Optimum Finite Element Mesh to Include Stress Concentration Effect in Fatigue Analysis

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1. Introduction

USNRC Regulatory Guide 1.207 issued in 2007 specifies a new procedure for fatigue analysis to consider the effects of the reactor coolant environment on the fatigue life of the primary components of the nuclear power plant. If these environmental fatigue requirements are applied to the primary components of the nuclear power plant, some locations having high cumulative fatigue usage factors (CUFs) are anticipated to violate the NRC criteria. To solve this problem, a broad research was performed to calculate more realistic CUFs by developing optimized procedures. As a portion of this research, the effect of mesh density is evaluated using various element mesh sizes, and the possible conservatism of stress concentration factors (SCFs) applied in the finite element analysis (FEA) is investigated through the analysis of Primary Piping Charging Inlet Nozzle (CI Nozzle).

2. Analysis Methodology

2.1 Fatigue Analysis Procedure

Fatigue analysis of Class 1 components is performed in accordance with ASME Section III NB-3222.4. According to these requirements, the effects of local structural discontinuities should be evaluated for all conditions using SCFs determined by theoretical and experimental studies, or numerical stress analysis techniques [1]. The SCF is multiplied to the membrane plus bending stress to get the total stress.

Hechmer says the FEA method is included in the numerical techniques, and if FEA is used the SCFs are automatically included in the results if an adequately refined modeling is used [2]. But the analysts usually apply SCFs in the FEA fatigue analysis because there is no specific standard or guideline for the degree of mesh refinement to get stresses accurate enough not to apply theoretical SCFs.

When we consider the powerful computing systems of today we can try to use very refined models even in a three-dimensional analysis and neglect the theoretical SCFs if we can verify the accuracy of the analysis.

2.2 Finite Element Analysis

Fig. 1 shows the three-dimensional finite element model of the CI Nozzle used for fatigue analysis.

As shown in Fig. 2, the stress concentration occurs at outside of Cut-A and E, inside of Cut-B, C and D due to geometrical discontinuity. Therefore, SCFs are usually considered in fatigue analysis for these locations. In this study, the analysis is performed with various finite element mesh sizes as shown in Fig. 3. Table 1 summarizes the number of elements for each model.

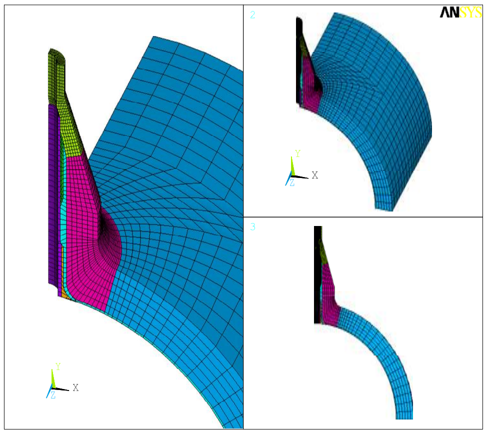


Fig.1 3D FE Model of the Charging Inlet nozzle

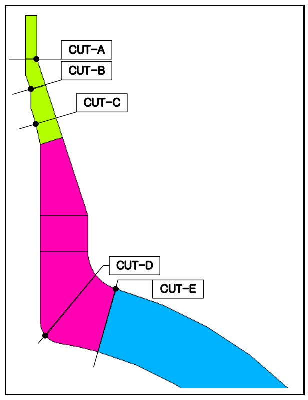


Fig. 2 Location of Evaluation Section

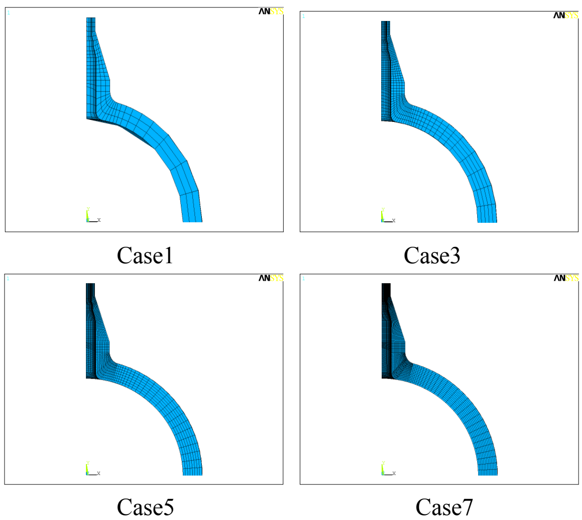


Fig.3 Finite Element Model of sample Cases

Table 1 Element Parameters for Each Case

Case	T	L	C	E	N
Case1	3	31	4	435	748
Case2	4	51	8	1952	2800
Case3	5	65	12	4445	5874
Case4	6	82	16	9432	11837
Case5	8	102	20	18888	22545
Case6	10	122	24	33120	38291
Case7	12	142	28	54096	61165
Case8	16	466	32	106560	117453

