ENCLOSURE 3
"FEEDWATER NOZZLE GREEN'S FUNCTIONS"
(FILE NO. OC-05Q-307), REVISION 0

ATTACHMENT 1
Design Analysis Cover Sheet
Page 1

Design Analysis (Major Revision) | **Last Page No.** [6] 31 (calc.) & A17 (Appx.)

Analysis No.: [1] SIA # OC-05Q-307 | **Revision:** [2] 0

Title: [3] Feedwater Nozzle Green's Functions

EC/ECR No.: [4] 05 - 00365 | **Revision:** [5] 0

		Component(s): [14]	
Station(s): [7]	Oyster Creek		
Unit No.: [8]	1		
Discipline: [9]	Mechanical Eng.		
Descrip. Code/Keyword: [10]	Fatigue Analysis		
Safety/QA Class: [11]	Q		
System Code: [12]	422 & 104		
Structure: [13]	Feedwater Nozzle		

CONTROLLED DOCUMENT REFERENCES [15]

Document No.:	From/To	Document No.:	From/To
MPR Report # MPR-783	From		
SIA Report # SIR-88-028	From		
Calculation # C-1302-422-E540-046	From		

Is this Design Analysis Safeguards Information? [16] Yes ☐ No ☒ If yes, see SY-AA-101-106

Does this Design Analysis contain Unverified Assumptions? [17] Yes ☐ No ☒ If yes, ATI/AR#:

This Design Analysis SUPERCEDES: [18] ______ **in its entirety.**

Description of Revision (list affected pages for partials): [19]

Initial Issue to OC Records Management, as part of Licensing Renewal Project.

Preparer: [20] See Page 1b for SIA Sign's (Print Name) ______ (Sign Name) ______ (Date)

Method of Review: [21] **Detailed Review** ☒ **Alternate Calculations (attached)** ☐ **Testing** ☐

Reviewer: [22] See Page 1b for SIA Sign's (Print Name) ______ (Sign Name) ______ (Date)

Review Notes: [23] Independent review ☒ Peer review ☐

(For External Analyses Only)
External Approver: [24] See Page 1b for SIA Sign's (Print Name) ______ (Sign Name) ______ (Date)

Exelon Reviewer: [25] Julien Abramovici (Print Name) [signature] (Sign Name) 8-11-05 (Date)

Is a Supplemental Review Required? [26] Yes ☐ No ☒ If yes, complete Attachment 3

Exelon Approver: [27] F. Howie Ray (Print Name) [signature] (Sign Name) 8-15-05 (Date)

Exelon Nuclear

ATTACHMENT 2
Owners Acceptance Review Checklist for External Design Analysis
Page 1 of 1

DESIGN ANALYSIS NO. SIA # OC-05Q-307 **REV:** 0 **SHEET** 1a of –

		Yes	No	N/A
1.	Do assumptions have sufficient rationale?	☒	☐	☐
2.	Are assumptions compatible with the way the plant is operated and with the licensing basis?	☒	☐	☐
3.	Do the design inputs have sufficient rationale?	☒	☐	☐
4.	Are design inputs correct and reasonable?	☒	☐	☐
5.	Are design inputs compatible with the way the plant is operated and with the licensing basis?	☒	☐	☐
6.	Are Engineering Judgments clearly documented and justified?	☒	☐	☐
7.	Are Engineering Judgments compatible with the way the plant is operated and with the licensing basis?	☒	☐	☐
8.	Do the results and conclusions satisfy the purpose and objective of the Design Analysis?	☒	☐	☐
9.	Are the results and conclusions compatible with the way the plant is operated and with the licensing basis?	☒	☐	☐
10.	Does the Design Analysis include the applicable design basis documentation?	☒	☐	☐
11.	Have any limitations on the use of the results been identified and transmitted to the appropriate organizations?	☐	☐	☒
12.	Are there any unverified assumptions?	☐	☒	☐
13.	Do all unverified assumptions have a tracking and closure mechanism in place?	☐	☐	☒
14.	Have all affected design analyses been documented on the Affected Documents List (ADL) for the associated Configuration Change?	☒	☐	☐
15.	Do the sources of inputs and analysis methodology used meet current technical requirements and regulatory commitments? (If the input sources or analysis methodology are based on an out-of-date methodology or code, additional reconciliation may be required if the site has since committed to a more recent code)	☒	☐	☐
16.	Have vendor supporting technical documents and references (including GE DRFs) been reviewed when necessary?	☒	☐	☐

EXELON REVIEWER: Julien Abramovici [signature] Print / Sign **DATE:** 9-11-05

STRUCTURAL INTEGRITY Associates, Inc.	CALCULATION PACKAGE	FILE No.: OC-05Q-307 PROJECT No.: OC-05Q

PROJECT NAME: Oyster Creek Neutron Embrittlement and Fatigue License Renewal Activities

CLIENT: Exelon Generation Company, LLC

CONTRACT NUMBER: 10002039 dated 6/8/2004

CALCULATION TITLE: Feedwater Nozzle Green's Functions

Document Revision	Affected Pages	Revision Description	Project Mgr. Approval Signature & Date	Preparer(s) & Checker(s) Signatures & Date
0	1-31, Appendix A A1-A17 In Computer Files	Initial issue.	G. L. Stevens Gary L. Stevens 7/20/2005	Eric Jones EEJ 07/20/2005 M. Qin MQ 07/20/2005

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1.0 OBJECTIVE

The objective of this calculation is to develop Green's Functions (GF) for the feedwater nozzle at Oyster Creek (OC). To accomplish this task, a temperature step change was applied to a detailed, two-dimensional (2-D) axisymmetric finite element model (FEM) of the feedwater nozzle, exclusive of the thermal sleeve. Bounding stress histories were extracted from two peak stress locations, one each in the blend radius and the safe end regions. These stress histories were then divided by the actual temperature step change applied to develop Green's Functions for each location. The Green's Function methodology is described in Section 3.3.1 of Reference [7]. This Green's Function is input to the **FatiguePro** software, and is used with actual plant feedwater temperature data to develop "on-line" thermal stress histories for the feedwater nozzle. From these stress histories, fatigue usage is determined and monitored at each feedwater nozzle location.

2.0 GEOMETRY

A 2-D axisymmetric finite element model (FEM) was developed using the ANSYS finite element analysis software [2]. The geometry and material properties used in Reference [1] and [4] were utilized in this evaluation. The meshed model is shown in Figure 1. Reference [1] reflects the changes made in geometry due to work done on the nozzles in 1977.

3.0 MATERIAL PROPERTIES

The original construction drawing, Reference [4], designates the material for the feedwater nozzle safe-end to be SA-105, Grade II[1]. The nozzle forging is SA-336 (equivalent to SA-508 Class 2) and the vessel plate material is SA-302 Grade B low alloy steel. The material properties used for the finite element analysis can be found in Table 1. For the FEM analysis, material properties at 325°F were used, because it is the average of the original feedwater nozzle temperature (550°F) and the thermal shock temperature (100°F).

Use of temperature dependent material properties is not appropriate since this is a linear analysis that uses Green's Functions to determine stresses. The Green's Function integration process requires linear characteristics, so the introduction of temperature dependent non-linearities would lead to inaccuracies and difficulties in the Green's Function integration process. In addition, the product of E_a for low ally steel, which is the most influential parameter for thermal stress analysis, varies by less than 6% between 325°F and the maximum operating temperature of 550°F. This is considered to be

[1] Note: All material identifiers in this calculation utilize "SA" designations to line up with current-day material specifications. It is recognized that most OC material identifiers originally used "A" designations. For the purposes of this calculation, both identifiers are considered to be identical.

within the accuracy of this analysis. Considering that the peak stress for many of the significant (controlling) transients occurs at a temperature less than 325°F, the use of the E_a product at 325°F is bounding for these severe transients (since E_a is less for low temperatures).

The coefficients of thermal expansion (α) are instantaneous coefficients. They are used instead of mean values because they are more conservative. Also, since temperature dependent coefficients are not used, and the instantaneous coefficient at 325°F is very close to the mean value at 550°F, so the usage of an instantaneous coefficient is appropriate.

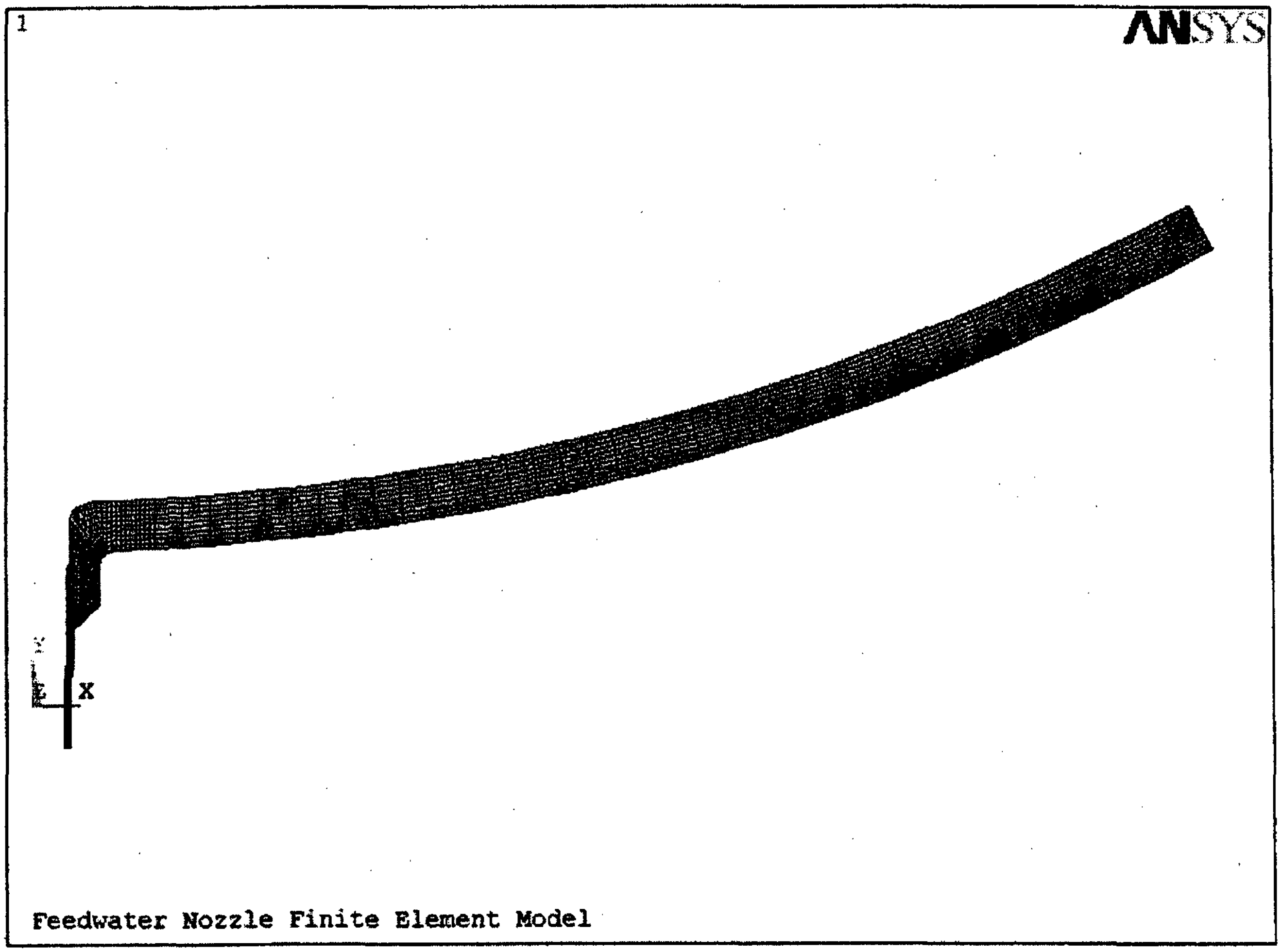

Figure 1: Oyster Creek Unit 1 Feedwater Finite Element Model

Table 1: Feedwater Nozzle Material Properties

Material Properties

All Steels:	*Poisson's Ratio*		0.3		
	Density		0.283		

Reactor Vessel Plate (SA 302 Gr.B) [5, Material Group D]

T	*α*	*E*	*Thermal Conductivity, K*	*Thermal Diffusivity*	*Specific Heat, Cp*
F	*in/in*F*	*psi*	*BTU/hr*ft*F*	*ft^2/hr*	*BTU/lb*F*
300	7.74E-06	2.80E+07	24.7	0.42	0.12
350	7.88E-06		24.7	0.409	0.123
400	8.01E-06	2.74E+07	24.6	0.398	0.126
325	**7.81E-06**	**2.79E+07**	**24.7**	**0.4145**	**0.1215**

Nozzle Forging (SA 336 with Code Case 1236-1) [5, Material Group A]

T	*α*	*E*	*Thermal Conductivity, K*	*Thermal Diffusivity*	*Specific Heat, Cp*
F	*in/in*F*	*psi*	*BTU/hr*ft*F*	*ft 2/hr*	*BTU/lb*F*
300	7.30E-06	2.85E+07	23.9	0.406	0.120
350	7.49E-06		23.7	0.396	0.122
400	7.66E-06	2.79E+07	23.6	0.385	0.125
325	**7.395E-06**	**2.84E+07**	**23.8**	**0.401**	**0.121**

Safe End (CS-I SA-105 Gr. II) [5, Material Group B]

T	*α*	*E*	*Thermal Conductivity, K*	*Thermal Diffusivity*	*Specific Heat, Cp*
F	*in/in*F*	*psi*	*BTU/hr*ft*F*	*ft^2/hr*	*BTU/lb*F*
300	7.18E-06	2.81E+07	28.4	0.481	0.1207
350	7.47E-06		28.0	0.464	0.1234
400		2.75E+07			
325	**7.325E-06**	**2.80E+07**	**28.2**	**0.4725**	**0.1221**

4.0 APPLIED LOADS

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

4.1 Pressure Load

A uniform pressure of 1000 psi was applied along the inside surface of the feedwater nozzle and the reactor 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 to account for the attached piping, which is not modeled. This cap load was calculated as follows:

$$P_{CAP} = \frac{P * D_i^2}{D_o^2 - D_i^2}$$

where:

P = Pressure = 1000 psi
D_i = Inner Diameter = 9.375 in
D_o = Outer Diameter = 11.000 in

Therefore, the cap load is 2654.6 psi. The calculated value was given a negative sign in order for it to exert tension on the end of the model. The nodes on the end of the safe-end are coupled in the axial direction (UY) to ensure mutual displacement of the end of the nozzle due to attached piping.

