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Study on effect of drop attitude during 9 m slap-down drop using dynamic analysis

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Abstract

FEM analysis was performed using the LS-DYNA software to evaluate the effect of the secondary impact load on a slap-down drop. The finite element analysis (FEA) model, which has shock absorbers in the head and bottom, modeled a large virtual nuclear fuel transportation package that constituted a containment boundary with a primary and a secondary lid. It had a weight of 136 ton. The drop attitude angle was also considered in the slap-down drop for drop test I. The FEA model has a gap between the BWR fuel assembly and the basket lattice, and it makes a delayed drop from the BWR fuel assembly to the basket lattice. Through a case study employing 10 different drop attitude angles, the time histories of impact acceleration of representative points on the package in the drop direction and the load of both primary and secondary lid bolt shafts and basket stress were summarized.

The results of the case study could not represent the maximum damage for one of the drop attitude angles for the evaluation items. By using a beam element for the bolt shafts of the FEA model, the evaluation of stress for the bolt shafts became simplified and made the computing faster than it was using solid elements.

By studying these results, it was found that the drop attitude angle that produced the maximum damage was different for each evaluation item. Therefore, it was concluded that slap-down drops need to be studied with multiple angles of attitude for evaluating the structural integrity of the package.

Introduction

IAEA Specific Safety Guide (number SSG-26[1] paragraph 702.2) mentions that the experience of the drop tests suggests the effect of the secondary impact is often more severe for a package with an aspect ratio greater than 5. Recent studies[2, 3] indicated that the secondary impact acceleration exceeded twice the first impact acceleration of a package with an aspect ratio less than 3. This study looked at the effect of the drop attitude angle on the maximum damage of the secondary impact during slap-down drop of a package with an aspect ratio less than 3.

1. Analysis model

The analysis model[4] is shown in Figure 1. The axial length of the body is approximately 5.5 m and the diameter of the body is approximately 2.5 m. The gap between the basket and the fuel assemblies is 7 mm for delaying the impact. The attachment bolts of the shock absorbers are not modeled. The total number of nodes is approximately 170,000. The finite element analysis (FEA) software package LS-DYNA Ver. 7.1.1 was used for dynamic analysis. The main material properties are shown in Table 1. The stress–strain curves of the woods of the shock absorbers are shown in Figure 2.

1.1 Mass condition

The main mass condition is shown in Table 2.

1.2 Constrain condition

The analysis model was 1/2 symmetric on the symmetric plane of the analysis model in the circumferential direction.

1.3 Boundary condition

The velocity of the package in the drop direction was 13.3 m/s onto the rigid floor for drop test I. The acceleration due to gravity of the package in the drop direction was 1g.

1.4 Damping condition

The damping factor of the package was 2 %.

1.5 Modeling of bolts

For all the lid bolts, solid elements were used for the head of the bolt, and beam elements were used for the shaft of the bolt. For the joints of each head to the shaft and the shaft to the flange of the body, beam elements were kept perpendicular to the joints when the beam elements experienced a force due to the impact. Before the drop was initiated, the lid bolt shafts were set to the initial tensile condition by performing thermal stress analysis for clamping the bolt.

1.6 Friction coefficients

The main friction coefficients are shown in Table 3.

