ASME Code Stress Evaluation of Re-engineered APR1400 SG Steam Nozzle

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1. Introduction

Structural integrity of the Steam generator (SG) is of utmost importance to the nuclear power plant to avoid release of radioactive material to outside environment from the reactor coolant system and/or the secondary system. Steam nozzles form structural discontinuities on the secondary side of the SG hence the need to evaluate the conformance to the ASME BPVC section III [1]. The nozzle and part of SG secondary head were modeled as 2D axisymmetric model using ANSYS V.18.1 and stresses were evaluated for design and normal operating condition. The stress result were further processed to get membrane and bending stress by ANSYS linearized stress path capabilities which were further inspected to check if they are over the ASME allowable stress intensity limits [1]. This study confirms compliance of the APR1400 steam nozzles to the ASME BPVC Section III subsection NC requirements.

2. Methodology

2.1 Evaluation criteria

For the purposes of this study, the evaluation was limited to the design and level A conditions from the requirements of ASME section III division 1 subsection NC-3217 where from table NC–3217-1[2], the figure XIII-1141-1[3] in the appendix XIII of ASME section III division 1 reduces to the form below:

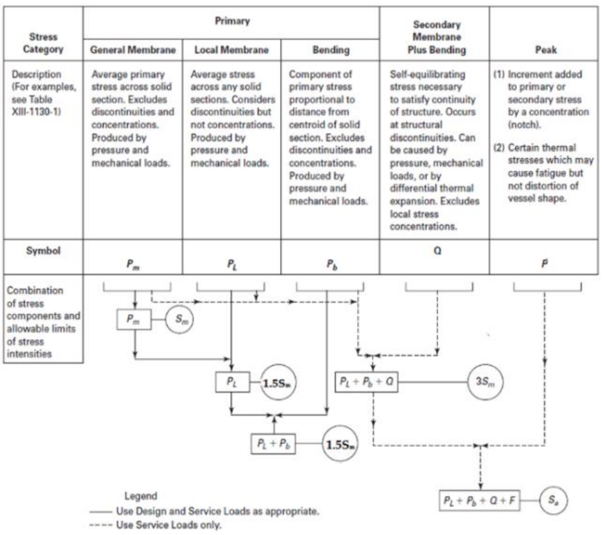

Figure 1: A reviewed figure XIII-1141-1 as per NC 3217

2.2 Problem set up

2.2.1 The model set up

A 2D axisymmetric model of the model was developed as the Figure 2 below putting into consideration the most vital aspects of the steam outlet nozzle that need to be considered.

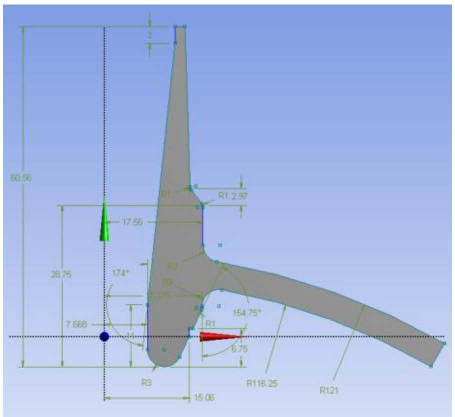

Figure 2: A 2D axisymmetric view of the steam outlet nozzle

To improve the quality of the mesh in the model for effective evaluation, we improved the model quality using edge sizing with an effective bias level focusing on the points of interest especially edges. For effective analysis and investigation of the stress conditions of the steam outlet nozzle at the design and level A conditions, we created 17 construction paths as per the Figure 3 and Figure 4 below. The construction paths considered all the expected stress concentration areas in both the nozzle and the secondary head shell for effective evaluation.

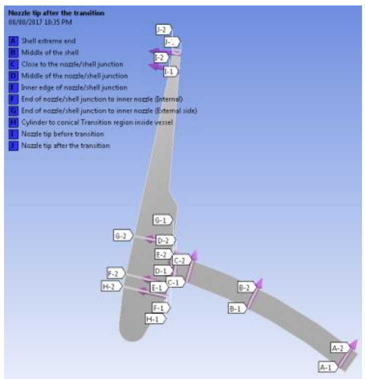

Figure 3: Steam Nozzle stress Path positions 1(A) to 10 (J)

