CFD analysis of cavitation occurring in an orifice in the auxiliary feedwater system

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1. Introduction

The auxiliary feedwater system (AFWS) of a nuclear power plant (NPP) supplies auxiliary feedwater when the main feedwater supply is impossible to the steam generator (SG) during normal operation, and supplies auxiliary feedwater to the steam generator to perform a residual heat removal function of the reactor core when the reactor is shutdown. In addition, in the operation mode 2 to 5 of the NPP, the auxiliary feedwater is charged to the steam generator.

In the past, according to the operation experience of the NPPs, there were several cases where the check valve of the auxiliary water supply system was damaged or replaced during the startup and overhaul (O/H) period. Through failure cause analysis, it was concluded that fluttering phenomenon resulted from fluid disturbance and vortex caused by overflow and insufficient length of straight pipe.

In this study, computational fluid analysis (CFD) was performed to analyze the reduction of flow rate, and the cause was identified through detailed flow field analysis.

2. CFD Analysis

2.1 Analysis of field data

Fig. 1 is a model of a part of the AFWS which includes the main fluid apparatuses, the flow control valve (type : globe) and the orifice (type : concentric). The sudden reduction of flow rate occurred during the SG filling operation using the auxiliary feedwater pump, causing great noise and vibration. This phenomenon occurred while gradual opening of the flow control valve (FCV), and occurred when the opening rate was about 30%; a stable flow rate flowed under the smaller opening rate condition. The opening rate of 30% is a condition in which a flow rate is higher than the flow rate of about 150 gpm which is recommended in the operating procedure.

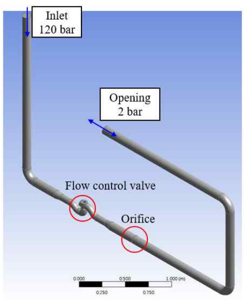


Fig. 1 CFD geometrical model

The flow information of the system is summarizes in table I. For reference, the filling operation was performed under the condition of the back pressure at the outlet side (open to the steam generator), and the inlet pressure by the auxiliary feedwater pump was maintained at 120 bar.

Table I: Flow information

Inlet pressure	About 120 bar
Outlet pressure	2 bar (atmosphere + hydraulic head)
Flow rate	16~18 lps
Fluid temperature	25°C

2.2 Analysis method

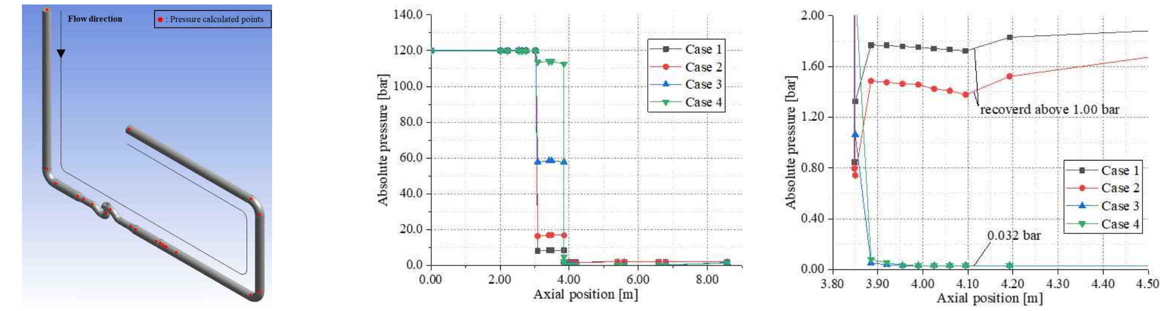
The flow region for CFD analysis is shown in Fig. 1. The check valve was not included in the analysis region because the check valve itself would not be the cause of the failure. The inlet and outlet regions were modeled to be located far enough away from the flow control valve and orifice where rapid changes in pressure are expected. ICEM-CFD and ANSYS-CFX were used for meshing and solver, respectively. Detailed analysis-related information is summarized in table II. Cases of analysis were selected by considering the occurrence or absence of cavitation. The flow area was changed by adjusting the stem height of the flow control valve. Information of variables for each case is summarized in table III. The reference case reflecting the field data is case 3.

Table II: Detailed analysis-related information

Analysis type	Steady state
Mass transfer (fluid pair option)	Cavitation (vapor pressure : 0.0317 bar)
Inlet	Inlet type, 120 bar
Outlet	Opening type, 2 bar
Number of mesh	Over 14 million (number of elements)