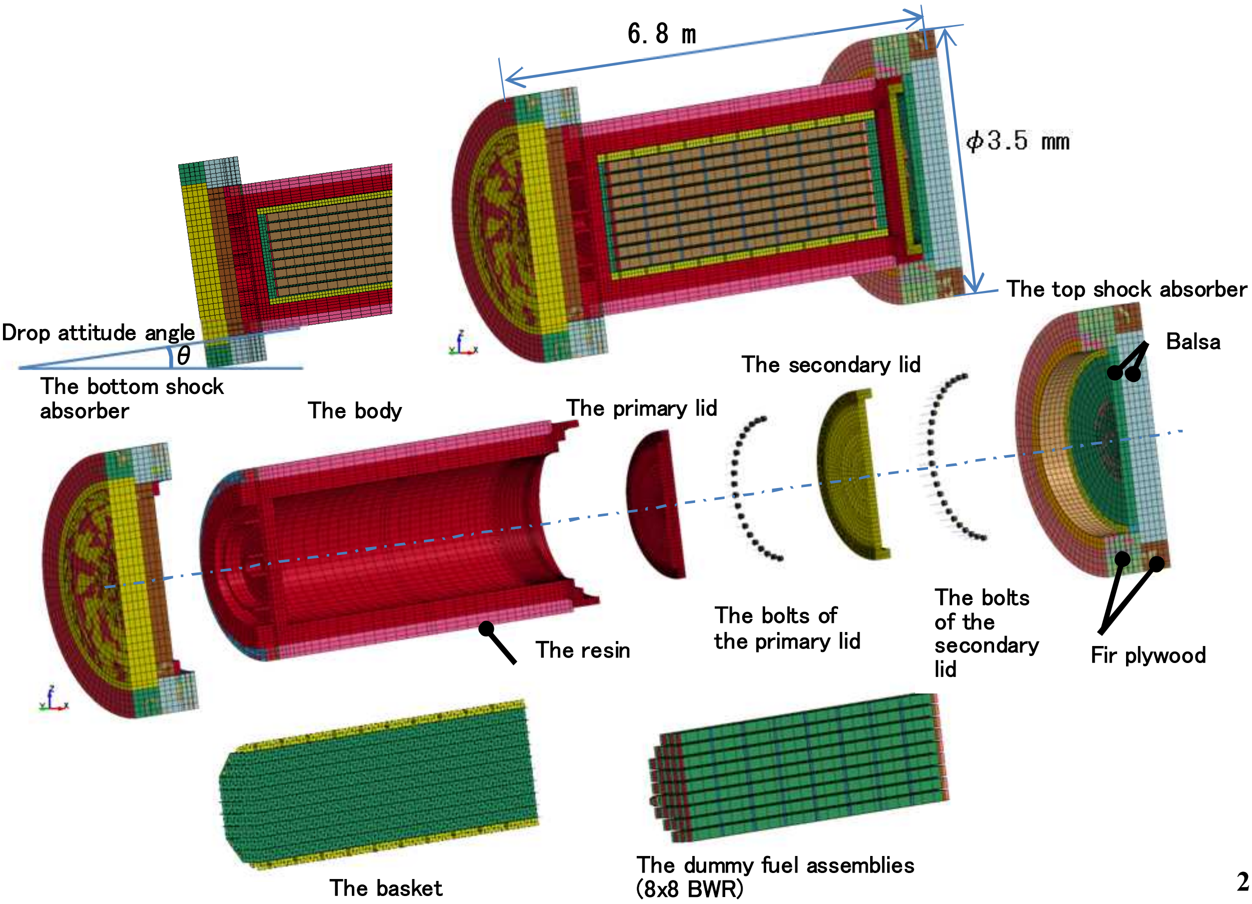


Figure 1. Analysis model

2. Evaluation items

The evaluation items are as follows,

1) The final strain distribution of the body
2) The time history of the velocity in the drop direction at the corner of the top shock absorber
3) The time history of the impact acceleration in the drop direction, at the body
4) The time history of the von Mises stress around the basket
5) The time history of the bending moment around the lid bolts

The time history of the evaluation items was evaluated for 2° increments of the drop attitude angle from 0° to 18°. The final strain distribution of the horizontal drop and the drop attitude angle of 8° were evaluated. For only the time history of impact acceleration, a low-pass filter was applied by using a second-order of the Butterworth low pass filter with a cut-off frequency of 120 Hz for post processing. Figure 3(1)–(4) shows the evaluation position of the package.

<u>2.1 The evaluation of the body</u>

Acceleration was generated in the body owing to the drop impact. The time history of the acceleration of the representative positions was summarized.

<u>2.2 The evaluation of the basket</u>

Compression stress was generated in the basket by drop impact. The time history of the von Mises stress of representative positions was summarized.

<u>2.3 The evaluation of the lid bolts</u>

Bending moment was generated in the bolts of the primary lid (M42x40) and the bolts of the secondary lid (M42x42) by drop impact. The time history of the bending moment in the bolts was summarized.

3. Analysis results

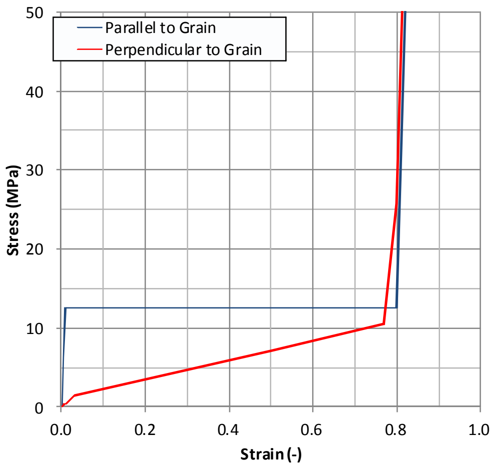
<u>3.1 The effective plastic strain of the body</u>

Figure 4(1) shows that there was a small strain at the positions of the equivalent attachment bolts of the shock absorbers. Figure 4(2) show that there were strains of approximately more than 10 % at the positions of the equivalent attachment bolts of the shock absorbers. In case the attachment bolts rupture, there is a possibility that the shock absorbers can fall off.

