CALCULATION/DESIGN COVER SHEET

Calculation/Design No CA 0540-064-001

Title: EMERGENCY CONDENSER

Client: CPC Project: BIG ROCK POINT

Job No: 0540-064-1359

Design Input/References:

LISTED WITHIN

Assumptions:

STATED WITHIN

Method:

STATED WITHIN

Remarks:

REV. NO.	REVISION	APPROVED	DATE
0	ORIGINAL	DAWesley	11/21/90
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BIG ROCK EMERGENCY CONDENSER

PURPOSE & INTRODUCTION

THE PURPOSE OF THIS CALCULATION IS TO EVALUATE THE BIG ROCK POINT EMERGENCY CONDENSER TANK FOR SEISMIC AND DEAD LOADS. THIS EVALUATION BUILDS UPON AND USES THE RESULTS OF A PREVIOUS ANALYSIS [REF 1]. THE PREVIOUS ANALYSIS USED FLOOR RESPONSE SPECTRA FROM REF 2. THIS EVALUATION WILL USE FLOOR SPECTRA FROM REF 3.

STRESSES ARE EVALUATED FOR THE TANK SHELL AT THE HORN OF THE FIXED SADDLE SUPPORT AND FOR THE FIXED SADDLE SUPPORT GUSSET PLATE. THESE LOCATIONS WERE FOUND TO BE CRITICAL IN THE PREVIOUS ANALYSIS.

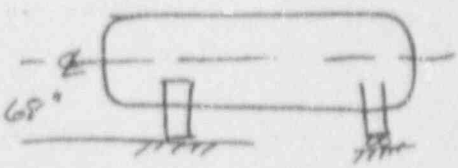
THE PREVIOUS ANALYSIS [REF 1] TREATED THE WATER IN THE TANK AS A RIGID INERTIAL MASS. ON PAGES 1 THROUGH 15 THE TANK IS EVALUATED WITH THIS SAME ASSUMPTION USING THE NEW SPECTRA FROM REF 3. BEGINNING ON PAGE 16, ANOTHER EVALUATION IS PERFORMED WHICH ACCOUNTS FOR THE HYDRODYNAMIC (IMPULSIVE AND SLOSHING) RESPONSE OF THE FLUID.

BIG ROCK EMERGENCY CONDENSER

REF: SMA CALC ROC/H13 11/81

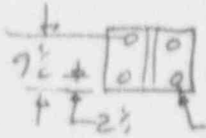
13703.01 pp. 1-23 [REF 1]

OPER. WT. 99240 lb



FRONT SADDLE

$I_{xx} = I_{yy} = 72 \text{ in}^4$

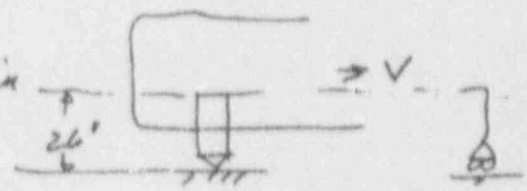


7/8" ⌀ BOLT (ASSUMED A-307)

$S_y \approx 36$ ksi

STRESS AREA = 0.461 in²

$M = 26\,V$ $K_\theta = 3^{-},750 \frac{k\text{-in}}{rad}$



$\theta = \dfrac{26V}{K_\theta}$

$\delta_1 = 26\,\theta = \dfrac{26^2 V}{K}$ MASS = $\dfrac{99{,}240}{386}$ = 257. $\frac{lb\text{-sec}}{in}$

$k_1 = \dfrac{V}{\delta_1} = \dfrac{K_\theta}{26^2} = 52{,}900$ lb/in

PG. 2 FOLLOWS 1A

INCLUDE SHEAR DEFORM. ALONG W/ BENDING

$$\delta_2 = \frac{l^3}{3EI} + \frac{l}{kGA}$$

$$= \frac{26^3}{3\cdot 29\cdot 10^6\cdot .72} + \frac{2\cdot 26\,(1+0.3)}{0.833\cdot 29\cdot 10^6\cdot 6}$$

$$= 2.806\cdot 10^{-6} + 4.664\cdot 10^{-7} = 3.272\cdot 10^{6}$$

$$K_2 = \frac{1}{\delta_2} = 305{,}600 \text{ lb/in}$$

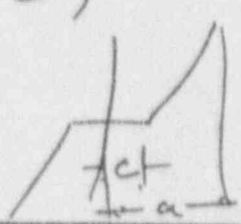
$$K_E = \frac{2}{1/K_1 + 1/K_2} = 90{,}200 \text{ lb/in}$$

$$\omega_{elastic} = \sqrt{\frac{K}{M}} = \left(\frac{90{,}200}{257.}\right)^{1/2} = 18.7 \text{ rad/sec}$$

$$f_{AXIAL\,(elastic)} = 2.98 \text{ Hz.}$$

$$\delta_E = 1.1 \text{ in} \quad (\text{FOR } 1g)$$

IF THE FRONT SUPPORT SLIDES IN THE BOLT CLEARANCE ($\pm$ 1/16" = C)



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JOB NO 0540-064-1369
CALC NO CA-0540-064-001
PAGE 2 OF 65

$$\ddot{y} + f(y) = 0$$

$$f^*(y) = p^2 y$$

MINIMIZING THE MOMENT OF THE DIFFERENCE OF $r(y) = f(y) - f^*(y)$

$$r(y)y = [f(y) - p^2(y)]y$$

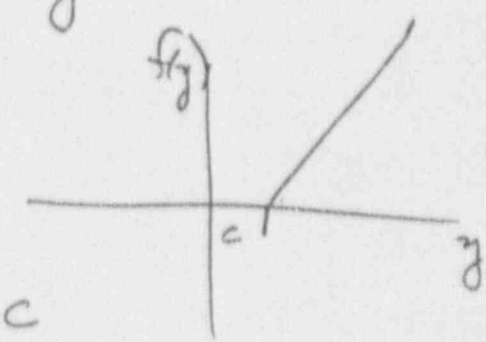
OR MINIMIZING THE INTEGRAL

$$I = \int_{-a}^{a} \{[f(y) - p^2(y)]y\}^2 dy$$

$$\text{ie} \quad \frac{d}{d(p^2)} \int_{-a}^{a} \{[f(y) - p^2(y)]y\} dy = 0$$

$$p^2 = \frac{5}{a^5} \int_0^a f(y) y^3 dy$$

$$f(y) = K(y-c) \quad y > c$$
$$f(y) = -K(y+c) \quad y < -c$$
$$f(y) = 0 \quad -c \le 0 \le c$$



$$p^2 = \frac{5}{a^5}\left[\int_0^c 0 \cdot y^3 dy + \int_c^a \frac{K}{M}(y^4 - y^3 c) dy\right.$$

$$= \frac{5}{a^5}\left[\frac{x^5}{5} - \frac{x^4 c}{4}\right]_c^a \cdot \frac{K}{M}$$

$$= \frac{5}{a^5}\left(\frac{a^5}{5} - \frac{a^4 c}{4} - \frac{c^5}{5} + \frac{c^5}{4}\right)\frac{K}{M}$$

$$= \left(1 - \frac{5c}{4} - \frac{c^5}{a^5} + \frac{5c^5}{4a^5}\right)\frac{K}{M}$$

@ $c=0$ (LINEAR) $p^2 = \frac{K}{M}$ OK

$c = 1/16" = 0.0625"$

$a = 1.1 \cdot \frac{S_a}{g} = 1.1"$ @ $S_a = 1g$

$c/a = .057$

$$p^2 \approx \left(1 - \frac{5}{4} \cdot 0.057\right)\frac{K}{M}$$

$p \approx 0.96\, p_{elastic} = 2.87$ Hz

(SLIDING @ 1g (S_a) BUT NO DUCTILITY

BENDING STRESS $\sigma_b = \frac{Mc}{I}$

$= 26 \cdot V \cdot \frac{6}{72}$; $V = \frac{W}{2}$ @ 1g

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0	MW	10/16	DKN	11.9.90

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CALC NO CA-0540-064-001

$$\sigma_b = \frac{26 \cdot 6}{72} \cdot \frac{99240}{2} = 107,510 \quad @ \ 1g$$

$$\sigma_b = \sigma_{yld} \approx 35,000 \text{ psi} \qquad Sa_{yld} \approx 0.33g$$

$$a_{yld} \approx 1.1 \cdot 0.33 = 0.36 \text{ in}$$

$$c/a = \frac{0.0625}{0.36} = 0.175$$

$$p^2 = \left(1 - \frac{5}{4} \cdot 0.175\right) \frac{K}{M} = (1 - 0.218) p^2_{elastic}$$

$$p \approx 0.88 \, p_{elastic} = 2.635 \text{ Hz} \quad @ \text{ yld.}$$

ANCHOR BOLT SHEAR @ $S_a = 0.33g$

$$V = 0.33 \cdot \frac{99,240}{2} = 16,370 \ \frac{lb}{pad} \ @ \ .33g_{Sa}$$

$$\tau = \frac{16,370}{4 \cdot 0.461} = 8880 \text{ psi}$$

BOLT WILL YIELD IN TENSION BUT IS DEFORMATION CONTROLLED ; WILL NOT YIELD IN SHEAR

FRICTION $\mu \approx 0.4$ TO 0.8 STEEL/STEEL

$N = \frac{W}{4} \pm$ VERT. EQ. PER PAD

$F_{friction} = \mu N \approx 0.4N$ TO $0.8N$

VERT FREQ > 33 Hz (RDC CALC.)

USING ORIG D'APP VERT FRS (FIG A-27)

$Sa_v \approx 0.2g$ @ 0.12g HORIZ

E-W (Fig A-26) $Sa \approx 0.5g$ 7% DAMPING ; 2.6 Hz

$Sa \approx 0.6g$ 7% " 3.0 Hz

WHERE ABOVE VALUES INCLUDE ±15% FREQ BROADENING

USING LATER D'APP SPECTRA (Fig. 5.1-3)

$S_{av} \approx 0.15g$ @ 33 Hz 7% DAMPING (@ 0.104g HORIZ)

E-W (Fig 5.1-2) $Sa \approx 0.20g$ 7% ; 2.6 Hz

$Sa = 0.25g$ 7% 3.0 Hz

AGAIN w/ ±15% BROADENING

REV	BY	DATE	CHECKED	DATE
0	MW	10/16	DHN	11.9.90

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CALC NO CA-0540-064-001

$N = \frac{99240}{4}(1 \pm S_{a_v})$; $V = \frac{W}{4} S_{a_{E-W}}$

@ $S_{a_{E-W}} = 0.33g$ (ie @ YIELD)

	OLD		NEW	
	2.6 Hz	3.0 Hz	2.6 Hz	3.0 Hz
S_{a_v} =	0.132	0.11	.248	.198
$N = \frac{W}{4} \cdot$	(1.132 to .868)	(1.11 to .89)	(1.248 to .752)	(1.198 to .802)
=	(28,085 to 21,535)	(27,590 to 22,080)	(30960 to 18,660)	(29720 to 19900)
F_{frict} .4 to .8 =	(22,470 to 8614) 15,590 AVG	(22030 to 8830) 15430 AVG	(24770 to 7460) 16,115 AVG	(23780 to 7960) 15 870 AVG
V	12,400	14890	4960	6200

∴ ALTHOUGH SLIDING MAY OCCUR W/OLD SPECTRA IT IS UNLIKELY

YIELD MOMENT OF SUPPORT

$M_{yld} = \frac{35,000 \cdot 72}{6} = 420,000$ in-lb

$V_{yld} = 16,370$ lb (p 5)

REV	BY	DATE	CHECKED	DATE
0	DW	10/16	DKN	11.9.90

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CALC NO CA-0540-064-001

$M_{ULT} = 630,000$ in-lb (RDC CALC REF 1)

$V_{ULT} = 24,230$ lb

BOLT SHEAR @ V_{ULT}

$$\tau = \frac{24,230}{4 \cdot 0.461} = 13,140 < \tau_{yld}$$

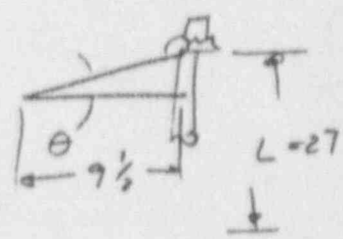
SUPPORT END SLOPE @ YIELD

$$\theta_{support} = \frac{Vl^2}{2EI} = \frac{16370 \cdot 26^2}{2 \cdot 29 \cdot 10^6 \cdot 72} = .00265$$

$$\theta_{shell} = \frac{26V}{k_\theta} = \frac{26 \cdot 16370}{35.75 \cdot 10^6} = 0.0119$$

BOLT ELONG $= 9.5 \cdot \theta$

$= 0.365''$



BOLT LENGTH ~27" REF DWG C-114

∴ BOLT STRAIN ~ 0.014 i.e. > YIELD

RDC TOOK LATERAL OTM FROM TANK ℄
i.e. 68"

FROM DWG NO. 271-34D (CLEAVER-BROOKS)

REV	BY	DATE	CHECKED	DATE
0	DW	10/16	DKN	11-9-90

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JOB NO 0540-064-1359

CALC NO CA-0540-064-001

PAGE 8 OF 65

DRY WT = 32192 lb REF CLEAVER-BROOKS DWG 271-340 REV 9

OPER. WT. = 99,238 lb

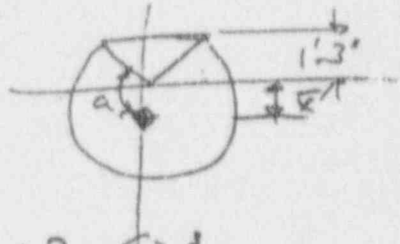
WATER = 67,096 lb

WT. BREAKDOWN & CG

ITEM			$\overline{X}$	$W\overline{X}$
	SHELL	19,320	68"	1,313,760
	BUNDLE	2 · 3420	47	321,480
	WATER BOX	2 · 1240	47	116,560
	WATER BOX	2 · 900	47	84,600
	COVER	1 · 102	102	10,400
	WATER	67,046	50.4	3,380,550
		97,690		5,227,350

$\overline{X}$ = 53.5 in (FROM BOTTOM OF SUPPORT PLT)

WATER



$$\overline{x}' = \frac{4R\ \sin^3 a}{3(2a - \sin 2a)}$$

$$a \approx 90 + \sin^{-1}\frac{15}{60} = 104.5^\circ = 1.823\ \text{rad}$$

$$= \frac{4 \cdot 60 \cdot 0.968^3}{3(2 \cdot 1.823 + .484)}$$

$$= \frac{72.618}{3.647 + .489} = 17.6\ \text{in}$$

$$\overline{x} = 68 - 17.6 = 50.4$$

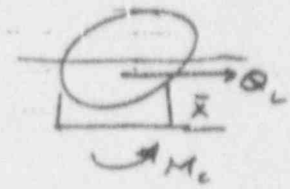
REV	BY	DATE	CHECKED	DATE		
0	RW	10/16	DKN	11·9·90		
					ABB ASEA BROWN BOVERI ABB IMPELL CORPORATION	JOB NO 0540-064-1359 CALC NO CA-0540-064-001 PAGE 9 OF 65

∴ RATIO RDC OTM BY $\frac{53.5-8}{60}$ 0.758

ALSO STRESSES

$\sigma_\phi = 0.758 \cdot 0.205\, Q_L$

$\sigma_x = 0.758 \cdot 0.533\, Q_L$



or $\sigma_\phi = 0.155\, Q_L$

$\sigma_x = 0.404\, Q_L$

$Q_{LAT} = \frac{Sa_{H+S}}{2} \cdot 99240$

$Q_{VERT} = \left(1 \pm \frac{Sa_V}{2}\right) 99240$

USING OLD D'App SPECTRA

$\sigma_{x_V} = \pm 18.2$ psi

$\sigma_{x_V} = -17$ psi (DEAD WT)

$\sigma_{x_{LAT}} = \pm 7.8 \cdot \frac{Sa}{0.48} \cdot 0.758 = 5.9$ psi

REV	BY	DATE	CHECKED	DATE
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JOB NO 0540-064-1359
CALC NO CA-0540-064-001
PAGE 10 OF 65

MEMBRANE STRESS @ HORN - RDC REF 1 p 7

$\sigma_{\phi_{DEAD\ WT.}} = -2367$ psi

$\sigma_{\phi_{SSE-VERT.}} = -473$ psi

$\sigma_{\phi_{SSE-LAT.}} = \pm 4883 \cdot 0.758 = \pm 3700$ psi

$\sigma_{x_{SSE-LAT.}} = 12696 \cdot 0.758 = 9624$ psi

STRESSES IN SHELL FROM AXIAL, PRESSURE, & DW WILL REMAIN THE SAME BASED ON BROADENED, OLD F.R.S.

SEE RDC p. 13 REF 1

REV	BY	DATE	CHECKED	DATE
0	DW	10/17	DKN	11.9.90

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JOB NO 0540-064-1359

CALC NO CA-0540-064-001

STRESS COMBINATION AT SADDLE HORN

LOAD	σ_x	σ_ϕ	τ	
D.W. (BEAM BENDING)	-17	0	625	1g down
HYDROSTATIC PRESS.	219	438	0	
LOCAL MEMBRANE @ HORN	0	-2367	0	
NORMAL STRESS (TOTAL)	202	-1929	625	
VERT. SEISMIC (BEAM BENDING)	-3	0	125	.2g down
VERT. SEISMIC (PRESSURE STRESS)	44	88	0	
VERT. SEISMIC (LOCAL MEMBRANE @ HORN)	0	-473	0	
VERTICAL SEISMIC (TOTAL)	41	-385	125	
LATERAL SEISMIC (BEAM BEND.)	± 6	0	± 238	
LATERAL SEISMIC (PRESS. STRESS)	± 108	± 216	0	.48g
LATERAL SEISMIC (LOCAL MEMBRANE) @ HORN	∓ 9624	∓ 3700	0	
LATERAL SEISMIC (TOTAL)	∓ 9510	∓ 3484	± 238	
LONGITUDINAL SEISMIC (PRESS. STRESS)	± 270	± 540	0	
LONG. SEISMIC (LOCAL MEMBRANE) @ HORN	± 13500	± 36970	-	.45g
LONG. SEISMIC (SHEAR FLOW)	—	—	± 8110	
LONGITUDINAL SEISMIC (TOTAL)	± 13770	± 37510	± 8110	
SRSS OF SEISMIC	± 16375	± 37673	± 8114	
NORMAL + SSE (OLD SPECTRA - ELASTIC)	- 16,533	- 39,602	8739	

STRESS COMBINATION AT SADDLE HORN

LOAD	σ_x	σ_ϕ	T	
D.W. (BEAM BENDING)	-17	0	625	1g down
HYDROSTATIC PRESS.	219	438	0	
LOCAL MEMBRANE @ HORN	0	-2367	0	
NORMAL STRESS (TOTAL)	202	-1929	625	
VERT SEISMIC (BEAM BENDING)	-2	0	94	.15 g down
VERT. SEISMIC (PRESSURE STRESS)	33	66	0	
VERT. SEISMIC (LOCAL MEMBRANE @ HORN)	0	-355	0	
VERTICAL SEISMIC (TOTAL)	31	-289	94	
LATERAL SEISMIC (BEAM BEND.)	± 4	0	± 159	.22 g
LATERAL SEISMIC (PRESS. STRESS)	± 72	± 144	0	
LATERAL SEISMIC (LOCAL MEMBRANE @ HORN)	∓ 6416	∓ 2467	0	
LATERAL SEISMIC (TOTAL)	∓ 6340	∓ 2323	± 159	
LONGITUDINAL SEISMIC (PRESS. STRESS)	± 104	± 208	0	.25 g
LONG. SEISMIC (LOCAL MEMBRANE @ HORN)	± 5192	± 14,219	-	
LONG. SEISMIC (SHEAR FLOW)	—	—	± 3119	
LONGITUDINAL SEISMIC (TOTAL)	± 5296	± 14427	± 3119	
SRSS OF SEISMIC	± 8261	± 14,616	± 3124	
NORMAL + SSE NEW SPECTRA - ELASTIC	-8059	-16,545	3749	

REV	BY	DATE	CHECKED	DATE
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JOB NO 0540-064-1359
CALC NO CA-0540-064-001

PRINCIPAL STRESS (OLD SPECTRA)

$$S_1 = \left(\frac{-39{,}602 - 16{,}533}{2}\right) - \left[\left(\frac{39{,}602 - 16{,}533}{2}\right)^2 + 8759^2\right]^{\frac{1}{2}}$$

$= -42{,}539$ psi

$$S_2 = \left(\frac{-39602 - 16533}{2}\right) + \left[\left(\frac{39602 - 16533}{2}\right)^2 + 8759^2\right]^{\frac{1}{2}}$$

$= -13{,}596$ psi

$S_3 = 0$

MAX STRESS INTENSITY $S = S_1 - S_3 = -42539$ psi

ALLOWABLE $= 2.4\,S = 2.4 \cdot 16{,}300 = 39120$ psi

$$M.S. = 1 - \frac{42539}{39120} = -0.088$$

PRINCIPAL STRESS (NEW SPECTRA)

$$S_1 = \left(\frac{-16{,}560 - 8248}{2}\right) - \left[\left(\frac{16560 - 8248}{2}\right)^2 + 3749^2\right]^{\frac{1}{2}}$$

$= -17{,}964$ psi

$$S_2 = \left(\frac{-16545 - 8059}{2}\right) + \left[\left(\frac{16545 - 8059}{2}\right)^2 + 3749^2\right]^{\frac{1}{2}}$$

$= -6640$ psi

$S_3 = 0$

$$M.S. = 1 - \frac{17964}{39120} = +0.541$$

REV	BY	DATE	CHECKED	DATE		
0	DW	10/18	DKN	11-9-90		
					ABB ASEA BROWN BOVERI ABB IMPELL CORPORATION	JOB NO 0540-064-1359
						CALC NO CA-0540-064-001

BOTH SHELL & SUPPORT WILL YIELD "@ SSE USING OLD SPECTRA - BOTH LESS THAN YIELD WITH NEW

	OLD	NEW
SHELL	42,540 psi	17,960 psi
SUPPORT (bending)	69,880 psi	26,880 psi

BOTH SETS OF RESULTS ABOVE ARE BASED ON DESIGN DAMPING FOR STRUCTURE, ±15 F.R.S. BROADENING, NO EQUIP. DUCTILITY ETC. & ARE THEREFORE CONSERVATIVE.

