Containment Performance of Transportable Storage Casks at 9m Drop Test

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Introduction

Spent fuel transportable storage casks usually have a double lid closure system, which consists of primary and secondary lids, and gaskets, to keep the containment function during transportation and storage, and to monitor a leakage or containment function during storage. Metal gasket is planning to be used not only during storage but transportation of both before and after storage. As metal gasket will degrade its containment function by creep during storage period of 50 years, relative displacement such as opening and slide displacement between the flange of the containment vessel and the lid should be restricted to a small range.

To maintain the containment performance, we provisionally adopted the maximum opening limit of 0.1mm and the maximum slide displacement limit of 3.0mm in the full-scale cask design based on the report of the fundamental experiment on the metal gasket which examines the relation between leakage rate and sealing gap [1].

The purpose of this study is to analyse the behaviour of the sealed parts (lid & vessel body) under 9m-drop impact test conditions and to establish some analytical method to evaluate this behaviour. In this study, the drop test of 1/3scale model of Hitz-B69 cask with the double lids closure system was carried out, the behaviours of the seal part were measured by displacement sensors, and they were compared with the result of the numerical analysis carried out separately.

Description of test model

The secondary lid of Hitz-B69 cask is regarded as a containment boundary under 9m-drop test condition required in the IAEA transport regulation [2]. A basic configuration of 1/3 scale test model of Hitz-B69 cask is shown in Figure 1. And the dimensions of the test model are shown in Table1. Figure 2 is an enlargement of the seal part.

Table 1 : Dimensions and materials of 1/3scale model of Hitz-B69 cask

Cask body	Primary lid	Secondary lid	Impact limiter
Height: 1770mm Flange diameter (1): 540 mm Flange diameter (2): 623.7mm Material: JIS G3201 SF490A Outer shell Outer diameter: 830mm Material: JIS G3101 SS400 Resin cover Material: JIS G3101 SS400	Thickness: 90mm Flange diameter (1): 538mm Material: JIS G4304 SUSF304 Bolt holes Pitch circle diameter: 600mm Bolt hole diameter: 14.5mm Resin Material: epoxide resin form "NS4-FR"	Thickness: 45mm Flange diameter (2): 623.2 Material: JIS G3201 SF490 Bolt holes Pitch circle diameter: 672mm Bolt hole diameter: 14.5mm **Lid bolts** Type: Hexagon Socket Head cap screw bolts M12 Material: JIS G4108 SNB23-3	Height: 300mm Major diameter: 1170mm Minor diameter: 817mm Material: Plywood Cover & Rib Material: JIS G4304 SUS304

<u>Weight</u>
Total weight was 4.95ton including the weight of impact limiters (0.22ton) and the content (dummy basket, 1.22ton) of cask. The weight of the model was one twenty-seventh of the actual cask. The resin around the side of the cask was omitted and its weight was taken into consideration by increasing the thickness of the outer shell plate.

<u>Bolt</u>
The 56 lid bolts of M12 for each lid were tightened up to the same torque by a torque wrench. Initial axial stress with 20-40% of nominal yield strength of 890MPa were measured with strain gauge built in the eight bolts which were arranged on the flange at a 45-degrees pitch for each lid.

Impact limiter
An impact limiter consists of plywood, stainless steel rib plates that are arranged in the radial direction at a 45-degrees pitch, and stainless steel cover plates that enclose plywood. Since plywood is an anisotropic material, having lower strength at the direction perpendicular to its layer than parallel to its layer, two layer directions are combined to prevent excessive deformation. A pair of impact limiters is attached on the top and the bottom end of the cask with 12 bolts of M16 respectively.

Clearance between cask body and lids
The primary lid is inserted into the cask body, and the secondary lid is placed on the top end of the cask. A fitting diameter of the cask body is 540mm for the primary lid and 623.7mm for the secondary lid. The clearance at the primary lid is 2.0mm with tolerance, the secondary lid 0.5mm respectively. And a clearance of 2.5mm in the diameter exists between the bolt shank and the bolthole of the lid.

Target block for drop test
The target for drop tests was a reinforced concrete block (BWH 3.5mX3.5mx3.0m) with a 40mm thick steel-plate on its top. The target block is buried in the ground and the top surface was the same level as the ground surface. The mass of the target was about 20times to the drop object, which meets the requirement of the IAEA regulation.

Drop orientation
The Side drop, the top end drop, and the corner drop tests were carried out from 9m heights with impact velocity of 13.4m/s. For the corner drop test, the cask was tilted about 20.3-degrees from the vertical line so that the center of gravity was right above the impact point.

