Local Stress Estimation of Wall-Thinned Pipes considering Fluid-Structure Interaction

Ki-Hun Song,a Sang-Min Lee,a Yoon-Suk Chang,a Jae-Boong Choi,a Young-Jin Kim,a

a School of Mechanical Engineering, Sungkyunkwan University,300 Chunchun-dong, Jangan-gu, Suwon, Kyounggi-do 440-746, Korea, yjkim50@skku.edu

1. Introduction

The wall-thinning of pipes due to erosion/corrosion or FAC (Flow Accelerated corrosion) is one of critical issue in nuclear power plant. In order to assess the integrity of nuclear pipe, guidelines such as ASME section Ⅲ, ANSI/ASME B31G[1~2] and ASME Code Case N-597[3] are required, however, there is a limitation in these guidelines. For example, most of these guidelines are based on design criteria, which give unduly conservative result. In this respect, it is necessary to consider a new analysis procedure combining CFD (Computational Fluid Dynamics) and FEM (Finite Element Method) is considered as an appropriate method for wall-thinned nuclear pipe.

The objective of this paper is to predict of the local stress of wall-thinned nuclear pipe reflecting field operating conditions such as internal pressure and fluid flow etc. The CFD and FE analyses are performed to evaluate the local stress of pipe under given loading conditions and to investigate the effect of governing parameters, such as defect depth and fluid flow velocity, on the local stress.

2. CFD Analysis
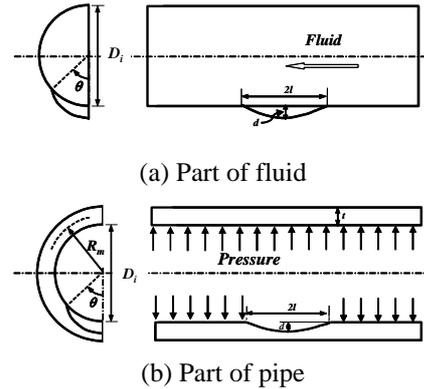
2.1 Analysis model and conditions

CFD analyses are carried out using FLUENT to obtain the variation effects of pressure due to relative fluid flow velocity and a defect like local wall thinning on the wall of pipe. 3-D viscosity region of fluid in CFD analysis is considered with incompressibility and stead-state flow in the pipe. The fluid conditions are assumed water which has one phase.

Boundary conditions, velocity-inlet condition at the inlet and pressure-outlet condition at the outlet, are applied in the pipe. In addition to applied no-slip condition at surface of the wall. The analyses are performed to reduce the computing time with half model as shown in Fig. 1(a).

2.2 CFD analysis and results

In this present work, quantitative characteristics of wall-thinned pipe are analyzed by calculating internal pressure and relative velocity of it according to fluid flow and defect geometry. However, cavitations and diffusers of pipe are not considered in the present work. As a result, the value of internal pressure increased over than 30% with increasing d/t and fluid flow velocity at the deepest point. The results of CFD are applied to the input conditions of FE analysis.


(a) Part of fluid

(b) Part of pipe

Fig. 1 Schematic illustration of wall-thinned pipe subject to internal pressure

3. FE Analysis

3.1 Analysis model and conditions

The aforementioned two variables are varied systematically to cover a practical interesting range; the relative defect depth, d/t; the fluid flow velocity, V and then both the half axial length to thickness ratio, l/t, and the normalized circumferential angle, θ/π, are constant value. For instance, three different values of d/t are considered, ranging for d/t, 0.25, 0.50 and 0.75; and two different values for V, 17 and 65m/s; and l/t=10, θ/π=0.25. ABAQUS was used for FE analysis and geometry of pipe was modeled 1/2 model under the symmetry conditions. Note that the defect was modeled as a circular shape in both axial and circumferential directions, as shown in Fig. 1(b).
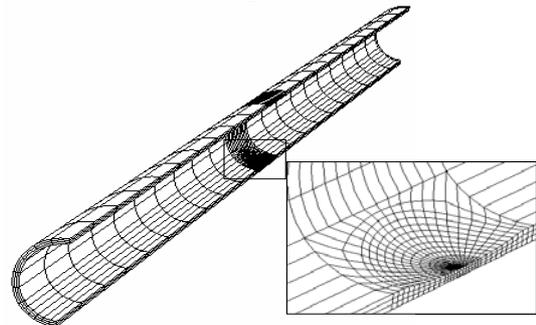
Fig. 2 Typical FE mesh employed in the present work

Table 1 Material properties of A333 Gr. 6

Young's modulus [GPa]	204
Poisson's ratio	0.3
Yield strength, σ_Y [MPa]	360
Ultimate tensile strength, σ_U [MPa]	452

The element of FE model was used C3D20R of finite elements type as shown in Fig. 2. Regarding loading condition, internal pressure was considered. For internal pressure, pressure was applied to the inner surface of the FE model and the corresponding tension load was applied to the pipe end to simulate the end-cap condition.

