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PROJECT NAME:

Environmental Fatigue Analysis of VYNPS

CONTRACT NO.:

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CLIENT:	PLANT:
Entergy Nuclear Operations, Inc.	Vermont Yankee Nuclear Power Station

CALCULATION TITLE:

Recirculation Outlet Stress History Development for Nozzle Green Function

Document Revision	Affected Pages	Revision Description	Project Manager Approval Signature & Date	Preparer(s) & Checker(s) Signatures & Date
0	1-29, Appendix: A1-A2	Initial Issue	Terry J. Herrmann 07/18/2007 [signature]	Jennifer E. Smith 07/18/2007 [signature] Minghao Qin 07/18/2007 [signature]

U.S. NUCLEAR REGULATORY COMMISSION
In the Matter of Entergy Nuclear Vermont Yankee LLC
Docket No. 50-271 Official Exhibit No. E2-14-VY
OFFERED by Applicant/Licensee Intervenor ______
NRC Staff Other ______
IDENTIFIED on 7/21/08 Witness/Panel NEC2
Action Taken: ADMITTED REJECTED WITHDRAWN
Reporter/Clerk MAC

DOCKETED
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August 12, 2008 (11:00am)
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DS-03

Table of Contents

List of Tables

List of Figures

1.0 OBJECTIVE

The objective of this calculation is to compute the pressure stresses, thermal stresses, and the Green's Functions for high (100%), mid (50%), and no (0%) flow thermal loading of the Vermont Yankee Nuclear Power Station recirculation outlet nozzle.

2.0 RECIRCULATION OUTLET NOZZLE MODEL

An axisymmetric finite element model of the recirculation outlet nozzle was developed in Reference [1] using ANSYS [2]. The geometry and model in Reference [1] is used in this calculation. The material properties are taken at an average temperature of 300°F. This average temperature is based on a thermal shock of 500°F to 100°F which will be applied to the FE model for Green's Function development. Table 1 listed the material properties at 300°F. The meshed model is shown in Figure 1.

3.0 APPLIED LOADS

Both pressure and thermal loads will be applied to the finite element model.

3.1 Pressure Load

A uniform pressure of 1000 psi was applied along the inside surface of the recirculation outlet nozzle and the vessel wall. A pressure load of 1000 psi was used because it is easily scaled up or down to account for different pressures that occur during transients. In addition, a cap load was applied to the piping at the end of the nozzle. This cap load was calculated as follows:

$$P_{cap} = P \cdot \frac{(D_i^2)}{(D_o^2 - D_i^2)}$$

where:

- P = Pressure = 1,000 psi
- D_i = Inner Radius = 12.96875 in
- D_o = Outer Radius = 14.18750 in
- P_{cap} = Tension stress on the end of the nozzle. (psi)

Therefore, the cap load is 5081.7 psi. The calculated value was given a negative sign in order for it to exert tension on the end of the model. The ANSYS input file VY_RON_P.INP, in the computer files, applies the pressure loading to the geometry in file RON_VY.INP. Figures 2, 3, and 4 show the internal pressure distribution, cap load, and symmetry condition applied to the vessel end of the model, respectively.

3.2 Thermal Load

Thermal loads are applied to the recirculation outlet nozzle model. The heat transfer coefficients after power uprate were determined by scaling the values from Reference [4]. These values were determined for various regions of the finite element model and for 100% (28,294 GPM, converted from 12.3 Mlbm/hr [7]), 50% (14,147 GPM), and 0% (0 GPM) flow rates. The temperatures used are based upon a thermal shock from 500°F to 100°F. The calculated heat transfer coefficients for each region are shown below. The GPM values are calculated from the Mlbm/hr values at an average temperature of 300°F.

3.2.1 *Heat Transfer Coefficients*

The heat transfer coefficients for the 100% flow and 50% flow cases were calculated from Reference [4] as follows:

$$h_{Df} = h_{300}\left(\frac{f_{Df}}{25}\right)^{0.8}\left(\frac{26}{D_{Df}}\right)^{0.2}$$

Where:
h_{Df} = the heat transfer coefficient at a Diameter and flow rate
h_{300} = the heat transfer coefficient from Reference [4] at 300°F
f_{Df} = the flow rate corresponding to h_{Df} (ft/sec)
D_{Df} = the diameter corresponding to h_{Df} (in)

The heat transfer coefficients for 0% flow were calculated in spreadsheet Ht_coeffs.xls for natural convection and are shown in Tables 3 and 4.

As shown in Figure 5, the following heat transfer coefficients were applied:

Region 1

The heat transfer coefficient, h, for 100% flow is $4789\left(\frac{17.364}{25}\right)^{0.8}$ = 3577.8 BTU/hr-ft^2-°F at 300°F. [4]

where 17.364 ft/sec is converted from 28,294 GPM and 25.8 in ID.

The heat transfer coefficient, h, for 50% flow is $4789\left(\frac{8.682}{25}\right)^{0.8}$ = 2054.9 BTU/hr-ft^2-°F at 300°F. [4]

where 8.682 ft/sec is converted from 14,147 GPM and 25.8 in ID.

The heat transfer coefficient, h, for 0% flow is 112.34 BTU/hr-ft^2-°F at 300°F. [Table 3, for natural convection]

Region 2

The heat transfer coefficient for Region 2 is linearly transitioned from the value of the heat transfer coefficient used in Region 1 to the value used for Region 3.

Region 3 (the point between Region 2 and Region 4)

The heat transfer coefficient, h, for 100% flow is $4789 \left(\frac{17.364}{25}\right)^{0.8} \cdot \left(\frac{26}{35.49}\right)^{0.2} = 3361$ BTU/hr-ft^2-°F at 300°F. [4]

where the flow rate is the same as that for Region 1, and the ID is 35.49 in.

The heat transfer coefficient, h, for 50% flow is $4789 \left(\frac{8.682}{25}\right)^{0.8} \cdot \left(\frac{26}{35.49}\right)^{0.2} = 1930.9$ BTU/hr-ft^2-°F at 300°F. [4]

where the flow rate is the same as that for Region 1, and the ID is 35.49 in.

The heat transfer coefficient, h, for 0% flow is 112.34 BTU/hr-ft^2-°F at 300°F. using the same HTC as Region 1 [Table 3, for natural convection]

Region 4

Per Reference [1], the heat transfer coefficient for Region 4 (Nozzle Blend Radius) is linearly transitioned from the value of the heat transfer coefficient used in Region 3 to the value used in Region 5.

Region 5

The heat transfer coefficient, h, for 100% flow is 0.5 x 3577.8 = 1788.9 BTU/hr-ft^2-°F at 300°F. [4]

The heat transfer coefficient, h, for 50% flow is 0.5 x 2054.9 = 1027.4 BTU/hr-ft^2-°F at 300°F. [4]

The heat transfer coefficient, h, for 0% flow is 101 BTU/hr-ft^2-°F at 300°F. [Table 4, for natural convection] by using 40 in. hydraulic diameter [4].

Region 6

The heat transfer coefficient, h, is 0.4 BTU/hr-ft^2-°F [4].

3.2.2 *Boundary Fluid Temperatures*

For the Green's Functions, a 500°F to 100°F thermal shock is run to determine the stress response to a one-degree change in temperature. The following temperatures are valid when there is water flow. Values between defined points are linearly interpolated. For the 100%, 50%, and 0% flow cases, the thermal shock is run as follows:

Regions 1 to 5
T = 500°F – 100°F
Region 6
T = 120°F

4.0 THERMAL AND PRESSURE LOAD RESULTS

The three flow dependent thermal load cases outlined in Section 3.0 were run on the finite element model. Appendix A contains the thermal transient input files VY_RON_T_100.INP, VY_RON_T_50.INP, and VY_RON_T_0.INP for 100%, 50%, and 0% flow rates, respectively. The three flow dependent input files for the stress runs are also included in Appendix A. The stress filenames are VY_RON_S_100.INP, VY_RON_S_50.INP, and VY_RON_S_0.INP for 100%, 50%, and 0% flow rates, respectively.

The critical safe end location was chosen as node 6395, which has the highest stress intensity due to thermal loading under high flow conditions. As shown in Figures 6 and 7, Node 6395 is located on the inside diameter of the nozzle safe end of the model and the maximum stress occurs at 5.1 seconds.

The critical blend radius location was chosen, based upon the highest pressure stress. Assumed the cladding has cracked, therefore, as shown in Figures 8 and 9, the critical location is selected as node 3829 at base metal of the nozzle.

The stress intensity for use in the Green's functions are calculated from the component stresses (X, Y, and Z) and compared to the stress intensity reported by ANSYS. As seen in Figure 10, the Y-X calculated total stress intensity best matches the ANSYS reported stress intensity for 100% flow at the safe end. Therefore, the Y-X stress will be used for the total and membrane plus bending Green's functions for all flow rates for the safe end. As seen in Figure 11, the Z-X calculated total stress intensity best matches the ANSYS reported stress intensity for 100% flow at the blend radius in very beginning. Therefore, the Z-X stress will be used for the total and membrane plus bending Green's functions for all flow rates for the blend radius.

The stress time history for the critical paths was extracted during the stress run for 100% flow rate. This produced two files, HFSE.OUT and HFBR.OUT, which contain the thermal stress history. The membrane plus bending stresses and total stresses for the Green's Functions were extracted from these files to produce the files HFSE_Inside.RED and HFBR_Inside.RED, where SE and BR corresponded to the safe end and blend radius locations, respectively. The total stress intensity (SI) was extracted from these files to produce the files HFSE.CLD and HFBR.CLD, where SE and BR corresponded to the safe end and the blend radius, respectively.

The stress time history for the critical paths was extracted during the stress run for 50% flow rate. This produced two files, MFSE.OUT and MFBR.OUT which contains the thermal stress history. The membrane plus bending stresses and total stresses for the Green's Functions were extracted from the file to produce the file MFSE_Inside.RED, where SE corresponds to the safe end location.

The stress time history for the critical paths was extracted during the stress run for 0% flow rate. This produced two files, LFSE.OUT and LFBR.OUT which contain the thermal stress history. The membrane plus bending stresses and total stresses for the Green's Functions were extracted from the file to produce the file LFSE_Inside.RED, where SE corresponds to the safe end location.

The stress time history for the recirculation outlet nozzle during 100% flow, 50% flow, and 0% flow are shown in Figures 12 to 23. The data for the Green's Functions is included in the files HFBR_M+B-Green.xls, HFBR_T-Green.xls, HFSE_M+B-Green.xls, HFSE_T-Green.xls, MFBR_M+B-Green.xls, MFBR_T_Green.xls, MFSE_M+B-Green.xls, MFSE_T-Green.xls, LFBR_M+B-Green.xls, LFBR_T-Green.xls, LFSE_M+B-Green.xls, and LFSE_T-Green.xls in the project Files. Where HF, MF, and LF corresponded to 100% flow, 50% flow, and 0% flow rate, respectively. M+B and T corresponded to membrane plus bending stress and total stress, respectively.

The pressure stress intensities for the path were extracted during the pressure run. The pressure stresses were extracted along the nodal path as shown in Figures 7 and 9. This produced two files, PSE.OUT and PBR.OUT for the safe end and blend radius locations, respectively.

For the pressure loading specified (1000 psig), the total stress intensities at Node 6395 and Node 3829 were determined to be 11490 psi and 31300 psi, respectively. The membrane plus bending stress intensities at Node 6395 and Node 3829 were determined to be 11350 psi and 33640 psi, respectively. Table 2 shows the final pressure results.

Results were also extracted from the vessel portion of the model to verify the accuracy of the results obtained from the ANSYS model, and to check the results due to the use of the 2.0 multiplier on the vessel radius. These results are contained in the file PVESS.OUT. The radius of the finite element model (FEM) was multiplied by a factor of 2.0 [1] to account for the fact that the vessel portion of the 2D axisymmetric model is a sphere but the true geometry is the intersection of two cylinders.

