# Oblique 9-Meter Drop Test of Scale Model for KSC-7 Cask

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## INTRODUCTION

A type B(U) shipping cask (KSC-7 cask) with a capacity of 7 PWR spent-fuel assemblies has been developed for transportation of domestic spent fuels from the storage pool of nuclear power plants to the interim storage facility. The KSC-7 cask was designed in consideration of 50,000 MWD/MTU burnup fuel with 1.5 years cooling time.

According to the domestic and IAEA regulations(IAEA 1985a) for nuclear spent-fuel transport, all shipping casks should maintain their structural integrity against drop accident. A one-third scale model for the KSC-7 cask was designed and fabricated to confirm the structural design. A series of drop tests was conducted on this scale model by changing its impact limiters to verify that the cask is structurally adequate to survive hypothetical accident drop conditions.

The nonlinear dynamic analysis with LS-DYNA3D code was carried out for the scale model prior to the drop tests to select test drop orientation(Ku et al. 1995). It was found from the analysis that a 20 degree bottom oblique drop condition will give the maximum damage to the KSC-7 cask among the possible drop orientations. In addition, this oblique drop impact showed very complicated impact behavior because of the sequential impacts with rotation of the cask after primary impact.

This paper describes the 20 degree bottom oblique drop test of the scale model. The objective of this study is to assess the structural integrity of the KSC-7 cask and to verify the validity of the analytical method for the impact(Miller 1993). The measured items of the drop test were strains and accelerations of the model cask and deformations of the impact limiters. The results of strains and accelerations from the analysis were compared with the results of the drop test.

## TEST MODEL

The scale theory, as described in IAEA Safety Series No. 37, can be successfully applied with a model of larger than 1/4 scale for the drop test. Therefore, a 1/3 scale model was selected for the 9-m free drop test. The dimensions were adopted one-third linear scale sizes as possible and all materials were the same as in the prototype. The basic dimensions and materials of the scale model are compared with the prototype in Table 1.

Fig. 1 shows the basic dimensions of scale model and gauge installation locations. The cask body consists of stainless steel shells for structure, lead for gamma shielding and silicone mixture for neutron shielding. However, the heat-transfer fins, which are made of copper plate and inserted between intermediate shell and outer shell, are neglected for simplicity. Balsa wood and redwood were used for shock-absorbing materials of impact limiters. The case and gusset plates of the impact limiters were made of 2 mm thick steel plate. The outer diameter of the model body is 625 mm, and the overall length including impact limiters is 2,033 mm. The total weight of the scale model is about 2.9 tons.

## TESTING

The test was conducted as specified in the IAEA transport regulations at KAERI's test facility. This test facility can conduct the drop testing up to 10 tons with tower hoist, steel target with massive concrete foundation, and release device, etc. The target at the facility meets IAEA criteria for being essentially unyielding.

In order to examine the integrity of the containment boundary against the drop impact, leak tests were conducted for 7 bar during 30 minutes prior to and after the test, respectively. Impact limiters were secured by four retaining bolts to both ends of the cask before the cask was lifted.

Fig. 2 shows the schematic diagram of the data acquisition system for the test. The model was tilted to 20 degrees, then lifted up to 9-m height. The bottom end of the cask impacted the target first, and the top end was subjected to the secondary impact.

Numerous accelerometers and strain gauges(Perry and Lissner 1962, Bruel and Kjaer 1975) were mounted on the model in axial and radial directions to monitor the response of the model during the impact. Instrumentation for strain acquisition consisted of strain gauges, signal conditioning amplifier, and tape recorder and for acceleration data acquisition system consisted of accelerometers, power unit, and spectrum analyzer.

## TEST RESULTS

Fig. 3 shows the sequential photographs of the 20 degree oblique drop test. It shows the cask, just before the drop, dropping before the impact, and impact instance, respectively. The impact duration was about 80 msec.

The model cask maintained its structural integrity during the drop test. However, disassembly of the system was complicated by the collapse of the bolt guide tubes of the impact limiters. The impact limiter retaining bolts of the top end of the cask had failed, allowing to move outward slightly. The impact limiters were crushed and flattened in the area adjacent to impacted parts, but it was judged to be adequate for the drop test. Damage to the impact limiters consisted of crush of wood structures, some tearing of sheet metal and buckling of gusset plates. From the test result, it was concluded that the impact limiter retaining bolts should be designed to have adequate strength against the impact shear force.