Orientation of displacement sensor
Figure 3 shows a flange section for the eddy current displacement sensors, which were used to measure dynamically the opening or the slide displacement between the lid and the cask body. The eddy current sensor measures the clearance distance between the target piece and the sensor its own. Both lids were equipped with target pieces on the edge of bottom circle at a 45degrees pitch for slide displacement sensors, which is installed on the cask body. Total of 22 displacement sensors were installed on the test model as shown on the Table 2.

Table 2: Orientation of eddy current displacement sensors

		0°	45°	90°	135°	180°	225°	270°	315°
Primary Lid	Opening	○	○	○	○	○	-	-	-
	Slide	○	○	○	○	○	-	-	-
Secondary Lid	Opening	○	-	○	-	○	○	○	○
	Slide	○	-	○	-	○	○	○	○

Description of Finite element model

A Finite Element (FE) code (LS-DYNA) was used to compare the measurement results with the analysis results and to investigate the behaviour of the lids. A half part was modelled in consideration of symmetry of geometry and loading. Total of 93933-nodes and 91419-elements were used. The cask body, the lids, the bolts, the plywood, the resin in the primary lid, and the dummy basket were modelled with 69357-eight-node solid elements. The outer casing, the resin cover, the impact limiter except for plywood were modelled with 22050-four-node shell elements. And the impact limiter attachment bolts were modelled with 12 two-node beam elements.

Clearances and contacts were taken into consideration in the FE-model. A contact friction factor of 0.2 was applied for all contact surfaces as follows:

Impact limiter <–> Secondary lids, cask body, resin cover, bracket for impact limiter
Both lids <–> Cask body, Lid bolts
Primary lid <–> Secondary lid

Carbon steel (Japanese Industrial Standard SF490A, SS400, SNB23-3, see Table1), and the stainless steel (JIS SUS304) in the cask were modelled assumed as a linear strain-hardening material. A value of one-hundredth of the modulus of elasticity was used as the one of strain hardening.

As for the mechanical properties of the plywood, the stress-strain curve was acquired by the compressive test, which was carried out with the test piece of 94mm thickness, 70mmx70mm width and depth. Tests were performed in the two directions, parallel to the layer and perpendicular to the layer. An anisotropic material was used for plywood in the LS-DYNA FE-model.

Comparison of test results and simulation results

Results from three kinds of tests are compared with corresponding analysis results. The deformations of the impact limiter, the accelerations of the cask body, the behaviour of secondary lid were discussed in this section.

<u>Deformations and accelerations</u>
Deformation of the impact limiter at the time of the lowest position of the cask is compared in Figure 5. Figure 6 shows the comparison of the acceleration time history of the cask body with the low path filter at 400Hz from both the analysis and the measurement.

<u>·Side drop</u>
The actual deformation of the impact limiter matches the analysis result. The time history of acceleration matches well in both magnitude and timing for the analysis result. The difference between the measured data and the analyzed data, which appears particularly at the early stage of the acceleration curve, is thought to be resulting from the difference in modelling of a mechanical property of plywood. A load-displacement relation curve acquired by a unidirectional compression test of a plywood block shows oscillation in its curve due to a separation or a local buckling in each plies and laminations. A stress-strain relation derived from the load-displacement relation is defined, as a monotone increasing multilinear function in the FE-model because of the oscillation in the stress strain relation cannot be solved stably. These modelling may cause the difference.

<u>·End drop</u>
The actual deformation of the impact limiter matches the analysis results. The measurement data of acceleration was imperfect due to a measurement cable breakage during the drop test, and a maximum acceleration of 350G was measured before the cable breakage. In the analysis result, an acceleration peak appears twice in the curve, the value of 280G at first peak and the value of 300G at next peak. The impact limiter has two different outer diameters along a direction of the cask axis, which seems to generate the two peaks in acceleration curve.

<u>·Corner drop</u>
Though the actual deformation of impact limiter matches roughly the analysis result, there is difference in detail. The experimental model shows a rupture at a corner welding of impact limiter cover, and the plywood in the cover can be seen from outside. This phenomenon appeared also in the time history data of acceleration. Though the measurement and the analysis result accelerations are matching for the initial period of time, it turns out that the acceleration of analysis becomes larger as time goes by, and the time for the peak is earlier than the measurements. In the FEM model, nodes are common both the impact limiter cover and the plywood. This model couldn't reproduce the delamination fracture between the cover plate and the plywood. And the rupture along the welding line of the impact limiter cover is not taken into consideration. Therefore the compressed plywood cannot go out from the impact limiter cover in the FE-model, the acceleration of analysis result may increase.

