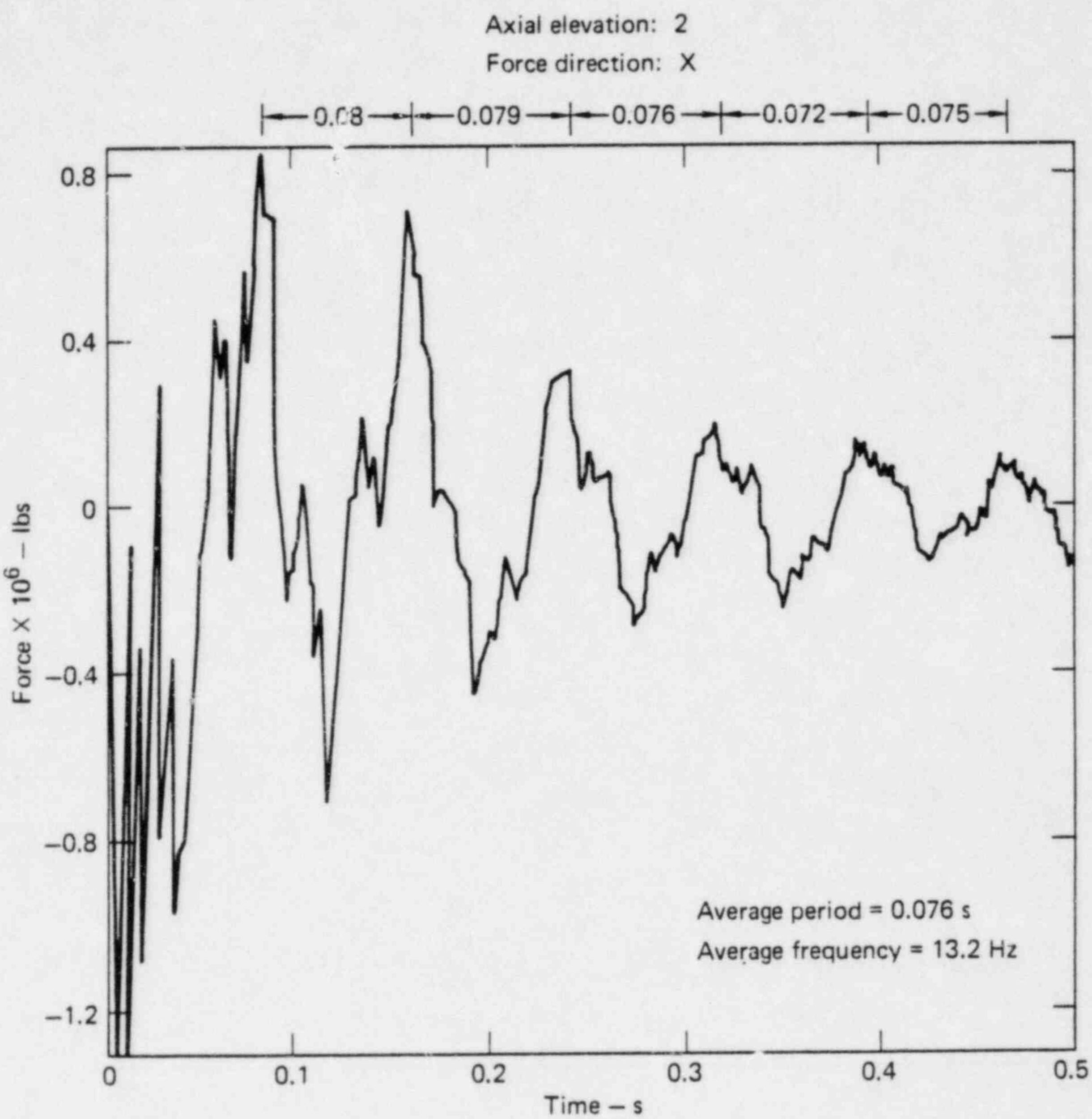
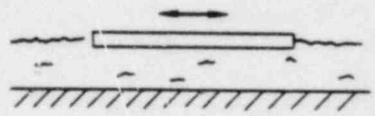
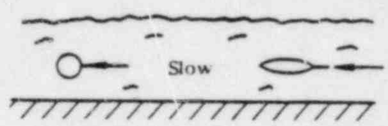
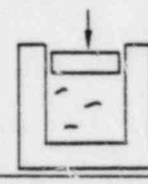
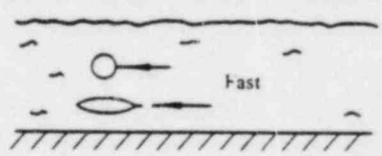
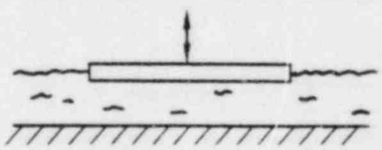
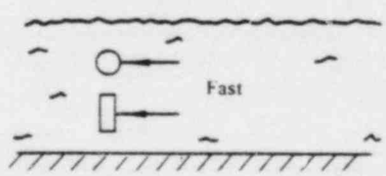
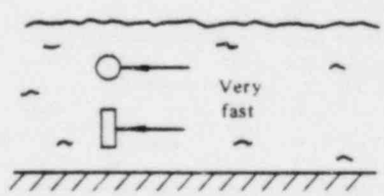


Fig. 3. Blowdown excitation; horizontal force on core barrel.

Table 4. Hydrodynamic theories.

Theories	Applicable conditions	
Incompressible invicid (Potential theory)	• Virtually no boundary layer • Fluid escape is easy	 
Compressible invicid	• Virtually no boundary layer • Fluid escape is not easy	
Incompressible viscous	• Appreciable boundary layer • Fluid escape is easy	
Compressible viscous (Navier–Stokes)	• Appreciable boundary layer • Fluid escape is not easy or velocity is high	 
Nonlinear	• Appreciable boundary layer • Velocity is very high	

4. SOME METHODS USED FOR CURRENT DESIGN ANALYSIS

Our survey of industrial firms revealed a variety of methods (see, Table 5), for calculating added mass and damping. The firms' identifications are kept in confidence, as was desired by a majority of those providing information. Some overlap exists, so that each method shown may represent more than one firm. The philosophy behind each method is illustrated using a simplified representation of a fuel bundle with its can enclosure. For clarity, we show only four fuel elements per bundle, although in reality a typical fuel bundle has from 60 to 200 fuel elements. A single fuel bundle with its can is an example of a single isolated member in Table 5, and two or more fuel bundles are examples of multiple members. The volumes of water included in the calculations of virtual mass are shaded in crosshatch. In the case of fuel bundles, the mass of the water within the can is simply taken as part of the structural mass. The mass of a certain volume of water outside of the can is added to the structural mass, and this is commonly referred to as the added mass from submersion. The methods used for calculating this added mass is quite varied, as indicated in Table 5, and they are largely based on engineering judgment together with whatever analytical and/or experimental information was available at the time.

A detailed description of the basis for each method was not provided by the firms contacted; perhaps for most, the only basis was engineering judgement. In a few cases, references were cited; however, we found no direct relation between the methods and the references.

Table 5 is self-explanatory for most of the cases shown. In method 5, the procedure presented by Fritz[7] for coaxial cylinders was used to approximate the interaction between the central member and the eight peripheral members of a 3 x 3 array. In method 9, the cans are in contact with each other, so that virtually no water exists between adjacent cans.

The bases for the damping value used are likewise quite varied. Zero damping was chosen in some cases to ensure conservatism. In some instances, the structural plus added damping was taken as 2 to 2-½ times the structural damping. The basis for this appears to be various references, such as 3 and 17, which choose to present experimental results for total damping in terms of a factor, such as 2, times the structural damping. We disagree with this interpretation, for it implies that the submerging water somehow knows how much damping is in the structure, and it subsequently adds an equal amount. The experimental results given in Ref. 3 and 17 could just as well be expressed in terms of an added damping, which we feel is a more valid interpretation. It is our opinion that the use of a factor times the structural damping, as used in method 3 and considered for use in methods 7 and 8, should be discouraged.

Our assessment of the methods described in Table 5 is given in Section 9.5 of this report.

Table 5. Design methods for evaluating added mass in current use for seismic excitations.

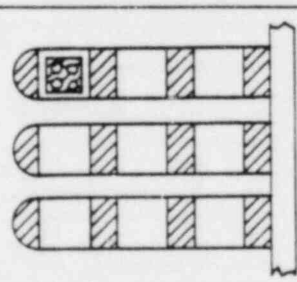
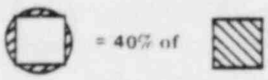
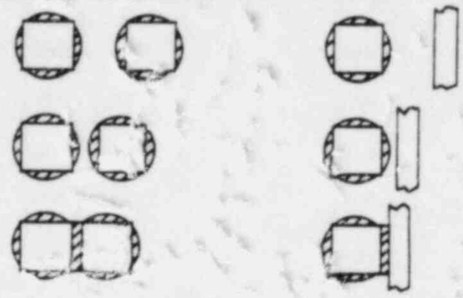
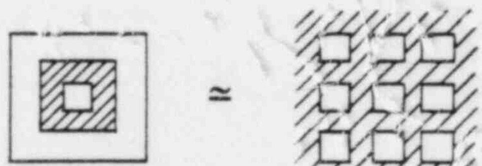
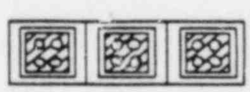
Method number	Single, isolated member	Multiple members	Damping
1	Potential theory (perfect fluid)	Potential theory	
2	Potential theory	Potential theory modified by experiments	
3			2 times structural damping

Table 5. (continued)

Method number	Single, isolated member	Multiple member	Damping
4	 Where 		Added damping = 0%
5	Potential theory	 Fritz (Ref. 7)	Added damping = 0 to 3%
6	Added mass = displaced water	For natural frequency evaluations  For inertial load evaluations 	Added damping = 2%
7	Added mass = displaced water	Use the smaller of: • Actual measured amount of water surrounding the racks • Evaluate the added mass as if the cans were single and isolated	Prefer to use 2 to 2-½ × structural damping, but are using added damping of 2% per NRC's request
8			Added damping = Usually 0%, but might consider using 2 times structural damping
9		 Very thin film of water	Added damping = 0%

An assessment of validity of these methods is given in Section 9.5 of this report. A method recommended by LLL, not shown in this table, is explained in Sections 9.1 and 9.2 of this report.

5. SINGLE ISOLATED MEMBERS

5.1 Procedure Recommended By Newmark and Rosenblueth

A procedure for evaluating the added mass and damping of single isolated members submerged in a fluid was suggested by Newmark and Rosenblueth.[5] For added mass, they suggested:

"If the structure is a long, rigid prism on flexible supports, moving in a direction perpendicular to its axis, flow of liquid around the structure is essentially two-dimensional. Under these conditions, the added mass is that of a circular cylinder of liquid having the same length as the prism and a diameter equal to the width of the projection of the prism on a plane perpendicular to the direction of motion (Fig. 4)."
For added damping they said:
"...damping due to liquid viscosity may be disregarded. Energy dissipation due to radiation into the liquid may be more important, but the model tests to which we have referred [1] indicate that it will not exceed about 2% of critical for submerged structures of ordinary dimensions."
An evaluation was carried out and included in our presentation.

5.2 Added Mass for Single Isolated Members

If a single isolated member is accelerated in a stationary fluid, its acceleration induces the fluid in its immediate neighborhood to accelerate. The accelerating fluid in return induces an added mass effect onto the member. Under sufficiently small amplitudes of motion, cyclic or unidirectional, the added mass phenomenon can be described in terms of an added mass coefficient C_m defined as

$$C_m = \frac{\text{added mass of fluid}}{\text{reference fluid mass}} ,$$

where the reference fluid mass is that of the cylinder of fluid of diameter equal to the dimension perpendicular to the direction of motion, or, in some cases, it is the mass of the displaced fluid. The added mass phenomenon for single isolated members has been rather extensively investigated experimentally and analytically. Theoretical treatment has been quite successful using the potential theory.

Experimental data for single isolated members are available in Refs. 1, 3, 4, 6, 12, 13, 17, 20, and 29. Potential theory results are given in Refs. 2 and 7, Table 6. The available experimental data, potential theory results, and Newmark and Rosenblueth's (N&R) recommendations are compared in Figs. 5a through 5i for a variety of specimen geometries. N&R's recommendation as worded in Ref. 5 applies only to the situations of Figs. 5a, 5c, and 5d; therefore, comparison with the recommendation is carried out only for these three cases. Notice that the added mass coefficient is independent of the cross-sectional geometry of the specimen for N&R's recommendation. This is a simplification embodied in the recommendation, which is important to keep in mind, for we will see later that it will give rise to some uncertainties about conservatism when using the recommendation.

A comparison between Figs. 5a and 5b and between Figs. 5e and 5f reveals that the value of C_m for a fluid moving around a stationary specimen is higher than the value for a specimen moving in a stationary fluid. This higher value of C_m is exhibited theoretically,[6,11] as well as experimentally, and is important to account for in real applications. For a stationary circular cylinder in a moving fluid, C_m = 2, which means the hydrodynamic force acting on the stationary cylinder is *twice* the mass of fluid displaced times the acceleration of the fluid. By comparison, for a translating circular cylinder in a stationary fluid, C_m = 1, which means the total force required to accelerate the cylinder is the mass of the cylinder plus the mass of the displaced fluid multiplied by acceleration *of the cylinder*. For the case in which both the cylinder and fluid are in motion, these two force contributions should be calculated separately and superimposed.

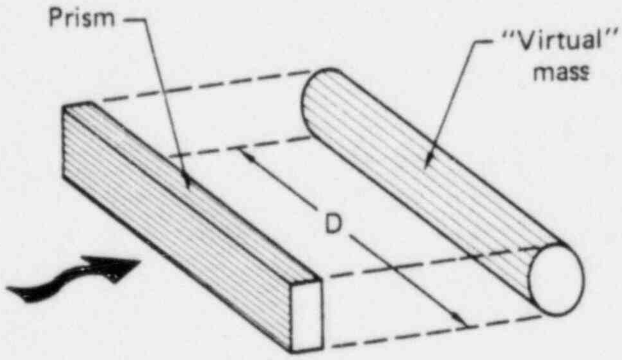


Fig. 4. Submerged body and its virtual mass.[5]

Table 6. Two-dimensional bodies.[2]

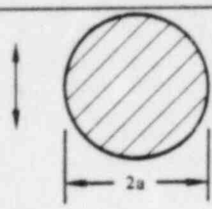
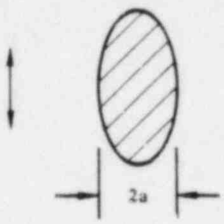
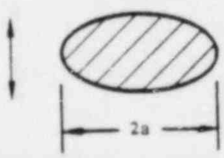
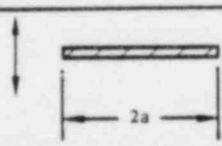
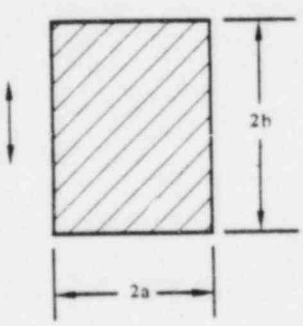
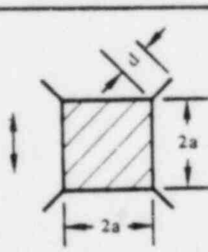
Section through body		Translational direction	Hydrodynamic mass per unit length
		Vertical	$m_h = 1\pi\rho a^2$
		Vertical	$m_h = 1\pi\rho a^2$
		Vertical	$m_h = 1\pi\rho a^2$
		Vertical	$m_h = 1\pi\rho a^2$
	$a/b = \infty$	Vertical	$m_h = 1\pi\rho a^2$
	$a/b = 10$		$m_h = 1.14\pi\rho a^2$
	$a/b = 5$		$m_h = 1.21\pi\rho a^2$
	$a/b = 2$		$m_h = 1.36\pi\rho a^2$
	$a/b = 1$		$m_h = 1.51\pi\rho a^2$
	$a/b = 1/2$		$m_h = 1.70\pi\rho a^2$
	$a/b = 1/5$		$m_h = 1.98\pi\rho a^2$
	$a/b = 1/10$		$m_h = 2.23\pi\rho a^2$
	$d/a = 0.05$	Vertical	$m_h = 1.61\pi\rho a^2$
	$d/a = 0.10$		$m_h = 1.72\pi\rho a^2$
	$d/a = 0.25$		$m_h = 2.19\pi\rho a^2$

Table 6. (continued)

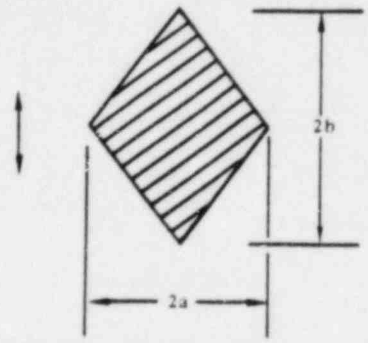
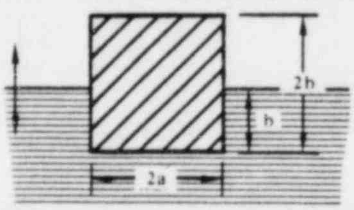
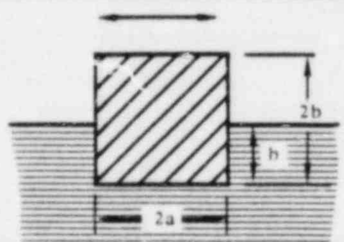
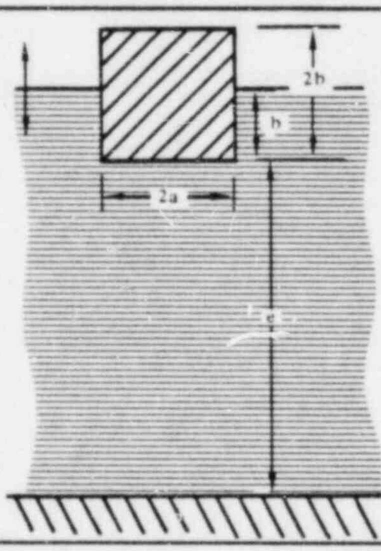
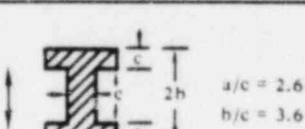
Section through body		Translational direction	Hydrodynamic mass per unit length
	a/b = 2	Vertical	$m_h = 0.85\,\pi \rho a^2$
	a/b = 1		$m_h = 0.76\,\pi \rho a^2$
	a/b = 1/2		$m_h = 0.67\,\pi \rho a^2$
	a/b = 1/5		$m_h = 0.61\,\pi \rho a^2$
	a/b = 1	Vertical (normal to free surface)	$m_h = 0.75\,\pi \rho a^2$
	a/b = 1	Horizontal (parallel to free surface)	$m_h = 0.25\,\pi \rho a^2$
	a/b = 1; e/b = ∞	Vertical (normal to free surface)	$m_h = 0.75\,\pi \rho a^2$
	e/b = 2.6		$m_h = 0.83\,\pi \rho a^2$
	e/b = 1.8		$m_h = 0.89\,\pi \rho a^2$
	e/b = 1.5		$m_h = 1.00\,\pi \rho a^2$
	e/b = 0.5		$m_h = 1.35\,\pi \rho a^2$
	e/b = 0.25		$m_h = 2.00\,\pi \rho a^2$
	a/c = 2.6 b/c = 3.6	Vertical	$m_h = 2.11\,\pi \rho a^2$

Table 6. (continued)

Three-dimensional bodies

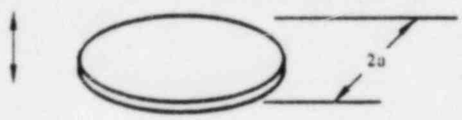
Body shape	Translational direction	Hydrodynamic mass

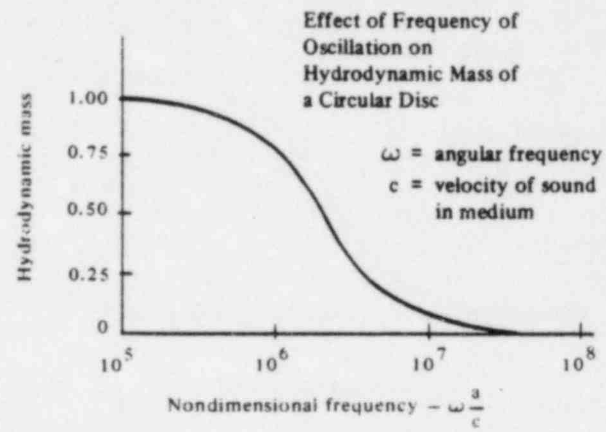
1. FLAT PLATES

Circular disk

Translational direction: Vertical

$$m_h = \frac{8}{3} \rho a^3$$

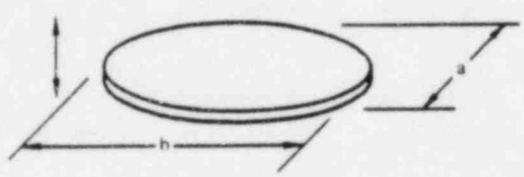




Elliptical disk

Translational direction: As shown

$$m_h = Kba^2 \frac{\pi}{6} \rho$$

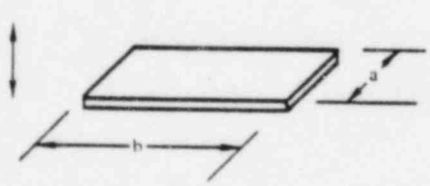


b/a	K
∞	1.00
14.3	0.991
12.75	0.987
10.43	0.985
9.57	0.983
8.19	0.978
7.00	0.972
6.00	0.964
5.02	0.952
4.00	0.933
3.00	0.900
2.00	0.826
1.50	0.748
1.00	0.637

Rectangular plates

Translational direction: Vertical

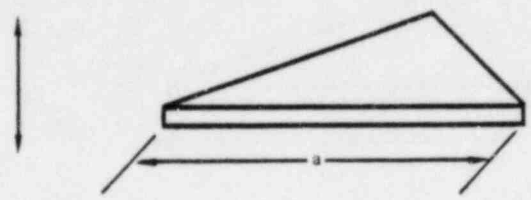
$$m_h = K \pi \rho \frac{a^2}{4} b$$



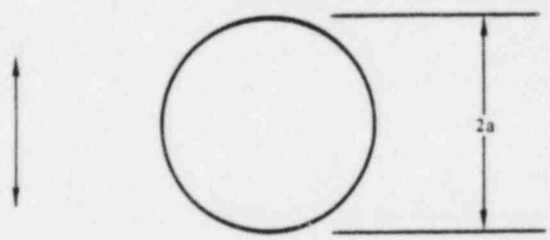
b/a	K
1.0	0.478
1.5	0.680
2.0	0.840
2.5	0.953
3.0	1.00
3.5	1.00
4.0	1.00
–	1.00

Table 6. (continued)

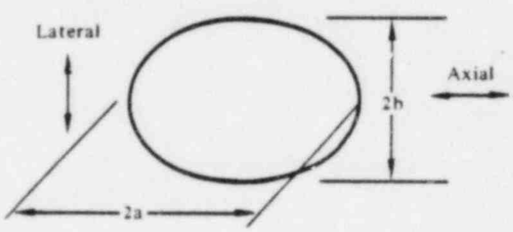
Body shape	Translational direction	Hydrodynamic mass
Triangular plates	Vertical	$m_h = \frac{\rho}{3} a^3 \frac{(\mathrm{TAN}\ \theta)^{3/2}}{(\pi)}$



Body shape	Translational direction	Hydrodynamic mass
2. BODIES OF REVOI UTION Spheres	Vertical	$m_h = \frac{2}{3} \pi \rho a^3$



Body shape	Translational direction	Hydrodynamic mass
Ellipsoids	Vertical	$m_h = K \cdot \frac{4}{3} \pi \rho a b^2$

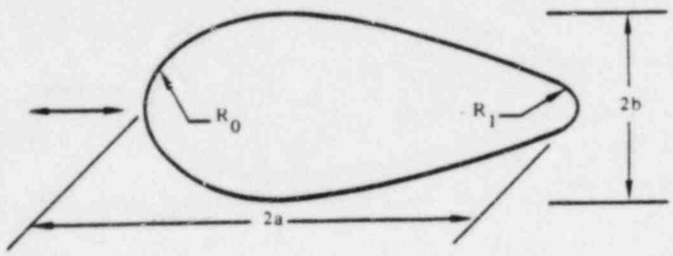


a/b	K for axial motion	K for lateral motion
1.00	0.500	0.500
1.50	0.305	0.621
2.00	0.209	0.702
2.51	0.156	0.763
2.99	0.122	0.803
3.99	0.082	0.860
4.99	0.059	0.895
6.01	0.045	0.918
6.97	0.036	0.933
8.01	0.029	0.945
9.02	0.024	0.954
9.97	0.021	0.960
	0	1.000

Table 6. (continued)

Body shape	Translational direction	Hydrodynamic mass

Approximate method for elongated bodies of revolution.



$$m_h = K_1 \rho V = Ke\left[1 + 17.0\left(Cp - \frac{2}{3}\right)^2 + 2.49\left(M - \frac{1}{2}\right)^2 + 0.283\left[\left(r_0 - \frac{1}{2}\right)^2 + \left(r_1 - \frac{1}{2}\right)^2\right]\right]$$

where; K_1 – Hydrodynamic mass coefficient for axial motion

K_e – Hydrodynamic mass coefficient for axial motion of an ellipsoid of the same ratio of a/b

V · Volume of body

C_p – Prismatic coefficient $= \frac{4V}{b^2\,(2a)}$

M – Nondimensional abscissa $\frac{X_m}{1}$ corresponding to maximum ordinate

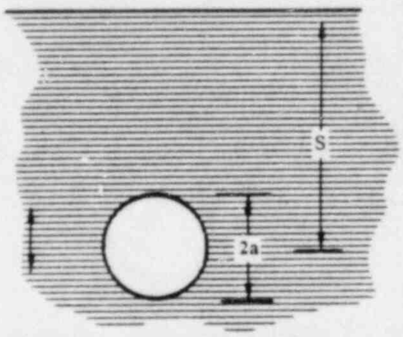
r_0, r_1 – Dimensionless radii of curvature at nose and tail

$r_0 = \frac{Ro\,(2a)}{b^2}$ $\qquad$ $r_1 = \frac{R1\,(2a)}{b^2}$

	Lateral motion	Munk has shown that the hydrodynamic mass of an elongated body of revolution can be reasonably approximated by the product of the density of the fluid, the volume of the body, and the k factor for an ellipsoid of the same a/b ratio.