In order to properly model the feedwater nozzle in ANSYS, the analysis was done as a penetration in a sphere and not a cylinder. To make up for this difference in geometry, a conversion factor of 3.2 times the cylinder radius was used to model the sphere (sphere radius equals 341.501").

The ANSYS input file OC_FWN_GEOM.inp generates the feedwater nozzle geometry and OC_FWN_PRES.inp performs the internal pressure load case just described. Figures 2, 3, and 4 show the applied axial cap load on the safe end, the applied internal pressure distribution, and the applied symmetric boundary conditions on the vessel wall and coupling on the safe end, respectively.

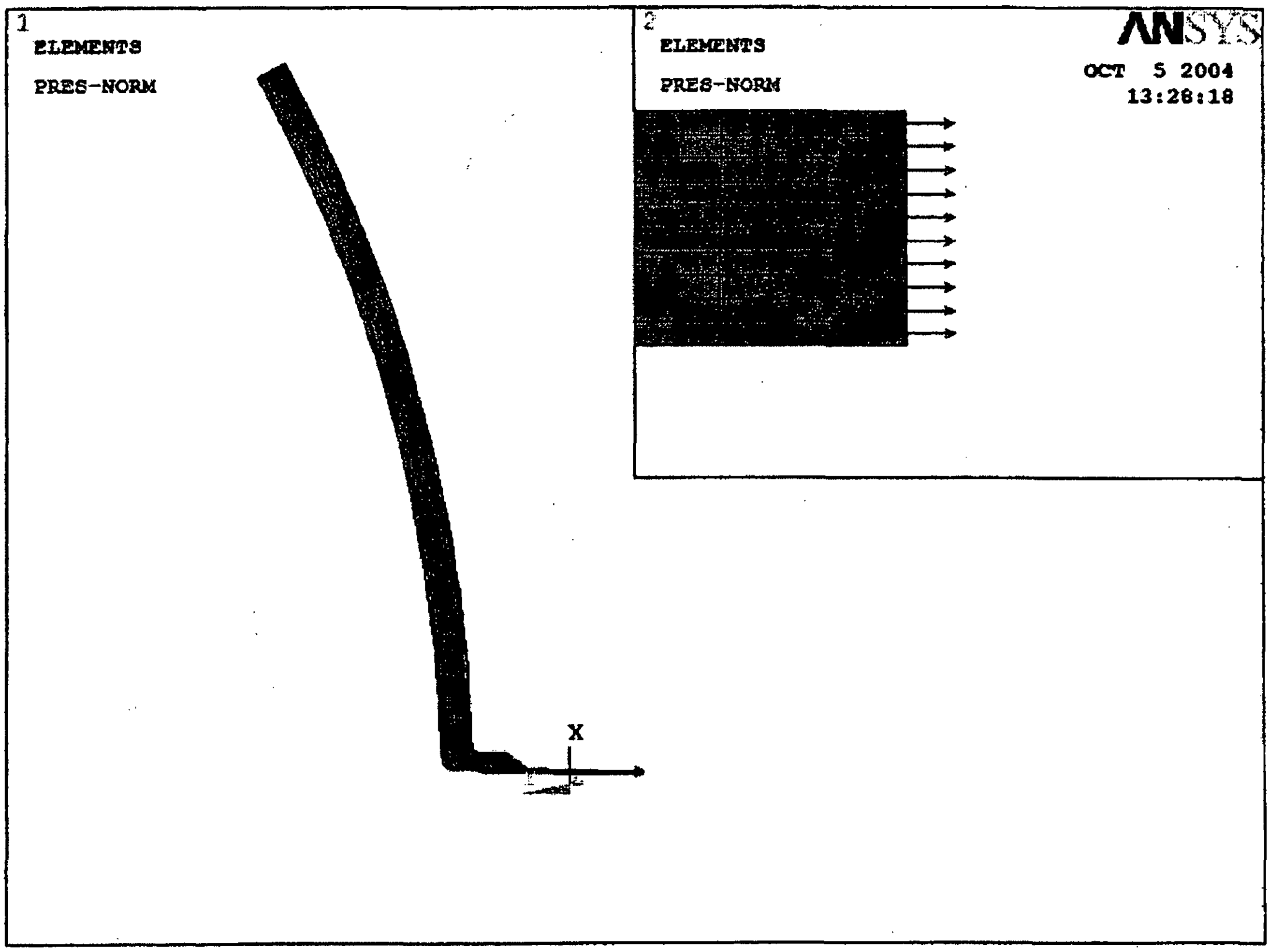

Figure 2: Element Plot of Applied Cap Load to As-Modeled FW Nozzle

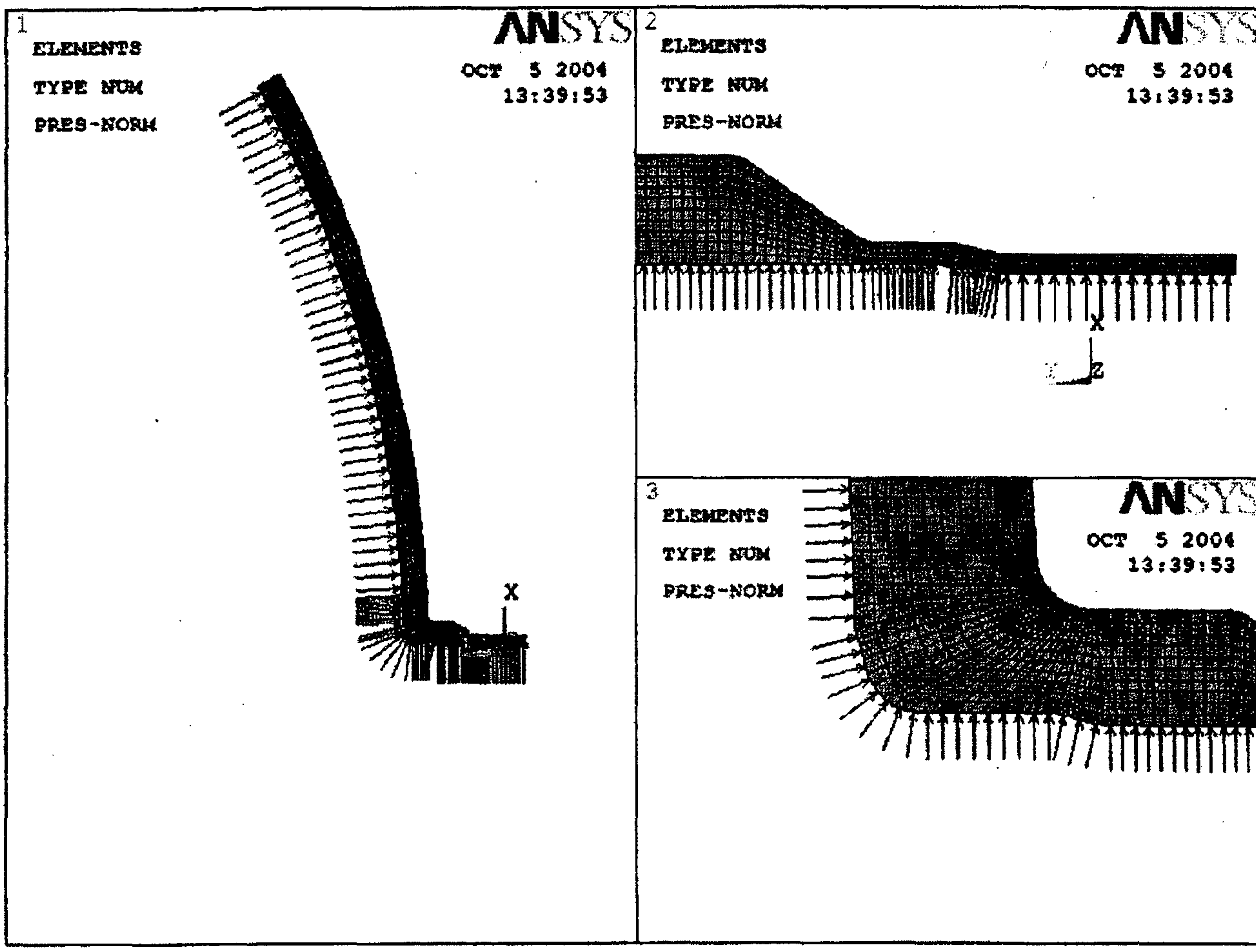

Figure 3: Element Plot of Applied Internal Pressure Load to As-Modeled FW Nozzle

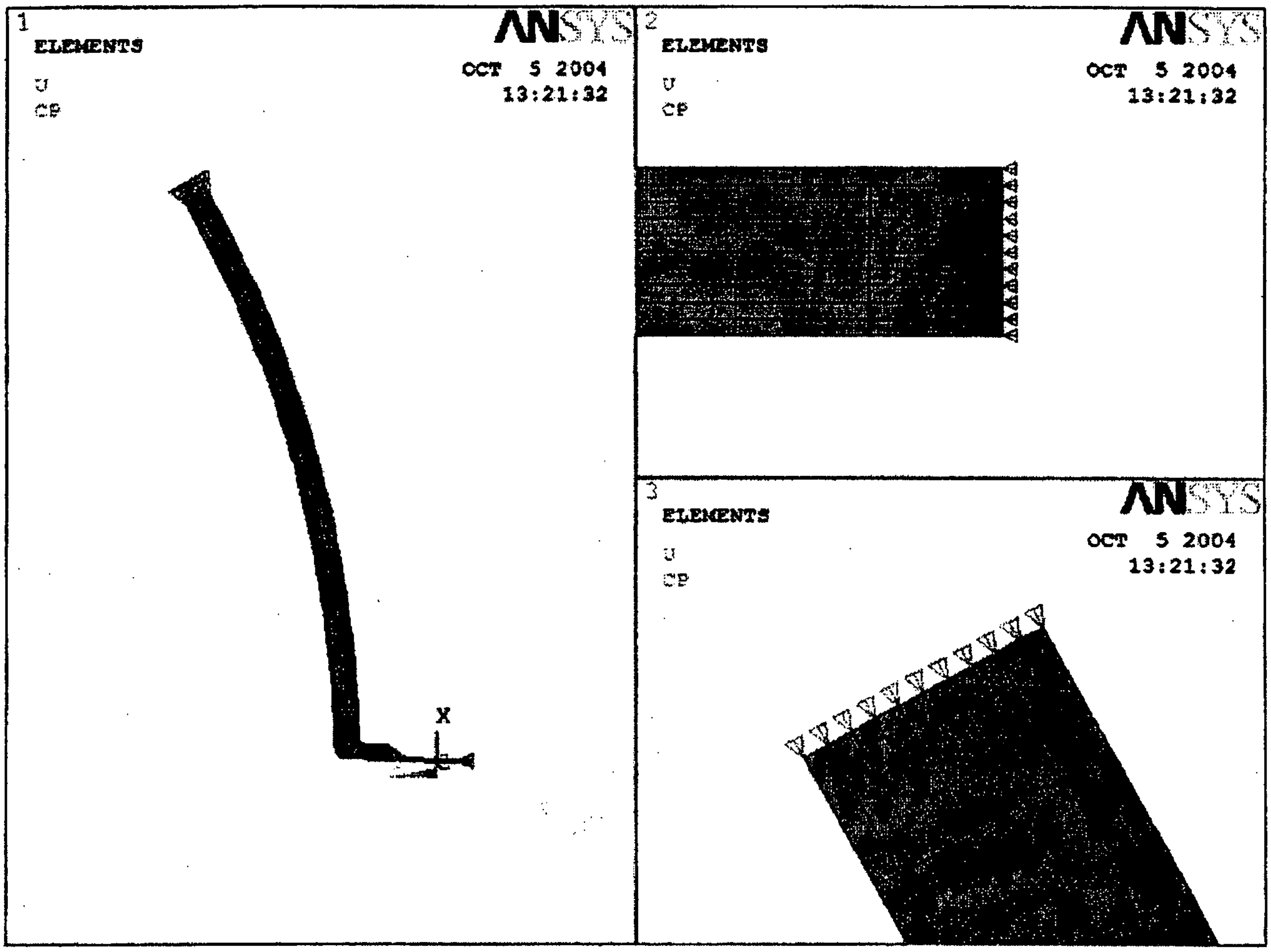

Figure 4: Element Plot of Applied Mechanical Boundary Conditions to As-Modeled FW Nozzle

4.2 Thermal Load

Thermal loads are applied to the feedwater nozzle model for a 100% rated flow thermal shock. The regions were given an initial temperature of 550°F and then the heat transfer coefficients and temperatures were changed to simulate the 100°F flow condition. The total flow rate of the feedwater system is 7.217 Mlb/hr divided into four feedwater nozzles. Thus, the total flow rate divided by four gives a rated flow rate for each feedwater nozzle equal to 1.80425 Mlb/hr, or 3,964 gallons per minute (gpm).

