Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 29-30, 2015

Effects of Piping Supports Failure to Main Steam Line Integrity under Steam Explosion Condition

Seung Hyun Kim[a], Yoon-Suk Chang[a,*], Sungchu Song[b] and Yong-Jin Cho[b]
[a]*Dept. of Nuclear Engineering, Kyung Hee University, 1732 Deokyoungdae-ro, Yongin, Kyunggi, Korea*
[b]*Korea Institute of Nuclear Safety, 34 Gwahak-ro, Yuseong, Daejeon, Korea*
[*]*Corresponding author: yschang@khu.ac.kr*

1. Introduction

In order to mitigate hypothetical severe accident scenarios in an advanced light water reactor, either a core catcher is placed or an ERVC (External Reactor Vessel Cooling) strategy is adopted during design stage. However, when molten core penetrates RPV (Reactor Pressure Vessel) lower plenum and contacts with water in the reactor cavity, serious structural damage may occur. For instance, the dynamic loads on the reactor cavity and the reactor lower plenum could potentially lead to failure of the MSL (Main Steam Line) connected to the steam generators. In addition, since the MSL extends to the containment wall, failure of the containment building may occur[1,2].

The goal of this research is to examine structural integrity of MSL piping under typical ex-vessel steam explosion conditions through FE analyses. Moreover, influence due to the failure of supports connecting main steam line piping was evaluated.

2. Numerical Analysis

2.1 Analysis conditions

The analysis method of the steam expansion phase, adopted in this research, is based on the Hicks-Menzies thermodynamic approach taking into account the microinteraction zone concept[1]. Due to the assumption of the adiabatic vapor expansion, the density of the mixture during the expansion process can be calculated solely as a function of pressure:

$$\rho_{2\to3}^{mix}(p)=\frac{\rho_2^{mix}}{(1-\alpha_2^{vap})+\frac{\alpha_2^{vap}\rho_2^{vap}}{\rho_{2\to3}^{mix}(p)}}=\frac{\rho_2^{mix}}{1+\alpha_2^{vap}\left(\left(\frac{p_2}{p}\right)^{\frac{1}{\kappa}}-1\right)}$$

where ρ_2^{mix} is the mixture density at the start of the expansion phase and $\rho^{vap}{}_{2\to3}$ is the vapor density during the expansion phase. So, the behaviors of the molten core mixture as well as liquid and air state coolant were analyzed by a CFD code[3].

Structural analyses of the MSL were performed by using commercial FEM code[4]. Table I summarizes the material properties used in the structural assessment. With regard to analysis cases, vessel failure modes such as SVF (Side Vessel Failure) were considered[5]. Also, influence due to the upper and bottom supports failure connecting MSL was evaluated.

Table I Material properties used in structural assessment[6]

Material		Modulus of elasticity (GPa)	Poisson's ratio	Yield strength (MPa)	Tensile strength (MPa)
Concrete		31.12	0.2	38.68*	2.18
Liner plate	SA508 Gr.1A	199.95	0.3	353.36	455.05
Rebar	SA615 Gr.60	199.95	0.3	510.21	751.53
Head fitting & sleeve	SA540 Gr.B23	183.92	0.3	296.47	503.32
MSL piping	SA106 Gr.C	183.08	0.3	303.36	503.32

[Note] *: compressive strength

2.2 FE models

The FE models of the MSL and containment building used for structural analysis from a load by steam explosion are illustrated in Fig. 1. The steel liner plate was modeled by employing shell elements and merged with the concrete. The vertical and horizontal rebars embedded in the concrete were modeled by using beam elements with 11,912 nodes and 8,117 elements. The steam generator was modeled by 8-node solid elements with 23,695 nodes and 12,133 elements. Also, head fitting and sleeve were modeled by employing 8-node solid elements consist of 9,360 nodes and 5,840 elements. MSL piping were generated by 8-node solid elements with 11,254 and 8,452 elements, respectively. Element types of each component were employed from general-purpose commercial program element library[3].

