COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.
CHARGE NO.

NUMBER 5-212-P | A 231
SHEET 59 OF 80
DATE 4-22-68 BY COCKRELL
CHECK DATE 4-22-68 BY HEILKER

DESCRIPTION STRUCTURAL AND FATIGUE EVALUATION OF OUTLET NOZZLE – VESSEL SUPPORTS

5. DETAILED ANALYSIS:
e. STRESSES:
1. COMBINED STRESSES – UNCONCENTRATED

LOCATION 10B

TRANSIENT		PRESSURE STRESS			THERMAL STRESS		THERMAL INDUCED PIPE REACTION STRESS			SEISMIC PIPE REACTION STRESS			STATIC WEIGHT STRESS		
		σ_x	σ_θ	σ_r	σ_x	σ_θ	σ_x	σ_θ	$\tau_{x\theta}$	σ_x	σ_θ	$\tau_{x\theta}$	σ_x	σ_θ	$\tau_{x\theta}$
h	10 sec	18.19	31.21	0	2.47	-0.39	-6.26	-5.09	-0.03	0	0	0	1.89	1.52	0
	90	15.98	27.42		2.48	-0.38	-6.26	-5.09	-0.03						
i	220 min	25.61	43.94		0	0	0	0	0						
j	H.U. 3.0 HRS	10.24	17.58		-0.96	-0.30	-4.20	-3.42	-0.02						
	S.S.	20.48	35.15		-0.02	-0.09	-4.20	-3.42	-0.02						
	C.D. 3.0 HRS	2.58	4.43		0.83	0.20	0	0	0						
k	~	19.26	33.04		2.47	-0.39	-6.26	-5.09	-0.03						
	~	17.62	30.23												
l	12 sec	19.44	31.64												
	18.5	19.44	31.64												
m	12 sec	22.53	38.67												
	26	16.39	29.12												
	144	12.09	20.74		2.48	-0.38									
n	33 sec	2.46	4.22		2.48	-0.37									
	54	5.74	9.34		2.48	-0.37									

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO. ______
DESCRIPTION Structural And Fatigue Evaluation Of Outlet Nozzle - Vessel Support

NUMBER 5-212-P | A232
SHEET 60 OF 80
DATE 4-22-68 BY Cockrell
CHECK DATE 4-22-68 BY Heilker

5. Detailed Analysis:

e. Stresses:

1. Combined Stresses - Unconcentrated:

Location 10B

Transient		Earthquake Loading Through Supports Stress σ_x	σ_θ	$\tau_{x\theta}$	Expansion And Contraction Stress σ_x	σ_θ	Total Stress σ_x	σ_θ	σ_r	$\tau_{x\theta}$	Principal Stress σ_1	σ_2	σ_3	Stress Intensity $\sigma_1-\sigma_2$	$\sigma_1-\sigma_3$	$\sigma_2-\sigma_3$
a- Heatup	4.00 Hrs	-0.45	-0.36	0.54	-1.71	-1.80	6.58	19.61	0	1.42	19.76	6.42	0	13.34	19.76	6.42
	4.25						7.83	22.08			22.22	7.69		15.53	22.22	7.69
	4.35						8.34	23.09			23.22	8.21		15.01	23.22	8.21
	4.47						9.06	24.28			24.41	8.93		15.48	24.41	8.93
	5.00						9.32	24.45			24.53	9.19		15.39	24.53	9.19
	4.00	0.45	0.36	-0.54			11.41	22.88		-1.47	23.07	11.22		11.85	23.07	11.22
	4.25						12.66	26.35		-1.47	25.52	12.49		13.03	25.52	12.49
	4.35						13.16	26.33		-1.49	26.49	12.99		13.50	26.49	12.99
	4.47						13.89	27.55			27.71	13.73		13.98	27.71	13.73
	5.00						14.16	27.72			27.88	14.00		13.88	27.88	14.00
No Load Steady State		0	0	0	0	0	14.04	27.92		-0.03	27.92	14.04		13.88	27.92	14.04
b- Cooldown	4.00 Hrs	-0.45	-0.36	0.54	1.71	1.80	4.06	5.80		1.44	6.62	3.25		13.90	6.62	3.25
	4.25						4.41	6.09		1.45	6.92	3.58		3.37	6.92	3.58
	4.35						4.55	6.21		1.45	7.05	3.71		3.34	7.05	3.71
	4.47						4.59	6.31			7.13	3.77		3.33	7.13	3.77
	5.00						4.33	6.14			6.94	3.53		3.36	6.94	3.53
	4.00	0.45	0.36	-0.54			8.10	9.07			10.44	7.53		3.41	10.44	7.53
	4.25						9.25	9.36			10.75	7.86		2.90	10.75	7.86
	4.55						9.39	9.48			10.88	7.99		2.90	10.88	7.99
	4.47						9.43	9.58			10.95	8.06		2.90	10.95	8.06
	5.00						9.17	9.41			10.74	7.94		2.90	10.74	7.84

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO. ______

DESCRIPTION *Structural and Fatigue Evaluation of Outlet Nozzle – Vessel Supports*

NUMBER *5-212-P* | *A233*
SHEET *61* OF *80*
DATE *4-22-68* BY *Cockrell*
CHECK DATE *4-22-69* BY *Heilker*

5- Detailed Analysis:

e- Stresses:

1- Combined Stresses – Unconcentrated

Location 108

Transient		Earthquake Loading Through Supports Stress σ_x	σ_θ	$\tau_{x\theta}$	Expansion and Contraction Stress σ_x	σ_θ	Total Stress σ_x	σ_θ	σ_r	$\tau_{x\theta}$	Principal Stress σ_1	σ_2	σ_3	Stress Intensity $\sigma_1-\sigma_2$	$\sigma_1-\sigma_3$	$\sigma_2-\sigma_3$
c Plant Loading	10 min	0	0	0	0	0	13.64	28.09	0	-0.03	28.09	13.64	0	14.45	28.09	13.64
	15						13.40	28.22			28.22	13.40		14.82	28.22	13.40
	20						13.21	28.46			28.46	13.21		15.25	28.46	13.21
	25						13.17	28.62			28.62	13.17		15.45	28.62	13.17
	30						13.30	28.69			28.69	13.30		15.39	28.69	13.30
Full Load Steady State							15.22	29.11			29.11	15.22		13.90	29.11	15.22
d Plant Unloading	10 min						14.23	29.13			29.13	14.23		14.90	29.13	14.23
	15						14.63	28.96			28.96	14.63		14.33	28.96	14.63
	20						14.72	28.81			28.81	14.72		14.09	28.81	14.72
	25						14.62	28.66			28.66	14.62		14.05	28.66	14.62
	30						14.69	28.49			28.49	14.69		13.80	28.49	14.69
e	100 sec						15.64	26.13			26.13	15.64		10.49	26.13	15.64
	225						16.75	28.03			28.03	16.75		11.29	28.03	16.75
f	40 sec						17.11	28.66			28.66	17.11		11.55	28.66	17.11
	100						16.62	27.82			27.82	16.62		11.20	27.92	16.62
	260						15.64	26.13			26.13	15.64		10.49	26.13	15.64
g	3.5 min						17.36	29.08			29.08	17.36		11.72	29.08	17.36
	11						15.72	26.27			26.27	15.72		10.55	26.27	15.72
	15.5						16.54	27.68			27.68	16.54		11.14	27.68	16.54

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER 5-212-P | A234
SHEET 62 OF 80

CHARGE NO. ______

DATE 4-22-68 BY COCKRELL

DESCRIPTION STRUCTURAL AND FATIGUE EVALUATION OF OUTLET NOZZLE - VESSEL SUPPORTS

CHECK DATE 4-22-68 BY HEILKER

5. DETAILED ANALYSIS:

e. STRESSES:

1. COMBINED STRESSES - UNCONCENTRATED:

LOCATION 10B

Transient		Earthquake Loading Through Supports Stress			Expansion and Contraction Stress		Total Stress				Principal Stress			Stress Intensity		
		σ_x	σ_θ	$\tau_{x\theta}$	σ_x	σ_θ	σ_x	σ_θ	σ_r	$\tau_{x\theta}$	σ_1	σ_2	σ_3	$\sigma_1-\sigma_2$	$\sigma_1-\sigma_3$	$\sigma_2-\sigma_3$
h	10 sec	0 →	0 →	0 →	0 →	0 →	16.29	27.25	0 →	-0.03	27.25	16.29	0 →	10.96	27.25	16.29
	90						14.08	23.46		-0.03	23.46	14.08		9.38	23.46	14.08
i	200 min						27.49	45.45		0	45.45	27.49		17.96	45.45	27.49
j	H.U. 3.0 HRS						7.07	15.38		-0.02	15.38	7.07		8.31	15.38	7.07
	S.S.						18.15	33.15		-0.02	33.15	18.15		15.00	33.15	18.15
	C.D 3.0 HRS						5.30	6.14		0	6.14	5.30		0.84	6.14	5.30
k	~						17.36	29.08		-0.03 →	29.08	17.36		11.72	29.08	17.36
	~						15.72	26.27			26.27	15.72		10.55	26.27	15.72
l	12 sec						16.54	27.67			27.67	16.54		11.13	27.67	16.54
	195						16.54	27.67			27.67	16.54		11.13	27.67	16.54
m	12 sec						20.64	34.70			34.70	20.64		14.06	34.70	20.64
	26						14.49	24.16			24.16	14.49		9.66	24.16	14.49
	144						10.19	16.78			16.78	10.19		6.59	16.78	10.19
n	33 sec						0.57	0.27			0.27	0.57		-0.30	0.27	0.57
	54						3.85	5.90			5.90	3.85		2.05	5.90	3.85

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER 5-212-P | A235
SHEET 63 OF 80
CHARGE NO.
DATE 4-22-68 BY COCKRELL
DESCRIPTION STRUCTURAL AND FATIGUE EVALUATION OF OUTLET NOZZLE - VESSEL SUPPORT
CHECK DATE 4-22-68 BY HEILKER

5- DETAILED ANALYSIS:

e- STRESSES

1- COMBINED STRESSES - UNCONCENTRATED:

CONSIDER STRESSES DURING NO LOSS OF FUNCTION SEISMIC LOADING:

IN THIS SECTION THE ALLOWABLE STRESSES LISTED ON SHEET 7 FOR CRITERION 5.b.1, 5.b.3, AND 5.b.4 WILL BE INCREASED BY A FACTOR OF 1.2, SEE REF. 10.

CONSIDER CRITERION 5.b.1:

LOCATION	PRESSURE STRESS			STRESS DUE TO EXTERNAL LOADS		PRINCIPAL STRESS			STRESS INTENSITY		
	σ_x	σ_θ	σ_r	σ_x	$\tau_{x\theta}$	σ_1	σ_2	σ_3	$\sigma_1-\sigma_2$	$\sigma_1-\sigma_3$	$\sigma_2-\sigma_3$
7	1.51	3.99	-2.5	4.18	-0.36	5.76	3.92	-2.5	1.84	8.26	6.42
	↓	↓	-2.5	-4.30	-2.76	4.97	-3.77	-2.5	8.74	7.47	6.27
8	↓	↓	0	7.01	0.36	8.55	3.96	0	4.59	8.55	3.96
	↓	↓	0	-7.13	-3.48	5.12	-6.75	0	11.85	5.12	-6.75

$SI_{max} = \sigma_1 - \sigma_2 = \underline{11.85\ KSI} < 1.2\ S_m = 32.04\ KSI$ LOCATION 8

CONSIDER CRITERION 5.b.3:

LOCATION	PRESSURE STRESS			STRESSES DUE TO EXTERNAL LOADS			PRINCIPAL STRESS			STRESS INTENSITY		
	σ_x	σ_θ	σ_r	σ_x	σ_θ	$\tau_{x\theta}$	σ_1	σ_2	σ_3	$\sigma_1-\sigma_2$	$\sigma_1-\sigma_3$	$\sigma_2-\sigma_3$
9 A	6.92	31.08	-2.5	6.91	2.16	1.02	33.29	13.78	-2.5	19.51	35.79	16.28
B	6.92	31.08	↓	9.21	3.38	2.67	34.84	15.75	↓	9.09	37.34	18.25
C	20.53	6.84	↓	6.00	12.07	0.25	26.54	18.90	↓	7.64	29.04	21.40
D	20.53	6.84	↓	6.30	12.60	-2.37	27.52	18.75	↓	8.77	30.02	21.25
10 A	6.92	31.08	0	10.13	8.95	-1.07	40.08	17.00	0	23.08	40.08	17.00
B	6.92	31.08	↓	8.43	6.89	-2.70	38.16	15.16	↓	23.00	38.16	15.16
C	20.53	6.84	↓	8.12	12.84	0.69	28.70	19.63	↓	9.07	28.70	19.63
D	20.53	6.84	↓	9.60	14.85	1.35	30.34	21.48	↓	8.86	30.34	21.48

$SI_{max} = \sigma_1 - \sigma_3 = \underline{40.08\ KSI} < 1.2(1.5\ S_m) = 48.1\ KSI$ LOCATION 10A

5- DETAILED ANALYSIS:

e- STRESSES:

1- COMBINED STRESSES - UNCONCENTRATED:

CONSIDER CRITERION 5.b.4:

SAFE END

LOCATION	PRESSURE STRESS			STRESS DUE TO SEISMIC LOADS		PRINCIPAL STRESS			STRESS INTENSITY		
	σ_x	σ_θ	σ_r	σ_x	$\tau_{x\theta}$	σ_1	σ_2	σ_3	$\sigma_1-\sigma_2$	$\sigma_1-\sigma_3$	$\sigma_2-\sigma_3$
1	6.59	11.80	-2.5	11.35	2.27	18.69	11.05	-2.5	7.64	21.19	13.55
	↓	↓	-2.5	-10.37	0.97	11.86	-3.84	-2.5	15.70	14.36	-1.34
2	↓	↓	0	13.24	2.38	20.48	11.15	0	9.33	20.48	11.15
	↓	↓	0	-12.26	0.86	11.84	-5.71	0	17.55	11.84	-5.71

$S.I._{MAX} = \sigma_1 - \sigma_3 = \underline{21.19 KSI} < 1.2(1.5S_m) = 30.06 KSI$ LOCATION-1

SMALL END OF NOZZLE

LOCATION	PRESSURE STRESS			STRESS DUE TO SEISMIC LOADS		PRINCIPAL STRESS			STRESS INTENSITY		
	σ_x	σ_θ	σ_r	σ_x	$\tau_{x\theta}$	σ_1	σ_2	σ_3	$\sigma_1-\sigma_2$	$\sigma_1-\sigma_3$	$\sigma_2-\sigma_3$
3	7.16	12.16	-2.5	12.33	2.47	20.24	11.41	-2.5	8.83	22.74	13.91
	↓	↓	-2.5	-11.27	1.05	12.23	-4.18	-2.5	16.41	14.73	-1.68
4	↓	↓	0	14.22	2.58	22.05	11.49	0	10.56	22.05	11.49
	↓	↓	0	-13.16	0.94	12.21	-6.05	0	18.26	12.21	-6.05

$S.I._{MAX} = \sigma_1 - \sigma_3 = \underline{22.74 KSI} \leq 1.2(1.5S_m) = 48.06 KSI$ LOCATION-3

5- DETAILED ANALYSIS:

e- STRESSES:

1- COMBINED STRESSES - UNCONCENTRATED:

CONSIDER THE COMBINED FORCES ON THE PAD:

THE MAXIMUM AND MINIMUM VERTICAL FORCE ON THE OUTLET NOZZLE PADS WAS FOUND TO BE,

$\bar{V}_{MAX}$ = 1237.3 KIPS
$\bar{V}_{MIN}$ = 114.9 KIPS

NOTE HERE THAT THESE FORCES WERE DETERMINED USING THE DESIGN SEISMIC PIPE LOADS, THERMAL INDUCED PIPE LOADS AND THE SEISMIC SHOCK FACTORS GIVEN IN REF 9 & 10.

NOTE THAT SINCE THE MINIMUM VALUE OF $\bar{V}$ IS POSITIVE, THE VESSEL WILL NOT LIFT OFF THE SUPPORT STRUCTURE UNDER THE DEIGN CONDITIONS

THE MAXIMUM HORIZONTAL FORCE ON THE OUTLET NOZZLE PADS WAS FOUND TO BE,

$\bar{H}_{MAX}$ = 821.0 KIPS   SEE NOTE ABOVE FOR $\bar{V}_{MAX}$ & $\bar{V}_{MIN}$.

THE ABOVE MAXIMUM FORCES PRODUCE BEARING STRESSES ON THE PAD EQUAL TO,

$$\sigma_{BRG} = \frac{\bar{V}_{MAX}}{A} = \frac{1237.3}{10 \times 22} = 5.6 \text{ KSI}$$

$$\sigma_{BRG} = \frac{\bar{H}_{MAX}}{A} = \frac{821.0}{2.5 \times 10} = 32.8 \text{ KSI}$$

$< S_y = 44.5$ KSI @ 400°F

NOTE THAT THE BEARING STRESS ON THE BOTTOM OF THE PAD IS 3.6 KSI WHEN CONSIDERING DEAD WEIGHT AND THERMAL INDUCED PIPE REACTIONS ONLY. THIS COMPARES WITH A DESIRED BEARING STRESS OF 5.0 KSI. THIS STRESS BECOMES 4.8 KSI WHEN CONSIDERING THREE SUPPORTS ONLY

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.
CHARGE NO. ____________

DESCRIPTION: STRUCTURAL AND FATIGUE EVALUATION OF OUTLET NOZZLE - VESSEL SUPPORTS

NUMBER: S-212-P | A238
SHEET: 66 OF 80
DATE: 4-22-68 BY: COCKRELL
CHECK DATE: 4-22-68 BY: HEILKER

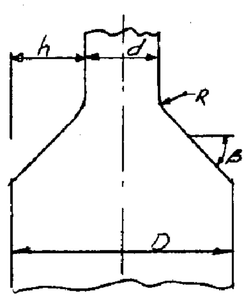
5- DETAILED ANALYSIS:

e. STRESSES

2- PEAK STRESS:

THE FOLLOWING VALUES OF STRESS CONCENTRATION FACTORS WILL BE USED TO CALCULATE PEAK STRESSES AT LOCATION 6, 8 AND 10. THE STRESS CONCENTRATION FACTORS AT ALL OTHER LOCATION WILL BE ONE; HENCE, THE EXPRESSIONS FOR PEAK STRESS WILL BE THE SAME AS THOSE GIVEN ON SHEETS 43→53 WITH THE FOLLOWING EXCEPTIONS (1) THE TERM $\frac{E\alpha}{1-\nu}(T_m - T)$ IS ADDED TO REFLECT THE STRESS DUE TO THE RADIAL GRADIENT (2) THE $\frac{6M}{t^2}$ AND $\frac{\nu 6M}{t^2}$ TERMS FOR STRESSES DUE TO THERMAL EFFECTS WILL INCLUDE THE THERMAL MOMENT DUE TO THE RADIAL GRADIENT, AND (3) FOR LOCATION 10, THE PRESSURE STRESS WILL BE CALCULATED USING THE STRESS INDICES GIVEN IN I-612 OF SECTION III.

LOCATION 6:



$D = 20.562$ $h = 7.969$ $\beta = 45°52'$ $\Delta = \frac{D}{d} = 4.447$

$d = 4.624$ $R = 5.406$ $\frac{\beta}{90} = 0.510$ $\frac{h}{R} = 1.474$

FROM EQUATIONS 6.20 AND 6.24 OF REF. 5:

$K_{TO} = 1.30$

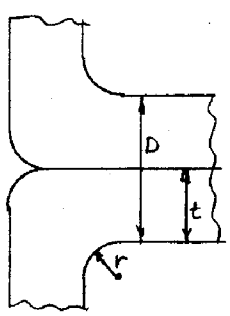
$K_{BO} = 1.15$

FROM EQUATION 6.22 OF REF. 5:

$K_T = 1.27$ ←

$K_B = 1.13$

LOCATION - 8 & 10:



$t = 10.042''$ $r = 5.375$

$D = 20.084$ $\frac{r}{t} = 0.535$

FOR $\frac{r}{t} = 0.535$

$K_T = 1.77$ } FROM FIG. A.7-1 REF 3 ←
$K_B = 1.48$ }

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER 5-212 P | A 239
SHEET 67 OF 80
CHARGE NO.
DATE 4-22-68 BY COCKRELL
DESCRIPTION STRUCTURAL AND FATIGUE EVALUATION OF OUTLET NOZZLE - VESSEL SUPPORTS
CHECK DATE 4-22-68 BY HEILKER

5. DETAILED ANALYSIS:

e. STRESSES:

2. PEAK STRESS:

THE FOLLOWING EXPRESSIONS FOR STRESS WILL BE USED TO CALCULATE PEAK STRESSES AT LOCATION 6, 8 AND 10.

LOCATION 6:

PRESSURE STRESS:

$$\sigma_x = -\frac{6M_2}{t_{2A}^2}K_B + \frac{b^2P}{2R_A t_{2A}}K_T = -0.8568M_2 + 2.9897P$$

$$\sigma_\theta = -\frac{\nu 6M_2}{t_{2A}^2}K_B + \frac{EW_{22}}{R_2} + \frac{bP}{t_{2A}} = -0.2570M_2 + 0.0630EW_{22} + 5.1546P$$

$$\sigma_r = 0$$

THERMAL STRESS:

$$\sigma_x = -\frac{6(M_2+M_{2T})}{t_{2A}^2}K_B + \frac{E\alpha_i}{(1-\nu)}(T_m-T)K_T = -0.8568(M_2+M_{2T}) + 1.8143E\alpha_i(T_m-T)$$

$$\sigma_\theta = -\frac{\nu 6(M_2+M_{2T})}{t_{2A}^2}K_B + \frac{EW_{22}}{R_2} + \frac{E\alpha_i}{(1-\nu)}(T_m-T) = -0.2570(M_2+M_{2T}) + 0.0630EW_{22} + 1.4286(T_m-T)$$

THERMAL INDUCED PIPE REACTIONS:

$$\sigma_x = -\frac{\bar{F}_x}{A}K_T + \frac{\bar{M}c}{I}K_B = -0.00446\bar{F}_x + 0.00053\bar{M}_z \quad \text{POINT A}$$
$$= -0.00446\bar{F}_x - 0.00053\bar{M}_z \quad \text{B}$$
$$= -0.00446\bar{F}_x + 0.00053\bar{M}_y \quad \text{C}$$
$$= -0.00446\bar{F}_x - 0.00053\bar{M}_y \quad \text{D}$$

$$\tau_{x\theta} = \frac{FQ}{Ib'}K_B \pm \frac{Mc}{2I}K_B = 0.00789\bar{F}_z + 0.00027\bar{M}_x \quad \text{POINT A}$$
$$= 0.00789\bar{F}_z - 0.00027\bar{M}_x \quad \text{B}$$
$$= 0.00789\bar{F}_y + 0.00027\bar{M}_x \quad \text{C}$$
$$= 0.00789\bar{F}_y - 0.00027\bar{M}_x \quad \text{D}$$

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.
CHARGE NO.
DESCRIPTION STRUCTURAL AND FATIGUE EVALUATION OF OUTLET NOZZLE - VESSEL SUPPORTS

NUMBER 5-212-P | A240
SHEET 68 OF 80
DATE 4-22-68 BY COCKRELL
CHECK DATE 4-22-68 BY HEILKER

5- DETAILED ANALYSIS:

e- STRESSES:

2- PEAK STRESSES:

SEISMIC PIPE REACTIONS:

THE FORMULAS FOR CALCULATING THE STRESSES DUE TO THE SEISMIC PIPE REACTIONS ARE THE SAME AS FOR THE THERMAL INDUCED REACTIONS.

LOCATION B:

PRESSURE STRESS:

$$\sigma_x = -\frac{6M_4}{t_{4A}^2}\frac{R_4}{R_{4A}}K_B + \frac{b^2P}{2R_m t_{4A}}K_T = -0.09428M_4 + 1.06979P$$

$$\sigma_\theta = -\frac{\nu 6M_4}{t_{4A}^2}\frac{R_4}{R_{4A}}K_B + \frac{EW_{44}}{R_{4A}} + \frac{bP}{t_{4A}} = -0.02827M_4 + 0.0493EW_{44} + 1.5961P$$

$$\sigma_r = 0$$

THERMAL STRESS:

$$\sigma_x = -\frac{6(M_4+M_{4T})}{t_{4A}^2}\frac{R_4}{R_{4A}}K_B + \frac{E\alpha_i}{(1-\nu)}(T_m-T)K_T = -0.09428(M_4+M_{4T}) + 2.52857K_T$$

$$\sigma_\theta = -\frac{\nu 6(M_4+M_{4T})}{t_{4A}^2}\frac{R_4}{R_{4A}}K_B + \frac{EW_{44}}{R_{4A}} + \frac{E\alpha_i}{(1-\nu)}(T_m-T) = -0.02827(M_4+M_{4T}) + 0.0493EW_{44} + 1.42357(T_m-T)$$

THERMAL INDUCED PIPE REACTIONS:

$$\sigma_x = -\frac{\bar{F}_x}{A}K_T \pm \frac{Mc}{I}K_B = -0.00145\bar{F}_x + 0.00015\bar{M}_z$$
$$= -0.00145\bar{F}_x - 0.00015\bar{M}_z$$
$$= -0.00145\bar{F}_x + 0.00015\bar{M}_y$$
$$= -0.00145\bar{F}_x - 0.00015\bar{M}_y$$

$$\tau_{x\theta} = \frac{\bar{F}Q}{Ib'}K_B \pm \frac{\bar{M}c}{2I}K_B = 0.00231\bar{F}_z + 0.000071\bar{M}_x$$
$$= 0.00231\bar{F}_z - 0.000071\bar{M}_x$$
$$= 0.00231\bar{F}_y + 0.000071\bar{M}_x$$
$$= 0.00231\bar{F}_y - 0.000071\bar{M}_x$$

5- DETAILED ANALYSIS:

e- STRESSES:

2- PEAK STRESSES:

THE EQUATIONS FOR STRESS DUE TO SEISMIC PIPE REACTIONS, STATIC LOADING THROUGH SUPPORTS, EARTHQUAKE LOADING THROUGH SUPPORTS, AND THERMAL EXPANSION & CONTRACTION ARE THE SAME AS FOR THE THERMAL INDUCED PIPE REACTIONS. THE VALUES OF F_x, F_y, F_z, $\bar{M}_x$, $\bar{M}_u$, AND $\bar{M}_z$ ARE THE SAME AS THOSE LISTED ON SHEETS 47 & 48.

LOCATION 10:

PRESSURE STRESS:

	POINTS A&B LONGITUDINAL PLANE	POINTS C&D CIRCUMFERENTIAL PLANE
$\sigma_x = i_x\left(\frac{bP}{t} + \frac{P}{2}\right)$	$= 8.4477P$	$= 17.7402P$
$\sigma_\theta = i_\theta\left(\frac{bP}{t} + \frac{P}{2}\right)$	$= 10.1373P$	$= 21.9641P$
$\sigma_r = 0$		

THERMAL STRESS:

POINTS A&B (LONGITUDINAL PLANE):

$$\sigma_x = -\frac{6}{t_5^2}(M_4+M_{5T})K_B - \frac{H_4}{t_5}K_T + \frac{E\alpha_i}{(1-\nu)}(T_m - T)K_T = -0.07684(M_4+M_{5T}) - 0.16465H_4 + 2.5286E\alpha_i(T_m - T)$$

$$\sigma_\theta = -\frac{\nu 6}{t_5^2}(M_4+M_{5T})K_B + \frac{EW_{54}}{R_5 \sin\phi} + \frac{E\alpha_i}{(1-\nu)}(T_m - T) = -0.02305(M_4+M_{5T}) + 0.0501EW_{54} + 1.42857E\alpha_i(T_m - T)$$

POINTS C&D (CIRCUMFERENTIAL PLANE):

$$\sigma_x = -\frac{\nu 6}{t_5^2}(M_4+M_{5T})K_B + \frac{EW_{54}}{R_5 \sin\phi} + \frac{E\alpha_i}{(1-\nu)}(T_m - T) = -0.02305(M_4+M_{5T}) + 0.0501EW_{54} + 1.42857E\alpha_i(T_m - T)$$

$$\sigma_\theta = -\frac{6}{t_5^2}(M_4+M_{5T})K_B - \frac{H_4\cos\phi}{t_5}K_T + \frac{E\alpha_i}{(1-\nu)}(T_m - T)K_T = -0.07684(M_4+M_{5T}) - 0.16288H_4 + 2.5286E\alpha_i(T_m - T)$$

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER 5-212-P | A 242
SHEET 70 OF 80
CHARGE NO.
DATE 4-22-68 BY COCKRELL
DESCRIPTION STRUCTURAL AND FATIGUE EVALUATION OF OUTLET NOZZLE - VESSEL SUPPORTS
CHECK DATE 4-22-68 BY HEILKER

5. DETAILED ANALYSIS:
e. STRESSES:
2. PEAK STRESSES:

THERMAL INDUCED PIPE REACTIONS:

$$\sigma_x = -\left(\frac{N_x}{\bar{F}_x/R_m}\right)\frac{\bar{F}_x}{R_m T}K_T \pm \left(\frac{M_x}{\bar{F}_x}\right)\frac{6\bar{F}_x}{T^2}K_B \pm \left(\frac{N_x}{\bar{M}/R_m^2\beta}\right)\frac{\bar{M}}{R_m^2\beta T}K_T \pm \left(\frac{M_x}{\bar{M}/R_m\beta}\right)\frac{6\bar{M}}{R_m\beta T^2}K_B$$

$= -0.00832\bar{F}_x + 0.00027\bar{M}_z$ POINT A
$= -0.00832\bar{F}_x - 0.00027\bar{M}_z$ B
$= -0.00832\bar{F}_x + 0.00023\bar{M}_y$ C
$= -0.00832\bar{F}_x - 0.00023\bar{M}_y$ D

$$\sigma_\theta = -\left(\frac{N_\theta}{\bar{F}_x/R_m}\right)\frac{\bar{F}_x}{R_m T}K_T \pm \left(\frac{M_\theta}{\bar{F}_x}\right)\frac{6\bar{F}_x}{T^2}K_B \pm \left(\frac{N_\theta}{\bar{M}/R_m^2\beta}\right)\frac{\bar{M}}{R_m^2\beta T}K_T \pm \left(\frac{M_x}{\bar{M}/R_m\beta}\right)\frac{6\bar{M}}{R_m\beta T^2}K_B$$

$= -0.01054\bar{F}_x + 0.00023\bar{M}_z$ POINT A
$= -0.01054\bar{F}_x - 0.00023\bar{M}_z$ B
$= -0.01054\bar{F}_x + 0.00036\bar{M}_y$ C
$= -0.01054\bar{F}_x - 0.00036\bar{M}_y$ D

$T_{x\theta} = \pm\frac{\bar{F}}{\pi r_o T}K_B + \frac{\bar{M}_x}{2\pi R_o^2 T}K_B = 0.00162\bar{F}_z + 0.00003\bar{M}_x$ POINT A
$= -0.00162\bar{F}_z + 0.00003\bar{M}_x$ B
$= 0.00162\bar{F}_y + 0.00003\bar{M}_z$ C
$= -0.00162\bar{F}_y + 0.00003\bar{M}_z$ D

THE EQUATIONS FOR STRESS DUE TO SEISMIC PIPE REACTIONS, STATIC LOADING THROUGH SUPPORTS, EARTHQUAKE LOADING THROUGH SUPPORTS, AND THERMAL EXPANSION AND CONTRACTION ARE THE SAME AS FOR THE THERMAL INDUCED PIPE REACTIONS. THE VALUES OF $\bar{F}_x$, $\bar{F}_y$, $\bar{F}_z$, $\bar{M}_x$, $\bar{M}_y$, $\bar{M}_z$ ARE THE SAME AS THOSE GIVEN ON SHEETS 52 & 53.

5- DETAILED ANALYSIS:

e- STRESSES:

2- PEAK STRESSES:

THE FOLLOWING VALUES OF ($T_{MEAN} - T_{SURFACE}$) FOR THE INSIDE AND OUTSIDE SURFACES ARE TO BE USED TO CALCULATE PEAK STRESSES FOR THE FATIGUE EVALUATION.

TRANSIENT		CUT-1 BODY-1		CUT-1 BODY-2		CUT-2 BODY-2		CUT-4 BODY-4 & BODY-5	
		ΔT_{INSIDE}	$\Delta T_{OUTSIDE}$	ΔT_{INSIDE}	$\Delta T_{OUTSIDE}$	ΔT_{INSIDE}	$\Delta T_{OUTSIDE}$	ΔT_{INSIDE}	$\Delta T_{OUTSIDE}$
a. HEATUP	4.00 HRS	-8	3	-4	3	-7	4	-55	25
	4.25	↓	↓	↓	↓	↓	↓	↓	↓
	4.35	↓	↓	↓	↓	↓	↓	↓	↓
	4.47	↓	↓	↓	↓	↓	↓	-56	24
	5.00	0	1	0	1	-2	2	-27	13
NO LOAD STEADYSTATE		0	0	0	0	0	0	0	0
b- COOLDOWN	4.00 HRS	8	-3	4	-3	7	-4	55	-25
	4.25	↓	↓	↓	↓	↓	↓	↓	↓
	4.35	↓	↓	↓	↓	↓	↓	↓	↓
	4.47	↓	↓	↓	↓	↓	↓	56	-24
	5.00	0	-1	0	-1	2	-2	27	-13
c- PLANT LOADING	10 min	-12	4	-7	4	-7	4	-2	1
	15	-14	4	-8	4	-8	5	-3	↓
	20	-14	5	-9	5	-9	6	-4	↓
	25	-5	2	-3	2	-5	4	-3	↓
	30	-3	1	-1	1	-3	2	-1	2
FULL LOAD STEADYSTATE		0	0	0	0	0	0	16	-13
d- PLANT UNLOADING	10 min	12	-4.5	7	-4.5	7	-7	19	-14.5
	15	14	-4	8	-4	7	-8.5	20	-14.5
	20	14	-4	9	-4	8	-5.5	20	-15
	25	5	-2	3	-2	6	-3	19	-15
	30	2	-1	1	-1	3	-2	17	-14

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO.

DESCRIPTION Structural And Fatigue Evaluation Of Outlet Nozzle - Vessel Supports

NUMBER 5-212-P | A244
SHEET 72 OF 80
DATE 4-22-68 BY Cockrell
CHECK DATE 4-22-68 BY Heilker

5- Detailed Analysis:
e- Stresses:
2- Peak Stresses:

Transient		Cut-1 & Cut-2 Body-1 & Body-2 ΔT_{inside}	Cut-1 & Cut-2 Body-1 & Body-2 $\Delta T_{outside}$	Cut-3 Body-3 & Body-4 ΔT_{inside}	Cut-3 Body-3 & Body-4 $\Delta T_{outside}$
e	100 sec	11.2	0	11.2	-13
	225	1.7	↓	1.7	↓
f	40 sec	-9.3	↓	-9.3	↓
	100	-13.3	↓	-13.3	↓
	260	-1.3	↓	-1.3	↓
g	3.5 min	-8	↓	5	↓
	11	14	↓	21	↓
	15.5	-11	↓	22	↓
h	10 sec	20	↓	10	↓
	90	46	↓	28	↓
i		0	↓	0	0
j	H.U 3.0 HRS	-8	3	-56	24
	SS.	0	0	0	0
	C.D 3.0 HRS	8	-3	56	-24
k	~	6	0	6	-13
	~	-6	↓	-6	↓
l	12 sec	0	↓	52	↓
	18.5	89	↓	21	↓
m	12 sec	-38	↓	-11	↓
	26	-17	↓	-21	↓
	144	45	↓	25	↓
n	33 sec	117	↓	117	0
	54	197	↓	197	0

5- DETAILED ANALYSIS:

e- STRESSES

2- PEAK STRESSES

NOTE HERE THAT PEAK STRESSES WERE CALCULATED AT THE TEN LOCATIONS AS SHOWN ON SHEET 14 FOR THE FOUR ORIENTATIONS A, B, C AND D. THE FOLLOWING TABLE GIVES THE OVERALL USAGE FACTORS FOR EACH LOCATION AND EACH ORIENTATION. STRESSES AND STRESS INTENSITIES PRODUCING THESE USAGE FACTORS WILL NOT BE PRESENTED FOR ALL LOCATIONS AND ORIENTATIONS. ONLY STRESSES AND STRESS INTENSITIES AT THE LOCATION AND ORIENTATION WHICH PRODUCE THE HIGHEST OVERALL USAGE FACTOR WILL BE PRESENTED. THIS WAS LOCATION 9A.

LOCATION AND ORIENTATION	$U_{OVERALL}$	LOCATION AND ORIENTATION	$U_{OVERALL}$	LOCATION AND ORIENTATION	$U_{OVERALL}$
1 A	0.000004	5 A	0.0052	9A	0.022 ←
B	0.000003	B	0.0006	B	0.017
C	0.000003	C	0.0014	C	0.014
D	0.000004	D	0.0017	D	0.0013
2A	0	6A	0	10A	0.0056
B	0	B	0.0003	B	0.0005
C	0	C	0	C	0.018
D	0	D	0	D	0.021
3 A	0.0031	7 A	0.0029		
B	0.0034	B	0.0039		
C	0.0032	C	0.0036		
D	0.0032	D	0.0038		
4 A	0.0008	8A	0.0052		
B	0.0009	B	0.0031		
C	0.0001	C	0.0042		
D	0.0004	D	0.0044		

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO.

DESCRIPTION Structural And Fatigue Evaluation Of Outlet Nozzle – Vessel Support

NUMBER S-212-P | A 246
SHEET 74 OF 80
DATE 4-22-68 BY Cockrell
CHECK DATE 4-22-68 BY Heilker

5- Detailed Analysis:
e- Stresses:
2. Peak Stresses

Location 9A

	Transient	Pressure Stress			Thermal Stress		Thermal Induced Pipe Reaction Stress			Seismic Pipe Reaction Stress			Static Weight Stress		
		σ_x	σ_θ	σ_r	σ_x	σ_θ	σ_x	σ_θ	$\tau_{x\theta}$	σ_x	σ_θ	$\tau_{x\theta}$	σ_x	σ_θ	$\tau_{x\theta}$
a- Heatup	4.00 HRS	-3.18	49.29	-1.88	-13.44	-15.77	-4.64	-1.48	-0.05	-2.56	-1.32	-0.43	1.62	0.55	0
	4.25	-3.51	54.42	-2.08	-13.59	-15.91	-4.93	-1.57	↓	↓	↓	↓	↓	↓	↓
	4.35	-3.64	56.46	-2.16	-13.63	-15.96	-5.04	-1.61	↓	↓	↓	↓	↓	↓	↓
	4.47	-3.80	58.92	-2.25	-14.19	-16.37	-5.18	-1.65	↓	↓	↓	↓	↓	↓	↓
	5.00	-3.80	58.92	-2.25	-6.50	-7.84	-5.18	-1.65	↓	↓	↓	↓	↓	↓	↓
	4.00	-3.18	49.29	-1.88	-13.44	-15.44	-4.64	-1.48	↓	2.56	1.32	0.43	↓	↓	↓
	4.25	-3.51	54.42	-2.08	-13.58	-15.91	-4.93	-1.57	↓	↓	↓	↓	↓	↓	↓
	4.35	-3.64	56.46	-2.16	-13.62	-15.96	-5.04	-1.61	↓	↓	↓	↓	↓	↓	↓
	4.47	-3.80	58.92	-2.25	-14.14	-16.36	-5.18	-1.65	↓	↓	↓	↓	↓	↓	↓
	5.00	-3.80	58.92	-2.25	-6.50	-7.84	-5.18	-1.65	↓	↓	↓	↓	↓	↓	↓
No Load Steady State		-3.80	58.92	-2.25	0.17	-0.08	-5.18	-1.65	↓	0	0	0	↓	↓	↓
b- Cooldown	4.00 HRS	-0.53	8.25	-0.31	12.24	14.29	-0.54	-0.17	-0.01	-2.56	-1.32	-0.43	↓	↓	↓
	4.25	↓	↓	↓	12.10	14.15	-0.26	-0.08	0	↓	↓	↓	↓	↓	↓
	4.35	↓	↓	↓	12.04	14.09	-0.14	-0.04	↓	↓	↓	↓	↓	↓	↓
	4.47	↓	↓	↓	12.39	14.34	0	0	↓	↓	↓	↓	↓	↓	↓
	5.00	↓	↓	↓	5.57	6.64	0	0	↓	↓	↓	↓	↓	↓	↓
	4.00	↓	↓	↓	12.24	14.29	-0.54	-0.17	-0.01	2.56	1.32	0.43	↓	↓	↓
	4.25	↓	↓	↓	12.10	14.15	-0.26	-0.08	0	↓	↓	↓	↓	↓	↓
	4.35	↓	↓	↓	12.04	14.09	-0.14	-0.04	↓	↓	↓	↓	↓	↓	↓
	4.47	↓	↓	↓	12.39	14.34	0	0	↓	↓	↓	↓	↓	↓	↓
	5.00	↓	↓	↓	5.57	6.64	0	0	↓	↓	↓	↓	↓	↓	↓

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO.

NUMBER 5-212-P | A247
SHEET 75 OF 80
DATE 4-22-68 BY Cockrell
CHECK DATE 4-22-68 BY Heller

DESCRIPTION Structural And Fatigue Evaluation Of Outlet Nozzle – Vessel Supports

5. Detailed Analysis:
e. Stresses:
2. Peak Stresses:

LOCATION 9A

Transient		Pressure Stress σ_x	Pressure Stress σ_θ	Pressure Stress σ_r	Thermal Stress σ_x	Thermal Stress σ_θ	Thermal Induced Pipe Reaction Stress σ_x	Thermal Induced Pipe Reaction Stress σ_θ	Thermal Induced Pipe Reaction Stress $\tau_{x\theta}$	Seismic Pipe Reaction Stress σ_x	Seismic Pipe Reaction Stress σ_θ	Seismic Pipe Reaction Stress $\tau_{x\theta}$	Static Weight Stress σ_x	Static Weight Stress σ_θ	Static Weight Stress $\tau_{x\theta}$
c. Plant Loading	10 min	-3.80	58.92	-2.25	-1.78	-0.49	-5.18	-1.65	-0.05	0	0	0	1.62	0.55	0
	15				-2.94	-0.66									
	20				-4.25	-0.77									
	25				-4.41	-0.36									
	30				-4.06	0.21									
Full Load Steadystate					-1.88	4.51									
d. Plant Unloading	10 min				1.57	6.19									
	15				2.68	6.24									
	20				3.59	6.16									
	25				4.03	5.86									
	30				3.52	5.08									
e	100 sec	-3.62	56.04	-2.14	-3.22	1.26									
	225	-3.84	59.58	-2.27	-6.15	-1.68									
f	40 sec	-3.92	60.76	-2.32	-9.54	-5.07									
	100	-3.82	59.18	-2.26	-10.78	-6.30									
	260	-3.62	56.04	-2.14	-7.08	-2.60									
g	3.5 min	-3.97	61.54	-2.35	-5.13	-0.67									
	11	-3.63	56.30	-2.15	-0.21	4.26									
	15.5	-3.80	58.92	-2.25	0.09	4.57									

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.
CHARGE NO.
DESCRIPTION *Structural and Fatigue Evaluation of Outlet Nozzle – Vessel Supports*

NUMBER *5-212-P* | *A248*
SHEET *76* OF *80*
DATE *4-22-68* BY *Cockrell*
CHECK DATE *4-22-68* BY *Heilker*

5. Detailed Analysis:
e. Stresses:
2. Peak Stresses

Location 9A

Transient		Pressure Stress			Thermal Stress		Thermal Induced Pipe Reaction Stress			Seismic Pipe Reaction Stress			Static Weight Stress		
		σ_x	σ_θ	σ_r	σ_x	σ_θ	σ_x	σ_θ	$\tau_{x\theta}$	σ_x	σ_θ	$\tau_{x\theta}$	σ_x	σ_θ	$\tau_{x\theta}$
h	10 sec	-3.75	58.14	-2.22	-3.59	0.87	-5.18	-1.65	-0.05	0	0	0	1.62	0.55	0
	90	-3.28	50.80	-1.94	1.94	6.41	-5.18	-1.65	-0.05	↓	↓	↓	↓	↓	↓
i	220 min	-5.28	81.84	-3.12	0	0	0	0	0	↓	↓	↓	↓	↓	↓
j	H.U. 3.0 HRS	-2.11	32.73	-1.25	-13.32	-15.46	-3.48	-1.11	-0.03	↓	↓	↓	↓	↓	↓
	S.S.	-4.22	65.47	-2.50	0.11	-0.06	-3.48	-1.11	-0.03	↓	↓	↓	↓	↓	↓
	C.O. 3.0 HRS	-0.53	8.25	-0.31	13.51	14.27	0	0	0	↓	↓	↓	↓	↓	↓
k	~	-3.97	61.54	-2.35	-4.82	-0.36	-5.18	-1.65	-0.05	↓	↓	↓	↓	↓	↓
	~	-3.63	56.30	-2.15	-8.51	-4.05	↓	↓	↓	↓	↓	↓	↓	↓	↓
ℓ	12 sec	-3.80	58.92	-2.25	9.32	13.78	↓	↓	↓	↓	↓	↓	↓	↓	↓
	18.5	-3.80	58.92	-2.25	-0.15	4.26	↓	↓	↓	↓	↓	↓	↓	↓	↓
m	12 sec	-4.65	72.02	-2.75	-10.05	-5.59	↓	↓	↓	↓	↓	↓	↓	↓	↓
	26	-3.38	54.38	-2.00	-13.13	-8.67	↓	↓	↓	↓	↓	↓	↓	↓	↓
	144	-2.49	38.63	-1.47	1.02	5.49	↓	↓	↓	↓	↓	↓	↓	↓	↓
n	33 sec	-0.51	7.86	-0.30	29.03	33.53	↓	↓	↓	↓	↓	↓	↓	↓	↓
	54	-1.18	18.33	-0.70	53.46	57.95	↓	↓	↓	↓	↓	↓	↓	↓	↓

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER S-212-P | A 249
SHEET 77 OF 80
CHARGE NO. ______
DATE 4-22-68 BY COCKRELL
DESCRIPTION STRUCTURAL AND FATIGUE EVALUATION OF OUTLET NOZZLE - VESSEL SUPPORT
CHECK DATE 4-22-68 BY HEILKER

5. DETAILED ANALYSIS:

e. STRESSES:

2. PEAK STRESSES:

LOCATION 9A

TRANSIENT		EARTHQUAKE LOADING THROUGH SUPPORTS STRESS σ_x	σ_θ	$\tau_{x\theta}$	EXPANSION AND CONTRACTION STRESS σ_x	σ_θ	TOTAL STRESS σ_x	σ_θ	σ_r	$\tau_{x\theta}$	PRINCIPAL STRESS σ_1	σ_2	σ_3	STRESS INTENSITY $\sigma_1-\sigma_2$	$\sigma_1-\sigma_3$	$\sigma_2-\sigma_3$
a- HEATUP	4.00 HRS	-0.38	-0.13	-0.20	-0.28	0.53	-22.86	31.67	-1.88	-0.68	31.68	-22.87	-1.88	54.55	33.56	-20.99
	4.25	↓	↓	↓	↓	↓	-23.63	36.57	-2.08	-0.68	36.58	-23.64	-2.08	60.21	38.65	-21.56
	4.35	↓	↓	↓	↓	↓	-23.92	38.52	-2.16	-0.68	38.53	-23.92	-2.16	62.45	40.69	-21.77
	4.47	↓	↓	↓	↓	↓	-24.73	40.54	-2.25	-0.69	40.54	-24.73	-2.25	65.28	42.79	-22.48
	5.00	↓	↓	↓	↓	↓	-17.08	49.06	-2.25	-0.69	49.07	-17.09	-2.25	66.16	51.32	-14.84
	4.00	0.38	0.13	0.20	↓	↓	-16.97	34.56	-1.88	0.59	34.57	-16.98	-1.88	51.55	36.45	-15.10
	4.25	↓	↓	↓	↓	↓	-17.74	39.46	-2.08	0.59	39.47	-17.74	-2.08	57.22	41.55	-15.67
	4.35	↓	↓	↓	↓	↓	-18.03	41.42	-2.16	0.58	41.42	-18.03	-2.16	59.46	43.58	-15.88
	4.47	↓	↓	↓	↓	↓	-18.84	43.43	-2.25	0.58	43.44	-18.84	-2.25	62.28	45.69	-16.59
	5.00	↓	↓	↓	↓	↓	-11.20	51.95	-2.25	0.58	51.96	-11.20	-2.25	63.16	54.21	-8.95
NO LOAD STEADY STATE		0	0	0	0	0	-7.20	57.73	-2.25	-0.05	57.74	-7.20	-2.25	64.93	59.99	-4.95
b- COOLDOWN	4.00 HRS	-0.38	-0.13	-0.20	0.28	-0.53	10.11	20.94	-0.31	-0.64	20.98	10.08	-0.31	10.90	21.29	10.39
	4.25	↓	↓	↓	↓	↓	10.27	20.89	↓	-0.64	20.93	10.23	↓	10.70	21.24	10.55
	4.35	↓	↓	↓	↓	↓	10.32	20.87	↓	-0.64	20.91	10.28	↓	10.63	21.22	10.59
	4.47	↓	↓	↓	↓	↓	10.81	21.16	↓	-0.63	21.20	10.77	↓	10.43	21.52	11.09
	5.00	↓	↓	↓	↓	↓	3.99	13.46	↓	-0.63	13.50	3.95	↓	9.56	13.82	4.26
	4.00	0.38	0.13	0.20	↓	↓	16.00	23.83	↓	0.63	23.88	15.95	↓	7.93	24.19	16.26
	4.25	↓	↓	↓	↓	↓	16.15	23.79	↓	0.63	23.84	16.10	↓	7.74	24.15	16.41
	4.35	↓	↓	↓	↓	↓	16.20	23.76	↓	0.63	23.81	16.15	↓	7.66	24.13	16.46
	4.47	↓	↓	↓	↓	↓	16.69	24.05	↓	0.63	24.11	16.64	↓	7.47	24.42	16.95
	5.00	↓	↓	↓	↓	↓	9.87	16.35	↓	0.63	16.41	9.81	↓	6.60	16.73	10.12

IPEC00069751

RIV000052B
Submitted: December 22, 2011

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.
CHARGE NO.
DESCRIPTION *Structural and Fatigue Evaluation of Outlet Nozzle – Vessel Supports*

NUMBER S-212-P | A 250
SHEET 78 OF 80
DATE 4-22-68 BY Cockrell
CHECK DATE 4-22-68 BY Heiker

5- Detailed Analysis:

e- Stresses:

2- Peak Stresses:

Location 9A

Transient		Earthquake Loading Through Supports Stress			Expansion and Contraction Stress		Total Stress				Principal Stress			Stress Intensity		
		σ_x	σ_θ	$\tau_{x\theta}$	σ_x	σ_θ	σ_x	σ_θ	σ_r	$\tau_{x\theta}$	σ_1	σ_2	σ_3	$\sigma_1-\sigma_2$	$\sigma_1-\sigma_3$	$\sigma_2-\sigma_3$
c Plant Loading	10 min	0	0	0	0	0	-9.15	57.33	-2.25	-0.05	57.33	-9.15	-2.25	66.47	59.58	-6.90
	15						-10.31	57.16			57.16	-10.31		67.47	59.41	-8.06
	20						-11.61	57.05			57.05	-11.61		68.66	59.30	-9.36
	25						-11.78	57.45			57.45	-11.78		69.23	59.70	-9.53
	30						-11.43	58.03			58.03	-11.43		69.46	60.28	-9.18
Full Load Steady State							-9.25	62.33			62.33	-9.25		71.58	64.58	-7.00
d Plant Unloading	10 min						-5.80	64.01			64.01	-5.80		69.80	66.26	-3.55
	15						-4.69	64.06			64.06	-4.69		68.75	66.31	-2.44
	20						-3.78	63.98			63.98	-3.78		67.75	66.23	-1.53
	25						-3.33	63.68			63.68	-3.33		67.01	65.93	-1.08
	30						-3.84	62.90			62.90	-3.84		66.74	65.15	-1.59
e	100 sec						-10.40	56.19	-2.14		56.19	-10.40	-2.14	66.59	58.33	-8.26
	225						-13.56	56.80	-2.27		56.80	-13.56	-2.27	70.35	59.07	-11.28
f	40 sec						-17.03	54.58	-2.32		54.58	-17.03	-2.32	71.61	56.90	-14.71
	100						-18.16	51.78	-2.26		51.78	-18.16	-2.26	69.94	54.04	-15.90
	260						-14.26	52.34	-2.14		52.34	-14.26	-2.14	66.59	54.48	-12.12
g	3.5 min						-12.66	59.77	-2.35		59.77	-12.66	-2.35	72.43	62.12	-10.31
	11						-7.40	59.46	-2.15		59.46	-7.40	-2.15	66.86	61.61	-5.25
	15.5						-7.27	62.38	-2.25		62.38	-7.27	-2.25	69.65	64.63	-5.02

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO. ____________

DESCRIPTION: Structural And Fatigue Evaluation Of Outlet Nozzle - Vessel Supports

NUMBER: 5-212-P | A251
SHEET 79 OF 80
DATE 4-22-68 BY Cockrell
CHECK DATE 4-22-68 BY Heilker

5. Detailed Analysis:

e. Stresses:

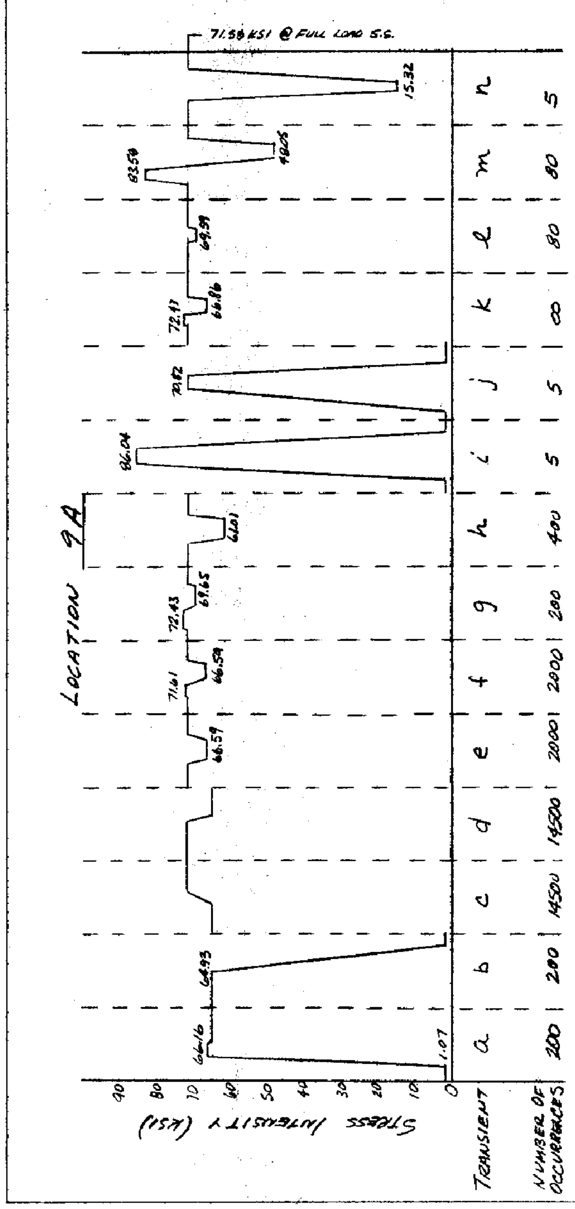
2- Peak Stresses

Location 9A

Transient		Earthquake Loading Through Supports Stress			Expansion And Contraction Stress		Total Stress				Principal Stress			Stress Intensity		
		σ_x	σ_θ	$\tau_{x\theta}$	σ_x	σ_θ	σ_x	σ_θ	σ_r	$\tau_{x\theta}$	σ_1	σ_2	σ_3	$\sigma_1-\sigma_2$	$\sigma_1-\sigma_3$	$\sigma_2-\sigma_3$
h	10 sec	0	0	0	0	0	-10.91	57.90	-2.22	-0.05	57.90	-10.91	-2.22	68.81	60.12	-8.69
	90	↓	↓	↓	↓	↓	-4.90	56.11	-1.94	-0.05	56.11	-4.90	-1.94	61.01	58.05	-2.96
i	220 min	↓	↓	↓	↓	↓	-3.66	82.38	-3.12	0	82.38	-3.66	-3.12	86.04	85.51	-0.54
j	H.U. 3.0 HRS	↓	↓	↓	↓	↓	-17.29	16.72	-1.25	-0.03	16.72	-17.29	-1.25	34.01	17.97	-16.04
	S.S.	↓	↓	↓	↓	↓	-5.97	64.85	-2.50	-0.03	64.85	-5.97	-2.25	70.82	67.35	-3.47
	C.D. 30 HRS	↓	↓	↓	↓	↓	14.60	23.06	-0.31	0	23.06	14.60	-0.31	8.46	23.38	14.91
k	~	↓	↓	↓	↓	↓	-12.36	60.08	-2.35	-0.05	60.08	-12.36	-2.35	72.43	62.43	-10.01
	~	↓	↓	↓	↓	↓	-15.71	51.15	-2.15	↓	51.15	-15.71	-2.15	66.86	53.30	-13.56
l	12 sec	↓	↓	↓	↓	↓	1.96	71.60	-2.25	↓	71.60	1.96	-2.25	69.64	73.85	4.21
	18.5	↓	↓	↓	↓	↓	-7.51	62.08	-2.25	↓	62.08	-7.51	-2.25	69.59	64.33	-5.26
m	12 sec	↓	↓	↓	↓	↓	-18.26	65.32	-2.75	↓	65.32	-18.26	-2.75	83.58	68.07	-15.51
	26	↓	↓	↓	↓	↓	-20.07	42.60	-2.00	↓	42.60	-20.07	-2.00	62.67	44.60	-18.07
	144	↓	↓	↓	↓	↓	-5.04	43.01	-1.47	↓	43.01	-5.04	-1.47	48.05	44.49	-3.56
n	33 sec	↓	↓	↓	↓	↓	24.96	40.28	-0.30	↓	40.28	24.96	-0.30	15.32	40.58	25.26
	54	↓	↓	↓	↓	↓	48.71	75.18	-0.70	↓	75.18	48.71	-0.70	26.47	75.88	49.41

5. Detailed Analysis:

f- Fatigue Evaluation:



S_{MAX}	S_{MIN}	S_{ALT}	No. of Occurrences	N*	U
86.04	1.07	42.49	5	7000	.0007
83.58	1.07	41.26	80	7700	.0104
72.43	1.07	35.68	120	11500	.0104
70.92	1.07	34.88	5	13000	.0004
72.43	15.32	28.56	5	26000	.0002
72.43	48.05	12.19	80	∞	0

* From Fig. N-415(A) Reference 1

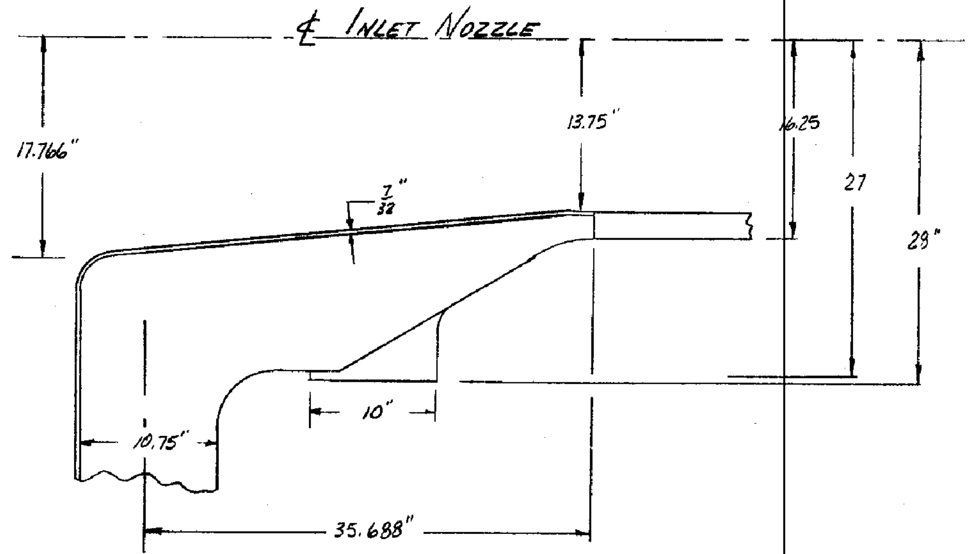
$U_{OVERALL} = 0.022$

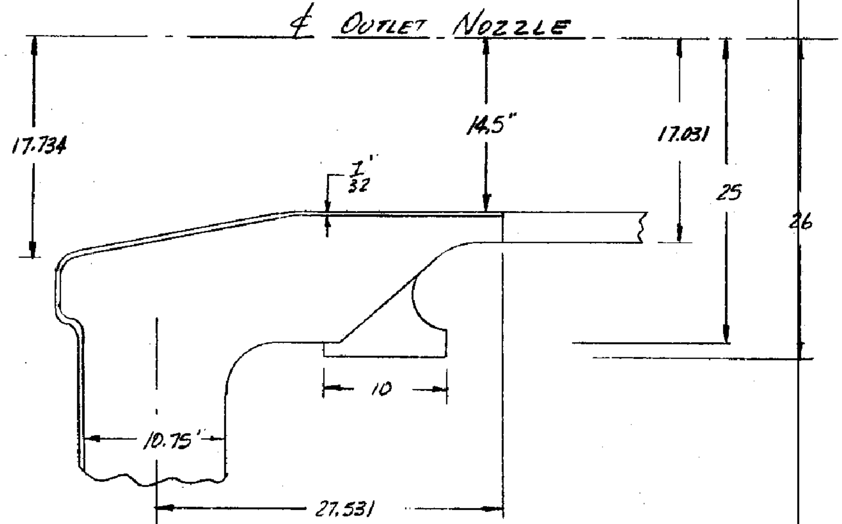
COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.
CHARGE NO.
DESCRIPTION Structural Analysis Of Inlet & Outlet Nozzles Vessel Supports Under Pipe Break Loads

NUMBER 5-214-P | A 253
SHEET 5 OF 19
DATE 1-11-67 BY Cockrell
CHECK DATE 1-11-67 BY Caudle

5. Detailed Analysis:

a. System Geometry:

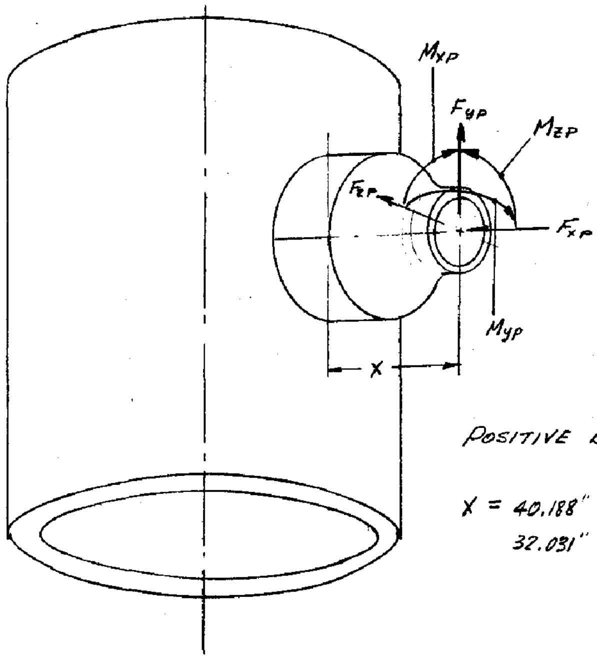




COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER S-214-P | A 254
SHEET 6 OF 19
CHARGE NO.
DATE 1-11-67 BY COCKRELL
DESCRIPTION STRUCTURAL ANALYSIS OF INLET & OUTLET NOZZLES VESSEL SUPPORTS UNDER PIPE BREAK LOADS
CHECK DATE 1-11-67 BY CAUDLE

DETAILED ANALYSIS:
b SYSTEM LOADS:
1. LOADING ON NOZZLES:



POSITIVE DIRECTION A SHOWN

X = 40.188" (INLET NOZZLE)
32.031" (OUTLET NOZZLE)

CASE	NOZZLE	F_{XP}	F_{YP}	F_{ZP}	M_{XP}	M_{YP}	M_{ZP}
1	INLET	1185	0	604	0	0	0
2	OUTLET	1470	0	0	0	0	0
3	INLET	1330	0	0	0	0	0
4	OUTLET	945	-461	0	0	0	-88500
5	INLET	0	0	253	253	-72800	0

NOTE THAT UNITS ON FORCES AND MOMENTS ARE KIPS AND KIP-INS.