The heat transfer coefficients (HTC) for each of the GFs were determined and obtained from FWN-HT-COEFF.xls. This set of Excel worksheets calculates HTC's with geometry and flow condition input. HTC's were found for regions 1-4 and 6 of Figure 5. Region 5 uses a HTC that is an average of Region 1 and Region 2. The HTC's calculated from this spreadsheet are similar to the ones used in the original **FatiguePro** calculations [3]. The HTC value for region 4 at 100% flow case is the same as that used in reference [3], because the spreadsheet used in the calculations for other regions does not allow for HTC calculation at the inner wall of a vessel. Figure 5 shows the regions for application of HTC's. Table 2 depicts the HTC's at no flow and full flow conditions.

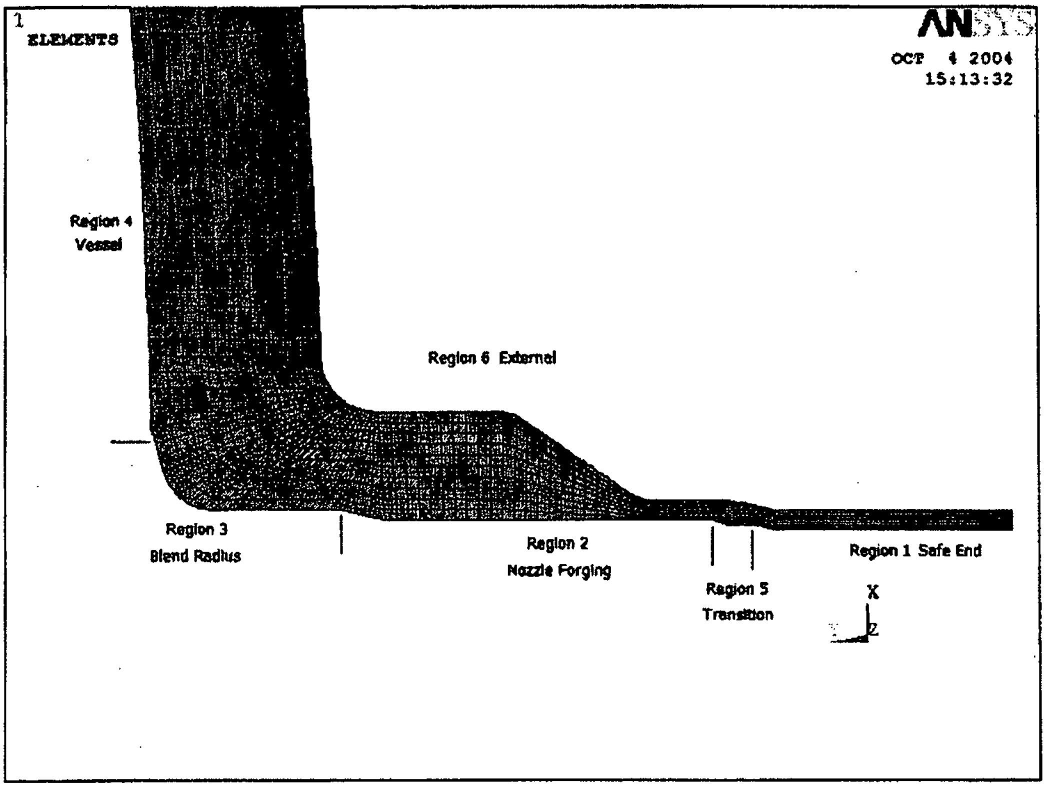

Figure 5: Thermal Regions of Oyster Creek Feedwater Nozzle

Table 2: Heat Transfer Coefficients for Oyster Creek Feedwater Nozzle

0% Flow Case			100% Flow Case		
Region	Temperature °F	Heat Transfer Coefficient Btu/hr-ft^2-°F	Region	Temperature °F	Heat Transfer Coefficient Btu/hr-ft^2-°F
1	550.0	205.1	1	100.0	2108.8
2	550.0	205.1	2	325.0	673.9
3	550.0	205.1	3	325.0	191.8
4	550.0	205.1	4	550.0	1000.0

Figure 6 depicts the graphical representation of the applied temperature step change to the feedwater nozzle. Thermal Regions 1, 2, 3, and 5 experience the step change. Thermal Region 4 remains at 550°F and Thermal Region 6 remains at 70°F (ambient temperature) during the step change, which occurs on the inner diameter of the feedwater nozzle (i.e., flow path). The thermal response of the shock is analyzed out to 20,000 seconds.

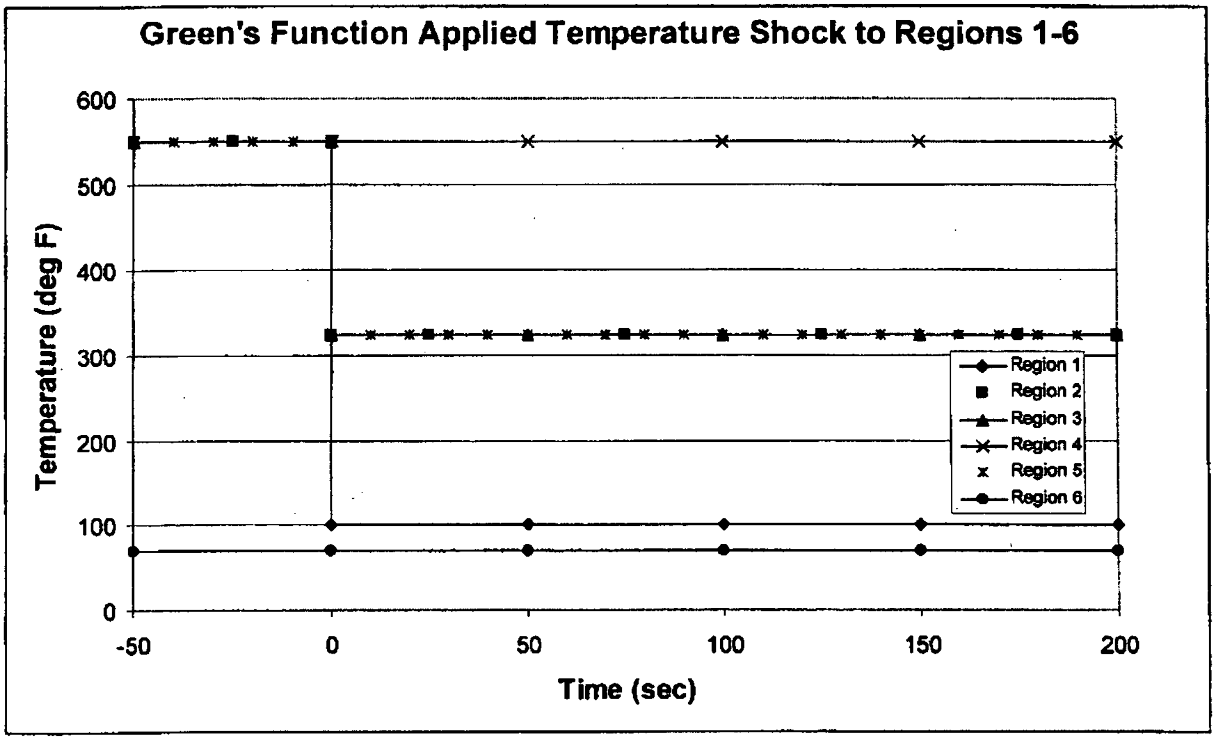

Figure 6: Applied Green's Function Temperature Step Change

5.0 THERMAL AND PRESSURE LOAD RESULTS

The thermal load described in the previous section was run on the feedwater FEM. The thermal transient input file is OC_FWN_THM. The input file used to find the stress due to thermal loading is OC_FWN_THSTR.inp.

Fatigue usage in components such as the feedwater nozzle are almost always controlled by limiting stresses caused by the severe "step change" thermal transients specified in the design basis. Since the Green's Function unit input transient is a step change, the peak stress response from this input transient provides a valid way of establishing the limiting point.

The limiting safe end location was chosen as the node with the highest stress intensity due to thermal loading. Figure 7 shows the temperature distribution for steady-state condition at 550°F. Figure 8 shows the temperature distribution at time = 3.1 seconds, which corresponds to the greatest thermal response produced by the applied temperature step change. The highest total stress intensity due to thermal loading occurs at Node 1344 on the inside diameter of the feedwater nozzle safe-end at a time of 3.1 seconds. Figure 9 depicts the location showing a total thermal stress intensity value of 67,246 psi for Node 1344. Node 1344, shown in Figure 11, was therefore selected as the limiting safe end location for analysis.

The limiting blend radius location was chosen based upon the highest total stress intensity due to pressure loading as shown in Figure 10. The input file used to apply the pressure loading is OC_FWN_PRES.inp. The limiting location is at Node 584 and is depicted in Figure 12.

The stress intensity time history for the limiting safe-end and blend radius locations were extracted using the ANSYS post-processing files XTR_BR.POS and XTR_SE.POS for the blend radius and safe end locations, respectively. The ANSYS PRESECT command is executed to extract the linearized stress history along a path from the selected location (safe end and blend radius) to a node on the external surface. Figures 11 and 12 show the linearized stress path for the safe end and blend radius, respectively. The post-processing file produces two raw output files, one for the safe-end and one for the blend radius location (contain the membrane plus bending and Total thermal stress histories), SE_FLW.out and BR_FLW.out. The membrane plus bending (M+B) stresses and total stresses for the Green's Functions were extracted from the raw output files to produce the corresponding 'clean' files SE.cln and BR.cln.

All *.POS, *.OUT, and *.CLN files are located in the computer files.

As the models were run with a 450°F step change in temperature at the safe end and 225°F step change at the blend radius and the Green's Functions are for a 1°F step change in temperature, all safe end data values were divided by -450 (ΔT) and blend radius data values were divided by -450

(ΔT). The governing Green's Function plots for the feedwater nozzle safe-end and blend radius locations are shown in Figures 14 and 15. The data for the Green's Functions is contained in Excel files OC_GreenFCN.XLS, which is located in the computer files.

The pressure stress intensities for the safe-end and blend radius paths were extracted using the ANSYS post-processing files XTR_SE_PRES.POS and XTR_BR_PRES.POS for the Safe End and Blend Radius locations, respectively. These files produced SE_PRES_FLW.OUT for the safe-end and BR_PRES_FLW.OUT for the blend radius.

Results of the internal pressure load case are for Node 584 (blend radius) with total stress intensity of 56,070 psi (BR_PRES_FLW.OUT) and for Node 1344 (safe-end) a total stress intensity of 7,767 psi (SE_PRES_FLW.OUT). The M+B stress intensity at Node 584 and Node 1344 are 53,150 psi and 7,732 psi, respectively. Table 3 shows the final pressure results for the safe-end and blend radius.