<u>Opening and slide displacement of the secondary lid</u>
The measurement result of an opening and a slide displacement between the flange of cask body and the secondary lid was compared with the analysis result. Since the opening displacement of the interest point just close to the O-ring couldn't be measured directly, measurement results at the measured position were compared with analysis results. Figure 7–9 shows the time history data of the displacements measured by eddy current displacement sensors. An opening is indicated by a positive value of displacement in a vertical axis. A zero value or minus value means no gap between the flanges of the cask body and the secondary lid. A slide displacement is defined as a clearance between the cask body and the secondary lid in a radial direction at a fit position. An initial clearance is defined as zero, and a positive value means the increasing clearance and a negative value means the decreasing clearance.

<u>·Side drop</u>
The measurement data show that no opening was occurred during the test. A minimum value of -10 micrometers was measured at a 180-degree position, it is thought that an elastic deformation of parts which are fixing the eddy current sensor lead to a negative value. For a slide displacement, a clearance is small at 0-degree side, and a clearance is large at 180-degree side. A displacement of -0.33mm at 0 degree and a 0.22mm at 180 degree position

were remaining after receiving impact load. This shows the relative movement of the secondary lid from 180 degree side to 0 degree side.
The analysis results also show the same behaviour as the measurement, an opening was not generated. A difference in the behaviour appears in the slide displacement at 180-degree position, where the clearance becomes small rapidly and returns immediately in the measurement, those phenomenons were not appeared in the analysis.

・End drop

A maximum of 40 micrometers of opening appear when the impact load was applied, after unloaded it returned to be zero. When a center of the secondary lid is deformed along a cask axis by the impact load, an edge of the inner diameter of a cask flange work as a support to the lid. This deformation of the secondary lid leads to an opening at outer position to the support circle. In a same manner, a slide displacement, which is measured as a clearance, become small at all measuring points. Since the target of displacement sensor is located on the bottom edge of secondary lid, the deformation of the lid makes a clearance small.
The analysis result and the measurement result are similar but an opening differs from a measurement result with negative displacements. A contact judgement in the numerical analysis may allow each contact surface penetration, this phenomenon may be removed if the element mesh size is made smaller.

・Corner drop

An opening did not occur at 0-degree side, but occurred in 180-degree side during the impact load is applied. This opening is caused by the deformation of the secondary lid in the same way in the end drop, but the most deformed region of the lid is shifted to 180degree side. The analysis of the slide displacement shows a larger value than the one from the actual measurement results. As seen in the acceleration time history result, the analysis result showed a large impact acceleration. It is thought that the slide displacement also became large.

Conclusion

9m-drop tests of 1/3scale model of Hitz-B69 cask were carried out under three different drop orientation to verify the behaviour of the seal part. The measured behaviours, which are represented as an opening and a slide displacement between the cask flange and the lid, are compared with FEM analysis results. The following conclusions were obtained.

・The characteristic behaviour of the lid under the 9m-drop test became clear by measurements.

・The maximum opening of 50micrometers between the cask flange and the secondary lid was measured at the moment of receiving impact load in the top end drop condition, and it returned to zero after the impact load.

・The slide displacements of 200-350 micrometers remained after the side drop test. The relative movement between the cask body and the secondary lid occurred at the side drop condition.

・The relative displacement between the cask and the lids during the drop tests met the provisional limit value of 0.03mm and 1.0mm in the opening and the slide displacement respectively in the 1/3 scale model.

・FEM analysis model was able to predict the behaviour of the lid accurately and was useful to understand the behaviour of the lid.

・To predict the behaviour of the seal parts, it is better to model the lid bolts with solid elements and to take into consideration the initial tightening force of bolts and to define the pair of surface possible to contact in the FE-model.

・To improve the accuracy of the FEM analysis, the fine mesh model at the cask flange may be needed, and the modelling technique for the plywood in the impact limiter should be examined.

References:

[1]Nuclear Power Engineering Corporation, The demonstration Examination for Metal Strage Technology Establishment. 2003 Edition (Japanese)
[2]Regulations for the Safe Transport of Radioactive Material, 1996 Edition (Revised), Regulation No TS-R-1, IAEA,2001
[3]LS-DYNA Users Manual Ver960, LSTC,2003