REV	BY	DATE	CHECKED	DATE
0	MW	10/18	DKN	11·9·90

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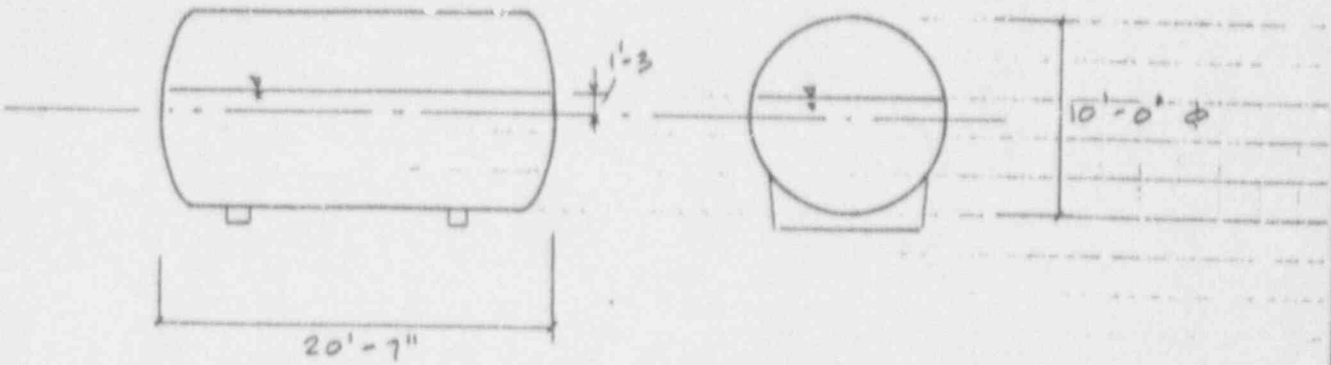
JOB NO 0540-064-1359

CALC NO CA-0540-064-001

INVESTIGATE HYDRODYNAMIC EFFECTS



WT OF WATER = 67046 LB.

IDEALIZE AS A RECTANGULAR TANK WITH LENGTH AND WIDTH BASED ON THE DIMENSIONS OF THE FREE SURFACE AND AN EQUIVALENT WATER DEPTH TO GIVE THE SAME VOLUME OF WATER.

FOR THE EQUIVALENT RECTANGULAR TANK

LET $L_1 = \frac{1}{2}(20.58) = 10.29'$. LONG. DIRECTION (EW)

$L_2 = \sqrt{5^2 - 1.25^2} = 4.84'$ TRANS. DIRECTION (NS)

VOL OF WATER = 67046 LB / 62.4 LB/FT^3 = 1074.5 FT^3

$$h_E = \frac{1074.5\ FT^3}{(2 \times 10.29')(2 \times 4.84')} = 5.39'$$

h_E = EQUIVALENT HEIGHT OF WATER FOR RECTANGULAR TANK

0	DKN	11-9-90	DW	11/19/90	BIG ROCK EMERGENCY CONDENSER
					IMPELL CORPORATION — JOB NO 0540-064-1369; CALC NO CA-0540-064-001; PAGE 16 OF 65
REV	BY	DATE	CHECKED	DATE	

USE ANALYSIS METHODOLOGY FROM REF 6 "NUCLEAR REACTORS AND EARTHQUAKES," TID-7024, CHAPTER 6 AND APPENDIX F

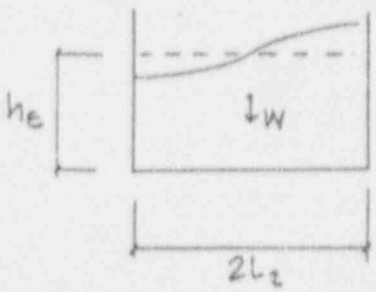
ASSUME A RIGID TANK.

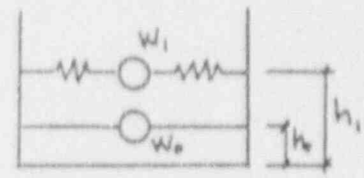
- FOR THE TRANSVERSE DIRECTION (NS)

NS FREQ IS IN RIGID RANGE [REF 1] ⇒ ASSUME SUPPORTS ARE RIGID AND TANK IS EFFECTIVELY SUPPORTED ON THE GROUND.

$L_2 = 4.84'$ $\quad h_E = 5.39'$ $\quad L_2/h_E = \frac{4.84}{5.39} = 0.898$

$W = 67046$ LB





ANALYTICAL MODEL

IMPULSIVE MODE FROM REF 6

$$\frac{W_0}{W} = \frac{\tanh(\sqrt{3}\,L_2/h_E)}{\sqrt{3}\,L_2/h_E}$$

$$= \frac{\tanh(\sqrt{3}(0.898))}{\sqrt{3}(0.898)} = 0.588 \checkmark$$

$$h_0 = \frac{h}{8}\left[\frac{4}{\frac{\tanh(\sqrt{3}\,L_2/h_E)}{\sqrt{3}\,L_2/h_E}} - 1\right] = \frac{5.39'}{8}\left[\frac{4}{0.588} - 1\right]$$

$$= 3.91' \checkmark$$

INCL. BOTTOM PRESSURE

REV	BY	DATE	CHECKED	DATE			
0	DKN	11-9-90	DW	11/13/91	BIG ROCK EMERGENCY CONDENSER		
					IMPELL CORPORATION	JOB NO 0540-064-1359	PAGE 17
						CALC NO CA-0540-064-001	OF 65

IMPULSIVE MODE -

h_o = 3.91' INCL BOTTOM PRESSURE

$h_o = \frac{3}{8} h_E$ = (3/8)(5.39') = 2.02' EXCL. BOTTOM PRESSURE

FOR A RIGID TANK : S_A = EPA OF FLOOR SPECTRA

OLD SPECTRA - NS

@ 33 Hz S_a = 0.48g [REF 2, FIG A-25] ATTACHED

NEW SPECTRA - NS

@ 33 Hz S_a = 0.30g [REF 3, FIG 5.1-1] ATTACHED

EVALUATE SHEAR AND OVERTURNING MOMENT AT BOTTOM OF TANK - IMPULSIVE MODE

$$V = (W_o + W_{TANK}) S_a$$

$$M = (W_o h_o + W_{TANK} \bar{h}_{TANK}) S_a$$

W_{TANK} = 32192 LB (PG 9) $\bar{h}_{TANK}$ = 5'
(DIST FROM CG TO BOTT. OF TANK)

W_o = 0.588 W

= 0.588 × 67046 = 39423 LB

V = (39423 + 32192)(0.48g) = 34375 LB (OLD SPECTRA)

= (39423 + 32192)(0.30g) = 21485 LB (NEW SPECTRA)

$M = (39423^{\#} \times 3.91' + 32192^{\#} \times 5')(0.48g) = 151250$ FT-LB (OLD SPECTRA)

$= (39423^{\#} \times 3.91' + 32192 \times 5')(0.30g) = 94530$ FT-LB (NEW SPECTRA)

IMPULSIVE MODE

	OLD SPECTRA	NEW SPECTRA
V	34375#	21485#
M	151250#-'	94530#-'

IMPULSIVE MODE HYDRODYNAMIC PRESSURE

$$p = \rho h_E S_a \frac{\sqrt{3}}{2} \tanh(\sqrt{3} L_2 / h_E)$$ REF 6.

← MAX PRESSURE @ TANK BOTTOM

$$p = \left(\frac{62.4\ \#/FT^3}{g}\right)(5.39')\frac{\sqrt{3}}{2}\tanh(\sqrt{3} \times 4.84'/5.39)\,S_a$$

$$= \frac{266}{g} S_a \text{ PSF}$$

$$p = \frac{266}{g}(0.48g) = 128 \text{ PSF (OLD SPECTRA)}$$

$$= \frac{266}{g}(0.30g) = 80 \text{ PSF (NEW SPECTRA)}$$

REV	BY	DATE	CHECKED	DATE	
0	DKN	11.12.90	(initials)	11/13/90	BIG ROCK EMERGENCY CONDENSER

IMPELL CORPORATION

JOB NO 0540-064-1359

CALC NO CA-0540-064-001

• TRANSVERSE DIRECTION (CONT.)

CONVECTIVE (SLOSHING) MODE

$$\frac{W_1}{W} = 0.527 \frac{L_2}{h_e} \tanh\left(1.58\, h_e/L_2\right)$$

$$= 0.527\left(\frac{4.84}{5.39}\right) \tanh\left(1.58 \times 5.39/4.84\right) = \underline{0.446} \checkmark$$

$$\frac{h_1}{h} = 1 - \frac{\cosh\left(1.58\, h_e/L_2\right) - 1}{1.58 \frac{h_e}{L_2} \sinh\left(1.58\, h_e/L_2\right)}$$

$$= 1 - \frac{\cosh\left(1.58 \times 5.39/4.84\right) - 1}{1.58\left(\frac{5.39}{4.84}\right) \sinh\left(1.58 \times 5.39/4.84\right)} = 0.599 \checkmark$$

(EXCL. BOTT PRESS)

$$\frac{h_1}{h} = 1 - \frac{\cosh\left(1.58\, h_e/L_2\right) - 2}{1.58 \frac{h_e}{L_2} \sinh\left(1.58\, h_e/L_2\right)} =$$

$$= 1 - \frac{\cosh\left(1.58 \times 5.39/4.84\right) - 2}{1.58\left(\frac{5.39}{4.84}\right) \sinh\left(1.58 \times 5.39/4.84\right)} = 0.800 \checkmark$$

(INCL. BOTT PRESS)

$h_1 = 0.599 \times 5.39' = 3.23'$ ✓ (EXCL. BOTTOM PRESS)

$= 0.800 \times 5.39' = 4.31'$ ✓ (INCL BOTTOM PRESS)

SLOSHING FREQ

$$\omega^2 = \frac{1.58g}{L_2} \tanh(1.58\, h_0/L_2)$$

$$= \frac{1.58(32.2)}{4.84} \tanh(1.58 \times 5.39/4.84) = 9.91$$ ✓

$$\omega = \sqrt{9.91} = 3.15 \text{ RAD/SEC}$$ ✓

$$f_{SLOSH} = 3.15/2\pi = 0.5 \text{ Hz}$$ ✓

SPECTRAL ACCEL FOR 0.5% DAMPING

@0.5Hz S_a = 0.22g OLD SPECTRA [REF 2, FIG A-25] ATTACHED

@0.5Hz S_a = 0.22g NEW SPECTRA [REF 3, FIG 5.1-1] ATTACHED.

SHEAR AND OVERTURNING MOMENT

$V = W_1 S_a$ $\qquad W_1 = 0.446\,W$

$M = W_1 h_1 S_a$ $\qquad = 0.446(67041b) = 29903$ LB

$V = 29903 \times 0.22g = \underline{6579 \text{ LB}}$ ✓

$M = 29903 \times 4.31' \times 0.22g = \underline{28354 \text{ FT}\cdot\text{LB}}$ ✓

SAME V & M FOR BOTH OLD AND NEW SPECTRA SINCE S_a IS SAME

REV	BY	DATE	CHECKED	DATE			
0	DKN	11.12.90	RW	11/13/90	BIG ROCK EMERGENCY CONDENSER		
					IMPELL CORPORATION	JOB NO 0540-064-1359	PAGE 21
						CALC NO CA-0540-064-001	OF 65

SLOSHING HYDRODYNAMIC PRESSURE

$\theta_h = 1.58 \frac{A_1}{L_2} \tanh(1.58 h_B / L_2)$ REF 6

$A_1 = S_d = \frac{S_a}{\omega^2}$

$= \frac{0.22(32.2)}{(3.15)^2} = 0.714'$ ✓

$\theta_h = 1.58 \frac{(0.714')}{4.84'} \tanh(1.58 \times 5.39/4.84) = 0.220$ RAD ✓

HYDRODYNAMIC PRESSURE

$p_1 = \rho \frac{L_2^2}{3} 1.58 \frac{\cosh(1.58\, Y/L_2)}{\sinh(1.58\, h/L_2)} \omega^2 \theta_h$

$= \left(\frac{62.4}{32.2}\right)\frac{(4.84)^2}{3} \frac{(1.58)(3.15)^2(0.220)}{\sinh(1.58 \times 5.39/4.84)} \cosh(1.58\, Y/L_2)$

$= 18.515 \cosh(1.58\, Y/L_2)$ PSF ✓

FOR $y = h_B = 5.39'$

$p_1 = 18.515 \cosh(1.58 \times 5.39'/4.84) =$ **55 PSF** ✓

REV	BY	DATE	CHECKED	DATE	
0	DKN	11.12.90	DW	11/19/90	BIG ROCK EMERGENCY CONDENSER

$$p = \rho h_E \ddot{u}_2 \frac{\sqrt{3}}{2} \tanh(\sqrt{3} L_1 / h_E)$$

$$= \left(\frac{62.4}{g}\right) \times 5.39' \times 0.695g \frac{\sqrt{3}}{2} \tanh(\sqrt{3} \times 10.29 / 5.39)$$

= 202 PSF ✓ MAX FLUID PRESS AT TANK BOTTOM.

SUMMARY : LONGITUDINAL DIRECTION - OLD SPECTRA

BASE SHEAR V = 39178 LB ✓ PG 32

MAX SLOSHING FLUID PRESS = 171 PSF = 1.19 PSI

MAX IMPULSIVE FLUID PRESS = 202 PSF = 1.40 PSI

SRSS FLUID PRESS $= (171^2 + 202^2)^{1/2}$

= 265 PSF ✓

= 1.84 PSI ✓

REV	BY	DATE	CHECKED	DATE	
0	DKN	11.14.90	1/(W)	11/19/90	BIG ROCK EMERGENCY CONDENSER

IMPELL CORPORATION

JOB NO 0540-064-1359

CALC NO CA-0540-064-001

EVALUATE DISPL, FORCES, AND FLUID PRESSURE FOR NEW SPECTRA

DISPLACEMENTS:

1ST MODE $\{u\}_1 = \Gamma_1 \{\phi_1\} S_{d_1}$

$$= 1.0048 \begin{Bmatrix} 1.0 \\ 0.004266 \end{Bmatrix} \frac{0.18 \times 32.2}{(1.829)^2}$$ — PG 30

$$= \begin{Bmatrix} 1.7409 \\ 0.007322 \end{Bmatrix} \text{ FT.}$$

2ND MODE $\{u\}_2 = \Gamma_2 \{\phi_2\} S_{d_2}$

$$= -0.0048 \begin{Bmatrix} 1.0 \\ -206.889 \end{Bmatrix} \frac{0.35 \times 32.2}{(26.43)^2}$$ PG 30

$$= \begin{Bmatrix} -0.00007744 \\ 0.01602 \end{Bmatrix} \text{ FT.}$$

FORCES: $\{F\} = [K]\{u\}$

1ST MODE

$$\{F\}_1 = \begin{bmatrix} 4778.3 & -4778.3 \\ -4778.3 & 1137578 \end{bmatrix} \begin{Bmatrix} 1.7409 \\ 0.007322 \end{Bmatrix} = \begin{Bmatrix} 8284 \\ 10.8 \end{Bmatrix} \text{ LB}$$

BASE SHEAR = 8284 + 10.8 = 8294.8 LB

8668 0509

0	DKN	11.12.90	TKW	11/13/90	BIG ROCK EMERGENCY CONDENSER
REV	BY	DATE	CHECKED	DATE	IMPELL CORPORATION

JOB NO 0540-064-1359 PAGE 36 OF 65

CALC NO CA-0540-064-001

2ND MODE :

$$\{F\}_2 = \begin{bmatrix} 4778.3 & -4778.3 \\ -4778.3 & 1137578 \end{bmatrix} \begin{Bmatrix} -0.00001744 \\ 0.01602 \end{Bmatrix} = \begin{Bmatrix} -76.9 \\ 18224 \end{Bmatrix} \text{ LB}$$

BASE SHEAR = −76.9 + 18224 = 18147.1 LB

TOTAL BASE SHEAR (SRSS 2 MODES)

$$V = \left[(8294.8)^2 + (18147.1)^2 \right]^{1/2}$$

$$= 19953 \text{ LB} \quad \text{(NEW SPECTRA)}$$

FLUID PRESSURES

SLOSHING RESPONSE 1ST MODE $\{u\}_1 = \begin{Bmatrix} 1.7409' \\ 0.007322' \end{Bmatrix}$ PG 36

$$A_1 = 1.7409' - 0.007322'$$

$$= 1.7336'$$

$$\theta_h = 1.58 \frac{A_1}{L_1} \tanh(1.58 h_e / L_1)$$

$$= 1.58 \times \frac{1.7336'}{10.29'} \tanh(1.58 \times 5.39 / 10.29) = 0.181 \text{ RAD}$$

REV	BY	DATE	CHECKED	DATE	
0	DKN	11-12-90	[illegible]	11/19/90	BIG ROCK EMERGENCY CONDENSER

IMPELL CORPORATION

JOB NO 0540-064-1359

CALC NO CA-0540-064-001

$$p_1 = \rho \frac{L_1^2}{3} 1.58 \frac{\cosh(1.58\,Y/L_1)}{\sinh(1.58\,h_E/L_1)} \omega_1^2 \theta_n$$

$$= \left(\frac{62.4}{32.2}\right) \frac{(10.29)^2}{3} \times 1.58 \frac{\cosh(1.58\,Y/10.29)}{\sinh(1.58 \times 5.39/10.29)} (1.829)^2 (0.181)$$

$$= 70.7 \cosh(1.58\,Y/10.29) \quad \text{PSF}$$

MAX PRESS @ $Y = h_E = 5.39'$ $p_1 = \underline{90 \text{ PSF}}$

$= \underline{0.67 \text{ PSI}}$

NEGLECT 2ND MODE SLOSHING PRESSURE

IMPULSIVE FLUID PRESSURE :

NEGLECT 1ST MODE CONTRIBUTION

2ND MODE $\{\ddot{u}\}_2 = \Gamma_2 \{\Phi_2\} Sa_2$

$$= -0.0048 \begin{Bmatrix} 1.0 \\ -206.889 \end{Bmatrix} 0.35g \quad \text{PG 30}$$

$$= \begin{Bmatrix} -0.00168\,g \\ 0.348\,g \end{Bmatrix}$$

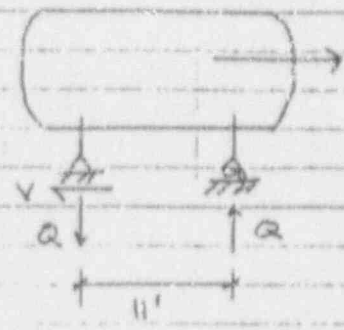
$$p = \rho h_E \ddot{u}_2 \frac{\sqrt{3}}{2} \tanh(\sqrt{3}\,L_1/h_E)$$

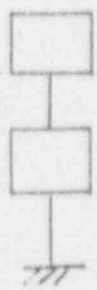
$$= \left(\frac{62.4}{g}\right) \times 5.39 \times 0.348g \frac{\sqrt{3}}{2} \tanh(\sqrt{3} \times 10.29/5.39)$$

$= 101$ PSF $= 0.70$ PSI MAX PRESS @ TANK BOTT.