Table 3: Pressure Results

Location	Membrane plus Bending Stress Intensity (psi)	Total Stress Intensity (psi)
Safe End	7,732	7,767
Blend Radius	53,150	56,070

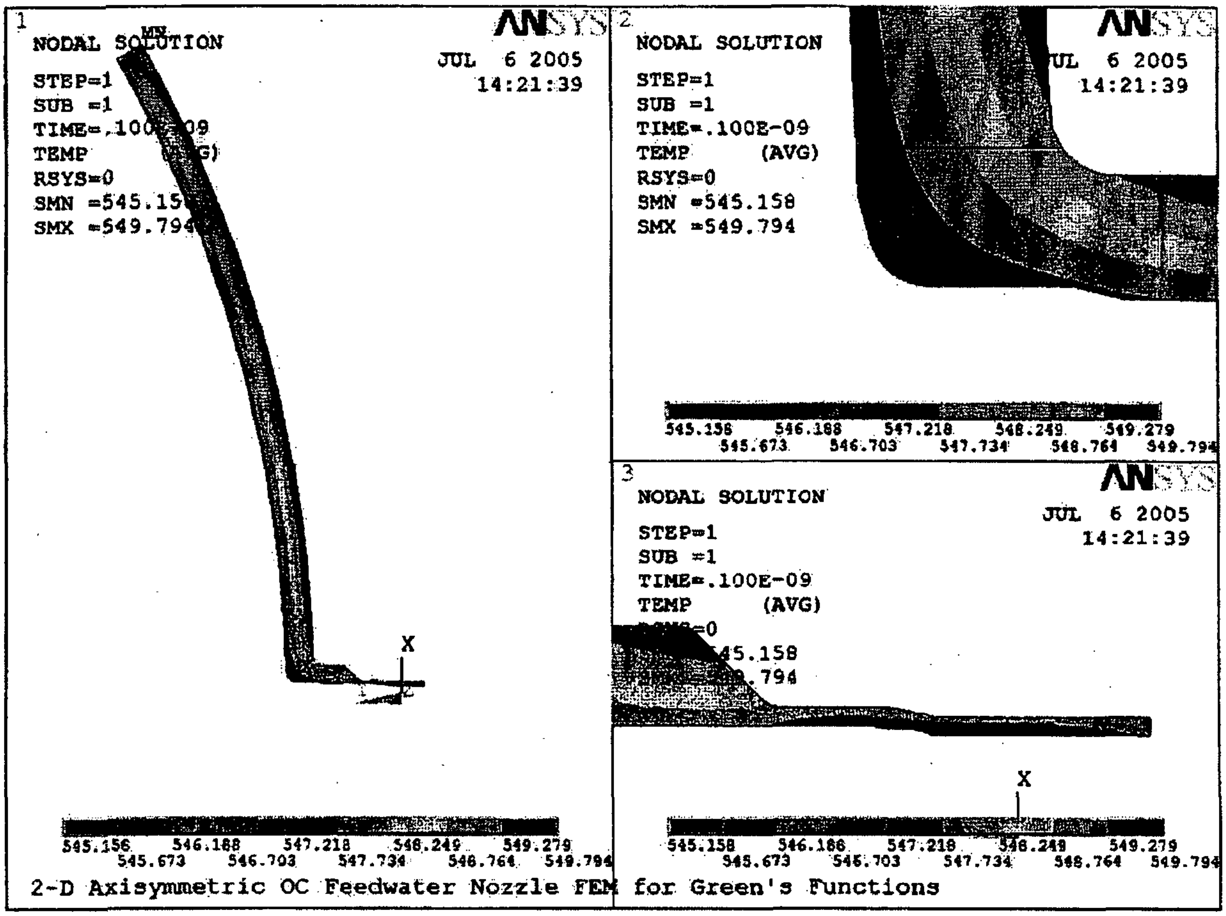

Figure 7: Temperature Plot of Steady-State Condition (550°F)

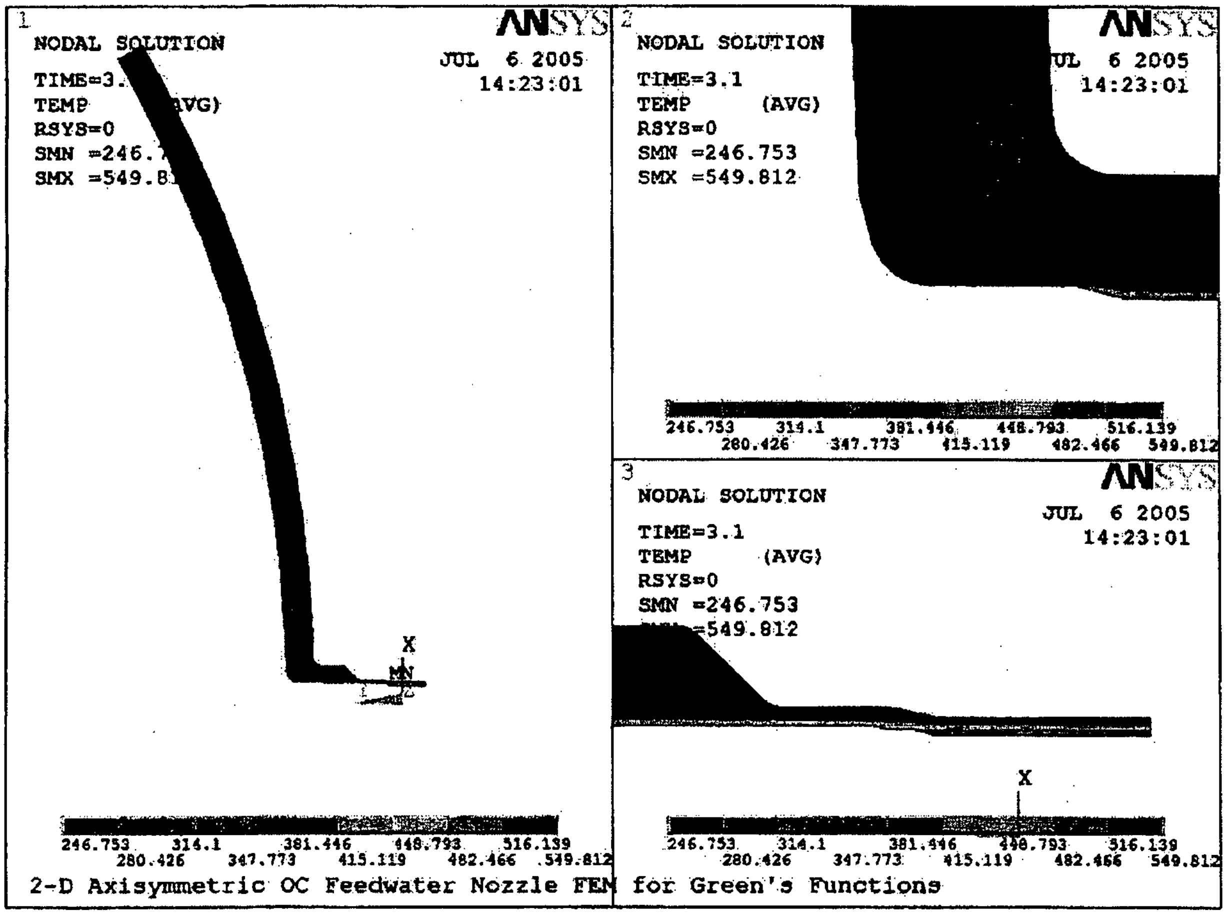

Figure 8: Temperature Plot at Time = 3.1 Seconds

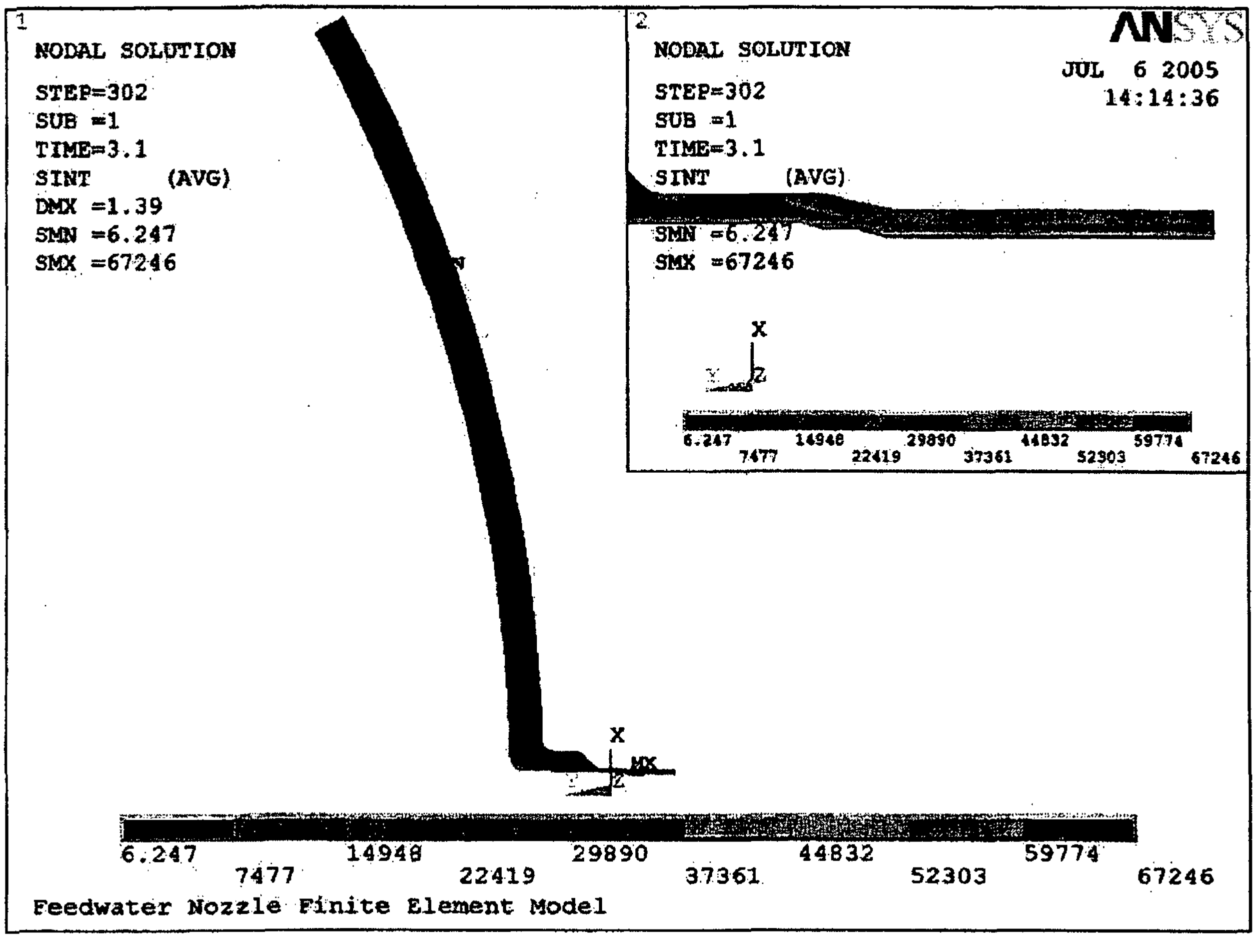

Figure 9: Maximum Total Thermal Stress Intensity (Time = 3.1 seconds)