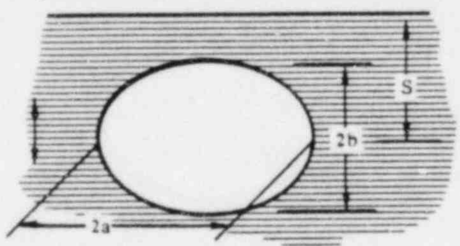
Table 6. (continued)

Body shape	Translational direction	Hydrodynamic mass
Sphere near a free surface	Vertical	$m_h = K\frac{2}{3}\pi\rho a^3$



s/2a	K
0	0.50
0.5	0.88
1.0	1.08
1.5	1.16
2.0	1.18
2.5	1.18
3.0	1.16
3.5	1.12
4.0	1.04
4.5	1.00

Body shape	Translational direction	Hydrodynamic mass
Ellipsoid near a free surface	Vertical	$m_h = K \cdot \frac{4}{3}\pi\rho ab^2$

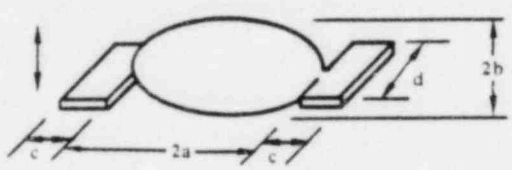


$a/b = 2.00$

s/2b	K
1.00	0.913
2.00	0.905

3. BODIES OF ARBITRARY SHAPE

Body shape	Translational direction	Hydrodynamic mass
Ellipsoid with attached rectangular flat plates	Vertical	$m_h = K \cdot \frac{4}{3}\pi\rho ab^2$

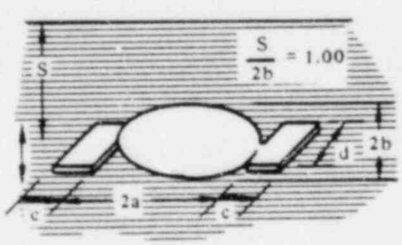


$a/b = 2.00;\ c = b$

$c.d = N\ \pi\ ab$

N	K.
0	0.7024
0.20	0.8150
0.30	1.0240
0.40	1.1500
0.50	1.2370

Body shape	Translational direction	Hydrodynamic mass
Ellipsoid with attached rectangular flat plates near a free surface	Vertical	$m_h = K \cdot \frac{4}{3}\pi\rho ab^2$



$a/b = 2.00;\ c = b$

$c.d = N\ \pi\ ab$

N	K.
0	0.9130
0.20	1.0354
0.30	1.3010
0.40	1.4610
0.50	1.5706

Table 6. (continued)

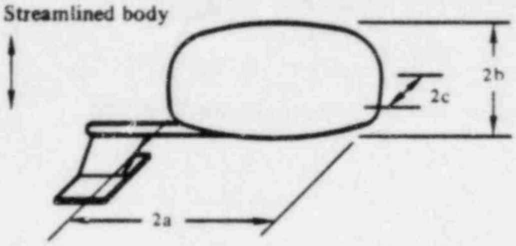
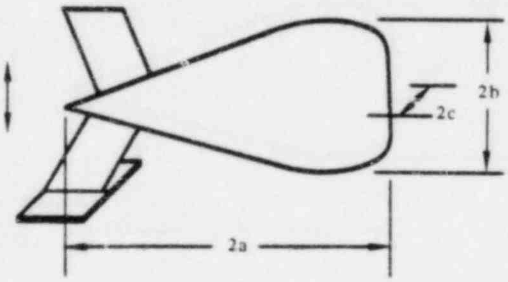
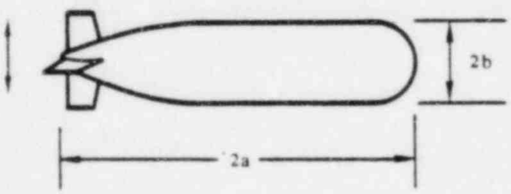
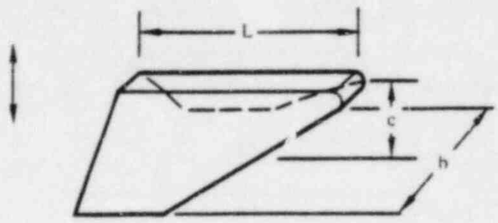
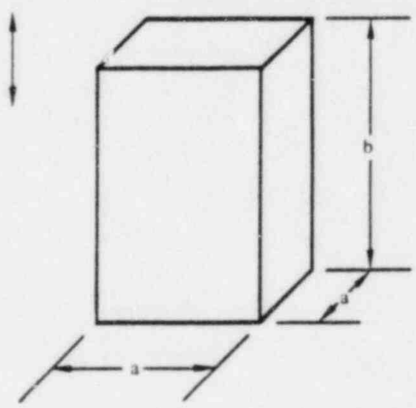
Body shape	Translational direction	Hydrodynamic mass
Streamlined body  $\frac{a}{b} = 2.38$ $\frac{a}{c} = 2.11$	Vertical	$m_h = 1.124\,\rho\left[\frac{4}{3}\,\pi\,ad^2\right]$ $d = \frac{c + b}{2}$
Area of horizontal "tail" = 25% of area of body maximum horizontal section.		
Streamlined body  $\frac{a}{b} = 2.4$ $\frac{a}{c} = 3.0$	Vertical	$m_h = 0.672\,\rho\left[\frac{4}{3}\,\pi\,ad^2\right]$ $d = \frac{c + b}{2}$
Area of horizontal "tail" – 20% of area of body maximum horizontal section.		
"Torpedo" type body  $\frac{a}{b} = 5.0$	Vertical	$m_h = 0.818\,\pi\,\rho\,b^2(2a)$
Area of horizontal "tail" = 10% of area of body maximum horizontal section.		

Table 6. (continued)

Body shape	Translational direction	Hydrodynamic mass
V-Fin type body  $\frac{L}{h} = 1.0$ $\frac{L}{c} = 2.0$	Vertical	$m_h = .3975\, \rho\, L^3$
Parallelepipeds 	Vertical	$m_h = K \rho a^2 b$

b/a	K
1	2.32
2	0.86
3	0.62
4	0.47
5	0.37
6	0.29
7	0.22
10	0.10

Some scatter is seen in the experimental data. Various possible effects contributing to the scatter includes specimen flexibility, frequency dependency, amplitude dependency, and normal experimental variability. Specimen flexibility appears to be an important factor that tends to lower the added mass.[13] The cantilevered and the thin-walled specimens exhibited lower added masses than do spring-mounted rigid specimens. Taking into consideration this lowering effect from specimen flexibility, the agreement between experiments and potential theory can be considered quite good. The exception is Fig. 5i, where we suspect the theoretical results reported in Refs. 2 and 7 are incorrect. Our reasoning is that C_m for a cube and a sphere should be similar. Yet, Fig. 5i gives $C_m = 2.32$ for a cube ($b/a = 1$), while Fig. 5e gives $C_m = 0.5$ for a sphere. The experimental value for a cube shown in Fig. 5i is $C_m = 0.67$. This compares much more favorably with C_m for a sphere than with the theoretical value for a cube, which supports our contention that the theoretical results of Fig. 5i are incorrect. To our knowledge, the case of Fig. 5i is the only error contained in Refs. 2 and 7; however, some caution might be exercised in using these references for cases in which no experimental data is available for comparison.

The good agreement between potential theory and experimental data lead us to conclude that potential theory satisfactorily describes the added mass phenomenon. This confirms the opinion, as expressed in Refs. 15, and 16, that for single isolated members the compressibility and viscous effects of the water are negligible compared with inertial effects. Potential theory, while unable to model compressibility and viscosity, can model inertial effects quite well. Taking the position that the added mass given by potential theory is valid, a basis for evaluating the adequacy of N&R's recommendation becomes possible. In the case of a circular cylinder moving in a stationary fluid, N&R's recommendation coincides with potential theory, Fig. 5a. In the case of a rectangular cylinder moving in a stationary fluid, N&R's C_m value can be less than (Fig. 5c) or greater than (Fig. 5d) that given by potential theory, depending on the direction of motion of the specimen as illustrated by Figs. 5c and 5d. The difference between N&R's C_m values and those given by potential theory can be quite significant. For example, consider a cylinder of square geometry; i.e., $a/b = 1.0$. In Fig. 5e, the theoretical C_m value is 1.5 compared with N&R's C_m value of again 1.0. We will show later that to help assure conservatism we would want to maximize C_m under some conditions and to minimize C_m under others. Because using N&R's recommendation can result in C_m values either greater than or less than the theoretical C_m values, conservatism is not necessarily ensured by following this recommendation. The use of potential theory to evaluate added mass is preferred in terms of greater control over the conservatism as well as providing greater general accuracy.

5.3 Effect of Finite Length on Added Mass for Single Isolated Members

In the case of a finite length member, the fluid flows around the end(s) as well as around the length. Therefore, the inertial resistance to motion is less than that for an infinitely long member. Figures 6 and 7, from Ref. 4, illustrate the effect experimentally and theoretically for specimens with both ends free for fluid to flow around. These curves could apply in an approximate sense to cross sections other than those of the figures.

5.4 Effect of Partial Submersion on Added Mass for Single Isolated Members

The added mass effect decreases near the water surface for a partially submerged member. The added mass distribution based on potential theory is shown in Fig. 8 for a vertical circular pier for three levels of partial submersion.[5,9] The decrease in total added mass as a function of depth of submersion is given in terms of a correction factor in Fig. 9. Experimental results for vertical cylinders are shown in Fig. 10 with the partial submersion given as a fraction of the total length.[3] Unfortunately, the specimen length was not given, so that no comparison can be made with Fig. 9. The general trend, however, agrees with that of Fig. 9. The correction factors of Fig. 9 could apply in an approximate sense to vertical cylinders of cross sections other than circular.

5.5 Added Damping for Single Isolated Members

The damping force acting on a submerged member is usually relatively small and not included in analysis as an acting force. Instead, the effect is usually

$$C_m = \frac{\text{Added mass of water}}{\text{Reference water mass}}$$

Ref. water mass = Cylinder of water of diameter equal to dimension perpendicular to direction of motion unless otherwise noted

Curves:

——————— Potential theory (Refs. 2 and 7)

– – – – – – Newmark and Rosenblueth's recommendation (Ref. 5)

Experimental results:

○	Solid on springs	Ref. 1
□	Cantilevered beams	Ref. 1
△	Cantilevered beams	Ref. 3
◁	Solid on springs	Ref. 4
▷	Fixed solid in flow	Ref. 13
◇	Fixed solid in oscillating fluid	Ref. 6
ɓ	Solid oscillating in fluid	Ref. 12
ɗ	Thin-walled hollow beams	Ref. 17
ρ	Solid oscillating in fluid	Ref. 20
Q	Fixed solid in oscillating fluid	Ref. 29

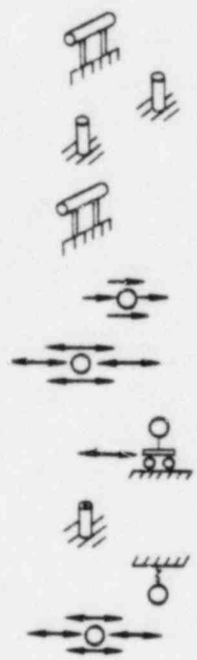


Fig. 5. Comparisons of the potential theory, Newmark and Rosenblueth's recommendations, and experimental data.

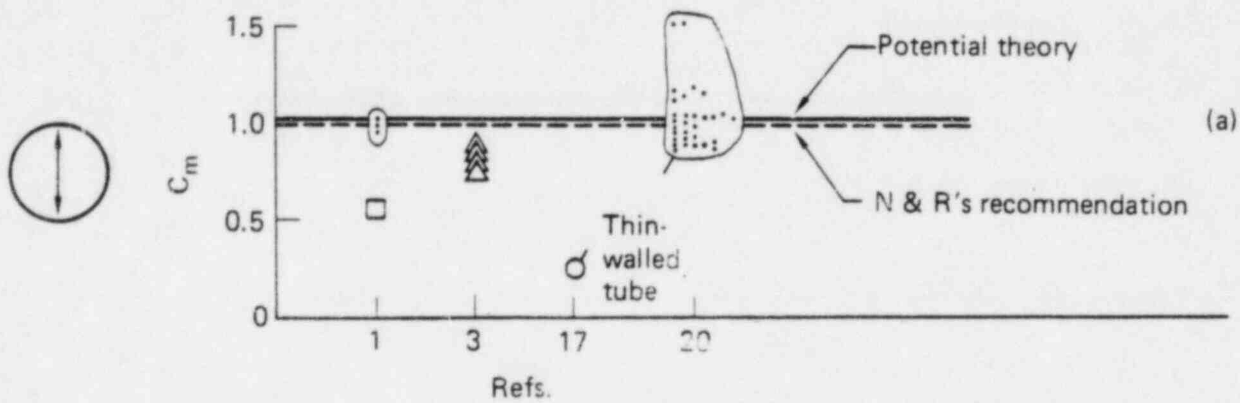


Fig. 5a. Comparisons for an oscillation circular cylinder in still fluid.

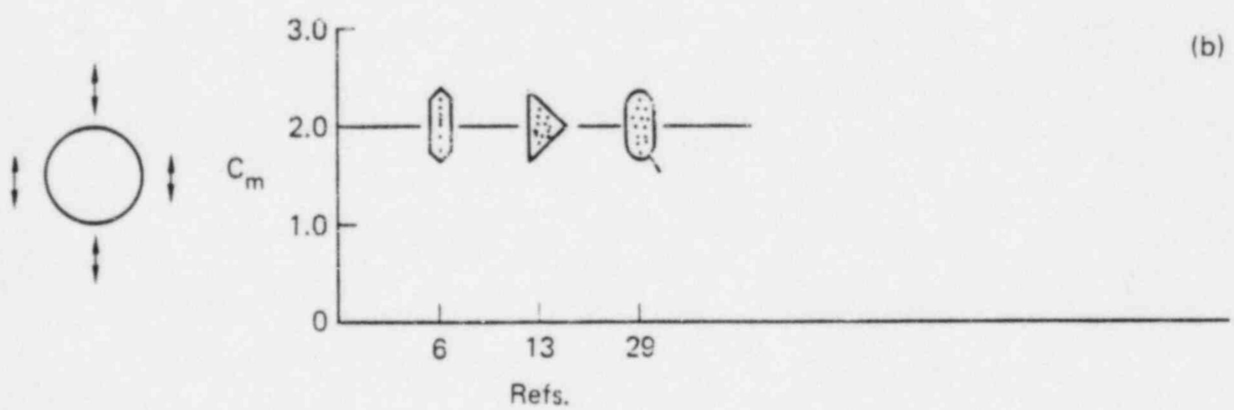


Fig. 5b. Comparisons for a fixed circular cylinder in oscillating fluid.

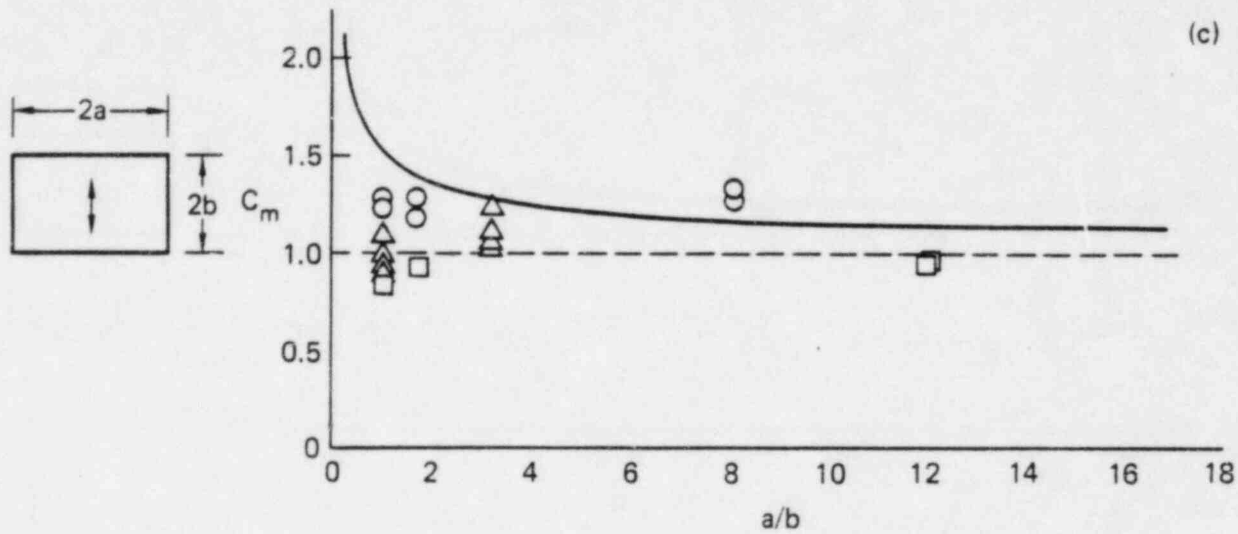


Fig. 5c. Comparisons for an oscillating rectangular cylinder in still fluid.

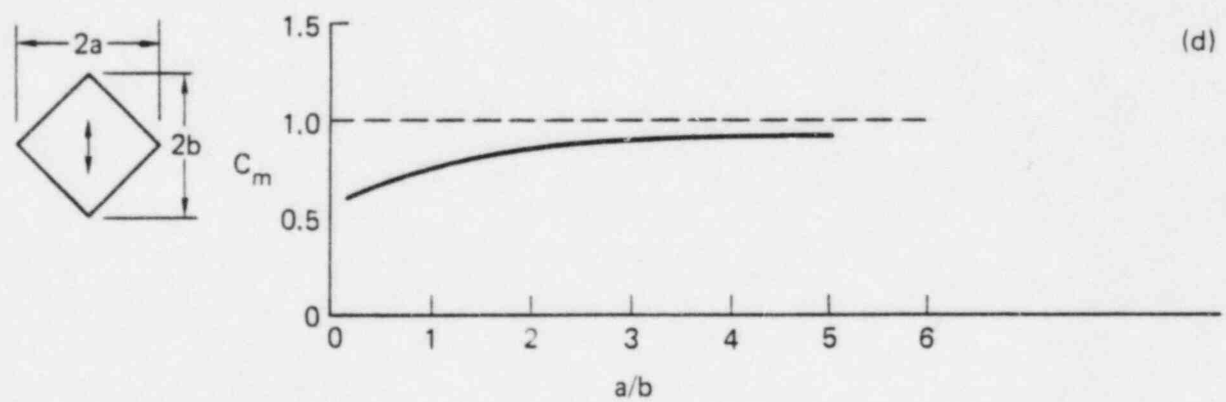


Fig. 5d. Comparisons for an oscillating rhombic cylinder in still fluid.

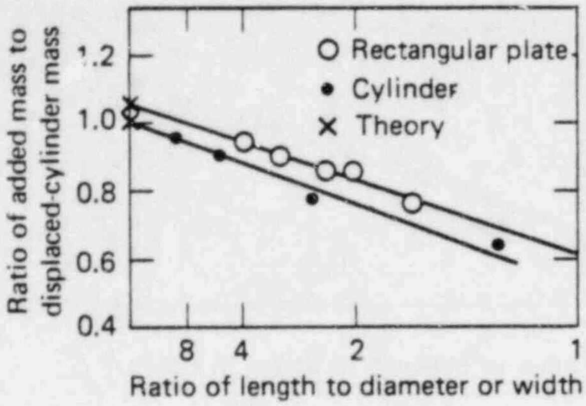


Fig. 6. Circular cylinders and rectangular plates.[4]

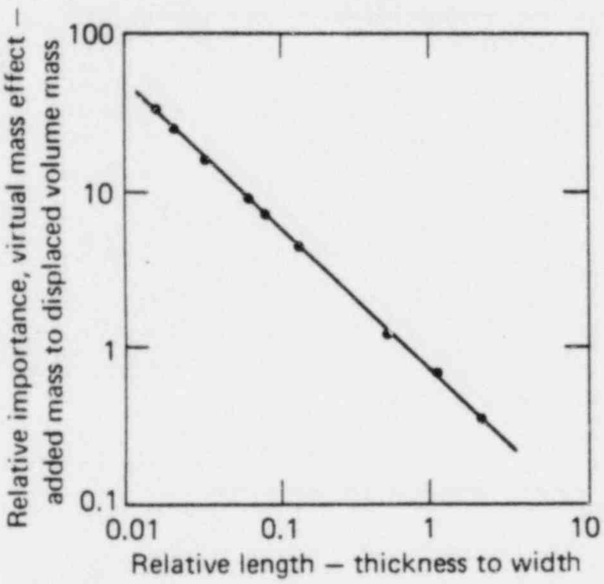


Fig. 7. Relative effect of virtual mass in parallelepipeds – square side moving broadside on.[4]

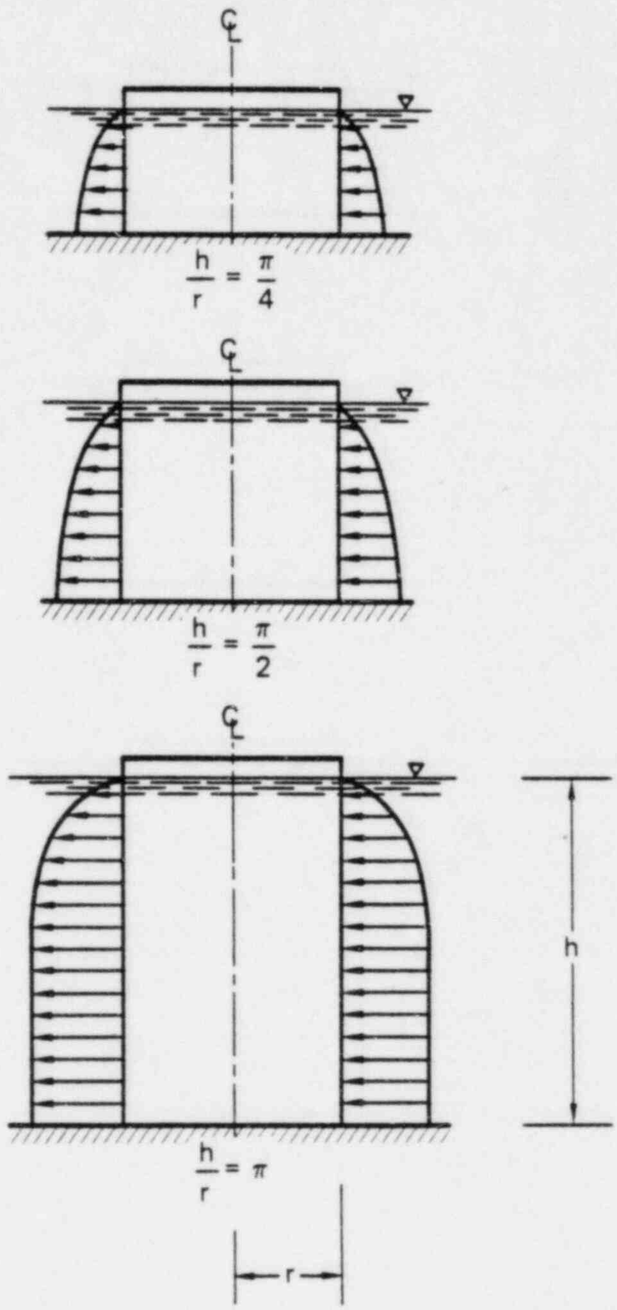


Fig. 8. Added mass distribution for a partially submerged member.[5,9]

described as an equivalent viscous damping. The contributions to added damping are:

- Fluid viscosity.
- Component impact.
- Wave generation.
- Acoustic generation.

The last two are forms of radiation damping; i.e., wave or acoustic energy generated radiate away from the submerged member. We do not expect a significant amount of acoustic energy generation for the structures and excitations of concern. Wave generation is generally not important for fully submerged structures under seismic excitation,[1,5] and it seems reasonable to extend this to other types of excitations, such as vibrations induced in the main steam-relief valve line by normal pressure relief. For partially or fully submerged members in a finite-size water enclosure, radiation damping is again, usually not taken into consideration, because the radiation energy may bounce off the enclosure walls back to the submerged member. Therefore, in the actual structures of concern, we choose to ignore wave generation as a source of damping. Component impact may be a significant source of damping for

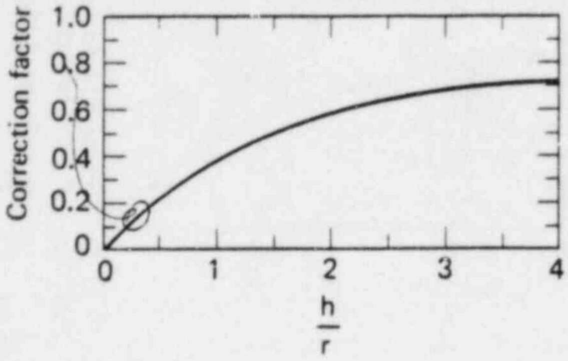


Fig. 9. Liquid mass correction factor in circular pier.[5,9]

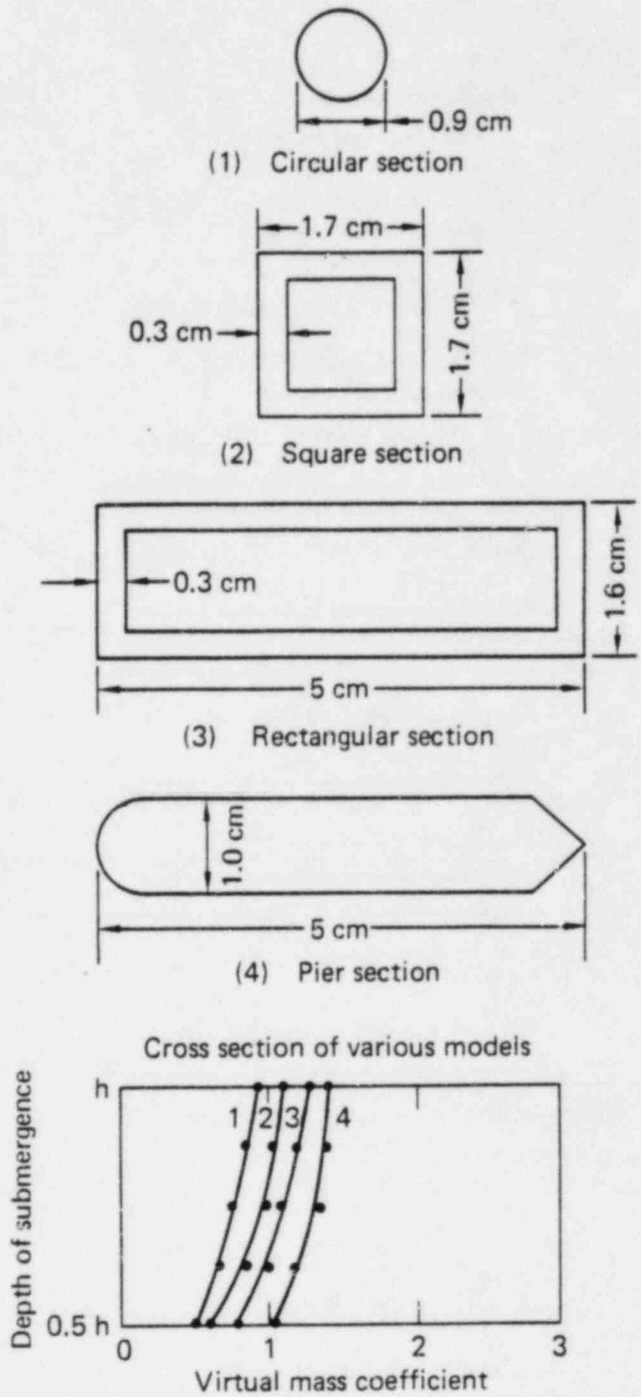


Fig. 10. Variation of virtual mass vs depth of submergence.[3]

multiple members, and this will be discussed further when we address multiple members later in this report; however, it is not a source of damping for single isolated members. Therefore, for single isolated members, fluid viscosity is the only source of damping in need of consideration.

Added damping is not as thoroughly investigated in the literature as was added mass. Theoretical predictions of damping are seldom attempted because experimental values are usually more reliable. Therefore, our conclusions on added damping are based whenever possible on published experimental data.

Experimental data on added damping are represented in Refs. 1, 3, 20, and 27 covering a variety of specimen shapes and experimental conditions. The most extensive set of data is found in Ref. 20 where circular cylinders of 0.31-, 0.5-, 0.75-, and 1.0-in. diameters are investigated over the frequencies 2.5 to 18.6 Hz and amplitude-to-diameter (A/D) ratios of up to 2.0. The data of Ref. 20 indicate that viscous damping applies up to an A/D value of 0.32 for the smallest specimen (0.31 in. diam) and 0.5 for the largest (1.0 in. diam). Beyond the viscous damping range is the nonlinear range where the damping force becomes proportional to the square of the velocity. The change from linear to nonlinear behavior with increasing A/D value was quite distinct as indicated in Fig. 11 for two examples from Ref. 20. Nonlinear damping is seen to be greater than linear damping, so that using the linear damping value as an approximation in the nonlinear range will be conservative. The A/D values where the change from linear to nonlinear damping occurs are plotted vs. specimen diameter in Fig. 12. A gradual increase with diameter is seen; however, without data for larger diameters we are uncertain if the trend would continue to increase for the sizes of actual structures of concern.

