An Assessment of Concrete Silo Responses to Blast Load Dependent on DIF Relations

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1. Introduction

National and military infrastructures have required a robust structural design for such important facilities to withstand blast loads from explosion events caused by malicious acts launched towards a targeted facility. The dry storage facility using concrete silo for Spent Nuclear Fuel (SNF) is seen as an attractive target for vicious man activities [1]. The blast effect may cause severe damage to the dry storage facility generating radioactive materials leakage leading to a deleterious effect on the public and the environment.

Concrete structure subjected to blast load is usually at a high strain rate [2] accompanied by strength enhancement. To consider this phenomenon, the concept of Dynamic Increase Factor (DIF), i.e. the ratio of the dynamic to static strength, should be adopted. Thus, this study is intended to investigate the behavior of the Reinforced Concrete (RC) specimen with different DIFs using LS-DYNA to suggest an optimal DIF model. The structural integrity for the silo utilizing the determined DIF model was evaluated through the responses of the concrete structure.

2. Analysis method

2.1 DIF relations

The CEB DIF model has been widely used to consider the enhancement of concrete strength at a high strain rate [3]. However, the CEB DIF model underestimated the tensile strength enhancement. Malvar and Crawford suggested a modified CEB DIF model in tension to predict the tensile behavior more accurately than the previous DIFs. These models have been applied in this study, in addition to No DIF.

2.2 Material models

The plasticity-based Karagozian & Case Concrete (KCC) model [4,5] has an advantage for capturing the non-linear behavior of the material under dynamic loading, which was adopted for the concrete material. For rebar and liner, a piecewise linear plasticity metal material model was adopted. The Cowper-Symonds model that scales the yield stress [6] was used to take into account the strain rate of steel materials. The material properties of concrete and rebar for the structure were referred to test data [7]. For the liner, A516 carbon steel was applied [8]. Table I summarizes the data used for analyses.

Table I: Material properties of components [7,8]

Components	Properties (Unit)	Value
Concrete	Compressive strength (MPa)	25.6
	Tensile strength (MPa)	2.2
	Poisson's ratio	0.166
Rebar	Yield strength (MPa)	400
	Mass density (kg/m^3)	7,850
	Young's modulus (GPa)	200
	Poisson's ratio	0.3
Liner	Yield strength (MPa)	485
	Mass density (kg/m^3)	7,800
	Young's modulus (GPa)	200
	Poisson's ratio	0.3

3. Analysis of RC specimen

3.1 Analysis model and conditions

Figure 1 represents the schematic of RC specimen model including the finite element and node information. The dimensions of the concrete slab are $1000 \times 1000 \times 150$ mm. Two layers of rebar are constrained in the concrete slab with 82 mm spacing in x- and y-directions. A 15.88 kg TNT explosion took place at a height of 1.5 m above the center of the RC specimen. The upper and lower edges were fully fixed in both translation and rotation to substitute the role of specimen-supporting angles and clamps.

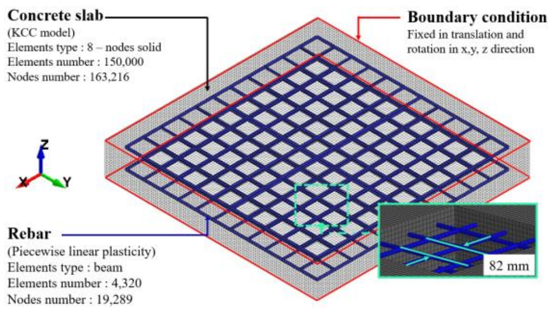

Fig. 1. Schematic of RC specimen [7]

3.2 Analysis results

Figure 2 represents the displacement results of RC specimen from test [7] and numerical analyses using three different DIF models. In comparison with no DIF and CEB DIF, modified CEB DIF model provided better comparable results to the test data with about 1.2 mm difference of maximum displacement. Accordingly, the modified CEB DIF model was employed for the analysis of concrete silo.

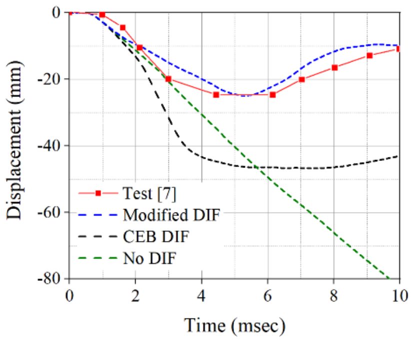

Fig. 2. Comparison of displacement-time histories between test and analysis results

4. Analysis of concrete silo

4.1 Analysis model and conditions

As shown in Fig. 3, the concrete silo was modeled as a cylindrical structure with a radius of 1.5 m and a height of 6.5 m. The rebar with diameters of 30 mm is located in the concrete wall stretching for radial and vertical directions. A liner with 9.5 mm thickness was located inside the concrete wall. The explosive was set at 3.5 m stand-off away from the surface of the structure and at 3 m high with charge weights of 45 kg, 454 kg and 907 kg based on criteria suggested by ASCE [9]. The bottom surface of the concrete wall is fixed in translation and rotation for all directions and the rebar is constrained in the concrete wall.

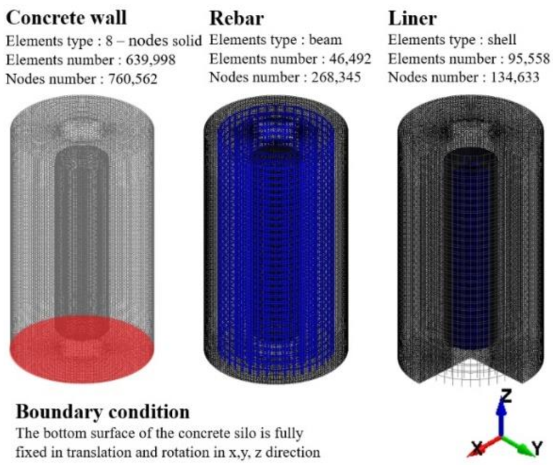

Fig. 3. FE models of concrete silo

4.2 Analysis results

The effective stresses were compared to the yield strength of the liner to evaluate structural integrity of the silo for each blast scenario. Figure 4 represents the analysis results. The resultant maximum effective stress on the liner was 284 MPa in case of 907 kg weight of TNT which is about 42 % lower than the yield strength of the liner.

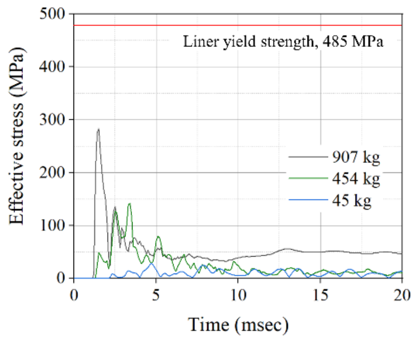

Fig. 4. Comparison of effective stress histories of liner for each charge weight

5. Conclusions

In the present study, the influence of DIF relations with the RC specimen was evaluated and the structural integrity assessment of the concrete silo was performed. The conclusions of this study are as follows:

(1) The modified CEB DIF model predicted the most accurate behavior of the RC specimen within 5 % difference of maximum displacement at the bottom center compared to the experimental data. No DIF and CEB DIF models overestimated the responses of the RC specimen.

(2) The resultant maximum effective stresses on the liner for all charge weights were less than the yield strength. Numerical results demonstrate that the concrete silo was evaluated to be safe under all the chosen explosive charge weights.

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