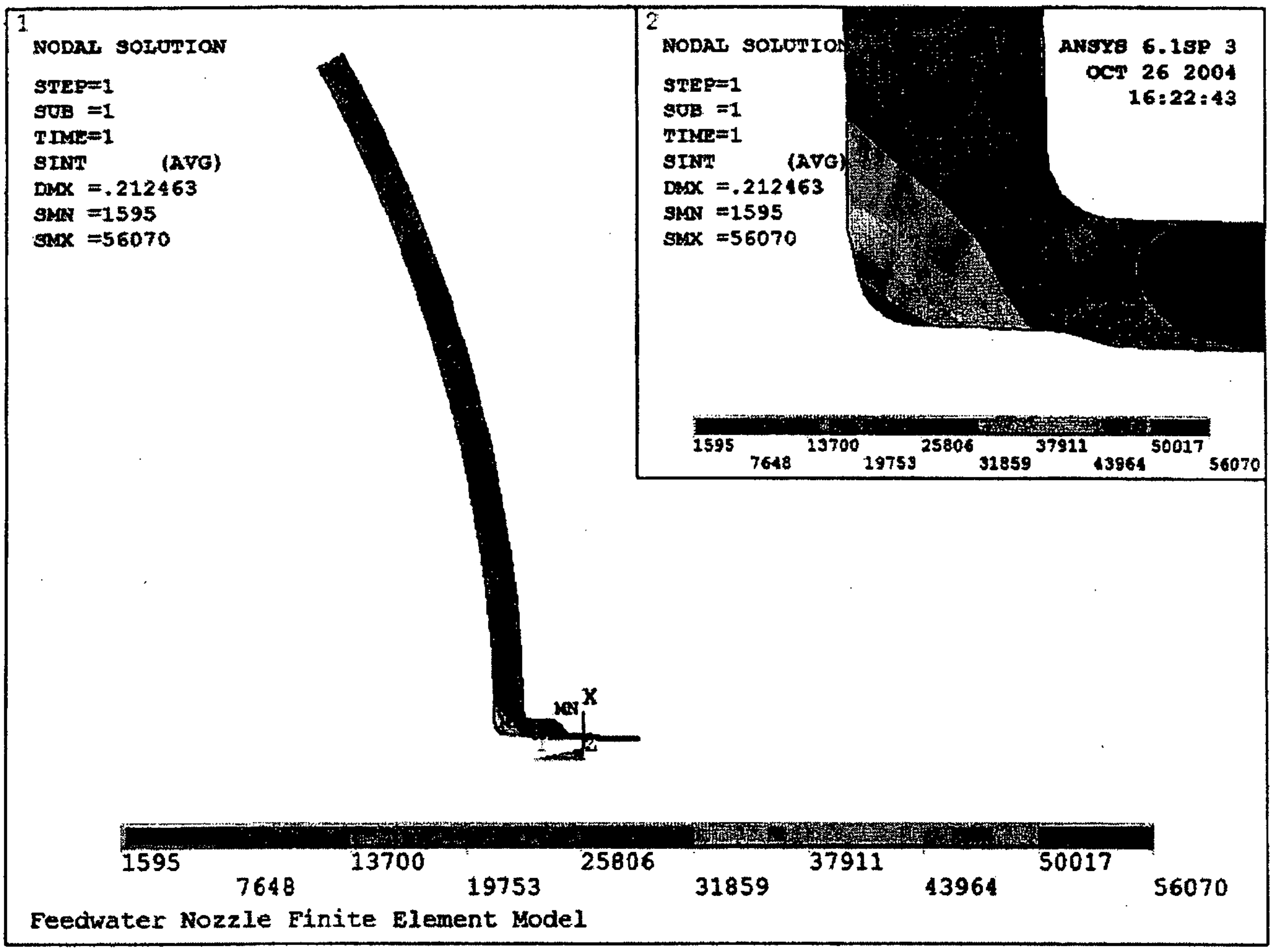

Figure 10: Maximum Total Pressure Stress Intensity from Applied Pressure Load

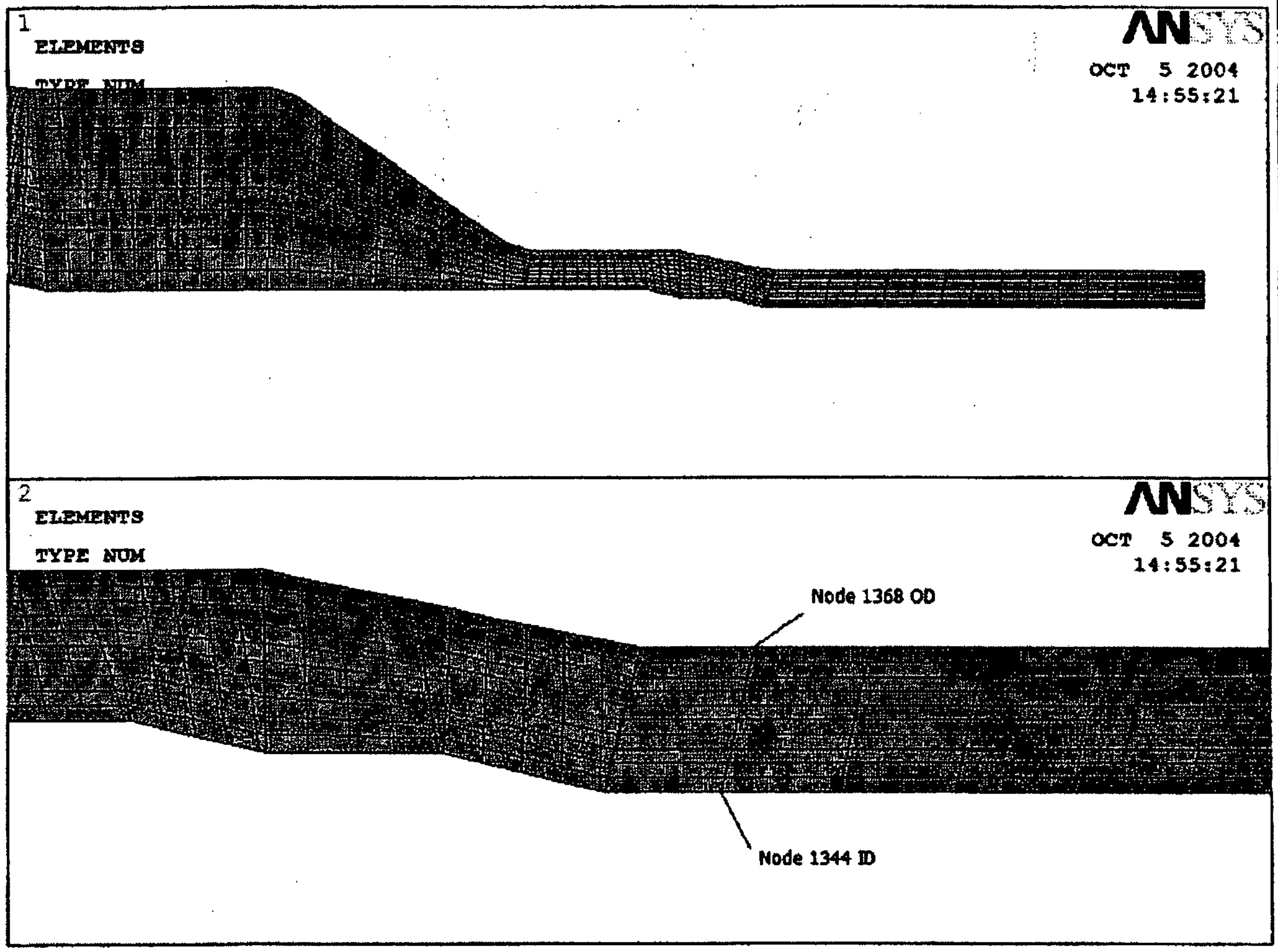

Figure 11: Safe End Critical Thermal Stress Location, Node 1344

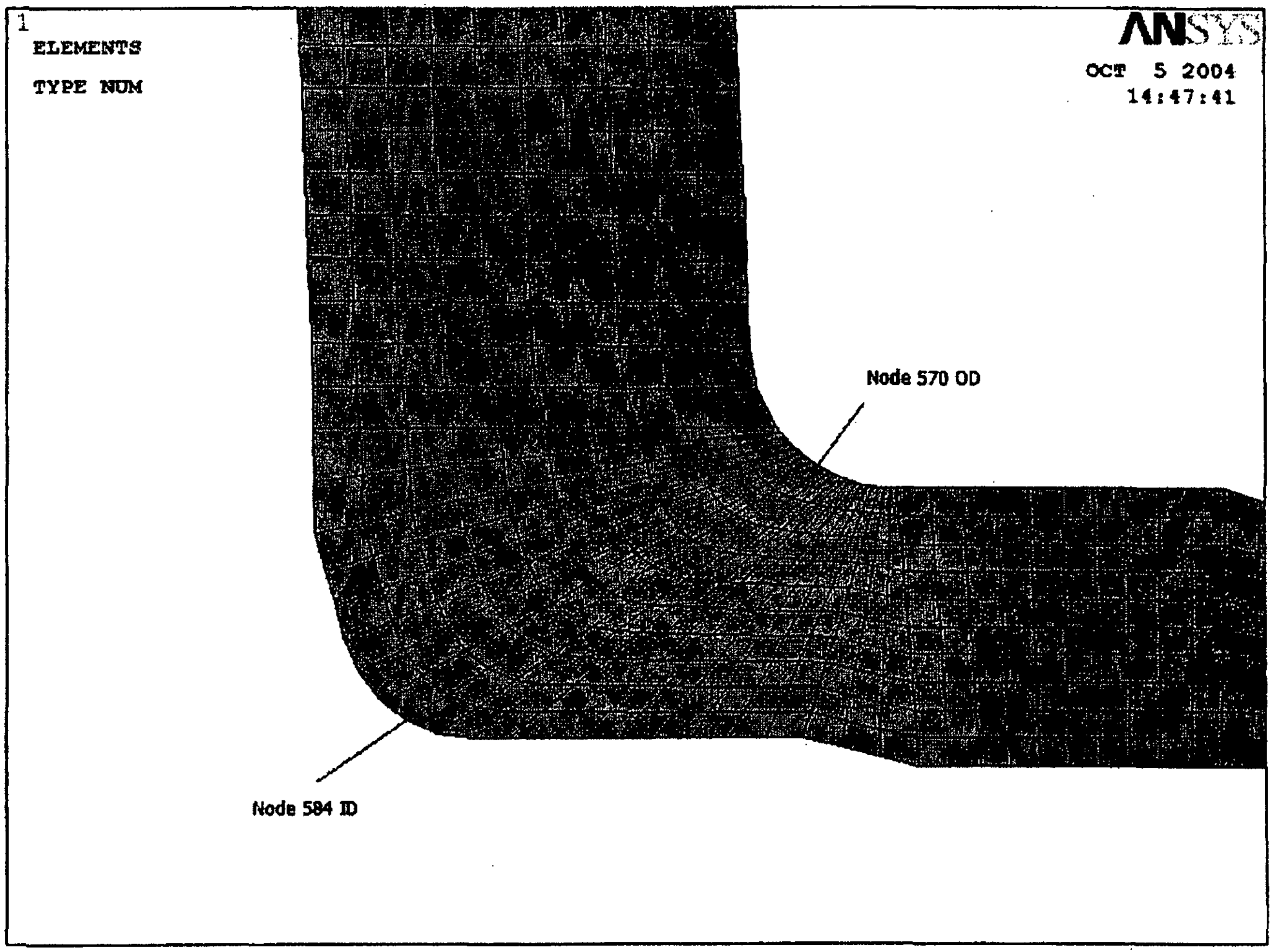

Figure 12: Blend Radius Critical Pressure Stress Location, Node 584

6.0 ATTACHED PIPING LOADS

Along with pressure and thermal effects, the piping stress intensity (stress caused by the attached piping) was determined. These piping forces and moments are determined as shown in Figure 13.

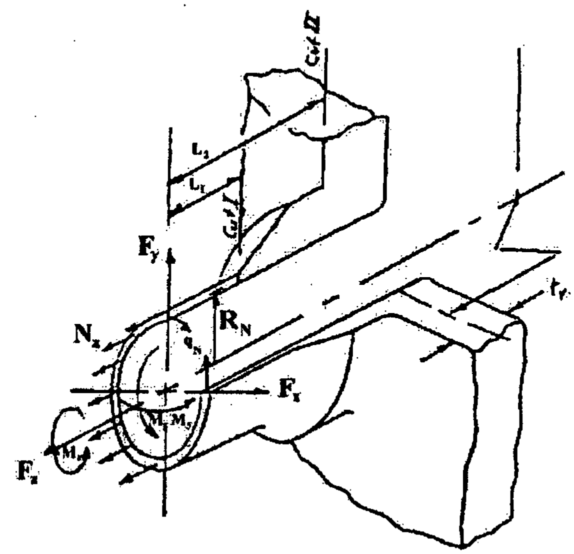

Figure 13: External Forces and Moments on the Recirculation Outlet Nozzle

The following formulas are used to determine the maximum stress intensity in the nozzle at the two locations of interest. From engineering statics, the piping loads at the end of the model can be translated to the first and second cut locations using the following equations:

For Cut I:
$$(M_x)_1 = M_x - F_y L_1$$
$$(M_y)_1 = M_y + F_x L_1$$

For Cut II:
$$(M_x)_2 = M_x - F_y L_2$$
$$(M_y)_2 = M_y + F_x L_2$$

The total bending moment and shear loads are obtained using the equations below:

For Cut I:
$$M_{xy} = \sqrt{(M_x)_1^2 + (M_y)_1^2}$$
$$F_{xy} = \sqrt{(F_x)_1^2 + (F_y)_1^2}$$

For Cut II:
$$M_{xy} = \sqrt{(M_x)_2^2 + (M_y)_2^2}$$
$$F_{xy} = \sqrt{(F_x)_2^2 + (F_y)_2^2}$$

The distributed loads for a thin-walled cylinder are obtained using the equations below:

$$N_z = \frac{1}{\pi R_N}\left[\frac{1}{2}F_z + \frac{M_{xy}}{R_N}\right]$$
$$q_N = \frac{1}{\pi R_N}\left[F_{xy} - \frac{M_z}{2R_N}\right]$$

To determine the primary stresses, P_M, due to internal pressure and piping loads, the following equations are used.

For Cut I, using thin-walled equations:

$$(P_M)_z = \frac{Pa_N}{2t_N} + \frac{Nz}{t_N}$$
$$(P_M)_\theta = \frac{Pa_N}{t_N}$$
$$(P_M)_R = -P$$
$$\tau_M = \frac{q_N}{t_N}$$
$$SI_{MAX} = 2\sqrt{\left(\frac{(P_M)_\theta - (P_M)_R}{2}\right)^2 + (\tau_M)_{z\theta}^2}$$

or

$$SI_{MAX} = 2\sqrt{\left(\frac{(P_M)_z - (P_M)_R}{2}\right)^2 + (\tau_M)_{z\theta}^2}$$

Note: For this analysis, the pressure load was applied to the ANSYS model and the resulting pressure stresses were taken from ANSYS. Therefore, they were excluded from the above equations.

Because pressure was not considered in this analysis, the equations used for Cut I are valid for Cut II.

where:
- L_1 = The length from the end of the nozzle where the piping loads are applied to the location of interest in the safe end.
- L_2 = The length from the end of the nozzle where the piping loads are applied to the location of interest in the blend radius.
- M_{xy} = The maximum bending moment in the xy plane.
- F_{yx} = The maximum shear force in the xy plane.
- N_z = The normal force per inch of circumference applied to the end of the nozzle in the z direction.
- q_N = The shear force per inch of circumference applied to the nozzle.
- R_N = The mid-wall nozzle radius.

