Study on the Impact Limiter Design for the Spent Fuel Transport Casks

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1. Introduction

A shipping cask transporting the spent nuclear fuels of nuclear power plants should secure the safety from the risk of public exposure to a radioactive material. According to the applicable codes and standards, the cask should maintain the structural integrity not only in normal condition but in hypothetical accident condition so that the inner material may not leak. The case of 9-m drop is significantly considered as the worst scenario among the accident conditions in structural design viewpoint.

In general design, impact limiters are attached near the top and the bottom of a cask body to release the impact force by cask drop as a shock absorber. The steel casing of impact limiters are filled with light and plastic or combined materials like Polyurethane foam and Balsa wood, which transfers a reduced impact load to the cask body by absorbing the kinetic energy of a cask assembly by plastic deformation of the limiters.

2. Modeling and Analysis Method

Drop analysis of the cask can be generally performed using a simplified 3-D half model based on the structural symmetry to reduce the analysis time. Fig.2 is an actual FEM model of the cask with impact limiter attached which is used for the 9m free drop analysis. The 4 lifting lugs are omitted for the modeling purpose because those do not affect to the impact behavior of the whole assembly. The effect of bolting at the mating surfaces between the cask body and the lid is expressed by modeling a contact surface of the ABAQUS/Explicit program. The internal structure of cask, where the fuel assemblies are stored, is simplified as a mass dummy for the analysis purpose. The impact limiter is assumed to be made of Balsa wood inside the casings, and to have a thickness of 400 ㎜ in both radial and axial direction. The limiter casing is assumed to be very thin so that its structural effect can be negligible, thus it is not separately modeled in this analysis. The surface between the cask and impact limiter is assumed to be frictionless. Because it appears discontinuous and geometric nonlinearity in case friction exists at the surface, it is assumed to transfer only the axial stress thru the surface. The element used for the cask body model is 3-D 8-node solid element, C3D8R in ABAQUS.

A desirable design direction of the impact limiters are searched by some trial design changes and sensitivity analysis to minimize the impact of the cask body at 9m drop accident.

3. Design Evaluation

For the safety evaluation of the cask, the stresses of each component are compared with the allowable stresses based on the Tresca's maximum shear stress theory. The structural integrity of the cask is assumed to be maintained if the stress remains less than the lesser of 2.4 times of the design stress intensity S_m or 0.7 times of the ultimate strength of the material S_u in accidental condition.

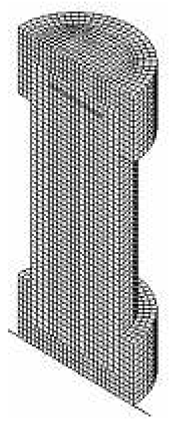

Fig. 1 FEM Model of the Cask and Impact Limiter

Table 1 Mechanical Properties of Cask and Limiter Materials

Mechanical Properties	SA-350	Balsa Wood
Young's Modulus(MPa)	191674	670
Poisson's Ratio	0.3	0.49
Yield Stress (MPa)	258.6	13.6
Tensile Strength (MPa)	482.6	-
Density (kg/m³)	7800	163

4. Effect of Impact Limiter Material

The 9m drop impact analysis has been done by gradually increasing the Young's modulus of the limiter material under the assumption that the Balsa wood is isotropic and elastic-perfect plastic. As depicted in Fig.9, the maximum stress of the cask appears near13.6MPa of the yield stress of the limiter material. Though it shows a nonlinear trend for the whole range of the yield stress, the max. stress of the cask can be avoided by choice.

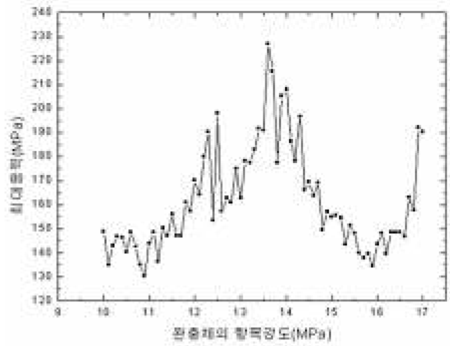

Fig.2 Max. Stress of Cask vs. Yield Stress of Limiter

5. Effect of Impact Limiter Size

As the overall size of cask impact limiter becomes less, it would increase the efficiency of handling and transportation of the cask. However, the design should be optimized to maximize the absorption of impact load transferred from outside to the cask body and to assure the cask stress within the allowable limit.

The size of the impact limiter is considered for the thickness in two sectional directions as shown in Fig.11. And the sensitivity analysis is done by changing the design parameters of radial direction and of circumferential direction. In Fig.12, it is shown how the stress of the cask body is affected by the change of limiter thickness through the 9-m drop impact analysis of the cask. In vertical drop accident analysis, as it can be expected, the stress of the cask body turns out to be more sensitive to the thickness change of limiter in axial direction while the thickness change in radial direction has negligible effect. And in horizontal drop accident, it shows in opposite way to the vertical case. In vertical drop, by the way, the cask stress initially decreases as the axial thickness of the limiter increase until it reaches 200mm. However, the stress changes to increase unexpectedly as the thickness increases from the point. And this trend also appears similarly in case of horizontal drop.

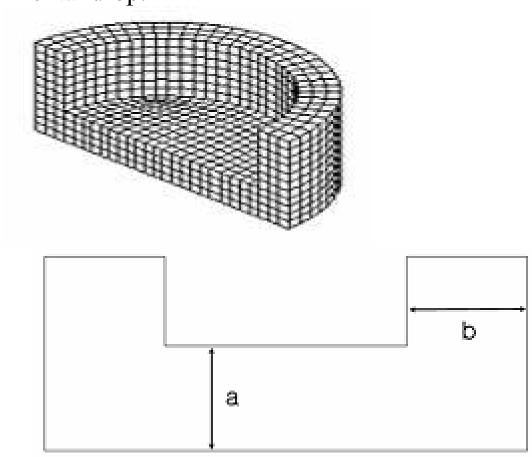

Fig.3 Sectional Thickness Design of Impact Limiter

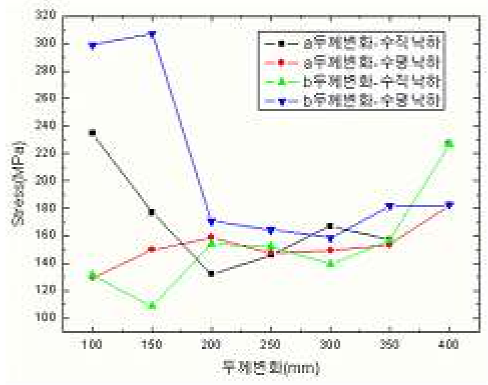

Fig.4 Stress of Cask Body by Impact Limiter Thickness Change

6. Conclusions

Impact analysis using FEM model has been performed for the various design size and material property of the impact limiter. The result is evaluated for the effect of limiter design on the structural integrity of the spent fuel cask body by drop impact. From the results, followings are concluded.

(1) It is proposed how the structural integrity of the transport cask body can be checked through 3-D dynamic analysis and simplified modeling of the cask made up of complicated component and various material.

(2) The design sensitivity of the width and thickness of the impact limiter on the stress of the cask body is evaluated

(3) The effect of material selection of the impact limiter is investigated on the limitation function of the cask drop impact load.

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