Proceedings of the 18th International Symposium on the Packaging and Transportation of Radioactive Materials
PATRAM 2016
September 18-23, 2016, Kobe, Japan

Paper No. 1042

Drop Test of 1/3 Scale Model for Modified TK Type Transport and Storage Cask - Experimental Results of Drop Test -

Jun Shimojo
Kobe Steel, Ltd.
2-3-1, Araicho Shinhama,
Takasago, Hyogo, JAPAN

Hiroshi Akamatsu*
Kobe Steel, Ltd.
2-3-1, Araicho Shinhama,
Takasago, Hyogo, JAPAN

Keisuke Umehara
Kobe Steel, Ltd.
2-3-1, Araicho Shinhama,
Takasago, Hyogo, JAPAN

Masayoshi Okumura
Transnuclear, Ltd.
1-18-16, Shinbashi,
Minato-ku, Tokyo, JAPAN

Takao Shirakura
Transnuclear, Ltd.
1-18-16, Shinbashi,
Minato-ku, Tokyo, JAPAN

Hiroaki Taniuchi
Transnuclear, Ltd.
1-18-16, Shinbashi,
Minato-ku, Tokyo, JAPAN

Abstract

Transnuclear and Kobe Steel have been developed and designed the transport and storage casks called TK type series. The TK type cask consists of a forging shell body with neutron shielding material, a primary lid, a secondary lid as storage configuration, and a tertiary lid and shock absorbing covers (SAC) made of redwood are additionally attached for transport condition.

As phase-1, drop tests using 1/3 scale model cask for the basic type of TK series were already done [1)]. This time as phase-2, the drop tests for the modified cask have been done. This cask is designed to optimize lids and top SAC for decreasing of deformation of lids, etc. against delayed impact under vertical drop test.

The model was 1/3 scale, the height of drop test was 9m and these tests were performed with 3 different conditions, i.e. horizontal, vertical, and slap-down. The trends of G-values and deformations between these 2 series of tests were almost same. It was also confirmed that the G-values for all conditions were less than the target values and that the deformations of the SACs were also within the target range without bottoming. In addition, no significant tears on outer cover plates of stainless steel for SACs or no outer damage of the cask itself were observed. Therefore the structural integrity of the modified TK type cask is confirmed by phase-2 tests as same as the results of phase-1. And these test results are used for confirming validity of the safety analysis procedures on 9m drop test conditions for TK type casks.

1. Introduction

In design requirements of transport and storage casks, 9m drop test condition is one of the most severe design conditions. In Japan, static analysis methods by FEM codes with inertial force of acceleration are used for 9m drop test as the accident condition of transport. The validation of

*) Present affiliation is Transnuclear, Ltd., Japan.

analysis methods is very important and to confirm it, drop tests are usually conducted to obtain the necessary data such as acceleration and deformation of SACs.

Recently the influence of delayed drop impact by contents such as fuel assemblies and basket for cask is focused. As for this event, Japan Nuclear Energy Safety Organization (JNES, present the Secretariat of the Nuclear Regulation Authority) preformed 9m drop test using actual size model cask and reported that the content had larger acceleration than its main shell affected by content itself [2)]. In addition, the influence for lids by slap-down drop test is also focused. To confirm influence for lids, acceleration ratio of slap-down to horizontal drop is important index.

As phase-1, a series of 9m drop tests using 1/3 scale model of TK type cask were already conducted including slap-down drop [1)]. This time as phase-2, the additional series of drop tests for the modified cask have been done. The test results are reported in this paper, and the validation of drop test analysis using these drop test results is reported by Okumura et al.[3)].

2. Specificaions of modified TK type transport and storage cask

The modified TK-69 and TK-52 (here after called just TK-69 or TK-52) have been designed for transport and storage of BWR spent fuels by Transnuclear, Ltd. and Kobe Steel, Ltd. The structure of TK-69 is shown in Figure 1 and main specifications of these casks are shown in Table1. This cask is designed to optimize lids and top SAC for decreasing of deformation of lids, etc. against delayed impact under vertical drop test. In concrete, it has two characteristics of design compared to the basic type,

- The secondary lid has neutron shielding instead of the primary lid in order to have enough structural strength around lids part with simpler design.
- The top SAC has the additional absorbing part in its centre to support lids.