There are four feedwater nozzles in the system (N4A, N4B, N4C, and N4D). The largest reaction forces need to be found and applied for this analysis. It is assumed that nozzles N4A and N4B bound N4C and N4D. Nodes 5 and 140 represent N4A and N4B. The node with greater reaction forces found from previous Autopipe analysis [8] will be the one used to base the piping load analysis.

In this case, the reaction loads from node 5 are higher than node 140 for the "MAX LVL A" load case [8, pg. 126]. This load case is used because it models the most severe conditions. The forces and moments from node 5 are shown below.

F_x = 1341 lbs	M_x = 241,920 in-lb
F_y = 2206 lbs	M_y = 77,820 in-lb
F_z = 1786 lbs	M_z = 62,592 in-lb

The loads are rotated into the local coordinate system shown in Figure 13 based on the coordinate values of nodes 5 and 10 [8]. The converted loads are as follows:

F_x' = 2,211 lbs	M_x' = 215,233 in-lb
F_y' = 2206 lbs	M_y' = 77,820 in-lb
F_z' = 315 lbs	M_z' = -126,804 in-lb

Since the location of the input piping load is on the outside surface of the vessel, it is assumed this location is equivalent to the second cut. Therefore, the L_2 is equal to zero and the L_1 is with a negative value for the distance between first cut and second cut (Cut II). The calculations for the safe end and blend radius are shown in Table 4. The first cut location is the same as the Green's Function cross section at the safe end, and the second cut is assumed to be on the vessel ID (i.e., Node 5 from the AUTOPIPE model [8]). The maximum stress intensities due to piping loads are **4598.60** psi at the safe end and **343.12** psi at the blend radius, respectively.

Table 4: Piping Load Calculations

Safe End External Piping Loads			Blend Radius External Piping Loads		
Parameters			Parameters		
F_x =	2.21	kips	F_x =	2.21	kips
F_y =	2.21	kips	F_y =	2.21	kips
F_Z =	0.31	kips	F_Z =	0.31	kips
M_x =	215.32	in-kips	M_x =	215.32	in-kips
M_y =	77.82	in-kips	M_y =	77.82	in-kips
M_Z =	-126.80	in-kips	M_Z =	-126.80	in-kips
OD=	11.00	in	OD=	20.00	in
ID=	9.375	in	ID=	11.140	in
R_N =	5.09	in	R_N =	7.79	in
L =	-18.72	in	L =	0.00	in
t_N =	0.81	in	t_N =	4.43	in
$(M_x)_2$ =	256.62	in-kips	$(M_x)_2$ =	215.32	in-kips
$(M_y)_2$ =	36.43	in-kips	$(M_y)_2$ =	77.82	in-kips
M_{xy} =	259.19	in-kips	M_{xy} =	228.95	in-kips
F_{xy} =	3.12	kips	F_{xy} =	3.12	kips
N_Z =	3.19	kips/in	N_Z =	1.21	kips/in
q_N =	0.97	kips/in	q_N =	0.46	kips/in
Primary Membrane Stress Intensity			Primary Membrane Stress Intensity		
PM_Z =	3.93	ksi	PM_Z =	0.27	ksi
τ =	1.20	ksi	τ =	0.10	ksi
SI_{max} =	4.60	ksi	SI_{max} =	0.34	ksi
SI_{max} =	4598.60	psi	SI_{max} =	343.12	psi

7.0 PEAK STRESS FACTOR

The piping load stress intensity value is also included in Tables 5 and 6. Total stress intensity values for membrane plus bending are obtained by combining the thermal membrane plus bending stress for 450°F, the pressure membrane plus bending stress, and the piping stress intensity. Total stress intensity values for membrane plus bending plus peak are then obtained by combining the total thermal stress for 450°F, the total pressure stress, and the piping stress intensity. These values are also given in Tables 5 and 6.

Maximum (σ_{max}) and steady-state (σ_{ss}) values are then determined for the membrane plus bending and total stress cases. Then the maximum possible stress range ($2\sigma_{max} - \sigma_{ss}$) is obtained. The ratio of this range for membrane plus bending over total equals the Peak Stress Factor (PSF), which is calculated for both feedwater locations, as shown in Tables 5 and 6. These values are implemented into **FatiguePro**. The peak stress factor for the nozzle safe end is **0.677** and the peak stress factor for the blend radius is **0.993**. All peak stress calculations are included in the Excel file *OC_GreenFCN.xls*, which is included in the project files.

8.0 CONCLUSIONS

The files *SE.CLN* and *BR.CLN* contain the stress histories necessary to develop 100% flow Green's Functions. A total stress intensity history Green's Function is produced for each of these files. The Green's Function is calculated by dividing the Total Stress Intensity (sixth column) by the change in temperature. It should be noted that the (Membrane + Bending) column (fourth column) does not always equal the sum of Column 2 (Membrane) and Column 3 (Bending) because the values are stress intensities and therefore vary due to changing magnitudes of stress direction. Tables 5 and 6 and Figures 14 and 15 show the thermal stress histories produced by *SE.CLN* and *BR.CLN*.

The project files contain all files associated with this calculation.

Table 5: Safe-End Node 1344 Data

Inputs:	ΔT=	-450	
	M+B Pressure Stress Intensity, Safe End =	7,732	
	Total Pressure Stress Intensity, Safe End =	7,767	
	Piping Load SI_{MAX} =	4,599	
Results:	***Peak Stress Factor, PSF*** =	0.677	
	σ_{max} =	57,611	79,616
	σ_{ss} =	25,261	26,396
	$2 * \sigma_{max} - \sigma_{ss}$ =	89960.60	132835.60

TIME (sec)	Membrane (psi)	Bending (psi)	Membrane + Bending (psi)	Peak (psi)	Total (psi)	TOTAL Green's Function (psi/F)	MEM+BND Stress Intensity (Thermal+Pressure) (psi)	TOTAL Stress Intensity (Thermal+Pressure) (psi)
1.00E-10	35	32	64	14	63	-0.14	12,395	12,429
0.01	19	267	272	3027	3259	-7.24222222	12,603	15,625
0.02	68	566	606	5799	6319	-14.0422222	12,937	18,685
0.03	117	864	937	8336	9144	-20.32	13,268	21,510
0.04	163	1162	1266	10660	11750	-26.1111111	13,597	24,116
0.05	208	1459	1594	12790	14170	-31.4888889	13,925	26,536
0.06	252	1755	1919	14750	16410	-36.4666667	14,250	28,776
0.07	294	2049	2243	16540	18480	-41.0666667	14,574	30,846
0.08	335	2343	2564	18200	20410	-45.3555556	14,895	32,776
0.09	375	2634	2882	19720	22210	-49.3555556	15,213	34,576
0.1	414	2925	3199	21120	23880	-53.0666667	15,530	36,246
20000	7566	9169	12930	5103	14030	-31.1777778	25,261	26,396

Note: The actual EXCEL spreadsheet (OC_GreenFCN.xls) contains more time points than are shown here.

Table 6: Blend Radius Node 584 Data

Inputs:	ΔT=	-450	
	M+B Pressure Stress Intensity, Blend Radius=	53,150	
	Total Pressure Stress Intensity, Blend Radius=	56,070	
	Piping Load SI_{MAX} =	343	
Results:	***Peak Stress Factor, PSF*** =	0.993	
	σ_{max} =	85,033	85,673
	σ_{ss} =	85,033	85,673
	$2 * \sigma_{max} - \sigma_{ss}$ =	85033.12	85673.12

TIME (sec)	Membrane (psi)	Bending (psi)	Membrane + Bending (psi)	Peak (psi)	Total (psi)	TOTAL Green's Function (psi/F)	MEM+BND Stress Intensity (Thermal+Pressure) (psi)	TOTAL Stress Intensity (Thermal+Pressure) (psi)
1.00E-10	3160	3162	6274	1196	5886	-13.08	59,767	62,299
0.01	3161	3160	6273	1196	5896	-13.1022	59,766	62,309
0.02	3161	3158	6272	1196	5907	-13.1267	59,765	62,320
0.03	3162	3156	6271	1197	5917	-13.1489	59,764	62,330
0.04	3162	3154	6270	1197	5927	-13.1711	59,763	62,340
0.05	3163	3151	6269	1199	5937	-13.1933	59,762	62,350
0.06	3163	3149	6268	1200	5948	-13.2178	59,761	62,361
0.07	3164	3147	6267	1202	5958	-13.24	59,760	62,371
0.08	3164	3145	6267	1204	5968	-13.2622	59,760	62,381
0.09	3165	3143	6266	1206	5978	-13.2844	59,759	62,391
0.1	3165	3141	6265	1209	5988	-13.3067	59,758	62,401
20000	13630	18030	31540	9486	29260	-65.0222	85,033	85,673

Note: The actual EXCEL spreadsheet (OC _GreenFCN.xls) contains more time points than are shown here.

