Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 26-27, 2017

APR1400 SG Support Stress Evaluation According to ASME BPVC Section III subsection NB and NF

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1. Introduction

In APR1400 Nuclear Power Plant, Steam Generator (SG) forms reactor coolant system and maintains primary pressure boundary. The SG support is a conical type sliding skirt that supports all weight of SG and maintain RCS topology during all operating condition. The integrity of SG support is important to prevent breach of pressure boundary that may results in release of radioactive coolant to the environment. Hence rigorous stress analysis is required to ensure intactness of structure for all operating condition. The SG support is welded into the primary head, hence the analysis model include support as well as part of primary head. The 2D axisymmetric model was created using ANSYS V.18.1 and analyzed for membrane and bending stress using linearized stress analysis post-process option. The resulting stresses for design and level A condition are within the allowable limits of ASME Section III, subsection NB and NF.

2. Methodology

2.2.1 Method

The analysis method is axisymmetric analysis since the cross section of the support is persistent around the central axis. In ANSYS, loading conditions are applied to the geometry, and relevant results are calculated by axisymmetric analysis. From the dimensions of the APR 1400 SG, we create the 2D model of the support in ANSYS. To setup the loads easily we create the 2D model with the primary head and the tube sheet as depicted in the Figure 1.

2.2.2 Requirements

The design limits are defined in ASME Section III Article NF-3000 Design [1]. The support is of class 1 and categorized as shell-type support and shall follow the "Design rules for plate- and shell-type supports" as stated in Article NF-3200. In accordance with Article NF-3220, the stress intensity limits that must be satisfied for design loadings are:

(a) General primary membrane stress intensity $P_m < S_m$.

(b) Primary membrane plus bending stress intensity $P_m + P_b < 1.5S_m$

Where S_m is material stress intensity. The material of the support is selected to be the same material with the steam generator shell, which is SA-508 Grade 3 Class 1. From ASME Section II Part D, the S_m value is found to be as the following Table 1 at design temperature [2].

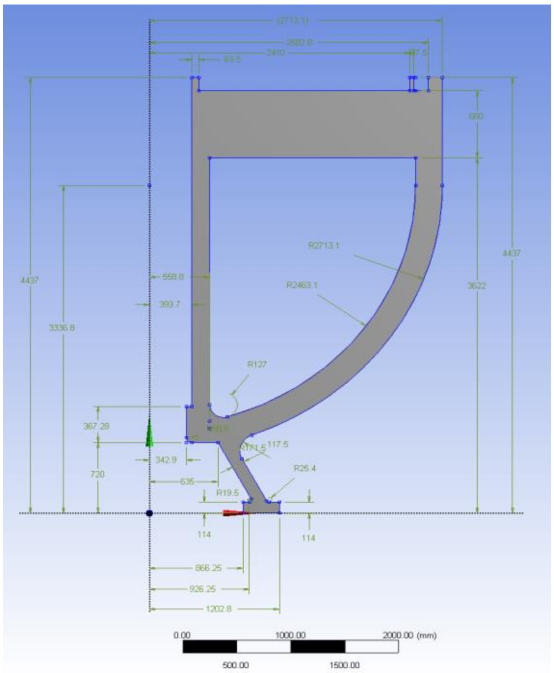

Figure 1 The sketch of the steam generator support

Table 1: Allowable stress intensity

Stress category	Allowable stress intensity (MPa):
S_m	184
1.5 S_m	276

In the level A, the load condition includes design pressure and dead weight of the steam generator. "The rules and stress limits which must be satisfied in an elastic analysis for any Level A Service Loadings stated in the Design Specification are those given in NF-3221.1 and NF-3223 multiplied by the appropriate stress intensity limit factor from Table NF-3221.2-1 for the particular loading and stress categories". As the table NF – 3221.2-1, the stress limit factor applicable to the design allowable membrane stress intensity or membrane plus bending stress intensity (K_{bk}, K_m) and stress limit factor applicable to the Design allowable shear stress (K_v) are 1.0. In the article NF – 3121.11, evaluation of thermal stresses in the support is not required [1].

2.2.3 Load calculation

a. The mass of the steam generator's parts

From the dimensions of APR1400 steam generator, we do the model of SG so we have the estimated mass of the parts as the following table:

Table 2: The mass of the steam generator's parts

No	Description	values	unit
1	Shell weight	555,451.60	kg
2	Tube sheet and tube bundle	362,903.65	kg
3	Shroud and other on top	59,817.41	kg
4	Mass of water	110,311.70	kg

b. Load combinations

* Design limits [3]:

Design limits include design pressure and dead weight of the components:

Table 3 The design limits

No	Description	Value	unit
	Primary side		
1	Design pressure	2500	Psi
2	Design temperature	650	ºF
	Secondary side		
3	Design pressure	1200	Psi
4	Design temperature	570	ºF
	The loads		
5	Load cause by the shell weight	2.56	Mpa
6	Load cause by the inside pressure	66.65	Mpa
7	Load on shroud	1.24	Mpa
8	Load on tube sheet	0.199715	Mpa
9	Load cause by the weight of water	0.052637	Mpa

* Level A service limits: [3]

Level A service limit is in normal operation of the plant which includes operating pressure and dead weight of the components.

