Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 17-18, 2018

A Coupled Method to Analyze Influence of Blast Wave

Tae-Jin Kim [a] and Yoon-Suk Chang [a*]
[a]*Dept. of Nuclear Engineering, Kyung Hee University, 1732 Deokyoungdae-ro, Yongin, Kyunggi, 446-701, Korea*
[*]*Corresponding author: yschang@khu.ac.kr*

1. Introduction

When a sudden rupture occurs in high energy lines such as MSL (Main Steam Line) and safety injection line of NPPs (Nuclear Power Plants), inner fluid would be ejected with high temperature and pressure. It may cause jet impingement, pipe whip and jet reflection as well as blast wave which can lead to damage of structures. Among these four phenomena, however, the blast wave was not considered in ANSI/ANS 58.2 standard that provides design concept and requirements against rupture of high energy piping system [1].

In this context, to perform structural integrity assessment under HELB (High Energy Line Break) conditions by the blast wave, 3-dimensional FE (Finite Element) model of containment wall, steam generator, MSL piping and head fitting & sleeve was constructed. Subsequently, blast wave analyses were performed for quantifying dynamic effects by comparing stresses and strains of the structures with their failure criteria.

2. Analysis Method

2.1 Coupled Analysis using TNT Model

CEL (Coupled Eulerian-Lagrangian) technique has been widely used due to its effectiveness in modeling and large deformation analyses without re-meshing procedure [2]. The technique is based on two-way coupling with Lagrangian and Eulerian methods at the intersection.

TNT model which is commonly used as explosive material was applied to simulating the blast wave phenomenon in lots of studies. Also, in this research, the TNT model was chosen by employing the CEL technique. The well-known JWL (Jones-Wilkins-Lee) EOS (Equation of State) was considered to demonstrate detonation products [3]:

$$P(V,E) = A\left(1-\frac{\omega}{R_1 V}\right)e^{-R_1 V} + B\left(1-\frac{\omega}{R_2 V}\right)e^{-R_2 V} + \frac{\omega}{V}E \quad (1)$$

where P is the pressure caused by explosion, V is the relative volume as a ratio between explosive volume and initial volume (v/v_0) of explosive material. A, B, R_1, R_2 and ω are material constants which have independency on each other.

2.2 Material Properties and Failure Criteria

Since dynamic loads cause rapid change of strain due to the blast wave, strengths of the structures become higher than those under static loading conditions. So, material properties for dynamic analyses were compensated by considering DIF (Dynamic Increase Factor; 1.00~1.29). Table I summarizes material properties used for FE analysis taking into account the DIF values.

Table I: Material properties considering the DIF values [4]

Structures & materials		Modulus of elasticity (GPa)	Poisson's ratio	Yield strength (MPa)	Tensile strength (MPa)
Containment wall	Concrete	31.12	0.2	38.68*	2.18
Steam generator	SA106 Gr.C	183.08	0.3	303.36	503.32
MSL piping					
Head fitting & sleeve	SA540 Gr.B23	183.92	0.3	296.47	503.32

[Note] *: Compressive strength

To ensure integrity of major structures and containment wall, a lot of research has been conducted to define failure criteria of materials. In case of concrete, strain-based criterion proposed by IAEA can be adopted with the limiting value. The value was 0.005, which was applied at the containment wall. Meanwhile, in case of steel materials, maximum normal stress criterion was adopted. According to this criterion, it was assumed that failure occurs when the maximum principal stress reaches to tensile strength. The criterion was applied for the steam generator, MSL piping and head fitting & sleeve. If these failure criteria of concrete and structures are violated, from a conservative point of view, it can be regarded as damage by loss of structural integrity due to the blast wave.

3. Blast Wave Analysis

3.1 FE Model

3-dimensional FE model was constructed to perform integrity assessment. It was combined each of them for air, explosive region and the structures (containment wall, steam generator, MSL piping, head fitting & sleeve) as shown in Fig. 1. The breaking point of MSL piping was selected as the riskiest rupture location, and shape of explosive region which has the most conservative results was chosen from previous studies [5, 6].

The Eulerian method was adopted at the air and explosive region, and Lagrangian method was adopted at the structures in the CEL technique. The explosive region was also assigned by the TNT model. Mesh information used in the blast wave analyses was depicted in Fig. 1. The whole FE model was generated 8 node hexahedral elements.