The acceleration time histories in Fig. 4 show the accelerations measured for the vertical direction, because these are dominant compared to axial component. The accelerometer data were digitized and filtered for level of 2.5 kHz. The peak acceleration values measured at A3, which was installed vertically at the center part of intermediate shell, were 330g in the primary impact and 1,305g in secondary impact, which was about 295% higher than the first peak. The important fact was that the peak acceleration value from A2, which measured at the top part of inner shell, during the secondary impact was much higher than the peak value from A7, which measured at the bottom part of intermediate shell, during the primary impact.

Fig. 5 shows the strain time histories measured for the axial direction, which are dominant direction for strain. The strains measured at S5 represent the axial strain at top upper part of inner shell, and S4 represents that of center bottom part of intermediate shell. As shown in Fig. 5, the secondary impact produced much higher strains than the primary impact. This trend was very similar as in accelerations.

No appreciable leakage was detected after the impact test, and it was confirmed that the containment boundary was not impaired from the impact.

## ANALYSIS

Nonlinear dynamic analysis was also performed for the scale model using LS-DYNA3D code. The half-section of the model cask was modeled by 3D solid elements and shell elements by using its symmetry. The rigid target was simulated by stone wall surface and interfaces between the materials were considered by single surface contact elements (Hallquist 1993). The interfaces between cask body and impact limiters were simulated by combining their retaining parts with tied interface.

Especially, the metal structure of steel case and gusset plates and their interfaces with wood blocks were considered. Two types of analysis were carried out for the impact limiters. The one case considered the steel case and gussets and another neglected them. From the comparision of the two results, it was concluded that the steel case and gussets should be considered in FEM analysis because it gives more conservative results.

Fig. 6 shows the stress contour and deformed shape of the cask at secondary impact. The impact behavior was consistent with the test when we compared the deformation. Fig. 7 shows impact force time history during 20 degree oblique drop impact. The cask had rotated at 15 msec, and the secondary impact started at 39 msec. Fig. 8 shows the comparison of the acceleration histories from the test and analysis results at the center part of the intermediate shell. The first peak acceleration value of the primary impact was calculated as 933g, which was 183% higher than the test result, and the second peak acceleration was 2,183g, which was 67% higher than the test results. Though the calculated acceleration values were higher than the test results, the impact duration was similar with the test. This result indicates that analysis gives conservative results compared to test results for the drop impact.

## DISCUSSIONS AND CONCLUSION

The oblique drop impact test was successfully conducted at KAERI's test facility. Impact limiters greatly mitigate the impact forces acting on the cask body from the 9-m drop impact. Also, the metal structure of steel case and gusset plates contributes to the impact so much that it should be considered in the impact analysis by FEM.

The secondary accelerations detected from the top end during the secondary impact were higher than those observed on the bottom end during the primary impact. Most of the kinetic energy of the cask due to the 9-m free drop is absorbed during the secondary impact. The distance from the primary impact part to the center of gravity of the cask makes the cask rotate so rapidly that the secondary impact velocity is increased. Therefore, the secondary impact is more severe when the cask is subjected to the slightly slanted oblique drop impact.

Table 1. Basic dimensions of scale model and KSC-7 cask

(unit : mm )

| Items | | Scale Model | Prototype | Remarks |
|---|---|---|---|---|
| Basic Dimension | Overall | OD833 x 2,033L | OD2,440 x 6,100L | |
| | Cask Body | OD625 x 1,733L | OD1,876 x 5,200L | |
| | Inner Shell | ID310 x 5t | ID930 x 15t | |
| | Interm. Shell | ID434 x 12t | ID1,306 x 35t | |
| | Outer Shell | ID552 x 3t | ID1,656 x 10t | |
| Materials | Cask Body | S.S.304, Lead, Silicone Mix. | S.S.304, Lead, Silicone Mix. Copper Fin | Copper Fins were neglected in Scale Model |
| | Impact Limiter | Balsa wood, Redwood | Balsa wood, Redwood | |

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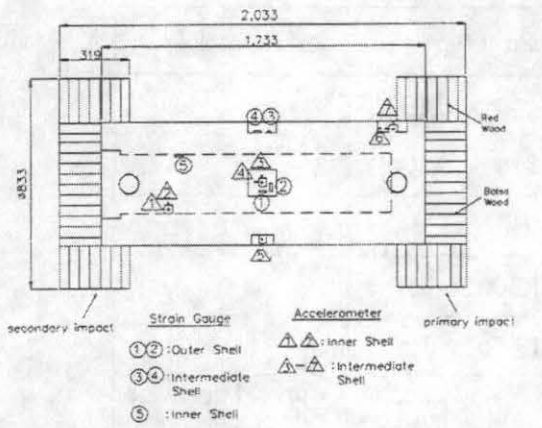


