MASTER

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STRESS ANALYSIS OF LOFT STEAM GENERATOR
BLOWDOWN CROSS-OVER LINE

J. N. Singh

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DEPARTMENT OF ENERGY

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LOFT TECHNICAL REPORT LTR 115-36

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APPLIED MECHANICS BRANCH

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STRESS ANALYSIS OF LOFT STEAM GENERATOR

BLOWDOWN CROSS-OVER LINE

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<i>[Signature]</i> RSB Mgr		
<u>SUMMARY</u>		

The purpose of this report is to demonstrate compliance of the LOFT Steam Generator Blowdown Cross-Over Piping with the ASME Boiler and Pressure Vessel Code, Section III, Subsection NC. Deadweight, thermal expansion, seismic, LOCE, and LOCA loads have been considered. With the addition of two snubbers, as shown in this report, the system conforms to all requirements.

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STRESS ANALYSIS OF LOFT STEAM GENERATOR
BLOWDOWN CROSS-OVER LINE

I. INTRODUCTION

This report is a stress analysis for the LOFT Steam Generator Blowdown Cross-Over Piping. The system has been analyzed for the effect of deadweight, thermal, safe shutdown earthquake (SSE), loss-of-coolant experiment (LOCE), and loss-of-coolant accident (LOCA) loads. The operating basis earthquake (OBE) case was not analyzed since meeting the requirements of SSE satisfies OBE. The OBE response is one-half the magnitude of the SSE response but the allowable stress limits for OBE is two-thirds of the allowable stress limits for SSE. The analysis includes demonstration of compliance with Section III of the ASME Boiler and Pressure Vessel Code^[1].

This system is a part of the total system consisting of a 1/2-inch bottom blowdown, a shell drain line (P4 and P5), and a 1/2-inch cross-over line. This is a Class 2, Schedule 80 piping system. The analysis of parts P4 and P5 was reported in LTR 115-11^[2]. The section covered in this report is shown in Figure 1.

The operating and design conditions used here are given below in Table I. Stress free temperature for the system is equal to 70°F (Ref. 2).

TABLE I
OPERATING AND DESIGN CONDITIONS

<u>Pressure</u>	<u>Temperature</u>	<u>Pressure</u>	<u>Temperature</u>
1100 psig	600°F	862 psig	530°F

Finite Element Model of LOFT Steam
Generator Blowdown Cross-Over Line

S - SNUBBER

Figure-1

II. ANALYSIS

A finite-element model of the LOFT Steam Generator Blowdown Cross-Over Line (Figure 1), along with lines P4 and P5 (Figure 2), was prepared to be used in SAP IV^[3] computer program. SAP IV is a structural analysis program for static and dynamic responses of linear elastic systems. In this particular case, the static portion of the program was used to determine the forces and moments in the pipe due to deadweight and thermal expansion while the dynamic portion provided the loads due to LOCE, LOCA, and SSE response spectra. These response spectra are shown in Figures 3, 4, and 5, respectively. The anchor displacements were very insignificant and, hence, did not warrant analysis.

1. MODEL

The LOFT Steam Generator Blowdown Cross-Over Piping was modeled as a combination of straight and curved elements. The snubbers were represented with boundary elements in the dynamic part of the analysis and neglected in the static section due to their peculiar behavior. Table II shows the node locations of the model (the cross-over line only). Figure 1 also shows the node numbers and element numbers.

2. COMPUTER RUNS

The computer model was analyzed both statically and dynamically. The static run considered loads due to deadweight and thermal expansion. The dynamic analysis analyzed loads due to LOCE, LOCA, and SSE response spectra.

LINE P4 AND P5

1 1/2" NOMINAL

FIGURE 2

Finite Element Model of Lines
P4 and P5 as given in LTR 115-11

NODE LOCATIONS FOR MAIN FEED
SYSTEM

LINE P4 AND P5

REFER To :
DWG. NO. 204259

LTR 115-36

FIGURE 3

STEAM GENERATOR
LOCE RESPONSE SPECTRUM

1% DAMPING

DIRECTION FACTORS

X = 1.0

Y = 1.0

Z = 0.33

ACCELERATION ~ IN./SEC²

4000

3000

2000

1000

0.0

0

10.