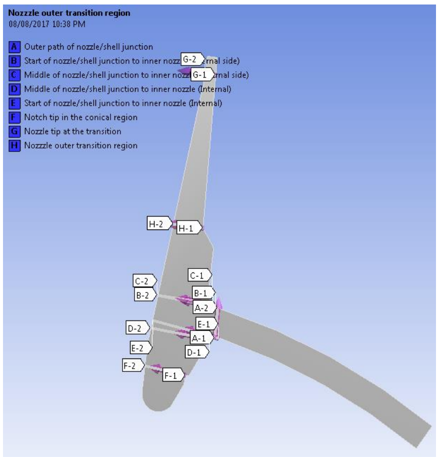

Figure 4: Steam Nozzle stress Path positions 11(A) to 18 (H)

2.2.2 Stress evaluation under design conditions

For design conditions as per the ASME code the conditions necessary are the pressure and mechanical loads the values of which were obtained from the SSAR of the APR1400 as 1,200psia (84.36kg/cm^{2}A) [4]. The internal pressure causes some stress on the wall which can be evaluated as per the equation (1) below and the model set up in Figure 5

$$Force\ on\ the\ nozzle\ wall = Force\ inside\ the\ nozzle$$

$$\sigma_{wall} x\ A_{wall} = p_{internal} x\ A_{internal}$$

$$\sigma_{wall} x\ \pi\left(R_{external}^2 - R_{internal}^2\right) = p_{internal} x\ \pi R_{internal}^2 \quad (1)$$

$$\sigma_{wall} = \frac{R_{internal}^2}{\left(R_{external}^2 - R_{internal}^2\right)} p_{internal}$$

$$\sigma_{wall} = \frac{0.36392^2}{(0.39107^2 - 0.36392^2)} x\ 8.2737MPa = 53.46MPa$$

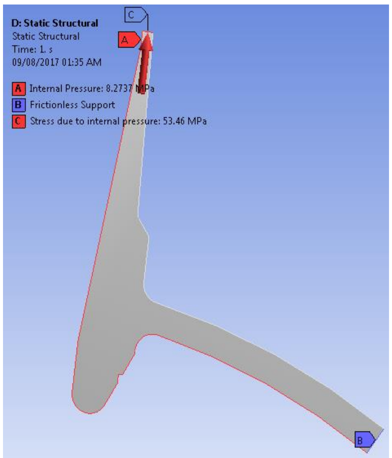

Figure 5: Design loading of the Steam nozzle in ANSYS

2.2.3 Stress evaluation for Level A conditions

The level A (operating) conditions were also gotten from the SSAR as 1,000psia and 284.40C[4]. Thermal gradient was first applied to the model by application of fluid temperature on the internal side and a perfect insulation on the outer side.

The thermally loaded model was imported into static structural, the internal pressure applied, and the wall stresses were applied. The changes in pressure changes the wall stresses in level A since using equations (1), the wall stresses become 44.55MPa. The model was then set as per Figure 6.

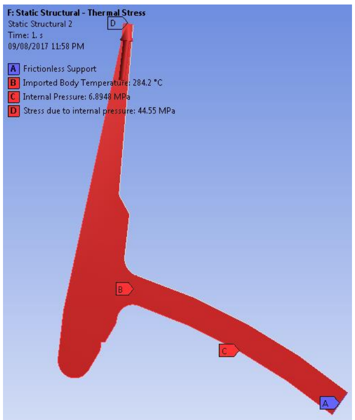

Figure 6: Steam nozzle Level A conditions loading

3. Results

3.1 Design conditions

The deformation on the nozzle is highest on the part that is inside the shell and towards the outer side of the nozzle.

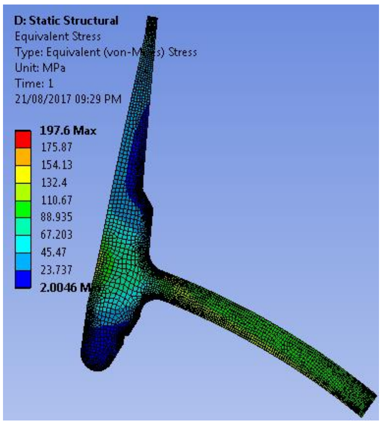

Figure 7: Equiv. stress distribution at design conditions

This though only indicates how the model points shift from the datum not due to stress as it is informed by the equivalent von misses stresses (Figure 7) and strains which shows the points to have the lowest stress and strain distribution. The stress intensity solutions for the paths were evaluated Figure 8 and results of the highest magnitude tabulated in Table 1.