The design concepts of these casks are the same, but the loaded fuel specifications are different, i.e. fuel burnup of TK-52 is higher than that of TK-69 and cooling time of TK-52 is shorter than that of TK-69. Therefore the shielding thickness of shell for TK-52 is larger than that of TK-69, which results in that the margin of structural integrity for TK-52 is larger than that for TK-69.

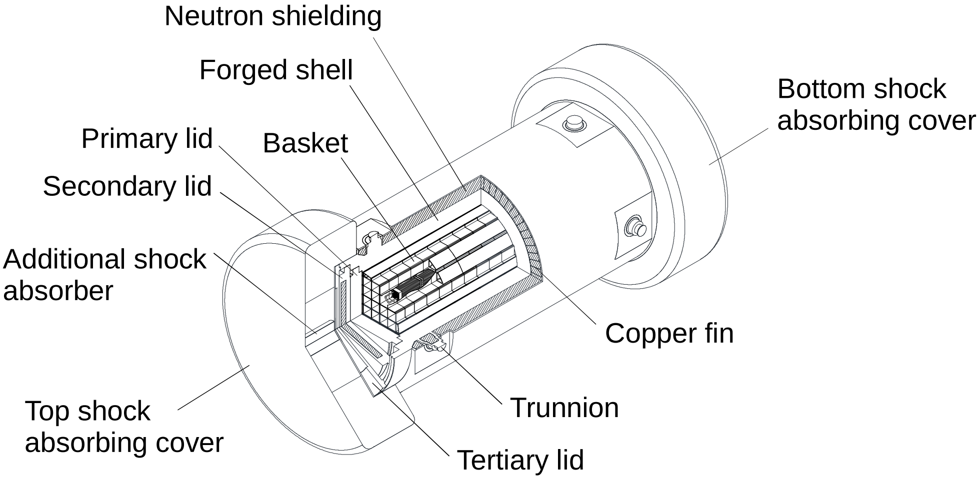


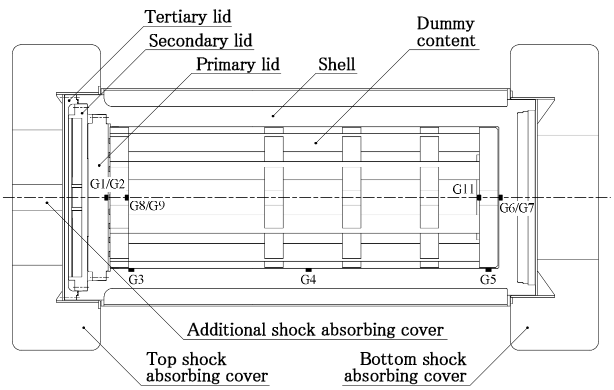
Figure 1 Structure of modified TK-69

Table 1 Main specifications of modified TK-69 and TK-52

Items	TK-69	TK-52
Weight and dimension		
- Total weight : transport / storage (ton)	Approx. 134 / 121	Approx. 132 / 120
- Length : transport / storage (m)	Approx. 6.8 / 5.3	Approx. 6.8 / 5.4
- Diameter : transport / storage (m)	Approx. ϕ3.5 / ϕ2.5	Approx. ϕ3.4 / ϕ2.4
Loading capacity	69 BWR fuels	52 BWR fuels
Materials		
- Shell and Bottom plate	Low alloy steel or Carbon steel	Low alloy steel or Carbon steel
- Neutron shielding	Resin	Resin
- Primary and Secondary lids	Low alloy steel or Carbon steel	Low alloy steel or Carbon steel
- Tertiary lid	Stainless steel	Stainless steel