Fig. 1. Basic dimensions of scale model and gauge installation locations

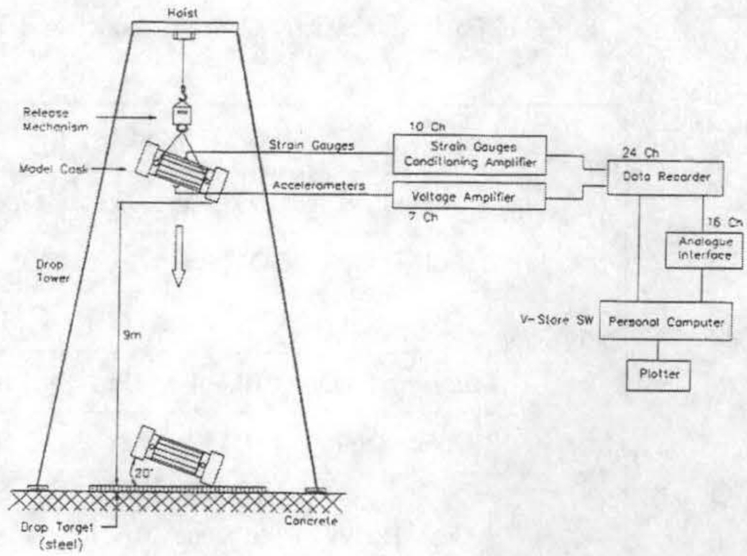


Fig. 2. Schematic diagram of the data acquisition system

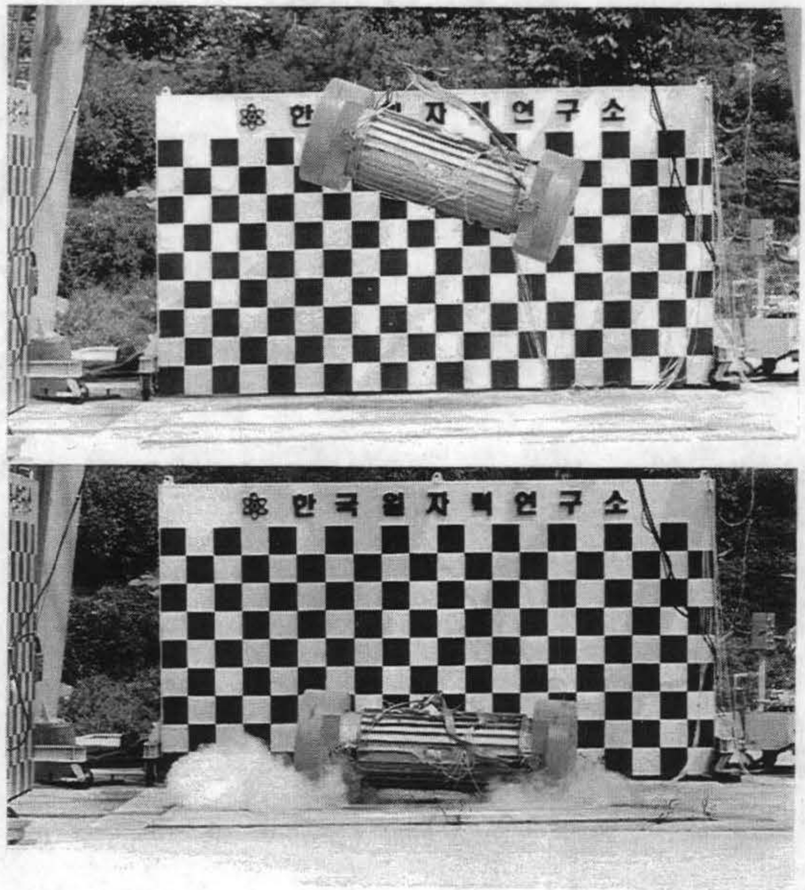


Fig. 3. Sequential photographs of 20 degree oblique drop test

