INERTIA EFFECT OF THE FUELS IN A STORABLE TRANSPORT CASK ON THE IMPACT ACCIDENTS

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SUMMARY

A storable transport cask named KSC-28 has been developed by KAERI in Korea. The structural evaluation of the KSC-28 cask was carried out for typical impact orientations to assess the inertia effect of the massive weight of spent fuels loaded in the cask on the impact conditions. The impact analysis model considered the internal structures of the cask, such as fuel baskets and basket fixing disc plates, as well as dummy fuel elements. The impact forces, stresses, and deformations were compared for both the empty and loaded casks. The results show that the inertia of fuels increases the impact damage of the cask significantly and changes the stress distributions of the cask.

INTRODUCTION

The Korea Atomic Energy Research Institute (KAERI) has developed a large storable transport cask (KSC-28). All casks used for the storage and transportation of spent nuclear fuels must demonstrate the ability to maintain their structural integrity during the hypothetical drop impact accidents using the load conditions which will give the maximum damage to the cask as required by the domestic regulations and the IAEA standards (IAEA 1990). The KSC-28 cask can transport and store 28 PWR spent nuclear fuel assemblies with 10 years of cooling time. This large number of spent fuel assemblies weighs about 18 tons and serves as an inertia load on the impact accidents. Therefore the structural evaluation of the large cask should consider the effect of spent fuels and internal structures on the impact accidents carefully.

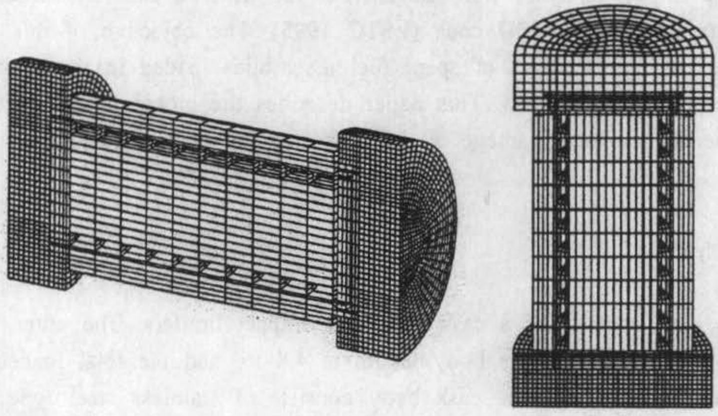
The free drop impact analyses were carried out for KSC-28 cask by finite element analysis using the LS-DYNA3D code (LSTC 1995). The objective of this study is to investigate the inertia effect of spent fuel assemblies loaded in the cask against the accidental impact conditions. This paper describes the global impact behavior of the cask, whereas the local damage of the cask was not considered.

ANALYSIS MODEL

The KSC-28 cask consists of a cask body and impact limiters. The outer diameter of the cask body is 2.5 m, the body length is 4.8 m, and the total loaded weight of cask is about 110 tons. The cask body consists of stainless steel type 304 for the structure, lead for the gamma shield and silicone mixture for the neutron shield. The multi-layered structural shells consist of inner shell, intermediate shell, and outer shell. The impact limiters are constructed from stainless steel casings and wood blocks. The steel casings have internal gussets which enclose the wood blocks. Balsa wood and redwood are used for energy absorbing materials.

The structural analysis was conducted by three dimensional analysis models using the LS-DYNA3D code. A half-section of the cask was modeled using symmetric geometry and the symmetry boundary condition was applied to all nodes located at the symmetry plane. Fig. 1 shows the FEM models used for the 9-m horizontal drop and vertical drop. The model-(a) consists of 40,472 nodes, 24,096 solid elements and 8,279 shell elements. The impact limiters are modeled using shell elements for the steel case and gusset plates and solid elements for the wood blocks. For the bottom-end on drop analysis, the top impact limiter parts were replaced by coarse mesh.

Lead and silicone mixture were poured into the space between the shell structures, and the interfaces between the stainless steel structures and the shielding materials are remained in a simple contact state instead of chemical bonding. Therefore, several parts of the components were modeled separately and assembled together, and these interfaces between the materials were considered using the automatic contact elements. The interfaces of the bolted area between the cask body and impact limiters were constrained by combining their retaining parts with tied interfaces. For simplicity, the bolted area of the cask lid was constrained to the cask body by the rigid nodal constraint condition.



(a) horizontal drop (b) vertical drop

Fig. 1 FEM models of KSC-28 cask for impact analysis.

The metal structure of steel case and gusset plates and their interfaces with wood blocks were taken into account, because balsa wood and redwood blocks are inserted into the steel case in axial and radial directions, and have orthogonal crush characteristics (Attaway and Yoshimura 1989). Accordingly, the interfaces between the wood blocks and the steel case were considered by the automatic single surface contact option, and the crush characteristics of woods according to the grain directions were considered (Cramer et al. 1995). Fuel baskets and basket retaining discs were modeled using shell elements, and spent fuel assemblies were modeled using solid elements with an equivalent density, according to the load combination regulations, as described in Regulatory Guide 7.8 (U.S. NRC 1989). For the impact analysis of the empty cask, these fuel elements were omitted.