In structural analysis, damping is expressed as either a damping coefficient or a percent of critical damping. Damping coefficient describes the damping independent of the mass and stiffness of a structure, whereas, the percent of critical damping is a description associated with the mass and stiffness. To see which description best fits the added damping from water we converted the data in Ref. 20 to both an added coefficient and an added percent of critical

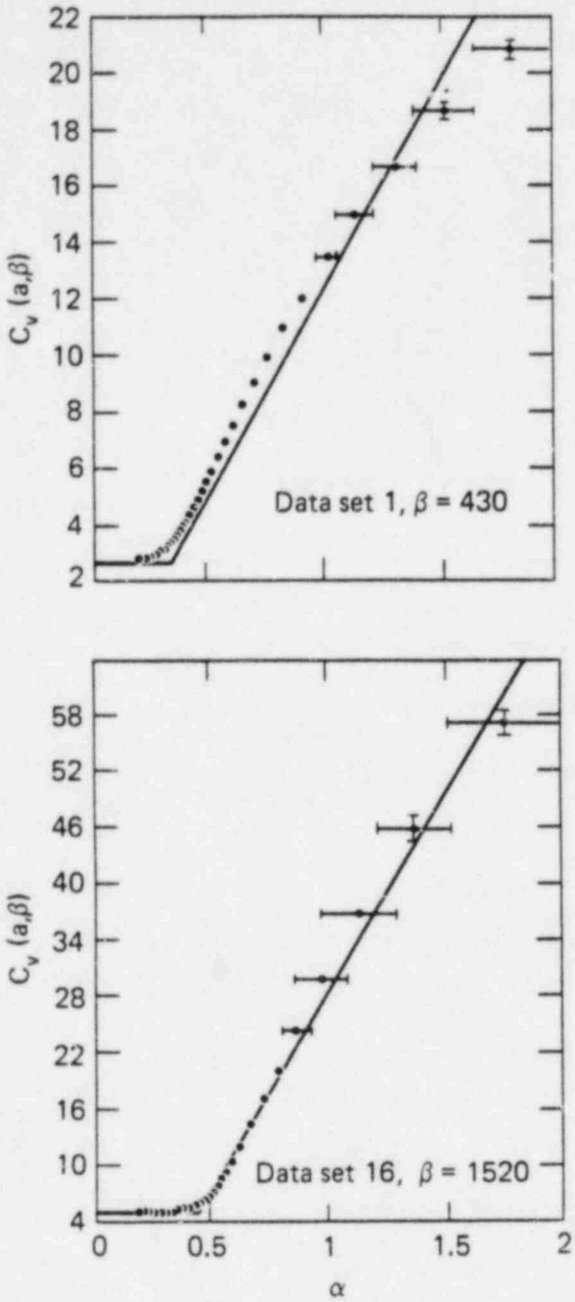


Fig. 11. The calculated viscous damping coefficient $C_v(\alpha, \beta)$ vs the dimensionless amplitude $\alpha = A/D$. The calculated points are denoted by the "+" symbol and the inherent error bounds on these points are enclosed by the "( )" symbol. The solid curve is the two-segment straight line fit to the calculated points.[20]

damping. These are plotted vs. frequency in Figs. 13a and 13b, respectively. The added coefficient varied significantly with frequency in an inconsistent manner; i.e., the 0.13-, 0.5-, and 0.75-in. specimen showed an increase with frequency, whereas the 1.0-in.-specimen showed a decrease. The added percent

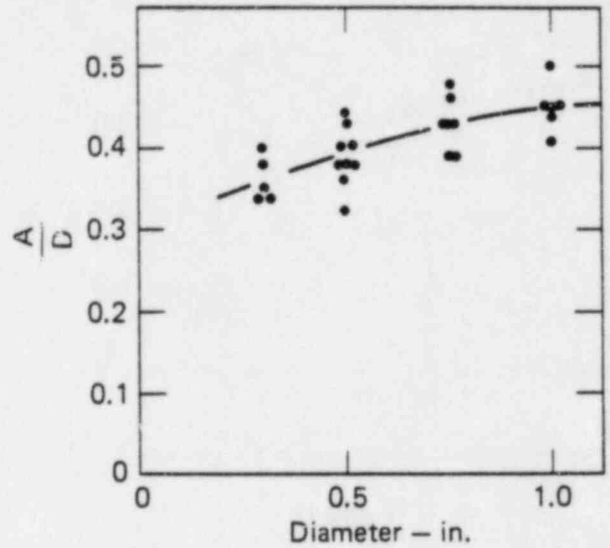
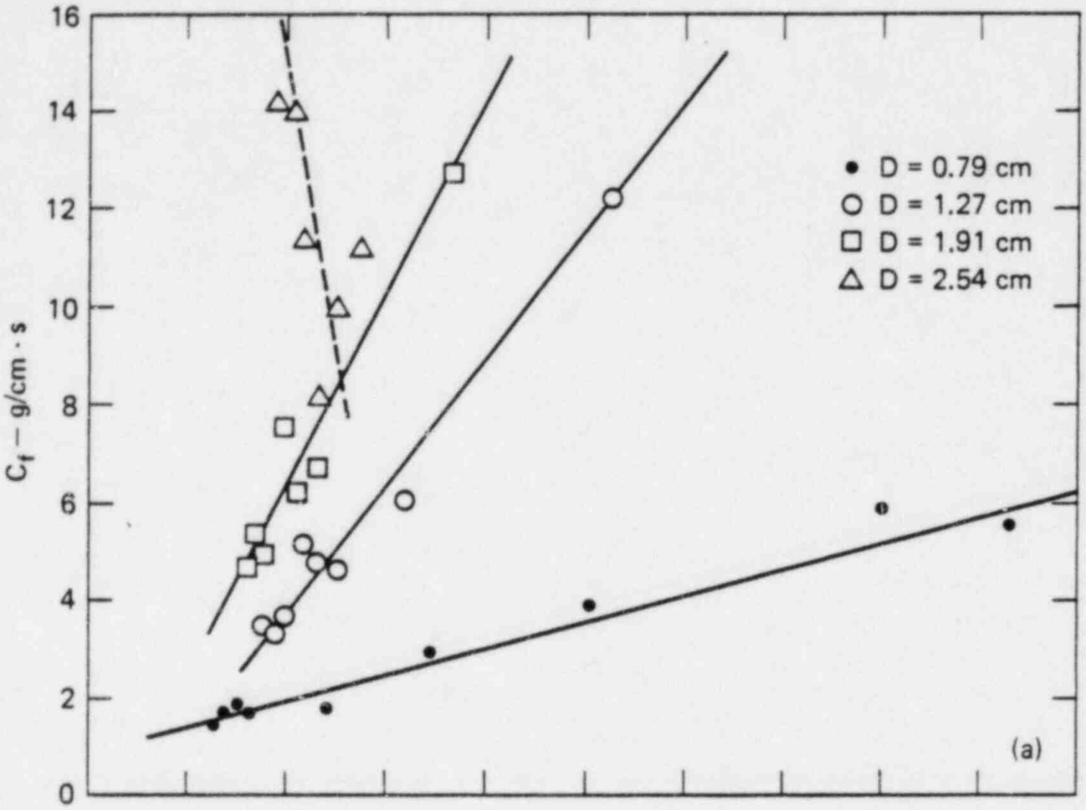


Fig. 12. Amplitude/diameter value for linear damping, oscillating submerged circular cylinders.[20]

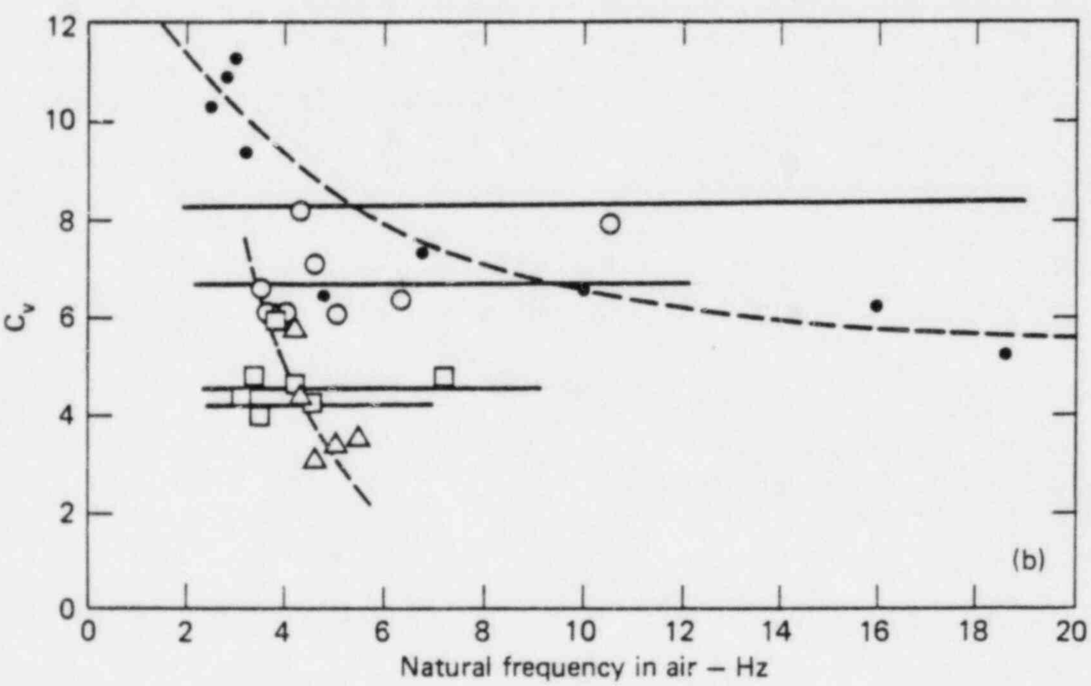
of critical damping varied less and was more consistent; i.e., all specimens showed either a constant value or decreasing value with frequency. Those showing decreasing values are the 0.31- and 1.0-in. specimens, as indicated by dashed curves in Fig. 13b. At this point, we chose to impose a simplification to proceed with forming a workable recommendation. Therefore, we chose to describe the percent of critical damping as a constant with respect to frequency. The constant values are indicated by the solid curves in Fig. 13b, and are plotted in Fig. 14 as a function of specimen size. Experimental data from Refs. 1, 3, and 27 are added, and these included specimens of circular, square, and plate cross-sections. The data points are few, and the scatter is moderate; yet a general trend is apparent in that added damping decreases with increasing specimen size. The trend was established by the data for circular specimens and was not contradicted by the data for square and plate specimens. Further discussion of this trend follows.

5.6 Effect of Structural Size on Added Damping for Single Isolated Members

The decrease in added damping with increasing structural size indicated in Fig. 14 is further confirmed by comparing with a similar trend established for damping of water sloshing in pools. The latter trend is well established, and expressions for the dependence of damping on pool size are given



Added damping in terms of damping coefficient.



Added damping in terms of the percent of critical damping.

Fig. 13. Damping data on oscillating circular cylinders in still water.[20]

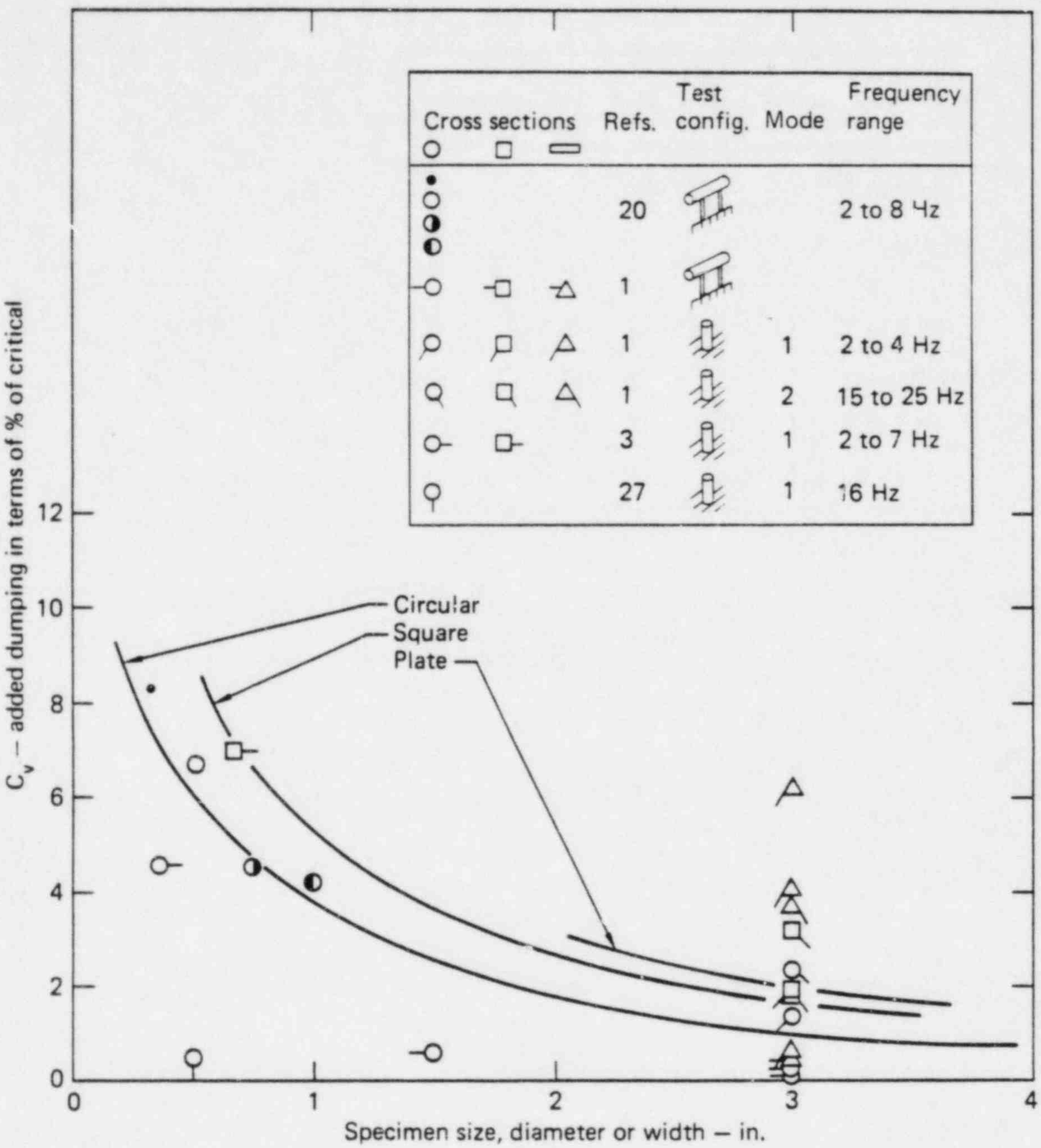


Fig. 14. Percent of added damping for various specimen cross sections and sizes.

in Refs. 51, 52, and 53. Several different expressions are seen in these references; however, they all have a common form of,

$$\log(\delta) = \log(A) - (q)\log(R) \ ,$$

where δ is the damping of the water sloshing in the pool, A is a constant, q is the constant defining the dependence on the pool size, and R is the length of the pool. Depending on the expression used, the value of q ranged from 0.75 to 1.0.

To see if the decrease in added damping for submerged single isolated members follows the trend established for water sloshing in pools, the data in Fig. 14 is replotted in Fig. 15 in terms of log (damping) vs log (specimen size). The scatter is rather wide; however, the decreasing trend is apparent. A straight line was least-square fitted to the data as shown. The slope of this line gave q = 0.85. Because the value of 0.85 fell between the values of 0.75 and 1.0 established for pools, we interpret this as good

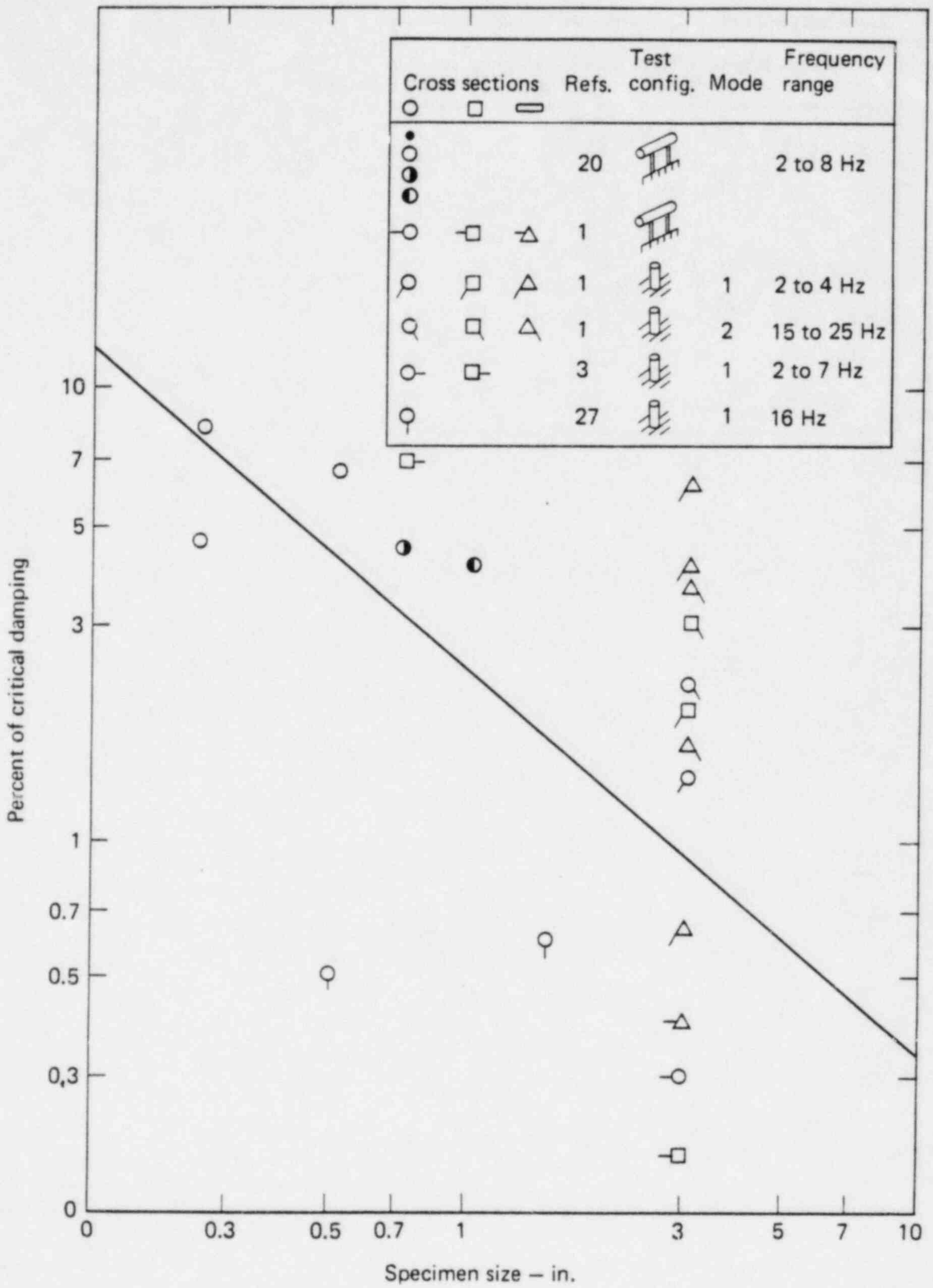


Fig. 15. A log vs log plot of the percent of added damping for various specimen cross sections and sizes.

confirmation that added damping for submerged single isolated members decreases with increasing structural size and that the dependence on structural size is reasonably characterized by Fig. 15. Our findings were shown to D. D. Kana of the Southwest Research Institute,[54] and he agreed that our treatment and interpretations are reasonable in view of the current state of understanding of the added damping phenomenon. We, then, used Fig. 15 to extrapolate the added damping values for the structural sizes of concern shown in Table 3. The results are given in Table 7. Except for single isolated fuel elements, the damping for all other single isolated members of the structures shown in Table 7 is quite low. These low values are in agreement with Newmark and Rosenblueth's suggestion[5] (See Section 5.1 of this report) that "damping due to liquid viscosity may be disregarded" for single isolated members of common structural sizes.

5.7 Range of Applicability of the Added Mass and Added Damping Concept for Single Isolated Members

The range of applicability of the added mass and added damping concept for single isolated members can be considered as being defined by the smaller of either the range for added mass or the range for added damping. In Section 5.4 of this report, the range of applicability of added linear damping was found to vary from an amplitude to diameter (A/D) ratio of 0.32 for a 0.31-in. diameter specimen to an A/D value of 0.5 for a 1.0-in. diameter specimen. The applicable range increases with specimen size, so that we would expect the range to be greater than an A/D value of 0.5 for specimen diameters larger than 1.0 in. Also in Section 5.4, we observed that beyond the range of applicability for linear damping, the damping increases. Therefore, using linear damping beyond the linear range would be conservative. Consequently, depending on the degree of conservatism desired, linear added damping may be used to some degree beyond its applicability range. Again in Section 5.4 of this report, the added damping values for single isolated members of structural sizes of actual concern are generally quite low. (See Table 7). Except for the single isolated fuel element, we may choose to ignore the added damping. In this case, the range of applicability for the added damping concept may be disregarded.

Turning now to the range of applicability of the added mass concept for single isolated members, experimental results for added mass coefficient C_m over a wide range of amplitudes for various specimen geometries are shown in Figs. 16 through 19. The abscissa in all four figures is $U_m T/D$ which is simply 2π times the A/D ratio; U_m is the velocity amplitude, and T is the period of oscillation in seconds per cycle. Comparing these curves with the theoretical value for C_m obtained using potential theory we defined the range of applicability as the range of $U_m T/D$ corresponding to experimental values of C_m within $\pm$ 10% of the theoretical value. The resulting A/D values for the applicable range of added mass are tabulated in Table 8. The A/D values for the applicable range of linear damping are also indicated.

The four values of A/D in Table 8 for the applicable range of the added mass concept are in good agreement. The A/D value for a sphere is expected to be higher than that for a cylinder or plate because it is a finite length specimen (more streamlined), and, therefore, potential flow can be expected to apply over higher values of displacements. The A/D range of 0.32 to 0.5 for the applicability of linear damping is not drastically different from the 0.8 and 1.4 values for added mass. Therefore, we consider the ranges for both to be mutually supportive.

Because the smallest structure of concern shown in Table 7 is 0.5-in. diameter, the range of applicability for the added mass and added damping concept for these structures, as single isolated members, can be considered to be no less than an A/D value of 0.4 according to Table 8. If added damping should be ignored, then the range would be an A/D value of

Table 7. Added damping values projected in Fig. 15 for single, isolated structures

Structure	Size, in.	Added damping, % of critical
Fuel elements	~0.5 D	≤4.2
BWR fuel bundle	~5.5 X 5.5	≤0.55
PWR fuel bundle	~10 X 10	≤0.33
Main steam-relief valve line	8 D	≤0.40
	12 D	≤0.29

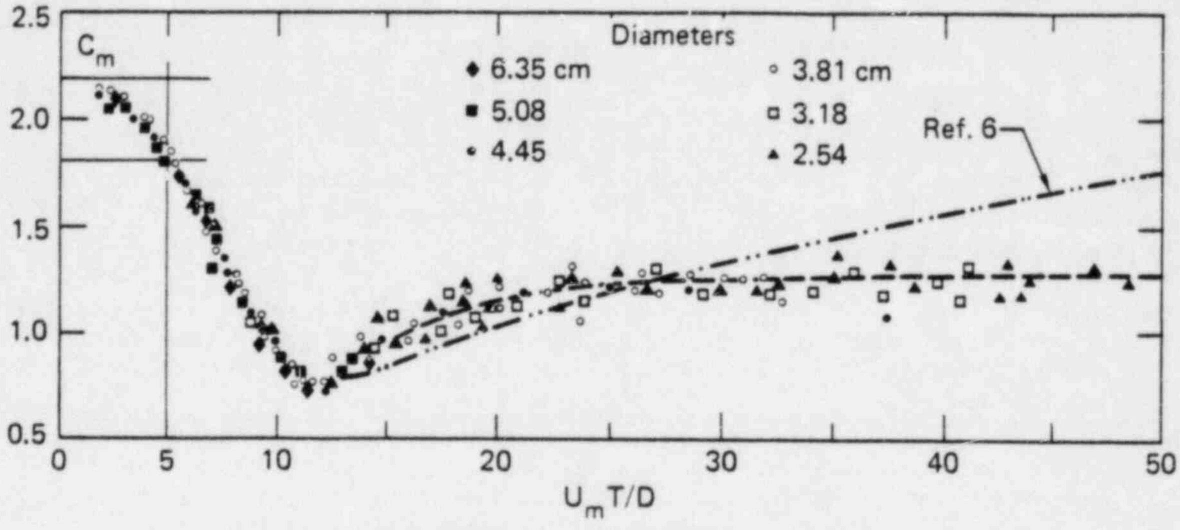


Fig. 16. Mass coefficient vs the period parameter for a cylinder.[29]

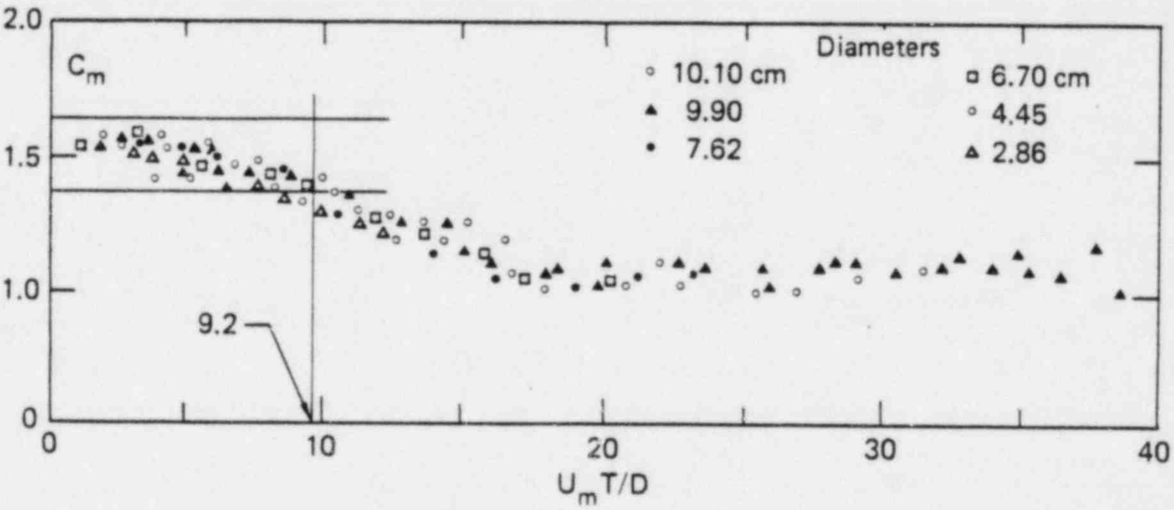


Fig. 17. Mass coefficient vs the period parameter for a sphere.[29]

Table 8. Applicable range of motion amplitude determined from added mass and added damping experimental data

Type of data	Specimen geometry	$A/D = U_m\ T/2\pi D$*
Added mass	Circular cylinder[29]	0.8
	Sphere[29]	1.4
	Circular cylinder[6]	0.8
	Plate[6]	0.8
Added damping	Circular cylinder[20]	
	diameter:	
	0.31 in.	0.32
	0.5 in.	0.4
	0.75 in.	0.43
	1.0 in.	0.5

*U_m = maximum oscillating velocity
T = period in seconds/cycle
D = specimen diameter or width
A = maximum oscillating displacement

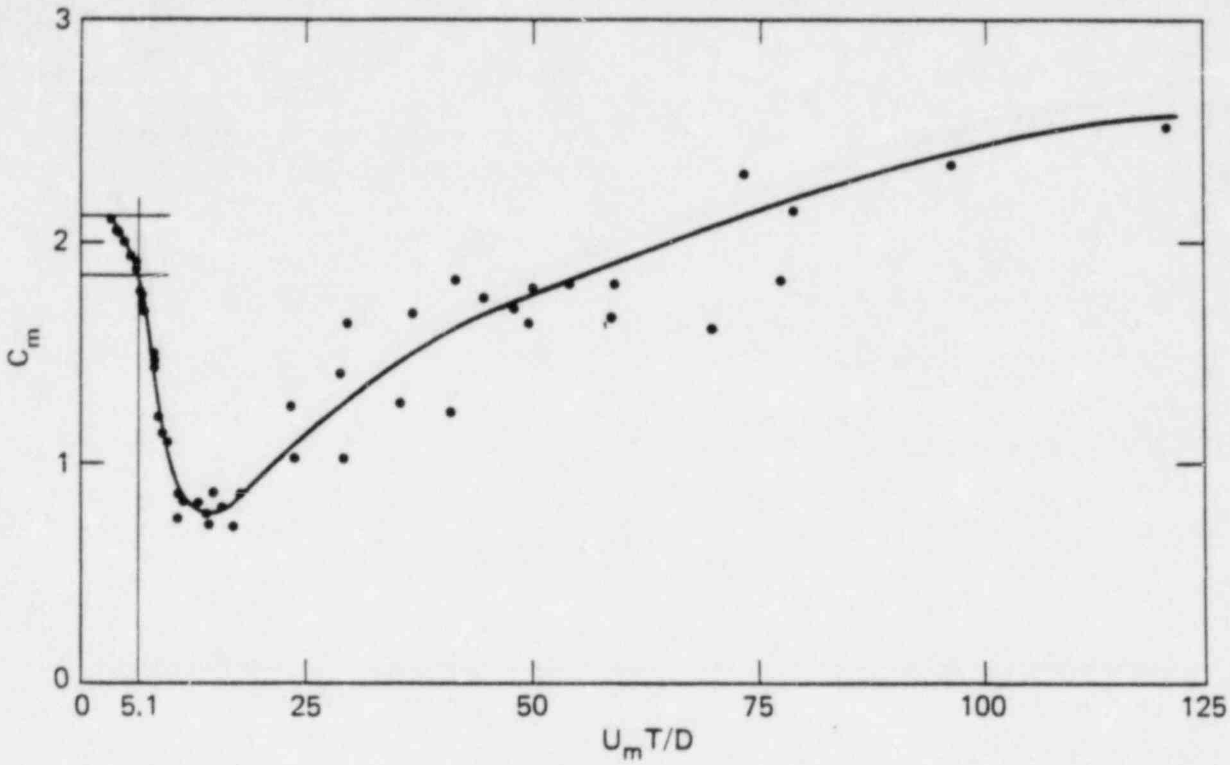


Fig. 18. Variations of the mass coefficient of cylinder.[a]

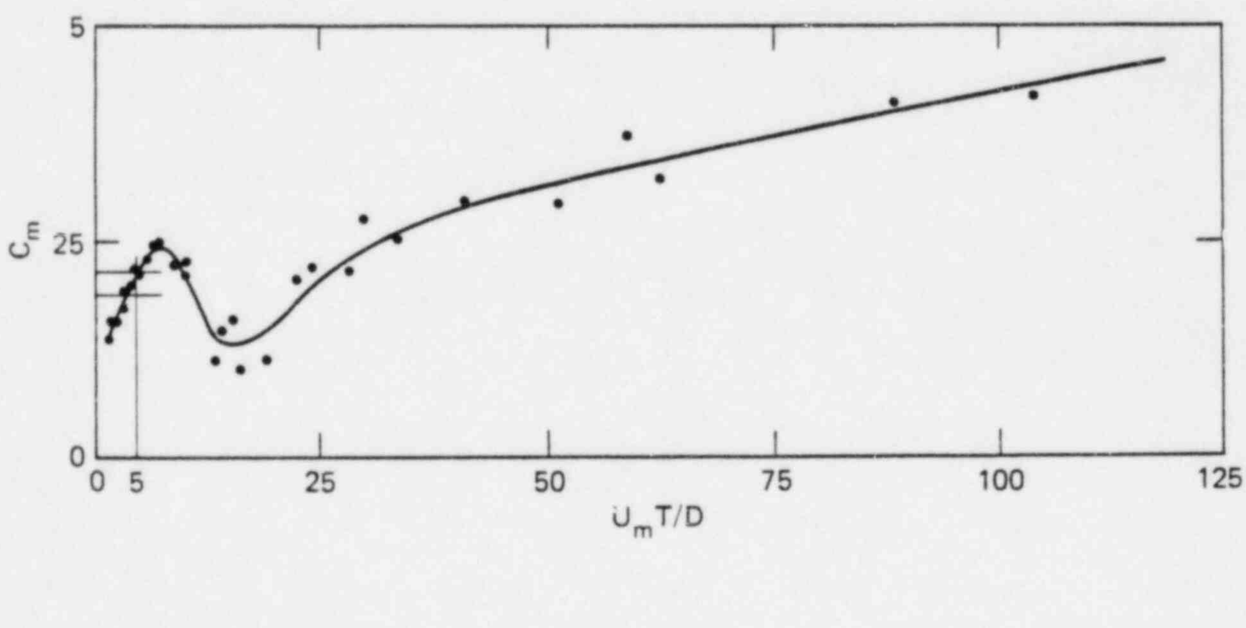


Fig. 19. Variations of the mass coefficients of plates.