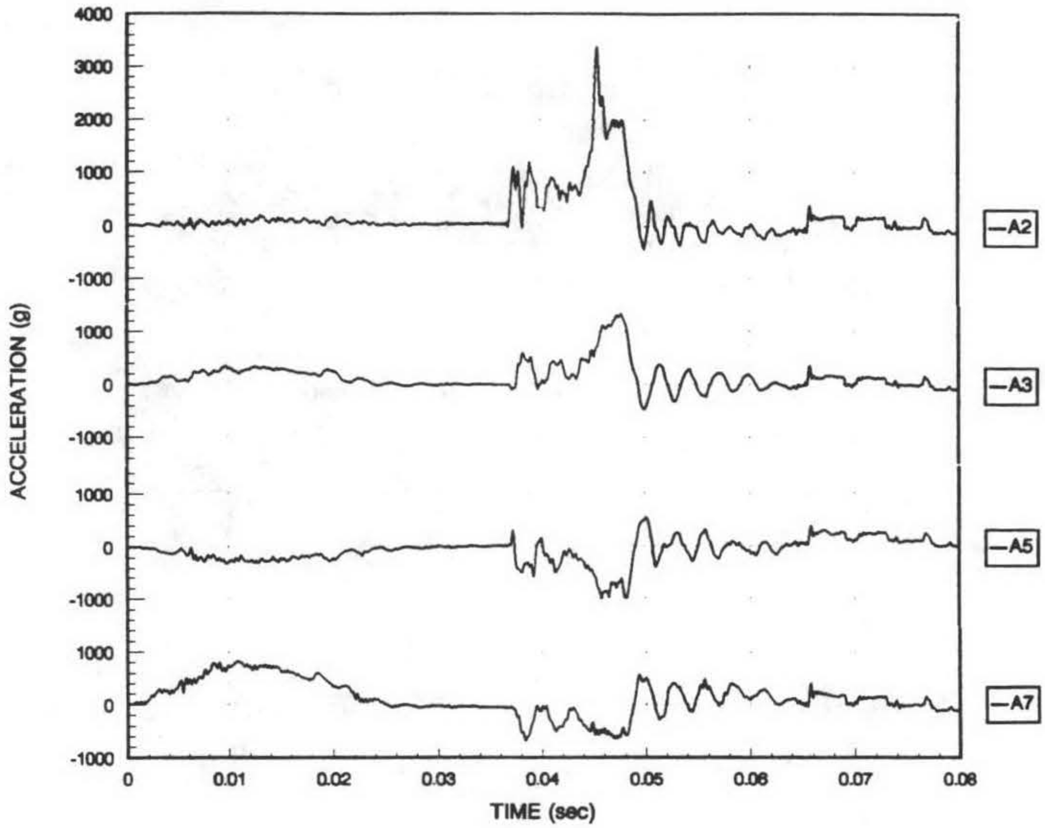


Fig. 4. Acceleration time histories of the cask body measured from accelerometers (A2, A3, A5, A7)

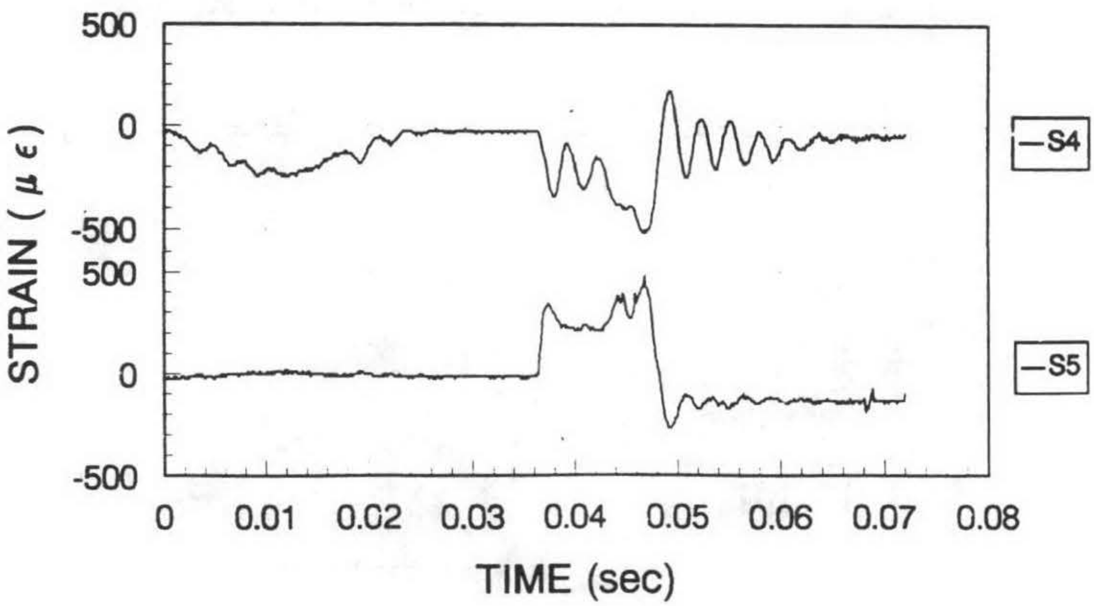


Fig. 5. Strain time histories of the cask body measured from strain gauges (S4, S5)