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO. ______

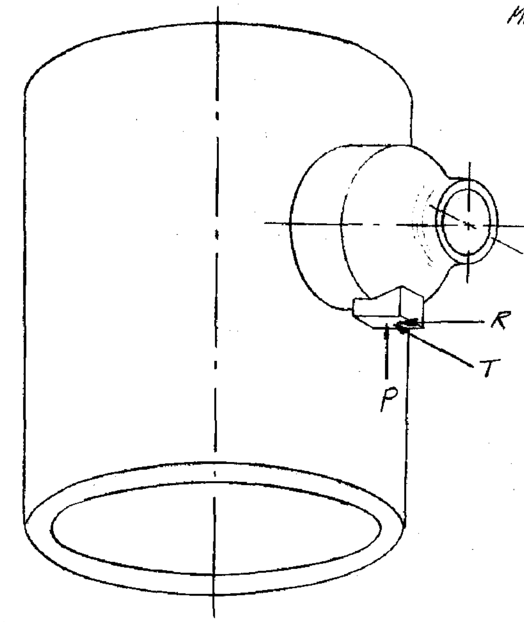
DESCRIPTION STRUCTURAL ANALYSIS OF INLET & OUTLET NOZZLE VESSEL SUPPORTS UNDER PIPE BREAK LOADS

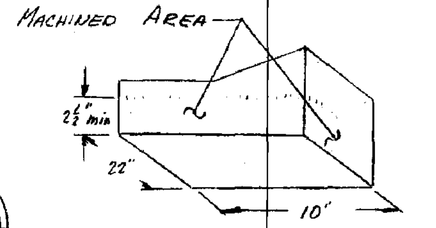
NUMBER 5-214-P | A 255
SHEET 7 OF 19
DATE 1-11-67 BY COCKRELL
CHECK DATE 1-11-67 BY CAUDLE

5. DETAILED ANALYSIS:

b- SYSTEM LOADS:

2- LOADING ON VESSEL SUPPORT PAD:





THE TEMPERATURE OF THE PAD WILL BE TAKEN AS 300°F MAXIMUM; HENCE, THE ALLOWABLE BEARING STRESS IS $S_y = 45.25$ KSI

FORCE KIPS	A REACTOR VESSEL WEIGHT & PIPING REACTIONS	B PIPE BREAK CASE II	C PIPE BREAK CASE III	D EARTHQUAKE Z & VERTICAL DIRECTIONS	Σ A+B	Σ A+C	Σ A+D
P	934	—	525	395	934	1459	1329
R	322	—	—	—	322	322	322
T	140	866	473	969	1006	613	1109

C- SYSTEM ALLOWABLES:

1- THE COMBINATION OF MEMBRANE PLUS BENDING IN THE VESSEL WALL AT THE NOZZLE JUNCTURE SHALL NOT EXCEED $1.5 S_m$ AT THE ACTUAL METAL TEMPERATURE.

2- THE BENDING STRESS IN THE COOLANT NOZZLE SHALL BE LESS THAN $1.27 S_y$ AT ACTUAL METAL TEMPERATURE.

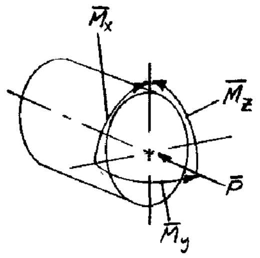
3- THE BEARING STRESS ON THE VESSEL SUPPORT PAD WELD BUILD-UP SHALL BE LESS THAN S_y AT ACTUAL METAL TEMPERATURE.

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER S-214-P | A 256
SHEET 8 OF 19
CHARGE NO.
DATE 1-11-67 BY COCKRELL
DESCRIPTION STRUCTURAL ANALYSIS OF INLET & OUTLET NOZZLES VESSEL SUPPORTS UNDER PIPE BREAK LOADS
CHECK DATE 1-11-67 BY CAUDLE

5 DETAILED ANALYSIS:
d- FORCES ON VESSEL WALL:

WESTINGHOUSE PAR No. 32 STATES THAT THE AXIAL LOAD (F_{XP} AS SHOWN ON THE SHEET 6) "SHOULD NOT BE CONSIDERED AS ACTING ON THE NOZZLES BUT MUST BE REACTED BY THE NOZZLE SUPPORTS". SINCE THERE ARE NO OTHER FORCES ACTING FOR CASES No. 2 & 3, THESE CASES WILL BE DISREGARDED; AND, THE AXIAL LOAD F_{XP} WILL BE DISREGARDED FOR ALL CASES WHEN CONSIDERING THE NOZZLES.



$\bar{P} = 0$ (FOR ALL CASES)

$\bar{M}_x = \bar{M}_{xp}$

$\bar{M}_y = \bar{M}_{yp} - x F_{zp}$

$\bar{M}_z = M_{zp} + x F_{yp}$

CASE	NOZZLE	$\bar{P}$	$\bar{M}_x$	$\bar{M}_y$	$\bar{M}_z$
1	INLET	0	0	-24274	0
4	OUTLET	0	0	0	-103266
5	INLET	0	253	-82968	0

THE METHOD OF DETERMINING THE FORCES EXERTED IN THE LONGITUDINAL AND CIRCUMFERENTIAL DIRECTIONS OF THE VESSEL DUE TO THE APPLIED EXTERNAL LOADS IS AS OUTLINED IN REFERENCE 20

$\beta = \frac{0.875 r_0}{a} = 0.260$ (INLET NOZZLE)
0.240 (OUTLET NOZZLE)

$\gamma = \frac{a}{t} = 8.468$

FOR,
$r_0 = 27''$ (INLET NOZZLE RADIUS)
25'' (OUTLET NOZZLE RADIUS)
$a = 91.031''$ (VESSEL RADIUS)
$t = 10.75''$ (VESSEL WALL THICKNESS)

DESCRIPTION STRUCTURAL ANALYSIS OF INLET & OUTLET NOZZLES VESSEL SUPPORTS UNDER PIPE BREAK LOADS

5- DETAILED ANALYSIS:

d- FORCES ON VESSEL WALL:

FOR EXTERNAL LONGITUDINAL MOMENT $\bar{M}_z$:

INLET NOZZLE:

$\frac{N_\phi}{\bar{M}_z/a^2\beta} = 0.95$; $N_\phi = \frac{0.95\,\bar{M}_z}{(91.031)^2(.260)} = 0.00044\,\bar{M}_z$

$\frac{N_x}{\bar{M}_z/a^2\beta} = 0.22$; $N_x = \frac{0.22\,\bar{M}_z}{(91.031)^2(.260)} = 0.00010\,\bar{M}_z$

$\frac{M_\phi}{\bar{M}_z/a\beta} = 0.041$; $M_\phi = \frac{0.041\,\bar{M}_z}{(91.031)(.260)} = 0.00173\,\bar{M}_z$

$\frac{M_x}{\bar{M}_z/a\beta} = 0.063$; $M_x = \frac{0.063\,\bar{M}_z}{(91.031)(.260)} = 0.00266\,\bar{M}_z$

OUTLET NOZZLE:

$\frac{N_\phi}{\bar{M}_z/a^2\beta} = 0.92$; $N_\phi = \frac{0.92\,\bar{M}_z}{(91.031)^2(.240)} = 0.00046\,\bar{M}_z$

$\frac{N_x}{\bar{M}_z/a^2\beta} = 0.20$; $N_x = \frac{0.20\,\bar{M}_z}{(91.031)^2(.240)} = 0.00010\,\bar{M}_z$

$\frac{M_\phi}{\bar{M}_z/a\beta} = 0.043$; $M_\phi = \frac{0.043\,\bar{M}_z}{(91.031)(.240)} = 0.00197\,\bar{M}_z$

$\frac{M_x}{\bar{M}_z/a\beta} = 0.069$; $M_x = \frac{0.069\,\bar{M}_z}{(91.031)(.240)} = 0.00316\,\bar{M}_z$

CASE	NOZZLE	$\bar{M}_z$	N_ϕ	N_x	M_ϕ	M_x
1	INLET	0	0	0	0	0
4	OUTLET	-103266	-47.502	-10.327	-203.434	-326.321
5	INLET	0	0	0	0	0

FOR EXTERNAL CIRCUMFERENTIAL MOMENT $\bar{M}_y$:

INLET NOZZLE:

$\frac{N_\phi}{\bar{M}_y/a^2\beta} = 0.33$; $N_\phi = \frac{0.33\,\bar{M}_y}{(91.031)^2(.260)} = 0.00015\,\bar{M}_y$

$\frac{N_x}{\bar{M}_y/a^2\beta} = 0.52$; $N_x = \frac{0.52\,\bar{M}_y}{(91.031)^2(.260)} = 0.00024\,\bar{M}_y$

$\frac{M_\phi}{\bar{M}_y/a\beta} = 0.092$; $M_\phi = \frac{0.092\,\bar{M}_y}{(91.031)(.260)} = 0.00389\,\bar{M}_y$

$\frac{M_x}{\bar{M}_y/a\beta} = 0.053$; $M_x = \frac{0.053\,\bar{M}_y}{(91.031)(.260)} = 0.00224\,\bar{M}_y$

OUTLET NOZZLE

$\frac{N_\phi}{\bar{M}_y/a^2\beta} = 0.30$; $N_\phi = \frac{0.30\,\bar{M}_y}{(91.031)^2(.240)} = 0.00015\,\bar{M}_y$

$\frac{N_x}{\bar{M}_y/a^2\beta} = 0.50$; $N_x = \frac{0.50\,\bar{M}_y}{(91.031)^2(.240)} = 0.00025\,\bar{M}_y$

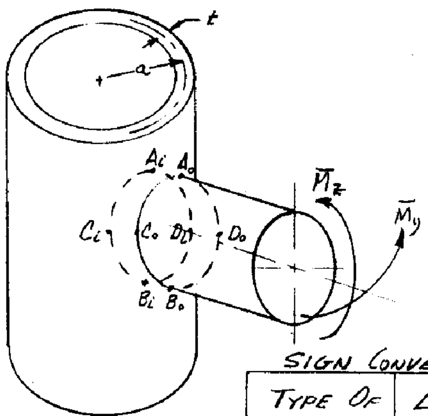
$\frac{M_\phi}{\bar{M}_y/a\beta} = 0.094$; $M_\phi = \frac{0.094\,\bar{M}_y}{(91.031)(.240)} = 0.00430\,\bar{M}_y$

$\frac{M_x}{\bar{M}_y/a\beta} = 0.055$; $M_x = \frac{0.055\,M_x}{(91.031)(.240)} = 0.00252\,\bar{M}_y$

CASE	NOZZLE	$\bar{M}_y$	N_ϕ	N_x	M_ϕ	M_x
1	INLET	-24274	-3.641	-5.826	-94.426	-54.374
4	OUTLET	0	0	0	0	0
5	INLET	-82968	-12.445	-19.912	-322.746	-185.848

5 DETAILED ANALYSIS:

e- STRESSES IN VESSEL WALL:



$a = 91.031''$

$t = 10.75''$

$r = 27''$ (INLET NOZZLE)

$25''$ (OUTLET NOZZLE)

$\frac{1}{t} = 0.09302$

$\frac{6}{t^2} = 0.05191$

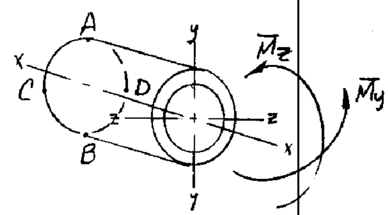
SIGN CONVENTION FOR STRESSES

TYPE OF STRESS	LOCATION	EXTERNAL LOAD $\bar{M}_z$	EXTERNAL LOAD $\bar{M}_y$
MEMBRANE $\frac{N_x}{t}$ & $\frac{N_\phi}{t}$	A_o & A_i	−	
	B_o & B_i	+	
	C_o & C_i		+
	D_o & D_i		−
BENDING $\frac{6M_x}{t^2}$	A_i	+	
	A_o	−	
	B_i	−	
	B_o	+	
	C_i		−
	C_o		+
	D_i		+
	D_o		−
BENDING $\frac{6M_\phi}{t^2}$	A_i	+	
	A_o	−	
	B_i	−	
	B_o	+	
	C_i		−
	C_o		+
	D_i		+
	D_o		−

5- DETAILED ANALYSIS:

e- STRESSES IN VESSEL WALL:

CASE NO. 1
INLET NOZZLE



σ_x KSI

POINT	SURFACE	DUE TO $\overline{M}_z$ $\frac{N_x}{t}$	DUE TO $\overline{M}_z$ $\frac{6M_x}{t^2}$	DUE TO $\overline{M}_y$ $\frac{N_x}{t}$	DUE TO $\overline{M}_y$ $\frac{6M_x}{t^2}$	TOTAL
A	IN	0	0	0	0	0
	OUT	↓	↓	↓	↓	↓
B	IN	↓	↓	↓	↓	↓
	OUT	↓	↓	↓	↓	↓
C	IN	↓	↓	− 0.54	+ 2.82	2.28
	OUT	↓	↓	− 0.54	− 2.82	−3.36
D	IN	↓	↓	+ 0.54	− 2.82	−2.28
	OUT	↓	↓	+ 0.54	+ 2.82	3.36

σ_θ KSI

POINT	SURFACE	DUE TO $\overline{M}_z$ $\frac{N_\phi}{t}$	DUE TO $\overline{M}_z$ $\frac{6M_\phi}{t^2}$	DUE TO $\overline{M}_y$ $\frac{N_\phi}{t}$	DUE TO $\overline{M}_y$ $\frac{6M_\phi}{t^2}$	TOTAL
A	IN	0	0	0	0	0
	OUT	↓	↓	↓	↓	↓
B	IN	↓	↓	↓	↓	↓
	OUT	↓	↓	↓	↓	↓
C	IN	↓	↓	− 0.34	+ 4.90	4.56
	OUT	↓	↓	− 0.34	− 4.90	−5.24
D	IN	↓	↓	+ 0.34	− 4.90	−4.56
	OUT	↓	↓	+ 0.34	+ 4.90	5.24

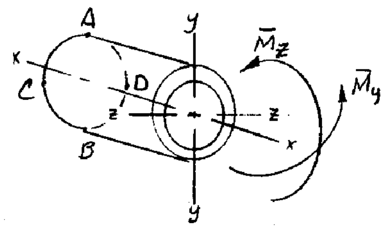
$S.I._{MAX} = \sigma_\theta - \sigma_r = 5.24 KSI$

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER S-214-P | A 260
SHEET 12 OF 19
CHARGE NO. ____
DATE 1-11-67 BY COCKRELL
DESCRIPTION STRUCTURAL ANALYSIS OF INLET & OUTLET NOZZLES VESSEL SUPPORTS UNDER PIPE BREAK LOADS
CHECK DATE 1-11-67 BY CAUDLE

5- DETAILED ANALYSIS:
e- STRESSES IN VESSEL WALL:

CASE NO. 4
OUTLET NOZZLE



σ_x KSI

POINT	SURFACE	DUE TO $\bar{M}_z$: $\frac{N_x}{t}$	DUE TO $\bar{M}_z$: $\frac{6M_x}{t^2}$	DUE TO $\bar{M}_y$: $\frac{N_x}{t}$	DUE TO $\bar{M}_y$: $\frac{6M_x}{t^2}$	TOTAL
A	IN	+ 0.96	− 16.94	0	0	−15.98
	OUT	+ 0.96	+ 16.94	↓	↓	17.90
B	IN	− 0.96	+ 16.94	↓	↓	15.98
	OUT	− 0.96	− 16.94	↓	↓	− 17.90
C	IN	0	0	↓	↓	0
	OUT	↓	↓	↓	↓	↓
D	IN	↓	↓	↓	↓	↓
	OUT	↓	↓	↓	↓	↓

σ_ϕ KSI

POINT	SURFACE	DUE TO $\bar{M}_z$: $\frac{N_\phi}{t}$	DUE TO $\bar{M}_z$: $\frac{6M_\phi}{t^2}$	DUE TO $\bar{M}_y$: $\frac{N_\phi}{t}$	DUE TO $\bar{M}_y$: $\frac{6M_\phi}{t^2}$	TOTAL
A	IN	+ 4.42	− 10.56	0	0	− 6.14
	OUT	+ 4.42	+ 10.56	↓	↓	14.98
B	IN	− 4.42	+ 10.56	↓	↓	6.14
	OUT	− 4.42	− 10.56	↓	↓	− 14.98
C	IN	0	0	↓	↓	0
	OUT	↓	↓	↓	↓	↓
D	IN	↓	↓	↓	↓	↓
	OUT	↓	↓	↓	↓	↓

$SI_{MAX} = \sigma_x - \sigma_r$
$= 17.9$ KSI

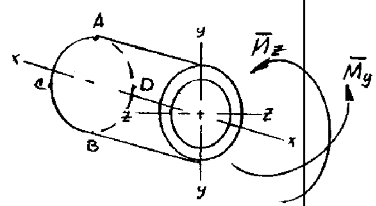
COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.
CHARGE NO.

NUMBER S-214-P | A 261
SHEET 13 OF 19
DATE 1-11-67 BY COCKRELL
CHECK DATE 1-11-67 BY CAUDLE

DESCRIPTION STRUCTURAL ANALYSIS OF INLET & OUTLET NOZZLES VESSEL SUPPORTS UNDER PIPE BREAK LOADS

5. DETAILED ANALYSIS:
e- STRESSES IN VESSEL WALL:

CASE NO. 5
INLET NOZZLE



σ_x KSI

POINT	SURFACE	DUE TO $\bar{M}_z$ $\frac{N_x}{t}$	DUE TO $\bar{M}_z$ $\frac{6M_x}{t^2}$	DUE TO $\bar{M}_y$ $\frac{N_x}{t}$	DUE TO $\bar{M}_y$ $\frac{6M_x}{t^2}$	TOTAL
A	IN	0	0	0	0	0
	OUT	↓	↓	↓	↓	↓
B	IN					
	OUT			↓	↓	↓
C	IN			− 1.85	+ 9.65	7.80
	OUT			− 1.85	− 9.65	− 11.50
D	IN			+ 1.85	− 9.65	− 7.80
	OUT	↓	↓	+ 1.85	+ 9.65	11.50

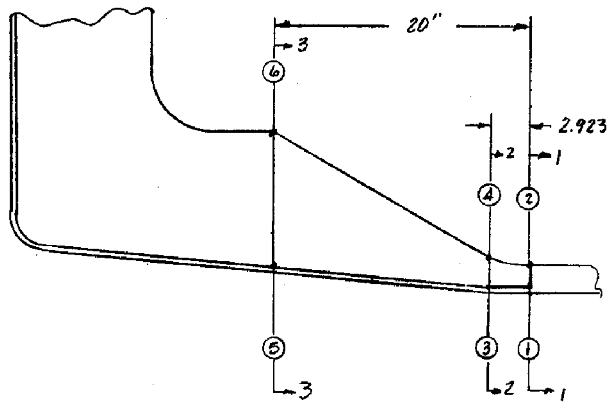
σ_θ KSI

POINT	SURFACE	DUE TO $\bar{M}_z$ $\frac{N_\phi}{t}$	DUE TO $\bar{M}_z$ $\frac{6M_\phi}{t^2}$	DUE TO $\bar{M}_y$ $\frac{N_\phi}{t}$	DUE TO $\bar{M}_y$ $\frac{6M_\phi}{t^2}$	TOTAL
A	IN	0	0	0	0	0
	OUT	↓	↓	↓	↓	↓
B	IN					
	OUT			↓	↓	↓
C	IN			− 1.16	+ 16.75	15.59
	OUT			− 1.16	− 16.75	− 17.91
D	IN			+ 1.16	− 16.75	− 15.59
	OUT	↓	↓	+ 1.16	+ 16.75	17.91

$S.I._{MAX} = \sigma_\theta - \sigma_r$
$= 17.91$ KSI

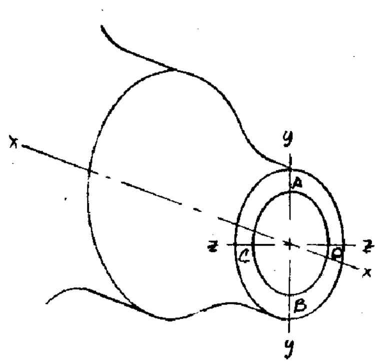
5. DETAILED ANALYSIS:
f. STRESSES IN NOZZLE:

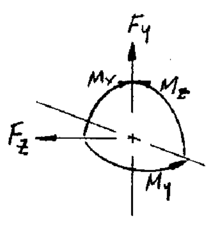
INLET NOZZLE:



STRESSES WILL BE CALCULATED FOR THE SIX LOCATIONS AS SHOWN AND FOR THE FOUR POINTS A, B, C & D AT EACH LOCATION.

℄ INLET NOZZLE





SECTION 1-1
$M_x = M_{xp}$
$M_y = M_{yp}$
$M_z = M_{zp}$

SECTION 2-2
$M_x = M_{xp}$
$M_y = M_{yp} - 2.923\,F_{zp}$
$M_z = M_{zp} + 2.923\,F_{yp}$

SECTION 3-3
$M_x = M_{xp}$
$M_y = M_{yp} - 20F_{zp}$
$M_z = M_{zp} + 20F_{yp}$

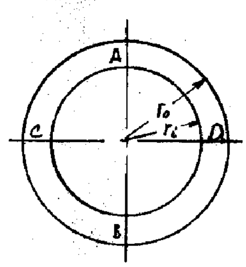
COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.
CHARGE NO.

NUMBER S-214-P | A 263
SHEET 15 OF 19
DATE 1-11-67 BY COCKRELL
DESCRIPTION STRUCTURAL ANALYSIS OF INLET & OUTLET NOZZLES VESSEL SUPPORT UNDER PIPE BREAK LOADS
CHECK DATE 1-11-67 BY CAUDLE

5- DETAILED ANALYSIS:
f- STRESSES IN NOZZLE:

INLET NOZZLE:

SECTION 1-1

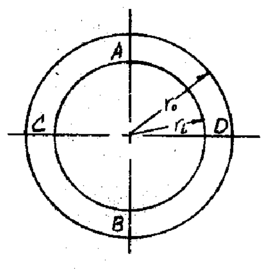


$I = \frac{\pi}{4}(r_o^4 - r_i^4) = 24861\ in^4$

$\sigma_x = \mp \frac{M_z c}{I} = \mp 0.00056 M_z$ (LOCATION 1, POINTS A&B)
$\sigma_x = \mp \frac{M_y c}{I} = \pm 0.00056 M_y$ (LOCATION 1, POINTS C&D)
$\sigma_x = \mp \frac{M_z c}{I} = \mp 0.00065 M_z$ (LOCATION 2, POINTS A&B)
$\sigma_x = \mp \frac{M_y c}{I} = \pm 0.00065 M_y$ (LOCATION 2, POINTS C&D)

$\tau_{x\theta} = \frac{M_x c}{2I} = 0.00028 M_x$ (LOCATION 1, POINTS A,B,C&D)
$\tau_{x\theta} = \frac{M_x c}{2I} = 0.00033 M_x$ (LOCATION 2, POINTS A,B,C&D)

SECTION 2-2

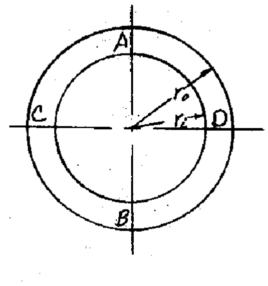


$I = \frac{\pi}{4}(r_o^4 - r_i^4) = 26562\ in^4$

$\sigma_x = \mp \frac{M_z c}{I} = \mp 0.00053 M_z$ (LOCATION 3, POINTS A&B)
$\sigma_x = \mp \frac{M_y c}{I} = \pm 0.00053 M_y$ (LOCATION 3, POINTS C&D)
$\sigma_x = \mp \frac{M_z c}{I} = \mp 0.00062 M_z$ (LOCATION 4, POINTS A&B)
$\sigma_x = \mp \frac{M_y c}{I} = \pm 0.00062 M_y$ (LOCATION 4, POINTS C&D)

$\tau_{x\theta} = \frac{M_x c}{2I} = 0.00027 M_x$ (LOCATION 3, POINTS A,B,C&D)
$\tau_{x\theta} = \frac{M_x c}{2I} = 0.00031 M_x$ (LOCATION 4, POINTS A,B,C&D)

SECTION 3-3



$I = \frac{\pi}{4}(r_o^4 - r_i^4) = 361,761\ in^4$

$\sigma_x = \mp \frac{M_z c}{I} = \mp 0.00005 M_z$ (LOCATION 5, POINTS A&B)
$\sigma_x = \mp \frac{M_y c}{I} = \pm 0.00005 M_y$ (LOCATION 5, POINTS C&D)
$\sigma_x = \mp \frac{M_z c}{I} = \mp 0.00007 M_z$ (LOCATION 6, POINTS A&B)
$\sigma_x = \mp \frac{M_y c}{I} = \pm 0.00007 M_y$ (LOCATION 6, POINTS C&D)

$\tau_{x\theta} = \frac{M_x c}{2I} = 0.00003 M_x$ (LOCATION 5, POINTS A,B,C&D)
$\tau_{x\theta} = \frac{M_x c}{2I} = 0.00004 M_x$ (LOCATION 6, POINTS A,B,C&D)

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.
CHARGE NO. ____

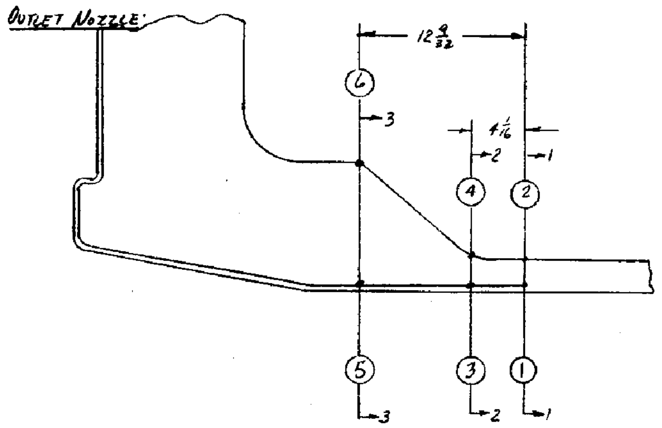
NUMBER S-24-P | A 264
SHEET 16 OF 19
DATE 1-11-67 BY COCKRELL
CHECK DATE 1-11-67 BY CAUDLE

DESCRIPTION: STRUCTURAL ANALYSIS OF INLET & OUTLET NOZZLES VESSEL SUPPORTS UNDER PIPE BREAK LOADS

5. DETAILED ANALYSIS:

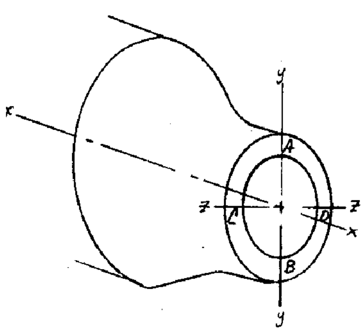
f. STRESSES IN NOZZLE:

OUTLET NOZZLE:



STRESSES WILL BE CALCULATED FOR THE SIX LOCATIONS AS SHOWN AND FOR THE FOUR POINTS A, B, C & D AT EACH LOCATION

℄ OUTLET NOZZLE



SECTION 1-1

$M_x = M_{xp}$

$M_y = M_{yp}$

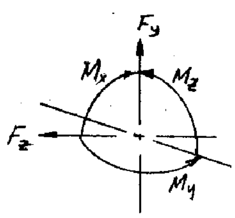
$M_z = M_{zp}$

SECTION 2-2

$M_x = M_{xp}$

$M_y = M_{yp} - 4.063\, F_{zp}$

$M_z = M_{zp} + 4.063\, F_{yp}$



SECTION 3-3

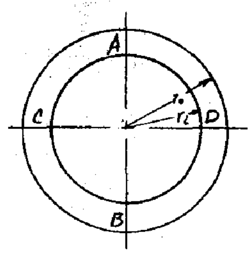
$M_x = M_{xp}$

$M_y = M_{yp} - 12.281\, F_{zp}$

$M_z = M_{zp} + 12.281\, F_{yp}$

5. DETAILED ANALYSIS:
f- STRESSES IN NOZZLE:

OUTLET NOZZLE:
SECTION 1-1:

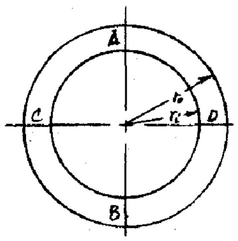


$I = \frac{\pi}{4}(r_o^4 - r_i^4) = 29217\ in^4$

$\sigma_x = \mp \frac{M_z c}{I} = \mp\ 0.00050\ M_z$ (LOCATION 1, POINTS A & B)
$\sigma_x = \mp \frac{M_y c}{I} = \pm\ 0.00050\ M_y$ (LOCATION 1, POINTS C & D)
$\sigma_x = \mp \frac{M_z c}{I} = \mp\ 0.00058\ M_z$ (LOCATION 2, POINTS A & B)
$\sigma_x = \mp \frac{M_y c}{I} = \pm\ 0.00058\ M_y$ (LOCATION 2, POINTS C & D)

$\tau_{x\theta} = \frac{M_x c}{2I} = 0.00025\ M_x$ (LOCATION 1, POINTS A, B, C & D)
$\tau_{x\theta} = \frac{M_x c}{2I} = 0.00029\ M_x$ (LOCATION 2, POINTS A, B, C & D)

SECTION 2-2:

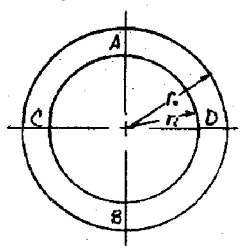


$I = \frac{\pi}{4}(r_o^4 - r_i^4) = 33179\ in^4$

$\sigma_x = \mp \frac{M_z c}{I} = \mp\ 0.00044\ M_z$ (LOCATION 3, POINTS A & B)
$\sigma_x = \mp \frac{M_y c}{I} = \pm\ 0.00044\ M_y$ (LOCATION 3, POINTS C & D)
$\sigma_x = \mp \frac{M_z c}{I} = \mp\ 0.00052\ M_z$ (LOCATION 4, POINTS A & B)
$\sigma_y = \mp \frac{M_y c}{I} = \pm\ 0.00052\ M_z$ (LOCATION 4, POINTS C & D)

$\tau_{x\theta} = \frac{M_x c}{2I} = 0.00022\ M_x$ (LOCATION 3, POINTS A, B, C & D)
$\tau_{x\theta} = \frac{M_x c}{2I} = 0.00026\ M_x$ (LOCATION 4, POINTS A, B, C & D)

SECTION 3-3:



$I = \frac{\pi}{4}(r_o^4 - r_i^4) = 270,000\ in^4$

$\sigma_x = \mp \frac{M_z c}{I} = \mp\ 0.00005\ M_z$ (LOCATION 5, POINTS A & B)
$\sigma_x = \mp \frac{M_y c}{I} = \pm\ 0.00005\ M_y$ (LOCATION 5, POINTS C & D)
$\sigma_x = \mp \frac{M_z c}{I} = \mp\ 0.00009\ M_z$ (LOCATION 6, POINTS A & B)
$\sigma_x = \mp \frac{M_y c}{I} = \pm\ 0.00009\ M_z$ (LOCATION 6, POINTS C & D)

$\tau_{x\theta} = \frac{M_x c}{2I} = 0.00003\ M_x$ (LOCATION 5, POINTS A & B)
$\tau_{x\theta} = \frac{M_x c}{2I} = 0.00105\ M_x$ (LOCATION 6, POINTS C & D)

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO.

DESCRIPTION Structural Analysis Of Inlet & Outlet Nozzles Vessel Supports Under Pipe Break Loads

NUMBER S-214-P | A 266
SHEET 18 OF 19
DATE 1-11-67 BY Cockrell
CHECK DATE 1-11-67 BY Caudle

5. Detailed Analysis:

f - Stresses In Nozzle:

Location	Point	Case 1 Inlet Nozzle M_x	M_y	M_z	σ_x	$\tau_{x\theta}$	Case 4 Outlet Nozzle M_x	M_y	M_z	σ_x	$\tau_{x\theta}$	Case 5 Inlet Nozzle M_x	M_y	M_z	σ_x	$\tau_{x\theta}$
1	A	0	0	0	0	0	0	0	-88500	44.25	0	+253	-72800	0	0	0.07
	B									-44.25					0	
	C									0					-40.77	
	D									0					+40.77	
2	A									51.33					0	0.08
	B									-51.33					0	
	C									0					-47.32	
	D									0					+47.32	
3	A		-1766						-90373	39.76			-73540		0	0.07
	B									-39.76					0	
	C				-0.94					0					-38.98	
	D				+0.94					0					+38.98	
4	A				0					46.99					0	0.08
	B				0					-46.99					0	
	C				-1.09					0					-45.59	
	D				+1.09					0					+45.59	
5	A		-12080		0				-94162	4.71			-77860		0	0.01
	B				0					-4.71					0	
	C				-0.60					0					-3.89	
	D				+0.60					0					+3.89	
6	A				0					8.47					0	0.01
	B				0					-3.47					0	
	C				-0.85					0					-5.45	
	D				+0.85					0					+5.45	

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT. CHATTANOOGA, TENN.
CHARGE NO.

NUMBER S-214-P | A 267
SHEET 19 OF 19
DATE 1-11-67 BY COCKRELL
CHECK DATE 1-11-67 BY CAUDLE

DESCRIPTION STRUCTURAL ANALYSIS OF INLET & OUTLET NOZZLES VESSEL SUPPORTS UNDER PIPE BREAK LOADS

5- DETAILED ANALYSIS:

f- STRESSES IN NOZZLE:

FROM THE TABLE ON SHEET-18, THE HIGHEST STRESS IS,

$\sigma_x = 51.3\ KSI < 1.27\ S_y = 54.1\ KSI$ @ 550°F

g- STRESSES ON SUPPORT PAD:

THE MAXIMUM SURFACE TEMPERATURE OF THE SUPPORT PADS IS TAKEN AS 300°F; HENCE, THE FOLLOWING BEARING STRESSES WILL BE COMPAIRED TO THE YIELD STRENGTH AT THE 300°F.

MAXIMUM BEARING STRESS ON SIDE OF PAD:

$$\sigma_{BRG.} = \frac{T_{MAX}}{A_{BRG}} = \frac{1109}{25} = 44.4\ KSI < S_y = 45.25 \text{ @ } 300°F$$

$A_{BRG} = 10 \times 2.5 = 25\ in^2$
$T_{MAX} = 1109$ KIPS

MAXIMUM BEARING STRESS ON FRONT OF PAD:

$$\sigma_{BRG} = \frac{R_{MAX}}{A_{BRG}} = \frac{322}{55} = 5.9\ KSI < S_y = 45.25 \text{ @ } 300°F$$

$A_{BRG} = 22 \times 2.5 = 55\ in^2$
$R_{MAX} = 322$ KIPS

MAXIMUM BEARING STRESS ON BOTTOM OF PAD:

$$\sigma_{BRG.} = \frac{P_{MAX}}{A_{BRG}} = \frac{1459}{220} = 6.6\ KSI < S_y = 45.25 \text{ @ } 300°F$$

$A_{BRG} = 22 \times 10 = 220\ in^2$
$P_{MAX} = 1459$ KIPS

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.
CHARGE NO.

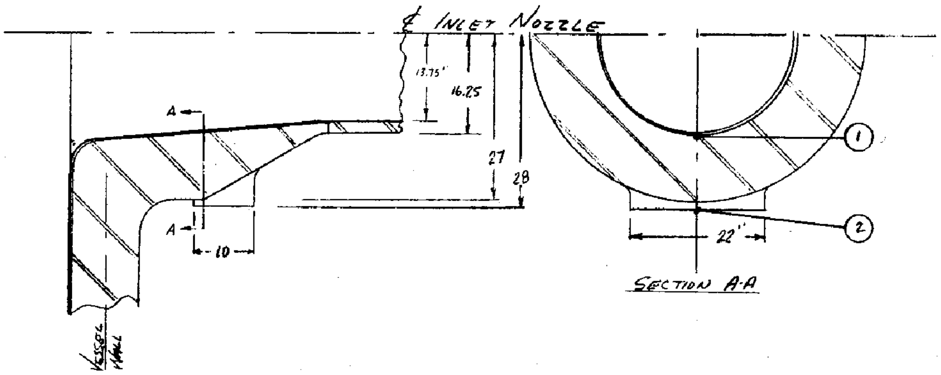
NUMBER 5-215-P | A 268

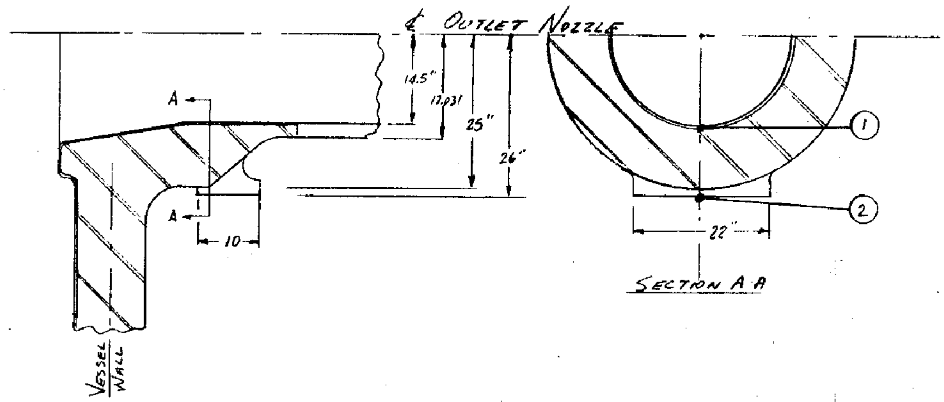
DATE 2-3-67 BY COCKRELL
DESCRIPTION FATIGUE EVALUATION OF VESSEL SUPPORT PADS CHECK DATE 2-3-67 BY ALEXANDER

5. DETAILED ANALYSIS:

a. SYSTEM GEOMETRY:

A CROSS SECTION OF THE INLET AND OUTLET NOZZLES IS SHOWN BELOW.





b. SYSTEM ALLOWABLES:

SHOW THAT EACH POINT MEETS THE REQUIREMENTS FOR PEAK STRESS INTENSITY GIVEN IN N-414.5 OF THE ASME CODE SECTION III. THE PROCEDURE WILL BE AS OUTLINED IN N-415.2 OF SECTION III.

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO.

DESCRIPTION Fatigue Evaluation Of Vessel Support Pads

NUMBER S-215-P | A 269
SHEET 5 OF 16
DATE 2-3-67 BY Cockrell
CHECK DATE 2-3-67 BY Alexander

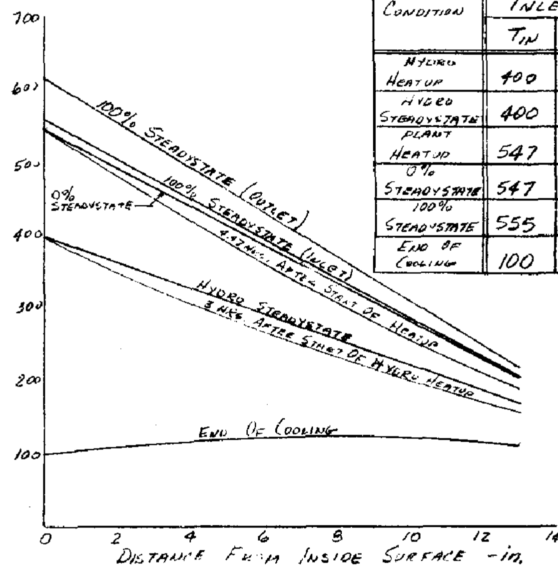
5- DETAILED ANALYSIS:

C. SYSTEM LOADS:

THE VESSEL SUPPORT PAD AT SECTION A-A AS SHOWN ON SHEET-4 WILL BE INVESTIGATED FOR THE FOLLOWING LOADS:

1- THE PRESSURE AND THERMAL TRANSIENTS AS GIVEN IN REFERENCE-9:
THE VESSEL IS SUPPORTED BY FOUR NOZZLES (TWO INLET AND TWO OUTLET). THE TEMPERATURE GRADIENT THRU THE NOZZLE WALL AND SUPPORT PAD FOR THE HEATUP AND COOLDOWN TRANSIENTS AND STEADYSTATE CONDITIONS WILL BE AS FOLLOWS

CONDITION	INLET NOZZLE			OUTLET NOZZLE		
	T_{IN}	T_{OUT}	T_m	T_{in}	T_{OUT}	T_m
HYDRO HEATUP	400	150	263	400	150	263
HYDRO STEADYSTATE	400	170	285	400	170	285
PLANT HEATUP	547	186	354	547	186	354
0% STEADYSTATE	547	203	375	547	203	375
100% STEADYSTATE	555	203	379	613	217	415
END OF COOLING	100	115	120	100	115	120



FOR ALL TRANSIENTS OTHER THAN THE HEATUP AND COOLDOWN TRANSIENT, THE INSIDE SURFACE OF THE NOZZLE (POINT-1 AS SHOWN IN SHEET-4) WILL BE AT A TEMPERATURE EQUAL TO THE REACTOR COOLANT TEMPERATURE, WHILE THE OUTSIDE SURFACE (POINT-2), AND THE MEAN TEMPERATURE OF THE CROSSSECTION WILL BE AT A TEMPERATURE CORRESPONDING TO STEADYSTATE CONDITIONS.

IPEC00069771

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO.

DESCRIPTION Fatigue Evaluation Of Vessel Support Pad

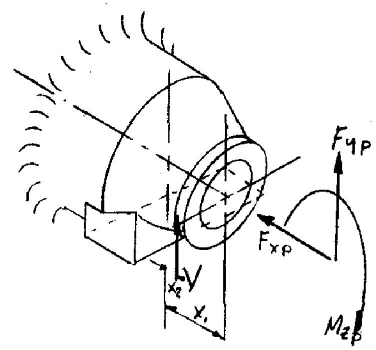
NUMBER S-215-P
SHEET 5 OF 16
DATE BY Cockrell
CHECK DATE BY

5. Detailed Analysis:

C. System Loads

2. External Loads

The External Loads Consist Of Thermal And Seismic Pipe Reactions, Static Weight And Earthquake Loading. The Following Figure Shows The Pipe Reactions And Loading Through The Supports Which Produce Stresses At The Points In Consideration.



Force	Inlet Nozzle				Outlet Nozzle			
	Thermal Induced Pipe Reactions	Seismic Pipe Reactions	Static Weight	Earthquake Loading Through Supports	Thermal Induced Pipe Reactions	Seismic Pipe Reactions	Static Weight	Earthquake Loading Through Supports
$\bar{F}_x$	14.8	± 57.9	0	0	26.2	± 122	0	0
$\bar{F}_y$	-92.0	∓ 67.0	0	0	-230.0	∓ 90	0	0
$\bar{M}_z$	9291	± 11250	-1515	± 341	29909	± 9387	-1796	± 424
V	0	0	561.1	∓ 126.4	0	0	561.1	∓ 132.5

The Above Loads Are The Resolved Loads To The Cross Section In Consideration As Follows

$\bar{F}_x = F_{xP}$

$\bar{F}_y = F_{yP}$

$\bar{M}_z = M_{zP} - X_1 F_{yP} - X_2 V$

5- DETAILED ANALYSIS:

d- STRESSES:

THE FOLLOWING EXPRESSIONS WILL BE USED TO CALCULATE STRESSES AT THE TWO POINTS 1 AND 2 AS INDICATED ON SHEET-4.

INLET NOZZLE:

PRESSURE STRESSES:

$$\sigma_x = \pm \frac{6M}{t^2} + \frac{b^2P}{2Rt} = 3.26717P \quad \text{POINT-1}$$
$$-2.14795P \quad \text{POINT-2}$$

$$\sigma_\theta = \pm \frac{\nu 6M}{t^2} + \frac{E\Delta}{R} + \frac{bP}{t}$$
$$= 3.39898P \quad \text{POINT 1}$$
$$= 1.77444P \quad \text{POINT 2}$$

THERMAL STRESSES:

$$\sigma_x = \pm \frac{6M}{t^2} + \frac{E\alpha(T_m - T)}{(1-\nu)}$$
$$= \pm 0.05254M + 1.42857E\alpha(T_m - T)$$

$$\sigma_\theta = \pm \frac{\nu 6M}{t^2} + \frac{E\Delta_{FORCED}}{R} + \frac{E\alpha(T_m-T)}{(1-\nu)}$$
$$= \pm 0.01576M + 0.04617E\Delta_{FORCED} + 1.42857E\alpha(T_m - T)$$

OUTLET NOZZLE:

PRESSURE STRESSES:

$$\sigma_x = \pm \frac{M}{t^2} + \frac{bP}{2Rt} = 2.91772P \quad \text{POINT-1}$$
$$-1.83498P \quad \text{POINT-2}$$

$$\sigma_\theta = \pm \frac{\nu 6M}{t^2} + \frac{E\Delta}{R} + \frac{bP}{t}$$
$$= 3.20524P \quad \text{POINT 1}$$
$$1.77942P \quad \text{POINT 2}$$ ‡

THERMAL STRESSES:

$$\sigma_x = \pm \frac{6M}{t^2} + \frac{E\alpha(T_m - T)}{(1-\nu)}$$
$$= \pm 0.05950M + 1.42857E\alpha(T_m - T)$$

$$\sigma_\theta = \pm \frac{\nu 6M}{t^2} + \frac{E\Delta_{FORCED}}{R} + \frac{E\alpha(T_m-T)}{(1-\nu)}$$
$$= \pm 0.01785M + 0.05005E\Delta_{FORCED} + 1.42857E\alpha(T_m - T)$$

WHERE:

$M = M_1 + M_T$

M_1 IS THE REDUNDANT MOMENT DETERMINED IN THE THERMAL INTERACTION

M_T IS THE THERMAL MOMENT AT THE CROSSECTION DUE TO THE RADIAL GRADIENT

INLET NOZZLE:

SUPPORT LOAD STRESSES:

$$\sigma_x = -\frac{F_{xp}}{A} + \frac{M_z C}{I}$$
$$= -0.00069F_{xp} - 0.00005\bar{M}_z \quad \text{POINT 1}$$
$$= -0.00069F_{xp} - 0.00007\bar{M}_z \quad \text{POINT 2}$$

WHERE:

$$\bar{M}_z = M_{zp} - x_1(F_{yp}) - x_2 V$$

$$\sigma_r = -\frac{V}{A_{PAD}} = -0.00455V \quad (\text{POINT 2})$$

OUTLET NOZZLE:

SUPPORT LOAD STRESSES:

$$\sigma_x = -\frac{F_{xp}}{A} + \frac{M_z C}{I}$$
$$= -0.00078F_{xp} - 0.00005\bar{M}_z \quad \text{POINT 1}$$
$$= -0.00078F_{xp} - 0.00009\bar{M}_z \quad \text{POINT 2}$$

WHERE

$$M_z = M_{zp} - x_1(F_{yp}) - x_2 V$$

$$\sigma_r = -\frac{V}{A} = -0.00455V \quad (\text{POINT 2})$$

COMBUSTION ENGINEERING, INC.

ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER S-215-P | A 272

SHEET 8 OF 16

CHARGE NO.

DATE 2-3-67 BY Cockrell

DESCRIPTION Fatigue Evaluation Of Vessel Support Pads CHECK DATE 2-3-67 BY Alexander

5. Detailed Analysis:

d. Stresses:

Transient		Internal Pressure KSI	Inlet Nozzle M	Inlet Nozzle EΔ	Inlet Nozzle T_{IN}	Inlet Nozzle T_{OUT}	Inlet Nozzle T_m	Inlet Nozzle $E\alpha_i$	Outlet Nozzle M	Outlet Nozzle EΔ	Outlet Nozzle T_{IN}	Outlet Nozzle T_{OUT}	Outlet Nozzle T_m	Outlet Nozzle $E\alpha_i$
a	4.47 HRS	2.250	51.584	43.232	547	186	354	0.201	31.778	35.395	547	186	354	0.201
b	4.47 HRS	0.315	-43.494	-43.279	100	115	120	0.180	-11.134	-20.673	100	115	120	0.180
c	20 min	2.250	6.065	-1.302	554.8	203	375	0.202	33.714	7.963	603	203	375	0.202
Full Load Steady State		2.250	↓	↓	555	203	379	↓	8.541	-11.015	613	217	415	0.205
d	20 min	2.250	↓	↓	547	203	379	↓	-4.250	-18.516	556	217	415	0.205
No Load Steady State		2.250	↓	↓	547	203	375	↓	17.157	7.489	547	203	375	0.202
e	100 sec	2.140	↓	↓	543.6	203	379	↓	8.541	-11.015	572.8	217	415	0.205
f	100 sec	2.260	↓	↓	568.1	↓	↓	↓	↓	↓	597.3	↓	↓	↓
g	3.2 sec / 3.5 sec	2.350	↓	↓	570	↓	↓	↓	↓	↓	628	↓	↓	↓
h	10 sec / 65 sec / 90 sec	2.320 / 1.910 / 1.940	↓	↓	564 546	↓	↓	↓	↓	↓	592 547	↓	↓	↓
i	220 min	3.125	0	0	100	100	100	~	0	0	100	100	100	~
j	Heatup 3.5 HRS	1.250	51.584	43.232	400	150	263	0.193	31.778	35.395	400	150	263	0.193
	S.S.	2.500	6.065	-1.302	400	170	285	0.197	17.157	7.489	400	170	285	0.197
	Cooldown 3.5 HRS	0.315	-43.494	-43.279	100	115	120	0.180	-11.134	-20.673	100	115	120	0.180
k	~	2.350	6.065	-1.302	549.9	203	379	0.202	8.541	-11.015	607	217	415	0.205
	~	2.150	↓	↓	560.8	↓	↓	↓	↓	↓	619	↓	↓	↓
l	12 sec	2.250	↓	↓	521.8	↓	↓	↓	↓	↓	613	↓	↓	↓
m	10 sec / 12 sec	2.760 / 2.750	↓	↓	595	↓	↓	↓	↓	↓	653	↓	↓	↓
	285 sec / 285 sec	2.120 / 2.000	↓	↓	596	↓	↓	↓	↓	↓	635	↓	↓	↓
	160 sec / 144 sec	1.440 / 1.475	↓	↓	559.6	↓	↓	↓	↓	↓	550	↓	↓	↓
n	64 sec	0.700	↓	↓	350	203	375	↓	17.157	7.489	430	203	375	0.202

(Inlet nozzle / Outlet nozzle)

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER 5-215-P | A-273
SHEET 9 OF 16
CHARGE NO. ________
DATE 2-3-67 BY Cockrell
DESCRIPTION Fatigue Evaluation Of Vessel Support Pads
CHECK DATE 2-3-67 BY Alexander

5- Detailed Analysis:

d- Stresses

Inlet Nozzle Point-1

Transient		Pressure Stress σ_x	Pressure Stress σ_θ	Pressure Stress σ_r	Thermal Stress σ_x	Thermal Stress σ_θ	Pipe Load Stress σ_x	Pipe Load Stress σ_r	Total Stress σ_x	Total Stress σ_θ	Total Stress σ_r	Stress Intensity $\sigma_x-\sigma_\theta$	Stress Intensity $\sigma_x-\sigma_r$	Stress Intensity $\sigma_\theta-\sigma_r$
a	4.47 hrs	7.35	7.65	-2.25	-52.71	-52.61	-1.02	0	-46.38	-44.96	-2.25	-1.42	-44.13	-42.71
b	4.47 hrs	1.03	1.07	-0.32	2.85	2.45	0.70		4.58	3.52	-0.32	1.06	4.90	3.84
c	20 min	7.35	7.65	-2.25	-51.56	-51.84	-0.40		-44.61	-44.19	-2.25	-0.42	-42.36	-41.94
Full Load Steady State		7.35	7.65	-2.25	-50.47	-50.75			-43.52	-43.10	-2.25	-0.42	-41.27	-40.85
d	20 min	7.35	7.65	-2.25	-48.16	-48.44			-41.21	-40.79	-2.25	-0.42	-38.96	-38.54
No Load Steady State		7.35	7.65	-2.25	-49.31	-49.59			-42.36	-41.94	-2.25	-0.42	-40.11	-39.69
e	100 sec	6.99	7.27	-2.14	-47.18	-47.46			-40.59	-40.19	-2.14	-0.40	-38.45	-38.05
f	100 sec	7.38	7.68	-2.26	-54.25	-54.53			-47.27	-46.85	-2.26	-0.42	-45.01	-44.59
g	3.2 min	7.68	7.99	-2.35	-54.80	-55.08			-47.52	-47.09	-2.35	-0.43	-45.17	-44.74
h	10 sec	7.25	7.55	-2.22	-53.07	-53.35			-46.22	-45.80	-2.22	-0.42	-44.00	-43.58
	65 sec	6.24	6.49	-1.91	-47.87	-48.15			-42.03	-41.66	-1.91	-0.37	-40.12	-39.75
i	220 min	10.21	10.62	-3.13	0	0	0.08		10.29	10.62	-3.13	-0.33	13.42	13.75
j	Heatup 3.5 hrs	4.08	4.25	-1.25	-35.06	-34.96	-0.40		-31.38	-30.71	-1.25	-0.67	-30.13	-29.46
	S.S.	8.17	8.50	-2.50	-32.04	-32.32	-0.40		-24.27	-23.82	-2.50	-0.45	-21.77	-21.32
	Cooldown 3.5 hrs	1.03	1.07	-0.32	2.85	2.45	0.08		3.96	3.52	-0.32	0.44	4.28	3.84
k	~	7.68	7.99	-2.35	-48.68	-48.96	-0.40		-41.40	-40.97	-2.35	-0.43	-39.05	-38.62
	~	7.02	7.31	-2.15	-52.14	-52.42			-45.52	-45.11	-2.15	-0.41	-43.37	-42.96
l	12 sec	7.35	7.65	-2.25	-40.89	-41.17			-33.94	-33.52	-2.25	-0.42	-31.69	-31.27
	10 sec	9.02	9.38	-2.76	-59.13	-59.41			-50.51	-50.03	-2.76	-0.48	-47.75	-47.27
m	28 sec	6.93	7.21	-2.12	-62.30	-62.58			-56.05	-55.37	-2.12	-0.68	-53.93	-53.25
	160 sec	4.70	4.89	-1.44	-51.80	-52.08			-47.50	-47.19	-1.44	-0.31	-46.06	-45.75
n	54 sec	2.29	2.38	-0.70	7.53	7.25			9.42	9.63	-0.70	-0.21	10.12	10.33

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO. ______

DESCRIPTION *Fatigue Evaluation Of Vessel Support Pads*

NUMBER *S-215-P* | *A 274*
SHEET *10* OF *16*
DATE *2-3-67* BY *Cockrell*
CHECK DATE *2-3-67* BY *A. Eyaduek*

5. Detailed Analysis:

d. Stresses:

INLET NOZZLE POINT-2

Transient		Pressure Stress			Thermal Stress		Pipe Load Stress		Total Stress			Stress Intensity		
		σ_x	σ_θ	σ_r	σ_x	σ_θ	σ_x	σ_r	σ_x	σ_θ	σ_r	$\sigma_x-\sigma_\theta$	$\sigma_x-\sigma_r$	$\sigma_\theta-\sigma_r$
Dead Weight Only		0	0	0	0	0	0	-2.55	0	0	-2.55	0	2.55	2.55
a	4.47 HRS	-4.83	3.99		45.53	49.43	-1.40	-2.70	39.30	53.42	-2.70	-14.12	42.00	56.12
b	4.47 HRS	-0.68	0.56		3.58	-0.02	0.96	-3.35	3.86	0.54	-3.35	3.32	7.71	4.39
c	20 min	-4.83	3.99		49.31	49.47	-0.55	-2.97	43.93	53.46	-2.97	-9.53	46.90	56.43
Full Load Steady State		-4.83	3.99		50.47	50.63			45.09	54.62		-9.53	48.06	57.59
d	20 min	-4.83	3.99		50.47	50.63			45.09	54.62		-9.53	48.06	57.59
No Load Steady State		-4.83	3.99		49.31	49.47			43.93	53.46		-9.53	46.90	56.43
e	100 sec	-4.60	3.80		50.47	50.63			45.32	54.43		-9.11	48.29	57.40
f	10 sec	-4.85	4.01						45.07	54.64		-9.57	48.04	57.61
g	3.2 min	-5.05	4.17						44.87	54.80		-9.93	47.84	57.77
h	10 sec	-4.77	3.94						45.15	54.57		-9.42	48.12	57.54
	25 sec	-4.10	3.39		↓	↓	↓	↓	45.32	54.02	↓	-8.20	48.79	56.99
i	225 min	-6.71	5.59		0	0	0.11	-2.55	-6.60	5.59	-2.55	-12.19	-4.05	8.14
j	Heat up 3.5 HRS	-2.68	2.22		28.45	32.35	-0.55	-2.97	25.22	34.57	-2.97	-9.35	28.19	37.54
	S.S.	-5.37	4.44		32.04	32.20	-0.55	-2.97	26.12	36.64	-2.97	-10.52	29.09	39.61
	Cooldown 3.5 HRS	-0.68	0.56		3.58	-0.02	0.11	-2.55	3.01	0.54	-2.55	2.47	5.56	3.09
k	~	-5.05	4.17		50.47	50.63	-0.55	-2.97	44.87	54.80	-2.97	-9.93	47.84	57.77
	~	-4.62	3.82						45.30	54.45		-9.15	48.27	57.42
l	12 sec	-4.83	3.99						45.09	54.62		-9.53	48.06	57.59
m	10 sec	-5.93	4.90						43.99	55.53		-11.54	46.96	58.50
	28 sec	-4.55	3.76						45.37	54.39		-9.02	48.34	57.36
	160 sec	-3.09	2.56		↓	↓			46.83	53.19		-6.36	49.30	56.16
n	54 sec	-1.50	1.24	↓	49.31	49.47	↓	↓	47.26	50.71	↓	-3.45	50.23	53.68

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.
CHARGE NO.