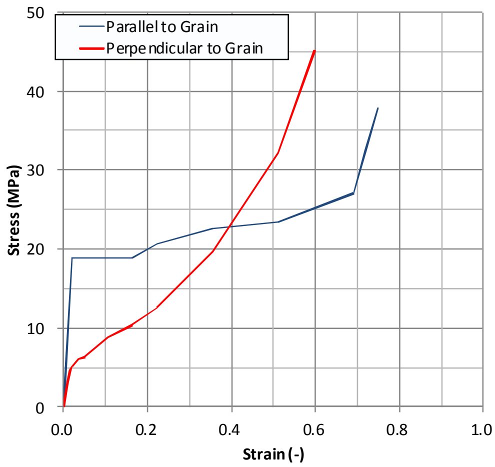
Table 1. Main material properties

No.	Part	Material	Elastic modulus (MPa)	Poisson's ratio (-)	Density (ton/mm^3)	Yield strength (MPa)	Tangent modulus *1 (MPa)
1	Body Bottom Plate	ASTM A350M LF5 CL1	203459	0.3	7.86E-09	205	2034
2	Primary & Secondary Lid	ASTM A350M LF5 CL1	203459	0.3	7.86E-09	205	2034
3	Cover & Rib of shock absorber	JIS SUS304	195000	0.3	7.78E-09	205	1950
4	Outer shell	JIS SM400A	203000	0.285	7.86E-09	215	2030
5	Cover Resin of Secondary Lid	JIS SS400	203000	0.3	7.86E-09	215	2030
6	Resin	Epoxy	3870	0.3	1.68E-09	60.5	38.7
		Cement	11500	0.167	1.58E-09	-	-
7	Bolt of Primary Lid Bolt of Secondary Lid	JIS SNB23-3	202000	0.3	7.85E-09	890	2020
8	Basket	Boron doped aluminum	72600	0.3	3.29E-09	303	-
9	Rib of Basket	JIS H 4000 A6061P T651	72600	0.3	2.70E-09	276	-
10	Wood-1 of shock absorber	Balsa	1830.0	0.0	2.00E-10	-	-
11	Wood-2 of shock absorber	Fir plywood	1880.0	0.0	5.60E-10	-	-

*1: the strain rate effects are not considered.



a) Balsa



b) Fir plywood

Figure 2. Stress–strain curves of the types of wood in the shock absorber

Table 2. Main mass conditions

No.	Part	Mass (ton)
1	Vessel (including Primary Lid & Secondary Lid)	92.20
2	Top shock absorber	7.60
3	Bottom shock absorber	8.62
4	Basket	5.70
5	Dummy fuel assemblies	21.80
	Summary	135.90

Table 3. Main friction coefficients of contact parts

No.	Contact Part-A	Contact Part-B	Friction Coefficient
1	Body	Secondary lid	0.17
2	Body	The cover of the shock absorbers	0.17
3	The flange of the body	Primary lid	0.20
4	The flange of the body	Secondary lid	0.20
5	The wood of the shock absorbers	The cover of the shock absorbers	0.49
6	The wood of the shock absorbers	The wood of the shock absorbers	0.48
7	Body	Basket	0.20
8	Basket	Primary lid	0.20
9	Basket	Dummy fuel assemblies	0.20
10	Dummy fuel assemblies	Primary lid	0.20
11	Dummy fuel assemblies	Bottom plate	0.20

3.2 The time history of velocity in the drop direction at the corner of the top shock absorber

Figure 5 shows the time history of velocity in the drop direction for the upper shock absorber. Table 4 shows the specific values of Figure 5. The maximum velocity just before the secondary impact occurred for a drop attitude angle of 8°.

3.3 The time history of the impact acceleration in the drop direction of the body

Figure 6(1) shows that the maximum value (104.5g) occurred for a drop attitude angle of 16° after the first impact. Figure 6(2) shows that the maximum value (275g) occurred for a drop attitude angle of 8° through the secondary impact at the vicinity of the primary lid of the body.

3.4 The time history of the von Mises stress of the basket

Figure 7(1) shows that the maximum value (260 MPa) was attained with a drop attitude angle of 2° after the first impact at the bottom of the basket. Figure 7(2) shows that the maximum value (178 MPa) occurs for a drop attitude angle of 0° after the first impact at the center of the basket. The stress values with a different drop attitude angle were almost the same. Figure 7(3) shows that the maximum value (320 MPa) occurred at the drop attitude angle of 8° due to the secondary impact at the top of the basket. The yield strength of the aluminum basket is 303 MPa. The result of the maximum stress in the horizontal drop indicates that there was no plastic region. In the case of the slap-down drop, there may be a plastic region.

3.5 Time history of the bending moment of the lid bolts

Figure 8(1) shows that the maximum values of all results were almost the same for all drop attitude angles at the bolt of the primary lid. For all the drop attitude angles, there was no difference in the bending moment. Figure 8(2) shows that the maximum value (3.1×10^6 N·mm^2) occurred with the drop attitude angle of 8° owing to the secondary impact at the bolt of the secondary lid.

$$\sigma_m+\sigma_b=1067\ \text{MPa} > \sigma_y\ (890\ \text{MPa}) \qquad (1)$$

The result of the maximum stress in the horizontal drop indicates that there is no plastic region. In case of the slap-down drop, plastic deformation may occur in the bolts of the secondary lid.

4. Consideration

The stresses on the bolt and basket were evaluated using dynamic analysis. The acceleration of the body has only meaning of the design parameter. The von Mises stress of the basket is related to the evaluation of criticality because the mutual distance between each fuel assembly is shortened. The bending moment of the bolts are related to structural integrity.