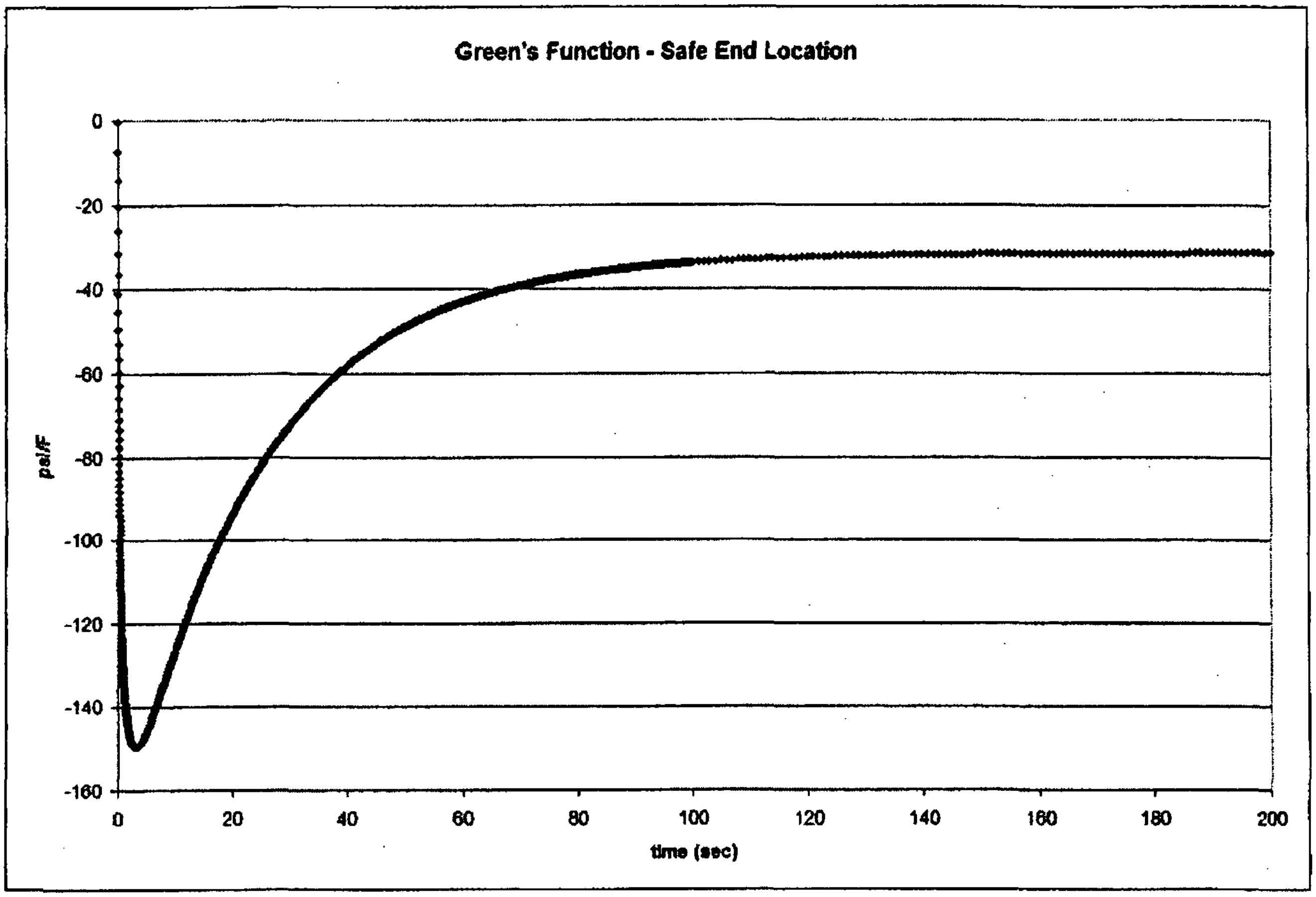

Figure 14: Safe-End Node 1344 Green's Function

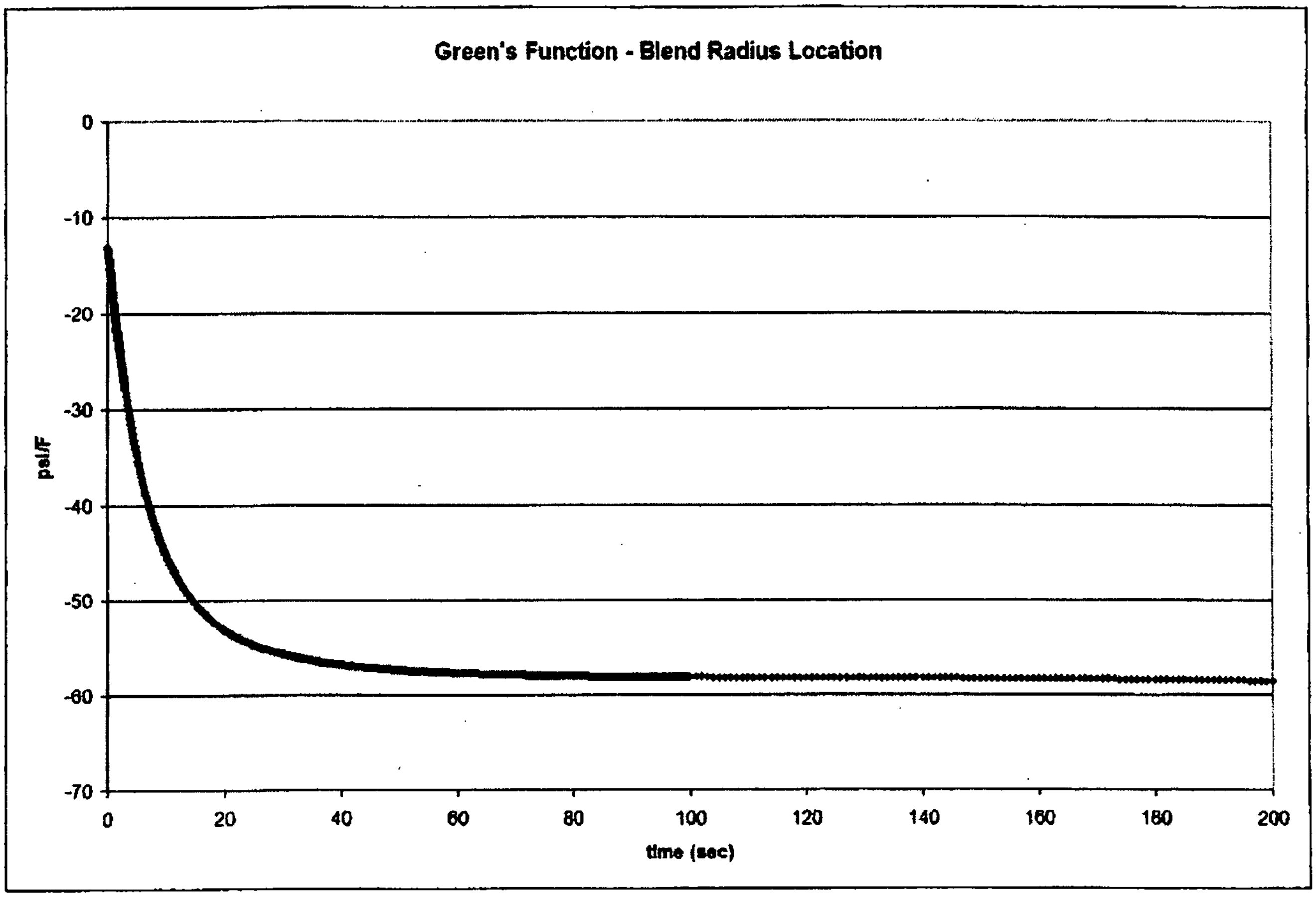

Figure 15: Blend Radius Node 584 Green's Function

9.0 REFERENCES

1. MPR Report No. MPR-783, "Oyster Creek Nuclear Generating Station Evaluation of Low Flow Feedwater Control System," August 1983, SI File No. OC-05Q-205.

2. ANSYS Release 8.1 (with Service Pack 1), ANSYS, Inc, April 2004.

3. Structural Integrity Report Number SIR-88-028, Revision 0, "Operating Instructions Feedwater and CRD Return Nozzle Thermal Transient Monitoring System Oyster Creek Nuclear Generating Station," September 16, 1988, SI File No. GPUN-13-101.

4. General Electric, Co. Drawing No. 232-566, "Nozzle Details – Vessel," Revision 6, 9-3-64, SI File No. OC-05Q-232.

5. ASME Boiler and Pressure Vessel Code, Section II, Part D – Properties, 1995 Edition (with 1996 Addenda).

6. E-mail from Michael J. May (OC) to Gary Stevens (SI) dated September 24, 2004, Subject: "Heat Balance," Attached "Heat Balance OC.pdf," SI File No. OC-05Q-228.

7. EPRI Report No. TR-107448, "FatiguePro, Version 2: Fatigue Monitoring Software," December 1997.

8. GPU Nuclear Report No. C-1302-422-E540-046, "Oyster Creek NSR Pipe Analysis, Feedwater System Reactor Nozzles N-4A & N-4B thru penetration X-4A to Anchor 422-14," Revision 2, January 2001, SI File No. OC-05Q-217.

APPENDIX A: COMPUTER INPUT AND OUTPUT FILES

The following list of electronic files is included in the project files:

FILENAME	DESCRIPTION
BR_FLW.OUT	Blend Radius Stress Intensity output file from extraction of Thermal Load application
BR_PRES_FLW.OUT	Blend Radius Stress Intensity output file from extraction of Pressure Load application
OC_FWN_GEOM.INP	Ansys input file for creation of Nozzle Geometry
OC_FWN_PRES.INP	Ansys input file for application of pressure loads
OC_FWN_THM.INP	Ansys input file for application of thermal transients
OC_FWN_THSTR.INP	Ansys input file for application of thermal shock
OC_GreenFCN.XLS	Excel file containing Safe End and Blend Radius Green's Functions
SE_FLW.OUT	Safe End Stress Intensity output file from extraction of thermal shock application
SE_PRES_FLW.OUT	Safe End Stress Intensity output file from extraction of pressure load application
FWN_HT_COEFF.XLS	Spreadsheet that generates Heat Transfer Coefficients
BR.CLN	Output file containing raw information for Blend Radius location Green's Function
SE.CLN	Output file containing raw information for Safe End location Green's Function
XTR_BR.POS	Stress Intensity extraction file for Blend Radius location from Thermal Load application
XTR_BR_PRES.POS	Stress Intensity extraction file for Blend Radius location from Pressure Load application
XTR_SE.POS	Stress Intensity extraction file for Safe End location from Thermal Load application
XTR_SE_PRES.POS	Stress Intensity extraction file for Safe End location from Pressure Load application

Listed Files in Appendix A:

OC_FWN_GEOM.INP	A3-A7
OC_FWN_PRES.INP	A8-A9
OC_FWN_THM.INP	A10-A14
OC_FWN_THSTR.INP	A15-A16
XTR_BR.POS	A17

OC_FWN_GEOM.INP

```
!finish
!/clear,start
!/config,nres,100000
!/filn,OC_FWN_GEOM
!/prep7
!et,1,plane42,,,1

!! Geometry for Oyster Creek Feedwater Nozzle !!

! Material 1 (Reactor Vessel Plate SA 302 Grade B)

mp,ex,1,2.79E+07
mp,alpx,1,7.81E-06
mp,kxx,1,24.7/3600/12
mp,c,1,0.1215
mp,nuxy,1,0.3
mp,dens,1,0.283

! Material 2 (Nozzle Forging SA 336)

mp,ex,2,2.84E+07
mp,alpx,2,7.395E-06
mp,kxx,2,23.8/3600/12
mp,c,2,0.121
mp,nuxy,2,0.3
mp,dens,2,0.283

! Material 3 (Safe End SA-105 Gr.II)

mp,ex,3,2.80E+07
mp,alpx,3,7.325E-06
mp,kxx,3,28.2/3600/12
mp,c,3,0.1221
mp,nuxy,3,0.3
mp,dens,3,0.283

! Geometry

*AFUN,deg
local,13,1,,,,,-90,

csys,13

! 0,0 is at the end of the Safe End, center line

! inner radius geometry - keypoints

k, 1,4.6875,,0
k, 2,4.6875,,3.844
k, 3,4.914 ,,4.75
k, 4,4.914 ,,5.75
k, 5,5.1015,,6.5
k, 6,5.1015,,20.003
k, 7,5.57 ,,21.875

! outer radius geometry - keypoints

k, 8,5.5  ,,0
k, 9,5.5  ,,0.75
```

```
k,10,5.5   ,,0.93957
k,11,5.5   ,,3.625
k,13,5.9375 ,,5.75
k,14,5.9375 ,,11.0625
k,15,9.625  ,,14.75
k,16,9.625  ,,25
k,19,5.57   ,,40
l,7 ,19
k,50,5.5   ,,-6
k,51,4.6875 ,,-6

! lines connecting inner/outer radius keypoints

l,1,2
l,2,3
l,3,4
l,4,5
l,5,6
l,6,7
l,50,51
l,8,9
l,9,10
l,10,11
l,11,13
l,13,14
l,14,15
l,15,16

! Creating vessel wall

local,14,1,,371.12,,,,
k,21,0,0,0
k,17,341.501,270,0
k,18,341.501,299,0
k,20,348.626,299,0
k,21,348.626,270,0

l,17,18
l,20,21
l,18,20

linter,15,17
ldele,20
linter,16,1
ldele,17
ldele,23
ldele,22

k,24,341.501,271.492674
k,25,343.7096,270
l,24,25

linter,1,15
linter,22,20

ldele,15
ldele,17
ldele,23

! Creating Fillets

lfillt,19,21,2.375
```

```
lfillt,13,14,1
lfillt,14,19,1
lfillt,3,4,0.125
lfillt,4,5,0.125
lfillt,5,6,0.125
lfillt,16,22,2.125
lfillt,2,3,0.125
ldele,9,11,1
ldele,2
l,2,51
l,11,50

! Mapping
! Vessel Wall

MSHKEY,1          ! Mapped Meshing - user defined
MAT,1
csys,13
k,53,10.625,,15             ! Additional geometry
k,54,10.625,,35
l,53,54
linter,10,15
linter,1,30
ldele,32
ldele,29
l,26,39
k,55,17.5,,15
k,56,17.5,,35
l,55,56
linter,10,29
linter,21,33
ldele,34,36,2
lesize,18,,,10
lesize,35,,,10
lesize,30,,,40
lesize,10,,,40
al,35,30,18,10              ! AREA 1

ldele,1
lesize,31,,,10
lesize,32,,,10
lesize,29,,,8
lesize,28,,,2
al,31,32,35,29,28   ! AREA 2

! Corner - Nozzle Forging

! Creating 2 pie shaped pieces - this is the first

Mat,2
kl,11,0.5,60
l,60,38
linter,1,26
linter,1,11
lesize,1,,,10
lesize,26,,,5
lesize,22,,,3
lesize,15,,,2
lesize,33,,,10
al,33,1,26,22,15,31 ! AREA 3

! Creating second pie shape
```

	Revision	0			
	Preparer/Date	EEJ 07/20/2005			
	Checker/Date	MQ 07/20/2005			
	File No. OC-05Q-307			**Page A5 of A17**	

```
l,6,26
lesize,11,,,10
lesize,21,,,12
lesize,16,,,9
lesize,7,,,3
al,21,11,7,16,1          ! AREA 4

! Meshing the final portion of the Nozzle End forging

csys,13
k,70, 5,,7.8125          ! Additional Geometry
k,71, 6,,7.8125
l,70,71
linter,6,34
ldele,38
linter,13,39
ldele,40
kl,36,0.4,73
kl,36,0.765,74
l,31,73
l,28,74

! First section (3) of the final portion of nozzle end forging

linter,13,36
linter,39,41
lesize,13,,,10
lesize,19,,,10
lesize,40,,,10
al,11,19,13,40           ! AREA 5

! Second section (3) of the final portion of nozzle end forging

lesize,39,,,10
lesize,17,,,2
lesize,14,,,8
lesize,20,,,2
lesize,42,,,12
al,39,17,14,20,42,13     ! AREA 6

! Third section (3) of the final portion of nozzle end forging

lesize,38,,,10
lesize,36,,,5
lesize,34,,,5
al,34,39,36,38           ! AREA 7

! Creating the first mesh (3) of Safe End

Mat,3

l,34,13
l,40,11
lesize,37,,,6
lesize,25,,,1
lesize,5,,,4
lesize,24,,,1
lesize,41,,,10
lesize,6,,,12
al,37,25,5,24,41,6,38    ! AREA 8
```

```
! Creating the second mesh (3) of Safe End

lesize,4,,,4
lesize,23,,,1
lesize,3,,,4
lesize,27,,,1
lesize,43,,,10
lesize,12,,,10
al,41,12,43,27,3,23,4           ! AREA 9

! Complete the final section---something wrong with Geometry...

ldele,2
l,40,51
lesize,8,,,10
lesize,2,,,15
lesize,9,,,15
al,2,8,9,43                     ! AREA 10

! Concatenating lines for Meshing
lccat,28,29                     ! For Area 2

flst,2,3,4,orde,3               ! For Area 3
fitem,2,15
fitem,2,22
fitem,2,26
lccat,p51x

lccat,7,16                      ! For Area 4

FLST,2,3,4,ORDE,3               ! For Area 6
FITEM,2,14
FITEM,2,17
FITEM,2,20
LCCAT,P51X

FLST,2,4,4,ORDE,4               ! For Area 8
FITEM,2,5
FITEM,2,24
FITEM,2,-25
FITEM,2,37
LCCAT,P51X

FLST,2,4,4,ORDE,4               ! For Area 9
FITEM,2,3
FITEM,2,-4
FITEM,2,23
FITEM,2,27
LCCAT,P51X

! Creating Meshes from areas

Mat,1                           ! Meshing for Material 1 Areas
amesh,1,2,1
mat,2                           ! Meshing for Material 2 Areas
amesh,3,7,1
mat,3                           ! Meshing for Material 3 Areas
amesh,8,10,1

/PNUM,LINE,1
/PNUM,KP,1
lplot
```