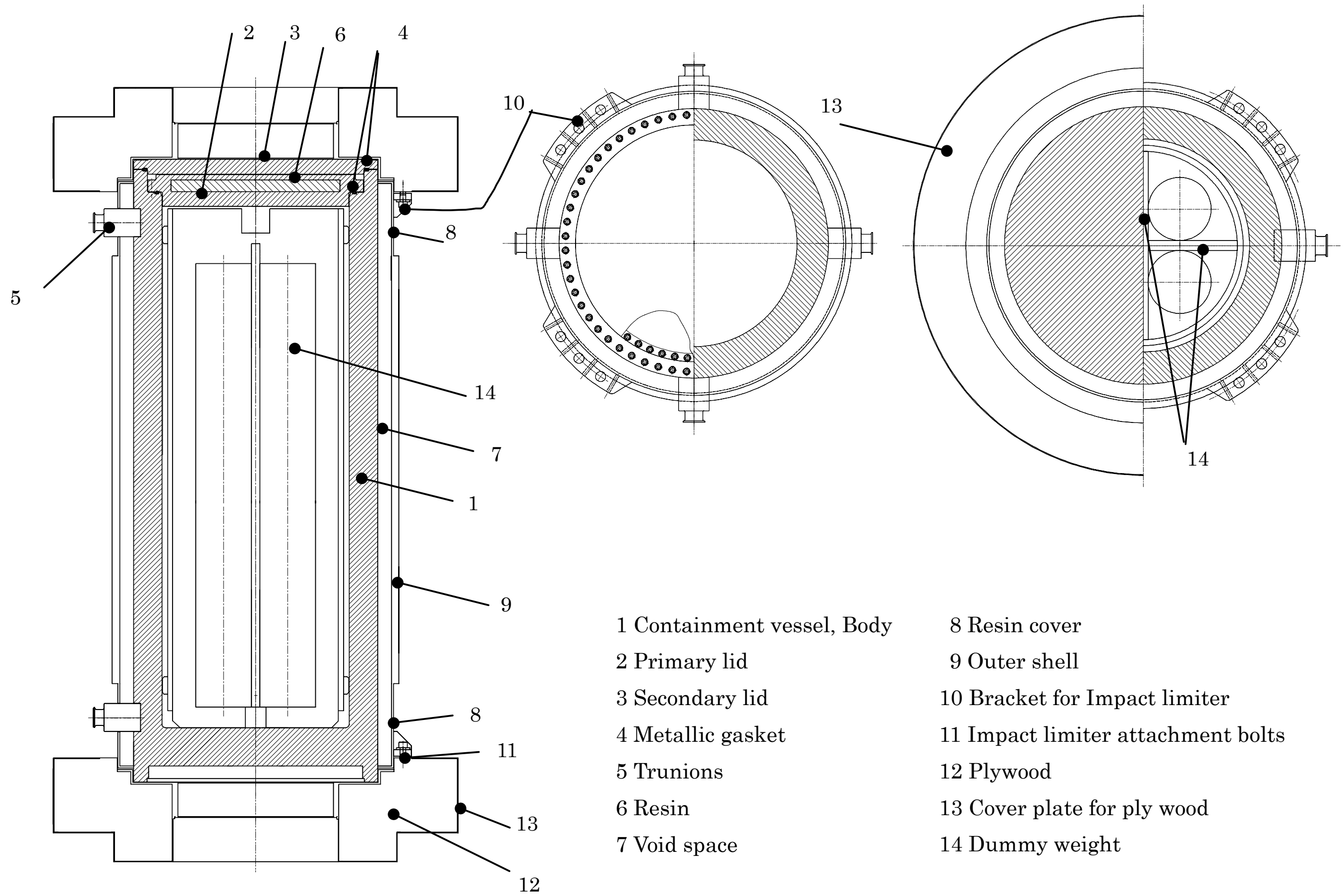

Figure 1: Principal components of 1/3 scale Hitz-B69 Cask with impact limiter

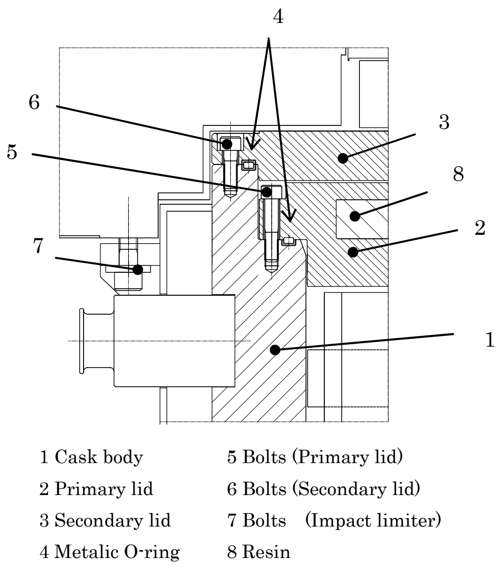

Figure 2: Enlarged part of the seal boundary