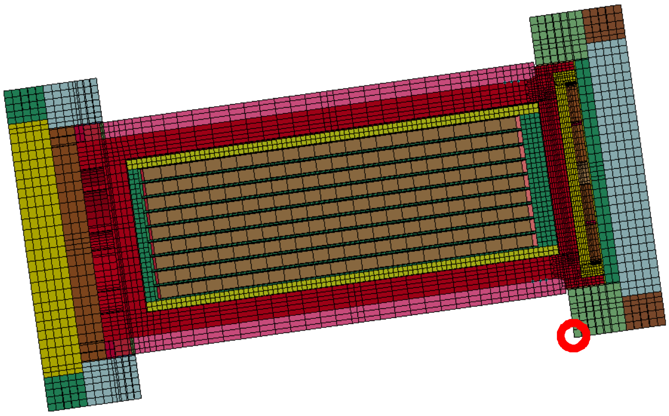


Figure 3(1). Evaluation position of the top shock absorber

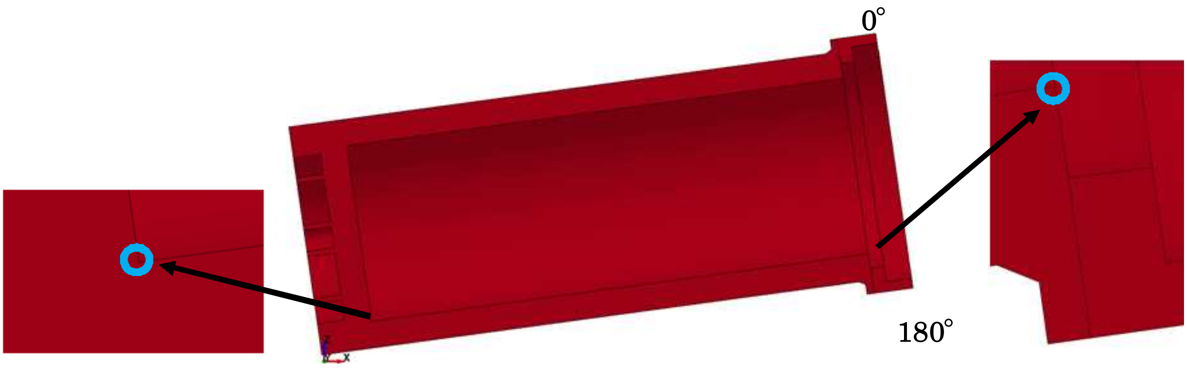


Figure 3(2). Evaluation positions of the body

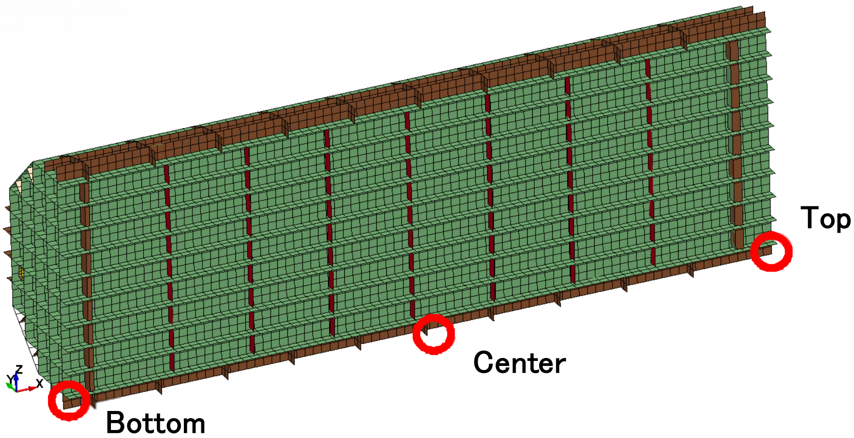


Figure 3(3). Evaluation positions of the basket

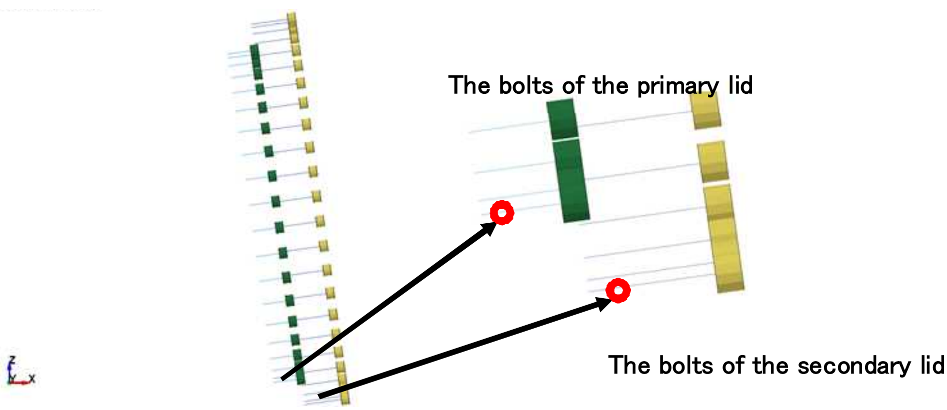


