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Numerical Analysis for Structural Integrity of a Fresh Fuel Shipping Container

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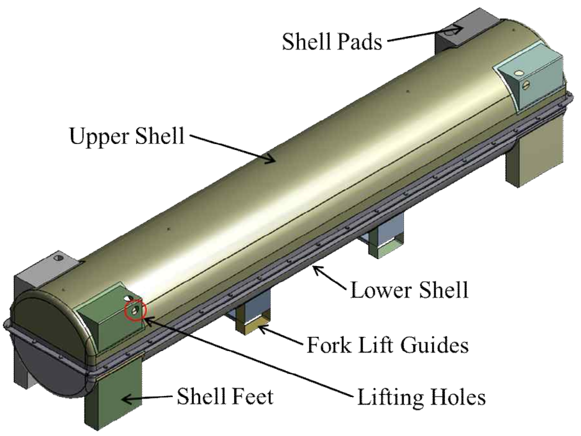
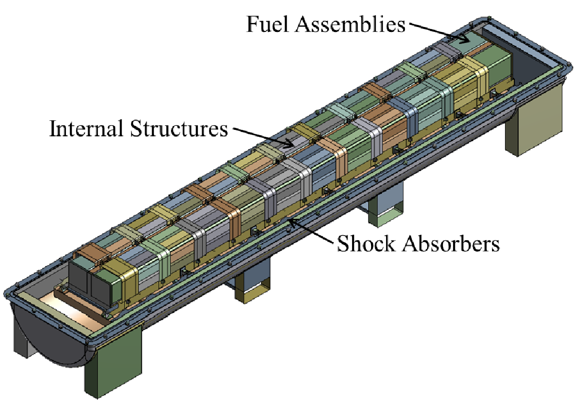
1. Introduction

The fresh fuel shipping container in the nuclear industry is used to prevent leakage of un-irradiated radioactive materials and to maintain integrity of nuclear fuels during transportation [1]. The structural behaviors are important to maintain the integrity of the shipping container in normal conditions of transport (NCT) based on the design requirements [2,3 and 4]. The structural behavior characteristics are dependent on stacking, shipping and handling situations. To satisfy these conditions, the design criteria for NCT follow the regulatory requirements proposed in NSSC Notice 2017-56 [2], 10CFR71 [3] and SSR-6 [4].

In this study, the finite element model of the shipping container was developed and analyzed to evaluate the structural characteristics in NCT. ANSYS version 17.2 [5] was used for numerical analyses.



(a) All components



(b) without upper shell

Fig. 1. Configuration of nuclear fuel shipping container

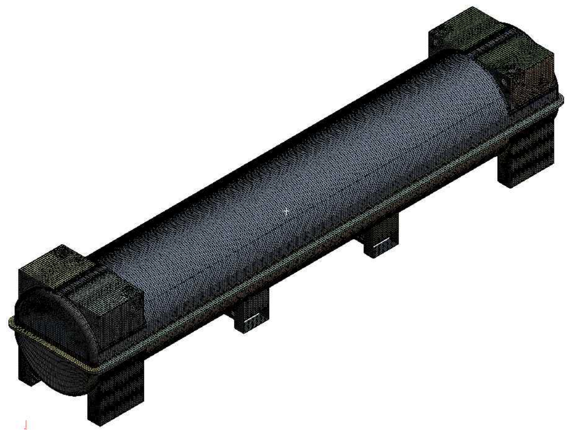


Fig. 2. Finite element model for analysis

2. Configuration

Fig. 1 shows the overall shape of the nuclear fuel shipping container. The container is composed of a pair of mating semi-cylindrical shells with both ends plugged. The upper and lower shells are double layered with the inner and outer shells charging the fire retardant polyurethane foam which is used for shock absorption and thermal insulation. Four shell pads are installed on the upper shell to allow vertical stacking of shipping containers during storage. The upper shell is removable to load and unload the fuel assemblies. The internal structures accommodate and secure the two fuel assemblies. Shock absorbers connected to lower shell support the internal structures and reduce vibration forces from outside.