0.8. In either case, however, the applicable range would probably adequately cover any response to seismic and normal steam-relief excitations. The response to an accident condition may or may not be within the applicability range depending on the structure involved and its location relative to the accident site.

Our conclusions are based on experimental data from rather small specimens, sizes up to 3.0 in. in diameter, and on rather low frequencies (0.35 Hz for Ref. 29, 0.48 Hz for Ref. 6, and from 2.5 to 18.6 Hz for Ref. 20). Theoretical considerations indicated in the added mass coefficients should be size and frequency independent. We made a simplifying assumption that added damping is frequency independent, and we developed a technique to describe added damping as a function of structural size. Although we feel comfortable with our assumptions and developments, some additional experimental verification at higher frequencies and with larger specimens would be highly desirable.

6. MULTIPLE MEMBERS

6.1 Complexities Associated with Multiple Members

The fluid dynamic effects on multiple members are more complex than for a single isolated member. The arrangement of the members, space between members, motion of one member relative to another, and the generation of lift forces are all additional important considerations. Added mass forces are no longer necessarily in line with the direction of motion, and lift forces may be generated which tend to act perpendicularly to the direction of motion.[10,26,36] Damping tends to be higher than for single isolated members, and tight spaces between members, in particular, can increase the damping measurably.[27,47,49] Multiple-member response, in general, is not too well understood. Current interest appears high as evidenced in recent publications, particularly relating to nuclear reactors. Many highly theoretical works are presented; some are rather complicated in terms of practical, everyday use in design analyses. Some experimental data are available to validate certain, often limited, aspects of the theoretical solutions. In general, additional experimental validation is needed, and the range of applicability of the various analytical techniques needs to be established.

Although many of the investigations are motivated by reactor internal concerns, the results published so far apply at best only to normal reactor operations and not to conditions associated with a blowdown accident. The flow rates and/or component motions are assumed small. Conditions associated with a blowdown accident are very likely beyond the range of applicability of the various techniques presented.

For our presentation, we separate our findings with respect to three types of structural arrangements:

(1) groups of cylinder, such as arrays,

(2) groups of cylinders, or a single cylinder, surrounded by a large circular cylinder, and

(3) coaxial flexible cylinders.

The first category can apply to the main steam-relief valve line next to the pressure suppression pool wall, an array of fuel elements in a fuel bundle, an array of fuel bundles in a spent-fuel storage rack, and an array of storage racks in a spent-fuel storage pool. The second and third categories can apply to the reactor-vessel internals.

6.2 Hydrodynamic Coupling for Groups of Cylinders

Closed form solutions using potential theory are presented in Refs. 10, 18, 19, 32, 33, 34, 35, 36, 42, 43, and 48 for added mass and lift forces for a group of cylinders. The solutions are given in terms of multiple summations and infinite series. The analyses are rather complicated but quite general; a group of different sized cylinders arranged arbitrarily can be handled, at least theoretically. A clear physical interpretation of the complex solutions is not immediately apparent. Some insight is provided in Refs. 32, 34, 35, and 36, where the solution is expressed in terms of "self-added" and "added" mass coefficients. The self-added mass coefficients characterize the hydrodynamic forces on a member from its own motion with all other members held stationary. The added mass coefficients characterize

the hydrodynamic forces in a stationary member with other members in motion. Because potential theory is linear, reciprocity applies; i.e., the force induced onto member i from the motion of member j is the same as the force induced onto member j from the motion of member i.

Experimental comparisons with theory are given in Refs. 30, 32, and 36 for a seven-member hexagonal array (Fig. 20) and a 3 x 3 square array (Fig. 21). In both configurations, the central member is in motion while the rest are stationary. The self-added mass coefficients for the central member are determined for four sizes of space between members. The agreement between theory and experiment is good. Comparisons between theory and experiment are made for a row of five cantilevered cylinders, a group of three cantilevered cylinders, and a group of four cantilevered cylinders[48] in terms of natural frequencies and mode shapes. The group arrangements are shown in Figs. 22, 23, 24, and 25, respectively, and the comparisons in Figs. 26, 27, and 28, respectively. The agreement between theory and experiment is good. Further comparisons were made in terms of acceleration response under steady-state sinusoidal excitation for the row of five cylinders and the group of three cylinders. The frequency of excitation was swept from 50 Hz to 80 Hz. The comparisons are shown in Figs. 29 and 30 for the two cases, respectively. The agreement is good in Fig. 29 and fair in Fig. 30.

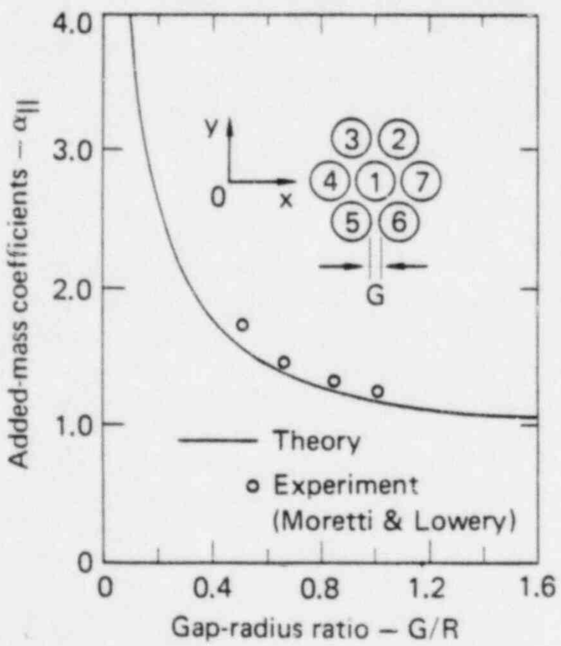


Fig. 20. Theoretical and experimental values of added mass coefficients for a seven-rod bundle.[23]

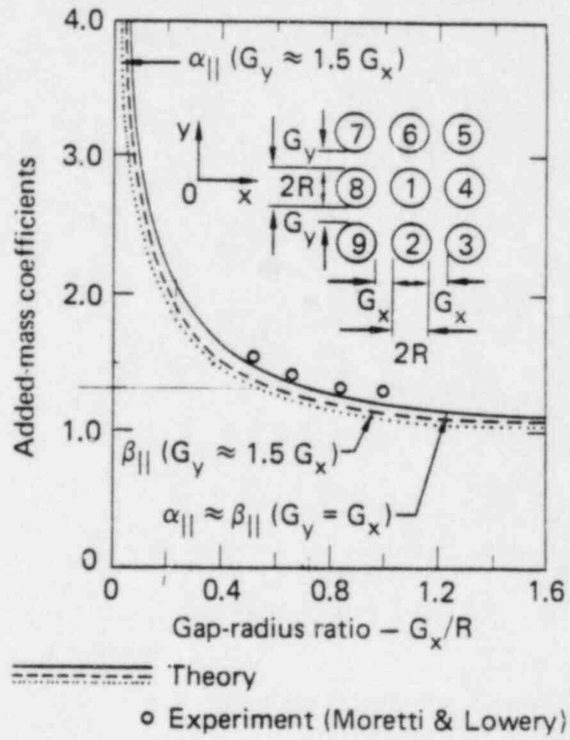


Fig. 21. Theoretical and experimental values of added mass coefficients for a nine-rod bundle.[32]

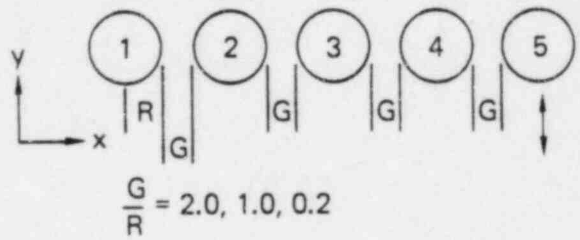


Fig. 22. Row of five cantilevered cylinders.[48]

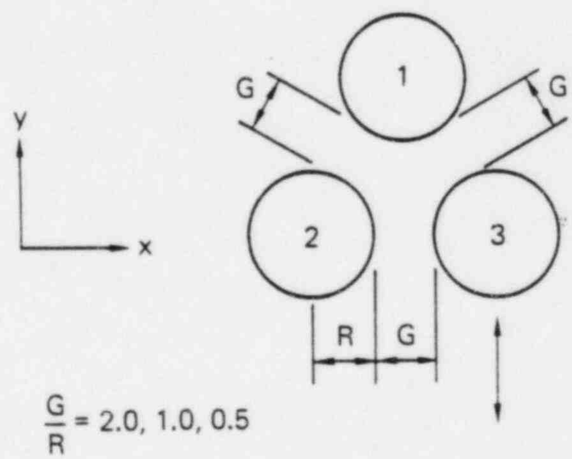


Fig. 23. Group of three cantilevered cylinders.[48]

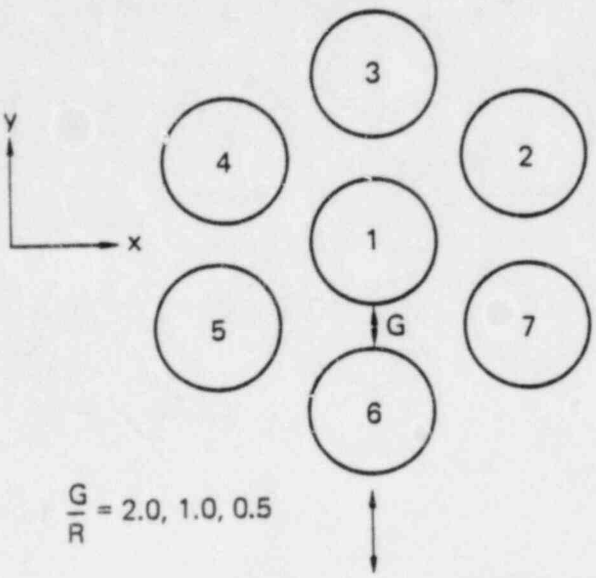


Fig. 24. Array of seven cantilevered cylinders.[48]

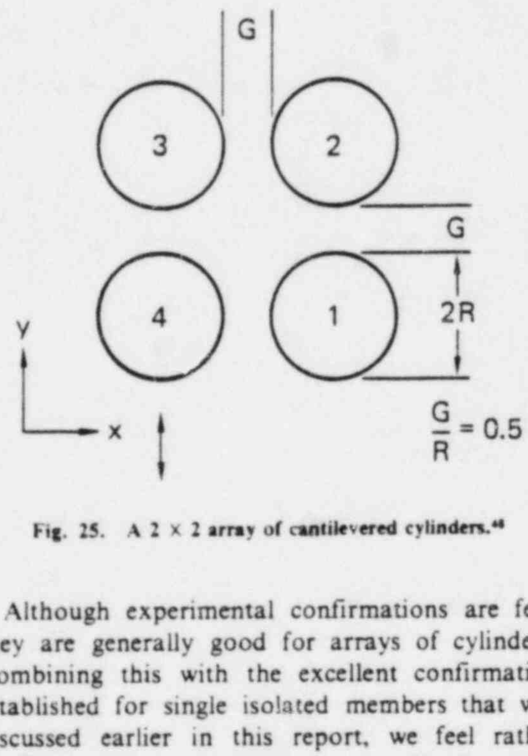


Fig. 25. A 2 × 2 array of cantilevered cylinders.[48]

Although experimental confirmations are few, they are generally good for arrays of cylinders. Combining this with the excellent confirmation established for single isolated members that was discussed earlier in this report, we feel rather confident that the potential theory will adequately describe the added mass and lift forces for groups of cylinders. We would expect the range of applicability with respect to motion amplitude to be less than that for single isolated members because of the close proximity of the members. Whether or not the potential theory will be adequate under excitations of normally expected earthquakes is unknown. However, for the time being, we believe the potential theory can be assumed adequate based on the rather high range of displacement amplitudes applicable for single isolated members; see Section 5.7.

The added mass and lift forces for a 4 x 4 array of cylinders moving in unison, as shown in Fig. 31, are calculated using potential theory.[10] This illustrates an important effect resulting from hydrodynamic coupling among groups of members. The added mass forces are not necessarily in line with the direction of the motion, and lift forces tending to act perpendicular to the direction of motion are generated. In addition, the distribution of forces is not uniform among the members. The total load on each member, the vector sum of the added mass and lift forces, accentuates this nonuniformity. In terms of the total load, cylinders 4 and 6 in Fig. 31 carry the highest, while cylinders 1 and 13 carry the lowest. Nonuniformity in the load for arrays are not accounted for among the design methods in current use outlined in Section 4 of this report. It may, or may not, be important, depending on the purpose of the analysis and on the configuration of the array; however, its existance and possible effects should be kept in mind.

For the 4 x 4 array shown in Fig. 31, the net lift force for the entire array is zero because of symmetry. The total added mass force, however, depends on the space between members. For the case where the X and Y center-to-center, distance-to-diameter (X/D and Y/D) ratios are both 1.5, the total added mass force is equal to 16 times that of a single isolated cylinder.[10] However, for X/D = 1.5 Y/D = 3.0, the total is 20 times that of a single isolated cylinder.[10] In the latter case, the total force carried by the array is greater than that carried by 16 individual isolated cylinders. The direction of the motion or flow, as well as the spacing, affect the force magnitudes as shown in Figs. 32 through 35 taken from Ref. 10. These effects, as well as the nonuniform load distribution, underscore the importance of considering hydrodynamic coupling for groups of cylinders.

If the spacing between members is increased, when will the members respond as if isolated? For a single isolated circular cylinder the added mass coefficient is unity, and the lift force is zero. Using these values as the criteria for defining when members of a group become essentially isolated, Figs. 33a and 34a indicate that the members of the 4 x 4 array of Fig. 31 become essentially isolated at X/D and Y/D ratios of 2.5.[10] Similarly, an X/D ratio of 2.5 was obtained for the case of two parallel cylinders as reported in Refs. 18, 19, and 26. Other arrangements also gave ratio values of 2.5; these include in-line and staggered arrangements of three cylinders and arrays other than 4 x 4 square arrangements (Refs. 18, 19, 26, 30, 31, 32, 34, 35, 36, and 42). Thus, a ratio value of 2.5 seems to be more or less universally applicable.

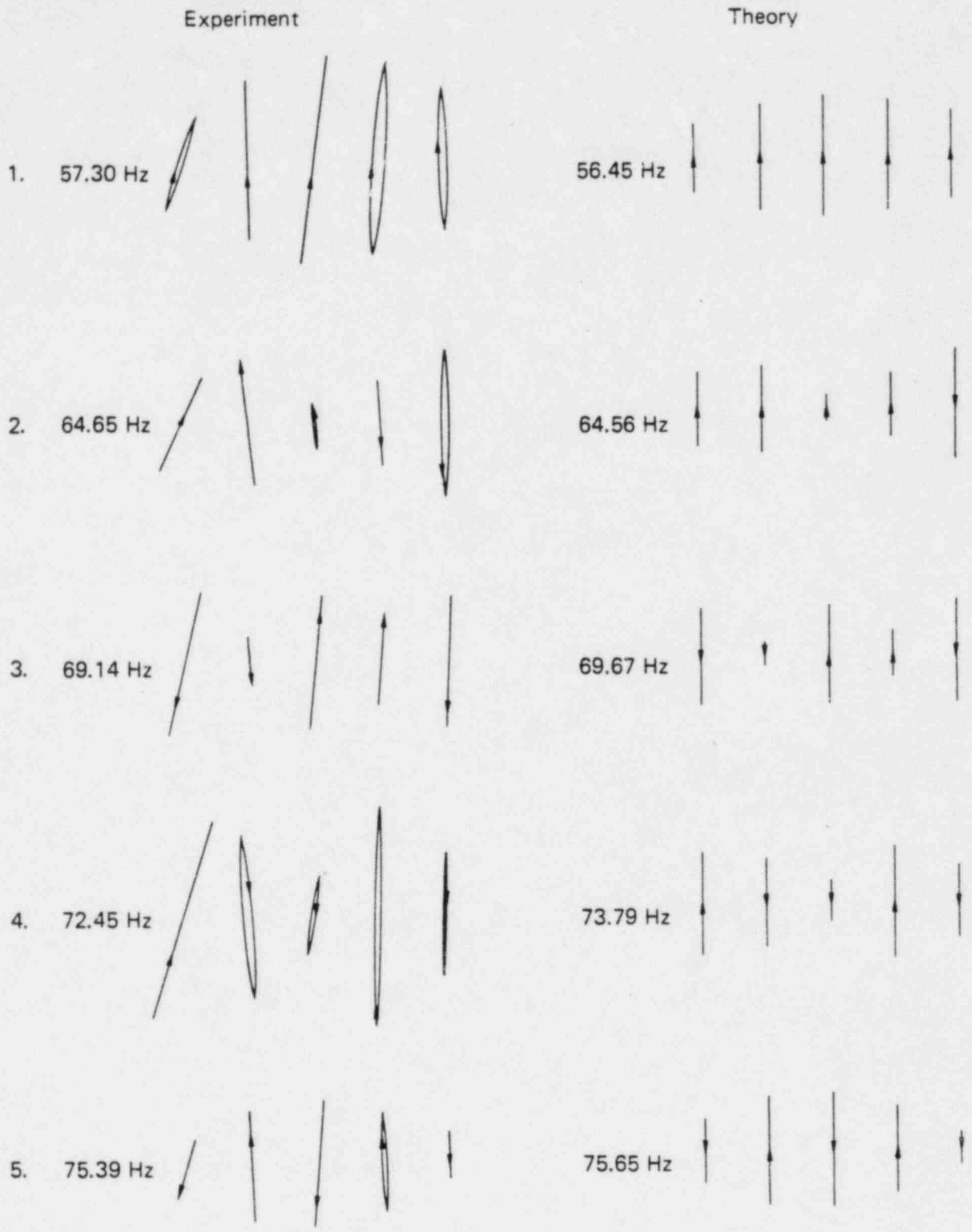


Fig. 26. Mode shapes of a row of five tubes with a G/R = 0.25.[48]

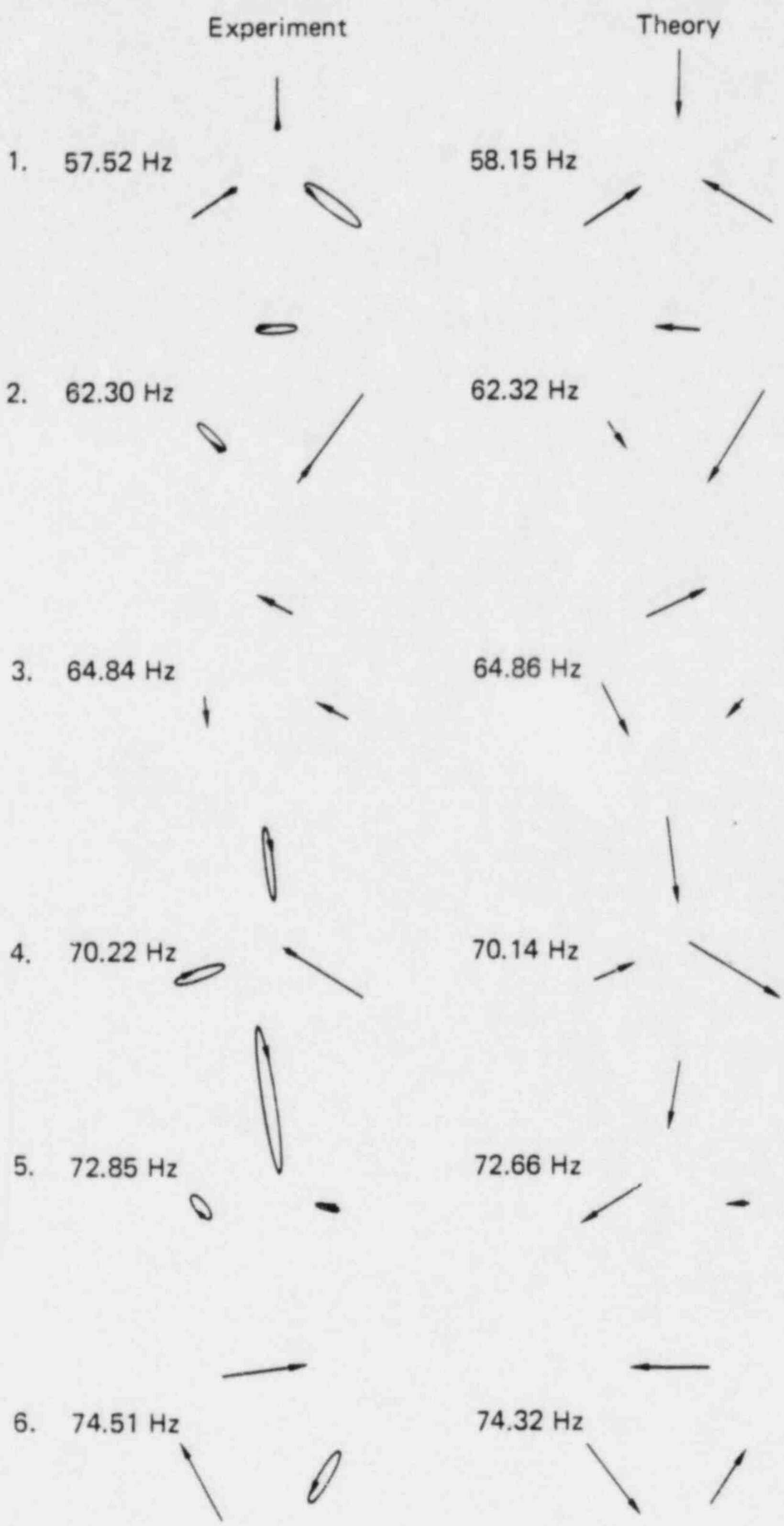


Fig. 27. Mode shapes of a group of three tubes with a G/R = 0.5.[48]

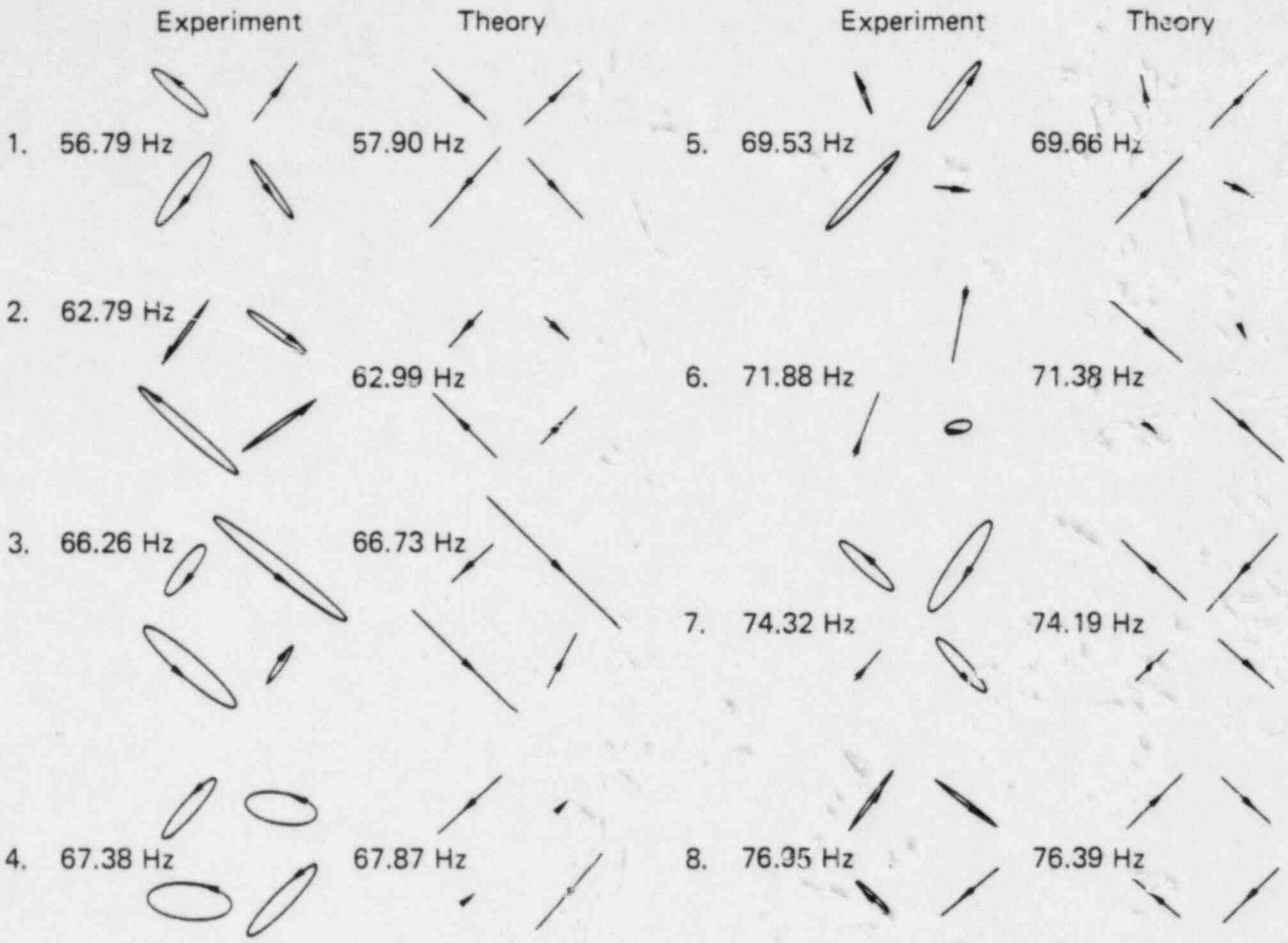


Fig. 28. Mode shapes of a group of four tubes in unconfined water.[41]

For applications practical to large arrays, a simplification was suggested in Ref. 35. In a regular array of cylinders the most significant hydrodynamic coupling for a given member is with its immediate neighbors, and coupling with members further removed can be neglected. This means that, regardless of the size of the array, it can be analyzed in subparts consisting of each member and its immediate neighbors. The author of Ref. 35 reached this conclusion upon theoretically analyzing regular hexagonal arrays of 7, 19, and 37 cylinders. For each case, the added mass coefficients of the central cylinder was calculated and compared from case to case. The coefficients for the 19- and 37-cylinder arrays matched almost identically, and those for the 7-cylinder array were close. Thus, the simplification suggested seemed reasonable. We can make a further confirmation of this simplification by examining the 4 x 4 array shown in Fig. 31. Considering the high degree of similarity in the magnitudes and directions of the forces on cylinders 6, 7, 10, and 11, each of these four centrally located cylinders must be influenced to approximately the same degree by the hydrodynamic coupling. Each is surrounded in the same manner by eight immediate neighbors so, had the simplification been applied, the forces on each would have been the same. This comparison may not provide strong additional confirmation, but it is supportive. A precaution needs to be mentioned: the highest loads are carried by the corner members, cylinders 14 and 16. The simplification was developed based on results for centrally located members, so that it may, or may not, apply to peripheral and corner members. In the case of the 4 x 4 array, the corner members are the most important to analyze. We suspect the corner members might also be the most important to analyze in other size arrays.