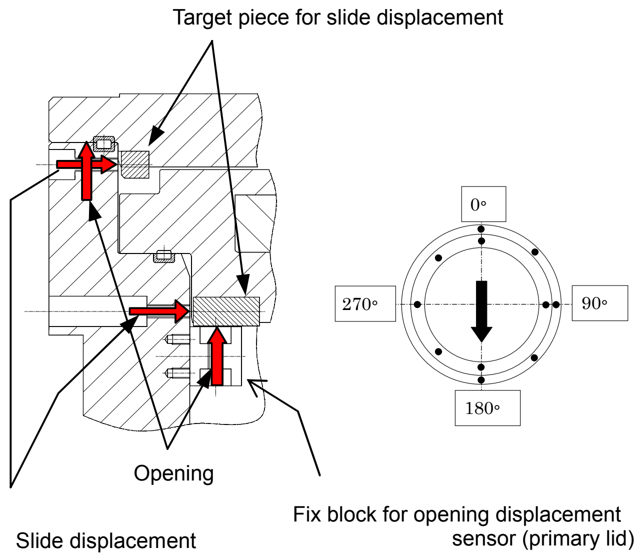

Figure 3: Location of displacement sensor

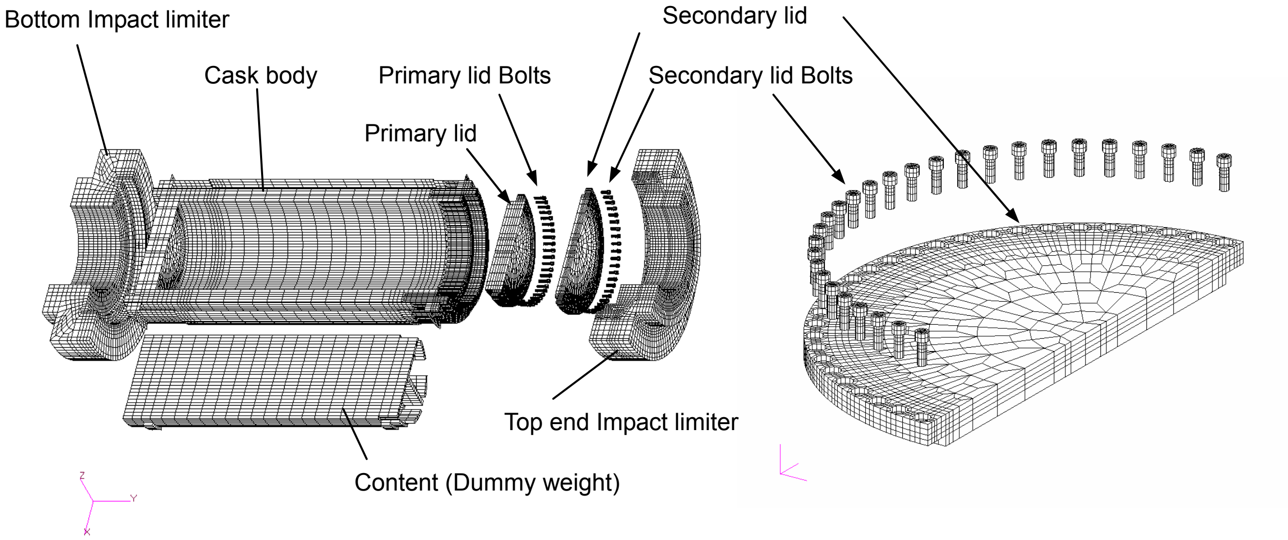

Figure 4. The FE model of 1/3 scale Hitz-B69 cask and a secondary lid and bolts

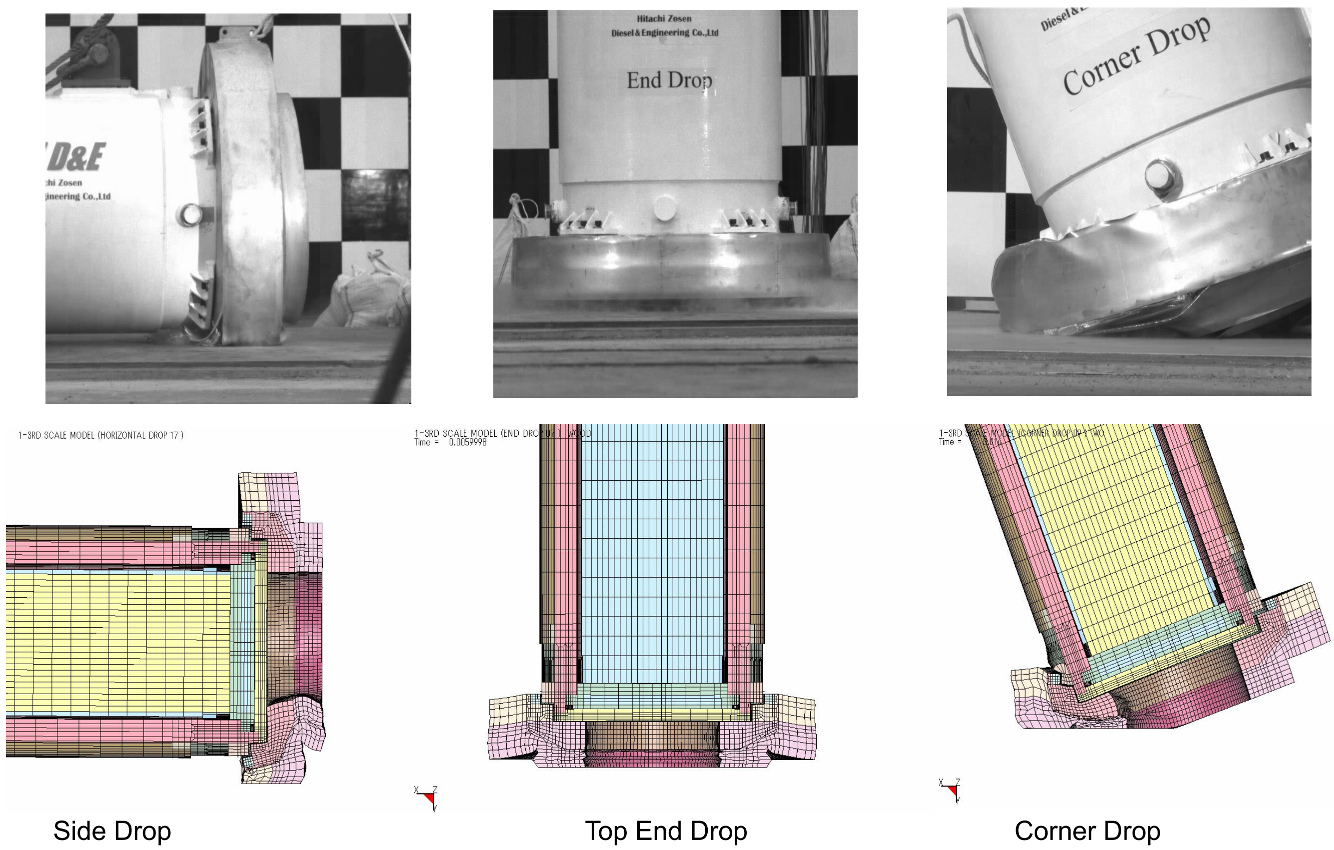