LONGITUDINAL DIRECTION (E-W) — OVERTURNING FORCES

TANK OVERTURNING MOMENT DUE TO SLOSHING FORCE, IMPULSIVE FORCE AND TANK SHELL INERTIA IS RESISTED BY THE SADDLE SUPPORTS AS A FORCE COUPLE.





W_1 SLOSHING MASS

$W_0 + W_{TANK}$ IMPULSIVE MASS + TANK MASS

FROM THE ANALYTICAL MODEL:

SLOSHING FORCE ACTS AT DISTANCE h_1 ABOVE TANK BOTTOM

IMPULSIVE FORCE ACTS AT DISTANCE h_0 ABOVE TANK BOTTOM

TANK INERTIA FORCE ACTS AT DISTANCE R (TANK RADIUS) ABOVE TANK BOT.

TANK BOTTOM IS 8" ABOVE THE FLOOR, ∴ NET OVERTURNING MOMENT

$$M_{SLOSH} = F_{SLOSH} (h_1 + 8")$$

$$M_{IMPUL} = F_{IMPUL} (h_0 + 8")$$

$$M_{TANK} = F_{TANK} (R + 8")$$

$$\text{TOTAL OTM} = M_{SLOSH} + M_{IMPUL} + M_{TANK}$$

$$Q = \frac{OTM}{11'}$$

REV	BY	DATE	CHECKED	DATE			
0	DKN	11-15-90	[illegible]	11/13/90	BIG ROCK EMERGENCY CONDENSER		
					IMPELL CORPORATION	JOB NO 0540-064-1359 CALC NO CA-0540-064-001	PAGE 39 OF 65

MODAL FORCE VECTORS HAVE ALREADY BEEN CALCULATED

FOR THE OLD SPECTRA :

1^{st} MODE $\{F\}_1 = \begin{Bmatrix} 14727^{\#} \\ 22.4^{\#} \end{Bmatrix}$ 2^{ND} MODE $\{F\}_2 = \begin{Bmatrix} -53.8^{\#} \\ 36449^{\#} \end{Bmatrix}$ ✓

PG 16

FORCE AT COORDINATE 2 IS DUE TO COMBINED MASS OF IMPULSIVE FLUID MASS AND TANK MASS.

$W_o = 20248^{\#}$ IMPULSIVE FLUID WT PG 26 ✓

$W_{TANK} = 32192^{\#}$ TANK DEAD WT PG 26 ✓

$W_o + W_{TANK} = 52440^{\#}$ ✓

FRACTION DUE TO IMPULSIVE MASS $= \frac{20248}{52440} = 0.386$ ✓

FRACTION DUE TO TANK WT. $= \frac{32192}{52440} = 0.614$ ✓

$h_1 = 9.87'$ (INCL. BOTTOM PRESSURE) PG 25 ✓

$h_o = 8.25'$ (INCL. BOTTOM PRESSURE) PG 24 ✓

FOR 1^{ST} MODE

$F_{SLOSH} = 14727^{\#}$ ✓

$M_{SLOSH} = (14727^{\#})(9.87' + 0.67') = 155223^{\#-'}$ ✓

$F_{IMPUL} = 0.386 \times 22.4^{\#} = 8.65^{\#}$ ✓

$M_{IMPUL} = (8.65^{\#})(8.25' + 0.67') = 77^{\#-'}$ ✓

REV	BY	DATE	CHECKED	DATE	
0	DKN	11-15-90	PG	11/13/91	BIG ROCK EMERGENCY CONDENSER

IMPELL CORPORATION

JOB NO 0540-064-1359

CALC NO CA-0540-064-001

1st MODE :

$F_{TANK} = 0.614 \times 22.4^{\#} = 13.8^{\#}$ ✓

$M_{TANK} = (13.8^{\#})(5' + 0.67') = 78^{\#-1}$ ✓

$OTM = M_{SLOSH} + M_{IMPUL} + M_{TANK}$

$= 155223 + 77 + 78 = 155378^{\#-1}$ ✓

FOR 2ND MODE PG 40

$F_{SLOSH} = -153.8^{\#}$ ✓

$M_{SLOSH} = -153.8^{\#}(9.87' + 0.67') = -1621^{\#-1}$ ✓

$F_{IMPUL} = 0.386 \times 36449^{\#} = 14069^{\#}$ ✓

$M_{IMPUL} = (14069^{\#})(8.25' + 0.67') = 125495^{\#-1}$ ✓

$F_{TANK} = 0.614(36449^{\#}) = 22380^{\#}$ ✓

$M_{TANK} = 22380^{\#}(5' + 0.67') = 126895^{\#-1}$ ✓

$OTM = -1621 + 125495 + 126895$

$= 250769^{\#-1}$ ✓

SRSS 2 MODES :

$OTM = (155378^2 + 250769^2)^{1/2}$

$= 295004^{\#-1}$ ✓ (OLD SPECTRA)

SADDLE REACTION $Q = \frac{295004}{11'} = \pm 26818^{\#}$ ✓ (OLD SPECTRA)

FOR THE NEW SPECTRA:

1ST MODE $\{F\}_1 = \begin{Bmatrix} 8284^{\#} \\ 10.8^{\#} \end{Bmatrix}$ ✓ 2ND MODE $\{F\}_2 = \begin{Bmatrix} -76.9^{\#} \\ 18224^{\#} \end{Bmatrix}$

PG 36, 37

FOR 1ST MODE

$F_{SL} = 8284^{\#}$ ✓

$M_{SLOSH} = 8284^{\#}(9.87' + 0.67') = 87313^{\#-'}$ ✓

$F_{IMPUL} = 0.386 \times 10.8^{\#} = 4.2^{\#}$ ✓

$M_{IMPUL} = 4.2^{\#}(8.25' + 0.67') = 37^{\#-'}$ ✓

$F_{TANK} = 0.614 \times 10.8^{\#} = 6.6^{\#}$ ✓

$M_{TANK} = 6.6^{\#}(5' + 0.67') = 37^{\#-'}$ ✓

$OTM = 87313 + 37 + 37 = 87387^{\#-'}$ ✓

FOR 2ND MODE

$F_{SLOSH} = -76.9^{\#}$

$M_{SLOSH} = -76.9^{\#}(9.87' + 0.67') = -811^{\#-'}$ ✓

$F_{IMPUL} = 0.386 \times 18224^{\#} = 7034^{\#}$ ✓

$M_{IMPUL} = 7034^{\#}(8.25' + 0.67') = 62743^{\#-'}$ ✓

$F_{TANK} = 0.614 \times 18224^{\#} = 11190^{\#}$ ✓

$M_{TANK} = 11190^{\#}(5' + 0.67') = 63447^{\#-'}$ ✓

$OTM = -811 + 62743 + 63447 = 125379^{\#-'}$ ✓

SSRS 2 MODES $OTM = (87387^2 + 125379^2)^{1/2} = 152828^{\#-'}$ ✓

REV	BY	DATE	CHECKED	DATE	
0	DKN	11-15-90	DW	11/19/90	BIG ROCK EMERGENCY CONDENSER

IMPELL CORPORATION

JOB NO 0540-064-1359

CALC NO CA-0540-064-001

SUMMARY - LONGITUDINAL DIRECTION

FOR THE OLD SPECTRA

BASE SHEAR V = 39178 LB ✓ PG 32

OVERTURNING MOMENT M = 295004 FT-LB ✓ PG 41

MAX SLOSHING FLUID PRESS = 171 PSF

MAX IMPULSIVE FLUID PRESS = 202 PSF ✓

SRSS FLUID PRESSURE = $(171^2 + 202^2)^{1/2}$ = 265 PSF ✓

= 1.84 PSI ✓

FOR THE NEW SPECTRA

BASE SHEAR V = 19953 LB ✓ PG 37

OVERTURNING MOMENT M = 152828 FT-LB ✓ PG 42

MAX SLOSHING FLUID PRESS = 96 PSF ✓

MAX IMPULSIVE FLUID PRESS = 101 PSF

SRSS FLUID PRESSURE = $(96^2 + 101^2)^{1/2}$ = 139 PSF ✓

= 0.97 PSI ✓

RE-EVALUATE TANK SHELL STRESSES AT SADDLE HORN USING REVISED SHEAR AND MOMENT FROM HYDRODYNAMIC EVALUATION.

TRANSVERSE DIRECTION (NS)

TRANSVERSE LOADING INCLUDING HYDRODYNAMIC EFFECTS INFLUENCES BEAM BENDING STRESS AT THE SUPPORT AND THE LOCAL MEMBRANE & SHEAR STRESS AT THE HORN.

FOR NEW BASE SHEAR, V, EACH SADDLE RESISTS FORCE $Q = \frac{1}{2}V$

• BEAM BENDING STRESS - PG 2 OF REF 1

$\sigma_x = 7.46 \times 10^{-6}\, Q C_L$

Q IN LBS
C_L = DIST. FROM TANK AXIS TO HORN
σ_b IN PSI

$C_L = 43.88"$ PG 6 OF REF 1

FOR OLD SPECTRA $Q = \frac{1}{2}V = \frac{1}{2}(35999^{\#}) = 18000^{\#}$ PG 23

$\sigma_x = (7.46 \times 10^{-6})(18000^{\#})(43.88")$

$= 5.9$ PSI ✓ (OLD SPECTRA)

FOR NEW SPECTRA $Q = \frac{1}{2}V = \frac{1}{2}(22470^{\#}) = 11235^{\#}$ PG 23

$\sigma_x = (7.46 \times 10^{-6})(11235^{\#})(43.88")$

$= 3.7$ PSI ✓ (NEW SPECTRA)

REV	BY	DATE	CHECKED	DATE	
0	DKN	11.13.90	[illegible]	11.15.90	BIG ROCK EMERGENCY CONDENSER

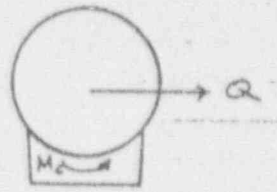
IMPELL CORPORATION

JOB NO 0540-064-1359
CALC NO CA-0540-064-001
PAGE 44 OF 65

• LOCAL STRESSES @ HORN DUE TO TRANSVERSE LOAD.

FROM PG 5 OF REF 1

$$\sigma_\phi = 2.52\left(\frac{M_c}{R^2 \beta t}\right)$$



M_c = OTM RESISTED BY SADDLE

R = TANK RADIUS = 60"

β = 0.41 BIJLAARD PARAMETER

t = THICKNESS = 1/2"

$$\sigma_x = 6.56\left(\frac{M_c}{R^2 \beta t}\right)$$

$$\tau_{x\phi} = \frac{Q}{4C_1 t} = 0.01Q$$

FOR OLD SPECTRA :

TOTAL V = 35999# ✓ TOTAL M = 153885#-' ✓ PG 23

Q = 1/2(35999) = 18000# ✓ M_c = 1/2(153885#-') = 76943#-' ✓

$$\sigma_\phi = 2.52\left(\frac{76943 \times 12}{60^2 \times 0.41 \times 0.5}\right) = \pm 3153 \text{ PSI}$$ ✓

$$\sigma_x = 6.56\left(\frac{76943 \times 12}{60^2 \times 0.41 \times 0.5}\right) = \pm 8207 \text{ PSI}$$ ✓

$$\tau_{x\phi} = 0.01(18000\#) = \pm 180 \text{ PSI}$$ ✓

0	DKN	11-13-90	[illegible]	11/13/90	BIG ROCK EMERGENCY CONDENSER
					JOB NO 0540-064-1359 / PAGE 45 OF 65
REV	BY	DATE	CHECKED	DATE	IMPELL CORPORATION — CALC NO CA-0540-064-001

FOR NEW SPECTRA :

TOTAL V = 22470# TOTAL M = 98691#-1 PG 23

$Q = \frac{1}{2}(22470^{\#}) = 11235^{\#}$ $M_c = \frac{1}{2}(98691^{\#\text{-}1}) = 49346^{\#\text{-}1}$

$\sigma_\phi = 2.52\left(\frac{49346 \times 12}{60^2 \times 0.41 \times 0.5}\right) = \pm \underline{2022 \text{ PSI}}$

$\sigma_x = 6.56\left(\frac{49346 \times 12}{60^2 \times 0.41 \times 0.5}\right) = \pm \underline{5264 \text{ PSI}}$

$\tau_{x\phi} = 0.01 \times 11235^{\#} = \pm \underline{112 \text{ PSI}}$

STRESSES DUE TO FLUID PRESSURE

DYNAMIC FLUID PRESSURES ARE GENERALLY LOW - CONSERVATIVELY ASSUME THE MAX FLUID PRESSURE IS UNIFORM WITHIN THE TANK TO ESTIMATE SHELL MEMBRANE STRESSES. RESULTING STRESSES WILL BE SMALL WRT OTHER SEISMIC MEMBRANE STRESSES - ASSUMPTION WON'T HAVE LARGE IMPACT ON OVERALL RESULTS

OLD SPECTRA : TRANSVERSE DIRECTION

MAX FLUID PRESS = 139.3PSF = 0.97PSI PG 23

$\sigma_\phi = \frac{PR}{t} = \frac{0.97 \times 60''}{0.5''} = \underline{116 \text{ PSI}}$

$\sigma_x = \frac{PR}{2t} = \frac{(0.97\ PSI)(60")}{2(0.5")}$

$= \underline{58\ PSI}$ ✓ OLD SPECTRA

NEW SPECTRA : TRANSVERSE

MAX FLUID PRESS = 97 PSF = 0.67 PSI PG 23

$\sigma_\phi = \frac{(0.67\ PSI)(60")}{0.5"} = \underline{80\ PSI}$ ✓

$\sigma_x = \frac{(0.67\ PSI)(60")}{2(0.5")} = \underline{40\ PSI}$ ✓

REV	BY	DATE	CHECKED	DATE	
0	DKH	11-14-90	[illegible]	11/13/90	BIG ROCK EMERGENCY CONDENSER

IMPELL CORPORATION

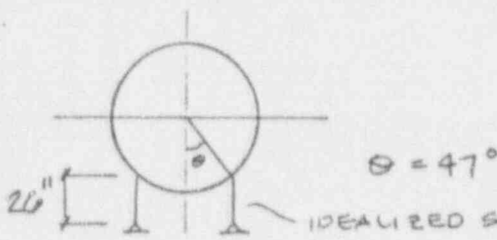
JOB NO 0540-064-1359

CALC NO CA-0540-064-001

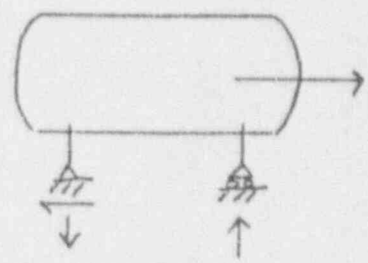
LONGITUDINAL DIRECTION (EW)

FIXED SUPPORT RESISTS ALL OF THE LONG. SEISMIC SHEAR.

FROM REF 1, THE FIXED SUPPORT SADDLE IS IDEALIZED AS 2 LEGS, EACH 26" HIGH, SINCE ONLY THOSE PARTS OF THE SADDLE ARE EFFECTIVE IN TRANSMITTING LOAD TO THE SHELL.



$\theta = 47°$

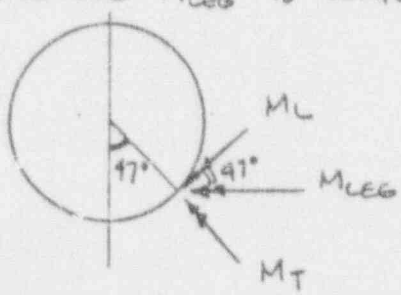


EACH LEG RESISTS HALF OF THE TOTAL BASE SHEAR

FOR BASE SHEAR V, $V_{LEG} = \frac{1}{2} V$

$$M_{LEG} = V_{LEG} \times 26"$$

RESOLVE M_{LEG} TO COMPONENTS CONSISTENT WITH SHELL AXES.