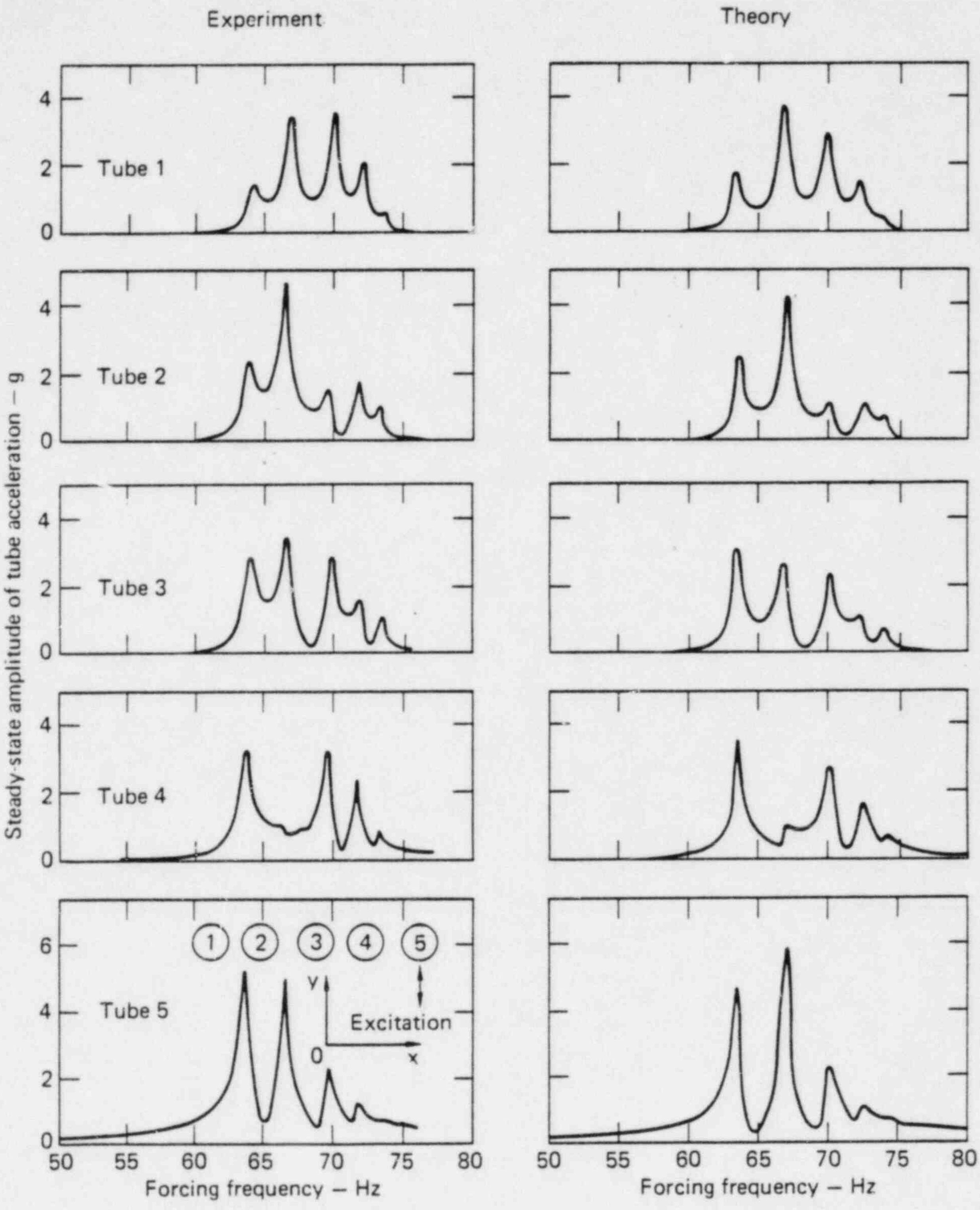


Fig. 29. Steady-state responses of a row of five tubes to an excitation on tube 5 with a G/R = 1.0.[48]

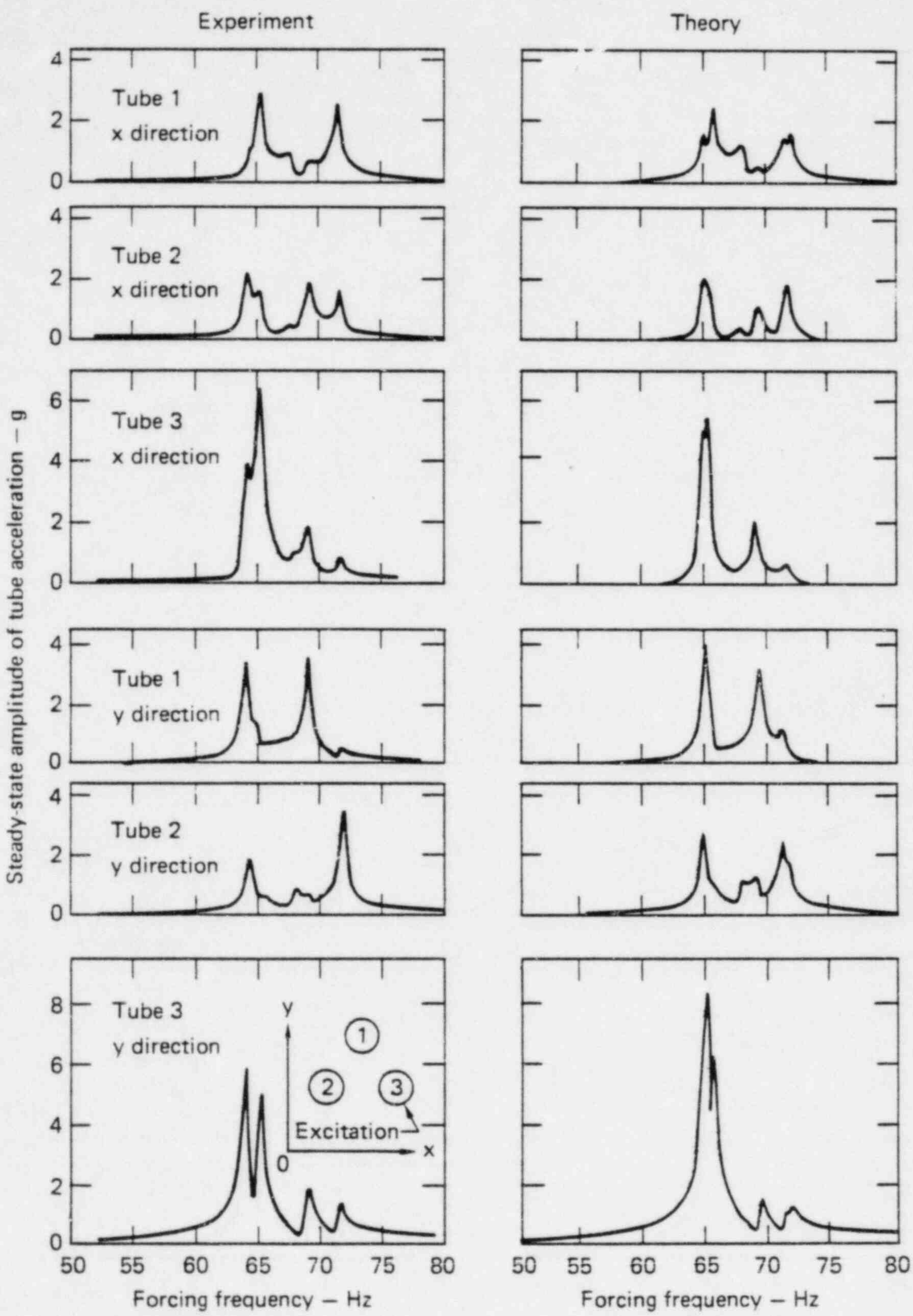


Fig. 30. Steady-state responses of a group of three tubes to an excitation on tube 3 with a G/R = 2.0.[48]

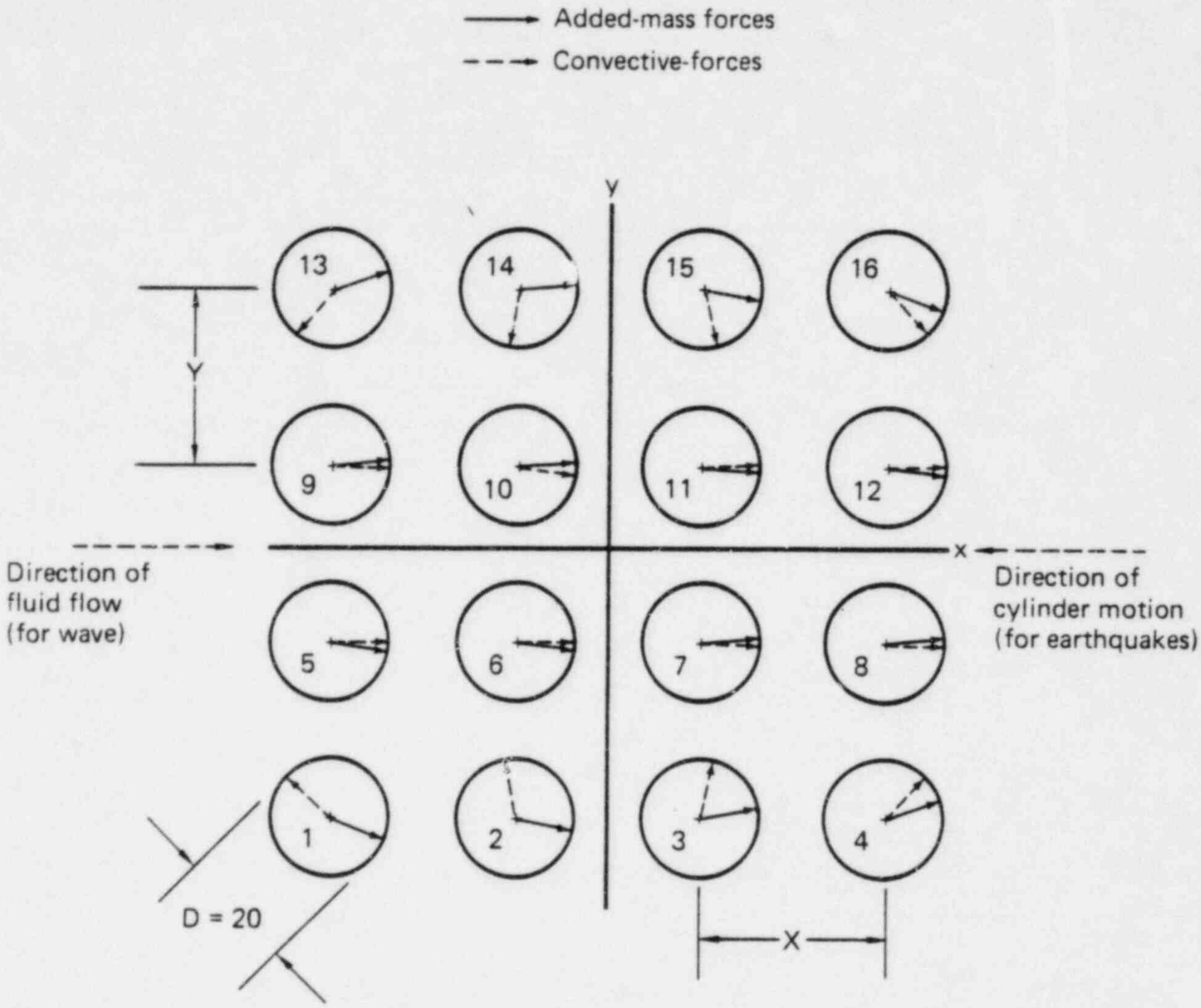


Fig. 31. Added-mass and convective forces on a 4 × 4 array with X = Y = 1.5 D.[19]

An approximation that is even simpler was suggested in Ref. 10. The total interaction is considered to be the sum of interactions between each two adjacent members. Therefore, the members of the array are analyzed two at a time and the results superimposed. The approximation was shown to be accurate to within 2 to 25% for a 4 x 4 array compared to a rigorous analysis. The accuracy varied depending on the member of the array. Corner members can be analyzed.

6.3 Hydrodynamic Coupling for Rigid Members Surrounded by a Rigid Circular Cylinder

A number of different member arrangements surrounded by a rigid circular cylinder have been investigated. Closed-form solutions based on potential theory are presented for coaxial cylinders (Refs. 7, 30, 26 and 34), eccentric cylinders (Refs. 26 and 34), and an array of cylinders surrounded by a cylinder (Refs. 26 and 34). A finite element method was developed and applied to coaxial cylinders and to an array of cylinders surrounded by a circular cylinder.[21,42] Analyses of coaxial cylinders using an incompressible viscous fluid theory are given in Refs. 27 and 45. For the remainder of Section 6.3 of this report, we will focus primarily on results pertaining to rigid coaxial cylinders. This is a simple model commonly used to simulate the internals of the reactor vessel under seismic excitation.

For two rigid coaxial cylinders in motion, as shown in Fig. 36, with the annular space filled with fluid, the potential theory solution is expressible in a form quite convenient for design applications. The

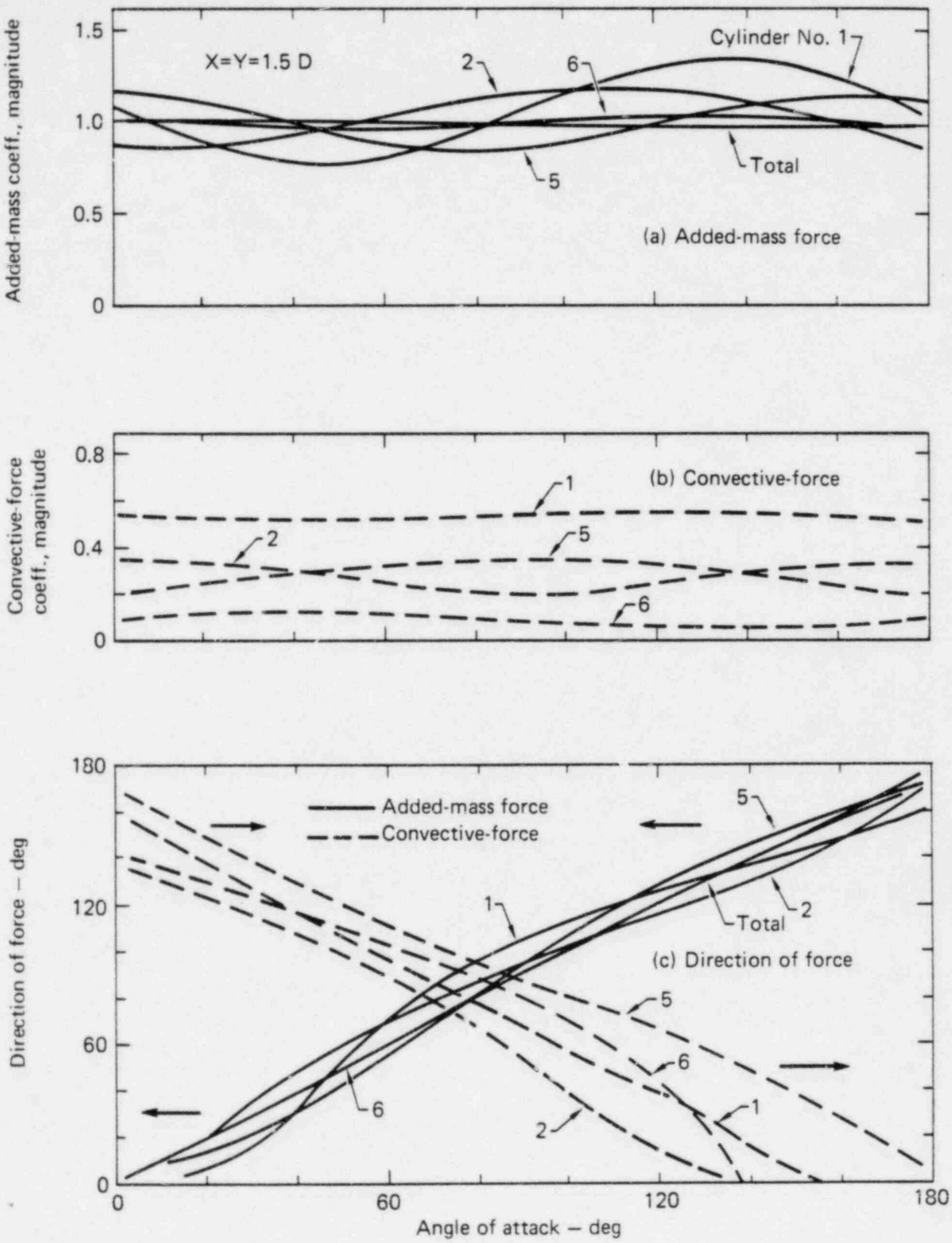


Fig. 32. Hydrodynamic forces vs angle of attack for a 4 × 4 array with X = Y = 1.5 D.[10]

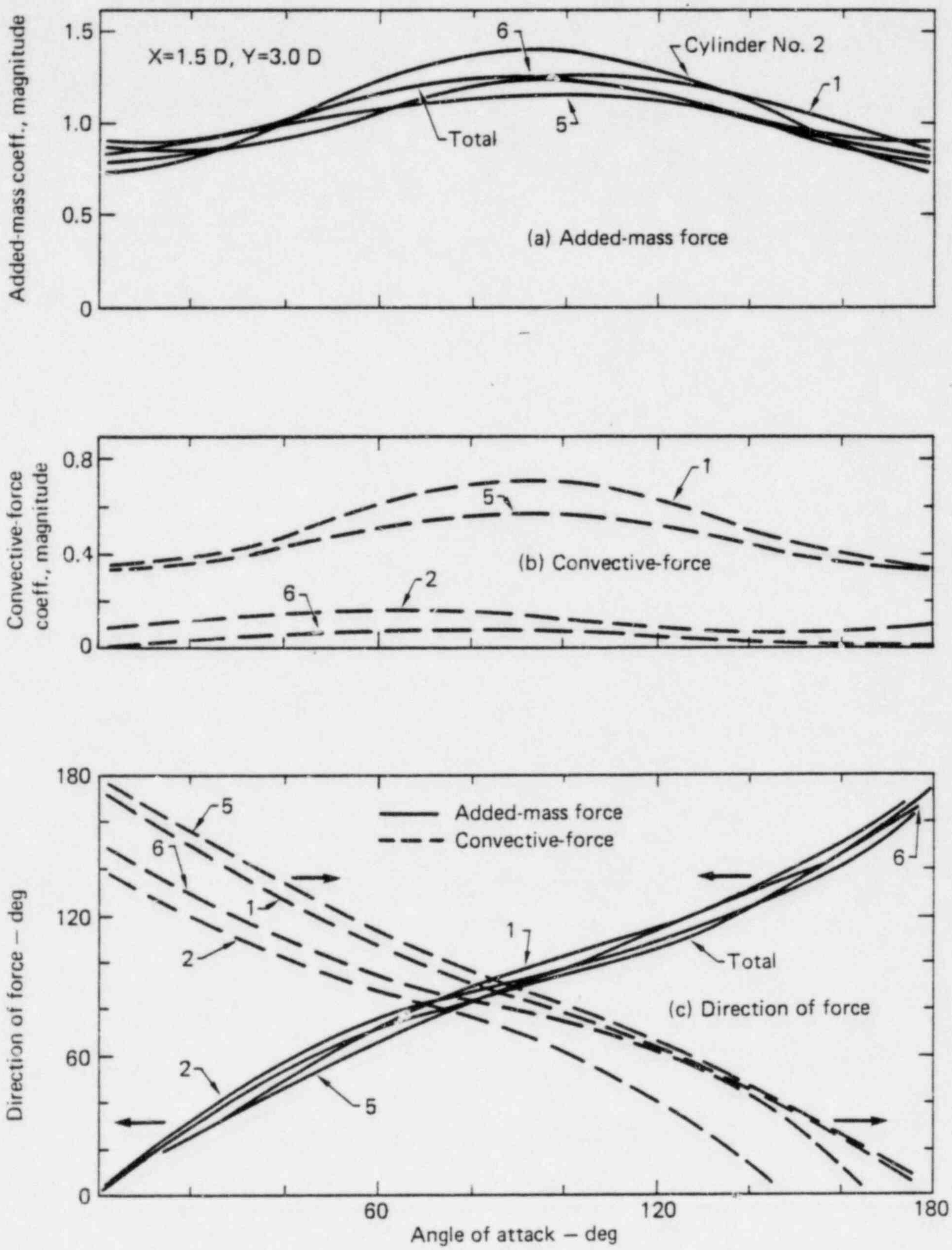


Fig. 33. Hydrodynamic forces vs angle of attack for a 4 × 4 array with X = 1.5 D and Y = 3 D.[10]

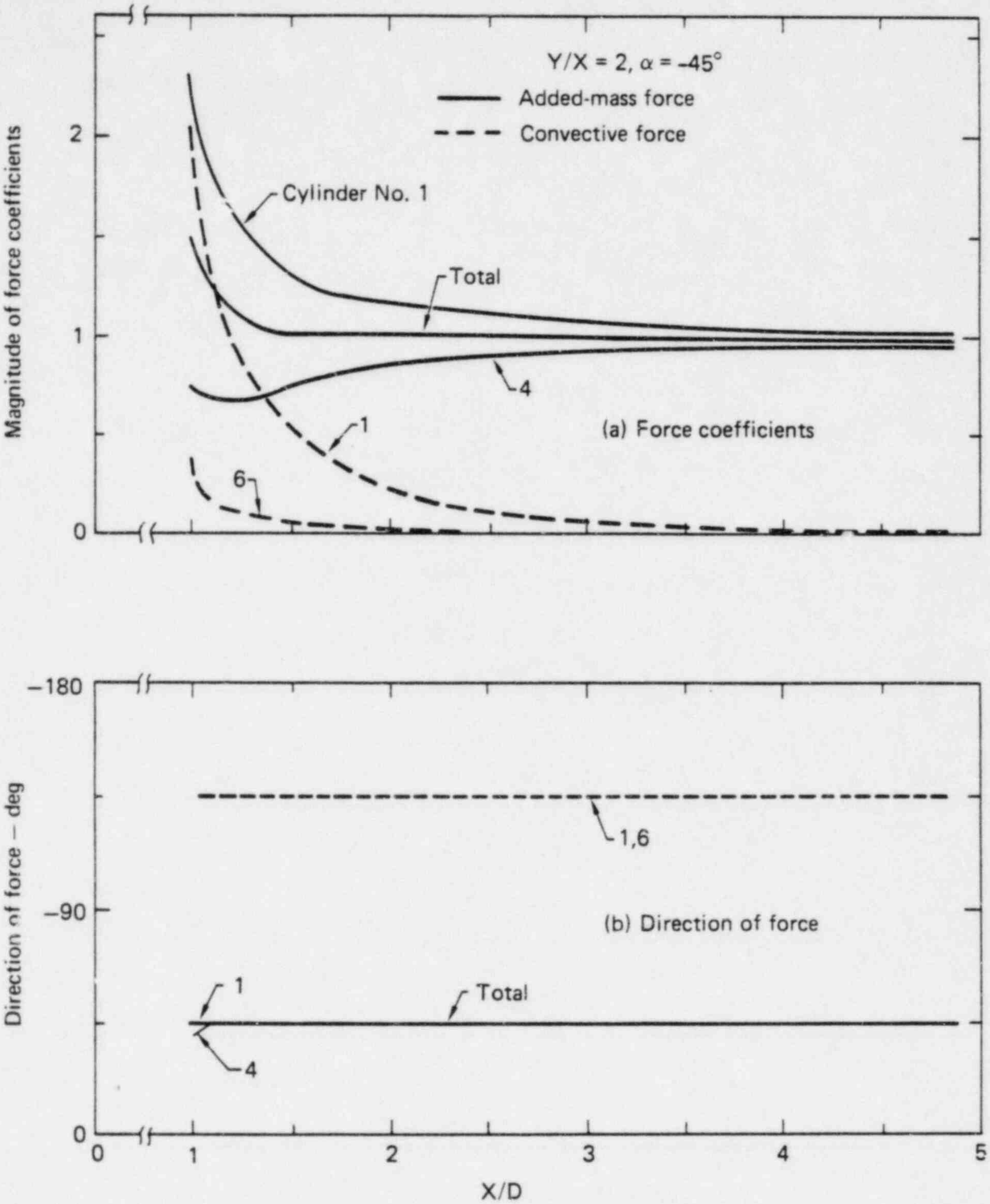


Fig. 34. Hydrodynamic forces vs spacing for a 4 × 4 array with Y/X = 1.0 and α 45 deg.[10]

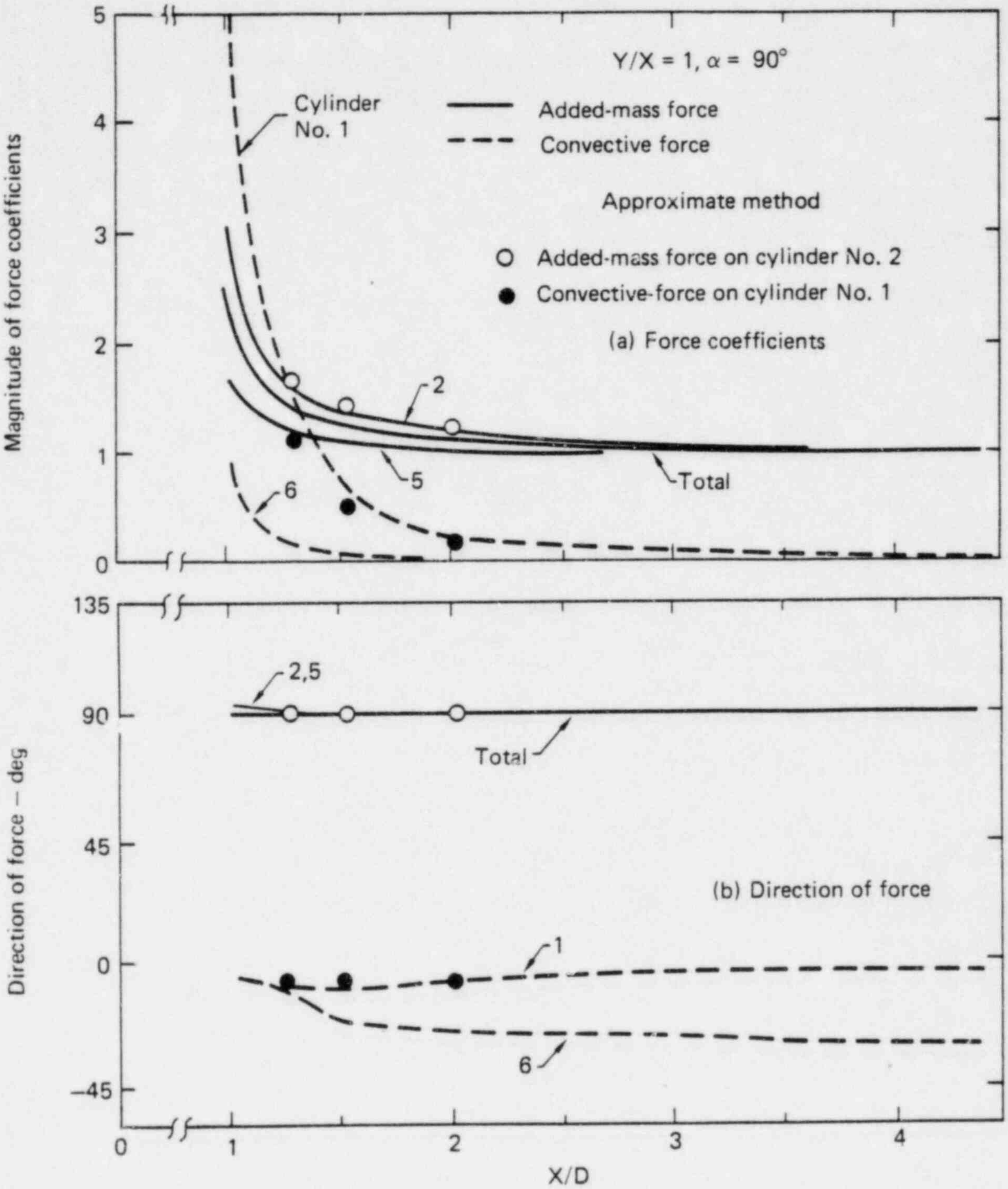


Fig. 35. Hydrodynamic forces vs spacing for a 4 × 4 array with Y/X = 2.0 and α = 90 deg.[10]

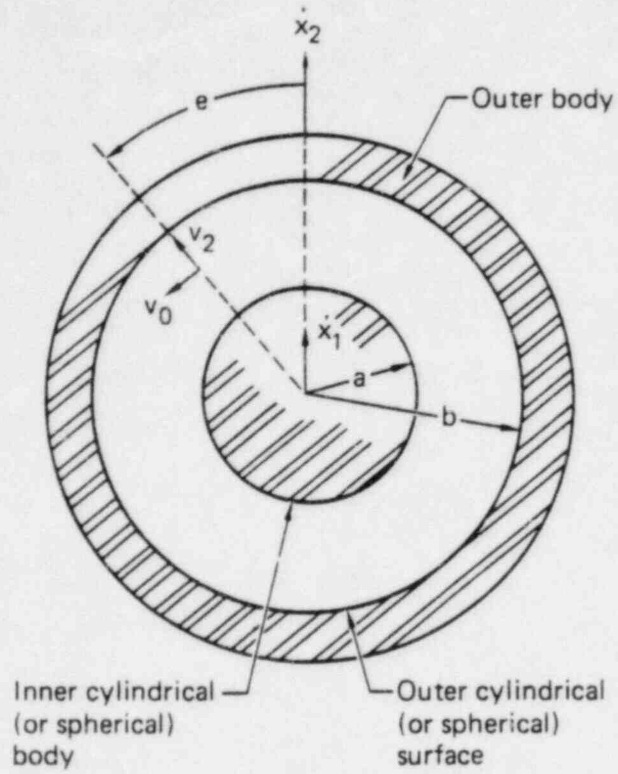


Fig. 36. Two-body motion with fluid coupling.[7]

fluid forces on the inner and outer cylinders are, respectively,[7]

$$F_{f_1} = -M_H \ddot{x}_1 + (M_1 \; M_H)\ddot{x}_2 \; , \qquad (1)$$

$$F_{f_2} = (M_1 + M_H)\ddot{x}_1 - (M_1 + M_2 + M_H)\ddot{x}_2 \; , \qquad (2)$$

where,

$M_1 = \pi a^2 L\rho$ = mass of fluid displaced by the inner cylinder (3)

$M_2 = \pi b^2 L\rho$ = mass of fluid that could fill the outer cylindrical cavity in the absence of the inner cylinder (4)

$$M_H = M_1 \frac{b^2 + a^2}{b^2 - a^2} =$$

= mass term depending on the relative sizes of the inner and outer cylinders. (5)

L = length of the cylinders

ρ = mass density of the fluid.