Figure 5. Actual and predicted deformed shapes for three positions of drop direction.

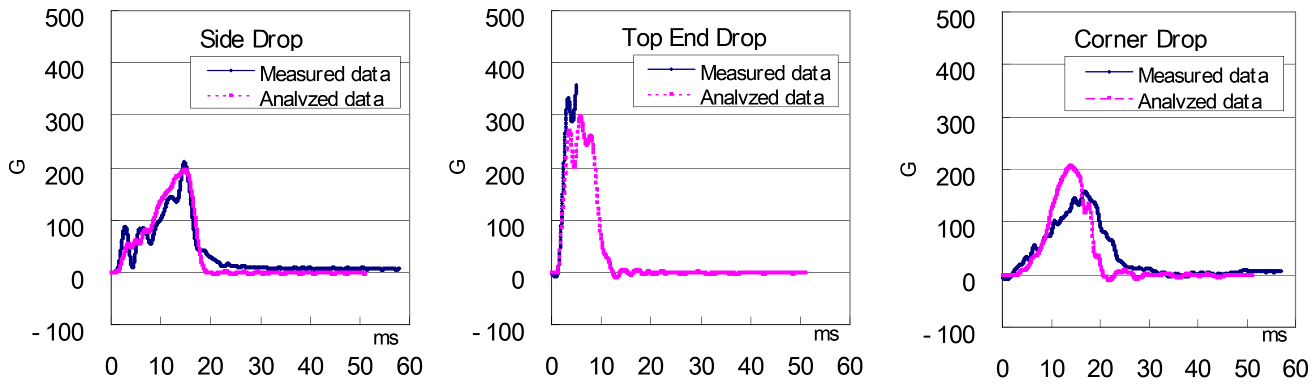

Figure 6. Actual and predicted accelelation for three positions of drop direction.