The equation for the membrane hoop stress for a sphere is:

$$\sigma = \left(\frac{(pressure) \times (radius)}{2 \times thickness} \right)$$

Considering a vessel base metal radius, R, of 105.906 inches increased by a factor of 2.0, a vessel base metal thickness, t, of 5.4375 inches, and an applied pressure, P, of 1,000 psi, the calculated stress for a sphere is PR/(2t) = 19,477 psi. This compares very well with the remote vessel wall membrane hoop stress from the ANSYS result file, PVESS.OUT, of 19,540 psi. Thus, considering the peak total pressure stress of 31,300 psi reported above, the stress concentrating effect of the nozzle corner is 31,300/19,477 = 1.61. In other words, the peak nozzle corner stress is 1.61 times higher than nominal vessel wall stress for the 2D axisymmetric model.

The equation for the membrane hoop stress in a cylinder is:

$$\sigma = \left(\frac{(pressure) \times (radius)}{thickness} \right).$$

Based on the previous dimensions, the calculated stress for a cylinder without the 2.0 factor is 19,477 psi. Increasing this by a factor of 1.61 yields an expected peak nozzle corner stress of 31,358 psi, which would be expected from a cylindrical geometry that is representative of the nozzle configuration. Therefore, the result from the ANSYS file for the peak nozzle corner stress (31,300 psi) is close to the peak nozzle corner stress for a cylindrical geometry because of the use of the 2.0 multiplier. This is consistent with SI's experience where a factor of two increase in radius is typical for representing the three-dimensional (3D) effect in a 2D axisymmetric model.

5.0 REFERENCES

1. SI Calculation No. VY-16Q-304, Revision 0, “Recirculation Outlet Nozzle Finite Element Model”
2. ANSYS, Release 8.1 (w/Service Pack 1), ANSYS, Inc., June 2004.
3. American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section II, Part D, 1998 Edition, 2000 Addenda.
4. CB&I, RPV Stress Report Section: T9 “Thermal Analysis Recirculation Outlet Nozzle Vermont Yankee Reactor Vessel.” 9-6201, SI document, VY-16Q-204.
5. J. P. Holman, "Heat Transfer," 4th Edition, McGraw-Hill, 1976.
6. J. P. Holman, "Heat Transfer," 5th Edition, 1981.
7. Entergy Nuclear Northeast Engineering Report, Report No. VY-RPT-05-00022, “Task T0100 Reactor Heat Balance EPU Task Report for ER-04-1409,” SI File No. VY-16Q-205.

Table 1: Material Properties @ 300°F(1)

Material	SA-533 Gr B (Mn-1/2Mo-1/2Ni)	SA-508 Cl 2 (3/4Ni-1/2Mo-1/3Cr-V)	SA-240 Type 304 (18Cr-8Ni)	SA-182 F316/ SA 376 TP316 (16Cr-12Ni-2Mo)
Modulus of Elasticity, e^{-6} psi	28.0	26.7	27.0	27.0
Coefficient of Thermal Expansion, e^{-6}, in/in/°F	7.7	7.3	9.8	9.8
Thermal Conductivity, Btu/hr-ft-°F	23.4	23.4	9.8	9.3
Thermal Diffusivity, ft^2/hr	0.401	0.401	0.160	0.150
Calculated Specific Heat, Btu/lb-°F (2)	0.119	0.119	0.125	0.127
Density, lb/in³	0.283	0.283	0.283	0.283
Poisson's Ratio	0.3	0.3	0.3	0.3

Notes: (1)The material properties applied in the analyses are taken from ASME Section II Part D 1998 Edition with 2000 Addenda. This is consistent with information provided in the Design Input Record (page 13 of VY EC No. 1773, SI File No. VY-16Q-209). The use of a later code edition than that used for the original design code is acceptable since later editions typically reflect more accurate material properties than was published in prior Code editions. Material Properties are evaluated at 300°F from the 1998 ASME Code, Section II, Part D, with 2000 Addenda, except for density and Poisson's ratio, which are assumed typical values.
(2) Calculated as $[k/(\rho d)]/12^3$.

Table 2: Pressure Results

Location	Membrane Plus Bending Stress Intensity (psi)	Total Stress Intensity (psi)
Safe End	11350	11490
Blend Radius	33640	31300

Table 3: 0% Flow Regions 1 and 3 Heat Transfer Coefficients

Pipe Inside Diameter, D =	25.800	inches =	2.150	ft					
		=	0.655	m					
Outer Pipe, Inside radius, r_o =	12.9	inches =	1.075	ft					
			0.328	m					
Inner Pipe Outside Diameter, D =	n/a	inches =	0.000	ft					
		=	0.000	m			0.000		
Inner Pipe, Outside radius, r_i =	0	inches =	0.000	ft					
			0.000	m					
Fluid Velocity, V =	17.364	ft/sec =	28293.595	gpm=		12.3 Mlb/hr			
Characteristic Length, L = D =	2.150	ft =	0.655	m					
(Outside) T_{fluid} - $T_{surface}$, ΔT =	8.40	12.00	24.00	36.00	48.00	60.00	72.00	°F	
=	4.67	6.67	13.33	20.00	26.67	33.33	40.00	°C	

		Value at Fluid Temperature, T [3]							Units
Water Property	Conversion Factor [1]	70 21.11	100 37.78	200 93.33	300 148.89	400 204.44	500 260.00	600 315.56	°F °C
k (Thermal Conductivity)	1.7307	0.5997 0.3465	0.6300 0.3640	0.6784 0.3920	0.6836 0.3950	0.6611 0.3820	0.6040 0.3490	0.5071 0.2930	W/m-°C Btu/hr-ft-°F
c_p (Specific Heat)	4.1869	4.185 1.000	4.179 0.998	4.229 1.010	4.313 1.030	4.522 1.080	4.982 1.190	6.322 1.510	kJ/kg-°C Btu/lbm-°F
ρ (Density)	16.018	997.1 62.3	994.7 62.1	962.7 60.1	917.8 57.3	858.6 53.6	784.9 49.0	679.2 42.4	kg/m^3 lbm/ft^3
β (Volumetric Rate of Expansion)	1.8	1.89E-04 1.05E-04	3.24E-04 1.80E-04	6.66E-04 3.70E-04	1.01E-03 5.60E-04	1.40E-03 7.80E-04	1.98E-03 1.10E-03	3.15E-03 1.75E-03	m^3/m^3-°C ft^3/ft^3-°F
g (Gravitational Constant)	0.3048	9.806 32.17	9.806 32.17	9.806 32.17	9.806 32.17	9.806 32.17	9.806 32.17	9.806 32.17	m/s^2 ft/s^2
μ (Dynamic Viscosity)	1.4881	9.96E-04 6.69E-04	6.82E-04 4.58E-04	3.07E-04 2.06E-04	1.93E-04 1.30E-04	1.38E-04 9.30E-05	1.04E-04 7.00E-05	8.62E-05 5.79E-05	kg/m-s lbm/ft-s
Pr (Prandtl Number)		6.980	4.510	1.910	1.220	0.950	0.859	1.070	---
Calculated Parameter	**Formula**	**70**	**100**	**200**	**300**	**400**	**500**	**600**	**°F**
Reynold's Number, Re	$\rho VD/\mu$	3473691	5061789	10891437	16454670	21515912	26132199	27337904	---
Grashof Number, Gr	$g\beta\Delta TL^3/(\mu/\rho)^2$	2441754517	1.2697E+10	2.417E+11	1.252E+12	3.977E+12	1.034E+13	2.16049E+13	---
Grashof Number, Gr_δ	$g\beta\Delta T(r_o-r_i)^3/(\mu/\rho)^3$	3.05E+08	1.59E+09	3.02E+10	1.57E+11	4.97E+11	1.29E+12	2.70E+12	---
Rayleigh Number, Ra	GrPr	17043446531	5.7265E+10	4.616E+11	1.528E+12	3.778E+12	8.883E+12	2.31172E+13	---
Rayleigh Number, Ra	$Gr_\delta Pr$	2.13E+09	7.16E+09	5.77E+10	1.91E+11	4.72E+11	1.11E+12	2.89E+12	---
From [1]:									
Inside Surface Forced Convection Heat Transfer Coefficient:									
H_{forced}	$0.023Re^{0.8}Pr^{0.4}k/D$	7,823.02 1,377.74	9,326.34 1,642.50	13,148.12 2,315.56	15,405.24 2,713.07	16,705.40 2,942.05	17,126.15 3,016.15	16,275.32 2,866.31	W/m^2-°C $Btu/hr-ft^2$-°F
From [1]:									
Inside Surface Natural Convection Heat Transfer Coefficient:									
Case:	Enclosed cylinder		C =	0.55	n =	0.25			
H_{free}	$C(GrPr)^n k/L$	181.85 32.03	258.65 45.55	469.34 82.66	637.89 112.34	773.57 136.24	875.17 154.13	933.22 164.35	W/m^2-°C $Btu/hr-ft^2$-°F

Table 4: 0% Flow Region 5 Heat Transfer Coefficient

Heat Transfer Coefficients

References: 1. J. P. Holman, "Heat Transfer," 4th Edition, McGraw-Hill, 1976.
2. J. P. Holman, "Heat Transfer," 5th Edition, 1981.
3. N. P. Cheremisinoff, "Heat Transfer Pocket Handbook," Gulf Publishing Co., 1984.
(Required Inputs are Shaded!)

Title =	Piping							
Pipe Inside Diameter, D =	40.000	inches =	3.333	ft				
		=	1.016	m				
Outer Pipe, Inside radius, r_o =	20	inches =	1.667	ft				
			0.508	m				
Inner Pipe Outside Diameter, D =	n/a	inches =	0.000	ft				
		=	0.000	m			0.000	
Inner Pipe, Outside radius, r_i =	0	inches =	0.000	ft				
			0.000	m				
Fluid Velocity, V =	7.224	ft/sec =	28293.595	gpm=	12.3 Mlb/hr			
Characteristic Length, L = D =	3.333	ft =	1.016	m				
(Outside) $T_{fluid} - T_{surface}$, ΔT =	8.40	12.00	24.00	36.00	48.00	60.00	72.00	°F
=	4.67	6.67	13.33	20.00	26.67	33.33	40.00	°C

