Numerical Analyses of 1400 MWe Power Plant under HELB-induced Blast Wave

Tae-Yong Kim [a] and Yoon-Suk Chang [a*]
[a]*Department of Nuclear Engineering, Kyung Hee University, 1732 Deogyeong-daero, Giheung-gu, Yongin-si, Gyeonggi-do 17104, Republic of Korea*
[*]*Corresponding author: yschang@khu.ac.kr*

1. Introduction

Postulated High Energy Line Break (HELB) has been considered as a part of design of nuclear safety-related Structures, Systems and Components (SSCs) for a long time. However, recently, technical controversy was raised over the adequacy in assumption of complex phenomena and assessment of dynamic loads. This study is to address blast wave evaluation under a typical main steam line break condition of 1,400 MWe power plant. At first, dynamic loads due to blast wave were estimated by using Computational Fluid Dynamics (CFD) approach. Subsequently, Finite Element (FE) analysis of representative SSCs was carried out to investigate effects of the estimated dynamics loads. Vulnerable position of the Steam Generator (SG) over time was predicted, and the averaged von-Mises stress-time histories on the positions were compared with reference values derived through theoretical correlation and trinitrotoluene (TNT) equivalent approach. Finally, the analysis result of SG was evaluated in accordance with allowable criteria presented by ASME section III [1] during pipe rupture event.

2. CFD analysis

2.1 Fluid model

The CFD model shown in Figure 1 was constructed and the air and compressive zone were optimized for efficient interpretation. Rupture position was determined by referring to a previous work [2], which performed jet impingement analyses.

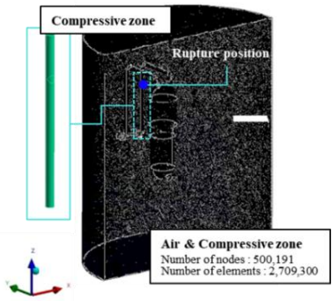

Fig. 1. Numerical model of analysis domains

2.2 Analysis conditions

The initial pressure of the compressive zone was set to 75 bar, which is the operating condition of the main steam line. Also, the optimized time step was set to 2e-5 sec to ensure convergence of each calculation step. The additional mesh adaptation option was applied to increase numerical accuracy by refining grid sizes based on the dynamic pressure gradient.

2.3 Dynamic loads

The CFD analysis was performed using the commercial program of ANSYS Fluent 19.1 [3]. Figure 2 shows the maximum pressure at eight representative points. As the distance from rupture position increases, the pressure values tend to decrease, but the amplified pressure was observed near the SG.

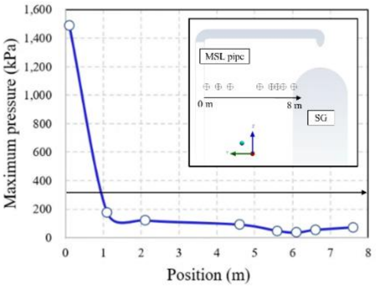

Fig. 2. Maximum pressure–position history

3. Structural integrity assessment

3.1 Analysis model

The structural analysis was performed using ANSYS Mechanical – transient structural 2020 R1 [4]. As shown in Figure 3, FE model composed of four components were developed using 8 nodes element, and their material properties considering Dynamic Increase Factor (DIF) [5] were summarized in Table I [5, 6].