$M_L = M_{LEG} \cos 47°$

$M_T = M_{LEG} \sin 47°$

CONSIDERING MEMBRANE STRESS ONLY

$$\frac{N\phi}{(M_L / R_m^2 \beta)} = 13$$

BIJLAARD ANALYSIS w/ $\beta = 0.1$ $\gamma = 120$ FROM PG 12 OF REF 1.

$$\frac{N_x}{(M_L / R_m^2 \beta)} = 4.5$$

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0	PKN	11.13.90	JJW	11/13/90	BIG ROCK EMERGENCY CONDENSER		
					IMPELL CORPORATION	JOB NO 0540-064-1359	PAGE 48
						CALC NO CA-0540-064-001	OF 65

$$\sigma_\phi = C_L \frac{N_\phi}{t} = C_L \times 13 \frac{M_L}{R_m^2 \beta t}$$ $C_L = 0.90$ PG 12 REF 1, $\beta = 0.1$ $t = 1/2"$

$$\sigma_x = C_L \frac{N_x}{t} = C_L \times 4.5 \frac{M_L}{R_m^2 \beta t}$$ $C_L = 0.95$ PG 12, REF 1

$$\tau_{x\phi} = \frac{V_{LEG}}{4 c_1 t} + \frac{M_T}{2\pi r^2 t}$$ $c_1 = 6"$ $r = 6"$ PG 12 REF 1

FOR THE OLD SPECTRA :

$V = 39178^{\#}$ TOTAL BASE SHEAR PG 43

$V_{LEG} = \frac{1}{2}(39178) = 19589^{\#}$

$M_{LEG} = V_{LEG} \times 26" = 19589^{\#} \times 26" = 509314^{\#-"}$

$M_L = M_{LEG} \cos 47° = 509314 \cos 47° = 347351^{\#-"}$

$M_T = M_{LEG} \sin 47° = 509314 \sin 47° = 372489^{\#-"}$

$$\sigma_\phi = 0.9 \times 13 \frac{M_L}{R_m^2 \beta t} = 0.9 \times \frac{13 \times 347351}{(60)^2 (0.10)(0.5)} = 22578 \text{ PSI}$$

$$\sigma_x = 0.95 \times 4.5 \frac{M_L}{R_m^2 \beta t} = \frac{0.95 \times 4.5 \times 347351}{(60)^2 (0.10)(0.50)} = 8250 \text{ PSI}$$

$$\tau_{x\phi} = \frac{V_{LEG}}{4 c_1 t} + \frac{M_T}{2\pi r^2 t}$$

$$= \frac{19589}{4 \times 6" \times 0.5"} + \frac{372489}{2\pi (6")^2 (0.5")} = 4926 \text{ PSI}$$

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IMPELL CORPORATION

JOB NO 0540-064-1359

CALC NO CA-0540-064-001

BENDING STRESS IN THE SUPPORT LEG

$$\sigma_b = \frac{M_{LEG}\, c}{I} \qquad I = 72\ \text{in}^4 \quad c = 6" \qquad \text{PG 11 REF 1.}$$

$$= \frac{509314^{\#-"} \times 6"}{72} = \underline{42443\ \text{PSI}}$$

$> \text{YIELD} = 35\ \text{KSI}$

FOR THE NEW SPECTRA

$V = 19953^{\#}$ TOTAL BASE SHEAR PG 43

$V_{LEG} = 1/2\,(19953) = 9977^{\#}$

$M_{LEG} = V_{LEG} \times 26" = 9977^{\#} \times 26" = 259402^{\#-"}$

$M_L = M_{LEG} \cos 47° = 259402 \cos 47° = 176912^{\#-"}$

$M_T = M_{LEG} \sin 47° = 259402 \sin 47° = 189715^{\#-"}$

$$\sigma_\phi = 0.9 \times 13\ \frac{M_L}{R_m^2 \beta t} = 0.9 \times 13 \times \frac{176912}{(60)^2 (0.10)(0.5)} = \underline{11499\ \text{PSI}}$$

$$\sigma_x = 0.95 \times 4.5\ \frac{M_L}{R_m^2 \beta t} = 0.95 \times 4.5 \times \frac{176912}{(60)^2 (0.10)(0.5)} = \underline{4202\ \text{PSI}}$$

$$\tau_{x\phi} = \frac{V_{LEG}}{4 c_1 t} + \frac{M_T}{2\pi r^2 t}$$

$$= \frac{9977}{4 \times 6 \times 0.5} + \frac{189715}{2\pi (6)^2 (0.5)} = \underline{2509\ \text{PSI}}$$

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IMPELL CORPORATION

JOB NO 0540-064-1359

CALC NO CA-0540-064-001

SUPPORT LEG BENDING STRESS

$$\sigma_b = \frac{M_{LEG}\, C}{I}$$

$$= \frac{259402^{\#\text{-}''} \times 6''}{72} = 21617 \text{ PSI}$$

σ_b < YIELD STRESS

< ALLOWABLE STRESS = 2.25S = 36.7 KSI PG 11 REF 1

SHELL STRESS DUE TO FLUID PRESSURE

CONSERVATIVELY ASSUME MAX FLUID PRESSURE IS UNIFORM IN THE TANK.

FOR THE OLD SPECTRA :

MAX FLUID PRESSURE = 265 PSF = 1.84 PSI PG 43

$$\sigma_\phi = \frac{PR}{t} = \frac{(1.84 \text{ PSI})(60'')}{0.5''} = \underline{221 \text{ PSI}}$$

$$\sigma_x = \frac{PR}{2t} = \frac{(1.84)(60)}{2 \times 0.5} = \underline{110 \text{ PSI}}$$

FOR THE NEW SPECTRA

MAX FLUID PRESSURE = 139 PSF = 0.97 PSI PG 43

$$\sigma_\phi = \frac{(0.97 \text{ PSI})(60'')}{0.5} = \underline{116 \text{ PSI}}$$

$$\sigma_x = \frac{(0.97 \text{ PSI})(60')}{(2)(0.5'')} = \underline{58 \text{ PSI}}$$

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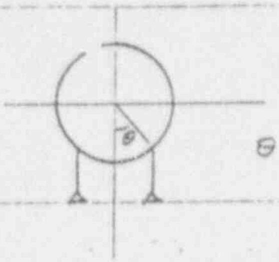
IMPELL CORPORATION

JOB NO 0540-064-1359

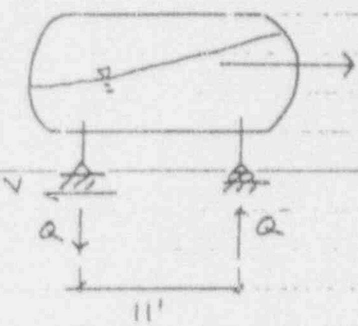
CALC NO CA-0540-064-001

LONGITUDINAL DIRECTION (EW)

EVALUATE STRESSES DUE TO VERTICAL FORCE IN SUPPORTS FROM THE TANK OVERTURNING MOMENT. FROM REF 1, IDEALIZE THE SADDLE SUPPORT AS 2 LEGS,



$\theta \approx 47°$

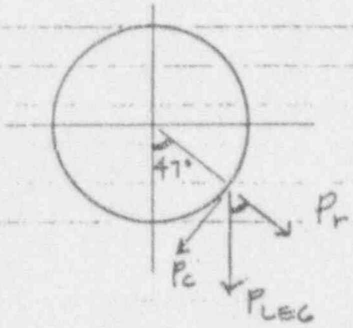


SADDLE REACTION $Q = OTM/11'$

EACH LEG RESISTS HALF OF THE SADDLE REACTION

$$P_{LEG} = \tfrac{1}{2} Q = \frac{OTM}{2 \times 11'}$$

RESOLVE P_{LEG} TO RADIAL AND CIRCUMFERENTIAL COMPONENTS



$P_r = P_{LEG} \cos 47°$

$P_c = P_{LEG} \sin 47°$

P_r INDUCES SHELL MEMBRANE STRESS

P_c INDUCES SHEAR STRESS

USE BIJLAARD METHOD TO EVALUATE SHELL STRESSES REF 7.

FROM REF 1 - ATTACHMENT DIMENSIONS FOR LEG GIVE

$$\beta = \frac{c}{R} = \frac{6}{60"} = 0.1$$

$$\gamma = \frac{R}{t} = \frac{60}{0.5} = 120$$

FROM FIG 3C REF 7

$$\frac{N_\phi}{P/R_m} = 12.5$$

$$\sigma_\phi = \frac{N_\phi}{t} = \frac{N_\phi}{P/R_m} \times \frac{P_r}{R_m t} = 12.5 \frac{P_r}{R_m t}$$

FROM FIG 3C REF 7

$$\frac{N_x}{P/R_m} = 12.5$$

$$\sigma_x = \frac{N_x}{t} = \frac{N_x}{P/R_m} \times \frac{P_r}{R_m t} = 12.5 \frac{P_r}{R_m t}$$

$$\tau_{\phi x} = \frac{P_c}{4 c_1 t} = \frac{P_c}{4 \times 6" \times 0.5} = 0.0833 P_c$$

THESE STRESSES SHOULD BE ADDED TO THE STRESSES RESULTING FROM THE SUPPORT LEG MOMENT.

FOR THE OLD SPECTRA :

$OTM = 295004^{\#-1}$ ✓ PG 43

$P_{LEG} = \frac{OTM}{2 \times 11'} = \frac{295004}{2 \times 11'} = 13409^{\#}$ ✓

$P_r = P_{LEG} \cos 47° = 13409 \cos 47° = 9145^{\#}$ ✓

$P_c = P_{LEG} \sin 47° = 13409 \sin 47° = 9807^{\#}$ ✓

$\sigma_\phi = 12.5 \frac{P_r}{Rt} = 12.5 \times \frac{9145}{60 \cdot 0.5} = \underline{3810 \text{ PSI}}$ ✓

$\sigma_x = 12.5 \frac{P_r}{Rt} = \underline{3810 \text{ PSI}}$ ✓

$\tau_{\phi x} = \frac{P_c}{4 c_1 t} = \frac{9807}{4 \times 6" \times 0.5} = \underline{817 \text{ PSI}}$ ✓

FOR THE NEW SPECTRA :

$OTM = 152828^{\#-1}$ ✓ PG 43

$P_{LEG} = \frac{OTM}{2 \times 11'} = \frac{152828}{2 \times 11'} = 6947^{\#}$ ✓

$P_r = P_{LEG} \cos 47° = 6947 \cos 47° = 4738^{\#}$ ✓

$P_c = P_{LEG} \sin 47° = 6947 \sin 47° = 5081^{\#}$ ✓

$\sigma_\phi = (4738/9145)(3810 \text{ PSI}) = \underline{1974 \text{ PSI}}$ ✓

$\sigma_x = \underline{1974 \text{ PSI}}$ ✓

$\tau_{\phi x} = (5081/9807)(817 \text{ PSI}) = \underline{423 \text{ PSI}}$ ✓

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IMPELL CORPORATION

JOB NO 0540-064-1359

CALC NO CA-0540-064-001

PAGE 54 OF 65

SUMMARY - LOCAL SHELL STRESSES FOR LONGITUDINAL (EW) EQ.

OLD SPECTRA : PGS 49 + 54

		DUE TO M		DUE TO P	
σ_ϕ	=	22578	+	3810	= 26388 PSI ✓
σ_x	=	8250	+	3810	= 12060 PSI ✓
$\tau_{x\phi}$	=	4926	+	817	= 5743 PSI ✓

NEW SPECTRA : PGS 50 + 54

σ_ϕ	=	11499	+	1974	= 13473 PSI ✓
σ_x	=	4202	+	1974	= 6176 PSI ✓
$\tau_{x\phi}$	=	2509	+	423	= 2932 PSI ✓

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STRESS COMBINATION AT SADDLE HORN - OLD SPECTRA

LOADING	σ_x (PSI)	σ_ϕ (PSI)	τ (PSI)	
DEAD LOAD (BEAM BENDING)	-17	0	625	
HYDROSTATIC PRESSURE	219	438	0	1g DOWN
D.L. LOCAL MEMBRANE @ HORN	0	-2367	0	
NORMAL STRESS (TOTAL)	202	-1929	625	
VERT. SEISMIC (BEAM BENDING)	-3	0	125	
VERT. SEISMIC (PRESSURE STRESS)	44	88	0	0.2g DOWN
VERT. SEISMIC (LOCAL MEMBR. @ HORN)	0	-473	0	
VERTICAL SEISMIC (TOTAL)	41	-385	125	
LATERAL SEISMIC (BEAM BENDING)	± 6	0	± 180	INCL. HYDRODYN. EFFECTS
LATERAL SEISMIC (PRESSURE STRESS)	± 58	± 116	0	
LATERAL SEISMIC (LOCAL MEMBR. @ HORN)	∓ 8207	∓ 3153	0	
LATERAL SEISMIC (TOTAL)	∓ 8143	∓ 3037	± 180	
LONG. SEISMIC (PRESSURE STRESS)	± 110	± 221	0	INCL. HYDRODYN EFFECTS
LONG. SEISMIC (LOCAL MEMBR. @ HORN)	± 12060	± 26388	0	
LONG. SEISMIC (SHEAR FLOW)	0	0	± 5743	
LONG. SEISMIC (TOTAL)	± 12170	± 26609	± 5743	
SRSS OF SEISMIC	± 14643	± 26785	± 5747	
NORMAL + SSE	- 14441	- 28714	6372	

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JOB NO 0540-064-1359

CALC NO CA-0540-064-001

STRESS COMBINATION AT SADDLE HORN - NEW SPECTRA

LOADING	σ_x (PSI)	σ_ϕ (PSI)	τ (PSI)	
DEAD LOAD (BEAM BENDING)	-17	0	625	
HYDROSTATIC PRESSURE	219	438	0	1.1g DOWN
LOCAL MEMBRANE @ HORN	0	-2367	0	
NORMAL STRESS (TOTAL)	202	-1929	625	
VERT. SEISMIC (BEAM BENDING)	-2	0	94	
VERT. SEISMIC (PRESSURE STRESS)	33	66	0	0.15g DOWN
VERT. SEISMIC (LOCAL MEMBR. @ HORN)	0	-355	0	
VERTICAL SEISMIC (TOTAL)	31	-289	94	
LATERAL SEISMIC (BEAM BENDING)	± 4	0	± 112	
LATERAL SEISMIC (PRESSURE STRESS)	± 40	± 80	0	INCL. HYDRODYN. EFFECTS.
LATERAL SEISMIC (LOCAL MEMBR. @ HORN)	∓ 5264	∓ 2022	0	
LATERAL SEISMIC (TOTAL)	∓ 5220	∓ 1942	± 112	
LONG. SEISMIC (PRESSURE STRESS)	± 58	± 116	0	
LONG. SEISMIC (LOCAL MEMBR. @ HORN)	± 6176	± 13473	0	INCL. HYDRODYN. EFFECTS
LONG. SEISMIC (SHEAR FLOW)	0	0	± 2932	
LONG. SEISMIC (TOTAL)	± 6234	± 13589	± 2932	
SRSS OF SEISMIC	± 8131	± 13730	± 2936	
NORMAL + SSE	-7929	-15659	3561	

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IMPELL CORPORATION

JOB NO 0540-064-1359

CALC NO CA-0540-064-001

PAGE 57 OF 65

PRINCIPAL STRESSES - OLD SPECTRA

$$S_1 = \left(\frac{-28714 - 14441}{2}\right) - \left[\left(\frac{28714 - 14441}{2}\right)^2 + (6372)^2\right]^{1/2}$$

$= -31145$ PSI ✓

$$S_2 = \left(\frac{-28714 - 14441}{2}\right) + \left[\left(\frac{28714 - 14441}{2}\right)^2 + (6372)^2\right]^{1/2}$$

$= -12010$ PSI ✓

$S_3 = 0$

MAX STRESS INTENSITY $S = S_1 - S_3 = -31145$ PSI ✓

ALLOWABLE $= 2.4S = 2.4(16300) = 39120$ PSI ✓ REF 1

$$M.S. = 1 - \frac{31145}{39120} = \underline{+0.204}$$ ✓

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JOB NO 0540-064-1359

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PRINCIPAL STRESSES - NEW SPECTRA

$$S_1 = \left(\frac{-15659 - 7929}{2}\right) - \left[\left(\frac{15659 - 7929}{2}\right)^2 + (3561)^2\right]^{1/2}$$

$= -17049$ PSI ✓

$$S_2 = \left(\frac{-15659 - 7929}{2}\right) + \left[\left(\frac{15659 - 7929}{2}\right)^2 + (3561)^2\right]^{1/2}$$

$= -6539$ PSI ✓

$S_3 = 0$

MAX STRESS INTENSITY $S = S_1 - S_3 = -17049$ PSI ✓

$$M.S = 1 - \frac{17049}{39120} = \underline{+0.564}$$ ✓

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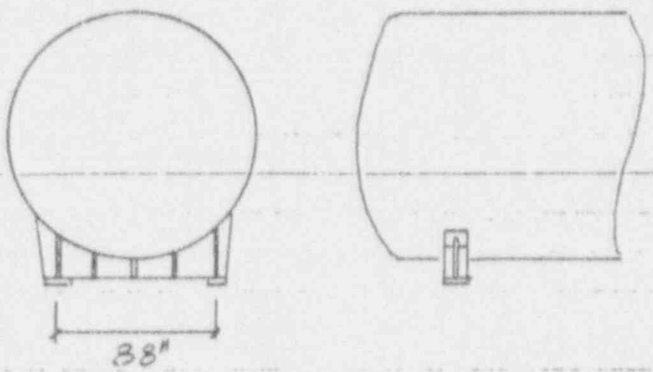
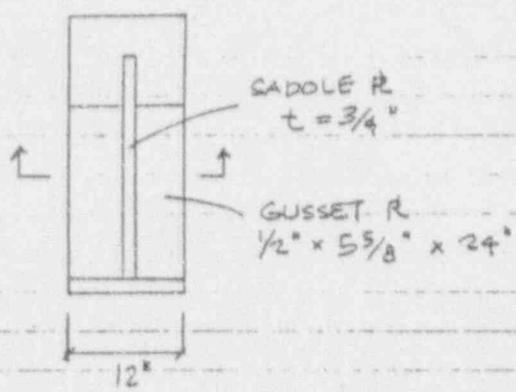
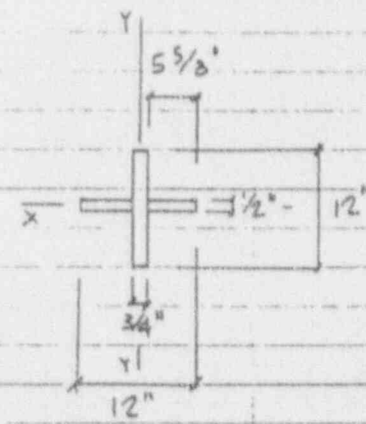
REV	BY	DATE	CHECKED	DATE	IMPELI CORPORATION — JOB NO 0540-064-1359 — CALC NO CA-0540-064-001 — PAGE 59 OF 65

SADDLE SUPPORT STRESS

AS IN REF 1 ASSUME A 12" × 12" CRUCIFORM SECTION AT EACH END OF THE SADDLE IS EFFECTIVE IN CARRYING LOAD FROM THE SHELL TO THE FLOOR.







EFFECTIVE SECTION FOR CARRYING LOAD

$A = 12 \times 3/4 + 2(5.625 \times 1/2)$

$= 14.63 \text{ IN}^2$ ✓

$I_{YY} = 72 \text{ IN}^4$ ✓ REF 1

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IMPELL CORPORATION

JOB NO 0540-064-1359

CALC NO CA-0540-064-001

PAGE 60 OF 65

CALCULATE F = AND STRESS IN SUPPORT LEG FOR DL & SEISMIC

TANK OPERATING WT = 99240#

FOR 1 LEG

P_{DL} = 99240#/4 = 24810# ✓

σ = 24810#/14.63 = 1696 PSI ✓ COMPRESS.

VERTICAL SEISMIC f_v > 33 Hz REF 1

@ 33 Hz S_a = 0.20 g OLD SPECTRA REF 2

@ 33 Hz S_a = 0.15 g NEW SPECTRA REF 3

P_v = 0.2 (99240 /4) = 4962# ✓ OLD SPECTRA

σ = 4962/14.63 = 339 PSI ✓ OLD SPECTRA

σ = (0.15/0.20) 339 = 254 PSI ✓ NEW SPECTRA

TRANSVERSE (LATERAL) SEISMIC

OTM = 153885#-' ✓ OLD SPECTRA PG 23

P_L = 153885#-' / (2 SADDLES)(88"/12) = 10492# ✓

σ = 10492#/14.63 = 717 PSI ✓ OLD SPECTRA

OTM = 98691#-' NEW SPECTRA PG 23

σ = [(98691/153885)](717) = 460 PSI ✓ NEW SPECTRA

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JOB NO 0540-064-1359

CALC NO CA-0540-064-001

LONGITUDINAL SEISMIC

OLD SPECTRA $P_{LEG} = 13409^{\#}$ $M_{LEG} = 509314^{\#-''}$ PG 49, 54

$$\sigma = \frac{13409}{14.63} + \frac{509314 \times 6}{72} = 43359 \text{ PSI}$$

NEW SPECTRA $P_{LEG} = 6947^{\#}$ $M_{LEG} = 259402^{\#-''}$ PG 50, 54

$$\sigma = \frac{6947}{14.63} + \frac{259402 \times 6}{72} = 22092 \text{ PSI}$$

SRSS SEISMIC STRESS

OLD SPECTRA $\sigma = (339^2 + 717^2 + 43359^2)^{1/2} = \pm 43366$ PSI

NEW SPECTRA $\sigma = (254^2 + 460^2 + 22092^2)^{1/2} = \pm 22098$ PSI

DL + SEISMIC:

$\sigma = -1696 - 43366 = 45062$ PSI OLD SPECTRA

ALLOWABLE $= 2.25S = 2.25(16300) = 36675$ PSI [REF 1]

$$M.S. = 1 - \frac{45062}{36675} = -0.229$$ OLD SPECTRA

NEW SPECTRA $\sigma = -1696 - 22098 = 23794$ PSI

$$M.S = 1 - \frac{23794}{36675} = 0.351$$ NEW SPECTRA

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IMPELL CORPORATION

JOB NO 0540-064-1359

CALC NO CA-0540-064-001

PAGE 62 OF 65

RESULTS SUMMARY

INCLUDING THE HYDRODYNAMIC EFFECTS, SLOSHING AND IMPULSIVE FLUID RESPONSE, WITH THE OLD SSE SPECTRA [REF 2], THE TANK SHELL REMAINS ELASTIC AND MEETS THE ALLOWABLE STRESS CRITERION. THE SADDLE SUPPORT STRESS EXCEEDS THE YIELD STRESS AND THE ALLOWABLE STRESS. USING THE NEW SSE SPECTRA [REF 3], THE TANK SHELL AND THE SUPPORT SADDLE STRESSES REMAIN ELASTIC AND BELOW THE ALLOWABLE LIMITS.