Figure 3(4). Evaluation positions of the lid bolts

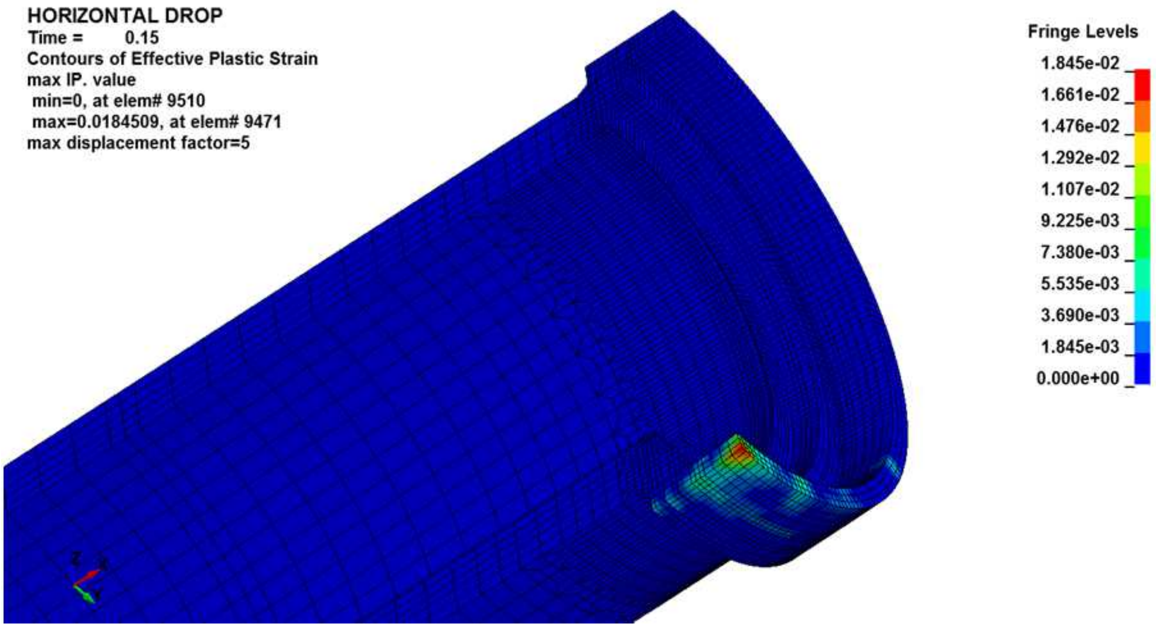


Figure 4(1). Distribution of the effective plastic strain (drop attitude angle: 0°)

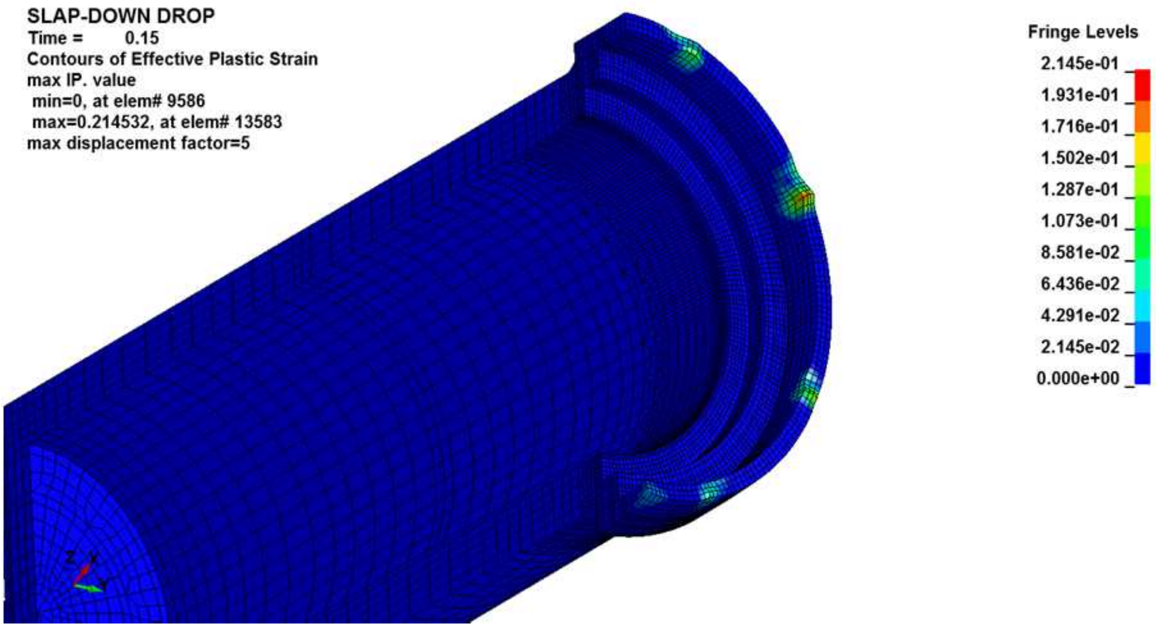
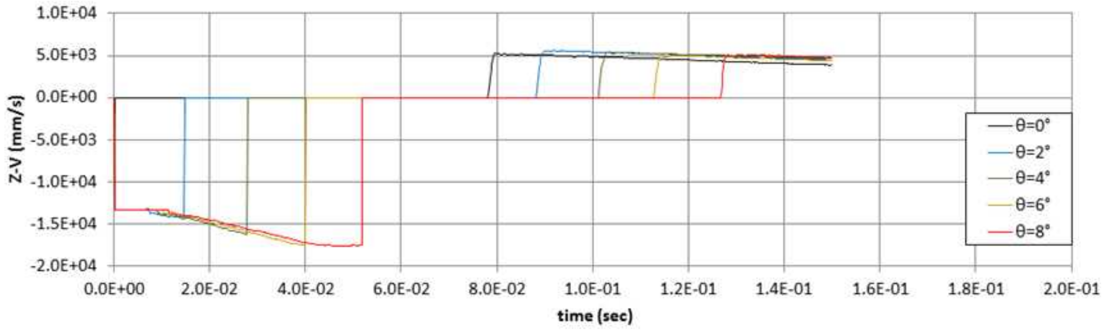


Figure 4(2). Distribution of the effective plastic strain (drop attitude angle: 8°)



