Effects of blast wave to main steam piping under high energy line break condition by TNT model

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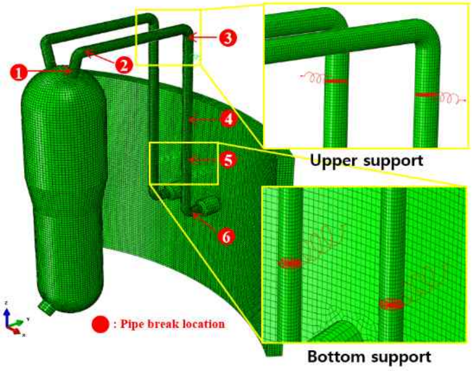
1. Introduction

If HELB (High Energy Line Break) accident occurs in nuclear power plants, not only environmental effect such as release of radioactive material but also secondary structural defects should be considered. Sudden pipe rupture causes ejection of high temperature and pressure fluid, which acts as a blast wave around the break location. The blast wave caused by the HELB has a possibility to induce structural defects around the components such as safe-related injection pipes and other structures[1]. The aim of this study is to examine effect of the blast wave according to pipe break position through FE (Finite Element) analyses.

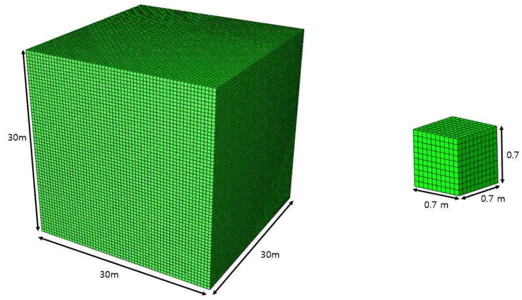
2. Numerical Analysis

2.1 Structural models

The FE models of the MSL (Main Steam Line) and containment building used for structural analysis from a load by the blast wave are illustrated in Fig. 1. The containment building was modeled by employing 8-node 3D concrete elements with 54 nodes and 79,536 elements. The SG (Steam Generator) was modeled by 8-node solid elements with 64,663 nodes and 55,020 elements. Also, head fitting and sleeve were modeled by employing 8-node solid elements consist of 1,728 nodes and 900 elements. MSL piping were generated by 8-node solid elements with 27,692 and 20,700 elements, respectively[2]. Element types of each component were employed from general-purpose commercial program element library[3]. Table I summarizes material properties used in the structural integrity assessment.



(a) MSL structure



(b) Air region (c) Explosive region

Fig. 1 FE models and pipe break locations

Table I: Material properties used in structural assessment[2]

Material		Modulus of elasticity (GPa)	Poisson's ratio	Yield strength (MPa)	Tensile strength (MPa)
Concrete		31.12	0.2	38.68*	2.18
Head fitting & sleeve	SA540 Gr.B23	183.92	0.3	296.47	503.32
MSL Piping and SG	SA106 Gr.C	183.08	0.3	303.36	503.32

[Note] *: compressive strength

2.2 Explosive models

The explosive material was modeled by using the Eulerian modeling technique. Figs. 1(b) and 1(c) show typical FE meshes of air and explosive regions. To model the air and explosive region, Eulerian continuum three-dimensional 8 node reduced integration elements (EC3D8R) have been used. Eulerian elements are necessary to efficiently propagate explosion wave through the air. Pressure-volume relation of the explosion has been simulated using JWL (Jones-Wilkins-Lee) EOS (Equation-Of-State). In this model, pressure (P) - density (ρ) relationship can be represented as the sum of functions[2];

$$P = A\left(1-\frac{\omega\rho}{R_1\rho_0}\right)e^{-R_1\frac{\rho_0}{\rho}} + B\left(1-\frac{\omega\rho}{R_2}\right)e^{-R_2\frac{\rho_0}{\rho}} + \omega\rho E_m \qquad (1)$$

where ρ_0 is the initial density of explosive material. The parameters A, B, $R1$, $R2$ and ω are material constants. E_m is the initial specific energy in JWL EOS, the first two exponential terms are high pressure terms and the last term on the right hand side is a low pressure term which deals with the high volume due to explosion. The parameters used herein for JWL have been listed in Table II[4].

Table II: Parameters of JWL equation of state[4]

A (GPa)	B (GPa)	R_1	R_2	ω	ρ (kg/m^3)	E_m (MJ/kg)
27.9	5.3	4.1	1.2	0.35	1900	3.63

2.3 Boundary and loading conditions

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[2].

Loading conditions as pressure under blast wave due to TNT explosion were equally applied to all cases. The SG and MSL piping were modeled to calculate the blast wave until 1 second. For this purpose, sudden rupture accident at penetration anchor was assumed. The pressure wave calculated from the TNT model was shown in Fig. 2.

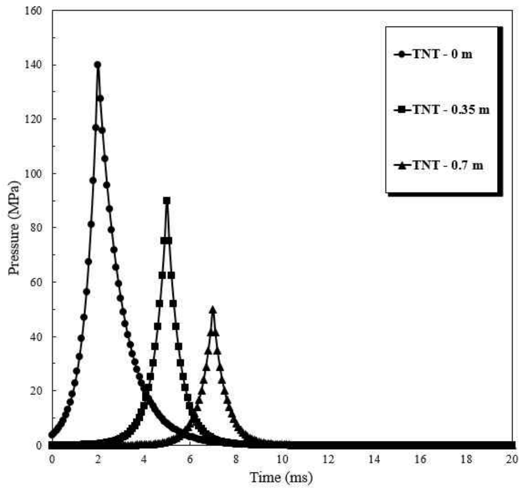


Fig. 2 Pressure histories of blast wave at pipe break point

3. Analysis Results

Table III and Fig. 3 compare maximum von Mises stresses of 6 cases, representatively. The resulting stresses were high at Case 2. The stresses were high at SG nozzle failure, however, the difference according to the pipe break locations was not significant. Also, maximum stresses of all component under each analysis case do not exceed their yield strengths so that they remained in elastic regime.

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

Case	Max. von Mises stress (MPa)	Max. displacement (mm)
1	53.71	8.23
2	277.23	287.73
3	182.23	284.51
4	143.15	86.32
5	125.56	63.45
6	260.23	299.23

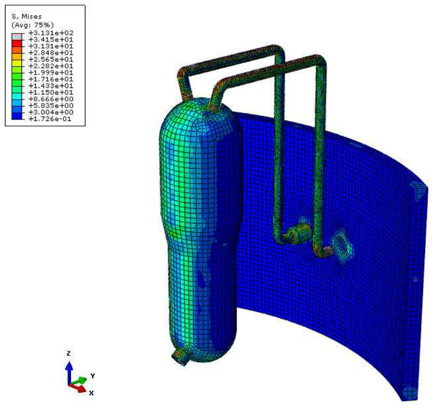


Fig. 3 von Mises stress contours in Case 2

4. Conclusions

In this study, parametric structural analyses of the MSL due to the blast wave were carried out under typical HELB and the following conclusions were derived.

(1) In Case 2, the highest maximum stresses were calculated at SG nozzle. However, the all stress values did not exceed their yield strengths.

(2) The displacements were high under Case 6. However, the movements of MSL piping did not affect other structures.

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