20.

30.

40.

50.

60.

70.

80.

90.

100.

FREQUENCY ~ HERTZ

FIGURE - 4

STEAM GENERATOR
LOCA RESPONSE SPECTRUM

1% DAMPING

DIRECTION FACTORS

X=1.0

Y=1.0

Z=0.33

ACCELERATION ~ IN./SEC.²

4000.

3000.

2000.

1000.

0.0

0.0

10.

20.

30.

40.

50.

60.

70.

80.

90.

100.

FREQUENCY ~ HERTZ

FIGURE - 5

MTA SEISMIC RESPONSE SPECTRUM

1% DAMPING

DIRECTION FACTORS

$$X = 1.0$$

$$Y = 0.55$$

$$Z = 1.0$$

TABLE IILOFT STEAM GENERATOR BLOWDOWN CROSS-OVER LINE NODES

<u>Node Pt.</u>	<u>X</u>	<u>Y</u>	<u>Z</u>
47	195.560	139.000	61.500
48	195.560	140.500	60.000
79	195.560	139.000	60.000
80	195.560	139.000	58.500
81	196.974	139.000	55.086
82	201.924	139.000	50.136
83	205.196	139.000	46.864
84	209.792	139.000	42.268
85	212.957	140.630	39.219
86	217.444	146.117	35.000
87	221.930	151.603	30.781
88	223.560	155.496	29.350
89	223.560	162.166	28.950
90	223.560	168.835	28.550
91	223.560	175.505	28.150
92	223.560	178.000	25.500
93	223.560	178.000	22.000
94	223.560	178.000	13.500
95	223.560	178.000	5.000

IV. REFERENCES

1. American Society of Mechanical Engineers, ASME Boiler and Pressure Vessel Code, Section III, Division 1, "Nuclear Power Plant Components", Subsection NC, 1974.
2. D. K. Morton, "LOFT Main Feed Piping System Stress Analysis", LOFT Technical Report LTR 115-11 (TR-793), June 17, 1976.
3. Klaus-Jurgen Bathe, et al, "SAP IV, A Structural Analysis Program for Static and Dynamic Response of Linear Systems", Earthquake Engineering Research Center, Berkeley, California, June 1973.

III. CALCULATIONS AND RESULTS

The applicable Code equations of NC-3652, NC-3652.2, and NC-3652.3 have been rearranged to arrive at a maximum allowable moment with given geometry and loadings. These are given in Appendix A. The maximum moments or combination of moments occurring at various sections of the pipe are listed in Appendix B. Comparing the allowable moment values, as calculated in Appendix A, with those arrived at and listed in Table IV of Appendix B, it is apparent that the Code conditions of equations 8, 9, and 10 are satisfied with the given configuration of snubbers.

APPENDIX A
REARRANGEMENT OF CODE EQUATIONS AND
ALLOWABLE MOMENTS

Appendix - A

Rearranging and expressing the equations of NC-3650 in terms of moments:

i) Equation for sustained loads: (Equation 8)

$$S_h \geq \frac{Pd^2}{D_o^2 - d^2} + \frac{0.75iM_A}{Z}$$

$$\text{or } M_A \leq \left(S_h - \frac{Pd^2}{D_o^2 - d^2} \right) \frac{Z}{0.75i}$$

where:

S_h = basic material allowable stress at design temperature (lb/in²).

P = operating internal pressure (lb/in²)

D_o = outside diameter of the pipe (in.)

d = nominal inside diameter of the pipe (in.)