Water Property	Conversion Factor [1]	Value at Fluid Temperature, T [3]							Units
		70	100	200	300	400	500	600	°F
		21.11	37.78	93.33	148.89	204.44	260.00	315.56	°C
k	1.7307	0.5997	0.6300	0.6784	0.6836	0.6611	0.6040	0.5071	W/m-°C
(Thermal Conductivity)		0.3465	0.3640	0.3920	0.3950	0.3820	0.3490	0.2930	Btu/hr-ft-°F
c_p	4.1869	4.185	4.179	4.229	4.313	4.522	4.982	6.322	kJ/kg-°C
(Specific Heat)		1.000	0.998	1.010	1.030	1.080	1.190	1.510	Btu/lbm-°F
ρ	16.018	997.1	994.7	962.7	917.8	858.6	784.9	679.2	kg/m^3
(Density)		62.3	62.1	60.1	57.3	53.6	49.0	42.4	lbm/ft^3
β	1.8	1.89E-04	3.24E-04	6.66E-04	1.01E-03	1.40E-03	1.98E-03	3.15E-03	m^3/m^3-°C
(Volumetric Rate of Expansion)		1.05E-04	1.80E-04	3.70E-04	5.60E-04	7.80E-04	1.10E-03	1.75E-03	ft^3/ft^3-°F
g	0.3048	9.806	9.806	9.806	9.806	9.806	9.806	9.806	m/s^2
(Gravitational Constant)		32.17	32.17	32.17	32.17	32.17	32.17	32.17	ft/s^2
μ	1.4881	9.96E-04	6.82E-04	3.07E-04	1.93E-04	1.38E-04	1.04E-04	8.62E-05	kg/m-s
(Dynamic Viscosity)		6.69E-04	4.58E-04	2.06E-04	1.30E-04	9.30E-05	7.00E-05	5.79E-05	lbm/ft-s
Pr		6.980	4.510	1.910	1.220	0.950	0.859	1.070	---
(Prandtl Number)									
Calculated Parameter	**Formula**	**70**	**100**	**200**	**300**	**400**	**500**	**600**	**°F**
Reynold's Number, Re	$\rho VD/\mu$	2240531	3264854	7024977	10613262	13877763	16855268	17632948	---
Grashof Number, Gr	$g\beta\Delta TL^3/(\mu/\rho)^2$	9099611606	4.732E+10	9.01E+11	4.667E+12	1.48E+13	3.85E+13	8.05143E+13	---
Grashof Number, Gr_δ	$g\beta\Delta T(r_o-r_i)^3/(\mu/\rho)^3$	1.14E+09	5.91E+09	1.13E+11	5.83E+11	1.85E+12	4.82E+12	1.01E+13	---
Rayleigh Number, Ra	GrPr	6.3515E+10	2.134E+11	1.72E+12	5.694E+12	1.41E+13	3.31E+13	8.61503E+13	---
Rayleigh Number, Ra	$Gr_\delta Pr$	7.94E+09	2.67E+10	2.15E+11	7.12E+11	1.76E+12	4.14E+12	1.08E+13	---
From [1]:									
Inside Surface Forced Convection Heat Transfer Coefficient:									
H_{forced}	$0.023Re^{0.8}Pr^{0.4}k/D$	3,552.89	4,235.64	5,971.33	6,996.42	7,586.90	7,777.99	7,391.58	W/m^2-°C
		625.71	745.95	1,051.63	1,232.17	1,336.16	1,369.81	1,301.76	$Btu/hr-ft^2$-°F
From [1]:									
Inside Surface Natural Convection Heat Transfer Coefficient:									
Case:	Enclosed cylinder		C =	0.55	n =	0.25			
H_{free}	$C(GrPr)^n k/L$	162.97	231.79	420.60	571.66	693.25	784.30	836.32	W/m^2-°C
		28.70	40.82	74.07	100.68	122.09	138.13	147.29	$Btu/hr-ft^2$-°F