3. Specification of 1/3 scale model

The 1/3 scale model is designed based on TK-69 because its weight of content is larger than that of TK-52 and the margin of structural integrity for TK-52 is larger than that of TK-69. The shape and dimensions, especially the space between flanges of lids and shell, and between shell and dummy content are almost modeled in 1/3. The dummy content is modeled to simulate weight and center of gravity. The trunnions are prepared only for handling the scale model. Main specifications of 1/3 scale model are shown in Table 2, and its cross section and outer view are shown in Figure 2 and Figure 3, respectively. In Figure 2, marks of G1 - G11 show the placements of acceleration sensor.



note) G1,G6,G8 : Vertical

G2,G3,G4,G5,G7,G9,G11 : Horizontal

Figure 2 Cross section of 1/3 scale model

Figure 3. Outer view of 1/3 scale model

Table 2 Main specifications of 1/3 scale model

Parts	Material	Scale ratio (actual /model)	Weight(kg)
Shell **Neutron shielding** **Outer shell**	Low alloy steel Light weight concrete [*1] Carbon steel	Thickness of shell : 3 Outer dia. : 3 Length : 3	2,850
Primary lid	Low alloy steel	Thickness : 3.1 Outer dia. : 3 Dia. of gasket : 2.5 [*2]	185
Secondary lid	Low alloy steel	Thickness : 2.8 Outer dia. : 3 Dia. of gasket : 2.5 [*2]	135
Tertiary lid	Stainless steel	Thickness : 3.1 Outer dia. : 3 Dia. of gasket : 3.3	85
SAC	Stainless steel and Redwood	Outer dia. : 3 Length (top/ bottom) : 3	200 (top) 200 (bottom)
Dummy content [*3]	Carbon steel	Outer dia. : 3 Length : 3	980
-	-	-	Total 4,635

Note*1) Equivalent material simulating only weight
Note*2) Restriction of manufacturing
Note*3) Modeled to simulate weight and center of gravity

4. Condition of drop tests

4.1 Drop test target floor

The drop test target floor is made of reinforced concrete basement covered with carbon steel plate of which thickness is 42mm as shown in Figure 4. The total weight of basement is about 100 tons, which is more than 10 times larger than that of the 1/3 scale model. Therefore, for drop tests of the scale model, this target satisfies the unyielding target specified by the IAEA Specific Safety Guide, No. SSG-26.

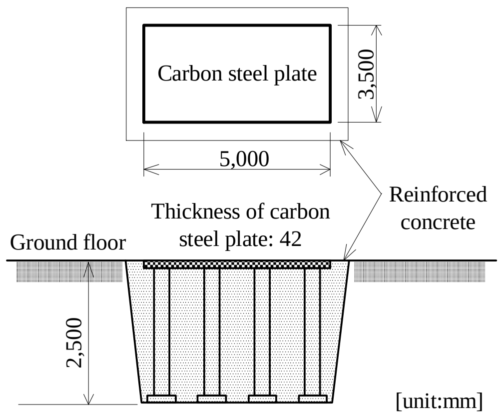
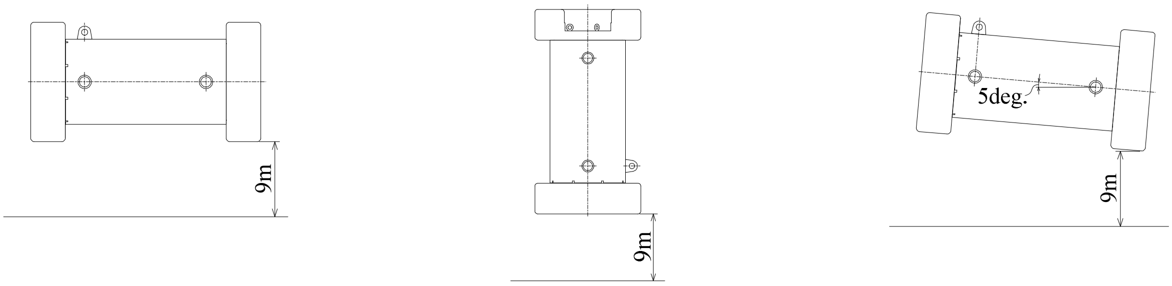


