Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, November 2-3, 2006

Development of the 3D Fatigue Analysis Procedure for APR1400 Major Components

Byongsup Kim, Taesoon Kim, Chankook Moon
Korea Hydro & Nuclear Power Co., 150 Dukjin-Dong, Yuseong-Gu, Daejeon, KOREA 305-353
E-mail : bskim@khnp.co.kr

1. Introduction

In the design of class 1 components to apply ASME code section III NB, a fatigue is considered as one of the important failure mechanisms. Fatigue analysis procedure and standard fatigue design curve(S-N curve) is suggested in ASME code, which had to be performed to meet the integrity of components at the design step [1]. As the plant life extension for operating power plants and the long-lived plant design, however, are being progressed, the fact which the existing ASME fatigue design curve can not consider fatigue effects sufficiently comes to the fore. To find the technical solution for these problems, a number of researches and discussion are continued up to now [2,3].

In this study, the detailed fatigue analyses using the 3 dimensional modeling for the fatigue-weakened components were performed to develop the optimized fatigue analysis procedure and their results are compared with other reference solutions.

2. Procedure of Fatigue Analysis

2.1 Fatigue Analysis by ASME Code

In ASME code section III NB-3200, fatigue analysis procedure is described as Figure 1.

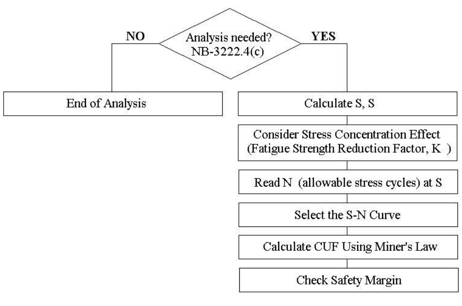

Figure 1. Procedure of ASME fatigue analysis.

First of all, 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 the applicable design fatigue curves for the given materials must be selected among the curves of Figure I-9-0 of ASME Section III App. I. In the next step, 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 [1].

If there are two or more types of stress cycle which produce significant stresses, their cumulative effect shall be evaluated, and the cumulative fatigue usage factors (CUF), U are presented as the Equation (1). Here the cumulative fatigue usage factor U shall not exceed 1.0.

$$U = \sum_{i=1}^{k} U_i \tag{1}$$

2.2 Detailed Fatigue Analysis

In this study, the detailed fatigue analysis procedure using the three dimensional finite element modeling is developed as stipulated in next steps below. 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.

By the way, as the ANSYS module can not consider the ratio of the modulus of elasticity given on the design fatigue curve to the value of the modulus of elasticity used in the analysis, we developed the FACAL code that is composed of FORTRAN programming language and can calculate the ratio of the modulus of elasticity and the cumulative fatigue usage factors [4]. The fatigue analysis procedure developed in this study is presented briefly in Figure 2.

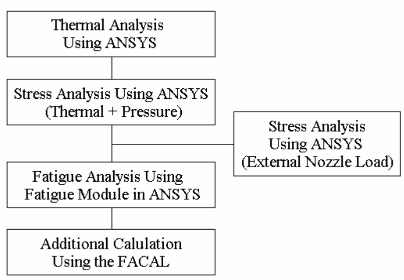

Figure 2. Fatigue analysis using ANSYS and FACAL code.

3. Fatigue Analysis

In order to perform the sample fatigue analysis, the chemical volume and control system (CVCS) charging inlet nozzle of the new advanced power reactor (APR1400) components is selected as the target. The inner diameter of the charging inlet nozzle is 30.0 in. and the inner diameter of the nozzle connected to the cold leg 2.0 in.

3.1 Thermal Analysis

For the thermal analysis for the charging inlet nozzle, the outer surface of the nozzle and pipe are assumed as the insulation material for a perfect adiabatic condition. And by symmetric condition, the 1/4 model of the component is modeled with the SOLID70 elements. Figure 3 shows the thermal distribution for the 'NSSS operation with the control system in the manual mode at 5-100' event resulted from thermal analysis of CVCS charging nozzle.