	OLD SPECTRA	NEW SPECTRA
TANK SHELL MAX STRESS INTENSITY	31145 PSI (M.S. = +0.204)	17050 PSI (M.S. = +0.564)
SADDLE SUPPORT AXIAL + BENDING STRESS	45060 PSI (M.S. = -0.229)	23790 PSI (M.S. = +0.351)

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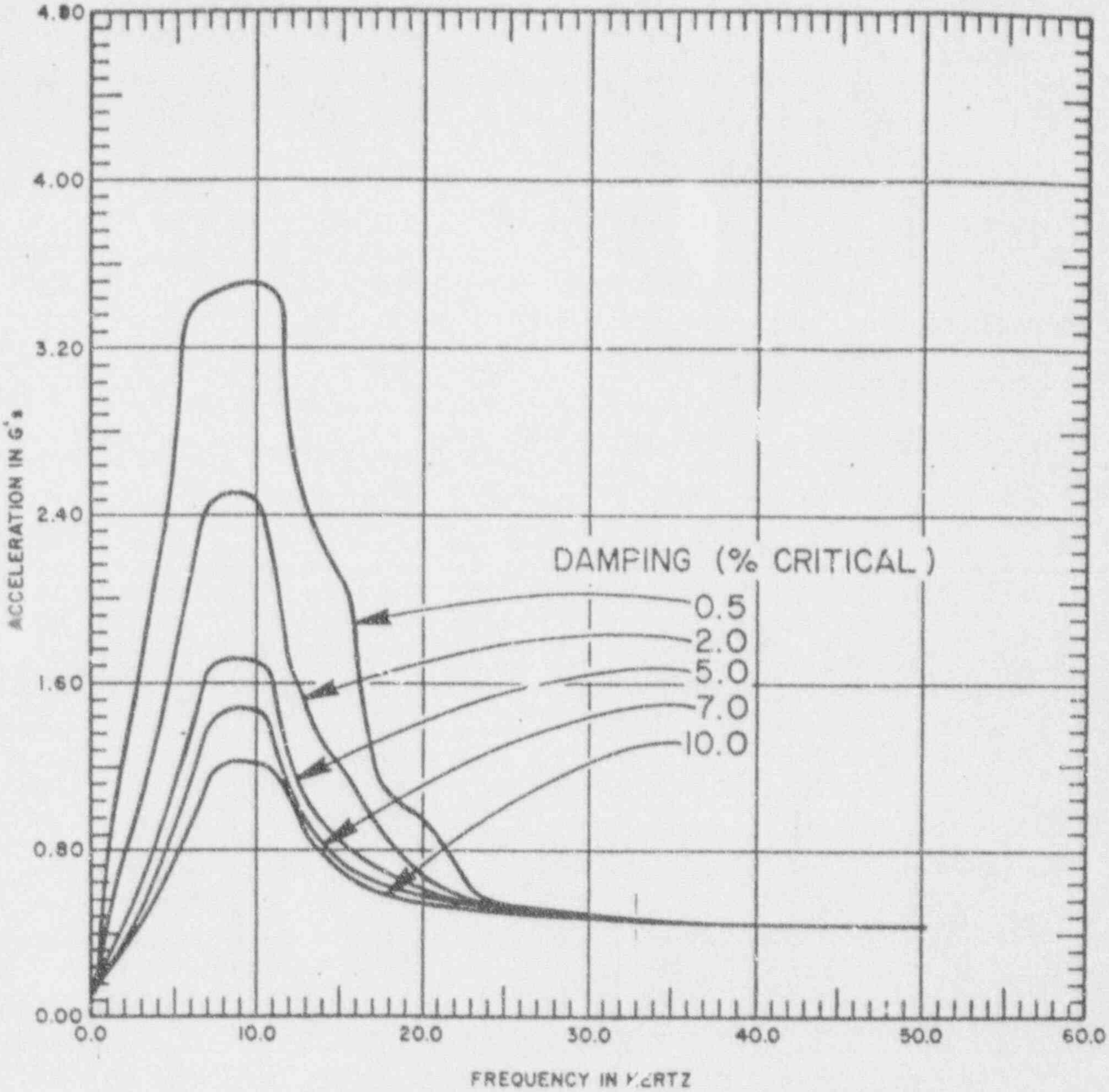

NODE 650 — DIRECTION X

FIGURE A-25

FLOOR RESPONSE SPECTRA
ELEVATION 657'-6"
SHEET 1 OF 3
REACTOR BUILDING AND CONTAINMENT SHELL
BIG ROCK POINT NUCLEAR POWER PLANT
PREPARED FOR

CONSUMERS POWER COMPANY
JACKSON, MICHIGAN

D'APPOLONIA

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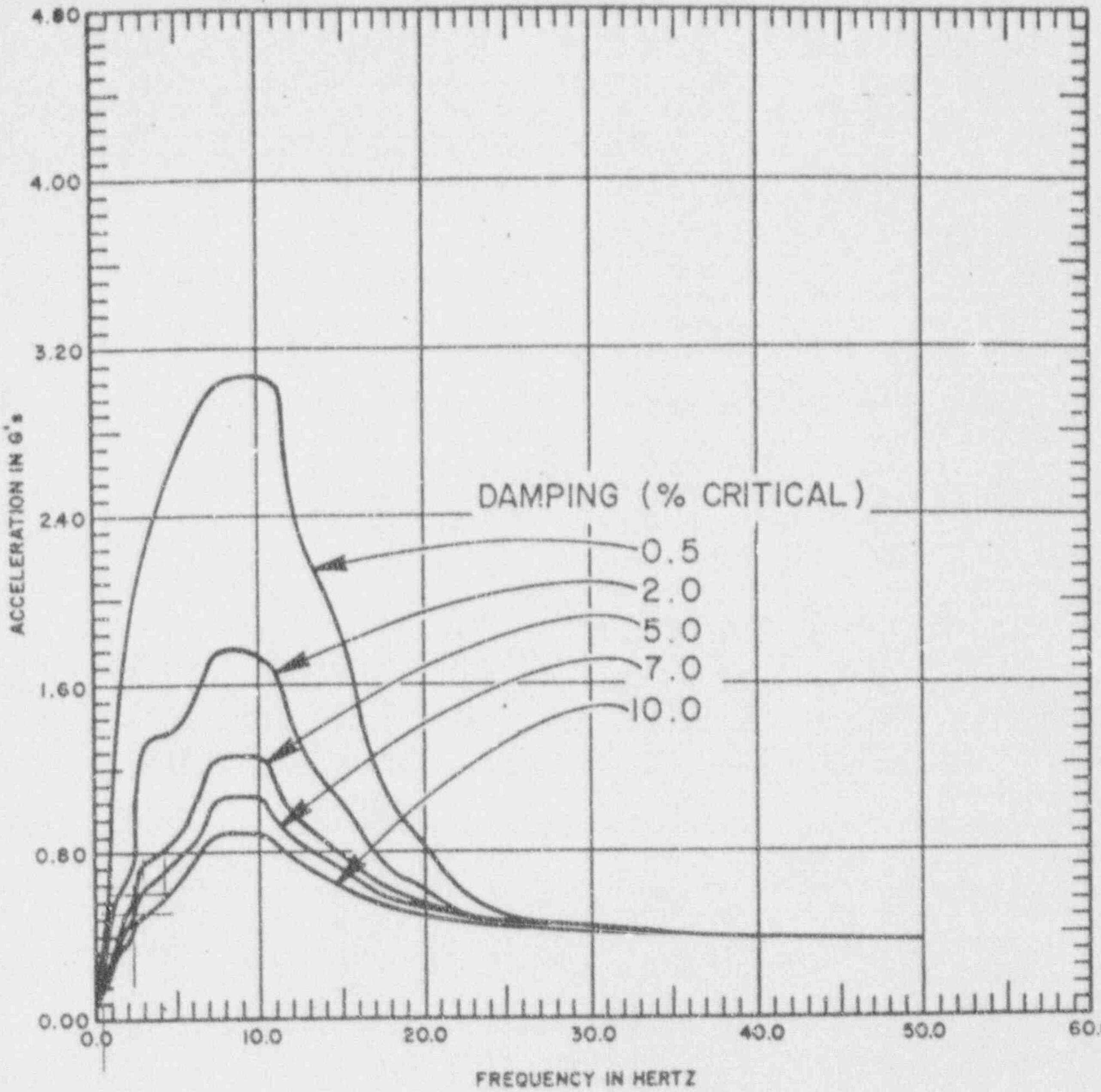


NODE 650 — DIRECTION Y

FIGURE A-26

FLOOR RESPONSE SPECTRA
ELEVATION 657'-6"
SHEET 2 OF 3
REACTOR BUILDING AND CONTAINMENT SHELL
BIG ROCK POINT NUCLEAR POWER PLANT

PREPARED FOR

CONSUMERS POWER COMPANY
JACKSON, MICHIGAN

D'APPOLONIA

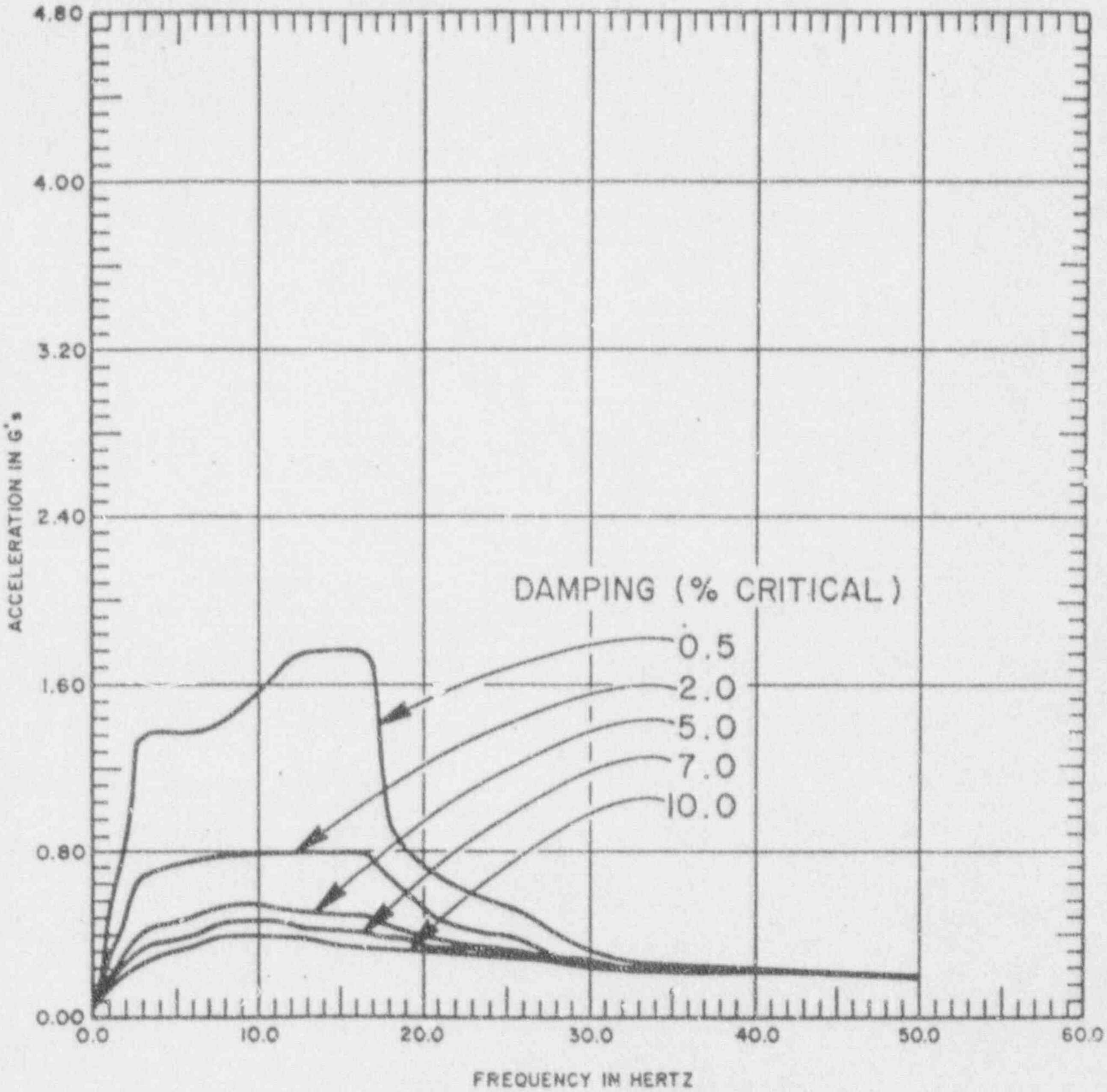
0000 8258 0541

JOB NO 0540-064-1359

CALC NO. CA-0540-064-001 ATTACH. 3 OF 6

VERT

DRAWN BY | 7/7/80 | CHECKED BY | APPROVED BY | DRAWING NUMBER 78-435C-A82



NODE 650 — DIRECTION Z

FIGURE A-27

FLOOR RESPONSE SPECTRA
ELEVATION 657'-6"
SHEET 3 OF 3
REACTOR BUILDING AND CONTAINMENT SHELL
BIG ROCK POINT NUCLEAR POWER PLANT

PREPARED FOR

CONSUMERS POWER COMPANY
JACKSON, MICHIGAN

D'APPOLONIA

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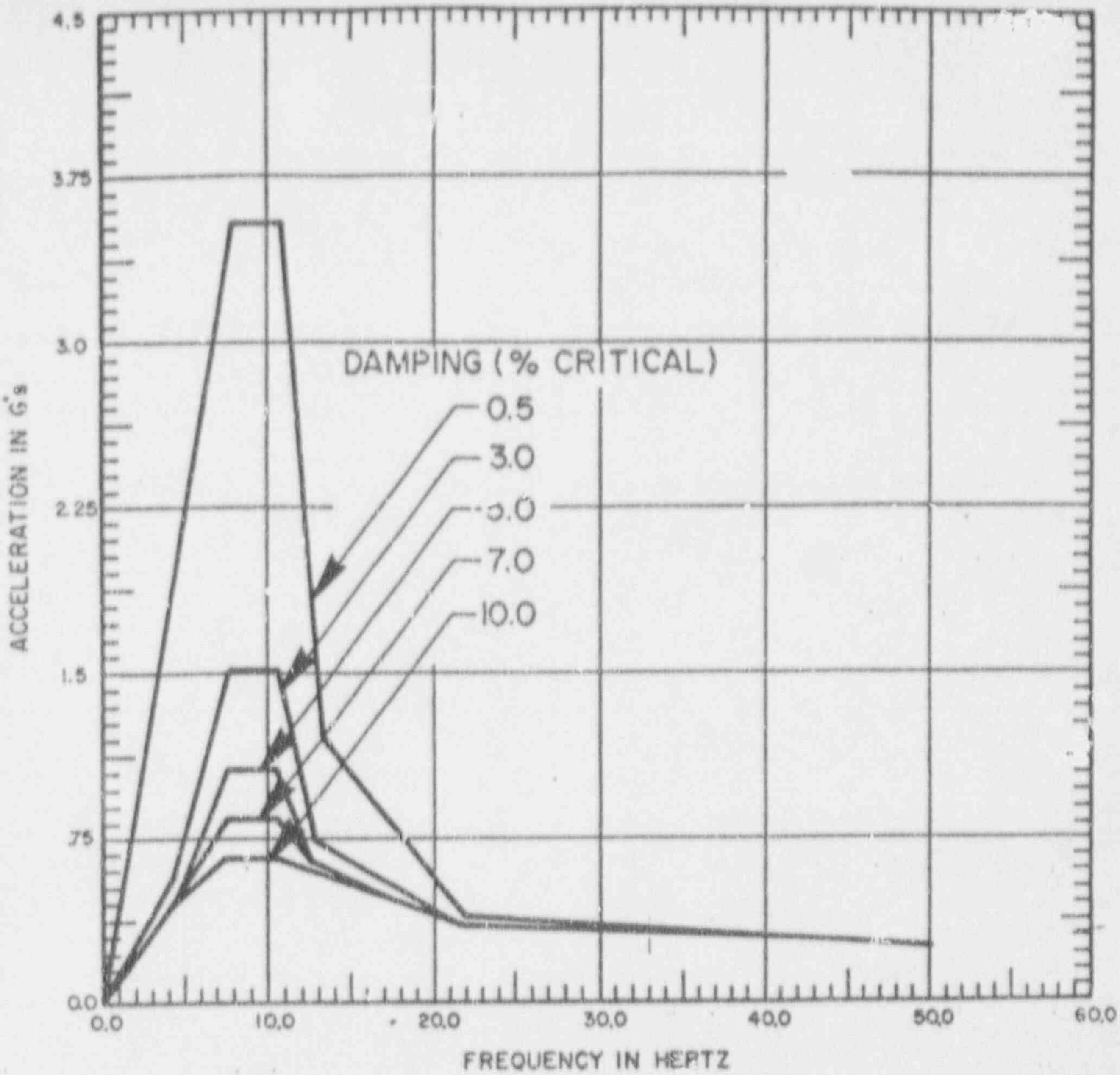

EMERGENCY CONDENSER DECK
DIRECTION X

FIGURE 5.1-1
REACTOR INTERNAL STRUCTURE
NODE 650 ELEVATION 657'-6"
SHEET 1 OF 3

SITE SPECIFIC EARTHQUAKE
FLOOR RESPONSE SPECTRA
BIG ROCK POINT NUCLEAR POWERPLANT
PREPARED FOR
CONSUMERS POWER COMPANY
JACKSON, MICHIGAN