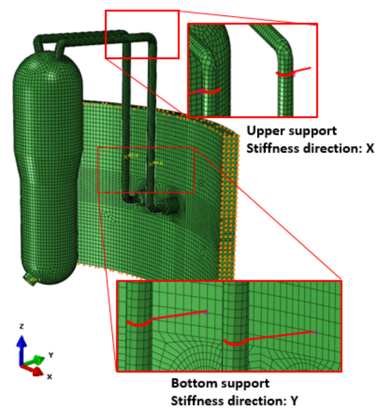


Fig. 1 Combined FE model and location of piping supports

2.3 Boundary and loading conditions

Also radial boundary conditions were defined on each side of the containment wall by using local coordinate system. Each of the MSL piping was supported by two supports mechanisms. Instead of defining non-deforming boundary conditions, linear springs were modeled as supports. Equivalent spring stiffness values were used for these supports.

Loading conditions were used by displacements of hot leg under steam explosion condition. Displacements and rotations calculated in the previous study were used as input loading[6]. Displacements and rotations captured the hot leg connection of the steam generator were applied as prescribed boundary conditions in the model[6].

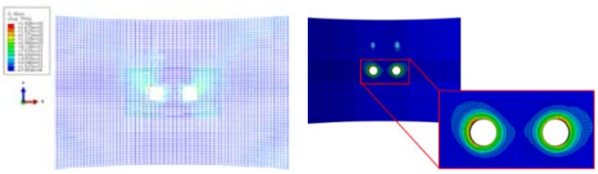
3. Analysis Results

3.1 Stress evaluation

Table II and Fig. 2 compare maximum von Mises stresses of the rebar, liner plate, MSL piping and head fitting and sleeve, representatively. The resulting stresses were high at the liner plate due to the supports failure. With regard to piping supports failure, the resulting stresses were high under both condition. However, all stress values did not exceed their yield strengths. Each stress acting on the components was ranged from 75MPa to 350MPa, approximately, so that belonged to elastic regime.

Table II: Maximum stresses of rebar, liner plates, MSL piping and head fitting and sleeve

Supports failure	Max. stress (MPa) @ rebar	Max. stress (MPa) @ liner plate	Max. stress (MPa) @ MSL piping	Max. stress (MPa) @ head fitting and sleeve
Non	38.12	302.43	160.57	74.76
Upper supports	40.27	312.41	170.62	77.03
Bottom supports	41.22	315.54	173.62	79.92
Both	48.15	350.25	210.22	85.56



(a) Rebar (b) Liner plate

Fig. 2 von Mises stress contours when both supports fail

3.2 Displacement evaluation

Table III summarizes the maximum radial displacements of MSL piping according to support failure conditions, respectively. The radial movement of MSL piping under both supports failure was higher than non-failure, and the radial movement of MSL piping under bottom supports failure was higher than upper supports failure. However, the resulting displacement was small comparing to the overall dimensions of the components.

Table III: Maximum radial displacements of MSL piping

Supports failure	Max. displacement (mm) @ MSL piping
Non	21.52
Upper supports	25.21
Bottom supports	26.87
Both	32.25

4. Conclusion

In this paper, parametric numerical analyses of the MSL due to the supports failure were carried out under typical steam explosion condition and the following conclusions were derived.

(1) The highest maximum stresses were calculated at liner plate under both failure condition. The all stress values did not exceed their yield strengths.

(2) The displacements were high under both failure conditions. However, the radial movements of MSL piping were small comparing to the overall dimensions of them.

REFERENCES

[1]L. Cizelj, B. Koncar and M. Leskovar, “Vulnerability of a partially flooded PWR reactor cavity to a steam explosion”, Nuclear Engineering and Design, Vol. 236, pp. 1617~1627, 2006.
[2]L. Cizelj, B. Koncar and M. Leskovar, “Estimation of ex-vessel steam explosion pressure load”, Nuclear Engineering and Design, Vol. 239, pp. 2444~2458, 2009.
[3]ANSYS CFX, “Introduction of CFX Ver. 14.0”, ANSYS Inc., 2012.
[4]ANSYS Civil FEM, "Introduction of Civil FEM Ver. 13.0", ANSYS Inc., 2012.
[5]S.H Kim, Y.S. Chang, S.C. Song, Y.J. Cho, “Structural assessment of fully flooded reactor cavity and penetration piping under steam explosion conditions”, International Journal of Pressure Vessels and Piping, Vol. 131, pp. 36~44, 2015.
[6]S.H Kim, Y.S. Chang, S.C. Song, Y.J. Cho, “Structural assessment of main steam line and containment building under steam explosion Conditions”, Proceedings of the ASME PVP 2015 Conference, PVP2015-4516, 2015.