Structure Evaluation of the High Capacity Cask for the Transport of CANDU Spent Fuel Bundle on the 0.3m Base Drop Condition

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1. Introduction

In the case of Wolsong Nuclear Power Plant, a heavy water reactor type nuclear power plant in Korea, Spent Nuclear Fuel (SNF) is stored in a dry storage facility. The current storage capacity is expected to reach the point of saturation within several years. Even when additional construction of the modules being promoted is completed, it is expected that SNF should be transported to interim storage facilities after around 2035. The HI-STAR63 transport cask currently in use in Wolsong Nuclear Power Plant can transport 120 bundles. When full scale transportation starts in the future as the storage space is insufficient, The HI-STAR63 is at a disadvantage in many respects such as transportation capacity, handling procedure, transportation cost, etc. Accordingly, a transportation cask that can transport a large amount of heavy water reactor spent nuclear fuel is required to be developed.

In the present study, we intend to evaluate the structural integrity of the high capacity cask for the transport of 360 CANDU spent fuel (HCC) being currently developed by way of free drop under normal conditions.

2. Analysis Methods

A free drop analysis of the HCC under normal transportation conditions was carried out being divided into two stages. In the first stage, a static analysis for application of a pre-load to the cask lid bolt was carried out. In the second stage, a free drop analysis was carried out using the bolt load as the initial condition.

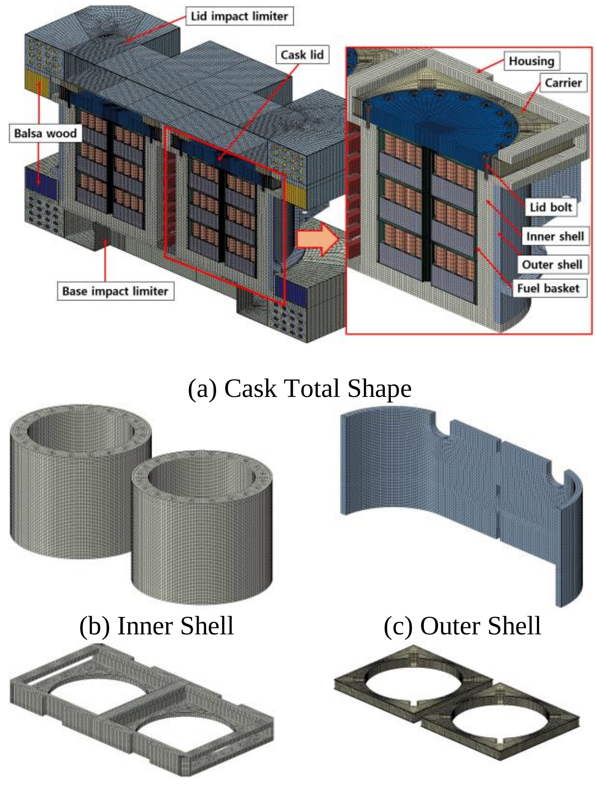
2.1 Material Properties

In the drop analysis under normal conditions, ASME B&PV Code Section II, Part D has been referred to for material properties of the transport cask.[1] For the balsa wood used as an impact absorber, the material properties obtained from a test were used.

2.2 Analysis Model

The shape of the HCC is as shown in Figure 1(a). The impact limiter for shock absorption are attached to the upper and lower sections of the transport cask. The impact limiter is a thin steel shell, inside of which is filled with balsa wood for shock absorption.

The HCC is comprised of two cylindrical inner shells and an outer shell that covers the inner shells. The two inner shells form the containment boundary together with the lids and total 6 fuel baskets(60 CANDU spent fuel) can be stored inside them. In the upper section of the cask, there is a carrier and a housing for opening and closing of the lid.



(a) Cask Total Shape

(b) Inner Shell (c) Outer Shell

(d) Housing (e) Carrier

Fig. 1 Analysis model

For evaluation of behaviors under different drop conditions, finite element modeling of the HCC was carried out using ABAQUS V.2017, a general purpose code.[2] An elastic analysis was carried out for the cask lid and inner shells that form the containment boundary in accordance with ASME B&PV Code Section III, Division. 3 WB, and an elasto-plastic analysis was carried out for other components.[3] As to the wood of the impact limiter, the crushable form material model of ABAQUS was used.

For the bolts fastening the base impact limiter, beam elements were used and solid elements were used for other components. For the finite element analysis model of the transport cask, 1,601,259 nodes, 1,135,133 solid elements, and 132 beam elements were used.

2.3 Load & Boundary Conditions

Drop height was applied to the drop analysis under normal transportation conditions depending on the weight in accordance with Announcement No. 2019-7 of the Nuclear Safety and Security Commission.[4] As the weight of the HCC is about 120 ton, it has been assumed that free drop is carried out at the height of 0.3 m. Fully restrained condition was applied to the bottom plate of the rigid body not to allow any change in the displacement and the degree of freedom when an impact is applied. As to the contact condition, the general contact option provided by ABAQUS was applied. As to the coefficient of friction, 0.2 which is the general coefficient of friction of metal material was applied.