Z = section modulus of pipe (in³)

= $\pi r^2 t_n$, where, r = mean cross sectional radius (in.)

t_n = nominal wall thickness (in.)

i = stress intensification factor (the product of 0.75i should never be less than 1.0)

M_A = resultant moment loading on cross section due to weight and other sustained loads (in. lb)

For the given piping system, the given quantities are ($\frac{1}{2}$ " pipe).

$$S_h = 15,000 \text{ lb/in}^2$$

$0.751 = 1.0$, for all 5D pipe-bends, (straight and curved elements only)

$$P = 862 \text{ lb/in}^2$$

$$D_o = 0.840 \text{ in.}$$

$$d = 0.546 \text{ in.}$$

$$r = 0.347 \text{ in.}$$

$$t_m = 0.147 \text{ in.}$$

$$Z = \pi r^2 t_m = \pi (0.347)^2 (0.147) = 0.056 \text{ in}^3$$

Therefore, for straight and curved pipe sections,

$$M_A \leq \left(15,000 - \frac{862 \times 0.546^2}{0.840^2 - 0.546^2} \right) \frac{0.056}{1.0} \text{ in lb}$$

$$\leq 805 \text{ in. lb.}$$

The stress intensification factor for ~~straight~~^a 5D bend, (i)

$$i = 0.9 / h^{2/3}; \text{ where } h = \frac{t_m R}{r^2} = \frac{0.147 \times 2.5}{0.347^2} = 3.052$$

$$\therefore i = \frac{0.9}{3.052^{2/3}} = 0.428$$

For a tee, then,

$$h = \frac{t_m}{r} = \frac{0.147}{0.347} = 0.424$$

$$i = \frac{0.9}{h^{2/3}} = \frac{0.9}{0.424^{2/3}} = 1.595$$

$$0.751 = 0.75 \times 1.595 = 1.196$$

The allowable moment, then

$$\therefore M_A \leq \frac{805}{1.196} = 673$$

ie,

$$M_A \leq 673 \text{ in. lb.}$$

(iii) Equation for thermal expansion: (Equation 10)

The effects of thermal expansion must meet the requirements,

$$S_A \geq \frac{i M_c}{Z}$$

$$\text{or } M_c \leq \frac{S_A Z}{i}$$

where,

$$S_A = f \cdot (1.25 S_{\text{cold}} + 0.25 S_{\text{hot}}),$$

Z = Section modulus of pipe (in^3),

i = Stress intensification factor,

M_c = thermal + anchor displacement moments.

Again,

$$S_A = f \cdot (1.25 S_{\text{cold}} + 0.25 S_{\text{hot}}); \text{ where } S_{\text{cold}} \text{ and } S_{\text{hot}} \text{ from}$$

allowable stress tables both equal $15,000 \text{ lb/in}^2$; $f=1.0$, for full temperature cycles $< 7,000$.^[2]

Therefore

$$S_A = 1.0 (1.25 \times 15000 + 0.25 \times 15000) = 22,500 \text{ lb/in}^2$$

Thus, for a straight or curved pipe (where $i=1$); $\frac{1}{2}$ " nominal

$$M_c \leq \frac{22,500 \times 0.056}{1.0}$$

$$\text{or } M_c \leq 1260 \text{ in. lb.}$$

For a tee, then

$$M_c \leq \frac{1260}{1.196} = 1054 \text{ in. lb.}$$

(ii) Equation for occasional loads: (Equation 9)

$$F.S_h > \frac{Pd^2}{D_o^2 - d^2} + 0.75i \left(\frac{M_A + M_B}{Z} \right)$$

$$\text{or } (M_A + M_B) \leq \left(F.S_h - \frac{Pd^2}{D_o^2 - d^2} \right) \frac{Z}{0.75i}$$

where, all the terms are as explained in (i), and further

M_B = occasional load moment (in. lb)

F = Occasional load factor

$$\left. \begin{aligned} &= 1.2 ; \text{ for LOCE} \\ &= 1.8 ; \text{ for SSE} \\ &= 2.4 ; \text{ for LOCA} \end{aligned} \right\} \text{Reference [2]}$$

Therefore,

$$(M_A + M_B) \leq \left(F.S_h - \frac{Pd^2}{D_o^2 - d^2} \right) \frac{Z}{0.75i}$$

$$\leq 973 \text{ in. lb for LOCE}$$

$$\leq 1477 \text{ in. lb for SSE}$$

$$\leq 1981 \text{ in. lb for LOCA}$$

For a tec, then, the various quantities are

$$(M_A + M_B) \leq \frac{973}{1.196} = 813 \text{ in. lb.}$$

$$\leq \frac{1477}{1.196} = 1235 \text{ in. lb.}$$

$$\leq \frac{1981}{1.196} = 1656 \text{ in. lb.}$$

APPENDIX B
COMBINATION OF VARIOUS MOMENTS
AS OBTAINED FROM ANALYSIS

Table III shows the moments at various node points due to various kinds of loadings.