NUMBER 5-215-P | A275
SHEET 11 OF 16
DATE 2-3-67 BY COCKRELL
DESCRIPTION FATIGUE EVALUATION OF VESSEL SUPPORT PADS
CHECK DATE 2-3-67 BY ALEXANDER

5- DETAILED ANALYSIS:

d- STRESSES

OUTLET NOZZLE POINT-1

	TRANSIENT	PRESSURE STRESS			THERMAL STRESS		PIPE LOAD STRESS		TOTAL STRESS			STRESS INTENSITY		
		σ_x	σ_θ	σ_r	σ_x	σ_θ	σ_x	σ_r	σ_x	σ_θ	σ_r	$\sigma_x-\sigma_\theta$	$\sigma_x-\sigma_r$	$\sigma_\theta-\sigma_r$
a	4.47HRS	6.59	7.21	-2.25	-53.53	-53.08	-1.96	0	-48.90	-45.87	-2.25	-3.03	-46.65	-43.62
b	4.47HRS	0.92	1.01	-0.32	4.48	3.91	0.63		6.03	4.92	-0.32	1.11	6.35	5.24
c	20min	6.59	7.21	-2.25	-63.78	-64.77	-1.42		-58.61	-57.56	-2.25	-1.05	-56.36	-55.31
	FULL LOAD STEADYSTATE	6.59	7.21	-2.25	-57.48	-58.39			-52.31	-51.18	-2.25	-1.13	-50.06	-48.93
d	20 min	6.59	7.21	-2.25	-41.54	-42.30			-36.37	-35.09	-2.25	-1.28	-34.12	-32.84
	NO LOAD STEADYSTATE	6.59	7.21	-2.25	-48.61	-48.95			-43.44	-41.74	-2.25	-1.70	-41.19	-39.49
e	100 sec	6.27	6.86	-2.14	-45.70	-46.61			-40.85	-39.75	-2.14	-1.10	-38.71	-37.61
f	100sec	6.62	7.24	-2.26	-52.88	-53.79			-47.68	-46.55	-2.26	-1.13	-45.42	-44.29
g	3.5min	6.88	7.53	-2.35	-61.87	-62.78			-56.41	-55.25	-2.35	-1.16	-54.06	-52.90
h	10 sec	6.50	7.12	-2.22	-51.33	-52.24			-46.25	-45.12	-2.22	-1.13	-44.03	-42.90
	90 sec	5.66	6.22	-1.94	-38.15	-39.06	↓		-33.91	-32.84	-1.94	-1.07	-31.97	-30.90
i	220 min	9.15	10.02	-3.13	0	0	0.09		9.24	10.02	-3.13	-0.78	12.37	13.15
j	HEATUP 3.5 HRS	3.66	4.01	-1.25	-35.88	-35.43	-1.42		-33.64	-31.42	-1.25	-2.22	-32.39	-30.17
	S.S.	7.32	8.01	-2.50	-31.34	-31.68	-1.42		-25.44	-23.67	-2.50	-1.77	-22.94	-21.17
	COOLDOWN 3.5 HRS	0.92	1.01	-0.32	4.48	3.91	0.09		5.49	4.92	-0.32	0.57	5.81	5.24
k	~	6.88	7.53	-2.35	-55.72	-56.63	-1.42		-50.26	-49.10	-2.35	-1.25	-47.91	-46.75
	~	6.29	6.89	-2.15	-59.23	-60.14			-54.36	-53.25	-2.15	-1.11	-52.21	-51.10
l	12 sec	6.59	7.21	-2.25	-57.48	-58.39			-52.31	-51.18	-2.25	-1.13	-50.06	-48.93
	12sec	8.05	3.35	-2.76	-69.19	-70.10			-62.56	-61.25	-2.76	-1.31	-59.80	-58.49
m	26sec	5.84	6.41	-2.00	-63.92	-64.83			-59.50	-58.42	-2.00	-1.08	-57.50	-56.42
	144sec	4.30	4.73	-1.48	-39.03	-39.94			-36.15	-35.21	-1.48	-0.94	-34.67	-33.73
n	54 sec	2.05	2.24	-0.70	-14.91	-15.25	↓	↓	-14.28	-13.01	-0.70	-1.27	-13.58	-12.31

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO. ____________

DESCRIPTION Fatigue Evaluation Of Vessel Support Pads

NUMBER 5-215-P | A 276
SHEET 12 OF 16
DATE 2-3-67 BY Cockrell
CHECK DATE 2-3-67 BY Alexander

5. Detailed Analysis:

d. Stresses:

Outlet Nozzle Point - 2

Transient		Pressure Stress σ_x	Pressure Stress σ_θ	Pressure Stress σ_r	Thermal Stress σ_x	Thermal Stress σ_θ	Fire Load Stress σ_x	Fire Load Stress σ_r	Total Stress σ_x	Total Stress σ_θ	Total Stress σ_r	Stress Intensity $\sigma_x - \sigma_\theta$	Stress Intensity $\sigma_x - \sigma_r$	Stress Intensity $\sigma_\theta - \sigma_r$
Dead Weight Only		0	0	0	0	0	0	-2.55	0	0	-2.55	0	2.55	2.55
a	4.47 hrs	-4.13	4.00	↓	46.36	49.44	-3.44	-3.41	38.79	53.44	-3.41	-14.65	42.20	56.85
b	4.47 hrs	-0.58	0.56		1.95	0.46	1.05	-4.61	2.42	1.02	-4.61	1.30	7.03	5.73
c	20 min	-4.13	4.00		47.62	49.43	-2.55	-3.60	40.94	53.43	-3.60	-12.49	44.54	57.03
Full Load Steady State		-4.13	4.00		57.49	57.29	↓	↓	50.30	61.21	↓	-10.41	54.40	64.81
d	20 min	-4.13	4.00		58.24	57.14			51.56	61.14		-9.58	55.16	64.74
No Load Steady State		-4.13	4.00		48.61	49.69			41.93	53.69		-11.76	45.43	57.19
e	100 sec	-3.93	3.81		57.48	57.29			51.00	61.10		-10.10	54.60	64.70
f	100 sec	-4.15	4.02		↓	↓			50.78	61.31		-10.53	54.38	64.91
g	3.5 min	-4.31	4.18						50.62	61.47		-10.85	54.22	65.07
h	10 sec	-4.07	3.95						50.86	61.24		-10.38	54.46	64.84
	5 sec / 90 sec	-3.56	3.45						51.37	60.74		-9.37	54.47	64.34
i	220 min	-5.73	5.56		0	0	0.16	-2.55	-5.57	5.56	-2.55	-11.13	-3.02	8.11
j	Heatup 3.5 hrs	-2.29	2.22		29.27	32.36	-2.55	-3.60	24.43	34.58	-3.60	-10.15	28.03	38.18
	S.S	-4.59	4.45		31.34	32.42	-2.55	-3.60	24.20	36.87	-3.60	-12.67	27.80	40.47
	Cooldown 3.5 hrs	-0.58	0.56		1.95	0.46	0.16	-2.55	1.53	1.02	-2.55	0.51	4.08	3.57
k	~	-4.31	4.18		57.48	57.29	-2.55	-3.60	50.62	61.47	-3.60	-10.85	54.22	65.07
	~	-3.95	3.83		↓	↓	↓	↓	50.98	61.12	↓	-10.14	54.58	64.72
l	12 sec	-4.13	4.00						50.80	61.29		-10.49	54.40	64.99
m	12 sec	-5.06	4.91						41.87	62.20		-12.33	53.47	65.80
	36 sec	-3.67	3.56						51.26	60.85		-9.59	54.86	64.45
	144 sec	-2.71	2.62						52.22	59.91		-7.69	55.82	63.51
n	54 sec	-1.29	1.25	↓	48.01	47.69	↓	↓	44.79	50.94	↓	-6.16	48.39	54.54

Maximum Bearing Stress On Pad = σ_r = -4.61 KSI ←

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

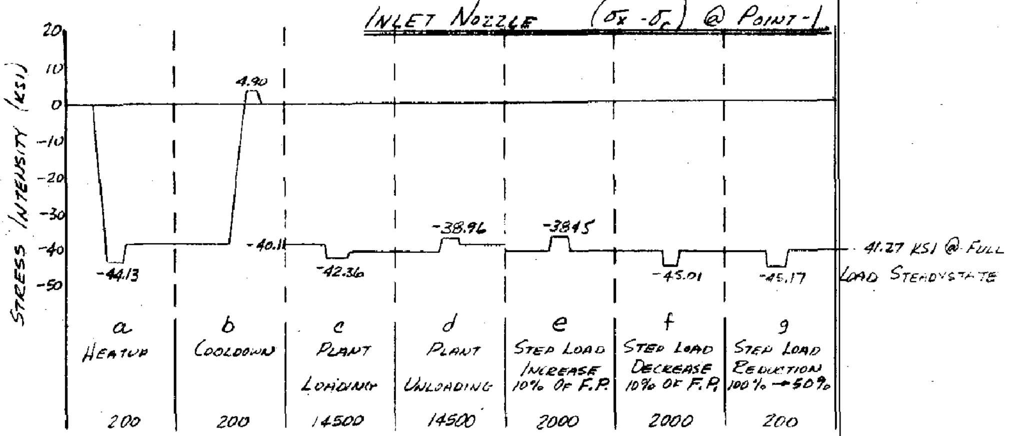
CHARGE NO.________

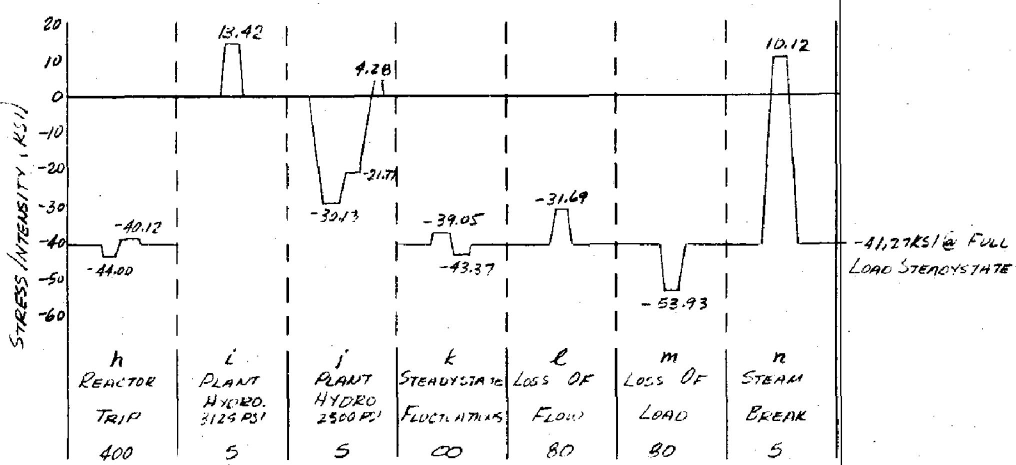
DESCRIPTION *Fatigue Evaluation of Vessel Support Pads*

NUMBER *S-215-P* | *A277*
SHEET *13* OF *16*
DATE *2-3-67* BY *Cockrell*
CHECK DATE *2-3-67* BY *Alexander*

5- Detailed Analysis:

e- Fatigue Evaluation:





S_{MAX}	S_{MIN}	Number of Occurrences	S_{ALT}	N^*	U
13.42	-53.93	5	33.68	15,000	0.00033
10.12	-53.93	5	32.03	18,000	0.00027
4.90	-53.93	70	29.42	23000	0.00304
4.90	-45.17	130	25.04	42000	0.00310
4.28	-45.17	5	24.73	43000	0.00012
-31.69	-45.17	65	6.74	∞	0

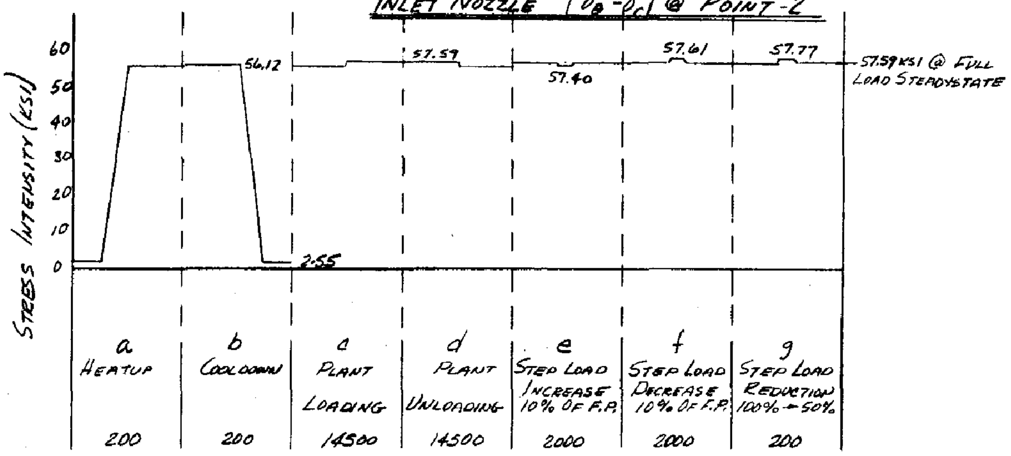
*From Fig. N-415(A) Reference 1

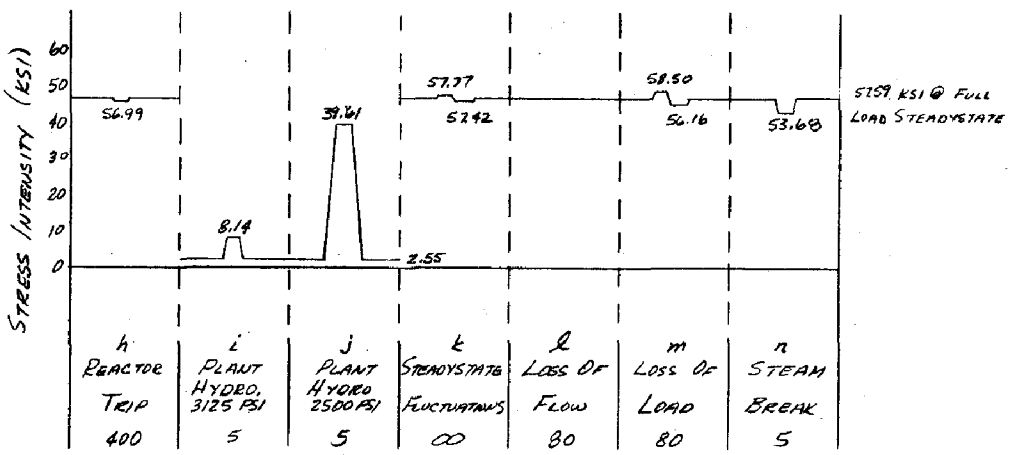
$U_{OVERALL} = 0.00686$

5. DETAILED ANALYSIS:

e. FATIGUE EVALUATION:

INLET NOZZLE $(\sigma_B - \sigma_C)$ @ POINT-2





S_{MAX}	S_{MIN}	NUMBER OF OCCURRENCES	S_{ALT}	N^*	U
58.50	2.55	80	27.98	27000	0.00296
57.77	2.55	120	27.61	29000	0.00413
39.61	2.55	5	18.53	130000	0.00003
57.77	53.68	5	2.05	∞	0

*FROM FIG. N-415(A) REFERENCE 1

$U_{OVERALL} = 0.00712$

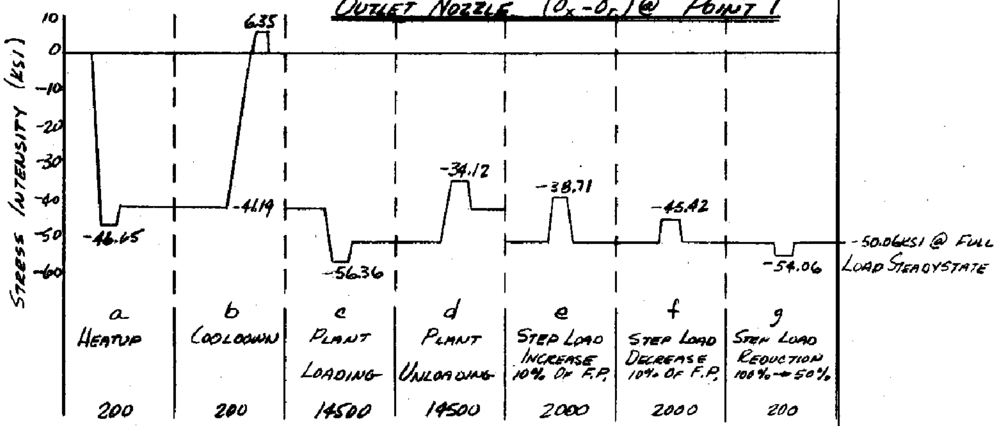
COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

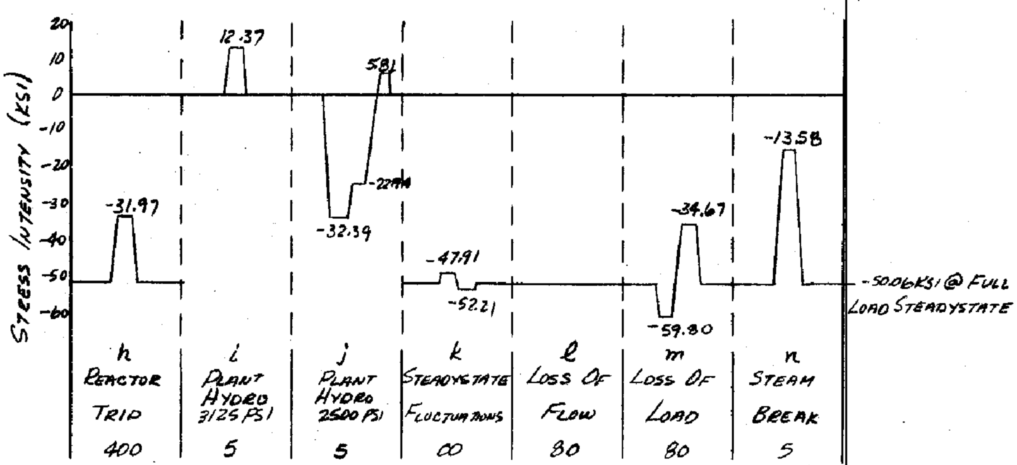
NUMBER 5-215-P A 279
SHEET 15 OF 16
CHARGE NO. ____
DATE 2-3-67 BY COCKRELL
DESCRIPTION FATIGUE EVALUATION OF VESSEL SUPPORT PADS
CHECK DATE 2-3-67 BY ALEXANDER

5- DETAILED ANALYSIS:

e. FATIGUE EVALUATION:

OUTLET NOZZLE $(\sigma_x - \sigma_r)$ @ POINT 1





S_{MAX}	S_{MIN}	NUMBER OF OCCURRENCES	S_{ALT}	N^*	U
12.37	-59.80	5	36.09	11,000	0.00045
6.35	-59.80	75	32.58	15,000	0.00500
6.35	-56.36	120	31.36	18,000	0.00667
-13.58	-56.36	5	21.39	76,000	0.00006
5.81	-32.39	5	18.75	101,000	0.00005
-31.97	-56.36	400	12.20	∞	0

* FROM FIG. N-415(A) REFERENCE 1

$U_{OVERALL} = 0.01223$

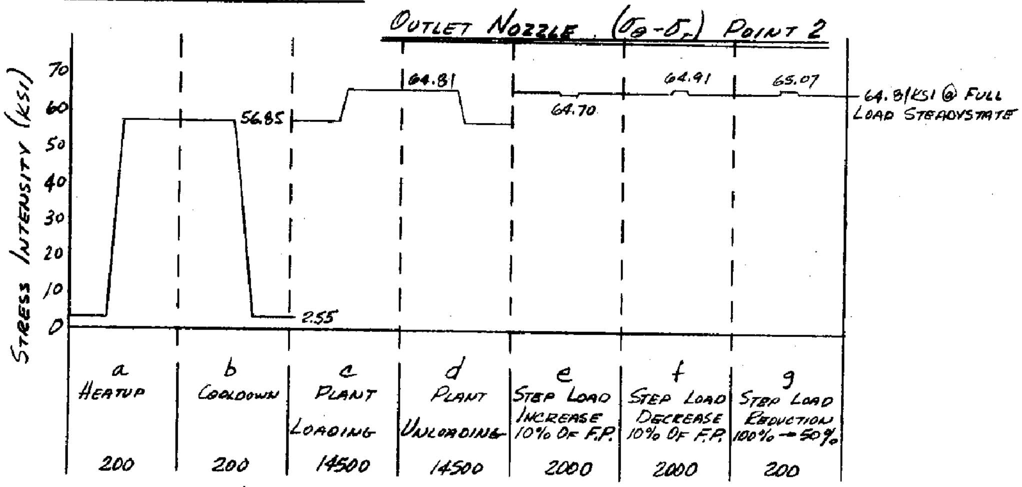
COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

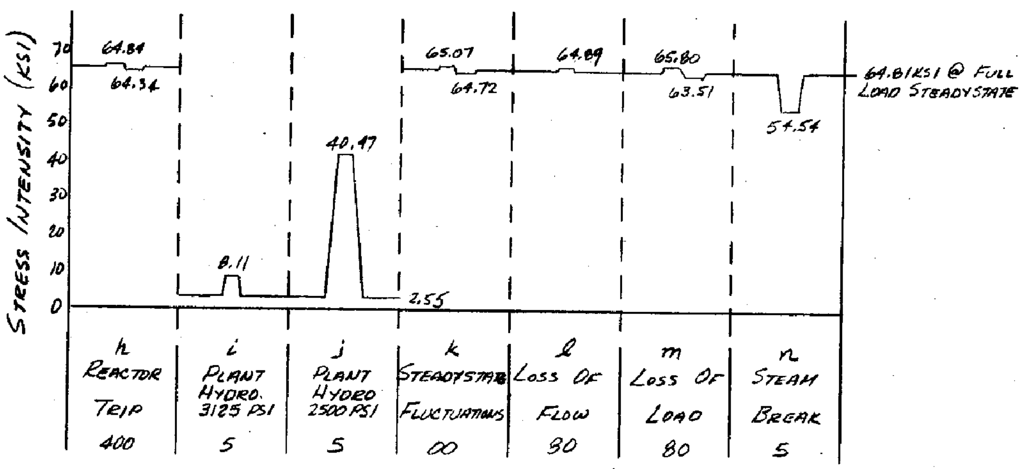
CHARGE NO.

NUMBER S-215-P | A 280
SHEET 16 OF 16
DATE 2-3-67 BY COCKRELL
CHECK DATE 2-3-67 BY ALEXANDER

DESCRIPTION FATIGUE EVALUATION OF VESSEL SUPPORT PADS

5- DETAILED ANALYSIS:
e - FATIGUE EVALUATION:





S_{MAX}	S_{MIN}	NUMBER OF OCCURRENCES	S_{ALT}	N^*	U
65.80	2.55	80	31.63	17,000	0.00470
65.07	2.55	120	31.26	18,000	0.00666
40.47	2.55	5	18.96	120,000	0.00004
65.07	54.54	5	5.27	∞	0

* FROM FIG. N-415(A) REFERENCE 1

$U_{OVERALL} = 0.01140$

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO.

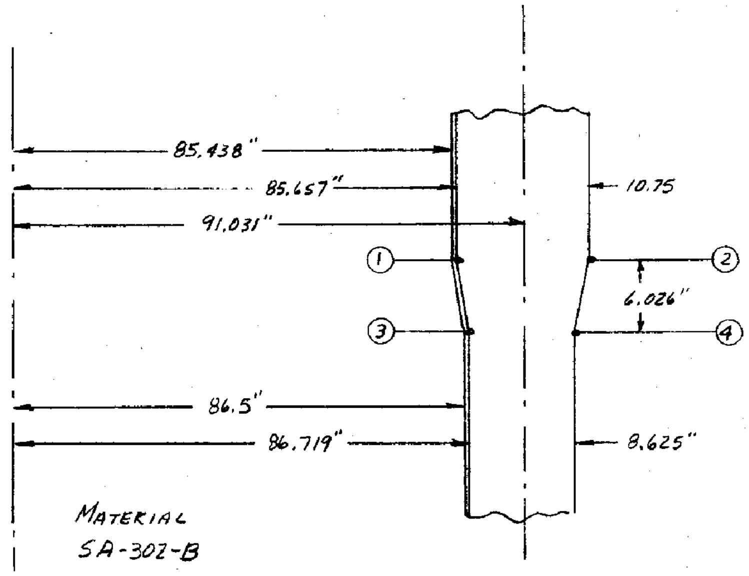
DESCRIPTION Structural And Fatigue Analysis Of The Vessel Wall Transition

NUMBER S-202-P | A 281
SHEET 4 OF 24
DATE May 26, 1966 BY Cockrell
CHECK DATE May 26, 1966 BY Alexander

5. Detailed Analysis:

a. System Geometry:

A Cross Section Of The Vessel Wall Transition Is Shown Below.



b. System Loads:

The Vessel Shell Juncture (Transition) As Shown Above Will Be Investigated For Design Conditions (Internal Press Of 2.5 ksi). The Effects Of The Following Transient Conditions Will Be Investigated.

Transient	Number Of Occurrences
a. Plant Heatup At 100°F Per Hour	200
b. Plant Cooldown At 100°F Per Hour	200
c. Plant Loading At 5% Of Full Power Per Min.	14,500
d. Plant Unloading At 5% Of Full Power Per Min.	14,500
e. Step Load Increase Of 10% Of Full Power But Not To Exceed Full Power	2,000

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER S-202-P | A 282
SHEET 5 OF 24
CHARGE NO.
DATE MAY 26, 1966 BY COCKRELL
DESCRIPTION STRUCTURAL AND FATIGUE ANALYSIS OF THE VESSEL WALL TRANSITION
CHECK DATE MAY 26, 1966 BY ALEXANDER

5- DETAILED ANALYSIS:

C- SYSTEM LOADS:

TRANSIENT	NUMBER OF OCCURRENCES
f- STEP LOAD DECREASE OF 10% OF FULL POWER FROM 100% POWER	2000
g- STEP LOAD REDUCTION FROM 100% TO 50% FULL POWER	200
h- REACTOR TRIP FROM FULL POWER	400
i- PLANT HYDROSTATIC TEST OF 3125 PSIA AT ROOM TEMP.	5
j- PLANT HYDROSTATIC TEST OF 2500 PSIA AT 100°F PER HOUR TO 400°F	5
k- STEADY STATE FLUCTUATIONS OF ±6°F AND ±100 PSI PER MIN.	∞
l- LOSS OF FLOW, ONE PUMP	80
m- LOSS OF LOAD	30
n- STEAM BREAK	5

C. SYSTEM ALLOWABLES:

THE FOLLOWING ALLOWABLE STRESSES ARE BASED ON THE A.S.M.E NUCLEAR CODE SECTION III, REFERENCE 1 AND ARE RELEVANT FOR THIS ANALYSIS.

1- THE AVERAGE PRIMARY STRESS INTENSITY ACROSS A SOLID SECTION SHALL NOT EXCEED S_m AT DESIGN TEMP. (650°F) AND DESIGN PRESSURE (2.5 ksi).

2- THE LOCAL PRIMARY STRESS ALONE OR COMBINED WITH 1- ABOVE SHALL NOT EXCEED $1.5 S_m$ AT DESIGN TEMP. (650°F) AND DESIGN PRESSURE (2.5 ksi).

3- THE PRIMARY BENDING STRESS ALONE OR COMBINED WITH 1- AND 2- ABOVE SHALL NOT EXCEED $1.5 S_m$ AT DESIGN TEMP (650°F) AND DESIGN PRESSURE (2.5 ksi).

4- THE RANGE OF PRIMARY PLUS SECONDARY STRESS RESULTING FROM MECHANICAL OR THERMAL LOADS SHALL NOT EXCEED $3S_m$ AT ACTUAL METAL TEMPERATURE AND OPERATING PRESSURE.

5- SHOW THAT EACH POINT MEETS THE REQUIREMENTS FOR PEAK STRESS INTENSITY GIVEN IN N-414.5 OF THE A.S.M.E CODE SECTION III. THE PROCEDURE WILL BE AS OUTLINED IN N-415.2 OF SECTION III.

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER 5-202-P | A 283
SHEET 6 OF 24

CHARGE NO.

DATE MAY 26, 1966 BY COCKRELL

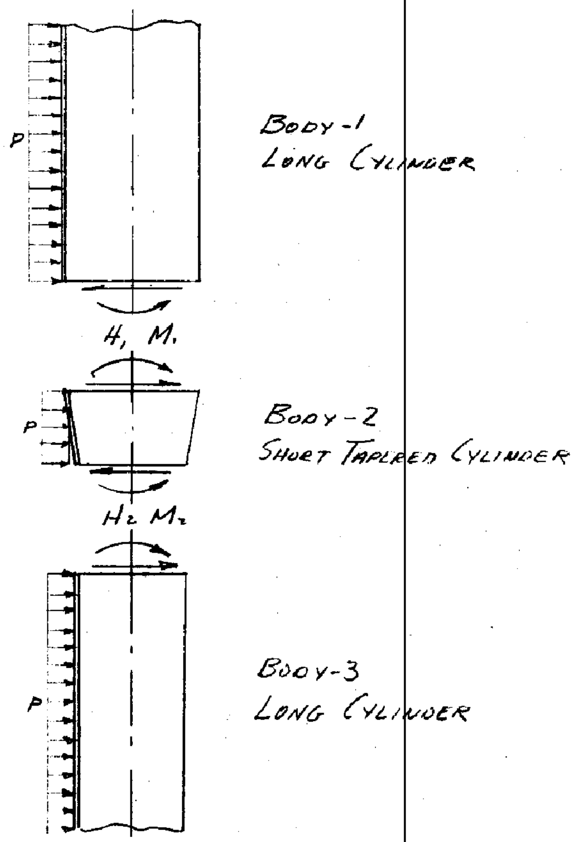
DESCRIPTION STRUCTURAL AND FATIGUE ANALYSIS OF THE VESSEL WALL TRANSITION

CHECK DATE MAY 26, 1966 BY ALEXANDER

5- DETAILED ANALYSIS:

d- DEVELOPMENT OF CONTINUITY EQUATIONS:

1- ANALYTICAL MODEL:



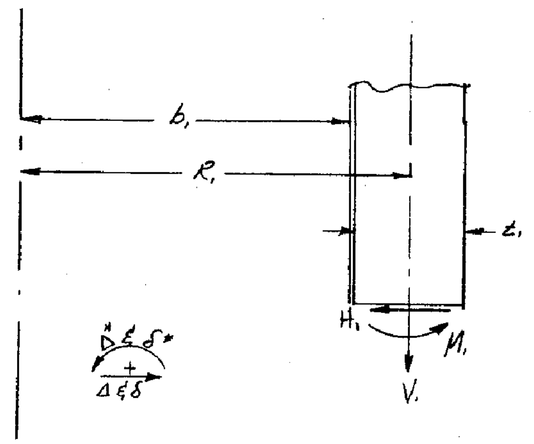
THE ACTUAL STRUCTURE IS DIVIDED INTO THE ANALYTICAL MODEL AS SHOWN ABOVE TO FACILITATE THE ANALYSIS. THE ASSUMED DIRECTIONS OF THE REDUNDANT FORCES ARE ILLUSTRATED.

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.
CHARGE NO.
DESCRIPTION STRUCTURAL AND FATIGUE ANALYSIS OF THE VESSEL WALL TRANSITION

NUMBER 5-202-P | A 284
SHEET 7 OF 24
DATE MAY 26, 1966 BY COCKRELL
CHECK DATE MAY 26, 1966 BY ALEXANDER

5- DETAILED ANALYSIS:
d- DEVELOPMENT OF CONTINUITY EQUATIONS:
2. MOVEMENTS DUE TO REDUNDANT AND APPLIED FORCES:

BODY-1:



$R_1 = 91.031''$

$b_1 = 85.438''$

$t_1 = 10.75''$

$\beta^4 = \frac{3(1-\nu^2)}{R_1^2 t_1^2}$

$\beta = 0.04109$

$D = \frac{Et^3}{12(1-\nu^2)} = 113.76345E$

DISPLACEMENTS DUE TO REDUNDANT FORCES:

$$E\Delta_{11} = -\frac{E}{2\beta^2 D}\left[\frac{1}{\beta}H_1 - M_1\right]$$

$$= -63.34937\,H_1 + 2.60306\,M_1$$

$$E\Delta^*_{11} = -\frac{E}{2\beta^2 D}\left[H_1 - 2\beta_1 M_1\right]$$

$$= -2.60306\,H_1 + 0.21392\,M_1$$

FROM REF. 12

DISPLACEMENTS DUE TO APPLIED FORCES:

$$E\delta_{11} = \frac{b_1^2}{t_1}\left(\frac{R_1}{b_1} - \frac{\nu}{2}\right)P = 621.63338P$$

$$E\delta^*_{11} = 0$$

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO. ____

DESCRIPTION: STRUCTURAL AND FATIGUE ANALYSIS OF THE VESSEL WALL TRANSITION

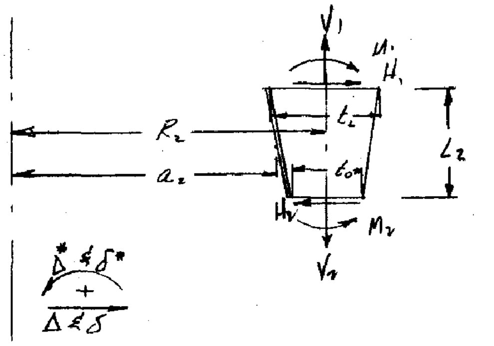
NUMBER: S-202-P | A 285
SHEET: 8 OF 24
DATE: MAY 26, 1966 BY: COCKRELL
CHECK DATE: MAY 26, 1966 BY: ALEXANDER

5- DETAILED ANALYSIS:

d- DEVELOPMENT OF CONTINUITY EQUATIONS:

2- MOVEMENTS DUE TO REDUNDANT AND APPLIED FORCES:

BODY-2:



$R_2 = 91.031''$
$a_2 = 85.969''$
$t_0 = 8.625''$
$t_L = 10.75''$
$L_2 = 6.026''$

$$\lambda = \frac{1}{L_2}(t_L - t_0) = 0.35264$$

THE INFLUENCE COEFFICIENTS FOR A SHORT TAPERED CYLINDER ARE CALCULATED BY THE METHOD OUTLINED OF PAGES 488 TO 492 OF REFERENCE 12 AND ARE PRINTED OUT ON C.E.'S COMPUTER PROGRAM IN THE FOLLOWING FORM.

DISPLACEMENTS DUE TO REDUNDANT FORCES:

$$E\Delta_{21} = -\phi_{33} H_1 + \phi_{34} M_1 - \phi_{31} H_2 + \phi_{32} M_2$$

$$= 546.07025 H_1 + 139.51823 M_1 + 288.79601 H_2 - 139.54705 M_2$$

$$E\Delta^*_{21} = \phi_{43} H_1 - \phi_{44} M_1 + \phi_{41} H_2 - \phi_{42} M_2$$

$$= -139.06016 H_1 - 48.24337 M_1 - 149.53615 H_2 + 48.23308 M_2$$

$$E\Delta_{22} = -\phi_{13} H_1 + \phi_{14} M_1 - \phi_{11} H_2 + \phi_{12} M_2$$

$$= -288.92626 H_1 - 150.09585 M_1 - 609.44900 H_2 + 150.20263 M_2$$

$$E\Delta^*_{22} = \phi_{23} H_1 - \phi_{24} M_1 + \phi_{21} H_2 - \phi_{22} M_2$$

$$= -139.21089 H_1 - 48.27559 M_1 - 149.77380 H_2 + 48.33899 M_2$$

5. Detailed Analysis:

d. Development Of Continuity Equations:

2. Movements Due To Redundant And Applied Forces:

Body 2 (cont'd):

Displacements Due To Applied Forces:

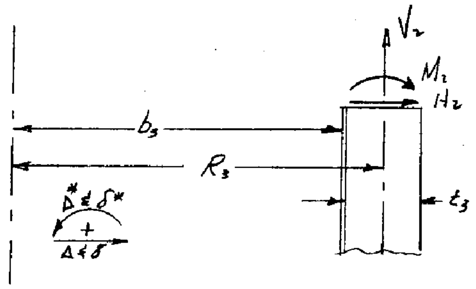
$$E\delta_{21} = a_2^2\left(\frac{R_2}{a_2} - \frac{\nu}{2}\right)\left[(\phi_{32}+\phi_{34})\frac{-\lambda^2}{6(1-\nu^2)} + \frac{1}{t_L}\right]P = \underline{629.27110P}$$

$$E\delta_{21}^{*} = -a_2^2\left(\frac{R_2}{a_2} - \frac{\nu}{2}\right)\left[(\phi_{42}+\phi_{44})\frac{-\lambda^2}{6(1-\nu^2)} - \frac{\lambda}{t_L^2}\right]P = \underline{22.03255P}$$

$$E\delta_{22} = a_2^2\left(\frac{R_2}{a_2} - \frac{\nu}{2}\right)\left[(\phi_{12}+\phi_{14})\frac{-\lambda^2}{6(1-\nu^2)} + \frac{1}{t_0}\right]P = \underline{762.47399P}$$

$$E\delta_{22}^{*} = -a_2^2\left(\frac{R_2}{a_2} - \frac{\nu}{2}\right)\left[(\phi_{22}+\phi_{24})\frac{-\lambda^2}{6(1-\nu^2)} - \frac{\lambda}{t_0^2}\right]P = \underline{22.09972P}$$

Body - 3:



$R_3 = 91.031''$
$b_3 = 86.5''$
$t_3 = 8.625''$

$\beta^4 = \frac{3(1-\nu^2)}{R_3^2 t_3^2}$ $\qquad D = \frac{Et^3}{12(1-\nu^2)}$

$\beta = 0.04587$ $\qquad = 58.7563\,E$

Displacements Due To Redundant Forces:

$$E\Delta_{32} = \frac{E}{2\beta^3 D}\left[\frac{1}{\beta}H_2 + M_2\right] = \underline{88.14883\,H_2 + 4.04373\,M_2}$$

$$E\Delta_{32}^{*} = -\frac{E}{2\beta^2 D}\left[H_2 + 2\beta M_2\right] = \underline{-4.04373\,H_2 - 0.37100\,M_2}$$

Displacements Due To Applied Forces:

$$E\delta_{32} = \frac{b_3^2}{t_3}\left(\frac{R_3}{b_3} - \frac{\nu}{2}\right)P = \underline{782.82249P}$$

$$E\delta_{32}^{*} = \underline{0}$$

} From Ref. 12

5. Detailed Analysis:

d. Development Of Continuity Equations:

3. Continuity Matrix And Loading Vectors:

From Continuity At Each Cut, We Write The Continuity Matrix In The Following Form,

$$E\Delta_{11} - E\Delta_{21} = E\delta_{21} - E\delta_{11}$$
$$E\Delta^*_{11} - E\Delta^*_{21} = E\delta^*_{21} - E\delta^*_{11}$$
$$E\Delta_{22} - E\Delta_{32} = E\delta_{32} - E\delta_{22}$$
$$E\Delta^*_{22} - E\Delta^*_{32} = E\delta^*_{32} - E\delta^*_{22}$$

In Matrix Form We Have,

$$\begin{bmatrix} -609.41962 & -136.91517 & -288.79601 & 139.54705 \\ 136.45710 & 48.45729 & 149.53615 & -48.23308 \\ -288.92626 & -150.09585 & -697.59783 & 146.15890 \\ -139.21089 & -48.27539 & -145.73007 & 48.70999 \end{bmatrix} \begin{bmatrix} H_1 \\ M_1 \\ H_2 \\ M_2 \end{bmatrix} = \begin{bmatrix} 7.63772 \\ 22.03255 \\ 20.34850 \\ -22.09972 \end{bmatrix} P$$

4. Redundant Load Values:

Solving The Above Matrix, We Get The Following Values For The Redundant Forces,

$H_1 = -0.81732P$
$M_1 = 5.22711P$
$H_2 = -0.84249P$
$M_2 = -0.12963P$

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO.________

DESCRIPTION STRUCTURAL AND FATIGUE ANALYSIS OF THE VESSEL WALL TRANSITION

NUMBER 5-202-P | A 288
SHEET 11 OF 24
DATE MAY 26, 1966 BY COCKRELL
CHECK DATE MAY 26, 1966 BY ALEXANDER

5- DETAILED ANALYSIS:

e STRESSES:

THE FOLLOWING EXPRESSIONS WILL BE USED TO CALCULATE STRESSES AT THE FOUR LOCATIONS AS SHOWN ON SHEET 4

LOCATION 1:

$$\sigma_x = \frac{6M_1}{t_1^2} + \frac{b_1^2 P}{2R_1 t_1} + \frac{E\alpha(T_m - T)}{1-\nu} = 0.05192\, M_1 + 3.72970\, P + 0.30714\,(T_m - T)$$

$$\sigma_\theta = \frac{\nu 6M_1}{t_1^2} + \frac{E\Delta_{11}}{R_1} + \frac{b_1 P}{t_1} + \frac{E\alpha(T_m - T)}{1-\nu} = 0.01558 M_1 + 0.01099 E\Delta_{11} + 7.94772\, P + 0.30714(T_m - T)$$

LOCATION 2:

$$\sigma_x = \frac{-6M_1}{t_1^2} + \frac{b_1^2 P}{2R_1 t_1} + \frac{E\alpha(T_m - T)}{1-\nu} = -0.05192 M_1 + 3.72970 P + 0.30714\,(T_m - T)$$

$$\sigma_\theta = \frac{-\nu 6M_1}{t_1^2} + \frac{E\Delta_{11}}{R_1} + \frac{b_1 P}{t_1} + \frac{E\alpha(T_m - T)}{1-\nu} = -0.01558 M_1 + 0.01099 E\Delta_{11} + 7.94772\, P + 0.30714(T_m - T)$$

LOCATION 3:

$$\sigma_x = \frac{6M_2}{t_3^2} + \frac{b_3^2 P}{2R_3 t_3} + \frac{E\alpha(T_m - T)}{1-\nu} = 0.08066\, M_2 + 4.76490\, P + 0.30714\,(T_m - T)$$

$$\sigma_\theta = \frac{\nu 6M_2}{t_1^2} + \frac{E\Delta_{32}}{R_3} + \frac{b_3 P}{t_3} + \frac{E\alpha(T_m - T)}{1-\nu} = 0.02420\, M_2 + 0.01099 E\Delta_{32} + 10.02899 P + 0.30714(T_m - T)$$

LOCATION 4:

$$\sigma_x = -\frac{6M_2}{t_3^2} + \frac{b_3^2 P}{2R_3 t_3} + \frac{E\alpha(T_m - T)}{1-\nu} = -0.08066\, M_2 + 4.76490\, P + 0.30714\,(T_m - T)$$

$$\sigma_\theta = -\frac{\nu 6M_2}{t_1^2} + \frac{E\Delta_{32}}{R_3} + \frac{b_3 P}{t_3} + \frac{E\alpha(T_m - T)}{1-\nu} = -0.02420\, M_2 + 0.01099 E\Delta_{32} + 10.02899 P + 0.30714(T_m - T)$$

NOTE THAT THERMAL STRESS WILL BE CONSERVATIVELY TREATED AS A SKIN TYPE STRESS.

$E\alpha = 0.215$ FOR SA-302B MATERIAL AT 550°F

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER 5-202-P | A 289
SHEET 12 OF 24
DATE MAY 26, 1966 BY COCKRELL
CHARGE NO.
DESCRIPTION STRUCTURAL AND FATIGUE ANALYSIS OF THE VESSEL WALL TRANSITION
CHECK DATE MAY 26, 1966 BY ALEXANDER

5- DETAILED ANALYSIS:
e. STRESSES:

LOCATION	M	$\pm\frac{6M}{t^2}$	$\frac{PR}{2t}$	σ_x	$\pm\frac{\nu 6M}{t^2}$	$E\Delta$	$\frac{E\Delta}{R}$	$\frac{PR}{t}$	σ_θ	σ_r	STRESS INTENSITY		
											$\sigma_x-\sigma_\theta$	$\sigma_x-\sigma_r$	$\sigma_\theta-\sigma_r$
1	13.068	0.68	9.32	10.00	0.20	163.46	1.80	19.87	21.87	-2.5	-11.87	12.50	24.37
2	13.068	-0.68	9.32	8.64	-0.20	163.46	1.80	19.87	21.47	0	-12.83	8.64	21.47
3	-0.324	-0.03	11.91	11.88	-0.01	-186.97	-2.05	25.07	23.01	-2.5	-11.13	14.38	25.51
4	-0.324	0.03	11.91	11.94	0.01	-186.97	-2.05	25.07	23.03	0	-11.09	11.94	23.03

THE VALUES OF H & M ARE TAKEN FROM SHEET 10.
THE MOVEMENT EQUATIONS ARE GIVEN ON SHEETS 7 & 9.

CRITERION 5.C.1 - PRIMARY GENERAL MEMBRANE:

$S.I._{MAX} = \sigma_\theta - \sigma_r = \frac{PR}{t} - \left(\frac{-P}{2}\right) = 25.07 + 1.25 = \underline{26.3\ ksi} < 26.7\ ksi$
@ LOCATION 3 & 4

CRITERION 5.C.2 - LOCAL MEMBRANE STRESS:

$S.I. = \sigma_\theta = \frac{E\Delta}{R} = -2.05 < 40\ ksi$ @ LOCATION 3 & 4

OR COMBINED WITH 1- ABOVE,

$S.I._{MAX} = \underline{24.3\ ksi} < 40\ ksi$ @ LOCATION 3 & 4

CRITERION 5.C.4 - RANGE OF STRESS INTENSITY:

$(S.I.)_{MAX} = (\sigma_\theta - \sigma_r) = \left[\frac{PR}{t} + \frac{E\Delta}{R} + \frac{\nu 6M}{t^2}\right] + P = \underline{23.0\ ksi} < 80\ KSI$ @ LOCATION 3

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.
CHARGE NO.

DESCRIPTION: STRUCTURAL AND FATIGUE ANALYSIS OF THE VESSEL WALL TRANSITION

NUMBER: S-202-P | A 290
SHEET 13 OF 24
DATE: MAY 26, 1966 BY: COCKRELL
CHECK DATE: MAY 26, 1966 BY: ALEXANDER

5- DETAILED ANALYSIS:

e. STRESSES:

THE FOLLOWING TABLES GIVE THE COMBINED PRESSURE AND THERMAL STRESSES (NEGLECTING STRESS CONCENTRATION FACTORS).

LOCATION - 1

TRANSIENT		INTERNAL PRESSURE KSIA	(T_m-T) °F	THERMAL STRESS $\sigma_x=\sigma_\theta$	PRESSURE STRESS σ_x	σ_θ	σ_r	TOTAL STRESS σ_x	σ_θ	σ_r	STRESS INTENSITY $\sigma_x-\sigma_\theta$	$\sigma_x-\sigma_r$	$\sigma_\theta-\sigma_r$
STEADY STATE		2.250	0	0	9.00	19.68	-2.25	9.00	19.68	-2.25	-10.68	11.25	21.93
a	4.47 hrs	2.250	-65	-19.96	9.00	19.68	-2.25	-10.96	-0.28	-2.25	-10.68	-8.71	1.97
b	4.47 hrs	0.315	65	19.96	1.26	2.76	-0.32	21.22	22.72	-0.32	-1.50	21.54	23.04
c	20 min	2.250	-7.8	-2.40	9.00	19.68	-2.25	6.60	17.28	-2.25	-10.68	8.85	19.53
d	20 min	2.250	7.8	2.40	9.00	19.68	-2.25	11.40	22.08	-2.25	-10.68	13.65	24.33
e	100 sec	2.140	11.2	3.44	8.56	18.72	-2.14	12.00	22.16	-2.14	-10.16	14.14	24.30
	225 sec	2.275	1.7	0.52	9.10	19.90	-2.28	9.62	20.42	-2.28	-10.80	11.90	22.70
f	40 sec	2.320	-9.3	-2.86	9.28	20.29	-2.32	6.42	17.43	-2.32	-11.01	8.74	19.75
	100 sec	2.260	-13.3	-4.08	9.04	19.77	-2.26	4.96	15.69	-2.26	-10.73	7.22	17.95
	260 sec	2.140	-1.3	-0.40	8.56	18.72	-2.14	8.16	18.32	-2.14	-10.16	10.30	20.46
g	2 min	2.370	-12.0	-3.69	9.48	20.73	-2.37	5.79	17.04	-2.37	-11.25	8.16	19.41
	3.2 min	2.350	-15.0	-4.61	9.40	20.53	-2.35	4.79	15.92	-2.35	-11.13	7.14	18.27
	10.4 min	2.150	0	0	8.60	18.81	-2.15	8.60	18.81	-2.15	-10.21	10.75	20.96
h	10 sec	2.220	-9.5	-2.92	8.88	19.42	-2.22	5.96	16.50	-2.22	-10.54	8.18	18.72
	65 sec	1.910	8.5	2.61	7.64	16.71	-1.91	10.25	19.32	-1.91	-9.07	12.16	21.23
i	220 min	3.125	0	0	12.50	27.34	-3.13	12.50	27.34	-3.13	-14.84	15.63	30.43
j	HEATUP 3.5 hrs	1.250	-64	-19.66	5.00	10.94	-1.25	-14.66	-8.72	-1.25	-5.94	13.41	-7.47
	S.S	2.500	0	0	10.00	21.87	-2.50	10.00	21.87	-2.50	-11.87	12.50	24.37
	COOLDOWN 3.5 hrs	0.315	64	19.66	1.26	2.76	-0.32	20.92	22.42	-0.32	-1.50	21.24	22.74
k	~	2.350	6.0	1.84	9.40	20.53	-2.35	11.24	22.37	-2.35	-11.13	13.59	24.72
	~	2.150	-6.0	-1.84	8.60	18.81	-2.15	6.76	16.97	-2.15	-10.21	8.91	19.12
l	12 sec	2.250	33.3	10.23	9.00	19.68	-2.25	19.23	29.91	-2.25	-10.68	21.48	32.16
m	10 sec	2.760	-30.2	-9.28	11.04	24.14	-2.76	1.76	14.86	-2.76	-13.10	4.52	17.62
	28 sec	2.120	-41.2	-12.65	8.48	18.55	-2.12	-4.17	5.90	-2.12	-10.07	-2.05	8.02
	160 sec	1.440	4.8	1.47	5.76	12.60	-1.44	7.23	14.07	-1.44	-6.84	8.67	15.51
n	33 sec	0.300	117	35.94	1.20	2.62	-0.30	37.14	38.56	-0.30	-1.42	37.44	38.86
	54 sec	0.700	197	60.51	2.80	6.12	-0.70	63.31	66.63	-0.70	-3.32	64.01	67.33

$S.I_{MAX} = (\sigma_\theta - \sigma_r) = 37.9$ KSI $< 3S_m = 80.1$ KSI (CRITERION S-C-4)

5- DETAILED ANALYSIS:

e. STRESSES:

LOCATION - 2

TRANSIENT		INTERNAL PRESSURE KSIA	$(T_m - T)$ °F	THERMAL STRESS $\sigma_x = \sigma_\theta$	PRESSURE STRESS σ_x	σ_θ	σ_r	TOTAL STRESS σ_x	σ_θ	σ_r	STRESS INTENSITY $\sigma_x - \sigma_\theta$	$\sigma_x - \sigma_r$	$\sigma_\theta - \sigma_r$
STEADY STATE		2.250	0	0	7.78	19.32	0	7.78	19.32	0	-11.54	7.78	19.32
a	4.47 hrs	2.250	33	10.14	7.78	19.32		17.92	29.46		-11.54	17.92	29.46
b	4.47 hrs	0.315	-33	-10.14	1.09	2.70		-9.05	-7.44		-1.61	-9.05	-7.44
c	20 min	2.250	0	0	7.78	19.32		7.78	19.32		-11.54	7.78	19.32
d	20 min	2.250			7.78	19.32		7.78	19.32		-11.54	7.78	19.32
e	100 sec	2.140			7.40	18.37		7.40	18.37		-10.97	7.40	18.37
	225 sec	2.275			7.87	19.53		7.87	19.53		-11.66	7.87	19.53
f	40 sec	2.320			8.02	19.92		8.02	19.92		-11.90	8.02	19.92
	100 sec	2.260			7.82	19.40		7.82	19.40		-11.58	7.82	19.40
	260 sec	2.140			7.40	18.37		7.40	18.37		-10.97	7.40	18.37
g	2 min	2.370			8.20	20.35		8.20	20.35		-12.15	8.20	20.35
	3.2 min	2.350			8.13	20.17		8.13	20.17		-12.04	8.13	20.17
	10.4 min	2.150			7.44	18.46		7.44	18.46		-11.02	7.44	18.46
h	10 sec	2.220			7.68	19.06		7.68	19.06		-11.38	7.68	19.06
	65 sec	1.910			6.61	16.40		6.61	16.40		-9.79	6.61	16.40
i	220 min	3.125			10.81	26.83		10.81	26.83		-16.02	10.81	26.83
j	HEATUP 3.5 hrs	1.250	33	10.14	4.32	10.73		14.46	20.87		-6.41	14.46	20.87
	S.S	2.500	0	0	8.65	21.46		8.65	21.46		-12.81	8.65	21.46
	COOLDOWN 3.5 hrs	0.315	-33	-10.14	1.09	2.70		-9.05	-7.44		-1.61	-9.05	-7.44
k	~	2.350	0	0	8.13	20.17		8.13	20.17		-12.04	8.13	20.17
	~	2.150			7.44	18.46		7.44	18.46		-11.02	7.44	18.46
l	12 sec	2.250			7.78	19.32		7.78	19.32		-11.54	7.78	19.32
m	10 sec	2.760			9.54	23.69		9.54	23.69		-14.15	9.54	23.69
	28 sec	2.120			7.33	18.20		7.33	18.20		-10.87	7.33	18.20
	160 sec	1.440			4.98	12.36		4.98	12.36		-7.38	4.98	12.36
n	33 sec	0.300			1.04	2.58		1.04	2.58		-1.54	1.04	2.58
	54 sec	0.700			2.42	6.01		2.42	6.01		-3.59	2.42	6.01

$S.I._{MAX} = (\sigma_\theta - \sigma_r) = 36.9$ ksi $< 3S_m = 80.1$ ksi (CRITERION 5-1-4

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO.

NUMBER 5-202-P | A 292
SHEET 15 OF 24
DATE MAY 26, 1966 BY COCKRELL
CHECK DATE MAY 26, 1966 BY ALEXANDER

DESCRIPTION STRUCTURAL AND FATIGUE ANALYSIS OF THE VESSEL WALL TRANSITION

5- DETAILED ANALYSIS:

C - STRESSES:

LOCATION - 3

Transient		Internal Pressure KSIA	$(T_m - T)$ °F	Thermal Stress $\sigma_x = \sigma_\theta$	Pressure Stress σ_x	Pressure Stress σ_θ	Pressure Stress σ_r	Total Stress σ_x	Total Stress σ_θ	Total Stress σ_r	Stress Intensity $\sigma_x - \sigma_\theta$	Stress Intensity $\sigma_x - \sigma_r$	Stress Intensity $\sigma_\theta - \sigma_r$
Steady State		2.250	0	0	10.70	20.71	-2.25	10.70	20.71	-2.25	-10.01	12.95	22.96
a	4.47 hrs	2.250	-43	-13.21	10.70	20.71	-2.25	-2.51	7.50	-2.25	-10.01	-0.26	9.75
b	4.47 hrs	0.315	43	13.21	1.50	2.90	-0.32	14.71	16.11	-0.32	-1.40	15.03	16.43
c	20 min	2.250	-7.8	-2.40	10.70	20.71	-2.25	8.30	18.31	-2.25	-10.01	10.55	20.56
d	20 min	2.250	7.8	2.40	10.70	20.71	-2.25	13.10	23.11	-2.25	-10.01	15.35	25.36
e	100 sec	2.140	11.2	3.44	10.17	19.70	-2.14	13.61	23.14	-2.14	-9.53	15.75	25.28
	225 sec	2.275	1.7	0.52	10.82	20.94	-2.28	11.34	21.46	-2.28	-10.12	13.62	23.72
f	40 sec	2.320	-9.3	-2.86	11.03	21.35	-2.32	8.17	18.49	-2.32	-10.32	10.49	20.81
	100 sec	2.260	-13.3	-4.08	10.75	20.80	-2.26	6.67	16.72	-2.26	-10.05	8.93	18.98
	260 sec	2.140	-1.3	-0.40	10.17	19.70	-2.14	9.77	19.30	-2.14	-9.53	11.91	21.44
g	2 min	2.370	-12.0	-3.69	11.27	21.81	-2.37	7.58	18.12	-2.37	-10.54	9.95	20.49
	3.2 min	2.350	-15.0	-4.61	11.17	21.63	-2.35	6.56	17.02	-2.35	-10.46	8.91	19.37
	10.4 min	2.150	0	0	10.22	19.79	-2.15	10.22	19.79	-2.15	-9.57	12.37	21.94
h	10 sec	2.220	-9.5	-2.92	10.55	20.43	-2.22	7.63	17.51	-2.22	-9.88	9.85	19.73
	65 sec	1.910	8.5	2.61	9.08	17.58	-1.91	11.69	20.19	-1.91	-8.50	13.60	22.10
i	220 min	3.125	0	0	14.86	28.76	-3.13	14.86	28.76	-3.13	-13.90	17.99	31.89
j	HEATUP 3.5 hrs	1.250	-43	-13.21	5.94	11.50	-1.25	-7.27	-1.71	-1.25	-5.56	-6.02	-0.46
	S.S	2.500	0	0	11.89	23.01	-2.50	11.89	23.01	-2.50	-11.12	14.39	25.51
	COOLDOWN 3.5 hrs	0.315	43	13.21	1.50	2.90	-0.32	14.71	16.11	-0.32	-1.40	15.03	16.43
k	~	2.350	6.0	1.84	11.17	21.63	-2.35	13.01	23.47	-2.35	-10.46	15.36	25.82
	~	2.150	-6.0	-1.84	10.22	19.79	-2.15	8.38	17.95	-2.15	-9.57	10.53	20.10
l	12 sec	2.250	33.3	10.23	10.70	20.71	-2.25	20.93	30.94	-2.25	-10.01	23.18	33.19
m	10 sec	2.760	-30.2	-9.28	13.12	25.40	-2.76	3.84	16.12	-2.76	-12.28	6.60	18.18
	28 sec	2.120	-41.2	-12.65	10.08	19.51	-2.12	-2.57	6.86	-2.12	-9.43	-0.45	8.98
	160 sec	1.440	4.8	1.47	6.85	13.25	-1.44	8.32	14.72	-1.44	-6.40	9.76	16.16
n	33 sec	0.300	117	35.94	1.43	2.76	-0.30	37.37	38.70	-0.30	-1.33	37.67	39.00
	54 sec	0.700	197	60.51	3.33	6.44	-0.70	63.84	66.95	-0.70	-3.11	64.54	67.65

$S.I._{\substack{MAX \\ RANGE}} = (\sigma_\theta - \sigma_r) = 32.4$ KSI $< 3S_m = 80.1$ KSI CRITERION 5-C-4

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER 5-202-P | A 293
SHEET 16 OF 24
CHARGE NO.
DATE MAY 26, 1966 BY COCKRELL
DESCRIPTION STRUCTURAL AND FATIGUE ANALYSIS OF THE VESSEL WALL TRANSITION
CHECK DATE MAY 26, 1966 BY ALEXANDER

5 - DETAILED ANALYSIS:

e - STRESSES:

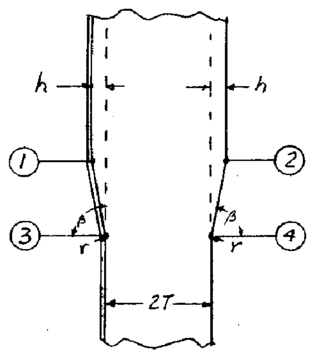
LOCATION - 4

Transient		Internal Pressure KSIA	$(T_o - T)$ °F	Thermal Stress $\sigma_x = \sigma_\theta$	Pressure Stress σ_x	Pressure Stress σ_θ	Pressure Stress σ_r	Total Stress σ_x	Total Stress σ_θ	Total Stress σ_r	Stress Intensity $\sigma_x - \sigma_\theta$	Stress Intensity $\sigma_x - \sigma_r$	Stress Intensity $\sigma_\theta - \sigma_r$
Steady State		2.250	0	0	10.74	20.72	0	10.74	20.72	0	-9.98	10.74	20.72
a	4.47 hrs	2.250	22	6.76	10.74	20.72		17.50	27.48	-	-9.98	17.50	27.48
b	4.47 hrs	0.315	-22	-6.76	1.50	2.90		-5.26	-3.86		-1.40	-5.26	-3.86
c	20 min	2.250	0	0	10.74	20.72		10.74	20.72		-9.98	10.74	20.72
d	20 min	2.250			10.74	20.72		10.74	20.72		-9.98	10.74	20.72
e	100 sec	2.140			10.22	19.71		10.22	19.71		-9.49	10.22	19.71
	225 sec	2.275			10.88	20.95		10.88	20.95		-10.07	10.88	20.95
f	40 sec	2.320			11.08	21.37		11.08	21.37		-10.29	11.08	21.37
	100 sec	2.260			10.79	20.82		10.79	20.82		-10.03	10.79	20.82
	260 sec	2.140			10.22	19.71		10.22	19.71		-9.49	10.22	19.71
g	2 min	2.370			11.32	21.83		11.32	21.83		-10.51	11.32	21.83
	3.2 min	2.350			11.22	21.64		11.22	21.64		-10.42	11.22	21.64
	10.4 min	2.150			10.27	19.80		10.27	19.80		-9.53	10.27	19.80
h	10 sec	2.220			10.60	20.45		10.60	20.45		-9.85	10.60	20.45
	65 sec	1.910			9.12	17.59		9.12	17.59		-8.47	9.12	17.59
i	220 min	3.125			14.92	28.78		14.92	28.78		-13.86	14.92	28.78
j	Heatup 3.5 hrs	1.250	22	6.76	5.97	11.51		12.73	18.27		-5.54	12.73	18.27
	S.S	2.500	0	0	11.94	23.02		11.94	23.02		-11.08	11.94	23.02
	Cooldown 3.5 hrs	0.315	-22	-6.76	1.50	2.90		-5.26	-3.86		-1.40	-5.26	-3.86
k	~	2.350	0	0	11.22	21.64		11.22	21.64		-10.42	11.22	21.64
	~	2.150			10.27	19.80		10.27	19.80		-9.53	10.27	19.80
l	12 sec	2.250			10.74	20.72		10.74	20.72		-9.98	10.74	20.72
m	10 sec	2.760			13.18	25.42		13.18	25.42		-12.24	13.18	25.42
	20 sec	2.120			10.12	19.53		10.12	19.53		-9.41	10.12	19.53
	160 sec	1.440			6.88	13.26		6.88	13.26		-6.38	6.88	13.26
n	33 sec	0.300			1.43	2.76		1.43	2.76		-1.33	1.43	2.76
	54 sec	0.700			3.34	6.45		3.34	6.45		-3.11	3.34	6.45

$S.I._{\substack{MAX \\ RANGE}} = \sigma_\theta - \sigma_r = 32.6$ ksi $< 3S_m = 80.1$ ksi   CRITERION 5-C-4

5- DETAILED ANALYSIS:
f- FATIGUE EVALUATION:

IN ORDER TO PERFORM THE FATIGUE EVALUATION, PEAK STRESSES MUST BE KNOWN AT THE FOUR LOCATIONS AS SHOWN BELOW. THE STRESS EXPRESSIONS GIVEN ON SHEET 10 WILL BE MODIFIED TO ACCOUNT FOR STRESS CONCENTRATIONS. WITH THE PEAK STRESSES, A FATIGUE EVALUATION WILL BE MADE BY THE CUMULATIVE METHOD WHERE SUPERPOSITION OF ALL CYCLES IS TAKEN INTO CONSIDERATION.