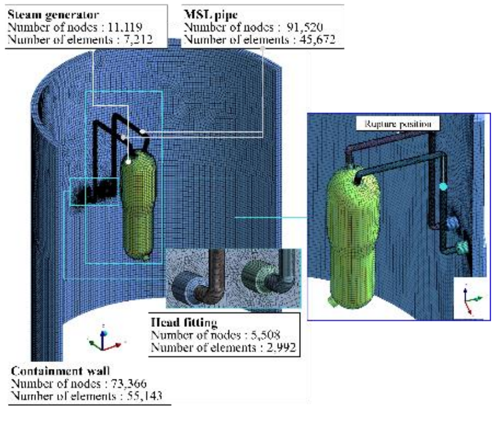

Fig. 3. FE model of SSCs

Table I: Material properties of components considering dynamic effect [5, 6]

Component	Elastic modulus (GPa)	Poisson's ratio	Yield strength (MPa)	Ultimate strength* (MPa)
Steam generator	183.08	0.2	352.32	S_u 583.99
MSL pipe	199.95	0.3	303.36	503.32
Head fitting	183.93	0.3	275.79	503.32
Containment wall	44.79	0.2	73.52**	57.93

*[NOTE] *: Tensile strength, **: Compressive strength*

3.2 Analysis conditions

Coordinate-based pressure values for 0.1 sec were applied to the exterior surface of FE models. Structural analysis was performed with an initial time step of 3e-4 sec, and simplified boundary conditions were also considered at the bottom of the concrete wall and SG.

3.3 Analysis results

The vulnerable positions were estimated through von-Mises stress as shown in Figure 4. Maximum von-Mises stress of SG was derived near the location where the boundary condition was applied, and primary membrane stress intensity (P_m) using stress classification line was about 2.51 MPa on the position.

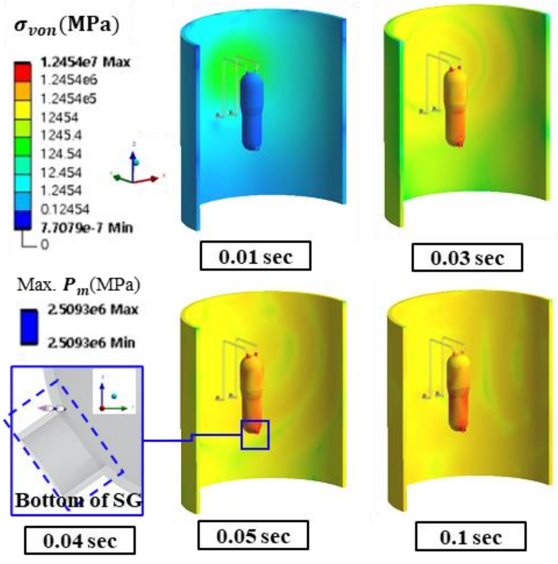

Fig. 4. Distribution of von-Mises stress at four times and Max. P_m of SG

Figure 5 represents averaged stress – time histories derived by three load calculation methods at the bottom of SG. The result of CFD method was comparable with those of other methods verified by previous study [7].

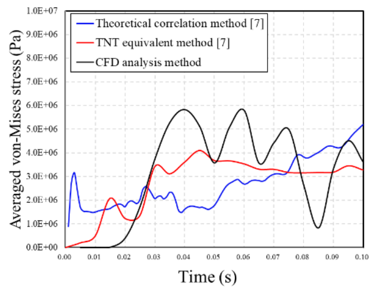

Fig. 5. Averaged stress–time histories at bottom of SG of three load calculation methods

The analysis results of SG were evaluated in accordance with allowable criteria of ASME section III [1] during pipe rupture event. The primary membrane stress intensity (P_m) of SG was compared with allowable ultimate strength limit ($0.7\,S_u$) specified in Table I. Structural integrity of the SG was maintained by satisfying the criteria under blast wave load.

4. Conclusions

In this study, the numerical analyses were performed to evaluate the dynamic load of blast wave and structural effect on SSCs under HELB event.

(1) Dynamic loads and load variation according to geometric conditions were evaluated by performing CFD analysis.

(2) The maximum averaged von-Mises stress at bottom of SG was about 5.9 MPa at 0.4 sec. The result was comparable with those of the other two methods.

(3) The primary membrane stress intensity (P_m) of SG at the vulnerable position was about 2.51 MPa, which is lower than allowable ultimate strength.

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