D'APPOLONIA

JOB NO 0540-064-1359
CALC NO. CA-0540-064-001 ATTACH. 5 OF 6

EW - LONG

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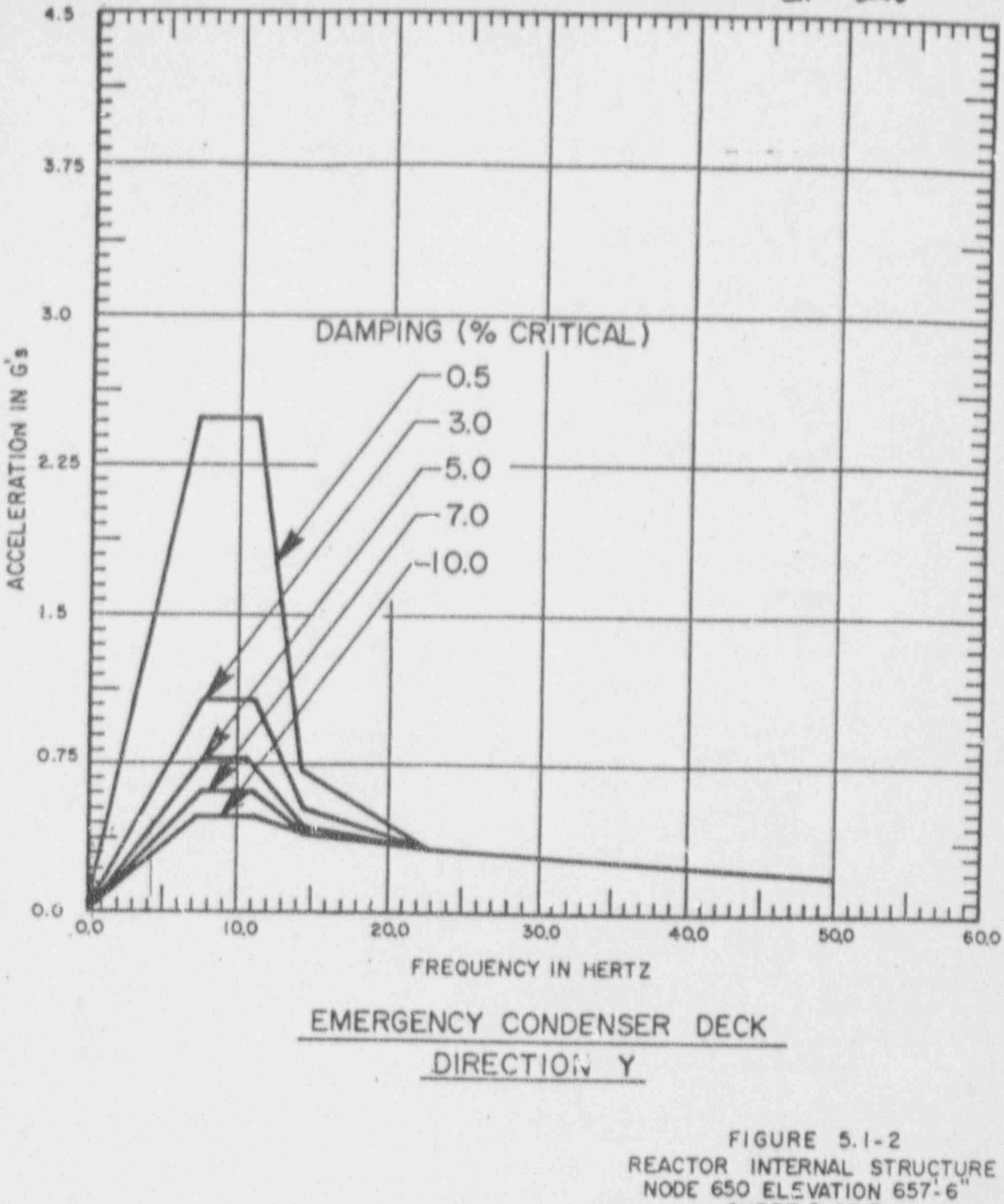
	3-19-82	APPROVED BY			



EMERGENCY CONDENSER DECK

DIRECTION Y

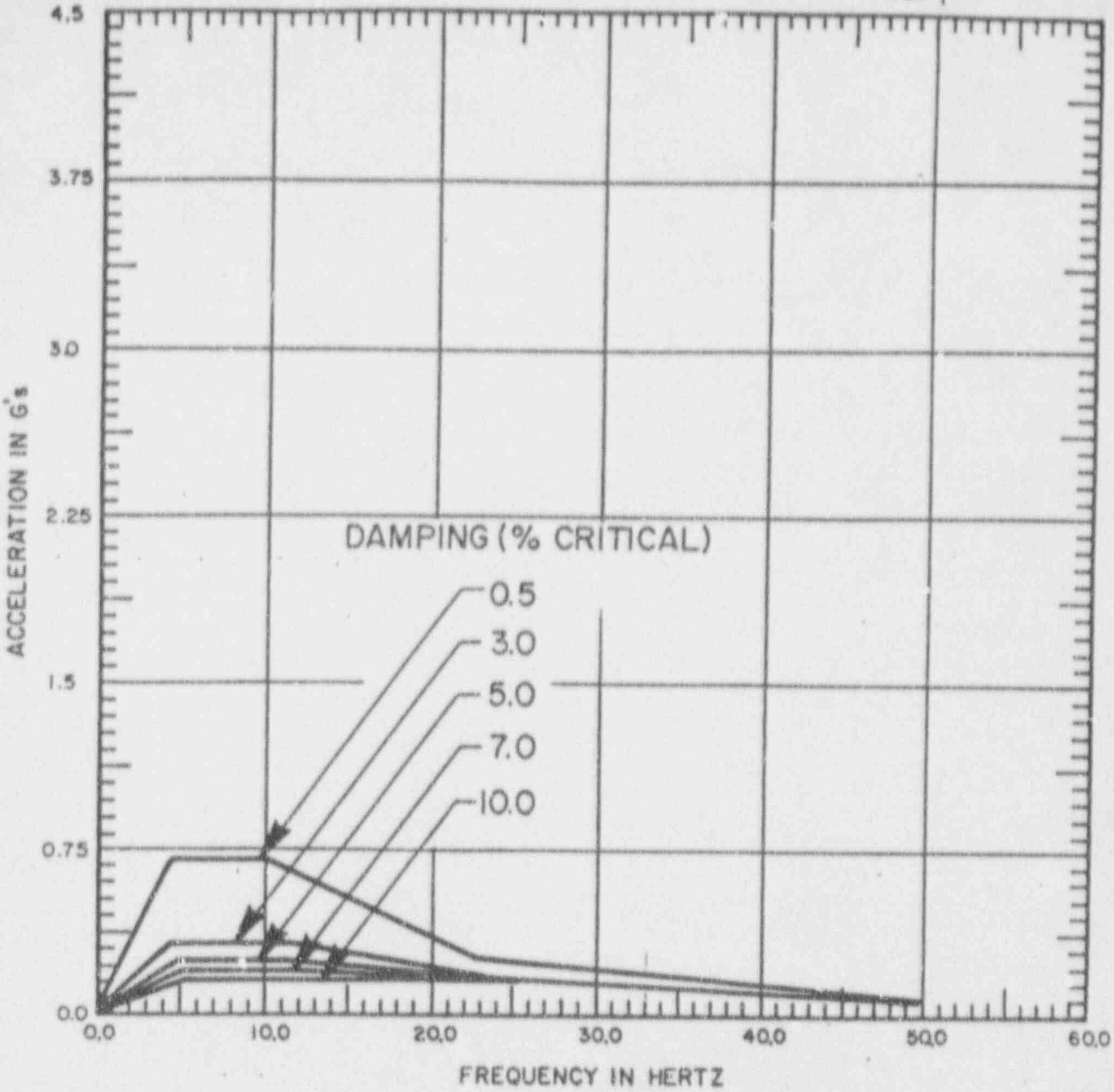
FIGURE 5.1-2
REACTOR INTERNAL STRUCTURE
NODE 650 ELEVATION 657'-6"
SHEET 2 OF 3

SITE SPECIFIC EARTHQUAKE
FLOOR RESPONSE SPECTRA
BIG ROCK POINT NUCLEAR POWER PLANT
PREPARED FOR

CONSUMERS POWER COMPANY
JACKSON, MICHIGAN

D'APPOLONIA

VERT



EMERGENCY CONDENSER DECK

DIRECTION Z

FIGURE 5.1-3

REACTOR INTERNAL STRUCTURE
NODE 650 ELEVATION 657'-6"
SHEET 3 OF 3

SITE SPECIFIC EARTHQUAKE
FLOOR RESPONSE SPECTRA
BIG ROCK POINT NUCLEAR POWER PLANT
PREPARED FOR
CONSUMERS POWER COMPANY
JACKSON, MICHIGAN

D'APPOLONIA

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	3-19-82	APPROVED BY			

STRUCTURAL
MECHANICS
ASSOCIATES
A Calif. Corp.
160 Birch Street, Newport Beach, Calif. 92660 (714) 833-7552

SMA 13702.01-C021

December 4, 1981

Mr. Rolfe B. Jenkins
Consumers Power Company
1945 W. Parnall Road
Jackson, MI 49201

Some recalculations have not been finalized, although the calculations provide a reasonable guide as to what equipment requires further support work.

Dear Mr. Jenkins:

SMA has performed seismic calculations of several vessels at Big Rock Point as part of our workscope under Purchase Order CP10-1691Q. Results of some of the calculations are negative and some modifications to supports will be necessary to meet the acceptance criteria proposed by CPC to the USNRC. The vessels analyzed and general conclusions are summarized as follows:

<u>Emergency Condenser</u> - Saddle support on anchored end needs to be modified to increase longitudinal earthquake capacity. There are five stiffening gussets on the saddle but only the two outboard gussets are tied to the floor. These gussets are overstressed to a point that revised site specific spectra and consideration of ductility will not alter the conclusions. The tube bundle does not have any positive lateral support. It is cradled in three channels that are positioned in an arc. Upon application of a lateral seismic load the bundle wants to move along the arc as a pendulum. A simple hand calculation indicates that the bundle is acceptable as is: thus, no modification of the internals appears necessary.

<u>Clean-Up Demineralizer</u> - The demineralizer is a vertical vessel supported by three 3-1/2 X 3-1/2 X 5/16 angle legs. The support legs are considerably overstressed and should be modified to meet acceptance criteria. Revised spectra and consideration of ductility are not anticipated to alter the conclusion.

<u>Non Regenerative Heat Exchanger</u> - This is a long vertical vessel supported by two lugs. The support lugs are overstressed by a large amount and an additional lateral support near the bottom of the heat exchanger is required. The heat exchanger is a 12 inch pipe with 3 inch and 6 inch pipe attached; thus, it really does not act as a pipe anchor. Final evaluation of the heat exchanger should be conducted in a dynamic system model including the attached piping loops.

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<u>Liquid Poison Tank</u> - This tank, though mounted high in the containment structure where accelerations are the greatest, is acceptable as is.

<u>Core Spray Test Tank</u> - This tank is normally empty; thus, the support system is acceptable as is. This is not safety related but serves as an anchor for a branch line from a safety related line.

Calculations and summary sheets for the above vessels are attached for your information. No attempt has been made to design any fixes for the above vessels. If automatic isolation valves are installed in the demineralizer system then the non-regenerative heat exchanger and demineralizer tank should not be considered as safety related and may not need fixing.

We are still waiting on detailed drawings and loads information for other components. I will coordinate directly with Barry Rogers with my want list.

If you have any questions regarding the attached calculations, please don't hesitate to call.

Very truly yours,

STRUCTURAL MECHANICS ASSOCIATES, INC.

R D Campbell

Robert D. Campbell
Project Manager

RDC:mw
Enclosure

SEISMIC EVALUATION SUMMARY OF EQUIPMENT

I. PLANT NAME: Big Rock

1. Utility: Consumers Power Co   TYPE: BWR [✓]
2. NSSS: GE   PWR [ ]
3. A-E: Bechtel

II. COMPONENT NAME: Emergency Condenser Tank

1. Model Number: NA   Quantity: 1
2. Vendor: AQUA - CHEM / Cleaver-Brooks
3. If the component is a cabinet or panel, name and model no. of the devices included: ______
4. Physical Description is:
   a. Appearance: Tank / twin saddle supports / Horizontal
   b. Dimensions: 10'-0"Φ x 20'-7" long
   c. Weight: Operating Wt 99,240 lbs
5. Location: Building: Containment Bldg
   Elevation: 661'-0" (Base)
6. Field Mounting Conditions: [✓] Bolt 16 - 7/8"Φ
   [ ] Weld ______
   [ ] ______
7. Natural Frequencies in Each Direction:
   Y-Y 3.0 cps   X-X & Z-Z Stiff

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8. a. Functional Description: Shutdown heat removal

b. Is the equipment required for [✓] Hot standby
[✓] Cold Shutdown [ ] LOCA

9. Pertinent Reference Design Specifications: NA

III. EQUIPMENT EVALUATION METHOD: [ ] Test

[✓] Analysis

[ ] Combination of Test & Analysis

Test and/or Analysis by: Structural Mechanics Assoc.
(Name of Company or Lab and Report No.)

IV. VIBRATION INPUT:

1. Loads Considered [✓] Seismic
[✓] Pressure
[✓] Temperature
[ ] Other (Specify) ______
[ ] Combination of ______

2. Required Response Spectra: X-X, Y-Y, + Z-Z Spectra @ Elev. 657'-6" D'Appolonia Report, F.; A.15 A.16 A.2

3. Required Acceleration in Each Direction: (Support)
0.65g Longitudinal (Y-Y) 0.48 g Lateral (X-X) 0.2g Vert (Z-Z

V. EVALUATION RESULTS:

1. Description of Test: NA

2. Method of Analysis:

[ ] Static [✓] Dynamic [ ] Equivalent Static

[✓] Response Spectrum [ ] Time History

3. Model Type: [ ] 3D [✓] 2D

[ ] Finite Element [ ] Beam

[ ] Closed Form Solution

4. Computer Codes: None

No. of Modes Considered: 1

[✓] Hand Calculation

5. Damping: 7%

6. Support Consideration: Saddle supports with only one end anchored longitudinally. Shell flexibility included in support flexibility

7. Critical Structural Elements: Gusset plates on saddle supports connecting base plate to doubler plate

Comparison with Code Allowable: σ_a = 71.5 ksi , σ_{allow} = 36.7 ksi

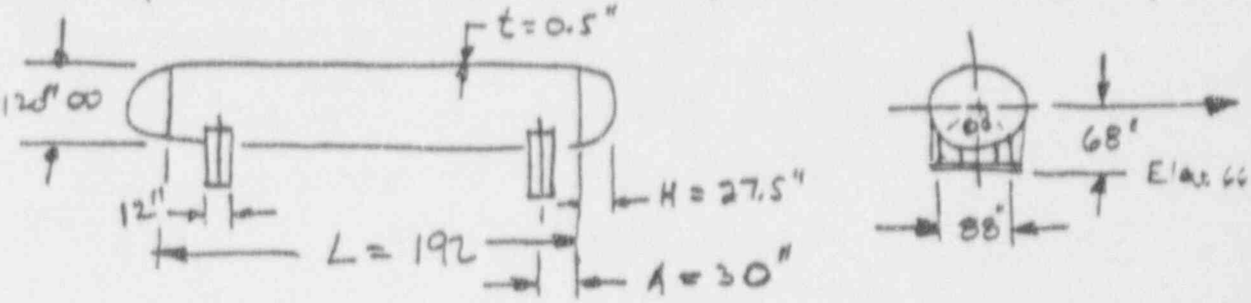
VI. QUALITY ASSURANCE

Checked by RDT/RDC Reviewed by RDC

Level of Checking All calculations checked

VII. COMMENTS Saddle supports, shell at saddle support junction and tube bundle were evaluated. Saddle support is only critical element. Nozzles not evaluated. They appear stronger than connecting pipe by inspection

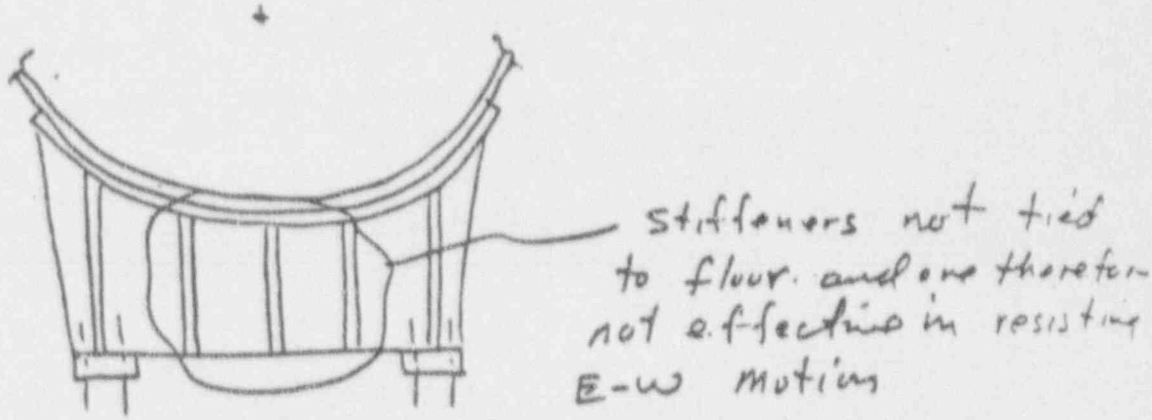
EMERGENCY CONDENSER — REF.: Clever-Brooks Draw. 172-[illegible]



Compute Response in Shell Due to Dead Weight plus Seismic. Use Spectra from Ref. 7, Elev. 657'6", Figs A-25 (N-S), A-26 (E-W), A-27 (V)

Compute response in 3 directions & resulting stresses.

Vessel and supports are rigid in N-S and vertical directions. Only one saddle is anchored in E-W Direction.



End View of Tank & Support

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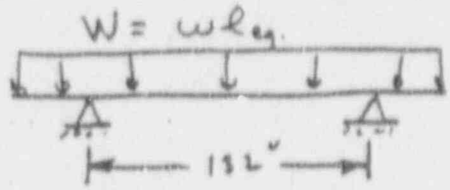
SHELL STRESSES DUE TO VERTICAL AND LATERAL LOADING.

VERTICAL LOAD is 1g D + 0.2g SSE (Fig A-27, Ref 7, $f_n > 33$)

Lateral load is 0.48 g (Fig A-25, Ref. 7, $f_n > 33$ Hz)

W = 99,240# Operating wt.

$W = w\ell_{eq}$



$\ell_{eq} = L + (4H/3)$ (Ref 6) $= 192 + \left(\frac{4(27.5)}{3}\right) = 228.67$

Shell is held round by stiffening rings near saddles & in center.