BY INSPECTION, WE SEE THAT THE STRESS CONCENTRATION FACTORS AT LOCATIONS 1 & 2 EQUAL 1. AT LOCATIONS 3 & 4, STRESS CONCENTRATION FACTOR FOR BENDING AND TENSION WILL BE DETERMINED BY THE METHOD PRESENTED IN REFERENCE 6.

$T = 4.3125''$

$h = 1.063''$ $\quad \frac{r}{T} = 0.464$ $\quad \frac{\beta}{90} = 0.889$

$\beta = 80°$

$r = 2''$ $\quad \frac{r}{h} = 1.881$

FROM FIGURE A.7-1 OF REF. 3

$K_T = 1.85$

$K_B = 1.53$

FROM FIGURE A.7-2 OF REF. 3

$\left[\frac{K'-1}{K_0-1}\right] = 0.4$

$K'_T = 1 + 0.4(K_T - 1) = \underline{1.34}$

$K'_B = 1 + 0.4(K_B - 1) = \underline{1.21}$

LOCATION 3

$$\sigma_X = \frac{6M_2}{t_3^2}K'_B + \frac{b_3^2 P}{2R_3 t_3}K'_T + \frac{E\alpha(T_m - T)}{1-\nu}K'_T = 6.37232P + 0.41157(T_m - T)$$

$$\sigma_\theta = \frac{\nu 6M_2}{t_3^2}K'_B + \frac{E\Delta_{32}}{R_3} + \frac{b_3 P}{t_3} + \frac{E\alpha(T_m - T)}{1-\nu} = 9.20326P + 0.30714(T_m - T)$$

LOCATION 4

$$\sigma_X = -\frac{6M_2}{t_3^2}K'_B + \frac{b_3^2 P}{2R_3 t_3}K'_T + \frac{E\alpha(T_m - T)}{1-\nu}K'_T = 6.39762P + 0.41157(T_m - T)$$

$$\sigma_\theta = -\frac{\nu 6M_2}{t_3^2}K'_B + \frac{E\Delta_{32}}{R_3} + \frac{b_3 P}{t_3} + \frac{E\alpha(T_m - T)}{1-\nu} = 9.21086P + 0.30714(T_m - T)$$

5- DETAILED ANALYSIS:

f- FATIGUE EVALUATION:

PEAK STRESS AT LOCATION -3

TRANSIENT		INTERNAL PRESSURE KSIA	$T_m - T$ °F	THERMAL STRESS σ_x	THERMAL STRESS σ_θ	PRESSURE STRESS σ_x	PRESSURE STRESS σ_θ	PRESSURE STRESS σ_r	PEAK STRESS σ_x	PEAK STRESS σ_θ	PEAK STRESS σ_r
STEADY STATE		2.250	0	0	0	14.34	20.71	-2.25	14.34	20.71	-2.25
a	4.47hrs	2.250	-43	-17.70	-13.21	14.34	20.71	-2.25	-3.36	7.50	-2.25
b	4.47hrs	0.315	43	17.70	13.21	2.01	2.90	-0.32	19.71	16.11	-0.32
c	20 min	2.250	-7.8	-3.21	-2.40	14.34	20.71	-2.25	11.13	18.31	-2.25
d	20 min	2.250	7.8	3.21	2.40	14.34	20.71	-2.25	17.55	23.11	-2.25
e	100 sec	2.140	11.2	4.61	3.44	13.64	19.69	-2.14	18.25	23.13	-2.14
	225 sec	2.275	1.7	0.70	0.52	14.50	20.94	-2.28	15.20	21.46	-2.28
f	40 sec	2.320	-9.3	-3.83	-2.86	14.78	21.35	-2.32	10.95	18.49	-2.32
	100 sec	2.260	-13.3	-5.47	-4.08	14.40	20.80	-2.26	8.93	16.72	-2.26
	260 sec	2.140	-1.3	-0.54	-0.40	13.64	19.69	-2.14	13.10	19.29	-2.14
g	2 min	2.370	-12.0	-4.94	-3.69	15.10	21.81	-2.37	10.16	18.12	-2.37
	3.2 min	2.350	-15.0	-6.17	-4.61	14.97	21.63	-2.35	8.80	17.02	-2.35
	10.4 min	2.150	0	0	0	13.70	19.79	-2.15	13.70	19.79	-2.15
h	10 sec	2.220	-9.5	-3.91	-2.92	14.15	20.43	-2.22	10.24	17.51	-2.22
	65 sec	1.910	8.5	3.50	2.61	12.17	17.58	-1.91	15.67	20.19	-1.91
i	220 min	3.125	0	0	0	19.91	28.76	-3.13	19.91	28.76	-3.13
j	HEATUP 3.5 hrs	1.250	-43	-17.70	-13.21	7.96	11.50	-1.25	-9.74	-1.71	-1.25
	S.S.	2.600	0	0	0	15.93	23.01	-2.50	15.93	23.01	-2.50
	COOLDOWN 3.5 hrs	0.315	43	17.70	13.21	2.01	2.90	-0.32	19.71	16.11	-0.32
k	~	2.350	6.0	2.47	1.84	14.97	21.63	-2.35	17.44	23.47	-2.35
	~	2.150	-6.0	-2.47	-1.84	13.70	19.79	-2.15	11.23	17.95	-2.15
l	12 sec	2.250	33.3	13.71	10.23	14.34	20.71	-2.25	28.05	30.94	-2.25
m	10 sec	2.760	-30.2	-12.43	-9.28	17.59	25.40	-2.76	5.16	16.12	-2.76
	28 sec	2.120	-41.2	-16.96	-12.65	13.51	19.51	-2.12	-3.45	6.86	-2.12
	160 sec	1.440	4.8	1.98	1.47	9.18	13.25	-1.44	11.16	14.72	-1.44
n	33 sec	0.300	117	48.15	35.94	1.91	2.76	-0.30	50.06	38.70	-0.30
	54 sec	0.700	197	81.08	60.51	4.46	6.44	-0.70	85.54	66.95	-0.70

5- DETAILED ANALYSIS:

f- FATIGUE EVALUATION:

PEAK STRESS AT LOCATION-4

TRANSIENT		INTERNAL PRESSURE	T_m-T	THERMAL STRESS		PRESSURE STRESS			PEAK STRESS		
		KSIA	°F	σ_x	σ_θ	σ_x	σ_θ	σ_r	σ_x	σ_θ	σ_r
STEADY STATE		2.250	0	0	0	14.39	20.72	0	14.39	20.72	0
a	4.47 hrs	2.250	22	9.05	6.76	14.39	20.72		23.44	27.48	
b	4.47 hrs	0.315	-22	-9.05	-6.76	2.01	2.90		-7.04	-3.86	
c	20 min	2.250	0	0	0	14.39	20.72		14.39	20.72	
d	20 min	2.250				14.39	20.72		14.39	20.72	
e	100 sec	2.140				13.69	19.71		13.69	19.71	
	225 sec	2.275				14.55	20.95		14.55	20.95	
f	40 sec	2.320				14.84	21.37		14.84	21.37	
	100 sec	2.260				14.46	20.82		14.46	20.82	
	260 sec	2.140				13.69	19.71		13.69	19.71	
g	2 min	2.370				15.16	21.83		15.16	21.83	
	3.2 min	2.350				15.03	21.65		15.03	21.65	
	10.4 min	2.150				13.75	19.80		13.75	19.80	
h	10 sec	2.220				14.20	20.45		14.20	20.45	
	65 sec	1.910				12.22	17.59		12.22	17.59	
i	220 min	3.125	↓	↓	↓	19.99	28.78		19.99	28.78	
j	Heatup 3.5 hrs	1.250	22	9.05	6.76	8.00	11.51		17.05	18.27	
	S.S	2.500	0	0	0	15.99	23.02		15.99	23.02	
	Cooldown 3.5 hrs	0.315	-22	-9.05	-6.76	2.01	2.90		-7.04	-3.86	
k	~	2.350	0	0	0	15.03	21.65		15.03	21.65	
	~	2.150				13.75	19.80		13.75	19.80	
l	12 sec	2.250				14.39	20.72		14.39	20.72	
m	10 sec	2.760				17.66	25.42		17.66	25.42	
	28 sec	2.120				13.56	19.53		13.56	19.53	
	160 sec	1.440				9.21	13.26		9.21	13.26	
n	33 sec	0.300				1.92	2.76		1.92	2.76	
	54 sec	0.700	↓	↓	↓	4.48	6.45	↓	4.48	6.45	↓

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER 5-202-P | A 297
SHEET 20 OF 24
CHARGE NO.
DATE May 26, 1966 BY Cocerel
DESCRIPTION Structural and Fatigue Analysis of The Vessel Wall Transition
CHECK DATE May 26, 1966 BY Alexander

5 Detailed Analysis:
f. Fatigue Evaluation:

Peak Stress Intensities

Transient		Location-1 $\sigma_x-\sigma_\theta$	Location-1 $\sigma_x-\sigma_r$	Location-1 $\sigma_\theta-\sigma_r$	Location-2 $\sigma_x-\sigma_\theta$	Location-2 $\sigma_x-\sigma_r$	Location-2 $\sigma_\theta-\sigma_r$	Location-3 $\sigma_x-\sigma_\theta$	Location-3 $\sigma_x-\sigma_r$	Location-3 $\sigma_\theta-\sigma_r$	Location-4 $\sigma_x-\sigma_\theta$	Location-4 $\sigma_x-\sigma_r$	Location-4 $\sigma_\theta-\sigma_r$
Steady State		-10.68	11.25	21.93	-11.54	7.78	19.32	-6.37	16.59	22.96	-6.33	14.39	20.72
a	4.47 hrs	-10.68	-8.71	1.97	-11.54	17.92	29.46	-10.86	-1.11	9.75	-4.04	23.44	27.49
b	4.47 hrs	-1.50	21.54	23.04	-1.61	-9.05	-7.44	3.60	20.03	16.43	-3.18	-7.04	-3.86
c	20 min	-10.68	8.85	19.53	-11.54	7.78	19.32	-7.18	13.39	20.56	-6.33	14.39	20.72
d	20 min	-10.68	13.65	24.33	-11.54	7.78	19.32	-5.56	19.80	25.36	-6.33	14.39	20.72
e	100 sec	-10.16	14.14	24.30	-10.97	7.40	18.37	-4.88	20.39	25.27	-6.02	13.69	19.71
	225 sec	-10.80	11.90	22.70	-11.66	7.87	19.53	-6.26	17.48	23.74	-6.40	14.55	20.95
f	40 sec	-11.01	8.74	19.75	-11.90	8.02	19.92	-7.54	13.27	20.81	-6.53	14.84	21.37
	100 sec	-10.73	7.22	17.95	-11.58	7.82	19.40	-7.79	11.19	18.98	-6.36	14.46	20.82
	260 sec	-10.16	10.30	20.46	-10.97	7.40	18.37	-6.19	15.24	21.43	-6.02	13.69	19.71
g	2 min	-11.25	8.16	19.41	-12.15	8.20	20.35	-7.96	12.53	20.49	-6.67	15.16	21.83
	3.2 min	-11.13	7.14	18.27	-12.04	8.13	20.17	-8.22	11.15	19.37	-6.62	15.03	21.65
	10.4 min	-10.21	10.75	20.96	-11.02	7.44	18.46	-6.09	15.85	21.94	-6.05	13.75	19.80
h	10 sec	-10.54	8.18	18.72	-11.38	7.68	19.06	-7.27	12.46	19.73	-6.25	14.20	20.45
	65 sec	-9.07	12.16	21.23	-9.79	6.61	16.40	-4.52	17.58	22.10	-5.37	12.22	17.59
i	220 min	-14.84	15.63	30.43	-16.02	10.81	26.83	-8.95	23.04	31.89	-9.79	19.99	28.78
j	Heatup 3.5 hrs	-5.94	13.41	-7.47	-6.41	14.46	20.87	-8.03	-8.49	-0.46	-1.22	17.05	18.27
	S.S	-11.87	12.50	24.37	-12.81	8.65	21.46	-7.08	18.43	25.51	-7.03	15.99	23.02
	Cooldown 3.5 hrs	-1.50	21.24	22.74	-1.61	-9.05	-7.44	3.60	20.03	16.43	-3.18	-7.04	-3.86
k	~	-11.13	13.59	24.72	-12.04	8.13	20.17	-6.03	19.79	25.82	-6.62	15.03	21.65
	~	-10.21	8.91	19.12	-11.02	7.44	18.46	-6.72	13.38	20.10	-6.05	13.75	19.80
l	12 sec	-10.68	21.48	32.16	-11.54	7.78	19.32	-2.89	30.30	33.19	-6.33	14.39	20.72
m	10 sec	-13.10	4.52	17.62	-14.15	9.54	23.69	-10.96	7.92	18.88	-7.76	17.66	25.42
	28 sec	-10.07	-2.05	8.02	-10.87	7.33	18.20	-10.31	-1.33	8.98	-5.97	13.56	19.53
	160 sec	-6.84	8.67	15.51	-7.38	4.98	12.36	-3.56	12.60	16.16	-4.05	9.21	13.26
n	33 sec	-1.42	37.44	38.86	-1.54	1.04	2.58	11.36	50.36	39.00	-0.84	1.92	2.76
	54 sec	-3.32	64.01	67.33	-3.59	2.42	6.01	18.59	86.24	67.65	-1.97	4.48	6.45

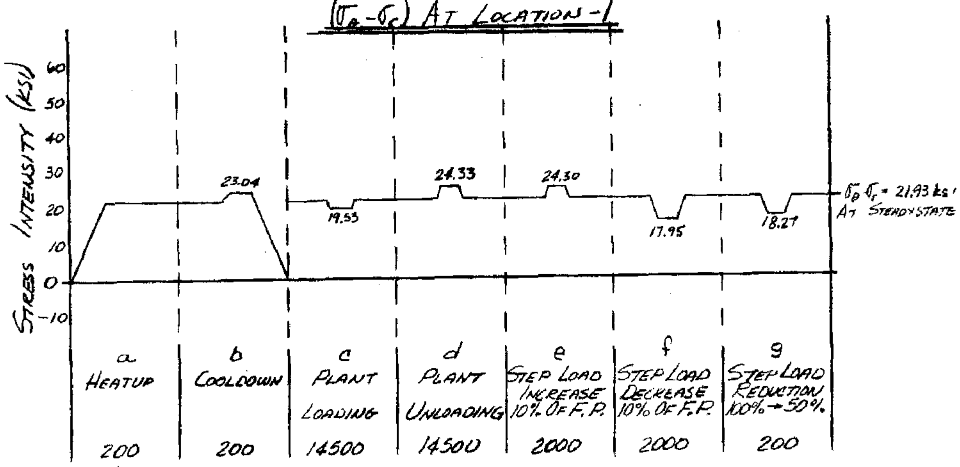
COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

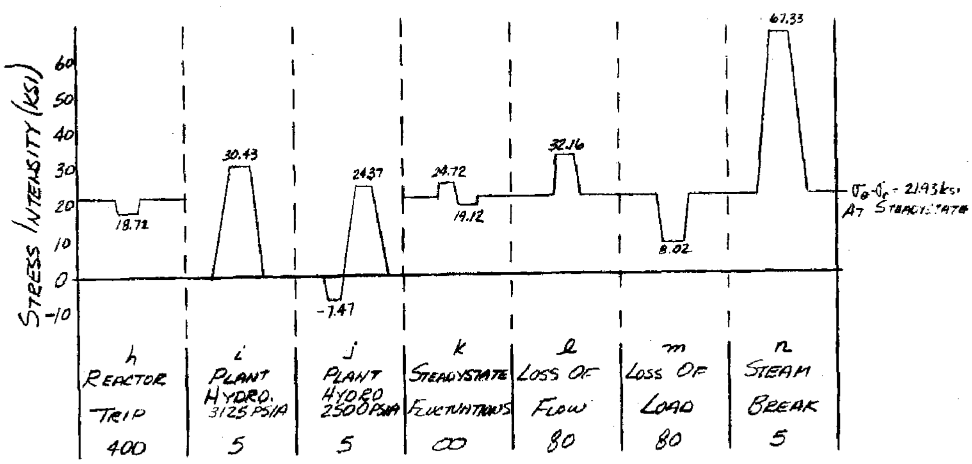
CHARGE NO.

DESCRIPTION Structural And Fatigue Analysis Of The Vessel Wall Transition

NUMBER S-202-P | A 298
SHEET 21 OF 24
DATE May 26, 1966 BY Cockrell
CHECK DATE May 26, 1966 BY Alexander

5- Detailed Analysis:
f- Fatigue Evaluation:





S_{MAX}	S_{MIN}	Number Of Occurrences	S_{ALT}	N^*	U
67.33	-7.47	5	37.4	10,000	0.00050
32.16	0	80	16.1	250,000	0.00030
30.43	0	5	15.2	340000	0.00001
24.72	0	115	12.4	∞	0

*From Fig. N-415(A) Reference 1

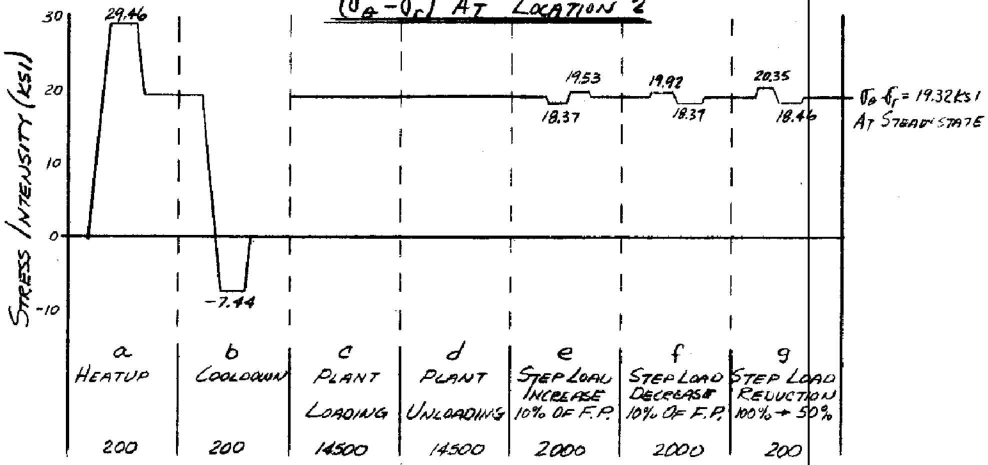
$U_{OVERALL}$ = 0.00106

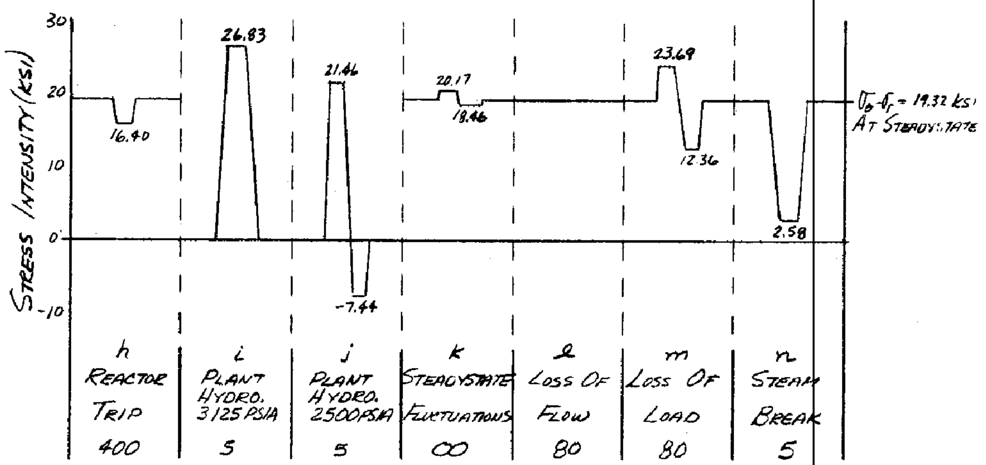
DESCRIPTION STRUCTURAL AND FATIGUE ANALYSIS OF THE VESSEL WALL TRANSITION

5. DETAILED ANALYSIS:

f. FATIGUE EVALUATION:

$(\sigma_\theta - \sigma_r)$ AT LOCATION 2





S_{MAX}	S_{MIN}	NUMBER OF OCCURRENCES	S_{ALT}	N^*	U
29.46	-7.44	200	18.5	135,000	0.00148
26.83	-7.44	5	17.1	190,000	0.00003
23.69	2.58	5	10.6	∞	0

*FROM FIG. N-415(A) REFERENCE 1

$U_{OVERALL}$ = 0.00151

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.
CHARGE NO. ____
DESCRIPTION STRUCTURAL AND FATIGUE ANALYSIS OF THE VESSEL WALL TRANSITION

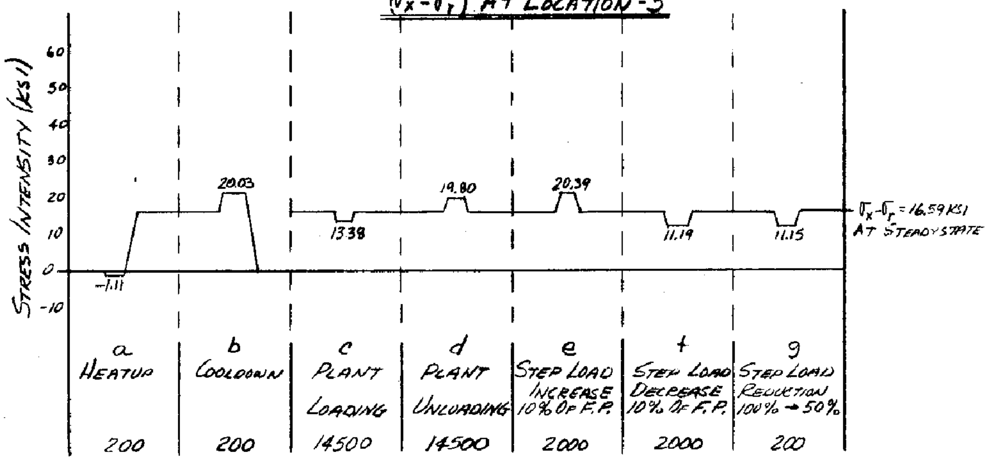
NUMBER 5-202-P | A 300

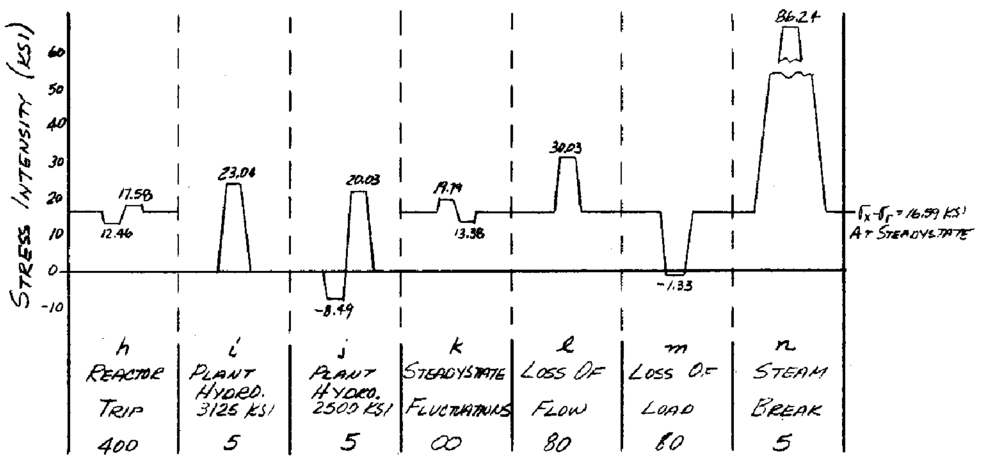
DATE MAY 26, 1966 BY COCKRELL
CHECK DATE MAY 26, 1966 BY ALEXANDER

5- DETAILED ANALYSIS:

f- FATIGUE EVALUATION:

$(\sigma_x - \sigma_r)$ AT LOCATION-3





S_{MAX}	S_{MIN}	NUMBER OF OCCURRENCES	S_{ALT}	N^*	U
86.24	-8.49	5	47.4	5000	0.00100
30.03	-1.33	80	15.7	290000	0.00027
23.04	-1.11	5	12.1	∞	0

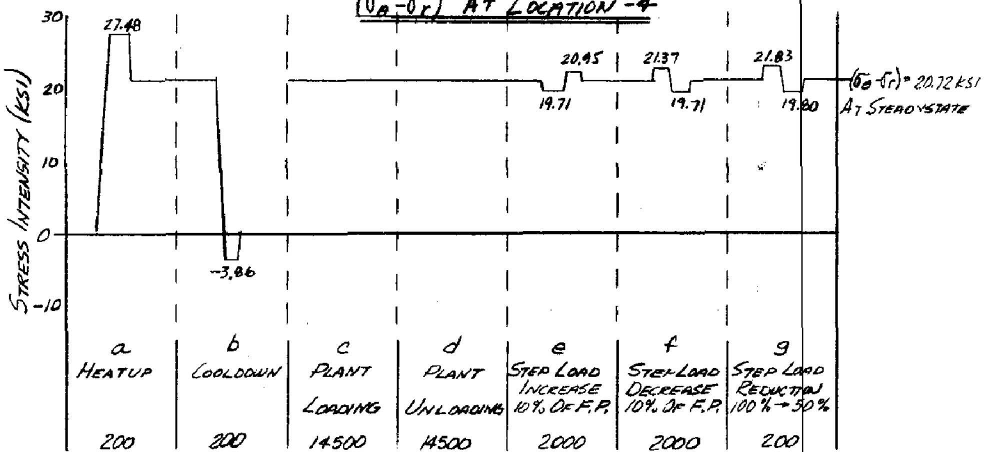
* FROM FIG. N-415(A) REFERENCE 1

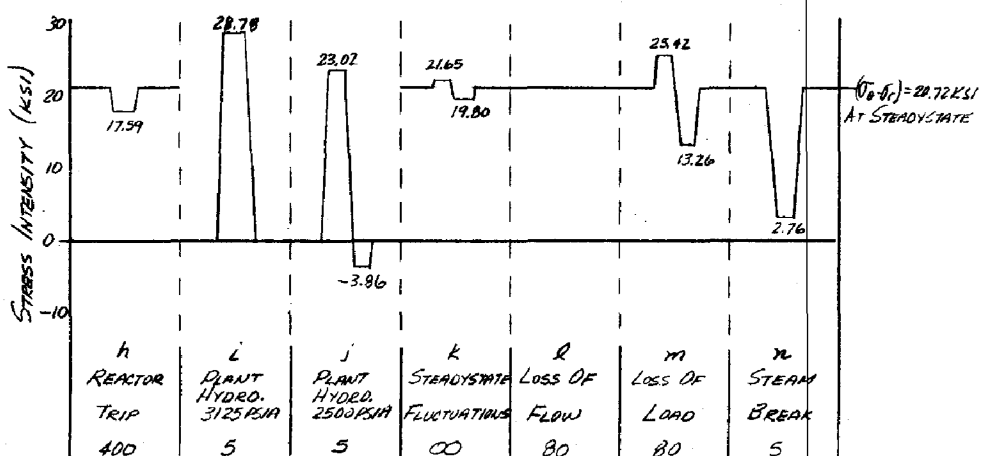
$U_{OVERALL} = 0.00127$

5- DETAILED ANALYSIS:

f. FATIGUE EVALUATION:

$(\sigma_\theta - \sigma_r)$ AT LOCATION-4





S_{MAX}	S_{MIN}	NUMBER OF OCCURRENCES	S_{ALT}	N^*	U
28.78	-3.86	5	16.3	230000	0.00002
27.48	-3.86	200	15.7	290000	0.00069
25.42	2.76	5	11.3	∞	0

*FROM FIG. N-415(A) REFERENCE 1

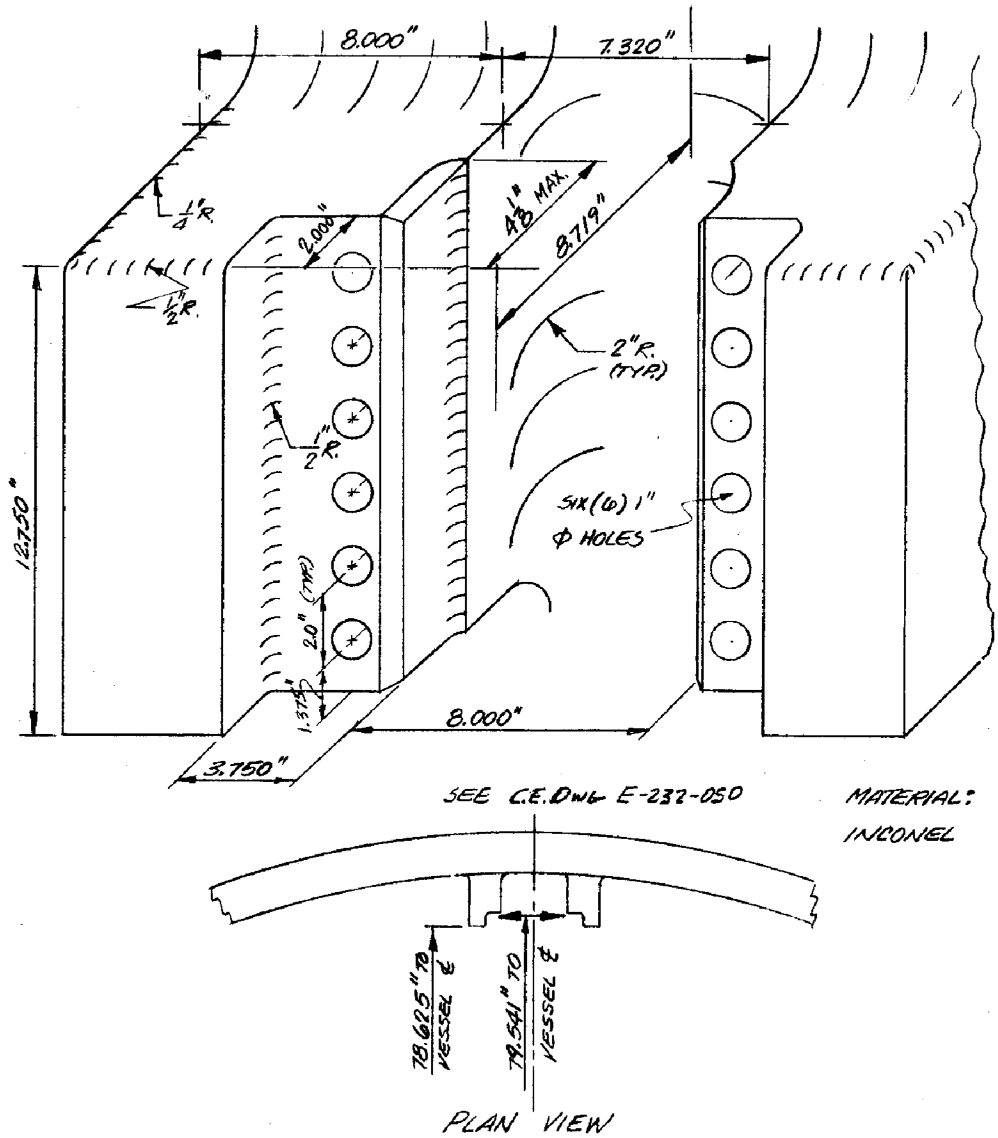
$U_{OVERALL} = 0.00071$

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.
CHARGE NO.
DESCRIPTION STRUCTURAL ANALYSIS OF CORE SUPPORT PADS

NUMBER S-201-P | A-302
SHEET 5 OF 31
DATE 1-27-67 BY ALEXANDER
CHECK DATE 1-27-67 BY CAUDLE

5. DETAILED ANALYSIS

a.) SYSTEM GEOMETRY



5. DETAILED ANALYSIS

b) SYSTEM LOADS

THE SYSTEM SHOWN ON SHEET 5 WILL BE ANALYZED FOR THE FOLLOWING LOADINGS:

1. A MOMENTARY VERTICAL LOAD OF 250 KIPS DURING INSERTION OF THE CORE.
2. A NON-CYCLIC STEADY LOADING OF 125 KIPS IN THE CIRCUMFERENTIAL DIRECTION.
3. A VERTICAL THERMAL GROWTH FRICTION LOAD OF 125 KIPS BETWEEN THE KEY ON THE CORE BARREL AND THE PAD AT ONE VERTICAL INTERFACE ONLY.
4. A CYCLIC LOADING OF PLUS/MINUS 100 KIPS ACTING IN THE CIRCUMFERENTIAL DIRECTION FOR AN INFINITE NUMBER OF CYCLES.
5. AN ADDITIONAL CYCLIC LOAD OF 125 KIPS IN THE CIRCUMFERENTIAL DIRECTION DUE TO EARTHQUAKE CONSIDERATIONS.
6. THE OPERATING TRANSIENTS DESCRIBED IN E-SPEC. #676208.

c) SYSTEM ALLOWABLES

1. SHOW THAT THE STRESS INTENSITY DERIVED FROM PRIMARY MEMBRANE (GENERAL OR LOCAL) PLUS PRIMARY BENDING STRESSES PRODUCED BY DESIGN PRESSURE AND OTHER MECHANICAL LOADS IS LESS THAN $1.5\ S_m$.
2. SHOW THAT THE RANGE OF STRESS INTENSITY AT EACH POINT DUE TO THE COMBINATION OF MECHANICAL LOADING PLUS THERMAL EFFECTS (NEGLECTING STRESS CONCENTRATIONS) IS LESS THAN $3S_m$.
3. SHOW THAT EACH POINT MEETS THE REQUIREMENTS FOR PEAK STRESS INTENSITIES GIVEN IN N-414.5 OF THE A.S.M.E. CODE. THE PROCEDURE WILL BE THAT DESCRIBED IN N-415.2 AND N-416.2 OF SECTION III.

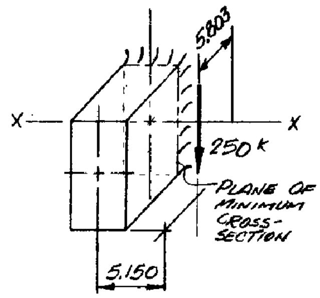
COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER 5-201-P | A 304
SHEET 7 OF 31
CHARGE NO.
DATE 1-27-67 BY ALEXANDER
DESCRIPTION STRUCTURAL ANALYSIS OF CORE SUPPORT PADS
CHECK DATE 1-27-67 BY CAUDLE

5. DETAILED ANALYSIS

d) STRESS DURING INSERTION OF CORE

CONSIDER LOADING 1 SHOWN ON SHEET 6. DURING INSTALLATION OF THE CORE, IF ALIGNMENT FAILS TO BE SMOOTH, A VERTICAL LOAD OF 250 KIPS OF MOMENTARY DURATION WILL BE TRANSMITTED TO ONE LUG AS SHOWN BELOW. STRESSES WERE CONSIDERED AT THE JUNCTURE OF THE LUG TO THE VESSEL WALL AND AT THE PLANE OF MINIMUM CROSS-SECTION. IT WAS DETERMINED THAT THE CONTROLLING LOCATION WAS THE PLANE OF MINIMUM CROSS-SECTION.



FOR THE MINIMUM CROSS-SECTION:

$$I_{x\text{-}x} = \frac{bh^3}{12} = \frac{8(12.75)^3}{12} = 1381.781 \text{ in.}^4$$

AND, FROM PG. 289, REF. 3 -

$$\frac{b}{c} = \frac{12.75}{8.0} = 1.59; \quad \alpha = 0.234$$

	SHORT SIDE	LONG SIDE
BENDING STRESS		
$\sigma = \frac{Mc}{I_{x\text{-}x}}$	$\frac{5.803(250)6.375}{1381.781} = 6.7 \text{ KSI}$	0
TORSION		
$\tau_T = \frac{T}{\alpha b c^2}$	$\frac{250(5.15)}{.234(8)12.75^2} = 4.2 \text{ KSI}$	$\frac{250(5.15)}{.234(12.75)8^2} = 6.7 \text{ KSI}$
DIRECT SHEAR		
$\tau_s = 1.5\frac{V}{A}$	0	$1.5\frac{250}{102.0} = 3.7 \text{ KSI}$

CONSIDER MID-POINT OF SHORT SIDE

$\sigma_1 = \frac{\sigma}{2} + \sqrt{\frac{\sigma^2}{2} + \tau^2} = 8.7 \text{ KSI}$

$\sigma_2 = \frac{\sigma}{2} - \sqrt{\frac{\sigma^2}{2} + \tau^2} = -2.0 \text{ KSI}$

$\sigma_1 - \sigma_2 = 8.7 - (-2.0) = 10.7 \text{ KSI} < 1.5 S_m = 35.0 \text{ KSI}$

CONSIDER MID-POINT OF LONG SIDE

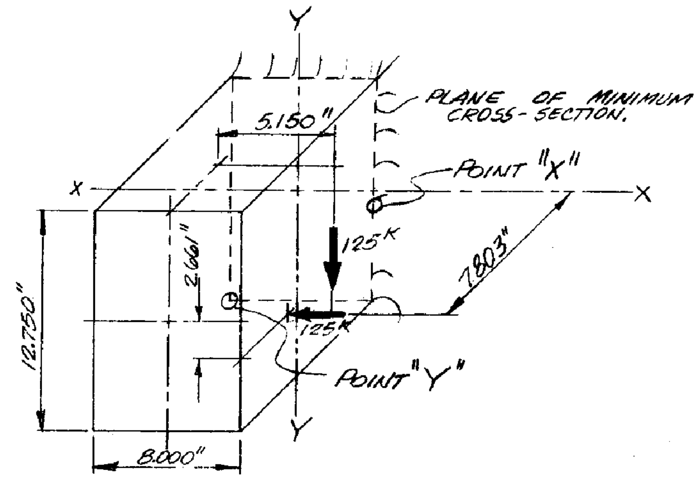
$\sigma = 0$

$\tau = 6.7 + 3.7 = 10.4 \text{ KSI} < 0.8 S_m = 18.6 \text{ KSI}$

5. DETAILED ANALYSIS

e.) STRESS DUE TO STEADY SIDE LOAD OF 125 KIPS, STEADY VERTICAL LOAD (THERMAL GROWTH) OF 125 KIPS AND DESIGN PRESSURE

AT THE MINIMUM CROSS-SECTION -



CONSIDERATION OF POINTS ALONG THE PERIPHERY OF THE PLANE OF MINIMUM CROSS-SECTION SHOWED THAT POINT "X" AS SHOWN ABOVE WAS THE CONTROLLING LOCATION FOR THIS PLANE. THE FOLLOWING IS A TABULATION OF THE STRESSES AT POINT "X".

$T = 125(5.150) + 125(2.661) = 976.375$ IN-KIPS

$\frac{b}{c} = \frac{12.750}{8.0} = 1.59, \quad \alpha = 0.234$ (PAGE 289, REF. 3)

$I_{YY} = \frac{bh^3}{12} = 544 \text{ IN.}^4$

BENDING STRESS $= \frac{Mc}{I_{YY}} = + \frac{125(5.803)\,4.0}{544} = +5.3$ KSI

TORSIONAL SHEAR $= \frac{T}{\alpha b c^2} = \frac{976.375}{.234(12.75)\,8.0^2} = 5.1$ KSI

DIRECT SHEAR $= 1.5\frac{V}{A} = 1.5\frac{125}{102} = 1.8$ KSI

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.
CHARGE NO.
DESCRIPTION STRUCTURAL ANALYSIS OF CORE SUPPORT PADS

NUMBER 5-201-P | A 306
SHEET 9 OF 31
DATE 1-27-67 BY ALEXANDER
CHECK DATE 1-27-67 BY CAUDLE

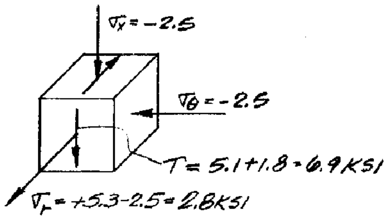
5. DETAILED ANALYSIS

e.) STRESS DUE TO STEADY SIDE LOAD OF 125 KIPS, STEADY VERTICAL LOAD (THERMAL GROWTH) OF 125 KIPS AND DESIGN PRESSURE

THE DESIGN PRESSURE IS 2.5 KSI WHICH GIVES –

$\sigma_x = \sigma_\theta = \sigma_r = -2.5$ KSI

CONSIDER A STRESS BLOCK AT POINT "X" –



$$\sigma_1 = \frac{\sigma_r + \sigma_x}{2} + \sqrt{\left(\frac{\sigma_r - \sigma_x}{2}\right)^2 + \tau^2} = 7.5 \text{ KSI}$$

$$\sigma_2 = \frac{\sigma_r + \sigma_x}{2} - \sqrt{\left(\frac{\sigma_r - \sigma_x}{2}\right)^2 + \tau^2} = -7.2 \text{ KSI}$$

$$\sigma_3 = -2.5 \text{ KSI}$$

$$S.I._{MAX} = (\sigma_1 - \sigma_2) = 7.5 - (-7.2) = 14.7 \text{ KSI} < 1.5 S_m = 35.0$$

CRITERION 5.C.1

AT THE VESSEL WALL –

CONSIDERATION OF POINTS AT THE JUNCTURE OF THE PAD TO THE VESSEL WALL SHOWS THAT THE CONTROLLING LOCATION IS POINT "Y" (SEE SHEET 8).

$$I_{Y\text{-}Y'} = \frac{bh^3}{12} \qquad \text{WHERE } ;\ b = 12.750 + 2(.75)2 = 15.75$$
$$h = 8.000 + 2(.75)2 = 11.0$$

$$= \frac{15.75(11)^3}{12} = 1746.938 \text{ IN.}^4$$

$$I_{XX'} = \frac{11.0(15.75)^3}{12} = 3581.402 \text{ IN.}^4$$

$T = 976.375$ IN-KIPS

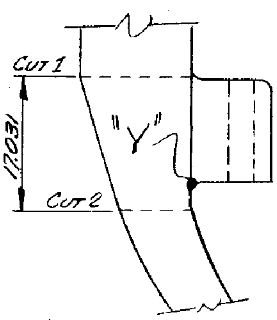
$$\text{BENDING STRESS} = -\frac{Mc}{I_{X\text{-}X'}} - \frac{Mc}{I_{YY'}} = -\frac{125(7.803)7.875}{3581.402} - \frac{125(7.803)5.5}{1746.938} = -5.2 \text{ KSI}$$

TORSION AND DIRECT SHEAR = 0

5. DETAILED ANALYSIS

e.) STRESS DUE TO STEADY SIDE LOAD OF 125 KIPS, STEADY VERTICAL LOAD (THERMAL GROWTH) OF 125 KIPS AND DESIGN PRESSURE

EXPRESSIONS FOR THE STRESSES AT THE INSIDE SURFACE OF THE VESSEL WERE PREVIOUSLY DERIVED AT CUTS 1 AND 2 (SEE BELOW) IN C.E. CALCULATION S-200-P. PRESSURE STRESSES AT POINT "Y" WILL BE DETERMINED BY PERFORMING A LINEAR INTERPOLATION BETWEEN CUTS 1 AND 2.



CUT	σ_x	σ_θ	σ_r	
1	5.285P	8.671P	-P	FROM SHEET 14, REF. 5.
2	9.910P	8.465P	-P	

INTERPOLATION YIELDS THE FOLLOWING STRESSES FOR POINT "Y":

$\sigma_x = 9.358P$ FOR $P = 2.5$; $\sigma_x = 23.4$ KSI

$\sigma_\theta = 8.490P$ $\qquad \sigma_\theta = 21.2$ KSI

$\sigma_r = -P$ $\qquad \sigma_r = -2.5$ KSI

COMBINING PRESSURE AND BENDING STRESSES –

$\sigma_x = 23.4$ KSI

$\sigma_\theta = 21.2$ KSI

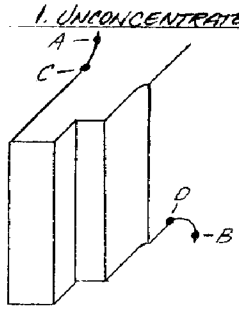
$\sigma_r = -5.2 - 2.5$ KSI $= -7.7$ KSI

$S.I._{MAX} = (\sigma_x - \sigma_r) = 31.1 \text{ KSI} < 1.5 S_m = 35.0 \text{ KSI}$

CRITERION 5.C.1

f) STRESSES

1. UNCONCENTRATED



THE LOCATIONS SHOWN AT LEFT WILL BE INVESTIGATED FOR THE FOLLOWING LOADS:

1.) A STEADY SIDE LOAD OF 125^K

2.) A CYCLIC LOADING OF $\pm 100^K$ IN THE CIRCUMFERENTIAL DIRECTION.

3.) A CYCLIC LOADING OF $\pm 125^K$ IN THE CIRCUMFERENTIAL DIRECTION DUE TO EARTHQUAKE CONSIDERATIONS

4.) THE EFFECTS OF THE OPERATING TRANSIENTS DESCRIBED IN E-SPEC. 676208.

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.
CHARGE NO.
DESCRIPTION STRUCTURAL ANALYSIS OF CORE SUPPORT PADS

NUMBER 5-201-P | A 308
SHEET 11 OF 31
DATE 1-27-67 BY ALEXANDER
CHECK DATE 1-27-67 BY CAUDLE

5. DETAILED ANALYSIS
f.) STRESSES
1. UNCONCENTRATED

THERMAL STRESSES -*
POINTS "A" & "B" -

$$\sigma_x = \sigma_\theta = \frac{E\alpha(T_m - T)}{1-\nu}$$

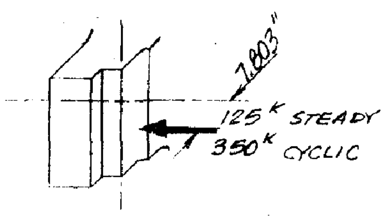
POINTS "C" & "D" -

$$\sigma_x = \sigma_r = \frac{E\alpha(T_m - T)}{1-\nu}$$

WHERE; $E\alpha$ = YOUNG'S MODULUS X COEFFICIENT OF THERMAL EXPANSION. TAKEN AS 0.214 FOR POINTS "A" & "B" AND 0.254 FOR POINTS "C" & "D".
T_m = MEAN TEMPERATURE AT STEADY STATE.
T = INSTANTANEOUS REACTOR INLET COOLANT TEMPERATURE DURING TRANSIENT.
ν = POISSON'S RATIO, TAKEN AS 0.3.

PRESSURE STRESSES -
POINT "A" -
$\sigma_x = 5.285\ P$ FROM PG. 10
$\sigma_\theta = 8.671\ P$
$\sigma_r = -P$
POINT "B" -
$\sigma_x = 9.358\ P$ FROM PG. 10
$\sigma_\theta = 8.490\ P$
$\sigma_r = -P$
POINTS "C" & "D"
$\sigma_x = \sigma_\theta = \sigma_r = -P$

STRESSES DUE TO APPLIED LOADS -
COMBINING THE CYCLIC AND STEADY LOADS AS GIVEN ON PAGE 10 YIELDS THE FOLLOWING APPLIED LOADING:



* NOTE - ALL THERMAL STRESSES CONSERVATIVELY TREATED AS "SKIN" TYPE STRESSES.

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.
CHARGE NO.
DESCRIPTION STRUCTURAL ANALYSIS OF CORE SUPPORT PADS

NUMBER S-201-P | A 309
SHEET 12 OF 31
DATE 1-27-67 BY ALEXANDER
CHECK DATE 1-27-67 BY CAUDLE

5. DETAILED ANALYSIS
f.) STRESSES
1. UNCONCENTRATED

STRESSES DUE TO APPLIED LOADS -
POINT "A" - (VESSEL WALL)

$$\sigma_r = -\frac{Mc}{I_{Y-Y'}} = \frac{-\binom{350}{125} 7.803 (5.5)}{1746.938} = \begin{matrix} -8.6 \text{ KSI} \\ -3.1 \text{ KSI} \end{matrix}$$

POINT "B" - (VESSEL WALL)

$$\sigma_r = \begin{matrix} +8.6 \text{ KSI} \\ +3.1 \text{ KSI} \end{matrix}$$

POINT "C" -

$$\sigma_r = -\frac{Mc}{I_{Y-Y}} = \frac{-\binom{350}{125} 5.803 (4)}{544} = \begin{matrix} -14.9 \text{ KSI} \\ -5.3 \text{ KSI} \end{matrix}$$

POINT "D" -

$$\sigma_r = \begin{matrix} +14.9 \text{ KSI} \\ +5.3 \text{ KSI} \end{matrix}$$

SHEAR STRESSES NEGLECTED.

NOTE: THE FOLLOWING TABLES SUMMARIZE THE STRESSES AND STRESS INTENSITIES FOR THE FOUR LOCATIONS AS SHOWN ON SHEET 10. COMPARISON WITH $3S_m$ ALLOWABLES (CRITERION 5-C-2) IS GIVEN AT THE END OF EACH TABLE. FOR THE $3S_m$ CONSIDERATION, THE FOLLOWING TRANSIENTS ARE NOT CONSIDERED:

1- "LOSS OF FLOW"
2- "STEAM BREAK"
3- "LOSS OF LOAD"

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO.
DESCRIPTION STRUCTURAL ANALYSIS OF CORE SUPPORT PADS

NUMBER 5-201-P | A310
SHEET 13 OF 31
DATE 1-27-67 BY ALEXANDER
CHECK DATE 1-27-67 BY CAURLE

5. DETAILED ANALYSIS

F.) STRESSES - 1. UNCONCENTRATED

SUMMARY OF STRESSES AND STRESS INTENSITIES AT LOCATION A

TRANSIENT	TIME	PRESS (KSI)	$(T_m - T)$	THERM. STRESS	PRESSURE STRESSES			LOAD STRESS	TOTAL STRESSES			STRESS INTENSITIES		
				$\sigma_x = \sigma_\theta$	σ_x	σ_θ	σ_r	σ_r	σ_x	σ_θ	σ_r	$\sigma_x - \sigma_\theta$	$\sigma_x - \sigma_r$	$\sigma_\theta - \sigma_r$
STEADY STATE	~	2.25	0	0	11.9	19.5	-2.3	-3.1	11.9	19.5	-5.4	-7.6	17.3	24.9
HEAT-UP	4.47 HRS.	2.25	-43	-13.1	11.9	19.5	-2.3	-8.6	-1.2	6.4	-10.9	-7.6	9.7	7.3
		2.25	-43	-13.1	11.9	19.5	-2.3	-3.1	-1.2	6.4	-5.4	-7.6	4.2	11.8
COOLDOWN	4.47 HRS.	0.32	43	13.1	1.7	2.8	-0.3	-8.6	14.8	15.9	-8.9	-1.1	23.7	24.8
		0.32	43	13.1	1.7	2.8	-0.3	-3.1	14.8	15.9	-3.4	-1.1	18.2	19.3
PLANT LOADING	20 MIN	2.25	-7.8	-2.4	11.9	19.5	-2.3	-8.6	9.5	17.1	-10.9	-7.6	20.4	28.0
		2.25	-7.8	-2.4	11.9	19.5	-2.3	-3.1	9.5	17.1	-5.4	-7.6	14.9	22.5
PLANT UNLOADING	20 MIN	2.25	7.8	2.4	11.9	19.5	-2.3	-8.6	14.3	21.9	-10.9	-7.6	25.2	32.8
		2.25	7.8	2.4	11.9	19.5	-2.3	-3.1	14.3	21.9	-5.4	-7.6	19.7	27.3
STEP LOAD	100 SEC.	2.14	11.2	3.4	11.3	18.6	-2.1	-8.6	14.7	22.0	-10.7	-7.3	25.4	32.7
INCREASE	100 SEC.	2.14	11.2	3.4	11.3	18.6	-2.1	-3.1	14.7	22.0	-5.2	-7.3	19.9	27.2
10% OF	225 SEC.	2.28	1.7	0.5	12.0	19.8	-2.3	-8.6	12.5	20.3	-10.9	-7.8	23.4	31.2
FULL POWER	225 SEC.	2.28	1.7	0.5	12.0	19.8	-2.3	-3.1	12.5	20.3	-5.4	-7.8	17.9	25.7
STEP	40 SEC.	2.32	-9.3	-2.8	12.3	20.1	-2.3	-8.6	9.5	17.3	-10.9	-7.8	20.4	28.2
LOAD	40 SEC.	2.32	-9.3	-2.8	12.3	20.1	-2.3	-3.1	9.5	17.3	-5.4	-7.8	14.9	22.7
DECREASE	100 SEC.	2.26	-13.3	-4.1	11.9	19.6	-2.3	-8.6	7.8	15.5	-10.9	-7.7	18.7	26.4
10% OF	100 SEC.	2.26	-13.3	-4.1	11.9	19.6	-2.3	-3.1	7.8	15.5	-5.4	-7.7	13.2	20.9
FULL	260 SEC.	2.14	-1.3	-0.4	11.3	18.6	-2.1	-8.6	10.9	18.2	-10.7	-7.3	21.6	28.9
POWER	260 SEC.	2.14	-1.3	-0.4	11.3	18.6	-2.1	-3.1	10.9	18.2	-5.2	-7.3	16.1	23.4
LOSS OF FLOW	12 SEC.	2.25	33.3	10.2	11.9	19.5	-2.3	-8.6	22.1	29.7	-10.9	-7.6	33.0	40.6
		2.25	33.3	10.2	11.9	19.5	-2.3	-3.1	22.1	29.7	-5.4	-7.6	27.5	35.1
STEAM BREAK	54 SEC.	0.70	197	60.2	3.7	6.1	-0.7	-8.6	63.9	66.3	-9.3	-2.4	73.2	75.6
		0.70	197	60.2	3.7	6.1	-0.7	-3.1	63.9	66.3	-3.8	-2.4	67.7	70.1

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER 5-201-P | A311
SHEET 14 OF 21
CHARGE NO.
DATE 1-27-67 BY ALEXANDER
DESCRIPTION STRUCTURAL ANALYSIS OF CORE SUPPORT PADS
CHECK DATE 1-27-67 BY CAUDLE

A

5. DETAILED ANALYSIS

f.) STRESSES - I. UNCONCENTRATED

TRANSIENT	TIME	PRESS. (KSI)	$(T_m - T)$	THERM. STRESS $\sigma_x = \sigma_\theta$	PRESSURE STRESSES σ_x	PRESSURE STRESSES σ_θ	PRESSURE STRESSES σ_r	LOAD STRESS σ_r	TOTAL STRESSES σ_x	TOTAL STRESSES σ_θ	TOTAL STRESSES σ_r	STRESS INTENSITIES $\sigma_x - \sigma_\theta$	STRESS INTENSITIES $\sigma_x - \sigma_r$	STRESS INTENSITIES $\sigma_\theta - \sigma_r$
STEP LOAD	2 MIN.	2.37	-12.0	-3.7	12.5	20.6	-2.4	-8.6	8.8	16.9	-11.0	-8.1	19.8	27.9
REDUCTION	2 MIN.	2.37	-12.0	-3.7	12.5	20.6	-2.4	-3.1	8.8	16.9	-5.5	-8.1	14.3	22.4
FROM 100%	3.2 MIN.	2.35	-15.0	-4.6	12.4	20.4	-2.4	-8.6	7.8	15.8	-11.0	-8.0	18.8	26.8
TO 50%	3.2 MIN.	2.35	-15.0	-4.6	12.4	20.4	-2.4	-3.1	7.8	15.8	-5.5	8.0	13.3	21.3
FULL	104 MIN.	2.15	0	0	11.4	18.6	-2.2	-8.6	11.4	18.6	-10.8	-7.2	22.2	29.4
POWER	104 MIN.	2.15	0	0	11.4	18.6	-2.2	-3.1	11.4	18.6	-5.3	-7.2	16.7	23.9
REACTOR	10 SEC.	2.22	-9.5	-2.9	11.7	19.2	-2.2	-8.6	8.8	16.3	-10.8	-7.5	19.6	27.1
TRIP FROM	10 SEC.	2.22	-9.5	-2.9	11.7	19.2	-2.2	-3.1	8.8	16.3	-5.3	-7.5	14.1	21.6
FULL	65 SEC.	1.91	8.5	2.6	10.1	16.6	-1.9	-8.6	12.7	19.2	-10.5	-6.5	23.2	29.7
POWER	65 SEC.	1.91	8.5	2.6	10.1	16.6	-1.9	-3.1	12.7	19.2	-5.0	-6.5	17.7	24.2
PLANT HYDRO	220 MIN.	3.13	0	0	16.5	27.1	-3.1	-8.6	16.5	27.1	-11.7	-10.6	28.2	38.8
AT 3125 PSIA	220 MIN.	3.13	0	0	16.5	27.1	-3.1	-3.1	16.6	27.1	-6.2	-10.6	22.7	33.3
PLANT	~	2.50	-43	-13.1	13.2	21.7	-2.5	-8.6	0.1	8.6	-11.1	-8.5	11.2	19.7
HYDRO		2.50	-43	-13.1	13.2	21.7	-2.5	-3.1	0.1	8.6	-5.6	-8.5	5.7	14.2
AT	~	0.32	43	13.1	1.7	2.8	-0.3	-8.6	14.8	15.9	-8.9	-1.1	23.7	24.8
2500 PSIA		0.32	43	13.1	1.7	2.8	-0.3	-3.1	14.8	15.9	-3.4	-1.1	18.2	19.3
STEADY STATE	~	2.35	6.0	1.8	12.4	20.4	-2.4	-8.6	14.2	22.2	-11.0	-8.0	25.2	33.2
FLUCTUATIONS		2.35	6.0	1.8	12.4	20.4	-2.4	-3.1	14.2	22.2	-5.5	-8.0	19.7	27.7
OF PRESS.	~	2.15	-6.0	-1.8	11.4	18.6	-2.2	-8.6	9.6	16.8	-10.8	-7.2	20.4	27.6
AND TEMP.		2.15	-6.0	-1.8	11.4	18.6	-2.2	-3.1	9.6	16.8	-5.3	-7.2	14.9	22.1
	10 SEC.	2.76	-30.2	-9.2	14.6	23.9	-2.8	-8.6	5.4	14.7	-11.4	-9.3	16.8	26.1
LOSS	10 SEC.	2.76	-30.2	-9.2	14.6	23.9	-2.8	-3.1	5.4	14.7	-5.7	-9.3	11.3	20.6
OF	28 SEC.	2.12	-41.2	-12.6	11.2	18.4	-2.1	-8.6	-1.4	5.8	-10.7	-7.2	9.3	16.5
LOAD	28 SEC.	2.12	-41.2	-12.6	11.2	18.4	-2.1	-3.1	-1.4	5.8	-5.6	-7.2	3.8	11.0
	160 SEC.	1.44	4.8	1.5	7.6	12.5	-1.4	-8.6	9.1	14.0	-10.0	-4.9	19.1	24.0
	160 SEC.	1.44	4.8	1.5	7.6	12.5	-1.4	-3.1	9.1	14.0	-4.5	-4.9	13.6	18.5

$S.I._{MAX.\ RANGE} = \sigma_\theta - \sigma_r = 38.8\ KSI < 3S_m = 80\ KSI$ (CRITERION 5-C-2)

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO.

NUMBER S-201-P | A 312
SHEET 15 OF 31
DATE 1-27-67 BY ALEXANDER
CHECK DATE 1-27-67 BY CAUDLE

DESCRIPTION STRUCTURAL ANALYSIS OF CORE SUPPORT PADS

5. DETAILED ANALYSIS

A) STRESSES - 1. UNCONCENTRATED

SUMMARY OF STRESSES AND STRESS INTENSITIES AT LOCATION B

TRANSIENT	TIME	PRESS (KSI)	$(T_m - T)$	THERM. STRESS $\sigma_x = \sigma_\theta$	PRESSURE STRESSES σ_x	PRESSURE STRESSES σ_θ	PRESSURE STRESSES σ_r	LOAD STRESS σ_r	TOTAL STRESSES σ_x	TOTAL STRESSES σ_θ	TOTAL STRESSES σ_r	STRESS INTENSITIES $\sigma_x - \sigma_\theta$	STRESS INTENSITIES $\sigma_x - \sigma_r$	STRESS INTENSITIES $\sigma_\theta - \sigma_r$
STEADY STATE	~	2.25	0	0	21.1	19.1	-2.3	3.1	21.1	19.1	0.8	2.0	20.3	18.3
HEAT-UP	4.47 HRS.	2.25	-43	-13.1	21.1	19.1	-2.3	8.6	8.0	6.0	6.3	2.0	1.7	-0.3
		2.25	-43	-13.1	21.1	19.1	-2.3	3.1	8.0	6.0	0.8	2.0	7.2	5.2
COOLDOWN	4.47 HRS.	0.32	43	13.1	3.0	2.7	-0.3	8.6	16.1	15.8	8.3	0.3	7.8	7.5
		0.32	43	13.1	3.0	2.7	-0.3	3.1	16.1	15.8	2.8	0.3	13.3	13.0
PLANT LOADING	20 MIN.	2.25	-7.8	-2.4	21.1	19.1	-2.3	8.6	18.7	16.7	6.3	2.0	12.4	10.4
		2.25	-7.8	-2.4	21.1	19.1	-2.3	3.1	18.7	16.7	0.8	2.0	17.9	15.9
PLANT UNLOADING	20 MIN.	2.25	7.8	2.4	21.1	19.1	-2.3	8.6	23.5	21.5	6.3	2.0	17.2	15.2
		2.25	7.8	2.4	21.1	19.1	-2.3	3.1	23.5	21.5	0.8	2.0	22.7	20.7
STEP LOAD	100 SEC.	2.14	11.2	3.4	20.0	18.2	-2.1	8.6	23.4	21.6	6.5	1.8	16.9	15.1
INCREASE	100 SEC.	2.14	11.2	3.4	20.0	18.2	-2.1	3.1	23.4	21.6	1.0	1.8	22.4	20.6
10% OF	225 SEC.	2.28	1.7	0.5	21.3	19.4	-2.3	8.6	21.8	19.9	6.3	1.9	15.5	13.6
FULL POWER	225 SEC.	2.28	1.7	0.5	21.3	19.4	-2.3	3.1	21.8	19.9	0.8	1.9	21.0	19.1
STEP	40 SEC.	2.32	-9.3	-2.8	21.7	19.7	-2.3	8.6	18.9	16.9	6.3	2.0	12.6	10.6
LOAD	40 SEC.	2.32	-9.3	-2.8	21.7	19.7	-2.3	3.1	18.9	16.9	0.8	2.0	18.1	16.1
DECREASE	100 SEC.	2.26	-13.3	-4.1	21.1	19.2	-2.3	8.6	17.0	15.1	6.3	1.9	10.7	8.8
10% OF	100 SEC.	2.26	-13.3	-4.1	21.1	19.2	-2.3	3.1	17.0	15.1	0.8	1.9	16.2	14.3
FULL	260 SEC.	2.14	-1.3	-0.4	20.0	18.2	-2.1	8.6	19.6	17.8	6.5	1.8	13.1	11.3
POWER	260 SEC.	2.14	-1.3	-0.4	20.0	18.2	-2.1	3.1	19.6	17.8	1.0	1.8	18.6	16.8
LOSS OF FLOW	12 SEC.	2.25	33.3	10.2	21.1	19.1	-2.3	8.6	31.3	29.3	6.3	2.0	25.0	23.0
		2.25	33.3	10.2	21.1	19.1	-2.3	3.1	31.3	29.3	0.8	2.0	30.5	28.5
STEAM BREAK	54 SEC.	0.70	197	60.2	6.6	5.9	-0.7	8.6	66.8	66.1	7.9	0.7	58.9	58.2
		0.70	197	60.2	6.6	5.9	-0.7	3.1	66.8	66.1	2.4	0.7	64.4	63.7

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO.

