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ASME Code Stress Evaluation of Re-engineered Primary Inlet Nozzle of APR1400 Steam Generator

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1. Introduction

In this paper, a re-engineered APR1400 Sg primary side inlet nozzle stresses are evaluated according to ASME code. As part of NPP mechanical system education, re-engineering of NPP component are being created. This year APR1400 steam generator based solely on basic system parameter was created and carried out structural integrity according to ASME codes.

Introduction of nozzles in a component such as in a SG bottom head, introduces elevated stresses due to structural discontinuity. Such regions have to be analyzed to assure structural integrity will be maintained under various conditions. This paper presents an evaluation of stress levels and distribution in the primary inlet nozzle under design and normal operation conditions. The evaluation is carried out as per the criteria described in ASME (American Society of Mechanical Engineers) code Section III, Subsection NB-3200 (design by analysis) [1][4].

The material used to manufacture APR1400 Steam Generator is carbon steel SA-508, Grade 3, Class 2 and has with a nominal composition of $\frac{3}{4}Ni, \frac{1}{2}Mo, Cr, V$. The material design limits are tensile strength 550MPa and yield strength 345 MPa. The design stress intensity for the operation temperature of 343.3°C (650°F) is 184 MPa [4]. The design and operating pressure for the SG are 2500 and 2250 Psi [2].

APR1400 design uses two (2) wet type recirculation steam generator each with a capacity to convert 2000Mw-thermal from the core coolant to steam. Each SG has two outlet nozzles and one inlet nozzle located on its hemi-spherical lower head. The inlet nozzle has an internal diameter of 42-inch. Figure 1 is a pictorial view of SG lower head with nozzles attached.

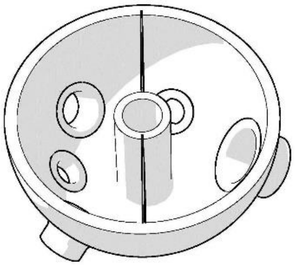

Figure 1. A view of the SG primary head

2. Loading conditions

The load conditions and limits are important to maintain public safety by preventing bursting failure (Design conditions); safe operation by preventing fatigue failure (operating conditions); and testing purposes (hydraulic, pneumatic, and leakage tests). The loading classification according to ASME code Section III, Subsection NB are shown in Table 1.

Table 1. Loading combination for ASME code class 1, 2, and 3 SSCs

Condition	Design Loading Combination
Design	Design Pressure (PD) + Dead weight (DW)
Level A (Normal)	Operating pressure (OD) + Dead weight (DW) + Thermal load
Level B (Upset)	Operating pressure (OD) + Dead weight (DW) +Thermal load
Level-C (Emergency)	Operating pressure (OD) + Dead weight (DW) + Dynamic system loading associated with emergency (DE)
Level D (Faulted)	Operating pressure (OD) + Dead weight (DW) + Dynamic system loading associated with pipe breaks (DF) + Safe shutdown earthquake (SSE)

In this analysis, only design condition and Level A conditions were considered. The condition for meeting ASME Section III, Subsection NB-3200.

The stress intensity limits that must be satisfied for design loadings are: [4]

(a) General primary membrane stress intensity

$$Pm < Sm.$$

(b) Primary membrane plus bending stress intensity

$$Pm + Pb < 1.5Sm$$

S_m is the material stress intensity.

$$(for\ SA - 508 = 184\ MPa).$$

Level A or normal operating conditions, the loading limits are.

(a) General primary membrane stress intensity

$$Pm < Sm.$$

(b) Primary membrane plus bending stress intensity

$$Pm + Pb < 3Sm$$

3. Methodology

The analysis method is axisymmetric since the cross-section of the inlet nozzle is symmetrical about the lower head surface. The analysis was carried out in two step; design condition, and level A condition. A 2-D axisymmetric model was created using ANSYS V.18.1 and analyzed for membrane, and bending stress using linearized stress analysis post-process option[1] [4].