Values for M_1 and M_2 can be determined experimentally or theoretically. Similar expressions are also presented in Ref. 30. These equations theoretically apply only to infinitely long cylinders; therefore, L should be significantly greater than the radii a and b. In addition, we expect that the solution's invalidity will diminish if the annular space is very small compared to radii a or b because the fluid would then be subjected to a significant amount of flow and shearing to accommodate the relative motions of the cylinders. The incompressible and invicid assumptions would be less valid. Unfortunately, we have found no published indication of the range of applicability of the Eqs. (1) through (5) with respect to annulus size and motion amplitude.

Some comparison with experiments for five cases of two coaxial rigid cylinders are given in Table 9 taken from Ref. 7. The outer cylinder is fixed while the inner cylinder is vibrated. The added mass values on the inner cylinder, evaluated with Eq. (1), were compared with measured values. In the first four cases, the theoretical value was higher than the experimental by 21 to 36%, and, in the fifth case, it was lower by 33%. The comparison was fair.

The finite element technique developed in Refs. 21 and 42 compared very well with potential theory in terms of added mass coefficients for two coaxial rigid cylinders. (See Table 10 from Ref. 21). The basis of comparison was the M_1, M_2, and M_4 of Eqs. (1) and (2). Therefore, the finite element technique is capable of duplicating the closed-form results very well. A comparison of the finite element technique with experimental results was presented in Ref. 42 for a 2 x 2 array of square cylinders surrounded by a circular cylinder, Fig. 37. Cylinder B is driven at a fixed displacement amplitude over the frequency range from 3 to 15 Hz, and the required force was monitored. The agreement between the finite-element and experimental results was reasonable.[42]

A somewhat more sophisticated treatment of coaxial rigid cylinders is given in Refs. 27 and 45 using an incompressible viscous theory. The solution expressions are much more complex than those for potential theory and are contained in the references. A comparison with experiment was made for a fixed outer cylinder and oscillating inner cylinder. The outer cylinder diameter was varied from 0.625 in. to 2.5 in., while the inner cylinder diameter was kept at 0.5 in. The agreement between analysis and experiment was quite good, as shown in Fig. 38, and it is noticeably better than the comparisons discussed earlier for the potential theory. A possible conclusion is that viscous effects may be important and perhaps should be included when analyzing coaxial rigid cylinders. More experimental comparisons are needed to confirm this possibility.

Table 9. Added mass on coaxial rigid cylinders[7]

Annulus						
Radius, in.	Clearance, in.	Liquid	Natural frequency, cpm	Calculated added mass, lbs	Experimental added mass, lbs	Difference, %
4.0	0.16	Water	370	280	180	36
3.9	0.39	Water	520	100	75	27
4.0	0.25	Water	425	170	127	25
4.0	0.25	Glycerol solution	390	190	150	21
4.0	0.25	Oil	320	150	200	−33

Table 10. Comparing added mass coefficients between closed form and finite elements solutions for coaxial rigid cylinders.[42]

	Closed form	Finite element
$M_H = \rho\pi a^2 \left(\frac{b^2 + a^2}{b^2 - a^2}\right)^*$	$5.23\ \rho$	$5.169\ \rho$
$M_1 + M_2 + M_H = \rho\pi b^2 \left(\frac{b^2 + a^2}{b^2 - a^2}\right)^*$	$20.95\ \rho$	$20.792\ \rho$
$M_1 + M_H = -2\rho\pi \left(\frac{a^2\ b^2}{b^2 - a^2}\right)^*$	$-8.38\ \rho$	$-8.29\ \rho$

*a = radius of inner cylinder = 1 in.
b = radius of outer cylinder = 2 in.

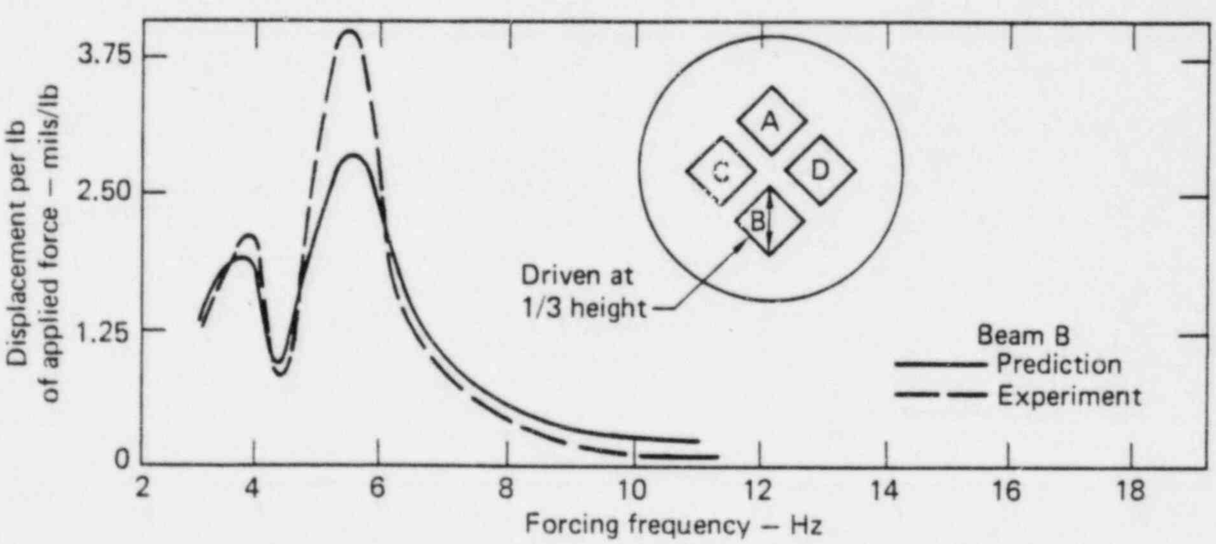


Fig. 37. Displacement response of a 2 × 2 square cylinder surrounded by a circular cylinder.[42]

6.4 Hydrodynamic Coupling for Flexible Coaxial Cylinders

Coaxial cylinders with the inner cylinder analyzed as a flexible shell probably constitute a more realistic model of the internals of the reactor vessel than would coaxial rigid cylinders. Such a mathematical model was analyzed in Ref. 38 using an incompressible invicid theory. The deformation of the inner cylinder is compared with experiment in Fig. 39 taken from Ref. 38, and the comparison is reasonable.

The case of three coaxial cylinders with the outer cylinder rigid and the inner cylinders flexible was analyzed in Ref. 46 using a compressible invicid fluid theory. A simpler case involving only one inner cylinder was compared with experiment in terms of natural frequencies in Tables 11 and 12 taken from Ref. 46. The m and n quantities are, respectively, the axial and circumferential mode numbers of the inner cylinder. The agreement between theory and experiment is very good.

A finite element analysis using the code NASTRAN was applied to two coaxial cylinders, the outer one rigid and the inner flexible.[47] A compressible invicid fluid theory was used. A comparison between analytical natural frequencies and experimental data is shown in Fig. 40 taken from Ref. 47. The comparison ranged from good to fair.

In general, based on the very limited amount of experimental comparison, the compressible invicid fluid theory seems to do better than the incompressible invicid potential theory. This indicates that fluid compressibility may be quite important to include when analyzing flexible members. Additional experimental confirmation is needed to fully establish this possibility.

6.5 Damping for Multiple Members

In Section 5.5 of this report we explained that for fully submerged structures in a finite size container, radiation damping can generally be ignored. The contributions to added damping that remain are fluid viscosity and component impact. Both theoretical and experimental values for fluid viscosity damping have been published, although no analytical treatment of impact damping has been found. For experiments involving both fluid viscosity and component impact, no separation of the measured total damping into these two contributions was made. Establishing a fixed value of damping for a general multiple member structure is very difficult, if not impossible, because damping can be significantly influenced by member arrangement, spacing, and relative motions among the members.

Analyses were carried out for two coaxial cylinders using a viscous fluid theory.[27,45] Three fluids were investigated in Ref. 27, and the theoretical damping was compared with the experimental as shown in Fig. 39 taken from Ref. 27. The agreement was quite good, indicating it is possible to obtain reliable damping values theoretically. Agreement was not as good in Ref. 45, where, by comparing the theoretical and experimental oscillatory motion amplitudes, it was determined that the theoretical damping underestimated the actual by a measureable amount.

The dependence of damping on the size of the annular space between two coaxial cylinders is clearly seen in Fig. 41. A sharp increase in damping is seen at a D/d ratio less than 1.75 to 2.75, depending on the fluid involved; the value of 1.75 applies to water. The quantities D and d are the diameters of the outer and inner cylinders, respectively. The diameter d was 0.5 in., and D varied from 0.625 in. to 2.5 in.

Experimental damping values for coaxial rigid cylinders submerged in three fluids are shown in Table 9 taken from Ref. 7. Adding the values for water to Fig. 41 indicates good agreement with the data from Ref. 27.

Experimentally determined damping from water viscosity are presented in Ref. 48 for a row of five cylinders (Fig. 22), a group of three cylinders (Fig. 23), a hexagonal array of seven cylinders (Fig. 24), a 2 x 2 array of cylinders (Fig. 25), a 2 x 2 array of cylinders near a wall (Fig. 42), and a 2 x 2 array of cylinders surrounded by a cylinder (Fig. 43). The results from Ref. 48 are reproduced in Tables 13 through 25. The tubes are all 0.5 in. diameter and 12.0 in. long. The damping values in these tables should be approximately the same as those in Fig. 41 because the inner cylinder used for Fig. 41 was also 0.5 in. diameter, and the space between cylinders reported in Tables 13 through 25 are generally within the gap size range covered in Fig. 41. In other words, space size-to-radius ratio values of 0.4 to 2.0 for Ref. 48 corresponds to D/d ratio values of 1.8 to 5.0 for Ref. 27. Comparing the damping values confirmed our speculation; i.e., the added damping values from Tables 13 through 25 ranged from 0.38 to 1.9% ; this range compares very closely with the range 0.5 to 1.8% shown for water in Fig. 41 and corresponding to D/d ratios from 1.8 to 5.0.

Up to this point, all experimental data for damping are mutually supportive, and the damping for multiple members 0.5-in. in diameter is characterized to a usable degree. The next question is how can

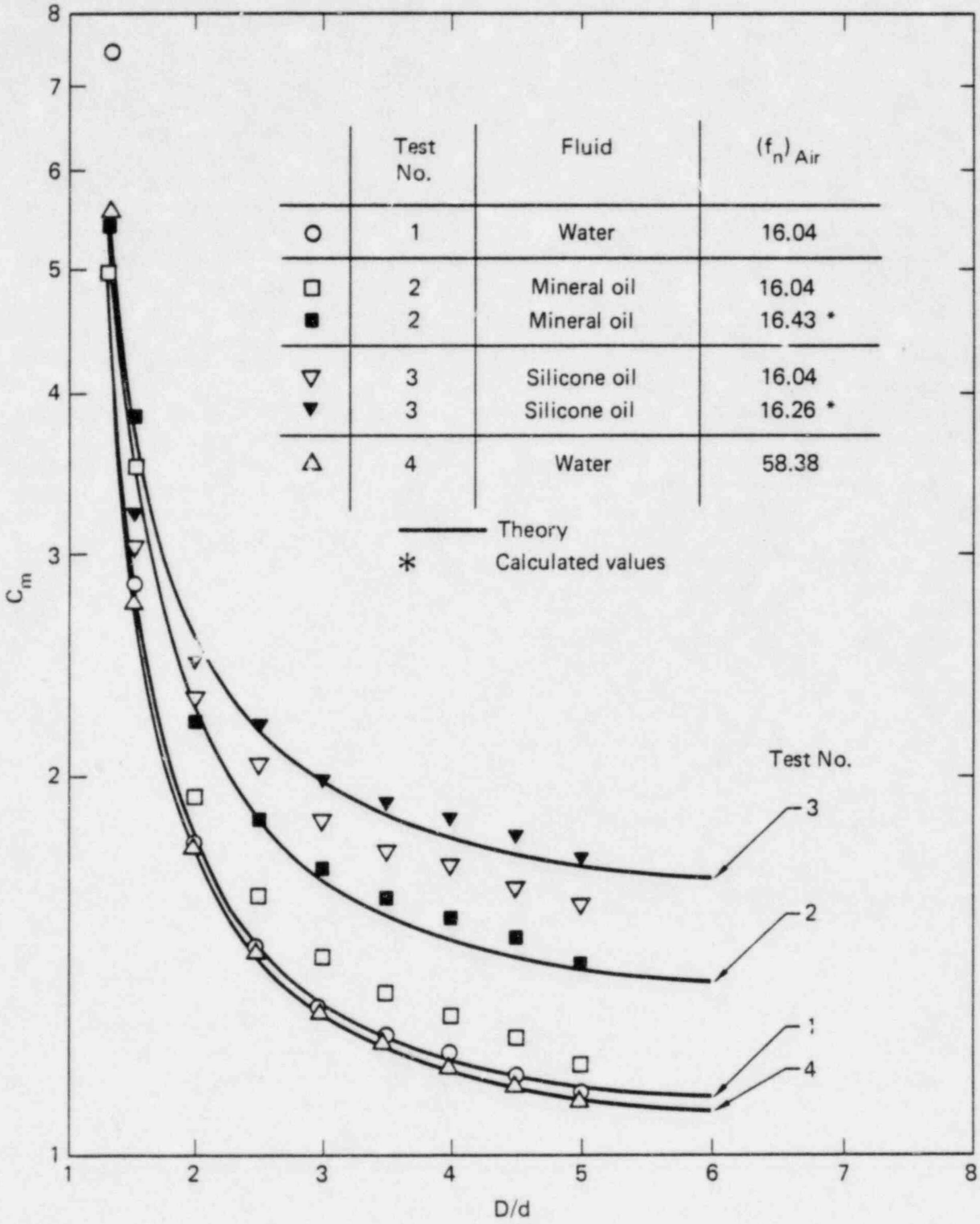
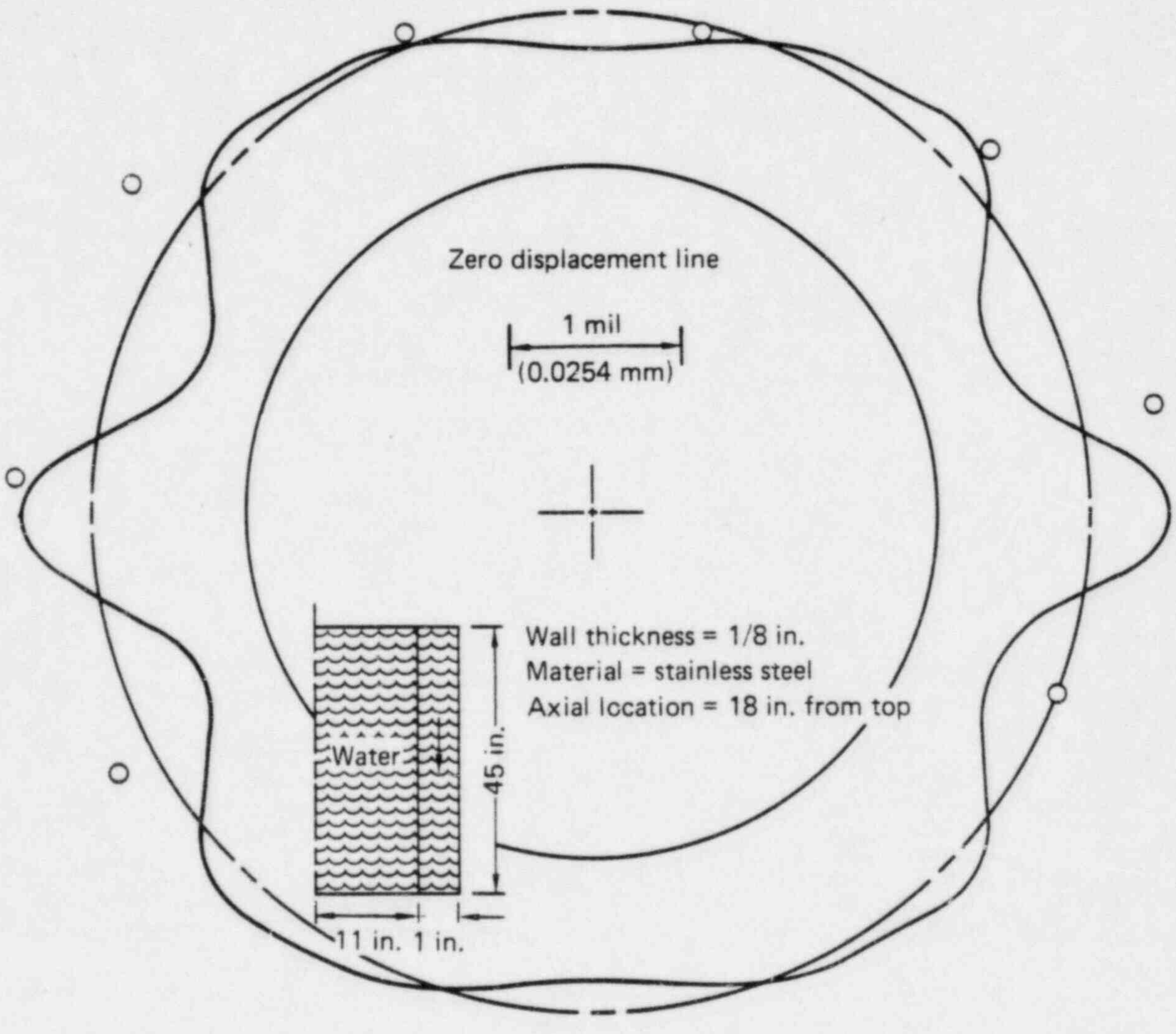


Fig. 38. Theoretical and experimental values of C_m as a function of D/d.[27]



—— Computed worst possible displacement (all ring modes in phase) 0.43–1.34 mils (0.0109 – 0.0340 mm)

– – – Computed host probable displacement (random phase between ring modes) 0.94 mils (0.0239 mm)

○ Measured displacement 0.90 – 1.26 mils (0.0229 – 0.0320 mm)

Fig. 39. Computed vs r.m.s. displacement of cylinder.[19]

Table 11. Measured and computed natural frequencies for coaxial cylinders, inner cylinder flexible, inner cylinder filled with water only.[42]

Mode (m, n)	Experimental frequency, Hz	Computed frequency, Hz	Discrepancies, % frequency
1, 3	103	90.6	12.0
1, 4	106	98.2	7.4
1, 5	145	144	0.7
1, 6	213	214	0.5
2, 5	219	203	7.3

Table 12. Measured and computed natural frequencies for coaxial cylinders, inner cylinder flexible, both inner and outer cylinders filled with water.[42]

Mode (m, n)	Experimental frequency, Hz	Computed frequency, Hz	Discrepancies, % frequency
1, 2	64	62.4	2.5
1, 3	54	46.2	14.0
1, 4	60	55.9	6.8
1, 5	90	89.2	0.9
1, 6	139	140.9	1.4
1, 7	206	209.2	1.6
2, 5	136	127.4	6.3
2, 6	165	163.7	0.8

we extrapolate the results to structural sizes of concern. At this point, there is no established way. The extrapolation technique we developed for single isolated members, (Figs. 14 and 15) cannot be trusted to apply to multiple members in the absence of experimental evidence. A possible method is the analytical technique developed in Ref. 27 to form relationships that can relate the 0.5-in. specimens to structural sizes of concern. This might be a very useful area for future exploration because damping is a topic of high interest.

Some measurements of total damping in actual reactors and models of reactors are reported in Ref. 41. The values are 2 to 5% for core-barrel beam modes, 1 to 2% for core-barrel shell modes, 2 to 5% for guide tubes. These values are measured under low-displacement amplitudes on actual reactors. When the coolant is flowing, the damping increases with increasing flow rate, giving rise to core barrel damping ranging from 8.8 to 12%. In the opinion of the authors of Ref. 41, a significant contribution to the total damping resulted from component impact, particularly while the coolant was flowing. Component impact was, therefore, very possibly responsible for a major part of the 8.8 to 12% damping measured. Unfortunately, no separation between fluid viscosity effects and component impact was made. Consequently, the usefulness of the damping values is limited for general application because the component impact contribution could vary from one reactor design to another.

Further evidence that component impact contributes significantly to the damping was found in Ref. 43. The effect of tube-support interaction on the dynamic response of heat-exchanger tubes was examined. The total damping measured was from 2 to 7.5%, whereas it was felt the combined structural damping and fluid viscosity damping should have been approximately 2%. Again, no separation between component impact and other contributions was made.

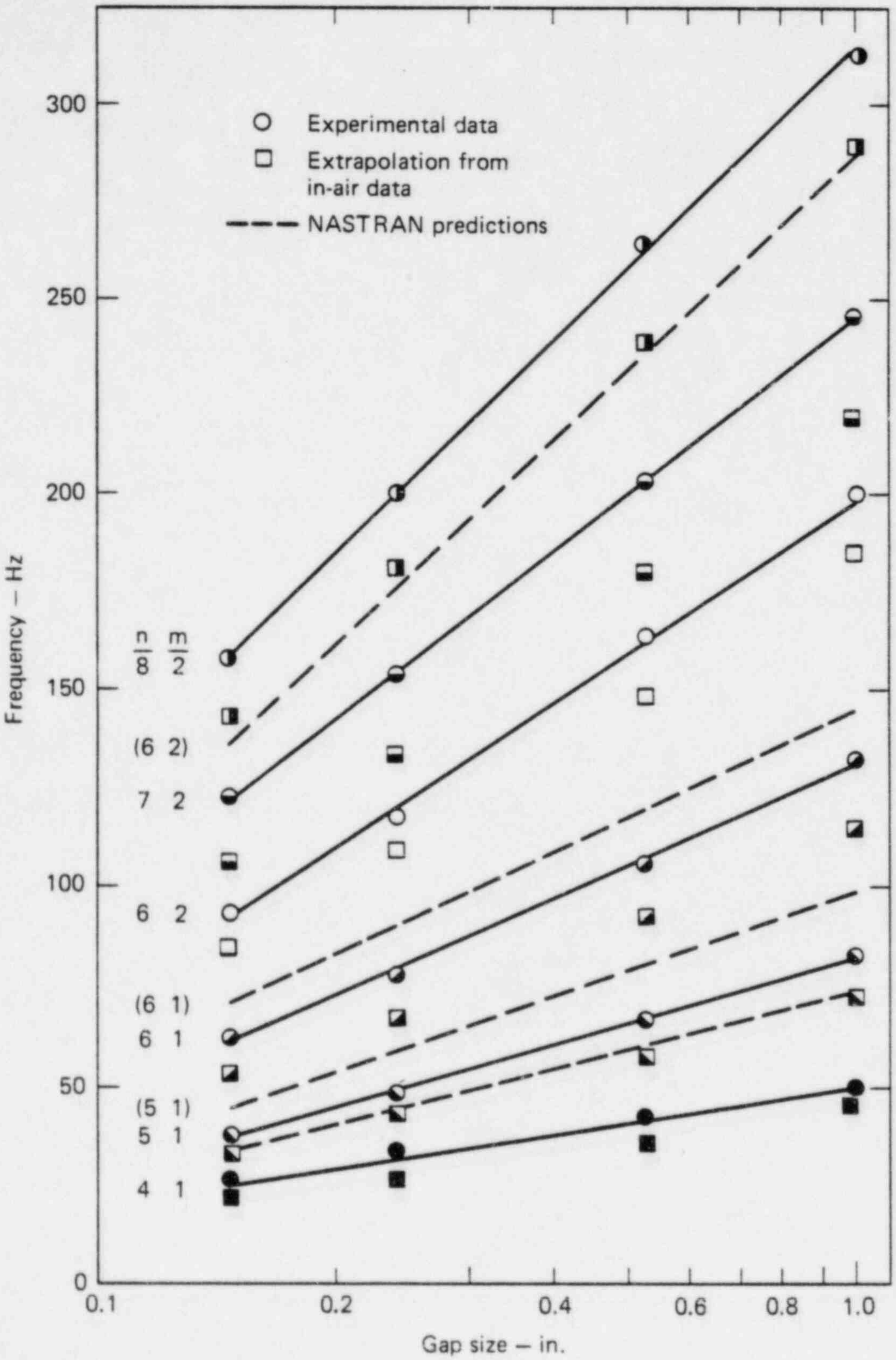


Fig. 40. Comparison of experimental and predicted vibration frequencies for the shell with a fluid filled gap.[47]

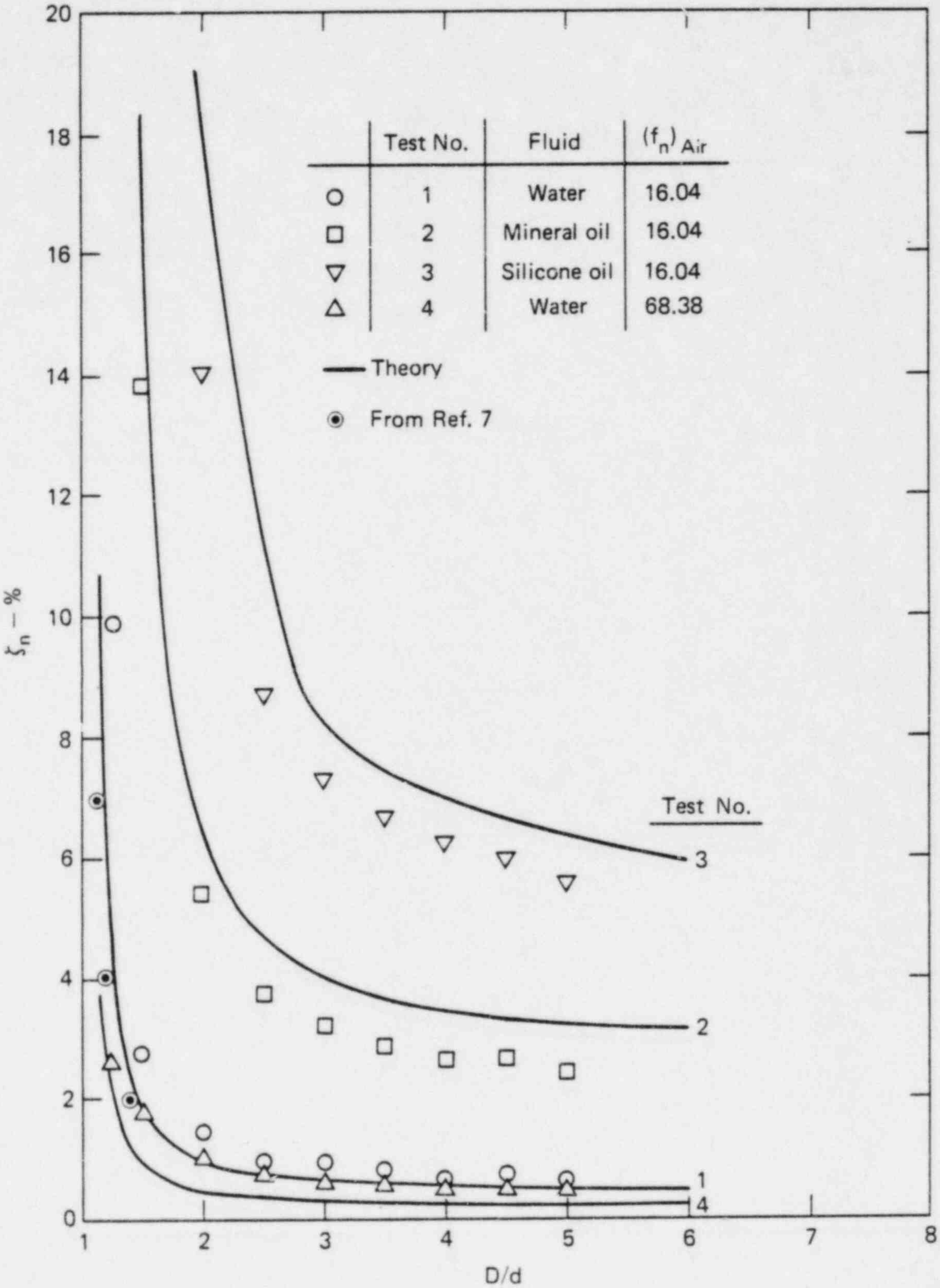


Fig. 41. Theoretical and experimental values of ζ_n as a function of D/d.[27]

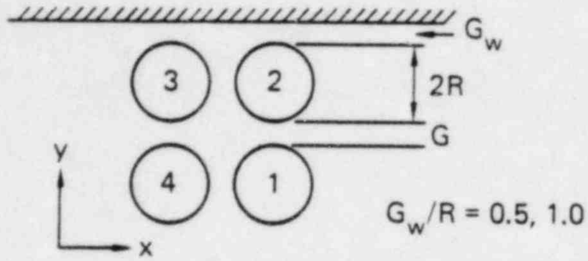


Fig. 42. A 2 × 2 array of cantilevered cylinders near a wall.[48]