Saddle reaction = Q

Moment over saddle $= \left(\frac{QL}{4}\right)\left(\frac{4A}{L}\right)\left(1 - \frac{1 - \frac{A}{L} + \frac{R^2 - H^2}{2AL}}{1 + \frac{4H}{3L}}\right)$ Ref 6

$$M = 30Q \left[1 - \frac{1 - \frac{30}{192} + \frac{60^2 - 27.5^2}{2(30)(192)}}{1 + \frac{4(27.5)}{3(192)}}\right]$$

$M = 2.53Q$ in#

$$\sigma_b = \frac{Mc}{I}$$

$I = \pi R^3 t = \pi (60)^3 (.5) = 339292 \text{ in}^4$ (shell held round)

$$\sigma_b = \frac{2.53Q \; c}{3.393 \times 10^5} = 7.46 \times 10^{-6} \; Qc$$

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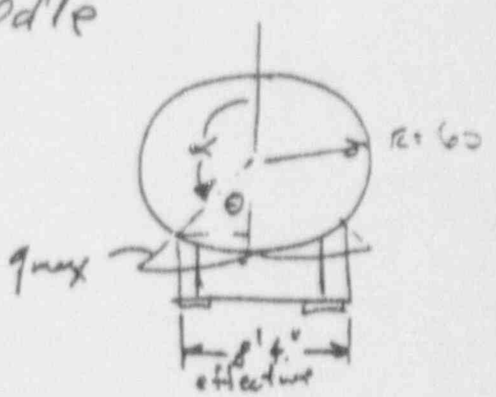
Tangential Shear Flow

Ref. 6, Fig 4, sect A-A - shell stiffened by rings adjacent to saddle.

q_{max} occurs at horn of saddle

$$q_{max} = \frac{Q \sin\alpha \; (L \cdot 2A - H)}{R(\pi - \alpha + \sin\alpha \cos\alpha)(L+H)}$$



$$\theta = \sin^{-1}\frac{50}{60} = 56.44°$$

$$\alpha = 180 - 56.44 = 123.56° = 2.156 \text{ rad.}$$

$$q_{max} = \frac{Q \sin 123.56° \; (192 - 60 - 27.5)}{60(\pi - 2.156 + \sin 123.56° \cos 123.56°)(192 + 27.5)} = 1.26 \times 10^{-2} Q$$

$$\tau = \frac{q_{max}}{2t} = \frac{1.26 \times 10^{-2} Q}{2(0.5)} = 1.26 \times 10^{-2} Q$$ (shear flow distributed to shell on both sides of saddle)

Membrane stress at saddle horn

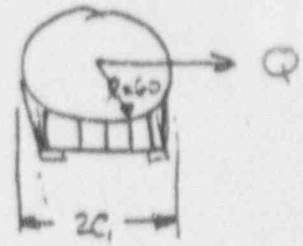
$$N_\phi = \int_{\phi=\alpha}^{\phi=\pi} q R\, d\phi = \int_{\phi=\alpha}^{\phi=\pi} \frac{Q \sin\phi\, R\, d\phi \;(L - 2A - H)}{R(\pi - \alpha + \sin\alpha\cos\alpha)(L+H)}$$

$$N_\phi = \frac{Q(L-2A-H)}{(\pi - \alpha + \sin\alpha \cos\alpha)(L+H)}\Big[-\cos\phi\Big]_\alpha^\pi$$

$$N_\phi = \frac{(192 - 60 - 27.5)Q}{(\pi - 2.156 + \sin 123.56° \cos 123.56°)(192 + 27.5)}\Big[1 - 0.553\Big] = 0.405 Q$$

$$\sigma_\phi = \frac{N_\phi}{A_{eff}} = \frac{0.405 Q}{t(b + 10t)} = \frac{0.405 Q}{0.5(12+5)} = 4.77 \times 10^{-2} Q$$ [b = saddle width = 12]

LATERAL LOAD



Use WRC 107 method for lateral load, Ref 4

$M = QR = 60Q$

$c_1 = 44+6 = 50''$

$c_2 = 6''$

$\beta_1 = \frac{c_1}{R_m} = \frac{50}{60} = .833 \qquad \beta_2 = \frac{c_2}{R_m} = \frac{6}{60} = 0.1$

For Membrane Forces

$$\beta = \sqrt[3]{\beta_1^2 \beta_2} = 0.41$$

C_c from Table 7,

$\beta_1/\beta_2 > 4$ therefore, assume $\beta_1/\beta_2 = 4$

$\gamma = \frac{R}{t} = 120$

$C_{c\phi} = 1.48$

$C_{cx} = 0.80$

$\frac{N_\phi}{Mc/R_m^2\beta} = 1.7(C_{c\phi}) = 1.7(1.48) = 2.52$ Fig 3A, Ref 4

$\frac{N_x}{Mc/R_m^2\beta} = 8.2(C_{cx}) = 8.2(0.8) = 6.56$ Fig 1A, Ref 4

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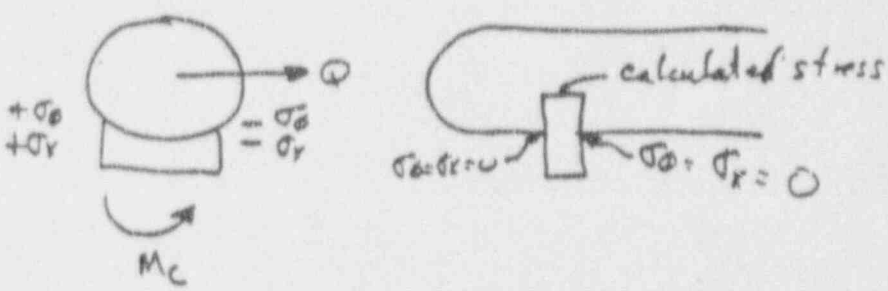
$$\sigma_\phi = 2.52\left(\frac{M_c}{R^2\beta t}\right) = \frac{2.52(60\,Q)}{(60)^2(0.41)(.5)} = 0.205\,Q$$

$$\sigma_x = 6.56\left(\frac{M_c}{R^2\beta t}\right) = \frac{6.56(60)(Q)}{60^2(0.41)(0.5)} = 0.533\,Q$$

signs are like at same point.



Membrane stresses apply at horn of saddle

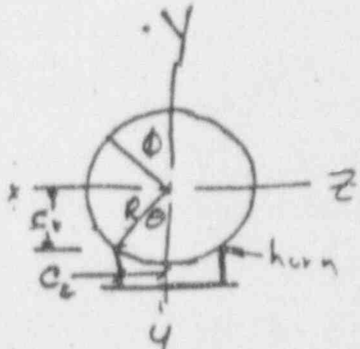
Shear Stress

$$\tau_{x\phi} = \frac{Q_L}{4 C_1 t} = 0.01\,Q$$

Worst combination of stresses will occur at horn of saddle for loading in all three directions. Therefore, compute shell stresses at horn of saddle for lateral and vertical loads.

$Q_V = \frac{1.2g}{2}(99240) = 59544^{\#}$

$Q_L = \frac{0.48g}{2}(99240) = 23820^{\#}$



θ = 47° at gusset in saddle.

Distance from axis to horn, c

$C_v = R\sin(90-\theta) = 40.92''$

$C_L = R\sin\theta = 43.88''$

$\sigma_{x_v} = -7.46\times10^{-6} Q_v C_v$

$= -7.46\times10^{-6}(59544)(40.92)$

$= 18.2$ psi

Seismic portion $= \frac{0.2}{1.2}(19.5) = -3$ psi

Dead wt, D, $= -17$ psi

$\sigma_{x_h} = \pm 7.46\times10^{-6} Q_L C_L$

$= \pm 7.46(10^{-6})(23820)(43.88)$

$= \pm 7.8$ psi

Tangential shear flow for vertical seismic + D

$Q_{V_D} = \frac{99240}{2} = 49620^{\#}$

$Q_{V_{SSE}} = 0.2(49620) = 9924^{\#}$

$\tau = 1.26 \times 10^{-2} Q$

$\tau_D = 1.26(10^{-2})49620 = 625$ psi

$\tau_{SSE} = 0.2(625) = 125$ psi

Membrane stress at saddle horn (circumferential

$\sigma_\phi = -4.77 \times 10^{-2} Q$

$\sigma_{\phi_D} = -4.77(10^{-2})(49620) = -2367$ psi

$\sigma_{\phi_{SSE}} = -4.77(10^{-2})(9924) = -473$ psi

Shear stress in shell for lateral seismic load

$\tau = 0.01 Q_L = 0.01(23820) = 238$ psi

Membrane stress at horn for lateral seismic load

$\sigma_\phi = 0.205 Q_L = 0.205(23820) = 4883$ psi

$\sigma_x = 0.533 Q_L = 0.533(23820) = 12696$ psi

Pressure Stress due to hydrostatic pressure and longitudinal and Lateral Earthquake

From hydrostatic pressure.

$$\sigma_x = \frac{pR}{2t} = \frac{120 \cdot R(1-\cos 47^\circ)\left(\frac{62.4}{1728}\right)(60)}{2(.5)} = +219$$

$$\sigma_\phi = \frac{pR}{t} = 438 \text{ psi}$$

From Long. Earthquake - $S_a = 0.65g$, 16' tank to support

$$\text{press} = 0.65(16')(12''/ft)\left(\frac{62.4}{1728}\right)\frac{\#}{in^3} = 4.5 \text{ psi}$$

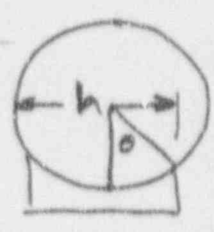
$$\sigma_x = \frac{4.5(60)}{2(.5)} = 270 \text{ psi}$$

$$\sigma_\phi = \frac{4.5(60)}{0.5} = 540$$

From Lateral Earthquake, $S_a = 0.48g$,

$$h = R + R\sin 47^\circ = 8.66'$$

$$p = \frac{8.66(62.4)}{144}(.48) = 1.8 \text{ psi}$$



$$\sigma_\phi = \frac{1.8(60)}{.5} = 216 \text{ psi}$$

$$\sigma_x = 108 \text{ psi}$$

Vertical Earthquake = 0.2 of Hydrostatic (1g) stress

$$\sigma_x = 44 \text{ psi}$$

$$\sigma_\phi = 88 \text{ psi}$$

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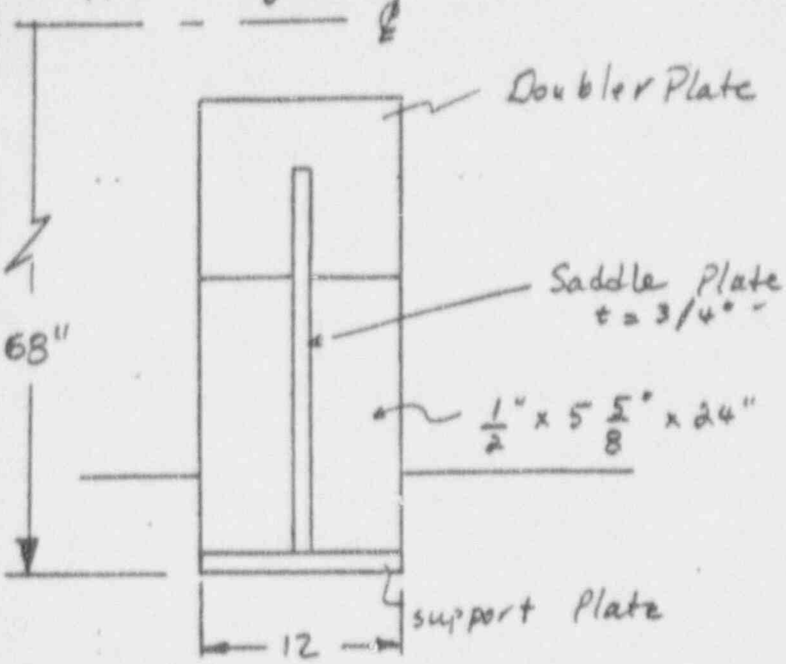
Support System

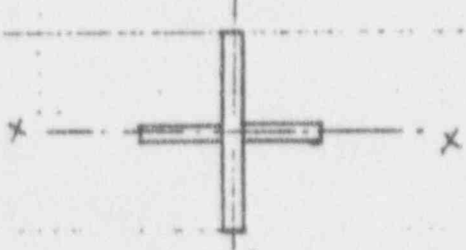


Doubler Plate ½" x 12 x 10'-10" (Arc = 124")

Shell ½" thick

→ Shell Axis

Assume a 12"x12" square part of the support is effective in transmitting the load into the shell. Other stiffeners are not anchored to floor and do not carry loading.



$I_{YY} = \frac{1}{12}\left(\frac{1}{2}\right)(12)^3 +$ ~~$2 \times \frac{1}{12}\left(\frac{12-\frac{1}{2}}{2}\right)\left(\frac{3}{4}\right)^3$~~ ≈ 0

$= 72$ in^4 (One on each side

Use Bijlaard's approach to estimate the shell flexibility (Ref 3)

$c_2 = 6"$ $c_1 = 6"$ $\beta = \frac{c}{a} = 0.1$. Approximate from $\beta_1 = 0.1$, $\beta_2 = 0.1$, $\beta = \sqrt[3]{\beta_1^2 \beta_2}$

$a = 60"$ tank radius

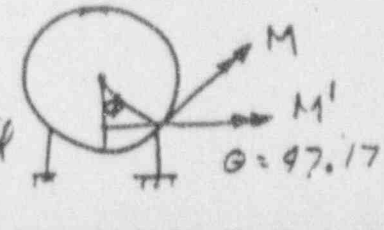
$E = 29.25 \times 10^6$

$\gamma = a/t = \frac{60}{0.5} = 120$

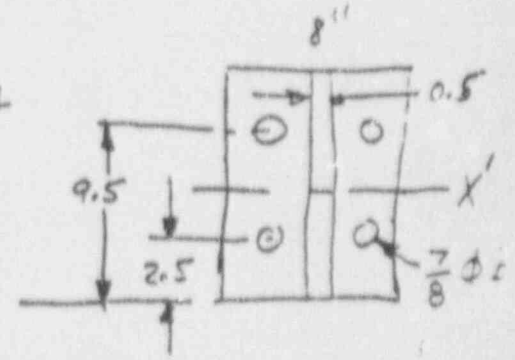
Fig. 7 Bijlaard's paper $\frac{\theta}{M/a^3\beta^2E} = 2600$ $\frac{M}{\theta} = \frac{a^3\beta^2E}{2600} = 24300$ K-in/rad

Transfer Moment to Vertical AXIS

$\frac{M'}{\theta} = \frac{M}{\theta \cos\phi} = \frac{24,300}{\cos 47.17°} = 35750$ K in/rad



Bolt Capacity to resist moment vs 1/2 x 12 saddle gusset.



$I_{x'-x'}$ ret $= \frac{bh^3}{12} = 72 \text{ in}^4$

stress area of bolts = 0.461

I_{x-x} bolt pattern

$I_{xx} = \sum(Ad^2 + I_o) = 2(0.461)[2.5^2 + 9.5^2] + 4I_o = 88.97 \text{ in}^4$ ($I_o \approx 0$)

Bolts are assumed to be A-307

S_y = 36 ksi for A-307

$S_y \sim 35$ ksi for A 212 Gr A Gusset

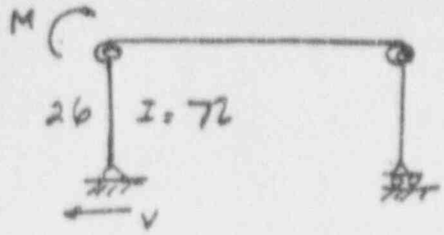
$M_{y_{bolt}} = \frac{I_{bolt}\,\sigma_{y_{bolt}}}{d_{max}} = \frac{88.97(36)}{9.5} = 337$ k-in

$M_{y_{gusset}} = \frac{I_{gusset}\,\sigma_{y_{gusset}}}{c} = \frac{72(35)}{6} = 420$ k-in

Bolt pattern is weaker and will not maintain moment fixity to yield gusset.

Pinned end model is valid.

Note, local yielding of bolt due to saddle rotation at base is strain controlled and is not considered a primary stress in anchor bolts



Operating Wt = 99,240 lbs

(ref. Dwg 271-34 C Cleaver-Brooks

$m = 0.2568$ Kip-sec²/in

$M = 26V \quad K_\theta = 35{,}750$

$\theta = \frac{26V}{K_\theta}$

$\delta_1 = 26\theta = \frac{26^2 V}{K_\theta} \qquad K_1 = \frac{V}{\delta_1} = \frac{K_\theta}{26^2} = 52.9$ Kip/in

$K_2 = \frac{3EI}{\ell^3} = \frac{3(35750)(72)}{26^3} = 439$ K/in

$K_\ell = 2/(1/K_1 + 1/K_2) = 94.4$ Kip/in

$\omega = \sqrt{\frac{K}{m}} = 19.17$ cps $\qquad f = 3.05$ cps

D'Appolonia Fig A-26 $S_a = 0.65g$ (7% damping)

$V = m S_a = 64.5$ Kips $\qquad$ 32.25 on each side

$M = 883.5$ Kip-in $\qquad \sigma = \frac{Mc}{I} = 69.9$ Ksi yielding in the support

Plates are made of A212 Gr A steel (discontinued)

$\sigma_y = 35$ Ksi

Plastic Moment capacity of the built-up support = 630 K-in (if no buckling occurs)

$S = 16.3$ Ksi $\qquad$ Allowable = 2.25 S = 36.7 Ksi

$D = \frac{99.24/4}{15 \text{ in}^2} = 1.65$ Ksi

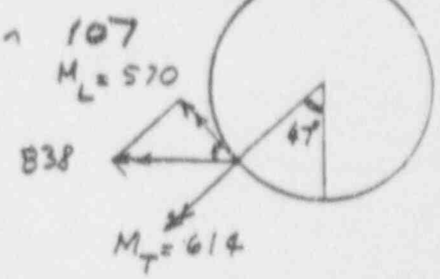
$S_1 = D + E = 71.55$ Ksi >> 36.7 Ksi allowable

Ductility of 1.3 won't reduce response to allowable!

$V = 32.25$ Kips

$M = 838.5$ Kip-in

From Welding Research Council Bulletin 107



$\beta_1 = \frac{c}{R_m} = \frac{6}{60} = 0.1$ $\quad \beta_2 = 0.1$ (because of bearing plate)

$\gamma = \frac{R_m}{T} = \frac{60}{0.5} = 120$

$\beta = \sqrt[3]{\beta_1^2 \beta_2} = 0.10$ $\quad (K_L = 1)$

$\frac{M_L}{R_m \beta} = \frac{570}{60 \times 0.10} = 95$ $\quad$ Fig 1B $\frac{M_\phi}{95} = 0.03$ $\quad M_\phi = 2.85$ K-in

Fig 2B $\frac{M_x}{95} = 0.043$ $\quad M_x = 4.08$ K-in/

$\frac{M_L}{R_m^2 \beta} = 1.58$ $\quad$ Fig 3B $\frac{N_\phi}{1.58} = 13$ $\quad N_\phi = 20.54$ K/in

Fig 4B $\frac{N_x}{1.58} = 4.5$ $\quad N_x = 7.11$ K/in

$\sigma_x = \frac{6M_x}{t^2} + \frac{N_x}{t}$ $\quad \frac{6M_x}{t^2}$ ignored because it is a secondary stress

$\sigma_x = 14.22$ Ksi $\quad C_L = 0.95$ $\quad \sigma_x = C_L(14.22) = 13.5$ Ksi

$\sigma_\phi = 41.08$ Ksi $\quad C_2 = 0.90$ $\quad \sigma_\phi = C_2(41.08) = 36.97$ Ksi

Stresses due to M_T ($\tau_{x\phi}$ & $\tau_{\phi x}$) are not critical & may be computed assuming a round attachment

Shear load $V = 32.2$ Kips on each side

$\tau_{x\phi} = \frac{V}{4 C_1 T} = 2.69$ Ksi

$\tau_{\phi x} = \frac{V}{4 C_2 T} = 2.69$ Ksi

For torsional moment $\tau_{x\phi} = \tau_{\phi x} = \frac{M_T}{2\pi r^2 T} = 5.42$ Ksi

(r = 6 in)

STRESS COMBINATIONS AT SADDLE HORN

Loading	σ_x	σ_ϕ	τ	Sign Convent
Dead wt. (Beam Bending	-17	0	625	1 g d.
Hydrostatic Press	219	438	0	
Local Membrane at Horn	0	-2367	0.	
Normal Stress (Total)	202	-1929	625	
Vertical Seismic (Beam Bending	-3	0	125	0.2 g d.
Vertical Seismic (Press Stress)	44	88	0	
Vertical Seismic (Local Membrane at horn)	0	-473	0	
Total Vertical Seismic	41	-385	125	
Lateral Seismic (Beam Bending)	±7	0	±238	
Lateral Seismic (Press Stress)	±108	±216	0	
Lateral Seismic (Local Membrane at horn)	∓12696	∓4883	0	
Total Lateral Seismic	∓12581	∓4667	±238	
Long Seismic (Press Stress)	±270	±540	0	
Long. Seismic (Local Membrane at horn)	±13500	±36970		
Long Seismic (Shear flow)	—	—	±8110	
Total Long. Seismic	±13770	±37510	±8110	
SRSS of Seismic	±18652	±37801	±8114	
Normal +SSE	-18450	-39730	8739	

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Principal Stresses

$$S_1 = \left(\frac{-39730 - 18528}{2}\right) - \sqrt{\left(\frac{39730-18528}{2}\right)^2 + (8739)^2} = \underline{-42868\ psi}$$

$$S_2 = \left(\frac{-39730 - 18528}{2}\right) + \sqrt{\left(\frac{39730-18528}{2}\right)^2 + 8739^2} = \underline{-15,390\ psi}$$

$S_3 = 0$

Max Stress Intensity $S = S_1 - S_3 = -42868$ psi

Allowable $= 2.4S = 2.4(16300) = 39,120$ psi

$$M.S. = 1 - \frac{42868}{39120} = -0.096$$

Apply Ductility of 1.3

Stress Response for seismic is reduced by $\frac{1}{F_\mu}$

$F_\mu = \sqrt{2(1.3)-1} = 1.26$

SSE – $\sigma_x = -14865$, $\sigma_\phi = -30000$ $\tau = 6400$

Normal + SSE – $\sigma_x = -14663$, $\sigma_\phi = -31929$ $\tau = 7065$

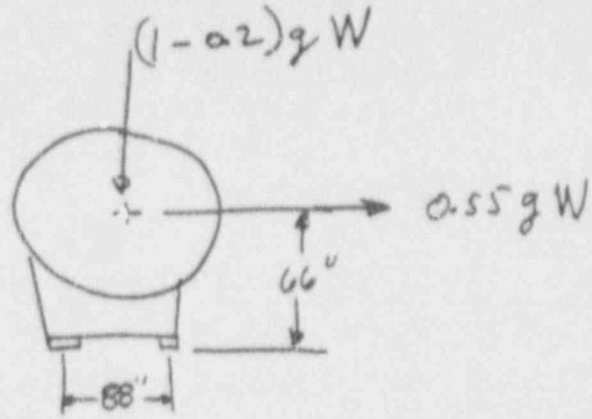
$$S_1 = \left(\frac{-31929 - 14663}{2}\right) - \sqrt{\left(\frac{31929 - 14663}{2}\right)^2 + 7065^2} = -34451$$

$S_2 = -12,141$

$S_3 = 0$

$S = S_1 - S_3 = 34451$

$$M.S. = 1 - \frac{34451}{39120} = \underline{+0.12}$$



Overturning Moment = 0.55g(66") W = 36.3 W in#

Restoring moment (minimum) = 0.8(44)W = 35.2 W in#

Bolts must resist (36.3 - 35.2)W = 1.1 W in#

8 bolts react $\frac{1.1(99240)}{88} = 1240$#

Load / bolt = $\frac{1240}{8} = 155$# <u>Negligible</u>

Shear / bolt.