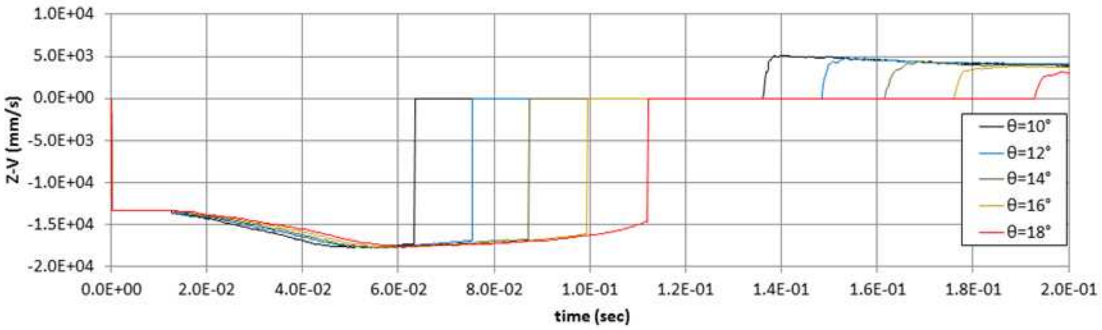


Figure 5. Time history of velocity in the drop direction at the corner of the top shock absorber

Table 4. Main character of the time history of velocity

No.	The drop attitude angle θ (°)	Start time of the secondary impact T_1 (sec)	End time of the secondary impact T_2 (sec)	Difference of the time ΔT (sec)	Velocity just before a secondary impact V_1 (m/s)
1	0	0.00E+00	7.82E-02	7.82E-02	-13.28
2	2	1.48E-02	8.82E-02	7.34E-02	-14.43
3	4	2.80E-02	1.01E-01	7.34E-02	-16.19
4	6	4.02E-02	1.13E-01	7.26E-02	-17.44
5	8	5.20E-02	1.27E-01	7.48E-02	-17.53
6	10	6.36E-02	1.36E-01	7.28E-02	-17.32
7	12	7.56E-02	1.49E-01	7.30E-02	-16.91
8	14	8.75E-02	1.62E-01	7.42E-02	-16.78
9	16	9.95E-02	1.76E-01	7.68E-02	-16.14
10	18	1.12E-01	1.93E-01	8.08E-02	-14.70