Figure 4 Drop test target floor

4.2 Drop test condition

The drop tests were performed with 3 different conditions i.e. horizontal, vertical and slap-down drop tests as shown in Figure 5. The height of drop tests was 9m which was from the lowest point of

SAC to the unyielding target of drop test facility. For the vertical drops, the scale model was dropped with its top side of cask on to the unyielding floor because lids' part is more important than bottom side on the containment point of view. For slap-down drop, the inclined angle was 5 degrees. This angle was selected in order to have the largest acceleration for lid part by preliminary dynamic drop analysis. Measuring items are accelerations, strains, axial force of lids bolts, opening displacements of lids and deformation of SAC. The main measuring specifications are shown in Table 4. The opening displacements of lid and the leak tests were performed only for reference because scale law is not strictly applicable.



(a) Horizontal drop **(b) Vertical drop** **(c) Slap-down drop**

Figure 5 Drop test conditions

Table 4 Main measuring specifications of 1/3 scale model

Measuring items	Measuring method	Measuring points
Acceleration	Acceleration sensor	- Primary lid: Centre of inner surface - Shell: Top, middle and bottom points of inner surface - Bottom plate: Centre of inner surface - Dummy content: Top and bottom points of center axis
Opening displacement of lids	Eddy current displacement sensor	- Primary lid : 4 orientations (0^o / 90^o / 180^o / 270^o) - Secondary lid : 4 orientations (0^o / 90^o / 180^o / 270^o)
Deformation of SAC	Ruler	- Top and Bottom SAC : deforming region
Leak tests for lids	He leak test	- Primary and Secondary lids
	Gas pressure rise leak test	- Tertiary lid

5. Results of drop tests

The drop tests were performed for each condition and the main results are summarized in Table 5. In the data analysis, cut-off frequency filter of 500 Hz was applied to the time history of acceleration, strain, lid opening displacement and axial force of lid bolts. This cut-off frequency was set according to the IAEA Specific Safety Guide, No. SSG-26. In this section, the main test results of acceleration, opening displacement of lids and deformation of SAC are mainly reported.

Table 5 Main results of drop tests

Items	Horizontal	Vertical	Slap-down
Maximum acceleration (G)			
- Target limitation [*1]	225	230	225
- Primary lid [*2]	145	181	185
- Shell (top / middle / bottom) [*2]	143 / 134 / 125	-	177 / 112 / 154
- Bottom [*2]	119	173	149
- Dummy content (top / bottom) [*2]	164 / 127	169 / -	192 / 142
Acceleration ratio of Dummy content / Shell or Primary lid	1.15 / - / 1.02	0.93 / - / -	1.08 / - / 0.92
Maximum deformation of SAC (mm)			
- Target limitation [*1]	120	150	120
- Top	87	57	98
- Bottom	65	-	68
Maximum lid opening displacement (mm)			
- Primary lid[*3]	0.032	0.067	0.032
- Secondary lid[*3]	0.002	0.008	0.002
Torque reduction of lid bolts	No		
Leak tightness difference between before and after drop tests	No		

Note*1) Target limitation is calculated with scale factor from actual size of cask.

Note*2) These are instantaneous maximum values.

Note*3) These are not permanent displacements but instantaneous.