8 bolts take longitudinal load (one end slotted)
16 bolts take lateral load

Long. load = $\frac{0.65g(99240)}{8} = 8063$#

Lat. Load = $\frac{0.48g(99240)}{16} = 2977$#

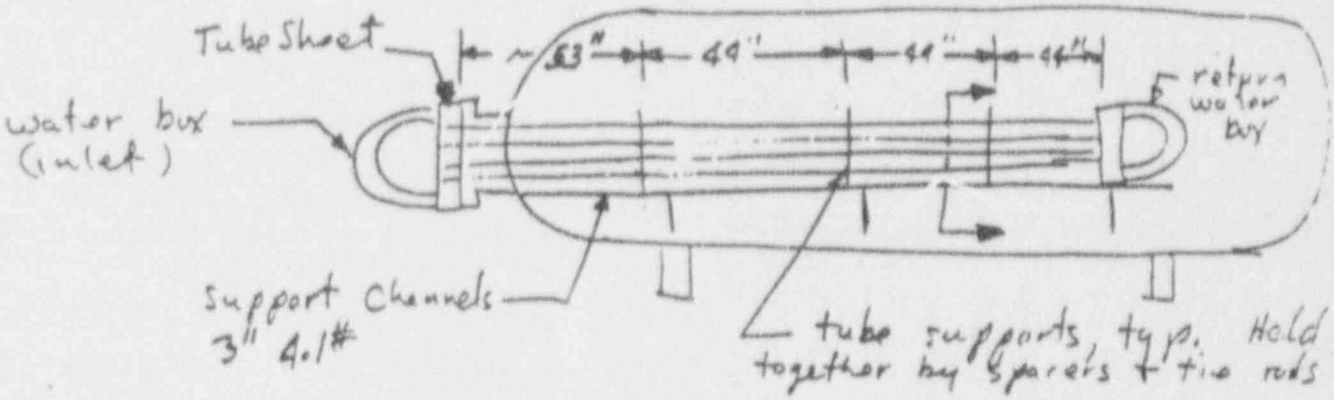
SRSS Response = $\sqrt{8063^2 + 2977^2} = 8595$#

Bolts are 7/8 ϕ $A = \frac{\pi}{4}(.875)^2 = 0.60$ in²

$\tau = \frac{8595}{0.6} = 14325$ psi

Allowable = 22,530 psi MS = $1 - \frac{14325}{22530} = +0.36$

Tube Bundle - Ref Aqua Chem Drawing 534-158
Cleaver Brooks Drawing 172-405D

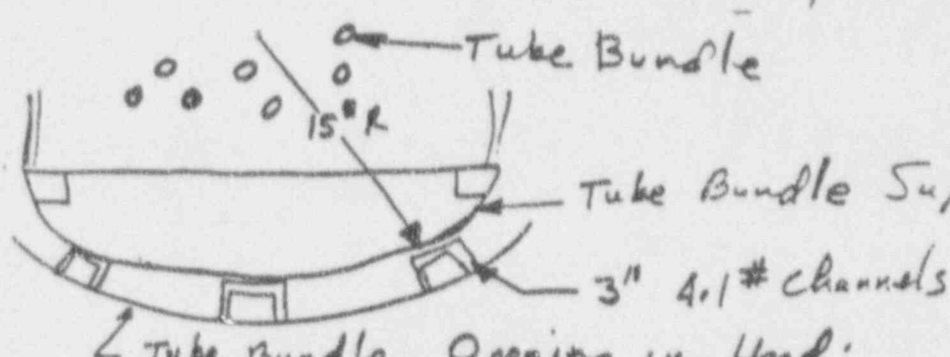


There are 113 tubes, 5/8" OD x 0.058 wall

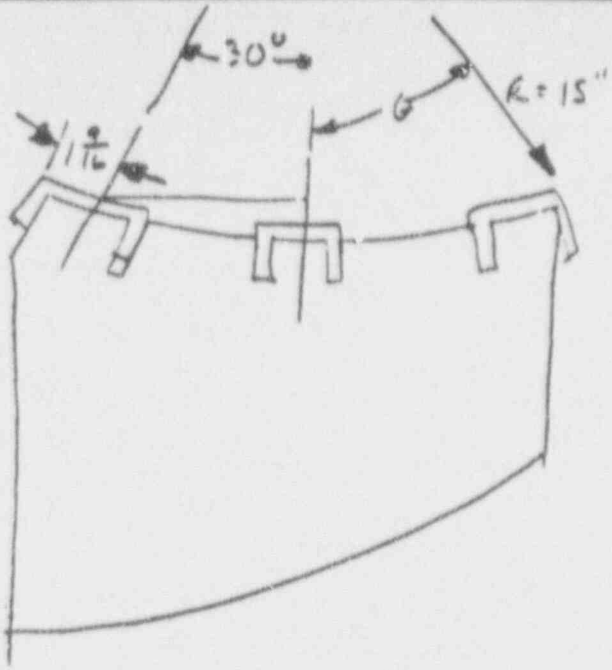
Design pressure = 1700 psig] Tube Side
Design Temperature = 650°F]

Tubes have sine wave bend, 6" displacement in 164" (Aqua Chem Drawing 938-491)

Tube supports provide vertical restraint but not lateral. Lateral restraint by friction only.

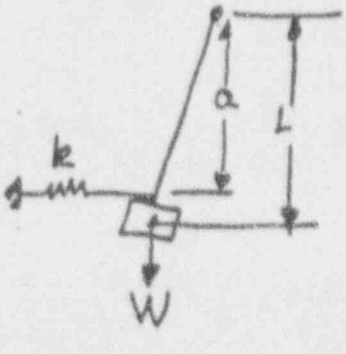


Tube bundle supports rest on channels in 4 places (3 tube supports plus tube sheet). No positive lateral restraint of bundle.



$$\theta = 30° + \frac{1\,9/16}{R}\,\frac{180}{\pi}$$
$$= 30° + 5.96° \sim 36°$$

Tube bundle will oscillate laterally as pendulum with lateral spring resistance due to bending of the tube bundle.



Tubes act as cantilever beams

$$I = 113\ \text{Tubes}\ (\pi)\left(\frac{.625}{2}\right)^3 (0.058) = 0.628\ in^4$$

Wt of Tubes - $113(\pi)(.625'')(.058'')(191.25'')(.28 \#/in^3) = 689\#$

Tube sheet (Return end) = 1180# (Draw 534-150)

Return Water Box = 900# (Draw 271-340)

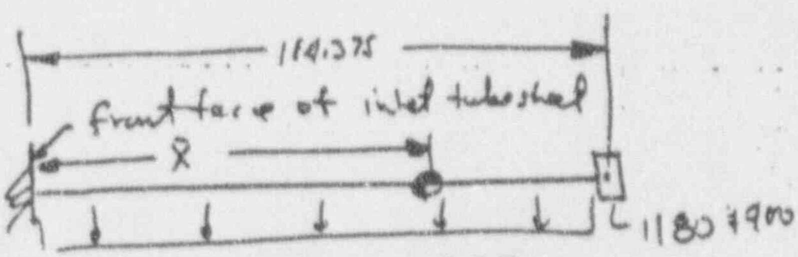
Inlet Tube Sheet = 910#

Tube Bundle wt. = 3920#

Inlet Tube Sheet is at fixed end, therefore vibrating part of bundle is (3920-910) = 2440#

Return tube sheet plus tubes weigh 1869#

Misc Hardware = 2440-1869 = 571#



W = 571+689 = 1260

$$\bar{x} = \frac{(900+1180)(184.375) + \frac{1260(184.375)}{2}}{1260+1180+900} = 149.6''$$

For equivalent cantilever beam of length 149.6,

$$k \text{ at } \ell = 149.6'' = \frac{W}{\delta} = \frac{W\,3EI}{W\ell^3} = \frac{3EI}{\ell^3}$$

Tubes are 304 SS   E at 650°F = 25.1×10^6 psi

$$k = \frac{3(25.1 \times 10^6)(0.428)}{(149.6)^3} = 14.92 \ \#/in$$

From Ref 8 pg 25.

$$f = \frac{1}{2\pi}\sqrt{\left(\frac{WL + ka^2}{WL^2}\right)g}$$

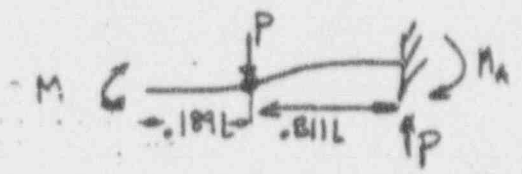
$a = L = 15"$, $k = 14.12$ #/in $\quad W = 3340$#

$$f = \frac{1}{2\pi}\sqrt{\left(\frac{3340(15) + 14.12(15)^2}{3340(15)^2}\right)386.09}$$

$f = 0.83$ Hz

S_a from Ref 7, $\approx 0.20g$

Equivalent system for stress computation (End tube sheet keeps tube rotations fixed unless tube length change)



find M such that $\theta(L) = 0$

From AISC Manual (1980) + Element of Strength of Materials (Timoshenko + Young)

$$EI\,v = \frac{P(.811L)^2}{6}(3L - 3x - .811L) + \frac{M(L-x)^2}{2}$$

$$EI\,v' = -\frac{P(.811L)^2}{2} - M(L-x) = 0$$

$EI\,v'(0) = 0 \qquad -PL^2\left(\frac{.811^2}{2}\right) - ML = 0$

$$M = -0.329\,PL$$

$$M_{A\,(x=L)} = P(x - .189L) - .329PL = 0.482\,PL$$

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Max moment @ $x = L$ $M_A = 0.482PL$

where $P = S_a W = 0.2g \cdot W$

$P = 3340(.20) = 668^{\#}$

$$\frac{\text{Max Moment}}{\text{tube}} = \frac{668^{\#}(184.375)(.482)}{113} = \underline{525 \text{ in-\#}}$$

$$\sigma_b = \frac{Mc}{I} = \frac{525\,(\text{in-lb})\,(.3125\text{ in})(113)}{0.628} = 29520 \text{ psi}$$

$s = 15.9$ ksi $\text{Allowable}_{\text{bending}} = 2.4(15.9) = 38.16$ ksi

$$\text{Pressure stress} = \frac{Pr}{2t} = \frac{1700(.3125)}{2(.058)} = 4580 \text{psi}$$

$$P_L + P_b = (29520 + 4600) - (-1700) = 35820 \text{ psi} < \underline{38.16 \text{ ksi}}$$

OK

$$MS = 1 - \frac{35.82}{38.16} = 0.06$$

with inclusion of friction, MS would be greater.

Tubes bending between supports

Longest span is inlet tube sheet to first support.

From Ref. 8, Pg. 142, for fixed, pinned beam

$$f_n = 2.45\sqrt{\frac{gEI}{wL^4}}$$

$w = \pi(.625)(.058)(.28) = .032\ \#/in$ metal

displaced water $= \frac{\pi}{4}(.625)^2\left(\frac{62.4}{1728}\right) = 0.011\ \#/in$

$w = 0.032 + 0.011 = 0.043\ \#/in$

$L = 53''$ $\qquad I = \pi r^3 t = \pi(.3125)^3(.058) = 0.00556$

$$f_n = 2.45\sqrt{\frac{386(25.1)10^6(0.00556)}{0.043(53)^4}} = 30.8\ Hz$$

Vertical $S_a = 0.25g$

$$M_{max} = \frac{WL}{8} = \frac{wL^2}{8} = \frac{0.043(53)^2}{8} = 15.1\ in\#$$ at fixed end.

$$\sigma_b = \frac{Mc}{I} = \frac{15.1(.3125)}{0.00556} = 849\ psi\ \text{seismic}$$

σ_b from weight $= \frac{1}{0.25}(849) = 3396$ psi

There is no lateral support between tube sheets other than friction.

For fixed-fixed tube of $L = 185''$

$$f_n = 3.56\sqrt{\frac{gEI}{wL^4}} = 3.56\sqrt{\frac{386(25.1)10^6(0.00556)}{0.043(185)^4}} = 3.63\ Hz$$

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Sa lateral (N S) = 0.65 g

$M_{max} = \frac{WL}{12} \cdot \frac{wL^2}{12} = \frac{0.043(185)^2}{12} = 122.7$ in#

$\sigma_b = \frac{Mc}{I} = \frac{122.7(.3125)}{0.005556} = 6896$ psi

with pressure,

∴ Axial stress = 6896 + 4580 = 11,476 psi

worst case stress intensity occurs at inlet tube sheet.

Normal = P + W = 4580 + 3396 = 7976 psi ± top / bottom

Vertical Seismic = ± 849 ± top / bottom

Lateral Seismic = 0 top + bottom

= ± 6896 side/side

Side to side governs

Normal = Press = + 4580 psi axial
−1700 psi radial

Seismic = 6896 psi axial

S = (6896+4580) − (−1700) = 13176 < 38160

M.S. = 1 − $\frac{13176}{38160}$ = 0.65

References

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3 Bijlaard, P.P., " Stresses from Radial Loads and External Moments in Cylindrical Pressure Vessels," Welding Resea. Supplement, December 1955.

4. Wichman, K.R. et al, " Local Stresses in Spherical and Cylindrical Shells Due to External Loadings," Welding Research Council Bulletin, March 1979.

5. Megyesy, E., " Pressure Vessel Handbook", Pressure Vessel Handbook Publishing Inc., 1978.

6. Zick, L.P., " Stresses in Large Horizontal Cylindrical Pressure Vessels on Two Saddle Supports," Welding Research Supplemer 1971.

7. D'Appolonia Consulting Engineering, " Seismic Safety Margin Evaluation - Reactor Building - Primary Coolant Loop, Big Rock Point Nuclear Power Plant," Sept. 1980.

8. Freberg + Kemler, Elements of Mechanical Vibrations, 2nd Ed. John Wiley + Sons. Inc. N.Y.

Consumers Power

POWERING MICHIGAN'S PROGRESS

BIG ROCK POINT NUCLEAR PLANT

Request for Modification

Plant: BIG ROCK POINT

Department: ENGINEERING

Proposal: MODIFY EMERGENCY CONDENSER SHELL SUPPORTS TO WITHSTAND SEISMIC LOADS GREATER THAN THOSE INDUCED BY THE ESTABLISHED SSE OF .12g AS DETAILED IN THE PRA ANALYSIS PER SEP TOPIC III-6. SEE LETTER TO NRC DATED AUGUST 29, 1983.

References: INTEGRATED PLAN ISSUE BN-014A (WEAK-LINKS)
AIR A-BRP-83-15

Reason
( ) Safety (X) Reg Reqmt ( ) ALARA ( ) Design Deficiency (X) Reliability ( ) Productivity
( ) Other-Explain

Expected Savings/Benefit: MODIFYING THE EMERGENCY CONDENSER SHELL SUPPORTS TO WITHSTAND LOADS GREATER THAN THOSE AT SSE WILL PREVENT CORE DAMAGE

Requested by	Date
[signature]	1-12-90

System	UFI	Equipment	UFI	Resp Supvr	Date
ECS	02212	HEAT EXCHANGER	13300	DE Moorgenberg	1-12-90

OO Only: Dept Head Approval ____ Date ____

Plant Modification Committee Action Required? ( ) Yes (✓) No; Plant Supt [initials] Mtg Date ____
Committee Action: ( ) Cancel ( ) Hold (✓) To TRG ( ) Recommend Approval

Technical Review Group (TRG) Action: Mtg Date 12-14-89
Was Item Ranked? (X) Yes ( ) No If Yes, Integrated Plant Issue No. BN-014A

( ) Approved Engg Proj (X) Approved Modification Classification: ( ) Major (✓) Minor
( ) Disapproved Because:

Plant Mgr	Date	Priority	Target Date
[signature]	1/12/90	( ) 1 (✓) 2 ( ) 3	REFOUT 1990

Offsite Support Requested	Comments
(X) Yes ( ) No	ESS - ENGINEERING FOR SEISMIC ANALYSIS

Project No.	PC No.	SC No.	SPC No.	Plant Resp Individual	Engg Supt	Date
847	661	—	—	T Sikavitsas	[signature]	1/12/90

Budget Year 1990 O&M Funds: Resp Area 5285 Function 3002.5 ( ) MRR Required ( ) Proj Plan Required
( ) Capital ( ) GMO ( ) MMO No. ____ Account ____

By upgrading the identified weak links to a level greater than the SSE, core damage can be prevented. The proposed upgrade for the emergency condenser will require a seismic capacity analysis with the appropriate modification to this heat exchanger. The anticipated modification will more than likely require some type of additional restraint for the longitudinal and transverse direction. Also additional reinforcement of the saddle supports may be required to overcome the vertical seismic compressive forces. The proposed upgrade for the subject block walls should only require a more detailed seismic analysis than that performed during the IE Bulletin 80-11 project. The referenced block walls were initially evaluated to IE Bulletin 80-11 criteria by Structural Mechanics Associates , Report No. 13703.01R003. The results of this analysis showed that these walls had a seismic capacity of at least .11g. However, the analysis was based on a two dimensional criteria and did not account for any non-linearity which would more than likely increase the seismic capacity of the block walls to a value greater than the .12g.

B. Implementation

1. Non-linear analysis of the block walls - prior to 1990 Refout
2. Emergency condenser capacity analysis and modification proposals - prior to 1990 Refout
3. Installation and inspection - partial installation and inspection pre-outage, balance 1990 Refout.
4. ISI requirements - as required post-installation.

C. Resources/Costs

1.	Contractor-Block wall analysis		300-400 man-hrs ($20-30k)
2.	ESS Engineering - Emergency condenser capacity analysis		100-200 man-hrs ($5-10k)
3.	BRP Proj. Eng. - Project coordination		5-6 man-mos
4.	Pre-outage work	best estimate:	80-100 man-hrs
5.	Outage	best estimate:	100-150 man-hrs (Combined - $10-20k)