OC_FWN_PRES.INP

```
finish
/clear,start
/config,nres,100000
/filn,OC_FWN_STR
/prep7
! Oyster Creek
/title, Feedwater Nozzle Finite Element Model

! 2D model for generating Greene's Functions

et,1,plane42,,,1      ! axisymmetric

/input,OC_FWN_GEOM,inp

!!!!!!!!!!!!!!!!!!!!!!!!!!
!! Boundary Conditions !!
!!!!!!!!!!!!!!!!!!!!!!!!!!

! Coupled Nodes on the Nozzle Safe End
FLST,5,11,1,ORDE,3
FITEM,5,1343
FITEM,5,1358
FITEM,5,-1367
NSEL,S, , ,P51X
cp,1,uy,all

! Symmetry Conditions
nsel,all
DL,18,,SYMM,,

/solu

! Define Pressure Value and Cap Load
*set,Pressure,1000              ! Pressure (psi), internal pressure applied
*set, PCAP, Pressure*((2*4.6875)**2)/((2*5.5)**2-(2*4.6875)**2)


! ** Apply Cap Load**
SFL,8,PRES,-PCAP

! ** Apply Pressure Load **
SFL, 2,PRES,Pressure ! ID of Safe End
SFL,27,PRES,Pressure ! ID of Safe End
SFL, 3,PRES,Pressure ! ID of Safe End
SFL,23,PRES,Pressure ! ID of Safe End
SFL, 4,PRES,Pressure ! ID of Safe End
SFL,24,PRES,Pressure ! ID of Safe End
SFL, 5,PRES,Pressure ! ID of Safe End
SFL,25,PRES,Pressure ! ID of Safe End
SFL,37,PRES,Pressure ! ID of Safe End
SFL,36,PRES,Pressure ! ID of Nozzle Forging
SFL,42,PRES,Pressure ! ID of Nozzle Forging
SFL,40,PRES,Pressure ! ID of Nozzle Forging
SFL, 7,PRES,Pressure ! ID of Nozzle Forging
SFL,16,PRES,Pressure ! ID of Nozzle Forging
SFL,26,PRES,Pressure ! ID of Nozzle Forging
SFL,22,PRES,Pressure ! ID of Nozzle Forging
SFL,15,PRES,Pressure ! ID of Nozzle Forging
SFL,32,PRES,Pressure ! ID of Vessel Wall
```

```
SFL,30,PRES,Pressure ! ID of Vessel Wall

SOLVE
SAVE
FINISH
/ANG,1,30,ZS,1
/REP,FAST
/ANG,1,30,ZS,1
/REP,FAST
/ANG,1,30,ZS,1
/REP,FAST
```

OC_FWN_THM.INP

```
finish
/clear,start
/config,nres,100000
/filn,OC_FWN_THM
/prep7

! Oyster Creek Feedwater Nozzle

/title, 2-D Axisymmetric OC Feedwater Nozzle FEM for Green's Functions

et,1,plane55,,,1      !Axisymmetric

/input,OC_FWN_GEOM,inp

!!!!!!!!!!!!!!!!!!!!!!!!!
!! Boundary Conditions !!
!!!!!!!!!!!!!!!!!!!!!!!!!

! Coupled Nodes on the Nozzle Safe End
FLST,5,11,1,ORDE,3
FITEM,5,1343
FITEM,5,1358
FITEM,5,-1367
NSEL,S, , ,P51X
cp,1,uy,all

! Symmetry Conditions
DL,18,,symm

/solu
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
! Thermal Boundary Conditions !
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!

! Heat Transfer Coefficients - Steady State

Tamb=70                          ! Ambient Temperature

h1=205.1/(3600*144)              ! Safe End
h2=205.1/(3600*144)              ! Nozzle Forging step 1
h3=205.1/(3600*144)              ! Nozzle Forging step 2
h4=205.1/(3600*144)              ! Vessel Wall
h5=(h1+h2)/2                     ! Thermal sleeve rest
ho=0.2/(3600*144)          ! Outside Heat Temperature Coefficient

T1=550
T2=550
T3=550
T4=550
T5=550

/solu

!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!! Load Step 1 - Steady-State, No Flow !!
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!

! Apply HTC's
```

```
! Region 1
SFL, 2,CONV,h1,,T1
SFL,27,CONV,h1,,T1
SFL, 3,CONV,h1,h5,T1,T5

! Region 5
SFL,23,CONV,h5,,T5
SFL, 4,CONV,h5,,T5
SFL,24,CONV,h5,,T5
SFL, 5,CONV,h5,h2,T5,T2

! Region 2
SFL,25,conv,h2,,T2
SFL,37,conv,h2,,T2
SFL,36,conv,h2,,T2
SFL,42,conv,h2,,T2
SFL,40,conv,h2,,T2
SFL, 7,conv,h2,h3,T2,T3

! Region 3
SFL,16,conv,h3,,T3
SFL,26,conv,h3,h4,T3,T4                ! Blend Radius

! Region 4
SFL,22,conv,h4,,T4
SFL,15,conv,h4,,T4
SFL,32,conv,h4,,T4
SFL,30,conv,h4,,T4

SFL,18,conv,ho,,Tamb
SFL,10,conv,ho,,Tamb
SFL,29,conv,ho,,Tamb
SFL,28,conv,ho,,Tamb
SFL,33,conv,ho,,Tamb
SFL,21,conv,ho,,Tamb
SFL,19,conv,ho,,Tamb
SFL,20,conv,ho,,Tamb
SFL,14,conv,ho,,Tamb
SFL,17,conv,ho,,Tamb
SFL,34,conv,ho,,Tamb
SFL, 6,conv,ho,,Tamb
SFL,12,conv,ho,,Tamb
SFL, 9,conv,ho,,Tamb
SFL, 8,conv,ho,,Tamb


!!!!!!!!!!!!!!!!!!!!!!!!!!
!! Perform Steady State Run
!!!!!!!!!!!!!!!!!!!!!!!!!!

ANTYPE,TRANS
allsel,all
outres,all,all
TIMINT,off
TIME,1e-10
SOLVE
SAVE

!!!!!!!!!!!!!!!!
!! Load Step 2 !!
!!!!!!!!!!!!!!!!
```

```
! Heat Transfer Coefficients - Shock

h1=2108.8/(3600*144)                    ! Safe End
h2=673.9/(3600*144)                     ! Nozzle Forging step 1
h3=191.8/(3600*144)                     ! Nozzle Forging step 2
h4=1000/(3600*144)                      ! Vessel Wall
h5=(h1+h2)/2                  ! Thermal sleeve rest
ho=0.2/(3600*144)             ! Outside Heat Temperature Coefficient

T1=100
T2=325
T3=325
T4=550
T5=325

/solu

!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!! Load Step 2 - Thermal Shock - Max Flow !!
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!

! Region 1
SFL, 2,CONV,h1,,T1
SFL,27,CONV,h1,,T1
SFL, 3,CONV,h1,h5,T1,T5

! Step Region
SFL,23,CONV,h5,,T5
SFL, 4,CONV,h5,,T5
SFL,27,CONV,h5,,T5
SFL, 5,CONV,h5,h2,T5,T2

! Region 2
SFL,25,conv,h2,,T2
SFL,37,conv,h2,,T2
SFL,36,conv,h2,,T2
SFL,42,conv,h2,,T2
SFL,40,conv,h2,,T2
SFL, 7,conv,h2,h3,T2,T3

! Region 3
SFL,16,conv,h3,,T3
SFL,26,conv,h3,h4,T3,T4             ! Blend Radius

! Region 4
SFL,22,conv,h4,,T4
SFL,15,conv,h4,,T4
SFL,32,conv,h4,,T4
SFL,30,conv,h4,,T4

SFL,18,conv,ho,,Tamb
SFL,10,conv,ho,,Tamb
SFL,29,conv,ho,,Tamb
SFL,28,conv,ho,,Tamb
SFL,33,conv,ho,,Tamb
SFL,21,conv,ho,,Tamb
SFL,19,conv,ho,,Tamb
SFL,20,conv,ho,,Tamb
SFL,14,conv,ho,,Tamb
SFL,17,conv,ho,,Tamb
SFL,34,conv,ho,,Tamb
```

```
SFL, 6,conv,ho,,Tamb
SFL,12,conv,ho,,Tamb
SFL, 9,conv,ho,,Tamb
SFL, 8,conv,ho,,Tamb

! Load Step 2 - Thermal Shock
nsel,all
esel,all
outres,all,all

KBC,1
TIMINT,ON
AUTOTS,OFF
NSUBST,300,
TIME,3
SOLVE
SAVE

! Load Step 3
nsel,all
esel,all
outres,all,all

KBC,1
TIMINT,ON
AUTOTS,OFF
NSUBST,70,
TIME,10
SOLVE
SAVE

! Load Step 4
nsel,all
esel,all
outres,all,all

KBC,1
TIMINT,ON
AUTOTS,OFF
NSUBST,900,
TIME,100
SOLVE
SAVE

! Load Step 5
nsel,all
esel,all
outres,all,all

KBC,1
TIMINT,ON
AUTOTS,OFF
NSUBST,900,
TIME,1000
SOLVE
SAVE

! Load Step 6
nsel,all
esel,all
outres,all,all
```

```
KBC,1
TIMINT,ON
AUTOTS,ON
NSUBST,100,200,10
NROPT,AUTO,,ON
TIME,20000
SOLVE
SAVE
FINISH
```

OC_FWN_THSTR.INP

```
finish
/clear,start
/CONFIG,NRES,100000
/FILN,OC_FWN_TS
/prep7
!, Oyster Creek Nuclear Power Plant
/title, Feedwater Nozzle Finite Element Model
/com, title, 2D Model for generating Greene's functions

et,1,plane42,,,1     ! axisymmetric

/input,OC_FWN_GEOM,inp

!!!!!!!!!!!!!!!!!!!!!!!!!
!! Boundary Conditions !!
!!!!!!!!!!!!!!!!!!!!!!!!!

! Coupled Nodes on the Nozzle Safe End
FLST,5,11,1,ORDE,3
FITEM,5,1343
FITEM,5,1358
FITEM,5,-1367
NSEL,S, , ,P51X
cp,1,uy,all

! Symmetry Conditions
nsel,all
DL,18,,SYMM,,

/solu

/COM,********************
/COM, Read Thermal Stress
/COM,********************
Tref,70
/COM, LOAD STEP 1, STEADY STATE
ldread,temp,,,1e-10,,OC_FWN_THM,rth
time,1e-10
solve

/COM, LOAD STEP 2, FIRST THREE SECONDS
*do,i,0.01,3,0.01
ldread,temp,,,i,,OC_FWN_THM,rth
time,i
solve
*enddo

/COM, LOAD STEP 3
*do,i,3.1,10,0.1
ldread,temp,,,i,,OC_FWN_THM,rth
time,i
solve
*enddo

/COM, LOAD STEP 4
*do,i,10.2,100,0.1
ldread,temp,,,i,,OC_FWN_THM,rth
time,i
solve
```

```
*enddo

/COM, LOAD STEP 5
*do,i,101,1000,1
ldread,temp,,,i,,OC_FWN_THM,rth
time,i
solve
*enddo

/COM, LOAD STEP 6
*do,i,1200,20000,200
ldread,temp,,,i,,OC_FWN_THM,rth
time,i
solve
*enddo


SAVE
FINI

! /INP,XTR_FLW,POS
```

XTR_BR.POS

```
CSYS,0
/postl
                                ! output safe end linearized stress to file
/out,BR_FLW,out

r= 6.2964
avprin,0,0,
csys,0
flst,2,2,1
fitem,2,584
fitem,2,570
path,br,2,30,20
ppath,p51x,1

set,,,1,,1e-10
pmap,ACCURATE,'   '
prsect,r,0

*do,i,0.01,3,0.01
set,,,1,,i
pmap,ACCURATE,'   '
prsect,r,0
*enddo

*do,i,3.1,10,0.1
set,,,1,,i
pmap,ACCURATE,'   '
prsect,r,0
*enddo

*do,i,10.2,100,0.1
set,,,1,,i
pmap,ACCURATE,'   '
prsect,r,0
*enddo

*do,i,101,1000,1
set,,,1,,i
pmap,ACCURATE,'   '
prsect,r,0
*enddo

*do,i,1200,20000,200
set,,,1,,i
pmap,ACCURATE,'   '
prsect,r,0
*enddo

/out
```