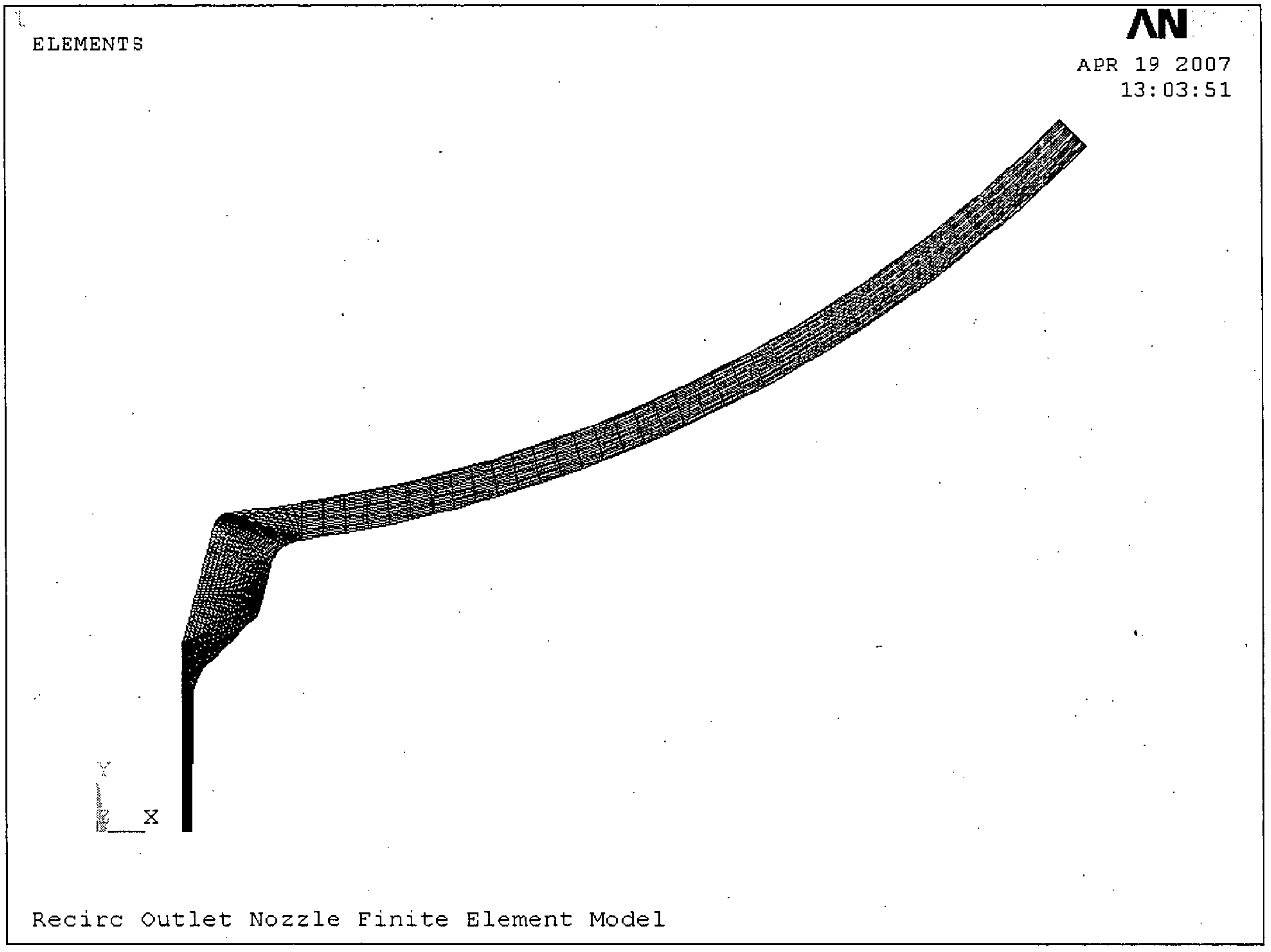

Figure 1: ANSYS Finite Element Model

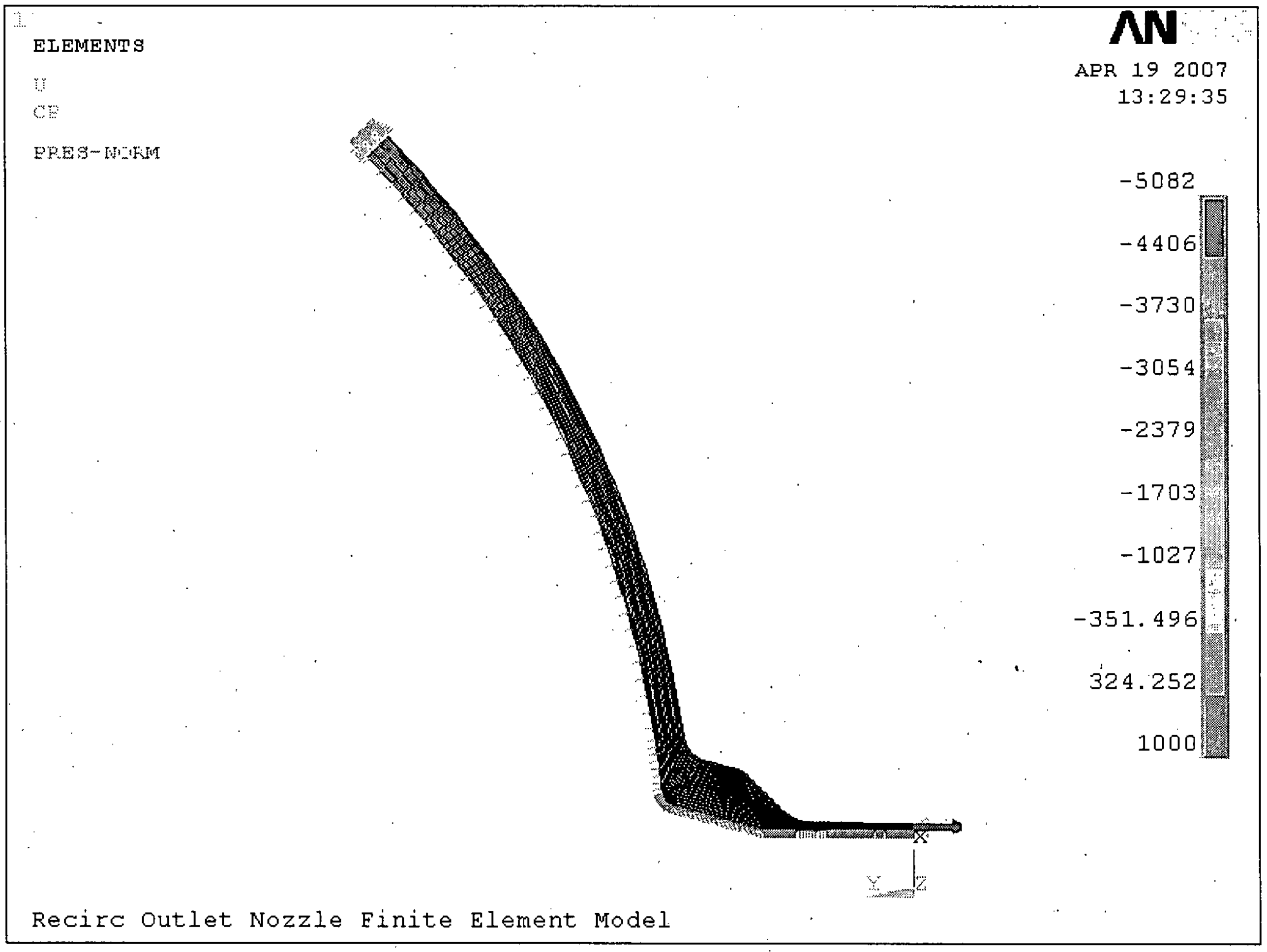

Figure 2: Recirculation Outlet Nozzle Internal Pressure Distribution

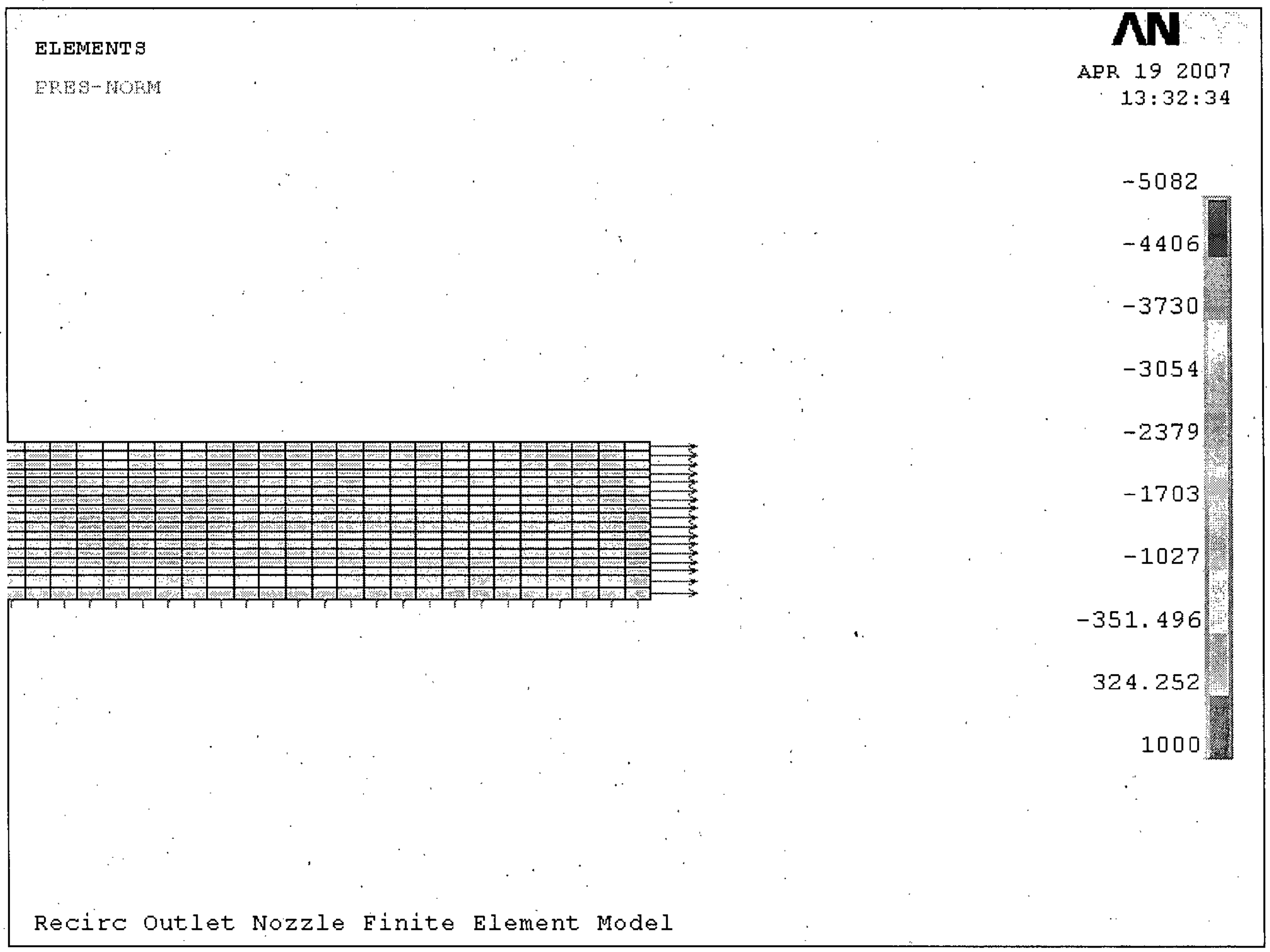

Figure 3: Recirculation Outlet Nozzle Pressure Cap Load

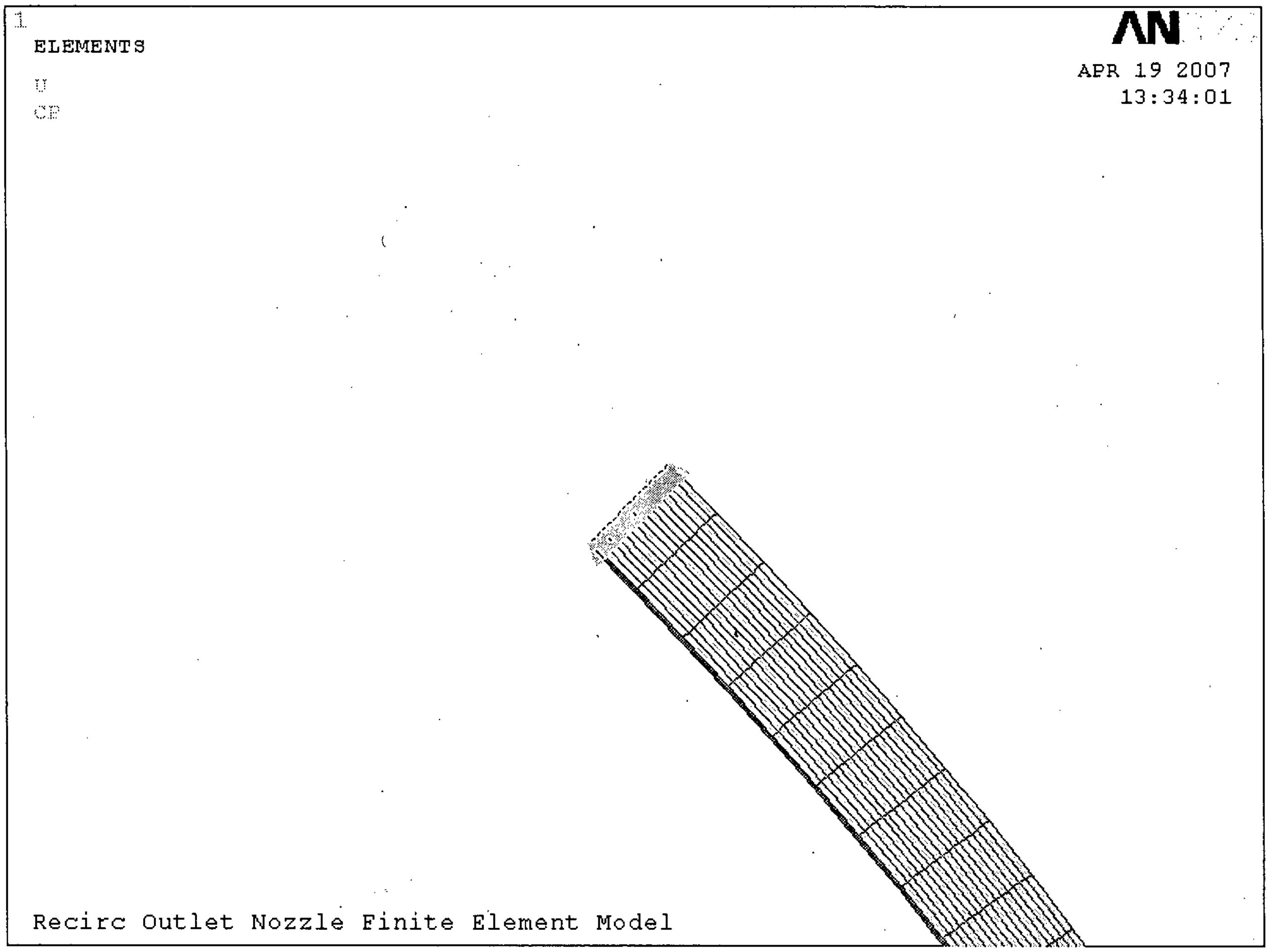

Figure 4: Recirculation Outlet Nozzle Vessel Boundary Conditions

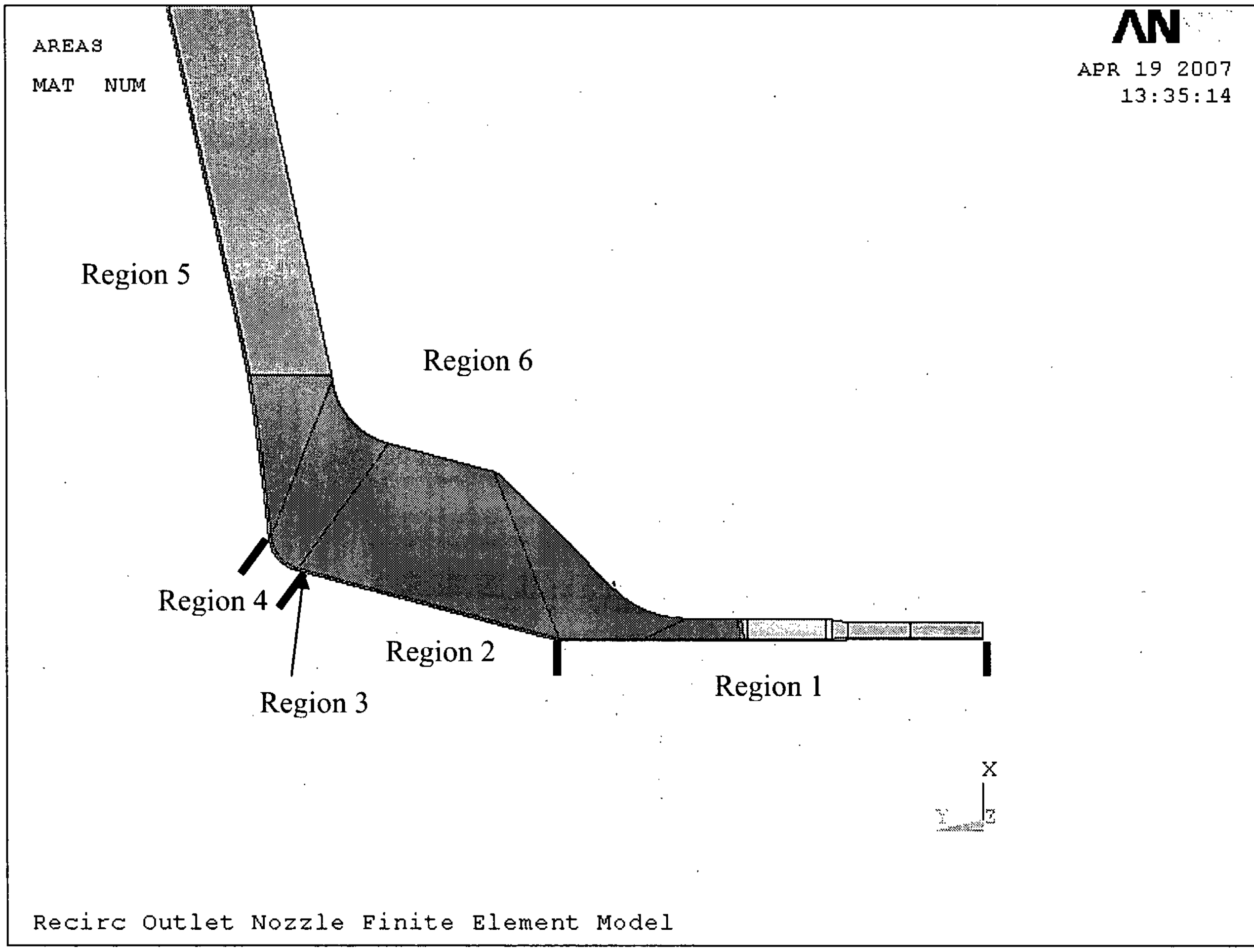

Figure 5: Nozzle and Vessel Wall Thermal and Heat Transfer Boundaries

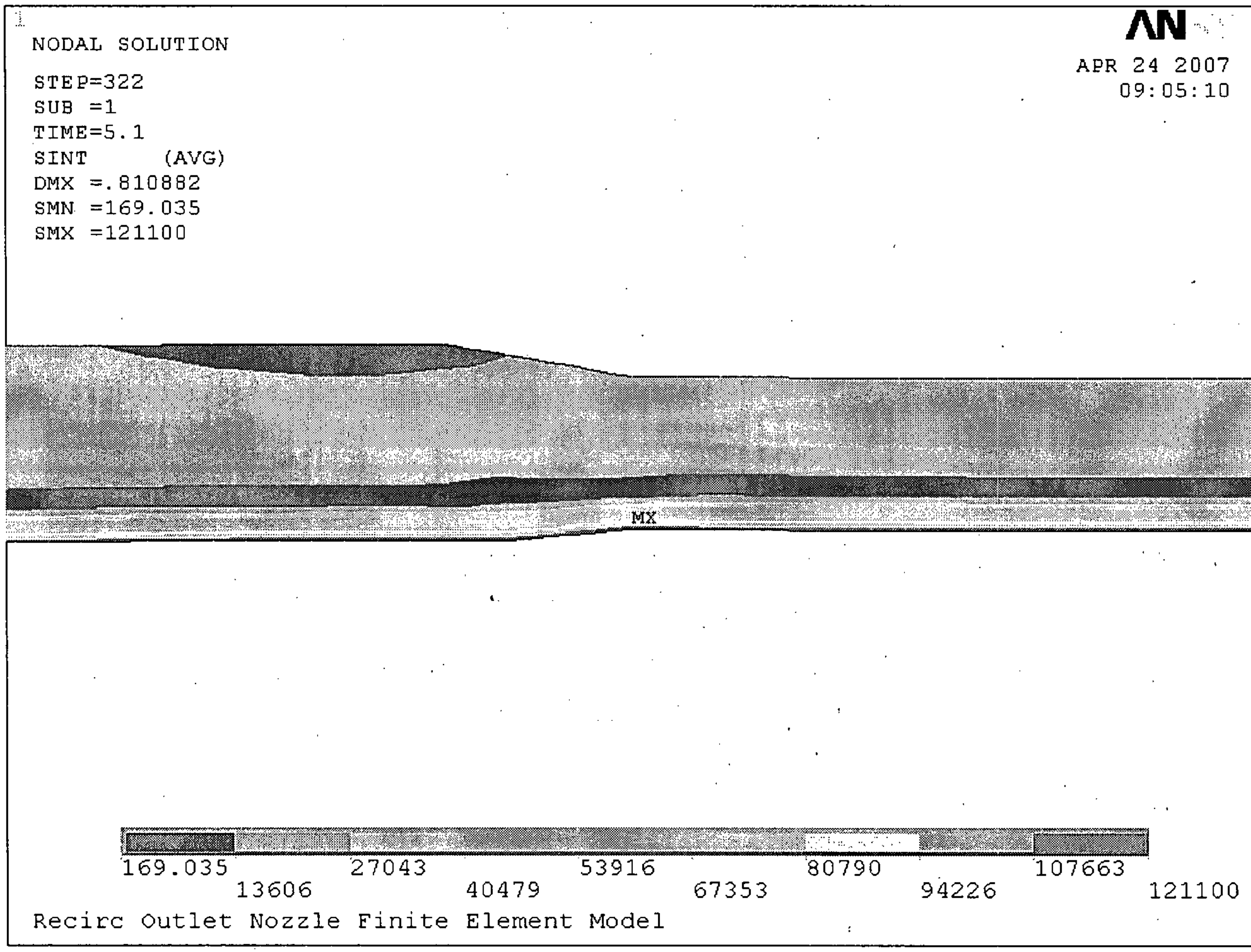

Figure 6: Safe End Critical Thermal Stress Location

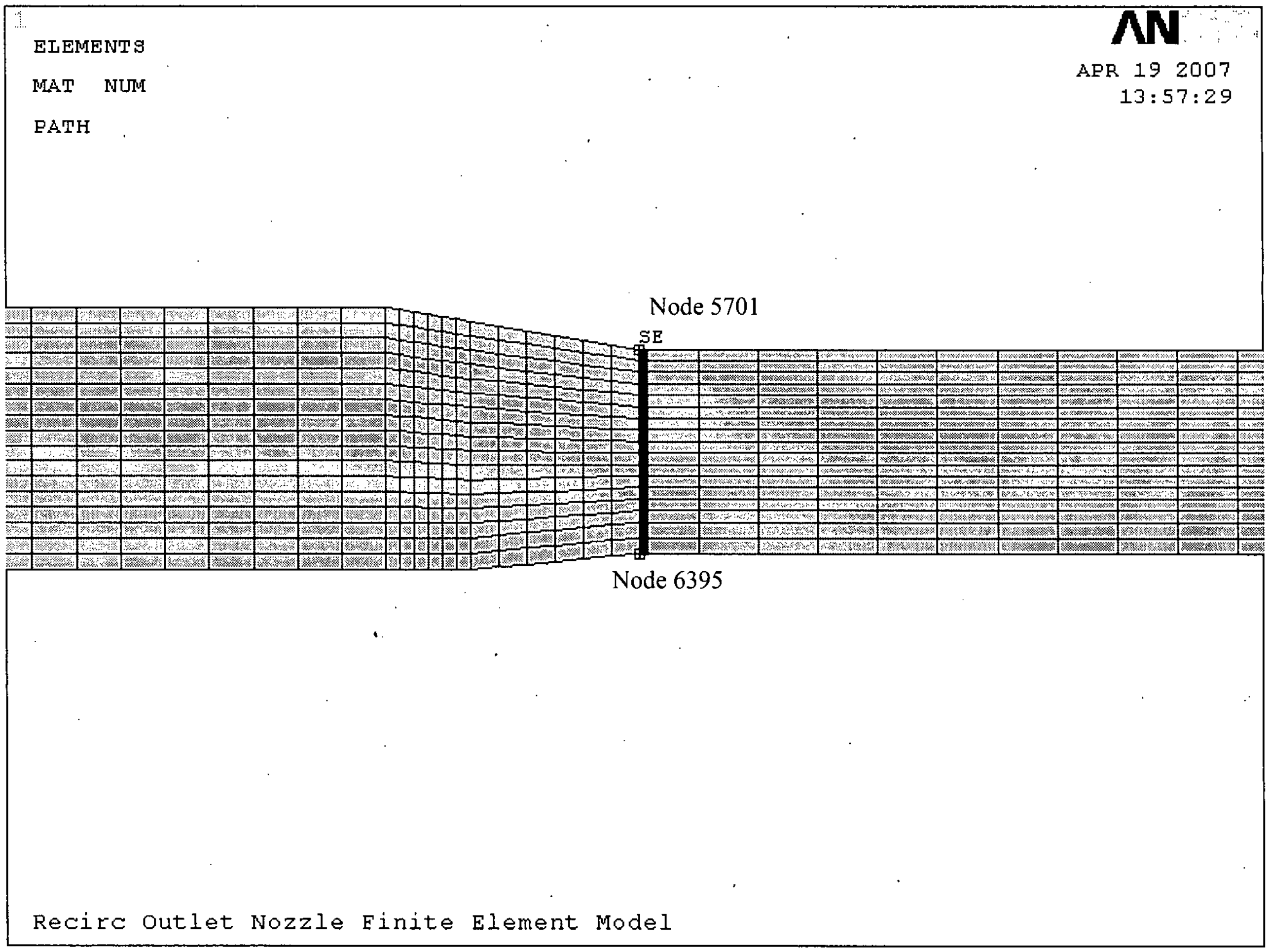

Figure 7: Safe End Limiting Linearized Stress Paths

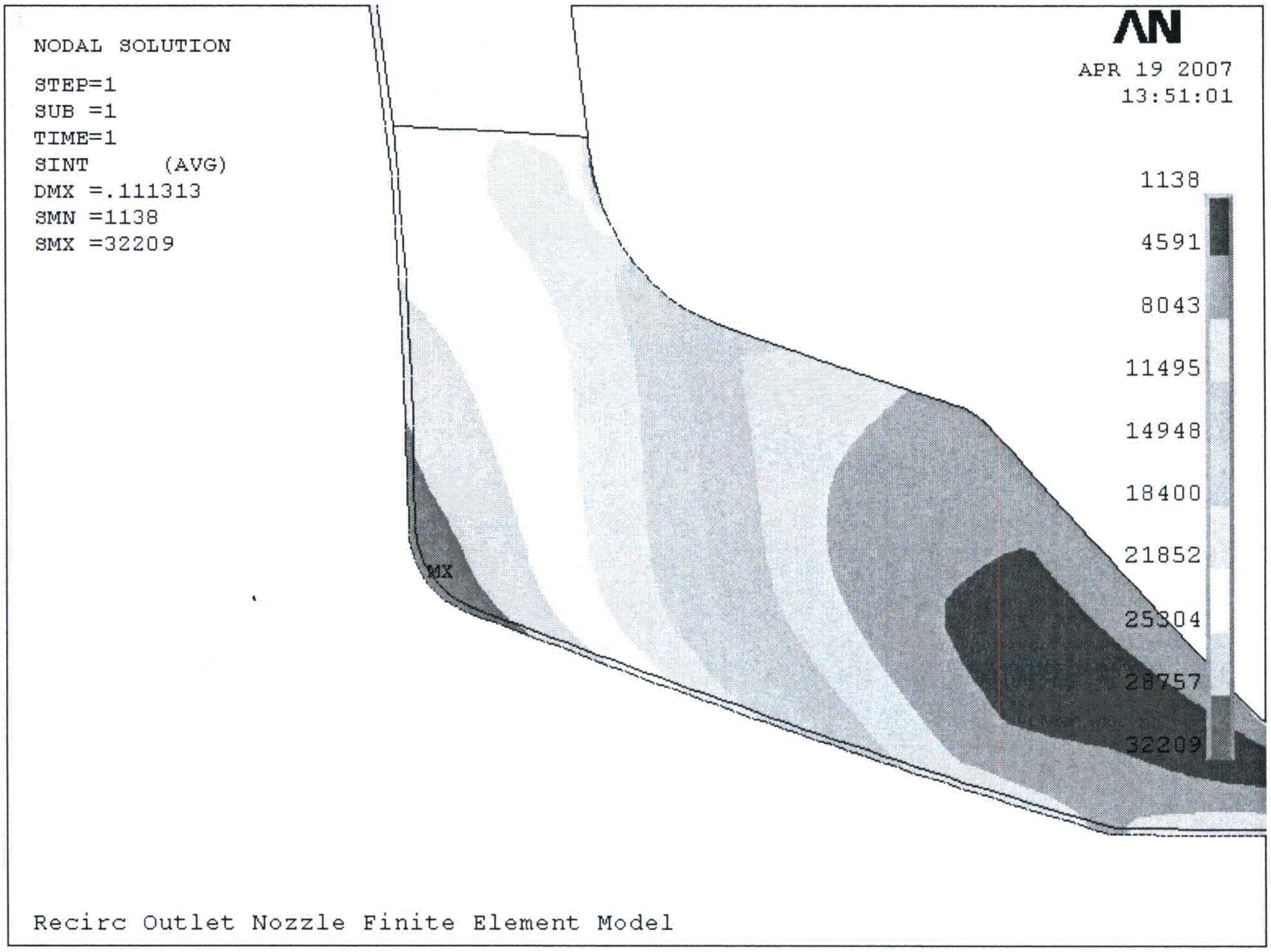