3. Analysis Result & Conclusion

A 0.3 m free drop analysis of the HCC was carried out under normal transportation conditions and the energy-time history curve is as shown in Figure 2. As the energy curve was gentle, no numerical instability was shown, and the energy loss which occurred during the analysis was shown to be less than 5 %. The analysis on the drop conditions was appropriately carried out.

The 0.3 m free drop analysis result of the HCC under the normal transportation conditions and the stress distribution are as shown in Table 1 and Figure 3. The allowable stress for the normal transportation conditions was applied in accordance with ASME B&PV Code Section III, Division. 3 WB. As a result of the analysis, all the components were shown to satisfy the stress limits as shown in Table 1. Though the biggest stress appeared at the bolt, it was generated by the pre-load. Excluding the bolt, the biggest stress was generated in the inner shells. As to the safety factor for allowable stress, Pm at the fuel basket was the smallest showing a value of about 1.4, and relatively high safety factor was secured for other components.

Table 1. Analysis result Unit : MPa

Component	Material	Stress Type	Allowable Stress	Result	Safety Ratio*
Lid Bolt	SA-193 Gr.B7	Average	482	311.2	13.5
		Shear	290	3.87	10.9
		Maximum	723	324.7	6.6
Cask Lid	SA-182 Gr.F6NM	Pm	264	30.2	8.7
		Pm+Pb**	396	58.2	6.8
Inner Shell	SA-350 Gr.LF3	Pm	161	9.9	16.3
		Pm+Pb	241.5	24.7	9.8
Bottom Plate	SA-350 Gr.LF3	Pm	161	25.7	6.3
		Pm+Pb	241.5	28.7	8.4
Outer Shell	SA-240 TP.304	Pm	138	29.3	4.7
		Pm+Pb	207	53.9	3.8
Fuel Basket	SA-240 TP.304L	Pm	115	79.8	1.4
		Pm+Pb	172.5	107.2	1.6

* Safety Ratio : Allowable stress / Result

** Pm : Primary membrane stress

Pb : Primary bending stress

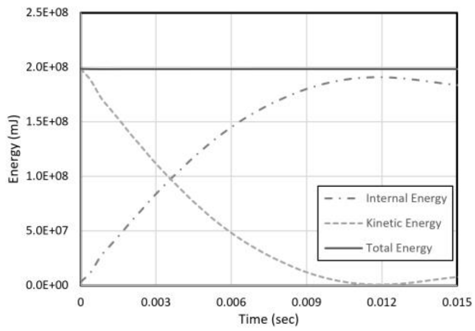


Fig. 2 Energy Time Relation

4. Analysis Result & Conclusion

As the result of a 0.3 m drop analysis under the normal transportation conditions showed that the stress at all components was smaller than the limit, the HCC was evaluated to have secured structural soundness. The inner shells and the cask lid that are the containment boundaries are maintaining containment.

ACKNOWLEDGMENTS

This work was supported by the Korea Institute of Energy Technology Evaluation and Planning(KETEP) and the Ministry of Trade, Industry & Energy(MOTIE) of the Republic of Korea (NO. 20171710201750)

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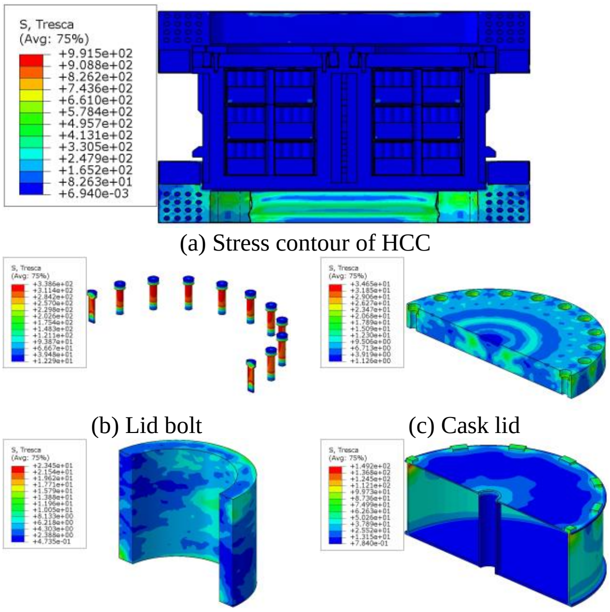

(a) Stress contour of HCC

(b) Lid bolt (c) Cask lid

(d) Inner shell (e) Fuel basket

Fig. 3 Stress Contour of 0.3m Base Drop