T: Number of Elements in Thickness direction (X-axis)
L: Number of Elements in Longitudinal direction (Y-axis)
C: Number of Elements in Circumferential direction (Z-axis)
E: Total Number of Elements, N: Total Number of Nodes

2.3 Stress Concentration Factor

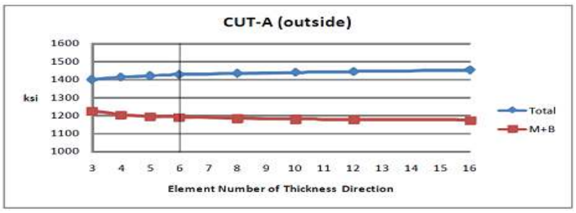
The theoretical SCF is calculated, for example, by using Equation (6.22) in reference [3]. The SCFs by the FEA can be defined as the ratio of the total stress and the membrane plus bending stress. Table 2 shows comparison of the theoretical SCFs obtained from domestic "A" plant [4] and the SCFs by FEA obtained from the results of Case 8. Even though Cut-A shows increased value, all the other cuts show decreased values, which means we can reduce the conservatism included in applying theoretical SCFs to the local membrane plus bending stress obtained by FEA.

Fig. 4 shows stress analysis results for Cut-A, C and E locations expressed as the functions of the number of elements in thickness direction. The results show that when the number of elements goes over six the total stress tends to increase and converge to a certain value while the membrane plus bending stress remains almost constant. Cut-B shows similar variation as Cut-C.

Based on these stress analysis results, we judged that six to eight elements through the thickness without applying SCFs and four to five elements through the thickness with applying SCFs will result in reasonably accurate stresses and CUFs.

Table 2 Comparison of SCFs

Location	Theoretical SCF(a)	SCF by FEA(b)	Ratio (b/a)
Cut-A Outside	1.142	1.237	1.08
Cut-B Inside	1.379	1.177	0.85
Cut-C Inside	1.411	1.127	0.80
Cut-E Outside	1.730	1.265	0.73



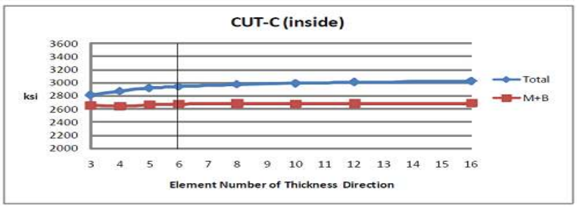


Fig. 4 Stress Analysis Results

3. Fatigue Analysis Results

The fatigue evaluation with SCFs applied in domestic "A" Plant was performed using four to six elements through the thickness and that without SCFs was performed using the case 4 model having six elements in the thickness direction.

Table 3 shows the comparison of CUFs with SCFs and without SCFs at cuts A, B, C, D and E locations. As shown, the CUFs without SCFs are much smaller than CUFs with SCFs.

Table 3 Comparison of CUFs

Cut ID	Inside		Outside		Inside	Outside
	U	C4	U	C4	C4/U (%)	C4/U (%)
A	**0.4418**	**0.1970**	**0.0305**	**0.0097**	44.6	31.8
B	0.3316	0.2746	0.0005	0.0024	82.8	480.0
C	0.0001	0.0000	0.0000	0.0000	0.0	-
D	0.0033	0.0036	0.0017	0.0000	109.1	0.0
E	0.0000	0.0000	0.0153	0.0000	-	0.0

U: CUFs with theoretical SCFs, from domestic "A" plant report [4]
C4: CUFs without SCFs using Case4 model

4. Conclusion

In the fatigue analysis using the FEA method, the stress concentration factor can yield over-conservative results when applied to a finite element model with relatively refined mesh. It is appropriate that fatigue analysis is performed using four to five elements through the thickness when SCFs are applied. It seems conservative to use more than five elements through the thickness with SCFs. We need to use six to eight elements through the thickness as minimum to get reasonably accurate CUFs without applying the theoretical SCFs.

REFERENCES

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[4] Structural and Fatigue Analysis of the Charging Inlet Nozzle, Calculation No. UE-241CN-206, Rev.01, 2000, Hanjung