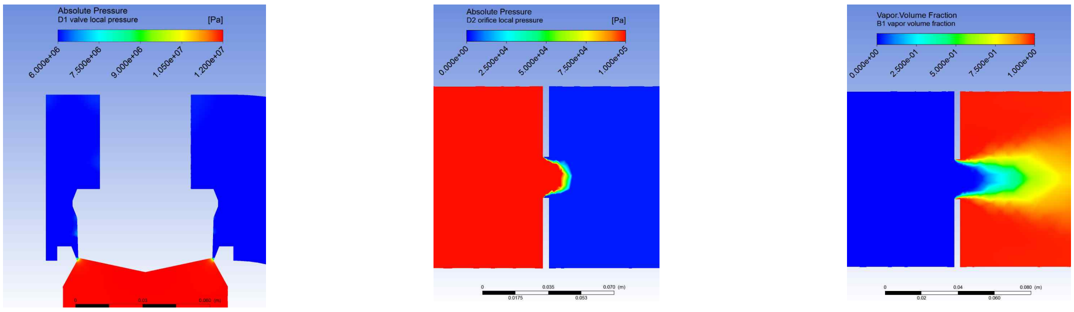
Table III: Information of variables in case studies

Case No.	Stem height	
	[inch]	[%]
1	0.25	10%
2	0.42	18%
3	0.75	31%
4	1.05	44%



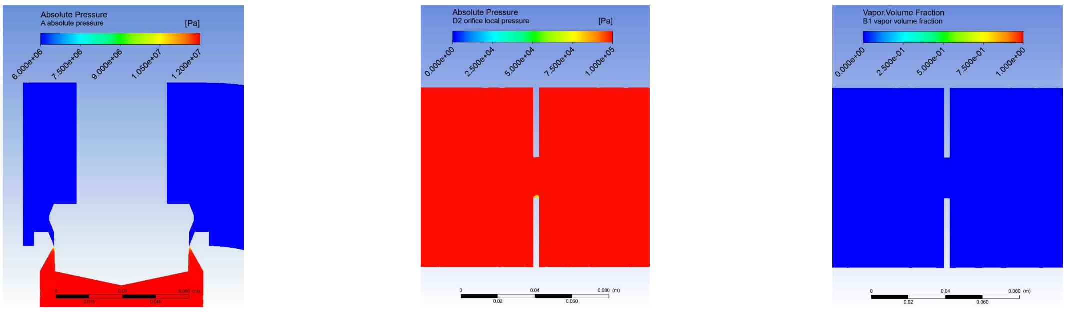
(a) Pressure calculated points (b) Absolute pressure (c) Absolute pressure nearby orifice

Fig. 2 CFD results - absolute pressure passing through the system



(a) absolute pressure (FCV) (b) absolute pressure (orifice) (c) Vapor volume fraction (orifice)

Fig. 3 CFD results - case 3: reference case



(a) absolute pressure (FCV) (b) absolute pressure (orifice) (c) Vapor volume fraction (orifice)

Fig. 4 CFD results - case 1: case of stable flow rate

2.3 Analysis results

Fig. 2 shows the absolute pressure (average value) that changes along the axial direction of the pipe. The fluid experienced two large pressure drops as it passed through the flow control valve and orifice. In case 3, a pressure drop of about 90 bar occurred as the fluid passed through the flow control valve, and the absolute pressure decreased to about 0.0317 bar as it passed through the orifice. After passing through the orifice, it was confirmed that the pressure was gradually recovered to the exit condition of 2 bar. It is possible to predict the occurrence of local cavitation, considering the vapor pressure of water at 25 °C is about 0.0317 bar.

Analysis results of case 3 are described in fig. 3. It was confirmed that a sudden pressure drop occurred while passing through a narrow gap of the flow control valve (fig. 3(a)). In addition, it was confirmed that the fluid pressure dropt to the absolute pressure level of 0 bar while passing through the orifice (fig. 3(b)). Consequently, the inside of the pipe was filled with vaporized fluid, as shown in fig. 3(c). It was confirmed that the cavitation was occurred even in the additionally calculated overflow condition (case 4), and as a result, no flow rate was formed.

On the other hand, in the cases calculated by setting the conditions below the recommended flow rate, a pressure drop of about 110 bar or more occurred while passing through the flow control valve, but it was confirmed that the absolute pressure at the rear end of the orifice maintained more than 1 bar (fig. 2). As a result, it was confirmed that there was little or no vaporized vapor present in the pipe at the rear end of the orifice (fig. 4).

3. Conclusions

In this study, CFD analysis was performed for the phenomenon of the reduction of flow rate that occurred in AFWS of the nuclear power plant. In a situation where the flow rate was gradually increased, a decrease of flow rate suddenly occurred. Therefore, various cases with different flow areas which means various opening rate of the flow control valve were calculated.

As a result of the analysis, it was confirmed that the rear end of orifice was filled with vaporized steam under conditions exceeding the flow rate recommended in the operating procedure. The possibility of cavitation, resulted from the condition at which an absolute pressure is lower than that of the vapor pressure, was confirmed. It is obvious that the occurrence of cavitation can have a great influence on the fluid apparatus, which may cause a failure of the check valve located at the rear end of the orifice. In conclusion, if the SG is filled under the back pressure condition, the filling operation should be performed by following the recommended flow conditions.

REFERENCES

[1] Korea Hydro & Nuclear Power Co., KRN 3&4 Final Safety Analysis Report, Chapter 10

[2] ANSYS, Inc., ANSYS CFX-Solver Manager User's Guide, Canonsburg PA, USA, 2018.