Design condition

The steps for design condition are shown in Figure 2, which involved which are:

1. Created the model in ANYISIS 18.1[3]
2. Applied and refined mesh shown in Figure 4
3. Same linearized paths applied for both cases as shown in Figure 6.
4. Applied boundary conditions as shown in **오류! 참조 원본을 찾을 수 없습니다.**.
5. Setup mechanical solver and obtained solution

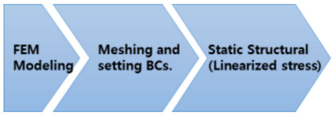

Figure 2. Design condition evaluation (ASME)

Level A condition

This involved thermal and structural analysis. Using the same model as above:

1. Applied thermal loads as shown in Figure 7
2. Solved for thermal stresses and imported the results to static structural
3. Applied boundary conditions for structural analysis
4. Solved for linearized stress intensities

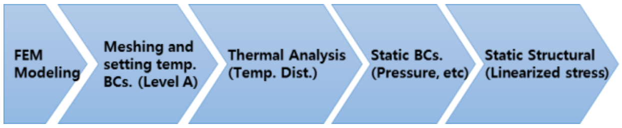

Figure 3. Level A condition evaluationNB-3210

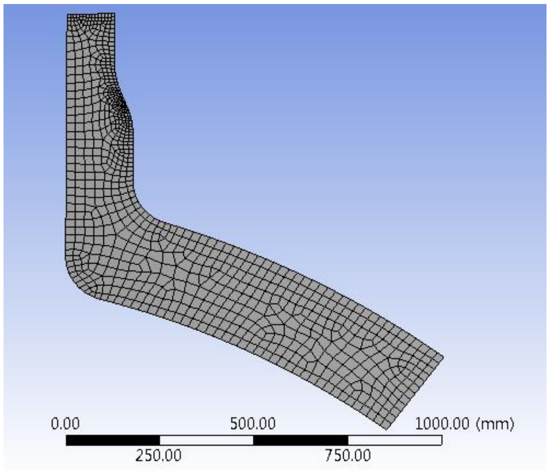

Figure 4. Meshed 2-D model of the inlet nozzle

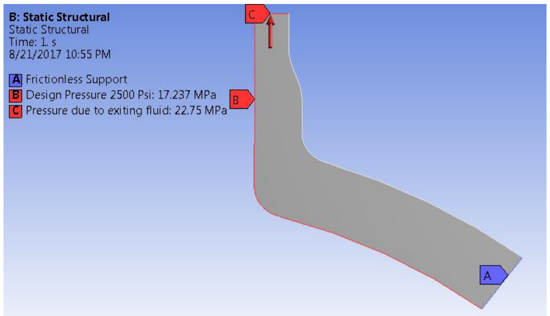

Figure 5. Boundary Conditions for design condition analysis

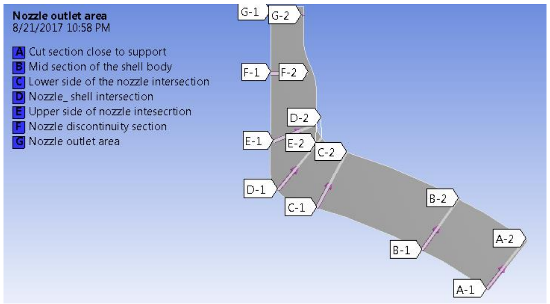

Figure 6. Linearized paths for Level A and Design condition analysis

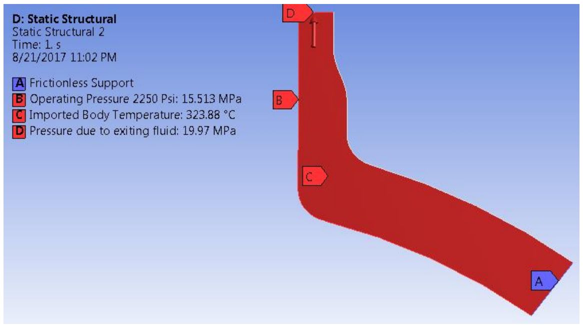

Figure 7. Boundary condition setup for Level A

4. Results

Stress intensities were analyzed along stress paths that are likely to have elevated stresses. The stress paths are shown in Figure 6.

