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Safety evaluation of HIC based on the Type A transport requirement

Dongin Park[a], Hyolim Lee[a], Sanghoon Lee[a*]
[a]*Department of Mechanical Engineering, Keimyung Univ., Daegu 42601, Korea*
**Corresponding author: shlee1222@kmu.ac.kr*
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1. Introduction

In South Korea, specialized containers are developed and utilized for the disposal of low- and intermediate-level radioactive waste. The structural safety of High Integrity Containers (HICs) is traditionally evaluated using elastic models to assess their mechanical robustness. However, conventional computational methods have limitations in directly analyzing the increase in surface radiation dose rates due to structural damage. To enhance accuracy, this study employs the Concrete Damage Plasticity (CDP) model to assess crack initiation and propagation within concrete. The structural integrity of a reference HIC with concrete overpack designed to meet Type A transport package requirements, was evaluated using both the elastic and CDP models. By comparing the results from both approaches, this study provides a comprehensive assessment of structural reliability and its influence on shielding performance.

2. Methods and Results

This section describes the safety test standards for Type A transport containers and the FEA using the elastic model. It includes the safety test standards, analysis conditions, and analysis results.

2.1 Type A transport requirement

The transport container for low- and intermediate-level radioactive waste must meet the IAEA's technical standards for Type A transport containers. These standards ensure that under normal conditions, no loss or dispersion of radioactive material occurs after testing, and the increase in surface dose rate remains below 20%. The key performance tests include:

- Stacking: A load five times the container's weight is applied to the top.
- Lifting: A load three times the container's weight is applied, simulating lifting conditions.
- Penetration: A hemispherical bar (3.2 cm diameter, 6 kg) is dropped freely from 1 meter onto the weakest point of container.
- Drop Test: A free-drop test is conducted with the most damaging posture based on the package weight as specified in Table 1.

Table I: Drop height

Weight (kg)	Drop height (m)
Weight < 5,000	1.2
5,000 < Weight < 10,000	0.9
10,000 < Weight < 15,000	0.6
15,000 < Weight < 20,000	0.3

2.2 FE modeling

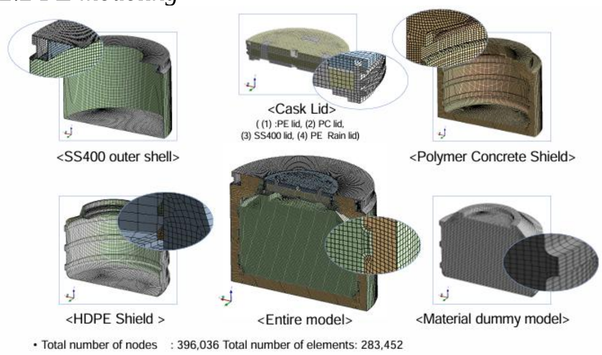

Fig. 1. Modeling of reference HIC

Table II: Material Properties

Component	Yield Strength (MPa)	Tensile Strength (MPa)	Compressive Strength (MPa)
HDPE	-	19	19
SS400	250	400	400
POLYMER CONCRETE	-	14	118

For efficient analysis, a finite element model of the reference HIC was developed using a 1/2 symmetry condition, as shown in Figure 1. Most regions were modeled with C3D8R elements, while S4 elements were used for the outer shell. The material properties were defined based on elasticity, with selected values provided in Table 2. Boundary and loading conditions varied for each test and are detailed in Figure 2 and Section 2.1.

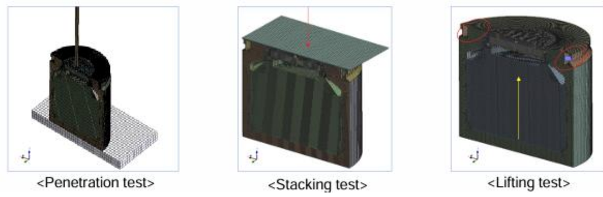

Fig. 2. Symmetry Model and Load condition

2.3 FEA results

The analysis results are shown in Figure 3. There is a high likelihood of cracking in the polymer concrete but the volume of concrete is maintained. This implies that the increase in external dose rate due to concrete damage is negligible. However, the cracking pattern predicted in this simulation is not accurate due to the limitation in the material model for concrete. To improve this, more sophisticated model for concrete is necessary, which can provide detailed information on the cracking pattern of concrete under impact load.