ASTM A333 Gr. 6 carbon steel used to nuclear secondary piping system was applied to analysis in this paper. Material properties of pipe were shown in Table 1.

3.2 FE analysis and results

3-D elastic FE analyses were performed using the result of CFD analysis to calculate the von-Mises stress and local stress at the deepest point of wall-thinned nuclear pipe. FSI (Fluid Structural Interaction) analyses were carried out to analyze the effect of variation, fluid flow velocity and shape of defect, on the von-Mises stress and local stress at deepest point of a wall-thinned nuclear pipe. As shown in Fig. 3, the von-Mises stresses, FSI analysis were higher than obtained calculated by FE analysis. Also, the value of von-Mises stress increased about from 1 to 70% with increasing d/t and fluid flow velocity.

4. Evaluation of wall-thinned pipes

The local stresses at the deepest point were compared $\sigma_{local\text{-}FSI}$ of FSI analysis with $\sigma_{local\text{-}Structural}$ of FE analysis using the Kim's equation[4]. It is given as follows:

$$\sigma_{local} = \frac{P}{\left(P_L / \sigma_Y\right)} \qquad (1)$$

where σ_Y is yield strength of material also and P_L is given as follows;

$$\frac{P_L}{\sigma_Y} = \frac{t}{R_m}\left(1 - \frac{d}{t} + \frac{d}{t}\frac{1}{\varphi}\right) \qquad (2)$$

The results of it were illustrated as shown in Fig. 4.

5. Conclusion

Resultant values of FSI analysis were shown that fluid flow had an effect on the stress of wall thinned pipe. In addition, integrity evaluation was required applying to fluid flow in the nuclear pipe, since the stress of the FSI analysis was about 33% higher than
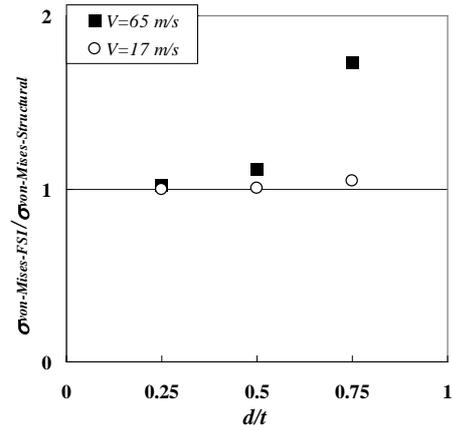
Fig. 3 The ratio of $\sigma_{von\text{-}Mises\text{-}FSI}$ /$\sigma_{von\text{-}Mises\text{-}Structural}$ for the locally wall-thinned pipe under internal pressure
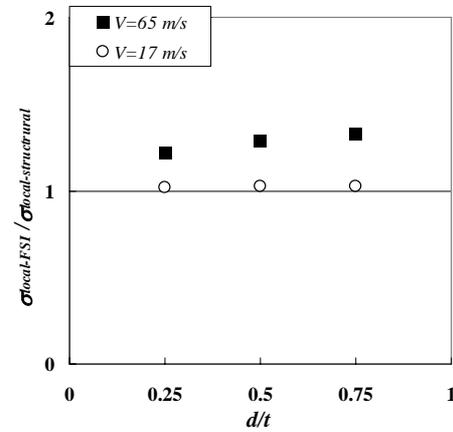
Fig. 4 The ratio of $\sigma_{local\text{-}FSI}$ /$\sigma_{local\text{-}Structural}$ for the locally wall-thinned pipe under internal pressure

that of commonly existing criterion for the wall-thinned pipe.

REFERENCES

[1] ANSI/ASME B31. G, Manual for Remaining Strength of Corroded Pipelines, 1991.
[2] ASME Boiler and Pressure Vessel Code Section III,, "Rules for Construction of Nuclear Power Plant Components," 1998.
[3] American Society of Mechanical Engineer, "Requirement for Analysis Evaluation of Pipe Wall Thinning," ASME B&PV Code XI, Division 1, Code Case N-597, 1998.
[4] H. Lim, D.J. Shim, Y.J. Kim and Y.J. Kim, "Development of Assessment Methodology for Locally Corroded Pipe Using Reference Stress Concept," Korea Society of Mechanical Engineering, 2003.
[5] Y.H. Choi and S.C. Kang, "Evaluation of Piping Integrity Thinned Main Feedwater Pipes," Journal of the Korean Nuclear Society, Vol. 32, pp. 67~76, 2000.
[6] Y.S. Chang, K.O. Yun, Y.J. Park and Y.J. Kim, "Study on Probabilistic Fracture Mechanics Analysis for Risk Assessment of Wall-Thinned Nuclear Piping," Korea Society of Mechanical Engineering, 04MF36, pp 218~228, 2004.