Table IV shows the combinations of moment resultants to be compared with equations (8), (9) and (10) of the reference^[4] to be compared with values as calculated in appendix-A.

Table III

Table of moments and resultant moments at the nodal points.

Node Pt.	MA				MB1				MB2				MB3				MC			
	Static moment (Total)				LOCE moment				LOCA moment (Steam generator)				SSE moment				Static moment (Temperature only)			
	Mx	My	Mz	Res. Mom.	Mx	My	Mz	Res. Mom.	Mx	My	Mz	Res. Mom.	Mx	My	Mz	Res. Mom.	Mx	My	Mz	Res. Mom.
79	-77	131	19	153	62	207	154	265	74	329	179	382	50	198	303	365	-41	55	48	84
80	-77	133	19	155	62	223	127	264	74	349	147	386	50	196	269	337	-41	55	44	82
81	1	78	-122	145	108	31	192	222	125	44	310	337	229	44	135	269	29	43	-50	72
82	-41	94	55	116	100	121	131	204	116	195	164	280	217	95	71	247	1	36	35	49
83	-41	76	41	96	100	118	176	234	116	158	208	286	217	148	167	311	1	28	21	35
84	-41	49	12	65	100	145	199	266	116	177	221	306	217	194	291	412	1	15	3	15
85	39	30	11	50	150	102	148	234	183	123	170	273	206	217	245	387	10	-6	0	12
86	3	14	2	15	69	110	104	166	83	146	123	208	35	194	175	264	11	-12	-9	19
87	3	-21	-22	30	69	68	218	239	83	99	259	289	35	38	82	96	11	-28	-18	35
88	-29	-15	-14	36	90	92	220	255	120	118	230	285	92	55	70	128	-29	-19	-20	40
89	-14	-21	57	62	46	317	139	349	53	366	210	425	44	443	69	450	-12	-37	29	49
90	-14	-13	97	99	46	160	127	209	53	190	249	312	44	337	105	356	-12	-39	43	59
91	-14	-5	137	138	46	128	170	218	53	141	291	328	44	213	164	272	-12	-41	58	72
92	2	12	-111	112	122	50	149	199	133	58	194	242	157	23	236	284	42	13	-56	71
93	2	-8	53	54	120	56	260	292	132	70	461	485	158	97	306	358	41	-17	47	65
94	2	2	-100	100	120	200	71	244	132	223	128	289	158	341	78	384	41	-20	24	52
95	2	12	-269	269	120	436	135	472	132	474	242	548	158	598	152	637	41	-23	1	47

Table - IV

Table of combination moments

Node Pt.	M_A	$M_A + 1/3 B_1$	$M_A + 1/3 B_2$	$M_A + M_{B2}$	M_C
79	153	418	535	518	84
80	155	419	541	492	82
81	145	367	482	414	72
82	116	320	396	363	49
83	96	330	382	407	35
84	65	331	371	477	15
85	50	284	328	437	12
86	15	181	223	279	19
87	30	269	319	126	35
88	36	291	321	164	40
89	62	411	487	512	49
90	99	308	417	455	59
91	138	356	466	410	72
92	112	311	354	396	71
93	54	346	539	412	65
94	100	344	389	484	52
95	269	741	817	906	47

