

Automated System for Blast Response Evaluation of Nuclear Containment Buildings

Tae Hee Lee^a, Yena Lee^a, Jung-Wuk Hong^{a*}

^aDepartment of Civil and Environmental Engineering, Korea Advanced Institute of Science and Technology, 291
Daehak-ro, Yuseong-gu, Daejeon 34141, Republic of Korea

*Corresponding author: j.hong@kaist.ac.kr, jwhong@alum.mit.edu, jungwukh@gmail.com

***Keywords :** blast, nuclear containment, automated system, structural response

1. Introduction

Recent studies on nuclear safety have emphasized the importance of evaluating containment buildings under a broader range of external loading conditions. While current regulatory frameworks primarily address conventional hazards such as seismic events, wind, and aircraft impacts, there remains no standardized methodology for assessing structural responses to blast-type loads. This gap makes it challenging to ensure reliable safety evaluations and to establish effective measures for safeguarding nuclear containment buildings against evolving external hazards.

In this study, an automated system is developed to streamline the entire process of blast scenario simulation and structural damage evaluation for nuclear containment buildings. The system integrates the load blast enhanced (LBE) method in LS-DYNA with a user-friendly pre-processing interface and an automated post-processing module. This integration enables rapid and consistent assessment of containment building safety under a variety of blast threat scenarios.

2. Automated Framework

2.1 Overview of Automated Framework

The automated framework consists of a pre-processing subsystem, referred to as the pre-system, and a post-processing subsystem, referred to as the post-system. These two subsystems work in sequence to minimize manual intervention, reduce the possibility of human error, and ensure that the evaluation process is consistent and reproducible across multiple blast scenarios.

2.2 Pre-system: Scenario Definition and Input Generation

The overall workflow of the pre-system is shown in Fig. 1, which presents the sequential process of scenario definition, blast parameter setting, coordinate calculation, and automatic input file generation. The pre-system is implemented in Python using graphical user interface library. Within this interface, the user specifies the target structural region of the containment building, such as the full containment, the dome, or a

specific wall section. The blast location and standoff distance are then defined, along with the explosive charge weight. The system calculates the three-dimensional coordinates of the blast origin and automatically generates the corresponding input file that is compatible with the LBE method [1]. To ensure the physical validity of the analysis, a validation algorithm checks the scaled distance and prevents the generation of files for unrealistic or non-physical conditions.

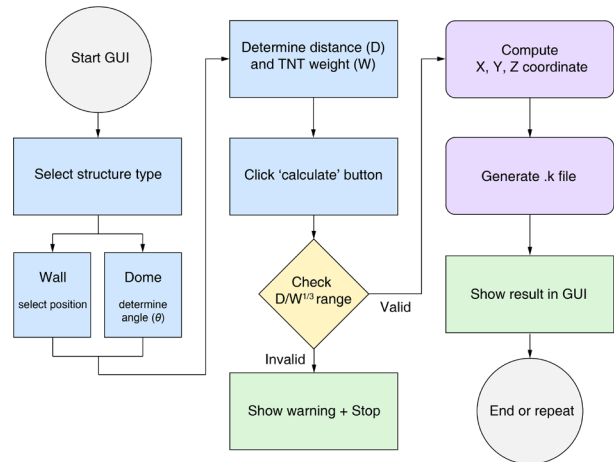


Fig. 1. Workflow of the pre-system for automated scenario definition and input generation.

2.3 Post-system: Automated Result Analysis

The post-system is designed to process the large amount of data generated by blast simulations efficiently and consistently. It extracts information on the time of element erosion from the message files. It correlates the eroded elements with their associated structural components, such as concrete, liner plates, reinforcing bars, and tendons. Using this data, cumulative damage curves for each component type are generated using a Python library. Additionally, the post-system automatically generates images and animations that display the temporal evolution of selected response quantities, including von Mises stress, effective plastic strain, displacement, and velocity. The user can select specific components to visualize, allowing detailed inspection of internal structural behavior that may otherwise be obscured by the exterior concrete walls. The workflow of the post-system is shown in Fig. 2,

highlighting the automated procedure from data extraction to visualization.

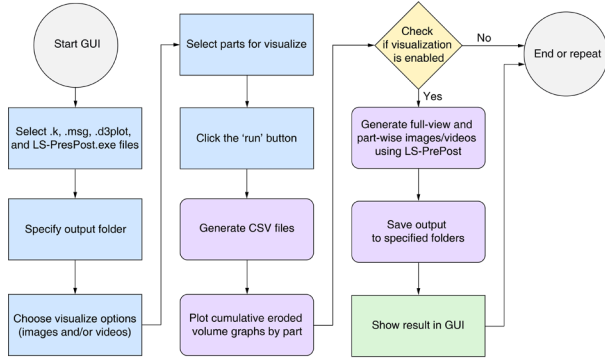


Fig. 2. Workflow of the post-system for automated result analysis.