Table 4 the level A service limits

No	Description	Value	unit
	Primary side		
1	Operating pressure	2250	Psi
2	Coolant inlet temperature	615	ºF
3	Coolant outlet temperature	555	ºF
	Secondary side		
4	Steam pressure	1000	Psi
5	Steam temperature	543.6	ºF
	Loads	As design limits	

3. Results

3.1 Results for the design limits

In mechanical, the model mesh was optimized through edge sizing, number of division type of mesh which depended on the sensitivity of the edge and the bias adjusted accordingly. All the edges were adjusted as depicted in Figure 2.

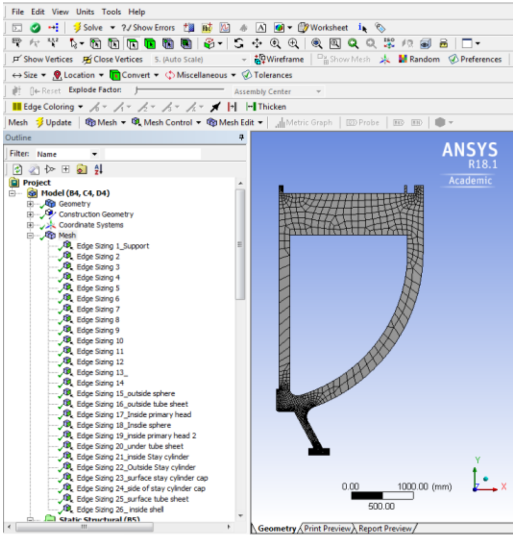

Figure 2 Mesh generation for the support

To enable the evaluation of the linearized stress intensity at various locations in the support, including the primary general membrane stress intensity, primary local membrane stress intensity, and bending stresses, paths were created in various locations of interest as Figure 3 to elaborately evaluate every portion of the support especially the discontinuity regions.

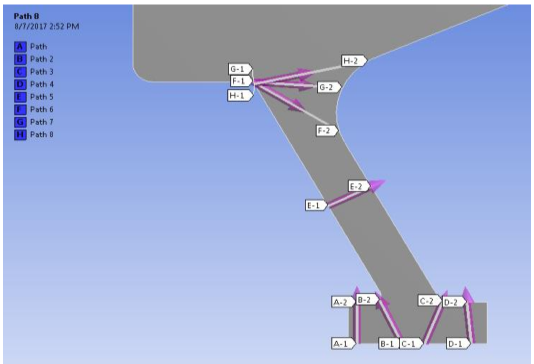

Figure 3: The paths to analysis the stresses

The load combination was applied on the cross section as Table 3 and a frictionless support applied to the support since it is a cut region as depicted in Figure 4. The model was then evaluated for total deformation (Figure 6); equivalent stress (Figure 5); equivalent strains; and linearized stress intensity (Figure 7, Figure 8 and Table 5).