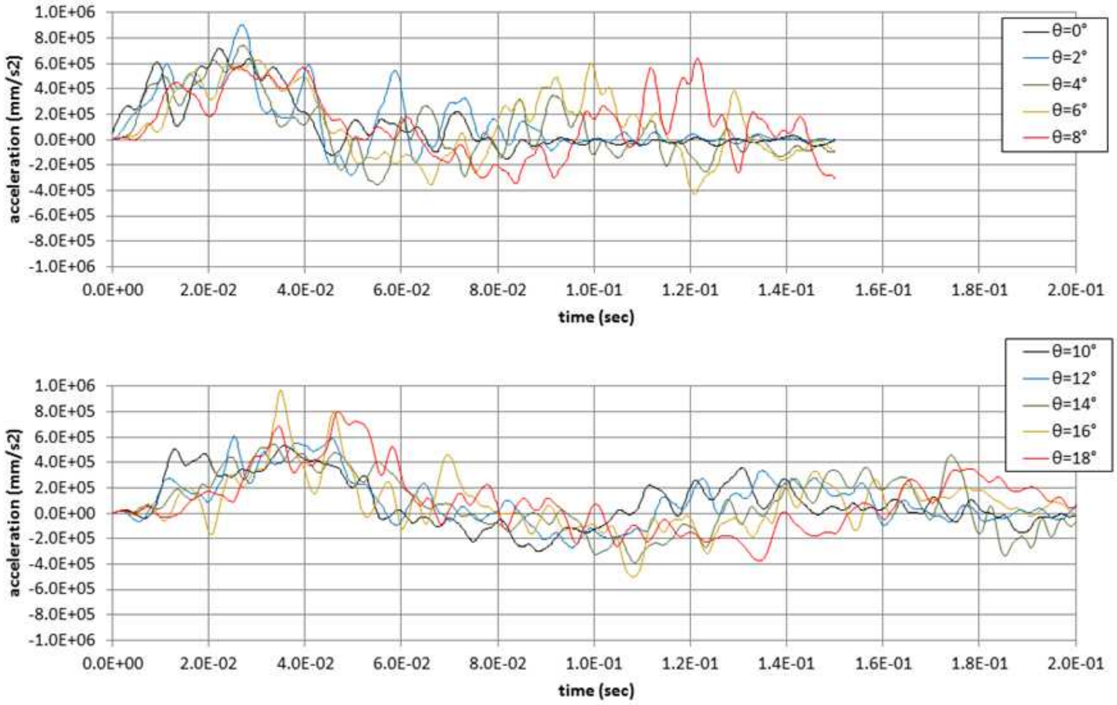


Figure 6(1). Time history of the acceleration at the bottom of the body

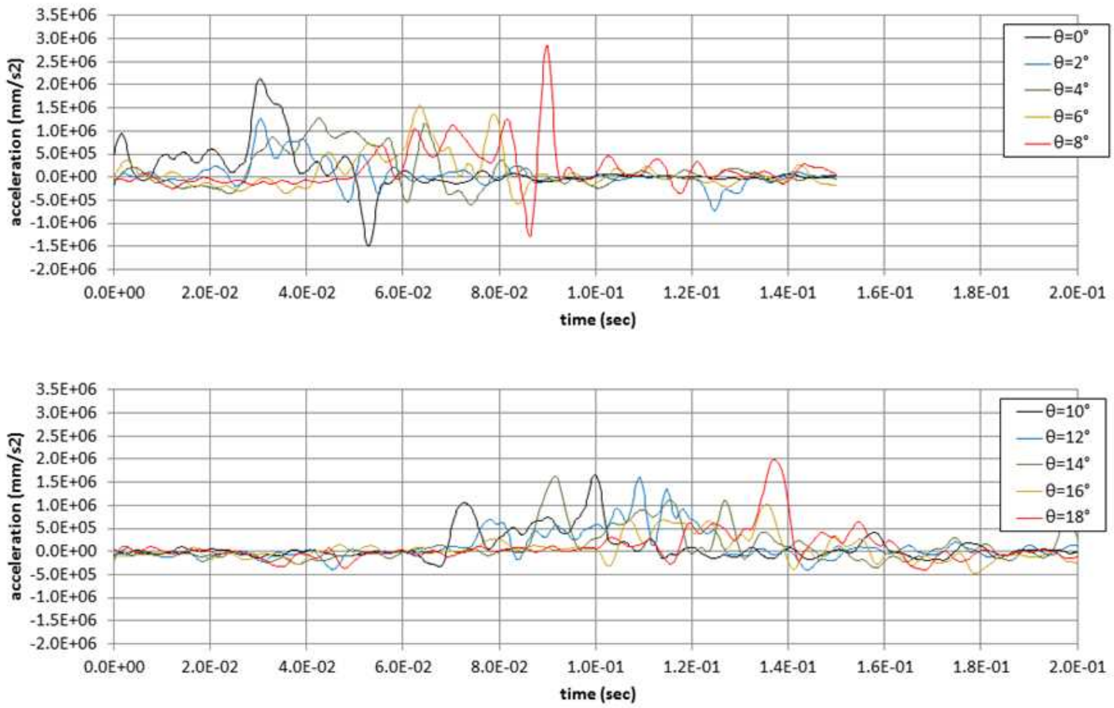


Figure 6(2). Time history of the acceleration in the vicinity of the primary lid

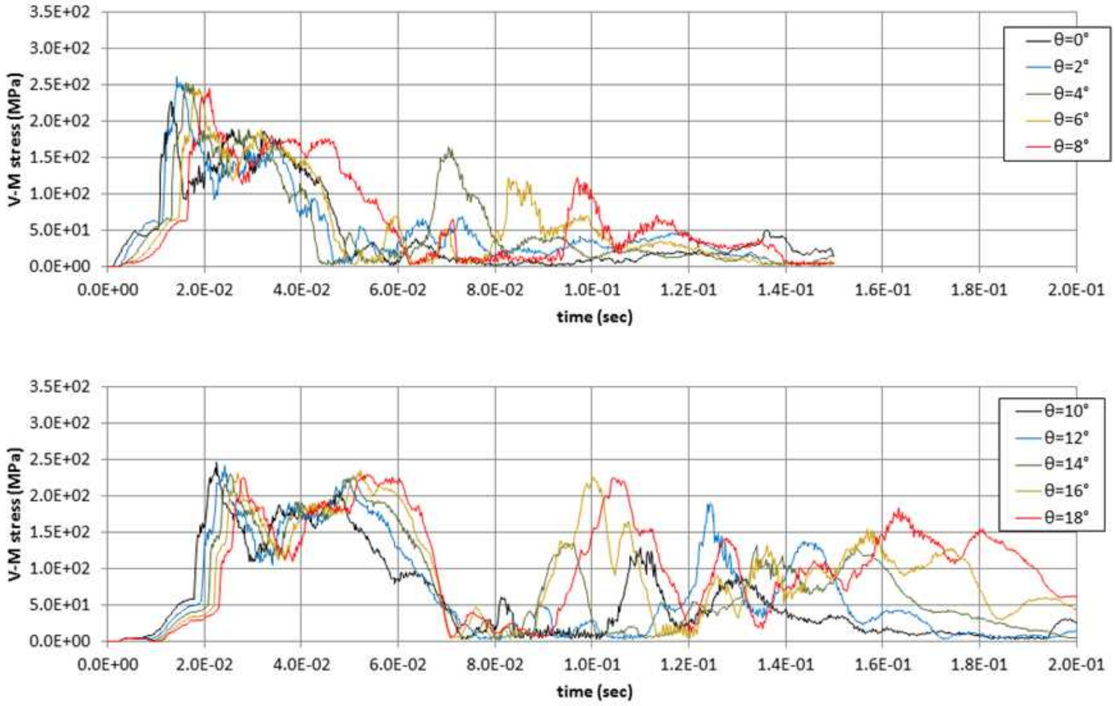