DESCRIPTION: STRUCTURAL ANALYSIS OF CORE SUPPORT PADS

NUMBER: S-201-P | A-313
SHEET: 16 OF 31
DATE: 1-27-67 BY: ALEXANDER
CHECK DATE: 1-27-67 BY: CAUDLE

5. DETAILED ANALYSIS
f.) STRESSES -1. UNCONCENTRATED

TRANSIENT	TIME	PRESS. (KSI)	$(T_m - T)$	THERM. STRESS $\sigma_x = \sigma_\theta$	PRESSURE STRESSES σ_x	PRESSURE STRESSES σ_θ	PRESSURE STRESSES σ_r	LOAD STRESS σ_r	TOTAL STRESSES σ_x	TOTAL STRESSES σ_θ	TOTAL STRESSES σ_r	STRESS INTENSITIES $\sigma_x - \sigma_\theta$	STRESS INTENSITIES $\sigma_x - \sigma_r$	STRESS INTENSITIES $\sigma_\theta - \sigma_r$
STEP LOAD	2 MIN.	2.37	-12.0	-3.7	22.2	20.1	-2.4	8.6	18.5	16.4	6.2	2.1	12.3	10.2
REDUCTION	2 MIN.	2.37	-12.0	-3.7	22.2	20.1	-2.4	3.1	18.5	16.4	0.7	2.1	17.8	15.7
FROM 100%	3.2 MIN.	2.35	-15.0	-4.6	22.0	20.0	-2.4	8.6	17.4	15.4	6.2	2.0	11.2	9.2
TO 50%	3.2 MIN.	2.35	-15.0	-4.6	22.0	20.0	-2.4	3.1	17.4	15.4	0.7	2.0	16.7	14.7
FULL	10.4 MIN.	2.15	0	0	20.1	18.3	-2.2	8.6	20.1	18.3	6.4	1.8	13.7	11.9
POWER	10.4 MIN.	2.15	0	0	20.1	18.3	-2.2	3.1	20.1	18.3	0.9	1.8	19.2	17.4
REACTOR	10 SEC.	2.22	-9.5	-2.9	20.8	18.8	-2.2	8.6	17.9	15.9	6.4	2.0	11.5	9.5
TRIP FROM	10 SEC.	2.22	-9.5	-2.9	20.8	18.8	-2.2	3.1	17.9	15.9	0.9	2.0	17.0	15.0
FULL	65 SEC.	1.91	8.5	2.6	17.9	16.2	-1.9	8.6	20.5	18.8	6.7	1.7	13.8	12.1
POWER	65 SEC.	1.91	8.5	2.6	17.9	16.2	-1.9	3.1	20.5	18.8	1.2	1.7	19.3	17.6
PLANT HYDRO	220 MIN.	3.13	0	0	29.3	26.6	-3.1	8.6	29.3	26.6	5.5	2.7	23.8	21.1
AT 3125 PSIA	220 MIN.	3.13	0	0	29.3	26.6	-3.1	3.1	29.3	26.6	0	2.7	29.3	26.6
PLANT	~	2.50	-43	-13.1	23.4	21.2	-2.5	8.6	10.3	8.1	6.1	2.2	4.2	2.0
HYDRO		2.50	-43	-13.1	23.4	21.2	-2.5	3.1	10.3	8.1	0.6	2.2	9.7	7.5
AT	~	0.32	43	13.1	3.0	2.7	-0.3	8.6	16.1	15.8	8.3	0.3	7.8	7.5
2500 PSIA		0.32	43	13.1	3.0	2.7	-0.3	3.1	16.1	15.8	2.8	0.3	13.3	13.0
STEADY STATE	~	2.35	6.0	1.8	22.0	20.0	-2.4	8.6	23.8	21.8	6.2	2.0	17.6	15.6
FLUCTUATIONS		2.35	6.0	1.8	22.0	20.0	-2.4	3.1	23.8	21.8	0.7	2.0	23.1	21.1
OF PRESS.	~	2.15	-6.0	-1.8	20.1	18.3	-2.2	8.6	18.3	16.5	6.4	1.8	11.9	10.1
AND TEMP.		2.15	-6.0	-1.8	20.1	18.3	-2.2	3.1	18.3	16.5	0.9	1.8	17.4	15.6
	10 SEC.	2.76	-30.2	-9.2	25.8	23.4	-2.8	8.6	16.6	14.2	5.8	2.4	10.8	8.4
LOSS	10 SEC.	2.76	-30.2	-9.2	25.8	23.4	-2.8	3.1	16.6	14.2	0.3	2.4	16.3	13.9
OF	28 SEC.	2.12	-41.2	-12.6	19.8	18.0	-2.1	8.6	7.2	5.4	6.5	1.8	0.7	-1.1
LOAD	28 SEC.	2.12	-41.2	-12.6	19.8	18.0	-2.1	3.1	7.2	5.4	1.0	1.8	6.2	4.4
	160 SEC.	1.44	4.8	1.5	13.5	12.2	-1.4	8.6	15.0	13.7	7.2	1.3	7.8	6.5
	160 SEC.	1.44	4.8	1.5	13.5	12.2	-1.4	3.1	15.0	13.7	.7	1.3	13.3	12.0

$S.I._{MAX.RANGE} = \sigma_x - \sigma_r = 29.3 \text{ KSI} < 3S_m = 80 \text{ KSI}$ CRITERION 5-C-2

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER 5-201-P | A 314
SHEET 17 OF 31
CHARGE NO.
DATE 1-27-67 BY ALEXANDER
DESCRIPTION STRUCTURAL ANALYSIS OF CORE SUPPORT PADS
CHECK DATE 1-27-67 BY CAUDLE

5. DETAILED ANALYSIS

f.) STRESSES - I. UNCONCENTRATED

SUMMARY OF STRESSES AND STRESS INTENSITIES AT LOCATION C

TRANSIENT	TIME	PRESS.	$(T_m - T)$	THERM. STRESS $\sigma_x = \sigma_r$	PRESS. STRESS $\sigma_x = \sigma_\theta = \sigma_r$	LOAD STRESS σ_r	TOTAL STRESSES σ_x	TOTAL STRESSES σ_θ	TOTAL STRESSES σ_r	STRESS INTENSITIES $\sigma_x - \sigma_\theta$	STRESS INTENSITIES $\sigma_x - \sigma_r$	STRESS INTENSITIES $\sigma_\theta - \sigma_r$
STEADY STATE	~	2.25	0	0	-2.3	-5.3	-2.3	-2.3	-7.6	0	5.3	5.3
HEAT-UP	4.47 HRS.	2.25	-43	-15.6	-2.3	-14.9	-17.9	-2.3	-32.3	-15.6	14.9	30.5
		2.25	-43	-15.6	-2.3	-5.3	-17.9	-2.3	-23.2	-15.6	5.3	20.9
COOL-DOWN	4.47 HRS.	0.32	43	15.6	-0.3	-14.9	15.3	-0.3	0.4	15.6	14.9	-0.7
		0.32	43	15.6	-0.3	-5.3	15.3	-0.3	10.0	15.6	5.3	-10.3
PLANT LOADING	20 MIN.	2.25	-7.8	-2.8	-2.3	-14.9	-5.1	-2.3	-20.0	-2.8	14.9	17.7
		2.25	-7.8	-2.8	-2.3	-5.3	-5.1	-2.3	-10.4	-2.8	5.3	8.1
PLANT UNLOADING	20 MIN.	2.25	7.8	2.8	-2.3	-14.9	0.5	-2.3	-14.4	2.8	14.9	12.1
		2.25	7.8	2.8	-2.3	-5.3	0.5	-2.3	-4.8	2.8	5.3	2.5
STEP LOAD INCREASE	100 SEC.	2.14	11.2	4.1	-2.1	-14.9	2.0	-2.1	-12.9	4.1	14.9	10.8
	100 SEC.	2.14	11.2	4.1	-2.1	-5.3	2.0	-2.1	-3.3	4.1	5.3	1.2
10% OF FULL POWER	225 SEC.	2.28	1.7	0.6	-2.3	-14.9	-1.7	-2.3	-16.6	0.6	14.9	14.3
	225 SEC.	2.28	1.7	0.6	-2.3	-5.3	-1.7	-2.3	-7.0	0.6	5.3	4.7
STEP LOAD DECREASE 10% OF FULL POWER	40 SEC.	2.32	-9.3	-3.4	-2.3	-14.9	-5.7	-2.3	-20.6	-3.4	14.9	18.3
	40 SEC.	2.32	-9.3	-3.4	-2.3	-5.3	-5.7	-2.3	-11.0	-3.4	5.3	8.7
	100 SEC.	2.26	-13.3	-4.8	-2.3	-14.9	-7.1	-2.3	-22.0	-4.8	14.9	19.7
	100 SEC.	2.26	-13.3	-4.8	-2.3	-5.3	-7.1	-2.3	-12.4	-4.8	5.3	10.1
	260 SEC.	2.14	-1.3	-0.5	-2.1	-14.9	-2.6	-2.1	-17.5	-0.5	14.9	15.4
	260 SEC.	2.14	-1.3	-0.5	-2.1	-5.3	-2.6	-2.1	-7.9	-0.5	5.3	5.8
LOSS OF FLOW	12 SEC.	2.25	33.3	12.1	-2.3	-14.9	9.8	-2.3	-5.1	12.1	14.9	2.8
		2.25	33.3	12.1	-2.3	-5.3	9.8	-2.3	4.5	12.1	5.3	-6.8
STEAM BREAK	54 SEC.	0.70	197	71.5	-0.7	-14.9	70.8	-0.7	55.9	71.5	14.9	-56.6
		0.70	197	71.5	-0.7	-5.3	70.8	-0.7	65.5	71.5	5.3	-66.2

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO. ________

DESCRIPTION: STRUCTURAL ANALYSIS OF CORE SUPPORT PADS

NUMBER: S-201-P | A 315
SHEET: 18 OF 31
DATE: 1-27-67 BY: ALEXANDER
CHECK DATE: 1-27-67 BY: CAUDLE

5. DETAILED ANALYSIS

f) STRESSES - 1. UNCONCENTRATED

TRANSIENT	TIME	PRESS.	$(T_m - T)$	THERM. STRESS	PRESS. STRESS	LOAD STRESS	TOTAL STRESSES			STRESS INTENSITIES		
				$\sigma_x = \sigma_r$	$\sigma_x = \sigma_\theta = \sigma_r$	σ_r	σ_x	σ_θ	σ_r	$\sigma_x - \sigma_\theta$	$\sigma_x - \sigma_r$	$\sigma_\theta - \sigma_r$
STEP LOAD	2 MIN.	2.37	-12.0	-4.4	-2.4	-14.9	-6.8	-2.4	-21.7	-4.4	14.9	19.3
REDUCTION	2 MIN.	2.37	-12.0	-4.4	-2.4	-5.3	-6.8	-2.4	-12.1	-4.4	5.3	9.7
FROM 100%	32 MIN.	2.35	-15.0	-5.4	-2.4	-14.9	-7.8	-2.4	-22.7	-5.4	14.9	20.3
TO 50%	32 MIN.	2.35	-15.0	-5.4	-2.4	-5.3	-7.8	-2.4	-13.1	-5.4	5.3	10.7
FULL	104 MIN.	2.15	0	0	-2.2	-14.9	-2.2	-2.2	-17.1	0	14.9	14.9
POWER	104 MIN.	2.15	0	0	-2.2	-5.3	-2.2	-2.2	-7.5	0	5.3	5.3
REACTOR	10 SEC.	2.22	-9.5	-3.4	-2.2	-14.9	-5.6	-2.2	-20.5	-3.4	14.9	18.3
TRIP	10 SEC.	2.22	-9.5	-3.4	-2.2	-5.3	-5.6	-2.2	-10.9	-3.4	5.3	8.7
FROM FULL	65 SEC.	1.91	8.5	3.1	-1.9	-14.9	1.2	-1.9	-13.7	3.1	14.9	11.8
POWER	65 SEC.	1.91	8.5	3.1	-1.9	-5.3	1.2	-1.9	-4.1	3.1	5.3	2.2
PLANT HYDRO	220 MIN.	3.13	0	0	-3.1	-14.9	-3.1	-3.1	-18.0	0	14.9	14.9
AT 3125 PSIA	220 MIN.	3.13	0	0	-3.1	-5.3	-3.1	-3.1	-8.4	0	5.3	5.3
PLANT	~	2.50	-43	-15.6	-2.5	-14.9	-18.1	-2.5	-33.0	-15.6	14.9	30.5
HYDRO	~	2.50	-43	-15.6	-2.5	-5.3	-18.1	-2.5	-23.4	-15.6	5.3	20.9
AT	~	0.32	43	15.6	-0.3	-14.9	15.3	-0.3	0.4	15.6	14.9	-0.7
2500 PSIA		0.32	43	15.6	-0.3	-5.3	15.3	-0.3	10.0	15.6	5.3	-10.3
STEADY STATE		2.35	6.0	2.2	-2.4	-14.9	-0.2	-2.4	-15.1	2.2	14.9	12.7
FLUCTUATIONS	~	2.35	6.0	2.2	-2.4	-5.3	-0.2	-2.4	-5.5	2.2	5.3	3.1
OF PRESS.	~	2.15	-6.0	-2.2	-2.2	-14.9	-4.4	-2.2	-19.3	-2.2	14.9	17.1
AND TEMP.		2.15	-6.0	-2.2	-2.2	-5.3	-4.4	-2.2	-9.7	-2.2	5.3	7.5
	10 SEC.	2.76	-30.2	-11.0	-2.8	-14.9	-13.8	-2.8	-28.7	-11.0	14.9	25.9
LOSS	10 SEC.	2.76	-30.2	-11.0	-2.8	-5.3	-13.8	-2.8	-19.1	-11.0	5.3	16.3
OF	28 SEC.	2.12	-41.2	-14.9	-2.1	-14.9	-17.0	-2.1	-31.9	-14.9	14.9	29.8
LOAD	28 SEC.	2.12	-41.2	-14.9	-2.1	-5.3	-17.0	-2.1	-22.3	-14.9	5.3	20.2
	160 SEC.	1.44	4.8	1.7	-1.4	-14.9	0.3	-1.4	-14.6	1.7	14.9	13.2
	160 SEC.	1.44	4.8	1.7	-1.4	-5.3	0.3	-1.4	-5.0	1.7	5.3	3.6

$S.I._{MAX.\ RANGE} = \sigma_\theta - \sigma_r = 40.8\ KSI < 3S_m = 69.9\ KSI$ (CRITERION 5-C.2)

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO.

DESCRIPTION: STRUCTURAL ANALYSIS OF CORE SUPPORT PADS

NUMBER 5-201-P | A316
SHEET 19 OF 31
DATE 1-27-67 BY ALEXANDER
CHECK DATE 1-27-67 BY CAUDLE

5. DETAILED ANALYSIS

f) STRESSES - UNCONCENTRATED

SUMMARY OF STRESSES AND STRESS INTENSITIES AT LOCATION D

TRANSIENT	TIME	PRESS.	$(T_m - T)$	THERM. STRESS $\sigma_x = \sigma_r$	PRESS. STRESS $\sigma_x = \sigma_\theta = \sigma_r$	LOAD STRESS σ_r	TOTAL STRESSES σ_x	σ_θ	σ_r	STRESS INTENSITIES $\sigma_x - \sigma_\theta$	$\sigma_x - \sigma_r$	$\sigma_\theta - \sigma_r$
STEADY STATE	~	2.25	0	0	-2.3	5.3	-2.3	-2.3	3.0	0	-5.3	-5.3
HEAT-UP	4.47 HRS.	2.25	-43	-15.6	-2.3	14.9	-17.9	-2.3	-3.0	-15.6	-14.9	0.7
		2.25	-43	-15.6	-2.3	5.3	-17.9	-2.3	-12.6	-15.6	-5.3	10.3
COOL-DOWN	4.47 HRS.	0.32	43	15.6	-0.3	14.9	15.3	-0.3	30.2	15.6	-14.9	-30.5
		0.32	43	15.6	-0.3	5.3	15.3	-0.3	20.6	15.6	-5.3	-20.9
PLANT LOADING	20 MIN.	2.25	-7.8	-2.8	-2.3	14.9	-5.1	-2.3	9.8	-2.8	-14.9	-12.1
		2.25	-7.8	-2.8	-2.3	5.3	-5.1	-2.3	0.2	-2.8	-5.3	-2.5
PLANT UNLOADING	20 MIN.	2.25	7.8	2.8	-2.3	14.9	0.5	-2.3	15.4	2.8	-14.9	-17.7
		2.25	7.8	2.8	-2.3	5.3	0.5	-2.3	5.8	2.8	-5.3	-8.1
STEP LOAD INCREASE 10% OF FULL POWER	100 SEC.	2.14	11.2	4.1	-2.1	14.9	2.0	-2.1	16.9	4.1	-14.9	-19.0
	100 SEC.	2.14	11.2	4.1	-2.1	5.3	2.0	-2.1	7.3	4.1	-5.3	-9.4
	225 SEC.	2.28	1.7	0.6	-2.3	14.9	-1.7	-2.3	13.2	0.6	-14.9	-15.5
	225 SEC.	2.28	1.7	0.6	-2.3	5.3	-1.7	-2.3	3.6	0.6	-5.3	-5.9
STEP LOAD DECREASE 10% OF FULL POWER	40 SEC.	2.32	-9.3	-3.4	-2.3	14.9	-5.7	-2.3	9.2	-3.4	-14.9	-11.5
	40 SEC.	2.32	-9.3	-3.4	-2.3	5.3	-5.7	-2.3	-0.4	-3.4	-5.3	-1.9
	100 SEC.	2.26	-13.3	-4.8	-2.3	14.9	-7.1	-2.3	7.8	-4.8	-14.9	-10.1
	100 SEC.	2.26	-13.3	-4.8	-2.3	5.3	-7.1	-2.3	-1.8	-4.8	-5.3	-0.5
	260 SEC.	2.14	-1.3	-0.5	-2.1	14.9	-2.6	-2.1	12.3	-0.5	-14.9	-14.4
	260 SEC.	2.14	-1.3	-0.5	-2.1	5.3	-2.6	-2.1	2.7	-0.5	-5.3	-4.8
LOSS OF FLOW	12 SEC.	2.25	33.3	12.1	-2.3	14.9	9.8	-2.3	24.7	12.1	-14.9	-27.0
		2.25	33.3	12.1	-2.3	5.3	9.8	-2.3	15.1	12.1	-5.3	-17.4
STEAM BREAK	54 SEC.	0.70	197	71.5	-0.7	14.9	70.8	-0.7	35.7	71.5	-14.9	-36.4
		0.70	197	71.5	-0.7	5.3	70.8	-0.7	76.1	71.5	-5.3	-76.8

DESCRIPTION STRUCTURAL ANALYSIS OF CORE SUPPORT PADS

5. DETAILED ANALYSIS

f) STRESSES - 1. UNCONCENTRATED

TRANSIENT	TIME	PRESS.	$(T_m - T)$	THERM. STRESS $\sigma_x = \sigma_r$	PRESS. STRESS $\sigma_x = \sigma_\theta = \sigma_r$	LOAD STRESS σ_r	TOTAL STRESSES σ_x	TOTAL STRESSES σ_θ	TOTAL STRESSES σ_r	STRESS INTENSITIES $\sigma_x - \sigma_\theta$	STRESS INTENSITIES $\sigma_x - \sigma_r$	STRESS INTENSITIES $\sigma_\theta - \sigma_r$
STEP LOAD	2 MIN.	2.37	-12.0	-4.4	-2.4	14.9	-6.8	-2.4	8.1	-4.4	-14.9	-10.5
REDUCTION	2 MIN.	2.37	-12.0	-4.4	-2.4	5.3	-6.8	-2.4	-1.5	-4.4	-5.3	-0.9
FROM 100%	32 MIN.	2.35	-15.0	-5.4	-2.4	14.9	-7.8	-2.4	7.1	-5.4	-14.9	-9.5
TO 50%	32 MIN.	2.35	-15.0	-5.4	-2.4	5.3	-7.8	-2.4	-2.5	-5.4	-5.3	0.1
FULL	10.4 MIN.	2.15	0	0	-2.2	14.9	-2.2	-2.2	12.7	0	-14.9	-14.9
POWER	10.4 MIN.	2.15	0	0	-2.2	5.3	-2.2	-2.2	3.1	0	-5.3	-5.3
REACTOR	10 SEC.	2.22	-9.5	-3.4	-2.2	14.9	-5.6	-2.2	9.3	-3.4	-14.9	-11.5
TRIP	10 SEC.	2.22	-9.5	-3.4	-2.2	5.3	-5.6	-2.2	-0.3	-3.4	-5.3	-1.9
FROM FULL	65 SEC.	1.91	8.5	3.1	-1.9	14.9	1.2	-1.9	16.1	3.1	-14.9	-18.0
POWER	65 SEC.	1.91	8.5	3.1	-1.9	5.3	1.2	-1.9	6.5	3.1	-5.3	-8.4
PLANT HYDRO	220 MIN.	3.13	0	0	-3.1	14.9	-3.1	-3.1	11.8	0	-14.9	-14.9
AT 3125 PSIA	220 MIN.	3.13	0	0	-3.1	5.3	-3.1	-3.1	2.2	0	-5.3	-5.3
PLANT	~	2.50	-43	-15.6	-2.5	14.9	-18.1	-2.5	-3.2	-15.6	-14.9	0.7
HYDRO	~	2.50	-43	-15.6	-2.5	5.3	-18.1	-2.5	-12.8	-15.6	-5.3	-15.3
AT		0.32	43	15.6	-0.3	14.9	15.3	-0.3	30.2	15.6	-14.9	-30.5
2500 PSIA.		0.32	43	15.6	-0.3	5.3	15.3	-0.3	20.6	15.6	-5.3	-20.9
STEADY STATE	~	2.35	6.0	2.2	-2.4	14.9	-0.2	-2.4	14.7	2.2	-14.9	-17.1
FLUCTUATIONS		2.35	6.0	2.2	-2.4	5.3	-0.2	-2.4	5.1	2.2	-5.3	-7.5
OF PRESS.	~	2.15	-6.0	-2.2	-2.2	14.9	-4.4	-2.2	10.5	-2.2	-14.9	-12.7
AND TEMP.		2.16	-6.0	-2.2	-2.2	5.3	-4.4	-2.2	0.9	-2.2	-5.3	-3.1
	10 SEC.	2.76	-30.2	-11.0	-2.8	14.9	-13.8	-2.8	1.1	-11.0	-14.9	-3.9
LOSS	10 SEC.	2.76	-30.2	-11.0	-2.8	5.3	-13.8	-2.8	-8.5	-11.0	-5.3	5.7
OF	28 SEC.	2.12	-41.2	-14.9	-2.1	14.9	-17.0	-2.1	-2.1	-14.9	-14.9	0
LOAD	28 SEC.	2.12	-41.2	-14.9	-2.1	5.3	-17.0	-2.1	-11.7	-14.9	-5.3	9.6
	160 SEC.	1.44	4.8	1.7	-1.4	14.9	0.3	-1.4	15.2	1.7	-14.9	-16.6
	160 SEC.	1.44	4.8	1.7	-1.4	5.3	0.3	-1.4	5.6	1.7	-5.3	-7.0

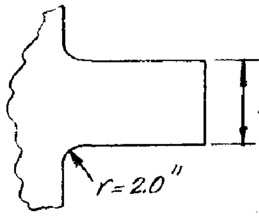
$S.I._{MAX.\ RANGE} = \sigma_\theta - \sigma_r = 40.8\ KSI < 3S_m = 69.9\ KSI$ CRITERION 5-C-2

5. DETAILED ANALYSIS

f.) STRESSES

2. CONCENTRATED

IN ORDER TO PERFORM THE FATIGUE EVALUATION, PEAK STRESSES MUST BE KNOWN AT POINTS "A", "B", "C" AND "D" (SEE PAGE 11). THE STRESS EXPRESSIONS GIVEN ON SHEETS 12 & 13 WILL BE MODIFIED TO ACCOUNT FOR STRESS CONCENTRATIONS. STRESS CONCENTRATION FACTORS FOR BENDING AND TENSION WILL BE DETERMINED BY THE METHOD PRESENTED IN REF. 2.



$\frac{r}{t} = \frac{2}{4} = 0.50$

FROM FIG. A.7-1 OF REF. 6

K_T = STRESS CONC. FACTOR FOR TENSILE STRESSES = 1.80

K_B = " " " " BENDING " = 1.50

APPLYING THE APPROPRIATE S.C.F. TO THE STRESS EXPRESSIONS PREVIOUSLY DERIVED YIELDS:

FOR THERMAL STRESSES -

POINTS "A" AND "B"

$$\sigma_x = \sigma_\theta = K_T \frac{E\alpha}{1-\nu}(T_M - T) = 0.55028\,(T_M - T)$$

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO. ______

DESCRIPTION STRUCTURAL ANALYSIS OF CORE SUPPORT PADS

NUMBER 5-201-P Δ319
SHEET 22 OF 31
DATE 1-27-67 BY ALEXANDER
CHECK DATE 1-27-67 BY CAUDLE

5. DETAILED ANALYSIS

f.) STRESSES

2. CONCENTRATED

POINTS "C" AND "D"

$\sigma_x = \sigma_r = K_T \frac{E\alpha}{1-\nu}(T_M - T) = 0.65313\ (T_m - T)$

FOR PRESSURE STRESSES -

POINT "A"

$\sigma_x = K_T\ 5.285\ P = 9.513\ P$

$\sigma_\theta = K_T\ 8.671\ P = 15.608\ P$

$\sigma_r = -K_T P = -1.80\ P$

POINT "B"

$\sigma_x = K_T\ 9.358\ P = 16.844\ P$

$\sigma_\theta = K_T\ 8.490\ P = 15.282\ P$

$\sigma_r = -K_T P = -1.80\ P$

POINTS "C" AND "D"

$\sigma_x = \sigma_\theta = \sigma_r = -K_T P = -1.80\ P$

FOR STRESSES DUE TO APPLIED LOADS -

POINT "A"

$\sigma_r = -K_B \frac{Mc}{I_{YY'}} = K_B \begin{pmatrix} -8.6\ KSI \\ -3.1\ KSI \end{pmatrix} = \begin{matrix} -12.9\ KSI \\ -4.7\ KSI \end{matrix}$

POINT "B"

$\sigma_r = K_B \begin{pmatrix} 8.6\ KSI \\ 3.1\ KSI \end{pmatrix} = \begin{matrix} 12.9\ KSI \\ 4.7\ KSI \end{matrix}$

POINT "C"

$\sigma_r = -K_B \frac{Mc}{I_{YY'}} = K_B \begin{pmatrix} -14.9 \\ -5.3 \end{pmatrix} = \begin{matrix} -22.4\ KSI \\ -8.0\ KSI \end{matrix}$

POINT "D" $\sigma_r = K_B \begin{pmatrix} 14.9 \\ 5.3 \end{pmatrix} = \begin{matrix} 22.4\ KSI \\ 8.0\ KSI \end{matrix}$

NOTE: DUE TO THE SYMMETRY OF POINTS C AND D ONLY POINT C WILL BE GIVEN IN THE FOLLOWING TABLES AND FATIGUE CURVES.

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO. ______

DESCRIPTION STRUCTURAL ANALYSIS OF CORE SUPPORT PADS

NUMBER 5-201-P | A 220
SHEET 23 OF 31
DATE 1-27-67 BY ALEXANDER
CHECK DATE 1-27-67 BY [illegible]

5. DETAILED ANALYSIS
f) STRESSES - 2. CONCENTRATED

SUMMARY OF STRESSES AND STRESS INTENSITIES AT LOCATION A

TRANSIENT	TIME	PRESS (KSI)	$(T_m - T)$	THERM. STRESS $\sigma_x = \sigma_\theta$	PRESSURE STRESSES σ_x	PRESSURE STRESSES σ_θ	PRESSURE STRESSES σ_r	LOAD STRESS σ_r	TOTAL STRESSES σ_x	TOTAL STRESSES σ_θ	TOTAL STRESSES σ_r	STRESS INTENSITIES $\sigma_x - \sigma_\theta$	STRESS INTENSITIES $\sigma_x - \sigma_r$	STRESS INTENSITIES $\sigma_\theta - \sigma_r$
STEADY STATE	~	2.25	0	0	21.4	35.1	-4.1	-4.7	21.4	35.1	-8.8	-13.7	30.2	43.9
HEAT-UP	4.47 HRS.	2.25	-43	-23.7	21.4	35.1	-4.1	-12.9	-2.3	11.4	-17.0	-13.7	14.7	28.4
		2.25	-43	-23.7	21.4	35.1	-4.1	-4.7	-2.3	11.4	-8.8	-13.7	6.5	20.2
COOLDOWN	4.47 HRS.	0.32	43	23.7	3.0	5.0	-0.6	-12.9	26.7	28.7	-13.5	-2.0	40.2	42.2
		0.32	43	23.7	3.0	5.0	-0.6	-4.7	26.7	28.7	-5.3	-2.0	32.0	34.0
PLANT LOADING	20 MIN.	2.25	-7.8	-4.3	21.4	35.1	-4.1	-12.9	17.1	30.8	-17.0	-13.7	34.1	47.8
		2.25	-7.8	-4.3	21.4	35.1	-4.1	-4.7	17.1	30.8	-8.8	-13.7	25.9	39.6
PLANT UNLOADING	20 MIN.	2.25	7.8	4.3	21.4	35.1	-4.1	-12.9	25.7	39.4	-17.0	-13.7	42.7	56.4
		2.25	7.8	4.3	21.4	35.1	-4.1	-4.7	25.7	39.4	-8.8	-13.7	34.5	48.2
STEP LOAD INCREASE 10% OF FULL POWER	100 SEC.	2.14	11.2	6.2	20.4	33.4	-3.9	-12.9	26.6	39.6	-16.8	-13.0	43.4	56.4
	100 SEC.	2.14	11.2	6.2	20.4	33.4	-3.9	-4.7	26.6	39.6	-8.6	-13.0	35.2	48.2
	225 SEC.	2.28	1.7	0.9	21.7	35.6	-4.1	-12.9	22.6	36.5	-17.0	-13.9	39.6	53.5
	225 SEC.	2.28	1.7	0.9	21.7	35.6	-4.1	-4.7	22.6	36.5	-8.8	-13.9	31.4	45.3
STEP LOAD DECREASE 10% OF FULL POWER	40 SEC.	2.32	-9.3	-5.1	22.1	36.2	-4.2	-12.9	17.0	31.1	-17.1	-14.1	34.1	48.2
	40 SEC.	2.32	-9.3	-5.1	22.1	36.2	-4.2	-4.7	17.0	31.1	-8.9	-14.1	25.9	40.0
	100 SEC.	2.26	-13.3	-7.3	21.5	35.3	-4.1	-12.9	14.2	28.0	-17.0	-13.8	31.2	45.0
	100 SEC.	2.26	-13.3	-7.3	21.5	35.3	-4.1	-4.7	14.2	28.0	-8.8	-13.8	23.0	36.8
	260 SEC.	2.14	-1.3	-0.7	20.4	33.4	-3.9	-12.9	19.7	32.7	-16.8	-13.0	36.5	49.5
	260 SEC.	2.14	-1.3	-0.7	20.4	33.4	-3.9	-4.7	19.7	32.7	-8.6	-13.0	28.3	41.3
LOSS OF FLOW	12.5 SEC.	2.25	33.3	18.3	21.4	35.1	-4.1	-12.9	39.7	53.4	-17.0	-13.7	56.7	70.4
		2.25	33.3	18.3	21.4	35.1	-4.1	-4.7	39.7	53.4	-8.8	-13.7	48.5	62.2
STEAM BREAK	54 SEC.	0.70	197	108.4	6.7	10.9	-1.3	-12.9	115.1	119.3	-14.2	-4.2	129.3	133.5
		0.70	197	108.4	6.7	10.9	-1.3	-4.7	115.1	119.3	-6.0	-4.2	121.1	125.3

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO. ______

DESCRIPTION: STRUCTURAL ANALYSIS OF CORE SUPPORT PADS

NUMBER: S-201-P | A 321
SHEET: 24 OF 31
DATE: 1-27-67 BY: ALEXANDER
CHECK DATE: 1-27-67 BY: [illegible]

5. DETAILED ANALYSIS
f.) STRESSES -2. CONCENTRATED

TRANSIENT	TIME	PRESS. (KSI)	$(T_m - T)$	THERM. STRESS $\sigma_x = \sigma_\theta$	PRESSURE STRESSES σ_x	σ_θ	σ_r	LOAD STRESS σ_r	TOTAL STRESSES σ_x	σ_θ	σ_r	STRESS INTENSITIES $\sigma_x - \sigma_\theta$	$\sigma_x - \sigma_r$	$\sigma_\theta - \sigma_r$
STEP LOAD	2 MIN.	2.37	-12.0	-6.6	22.5	37.0	-4.3	-12.9	15.9	30.4	-17.2	-14.5	33.1	47.6
REDUCTION	2 MIN.	2.37	-12.0	-6.6	22.5	37.0	-4.3	-4.7	15.9	30.4	-9.0	-14.5	24.9	39.4
FROM 100%	3.2 MIN.	2.35	-15.0	-8.3	22.4	36.7	-4.2	-12.9	14.1	28.4	-17.1	-14.3	31.2	45.5
TO 50%	3.2 MIN.	2.35	-15.0	-8.3	22.4	36.7	-4.2	-4.7	14.1	28.4	-8.9	-14.3	23.0	[illegible]
FULL	104 MIN.	2.15	0	0	20.5	33.6	-3.9	-12.9	20.5	33.6	-16.8	-13.1	37.3	50.4
POWER	104 MIN.	2.15	0	0	20.5	33.6	-3.9	-4.7	20.5	33.6	-8.6	-13.1	29.1	42.2
REACTOR	10 SEC.	2.22	-9.5	-5.2	21.1	34.6	-4.0	-12.9	15.9	29.4	-16.9	-13.5	32.8	46.3
TRIP FROM	10 SEC.	2.22	-9.5	-5.2	21.1	34.6	-4.0	-4.7	15.9	29.4	-8.7	-13.5	24.6	38.1
FULL	65 SEC.	1.91	8.5	4.7	18.2	29.8	-3.4	-12.9	22.9	34.5	-16.3	-11.6	39.2	50.8
POWER	65 SEC.	1.91	8.5	4.7	18.2	29.8	-3.4	-4.7	22.9	34.5	-8.1	-11.6	31.0	42.6
PLANT HYDRO	220 MIN.	3.13	0	0	29.8	48.9	-5.6	-12.9	29.8	48.9	-18.5	-19.1	48.3	[illegible]
AT 3125 PSIA	220 MIN.	3.13	0	0	29.8	48.9	-5.6	-4.7	29.8	48.9	-10.3	-19.1	40.1	59.2
PLANT	~	2.50	-43	-23.7	23.8	39.0	-4.5	-12.9	0.1	15.3	-17.4	-15.2	17.5	32.7
HYDRO		2.50	-43	-23.7	23.8	39.0	-4.5	-4.7	0.1	15.3	-9.2	-15.2	9.3	24.5
AT	~	0.32	43	23.7	3.0	5.0	-0.6	-12.9	26.7	28.7	-13.5	-2.0	40.2	42.2
2500 PSIA		0.32	43	23.7	3.0	5.0	-0.6	-4.7	26.7	28.7	-5.3	-2.0	32.0	34.0
STEADY STATE	~	2.35	6.0	3.3	22.4	36.7	-4.2	-12.9	25.7	40.0	-17.1	-14.3	42.8	57.1
FLUCTUATIONS		2.35	6.0	3.3	22.4	36.7	-4.2	-4.7	25.7	40.0	-8.9	-14.3	34.6	48.9
OF PRESS.	~	2.15	-6.0	-3.3	20.5	33.6	-3.9	-12.9	17.2	30.3	-16.8	-13.1	34.0	47.1
AND TEMP.		2.15	-6.0	-3.3	20.5	33.6	-3.9	-4.7	17.2	30.3	-8.6	-13.1	25.8	38.9
	10 SEC.	2.76	-30.2	-16.6	26.3	43.1	-5.0	-12.9	9.7	26.5	-17.9	-16.8	27.6	44.4
LOSS	10 SEC.	2.76	-30.2	-16.6	26.3	43.1	-5.0	-4.7	9.7	26.5	-9.7	-16.8	19.4	36.2
OF	28 SEC.	2.12	-41.2	-22.7	20.2	33.1	-3.8	-12.9	-2.5	10.4	-16.7	-12.9	14.2	27.1
LOAD	28 SEC.	2.12	-41.2	-22.7	20.2	33.1	-3.8	-4.7	-2.5	10.4	-8.5	-12.9	6.0	18.9
	160 SEC.	1.44	4.8	2.6	13.7	22.5	-2.6	-12.9	16.3	25.1	-15.5	-8.8	31.8	40.6
	160 SEC.	1.44	4.8	2.6	13.7	22.5	-2.6	-4.7	16.3	25.1	-7.3	-8.8	23.6	32.4

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER 5-201-F | A322
SHEET 25 OF 31
CHARGE NO. ______
DATE 1-27-67 BY ALEXANDER
DESCRIPTION STRUCTURAL ANALYSIS OF CORE SUPPORT PADS
CHECK DATE 1-27-67 BY [illegible]

5. DETAILED ANALYSIS

F) STRESSES - 2. CONCENTRATED

SUMMARY OF STRESSES AND STRESS INTENSITIES AT LOCATION B

TRANSIENT	TIME	PRESS (KSI)	$(T_m - T)$	THERM. STRESS $\sigma_x = \sigma_\theta$	PRESSURE STRESSES σ_x	σ_θ	σ_r	LOAD STRESS σ_r	TOTAL STRESSES σ_x	σ_θ	σ_r	STRESS INTENSITIES $\sigma_x - \sigma_\theta$	$\sigma_x - \sigma_r$	$\sigma_\theta - \sigma_r$
STEADY STATE	~	2.25	0	0	37.9	34.4	-4.1	4.7	37.9	34.4	0.6	3.5	37.3	33.3
HEAT-UP	4.47 HRS.	2.25	-43	-23.7	37.9	34.4	-4.1	12.9	14.2	10.7	8.8	3.5	5.4	1.9
		2.25	-43	-23.7	37.9	34.4	-4.1	4.7	14.2	10.7	0.6	3.5	13.6	10.1
COOLDOWN	4.47 HRS.	0.32	43	23.7	5.4	4.9	-0.6	12.9	29.1	28.6	12.3	0.5	16.8	16.3
		0.32	43	23.7	5.4	4.9	-0.6	4.7	29.1	28.6	4.1	0.5	25.0	24.5
PLANT LOADING	20 MIN.	2.25	-7.8	-4.3	37.9	34.4	-4.1	12.9	33.6	30.1	8.8	3.5	24.8	21.3
		2.25	-7.8	-4.3	37.9	34.4	-4.1	4.7	33.6	30.1	0.6	3.5	33.0	29.5
PLANT UNLOADING	20 MIN.	2.25	7.8	4.3	37.9	34.4	-4.1	12.7	42.2	38.7	8.8	3.5	33.4	29.9
		2.25	7.8	4.3	37.9	34.4	-4.1	4.7	42.2	38.7	0.6	3.5	41.6	38.1
STEP LOAD INCREASE 10% OF FULL POWER	100 SEC.	2.14	11.2	6.2	36.0	32.7	-3.9	12.9	42.2	38.9	9.0	3.3	33.2	29.9
	100 SEC.	2.14	11.2	6.2	36.0	32.7	-3.9	4.7	42.2	38.9	0.8	3.3	41.4	38.1
	225 SEC.	2.28	1.7	0.9	38.4	34.8	-4.1	12.9	39.3	35.7	8.8	3.6	30.5	26.9
	225 SEC.	2.28	1.7	0.9	38.4	34.8	-4.1	4.7	39.3	35.7	0.6	3.6	38.7	35.1
STEP LOAD DECREASE 10% OF FULL POWER	40 SEC.	2.32	-9.3	-5.1	39.1	35.5	-4.2	12.9	34.0	30.4	8.7	3.6	25.3	21.7
	40 SEC.	2.32	-9.3	-5.1	39.1	35.5	-4.2	4.7	34.0	30.4	0.5	3.6	33.5	29.9
	100 SEC.	2.26	-13.3	-7.3	38.1	34.5	-4.1	12.9	30.8	27.2	8.8	3.6	22.0	18.4
	100 SEC.	2.26	-13.3	-7.3	38.1	34.5	-4.1	4.7	30.8	27.2	0.6	3.6	30.2	26.6
	260 SEC.	2.14	-1.3	-0.7	36.0	32.7	-3.9	12.9	35.3	32.0	9.0	3.3	26.3	23.0
	260 SEC.	2.14	-1.3	-0.7	36.0	32.7	-3.9	4.7	35.3	32.0	0.8	3.3	34.5	31.2
LOSS OF FLOW	12 SEC.	2.25	33.3	18.3	37.9	34.4	-4.1	12.9	56.2	52.7	8.8	3.5	47.4	43.9
		2.25	33.3	18.3	37.9	34.4	-4.1	4.7	56.2	52.7	0.6	3.5	55.6	52.1
STEAM BREAK	54 SEC.	0.70	197	108.4	11.8	10.7	-1.3	12.9	120.2	119.1	11.6	1.1	108.6	107.5
		0.70	197	108.4	11.8	10.7	-1.3	4.7	120.2	119.1	3.4	1.1	116.8	115.7

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO.

DESCRIPTION STRUCTURAL ANALYSIS OF CORE SUPPORT PADS

NUMBER S-201-P | A 323
SHEET 26 OF 31
DATE 1-27-67 BY ALEXANDER
CHECK DATE 1-27-67 BY CAUSE

5. DETAILED ANALYSIS

f.) STRESSES - 2. CONCENTRATED

TRANSIENT	TIME	PRESS. (KSI)	$(T_m - T)$	THERM. STRESS	PRESSURE STRESSES			LOAD STRESS	TOTAL STRESSES			STRESS INTENSITIES		
				$\sigma_x = \sigma_\theta$	σ_x	σ_θ	σ_r	σ_r	σ_x	σ_θ	σ_r	$\sigma_x - \sigma_\theta$	$\sigma_x - \sigma_r$	$\sigma_\theta - \sigma_r$
STEP LOAD	2 MIN.	2.37	-12.0	-6.6	39.9	36.2	-4.3	12.9	33.3	29.6	3.6	3.7	24.7	21.0
REDUCTION	2 MIN.	2.37	-12.0	-6.6	39.9	36.2	-4.3	4.7	33.3	29.6	0.4	3.7	32.9	[illegible]
FROM 100%	3.2 MIN.	2.35	-15.0	-3.3	39.6	35.9	-4.2	12.9	31.3	27.6	8.7	3.7	22.6	18.9
TO 50%	3.2 MIN.	2.35	-15.0	-3.3	39.6	35.9	-4.2	4.7	31.3	27.6	0.5	3.7	30.8	27.1
FULL	10.4 MIN.	2.15	0	0	36.2	32.9	-3.9	12.9	36.2	32.9	9.0	3.3	27.2	23.9
POWER	10.4 MIN.	2.15	0	0	36.2	32.9	-3.9	4.7	36.2	32.9	0.8	3.3	35.4	32.1
REACTOR	10 SEC.	2.22	-9.5	-5.2	37.4	33.9	-4.0	12.9	32.2	28.7	8.9	3.5	23.3	19.8
TRIP FROM	10 SEC.	2.22	-9.5	-5.2	37.4	33.9	-4.0	4.7	32.2	28.7	0.7	3.5	31.5	28.0
FULL	65 SEC.	1.91	8.5	4.7	32.2	29.2	-3.4	12.9	36.9	33.9	9.5	3.0	27.4	24.4
POWER	65 SEC.	1.91	8.5	4.7	32.2	29.2	-3.4	4.7	36.9	33.9	1.3	3.0	35.6	32.6
PLANT HYDRO	220 MIN.	3.13	0	0	52.7	47.8	-5.6	12.9	52.7	47.8	7.3	4.9	45.4	40.5
AT 3125 PSIA	220 MIN.	3.13	0	0	52.7	47.8	-5.6	4.7	52.7	47.8	-0.9	4.9	53.6	48.7
PLANT	~	2.50	-43	-23.7	42.1	38.2	-4.5	12.9	18.4	14.5	8.4	3.9	10.0	6.1
HYDRO		2.50	-43	-23.7	42.1	38.2	-4.5	4.7	18.4	14.5	0.2	3.9	18.2	14.3
AT	~	0.32	43	23.7	5.4	4.9	-0.6	12.9	29.1	28.6	12.3	0.5	16.8	16.3
2500 PSIA		0.32	43	23.7	5.4	4.9	-0.6	4.7	29.1	28.6	4.1	0.5	25.0	24.5
STEADY STATE	~	2.35	6.0	3.3	39.6	35.9	-4.2	12.9	42.9	39.2	8.7	3.7	34.2	30.5
FLUCTUATIONS		2.35	6.0	3.3	39.6	35.9	-4.2	4.7	42.9	39.2	0.5	3.7	42.4	38.7
OF PRESS.	~	2.15	-6.0	-3.3	36.2	32.9	-3.9	12.9	32.9	29.6	9.0	3.3	23.9	20.6
AND TEMP.		2.15	-6.0	-3.3	36.2	32.9	-3.9	4.7	32.9	29.6	0.8	3.3	32.1	28.8
	10 SEC.	2.76	-30.2	-16.6	46.5	42.2	-5.0	12.9	29.9	25.6	7.9	4.3	22.0	17.7
LOSS	10 SEC.	2.76	-30.2	-16.6	46.5	42.2	-5.0	4.7	29.9	25.6	-0.3	4.3	30.2	25.9
OF	28 SEC.	2.12	-41.2	-22.7	35.7	32.4	-3.8	12.9	13.0	9.7	9.1	3.3	3.9	0.6
LOAD	28 SEC.	2.12	-41.2	-22.7	35.7	32.4	-3.8	4.7	13.0	9.7	0.9	3.3	12.1	8.8
	160 SEC.	1.44	4.8	2.6	24.3	22.0	-2.6	12.9	26.9	24.6	10.3	2.3	16.6	14.3
	160 SEC.	1.44	4.8	2.6	24.3	22.0	-2.6	4.7	26.9	24.6	2.1	2.3	24.5	22.5

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO. ____

DESCRIPTION: STRUCTURAL ANALYSIS OF CORE SUPPORT PADS

NUMBER: 5-201-P | A 324
SHEET: 27 OF 31
DATE: 1-27-67 BY: ALEXANDER
CHECK DATE: 1-27-67 BY: [illegible]

5. DETAILED ANALYSIS

f) STRESSES - 2. CONCENTRATED

SUMMARY OF STRESSES AND STRESS INTENSITIES AT LOCATION C *

TRANSIENT	TIME	PRESS.	$(T_m - T)$	THERM. STRESS	PRESS. STRESS	LOAD STRESS	TOTAL STRESSES			STRESS INTENSITIES		
				$\sigma_x = \sigma_r$	$\sigma_x = \sigma_\theta = \sigma_r$	σ_r	σ_x	σ_θ	σ_r	$\sigma_x - \sigma_\theta$	$\sigma_x - \sigma_r$	$\sigma_\theta - \sigma_r$
STEADY STATE	~	2.25	0	0	-4.1	-8.0	-4.1	-4.1	-12.1	0	8.0	8.0
HEAT-UP	4.47 HRS.	2.25	-43	-28.1	-4.1	-22.4	-32.2	-4.1	-54.6	-28.1	22.4	50.5
		2.25	-43	-28.1	-4.1	-8.0	-32.2	-4.1	-40.2	-28.1	8.0	36.1
COOL-DOWN	4.47 HRS.	0.32	43	28.1	-0.6	-22.4	27.5	-0.6	5.1	28.1	22.4	-5.7
		0.32	43	28.1	-0.6	-8.0	27.5	-0.6	19.5	28.1	8.0	-20.1
PLANT LOADING	20 MIN.	2.25	-7.8	-5.1	-4.1	-22.4	-9.2	-4.1	-31.6	-5.1	22.4	27.5
		2.25	-7.8	-5.1	-4.1	-8.0	-9.2	-4.1	-17.2	-5.1	8.0	13.1
PLANT UNLOADING	20 MIN.	2.25	7.8	5.1	-4.1	-22.4	1.0	-4.1	-21.4	5.1	22.4	17.3
		2.25	7.8	5.1	-4.1	-8.0	1.0	-4.1	-7.0	5.1	8.0	2.9
STEP LOAD INCREASE 10% OF FULL POWER	100 SEC.	2.14	11.2	7.3	-3.9	-22.4	3.4	-3.9	-19.0	7.3	22.4	15.1
	100 SEC.	2.14	11.2	7.3	-3.9	-8.0	3.4	-3.9	-4.6	7.3	8.0	0.7
	225 SEC.	2.28	1.7	1.1	-4.1	-22.4	-3.0	-4.1	-25.4	1.1	22.4	21.3
	225 SEC.	2.28	1.7	1.1	-4.1	-8.0	-3.0	-4.1	-11.0	1.1	8.0	6.9
STEP LOAD DECREASE 10% OF FULL POWER	40 SEC.	2.32	-9.3	-6.1	-4.2	-22.4	-10.3	-4.2	-32.7	-6.1	22.4	28.5
	40 SEC.	2.32	-9.3	-6.1	-4.2	-8.0	-10.3	-4.2	-18.3	-6.1	8.0	14.1
	100 SEC.	2.26	-13.3	-8.7	-4.1	-22.4	-12.8	-4.1	-35.2	-8.7	22.4	31.1
	100 SEC.	2.26	-13.3	-8.7	-4.1	-8.0	-12.8	-4.1	-20.8	-8.7	8.0	16.7
	260 SEC.	2.14	-1.3	-0.8	-3.9	-22.4	-4.7	-3.9	-27.1	-0.8	22.4	23.2
	260 SEC.	2.14	-1.3	-0.8	-3.9	-8.0	-4.7	-3.9	-12.7	-0.8	8.0	8.8
LOSS OF FLOW	12 SEC.	2.25	33.3	21.7	-4.1	-22.4	17.6	-4.1	-4.8	21.7	22.4	0.7
		2.25	33.3	21.7	-4.1	-8.0	17.6	-4.1	9.6	21.7	8.0	-13.7
STEAM BREAK	54 SEC.	0.70	197	128.7	-1.3	-22.4	127.4	-1.3	105.0	128.7	22.4	-106.3
		0.70	197	128.7	-1.3	-8.0	127.4	-1.3	119.4	128.7	8.0	-120.7

* DUE TO THE SYMMETRY BETWEEN POINTS C AND D, POINT D WILL NOT BE SHOWN HERE.

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER S-201-P | A 325
SHEET 28 OF 31
DATE 1-27-67 BY ALEXANDER
CHECK DATE 1-27-67 BY CAUDLE
CHARGE NO.
DESCRIPTION STRUCTURAL ANALYSIS OF CORE SUPPORT PADS

5. DETAILED ANALYSIS
A) STRESSES - 2. CONCENTRATED

TRANSIENT	TIME	PRESS.	$(T_m - T)$	THERM. STRESS	PRESS. STRESS	LOAD STRESS	TOTAL STRESSES.			STRESS INTENSITIES		
				$\sigma_x = \sigma_r$	$\sigma_x = \sigma_\theta = \sigma_r$	σ_r	σ_x	σ_θ	σ_r	$\sigma_r - \sigma_\theta$	$\sigma_x - \sigma_r$	$\sigma_\theta - \sigma_r$
STEP LOAD	2 MIN.	2.37	-12.0	-7.8	-4.3	-22.4	-12.1	-4.3	-34.5	-7.8	22.4	30.2
REDUCTION	2 MIN.	2.37	-12.0	-7.8	-4.3	-8.0	-12.1	-4.3	-20.1	-7.8	8.0	15.8
FROM 100%	3.2 MIN	2.35	-15.0	-9.8	-4.2	-22.4	-14.0	-4.2	-36.4	-9.8	22.4	32.2
TO 50%	3.2 MIN.	2.35	-15.0	-9.8	-4.2	-8.0	-14.0	-4.2	-22.0	-9.8	8.0	17.8
FULL	104 MIN.	2.15	0	0	-3.9	-22.4	-3.9	-3.9	-26.3	0	22.4	22.4
POWER	104 MIN.	2.15	0	0	-3.9	-8.0	-3.9	-3.9	-11.9	0	8.0	8.0
REACTOR	10 SEC.	2.22	-9.5	-6.2	-4.0	-22.4	-10.2	-4.0	-32.6	-6.2	22.4	28.6
TRIP	10 SEC.	2.22	-9.5	-6.2	-4.0	-8.0	-10.2	-4.0	-18.2	-6.2	8.0	14.2
FROM FULL	65 SEC.	1.91	8.5	5.6	-3.4	-22.4	2.2	-3.4	-20.2	5.6	22.4	16.8
POWER	65 SEC.	1.91	8.5	5.6	-3.4	-8.0	2.2	-3.4	-5.8	5.6	8.0	2.4
PLANT HYDRO	220 MIN.	3.13	0	0	-5.6	-22.4	-5.6	-5.6	-28.0	0	22.4	22.4
AT 3125 PSIA.	220 MIN.	3.13	0	0	-5.6	-8.0	-5.6	-5.6	-13.6	0	8.0	8.0
PLANT	~	2.50	-43	-28.1	-4.5	-22.4	-32.6	-4.5	-55.0	-28.1	22.4	50.5
HYDRO		2.50	-43	-28.1	-4.5	-8.0	-32.6	-4.5	-40.6	-28.1	8.0	36.1
AT	~	0.32	43	28.1	-0.6	-22.4	27.5	-0.6	5.1	28.1	22.4	-5.7
2500 PSIA.		0.32	43	28.1	-0.6	-8.0	27.5	-0.6	19.5	28.1	8.0	-20.1
STEADY STATE		2.35	6.0	3.9	-4.2	-22.4	-0.3	-4.2	-22.7	3.9	22.4	18.5
FLUCTUATIONS	~	2.35	6.0	3.9	-4.2	-8.0	-0.3	-4.2	-8.3	3.9	8.0	4.1
OF PRESS.	~	2.15	-6.0	-3.9	-3.9	-22.4	-7.8	-3.9	-30.2	-3.9	22.4	26.3
AND TEMP.		2.15	-6.0	-3.9	-3.9	-8.0	-7.8	-3.9	-15.8	-3.9	8.0	11.9
	10 SEC.	2.76	-30.2	-19.7	-5.0	-22.4	-24.7	-5.0	-47.1	-19.7	22.4	42.1
LOSS	10 SEC.	2.76	-30.2	-19.7	-5.0	-8.0	-24.7	-5.0	-32.7	-19.7	8.0	27.7
OF	28 SEC.	2.12	-41.2	-26.9	-3.8	-22.4	-30.7	-3.8	-53.1	-26.9	22.4	49.3
LOAD	28 SEC.	2.12	-41.2	-26.9	-3.8	-8.0	-30.7	-3.8	-38.7	-26.9	8.0	34.9
	160 SEC.	1.44	4.8	3.1	-2.6	-22.4	0.5	-2.6	-21.9	3.1	22.4	19.3
	160 SEC.	1.44	4.8	3.1	-2.6	-8.0	0.5	-2.6	-7.5	3.1	8.0	4.9

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.
CHARGE NO.

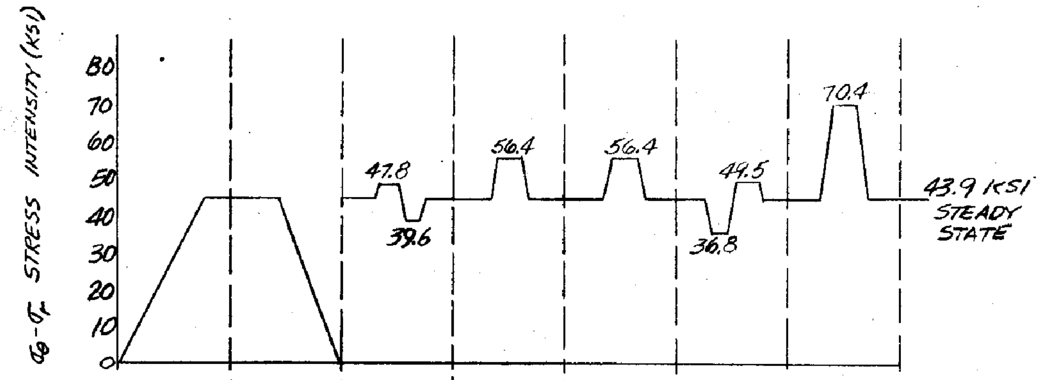
NUMBER S-201-P | A 376
SHEET 29 OF 31
DATE 1-27-67 BY ALEXANDER
CHECK DATE 1-27-67 BY CAUDLE

DESCRIPTION STRUCTURAL ANALYSIS OF CORE SUPPORT PADS

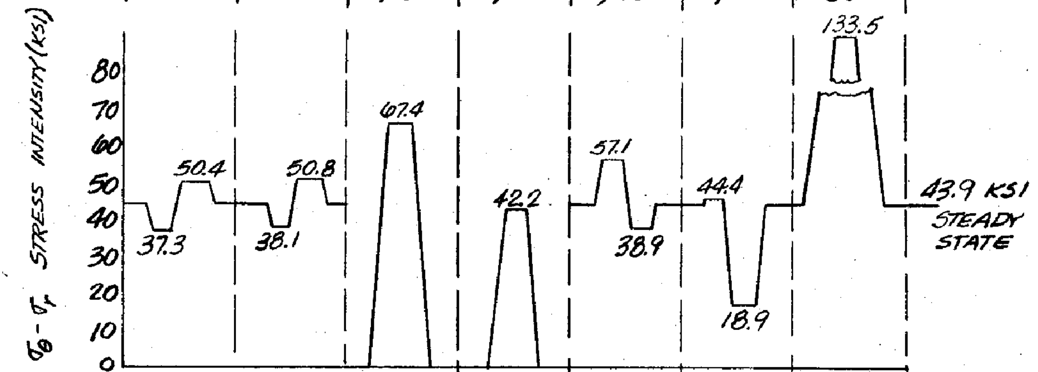
5. DETAILED ANALYSIS

9.) FATIGUE EVALUATION

$\sigma_\theta - \sigma_r$ AT LOCATION A



TRANSIENT	HEAT-UP	COOL-DOWN	PLANT LOADING	PLANT UNLOADING	STEP LOAD INCREASE 10% OF F.P.	STEP LOAD DECREASE 10% OF F.P.	LOSS OF FLOW
OCCURRENCES	200	200	14,500	14,500	2,000	2,000	80



TRANSIENT	STEP LOAD REDUCTION 100%-50% F.P.	REACTOR TRIP	PLANT HYDRO AT 3125	PLANT HYDRO AT 2600	STEADY STATE FLUCTUATIONS	LOSS OF LOAD	STEAM BREAK
OCCURRENCES	200	400	5	5	∞	80	5

$S_{MAX.}$	$S_{MIN.}$	NUMBER OF OCCURRENCES	S_A	N*	U
133.5	0	5	66.8	1800	0.00277
70.4	0	80	35.2	12,000	0.00666
67.4	0	5	33.7	15,000	0.00033
57.1	0	115	28.6	25,000	0.00460
42.2	0	5	21.1	80,000	0.00006
57.1	18.9	80	19.1	110,000	0.00072
57.1	36.8	2000	10.2	∞	0

$U_{OVERALL} = 0.01514$

* FROM FIG. N-415 (A) REF. 1

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

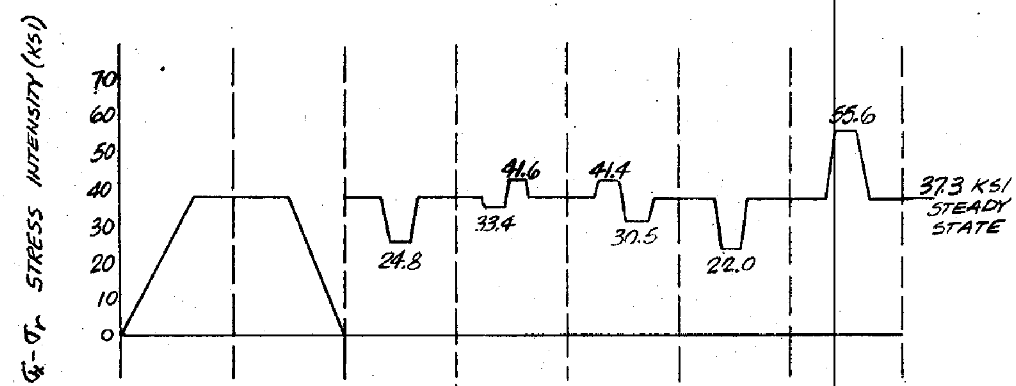
NUMBER S-201-P | A 327
SHEET 30 OF 31
DATE 1-27-67 BY ALEXANDER
CHECK DATE 1-27-67 BY [illegible]

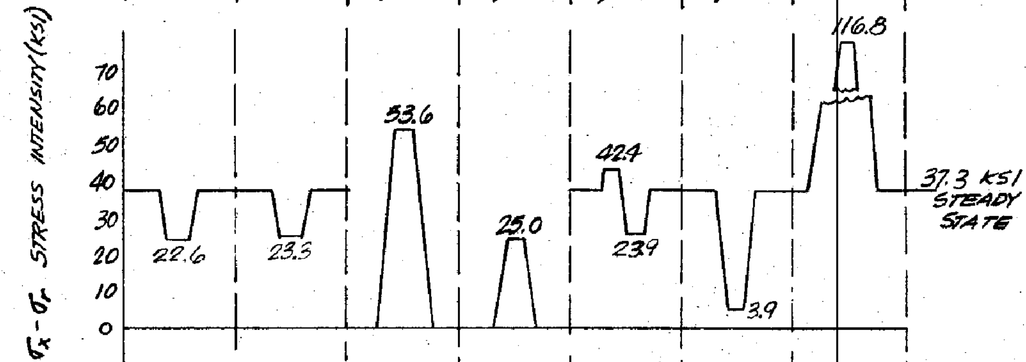
CHARGE NO.