Figure 8: Blend Radius Limiting Pressure Stress Location

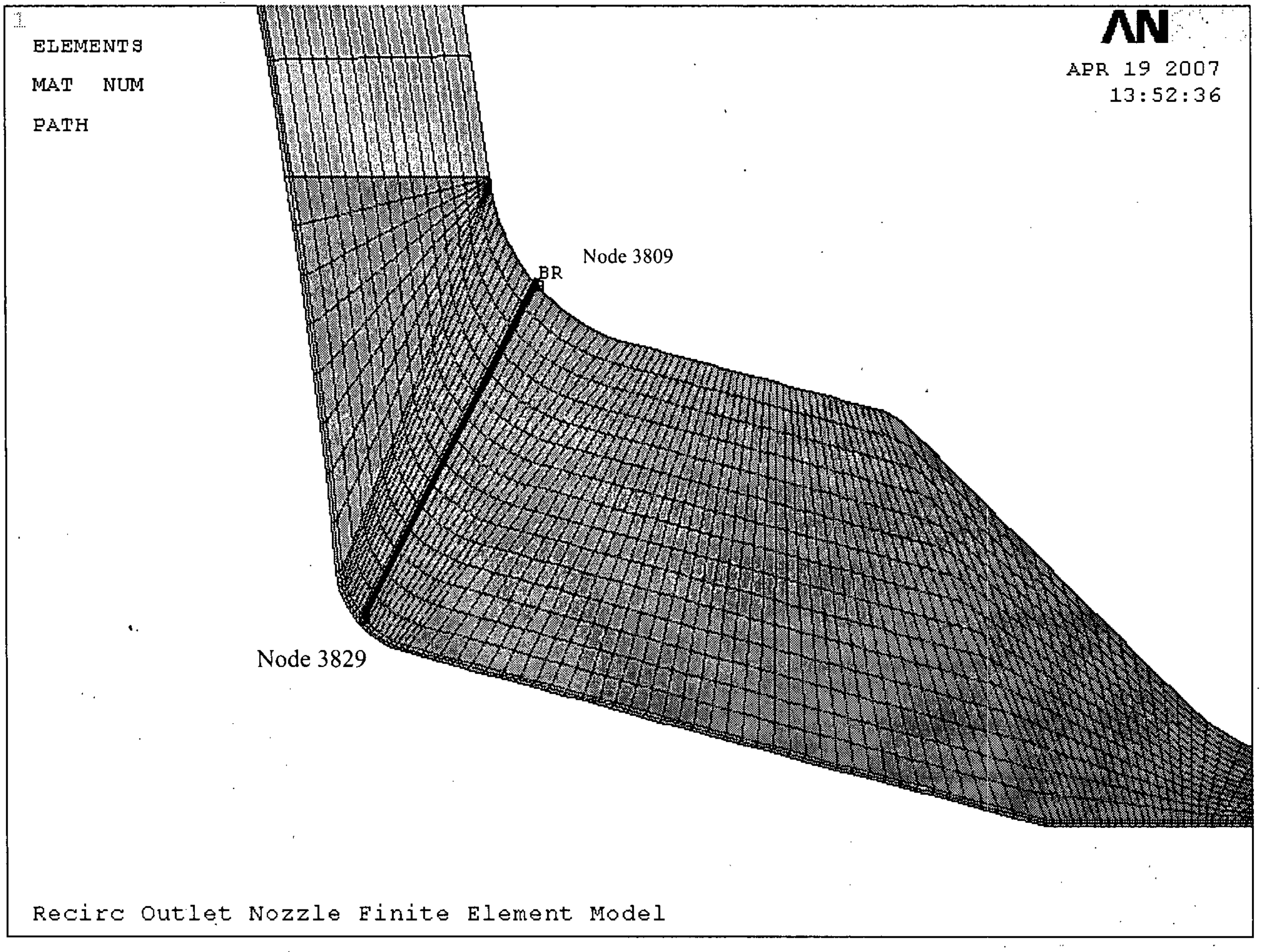

Figure 9: Blend Radius Linearized Stress Path

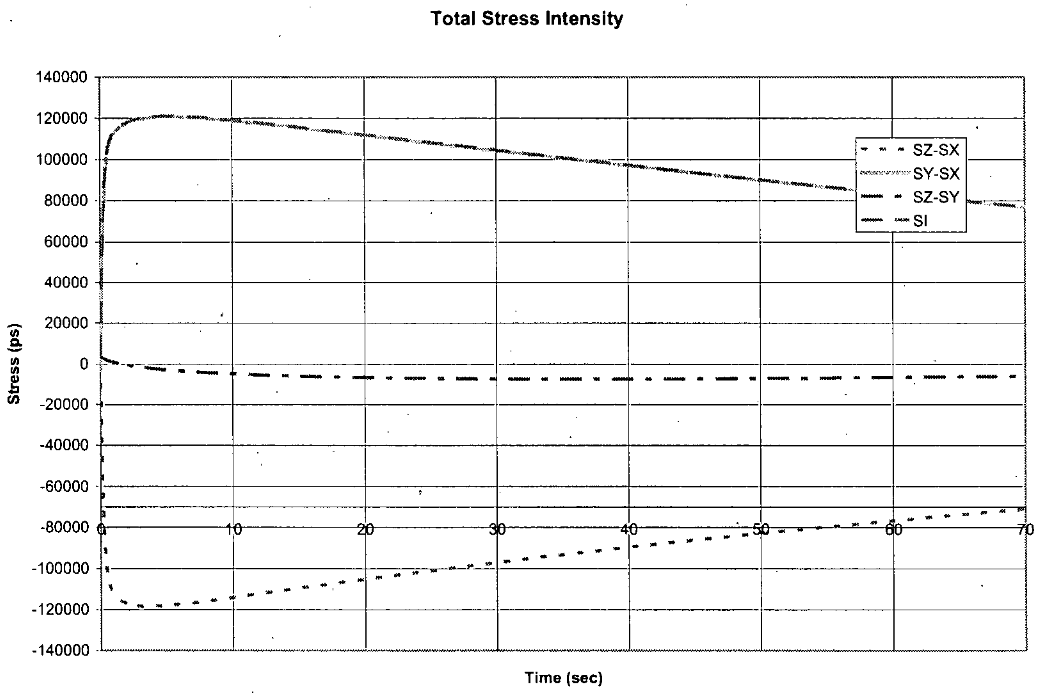

Figure 10: Safe End 100% Flow Total Stress Intensity

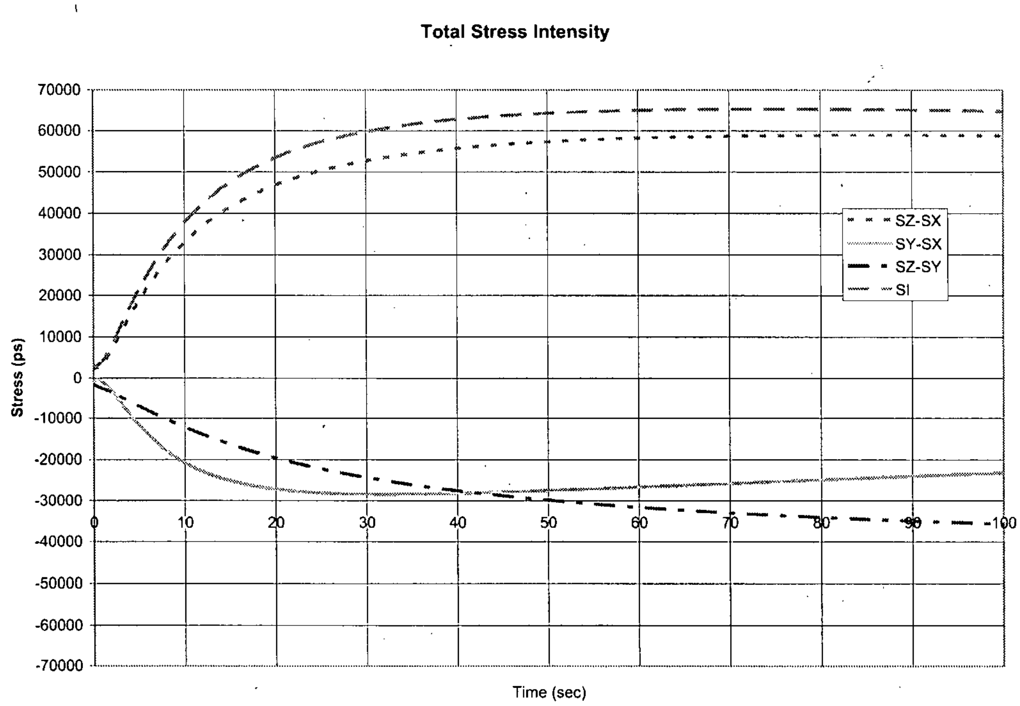

Figure 11: Blend Radius 100% Flow Total Stress Intensity

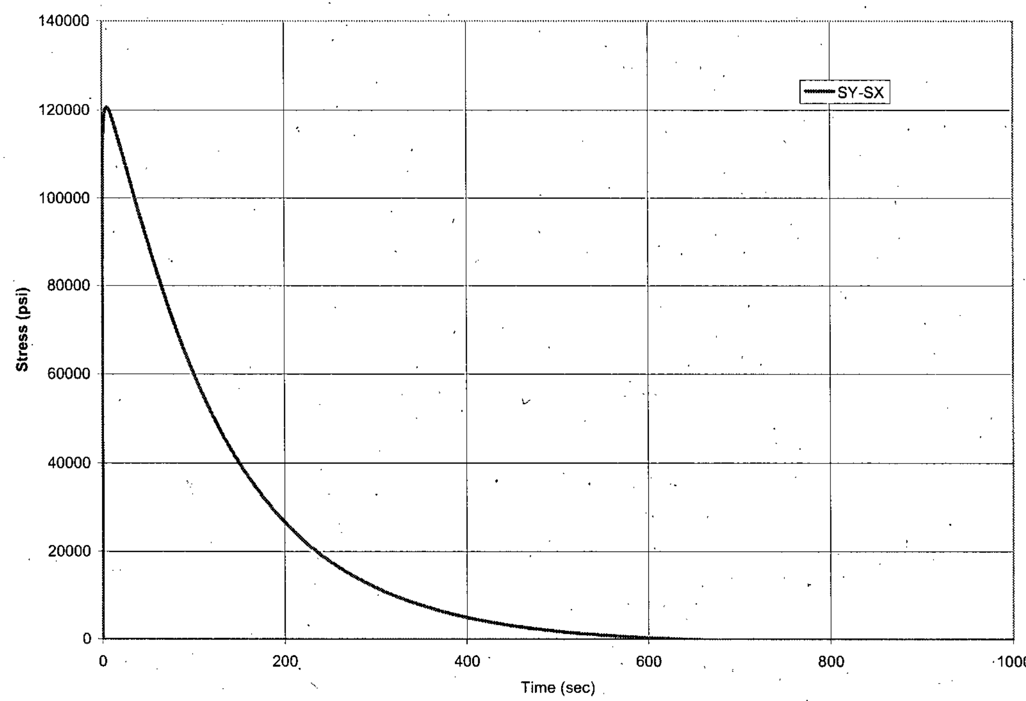

Figure 12: Safe End Total Stress History for 100% Flow

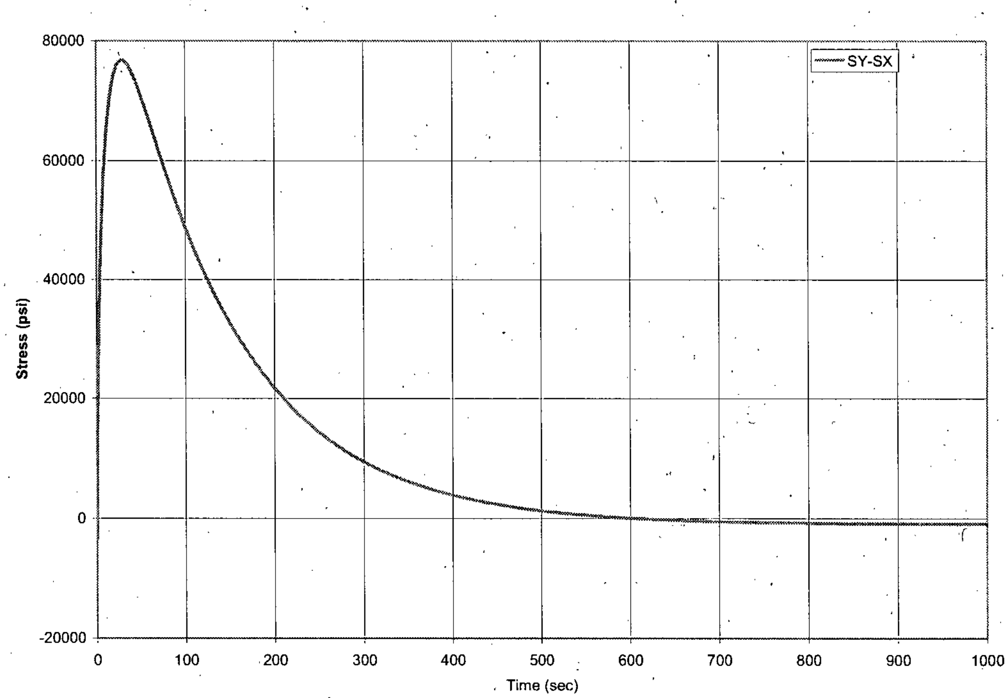

Figure 13: Safe End Membrane Plus Bending Stress History for 100% Flow

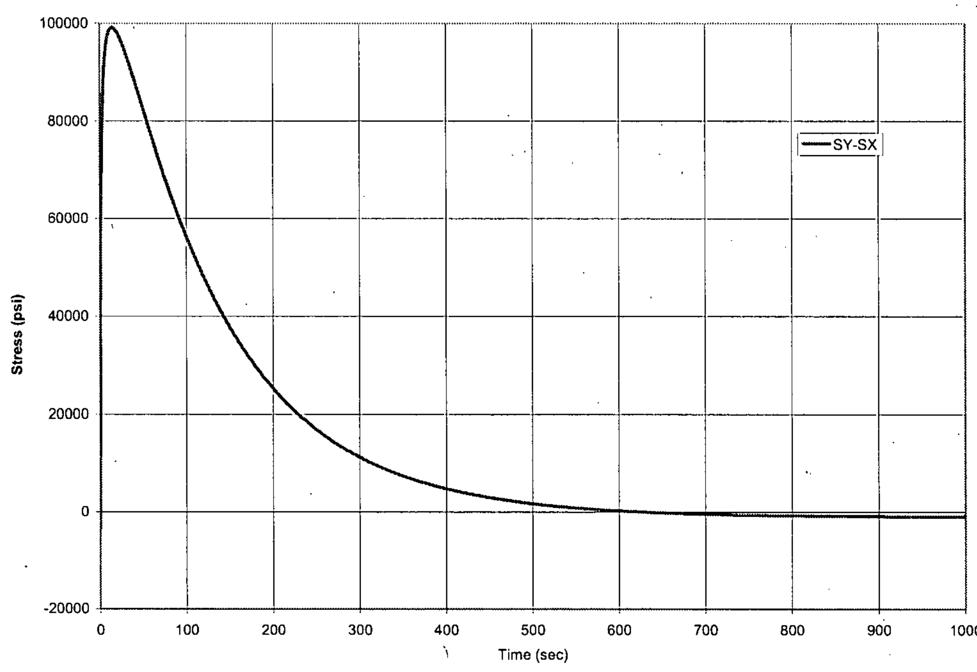

Figure 14: Safe End Total Stress History for 50% Flow

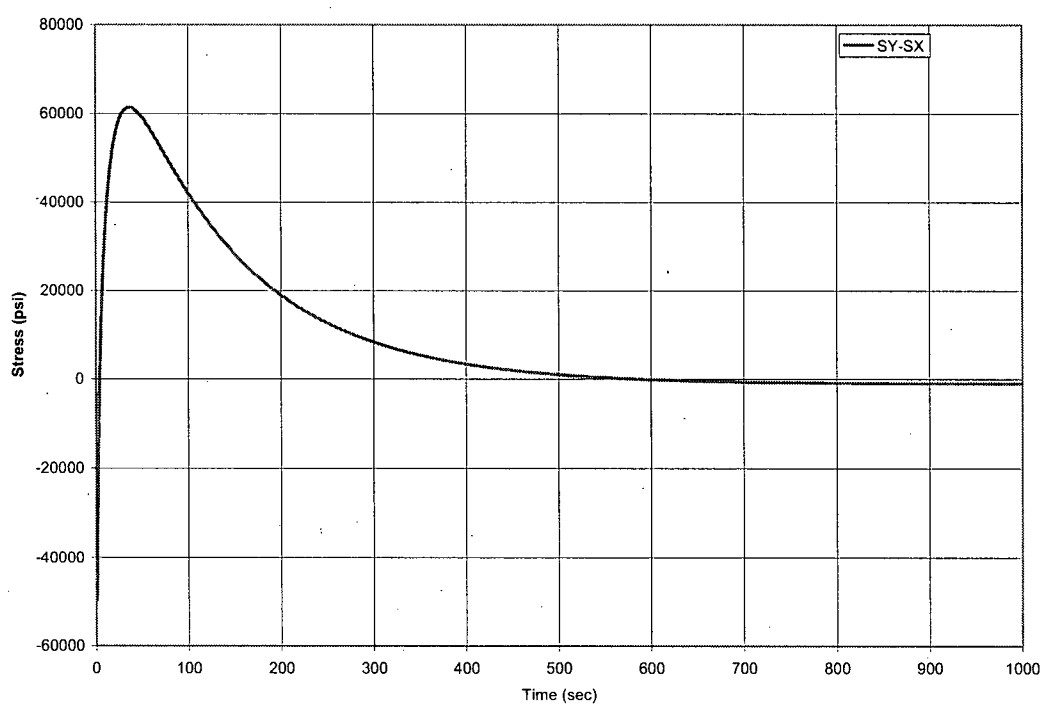

Figure 15: Safe End Membrane Plus Bending Stress History for 50% Flow

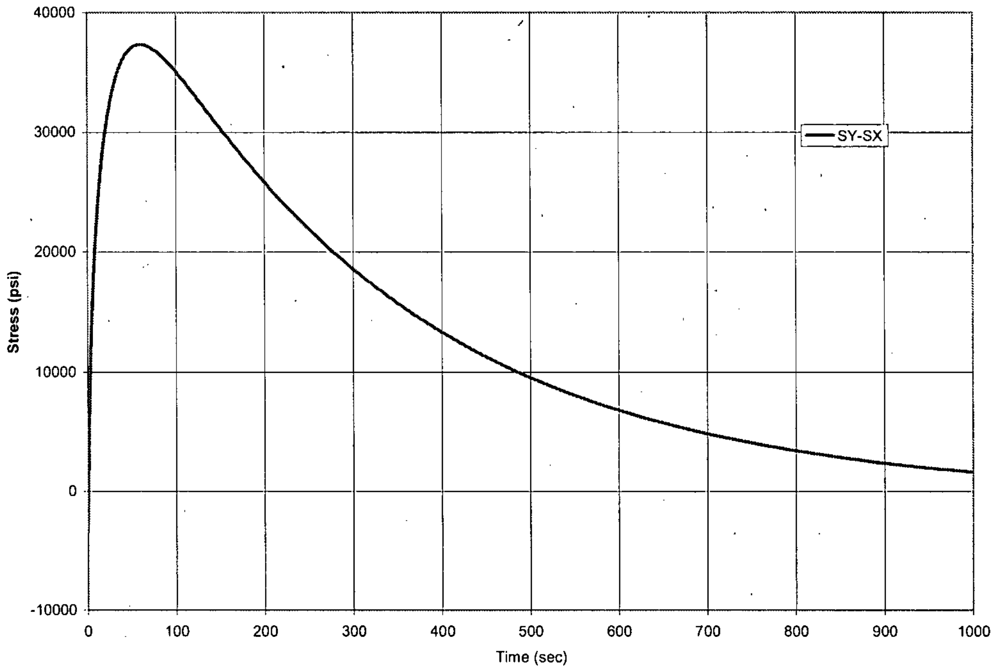