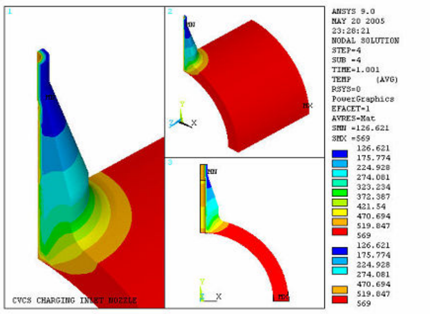

Figure 3. Thermal distribution of CVCS charging nozzle.

3.2 Stress Analysis

The model to analyze the stress intensity is composed of 34,464 nodes and 36,970 elements and the element type is the SOLID45 element which is the 3D structural solid element type and has 4 nodes. To consider the feature of deformational behavior, the longitudinal (z-directional) displacement of the nozzle center and the transverse (x-directional) displacement are constrained.

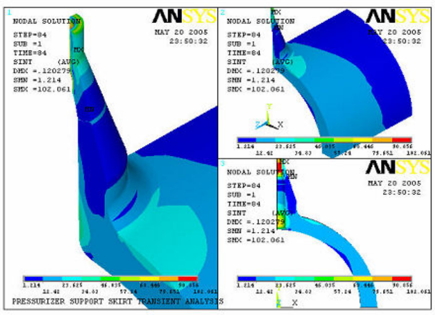

Figure 4. Stress distribution of CVCS charging nozzle.

And the y-directional displacement of the center surface is constrained by the symmetric boundary condition. Figure 4 shows the distribution of the stress intensity for the 'NSSS operation with the control system in the manual mode at 5-100' event which is one of the main transients to affect the fatigue analysis results.

3.3 Fatigue Analysis

To perform the fatigue analysis for the charging inlet nozzle, the fatigue-weakened location must be selected adequately by analyzing the thermal analysis results. The cumulative fatigue usage factors calculated at cut locations of the charging nozzle are compared with the reference results as shown in Figure 5.

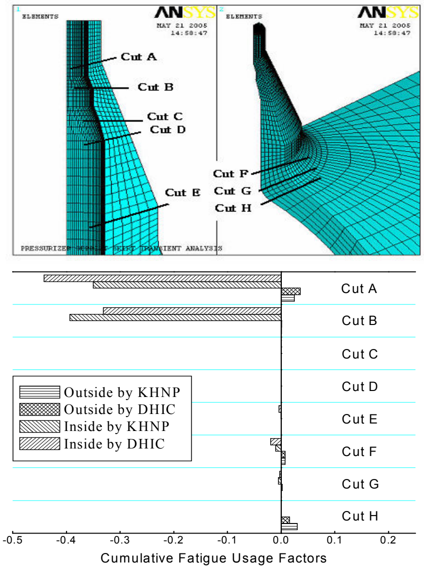

Figure 5. Cumulative fatigue usage factors at cut location of CVCS charging nozzle.

4. Conclusion

Based on 3D finite element modeling, the fatigue analysis for CVCS charging inlet nozzle of APR1400 components are performed to define the conservatism of fatigue analysis procedure and to produce the detailed fatigue analysis method. And the cumulative fatigue usage factors calculated by the detailed fatigue procedure are compared with the reference results.

REFERENCES

[1] ASME, ASME B&PV Code, Section III, "Rules for Construction of Nuclear Power Plant Component," 1998 Edition with 1998 Addenda in Effect as of Dec. 31.

[2] O. K. Chopra and W. J. Shack, "Low-cycle Fatigue of Piping and Pressure Vessel Steels in LWR Environments," Nuclear Engineering and Design, Vol. 184, pp. 49-76. 1998.

[3] NRC, "Application of NUREG/CR-5999 Interim Fatigue Curves to Selected Nuclear Power Plant Components," NUREG/CR-6260. 1995.

[4] R. E. Peterson, "Stress Concentration Design Factors," John Willey and Sons Inc. 1974.