DESCRIPTION STRUCTURAL ANALYSIS OF CORE SUPPORT PADS

5. DETAILED ANALYSIS

9.) FATIGUE EVALUATION $\sigma_x - \sigma_r$ AT LOCATION B





$S_{MAX.}$	$S_{MIN.}$	NUMBER OF OCCURRENCES	S_A	N*	U
116.8	0	5	58.4	2700	0.00185
55.6	0	80	27.8	27,000	0.00296
53.6	0	5	26.8	31,000	0.00016
42.4	0	115	21.2	80,000	0.00143
42.4	3.9	80	19.3	110,000	0.00072
25.0	0	5	12.5	∞	0

$U_{OVERALL} = 0.00712$

* FROM FIG. N-415 (A) REF. 1

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

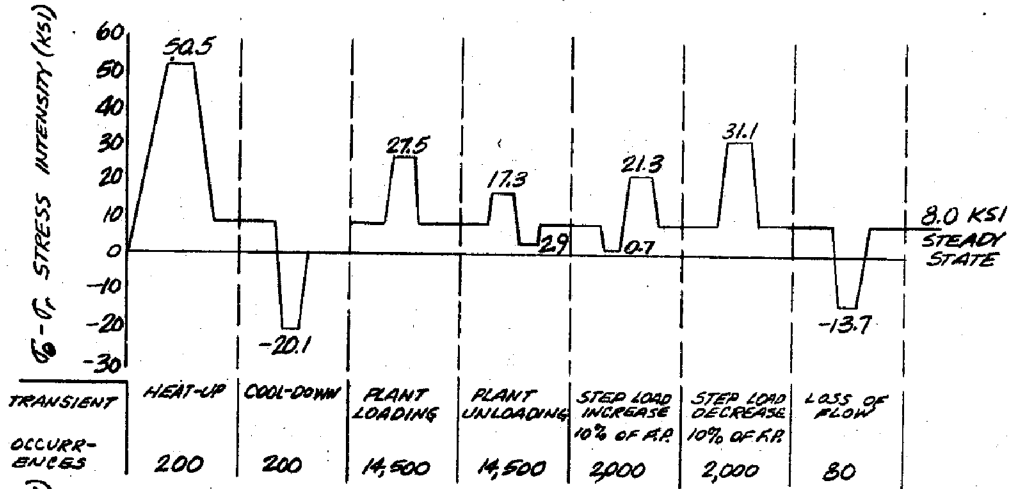
CHARGE NO.

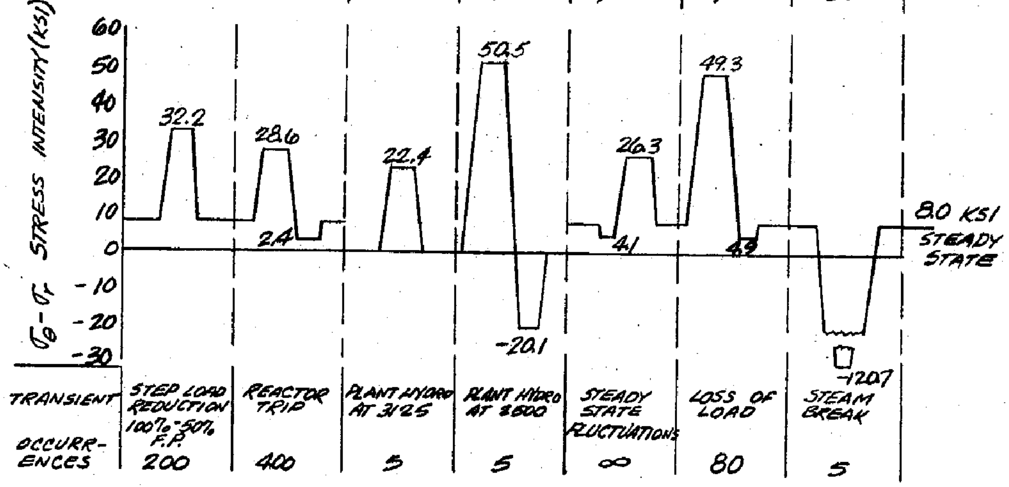
DESCRIPTION STRUCTURAL ANALYSIS OF CORE SUPPORT PADS

NUMBER S-201-P | A 328
SHEET 31 OF 31
DATE 1-27-67 BY ALEXANDER
CHECK DATE 1-27-67 BY CAUDLE

5. DETAILED ANALYSIS

9) FATIGUE EVALUATION $\sigma_\theta - \sigma_r$ AT LOCATION C





$S_{MAX.}$	$S_{MIN.}$	NUMBER OF OCCURRENCES	S_A	N*	U
50.5	-120.7	5	85.6	2300	0.00217
50.5	-20.1	195	35.3	130,000	0.00150
50.5	-20.1	5	35.3	130,000	0.00003
49.3	-13.7	80	31.5	250,000	0.00032
32.2	0.7	200	15.8	∞	0

* FROM FIG. N-415 (B) REF. 1

$U_{OVERALL} = 0.00402$

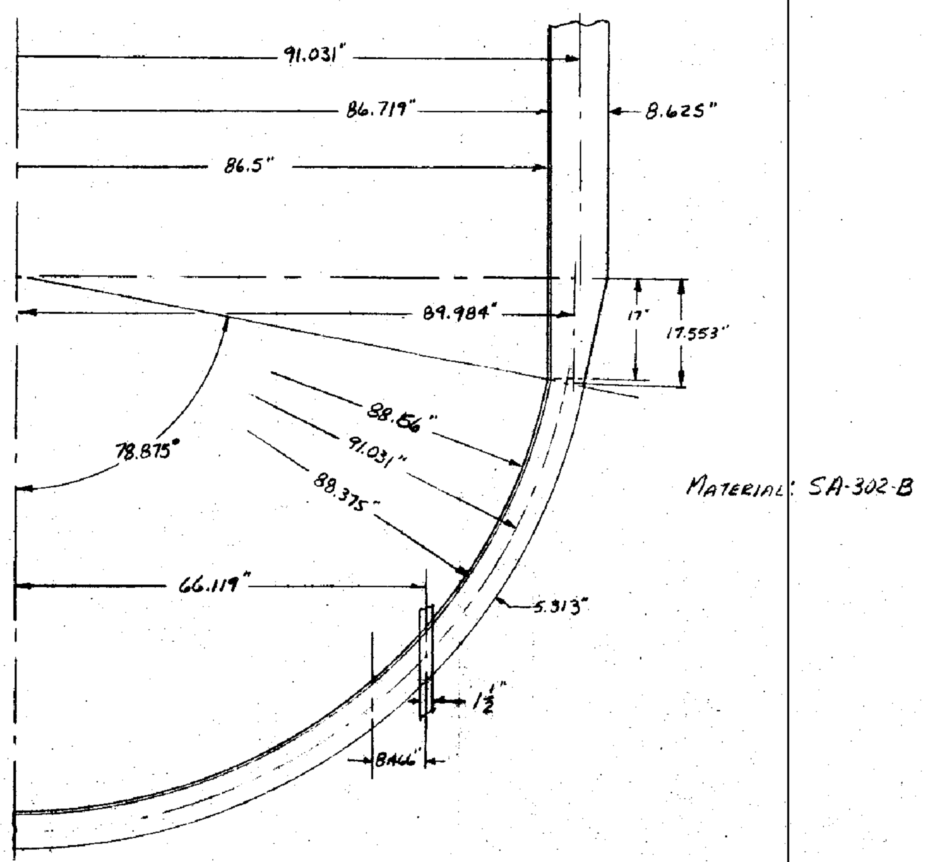
COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.
CHARGE NO.
DESCRIPTION Structural Analysis Of Vessel And Bottom Head Juncture

NUMBER S-200-P | A 329
SHEET 4 OF 15
DATE 10-27-65 BY Cockrell
CHECK DATE 10-29-65 BY Ferguson

5. Detailed Analysis:

a. System Geometry:

A Cross Section Of The Vessel Wall And Bottom Head Is Shown Below



5- DETAILED ANALYSIS:

b- SYSTEM LOADS:

THE VESSEL SHELL AND BOTTOM HEAD SHOWN ON THE PREVIOUS SHEET ARE INVESTIGATED FOR INTERNAL PRESSURE OF 2.5 ksi (DESIGN PRESSURE) AT DESIGN TEMPERATURE OF 650°F

c- SYSTEM ALLOWABLES:

THE FOLLOWING ALLOWABLE STRESSES ARE BASED ON THE A.S.M.E. SECTION III NUCLEAR CODE, REFERENCE 1 AND ARE RELEVANT FOR THIS ANALYSIS.

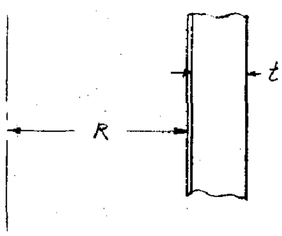
1- THE AVERAGE PRIMARY STRESS INTENSITY ACROSS A SOLID SECTION SHALL NOT EXCEED S_m AT 650°F.

2- THE LOCAL PRIMARY STRESS COMBINED WITH 1. ABOVE SHALL NOT EXCEED $1.5\,S_m$ AT 650°F

3- THE RANGE OF PRIMARY PLUS SECONDARY STRESS RESULTING FROM MECHANICAL OR THERMAL LOADS SHALL NOT EXCEED $3S_m$ AT ACTUAL METAL TEMPERATURE.

d- DESIGN SIZING:

CONSIDER THE SIZING OF THE VESSEL WALL:



MATERIAL SA-302-B
DESIGN PRESS = 2.5 ksi
DESIGN TEMP = 650°F
S_m = 26.7 ksi @ 650°F

FROM N-431 OF SECTION III NUCLEAR CODE

$$t = \frac{PR}{S_m - 0.5P} = \frac{2.5(86.5)}{26.7 - 1.25} = 8.497''$$

$\therefore$ THE 8.625" THICKNESS IS ADEQUATE

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER 5-200-P	A 331
SHEET 6	OF 15
DATE 10-27-65	BY COCKRELL
CHECK DATE 10-29-65	BY FERGUSON

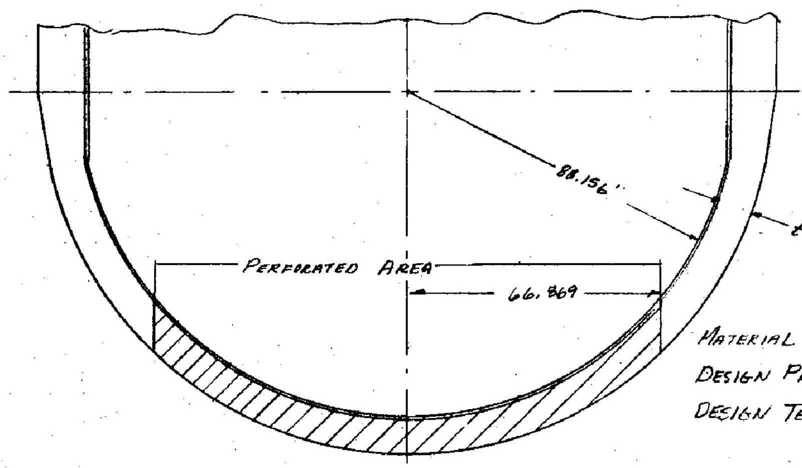
CHARGE NO.

DESCRIPTION STRUCTURAL ANALYSIS OF VESSEL AND BOTTOM HEAD JUNCTURE

5- DETAILED ANALYSIS:

d- DESIGN SIZING:

CONSIDER THE BOTTOM HEAD:



MATERIAL SA-302-B
DESIGN PRESS. 2.5 KSI
DESIGN TEMP. 650°F

CONSIDER THE REQUIRED THICKNESS IN THE UN-PERFORATED AREA:

REFERENCE PARAGRAPH N-431, SECTION III NUCLEAR CODE, WHERE

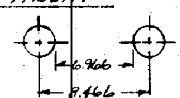
$$t_{REQ'D} = \frac{PR}{2S_m - P} = \frac{2.5(88.156)}{2(26.7) - 2.5}$$

$= 4.330''$ (USE $5\frac{5}{16}$ MIN TO ALLOW FOR PENETRATIONS)

$t_{REQ'D}$ = SHELL THICKNESS (EXCLUDING CLAD)
P = DESIGN PRESSURE
R = INSIDE RADIUS OF HEAD
S_m = ALLOWABLE STRESS AT 650°F

CONSIDER THE REQUIRED THICKNESS IN THE PERFORATED AREA:

THE REQUIRED THICKNESS MAY BE CONSERVATIVELY ESTIMATED BY ASSUMING THE LIGAMENT EFFICIENCY TO BE ($L.E. = \frac{6.966}{8.466} = 0.823$). THIS INSURES SATISFACTION OF THE PRIMARY STRESS, S_m, REQUIREMENT IN THE PERFORATED REGION



$L.E. = 0.823$

$$t_{REQ'D(PERFORATED)} = \frac{t}{L.E.} = \frac{4.330}{0.823} = 5.261'' < 5.313''$$

$$\sigma_{PRIMARY(PERFORATED)} = \frac{PR}{2t(L.E.)} + \frac{P}{2} = 26.5\ KSI < S_m = 26.7\ KSI$$

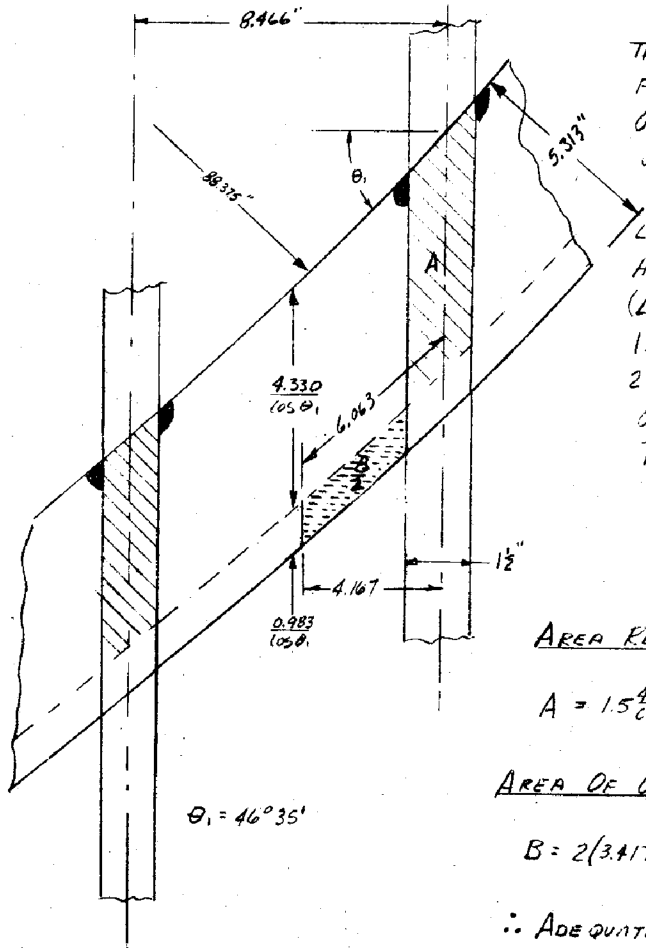
$\therefore$ CRITERION 5.C.1 IS SATISFIED

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.
CHARGE NO.
DESCRIPTION Structural Analysis Of Vessel And Bottom Head Juncture

NUMBER S-200-P | A 332
SHEET 7 OF 15
DATE 10-27-65 BY Cockrell
CHECK DATE 10-29-65 BY Ferguson

5- Detailed Analysis:
d- Design Sizing:

Another Approach Which May Be Used To Insure Adequate Head Thickness Is To Assume The Bottom Head Penetrations As Connections Which Require Reinforcement. The Controlling Location Is At The Extreme Position As Shown Below.



The General Requirements For Compensation Are Outlined In Par. N-451 - 456 Of Section III.

Limit Of Reinforcement Along Vessel Wall: (Larger Of)
1 - Dia. Of Opening = 1.5"
2 - Finished Radius Of Opening Plus Vessel Wall Thickness = 0.75 + 5.313 = 6.063"

Area Removed:

$$A = 1.5\frac{4.330}{\cos\theta_1} = 9.450\,in^2$$

Area Of Compensation:

$$B = 2(3.417)\frac{0.983}{\cos\theta_1} = 9.774\,in^2$$

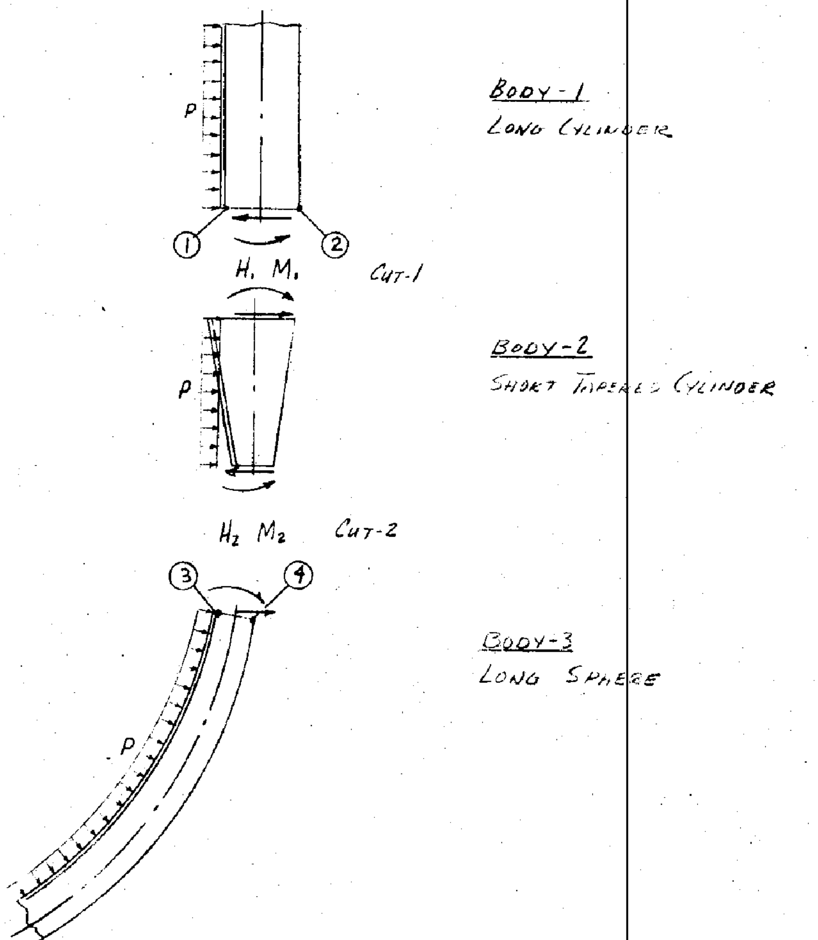
∴ Adequate Compensation Is Provided

5- DETAILED ANALYSIS:

e- DEVELOPMENT OF CONTINUITY EQUATIONS:

1- ANALYTICAL MODEL:

THE ACTUAL STRUCTURE IS DIVIDED INTO THE ANALYTICAL MODEL AS SHOWN BELOW TO FACILITATE THE ANALYSIS. THE ASSUMED DIRECTION OF THE REDUNDANT FORCES IS ILLUSTRATED.

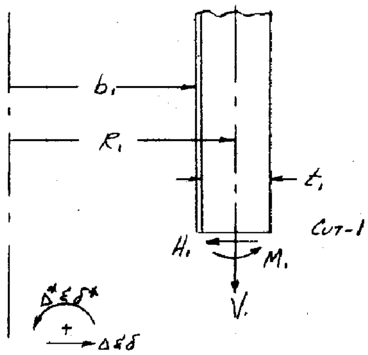


5. DETAILED ANALYSIS:

e. DEVELOPMENT OF CONTINUITY EQUATIONS:

2. MOVEMENTS DUE TO REDUNDANT AND APPLIED FORCES:

BODY-1:



$R_1 = 91.031''$

$b_1 = 86.500''$

$t_1 = 8.625''$

$\beta^4 = \frac{3(1-\nu^2)}{R_1^2 t_1^2}$

$\beta^2 = 0.00210$

$D = \frac{E t_1^3}{12(1-\nu^2)} = 58.7563E$

$V_1 = \frac{P b_1^2}{2R_1} = 41.09726P$

DISPLACEMENTS DUE TO REDUNDANT FORCES:

$$E\Delta_{11} = -\frac{E}{2\beta^3 D}\left[\frac{1}{\beta}H_1 - M_1\right]$$

$$= -88.14883H_1 + 4.04373M_1$$

$$E\Delta^*_{11} = -\frac{E}{2\beta^2 D}\left[H_1 - 2\beta M_1\right]$$

$$= -4.04373H_1 + 0.37100M_1$$

DISPLACEMENTS DUE TO APPLIED FORCES:

$$E\delta_{11} = \frac{b_1^2}{t_1}\left(\frac{R_1}{b_1} - \frac{\nu}{2}\right)P$$

$$= 782.82249P$$

$$E\delta^*_{11} = 0$$

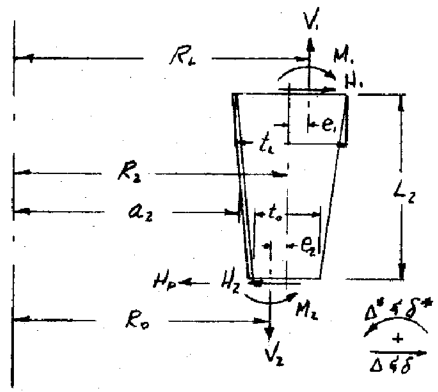
FROM THEORY OF PLATES AND SHELLS BY TIMOSHENKO, REF. 12

5- Detailed Analysis:

e- Development Of Continuity Equations:

2. Movements Due To Redundant And Applied Forces:

Body - 2:



$R_2 = 89.984''$

$a_2 = 86.500''$

$t_o = 5.313''$

$t_L = 8.625''$

$L_2 = 17.553''$

$R_\phi = 89.321''$

$R_L = 91.031''$

$e_1 = 1.047''$

$e_2 = 0.663''$

$V_1 = 41.09726P$

$V_2 = 41.88383P$

$H_p = V_2' \cos\theta$

$= 3.23624P$

$\lambda = \frac{1}{L}(t_L - t_o) = 0.18863$

$\beta^4 = \frac{12(1-\nu^2)}{t^2 R_2^2} = 0.03788$

The Influence Coefficients For A Short Tapered Cylinder Are Calculated By The Method Outlined On Pages 488 To 492 Of Reference **12** And Are Printed Out On C.E. Computer Program In The Following Form.

Displacements Due To Redundant Forces:

$$E\Delta_{21} = -\phi_{33} H_1 \frac{R_L}{R_2} + \phi_{34} M_1 \frac{R_L}{R_2} - \phi_{31} H_2 \frac{R_o}{R_2} + \phi_{32} M_2 \frac{R_o}{R_2}$$
$$= 240.74307 H_1 + 21.75745 M_1 + 132.07532 H_2 - 20.68908 M_2$$

$$E\Delta^*_{21} = \phi_{43} H_1 \frac{R_L}{R_2} - \phi_{44} M_1 \frac{R_L}{R_2} + \phi_{41} H_2 \frac{R_o}{R_2} - \phi_{42} M_2 \frac{R_o}{R_2}$$
$$= -21.79896 H_1 - 2.79456 M_1 - 24.31443 H_2 + 2.52823 M_2$$

$$E\Delta_{22} = -\phi_{13} H_1 \frac{R_L}{R_2} + \phi_{14} M_1 \frac{R_L}{R_2} - \phi_{11} H_2 \frac{R_o}{R_2} + \phi_{12} M_2 \frac{R_o}{R_2}$$
$$= -134.67524 H_1 - 24.74586 M_1 - 300.85321 H_2 + 25.38380 M_2$$

$$E\Delta^*_{22} = \phi_{23} H_1 \frac{R_L}{R_2} - \phi_{24} M_1 \frac{R_L}{R_2} + \phi_{21} H_2 \frac{R_o}{R_2} - \phi_{22} M_2 \frac{R_o}{R_2}$$
$$= -21.14812 H_1 - 2.57940 M_1 - 25.44608 H_2 + 2.94507 M_2$$

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO.____
DESCRIPTION: STRUCTURAL ANALYSIS OF VESSEL AND BOTTOM HEAD JUNCTURE

NUMBER: S-200-P | A 336

DATE: 10-27-65 BY: CAKRELL
CHECK DATE: 10-29-65 BY: FERGUSON

5- DETAILED ANALYSIS:

e- DEVELOPMENT OF CONTINUITY EQUATIONS:

2- MOVEMENTS DUE TO REDUNDANT AND APPLIED FORCES:

BODY-2

DISPLACEMENTS DUE TO APPLIED FORCES:

$$E\delta_{21} = a_2^2\left(\frac{R_1}{a_2} - \frac{\nu}{2}\right)\left[(\phi_{32}+\phi_{34})\frac{-\lambda^2}{6(1-\nu^2)} + \frac{1}{t_2}\right]P - \phi_{34} V_1 e_1 \frac{R_1}{R_2} + \phi_{32} V_2 e_2 \frac{R_0}{R_2} - \phi_{31} H_P \frac{R_0}{R_2}$$

$$= \underline{320.56163P}$$

$$E\delta_{21}^* = -a_2^2\left(\frac{R_1}{a_2} - \frac{\nu}{2}\right)\left[(\phi_{42}+\phi_{44})\frac{-\lambda^2}{6(1-\nu^2)} - \frac{\lambda}{t_2^2}\right]P + \phi_{44} V_1 e_1 \frac{R_1}{R_2} - \phi_{42} V_2 e_2 \frac{R_0}{R_2} + \phi_{41} H_P \frac{R_0}{R_2}$$

$$= \underline{16.37180P}$$

$$E\delta_{22} = a_2^2\left(\frac{R_1}{a_2} - \frac{\nu}{2}\right)\left[(\phi_{12}+\phi_{14})\frac{-\lambda^2}{6(1-\nu^2)} + \frac{1}{t_0}\right]P - \phi_{14} V_1 e_1 \frac{R_1}{R_2} + \phi_{12} V_2 e_2 \frac{R_0}{R_2} - \phi_{11} H_P \frac{R_0}{R_1}$$

$$= \underline{497.32142P}$$

$$E\delta_{22}^* = -a_2^2\left(\frac{R_1}{a_1} - \frac{\nu}{2}\right)\left[(\phi_{22}+\phi_{24})\frac{-\lambda^2}{6(1-\nu^2)} - \frac{\lambda}{t_0^2}\right]P + \phi_{24} V_1 e_1 \frac{R_1}{R_2} - \phi_{22} V_2 e_2 \frac{R_0}{R_1} + \phi_{21} H_P \frac{R_0}{R_2}$$

$$= \underline{9.56819P}$$

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER S-200-r A 337
SHEET 12 OF 15
DATE 10-27-65 BY COCKRELL
CHECK DATE 10-29-65 BY FERGUSON

CHARGE NO. ______

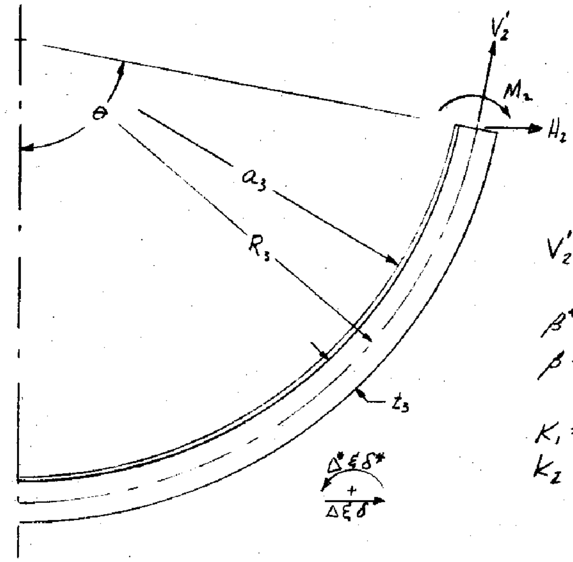
DESCRIPTION STRUCTURAL ANALYSIS OF VESSEL AND BOTTOM HEAD JUNCTURE

5- DETAILED ANALYSIS:

e- DEVELOPMENT OF CONTINUITY EQUATIONS:

2. MOVEMENTS DUE TO REDUNDANT AND APPLIED FORCES:

BODY-3:



$R_3 = 91.031''$
$a_3 = 88.156''$
$t_3 = 5.313$
$\theta = 78.875°$

$V_2' = \frac{a_3^2}{2R_3} P = 42.68590 P$

$\beta^4 = 3(1-\nu^2)\left(\frac{R}{t}\right)^2$

$\beta = 5.32066$

$K_1 = 1 - \frac{(1-2\nu)}{2\beta} \operatorname{ctn}\theta = 0.99261$

$K_2 = 1 - \frac{(1+2\nu)}{2\beta} \operatorname{ctn}\theta = 0.97044$

DISPLACEMENTS DUE TO REDUNDANT FORCES:

$$E\Delta_{32} = \frac{2\beta^2 \sin\theta}{t_3}\left[\frac{R_3 \sin\theta}{2\beta}\left(\frac{1}{K_1} + K_2\right)H_2 + \frac{1}{K_1} M_2\right]$$

$$= \underline{173.59527 H_2 + 10.53420 M_2}$$

$$E\Delta_{32}^* = -\frac{2\beta^2 \sin\theta}{t_3}\left[\frac{1}{K_1} H_2 + \frac{2\beta}{R_3 \sin\theta}\left(\frac{1}{K_1}\right)M_2\right]$$

$$= \underline{-10.53420 H_2 - 1.25498 M_2}$$

DISPLACEMENTS DUE TO APPLIED FORCES

$$E\delta_{32} = \frac{(1-\nu)a_3^2 P}{2t_3} \sin\theta = \underline{502.33558 P}$$

$$E\delta_{32}^* = 0$$

FROM THEORY OF PLATES AND SHELLS BY TIMOSHENKO, REF. 12

5- DETAILED ANALYSIS:

e- DEVELOPMENT OF CONTINUITY EQUATIONS:

3. CONTINUITY MATRIX AND LOADING VECTORS:

ONLY A PRESSURE SOLUTION IS REQUIRED FOR THIS ANALYSIS. THE REDUNDANT LOADS ARE DETERMINED BY REQUIRING RADIAL AND ROTATIONAL CONTINUITY. THE COLUMN VECTORS ARE WRITTEN IN TERMS OF P. THE MATRIX WILL BE ARRANGED AS FOLLOWS

$$E\Delta_{11} - E\Delta_{21} = E\delta_{21} - E\delta_{11}$$
$$E\Delta^*_{11} - E\Delta^*_{21} = E\delta^*_{21} - E\delta^*_{11}$$
$$E\Delta_{22} - E\Delta_{32} = E\delta_{32} - E\delta_{22}$$
$$E\Delta^*_{22} - E\Delta^*_{32} = E\delta^*_{32} - E\delta^*_{22}$$

THE CONTINUITY REQUIREMENTS ARE EXPRESSED BELOW IN MATRIX FORM.

$$\begin{bmatrix} -328.89140 & -17.71372 & -132.07532 & 20.68908 \\ 17.75523 & 3.16556 & 24.31443 & -2.52823 \\ -134.67524 & -24.74568 & -474.44948 & 14.84960 \\ -21.14812 & -2.57940 & -14.91188 & 4.20005 \end{bmatrix} \begin{bmatrix} H_1 \\ M_1 \\ H_2 \\ M_2 \end{bmatrix} = \begin{bmatrix} -462.26086 \\ 16.37180 \\ 5.01416 \\ -9.56919 \end{bmatrix} P$$

INVERTING THE ABOVE MATRIX AND MULTIPLYING TIMES THE COLUMN VECTORS YIELDS THE FOLLOWING REDUNDANTS RESULTING FROM PRESSURE. DESIGN PRESSURE IS 2.5 ksi.

4 REDUNDANT LOAD VALUES:

$H_1 = 1.85888 P$
$M_1 = 6.44620 P$
$H_2 = -0.59500 P$
$M_2 = 8.92778 P$

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.
CHARGE NO.
DESCRIPTION STRUCTURAL ANALYSIS OF VESSEL AND BOTTOM HEAD JUNCTURE
NUMBER S-200-P | A 339
SHEET 14 OF 15
DATE 10-27-65 BY COCKRELL
CHECK DATE 10-29-65 BY FERGUSON

5. DETAILED ANALYSIS:
f. STRESS CALCULATIONS:

THE STRESS EXPRESSIONS TO BE USED FOR THE LOCATIONS AS SHOWN OF SHEET 8 ARE GIVEN BELOW.

POINT-1

$$\sigma_x = \frac{6M_1}{t_1^2} + \frac{b_1^2 P}{2R_1 t_1} = 0.08065 M_1 + 4.76490P$$

$$\sigma_\theta = \frac{\nu 6M_1}{t_1^2} + \frac{E\Delta_{11}}{R_1} + \frac{bP}{t_1} = 0.02420 M_1 + 0.01099 E\Delta_{11} + 10.02898P$$

POINT-2

$$\sigma_x = -\frac{6M_1}{t_1^2} + \frac{b_1^2 P}{2R_1 t_1} = -0.08065 M_1 + 4.76490P$$

$$\sigma_\theta = -\frac{\nu 6M_1}{t_1^2} + \frac{E\Delta_{11}}{R_1} + \frac{bP}{t_1} = -0.02420M_1 + 0.01099 E\Delta_{11} + 10.02898P$$

POINT-3

$$\sigma_x = \frac{6M_2}{t_3^2} + \frac{H_2 \cos\theta}{t_3} + \frac{Pa_3^2}{2R_3 t_3} = 0.21255 M_2 + 0.03631 H_2 + 8.03423P$$

$$\sigma_\theta = \frac{\nu 6M_2}{t_3^2} + \frac{\nu H_2 \cos\theta}{t_3} + \frac{E\Delta_{32}}{R_3 \sin\theta} + \frac{t E\Delta_{32}^{*} \cos\theta}{2R_3 \sin\theta} + \frac{Pa_3^2}{2R_3 t_3}$$

$$= 0.06377 M_2 + 0.01089 H_2 + 0.01120 E\Delta_{32} + 0.00574 E\Delta_{32}^{*} + 8.03423P$$

POINT-4

$$\sigma_x = -\frac{6M_2}{t_3^2} + \frac{H_2 \cos\theta}{t_3} + \frac{Pa_3^2}{2R_3 t_3} = -0.21255 M_2 + 0.03631 H_2 + 8.03423P$$

$$\sigma_\theta = -\frac{\nu 6M_2}{t_3^2} + \frac{\nu H_2 \cos\theta}{t_3} + \frac{E\Delta_{32}}{R_3 \sin\theta} - \frac{t E\Delta_{32}^{*} \cos\theta}{2R_3 \sin\theta} + \frac{Pa_3^2}{2R_3 t_3}$$

$$= -0.06377 M_2 + 0.01089 H_2 + 0.01120 E\Delta_{32} - 0.00574 E\Delta_{32}^{*} + 8.03423P$$

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.
CHARGE NO.

DESCRIPTION STRUCTURAL ANALYSIS OF VESSEL AND BOTTOM HEAD JUNCTURE

NUMBER 5-200-P | A 340
SHEET 15 OF 15
DATE 10-27-65 BY [illegible]
CHECK DATE 10-29-65 BY FERGUSON

5- DETAILED ANALYSIS:

f- STRESSES:

POINT	$\pm\frac{6M}{t^2}$	$\frac{\cos\theta H}{t}$	$\frac{PR}{2t}$	σ_x	$\pm\frac{\nu 6M}{t^2}$	$\frac{\nu\cos\theta H}{t}$	$E\Delta$	$\frac{E\Delta}{R}$	$E\delta^*$	$\pm\frac{tE\delta^*}{2R}$	$\frac{PR}{2t}$ / $\frac{PR}{t}$	σ_θ	σ_r	Stress Intensity $\sigma_x-\sigma_\theta$	$\sigma_x-\sigma_r$	$\sigma_\theta-\sigma_r$
1	1.30	—	11.91	13.21	0.39	—	-344.48	-3.79	—	—	25.07	21.67	-2.5	-8.5	15.7	24.2
2	-1.30	—	11.91	10.61	-0.39	—	-344.48	-3.79	—	—	25.07	20.89	0	-10.3	10.6	20.9
3	4.74	-0.05	20.09	24.78	1.42	-0.02	-23.105	-0.26	-12.341	-0.07	20.09	21.16	-2.5	3.6	27.3	23.7
4	-4.74	-0.05	20.09	15.30	-1.42	-0.02	-23.105	-0.26	-12.341	0.07	20.09	18.46	0	-3.2	15.3	18.5

THE VALUES OF THE H'S & M'S ARE TAKEN FROM SHEET 13.
THE MOVEMENT EQUATIONS ARE GIVEN ON SHEETS 9 & 12.

CRITERION 5-C-1 PRIMARY GENERAL MEMBRANE:

$S.I._{MAX} = \sigma_\theta - \sigma_r = \frac{PR}{t} + \frac{P}{2} = \underline{23.9 KSI} < S_m = 26.7 KSI$ [FOR LOCATIONS 1 & 2]

CRITERION 5-C-2 LOCAL MEMBRANE STRESS:

FOR CUT 1:

$\sigma_\theta = \frac{E\Delta}{R} = -3.8 KSI$

OR COMBINED WITH GENERAL MEMBRANE,

$S.I._{MAX} = \frac{PR}{t} + \frac{E\Delta}{R} + \frac{P}{2} = \underline{20.1 KSI} < 1.5S_m = 40 KSI$ [FOR LOCATIONS 1 & 2]

FOR CUT 2:

$\sigma_\theta = \frac{\nu\cos\theta H}{t} + \frac{E\Delta}{R} = -0.3 KSI$

OR COMBINED WITH GENERAL MEMBRANE

$S.I._{MAX} = \frac{PR}{2t} + \frac{\nu\cos\theta H}{t} + \frac{E\Delta}{R} + \frac{P}{2} = \underline{21.1 KSI} < 1.5S_m = 40 KSI$ [FOR LOCATIONS 3 & 4]

CRITERION 5-C-3 RANGE OF STRESS INTENSITY:

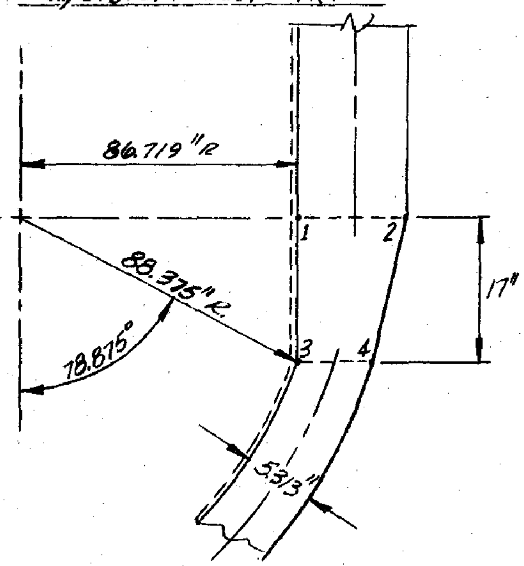
$S.I._{MAX} = \sigma_x - \sigma_r = \left[\frac{6M}{t^2} + \frac{\cos\theta H}{t} + \frac{PR}{2t}\right] + P = \underline{24.6 KSI} < 3S_m = 80 KSI$ [FOR LOCATION 3]

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER S-203-P | A341
SHEET 4 OF 16
CHARGE NO.
DATE 9-8-66 BY ALEXANDER
DESCRIPTION FATIGUE EVALUATION OF BOTTOM HEAD-TO-VESSEL JUNCTURE
CHECK DATE 9-8-66 BY CAUDLE

5. DETAILED ANALYSIS

a.) SYSTEM GEOMETRY



b.) SYSTEM LOADS

THE BOTTOM HEAD TO SHELL JUNCTURE WILL BE ANALYZED UNDER THE TRANSIENT CONDITIONS AS GIVEN IN REFERENCE 9.

c.) SYSTEM ALLOWABLES

1. THE RANGE OF PRIMARY PLUS SECONDARY STRESS RESULTING FROM MECHANICAL OR THERMAL LOADS SHALL NOT EXCEED $3S_m$ AT ACTUAL METAL TEMPERATURE AND OPERATING PRESSURE.

2. SHOW THAT EACH POINT MEETS THE REQUIREMENTS FOR PEAK STRESS INTENSITIES GIVEN IN N-414.5 OF THE A.S.M.E. CODE, SECTION III. THE PROCEDURE WILL BE AS OUTLINED IN N-415.2 OF SECTION III.

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO.

DESCRIPTION FATIGUE EVALUATION OF BOTTOM HEAD-TO-VESSEL JUNCTURE

NUMBER S-203-P | A 342
SHEET 5 OF 16
DATE 9-8-66 BY ALEXANDER
CHECK DATE 9-8-66 BY CAUDLE

5. DETAILED ANALYSIS

d.) UNCONCENTRATED STRESSES

AN INTERACTION ANALYSIS WAS MADE FOR THE BOTTOM HEAD TO SHELL AND REPORTED IN ANALYSIS NO. S-200-P. THE FOLLOWING EXPRESSIONS FOR STRESS DUE TO PRESSURE WERE TAKEN FROM THAT ANALYSIS. TO THESE EXPRESSIONS HAS BEEN ADDED A TERM FOR THE THERMAL STRESSES WHICH WILL BE CONSERVATIVELY TREATED AS SKIN STRESSES.

LOCATION 1

$$\sigma_x = \frac{6M_1}{t_1^2} + \frac{b_1^2 P}{2R_1 t_1} + \frac{E\alpha(T_m-T)}{(1-\nu)} = 0.08065\,M_1 + 4.76490\,P + 0.30571(T_m-T)$$

$$\sigma_\theta = \frac{\nu 6M_1}{t_1^2} + \frac{E\Delta_{11}}{R_1} + \frac{b_1 P}{t_1} + \frac{E\alpha(T_m-T)}{(1-\nu)} = 0.02420\,M_1 + 0.01099\,E\Delta_{11} + 10.02898\,P + 0.30571(T_m-T)$$

LOCATION 2

$$\sigma_x = -\frac{6M_1}{t_1^2} + \frac{b_1^2 P}{2R_1 t_1} + \frac{E\alpha(T_m-T)}{(1-\nu)} = -0.08065\,M_1 + 4.76490\,P + 0.30571(T_m-T)$$

$$\sigma_\theta = -\frac{\nu 6M_1}{t_1^2} + \frac{E\Delta_{11}}{R_1} + \frac{b_1 P}{t_1} + \frac{E\alpha(T_m-T)}{(1-\nu)} = -0.02420\,M_1 + 0.01099\,E\Delta_{11} + 10.02898\,P + 0.30571(T_m-T)$$

LOCATION 3

$$\sigma_x = \frac{6M_2}{t_3^2} + \frac{H_2 \cos\theta}{t_3} + \frac{P a_3^2}{2R_3 t_3} + \frac{E\alpha(T_m-T)}{(1-\nu)} = 0.21255\,M_2 + 0.03631\,H_2 + 8.03423\,P + 0.30571(T_m-T)$$

$$\sigma_\theta = \frac{\nu 6M_2}{t_3^2} + \frac{\nu H_2 \cos\theta}{t_3} + \frac{E\Delta_{32}}{R_3 \sin\theta} + \frac{t_3 E\Delta_{32}^* \cos\theta}{2R_3 \sin\theta} + \frac{P a_3^2}{2R_3 t_3} + \frac{E\alpha(T_m-T)}{(1-\nu)}$$

$$= 0.06377\,M_2 + 0.01089\,H_2 + 0.01120\,E\Delta_{32} + 0.00574\,E\Delta_{32}^* + 8.03423\,P + 0.30571(T_m-T)$$

LOCATION 4

$$\sigma_x = -\frac{6M_2}{t_3^2} + \frac{H_2 \cos\theta}{t_3} + \frac{P a_3^2}{2R_3 t_3} + \frac{E\alpha(T_m-T)}{(1-\nu)} = -0.21255\,M_2 + 0.03631\,H_2 + 8.03423\,P + 0.30571(T_m-T)$$

$$\sigma_\theta = -\frac{\nu 6M_2}{t_3^2} + \frac{\nu H_2 \cos\theta}{t_3} + \frac{E\Delta_{32}}{R_3 \sin\theta} - \frac{t_3 E\Delta_{32}^* \cos\theta}{2R_3 \sin\theta} + \frac{P a_3^2}{2R_3 t_3} + \frac{E\alpha(T_m-T)}{(1-\nu)}$$

$$= -0.06377\,M_2 + 0.01089\,H_2 + 0.01120\,E\Delta_{32} - 0.00574\,E\Delta_{32}^* + 8.03423\,P + 0.30571(T_m-T)$$

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO. ____

DESCRIPTION: FATIGUE EVALUATION OF BOTTOM HEAD-TO-SHELL JUNCTURE

NUMBER: S-203-P | A 343
SHEET: 6 OF 16
DATE: 9-8-66 BY: ALEXANDER
CHECK DATE: 9-8-66 BY: CAUDLE

5. DETAILED ANALYSIS

d.) UNCONCENTRATED STRESSES

SUMMARY OF STRESSES AND STRESS INTENSITIES AT LOCATION 1 *

TRANSIENT	TIME FROM START OF TRANS.	PRESS. (KSI)	$(T_m - T)$ °F	THERMAL STRESS $\sigma_x = \sigma_\theta$	PRESSURE STRESS σ_x	PRESSURE STRESS σ_θ	PRESSURE STRESS σ_r	TOTAL STRESSES σ_x	TOTAL STRESSES σ_θ	TOTAL STRESSES σ_r	STRESS INTENSITY $\sigma_x - \sigma_\theta$	STRESS INTENSITY $\sigma_x - \sigma_r$	STRESS INTENSITY $\sigma_\theta - \sigma_r$
STEADY STATE	~	2.25	0	0	11.9	19.5	-2.3	11.9	19.5	-2.3	-7.6	14.2	21.8
HEAT-UP	4.47 hrs.	2.25	-43	-13.1	11.9	19.5	-2.3	-1.2	6.4	-2.3	-7.6	1.1	8.7
COOL-DOWN	4.47 hrs.	0.32	43	13.1	1.7	2.8	-0.3	14.8	15.9	-0.3	-1.1	15.1	16.2
PLANT LOADING	20 min.	2.25	-7.8	-2.4	11.9	19.5	-2.3	9.5	17.1	-2.3	-7.6	11.8	19.4
PLANT UNLOADING	20 min.	2.25	7.8	2.4	11.9	19.5	-2.3	14.3	21.9	-2.3	-7.6	16.6	24.2
STEP LOAD INCREASE 10% OF FULL POWER	100 sec.	2.14	11.2	3.4	11.3	18.6	-2.1	14.7	22.0	-2.1	-7.3	16.8	24.1
	225 sec.	2.28	1.7	0.5	12.0	19.8	-2.3	12.5	20.3	-2.3	-7.8	14.8	22.6
STEP LOAD DECREASE 10% OF FULL POWER	40 sec.	2.32	-9.3	-2.8	12.3	20.1	-2.3	9.5	17.3	-2.3	-7.8	11.8	19.6
	100 sec.	2.26	-13.3	-4.1	11.9	19.6	-2.3	7.8	15.5	-2.3	-7.7	10.1	17.8
	260 sec.	2.14	-1.3	-0.4	11.3	18.6	-2.1	10.9	18.2	-2.1	-7.3	13.0	20.3
LOSS OF FLOW	12 sec.	2.25	33.3	10.2	11.9	19.5	-2.3	22.1	29.7	-2.3	-7.6	24.4	32.0
STEP LOAD REDUCTION FROM 100% TO 50% FULL POWER	2 min.	2.37	-12.0	-3.7	12.5	20.5	-2.4	8.8	16.8	-2.4	-8.0	11.2	19.2
	3.2 min.	2.35	-15.0	-4.6	12.4	20.4	-2.4	7.8	15.8	-2.4	-8.0	10.2	18.2
	10.4 min.	2.15	0	0	11.4	18.6	-2.2	11.4	18.6	-2.2	-7.2	13.6	20.8
REACTOR TRIP FROM FULL POWER	10 sec.	2.22	-9.5	-2.9	11.7	19.2	-2.2	8.8	16.3	-2.2	-7.5	11.0	18.5
	65 sec.	1.91	8.5	2.6	10.1	16.6	-1.9	12.7	19.2	-1.9	-6.5	14.6	21.1
PLANT HYDRO AT 3125 PSIG	220 min.	3.13	0	0	16.5	27.1	-3.1	16.5	27.1	-3.1	-10.6	19.6	30.2
PLANT HYDRO AT 2500 PSIG	HEAT.	1.25	-43	-13.1	6.6	10.8	-1.3	-6.5	-2.3	-1.3	-4.2	-5.2	-1.0
	S.S.	2.50	0	0	13.2	21.7	-2.5	13.2	21.7	-2.5	-8.5	15.7	24.2
	COOL.	0.32	43	13.1	1.7	2.8	-0.3	14.8	15.9	-0.3	-1.1	15.1	16.2
STEADY STATE FLUCTUATIONS	~	2.35	6.0	1.8	12.4	20.4	-2.4	14.2	22.2	-2.4	-8.0	16.6	24.6
		2.15	-6.0	-1.8	11.4	18.6	-2.2	9.6	16.8	-2.2	-7.2	11.8	19.0
LOSS OF LOAD	10 sec.	2.76	-30.2	-9.2	14.6	23.9	-2.8	5.4	14.7	-2.8	-9.3	8.2	17.5
	28 sec.	2.12	-41.2	-12.6	11.2	18.4	-2.1	-1.4	5.8	-2.1	-7.2	0.7	7.9
	160 sec.	1.44	4.8	1.5	7.6	12.5	-1.4	9.1	14.0	-1.4	-4.9	10.5	15.4
STEAM BREAK	51 sec.	0.10	191.0	60.2	3.7	6.1	-0.7	63.9	66.3	-0.7	-2.4	64.6	67.0

* THIS TABLE AND THE FOLLOWING ONES GIVE THE STRESSES AND STRESS INTENSITIES (UNCONCENTRATED) AT THE FOUR LOCATIONS AS SHOWN ON SHEET-4 USING THE EXPRESSIONS AS GIVEN ON SHEET-5.

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO. ______

DESCRIPTION FATIGUE EVALUATION OF BOTTOM HEAD-TO-SHELL JUNCTURE

NUMBER 5-203-P | A 344
SHEET 7 OF 16
DATE 9-8-66 BY ALEXANDER
CHECK DATE 9-8-66 BY CAUDLE

5. DETAILED ANALYSIS

d.) UNCONCENTRATED STRESSES

SUMMARY OF STRESSES AND STRESS INTENSITIES AT LOCATION 2

TRANSIENT	TIME FROM START OF TRANS.	PRESS. (KSI)	$(T_M - T)$ °F	THERMAL STRESS $\sigma_r = \sigma_\theta$	PRESSURE STRESS σ_x	PRESSURE STRESS σ_θ	PRESSURE STRESS σ_r	TOTAL STRESSES σ_x	TOTAL STRESSES σ_θ	TOTAL STRESSES σ_r	STRESS INTENSITY $\sigma_x - \sigma_\theta$	STRESS INTENSITY $\sigma_x - \sigma_r$	STRESS INTENSITY $\sigma_\theta - \sigma_r$
STEADY STATE	~	2.25	0	0	9.6	18.8	0	9.6	18.8	0	-9.2	9.6	18.8
HEAT-UP	4.47 hrs.	2.25	22	6.7	9.6	18.8		16.3	25.5		-9.2	16.3	25.5
COOL-DOWN	4.47 hrs.	0.32	-22	-6.7	1.4	2.7		-5.3	-4.0		-1.3	-5.3	-4.0
PLANT LOADING	20 min.	2.25	0	0	9.6	18.8		9.6	18.8		-9.2	9.6	18.8
PLANT UNLOADING	20 min.	2.25			9.6	18.8		9.6	18.8		-9.2	9.6	18.8
STEP LOAD INCREASE 10% OF FULL POWER	100 sec. 225 sec.	2.14 2.28			9.1 9.7	17.9 19.1		9.1 9.7	17.9 19.1		-8.8 -9.4	9.1 9.7	17.9 19.1
STEP LOAD DECREASE 10% OF FULL POWER	40 sec. 100 sec. 260 sec.	2.32 2.26 2.14			9.8 9.6 9.1	19.4 18.9 17.9		9.8 9.6 9.1	19.4 18.9 17.9		-9.6 -9.3 -8.8	9.8 9.6 9.1	19.4 18.9 17.9
LOSS OF FLOW	12 sec.	2.25			9.6	18.8		9.6	18.8		-9.2	9.6	18.8
STEP LOAD REDUCTION FROM 100% TO 50% FULL POWER	2 min. 3.2 min. 10.4 min.	2.37 2.35 2.15			10.1 10.0 9.1	19.8 19.6 18.0		10.1 10.0 9.1	19.8 19.6 18.0		-9.7 -9.6 -8.9	10.1 10.0 9.1	19.8 19.6 18.0
REACTOR TRIP FROM FULL POWER	10 sec. 65 sec.	2.22 1.91			9.4 8.1	18.6 16.0		9.4 8.1	18.6 16.0		-9.2 -7.9	9.4 8.1	18.6 16.0
PLANT HYDRO AT [illegible]	220 min.	3.13			13.3	26.2		13.3	26.2		-12.9	13.3	26.2
PLANT HYDRO AT ZERO PSIA	HEAT. S.S. COOL.	1.25 2.50 0.32	22 0 -22	6.7 0 -6.7	5.3 10.6 1.4	10.4 20.9 2.7		12.0 10.6 -5.3	17.1 20.9 -4.0		-5.1 -10.3 -1.3	12.0 10.6 -5.3	17.1 20.9 -4.0
STEADY STATE FLUCTUATIONS	~	2.35 2.15	0	0	10.0 9.1	19.6 18.0		10.0 9.1	19.6 18.0		-9.6 -8.9	10.0 9.1	19.6 18.0
LOSS OF LOAD	10 sec. 28 sec. 160 sec.	2.76 2.12 1.66			11.7 9.0 6.1	23.1 17.7 12.0		11.7 9.0 6.1	23.1 17.7 12.0		-11.4 -8.7 -5.9	11.7 9.0 6.1	23.1 17.7 12.0
STEAM BREAK	[illegible]	0.80			3.0	5.9		3.0	5.9		-2.9	3.0	5.9

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.
CHARGE NO.

NUMBER 5-203-P | A 345
SHEET 8 OF 16
DATE 9-8-66 BY ALEXANDER
CHECK DATE 9-8-66 BY CAUDLE

DESCRIPTION FATIGUE EVALUATION OF BOTTOM HEAD-TO-SHELL JUNCTURE

5. DETAILED ANALYSIS

d.) UNCONCENTRATED STRESSES

SUMMARY OF STRESSES AND STRESS INTENSITIES AT LOCATION 3.

TRANSIENT	TIME FROM START OF TRANS.	PRESS. (KSI)	$(T_m - T)$ °F	THERMAL STRESS	PRESSURE STRESS			TOTAL STRESSES			STRESS INTENSITY		
				$\sigma_x = \sigma_\theta$	σ_x	σ_θ	σ_r	σ_x	σ_θ	σ_r	$\sigma_x - \sigma_\theta$	$\sigma_x - \sigma_r$	$\sigma_\theta - \sigma_r$
STEADY STATE	~	2.25	0	0	22.3	19.0	-2.3	22.3	19.0	-2.3	3.3	24.6	21.3
HEAT-UP	4.47 hrs.	2.25	-18	-5.5	22.3	19.0	-2.3	16.8	13.5	-2.3	3.3	19.1	15.8
COOL-DOWN	4.47 hrs.	0.32	18	5.5	3.2	2.7	-0.3	8.7	8.2	-0.3	0.5	9.0	8.5
PLANT LOADING	20 min.	2.25	-7.8	-2.4	22.3	19.0	-2.3	19.9	16.6	-2.3	3.3	22.2	18.9
PLANT UNLOADING	20 min.	2.25	7.8	2.4	22.3	19.0	-2.3	24.7	21.4	-2.3	3.3	27.0	23.7
STEP LOAD INCREASE 10% OF FULL POWER	100 sec.	2.14	11.2	3.4	21.2	18.1	-2.1	24.6	21.5	-2.1	3.1	26.7	23.6
	225 sec.	2.28	1.7	0.5	22.6	19.3	-2.3	23.1	19.8	-2.3	3.3	25.4	22.1
STEP LOAD DECREASE 10% OF FULL POWER	40 sec.	2.32	-9.3	-2.8	23.0	19.6	-2.3	20.2	16.8	-2.3	3.4	22.5	19.1
	100 sec.	2.26	-13.3	-4.1	22.4	19.1	-2.3	18.3	15.0	-2.3	3.3	20.6	17.3
	260 sec.	2.14	-1.3	-0.4	21.2	18.1	-2.1	20.8	17.7	-2.1	3.1	22.9	19.8
LOSS OF FLOW	12 sec.	2.25	33.3	10.2	22.3	19.0	-2.3	32.5	29.2	-2.3	3.3	34.8	31.5
STEP LOAD REDUCTION FROM 100% TO 50% FULL POWER	2 min.	2.37	-12.0	-3.7	23.5	20.1	-2.4	19.8	16.4	-2.4	3.4	22.2	18.8
	3.2 min.	2.35	-15.0	-4.6	23.3	19.9	-2.4	18.7	15.3	-2.4	3.4	21.1	17.7
	10.4 min.	2.15	0	0	21.3	18.2	-2.2	21.3	18.2	-2.2	3.1	23.5	20.4
REACTOR TRIP FROM FULL POWER	10 sec.	2.22	-9.5	-2.9	22.0	18.8	-2.2	19.1	15.9	-2.2	3.2	21.3	18.1
	65 sec.	1.91	8.5	2.6	18.9	16.2	-1.9	21.5	18.8	-1.9	2.7	23.4	20.7
PLANT HYDRO AT 3125 PSIA	220 min.	3.13	0	0	31.0	26.5	-3.1	31.0	26.5	-3.1	4.5	34.1	29.6
PLANT HYDRO AT 2500 PSIA	HEAT.	1.25	-18	-5.5	12.4	10.6	-1.3	6.9	5.1	-1.3	1.8	8.2	6.4
	S.S.	2.50	0	0	24.8	21.2	-2.5	24.8	21.2	-2.5	3.6	27.3	23.7
	COOL.	0.32	18	5.5	3.2	2.7	-0.3	8.7	8.2	-0.3	0.5	9.0	8.5
STEADY STATE FLUCTUATIONS	~	2.35	6.0	1.8	23.3	19.9	-2.4	25.1	21.7	-2.4	3.4	27.5	24.1
		2.15	-6.0	-1.8	21.3	18.2	-2.2	19.5	16.4	-2.2	3.1	21.7	18.6
LOSS OF LOAD	10 sec.	2.76	-30.2	-9.2	27.4	23.4	-2.8	18.2	14.2	-2.8	4.0	21.0	17.0
	25 sec.	2.12	-41.2	-12.6	21.0	17.9	-2.1	8.4	5.3	-2.1	3.1	10.5	7.4
	160 sec.	1.44	4.8	1.5	14.3	12.2	-1.4	15.8	13.7	-1.4	2.1	17.2	15.1
STEAM BREAK	51 sec.	0.70	191.0	60.2	6.9	5.9	-0.7	67.1	66.1	-0.7	1.0	67.8	66.8

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER S-203-P | A 346
SHEET 9 OF 16
CHARGE NO. ______
DATE 9-8-66 BY ALEXANDER
DESCRIPTION FATIGUE EVALUATION OF BOTTOM HEAD-TO-SHELL JUNCTURE
CHECK DATE 9-8-66 BY CAUDLE

5. DETAILED ANALYSIS

d.) UNCONCENTRATED STRESSES

SUMMARY OF STRESSES AND STRESS INTENSITIES AT LOCATION 4.