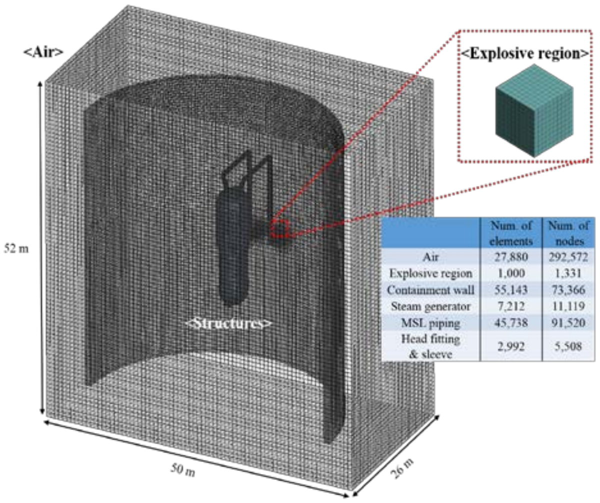


Fig. 1. 3-dimensional FE model for blast wave analysis [4]

3.2 Analysis Conditions

As analysis conditions, time was set to be 10.0 msec. It was determined as the blast wave sufficiently reaches to the neighboring structures. Analysis cases were set to increase the size of explosive region as summarized in Table II.

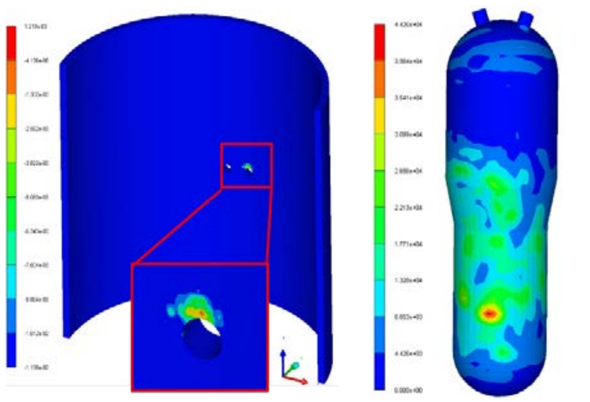
Table II: Analysis cases used for blast wave analysis

Case	Size of explosive region
1	0.1 m × 0.1 m × 0.1 m
2	0.15 m × 0.15 m × 0.15 m
3	0.2 m × 0.2 m × 0.2 m

Lower parts of the containment wall and steam generator were fully fixed as boundary condition. Major parameters of JWL EOS obtained from the RELAP-5 code which is a well-known system code, and used for integrity assessment based on the coupled analysis using TNT model from a previous study [4].

4. Analysis Results

Fig. 3 shows representative strain contours of the containment wall and stress contours of the steam generator, respectively. The maximum values were summarized in Table III.



(a) Containment wall (b) Steam generator

Fig. 2. Principal strain and stress contours at case 3

Table III: Maximum principal stresses and strains

Case	Structures	Max. principal strain	Max. principal stress (MPa)
1	Containment wall	5.17×10^{-4}	30.75
	Steam generator	3.65×10^{-5}	13.61
2	Containment wall	7.04×10^{-4}	47.66
	Steam generator	8.13×10^{-5}	18.72
3	Containment wall	1.22×10^{-3}	73.52
	Steam generator	1.92×10^{-4}	44.26

In case of the containment wall, maximum value of principal strain did not exceed the aforementioned failure criterion of concrete material. Also, in case of the steam generator, maximum principal stress did not exceed the failure criteria of each material.

5. Conclusions

In this research, blast wave analyses were performed under postulated HELB conditions and the following conclusions were derived.

(1) 3-dimensional FE model was generated by combining structures (containment wall, steam generator, MSL piping, head fitting & sleeve), air and explosive region.
(2) As analysis results, principal stress and strain values were calculated through the CEL technique, and larger size of explosive region had the more conservative results as expected. Resulting values did not exceed the corresponding failure criteria at all analysis cases.

ACKNOWLEGMENTS

This work was supported by the Korea Institute of Energy Technology Evaluation and Planning(KETEP) and the Ministry of Trade, Industry & Energy(MOTIE) of the Republic of Korea (No. 20151520101080).

REFERENCES

[1] ANSI/ANS-58.2, Design basis for protection of light water power plants against postulated rupture of piping, American Nuclear Society, 1998.
[2] S. T. Zahra and S. V. Jeffery, A comparison between different blast methods, 12th international LS-DYNA users conference, Dearborn, 2014.
[3] AUTODYN, User's manual, ver. 19.0, ANSYS INC, 2018.
[4] T.J. Kim and Y. S. Chang, Investigation of blast wave effects on containment wall and steam generator, ASME PVP2018-84325, Prague, 2018.
[5] S. H. Kim, S. Y. Je, Y. S. Chang, and C. Y. Choi, Evaluation of jet impingement phenomenon and pipe whip behavior under pipe break conditions, 24th international conference on SMiRT, Busan, 2017.
[6] S. H. Kim, Y. S. Chang, and Y. J. Choi, Effect of explosive region modeling on steam explosion analyses by TNT model, Transaction of the Korean nuclear society spring meeting, Jeju, 2016.