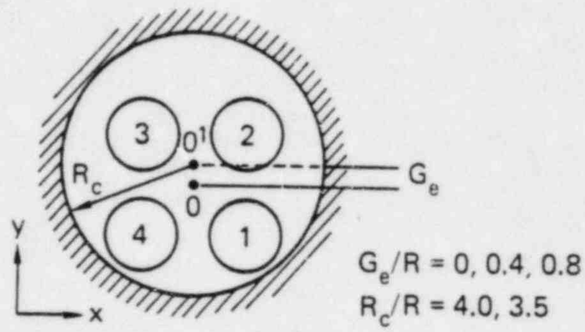


Fig. 43. A 2 × 2 array of cantilevered cylinders near a wall.[48]

Table 13. Experimental and analytical results for uncoupled vibration of a row of five tubes.[48]

Gap-to-radius ratio, C/R	Direction of motion	Tube number	Dimensionless spring constant, p_i	Measured uncoupled natural frequency, Hz		Measured damping ratio		Calculated uncoupled natural frequency in water, Hz
				In air	In water	In air	In water	
2.0 (1.988)	x	1	104.3	83.79	69.63	0.00118	0.0044	70.07
		2	99.0	84.67	70.41	0.00095	0.0049	70.58
		3	128.5	84.27	69.92	0.00031	0.0053	70.39
		4	155.2	84.38	70.21	0.00028	0.0045	70.57
		5	354.0	77.93	65.50	0.00062	0.0043	66.87
	y	1	129.0	84.08	70.02	0.00113	0.0042	70.31
		2	129.3	85.05	70.90	0.00032	0.0036	70.89
		3	242.6	84.86	70.51	0.00103	0.0044	70.86
		4	288.5	84.86	70.80	0.00078	0.0034	70.96
		5	354.0	77.93	66.70	0.00148	0.0042	66.87
1.0 (0.981)	x	1	105.1	83.40	69.24	0.00044	0.0063	69.54
		2	84.2	83.79	68.75	0.00052	0.0078	69.39
		3	98.3	83.69	68.85	0.00051	0.0088	69.43
		4	86.5	83.01	68.26	0.00063	0.0099	68.96
		5	186.6	77.05	64.94	0.00103	0.0047	65.93
	y	1	155.8	83.89	69.92	0.00032	0.0037	69.91
		2	114.1	84.28	69.53	0.00054	0.0043	69.72
		3	154.9	84.28	69.63	0.00073	0.0044	69.82
		4	127.4	83.59	69.04	0.00152	0.0051	69.37
		5	253.4	77.25	65.53	0.00092	0.0039	66.07
0.25 (0.248)	x	1	99.2	83.40	68.55	0.00093	0.0073	68.45
		2	85.2	83.50	66.99	0.00045	0.0124	67.08
		3	92.0	83.50	67.29	0.00146	0.0137	67.23
		4	97.2	83.40	67.38	0.00131	0.0190	67.28
		5	325.2	77.73	64.55	0.00108	0.0081	65.63
	y	1	131.5	83.79	69.24	0.00046	0.0062	68.52
		2	101.1	83.79	67.38	0.00055	0.0076	66.70
		3	97.2	83.59	66.80	0.00088	0.0070	66.53
		4	103.6	83.50	67.19	0.00069	0.0076	66.75
		5	930.5	78.02	65.42	0.00226	0.0046	65.66

Table 14. Experimental and analytical results for uncoupled vibration of a group of three tubes.[48]

Gap-to-radius ratio, G/R	Direction of motion	Tube number	Dimensionless spring constant, β_i	Measured uncoupled natural frequency, Hz		Measured damping ratio		Calculated uncoupled natural frequency in water, Hz
				In air	In water	In air	In water	
2.0 (1.933)	x	1	53.2	82.03	68.35	0.00152	0.0038	68.53
		2	141.4	84.38	70.21	0.00090	0.0041	70.35
		3	386.0	77.24	65.82	0.00341	0.0041	66.22
	y	1	55.2	82.13	68.55	0.00103	0.0037	68.59
		2	79.1	83.50	69.53	0.00095	0.0045	69.63
		3	123.2	76.46	65.33	0.00217	0.0034	65.55
1.0 (0.983)	x	1	62.6	82.23	69.26	0.00072	0.0047	68.28
		2	79.5	83.50	69.14	0.00109	0.0087	69.08
		3	115.8	76.76	65.04	0.00073	0.0071	65.36
	y	1	71.1	82.52	68.36	0.00095	0.0042	68.37
		2	63.4	83.01	68.55	0.00174	0.0075	68.75
		3	77.4	76.17	64.55	0.00215	0.0063	64.91
0.5 (0.475)	x	1	58.5	82.42	67.58	0.00076	0.0044	67.62
		2	94.0	83.98	67.68	0.00183	0.0051	68.26
		3	82.9	76.07	63.09	0.00226	0.0052	63.76
	y	1	52.6	82.13	66.99	0.00125	0.0048	66.75
		2	59.2	83.01	67.77	0.00233	0.0053	67.79
		3	88.3	76.17	63.87	0.00119	0.0055	64.12

Table 15. Experimental and analytical results for uncoupled vibration of a group of seven tubes.[48]

Gap-to-radius ratio, G/R	Direction of motion	Tube number	Dimensionless spring constant, p_i	Measured uncoupled natural frequency, Hz		Measured damping ratio		Calculated uncoupled natural frequency in water, Hz
				In air	In water	In air	In water	
1.5 (1.384)	x	1	52.2	82.42	67.91	0.00079	0.0049	68.29
		2	60.1	83.11	68.96	0.00044	0.0103	68.72
		3	73.6	83.06	68.75	0.00086	0.0043	69.94
		4	57.3	81.93	67.48	0.00050	0.0061	67.97
		5	55.9	81.98	68.02	0.00074	0.0054	68.03
		6	223.4	77.15	65.38	0.00052	0.0040	65.77
		7	47.4	81.78	67.19	0.00099	0.0047	67.29
	y	1	64.1	82.96	68.80	0.00107	0.0040	68.81
		2	79.5	83.74	69.17	0.00089	0.0045	69.32
		3	55.2	82.37	67.63	0.00140	0.0055	68.21
		4	72.0	82.47	68.46	0.00110	0.0033	68.49
		5	73.3	82.62	68.75	0.00054	0.0043	68.64
		6	106.4	76.46	64.45	0.00094	0.0039	65.05
		7	49.8	81.93	66.80	0.00109	0.0047	67.41
1.0 (0.867)	x	1	52.1	81.15	65.63	0.00104	0.0049	66.20
		2	54.7	81.84	66.21	0.00063	0.0040	66.61
		3	91.9	82.81	67.77	0.00083	0.0043	67.96
		4	75.7	82.62	67.19	0.00084	0.0040	67.48
		5	62.0	82.23	67.38	0.00085	0.0042	67.20
		6	88.3	75.49	63.39	0.00180	0.0043	63.68
		7	50.6	81.35	64.84	0.00092	0.0051	65.18
	y	1	71.5	81.93	67.19	0.00061	0.0044	67.09
		2	72.5	82.52	67.19	0.00063	0.0055	67.42
		3	61.2	81.98	66.60	0.00062	0.0049	66.75
		4	75.7	82.62	67.97	0.00084	0.0040	67.74
		5	63.2	82.28	68.16	0.00120	0.0041	67.49
		6	74.2	75.20	62.60	0.00134	0.0048	63.00
		7	48.9	81.25	64.84	0.00078	0.0055	65.10
0.4 (0.394)	x	1	66.2	82.62	67.20	0.00253	0.0072	64.11
		2	66.8	83.06	62.82	0.00263	0.0073	64.27
		3	61.1	82.62	65.14	0.00143	0.0056	65.72
		4	95.9	83.01	63.55	0.00121	0.0064	64.52
		5	91.2	82.81	61.91	0.00130	0.0010	64.40
		6	76.5	75.98	61.77	0.00048	0.0060	62.39
		7	48.8	81.64	59.13	0.00168	0.0103	60.13
	y	1	56.6	82.23	65.72	0.00250	0.0052	64.85
		2	53.2	82.62	66.11	0.00200	0.0050	64.99
		3	49.3	82.03	61.87	0.00082	0.0088	63.14
		4	77.1	82.62	69.77	0.00126	0.0050	65.26
		5	91.2	82.81	65.23	0.00118	0.0054	65.45
		6	62.6	75.59	59.52	0.00045	0.0066	60.28
		7	40.8	81.05	58.94	0.00062	0.0112	59.69

Table 16. Experimental and analytical results for uncoupled vibration of the four-tube array in unconfined water.[48]

Gap-to-radius ratio, G/R	Direction of motion	Tube number	Dimensionless spring constant, β_i	Measured uncoupled natural frequency, Hz		Measured damping ratio		Calculated uncoupled natural frequency in water, Hz
				In air	In water	In air	In water	
0.5 (0.585)	x	1	98.1	83.79	68.65	0.00099	0.0079	68.57
		2	60.6	83.98	68.85	0.00169	0.0138	68.42
		3	78.1	83.59	68.55	0.00566	0.0125	68.41
		4	1030.0	77.83	65.33	0.00091	0.0080	65.55
	y	1	75.0	83.30	67.77	0.00131	0.0072	68.17
		2	74.9	84.28	68.95	0.00286	0.0147	68.82
		3	86.4	83.78	68.46	0.00290	0.0089	68.57
		4	228.1	77.34	64.16	0.00633	0.0117	65.13

Table 17. Experimental and analytical results for uncoupled vibration of the four-tube array near a flat wall.[48]

Gap-to radius ratio, G_w/R	Direction of motion	Tube number	Measured uncoupled natural frequency, Hz	Measured damping ratio	Calculated uncoupled natural frequency, Hz
1.0	x	1	68.46	0.0066	68.27
		2	67.24	0.0071	66.87
		3	66.75	0.0059	66.88
		4	65.14	0.0101	65.29
	y	1	67.58	0.0078	67.93
		2	67.04	0.0065	67.38
		3	66.55	0.0087	67.15
		4	64.06	0.0070	64.93
0.5	x	1	68.51	0.0059	68.14
		2	65.53	0.0138	65.31
		3	65.38	0.0143	65.31
		4	65.19	0.0094	65.18
	y	1	67.48	0.0038	67.85
		2	66.16	0.0087	66.15
		3	66.06	0.0096	65.91
		4	64.21	0.0103	64.86

Table 18. Experimental and analytical results for uncoupled vibration of the four-tube array contained in a cylinder.[48]

Radius ratio, R_c /R	Eccentricity, G_c/R	Direction of motion	Tube number	Measured uncoupled natural frequency, Hz	Measured damping ratio	Calculated uncoupled natural frequency, Hz
4.0	0.0	x	1	65.33	0.0095	66.07
			2	65.77	0.0082	65.89
			3	65.92	0.0071	65.91
			4	62.26	0.0055	63.43
		y	1	64.70	0.0079	65.68
			2	65.53	0.0073	66.28
			3	65.87	0.0068	66.06
			4	62.26	0.0053	63.02
	0.4	x	1	65.48	0.0060	65.47
			2	65.14	0.0070	66.19
			3	65.38	0.0068	66.21
			4	62.60	0.0054	62.92
		y	1	64.94	0.0069	65.07
			2	65.33	0.0060	66.62
			3	64.84	0.0106	66.40
			4	62.55	0.0054	62.50
	0.8	x	1	65.33	0.0069	64.25
			2	62.84	0.0093	66.30
			3	63.82	0.0082	66.31
			4	62.79	0.0074	61.87
		y	1	65.82	0.0057	63.89
			2	64.21	0.0091	66.79
			3	62.94	0.0111	65.57
			4	62.45	0.0075	61.49
3.5	0.0	x	1	63.67	0.0079	64.43
			2	64.31	0.0092	64.25
			3	64.75	0.0094	64.27
			4	60.84	0.0105	62.02
		y	1	62.21	0.0101	64.05
			2	64.50	0.0091	64.63
			3	63.82	0.0100	64.42
			4	59.91	0.0102	61.62
	0.4	x	1	64.65	0.0069	62.73
			2	63.67	0.0085	64.94
			3	63.92	0.0070	64.96
			4	61.13	0.0128	50.56
		y	1	63.78	0.0085	62.36
			2	62.45	0.0073	65.40
			3	63.92	0.0090	65.19
			4	61.67	0.0067	60.17

Table 19. Experimental and analytical results for coupled vibration of five tubes.[48]

Gap-to-radius ratio, G/R	Direction of motion	Mode number	Measured coupled natural frequencies, Hz	Calculated coupled natural frequencies, Hz	Damping ratio
2.0 (1.988)	x	1	66.16	66.45	0.0043
		2	68.12	68.50	0.0047
		3	69.34	69.46	0.0047
		4	71.12	71.15	0.0046
		5	73.29	73.28	0.0051
	y	1	66.08	66.18	0.0040
		2	68.64	68.44	0.0039
		3	70.21	70.54	0.1040
		4	71.80	72.08	0.0038
		5	72.68	73.04	0.0041
1.0 (0.981)	x	1	63.77	64.56	0.0061
		2	65.72	66.24	0.0072
		3	68.09	68.16	0.0075
		4	70.98	70.91	0.0080
		5	74.83	74.48	0.0088
	y	1	63.77	63.35	0.0040
		2	66.67	66.74	0.0039
		3	69.80	69.98	0.0043
		4	71.90	72.31	0.0046
		5	73.52	73.88	0.0046
0.25 (0.248)	x	1	59.96	61.02	0.0126
		2	62.50	62.92	0.0105
		3	66.29	66.59	0.0102
		4	71.53	71.55	0.0127
		5	77.64	77.19	0.0152
	y	1	57.33	56.45	0.0058
		2	64.67	64.56	0.0059
		3	69.14	69.67	0.0063
		4	72.95	73.39	0.0074
		5	75.39	75.65	0.0081

Table 20. Experimental and analytical results for coupled vibration of three tubes.[48]

Gap-to-radius ratio, G/R	Mode number	Measured coupled natural frequencies, Hz	Calculated coupled natural frequencies, Hz	Damping ratio
2.0 (1.933)	1	64.02	64.61	0.0036
	2	65.20	65.23	0.0038
	3	67.65	67.76	0.0039
	4	69.04	69.10	0.0039
	5	71.28	71.10	0.0043
	6	71.52	71.61	0.0042
1.0 (0.983)	1	61.21	62.04	0.0061
	2	64.02	63.84	0.0063
	3	66.25	66.42	0.0060
	4	69.52	69.68	0.0065
	5	72.10	71.78	0.0069
	6	72.85	72.72	0.0070
0.5 (0.475)	1	57.42	58.15	0.0046
	2	62.29	62.32	0.0051
	3	64.76	64.86	0.0047
	4	70.24	70.14	0.0055
	5	72.88	72.66	0.0054
	6	74.47	74.32	0.0055

Table 21. Experimental and analytical results for coupled vibration of seven tubes.[48]

Gap-to-radius ratio, G/R	Mode number	Measured natural frequencies, Hz	Calculated natural frequencies, Hz	Calculated damping ratio
1.5 (1.384)	1	60.25	61.18	0.0043
	2	61.91	62.66	0.0045
	3	62.70	62.76	0.0052
	4	64.65	64.74	0.0040
	5	66.06	66.33	0.0045
	6	66.46	66.94	0.0048
	7	67.53	68.31	0.0043
	8	68.99	68.79	0.0055
	9	69.87	70.22	0.0051
	10	70.75	71.07	0.0060
	11	71.58	72.03	0.0066
	12	72.41	73.13	0.0050
	13	73.44	73.32	0.0056
	14	74.36	74.47	0.0049
1.0 (0.867)	1	55.61	56.87	0.0041
	2	58.20	58.73	0.0044
	3	58.89	58.86	0.0042
	4	62.06	62.12	0.0041
	5	64.45	64.43	0.0043
	6	65.33	64.99	0.0042
	7	68.36	67.68	0.0050
	8	69.29	68.23	0.0044
	9	70.85	70.12	0.0049
	10	71.63	71.26	0.0047
	11	72.66	72.69	0.0048
	12	74.07	74.04	0.0052
	13	74.46	74.27	0.0056
	14	75.54	75.79	0.0050
0.4 (0.394)	1	48.39	49.69	0.0048
	2	50.96	51.35	0.0077
	3	51.41	51.70	0.0066
	4	59.47	59.30	0.0052
	5	60.99	61.35	0.0054
	6	62.40	62.09	0.0050
	7	68.41	67.99	0.0067
	8	69.14	68.30	0.0057
	9	70.80	70.74	0.0074
	10	72.46	72.09	0.0062
	11	74.46	74.22	0.0079
	12	76.07	76.02	0.0094
	13	76.46	76.09	0.0099
	14	78.56	78.28	0.0065

Table 22. Experimental and analytical results for coupled vibration of the four-tube array in unconfined water.[48]

Gap-to-radius ratio, G/R	Mode number	Measured coupled natural frequencies, Hz	Calculated coupled natural frequencies, Hz	Damping ratio
0.5 (0.585)	1	56.79	57.90	0.0090
	2	62.79	62.99	0.0094
	3	66.26	66.73	0.0123
	4	67.38	67.87	0.0091
	5	69.53	69.66	0.0117
	6	71.88	71.38	0.0095
	7	74.32	74.19	0.0124
	8	76.95	76.39	0.0121

Table 23. Experimental and analytical results for coupled vibration of the four-tube array near a flat wall.[48]

Gap-to-radius ratio, G_w/R	Mode number	Measured coupled natural frequency, Hz	Calculated coupled natural frequency, Hz	Damping ratio
1.0	1	56.69	57.78	0.0066
	2	61.87	62.08	0.0071
	3	64.84	64.75	0.0077
	4	66.94	66.69	0.0071
	5	69.04	68.95	0.0079
	6	71.19	70.32	0.0077
	7	73.54	73.35	0.0080
	8	76.81	76.35	0.0083
0.5	1	56.25	57.17	0.0094
	2	60.11	60.52	0.0093
	3	64.36	64.08	0.0098
	4	66.70	66.11	0.0091
	5	68.51	68.30	0.0097
	6	70.68	69.60	0.0112
	7	72.99	72.82	0.0084
	8	76.51	76.[illegible]3	0.0115

Table 24. Experimental results for uncoupled vibration of the four-tube arrays in viscous fluids.[48]

Conditions	Direction of motion	Tube number	Measured uncoupled natural frequency, Hz		Measured damping ratio	
			Water	Mineral oil	Water	Mineral oil
In unconfined fluid	x	1	68.65	68.31	0.0079	0.0262
		2	68.85	69.14	0.0138	0.0318
		3	68.55	68.41	0.0125	0.0285
		4	65.33	65.04	0.0080	0.0309
	y	1	67.77	67.48	0.0072	0.0284
		2	68.95	69.14	0.0147	0.0336
		3	68.46	68.56	0.0089	0.0285
		4	64.16	64.99	0.0117	0.0290
Near a flat wall ($G_w/R = 0.5$)	x	1	68.51	68.56	0.0059	0.0254
		2	65.53	66.31	0.0138	0.0311
		3	65.38	65.58	0.0143	0.0308
		4	65.19	64.70	0.0094	0.0375
	y	1	67.48	67.48	0.0038	0.0350
		2	66.16	65.82	0.0087	0.0268
		3	66.06	66.02	0.0006	0.0323
		4	64.21	64.84	0.0103	0.0243

7. CONSERVATIVE CHOICE FOR ADDED MASS

The calculation of added mass will generally involve varying degrees of engineering judgment regarding such considerations as the effects of finite length, neighboring members, irregularities in geometry, etc. Decisions on these factors can be significantly influenced by considering whether conservatism is increased by maximizing or minimizing the added mass. This generally varies from situation to situation, and for some cases, a preliminary analysis may be required to help make the decision. We will make some suggestions regarding the structures of concern subjected to seismic excitations prescribed by the response spectrum in R.G. 1.60[50] (shown in Fig. 1).

Let us assume that we are interested in the inertial forces; therefore, we will deal with the spectral accelerations. The maximum spectral acceleration occurs at a frequency of 2.5 Hz, as indicated in Fig. 1. Therefore, to help ensure conservative inertial forces at frequencies above 2.5 Hz, we would maximize the added mass to bring the calculated natural frequency into regions of higher spectral acceleration. Conversely, we would minimize the added mass at frequencies below 2.5 Hz to achieve the same objective.

Figure 1 shows the natural frequency ranges of the structures of concern listed in Table 3. The natural frequencies are for representative existing structures. According to the frequency values shown in Fig. 1, we should maximize the added mass for the reactor core barrel. For spent-fuel storage racks, the natural frequency can fall on either side of 2.5 Hz. Therefore, the natural frequency in air should be first determined to see whether the added mass should be maximized or minimized. The natural frequency of one fuel bundle we examined was close to 2.5 Hz. Other fuel bundles can presumably fall above or below 2.5 Hz. Therefore, again the natural frequency in air should be first evaluated to determine whether to maximize or minimize the added mass. The natural frequency of the main steam-relief valve line generally falls above 2.5 Hz; however, the upper limit is quite close to 2.5 Hz. Therefore, for cases suspected of having a high natural frequency, it would be best to check the natural frequency first. Otherwise, we would generally minimize the added mass for main steam-relief valve lines. This discussion applies in principle to all acceleration response spectrums; the frequency at which the maximum spectral acceleration occurs may differ from the 2.5 Hz applying to the spectrum of R.G. 1.60.

Table 25. Experimental and analytical results for coupled vibration of the four-tube array contained in a cylinder.[48]

Radius ratio, R_c/R	Eccentricity, G_e/R	Mode number	Measured coupled natural frequency, Hz	Calculated coupled natural frequency, Hz	Damping ratio
4.0	0.0	1	56.15	57.86	0.0061
		2	59.52	59.98	0.0058
		3	62.21	62.11	0.0074
		4	62.25	62.37	0.0070
		5	67.53	68.31	0.0070
		6	69.43	69.27	0.0080
		7	72.27	72.22	0.0083
		8	76.66	76.43	0.0086
	0.4	1	56.25	57.81	0.0058
		2	59.40	59.12	0.0054
		3	61.67	61.96	0.0062
		4	62.26	62.80	0.0075
		5	67.68	68.06	0.0066
		6	69.43	69.15	0.0073
		7	72.11	72.34	0.0079
		8	76.61	76.43	0.0081
	0.8	1	55.86	57.29	0.0064
		2	58.11	57.63	0.0071
		3	60.74	61.25	0.0075
		4	62.65	63.14	0.0092
		5	67.29	67.33	0.0076
		6	68.60	68.79	0.0084
		7	71.53	72.34	0.0100
		8	76.32	76.35	0.0099
3.5	0.0	1	55.57	57.43	0.0091
		2	57.03	57.70	0.0090
		3	59.33	59.56	0.0085
		4	59.77	59.83	0.0087
		5	66.31	67.40	0.0105
		6	68.07	68.25	0.0100
		7	70.90	70.59	0.0102
		8	76.22	76.18	0.0113
	0.4	1	55.76	55.33	0.0076
		2	57.37	57.23	0.0084
		3	59.20	59.03	0.0078
		4	59.72	60.87	0.0076
		5	66.70	66.42	0.0088
		6	68.21	67.91	0.0087
		7	70.31	70.99	0.0089
		8	76.17	76.12	0.0099

8. COMPUTER CODES IN CURRENT USE

The computer codes used for various aspects of fluid-structure interaction analysis are listed in Table 26; this is not a complete list of such codes. The attributes or capabilities of these codes were not explored for this study.

Table. 26. Codes used in industry

Codes	Application	Firm
EDAC/MSAP4	Fluid motion in tanks	EDAC
ANSYS	Offshore reactor platform	Offshore Power Systems
SOLASURF	Incompressible fluid motions: waves	LASL
SOLAICE	Compressible fluid motions	LASL
SOLAFLEX	Internals of reactor vessel possible, said nus.	LASL
WECAN	Internals of reactor vessel	Westinghouse
N.ASTRAN	Booster tanks space shuttle tanks	Universal Analysis
MARC	General, including fluids	Marc Analysis Corp.
DYNA-3D	General, including fluids	LLL
PISCES	Fluid-structure interaction	Physics International
WATERHASS	Added mass	GE
MULTIFLEX	Internals of reactor vessel	Westinghouse
AMASS	Added mass	Argonne National Lab.
CESHOCK	Fluid-structure interaction	Combustion Engineering

9. CONCLUSIONS AND RECOMMENDATIONS

9.1 Idealized Single Isolated, and Multiple, Members

Hydrodynamic effects on submerged single isolated members are fairly well understood. The added mass and added damping concept is adequate under seismic and normal steam-relief excitations; however, it is probably inappropriate for blowdown accidents. The potential theory will accurately give the added mass values, and tabulated results are available in the literature for a wide variety of single member geometries (Table 6). A presentation of the potential theory can be found in standard textbooks on the mechanics of fluids, such as Ref. 16.

Values for added damping are generally determined experimentally, and values are published for single isolated specimens of small sizes; i.e., up to 3.0 in. in diameter. To project these values to structural sizes of concern, we devised an extrapolation technique based on the published data and established information for the damping of water sloshing in pools. This gave the damping values for the structures of concern shown in Table 7. We will emphasize that these values apply only to situations in which these structures can be considered single isolated members. The damping values for multiple members can be very different.

For multiple rigid members under seismic and normal steam-relief excitations, the concept of added mass and added damping seems also to apply, although the experimental confirmation is far less extensive than for single isolated members. If we accept the concept's validity then the added mass effect can be calculated using potential theory. Analytical description of the added mass effect is more complex than for a single isolated member; it involves "self-added" and "added" mass coefficients. The first characterizes the force on a member from its own motion with other members stationary, while the second characterizes the force on a stationary member from the motion of other members. Some published values for these coefficients are available for certain simple multiple member arrangements (Refs. 10, 18, 19, 26, 27, 30, 31, 32, 34, 35, 36, and 42). An extensive compilation covering all configurations of interest would be a major analytical undertaking because the coefficient values are influenced by the member arrangement, the space between members, and the geometry of the individual members. Reference 26 has perhaps the most extensive compilation of values.

An approximation was suggested in Ref. 35 to help simplify the analysis of large arrays: i.e., only the hydrodynamic coupling between a member and its immediate neighbors needs to be considered. Coupling with members farther away may be ignored. This allows an array to be analyzed in subparts. The approximation was founded on theoretical results for the central member of hexagonal arrays; therefore, we are not certain how valid it would be for peripheral members. In particular, the corner members of an array receive the highest loads, and this technique may not apply. No experimental confirmation of the approximation was given.

An approximation that is even simpler was suggested in Ref. 10. The total interaction is considered to be the sum of interactions between two adjacent members. Therefore, the members of the array are analyzed two at a time and the results superimposed. The approximation was shown to be accurate to within 2 to 25% for a 4 x 4 array compared to a rigorous analysis. The accuracy varied, depending on the member of the array. Corner members can be analyzed.

As the gap between members of an array is increased beyond a certain point, the members respond as if single and isolated. For circular cylindrical members, when the gap reaches 1.5 times the member diameter, the members can be treated as if single and isolated. This 1.5 value was applicable to virtually all multiple member arrangements we found for circular cylindrical members.

In the case of coaxial rigid cylinders, the potential theory solution can be expressed very conveniently for design applications. The inertial forces are given in terms of the mass of the fluid displaced by the inner cylinder and the mass of fluid filling the interior of the outer cylinder in the absence of the inner cylinder. In a more sophisticated analysis, an incompressible viscous fluid theory was used instead of the potential theory. The results generally agreed better with experiments than did the potential theory. This indicates that viscosity effects may be important for coaxial cylinders; however, the analytical expressions are more complicated than those for potential theory. We would like to see further confirmation before recommending the more complex theory over the easy-to-apply potential theory.

Coaxial flexible cylinders probably provide a more accurate model for the reactor internals than do coaxial rigid cylinders. Analytical treatments generally involve a compressible invicid fluid theory and are fairly complex. Much needs to be explored for this case before conclusions can be drawn regarding design oriented methods. Interest in this area is currently high.

Damping for multiple members is presently a broad, imprecise topic, mainly because of its dependence on member arrangement, gap size between members, member geometry, and whether the member motions are in-phase or out-of-phase. If the gap size is not less than 0.4 times the member size, the damping is approximately that of a single isolated member. This convenient simplification may not always apply in practice, but when it does, it eliminates the dependence of damping on member arrangement and whether the members are moving in-phase or out-of-phase. It holds for coaxial cylinders as well as for arrays. Unfortunately, it is established for very small specimens (0.5-in. diameter) rather than for structural sizes of concern. However, we believe we can assume the 0.4 factor also applies to larger structures.

For gap sizes less than 0.4 times the member size, the damping increases rapidly with decreasing gap size when the members are moving out-of-phase with each other. On the other hand, if the members are moving in unison, the damping is very low, i.e., more in the range of damping values for single isolated members. Damping values for small gaps are available for small specimens, i.e., 0.5-in. diameter. At present, there is no established way to extrapolate these values to the structural sizes of concern. The analytical treatment presented in Ref. 27 fairly successfully predicted the damping for 0.5-in.-diameter specimens. The same procedure could be applied to large structures; however, the success of doing this would need to be explored.

9.2 Spent-Fuel Storage Racks

The fuel elements in a fuel bundle constitute an array of multiple members. The cans in a spent-fuel storage rack also form an array. The racks in a spent-fuel storage pool form yet another array. The added mass and added damping concept is applicable to these arrays under seismic excitation. The discussions we gave on this concept for single isolated members and arrays are directly applicable to these structures.