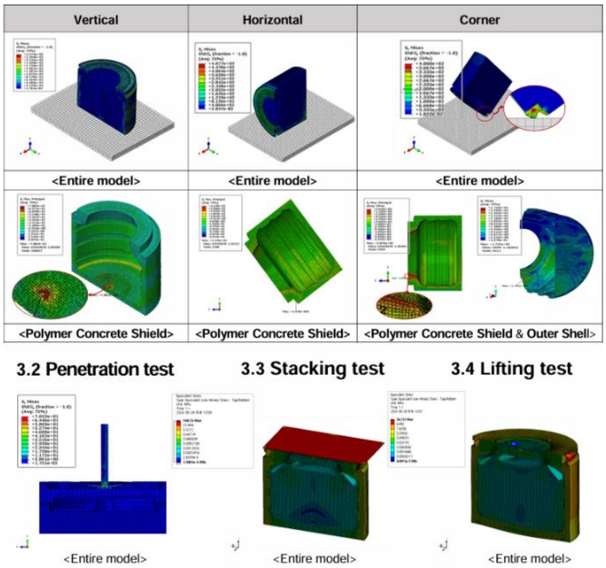

Fig. 3. Analysis result with concrete modeled as elastic

3. FEA by using CDP material model

3.1 CDP (Concrete Damaged Plasticity)

The CDP model is a material model for simulating concrete behavior in ABAQUS, enabling the assessment of concrete cracking through nonlinear analysis. The compressive stress-strain relationship of concrete was defined using the ABAQUS CDP material model, and the corresponding equation is as follows.

$$\varepsilon_c^{pl} = \varepsilon_c^{in} - \frac{d_c}{(1-d_c)}\frac{\sigma_c}{E_0}$$

where ε_c^{pl} is compressive plastic strain, ε_c^{in} is compressive inelastic strain, d_c is compressive damage parameter, σ_c is compressive stress, and E_0 is elastic modulus for undamaged concrete.

Damage parameter can be derived from a material test with ramped loading/unloading cycles shown in Fig. 4.

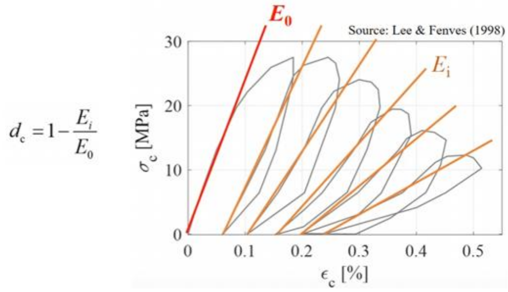

Fig. 4. Relation Equation of damage parameter

3.2 Method of concrete strength test

To obtain the material properties of concrete, compressive strength tests and splitting tensile strength tests will be conducted in accordance with KS F 2403 to define the compressive stress-strain relationship. The compressive test will be performed with an axial compression rate of 0.6 mm/s to prevent impact, while the tensile test will be conducted with a circumferential compression rate of the same value. The test methods and specimens are shown in Figure 6.

Fig. 6. Concrete test method (Left : compression, Right : Tensile)

3.3 CDP-Based FEA Results

The material parameters of the CDP will be derived from the concrete test data and will be validated by simulating the material test with ABAQUS. The validated CDP will be implemented into the FE model of reference HIC and the safety evaluation results will be compared in near future.

4.Conclusions

In this study, material tests were conducted using polymer concrete, and the obtained data were incorporated into the CDP material model for analysis. The results will be compared with those from conventional elastic analysis. Beyond existing analysis results for concrete containers, crack prediction will be performed to provide a more reliable assessment of the potential increase in external dose rate due to linear cracks within the concrete.

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