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3D Fatigue Analysis for the Steam Generator Economizer Feedwater Nozzle of the Advanced Reactor

Taesoon Kim,[a] Byongsup Kim,[a] Kwanghan Lee [b]
a Korea Hydro & Nuclear Power Co., 25-1 Jang-Dong, Yuseong-Gu, Daejeon, KOREA 305-343
E-mail : ktsoon@khnp.co.kr
b GNEC Professional Engineer's Office, 150 Dukjin-Dong, Yuseong-Gu, Daejeon, KOREA 305-353

1. Introduction

For the nuclear power plant with long lifetime more than 60 years, a fatigue is one of the failure mechanisms that have to very importantly consider in the design step. Fatigue analysis procedure and standard fatigue design curve to meet the integrity of components is suggested in ASME code, which had to be performed at the design step. But as the plant life extension for operating power plants are being fast progressed in domestic and overseas nuclear plants, the fact which the existing ASME fatigue design curve can not consider fatigue effects sufficiently comes to the fore.

Therefore the fatigue integrity evaluation procedure for major components needs to be improved better than now by removing its conservatism and using more detailed analysis method. To find the technical solution for these problems, a number of researches and discussion are continued up to now [1,2].

In this study, we suggested the detailed fatigue analyses procedure to perform efficiently the three dimensional analysis for the fatigue-weakened components and the fatigue analysis for the steam generator economizer feedwater nozzle were performed to develop the optimized fatigue analysis procedure by removing conservative factors included in the existing fatigue integrity evaluation procedure.

2. Fatigue Analysis Procedures

According to the ASME code section III NB-3200, the First step of the fatigue analysis procedure is that we determine the stress differences, S and the alternating stress, S_a for each condition of normal operation. Next, the effects of local structural discontinuities shall be evaluated for all conditions using stress concentration factors determined from theoretical and experimental, or numerical stress analysis techniques. And we multiply S_{alt} by ratio of the modulus of elasticity given on the design fatigue curve to the value of the modulus of elasticity used in the analysis. If there are two or more types of stress cycle which produce significant stresses, their cumulative effect shall be evaluated as the cumulative fatigue usage factors.

In this study, the detailed fatigue analysis procedure using the three dimensional finite element modeling is developed as illustrated in Figure 1. First, thermal analysis for the global transients using ANSYS code is performed, and the target zones for fatigue analysis are selected from the results of thermal analysis because the thermal gradient of the zones are higher than other zones.

From the thermal distribution by thermal analysis and the applied pressure value by the design specification, the stress intensity is calculated for each transient. If the stress intensity is obtained for the global transient that will be occurred in the operation period, the alternating stress intensity S_{alt} for global transient and the frequencies for the life time is estimated by the Rain-flow method of ANSYS modules. Because the ANSYS module can not consider the ratio of the modulus of elasticity given on the design fatigue, we developed the FACAL code to calculate the ratio of the modulus of elasticity [3].

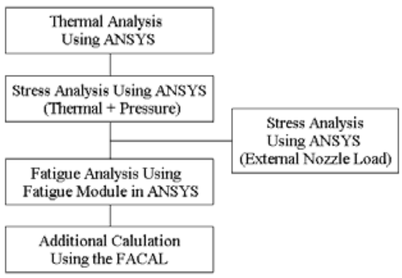

Figure 1. Procedure of the detailed fatigue analysis.

3. Fatigue Analysis for the steam generator economizer feedwater nozzle

As stated above, the purpose of this study is to develop the optimized fatigue analysis procedure which is removed its conservatism by using more detailed analysis method. In order to meet our goal, the steam generator economizer feedwater nozzle of the new advanced power reactor (APR1400) components is selected as the component for the sample problem.

Though the steam generator economizer feedwater nozzle is not the class 1 component to consider environmental effects, the fracture possibility is very high because its CUF value is larger than other components. The length of the shell and the safe end of the steam generator economizer feedwater nozzle used in this analysis is 30.0 in. and 15.0 in. respectively.

3.1 Analytical Conditions

In order to develop the analysis procedure which is removed its conservatism and has a detailed analysis method, the fatigue analysis conditions for the steam generator economizer feedwater nozzle are as shown in Table 1. In these conditions, the loading conditions such as transient, pressure and ultimate strength and the material conditions according to the 5 analytical cases are defined with the existing 2 dimensional method.

Table 1. Analytical conditions of S/G feedwater nozzle.