Item No.	Description	Checked	Comment
1.0	<u>Basic Design Data</u>		
1.1	Does the system have a Design Specification? (Include name and number of Design Specification in report.)	✓	
1.2	Includes all branch lines where $I_R/I_B \leq 7.0$?		N/A
1.3	Are all materials specified correctly?	✓	
1.4	Check pipe size, thickness, and uniform weight.	✓	
1.5	Are all valves coded correctly? Are all motor or pneumatic operated valves specified with lumped wts and cgs?		N/A
1.6	Is the system modeled correctly? (Length ratios, etc.)	✓	
1.7	Are all hanger/restraints modeled correctly per the analytical drawing?	✓	
1.8	Are all "node codes" specified correctly?	✓	
1.9	Is the design temperature and pressure listed correct?	✓	
1.10	Is the Quality Group and Safety Category of the system correct?		?
1.11	Are elbows explicitly modeled?		N/A
2.0	<u>Weight Analysis</u>		
2.1	Verify uniform pipe wts.	✓	
2.2	Verify valve wts and cgs.		N/A
2.3	Verify all rigid and spring hanger locations and types against drawing.	✓	
2.4	Check stresses against allowables.	✓	
2.5	Check deflections.		N/A
2.6	For Hydro-run verify that all spring hangers were pinned (rigid).		?
2.7	Are branch connections correctly reinforced?		N/A

Item No.	Description	Checked	Comment
3.0	<u>Thermal Analysis</u>		
3.1	Do defined thermal modes agree with the analyticals and process flow diagrams?		?
3.2	Are the branch and run pipe temperatures specified correctly for <u>all</u> modes?	✓	
3.3	Are the anchor movements specified correctly for all modes?		Negligible
3.4	Are all restraints coded correctly?	✓	
3.5	Are the thermal stresses acceptable?	✓	
3.6	Are equipment reactions acceptable?		N/A
4.0	<u>Seismic Analysis</u>		
4.1	Does the system have a seismic requirement?	✓	
4.2	Is the correct response spectra used?	✓	
4.3	Is the response spectra adequately identified?	✓	
4.4	Is the system correctly modeled for seismic analysis?	✓	
4.5	Correct length ratios?	✓	
4.6	Correct valve wts and cgs.		N/A
4.7	Correct snubber locations and directions?	✓	
4.8	Is equipment rigid?		N/A
4.9	If equipment is flexible, is it modeled correctly?		N/A
4.10	Are seismic stresses acceptable?	✓	
4.11	Are equipment loads acceptable?		N/A
4.12	Were the seismic anchor movements acceptable?	✓	

Item No.	Description	Checked	Comment
5.0	<u>Hydraulic Transient Analysis</u>		
5.1	Were all required fluid transient problems considered? a. RV discharge b. Valve closure c. Valve opening d. Water hammer		N/A
5.2	Are all necessary design parameters specified in the report? (Opening/closing times, flow rates, etc.)		N/A
5.3	Was the force calculation performed per the appropriate procedure?		N/A
5.4	Was the force calculation submitted to your Group Leader?		?
5.5	Was a dynamic or quasi-static analysis performed?	✓	
5.6	Were the forces input correctly in the SAP program?	✓	
5.7	Were the stresses acceptable?	✓	N/A
5.8	Were the equipment reactions included with the correct load set?		
6.0	<u>Combined Stress</u>		
6.1	Is the design pressure correct?		N/A
6.2	Is the material type correct?	✓	
6.3	Is the allowable stress for the correct material at the design temperature?	✓	
6.4	Are the number of earthquake cycles correct?	✓	
6.5	Are all thermal load combinations specified correctly?		?
6.6	Are all mechanical loads listed correctly as upset, emergency, or faulted?		?

Item No.	Description	Checked	Comment
6.7	Are all transient stresses identified and are the thermal transient runs properly documented?		?
6.8	Are all stresses and usage factors within allowables?	✓	
6.9	Were all high-stress/usage factor points run with the detailed output?		?
6.10	Were all special fittings (valve ends, branch connections, etc) run separately with the correct transient stresses?		N/A
6.11	Is the piping code used correct?	✓	
6.12	Were there any special considerations?	no	
6.13	Are testing conditions considered?		?
7.0	<u>Documentation</u>		
7.1	Does the stress report define all loading conditions to be considered and explain what loads are considered to be acting concurrently?	✓	
7.2	Does the stress report explain the omission of any transient or the enveloping of transients with less severe conditions?	yes	
7.3	Does the report explain how analysis report can be traced?	✓	
7.4	Does the report explain retention of documentation (computer runs and analyses)?		?