The racks are generally quite stiff so, more than likely, the entire rack will move in unison. If the rack is isolated, the added damping would be quite low, on the order of the values for fuel bundles shown in Table 7. Usually, however, the rack is next to other racks, or next to a wall. In this case, out-of-phase

motions between a rack and a neighboring structure could measurably increase the damping. Unfortunately, because of a lack of information, we are not in a position to recommend a damping value under this condition. On the other hand, in most cases, the racks are firmly anchored to the pool structure and to each other; consequently, out-of-phase motions would generally not occur. For this situation, the damping would be very low, on the order of the values for fuel bundles shown in Table 7.

Damping from component impact and the anchoring effect of water need to be addressed because they may be brought up as arguments against the use of such low damping values for racks. Component impact may occur between the fuel bundles and the cans, and, according to Refs. 41 and 43, component impact can contribute measurably to damping. However, without an indication of how much it contributes and how much it can vary from one rack design to another, we are not in a position to recommend a value for it. Because of the surrounding water, racks in a pool will tend to translate with the pool under seismic excitation. This is an anchoring effect, and it is a manifestation of inertial forces rather than damping. If the added mass effect is analyzed using the "self-added" and "added" mass coefficients described in Section 6.2 of this report, the anchoring effect of the water would be properly taken into account.

9.3 Main Steam-Relief Valve Line

The added mass and added damping concept can be applied to the main steam-relief valve line under seismic and normal steam-relief excitations. The line is submerged near the wall of the pressure suppression pool. If the gap between the line and pool wall is greater than 1.5 times the diameter of the line, the added mass can be evaluated as if the line is single and isolated. Otherwise, the presence of the wall needs to be taken into account, and the curve in Fig. 44 can provide the added mass coefficient for motions of the line in any direction.

If the gap is greater than 0.4 times the diameter of the line, the added damping can be assumed to be that of a single isolated member, and the values given in Table 7 apply. The damping will be greater if the gap is smaller. Unfortunately, without sufficient published information, we are not in a position to recommend damping values for this latter case.

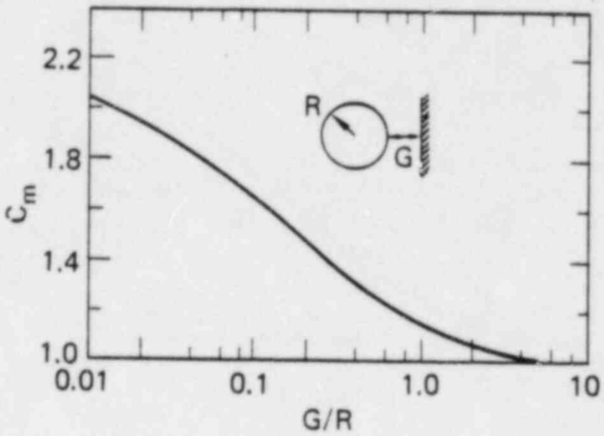


Fig. 44. Hydrodynamic mass coefficient for a cylinder vibrating near a wall.[24]

9.4 Internals of the Reactor Vessel

Seismic excitation and blowdown accidents are two important concerns for the internals of the reactor vessel. The blowdown accident is at least an order of magnitude more complex than the other phenomena addressed in this project, and the analysis techniques required are significantly more complex and sophisticated than those required for the others. From the very beginning of the project, it was realized that an investigation of the accident problem would very likely be beyond the financial and time limitations of the project. However, NRC and we agreed to include it in the project to see what we could find out about it, and, if our findings were inconclusive, that would be totally acceptable to NRC. As it turns out, our findings *are* generally inconclusive.

It became increasingly clear to us as we neared the end of the project that, indeed, a meaningful investigation of the accident problem is beyond the financial and time resources of the project. Moreover, it was beyond the guidelines of the project in that the work required to address the accident problem is research rather than an evaluation of methods for design calculations. The project's guidelines[55] were, in essence, to investigate analytical techniques in current use or having a potential use for practical design calculations. Because we tailored our efforts to this guideline, we subsequently did not come across references which dealt in depth with the accident problem. Our findings are generally more applicable to seismic and normal operation excitations.

Analytical models commonly used for the internals of the reactor vessel include:

(1) two coaxial rigid cylinders.

(2) two coaxial cylinders with the inner cylinder flexible and the outer one rigid.

(3) three coaxial cylinders with the two inner cylinders flexible and the outer one rigid.

Model (1) is generally used to approximate the first beam mode of the core barrel; models (2) and (3) are to approximate shell-bending modes. Model (3) models reactors with a thermal shield.

The added mass and added damping concept can be applied to model (1). The potential theory expressions for the added mass response are quite convenient for design applications and are characterized by fluid mass quantities that are simple to determine, as explained in Section 6.3 of this report. This technique is suitable for analysis of the first mode beam bending deformation of the core barrel under seismic or normal operation excitations. In a blowdown accident the hydrodynamic effects are most likely too severe for this treatment; however, the technique may provide a very rough estimate of the response. Because no experimental confirmation is available, we cannot make a more definite statement concerning blowdown accidents.

A more sophisticated analysis of model (1) using an incompressible viscous fluid theory is also available as explained in Section 6.3 of this report. The results seem to compare better with experimental results than did the added mass concept; however, the expressions are more complex. This is another technique suitable for analyzing the first mode beam-bending deformation of the reactor core barrel under seismic and normal-operation excitations. The same comments relating to the accident condition given in the preceding paragraph also apply here.

Models (2) and (3) are generally examined with a compressible invicid theory as discussed in Section 6.4 of this report. These models are appropriate for shell bending modes of the core barrel and thermal shield under seismic or normal operation excitations. Again, the technique might be feasible for an approximate analysis of the shell-bending deformation under an accident, provided the fluid properties are properly adjusted.

Because the annular gap between the core barrel and the reactor vessel is small, less than 0.4 times the diameter of the core barrel, damping from water viscosity can be expected to be important. Total (structural plus added) damping measured on actual reactors revealed 2 to 5% for core barrel beam modes, and 1 to 2% for shell modes.[41] These values are comparable with values in Fig. 41 for small D/d ratios; i.e., for D/d less than 1.8, where D and d are the outer and inner diameters, respectively, of coaxial rigid cylinders. We are not implying that Fig. 41, which is for 0.5-in.-diameter specimens, necessarily applies to sizes of a core barrel; however, the core barrel values measured are at least not contradictory to those in Fig. 41. Other damping values given in Ref. 41 for reactors includes both the effects of fluid viscosity and component impact. These ranged from 8.8 to 12%, and no separation with respect to the two contributions was made. We believe the damping from component impact is bound to vary from one reactor design to another; therefore, no reliable value of damping can be assigned to it. In addition, component impact must be, at least in most cases, an undesirable phenomenon that is to be avoided if possible. Therefore, if the sought-after condition is such that component impact is virtually absent, the fluid viscosity would be the dominating cause of added damping. Consequently, we would recommend usi[illegible] total (structural plus added) damping value [illegible] 2 to 5% for beam modes, and 1 to 2% for sh[illegible] modes.

9.5 Methods for Current Design Analysis of Fuel Racks*

As mentioned in Section 4 of this report, the methods in current use for design analysis shown in Table 5 are based on engineering judgment together with analytical and/or experimental information available at the time. We will provide an assessment of validity of each method as compared with our suggested method based on the material presented earlier in this report. Because of the complexity of multiple structure–water interaction, an accurate assessment needs rigorous analyses of the types described in Section 6 of this report. However, because the methods listed in Table 5 are numerous, this is an effort beyond the scope of this project. Consequently, our assessment is based on observations only.

The methods described in Table 5 are formulated for low-amplitude dynamic phenomenon, such as seismic excitation. Our assessment focuses on fuel racks, for which many of the methods are formulated; however, our conclusions are not necessarily limited to fuel racks. Three types of racks of particular interest to NRC are:

Type 1: A regular array of 9 x 9 in. cans spaced 4 in. apart.

Type 2: A regular array of 6 x 6 in. cans spaced 1 in. apart.

* These methods are described in Table 5.

Type 3: A regular array of cans with no space between cans.

The effective mass of a submerged can is the sum of the mass of the can, the mass of the contained fuel rods, the mass of the water contained within the can, and the added mass from interaction with the surrounding water. The terms added mass and added damping, as commonly used, pertain only to the interaction with the surrounding water.

We will begin our discussion by first describing LLL's recommendations for fuel racks. This will be followed by our assessment of the methods in Table 5.

9.5.1 LLL Recommendations for Fuel Racks

If the fuel racks are arranged so that the predominate modes of vibration consist of the cans translating in unison, we recommend using the coefficients in Table 27 to evaluate the added mass per can. The added mass per can is the coefficient times the mass of the water displaced by the exterior volume of the can.

The basis for our recommendations, in the absence of a rigorous analysis, is that we believe the added mass per can in an array should be the smaller of either the added mass for the can if single and isolated or the mass of the water actually surrounding the can in the array. For the three rack types of interest, the coefficient values for these two situations are shown in Table 28. Our recommendation is to use the coefficient values of the second situation.

Table 27. Added mass coefficients for evaluating added mass per can.

Rack type	Added mass coefficient
1	1.086
2	0.36
3	0

For the three rack types, we are, in essence, saying the water between the cans translates directly with the cans. Accordingly, as far as the water–structure interaction of an entire rack module is concerned, the module interacts essentially as a solid structure. Therefore, in addition to the added mass for each can, the added mass effect on the module should be accounted for. For the three rack types of interest it should be evaluated assuming the module is a solid structure. To our knowledge, the space between rack modules is generally small compared to the module dimensions. Assuming the rack modules translate in unison, we would recommend adding the mass of the water between modules to the mass of the modules.

If the cans do not translate in unison, the situation becomes significantly more complex. The analytical method we recommended in Sections 9.1 and 9.2 of this report should then be used. The modules, however, can still be taken as solid structures for the three rack types of interest.

The added damping for fuel racks is a complex issue, and there is insufficient published technical information on which to base a sound recommendation. Further comments are given in Section 9.2 of this report. A major difficulty is the use of the simple added damping concept to approximate a phenomenon that is measurably more complex in the case of multiple members. Unfortunately, no better alternatives were found for a design-oriented approach. Therefore, we currently suggest using the added damping values given in Table 7; i.e., 0.6% for rack type 1, and 0.4% for rack type 2, and 0% for rack type 3, based on the type 3 rack module responding as a unit. We recommend that further studies on damping be carried out, particularly experimental studies.

Table 28. The coefficient values for three rack types for (1) the added mass of a single isolated can and (2) the mass of water surrounding the can.

Rack type	Potential theory for situation 1	Actual surrounding water for situation 2*
1	1.186	1.086
2	1.186	0.36
3	1.186	0

* For 9 X 9 in. cans spaced 4 in. apart, $\frac{13 \times 13 - 9 \times 9}{9 \times 9} = 1.086$

For 6 X 6 in. cans spaced 1 in. apart, $\frac{7 \times 7 - 6 \times 6}{6 \times 6} = 0.36$

9.5.2 Methods No. 1 and No. 2

For single isolated members, potential theory will provide valid added mass values. Using the expressions tabulated in Table 6 is the same as applying potential theory.

Applying potential theory to evaluate the added mass for multiple members is likewise valid. However, the solution procedure is usually difficult, and approximate solutions are normally sought. The accuracy of the approximate analytical model may be of primary concern. Details on the approximations used, if any, and on the damping values used were not given by the firms using Methods No. 1 and No. 2.

9.5.3 Method No.3

For single isolated members, Method No. 3 gives the same results as the procedure recommended by Newmark and Rosenblueth (N&R).[5] Therefore, as discussed in Sections 5.1 and 5.2 of this report, the added mass value would be two-thirds that given by potential theory for a square member. We would recommend using potential theory over Method No. 3 for greater accuracy, for essentially the same level of analytical complexity in the case of single isolated members.

For multiple members, Method No. 3 does not appear to be extracted from the references (Refs. 1, 3, and others) mentioned by the user. For the three rack types of interest the resulting coefficient values are shown in Table 29, in comparison with LLL's recommendations. It appears Method No. 3 will significantly underestimate the LLL recommendation for added mass for rack types 1 and 2.

Our objections to using a total damping of two times the structural damping was discussed in Section 4 of this report.

9.5.4. Method No. 4

Method No. 4 does not appear to be extracted from the references (Refs. 1, 3, 4, 7, and others) mentioned by the user. For single isolated square members, the added mass is approximately one-third that given by potential theory. For the rack types of interest the added mass per can is given by the coefficients values in Table 30, in comparison with LLL's recommendations. It appears Method No. 4 will significantly underestimate the LLL recommendation for added mass for rack type 1.

Based on the information available on added damping the use of zero added damping is certainly conservative.

9.5.5. Method No. 5

Potential theory will provide valid added mass values for single isolated members.

For multiple members, the user is addressing more general motions than unison translation. Fritz's method[7] provides an approximation for a generic member surrounded by adjacent members. The procedure by which the user applied Fritz's method to an array was not totally clear to us. However, for unison motion, we speculated that recognition was probably given to the fact that a generic member plays two roles: as the central member and as part of the surrounding square cylinder for its adjacent members. Therefore, superimposing the forces given

Table 29. Coefficient values for three rack types comparing Method No. 3 of Table 5 with the LLL recommendation.

Rack type	Method No. 3 coefficients	LLL-recommended coefficients
1	0.44	1.086
2	0.17	0.36
3	0	0

Table 30. Coefficients for three rack types comparing Method No. 4 with the LLL recommendation.

Rack type	Method No. 4 coefficients	LLL-recommended coefficients
1	0.4	1.086
2	0.36	0.36
3	0	0

Table 31. Coefficients for three rack types comparing Method No. 5 with the LLL recommendation.

Rack type	Method No. 5 coefficients*	LLL-recommended coefficients
1	2.568	1.086
2	0.778	0.36
3	0	0

* For 9 X 9 in. cans spaced 4 in. apart, $\frac{17 \times 17 - 9 \times 9}{9 \times 9} = 2.568$

For 6 X 6 in. cans spaced 1 in. apart, $\frac{8 \times 8 - 6 \times 6}{6 \times 6} = 0.778$

in Fritz[7] for the two roles played by a generic member lead us to conclude that the added mass for a given member is the mass of the water between the member and its surrounding square cylinder. This would result in the added mass coefficients for the rack types of interest shown in Table 31, in comparison with LLL's recommendations. Consequently, according to our speculation of how the user applied Fritz's method, Method No. 5 overestimates the LLL recommendation for added mass for rack types 1 and 2.

The added damping ranged from 0 to 3% as compared with our previously recommended value. Because of insufficient information on their use of added damping, we are in a poor position to assess the validity of these values.

9.5.6. Method No.6

An added mass equal to the mass of water displaced by the exterior volume of a square can will be 0.843 times that given by potential theory, for single isolated square cans. We prefer using potential theory, for essentially the same analytical complexity.

For the three rack types of interest, the procedure for evaluating the natural frequency corresponds to LLL's recommendation. However, the procedure for evaluating inertial loads essentially ignores the added mass. Consequently, we consider Method No. 6 inappropriate (in comparison with LLL recommendations) for analyzing inertial effects for rack types 1 and 2.

An added damping of 2% does not correspond to the value we previously suggested.

9.5.7. Method No. 7

For single isolated members, the comments made for Method No. 6 also apply to Method No. 7. For multiple members translating in unison, Method No. 7 corresponds almost to LLL's recommendation. The only difference is LLL recommends using potential theory rather than the mass of the displaced water to evaluate the added mass for single isolated members. For the three rack types of interest, Method No. 7 and LLL's recommendations give the same values for the added mass.

We discourage the use of 2 to 2-½ times the structural damping as the total damping. An added damping of 2% does not correspond to the value we previously suggested.

9.5.8. Method No. 8

We consider Method No. 8 inappropriate (in comparison with LLL recommendations) for evaluating the added mass effect for rack types 1 and 2. We disagree with the use of two times the structural damping as the total damping for the reason discussed in Section 4 of this report.

9.5.9 Method No. 9

The user is apparently involved with only rack type 3, and Method No. 9 is appropriate for this configuration. The use of zero added damping could be appropriate and is certainly conservative.

10. ACKNOWLEDGMENTS

The author expresses his appreciation to G. A. Broadman, Leader, C. E. Walter, Deputy Leader, and F. J. Tokarz, Associate Leader, of the Nuclear Test Engineering Division, Mechanical Engineering Department, for their encouragement and support of this project. The project was initiated, sponsored, and funded by the U.S. Nuclear Regulatory Commission. The attention and advice given by Dr. C. H. Hofmayer and Dr. K. S. Herring of the Division of Operating Reactors has been most helpful and appreciated.

11. REFERENCES

1. R. W. Clough, "Effects of Earthquakes on Underwater Structures," *Proc. of 2nd World Conference on Earthquake Engineering*, (Tokyo, 1960).
2. K. T. Patton, *Tables of Hydrodynamic Mass Factors for Translational Motion*, ASME Paper No. 65-WA/UNT-2.
3. A. R. Chandrasekaran, S. S. Saini, and M. M. Malhotra, "Virtual Mass of Submerged Structures," *Journal of the Hydraulics Div., Proc. of the ASCE*, (May, 1972).
4. T. E. Stelson and F. T. Mavis, *Virtual Mass and Acceleration In Fluids*, ASCE Trans. Paper No. 2870, Vol. 122, 1957.
5. N. M. Newmark and E. Rosenblueth, *Fundamentals of Earthquake Engineering*, (Prentice-Hall Inc., Englewood Cliffs, N. J. 1971), Chapter 6.
6. G. H. Keulegan, and L. H. Carpenter, "Forces on Cylinders and Plates in an Oscillating Fluid," *Journal of Research of the National Bureau of Standards*, **6** (5), (May, 1958).
7. R. J. Fritz, "The effects of Liquids on the Dynamic Motions of Immersed Solids," *Journal of Engineering for Industry, Trans. ASME* (Feb., 1972).
8. G. B. Wallis, *One-Dimensional Two-Phase Flow* (McGraw-Hill Book Co., New York, 1969), Chapter 8.
9. L. S. Jacobsen, "Impulsive Hydrodynamics of Fluid Inside a Cylindrical Tank and of Fluid Surrounding a Cylindrical Pin," *Bull. of the Seismological Society of America*, **39** (1949).
10. T. Yamamoto and J. H. Nath, "Hydrodynamic Forces on Groups of Cylinders," *Offshore Technology Conference, 1976 Proc., Vol. 1*, OTC 2449.
11. H. B. Amey, Jr., and G. Pomonik, "Added Mass & Damping of Submerged Bodies Oscillating Near the Surface," *Offshore Technology Conference, 1976 Proc., Vol. 1*, OTC 1557.
12. C. J. Garrison, and R. B. Berklite, "Hydrodynamic Loads Induced by Earthquakes," *Offshore Technology Conference, 1976 Proc., Vol. 1*, OTC 1554.
13. T. Sarpkaya, "Separated Flow About Lifting Bodies and Impulsive Flow About Cylinders," *AIAA Journal*, **4** (3), (March, 1966).
14. A. Selby and R. T. Severn, "An Experimental Assessment of the Added Mass of Some Plates Vibrating In Water," *Earthquake Engineering and Structural Dynamics*, **1** (1972).
15. H. Schlichting, *Boundary Layer Theory* (McGraw-Hill Book Co., New York, 1968).
16. J. H. Shames, *Mechanics of Fluids* (McGraw-Hill Book Co., New York, 1972).
17. A. R. Chandrasekaran and S. S. Saini, "Vibration of Submerged Structures," *Irrigation and Power* (July, 1971).
18. T. Yamamoto, "Hydrodynamic Forces on Multiple Circular Cylinders," *Journal of the Hydraulics Division, Proc. of the ASCE* (Sept., 1976).
19. C. Dalton and R. A. Helfinstine, "Potential Flow Past A Group of Circular Cylinders," *Journal of Basic Engineering, Trans. ASME* (Dec., 1971).
20. R. A. Skop, S. E. Ramberg, and K. M. Ferer, *Add Mass and Damping Forces on Circular Cylinders*, ASME Paper 76-Pet-3, 1976.
21. S. Levy, J. P. D. Wilkinson, "Calculation of Added Water Mass Effect for Reactor System Components," *Trans. of the 3rd Int. Conf. on Structural Mechanics in Reactor Tech.* (Sept., 1975).
22. J. G. Alibaud, (Abstract Only) "Virtual Mass Effect of Water on the Internals of Pressurized Water Reactors, Theory and Experimental Results," *Trans. of the 3rd Int. Conf. on Structural Mechanics In Reactor Tech.* (Sept., 1975).

23. R. Assedo, M. Dubourg, M. Livolant, A. Epstein, "Vibration Behavior of PWR Reactor Internals Model Experiments and Analysis," Trans. of the 3rd Int. Conf. on Structural Mechanics in Reactor Tech. Sept. 1975.

24. C. Carmignani, E. Manfredi, S. Reale, P. Cewetti, A. Fedevico, "Influence of the Assembly Configurations on the Flow Induced Vibrations of BWR Fuel Elements," *Trans. of the 3rd Intern. Conf. on Structural Mechanics In Reactor Technology* (Sept., 1975).

25. D. T. Ramani, "Stress and Deflection Analysis of Reactor Internals Due to Seismic & Maximum Hypothetical LOCA Loading Conditions," *Trans of the 3rd Inter. Conf. On Structural Mechanics In Reactor Technology* (Sept., 1975).

26. S. S. Chen and H. Chung, *Design Guide for Calculating Hydrodynamic Mass, Part I: Circular Cylindrical Structures*, Argonne National Laboratory ANL-CT-76-45 (June, 1976).

27. S. S. Chen and M. W. Wambsganss, and J. A. Sendozejczyk, "Added Mass and Damping of a Vibrating Rod In Confined Viscous Fluids," *J. of Applied Mechanics*, **98** (2) (June, 1976).

28. M. Ohkusu, "Wave Action on Groups of Vertical Circular Cylinders," *Proc. of the Annual Spring Conf. of Japan Soc. of Naval Architects* (May, 1972).

29. T. Sarpkaya, "Forces on Cylinders and Spheres In A Sinusoidally Oscillating Fluid," *Trans. ASME, J. of Applied Mech.* (March, 1975).

30. P. M. Moretti, and R. L. Lowery, "Hydrodynamic Inertia Coefficients for a Tube Surrounded by Rigid Tubes," *Trans ASME J. of Pressure Vessel Technology* (August, 1976).

31. Y. S. Shin and M. W. Wambsganss, "Flow-Induced Vibration in LMFBR Steam Generators: A State-of-the-Art Review," *Nuclear Engineering and Design*, **40** (1977), pp. 235-284.

32. S. S. Chen, "Vibration of Nuclear Fuel Bundles," *Nuclear Engineering and Design*, **35** (1975), pp. 399-422.

33. L. W. Carpenter, "On the Motion of Two Cylinders in An Ideal Fluid," *Journal of Research of the National Bureau of Standards*, **61** (2) (August, 1958), Research Paper 2889, pp. 83-87.

34. H. Chung and S. S. Chen, *Vibration of a Group of Circular Cylinders in a Confined Fluid*, ASME Paper No. 77-APM-16 (1977), pp. 1-5.

35. S. S. Chen, *Dynamics of Heat Exchanger Tube Banks*, ASME Paper No. 76-WA/FE-28 (1976), pp. 1-7.

36. S. S. Chen, "Vibrations of a Group of Circular Cylindrical Structures in A Liquid," *Trans. of the 3rd International Conf. on Structural Mechanics in Reactor Technology, Vol. 1 Part D* (September, 1975), pp. 1-11.

37. M. Dubourg, R. Assedo, and C. Cauquelin, "Model Experimentation and Analysis of Flow-Induced Vibrations of PWR Internals," *Nuclear Engineering and Design*, **27** (1974), pp. 315-333.

38. M. K. Au-Yung, "Response of Reactor Internals to Fluctuating Pressure Forces," *Nuclear Engineering and Design*, **35** (1975), pp. 361-375.

39. D. T. Ramani, "Transient Dynamic Response and Stability Analysis of Reactor Core — Support Barrel Due to LOCA Pressure Pulse Loading," *Trans. 4th Int. Conf. on Structural Mechanics in Reactor Technology* (San Francisco, California, August, 1977) (Abstract available only).

40. R. Longo, F. W. Martsen, P. A. Perrotti, E. C. Bair, "Seismic Analysis of Spent Fuel Racks," *Trans. 4th Int. Conf. on Structural Mechanics in Reactor Technology* (San Francisco, California, August, 1977) (Abstract available only).

41. N. R. Singleton, and G. J. Bohm, "Damping of Reactor Internals," *Trans 4th Int. Conf. on Structural Mechanics in Reactor Technology* (San Francisco, California, August, 1977).

42. R. W. Wu, L. K. Liu, S. Levy, "Dynamic Analysis of Multibody System Immersed in a Fluid Medium," *Trans. 4th Int. Conf. on Structural Mechanics in Reactor Technology* (San Francisco, California, August, 1977).

43. Y. S. Shin, J. A. Jendrzejczyk, and M. W. Wambsganss, "The Effect of Tube-Support Interaction on the Dynamic Response of Heat Exchanger Tubes," *Trans. 4th Int. Conf. on Structural Mechanics in Reactor Technology* (San Francisco, California, August 1977).

44. J. J. Dubois, A. L. deRouvray, "Improved Coupled Euler-Lagrange Finite Element Analysis of the Fluid-Structure Dynamic Interaction Problem," *Trans. 4th Int. Conf. on Structural Mechanics in Reactor Technology* (San Francisco, California, August, 1977).

45. R. J. Fritz and E. Kiss, *The Vibration Response of a Cantilevered Cylinder Surrounded by An Annular Fluid*, KAPL-M-6539, General Electric Co., Schenectady, N.Y. (February, 1966).

46. M. K. Au-Yang, "Free Vibration of Fluid-Coupled Coaxial Cylindrical Shells of Different Length," *J. Of Appl. Mech.* **98** (3), (Sept., 1976).

47. T. M. Mulcahy, P. Turula, H. Chung and J. A. Jendrzejczyk, "Analytical and Experimental Study of Two Concentric Cylinders Coupled by a Fluid Gap," *Trans. 3rd Int. Conf. on Structural Mechanics in Reactor Technology* (London, Sept., 1975).

48. S. S. Chen, J. A. Jendrzejczyk, and M. W. Wambsganss, *Experiments on Fluid Elastic Vibrations of Tube Arrays*, ANL-CT-77-16, Argonne National Laboratory (April, 1977).

49. T. T. Yeh and S. S. Chen, *The Effect of Fluid Viscosity on Coupled Tube/Fluid Vibrations*, ANL-CT-77-24, Argonne National Laboratory (April, 1977).

50. U.S. Nuclear Regulatory Commission, Regulatory Guide 1.60, *Design Response Spectra for Seismic Design of Nuclear Power Plants* (Dec., 1973).

51. H. N. Abramson, *The Dynamic Behavior of Liquids in Moving Containers*, National Aeronautics and Space Administration, Rept. NASA SP-106 (1966).

52. D. D. Kana, and F. T. Dodge, "Design Support Modeling of Liquid Slosh in Storage Tanks Subject to Seismic Excitation," *presented at Second ASCE Specialty Conf. on Structural Design of Nuclear Plant Facilities*, (New Orleans, LA., Dec., 1975).

53. D. G. Stephens, H. W. Leonard, and T. W. Perry, Jr., *Investigation of the Damping of Liquids in Right-Circular Cylindrical Tanks, Including the Effects of a Time-Variant Liquid Depth*, NASA TN D-1367 (July, 1962), Wash. D.C.

54. D. D. Kana, of the Southwest Research Institute, San Antonio, Texas, Personal communications, August 18, 1977, in San Francisco, California.

55. Project Proposal, *Effective Mass and Damping of Submerged Structure*, Contract No. B&R 20 19 04 02 FIN AO203, August 1976.

KJM

Attachment 15

DOCUMENT/ PAGE PULLED

ANO. 8301030254

NO. OF PAGES 1

REASON

☐ PAGE ILLEGIBLE.

☐ HARD COPY FILED AT. PDR CF

OTHER ______

☐ BETTER COPY REQUESTED ON __/__/__

☒ PAGE TOO LARGE TO FILM.

☒ HARD COPY FILED AT. PDR (CF)

OTHER ______

☒ FILMED ON APERTURE CARD NO 8301030254-01

Attachment 16

DOCUMENT/ PAGE PULLED

ANO. 8301030254

NO. OF PAGES 1

REASON

- [ ] PAGE ILLEGIBLE.
  - [ ] HARD COPY FILED AT. PDR CF
    OTHER ____________
  - [ ] BETTER COPY REQUESTED ON ___/___/___
- [x] PAGE TOO LARGE TO FILM.
  - [x] HARD COPY FILED AT. PDR (CF)
    OTHER ____________
  - [x] FILMED ON APERTURE CARD NO 8301030254-02

Attachment 17

DOCUMENT/ PAGE PULLED

ANO. 8301030254

NO. OF PAGES ____

REASON

- ☐ PAGE ILLEGIBLE
  - ☐ HARD COPY FILED AT. PDR CF
    OTHER ____
  - ☐ BETTER COPY REQUESTED ON __/__/__
- ☒ PAGE TOO LARGE TO FILM.
  - ☒ HARD COPY FILED AT. PDR (CF)
    OTHER ____
  - ☒ FILMED ON APERTURE CARD NO 8301030254-03