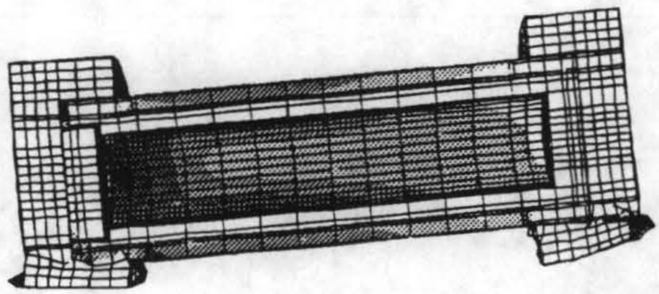

Fig. 6. Stress contour and deformed shape of the cask

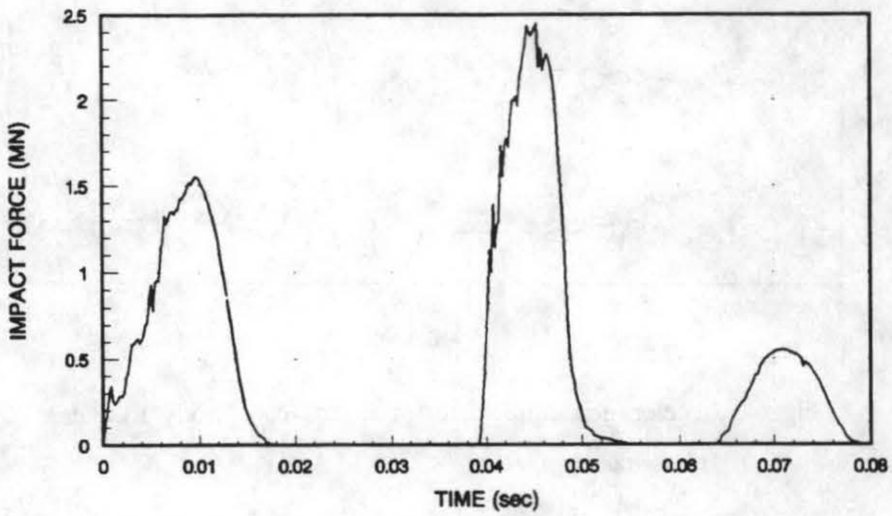


Fig. 7. Impact force time history during 20 degree oblique drop impact

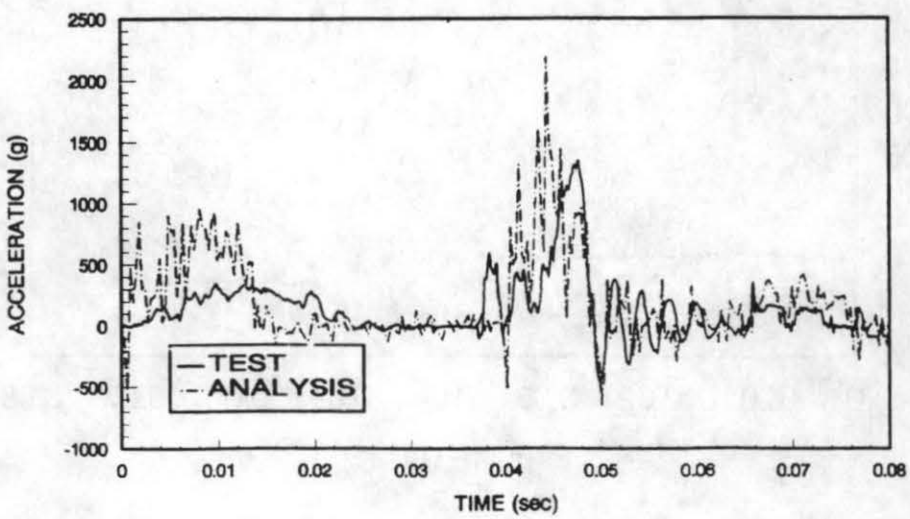


Fig. 8. Comparison of the acceleration histories from the test and analysis results