5.1 Horizontal Drop

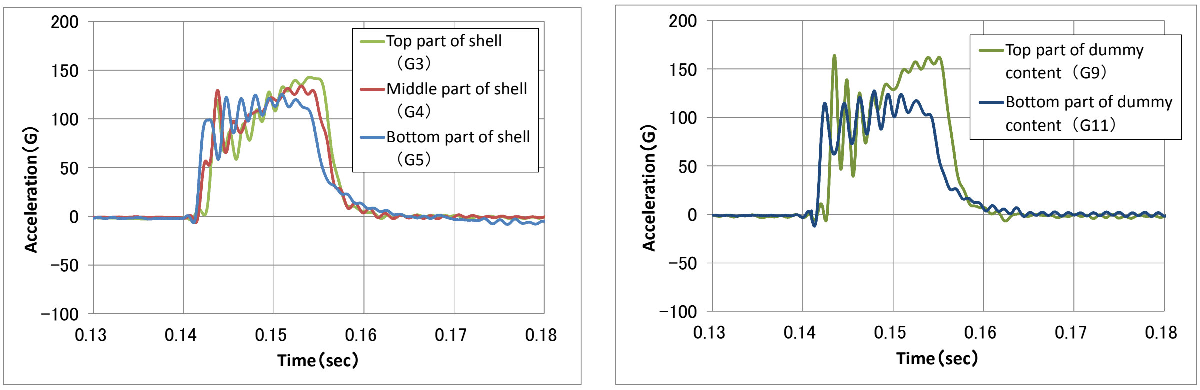
The time history of acceleration of each part of the scale model is shown in Figure 6. The ratio of the maximum accelerations between the dummy content and the shell of corresponding each part was 1.15 and 1.02, this factor is smaller than that of the horizontal drop test conducted by the JNES, 1.2[2)]. This multiplying factor is very important because it is required to be taken into consideration in safety analysis. The maximum deformation of SAC is less than 100mm and this value is smaller than target limitation which is set from the distance between top surface of trunnion and outer surface of SAC. Therefore the trunnions are not hit on the target floor.

5.2 Vertical Drop

The time history of acceleration of each part of the scale model is shown in Figure 7. The ratio of the maximum accelerations between the dummy content and the primary lid was 0.93, which was almost same as that of phase-1 tests, 0.92 for lid part, therefore the maximum ratio is thought to be 1.42 for bottom part [1)] though no acceleration data of dummy content for bottom part in phase-2 tests. These ratios are smaller than that of the vertical drop test conducted by the JNES, 2.6 [2)]. This multiplying factor is very important with the same reason of horizontal condition. The maximum deformation of SAC is about 57mm and this value is smaller than the target limitation.

