A Study on Leak Before Break Evaluation for Elbow

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1. Introduction

Currently, the LBB(Leak Before Break) concept is being applied to the piping of NPP(Nuclear Power Plant) to eliminate dynamic effects resulting from pipe rupture following the SRP 3.6.3 and NUREG-1061 Vol.3. In the LBB evaluation, leakage cracks are assumed, taking into account 1gpm of leakage rate in locations where defect are likely to occur in the pipe. As a subsequent step, crack stability evaluation is conducted using EPFM(Elastic-Plastic Fracture Mechanics) to ascertain if the assumed crack become instability crack growth. The crack stability can be assessed to *J*-integral, one of the EPFM parameter, straight pipe is generally assumed. However, when considering a crack at the location of the elbow, it is necessary to clearly confirm the difference through the comparison between the straight pipe and elbow.

In this study, the *J*-estimation scheme of the elbow presented in NUREG/CR-6765[1] is compared with the representative GE/EPRI method [2]. Additionally, *J*-integral for both straight pipe and elbow were compared, and further comparison is conducted through FEA (Finite Element Analysis).

2. Comparison of *J*-estimation Scheme

In this chapter, each *J*-estimation scheme for straight pipe and elbow for *J*-integral is expressed, and the allowable moment ratio through *J*-integral value is compared for elbow extrados and circumferential through-wall crack to determine each *J*-estimation scheme.

2.1 GE/EPRI method [1]

The GE-EPRI method is a *J*-estimation scheme developed in the early 1980s that uses a dimensionless influence function for the pipe geometry and crack length and strain hardening exponent presented through FEA[1]. The Eqs.(1)~(3) for elasticity and plasticity of *J*-integral for bending moment in piping are as follows.

$$J = J_e + J_p \tag{1}$$

$$J_e = \pi a \left(\frac{R_m}{I}\right)^2 \left\{\left(F^B\left(\frac{\theta}{\pi}, \frac{R_m}{t}\right)\right)\right\}^2 \frac{M^2}{E} \tag{2}$$

$$J_p = \alpha \sigma_0 \epsilon_0 c \frac{\theta}{\pi} h_1^B \left(\frac{\theta}{\pi}, \frac{R_m}{t}, n\right) \left(\frac{M_{pipe}}{M_L}\right)^{n+1} \tag{3}$$

2.2 NUREG/CR-6765[2]

To establish *J*-estimation scheme for expectation of *J*-integral, COD(Crack Opening Displacement) for extrados circumferential through-wall crack of elbow, engineering equation is developed in in NUREG/CR-6765 App. E. Eq.(4) is *J*-integral calculation of elastic and plastic component for circumferential through-wall crack of elbow. Figure 1 represents the schematic of through-wall crack location of elbow extrados.

$$J_e = \frac{1}{E}\left[F_B \sigma_B \sqrt{\pi a}\right]^2 \quad \sigma_B = \frac{M \times R_m}{\frac{\pi}{4}(R_o^4 - R_i^4)} \tag{4}$$

where $R_i$is inner radius of pipe, $R_o$is outer radius of pipe and $R_m$is mean radius of pipe. a is half crack length, F_B is geometric function for stress intensity factor and *J*-integral calculation. Eq.(5) is plastic component of *J*-integral for applied moment as follows.

$$J_p = \alpha \sigma_0 \epsilon_0 a \left(1 - \frac{\pi}{\theta}\right) h_1 \left(\frac{M_{elbow}}{M_L}\right)^{n+1} \tag{5}$$

where, M_L is plastic limit moment. In the equation, FEA determined geometric function(h_1) are function of geometry(R_m/t), crack length(θ/π) and strain hardening exponent(n) and the values of h_1 were tabulated are quite sufficient for practical nuclear applications.

2.3 Comparison of J-integral for elbow and pipe

In the relationship between J-integral and moment ratio in NUREG/CR-6765 described in Chapter 2.2, parametric analyses are performed on geometry (R_m/t) and crack length(θ/π). A circumferential through-wall crack is considered in the extrados of the elbow as shown Figure 1, and Table 1 represents the analysis case in according to the geometry (R_m/t) and crack length(θ/π).

Figure 2 shows the effect of applied moment ratio in accordance with the crack length (θ/π) and R/t. As R/t increases at θ/π of 0.125 to 0.25, the value of M_{pipe}/M_{elbow} reaches a maximum of 0.998, so the effect of straight pipe and elbow is small, and the results of straight pipe are conservative. Also, at θ/π=0.5, the effect of M_{pipe}/M_{elbow} is large depending on R_m/t and when R_m/t =8, the J-integral of the elbow is calculated to be larger than the straight pipe. Thus, when the leakage crack length is small(θ/t ≤0.25), the moment ratio(M_{pipe}/M_{elbow}) has little effect on R/t, and when the leakage crack length is large (θ/π >0.25), approximately $R_m/t \leq$ 6, straight pipe is more conservative than elbow.