TRANSIENT	TIME FROM START OF TRANS.	PRESS. (KSI)	(T_M-T) °F	THERMAL STRESS $\sigma_x=\sigma_\theta$	PRESSURE STRESS σ_x	PRESSURE STRESS σ_θ	PRESSURE STRESS σ_r	TOTAL STRESSES σ_x	TOTAL STRESSES σ_θ	TOTAL STRESSES σ_r	STRESS INTENSITY $\sigma_x-\sigma_\theta$	STRESS INTENSITY $\sigma_x-\sigma_r$	STRESS INTENSITY $\sigma_\theta-\sigma_r$
STEADY STATE	~	2.25	0	0	13.8	16.6	0	13.8	16.6	0	-2.8	13.8	16.6
HEAT-UP	4.47 hrs.	2.25	8	2.4	13.8	16.6		16.2	19.0		-2.8	16.2	19.0
COOL-DOWN	4.47 hrs.	0.32	-8	-2.4	2.0	2.4		-0.4	0		-0.4	-0.4	0
PLANT LOADING	20 min.	2.25	0	0	13.8	16.6		13.8	16.6		-2.8	13.8	16.6
PLANT UNLOADING	20 min.	2.25			13.8	16.6		13.8	16.6		-2.8	13.8	16.6
STEP LOAD INCREASE 10% OF FULL POWER	100 sec.	2.14			13.1	15.8		13.1	15.8		-2.7	13.1	15.8
	225 sec.	2.28			13.9	16.8		13.9	16.8		-2.9	13.9	16.8
STEP LOAD DECREASE 10% OF FULL POWER	40 sec.	2.32			14.2	17.1		14.2	17.1		-2.9	14.2	17.1
	100 sec.	2.26			13.8	16.7		13.8	16.7		-2.9	13.8	16.7
	260 sec.	2.14			13.1	15.8		13.1	15.8		-2.7	13.1	15.8
LOSS OF FLOW	12 sec.	2.25			13.8	16.6		13.8	16.6		-2.8	13.8	16.6
STEP LOAD REDUCTION FROM 100% TO 50% FULL POWER	2 min.	2.37			14.5	17.5		14.5	17.5		-3.0	14.5	17.5
	3.2 min.	2.35			14.4	17.4		14.4	17.4		-3.0	14.4	17.4
	10.4 min.	2.15			13.1	15.9		13.1	15.9		-2.8	13.1	15.9
REACTOR TRIP FROM FULL POWER	10 sec.	2.22			13.6	16.4		13.6	16.4		-2.8	13.6	16.4
	65 sec.	1.91			11.7	14.1		11.7	14.1		-2.4	11.7	14.1
PLANT HYDRO AT 3125 PSIA	220 min.	3.13	↓	↓	19.1	23.1		19.1	23.1		-4.0	19.1	23.1
PLANT HYDRO AT 2500 PSIA	HEAT. S.S. COOL.	1.25 2.50 0.32	8 0 -8	2.4 0 -2.4	7.6 15.3 2.0	9.2 18.5 2.4		10.0 15.3 -0.4	11.6 18.5 0		-1.6 -3.2 -0.4	10.0 15.3 -0.4	11.6 18.5 0
STEADY STATE FLUCTUATIONS	~	2.35	0	0	14.4	17.4		14.4	17.4		-3.0	14.4	17.4
		2.15			13.1	15.9		13.1	15.9		-2.8	13.1	15.9
LOSS OF LOAD	10 sec.	2.76			16.9	20.4		16.9	20.4		-3.5	16.9	20.4
	28 sec.	2.12			13.0	15.7		13.0	15.7		-2.7	13.0	15.7
	160 sec.	1.44			8.8	10.6		8.8	10.6		-1.8	8.8	10.6
STEAM BREAK	54 sec.	0.70	↓	↓	4.3	5.2	↓	4.3	5.2	↓	-0.9	4.3	5.2

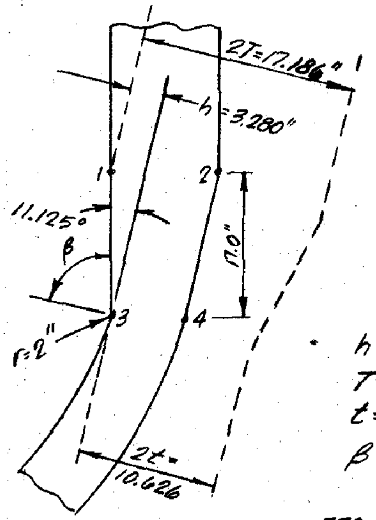
FROM THE ABOVE TABLES, WE SEE THAT THE MAXIMUM RANGE OF STRESS INTENSITY OCCURS AT LOCATION 3 AND IS $S.I._{max\ range} = 34.1$ KSI $< 3S_m = 80.1$ KSI CRITERION 5-C-1

IPEC00069848

5. DETAILED ANALYSIS

e) PEAK STRESSES

IN ORDER TO PERFORM THE FATIGUE EVALUATION, PEAK STRESSES MUST BE KNOWN AT THE FOUR LOCATIONS AS SHOWN BELOW. THE STRESS EXPRESSIONS GIVEN ON SHEET 5 WILL BE MODIFIED TO ACCOUNT FOR STRESS CONCENTRATIONS. WITH THE PEAK STRESSES, A FATIGUE EVALUATION WILL BE MADE BY THE CUMULATIVE METHOD WHEREIN SUPERPOSITION OF ALL CYCLES IS TAKEN INTO CONSIDERATION.



BY INSPECTION, WE SEE THAT THE STRESS CONCENTRATION FACTOR AT LOCATIONS 1, 2 AND 4 EQUALS 1.0. AT LOCATION 3, STRESS CONCENTRATION FACTORS FOR BENDING AND TENSION WILL BE DETERMINED BY THE METHOD PRESENTED IN REFERENCE 6.

$h \approx 17.0 \sin 11.125° = 3.280"$

$T = 8.593"$ $\qquad \frac{r}{t} = 0.376$

$t = 5.313"$ $\qquad \frac{r}{h} = 0.610$

$\beta = 78.875°$ $\qquad \frac{\beta}{90} = 0.876$

FROM FIGURE A.7-1 OF REF. 6:

$K_T = 2.0$, $K_B = 1.65$

FROM FIGURE A.7-2 OF REF. 6:

$$\left[\frac{K'-1}{K_o-1}\right] = 0.31 \qquad K'_T = 1+0.31(K_T-1) = 1+0.31(2-1) = 1.31$$

$$K'_B = 1+0.31(K_B-1) = 1+0.31(1.65-1) = 1.20$$

STRESS EXPRESSIONS FOR LOCATION 3

$$\sigma_X = \frac{6M_z}{t_3^2}K'_B + \frac{H_2 \cos\theta}{t_3}K'_T + \frac{Pa_3^2}{2R_3t_3}K'_T + \frac{E\alpha(T_m-T)}{(1-\nu)}K'_T = \underline{12.77366\,P + 0.40048(T_m-T)}$$

$$\sigma_\theta = \frac{\nu 6M_z}{t_3^2}K'_B + \frac{\nu H_2 \cos\theta}{t_3} + \frac{E\Delta_{3z}}{R_3 \sin\theta} + \frac{t_3 E\Delta^{*}_{2z} \cos\theta}{2R_3 \sin\theta} + \frac{Pa_3^2}{2R_3t_3} + \frac{E\alpha(T_m-T)}{(1-\nu)} = \underline{8.57704\,P + 0.30571(T_m-T)}$$

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.
CHARGE NO.

NUMBER 5-203-P | A 348
SHEET 11 OF 16
DATE 9-8-66 BY ALEXANDER
CHECK DATE 9-8-66 BY CAUDLE

DESCRIPTION FATIGUE EVALUATION OF BOTTOM HEAD-TO-VESSEL JUNCTURE

5. DETAILED ANALYSIS

e) PEAK STRESSES

WITH THE EXPRESSIONS FOR STRESSES AS GIVEN ON SHEET 10 WE GET THE FOLLOWING VALUES FOR PEAK STRESSES.

TRANSIENT	TIME	PRESS. (KSI)	$T_m - T$ (°F)	THERMAL STRESSES		PRESS. STRESSES			PEAK STRESSES		
				σ_x	σ_θ	σ_x	σ_θ	σ_r	σ_x	σ_θ	σ_r
STEADY STATE	—	2.25	0	0	0	28.7	19.3	-2.3	28.7	19.3	-2.3
HEAT-UP	4.47 HRS.	2.25	-18	-7.2	-5.5	28.7	19.3	-2.3	21.5	13.8	-2.3
COOL-DOWN	4.47 HRS.	0.32	18	7.2	5.5	4.1	2.7	-0.3	11.3	8.2	-0.3
PLANT LOADING	20 MIN.	2.25	-7.8	-3.1	-2.4	28.7	19.3	-2.3	25.6	16.9	-2.3
PLANT UNLOADING	20 MIN.	2.25	7.8	3.1	2.4	28.7	19.3	-2.3	31.8	21.7	-2.3
STEP LOAD INCREASE 10% OF FULL POWER	100 SEC.	2.14	11.2	4.5	3.4	27.3	18.4	-2.1	31.8	21.8	-2.1
	225 SEC.	2.28	1.7	0.7	0.5	29.1	19.6	-2.3	29.8	20.1	-2.3
STEP LOAD DECREASE 10% OF FULL POWER	40 SEC.	2.32	-9.3	-3.7	-2.8	29.6	19.9	-2.3	25.9	17.1	-2.3
	100 SEC.	2.26	-13.3	-5.3	-4.1	28.9	19.4	-2.3	23.6	15.3	-2.3
	260 SEC.	2.14	-1.3	-0.5	-0.4	27.3	18.4	-2.1	26.8	18.0	-2.1
LOSS OF FLOW	12 SEC.	2.25	33.3	13.3	10.2	28.7	19.3	-2.3	42.0	29.5	-2.3
STEP LOAD REDUCTION FROM 100% TO 50% FULL POWER	2 MIN.	2.37	-12.0	-4.8	-3.7	30.3	20.3	-2.4	25.5	16.6	-2.4
	3.2 MIN.	2.35	-15.0	-6.0	-4.6	30.0	20.2	-2.4	24.0	15.6	-2.4
	10.4 MIN.	2.15	0	0	0	27.5	18.4	-2.2	27.5	18.4	-2.2
REACTOR TRIP FROM FULL POWER	10 SEC.	2.22	-9.5	-3.8	-2.9	28.4	19.0	-2.2	24.6	16.1	-2.2
	65 SEC.	1.91	8.5	3.4	2.6	24.4	16.4	-1.9	27.8	19.0	-1.9
PLANT HYDRO AT 3125 PSIA	220 MIN.	3.13	0	0	0	40.0	26.8	-3.1	40.0	26.8	-3.1
PLANT HYDRO AT 2500 PSIA	HEAT.	1.25	-18	-7.2	-5.5	16.0	10.7	-1.3	8.8	5.2	-1.3
	S.S.	2.50	0	0	0	32.0	21.4	-2.5	32.0	21.4	-2.5
	COOL.	0.32	18	7.2	6.5	4.1	2.7	-0.3	11.3	8.2	-0.3
STEADY STATE FLUCTUATIONS	—	2.35	6.0	2.4	1.8	30.0	20.2	-2.4	32.4	22.0	-2.4
	—	2.15	-6.0	-2.4	-1.8	27.5	18.4	-2.2	25.1	16.6	-2.2
LOSS OF LOAD	10 SEC.	2.76	-30.2	-12.1	-9.2	35.3	23.7	-2.8	23.2	14.5	-2.8
	28 SEC.	2.12	-41.2	-16.5	-12.6	27.1	18.2	-2.1	10.6	5.6	-2.1
	160 SEC.	1.44	4.8	1.9	1.5	18.4	12.4	-1.4	20.3	13.9	-1.4
STEAM BREAK	54 SEC.	0.70	197.0	78.9	60.2	8.9	6.0	-0.7	87.8	66.2	-0.7

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER S-203-P | A 349
SHEET 12 OF 16
CHARGE NO.
DATE 9-8-66 BY ALEXANDER
DESCRIPTION FATIGUE EVALUATION OF BOTTOM HEAD-TO-VESSEL JUNCTURE
CHECK DATE 9-8-66 BY CAUDLE

5. DETAILED ANALYSIS

e.) PEAK STRESSES

PEAK STRESS INTENSITIES

TRANSIENT	LOCATION 1			LOCATION 2			LOCATION 3			LOCATION 4		
	$\sigma_x-\sigma_\theta$	$\sigma_x-\sigma_r$	$\sigma_\theta-\sigma_r$	$\sigma_x-\sigma_\theta$	$\sigma_x-\sigma_r$	$\sigma_\theta-\sigma_r$	$\sigma_x-\sigma_\theta$	$\sigma_x-\sigma_r$	$\sigma_\theta-\sigma_r$	$\sigma_x-\sigma_\theta$	$\sigma_x-\sigma_r$	$\sigma_\theta-\sigma_r$
STEADY STATE	-7.6	14.2	21.8	-9.2	9.6	18.8	9.4	31.0	21.6	-2.8	13.8	16.6
HEAT-UP	-7.6	1.1	8.7	-9.2	16.3	25.5	7.7	23.8	16.1	-2.8	16.2	19.0
COOL-DOWN	-1.1	15.1	16.2	-1.3	-5.3	-4.0	3.1	11.6	8.5	-0.4	-0.4	0
PLANT LOADING	-7.6	11.8	19.4	-9.2	9.6	18.8	8.7	27.9	19.2	-2.8	13.8	16.6
PLANT UNLOADING	-7.6	16.6	24.2	-9.2	9.6	18.8	10.1	34.1	24.0	-2.8	13.8	16.6
STEP LOAD INCREASE 10% OF FULL POWER	-7.3	16.8	24.1	-8.8	9.1	17.9	10.0	33.9	23.9	-2.7	13.1	15.8
	-7.8	14.8	22.6	-9.4	9.7	19.1	9.7	32.1	22.4	-2.9	13.9	16.8
STEP LOAD DECREASE 10% OF FULL POWER	-7.8	11.8	19.6	-9.6	9.8	19.4	8.8	28.2	19.4	-2.9	14.2	17.1
	-7.7	10.1	17.8	-9.3	9.6	18.9	8.3	25.9	17.6	-2.9	13.8	16.7
	-7.3	13.0	20.3	-8.8	9.1	17.9	8.8	28.9	20.1	-2.7	13.1	15.8
LOSS OF FLOW	-7.6	24.4	32.0	-9.2	9.6	18.8	12.5	44.3	31.8	-2.8	13.8	16.6
STEP LOAD REDUCTION FROM 100% TO 50% FULL POWER	-8.0	11.2	19.2	-9.7	10.1	19.8	8.9	27.9	19.0	-3.0	14.5	17.5
	-8.0	10.2	18.2	-9.6	10.0	19.6	8.4	26.4	18.0	-3.0	14.4	17.4
	-7.2	13.6	20.8	-8.9	9.1	18.0	9.1	29.7	20.6	-2.8	13.1	15.9
REACTOR TRIP FROM FULL POWER	-7.5	11.0	18.5	-9.2	9.4	18.6	8.5	26.8	18.3	-2.8	13.6	16.4
	-6.5	14.6	21.1	-7.9	8.1	16.0	8.8	29.7	20.9	-2.4	11.7	14.1
PLANT HYDRO AT 3125	-10.6	19.6	30.2	-12.9	13.3	26.2	13.2	43.1	29.9	-4.0	19.1	23.1
PLANT HYDRO AT 2500 PSIA	-4.2	-5.2	-1.0	-5.1	12.0	17.1	3.6	10.1	6.5	-1.6	10.0	11.6
	-8.5	15.7	24.2	-10.3	10.6	20.9	10.6	34.5	23.9	-3.2	15.3	18.5
	-1.1	15.1	16.2	-1.3	-5.3	-4.0	3.1	11.6	8.5	-0.4	-0.4	0
STEADY STATE FLUCTUATIONS	-8.0	16.6	24.6	-9.6	10.0	19.6	10.4	34.8	24.4	-3.0	14.4	17.4
	-7.2	11.8	19.0	-8.9	9.1	18.0	8.5	27.3	18.8	-2.8	13.1	15.9
LOSS OF LOAD	-9.3	8.2	17.5	-11.4	11.7	23.1	8.7	26.0	17.3	-3.5	16.9	20.4
	-7.2	0.7	7.9	-8.7	9.0	17.7	5.0	12.7	7.7	-2.7	13.0	15.7
	-4.9	10.5	15.4	-5.9	6.1	12.0	6.4	21.7	15.3	-1.8	8.8	10.6
STEAM BREAK	-2.4	64.6	67.0	-2.9	3.0	5.9	21.6	88.5	66.9	-0.9	4.3	5.2

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.
CHARGE NO.

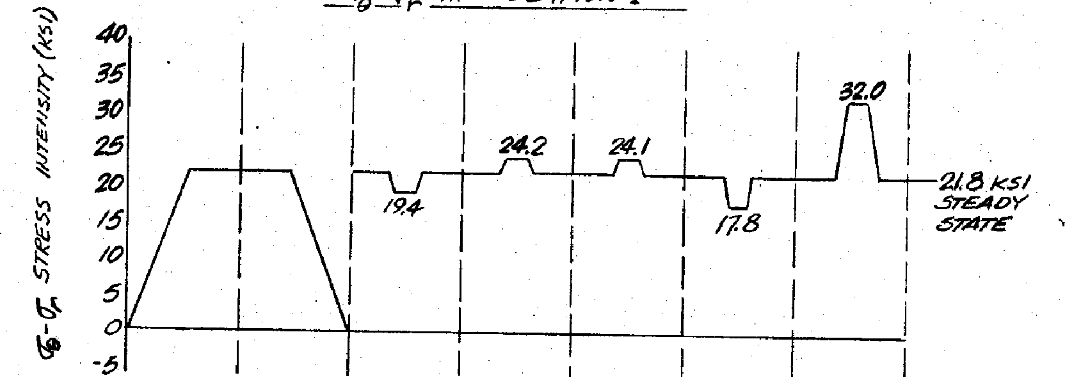
NUMBER S-203-P | A 350
SHEET 13 OF 16
DATE 9-8-66 BY ALEXANDER
CHECK DATE 9-8-66 BY CAUDLE

DESCRIPTION FATIGUE EVALUATION OF BOTTOM HEAD-TO-SHELL JUNCTURE

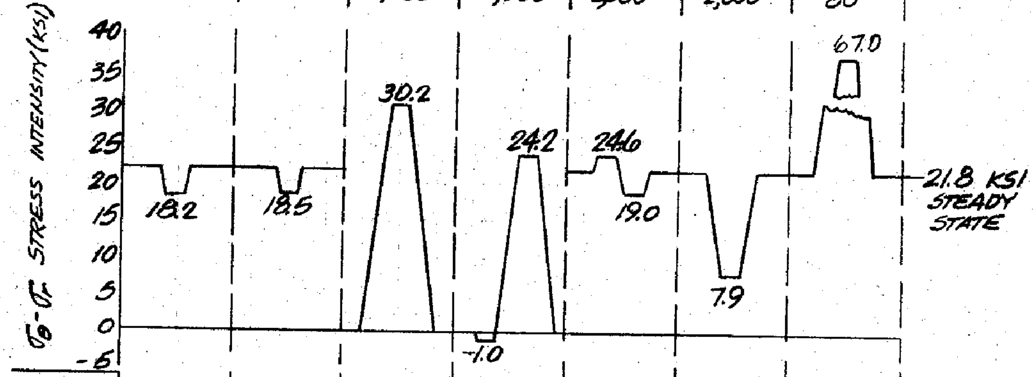
5 DETAILED ANALYSIS

f.) FATIGUE EVALUATION

$\sigma_\theta - \sigma_r$ AT LOCATION 1



TRANSIENT	HEAT-UP	COOL-DOWN	PLANT LOADING	PLANT UNLOADING	STEP LOAD INCREASE 10% OF F.P.	STEP LOAD DECREASE 10% OF F.P.	LOSS OF FLOW
OCCURRENCES	200	200	14,500	14,500	2,000	2,000	80



TRANSIENT	STEP LOAD REDUCTION 100%-50% F.P.	REACTOR TRIP	PLANT HYDRO AT 3125	PLANT HYDRO AT 1600	STEADY STATE FLUCTUATIONS	LOSS OF LOAD	STEAM BREAK
OCCURRENCES	200	400	5	5	∞	80	5

$S_{MAX.}$	$S_{MIN.}$	NUMBER OF OCCURRENCES	S_A	N*	U
67.0	-1.0	5	34.0	14,000	0.00035
32.0	0	80	16.0	250,000	0.00032
30.2	0	5	15.1	350,000	0.00001
24.6	0	115	12.3	∞	0

$U_{OVERALL} = 0.0007$

* FROM FIG. N-415 (A) REF. 1

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO. ______

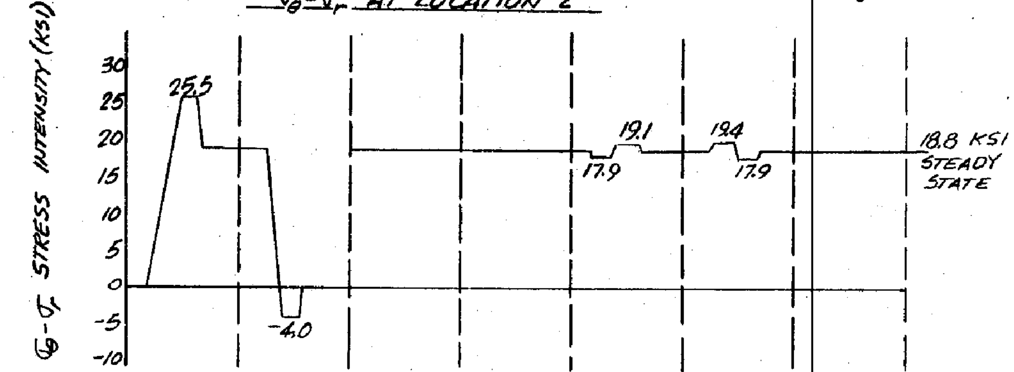
DESCRIPTION FATIGUE ANALYSIS OF BOTTOM HEAD-TO-VESSEL JUNCTURE

NUMBER S-203-P | A 351
SHEET 14 OF 16
DATE 9-8-66 BY ALEXANDER
CHECK DATE 9-8-66 BY CAUDLE

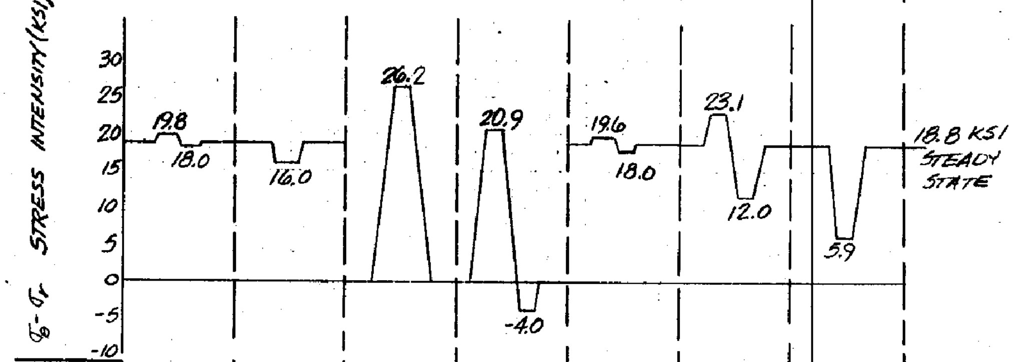
5. DETAILED ANALYSIS

f.) FATIGUE EVALUATION

$\sigma_\theta - \sigma_r$ AT LOCATION 2



TRANSIENT	HEAT-UP	COOL-DOWN	PLANT LOADING	PLANT UNLOADING	STEP LOAD INCREASE 10% OF F.P.	STEP LOAD DECREASE 10% OF F.P.	LOSS OF FLOW
OCCURRENCES	200	200	14,500	14,500	2,000	2,000	80



TRANSIENT	STEP LOAD REDUCTION 100%-50% F.P.	REACTOR TRIP	PLANT HYDRO AT 3125	PLANT HYDRO AT 2800	STEADY STATE FLUCTUATIONS	LOSS OF LOAD	STEAM BREAK
OCCURRENCES	200	400	5	5	∞	80	5

$S_{MAX.}$	$S_{MIN.}$	NUMBER OF OCCURRENCES	S_A	N*	U
26.2	-4.0	5	15.1	350,000	0.00001
25.5	-4.0	200	14.8	400,000	0.00050
23.1	5.9	5	8.6	∞	0

* FROM FIG. N-415 (A) REF. 1

$U_{OVERALL} = 0.0005$

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO.

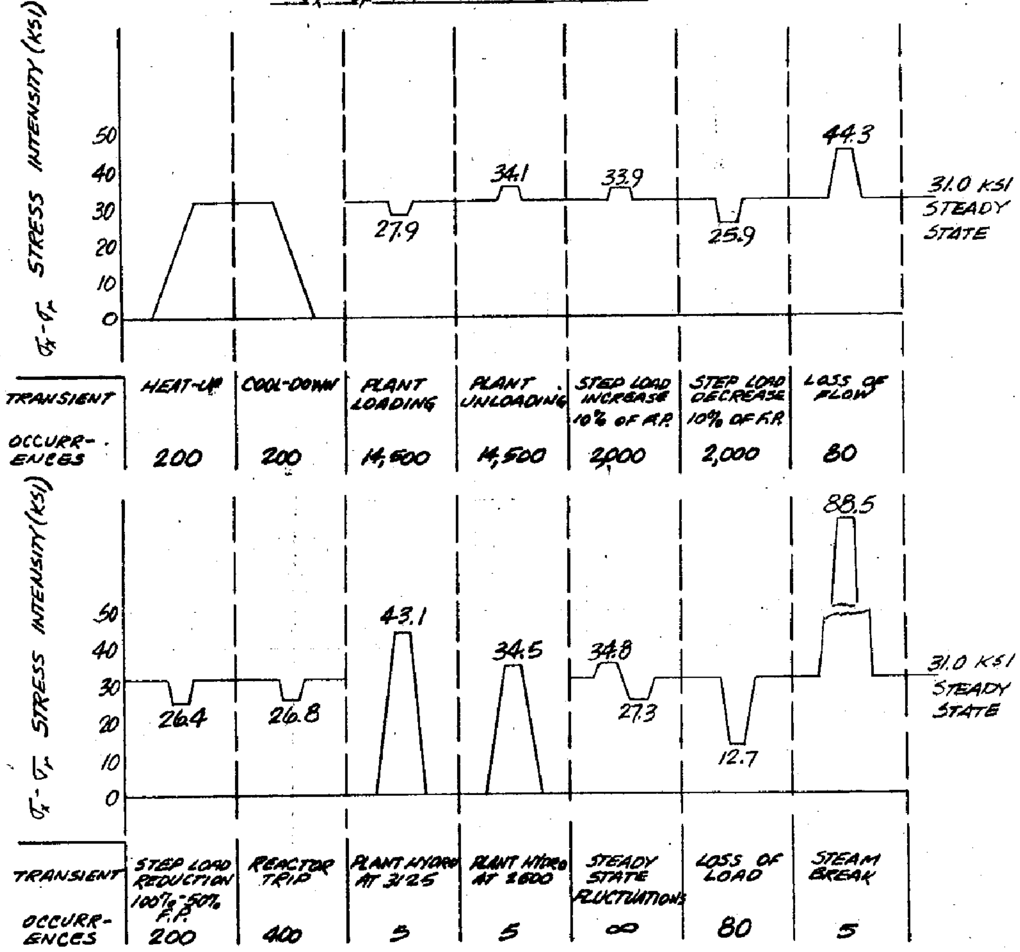
DESCRIPTION FATIGUE ANALYSIS OF BOTTOM HEAD-TO-VESSEL JUNCTURE

NUMBER S-203-P | A 3.52
SHEET 15 OF 16
DATE 9-8-66 BY ALEXANDER
CHECK DATE 9-8-66 BY CAUDLE

5. DETAILED ANALYSIS

f) FATIGUE EVALUATION

$\sigma_x - \sigma_r$ AT LOCATION 3



$S_{MAX.}$	$S_{MIN.}$	NUMBER OF OCCURRENCES	S_A	N*	U
88.5	0	5	44.3	6000	0.00084
44.3	0	80	22.2	60,000	0.00133
43.1	0	5	21.6	70,000	0.00007
34.8	0	115	17.4	170,000	0.00067
34.5	0	5	17.3	180,000	0.00002
34.8	12.7	80	11.1	∞	0

* FROM FIG. N-415 (A) REF. 1

$U_{OVERALL} = 0.003$

COMBUSTION ENGINEERING, INC.
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CHARGE NO.

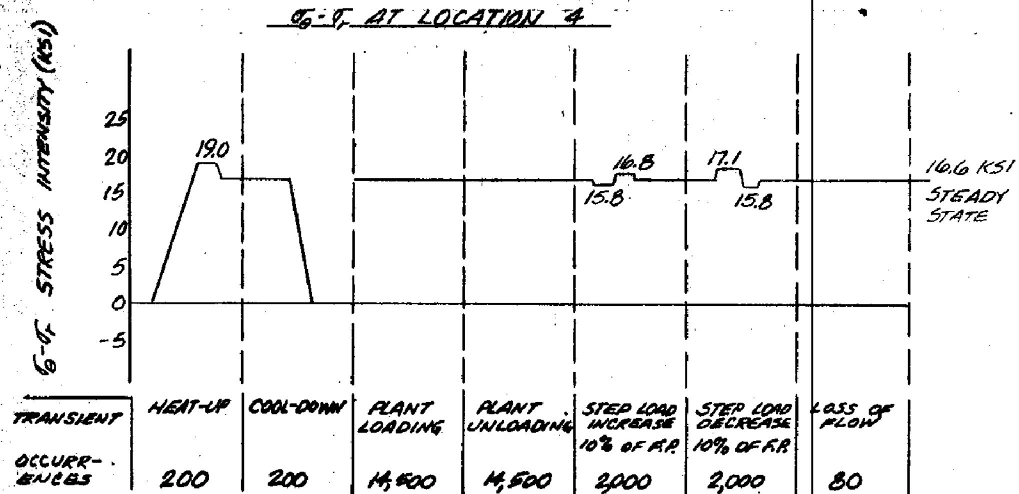
DESCRIPTION FATIGUE ANALYSIS OF BOTTOM HEAD-TO-VESSEL JUNCTURE

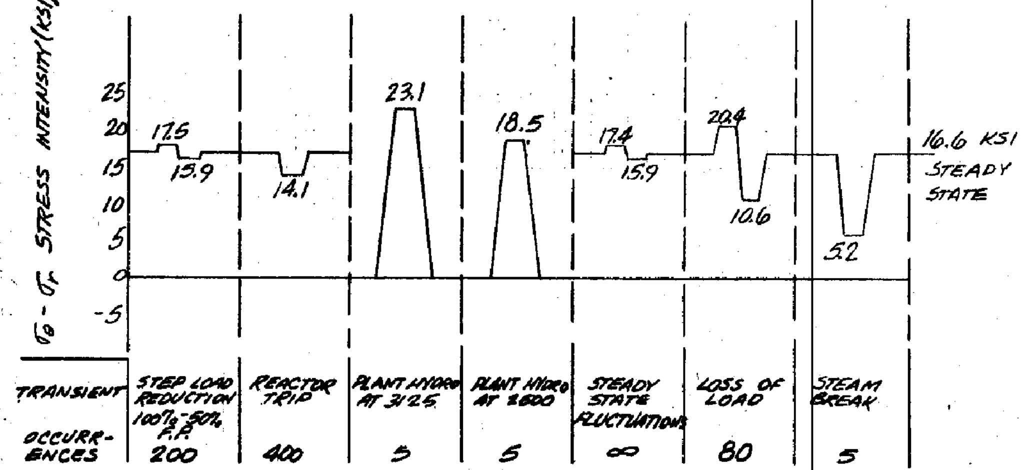
NUMBER S-203-P | A 353
SHEET 16 OF 16
DATE 9-8-66 BY ALEXANDER
CHECK DATE 9-8-66 BY CAUDLE

5. DETAILED ANALYSIS

f) FATIGUE EVALUATION

$\sigma_\theta - \sigma_r$ AT LOCATION 4





S_{MAX}	S_{MIN}	NUMBER OF OCCURRENCES	S_A	N*	U
23.1	0	5	11.6	∞	0

TOTAL U = 0

* FROM FIG. N-415 (A) REF. 1

COMBUSTION ENGINEERING, INC.
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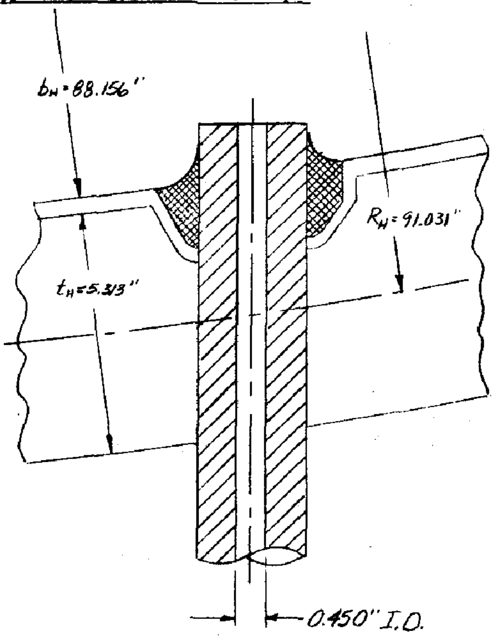
CHARGE NO.

NUMBER S-204-P | A 354
SHEET 5 OF 17
DATE 1-11-67 BY COCKRELL
CHECK DATE 1-11-67 BY CAUDLE

DESCRIPTION STRUCTURAL AND FATIGUE ANALYSIS OF BOTTOM HEAD INSTRUMENTATION PENETRATIONS

5- DETAILED ANALYSIS:

a- SYSTEM GEOMETRY:



MATERIAL:
BOTTOM HEAD ___ SA-302B
INST. TUBE ___ INCONEL

DIA. OF HEAD PENETRATION:

$1.500 \begin{smallmatrix} +0.002 \\ -0.000 \end{smallmatrix}$ INCHES

OUTSIDE DIA. OF INST. TUBE:

$1.499 \begin{smallmatrix} +0.000 \\ -0.001 \end{smallmatrix}$ INCHES

REF. DWG. E-232-056

b- SYSTEM LOADS:

THE BOTTOM HEAD INSTRUMENTATION PENETRATION AS SHOWN ABOVE WILL BE INVESTIGATED FOR THE FOLLOWING LOADS IN THIS ANALYSIS.

1- DESIGN PRESSURE OF 2.5 KSI AT DESIGN TEMPERATURE OF 650°F

2- THE THERMAL AND PRESSURE TRANSIENTS AS GIVEN IN REF.-9

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER 5-204-P | A 355
SHEET 6 OF 17
CHARGE NO. ______
DATE 1-11-67 BY COCKRELL
DESCRIPTION STRUCTURAL AND FATIGUE ANALYSIS OF BOTTOM HEAD INSTRUMENTATION PENETRATIONS
CHECK DATE 1-11-67 BY LAVOLE

5. DETAILED ANALYSIS:

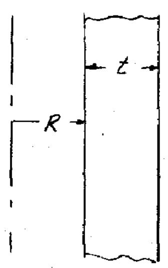
c. SYSTEM ALLOWABLES:

THE FOLLOWING ALLOWABLE STRESSES ARE BASED ON THE ASME NUCLEAR CODE SECTION III, REFERENCE - 1 AND ARE RELEVANT FOR THIS ANALYSIS.

1. THE AVERAGE PRIMARY STRESS INTENSITY ACROSS A SOLID SECTION SHALL NOT EXCEED S_m AT DESIGN TEMP. (650°F) AND DESIGN PRESSURE (2.5 KSI).
2. THE RANGE OF PRIMARY PLUS SECONDARY STRESS INTENSITY RESULTING FROM MECHANICAL AND THERMAL LOADS SHALL NOT EXCEED $3S_m$ AT ACTUAL METAL TEMP. AND OPERATING PRESSURE.
3. SHOW THAT EACH POINT MEETS THE REQUIREMENTS FOR PEAK STRESS INTENSITY GIVEN IN N-414.5 OF THE ASME CODE SECTION III. THE PROCEDURE WILL BE AS OUTLINED IN N-415.2 OF SECTION III.

d. DESIGN SIZING:

CONSIDER THE THICKNESS OF THE INST. TUBE



DESIGN PRESSURE = 2.5 KSI
DESIGN TEMPERATURE = 650°F
MATERIAL:
INCONEL TUBE, S_m = 23.3 KSI (FROM REF. 4)
R = 0.225 in
t_{ACT} = 0.524 in

FROM N-431 OF SECTION III ASME NUCLEAR CODE:

$$t_{REQ'D} = \frac{PR}{S_m - 0.5P} = \frac{2.5(0.225)}{23.3 - 1.25} = 0.026\,in < 0.524\,in$$

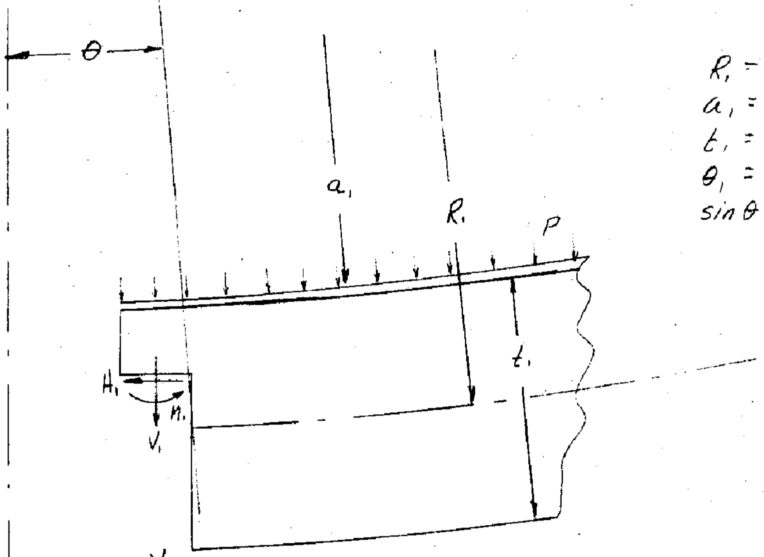
ACTUAL THICKNESS; HENCE, CRITERION 5-C-1 IS SATISFIED.

5- Detailed Analysis:

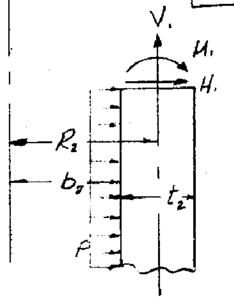
e- Interaction Analysis:

1- Analytical Model:

The Actual Structure Will Be Approximated By The Following Analytical Model. For The Purpose Of This Analysis, The Bottom Head (Element-1) Will Be Assumed To Be A Rigid Body With Local Flexibility Only When Calculating The Displacements Due To The Redundant Forces. Note That Element-1 Is Treated As A Perforated Shell With An Effective Young's Modulus Of E^* And An Effective Poisson's Ratio Based On The Ligament Efficiency When Calculating Deflections Due To Pressure.



$R_1 = 91.031"$
$a_1 = 88.156$
$t_1 = 5.313$
$\theta_1 = 28.3'$
$\sin\theta = 0.00823$



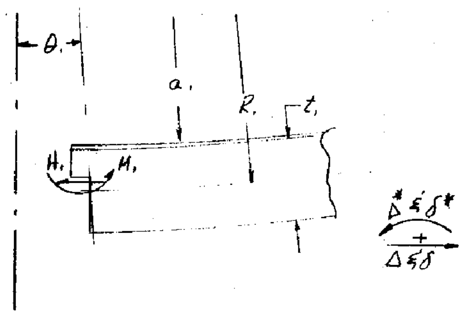
$R_2 = 0.497"$
$b_2 = 0.225"$
$t_2 = 0.524"$

5- DETAILED ANALYSIS:

e. INTERACTION ANALYSIS:

2- DEFLECTIONS:

ELEMENT 1:



$R_1 = 91.031''$

$a_1 = 88.156''$

$t_1 = 5.313''$

$\theta_1 = 28.3'$

$\frac{E^*}{E} = 0.88$, $\nu^* = 0.29$ } For L.E. = 0.823

$\frac{E_2}{E_1} = \frac{E_{INCONEL}}{E_{302B}} = 1.13793$

DISPLACEMENTS DUE TO REDUNDANT FORCES:

$$E_2\Delta_{11} = -1.408(1-\nu^2)\left[\left(\frac{R_2}{t_2}+\frac{1}{2}\right)\ln\left(\frac{R_2}{t_2}+\frac{1}{2}\right)-\left(\frac{R_2}{t_2}-\frac{1}{2}\right)\ln\left(\frac{R_2}{t_2}-\frac{1}{2}\right)+\frac{1}{2}\right]H_1+\frac{2.38(1-\nu-2\nu^2)}{t_2}M_1$$

$$= \underline{-1.76005\,H_1 + 2.36183\,M_1}$$

$$E_2\Delta^*_{11} = -\frac{2.38(1-\nu-2\nu^2)}{t_2}H_1 + \frac{6.36(1-\nu^2)}{(t_2)^2}M_1$$

$$= \underline{-2.36183\,H_1 + 21.07830\,M_1}$$

† From Ref. 18

DISPLACEMENTS DUE TO PRESSURE:

$$E_2\delta_{11} = \frac{(1-\nu^*)a^2}{2t_1}P\sin\theta\,\frac{E_1}{E^*}\times\frac{E_2}{E_1} = \frac{(1-0.29)(88.156)^2}{2(5.313)}P(0.00823)\left(\frac{1}{0.88}\right)(1.13793)$$

$$= \underline{5.52618\,P}$$

$$E_2\delta^*_{11} = 0$$

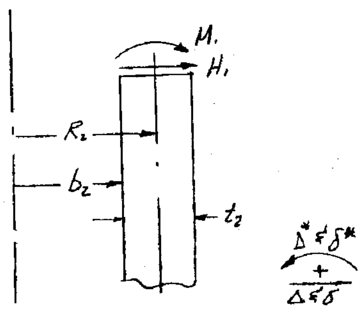
DISPLACEMENTS DUE TO TEMPERATURE

$$E_2\delta_{11} = R_{HOLE}(E\alpha)_1(T_{m_1}-70)\frac{E_2}{E_1} = 0.85345(E\alpha)_1(T_{m_1}-70)$$

$$E_2\delta^*_{11} = 0$$

5. Detailed Analysis:
e. Interaction Analysis:
2. Deflection:

Element 2:



$R_2 = 0.487''$
$b_2 = 0.225''$
$t_2 = 0.524''$
$\beta^4 = \frac{3(1-\nu^2)}{R^2 t^2} = 41.92187$
$\beta^2 = 6.47471$
$\beta = 2.54455$
$D = \frac{Et^3}{12(1-\nu^2)} = \frac{E}{75.29770}$

Displacements Due To Redundant Forces:

$$E_2 \Delta_{21} = \frac{E}{2\beta^3 D} H_1 + \frac{E}{2\beta^2 D} M_1 = 2.30338 H_1 + 5.86109 M_1$$

$$E \Delta^*_{21} = -\frac{E}{2\beta^2 D} H_1 - \frac{E}{\beta D} M_1 = -5.86109 H_1 - 29.82755 M_1$$

Displacements Due To Pressure

$$E_2 \delta_{21} = \frac{b_2^2}{t_2}\left(\frac{R_2}{b_2} - \frac{\nu}{2}\right) P = 0.19462 P$$

$$E_2 \delta^*_{21} = 0$$

Displacements Due To Temperature:

$$E_2 \delta_{21} = R_2 (E\alpha)_2 (T_{m_2} - 70) = 0.487 (E\alpha)_2 (T_{m_2} - 70)$$

$$E_2 \delta^*_{21} = 0$$

5. Detailed Analysis:

e. Interaction Analysis:

3. Continuity Matrix And Loading Vectors

From Continuity We Have,

$$E_2 \Delta_{11} - E_2 \Delta_{21} = E_2 \delta_{21} - E_2 \delta_{11} = -5.33156\, P - \left[0.85345(E\alpha)_1 (T_{m_1} - 70) - 0.487(E\alpha)_2 (T_{m_2} - 70)\right]$$

$$E_2 \Delta^*_{11} - E_2 \Delta_{21} = E_2 \delta^*_{21} - E_2 \delta^*_{11} = 0$$

Let,

$$W_P + W_T = -5.33156 P - \left[0.85345(E\alpha)_1 (T_{m_1} - 70) - 0.487(E\alpha)_2 (T_{m_2} - 70)\right]$$

In Matrix Form We Have,

$$\begin{bmatrix} -4.06343 & -3.49926 \\ 3.49926 & 50.90585 \end{bmatrix} \begin{bmatrix} H_1 \\ M_1 \end{bmatrix} = \begin{bmatrix} 1 \\ 0 \end{bmatrix} W_P + \begin{bmatrix} 1 \\ 0 \end{bmatrix} W_T$$

4. Redundant Load Values:

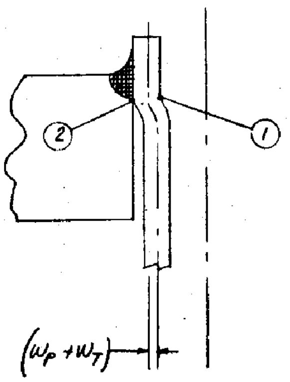
Solving The Above Matrix, We Get The Following Values For The Redundant Forces,

$$H_1 = -0.26158\,(W_P + W_T)$$

$$M_1 = 0.01798\,(W_P + W_T)$$

5. Detailed Analysis:

f. Stresses:



Typical Deflection Shape Due To Pressure Or Thermal Conditions In Which The Tube Is Cooler Than The Vessel Lower Head.

Stresses Will Be Calculated At The Two Locations As Shown. A Stress Concentration Factor Of Four (4) Will Be Used At Location-2 For The Fatigue Evaluation As Given In N-462.4(d)(3) Of ASME Code, Section III.

Location-1

$$\sigma_x = \frac{6M_1}{t_2^2} + \frac{b_2^2 P}{2R_2 t_2} = \frac{6(0.01798)(w_P+w_T)}{(0.524)^2} + \frac{(0.225)^2 P}{2(0.487)(0.524)}$$

$$= 0.39290(w_P+w_T) + 0.09919P$$

$$E\Delta_{21} = 2.30338H_1 + 5.86109M_1 = -0.49713(w_P+w_T)$$

$$\sigma_\theta = \frac{\nu 6M_1}{t_2^2} + \frac{E\Delta_{21}}{R_2} + \frac{b_2 P}{t_2} = \frac{0.3(6)(0.01798)(w_P+w_T)}{(0.524)^2} + \frac{(-0.49713)(w_P+w_T)}{(0.487)} + \frac{0.225P}{0.524}$$

$$= 0.11787(w_P+w_T) - 1.02080(w_P+w_T) + 0.42938P$$

Location-2

$$\sigma_x = -\frac{6M_1}{t_2^2} + \frac{b_2^2 P}{2R_2 t_2} = -0.39290(w_P+w_T) + 0.09919P$$

$$\sigma_x = -\frac{\nu 6M_1}{t_2^2} + \frac{E\Delta_{21}}{R_2} + \frac{b_2 P}{t_2} = -0.11787(w_P+w_T) - 1.02080(w_P+w_T) + 0.42938P$$

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DESCRIPTION STRUCTURAL AND FATIGUE ANALYSIS OF BOTTOM HEAD INSTRUMENTATION PENETRATIONS

5- DETAILED ANALYSIS:
f - STRESSES:

Transient		Internal Pressure KSIA	W_P	T_H °F	$(E\alpha)_1$ KSI/°F	T_P °F	$(E\alpha)_2$ KSI/°F	W_T	W_P+W_T	$\frac{6M}{t^2}$	$\frac{b^2P}{2Rt}$	$\frac{\nu 6M}{t^2}$	$\frac{E\Delta}{R}$	$\frac{bP}{t}$
a	0	0.315	-1.679	70	0.177	99	0.185	2.613	0.934	0	0.03	0	-0.95	0.14
	4.47hrs	2.250	-11.996	518	0.186	547	0.217	-20.707	-32.703	-12.85	0.22	-3.85	33.38	0.97
Steadystate		2.250	-11.996	547	0.186	547	0.217	-25.311	-37.307	-14.66	0.22	-4.40	38.08	0.97
b	0	2.250	-11.996	547	0.186	518	0.217	-28.376	-40.372	-15.86	0.22	-4.76	41.21	0.97
	4.47hrs	0.315	-1.679	99	0.178	70	0.180	-4.406	-6.085	-2.39	0.03	-0.72	6.21	0.14
c	20min	2.250	-11.996	547	0.186	554.8	0.218	-24.251	-36.247	-14.24	0.22	-4.27	37.00	0.97
d	20min	2.250	-11.996	554.3	0.186	547	0.217	-26.544	-38.545	-15.14	0.22	-4.54	39.35	0.97
e	100 sec	2.140	-11.410	583.7	0.186	572.5	0.218	-28.198	-39.608	-15.56	0.21	-4.67	40.43	0.92
	225sec	2.275	-12.129	583.7	0.196	582	0.218	-27.189	-39.318	-15.45	0.23	-4.63	40.14	0.98
f	40sec	2.320	-12.369	583.7	0.196	593	0.219	-25.766	-38.135	-14.98	0.23	-4.49	38.93	1.00
	100sec	2.260	-12.049	583.7	0.196	597	0.219	-25.340	-37.389	-14.69	0.22	-4.40	38.17	0.97
	260sec	2.140	-11.410	583.7	0.196	585	0.218	-26.271	-38.281	-15.04	0.21	-4.51	39.08	0.92
g	2min	2.370	-12.636	555	0.186	567	0.218	-24.225	-36.861	-14.48	0.24	-4.34	37.63	1.02
	3.2min	2.350	-12.529	555	0.196	570	0.218	-23.907	-36.436	-14.32	0.23	-4.29	37.19	1.01
	10.4min	2.150	-11.463	555	0.196	555	0.218	-25.499	-36.962	-14.52	0.21	-4.36	37.73	0.92

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DESCRIPTION STRUCTURAL AND FATIGUE ANALYSIS OF BOTTOM HEAD INSTRUMENTATION PENETRATIONS
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5- DETAILED ANALYSIS:

f - STRESSES:

TRANSIENT		INTERNAL PRESSURE KSIA	W_P	T_H °F	$(E\alpha)_1$	T_P °F	$(E\alpha)_2$	W_T	W_P+W_T	$\frac{6M}{t^2}$	$\frac{b^2P}{2Rt}$	$\frac{\nu 6M}{t^2}$	$\frac{E\Delta}{R}$	$\frac{bP}{t}$
h	10 sec	2.230	-11.836	554.8	0.186	564	0.218	-24.512	-36.348	-14.23	0.22	-4.28	37.10	0.95
	65 sec	1.910	-10.183	554.8	0.186	546	0.217	-26.655	-36.838	-14.47	0.19	-4.34	37.60	0.82
i	220 min	3.125	-16.661	70	0.177	70	0.180	0	-16.661	-6.55	0.31	-1.96	17.01	1.34
j	HEATUP 0 hrs	0.315	-1.679	70	0.177	86	0.183	1.426	-0.253	-0.10	0.03	-0.03	0.26	0.14
	S.S.	2.500	-13.329	400	0.185	400	0.212	-18.032	-31.361	-12.32	0.25	-3.70	32.01	1.07
	COOLDOWN 0 hrs	2.500	-13.329	400	0.185	384	0.211	-19.837	-33.166	-13.03	0.25	-3.91	33.86	1.07
k	~	2.350	-12.529	554.8	0.186	548.8	0.217	-26.359	-38.888	-15.28	0.23	-4.58	39.70	1.01
	~	2.150	-11.463	554.8	0.186	560.8	0.218	-24.852	-36.315	-14.27	0.21	-4.28	37.07	0.92
l	12 sec	2.250	-11.996	554.8	0.186	521.8	0.217	-29.212	-41.208	-16.19	0.22	-4.86	42.07	0.97
m	10 sec	2.760	-14.715	554.8	0.186	585	0.218	-22.283	-36.998	-14.54	0.27	-4.36	37.77	1.19
	23 sec	2.120	-11.303	554.8	0.186	596	0.219	-20.859	-32.162	-12.64	0.21	-3.79	32.83	0.91
	160 sec	1.440	-7.677	554.8	0.186	550	0.218	-25.998	-33.675	-13.23	0.14	-3.97	34.38	0.62
n	33 sec	0.300	-1.599	547.0	0.186	430	0.213	-38.377	-39.976	-15.71	0.03	-4.71	40.81	0.13
	54 sec	0.700	-3.732	547.0	0.186	350	0.209	-47.221	-50.953	-20.02	0.07	-6.01	52.01	0.30

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DESCRIPTION Structural And Fatigue Analysis Of Bottom Head Instrumentation Penetrations

5. Detailed Analysis:

f - Stresses:

Transient		Point-1 σ_x	σ_θ	σ_r	$\sigma_x-\sigma_\theta$	$\sigma_x-\sigma_r$	$\sigma_\theta-\sigma_r$	Point-2 σ_x	σ_θ	σ_r	$\sigma_x-\sigma_\theta$	$\sigma_x-\sigma_r$	$\sigma_\theta-\sigma_r$	$4(\sigma_\theta-\sigma_r)$
a	0	0.03	-0.81	-0.32	0.34	0.35	-0.49	0.03	-0.81	0	2.84	0.03	-0.81	-3.24
	4.47hrs	-12.63	30.50	-2.25	-43.13	-10.38	32.75	13.07	38.20	↓	-25.13	13.07	38.20	152.80
Steadystate		-14.44	34.65	-2.25	-49.09	-12.19	36.90	14.88	43.45		-28.57	14.88	43.45	173.80
b	0	-15.64	37.42	-2.25	-53.06	-13.39	39.67	16.08	46.94		-30.86	16.08	46.94	187.76
	4.47hrs	-2.36	5.63	-0.32	-7.99	-2.04	5.95	2.42	7.07		-4.65	2.42	7.07	28.29
c	20min	-14.02	33.70	-2.25	-47.72	-11.77	35.95	14.46	42.24		-27.78	14.46	42.24	168.96
d	30min	-14.92	35.78	-2.25	-50.70	-12.67	38.03	15.36	44.86		-29.50	15.36	44.86	179.44
e	100sec	-15.35	36.68	-2.14	-52.03	-13.21	38.82	15.77	46.02		-30.25	15.77	46.02	184.08
	225sec	-15.22	36.49	-2.28	-51.71	-12.94	38.77	15.68	45.75		-30.07	15.68	45.75	183.00
f	40sec	-14.75	35.44	-2.32	-50.19	-12.43	37.76	15.21	44.42		-29.21	15.21	44.42	177.68
	120sec	-14.47	34.74	-2.26	-49.21	-12.21	37.00	14.91	43.54		-28.63	14.91	43.54	174.16
	260sec	-14.83	35.49	-2.14	-50.32	-12.69	37.63	15.25	44.51		-29.26	15.25	44.51	178.04
g	2min	-.4.24	34.31	-2.57	-48.55	-11.87	36.68	14.72	42.99		-28.27	14.72	42.99	171.96
	3.2min	-14.09	33.91	-2.35	-48.00	-11.74	36.26	14.55	42.49		-27.94	14.55	42.49	169.96
	10.4min	- 431	34.19	-2.15	-48.60	-12.16	36.44	14.73	43.01	↓	-28.28	14.73	43.01	172.04

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DESCRIPTION Structural And Fatigue Analysis Of Bottom Head Instrumentation Penetrations

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CHECK DATE 1-11-67 BY Caudle

5- Detailed Analysis:

f. Stresses:

Transient		Point-1 σ_x	σ_θ	σ_r	$\sigma_x-\sigma_\theta$	$\sigma_x-\sigma_r$	$\sigma_\theta-\sigma_r$	Point-2 σ_x	σ_θ	σ_r	$\sigma_x-\sigma_\theta$	$\sigma_x-\sigma_r$	$\sigma_\theta-\sigma_r$	$4(\sigma_\theta-\sigma_r)$
h	10sec	-14.06	33.77	-2.22	-47.83	-11.84	35.99	14.50	42.33	0 ↓	-27.83	14.50	42.33	169.32
	65sec	-14.29	34.08	-1.91	-48.36	-12.37	35.99	14.66	42.76		-29.10	14.66	42.76	171.04
i	220min	-6.24	16.39	-3.13	-22.63	-3.11	19.52	6.86	20.31		-13.45	6.86	20.31	81.24
j	Heatup 0hrs	-0.07	0.37	-0.32	-0.44	0.25	0.69	0.13	0.43		-0.30	0.13	0.43	1.72
	S.S	-12.07	29.38	-2.50	-41.45	-9.57	31.88	12.57	36.78		-24.21	12.57	36.78	147.12
	Cooldown 0hrs	-12.78	31.02	-2.50	-43.80	-10.28	33.52	13.28	38.84		-25.56	13.28	38.84	155.36
k	~	-15.05	36.13	-2.35	-51.18	-12.70	38.48	15.51	45.29		-29.78	15.51	45.29	181.16
	~	-14.06	33.11	-2.15	-47.77	-11.91	35.86	14.48	42.27		-27.79	14.98	42.27	169.08
l	12sec	-15.97	38.18	-2.25	-54.15	-13.72	40.43	16.41	47.90		-31.49	16.41	47.90	191.60
m	10sec	-14.27	34.60	-2.76	-48.87	-11.51	37.36	14.81	43.32		-29.51	14.81	43.32	173.28
	28sec	-12.43	29.95	-2.12	-42.38	-10.31	32.07	12.85	37.53		-24.68	12.85	37.53	150.12
	160sec	-13.09	31.03	-1.44	-44.12	-11.65	32.47	13.37	38.97		-25.60	13.37	38.97	155.88
n	33sec	-15.68	36.23	-0.30	-51.91	-15.38	36.53	15.74	45.65		-29.91	15.74	45.65	182.60
	54sec	-19.95	46.30	-0.70	-66.25	-19.25	47.00	20.09	58.32	↓	-38.23	20.09	58.32	233.28

$S.I._{MAX} = \sigma_x - \sigma_x = \underline{53.90\,KSI} < 3S_m = 69.9\,KSI$ @ 550 °F

For Location-1

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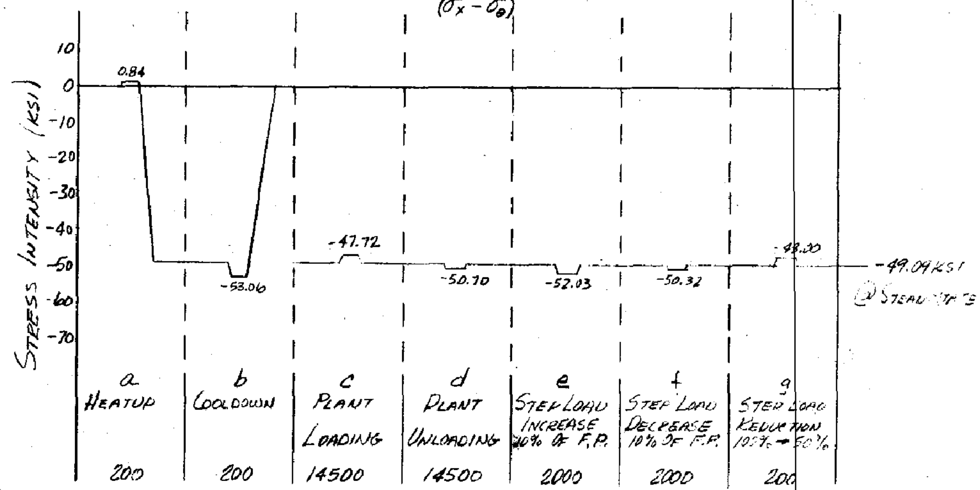
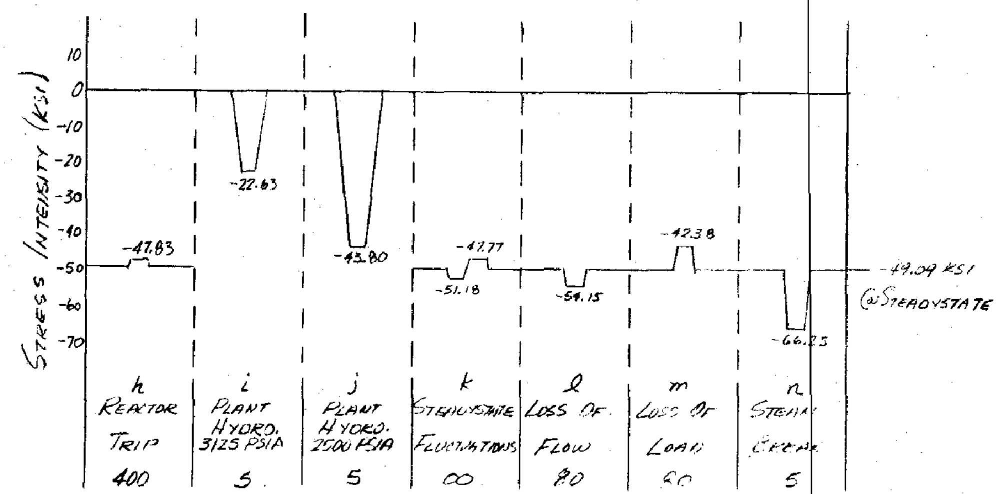
5. DETAILED ANALYSIS:

g- FATIGUE EVALUATION:

LOCATION-1
$(\sigma_x - \sigma_\theta)$





S_{MAX}	S_{MIN}	NUMBER OF OCCURRENCES	S_{ALT}	N^*	U
0.84	-66.25	5	33.55	190,000	0.00002
0.84	-54.15	80	27.50	660,000	0.00012
0.84	-53.06	115	26.95	800,000	0.00014
0	-43.80	5	21.90	∞	0

*FROM FIG. N-415(B) OF REF. -1

U_{TOTAL} = 0.00028

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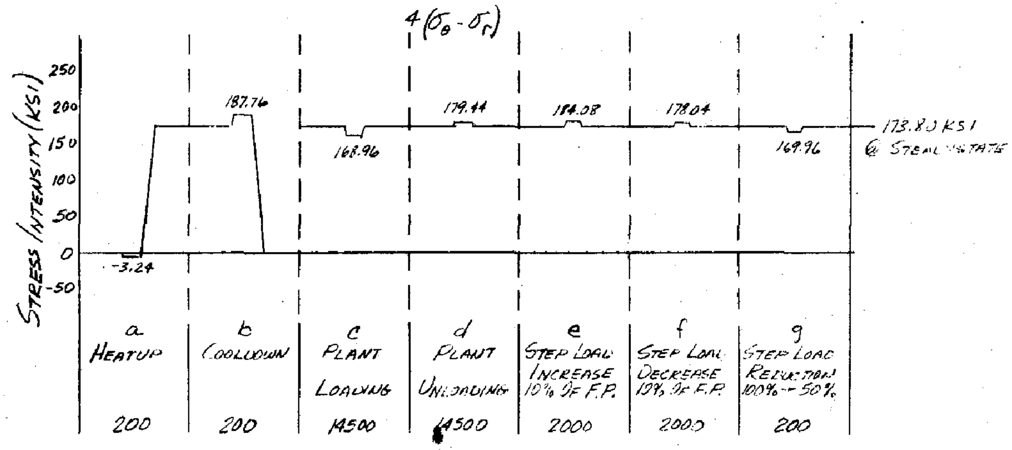
DESCRIPTION STRUCTURAL AND FATIGUE ANALYSIS OF BOTTOM HEAD INSTRUMENTATIONS PENETRATIONS

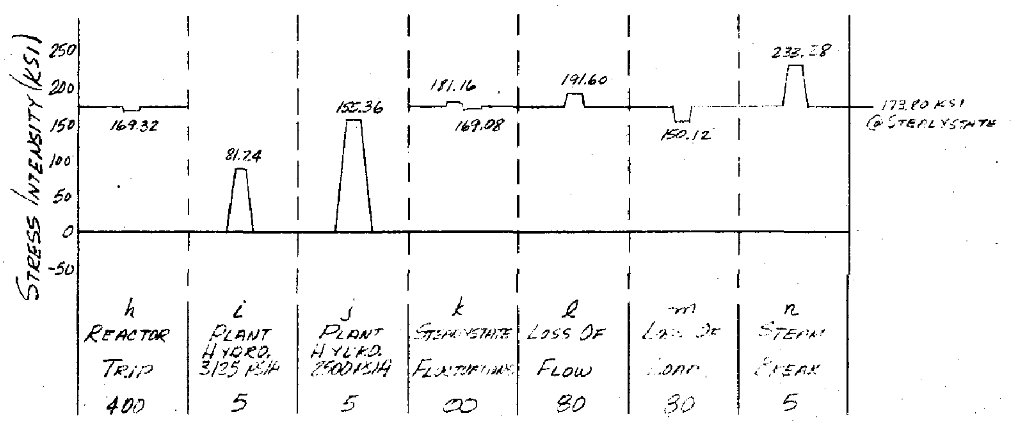
5. DETAILED ANALYSIS:

g - FATIGUE EVALUATION:

LOCATION - 2

$4(\sigma_\theta - \sigma_r)$





S_{MAX}	S_{MIN}	NUMBER OF OCCURRENCES	S_{ALT}	N^*	U
233.28	-3.24	5	118.26	800	0.00625
191.60	-3.24	80	97.42	1400	0.05714
187.76	-3.24	115	95.50	1500	0.07666
155.36	0	5	77.68	3300	0.00151
81.24	0	5	40.62	56000	0.00008
184.08	150.12	80	16.98	∞	0

*FROM FIG. N-415(B) OF REF.-1

$U_{OVERALL} = 0.14164$

NOMENCLATURE

ν = Poisson's ratio - taken to be 0.3

E = Elastic modulus (lbs/in^2)

α = Coefficient of thermal expansion ($in/in/^{o}F$)

P = Pressure (lbs/in^2)

W = Resultant axial force at any transverse cross-section (lbs)

T = Temperature (^{o}F or as specified)

V = Axial component of unit edge force (lbs/in)

H = Radial component (perpendicular to X-axis) of unit edge force (lbs/in)

M = Unit bending moment (in-lbs/in)

Δ & δ = Components of deflection normal to the X-axis; radial deflection; (positive outward) where results from the action of redundant forces and results from all other causes(in)

Δ^* & δ = Components of rotation(positive if radial deflections of successive adjacent points toward the positive X direction are increasing) where * results from the action of redundant forces and * results from all other causes (radians)

X = Axis of revolution

R = A radial distance measured normal to the axis of revolution (in)

t = Shell thickness as measured normal to the mid-surface (in)

σ = Normal stress; the subscripts x, and r denote meridional, circumferential, and radial (or lateral) stresses, respectively (lbs/in^2)

ϵ = Strain - Elongation per unit length (in/in)

APPENDIX B

THERMAL ANALYSIS

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B.1.0 INTRODUCTION

This appendix presents a summary of the thermal analysis of the Indian Point, Plant #2 Pressurized Water Reactor Vessel. The assumptions made, method of analysis and results of the investigations are presented. Temperature distributions obtained from two-dimensional heat flow analyses are presented on cross sections of the components considered. Results of the one-dimensional heat flow analyses are presented in the form of graphs. The times for which distributions are presented were selected to present the total effects of the transients.