Design condition

Results for equivalent stresses is shown in Figure 8. The stress distribution show that the stresses are highest (180.09 MPa) at the inner curved surface of the nozzle joint. Minimum stresses are at the nozzle outlet (46.38MPa). The maximum equivalent stress is below $276\ MPa = 1.5S_m$. The summary of the maximum stresses along the respective stress paths are shown in Table 2.

Table 2. Summary of linearized stresses for DC

Stress Path	P_L (MPa) Local Membrane	P_b (MPa) Bending	$P_L + P_b$	$1.5S_m$ (MPa)	$PL + Pb < 1.5S_m$ decision
A	97.67	21.99	114.48	276	Pass
B	104.12	16.54	118.17	276	Pass
C	128.70	39.09	138.15	276	Pass
D	138.29	64.23	184.22	276	Pass
E	127.56	44.21	156.37	276	Pass
F	87.07	27.63	111.83	276	Pass
G	69.77	14.92	84.68	276	Pass

From the results in Table 2, all the maximum stresses along the paths are below the required of $1.5S_m$ as required by ASME code.

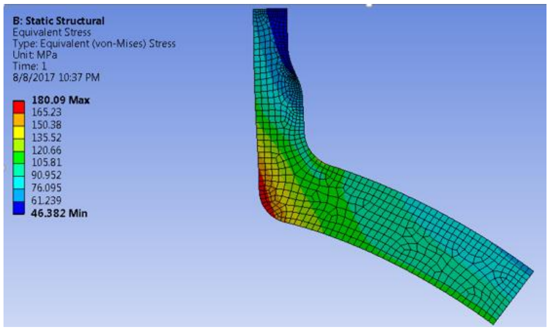

Figure 8. Equivalent Stress Distribution Design condition

The highest stresses (184.22 MPa) occurs along path D. This stress path is shown in Figure 9 and Figure 10

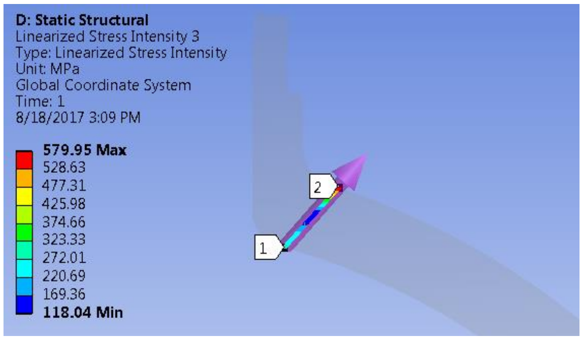

Figure 9. Stress distribution path D

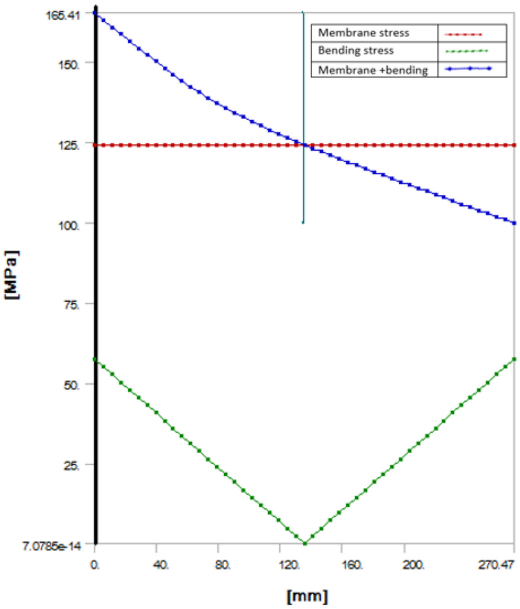

Figure 10. Graph for stress distribution along path D

Level A operating Conditions

The equivalent stress distribution for level A condition is shown in Figure 11. The distribution pattern is similar to the design case, but the stress values are lower due to lower operating pressure.