All material properties were assumed as elastic-plastic with their strain hardening moduli for the exact simulation as possible. Though the Regulatory Guide 7.6 (U.S. NRC 1978) requires the elastic analysis for containment boundaries, the concern of this study is focused on the exact impact behavior. The late tendency for structural analysis is establishing non-linear dynamic analysis criterion of the cask for more accurate characterization of the cask response under accident loadings.

The initial velocity of 13.3 m/sec was applied to all nodes as a load condition in a direction normal to the stonewall. This impact velocity is consistent with a free drop height of 9m. Other loads, such as internal pressure, were neglected, because there were not the concern of this study. The unyielding target was simulated by stone wall option as an infinite flat rigid surface fixed in the space, and all nodes which were expected to be contacted with the target surface were modeled as sliding with void interface element.

ANALYSIS RESULTS

Figure 2 shows a comparison of the impact force-time histories of empty and fuel loaded casks acting on the target for 9-m bottom-end on drop. This figure shows that the analysis results of the 9-m bottom-end on drop were very similar, except for a small difference in magnitude. The maximum impact forces were 72 MN at 17 ms after impact initiation for the empty cask, and 81 MN at 18 ms for the loaded cask. The impact behaviors were very similar with each other, but impact force was increased about 12% and impact duration was increased 3 ms for the loaded cask. Figure 3 shows the deformed shapes and stress contours of the loaded KSC-28 cask. The maximum deformations of the impact limiter were 147 mm for the loaded cask and 143 mm for the empty cask at 22 ms.

The maximum stresses of the loaded cask were 75 MPa in inner shell and 87 MPa in intermediate shell at 16 ms. For the empty cask, the maximum stresses were 80 MPa and 84 MPa each, and there were no significant difference. However, for the bottom part, which receives the impact force of spent fuels directly, the maximum stress was increased by about 39%, from 74 MPa to 103 MPa.

Figure 4 shows a comparison of the impact force-time histories of empty and fuel loaded casks acting on the target for 9-m horizontal drop. This figure shows a larger difference in magnitude than for the bottom-end on drop. The maximum impact force of the loaded cask was 72 MN at 37 ms, and the impact force was decreased rapidly after 38 ms. The maximum deformation of the impact limiter for the loaded cask was 306 mm at 37 ms, and this time was much delayed compared to the bottom-end on drop. However, the maximum impact force of the empty cask was decreased significantly by about 42%, to 50 MN at 27.5 ms.

The maximum stresses in the shells of the loaded cask were 81 MPa at inner shell and 93 MPa at intermediate shell at 30 ms after impact. Fig. 5 shows a comparison of the stress-time histories of the casks. The maximum stresses in the shells of the empty cask were decreased by up to 20% compared to loaded cask as 65 MPa at inner shell and 82 MPa at intermediate shell. The impact duration of the empty cask for horizontal drop impact was much shortened than for bottom-end on drop. The maximum deformation of the impact limiter was decreased by about 19%, to 254 mm at 33 ms. Fig. 6(a) and (b) show the deformed shapes and stress contours of loaded cask for horizontal drop impact.

DISCUSSION

For the vertical drop impact, the impact force of the loaded cask was increased by about 12% compared to the empty cask. The impact behaviors were very similar to each other, and the stresses in shells were not much affected by the loaded fuels in the cask. However, the bottom structural part, which receives the inertia load of the fuels directly, was much affected. On the contrary, for the horizontal drop impact, the weights of the loaded fuels directly affected the bottom part of the shells. This means that the increased inertia force due to the fuel weight of 18 tons (about 16% of total cask weight), so affects the parts related directly to the impact that the stresses in these parts are increased so significantly.

For vertical drop impact, the impact force is increased suddenly with the initiation of impact, gradually increased as the deformation rate of the impact limiter is decreased, and then decreased rapidly as the cask rebounds. For the vertical drop impact, the entire bottom area of the impact limiter is contacted with the target surface simultaneously, whereas, for horizontal drop, the flank of the cylindrically shaped impact limiter is contacted in the normal direction to the tangent.

Contrary to vertical drop impact, horizontal drop impacts showed different results for empty and loaded casks, as shown in Fig. 4. For horizontal drop impact of the empty cask, the maximum deformation of the impact limiter was 254 mm, and most of the impact energy was absorbed by this deformation. For loaded cask, the maximum deformation of the impact limiter was 313 mm. If the deformation of the impact limiter exceeds 292 mm, the outer shell and neutron shield layer are deformed together with the impact limiters. Therefore, the secondary rapid increase of the impact force time history started at the contact initiation of outer shell with the target surface.