3. Numerical Analysis

3.1 Numerical Simulation Setup

The automated system is demonstrated using a high-fidelity finite element model of the APR1400 containment building, consisting of approximately 1.2 million elements. Multiple blast scenarios are configured by varying the location, including wall center, wall buttress-adjacent, and dome apex, as well as the standoff distance, which ranged from 5 to 8 m. Each case assumes a 1,000 kg TNT equivalent charge. The blast locations considered in the simulation are shown in Fig. 3.

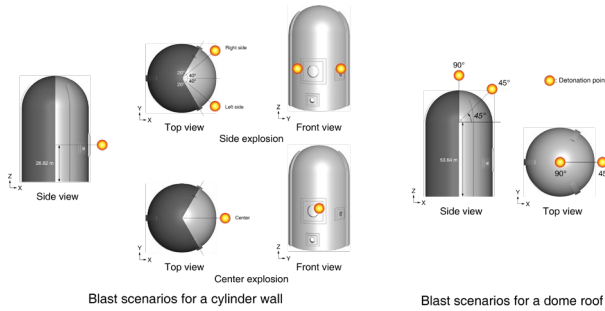


Fig. 3. Blast scenarios considered in the numerical simulations.

3.2 Numerical Simulation Results

As shown in Fig. 4, the total eroded volume curve indicates that most of the damage occurred within the first 50 ms, after which the damage plateaus. The results clearly demonstrate that the closer blast scenarios induced significantly larger damage volumes, whereas the increase in damage diminishes as the standoff distance increased.

To further examine the spatial characteristics of structural deterioration, the damage distribution pattern for the case with an 8 m standoff distance at the dome apex is shown in Fig. 5. The automatically generated damage images capture the progression of failure,

highlighting the concentration of damage near the dome surface and the gradual erosion of elements over time.

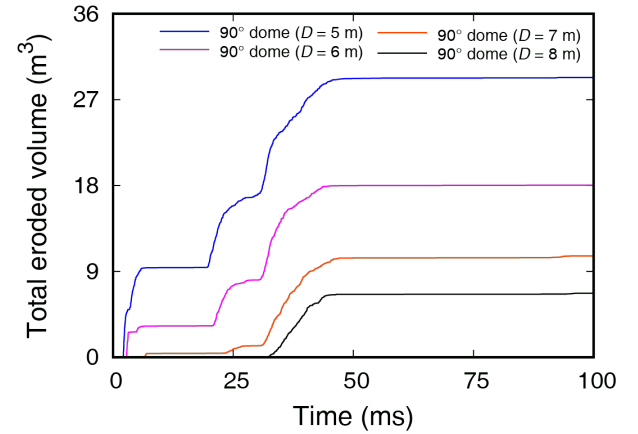


Fig. 4. Variation of total eroded volume for blast loads applied vertically above the dome.

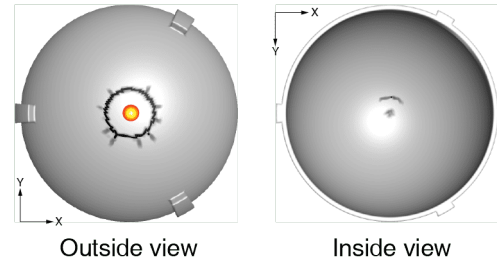


Fig. 5. Damage distribution pattern for the blast scenario with a 1,000 kg TNT equivalent charge detonated 8 m above the dome apex.

4. Conclusions

An automated system for evaluating the blast response of nuclear containment buildings is developed and verified. The system integrates blast scenario definition, finite element model preparation, simulation execution, and post-processing into a unified workflow. This integration eliminates the need for repetitive manual editing of input files, significantly reduces preparation and analysis times, and ensures reproducibility. The automatically generated outputs provide both quantitative and qualitative insights into blast-induced structural behavior, with particular emphasis on the temporal evolution and spatial distribution of damage. By enhancing efficiency, objectivity, and clarity, the system provides valuable support for regulatory safety assessments of nuclear facilities under potential explosive scenarios.

REFERENCES

- [1] LS-DYNA Keyword User's Manual, Livermore Software Technology Corporation, 2024.