Blast Effect Assessment for a Dry Storage Facility

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1. Introduction

Concrete silo is a dry storage facility for spent nuclear fuel (SNF) generated from CANDU reactors and is in operation at Wolsong nuclear power plant site in Korea [1]. SNF, which contains high radioactive materials, can have harmful effects on the surrounding environment and human body if the structural integrity of the containment is damaged.

Explosion such as terror attacks using high explosives have historically continued and may do severe damage to the structural integrity. The damage depends on the blast effect which causes large deformation and rotation which are directly related to the structural integrity and security.

In this study, analyses of the behavior of concrete silo by blast pressure and impulse according to the stand-off distance and explosive charge weight were carried out using LS-DYNA, and the damage levels for each case were evaluated.

2. Analysis Model and Conditions

Fig. 1 shows the concrete wall and reinforcement of concrete silo. As shown in this figure, the concrete wall model was constructed with an external diameter of 3000mm, an internal diameter of 1000mm, a height of 6500mm, and a thickness of 1000mm. The concrete wall was made of solid elements meshing spaced at a distance of 50mm. Reinforcement was modeled with a diameter of 30mm and the elements are made of beam meshing spaced with the same distance of wall elements.

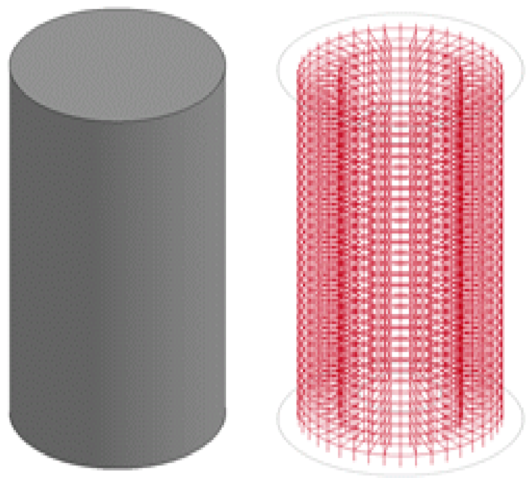


Fig. 1 Modeling of concrete silo

Continuous Surface Cap Model (CSCM) was adopted for the concrete wall. *MAT_CSCM is generally used to analyze dynamic loading of reinforced concrete structures. *MAT_LINEAR_PLASTICITY was adopted for reinforcements as this material model takes the strain rate effect of the steel into consideration so that a more accurate response can be acquired [2].

*CONSTRAINED_LAGRANGE_IN_SOLID card was used to incorporate reinforcements into the concrete mesh. Properties of concrete and reinforcements are shown in Table 1.

Table 1 Material properties

Material	Property (Unit)	Value
Concrete	Mass density (ton/m^3)	2.32
	Compressive strength (MPa)	30
	Young's modulus (GPa)	26.4
	Poisson's ratio	0.15
Reinforcing steel	Yield strength (MPa)	460
	Mass density (ton/m^3)	7.85
	Young's modulus (GPa)	200
	Poisson's ratio	0.3

*LOAD_BLAST_ENHANCED (LBE) provided in LS-DYNA predicts accurate structural behavior by blast load and pressure and it is already verified by previous researches [3]. Explosive charge weights are 1,000 lbs (454 kg), 2,000 lbs (907 kg), and 4,000 lbs (1,814 kg) based on explosion scenarios suggested by ASCE (American Society of Civil Engineers) [3]. The stand-off distance is 2m for all the analysis and explosive is 3m high from the ground which is the middle of the structure.

3. Analysis Results

The blast pressure and impulse were examined. Also, damage levels based on deflection was evaluated.

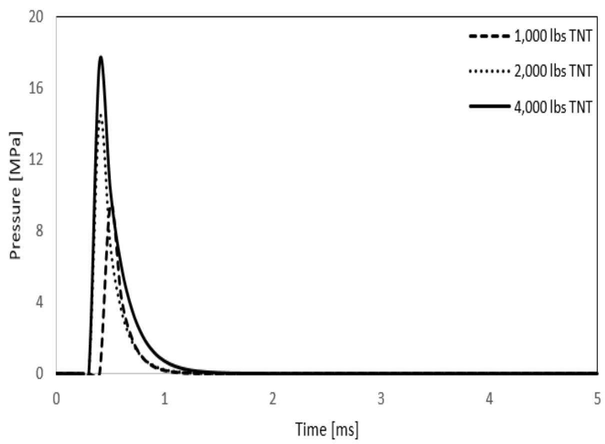
3.1 Blast pressure and impulse

Kinney presents a peak pressure (P_{so}) formulation based on the scaled distance, which depends on the explosive mass and the actual distance from the center of the spherical explosion [4]. The peak incident pressures from the formulation and computational analysis calculations are compared and shown in Table 2.

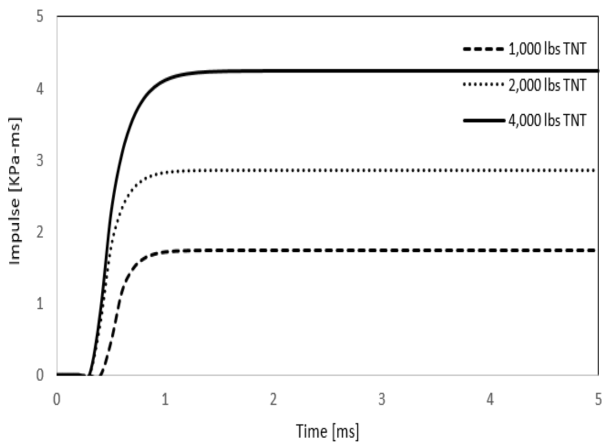
Fig. 2(a) shows the blast pressure-time and Fig. 2(b) represents the impulse-time histories for each explosive mass. The maximum peak incident pressure differences between Kinney formulation and LBE method was 16.36% for 1,000 lbs explosive charge and the minimum was 6.5% for 2,000 lbs TNT.

Table 2 Peak incident pressure P_{so}

Explosive charge (lbs)	Formulation result P_{so} (MPa)	Numerical result P_{so} (MPa)	Difference (%)
1,000	11.315	9.464	16.36
2.000	15.368	14.369	6.5
3,000	20.279	17.507	13.67



(a) Pressure-time history



(b) Impulse-time history

Fig. 2 Analytical results based on TNT weight

3.2 Failure criteria and assessment

ASCE provides the response limits of blast-resistant structures in term of the degree of damage, which are summarized in Table 3 [3].

Light damage means there is no obvious residual displacement. Moderate damage implies obvious bending failure, tensile crack and spallation appear at the bottom and severe damage means exfoliation and spalling occurs at the front and back of the beam, and concrete crack area perforate through the height of beam [5].

Blast assessment results such as relative displacements and damage levels are compared in Table 4 according to explosive charges.

Table 3 ASCE failure criteria

Criteria	Light damage	Moderate damage	Severe damage
Ratio of center-line deflection to span	4%	8%	15%

Table 4 Blast assessment results

Explosive charges (lbs)	Displacement / span length (δ/L)	Damage level
1,000	3.16%	No damage
2,000	6.34%	Light damage
4,000	13.89%	Moderate damage

4. Summary

In this study, blast effect assessment of concrete silo was carried out and the following key findings.
(1) The blast pressure and impulse for different charge weights were analyzed and compared with the formulation proposed by Kinney.
(2) The damage of concrete silo was evaluated according to the failure criteria of concrete structure in ASCE.
(3) With regard to 1,000 lbs explosive mass, there was no damage to the structure. However, for both 2,000 lbs and 4,000 lbs explosive charge weights, light damage and moderate damage were estimated.

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