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Parametric Study for Piping Thermal Expansion Stress under Limited Circumstances

Hwanho Lee [a*], Jinho Oh [a]
[a]*Kijang Research Reactor Design and Construction Project, KAERI, Daejeon, Korea*
[*]*Corresponding author: leo@kaeri.re.kr*

1. Introduction

A piping arrangement by free thermal expansion analysis for piping system is an important design factor at the beginning of the project. If the boundary conditions change when the design is already in progress, the design changes are subject to limitations and require lots of piping analysis. In particular, if the fittings can only be changed, such as piping size, thickness, and fitting type, under the fixed piping arrangement, the thermal expansion stress can be estimated using the ASME Code equations without additional analysis. In this study, the parameters for elbow are calculated and analyzed for each case.

2. Methods and Results

2.1 ASME Code Equations

For considering thermal expansion of the piping system, the ASME Code equations [1] are as follows:

The effects of thermal expansion must meet the requirements of Eq. (10a):

$$S_E = \frac{iM_c}{Z} \le S_A \quad (10a)$$

i = stress intensification factor
M_c = range of resultant moments due to thermal expansion, N·mm
Z = section modulus of pipe, mm^3
S_A = allowable stress range for expansion stresses, MPa

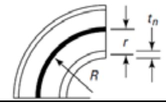
The effects of pressure, weight, other sustained loads, and thermal expansion shall meet the requirements of Eq. (11):

$$S_{TE} = \frac{PD_0}{4t_n} + 0.75i\left(\frac{M_A}{Z}\right) + i\left(\frac{M_C}{Z}\right) \le (S_h + S_A) \quad (11)$$

P = internal Design Pressure, MPa
D_o = outside diameter of pipe, mm
t_n = nominal wall thickness, mm
M_A = resultant moment loading on cross section due to weight and other sustained loads, N·mm
S_h = basic material allowable stress at Design Temperature, MPa

Table I shows the Code equations for stress intensification factor i of elbow.

Table I: Equations for Elbow SIF

Stress Intensification Factor i	Flexibility Characteristic h	Sketch
$\frac{0.9}{h^{2/3}}$	$\frac{t_n R}{r^2}$	

R = nominal bend radius of elbow, mm
r = mean radius of pipe, mm

2.2 Parametric Study

From the ASME Code equations, the i/Z parameter is important under the fixed piping arrangement. Table II shows the calculation inputs [2] for i/Z parameter. Table III and Figure 1 show the i/Z parameter results for various elbow size, thickness, and curvature based on existing design.

Table II: Calculation Inputs for i/Z Parameter

NPS, inch	D_o, mm	R (SR), mm	R (LR), mm	Z, mm^3
18	457.2	457.2	685.8	1.499 E+06
20	508.0	508.0	762.0	1.859 E+06
22	558.8	558.8	838.2	2.257 E+06

NPS: Nominal Pipe Size
SR: Short Radius (R = 1.0 D_o)
LR: Long Radius (R = 1.5 D_o)

Table III: Calculation Results for i/Z Parameter

Elbow Curvature	SR	LR	SR	LR
NPS, inch	Sch. 40S (t_n = 9.525 mm)		Sch. 80S (t_n = 12.70 mm)	
18	3.059 E-06	2.335 E-06	2.502 E-06	1.909 E-06
20	2.655 E-06	2.026 E-06	2.173 E-06	1.658 E-06
22	2.335 E-06	1.782 E-06	1.913 E-06	1.460 E-06

Sch.: Schedule

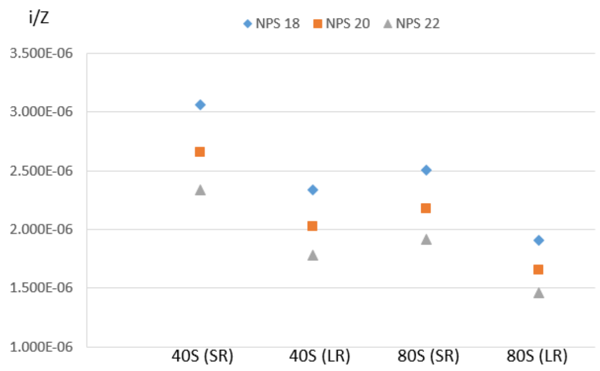


Fig. 1. i/Z parameter results of various elbows

As the equations (10a) and (11) show, the thermal expansion stress decreases as the i/Z parameter is smaller. Consequently, the thermal stress decreases as each the size, thickness, and curvature of elbow increases. Also, Figure 1 shows that the increase of curvature is more effective than increase of thickness in these cases. And, the calculated parameters show us to estimate the tendency of thermal stress change for various elbow types.

3. Conclusions

In this study, the parametric study for elbow was performed for piping thermal expansion stress under limited circumstances. From the i/Z parameter results, we can estimate thermal stress change without repeated piping analysis. This method can be expanded to other types of stress and fittings and useful in reducing the time and cost of additional piping analysis.

ACKONWLEDGEMENT

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REFERENCES

[1] ASME Boiler and Pressure Vessel Code, Section III, Subsection ND, Class 3 Components, American Society of Mechanical Engineers, 2004.
[2] ASME B16.9, Factory-made Wrought Buttwelding Fittings, American Society of Mechanical Engineers, 2001.