B.2.0 NOMENCLATURE

- a - Actual thickness of clad material, ft
- A - Cross section area, ft^2
- b - Dimension, ft
- C_j - Thermal capacitance of node j, BTU/°F
- c_p - Specific heat, BTU/lb-°F
- c - Actual thickness of base metal, ft
- d - Equivalent thickness of clad material, ft
- E - Modulus of elasticity, psi
- g - Acceleration of gravity, ft/sec^2
- h - Heat transfer coefficient, $BTU/hr\text{-}ft^2\text{-}^{o}F$
- k - Thermal conductivity, BTU/hr-ft-°F
- L - Length along a heat flow path, ft
- m - Slope of temperature vs time curve, °F/hr
- N_{Fo} - Fourier modulus, dimensionless
- p - Slope of temperature vs time curve at x=o, °F/hr
- q - Rate of heat flow, BTU/hr
- q_j - Heat generation of the node j, BTU/hr
- q''' - Rate of heat generation per unit volume, $BTU/hr\text{-}ft^3$
- q_o''' - Rate of heat generation per unit volume at the surface, $BTU/hr\text{-}ft^3$
- r - Dimension, ft
- R - Thermal resistance, hr-°F/BTU
- T - Temperature, °F
- T_o - Uniform initial temperature, °F
- T_1 - Temperature at x=b, °F
- ΔT - Temperature difference, °F
- u - Slope of temperature vs time curve at x=b, °F/Hr
- V - Volume, ft^3
- x - Dimension, ft
- α - Thermal diffusivity, ft^2/hr
- α' - Coefficient of thermal expansion, ft/ft-°F

β - Linear absorption coefficient for heat generation, 1/ft

ϵ - Emissivity for radiation, ft^2/hr

θ - $T-T_o$, Temperature change, ^oF

μ - Absolute viscosity, lb/ft-hr

ν - Poisson's ratio, dimensionless

ξ = $\frac{x}{b}$, distance ratio, dimensionless

ρ - Density, lb/ft^3

σ - Thermal stress, psi

τ - Time, hr

$\Delta\tau$ - Time difference, hr

φ = $\frac{\alpha\tau}{b^2}$, temperature ratio, dimensionless

ψ - Natural convection property function, $1/ft^3\ ^oF$

B.3.0 GENERAL SOLUTIONS

Various procedures were used to determine the thermal information presented in this appendix. The following paragraphs describe the techniques used and the conditions under which each would be applicable.

B.3.1 Transient and steady state temperature distributions determined by use of a finite difference method programmed for solution on a digital computer.

A code has been written which makes use of the general heat balance equations derived by Hellman, Habetler, and Babrov (1). Through the use of this code, temperature distributions can be obtained in bodies having irregular geometries and composed of different materials.

The object being investigated is divided into a system of blocks or nodes. The thermal capacitance of each node and the thermal resistance between nodes is calculated using the physical properties of the material.

The thermal capacitance of node j is:

$$C_j = \rho c_p V_j$$

The thermal resistance between homogeneous nodes j and i is:

$$_jR_i = \frac{_jL_i}{k_j A_i}$$

where ${}_jL_i$ is the length of the heat flow path between nodes j and i, ${}_jA_i$ is the area normal to ${}_jL_i$ and common to both nodes. k is the thermal conductivity of the material.

The thermal resistance between non-homogeneous nodes j and i in series is:

$${}_jR_i = \frac{{}_j(L_1)_i}{k_1 \; {}_j(A_1)_i} + \frac{{}_j(L_2)_i}{k_2 \; {}_j(A_2)_i} + \ldots . + \frac{{}_j(L_n)_i}{k_n \; {}_j(A_n)_i}$$

The thermal resistance for a film is:

$${}_jR_i = \frac{1}{h \; {}_jA_i}$$

The equation for the change in temperature of a particular node in the time $\Delta\tau$ is:

$$\Delta T = \frac{\Delta\tau}{C_j} [q(\text{conducted}) + q(\text{generated})]$$

The rate at which heat is conducted into the node is:

$$q = \sum_{i=1}^{n} \frac{T_i - T_j}{{}_jR_i}$$

where i represents each bordering node and ${}_jR_i$ is the thermal resistance between the i node and the node under consideration.

Thus, the equation for the change in temperature of a particular node becomes:

$$\Delta T_j = \frac{\Delta\tau}{C_j} \left[\sum_{i=1}^{n} \frac{T_i - T_j}{{}_jR_i} + q_j \right]$$

The temperature of each node is calculated at successive time intervals through the use of the finite difference equation:

$$T_{(\tau+\Delta\tau)} = T_\tau + \Delta T$$

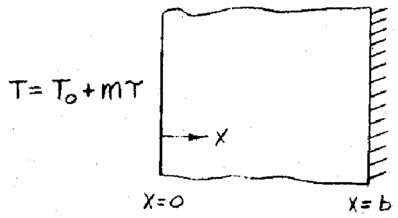
where ΔT is obtained from the previous equation and evaluated at time τ.

For a steady state problem, the term in brackets must be equal to zero; hence,

$$T_j = \frac{\sum_{i=1}^{n} \frac{1}{{}_jR_i} T_j + q_j}{\sum_{i=1}^{n} \frac{1}{{}_jR_i}}$$

This expression is equivalent to performing a heat balance about node j.

B.3.2 Transient solution for a finite slab in which one boundary has a linear temperature change, while the other boundary is insulated. Initially the slab is isothermal.



Assumptions:

1. One-dimensional heat flow.
2. Thermal properties of the material do not vary with temperature and may be evaluated at the average temperature over the range covered.
3. Infinite heat transfer coefficient at x=o.

Mathematical statement of the problem:

$$\frac{\partial^2 T}{\partial x^2} - \frac{1}{\alpha}\frac{\partial T}{\partial \tau} = 0 \quad \text{for} \quad 0< x <b \;, \; \tau>0$$

Boundary conditions:

$$T = T_o \quad \text{at} \quad \tau = 0 \quad \text{for} \quad 0< x <b$$

$$\frac{dT}{dx} = 0 \quad \text{at } x=b \quad \text{for } \tau>0$$

$$T = T_o + m\tau \quad \text{at } x=0 \quad \text{for } \tau>0$$

The solution is:

$$T = T_o + \varphi m\tau$$

where,

$$\varphi = \frac{1}{N_{Fo}}\left[N_{Fo} - \xi\left(1-\frac{\xi}{2}\right) + \frac{2}{\pi^3}\sum_{n=0}^{\infty}\frac{e^{-(n+\frac{1}{2})^2\pi^2 N_{Fo}}}{(n+\frac{1}{2})^3}\sin(n+\tfrac{1}{2})\pi\xi\right]$$

$$T_{mean} = \frac{1}{b}\int_o^b T\,dx$$

$$T_{mean} = \frac{1}{b}\int_o^b (T_o + \varphi m\tau)dx$$

$$T_{mean} = T_o + \frac{m\tau}{b}\int_o^b \varphi dx = T_o + \varphi_{mean}\, m\tau$$

where,

$$\varphi_{mean} = \frac{1}{N_{Fo}}\left[N_{Fo} - \frac{5}{6} + \frac{2}{\pi^4}\sum_{n=0}^{\infty}\frac{e^{-(n+\frac{1}{2})^2\pi^2 N_{Fo}}}{(n+\frac{1}{2})^4}\right]$$

This solution only considers slabs of one material. To include clad on the base metal, an equivalent thickness must be added to be base metal thickness.

The equation for the equivalent thickness of clad is:

$$d = -c + \sqrt{c^2 + \frac{a^2\alpha_2}{\alpha_1} + \frac{2k_2ac}{k_1}}$$

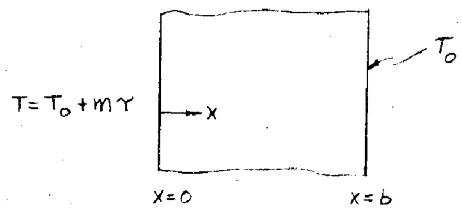
where,

d = equivalent thickness of clad material
c = actual thickness of base material
a = actual thickness of clad material
α_1 and k_1 = diffusivity and conductivity of clad
α_2 and k_2 = diffusivity and conductivity of base metal

The slab thickness "b" now becomes (d+c)

The final graph of temperature vs distance can be plotted using (d+c) as the total length. The temperatures in the section $d<x<(d+c)$ are correct for the base metal. However, the temperature distribution from $0<x<d$ must be "foreshortened" and replotted from $0<x<a$ where the temperature at x=a is the temperature calculated for x=d.

B.3.3 Transient solution for a finite slab with uniform initial temperature in which one boundary has a linear temperature change while the other boundary is kept at zero temperature.



Assumptions:

1. One-dimensional heat flow.
2. Thermal properties of the material do not vary with temperature and can be evaluated at the average temperature over the range covered.
3. Infinite heat transfer coefficient at x=0.

Mathematical statement of the problem:

$$\frac{\partial^2 T}{\partial x^2} - \frac{1}{\alpha}\frac{\partial T}{\partial \tau} = 0 \quad \text{for } 0< x <b \quad \text{and} \quad \tau>0$$

Boundary conditions:

$T = T_o$ at $\tau=0$ for $0 < x < b$

$\theta = 0$ at $x=b$

$T = T_o + m\tau$ at $x=0$ for $\tau>0$

The solution is:

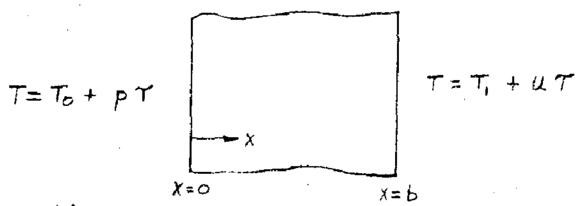
$T = T_o + \varphi m\tau$

where,

$$\varphi = \frac{\theta}{m\tau} = \frac{1}{N_{Fo}} \left\{ \frac{(1-\xi)[6N_{Fo} - \xi(2-\xi)]}{6} + \frac{2}{\pi^3} \sum_{n=1}^{\infty} \frac{e^{-n^2\pi^2 N_{Fo}}}{n^3} \sin n\pi\xi \right\}$$

$$T_{mean} = \frac{1}{b} \int_0^b (T + \varphi m\tau)dx$$

B.3.4 Transient solution for a finite slab with non-uniform initial temperature which undergoes a linear temperature change on each surface.



Assumptions:

1. One-dimensional heat flow
2. Thermal properties of the material do not vary with temperature and can be evaluated at the average temperature over the range covered.
3. Infinite heat transfer coefficient at x=o.
4. u=0 forcing the surface at x=b to remain at T_1.

Mathematical statement of the problem:

$$\frac{\partial^2 T}{\partial x^2} - \frac{1}{\alpha}\frac{\partial T}{\partial \tau} = 0 \quad \text{for} \quad 0 < x < b \quad \text{and} \quad \tau>0$$

Boundary conditions:

$T = f(x)$ at $\tau=0$ for $0 < x < b$

$T = T_o + p\tau$ at $x=0$ for $\tau>0$

$T = T_1 + u\tau$ at $x=b$ for $\tau>0$, but $u=0$

so $T = T_1$ at $x=b$

The solution is:

$$T = \frac{2}{b}\sum_{n=1}^{\infty} e^{\frac{-n^2\pi^2\alpha\tau}{b^2}} \sin\frac{n\pi x}{b}\left\{\int_o^b f(x)\sin\frac{n\pi x}{b}\,dx \;\ldots\right.$$

$$\left. + \frac{n\pi\alpha}{b}\int_o^{\tau} e^{\frac{\alpha n^2\pi^2\tau}{b^2}}\left[p\tau T_o - (-1)^n u\tau T_o\right]d\tau\right\}$$

If $f(x) = T_o + \frac{x}{b}(T_1 - T_o)$ the solution becomes

$$T = p\tau + \tau(u-p)\xi + \frac{b^2}{\alpha}\left[(u-p)\frac{\xi^3}{6} + p\frac{\xi^2}{2} - (u+2p)\frac{\xi}{6}\right]$$

$$+ \frac{2}{b}\sum_{n=1}^{\infty} e^{\frac{-\alpha n^2\pi^2\tau}{b^2}}\left[\frac{b}{n\pi}(T_o - T_1)(-1)^n \sin n\pi\xi\right]$$

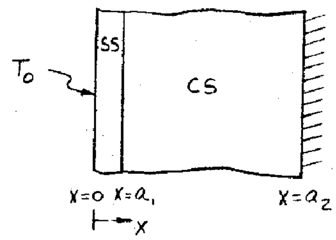
$$-\frac{2}{\pi}\sum_{n=1}^{\infty} e^{\frac{-\alpha n^2\pi^2\tau}{b^2}}\left[(T_o - T_1)(-1)^n\right]\sin n\pi\xi$$

$$+ \frac{2b^2}{\pi^3\alpha}\sum_{n=1}^{\infty}\left[p + (-1)^n u\right]\frac{e^{\frac{-\alpha n^2\pi^2\tau}{b^2}}}{n^3}\sin n\pi\xi$$

The equation for the mean temperature is:

$$T_{mean} = \frac{1}{b} \int_0^b T \, dx$$

B.3.5 Nonlinear gradient at steady state resulting from heat generation due to gamma ray capture in a two material finite slab with one surface at a fixed temperature and the other surface perfectly insulated.



Assumptions:

1. One-dimensional heat flow.
2. Thermal properties of the materials do not vary with temperature and can be evaluated at the mean temperature of the body in question.
3. No contact resistance at the junction of the two materials.
4. Heat generation of the form $q''' = q_o''' \, e^{-\beta x}$.

Mathematical statement of the problem:

$$-k_{ss} \frac{d^2T_{ss}}{dx^2} = q_o''' \, e^{-\beta x} \quad \text{for } 0 < x < a_1$$

$$-k_{cs} \frac{d^2T_{cs}}{dx^2} = q_o''' \, e^{-\beta x} \quad \text{for } a_1 < x < a_2$$

Boundary conditions:

$$T_{ss} = T_o \text{ at } x=0$$

$$-k_{ss} \frac{dT_{ss}}{dx} = -k_{cs} \frac{dT_{cs}}{dx} \text{ at } x=a_1$$

$T_{ss} = T_{cs}$ at $x=a_1$

$\frac{dT_{cs}}{dx} = 0$ at $x=a_2$

The solution is:

$$T_{ss} = \frac{q_o'''}{\beta k_{ss}} \left[\frac{1}{\beta} - \frac{e^{-\beta x}}{\beta} - x e^{-\beta a_2} \right] + T_o$$

$$T_{cs} = \frac{q_o'''}{\beta k_{cs}} \left[a_1 e^{-\beta a_2} + \frac{e^{-\beta a_1}}{\beta} - \frac{e^{-\beta x}}{\beta} - x e^{-\beta a_2} \right]$$

$$+ \frac{q_o'''}{\beta k_{ss}} \left[\frac{1}{\beta} - \frac{e^{-\beta a_1}}{\beta} - a_1 e^{-\beta a_2} \right] + T_o$$

Tangential thermal stresses at $x=a_1$ and $x=a_2$ due to this temperature distribution in a thin walled cylinder with ends free to expand axially but restrained from bending are:

$$\sigma_1 = \left(\frac{E\alpha'}{1-\nu}\right)\left(\frac{q_o'''}{k_{cs}\beta}\right) \left\{ e^{-\beta a_1} \left[\frac{1}{\beta} - \frac{1}{\beta^2 (a_2 - a_1)} \right] \right.$$

$$\left. + e^{-\beta a_2} \left[\frac{1}{\beta^2 (a_2 - a_1)} - \frac{a_2 - a_1}{2} \right] \right\}$$

$$\sigma_2 = \left(\frac{E\alpha'}{1-\nu}\right)\left(\frac{q_o'''}{k_{cs}\beta}\right) \left\{ \frac{e^{-\beta a_1}}{\beta^2 (a_2 - a_1)} - e^{-\beta a_2} \left[\frac{1}{\beta^2 (a_2 - a_1)} + \frac{1}{\beta} + \frac{a_2 - a_1}{2} \right] \right\}$$

where:

σ_1 = Tangential thermal stress at $x=a_1$
σ_2 = Tangential thermal stress at $x=a_2$
E = Modulus of elasticity
ν = Poisson's ratio
α' = Linear coefficient of thermal expansion

B.3.6 Thermal moment: A term used in the structural analysis generally at locations of discontinuity where cuts are taken. The moment is due to a radial temperature gradient and is defined mathematically as:

$$M_T = \frac{E\alpha'}{1-\nu} \int_a^b T\ (R-r)d(R-r)$$

The equation for the mean temperature at a cut through a cylinderical section is:

$$T_M = \frac{2}{b^2-a^2} \int_a^b Trdr$$

where,

a = Dimension to inside surface
b = Dimension to outside surface
r = Dimension ($a<r<b$)
R = Mean radius
α' = Coefficient of thermal expansion
ν = Poisson's ratio

B.3.7 Material Properties and Film Coefficients:

Properties of materials used in this appendix are presented below. All were evaluated at 325°F.

Stainless Steel

k = 9.8 Btu/hr-ft-°F
ρ = 495 lb/ft^3
c_p = .127 Btu/lb-°F

Carbon Steel

k = 26.2 Btu/hr-ft-°F
ρ = 490 lb/ft^3
c_p = .12 Btu/lb-°F

Air

k = .0204 Btu/hr-ft-°F
ψ = 3.0 x 10^5

Water

k = .40 Btu/hr-ft-°F
ψ = 4.7 x 10^9

The following equations were used to calculate the heat transfer coefficients used in the analysis of the head and vessel flanges.

Convection film coefficient in a vertically enclosed gap:

$$\frac{h_c x}{k} = \frac{0.071}{(L/x)^{\frac{1}{9}}} \left[\frac{x^3 \rho^2 g\beta\ \Delta T}{\mu^2}\left(\frac{c_p \mu}{k}\right)\right]^{\frac{1}{3}}$$

$$h_c = \frac{0.071\ k}{(L/x)^{\frac{1}{9}}} \left[\psi \Delta T\right]^{\frac{1}{3}}$$

where,

$$\psi = \frac{\rho^2 g\beta}{\mu^2}\left(\frac{c_p \mu}{k}\right)$$

Convection film coefficient in a horizontal enclosed gap:

$$\frac{h_c x}{k} = 0.075 \left[\frac{x^3 \rho^2 g\beta\Delta T}{\mu^2}\ \left(\frac{c_p \mu}{k}\right)\right]^{\frac{1}{3}}$$

$$h_c = 0.075k\ \left[\psi \Delta T\right]^{\frac{1}{3}}$$

Convection film off the top of a heated plate:

$$\frac{h_c L}{k} = 0.14 \left[\frac{L^3 \rho^2 g\beta\Delta T}{\mu^2}\ \left(\frac{c_p \mu}{k}\right)\right]^{\frac{1}{3}}$$

$$h_c = 0.14k[\ \Delta T]^{\frac{1}{3}}$$

The convection film coefficient on the bottom side of the same plate is assumed to be half that on the top side.

The equation for the radiation coefficient across the air gaps and off the top and bottom of the refueling plate is as follows:

$$h_r = \frac{0.173 \times 10^{-8}}{\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1} \frac{(T_1^4 - T_2^4)}{(T_1 - T_2)}$$

$$\epsilon_1 = \epsilon_2 = 0.65$$

B.4.0 APPLICATION OF GENERAL SOLUTIONS AND RESULTS AT SPECIFIC LOCATIONS

B.4.1 Head and Vessel Flanges: A representative section of the vessel flange - head flange region was divided into a series of nodes as in Figure B-1 on Page B-23. For calculating node volumes and heat transfer areas, a cylindrical sector with an angle equal to half the angle between two studs was taken. This model considers two dimensional heat flow (axial and radial) except in the head flange where the studs pass through. In this area, a third dimension is considered as heat is transferred between the stud and flange.

Assumptions:

a. Two-dimensional heat flow.
b. Heat generation negligible.
c. Thermal properties do not vary with temperature.
d. Natural convection is assumed in the gap between the core barrel and vessel flange.
e. All other surfaces in contact with primary coolant are assumed to have an infinite heat transfer coefficient.
f. Outside surfaces of flanges, vessel and head are perfectly insulated.
g. Natural convection and radiation is assumed in the annulus between the stud and head flange and in the gap between the head and vessel flanges.
h. The refueling plate transfers heat to the surroundings by both radiation and convection.

The head and vessel flanges were analyzed for the following thermal conditions using the method described in B.3.1.

a. Heatup Transient: Inside surfaces are heated from 100°F to 547°F at a linear rate of 100°F/hr while the ambient condition remains at 120°F.

b. Steady State: Inside surfaces are held constant at 547°F and the ambient at 120°F.

c. Cooldown Transient: The inside surfaces are cooled from 547°F to 100°F at a linear rate of 100°F/hr while the ambient is held at 120°F. The initial condition for this transient is the steady state condition described in b.

Results:

Nodal layouts of the flanges showing temperature distributions at times during heatup and cooldown transients plus steady state are presented in Figures B-1 thru B-9. Figure B-39 is a sketch of the flange region showing the locations of discontinuity where the effects of radial gradients were considered. At these locations, the radial gradients were plotted, and from these gradients values were obtained for the mean temperature at the cut and the thermal moment. The radial gradients are shown in Figures B-40 thru B-49, and the thermal moments resulting from these gradients are tabulated on Page B-100.

Axial gradients in the flanges were also plotted from the temperature distributions at times during heatup, cooldown and at steady state. These gradients are presented in Figures B-78 thru B-83.

For the Plant Hydrostatic Test (2500 psia), the inside surfaces are heated from 100°F to 400°F at 100°F/hr while the plant is being pressurized. During plant depressurization, the inside surfaces are cooled back to 100°F at 100°F/hr. These heatup and cooldown transients are at the same rate but over a shorter range than the normal heatup and cooldown. Therefore, it would be conservative to use the results of normal heatup and cooldown for the hydrostatic test transients.

Other operating transients applied to this region have faster rates than heatup and cooldown, but the range of temperature change is much shorter. Therefore, it was conservative to consider the mean temperature of the body did not change from the initial condition while the temperature of the inside surface followed the fluid transient. Differences between the mean temperature and the inside surface temperature at times during these transients are tabulated on Page B-121.

B.4.2 Inlet Nozzle: A cross section of the nozzle was divided into a series of nodes as in Figure B-10 on Page B-32. This model, consisting of a cylindrical sector with an angle of one radian, was used to perform a two-dimensional thermal analysis using the technique described in B.3.1 and the following assumptions.

a. Two-dimensional heat flow.
b. Heat generation negligible.
c. Thermal properties do not vary with temperature.
d. All surfaces in contact with the primary coolant are assumed to have an infinite heat transfer coefficient.
e. Outside surfaces are perfectly insulated.

Results:

Temperature distributions were obtained for times during a 100°F/hr heatup from 100°F to 547°F. These distributions are shown on nodal layouts in Figures B-10 thru B-13. Figure B-50 shows the locations of discontinuity where the effects of radial gradients were considered. At these locations, the radial gradients were plotted, and from these gradients values were obtained for the mean temperature at the cut and the thermal moment. The radial gradient plots are found in Figures B-51 thru B-55 and the thermal moments are tabulated on Page B-101.

Gradients in the axial direction were also plotted for the nozzle at times during the heatup transient. These plots are found in Figures B-84 and B-85.

Temperature distributions were not obtained for the cooldown transient. Since cooldown is over the same range and at the same rate as heatup, cooldown gradients would simply be mirror images of those for the heatup transient. Also, the values for thermal moments which were obtained for heatup, with signs reversed, can be used for corresponding times during cooldown.

The results of normal heatup and cooldown were used for the hydrostatic test transients as described for the flanges in B.4.1.

At steady state, the nozzle will be isothermal at the inlet coolant temperature since there is no heat sink.

The operating transients for the inlet nozzle were investigated in the same manner as for the flange analysis in Section B.4.1. The results are presented on Page B-122.

B.4.3 Outlet Nozzle: A representative section of the outlet nozzle was divided into a series of nodes as in Figure B-14 on Page B-36. This model, consisting of a cylindrical sector with an angle of one radian, was used to perform a thermal analysis using the method described in B.3.1.

Assumptions:

a. Two-dimensional heat flow.
b. Heat generation negligible.
c. Thermal properties do not vary with temperature.
d. All surfaces in contact with the primary coolant are assumed to have an infinite heat transfer coefficient.
e. Outside surfaces perfectly insulated.

Temperature distributions in the outlet nozzle were obtained for the following transient and steady state conditions.

a. Heatup: Inside surfaces are heated from 100°F to 547°F at a linear rate of 100°F/hr. Both inlet and outlet fluids follow the same transient.

b. 100% Power Steady State: The coolant inside the nozzle is held constant at 613°F while the coolant contacting the vessel shell adjacent to the nozzle is held at 555°F.

c. Operating Transients: Temperature distributions were obtained for operating transients including plant loading and unloading, step reduction from 100% to 50% load, reactor trip from full power, loss of flow, one pump and loss of load. Fluid transients for these cases are found in the Equipment Specification.

Results:

Nodal layouts of the outlet nozzle showing temperature distributions for times during heatup, plant loading, at 100% power steady state and during plant unloading are presented in Figures B-14 thru B-26. Figure B-56 is a sketch of the nozzle showing the locations of discontinuity where effects of radial gradients were considered. At these locations, radial gradients were plotted for the conditions above. From these gradients, values were obtained for the mean temperature at the cut and the thermal moment. The radial gradient plots are found in Figures B-57 thru B-71 and the resulting thermal moments are tabulated on Pages B-102 and B-103.

Axial gradients were also plotted for the nozzle at times during heatup, plant loading at 100% power steady state and during plant unloading. They are found in Figures B-86 thru B-91.

As in the inlet nozzle analysis, the cooldown transient was not completely analyzed. The gradients are mirror images of those for heatup and the thermal moments, with reversed signs, can be used for corresponding times during cooldown.

At zero power steady state, both inlet and outlet fluids are at 547°F. With the outer surface of the nozzle insulated there is no heat sink. Therefore, at this steady state the nozzle will be isothermal at 547°F.

The results of heatup and cooldown were also used for the plant hydrostatic test transients as described for the flange analysis in B.4.1.

Temperature distributions for operating transients including step reduction from 100% to 50% load, reactor trip from full power, loss of flow, one pump and loss of load are presented in Figures B-27 thru B-38. These transients have faster rates than heatup, plant loading and plant unloading, and their effects are only seen a short distance from the surface. In view of this, it was conservative to consider the inside surface follows the fluid temperature and calculate the ΔT between the mean temperature and inside surface temperature. These temperature differences are tabulated on Pages B-123 and B-124.

For the step load transients of ± 10% of full power and steam break from hot zero power where both inlet and outlet fluids follow the same transient, the inside surface temperature was assumed to follow the fluid temperature while the mean temperature of the nozzle did not change from the initial condition. Differences between the mean and surface temperatures are tabulated on Pages B-123 and B-124.

B.4.4 Closure Head: The vessel closure head was analyzed to determine the mean temperature of the head at the end of the 100°F/hr heatup and cooldown transients between 100°F and 547°F and at the end of the hydrostatic test transients during which the vessel is heated and cooled between 100°F and 400°F at 100°F/hr.

Results of the one-dimensional analytical solution as described in Section B.3.2 showed the mean temperature of the head to be 518°F at the end of heatup and 129°F at the end of cooldown. At the end of the hydro heatup and cooldown transients, the mean temperature of the head is 384°F and 116°F, respectively.

B.4.5 Vessel Wall: The procedure described in B.3.2 was used to perform the one-dimensional analysis of the vessel wall in the nozzle region and in the lower shell region for the heatup and hydro heatup transients.

Temperature distributions for the two wall sections, presented in the form of graphs, for times during heatup and hydro heatup are on pages B-94 thru B-97. Using these curves, the mean temperature and inside and outside surface temperatures were obtained for the times investigated. Differences between the mean temperature and the temperatures of the inside and outside surfaces are tabulated on Page B-104.

The procedure in B.3.5 was used in determining the maximum allowable rate of gamma heating in the thinner section of the vessel wall. This rate was calculated by substituting 2 S_m for σ_1 in the equation for thermal stress at $x=a_1$ and solving for q_o'''. With $\beta = 0.4\ in^{-1}$ and 2 S_m = 53,400 psi, the maximum value of q_o''' was determined to be 164,000 Btu/ft^3-hr.

B.4.6 Bottom Head: The method in B.3.2 was also used to determine the mean, inside surface and outside surface temperatures in the bottom head at times during the heatup and hydro heatup transients. Differences between the mean temperature and the temperatures of the inside and outside surfaces during these transients are presented on Page B-105.

B.4.7 Vessel Supports: The vessel is supported off the nozzles. Four nozzles, two inlet and two outlet, are used in the support arrangement. These nozzles have integral pads built up on the bottom sides and rest on support shoes. The support shoes are attached to a ring girder which rests on a concrete foundation. Although both inlet and outlet nozzles are used for supports, the geometry of the inlet nozzle presents the more severe case and was used for both nozzles in the analysis.

The following transients and steady state conditions were investigated. For all conditions, the back surface is held at 100°F. This temperature represents the temperature at the bottom of the support shoe and is assumed to be equal to the ambient temperature.

a. Plant Heatup - Inside surface is heated from 100°F to 547°F at a linear rate of 100°F/hr.

b. Hydro Heatup - Inside surface is heated from 100°F to 400°F at a linear rate of 100°F/Hr.

c. Steady State - at steady state, the temperature distribution through the nozzle wall and pad is assumed to be linear between the fluid temperature inside the nozzle and 100°F at the bottom of the support shoe.

   Inside temperatures for the steady states investigated are:

   1. Hydro Steady State - 400°F (inlet and outlet nozzles).
   2. Zero Power Steady State - 547°F (inlet and outlet nozzles).
   3. 100% Power Steady State - 555°F (inlet nozzle only).
   4. 100% Power Steady State - 613° (outlet nozzle only).

d. Plant Cooldown - Inside surface is cooled from 547°F to 100°F at a linear rate of 100°F/hr. The initial condition for this transient is the zero power steady state distribution.

e. Hydro Cooldown - This transient starts from the hydro steady state. The inside surface is cooled from 400°F to 100°F at 100°F/hr. The distribution at the end of hydro cooldown is assumed to be the same as that for the end of plant cooldown

The procedure in B.3.3 was used to perform the one-dimensional thermal analysis for plant heatup and hydro heatup. The plant cooldown transient was analyzed using the one-dimensional analytical solution described in B.3.4.

Temperature distributions thru the nozzle wall and pad at the end of plant heatup, hydro heatup and plant cooldown are presented in Figure B-76. Distributions for hydro, zero power and 100% power steady states are presented in Figure B-77. From these distributions temperatures of the inside and outside surfaces and the mean temperature were obtained. The ΔT between the mean temperature and the temperatures of the inside and outside surfaces was calculated. These results are presented on Page B-106.

B.5.0 REFERENCES

1. Hellman, Habetler, and Babrov, "Use of Numerical Analysis in Transient Solution of Two Dimensional Heat Transfer Problems with Natural and Forced Convection", ASME Transactions, 1956.
2. McAdams, W. H., Heat Transmission, Third Edition, McGraw-Hill Book Co., New York, 1954.
3. Anthony, M. L., "Temperature Distributions in Slabs with a Linear Temperature Rise at One Surface", General Discussion on Heat Transfer, 1951.
4. Mac Robert, T. M., Spherical Harmonics, 2nd Edition, 1948.
5. Westinghouse Equipment Specification No. 676208.
6. Westinghouse P.A.R. No. 27.
7. Westinghouse Drawing No. E.D. Sk. 328832-F.
8. CE Drawing No. E-232-042.
9. CE Drawing No. E-232-045.
10. CE Drawing No. E-232-046.

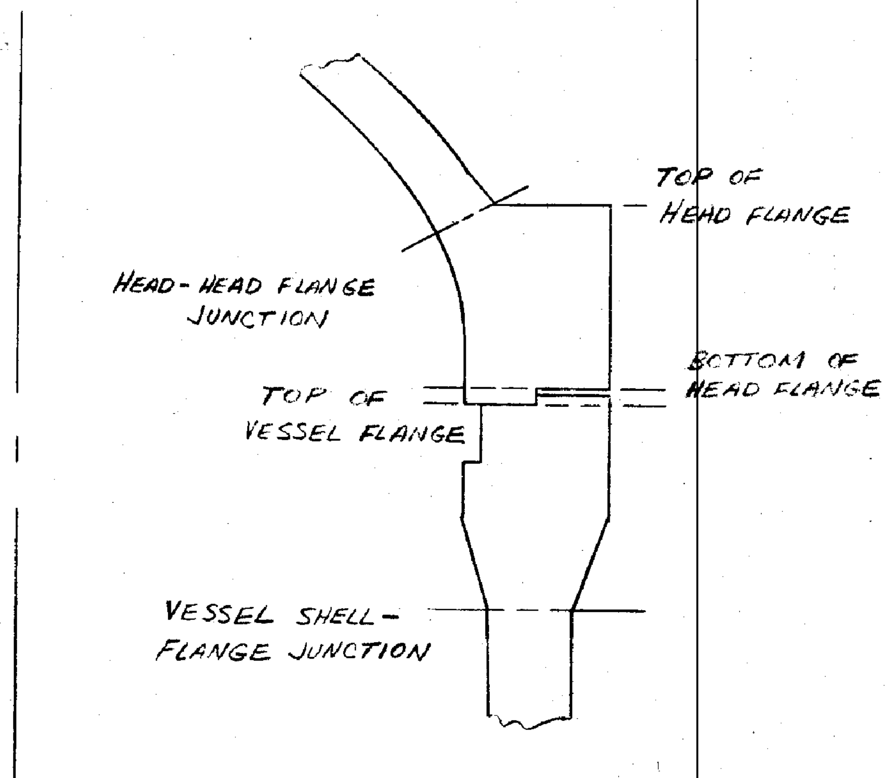
B.6.0 DETAILED RESULTS

INDICATOR SHEET

(QTY)	SIZE	SHEET DESCRIPTIONS
( )	8.5x14	
(38)	11x17	B-1 — B38
( )	Oversized	

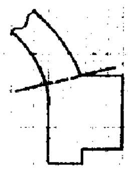
COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER
SHEET B-61 OF
CHARGE NO.
DATE BY
DESCRIPTION HEAD AND VESSEL FLANGES
CHECK DATE BY



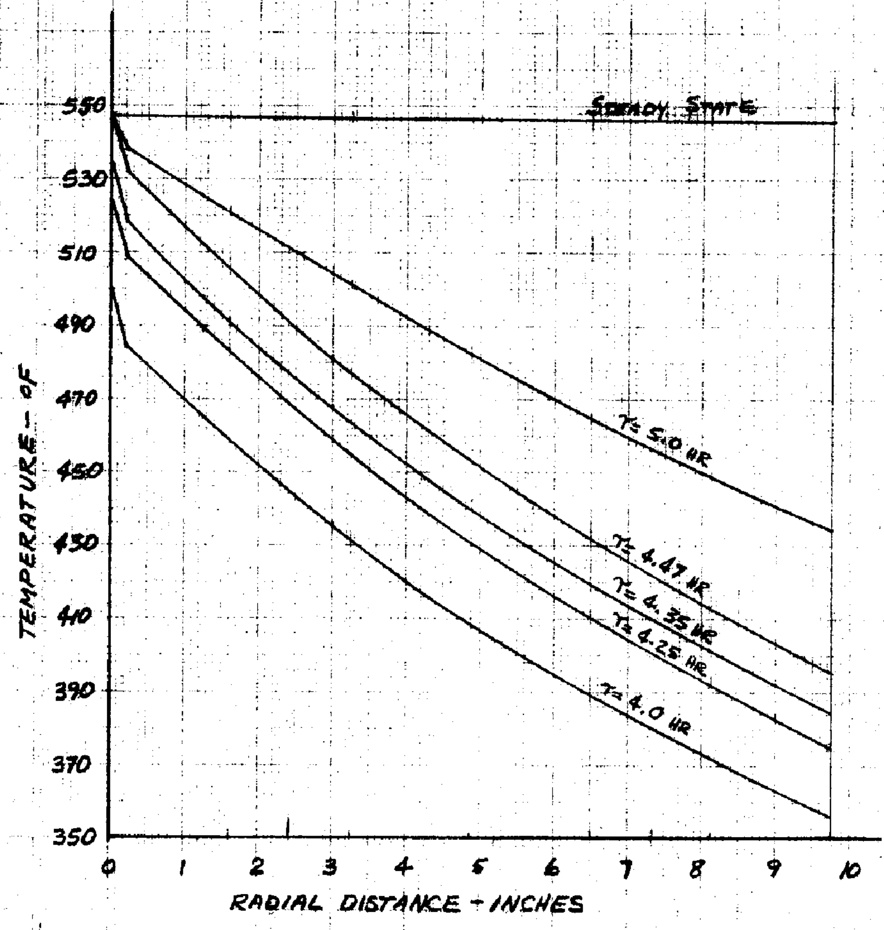
THIS SKETCH INDICATES THE LOCATIONS WHERE RADIAL GRADIENTS WERE PLOTTED AND THE THERMAL MOMENT CALCULATED.

FIGURE B-39



RADIAL GRADIENT AT HEAD - HEAD FLANGE JUNCTION
100 °F/HR HEATUP

FIGURE B-40



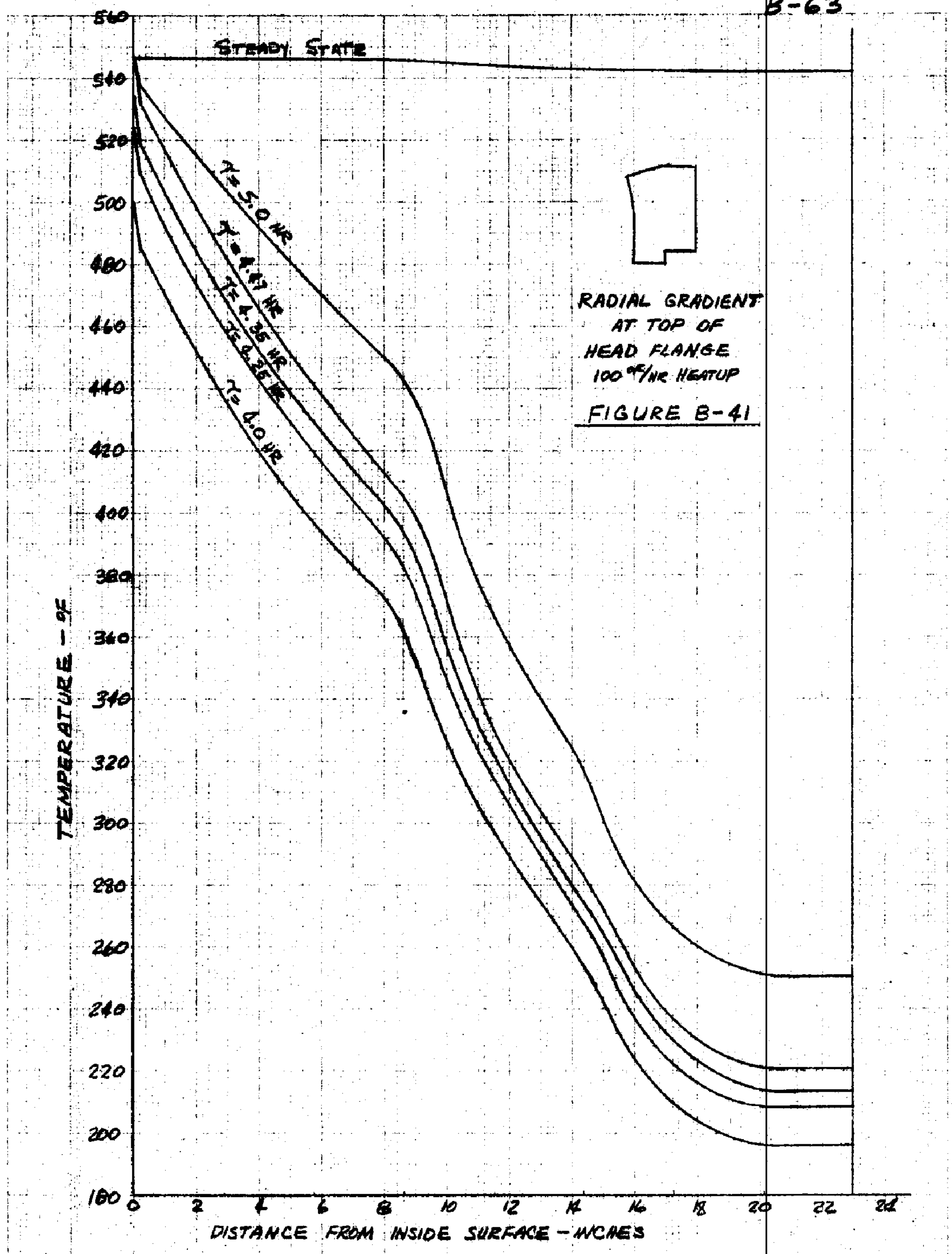
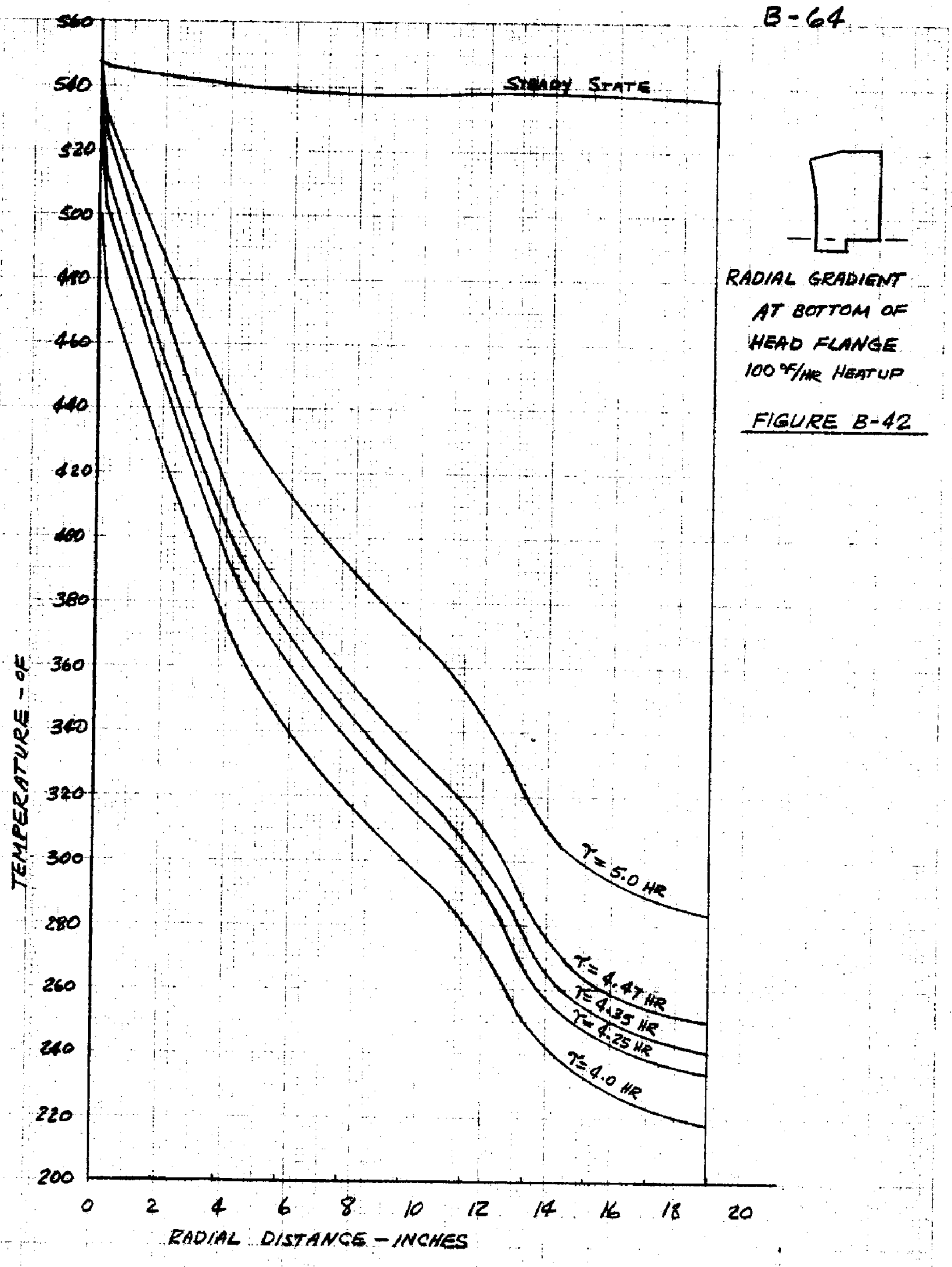
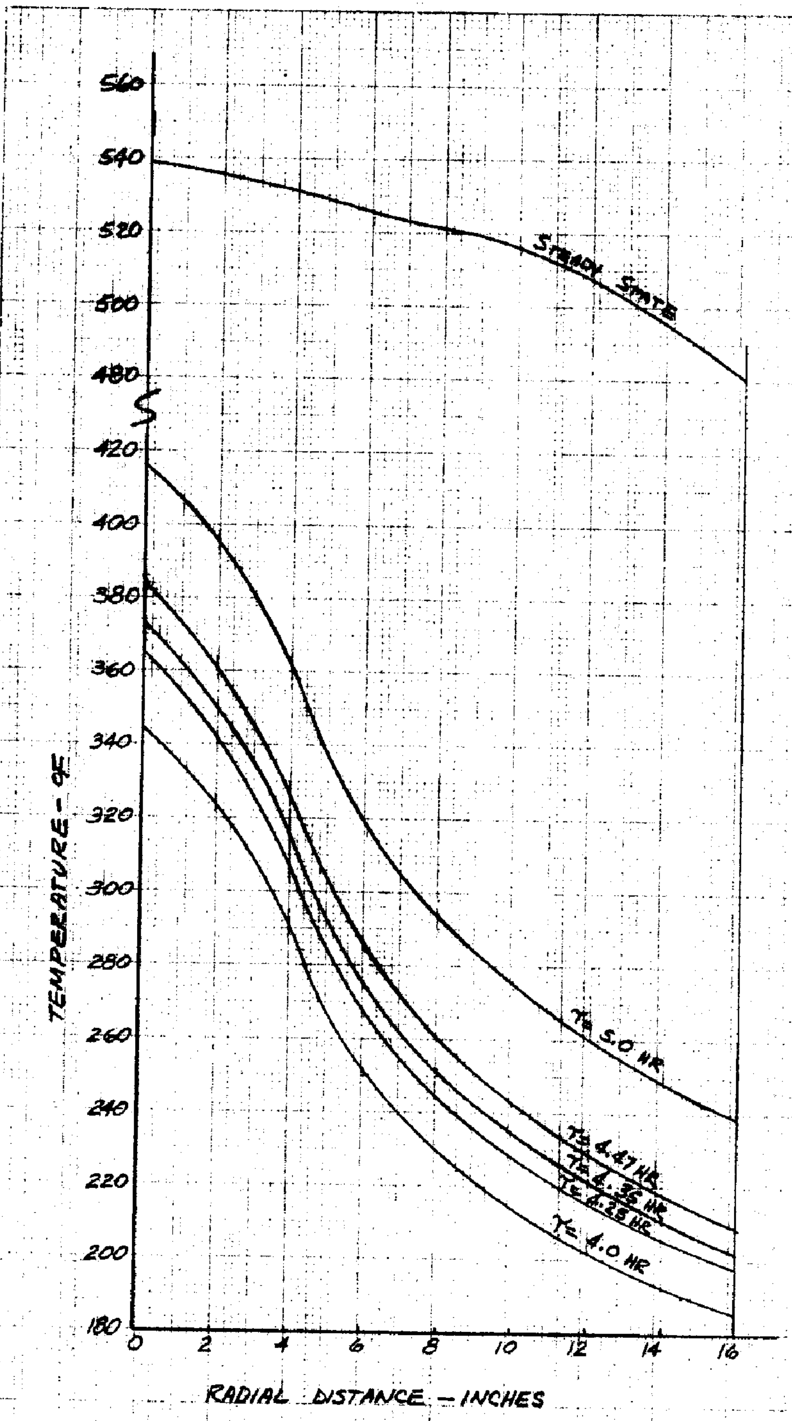

STEADY STATE
τ= 5.0 HR
τ= 4.67 HR
τ= 4.35 HR
τ= 6.35 HR
τ= 6.0 HR
RADIAL GRADIENT
AT TOP OF
HEAD FLANGE
100 °F/HR HEATUP
TEMPERATURE - °F
560
540
520
500
480
460
440
420
400
380
360
340
320
300
280
260
240
220
200
180
0
2
4
6
8
10
12
14
16
18
20
22
24
DISTANCE FROM INSIDE SURFACE - INCHES

FIGURE B-41



RADIAL GRADIENT AT BOTTOM OF HEAD FLANGE 100 °F/HR HEATUP

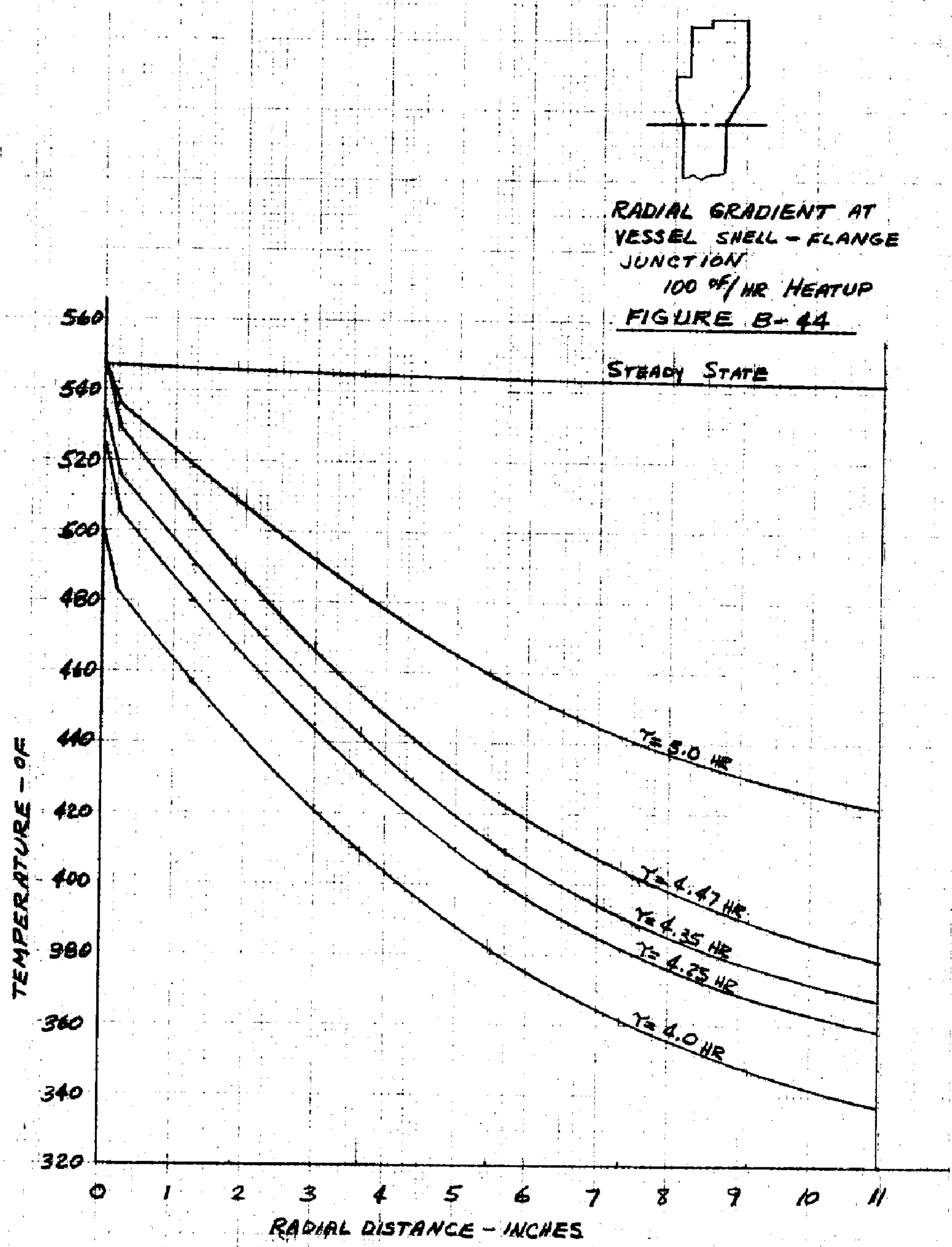
FIGURE B-42



RADIAL GRADIENT
AT TOP OF
VESSEL FLANGE
100 °F/HR HEATUP

FIGURE B-43

B-66


RADIAL GRADIENT AT
VESSEL SHELL - FLANGE
JUNCTION
100 °F/HR HEATUP
FIGURE B-44
STEADY STATE
τ = 5.0 HR
τ = 4.47 HR
τ = 4.35 HR
τ = 4.25 HR
τ = 4.0 HR
TEMPERATURE - °F
560
540
520
500
480
460
440
420
400
380
360
340
320
0
1
2
3
4
5
6
7
8
9
10
11
RADIAL DISTANCE - INCHES

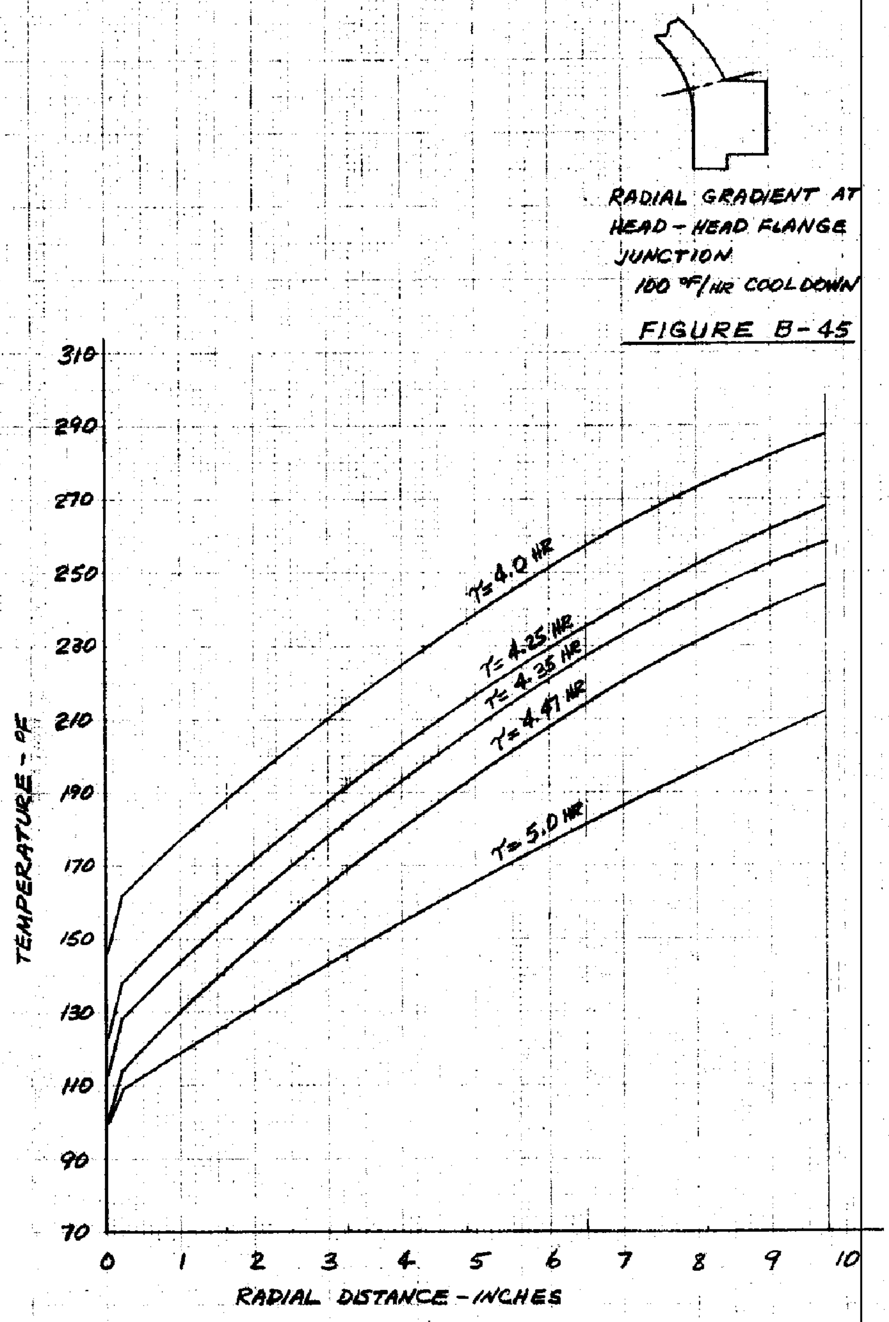

RADIAL GRADIENT AT
HEAD - HEAD FLANGE
JUNCTION
100 °F/HR COOLDOWN
TEMPERATURE - °F
310
290
270
250
230
210
190
170
150
130
110
90
70
τ= 4.0 HR
τ= 4.25 HR
τ= 4.35 HR
τ= 4.47 HR
τ= 5.0 HR
0
1
2
3
4
5
6
7
8
9
10
RADIAL DISTANCE - INCHES

FIGURE B-45