Environmental Assisted Fatigue Evaluation of Direct Vessel Injection Piping Considering Thermal Stratification

Taesoon Kim*, Dohwan Lee
KHNP, Central Research Institute, 70, 1312 Yuseong-daero, Yuseong-gu, Deajeon 34101, KOREA
**Corresponding author: taesoon.kim@khnp.co.kr*

1. Introduction

A Nuclear power plant consists of a number of components and pipes that have experienced various mechanical degradations during the plant operation. Recently, as design life of nuclear power plant is expanded over 60 years, a fatigue by thermal and mechanical loads has become one of most important degradation mechanisms for major components in terms of plant design. Moreover, as the environmentally assisted fatigue (EAF) due to the primary water conditions is to be a critical issue, the fatigue evaluation for the components and pipes exposed to light water reactor coolant conditions has become increasingly important. Therefore, many studies to evaluate the fatigue life of the components and pipes in LWR coolant environments on fatigue life of materials have been conducted.

Among many components and pipes of nuclear power plants, the direct vessel injection piping is known to one of the most vulnerable pipe systems because of thermal stratification occurred in that systems. Thermal stratification occurs because the density of water changes significantly with temperature. The differences between the fluid temperature at the top of a pipe and that at the bottom of the pipe cause stratification stresses which consist of global stresses and local stresses. In this study, fatigue analysis for DVI piping using finite element analysis has been conducted and those results showed that the results met design conditions related with the environmental fatigue evaluation of safety class 1 pipes in nuclear power plants.

2. Thermal Stratification of DVI Piping

As stated above, DVI piping is one of representative piping systems that consist of reactor coolant system (RCS) branch piping systems. The DVI piping which is not isolated from the RV can be susceptible of the thermal stratification due to turbulent penetration and valve leakage flow. So thermal stratification can be occurred in the horizontal section of the piping which is located between the DVI nozzle at the reactor vessel and the first isolation valve which the high temperature fluid can be contact with low temperature fluid by valve leakage. The thermal stratification phenomenon of DVI piping can be occurred in 2 operation modes which are the heat-up mode for normal operation and the low flow injection mode by the unintended operation of safety injection pump.

3. Structural Analysis

The material of the DVI piping used in analysis is SA312 TP316 stainless steel and its material properties are showed in Table I. Structural analysis of the DVI piping is performed 2 steps which are the step to calculate pipe bending moment and that for local stress analysis. The finite element model to analyze structural integrity of DVI piping is represented in Fig. I.

Table I: Tensile properties of type 316 at room temperature

Material	YS (MPa)	UTS (MPa)	Poisson ratio (%)
SA312 TP316	302	581	0.3

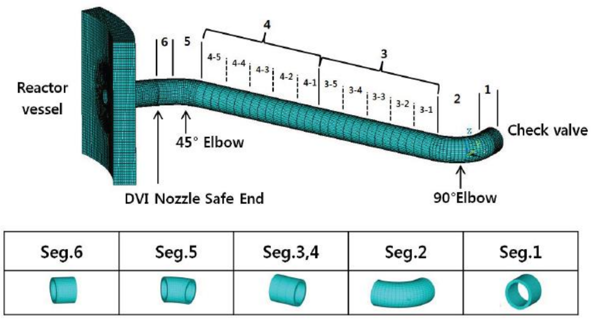

Fig. 1. Finite element model of DVI piping system

3.1 Bending Moment Load

The bending moment of piping system occurs by not only the temperature difference of piping section but also thermal expansion of piping constrained to supports and components. As the bending moments are very different according to the calculated location, the piping system needs to be divided into a number of segments as shown in Fig. I.

Thermal distribution of the DVI piping system calculated by computational fluid dynamics was represented in Fig. 2. In this figure, we showed that the thermal distribution of DVI piping system was not linear because of turbulent fluid flow. In order to calculate equivalent moment load including nonlinear thermal distribution, the contact analysis method was applied. The equivalent bending moments load calculated in each segment were shown in Fig. 3.