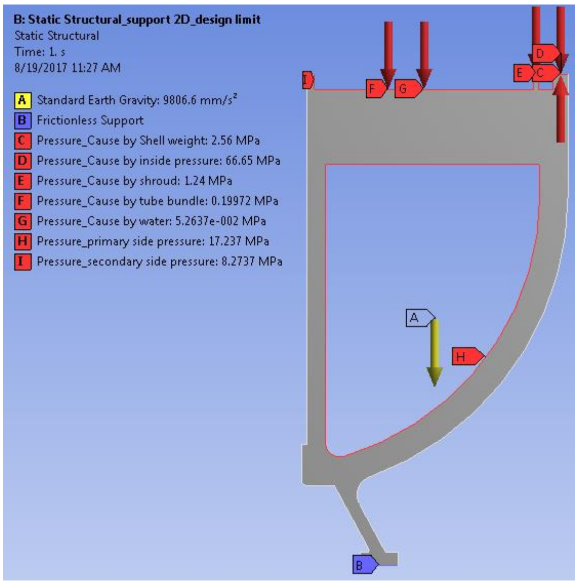

Figure 4 Load combination for design limits

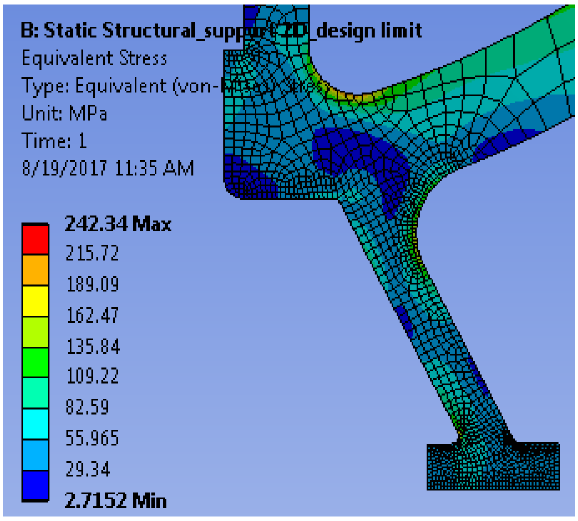

Figure 5 Equivalent stress of the support

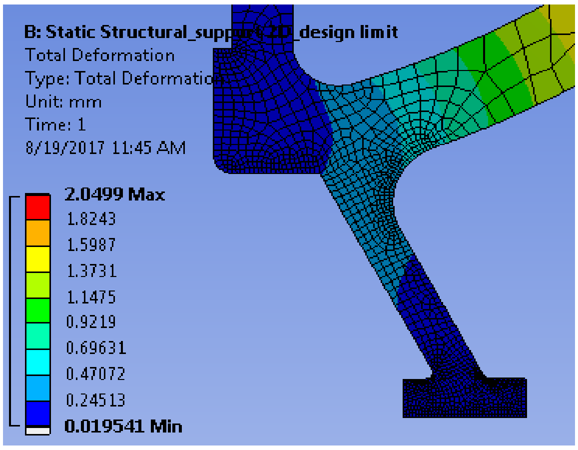

Figure 6 Total deformation

From the paths, we have the maximum bending, membrane stress as Table 5 then compare with the allowable stress intensity of the material S_m.

Table 5: Stress intensity analysis for design limit

Stress path	P_m MPa	P_m (or P_L) + P_b MPa	S_m MPa	$1.5S_m$ MPa
1 (A1-A2)	48.7	52.3	184	276
2 (B1-B2)	76.9	96.8	184	276
3 (C1-C2)	42.7	51.2	184	276
4 (D1-D2)	34.0	34.3	184	276
5 (E1-E2)	54.0	75.7	184	276
6 (F1-F2)	40.3	125.0	184	276
7 (G1-G2)	17.2	110.7	184	276
8 (H1-H2)	27.9	103.9	184	276

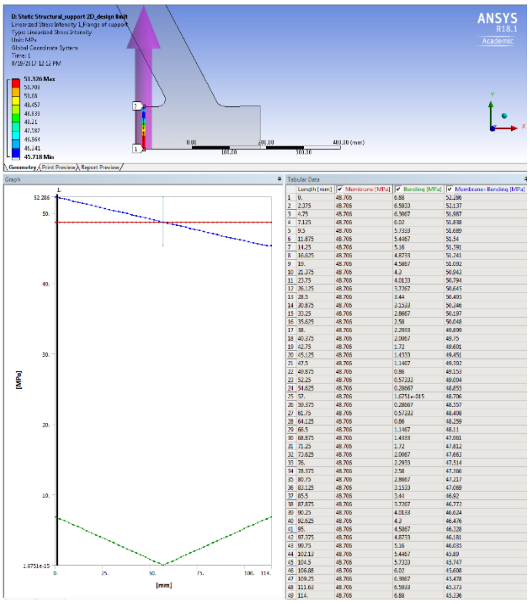

Figure 7 Linearized stress intensity on path 1

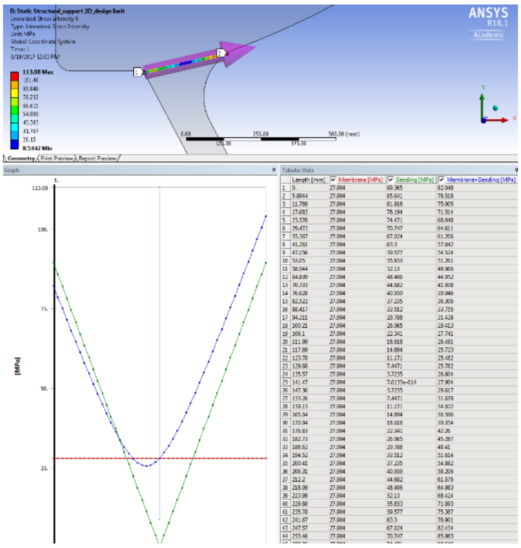

Figure 8 Linearized stress intensity on path 8

Following the path 1st, 4th and path 5th, the membrane stresses is the primary membrane stress (continuous position). In the path 2nd, 3rd, 6th, 7th, and 8th are in the discontinuous positions so the membrane stresses are the local membrane stress. In the support, the stresses of path 8th are largest. From Table 5, the support stress intensities are well below the limits provided by the design criteria in ASME BPVC code section III division 1 NF-3221.1 and NF-3223.

