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Fatigue Analysis of Tubesheet/Shell Juncture Applying the Mitigation Factor for Over-conservatism

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1. Introduction

If the environmental fatigue requirements are applied to the primary components of a nuclear power plant, to which the present ASME Code fatigue curves are applied, some locations with high level CUF (Cumulative Usage Factor) are anticipated not to meet the code criteria. The application of environmental fatigue damage is still particularly controversial for plants with 60-year design lives. Therefore, it is need to develop a detailed fatigue analysis procedure to identify the conservatisms in the procedure and to lower the cumulative usage factor [1].

Several factors are being considered to mitigate the conservatism such as three-dimensional finite element modeling. In the present analysis, actual pressure transient data instead of conservative maximum and minimum pressure data was applied as one of mitigation factors. Unlike in the general method, individual transient events were considered instead of the grouped transient events. The tubesheet/shell juncture in the steam generator assembly is the one of the weak locations and was, therefore, selected as a target to evaluate the mitigation factor in the present analysis.

2. Numerical Model and Analysis Method

The Finite Element Method is used to analyze the fatigue on a tubesheet/shell juncture in the steam generator assembly by ANSYS. The model used is based on a simplified axially symmetric substructure consisting of the lower secondary shell, tubesheet, and primary head. The geometry of the analysis model is shown in Fig. 1.

Because of the complicated multi-perforated region

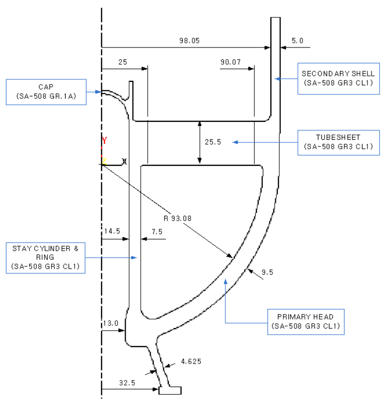

Fig. 1 Geometry of the tubesheet/shell juncture

of the tubesheet, two-dimensional finite element modeling was used. Plane 55 and Plane 42 elements were used for the two-dimensional thermal and stress analyses, respectively. In modeling the secondary shell, it has to be long enough so that length has no influence on the analysis results. The minimum length is calculated by the following Eq. (1) and a secondary shell was modeled that was 53 inches long.

$$L_{\min}=\frac{3}{\beta}, \qquad \beta=\sqrt[4]{\frac{3(1-\upsilon^2)}{R^2t^2}} \tag{1}$$

$$Blow-off\ Load=-\frac{(\pi r_i^2 P_D)}{\pi(r_o^2-r_i^2)} \tag{2}$$

The temperature distribution of the tubesheet, secondary shell and adjacent structure is not axisymmetric, so only a hot leg side is considered since it is more conservative than a cold leg side in the execution of thermal analysis. In addition, blow-off loads caused by the applied pressure in the each transient condition were considered at the end of the secondary shell in the stress analysis. The blow-off load was obtained from Eq. (2)

The distinctive feature of the model is that it represents the multi-perforated region of the tubesheet that includes the transition zone between the perforated region and the solid region. A method to calculate the stress intensities of the tubesheet from the equivalent solid plate stresses is provided in the ASME Code Sec. Ⅲ App. A-8000 [2]. The effective Young's modulus and Poisson's ratio are calculated by Fig. A-8131-1 in the ASME Code A-8000 and are used in the stress analysis. The values of the effective Young's modulus and Poisson's ratio are 0.17×E and 0.44, respectively. The pressure, temperature, load, and operating transient conditions in the Shin-Kori # 3,4 design specification [3] are applied to the analysis.

With thermal and stress analysis results, a fatigue analysis is executed according to the ASME code Section Ⅲ NB-3200[2] using ANSYS and FACAL programs.

3. Analysis Results

Fig. 2 shows one of the temperature distributions for the heat-up transient condition obtained from the thermal analysis. The point of time is when the temperature gradient reaches its maximum value.

Stress intensity distributions in which the maximum and minimum differential pressures were applied at the above time of thermal analysis for the heat-up transient condition, are shown in Fig. 3. The actual differential pressure at this analysis time was applied, and the stress intensity distributions are represented in Fig. 4.

Cut locations were selected for fatigue analysis and represented in Fig. 5 with the finite element model, and fatigue analysis was conducted at those locations. With the results of stress intensity using ANSYS, alternating stress intensity reflecting the elastic modulus ratio and Ke factor was calculated in the FACAL program. The usage factors were calculated for the each event-substep combination and were then finally summed up. The cumulative usage factors for each case are listed in Table I. The maximum CUF was at the bottom of the juncture between the tubesheet and secondary shell for both cases. Those values are less than 1.0. At all locations, CUFs from actual differential pressure data (Case 1) were less than those from the maximum and minimum differential pressure data (Case 2).