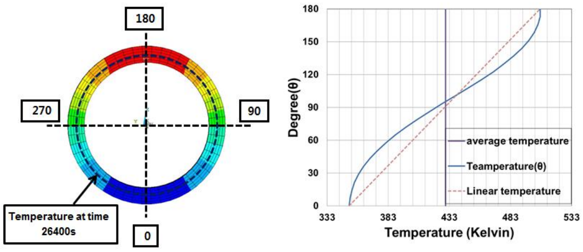

Fig. 2. Thermal distribution of DVI piping section

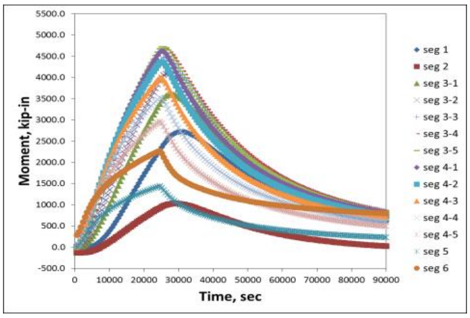

Fig. 3. Equivalent bending moment for operation mode

3.2 Local Stress Analysis

For the piping system which thermal stratification has been observed, the local stress due to the nonlinear thermal distribution of piping section occurs even though thermal expansion is not constraint. Therefore for the calculation of local stress using ANSYS program, the axial and circumferential displacements on the boundary surface of check valve were constrained while the radial displacement of piping system was free. Fig. 4 shows the thermal distribution in piping section by thermal stratification and Fig. 5 maximum stress intensity for each segment in the stratification mode of DVI piping system.

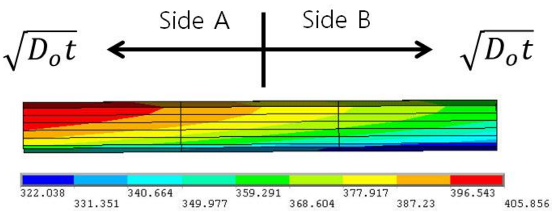

Fig. 4. Temperature contour plot at straight pipe

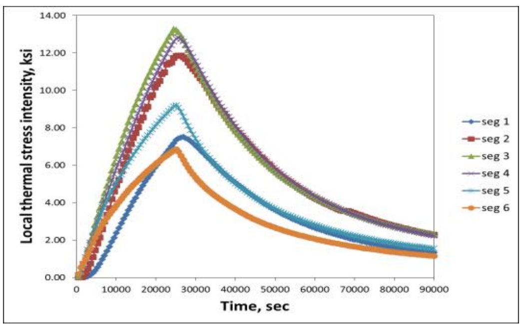

Fig. 5. Stress intensity in the stratification mode

4. Fatigue Analysis

The fatigue evaluation of the DVI piping system considering thermal stratification was carried out according to ASME B&PV Code Section III NB-3650. In order to consider the environmental effect of primary water condition of nuclear power plants, the environmental fatigue evaluation USNRC Regulatory Guide 1.207 and NUREG/CR-6909 was performed after the cumulative fatigue usage factors (CUFs) were calculated in the air condition. Fig. 6 shows the cumulative fatigue usage factors including environmental effects (CUFens) of DVI the piping system that thermal stratification occurs.

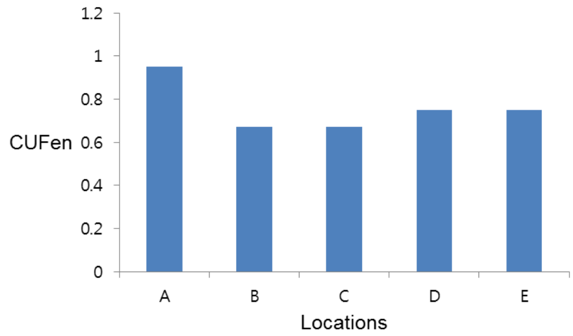

Fig. 6. Cumulative fatigue usage factors of the DVI piping in LWR environment

5. Conclusions

Structural and fatigue integrity for the DVI piping system that thermal stratification occurred during the plant operation has conducted. First of all, thermal distribution of the piping system is calculated by computational fluid dynamic analysis to analyze the structural integrity of that piping system. And the fatigue life evaluation considering environmental effects was carried out. Our results showed that the DVI piping system had enough structural integrity and fatigue life during the design lifetime of 60 years.

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