3. Finite Element Model

Fig. 2 shows the finite element model for the analyses. Only structural components were maintained in the finite element geometry. The model mainly consists of shell elements to represent the plates. The modeling of the internal structures was eliminated to simplify the finite element model and then the equivalent weight of the internal structures was applied to the lower shell by adding distributed mass. The number of nodes and elements are 417158 and 202465, respectively.

4. Structural Analyses

4.1 Design Requirements

The analyses consist of stacking and lifting conditions in this study. These analyses must abide by regulatory re

Table I: Material Properties for A240 Type 304

Material property	Value
Young's modulus	195000 MPa
Poisson's ratio	0.31
Yield strength	205 MPa
Tensile strength	515 MPa

-quirements. The requirements say the container must withstand a compressive load of five times the weight of the container in the stacking condition and the lifting attachment must resist three times the weight of the container in the lifting condition, respectively.

4.2 Material Properties

Most components of the container are made of A240 Type 304 stainless steel. The material properties for stainless steel are obtained from the ASME B&PV Code [6] as shown in Table I.

4.3 Boundary Conditions

For the stacking analysis, fixed supports were applied to the bottom surface of each shell foot. The compressive loads divided by the number of shell pads were applied to each shell pad and a gravitational acceleration was applied to all bodies.

Fixed supports were applied to the edges of the contact regions between the lifting hole and the lifting shackle for the lifting analysis. An acceleration equal to three times the standard gravitational acceleration was also applied to the container.

4.4 Analysis Results

The numerical analyses for the shipping container based on the design requirements were performed and the structural behaviors in NCT are represented below.

Fig. 3 shows the von Mises stress of the container in the stacking condition. The maximum stress is below the yield strength and appears on one of the shell feet.

Elastic-plastic analysis was performed for the lifting condition and Fig. 4 shows the von Mises stress. The maximum stress occurs in one of the lifting holes. The model shows that the lifting hole locally yields at the site of the contact with the lifting shackle to redistribute the applied loads but not fail. So, the integrity of the shell pad has no problem.

5. Conclusions

In this study, the analytical evaluations of the shipping container in NCT for the nuclear fresh fuel were performed in accordance with the regulatory requirements. The finite element model of the shipping container was developed to predict structural behavior c

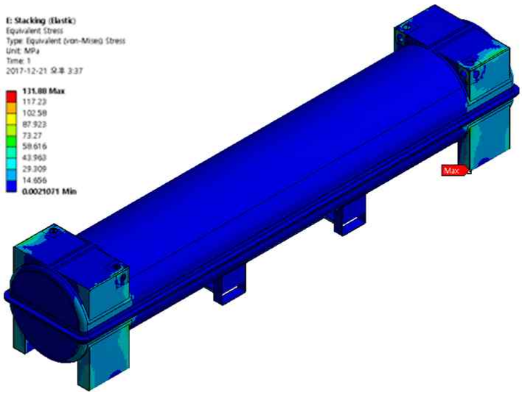


Fig. 3. Equivalent stress for stacking analysis result

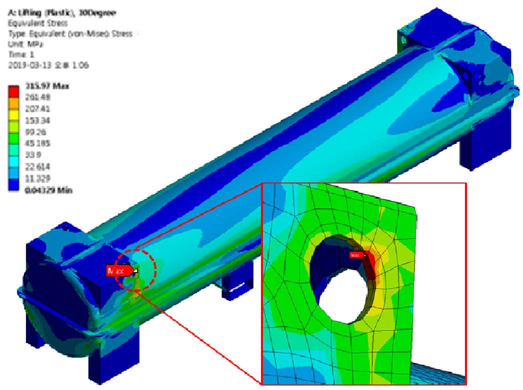


Fig. 4. Equivalent stress for lifting analysis result

-haracteristics. The material properties of stainless steel from ASME code were applied to the analysis model. As a result, the shipping container maintains the structural integrity. Especially, there was a locally yield region but no impact on the integrity of the container in the lifting condition.

The analysis results will be verified through comparison with the test results in the following study. The finite element model and the analysis results would be applicable to the container design modification and development as well.

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