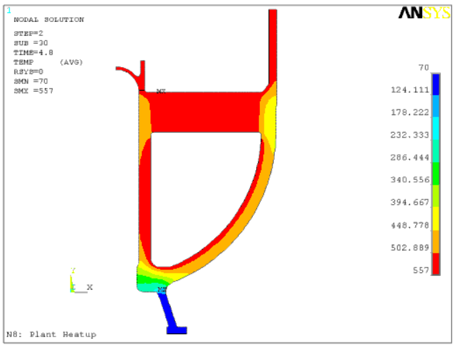

Fig. 2 Temperature distributions

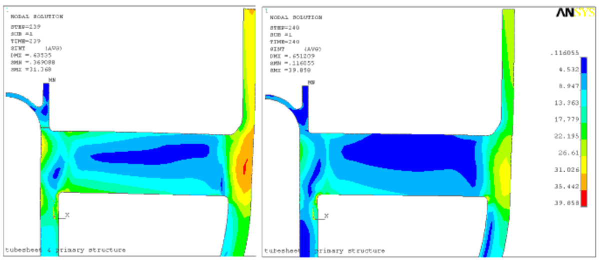

Fig. 3 Stress intensity distributions (left: maximum differential pressure, right: minimum differential pressure)

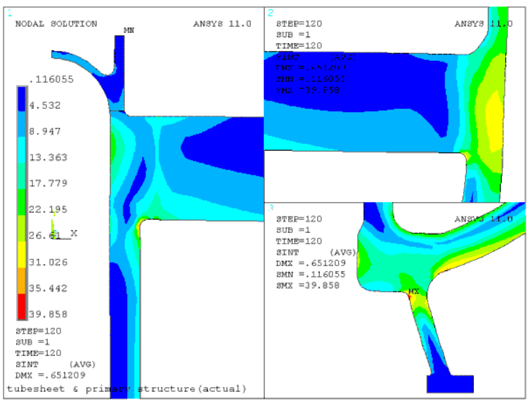

Fig. 4 Stress intensity distributions (actual differential pressure)

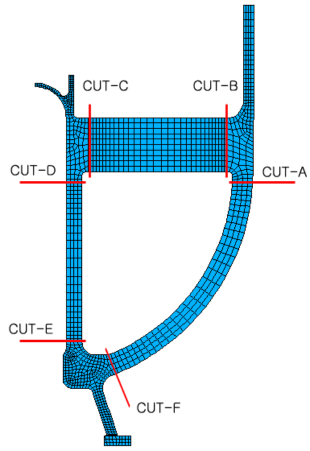

Fig. 5 Finite element model and cut locations for fatigue analysis

Table Ⅰ: Fatigue analysis results (CUFs)

Cut ID	locations	Case 1	Case 2	Case2/Case1 (%)
CUT-A	Inside	0.0278	0.0103	37.2
	Outside	0.0086	0.0037	43.0
CUT-B	Bottom	**0.1441**	**0.0436**	**30.3**
	Top	0.0385	0.0091	23.6
CUT-C	Bottom	0.0405	0.0083	20.5
	Top	0.0137	0.0134	97.8
CUT-D	Inside	0.0159	0.0034	21.4
	Outside	0.0026	0.0008	30.8
CUT-E	Inside	0.0558	0.0101	18.1
	Outside	0.0009	0.0008	88.9
CUT-F	Inside	0.0401	0.0208	51.9
	Outside	0.0152	0.0074	48.7

4. Conclusions

Fatigue analysis has been carried out for the tubesheet/shell juncture in the steam generator assembly by applying actual differential pressure data to mitigate the conservatism. It was found that using actual differential pressure data at the right analysis time is an effective mitigation factor through the results of the fatigue analysis.

REFERENCES

[1] KHNP, Development of the Optimized Fatigue Evaluation Technology to Verify 60 Years Design Life Time of the APR1400, Technical Memo TM.A06NS09.M2008.113, 2008.
[2] ASME, ASME Boiler and Pressure Vessel Code, Section Ⅲ, Rules for Construction of Nuclear Power Plant Component, 1998 Edition.
[3] KOPEC, Design Specification for Steam Generator Assembly for Shin-Kori 3 and 4, No.3L186-ME-DS265-00, Rev.4, 2008.