Comparison of Fatigue Evaluation Based on ASME and RCC-M Codes for Branch Nozzles

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1. Introduction

Fatigue evaluations were performed to assure structural integrity for Code Class 1 piping according to ASME Code NB-3600 or RCC-M Code B-3000. Due to the differences between ASME and RCC-M Codes requirements related with fatigue evaluation, the different results were obtained according to the Code applied.

In this paper, the cumulative usage factors(CUF) were calculated based on ASME Code[1] and RCC-M Code[2] for 3 nozzle geometries attached to main coolant loop piping and the conservatism of the results of RCC-M Code was discussed.

2-1. General Requirements for Fatigue Evaluation

Normally, the Code Class 1 piping is evaluated with ASME NB-3600 or RCC-M B-3600.

The fatigue evaluation was performed following the procedure given in the ASME Code Section III, NB-3600.

(1) The stress histories are calculated at structural locations subjected to applicable thermal loads from the transients. The stress peak and valley times are determined for each transient history, and associated temperature, pressure and piping loads are used as input to the fatigue usage factor calculation.

(2) The primary plus secondary stress intensity range(S_n) is calculated as defined for equation (10).

$$S_n = C_1 \frac{P_0 D_0}{2t} + C_2 \frac{D_0}{2I} M_i + C_3 E_{ab} |\alpha_a T_a - \alpha_b T_b| \le 3S_m$$

(ASME eq.10)

Where, All terms are the same as defined in Equation (10) of ASME NB-3653.1.

(3) The primary plus secondary stress intensity range(S_n) is compared to the limit of $3S_m$. If S_n exceeds $3S_m$, "Simplified Elastic-Plastic Discontinuity Analysis," as defined in NB-3653.6, must be considered to obtain the appropriate adjustment factor(K_e).

(4) The peak stress intensities, S_p, are calculated by using Equation (11) of NB-3653.2.

$$S_p = K_1 C_1 \frac{P_0 D_0}{2t} + K_2 C_2 \frac{D_0}{2I} M_i + \frac{1}{2(1-\nu)} K_3 E\alpha |\Delta T_1| + K_3 C_3 E_{ab} \times |\alpha_a T_a - \alpha_b T_b| + \frac{1}{1-\nu} E\alpha |\Delta T_2|$$

(ASME eq.11)

(5) The alternating stress intensity, S_{alt}, which is half of the peak stress intensity value for each stress cycle, is calculated by using equation (14) below.

$$S_{alt} = K_e \frac{S_p}{2}$$

(ASME eq. 14)

(6) Cumulative usage factors are calculated using the applicable design fatigue curve.

2-2. Differences between ASME and RCC-M Codes

RCC-M Code is similar to ASME Code in evaluating fatigue except for considering ΔT_1 term in calculating the primary plus secondary stress intensity range, different K_e factor and design fatigue curve.

(1) ΔT_1 Term In Primary Plus Secondary Stress Intensity Range

RCC-M B-3600 Equation (10) includes the absolute value of the range of the temperature difference between the outside and inside surfaces in addition to those of ASME NB-3600 Equation (10).

$$S_n = C_1 \frac{P_0 D_0}{2t} + C_2 \frac{D_0}{2I} M_i + C_3 E_{ab} |\alpha_a T_a - \alpha_b T_b| + \frac{1}{2(1-\nu)} K_3 E\alpha |\Delta T_1|$$

(RCC-M eq.10)

(2) K_e factor Calculation

In RCC-M Code, $S_{alt}(i,j)$ value corresponding to the fatigue pair shall be determined using two K_e factors; K_{e_mech} and K_{e_ther}. K_{e_mech} is an elastoplastic stress correction factor for the mechanical part and is related to the loads of mechanical origin comprising pressure, weight, earthquake(inertial and movement of anchors) as well as the effect of thermal expansion. K_{e_ther} is elastoplastic stress correction factor for the thermal part and is related to the loads of thermal origin comprising those of temperature gradients in the walls T_a-T_b, ΔT_1 and ΔT_2. See Equation 14 below.

$$S_{alt} = \frac{1}{2}\left\{ (K_{e\,mech})_{pq} (S_{p\,mech})_{ij} + (K_{e\,ther})_{pq} (S_{p\,ther})_{ij} \right\}$$

(RCC-M eq. 14)

(3) Design Fatigue Curve

In RCC-M fatigue evaluation, the usage factor shall be calculated from the design fatigue curve in Z I 9.0 in which the fatigue usage factor is considered equal to 0 if allowable cycles are greater than 10^6. However, design fatigue curve in ASME Code App.I provides applicable values up to 10^{11} cycles.