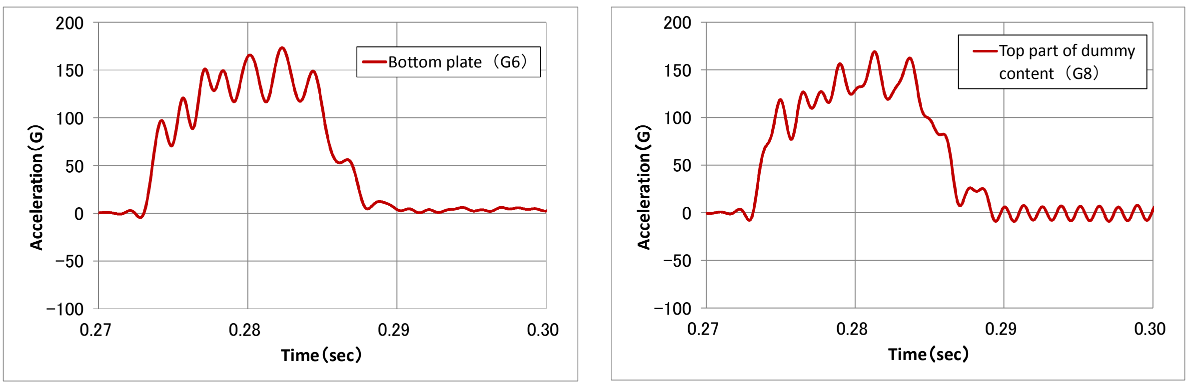
<u>5.3 Slap-down Drop</u>

On the condition of slap-down test, the bottom SAC first hits on the target floor, and after the first impact, the top SAC has the second impact because the scale model is slightly inclined to the horizontal line. The maximum acceleration of the primary lid 185G was larger than 149G of the bottom. And the ratio of the maximum accelerations between the dummy content and the shell for corresponding each region was 1.08 and 0.92. The maximum deformation of the top SAC was 98 mm, and this was larger than 68 mm of the bottom SAC, which satisfied the target limitation. These results mean that the second impact for the top SAC is larger than the first one for the bottom SAC. The time history of acceleration of each part of the scale model is shown in Figure 8. It shows that impact timing of each part is slightly delayed from bottom part to lid part of scale model due to the slightly incline of scale model with 5 degrees to the horizontal line. The comparison of accelerations and of SAC deformations between slap-down and horizontal drop tests are shown in Table 6. The maximum acceleration ratio 1.28 was obtained at the primary lid, which was slightly larger than that of phase-1 tests, 1.20 [1]. But it is still smaller than the factor 1.3 that is used structural analysis for TK type cask.



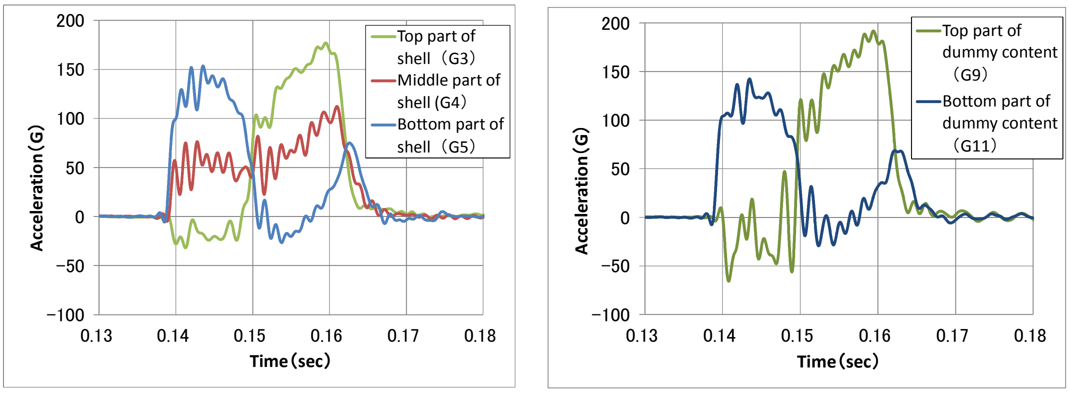
(a) Shell **(b) Dummy content**

Figure 6 Time history of acceleration of horizontal drop test



(a) Shell **(b) Dummy content**

Figure 7 Time history of acceleration of vertical drop test



(a) Shell **(b) Dummy content**

Figure 8 Time history of acceleration of slap-down drop test

Table 6 Comparison of maximum accelerations between slap-down and horizontal drop tests (unit : G)

Items		Slap-down	Horizontal	Ratio (Slap-down/Horizontal)
- Primary lid		185	145	1.28
- Shell	top	177	143	1.24
	middle	112	134	0.84
	bottom	154	125	1.23
- Dummy Content	top	192	164	1.17
	bottom	142	127	1.12
- Bottom		149	119	1.25

6. Conclusions

The 9m drop tests with 3 different conditions using 1/3 scale model for the modified TK type cask (lid parts and top SAC are modified) were conducted as phase-2. The maximum G values and deformation of SAC satisfied the target limitations, and these trends were almost same as those of phase-1 tests. The necessary data such as acceleration and deformation of SAC were obtained to validate structural analysis of 9m drop tests. These data can also be used for other TK type casks.

7. References

[1] Jun Shimojo, et al., "Drop test experimental results of 1/3 scale model for TK type transport and storage cask", Proceedings of 17th International Symposium on the Packaging and Transportation of Radioactive Material (PATRAM), #164, (2013).

[2] Japan Nuclear Energy Safety Organization, "Heisei 15, Corroborating Tests Report for Metal Cask Storage Technology", (2004). (in Japanese)

[3] Masayoshi Okumura, et al.: "Study of Analysis Model for Drop Test of TK Type Transport /Storage Cask", Proceedings of 18th International Symposium on the Packaging and Transportation of Radioactive Material (PATRAM), (2016).