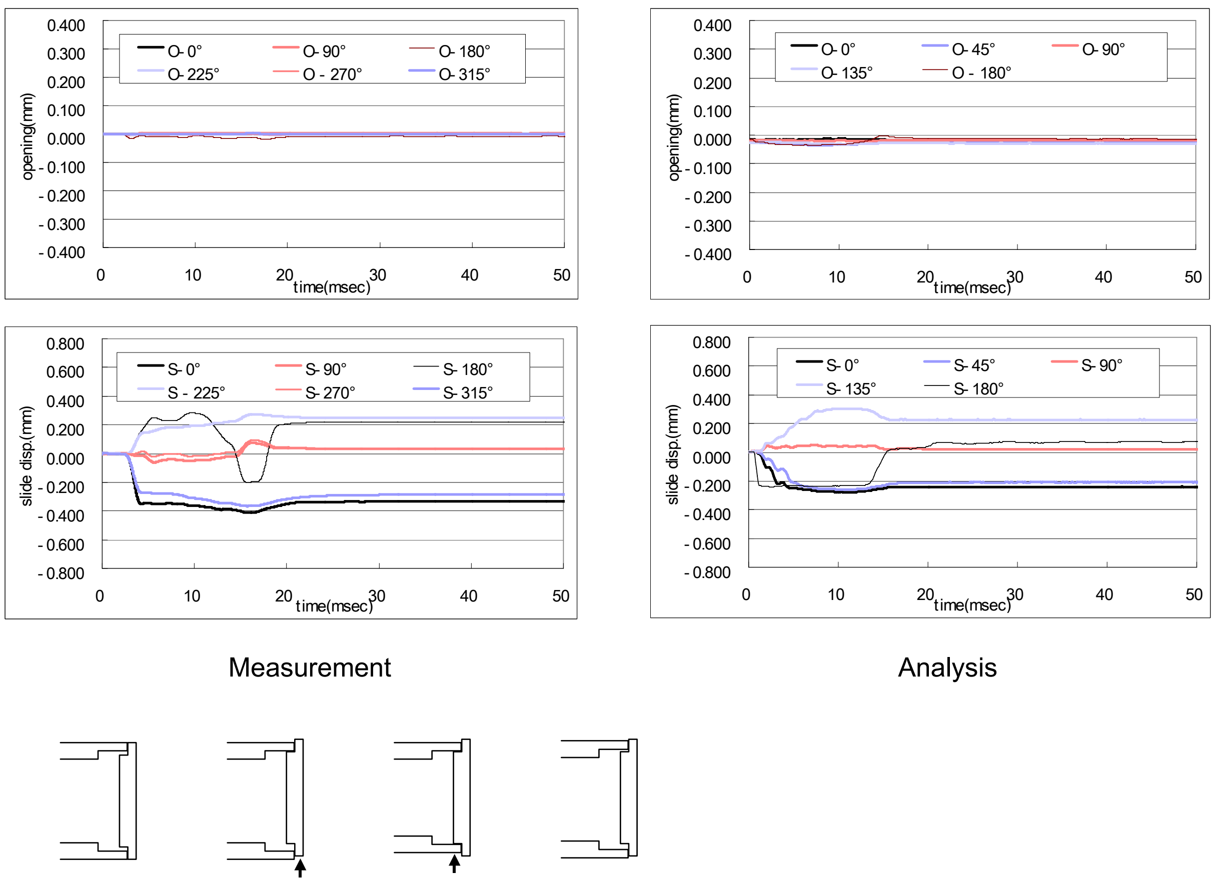

Figure 7. Comparison of Opening and slide displacement of the secondary lid at side drop