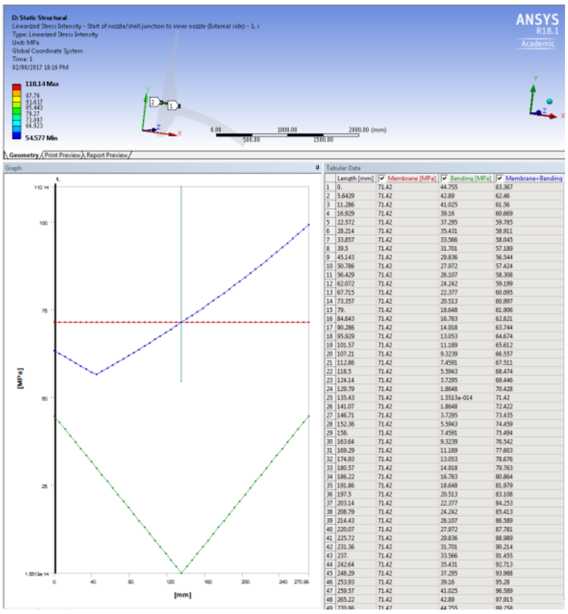

Figure 8: LSI on path 8 at design conditions

Table 1: Steam Nozzle Design conditions Stress Evaluations

Path	P_m	S_m	P_b	P_m+P_b	$1.5S_m$	Rem
1	107.89	184	10.92	118.80	276	Ok
2	114.33	184	13.57	127.89	276	Ok
3	120.96	184	10.55	122.44	276	Ok
4	72.14	184	106.27	154.40	276	Ok
5	51.25	184	90.34	109.56	276	Ok
6	99.21	184	72.83	150.42	276	Ok
7	73.35	184	42.48	104.19	276	Ok
8	98.86	184	75.59	125.89	276	Ok
9	81.68	184	57.12	119.56	276	Ok
10	93.63	184	73.96	131.24	276	Ok
11	77.29	184	43.66	103.67	276	Ok
12	83.90	184	52.40	107.88	276	Ok
13	49.30	184	27.08	73.74	276	Ok
14	21.88	184	9.22	31.05	276	Ok
15	49.16	184	10.93	58.62	276	Ok
16	53.46	184	13.96	66.83	276	Ok
17	60.36	184	8.86	69.10	276	Ok
18	27.12	184	14.02	40.71	276	Ok

The highest membrane stresses occur on the shell part increasing as you move away from the junction from 93.99MPa close to the junction to 107.44MPa at the extreme ends. This meets the code criterion that the general membrane stress be less than the stress intensity value which is 184MPa. The highest bending stresses occur at the junction of the nozzle and shell with a maximum value of 106.27MPa at the middle of the junction. For conformance to the code, the maximum general (local) membrane stresses plus bending stresses is 154.40MPa at the middle of nozzle and shell junction which is below $1.5S_m$ or 276MPa.

3.2 Level A conditions

The temperature distribution in all sections of the nozzle is uniform which leads to a near zero the heat flux distribution.

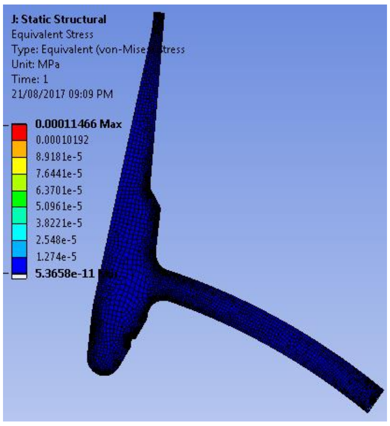

Figure 9: Equivalent stress distribution from thermal gradient

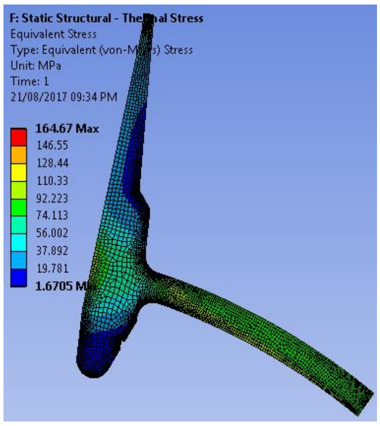

Figure 10: Equivalent stress distribution for full Level A conditions

The total deformation is highest towards the outlet tip of the nozzle but the Von-misses stresses (Figure 10) and strain levels are highest on the spherical shell side around the geometric discontinuity region. To evaluate further the linearized stress intensities were evaluated on the paths established in the methodology section and the results displayed as per Figure 11 and Table 2.

The highest membrane stresses still occur on the shell part increasing as you move away from the junction. It varies from 89.91MPa close to the junction to 100.80MPa at the extreme ends. This meets the ASME section III subsection NC-3217 (b) criterion where the highest membrane stress be less than the S_m value of

184MPa.