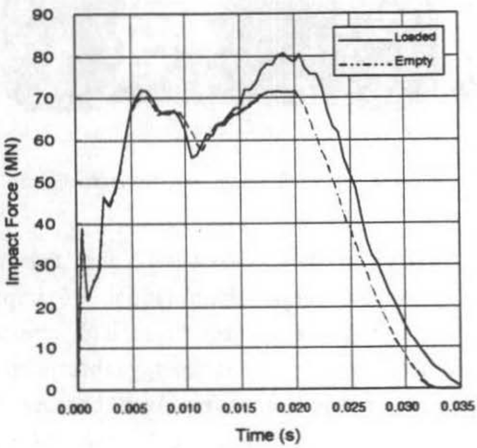


Fig. 2 Comparison of impact force-time histories for 9m bottom-end drop.

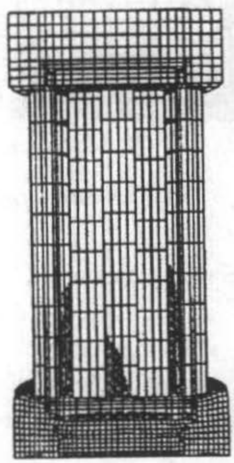


Fig. 3 Deformed shape and stress contour of KSC-28 cask under 9m bottom-end drop.

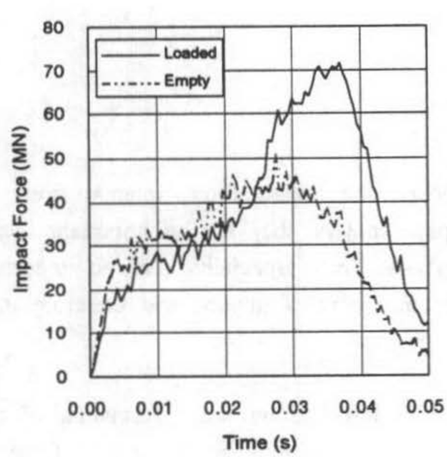


Fig. 4 Comparison of impact force-time histories for 9m horizontal drop.

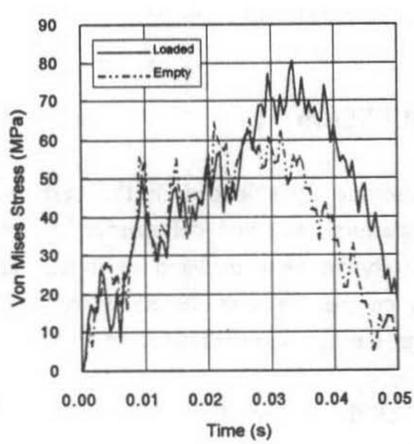


Fig. 5 Comparison of stress-time histories for 9m horizontal drop.

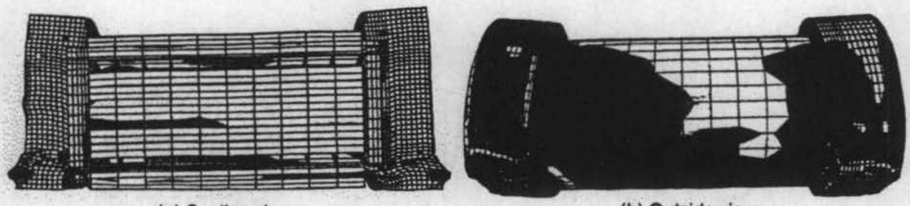


Fig. 6 Deformed shape and stress contour of KSC-28 cask under 9m horizontal drop.

In horizontal drop impact, the maximum stresses of the shells were higher than the stresses in the vertical drop impact, despite the larger deformations of impact limiters and longer impact duration. There are two reasons for these high stresses. Firstly, the total volume of the impact limiters participating in energy absorption is insufficient. The impact limiters absorb initial impact force very well because the cross sectional area related to energy absorption starts with a small area and then increases as impact is advanced. However, the total volume of the impact limiters which related to impact is small, and so some portion of the cask outer shell is impacted on the target plane, as shown in Fig. 6(b). Therefore, the peak impact force is increased, in spite of the small initial impact force and impact retardation effect. Secondly, the cask is impacted in the flank so that most of the loads act on one side of cylindrical shells.

CONCLUSION

Because the fuels loaded in the cask increase the impact force, internal stress of the structural part and deformation of impact limiters, they are an important factor which should be considered in impact analysis. They especially have an important effect on the stress of structural parts near the point of impact, and therefore may change the stress distributions of the cask.

Most of the impact force in vertical drop is absorbed by the deformation of the impact limiter. However, in horizontal drop, some portion of the impact force is absorbed by the deformation of the outer shell and the neutron shield besides the impact limiters. Therefore, horizontal drop is more affected by the inertia load of loaded fuels than vertical drop. The impact energy absorption by the deformation of the outer shell and the neutron shield in horizontal drop seems inevitable, and therefore should be considered together with the deformation of the impact limiters.

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