Figure 16: Safe End Total Stress History for 0% Flow

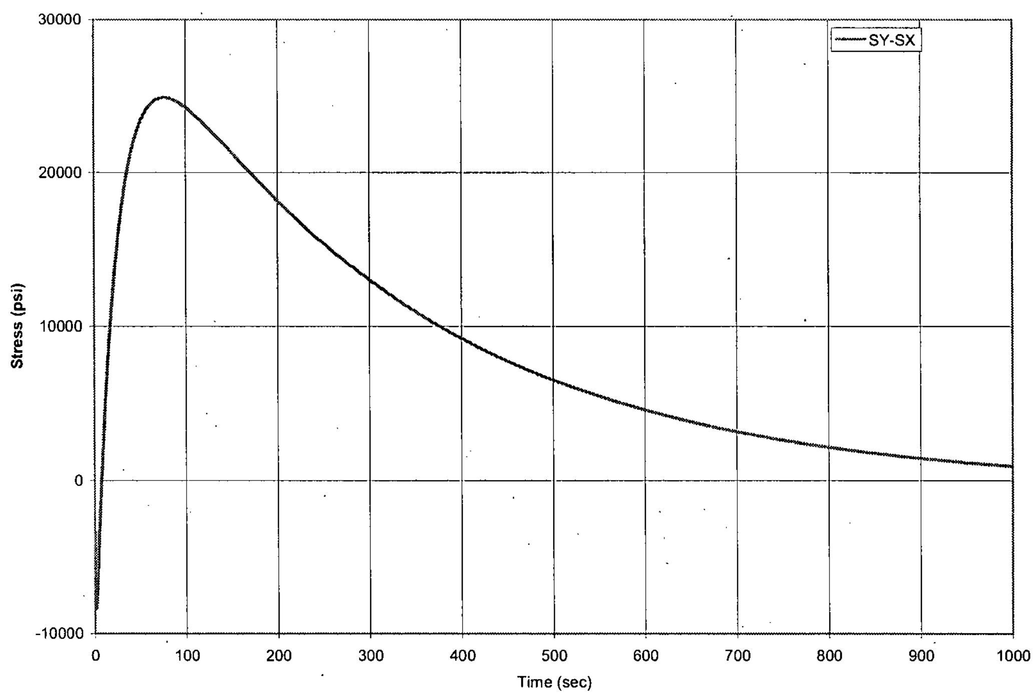

Figure 17: Safe End Membrane Plus Bending Stress History for 0% Flow

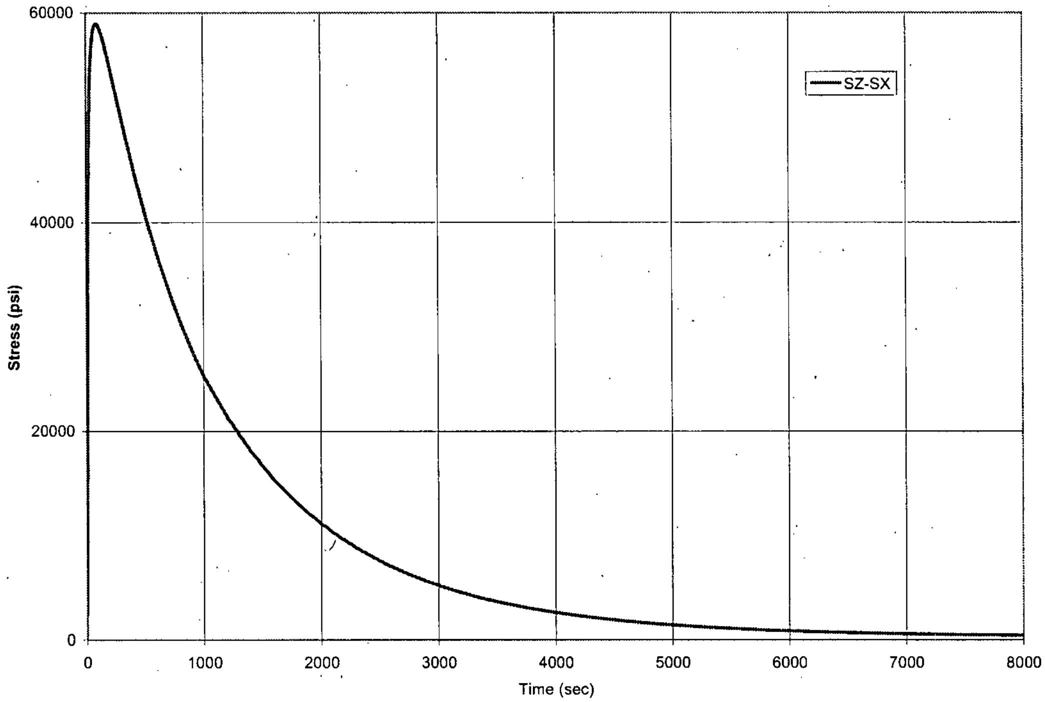

Figure 18: Blend Radius Total Stress History for 100% Flow

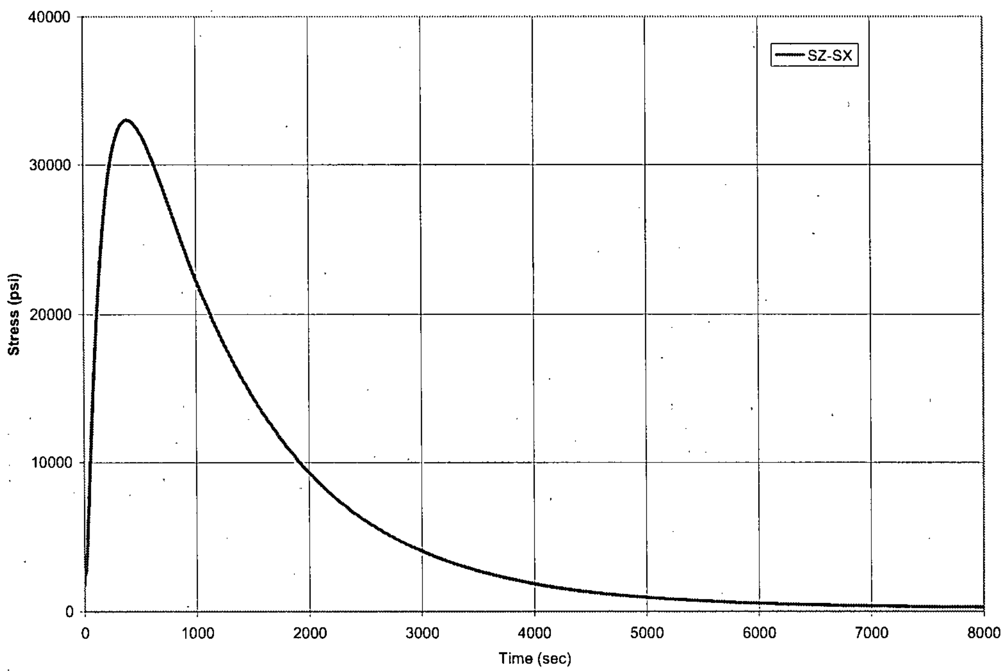

Figure 19: Blend Radius Membrane Plus Bending Stress History for 100% Flow

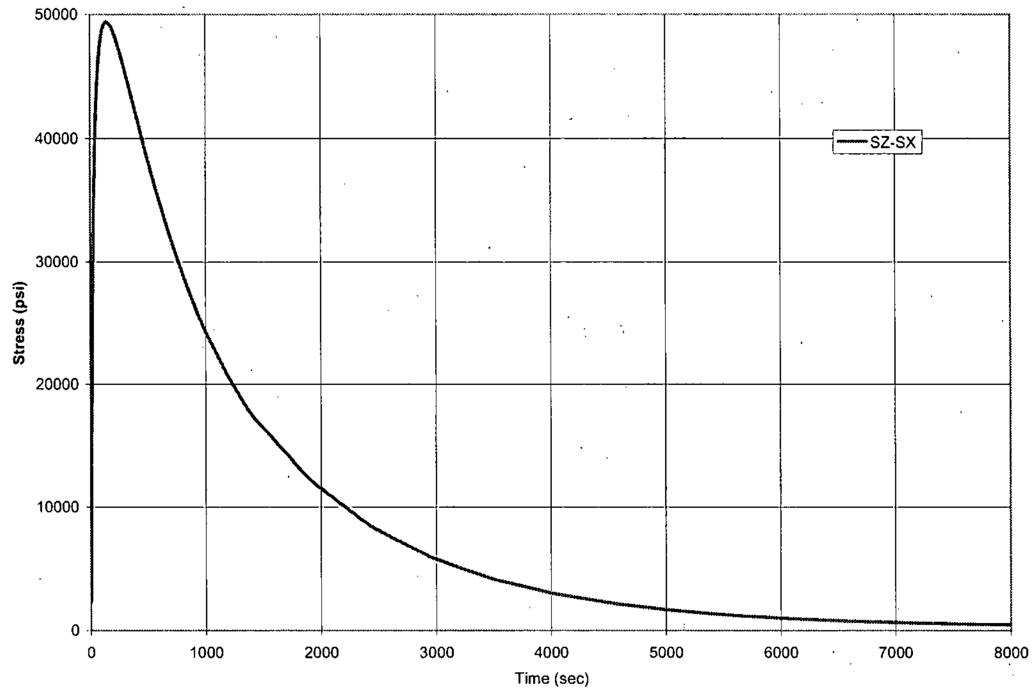

Figure 20: Blend Radius Total Stress History for 50% Flow

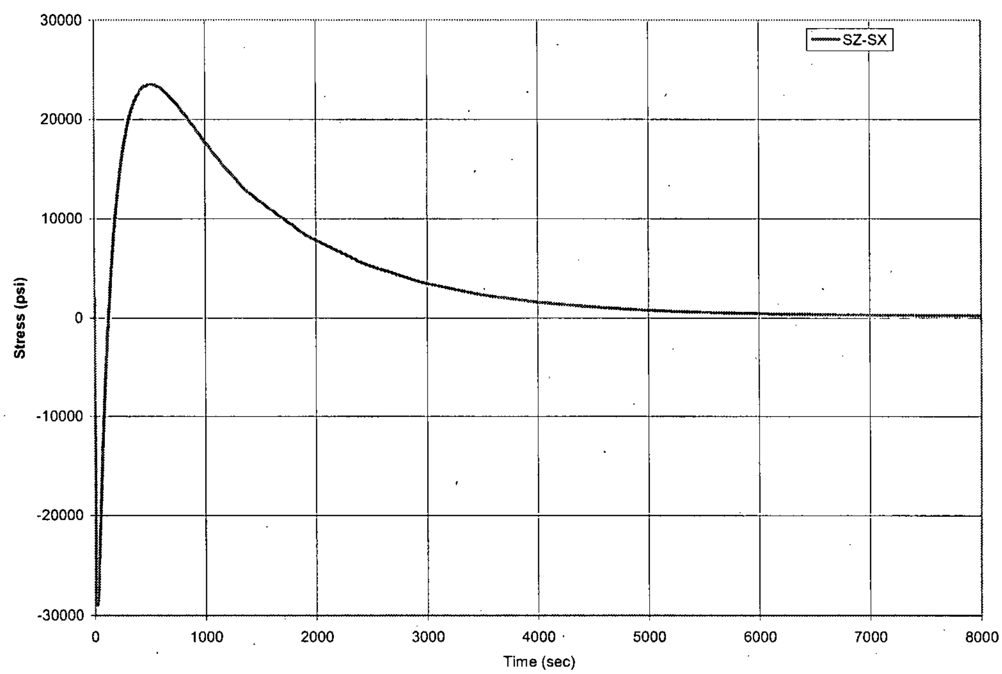

Figure 21: Blend Radius Membrane Plus Bending Stress History for 50% Flow

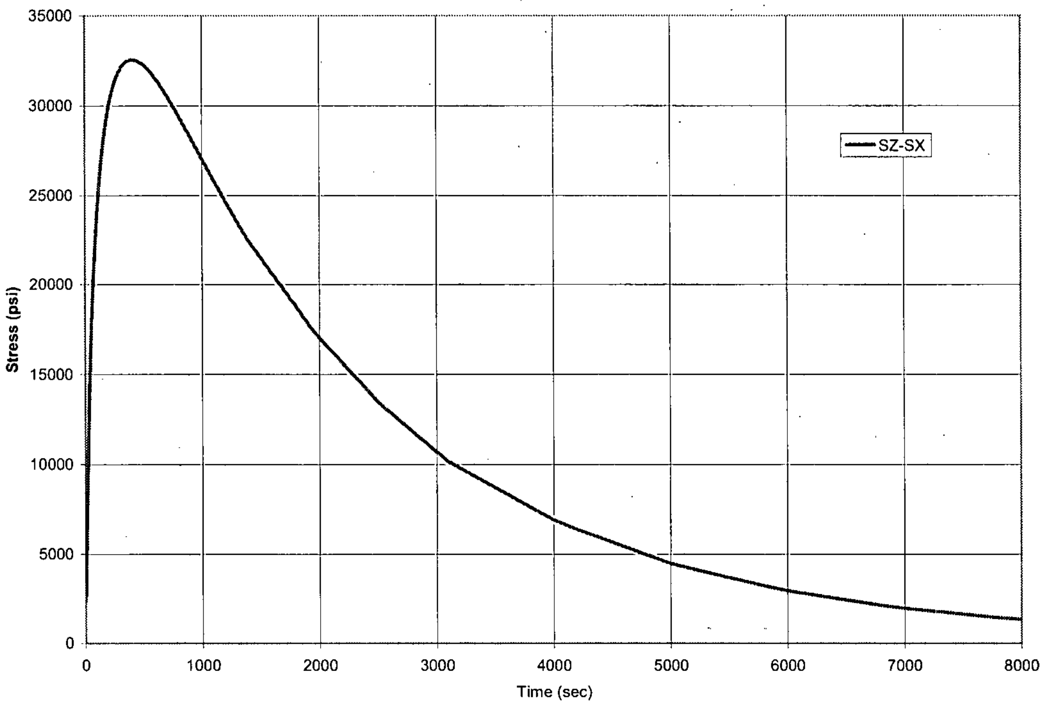

Figure 22: Blend Radius Total Stress History for 0% Flow

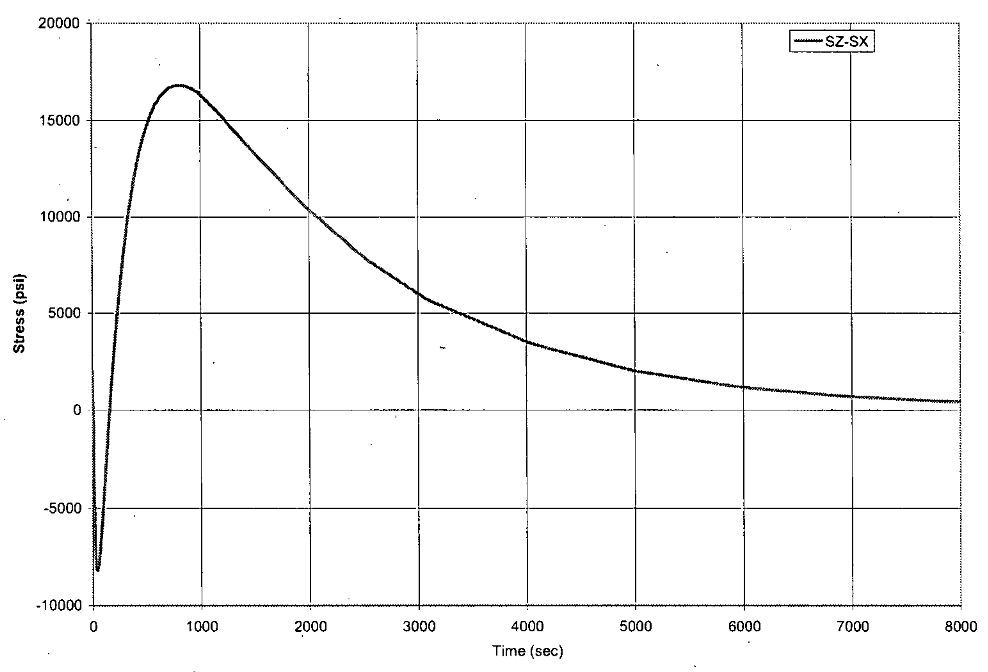