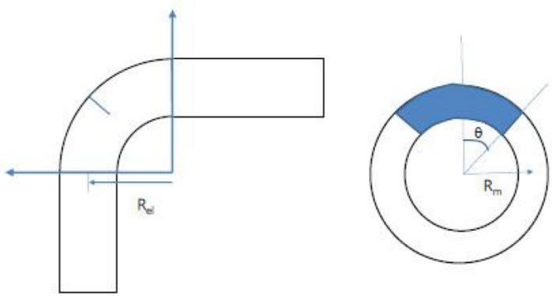


Figure 1. Schematic of elbow and crack location

Table 1. Analysis Cases

Crack	Loading	R/t	θ/π	a, n
Circumferential through-wall Crack in extrados	Pure bending moment	4.36 6 8 10	0.125 0.25 0.5	a = 1 n = 3

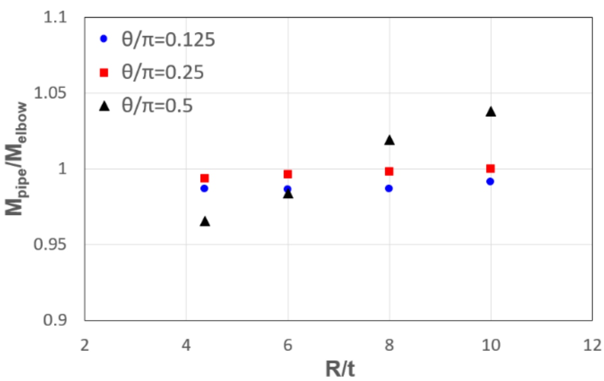


Figure 2. Comparison of moment ratio(M_{pipe}/M_{elbow}) according to the R/t, θ/π

3. FE analysis of Elbow

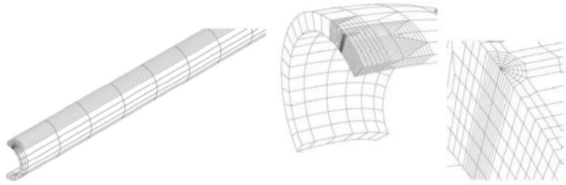
In this chapter, a FE model of surge line straight pipe and elbow are developed with circumferential through-wall crack, and the conservatism of the straight pipe evaluation is additionally evaluated by comparing the moment ratio according to *J*-integral obtained by FEA with straight pipe and elbow.

3.1 FE models and analysis conditions

Figure 3 shows the 3D FE model of a straight pipe and elbow, and the *J*-integral is calculated according to the applied moment. To consider the case where R_m/t =5 of the pipe, the outer diameter is 355.6 mm and the thickness is 32.327 mm. The crack length is θ/π=0.125. ABAQUS [3], a general-purpose FEA program, is used for FEA, and the C3D20R used.

In the loading condition, moment is applied by gradually increasing it through kinematic coupling at the opposite end of the crack, and is expressed by non-dimensional it as the plastic as the plastic limit moment of straight pipe. The plastic limit moment is as follows[1].

$$M_L = 4\sigma_0 R_m^2 t \left(cos\frac{\theta}{2} - \frac{1}{2}sin\theta\right) \quad (6)$$



(a) Straight pipe (b) elbow
Figure 3. FE models of straight pipe and elbow

3.2 FE analysis results

Figure 4 shows a comparison of the *J*-integrals according to the applied moment of straight pipe and elbow. In the case of an elbow with a circumferential through-wall crack in the extrados, the *J*-integral is similar to that of the straight pipe as shown in Figure 4, is more conservative than elbow.

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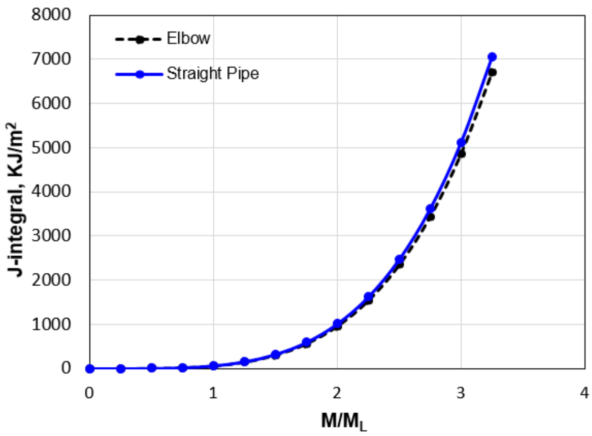

Figure 4. Comparison of J-integral according to the applied moment with straight pipe and elbow

4. Conclusions

By this study, straight pipe and elbow through the J-estimation scheme and FEA, the J-integral of straight pipe shows more conservative results than that of elbow at the same size of circumferential through-wall crack and applied moment.

REFERENCES

[1] EPRI, Ductile Fracture Handbook, NP-6301-D, 1989.
[2] U.S. NRC, Development of Technical Basis for Leak-Before-Break Evaluation Procedures, NUREG/CR-6765, May 2002.
[3] ABAQUS, “ABAQUS User’s Manual”, Ver.6-16.1, *Dassault System*, 2016.