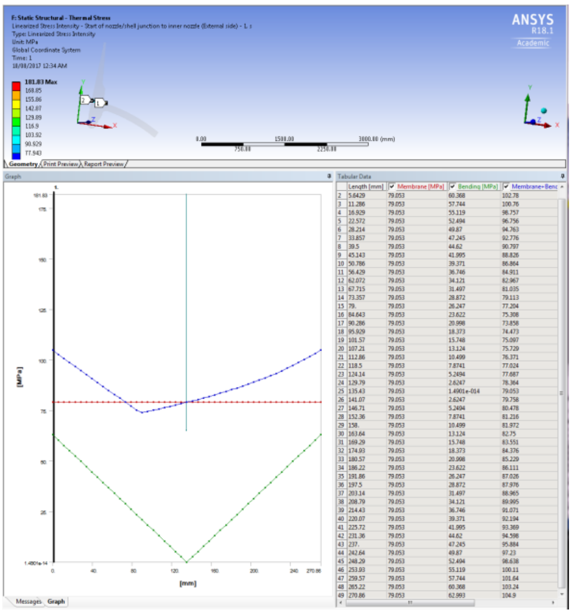

Figure 11: LSI on path 8 at Level A conditions

Table 2: Steam Nozzle Level A conditions Stress Evaluations

Path	P_m	S_m	P_b	$P_m + P_b + Q$	$3S_m$	Rem
1	89.91	184	9.10	99.00	552	ok
2	95.27	184	11.31	106.58	552	ok
3	100.80	184	8.79	102.03	552	ok
4	60.12	184	88.56	128.67	552	ok
5	42.71	184	75.28	91.30	552	ok
6	82.67	184	60.69	125.35	552	ok
7	61.11	184	35.40	86.83	552	ok
8	79.05	184	62.99	104.90	552	ok
9	68.06	184	47.06	99.63	552	ok
10	78.03	184	61.64	109.37	552	ok
11	64.41	184	36.38	86.40	552	ok
12	69.92	184	43.67	89.90	552	ok
13	41.08	184	22.56	61.45	552	ok
14	18.23	184	7.68	25.87	552	ok
15	40.97	184	9.11	48.85	552	ok
16	44.55	184	11.64	55.69	552	ok
17	50.30	184	7.38	57.59	552	ok
18	22.60	184	11.68	33.92	552	ok

The highest bending stresses occur at the junction of the nozzle and shell with a maximum value of 88.56MPa at the middle of the junction. For conformance to the code, the general (local) membrane stresses plus the bending stresses plus the thermal stresses is 128.67MPa at the middle of nozzle and shell junction which is below $3S_m$ which is the requirement of ASME section III subsection NC-3217.

4. Discussion and conclusion

The objective of this study was to evaluate the integrity of the APR1400 steam nozzle design based on the ASME section III division 1 subsection NC requirements for design and level A conditions. This ensures that the SG does not lose its integrity at the stated conditions. The model was set up as per the methodology in section 2, the results gotten and evaluated in section 0. It is worth noting that with higher temperatures, the stress magnitudes reduced. This is evident as the maximum P_m reduced from 107MPa to 100MPa, while the maximum $P_m + P_b$ reduced from 154.40MPa to 128.67MPa.

At design condition the maximum $P_m < S_m$ and maximum $P_m + P_b < 1.5S_m$, as seen in section 3.1 and displayed in Table 1, shows the nozzle conformance to the code as stated in paragraph NC-3217.

At the level A conditions, the maximum $P_m < S_m$ and maximum $P_m + P_b < 3S_m$, discussed in section 0 and presented in Table 2, shows conformance to the code as stated in paragraph NC-3217.

Acknowledgement

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5. References

[1] P. I. Namgung, “ASME Section III Design by Analysis - Lecture,” in *Lecture notes, Design by analysis*, KINGS, Ed. 2017.

[2] T. A. S. of M. Engineers, “Article NC-3000 Design,” in *ASME section III, Division 1*, ASME, Ed. ASME, 2010.

[3] T. A. S. of M. Engineers, “Mandatory Appendix XIII Article XIII-1000 Design based on stress analysis,” in *ASME section III, Division 1 - Appendices*, ASME, Ed. ASME, 2010.

[4] K. KEPCO, “Chapter 5 Reactor Coolant System and Connected Systems,” in *Standard safety analysis report (SSAR)*, 2011.