3. Fatigue Evaluation for Branch Nozzles

Three(3) finite element nozzle models(Nozzle A,B,C) attached to main coolant loop piping are generated to perform the fatigue evaluation based on the requirements of ASME and RCC-M Codes, respectively. Austenitic stainless steel material properties are applied to the models.

(1) Finite Element Model

The finite element model for fatigue evaluation is shown in Fig. 1 and thermal-structural analyses were performed by ANSYS[3]. Two locations at branch connection and junction were selected for evaluation.

(2) Fatigue Evaluation Results

The cumulative usage factors(CUF) obtained from nozzle A, B and C models are shown in Table 1 and Fig. 2.

From the results of the model analyses, CUFs calculated by RCC-M Code are usually more conservative than those by ASME Code due to different stress intensity ranges and K_e factors. The effect of ΔT_1 term in Equation 10 has significant influence on the conservative stress intensity ranges and K_e factors in RCC-M Code. The comparison of K_e factors is shown in Table 2.

RCC-M CUFs are bigger than those of ASME except that nozzle the B junction has opposite results due to the conservative ASME design fatigue curve.

4. Conclusions

Based on the comparative studies of different Code application for fatigue evaluation, ASME vs RCC-M Codes, it could be concluded as follows ;

1) Cumulative usage factors based on ASME Code are usually less conservative than RCC-M Code in fatigue evaluation.

2) ΔT_1 term in RCC-M Code equation (10) results in conservative stress intensity ranges and K_e factors.

3) RCC-M Code design fatigue curves are found to be less conservative than those of ASME Code.

REFERENCES

[1] ASME Boiler and Pressure Vessel code, Section III, NB-3600, 2000 Addendum.
[2] RCC-M code, Subsection B 3600, 2000.
[3] ANSYS User's Manual Ver.12.0.

Table 1 Comparison of cumulative usage factors according to the Codes

Nozzle	Location	CUF ASME Code	CUF RCC-M Code
A (3 inch)	Connection	0.0009	0.0030
	Junction	0.0004	0.0009
B (6 inch)	Connection	0.0062	0.0425
	Junction	0.0958	0.0470
C (14 inch)	Connection	0.1217	0.2815
	Junction	0.1234	0.1466

Table 2 Comparison of K_e factors (unit : ksi)

Nozzle	Location	ASME		RCC-M		
		S_n	K_e	S_n	K_{e_mech}	K_{e_ther}
A	Connection	12.2	1.0	**64.1**	2.04	1.53
	Junction	22	1.0	**50.4**	1.11	1.47
B	Connection	34.5	1.0	**104.8**	3.33	1.63
	Junction	29.7	1.0	**57.5**	1.58	1.5
C	Connection	**63.9**	2.04	**82.2**	3.27	1.58
	Junction	**49.9**	1.07	**63.6**	2.04	1.52

* 3Sm = 48.9 ksi

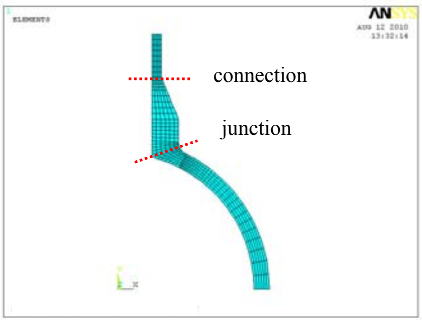

Fig. 1 FE model nozzle for fatigue analysis

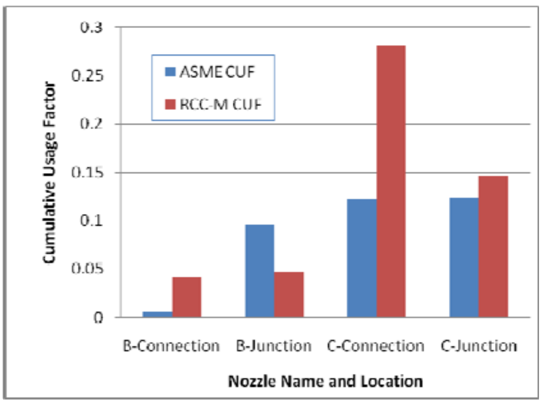

Fig. 2 Nozzles B and C cumulative usage factors