3.2 Results for the Level A limits

The load combination was applied on the cross section as Table 4 and a frictionless support applied to the support as Figure 9. Equivalent stresses are shown in Figure 10, and Linearized stress results of path 8 are shown in Figure 11.

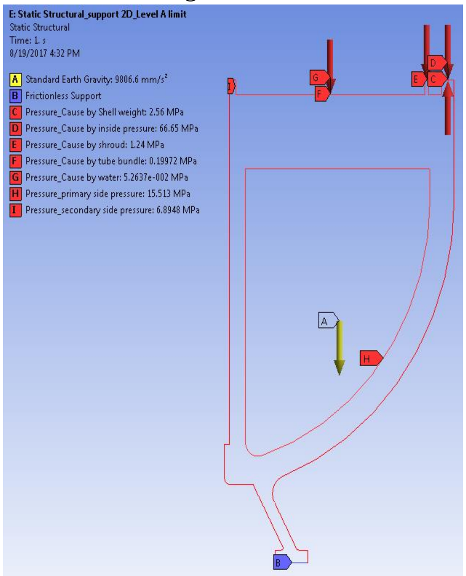

Figure 9 Load combination for level A

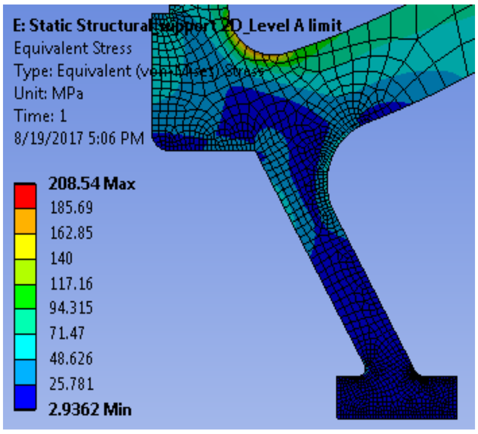

Figure 10 Equivalent stress for level A limits

Table 6 Stress intensity analysis for level A limits

Stress path	P_m MPa	P_m (or P_L) + P_b MPa	S_m MPa	$1.5S_m$ MPa
1 (A1-A2)	5.3	6.3	184	276
2 (B1-B2)	11.2	16.6	184	276
3 (C1-C2)	4.1	5.5	184	276
4 (D1-D2)	3.4	3.6	184	276
5 (E1-E2)	15.6	18.7	184	276
6 (F1-F2)	14.1	49.7	184	276
7 (G1-G2)	15.3	57.6	184	276
8 (H1-H2)	18.5	44.7	184	276

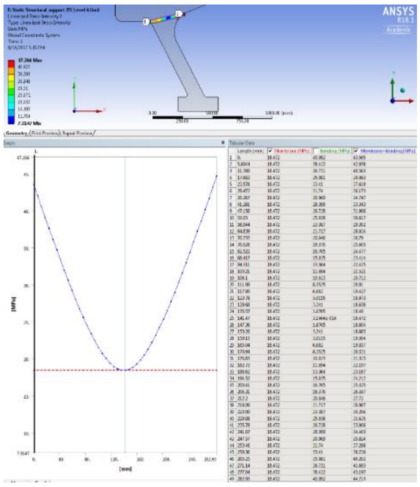

Figure 11 Linearized stress on path 8

From the results in Table 6, the support stress intensities at level A conditions are well below the limits provided by the design criteria in ASME code.

4. Conclusion

In this study, the shell-type support system was re-evaluated in term of stress analysis. The stress condition in support shows that the current support can satisfy the requirements. The stresses are significantly lower than the limit stress, which indicates that the support can subject the loadings, weight of the steam generator in the safe operation. A design for steam generator support had evaluated and analyzed by FEA method using ANSYS Workbench. The static structural analysis was conducted for some cases in some different positions. The analysis result was compared with ASME code limits to show that it follows the requirements. The report has verified the support's stress. Although the study is limited at this point, further considerations are recommended to evaluate more detailed conditions.

Acknowledgement

This research was supported by the 2017 Research Fund of the KEPCO International Nuclear Graduate School (KINGS), Republic of Korea.

5. References

[1] T. A. S. of M. Engineers, "ASME section III, D1 NF-3000," 2015.

[2] T. A. S. of M. Engineers, *ASME Boiler & Pressure Vessel Code - Section II Part D-2007*. Three Park Avenue, New York, NY 10016-5990, 2007.

[3] K. KEPCO, "APR1400 SSAR -Ch5 . Reactor Coolant System and Connected Systems," 2011.