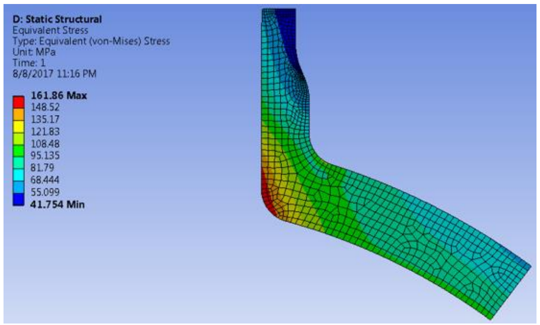

Figure 11. Equivalent stresses for operating condition

Results for the stress paths is shown in Table 3. The results shows that the stresses along the stress paths are within the acceptable range according to ASME code. The highest stresses, local membrane plus bending stress, occur on path D with is at the nozzle intersection as shown in Figure 12 and Figure 13 . The highest value of 165.41MPa occur at the inner wall. All the stresses are below $3S_m$ value of 552MPa.

Table 3. Summary of operating condition results

Path	P_L (MPa) Local Membrane	P_b (MPa) Bending	$P_L + P_b$	$1.5S_m$ (MPa)	$P_L+P_b < 1.5S_m$ decision
A	88.18	19.45	102.94	552	Pass
B	93.70	14.59	106.32	552	Pass
C	115.65	35.10	124.41	552	Pass
D	124.26	57.09	165.41	552	Pass
E	114.40	39.29	140.18	552	Pass
F	78.12	24.83	100.36	552	Pass
G	62.72	13.42	76.14	552	Pass

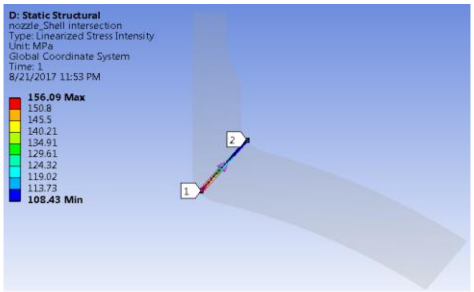

Figure 12. Stress condition along path D for Level.

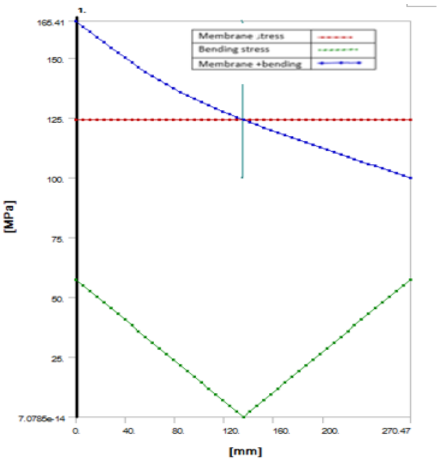

Figure 13. Graphical presentation of stresses along D

5. Conclusion

For the design condition case, the highest stresses occur at the nozzle intersection inner wall. However, the level of tresses obtained are lower than the SA-508 material limits prescribed in ASME code. Results for Level A also meets the ASME code criterial where the highest stresses should be less than $3S_m$ Based on the results, it can be concluded that the APR1400 SG primary inlet nozzle design meets the required design limits as per ASME code.

Acknowledgement

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6. References

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

[2] KHNP APR1400 SSAR, “Chapter 3 Design of Structures, Systems, Components, and Equipment,’”, 2011.

[3] I. Namgung, *ANSYS Workbook*. KINGS, 2016.

[4] ASME, BPVC Section III, Subsection NB-3200. 2015 ed. ASME 2015