Figure 23: Blend Radius Membrane Plus Bending Stress History for 0% Flow

APPENDIX A

FINITE ELEMENT ANALYSIS FILES

RON_VY.INP	Input File for Pressure Load	In Computer files
VY_RON_T_100.INP	Input File for 100% Flow Thermal Analysis	In Computer files
VY_RON_S_100.INP	Input File for 100% Flow Stress Analysis	In Computer files
VY_RON_T_50.INP	Input File for 50% Flow Thermal Analysis	In Computer files
VY_RON_T_50.INP	Input File for 50% Flow Stress Analysis	In Computer files
VY_RON_0.INP	Input File for 0% Flow Thermal Analysis	In Computer files
VY_RON_0.INP	Input File for 0% Flow Stress Analysis	In Computer files
PVESS.OUT	Stress Output across the shell with Pressure Load	In Computer files
PSE.OUT	Stress Output at Safe End with Pressure Load	In Computer files
PBLEND.OUT	Stress Output at Blend Radius with Pressure Load	In Computer files
#FSE.OUT	Stress Output at Safe End	In Computer files
#FBR.OUT	Stress Output at Blend Radius	In Computer files
#FSE_INSIDE.RED	Stress Extracted at Safe End	In Computer files
#FBR_INSIDE.RED	Stress Extracted at Blend Radius	In Computer files
#FSE_T-Green.XLS	Green Function with Total Stress at Safe End	In Computer files
#FSE_M+B-Green.XLS	Green Function with Membrane plus Bending Stress at Safe End	In Computer files
HFBR_T-Green.XLS	Green Function with Total Stress at Blend Radius at 100% flow	In Computer files
HFBR_M+B-Green.XLS	Green Function with Membrane plus Bending Stress at Blend Radius at 100% flow	In Computer files

Where # is H, M, L meaning 100%, 50%, and 0% flow rate, respectively.