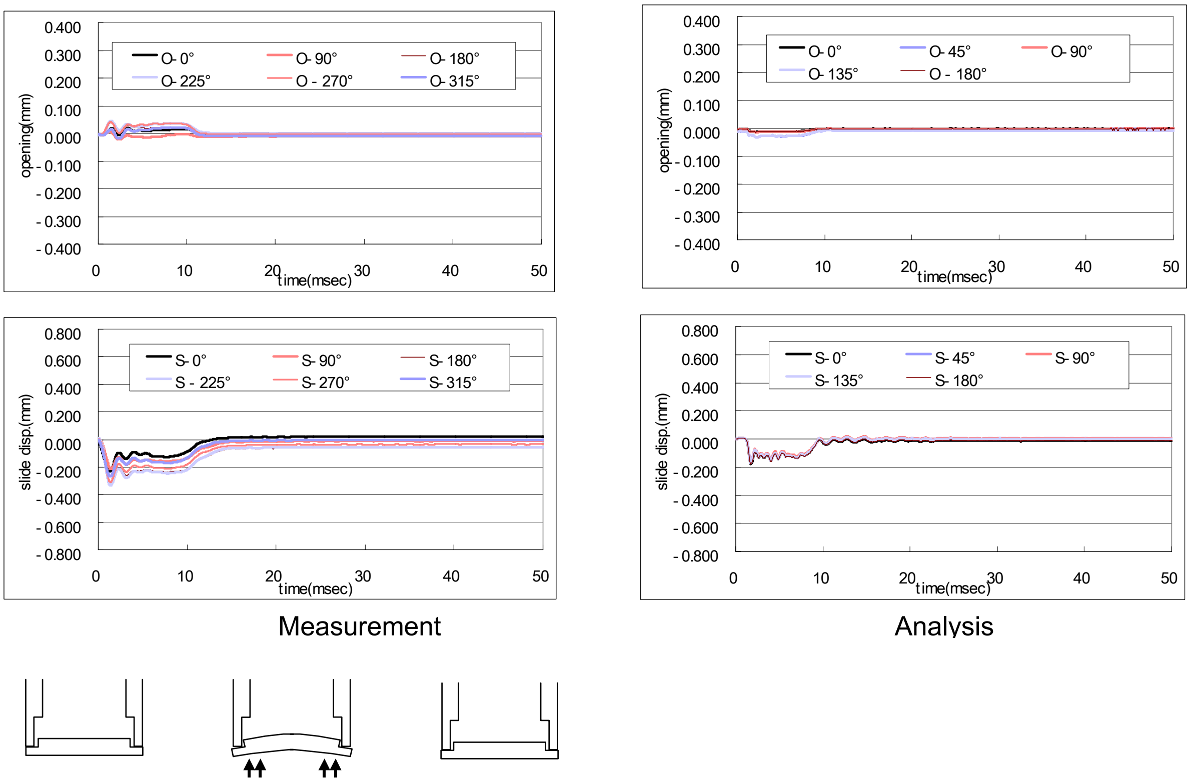

Figure 8. Comparison of Opening and slide displacement of the secondary lid at top end drop

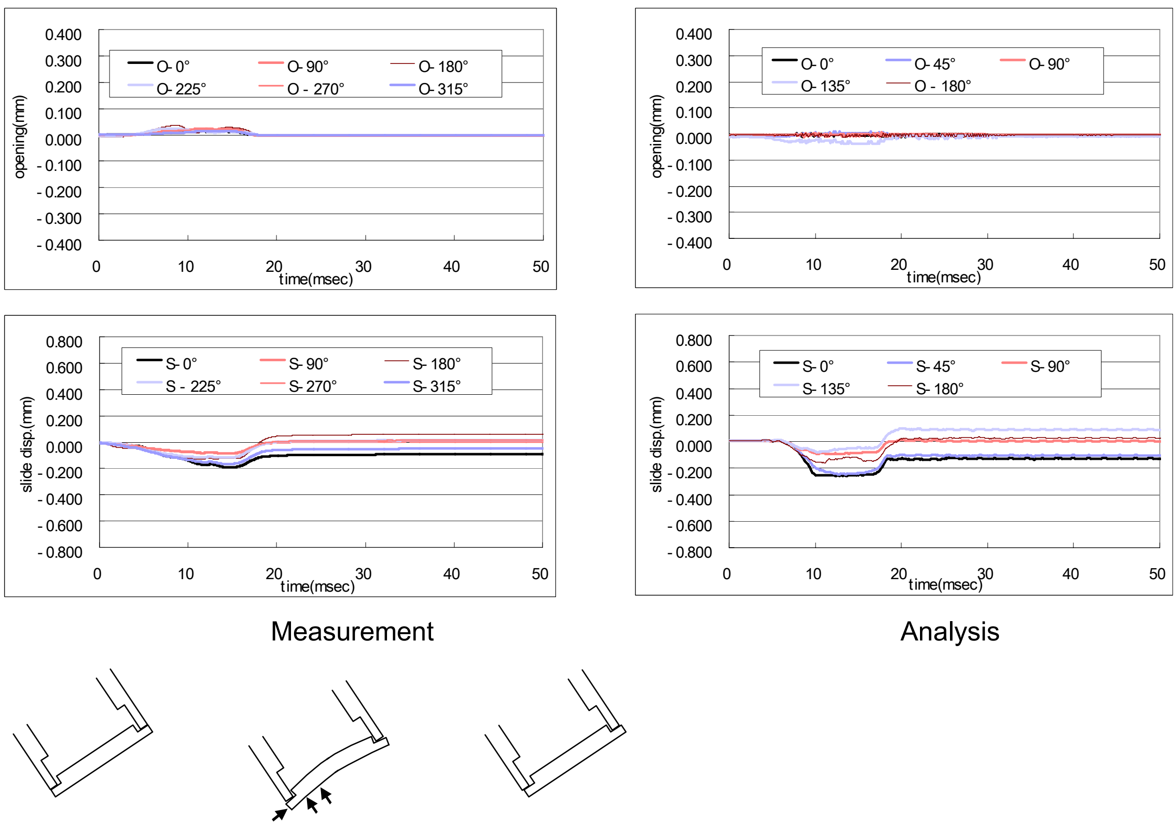

Figure 9. Comparison of Opening and slide displacement of the secondary lid at corner drop