	Loading	Material of nozzle	S_m (ksi)	S-N Curve (ksi)
2-D	P_{max}, P_{min} at Max. Thermal Stress	SA508 Cl.1	30.0	UTS ≤ 80
CASE1	P_{max}, P_{min} of Transient	SA508 Cl.1	26.7	UTS ≤ 80
CASE2	P_{max}, P_{min} of Transient	SA508 Cl.2	30.0	UTS ≤ 80
CASE3	P_{max}, P_{min} of Transient	SA508 Cl.2	30.0	UTS = 90 (interpolated)
CASE4	P_{max}, P_{min} at Max. Thermal Stress	SA508 Cl.2	30.0	UTS ≤ 80
CASE5	P_{max}, P_{min} at Max. Thermal Stress	SA508 Cl.2	30.0	UTS = 90 (interpolated)

First of all, to analyze thermal stress applied on the economizer feedwater nozzle, the finite element model of the nozzle is modeled as shown in Figure 2. By symmetric condition, the 1/4 model of the nozzle is modeled with the SOLID70 elements which are composed of 7,548 elements and 9,548 nodes. Figure 3 shows the thermal distribution for the 'plant heat up transient at 4.87 hour' event resulted from thermal analysis of the economizer feedwater nozzle. And Figure 4 shows the distribution of the stress intensity for the 'plant heat up' event which is one of the main transients to affect the fatigue analysis results.

3.2 Results of Fatigue Analysis

Figure 5 presents the cut locations of the economizer feedwater nozzle which must be selected adequately by analyzing the thermal analysis results and performed the fatigue. For 5 different cases, the cumulative fatigue usage factors calculated at the cut locations of the economizer feedwater nozzle are listed in Table 2.

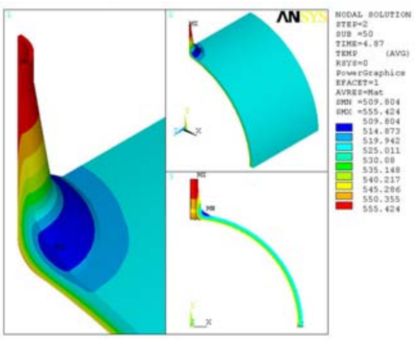

Figure 3. Thermal distribution of the economizer f/w nozzle.

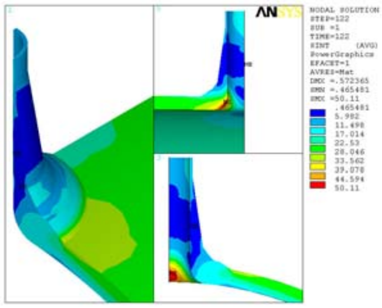

Figure 4. Stress distribution of CVCS charging nozzle.

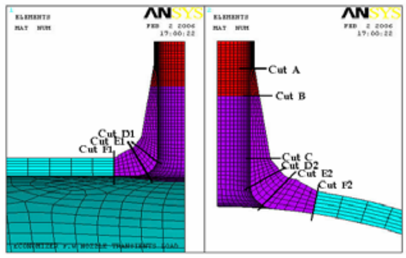

Figure 5. Cut location of the economizer f/w nozzle.

Table 2. Cumulative usage factors for 5 analytical cases at cut location of economizer f/w nozzle.

Cut	Cumulative Usage Factors (Inside)					
	2-D	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5
A	0.0132	0.0051	0.0076	0.0051	0.0071	0.0048
B	0.0156	0.0120	0.0201	0.0120	0.0186	0.0110
C	0.4319	0.1882	0.2186	0.1882	0.2117	0.1822
D1*	0.9675	2.7852	1.4967	1.4402	0.8789	0.7857
D2*	0.5587	0.5307	0.6511	0.5307	0.6116	0.4903
E1	0.9106	3.8524	1.9706	1.9442	0.9486	0.8594
E2	0.4710	0.3662	0.4867	0.3662	0.4713	0.3519
F1	0.0073	0.0526	0.0682	0.0526	0.0374	0.0272
F2	0.0059	0.0303	0.0408	0.0303	0.0217	0.0171

* 1 : Longitudinal section 2 : Transverse section

4. Conclusion

The detailed fatigue analyses procedure to perform efficiently the three dimensional analysis for the fatigue-weakened components has been suggested. By using the procedure, we have performed the fatigue analysis for the steam generator economizer feedwater nozzle and developed the optimized fatigue analysis procedure to remove conservative factors included in the existing fatigue integrity evaluation procedure.

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