Figure 7(1). Time history of the von Mises stress at the bottom of the basket

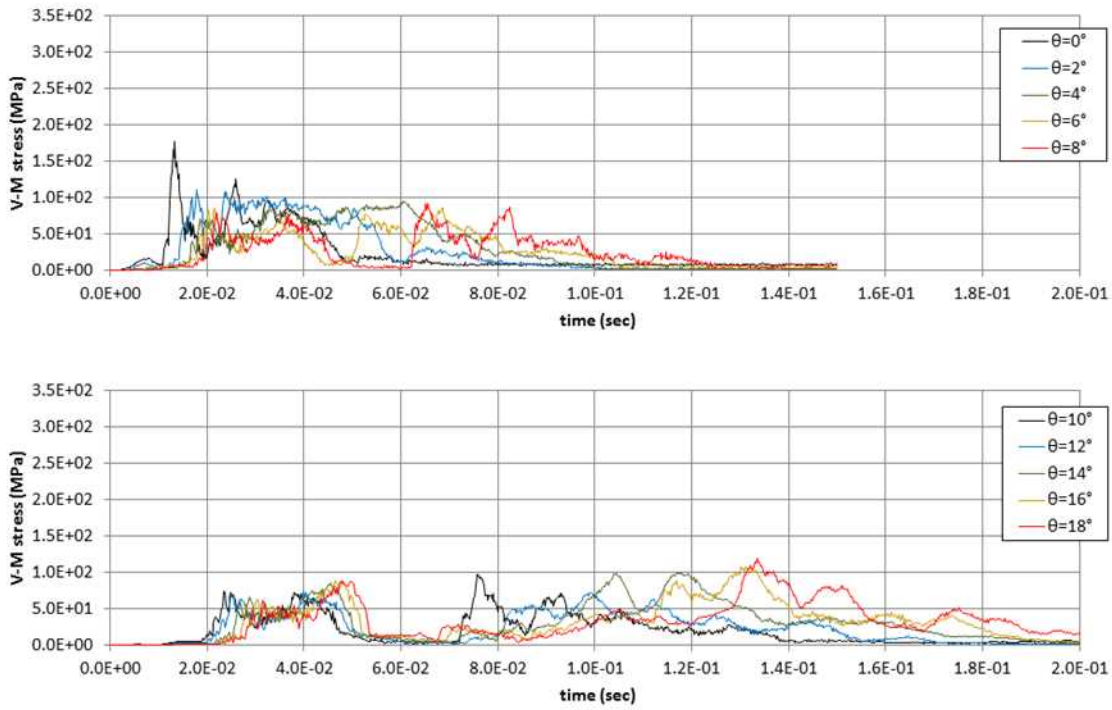


Figure 7(2). Time history of the von Mises stress at the center of the basket

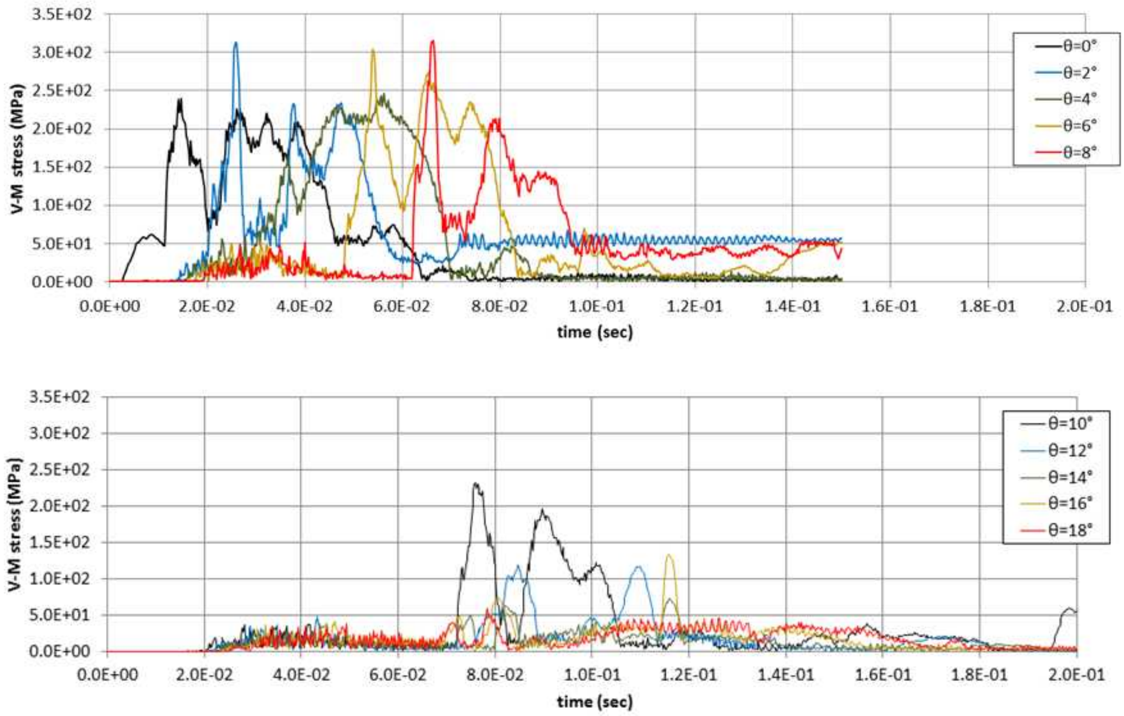


Figure 7(3). Time history of the von-Mises stress at the top of the basket

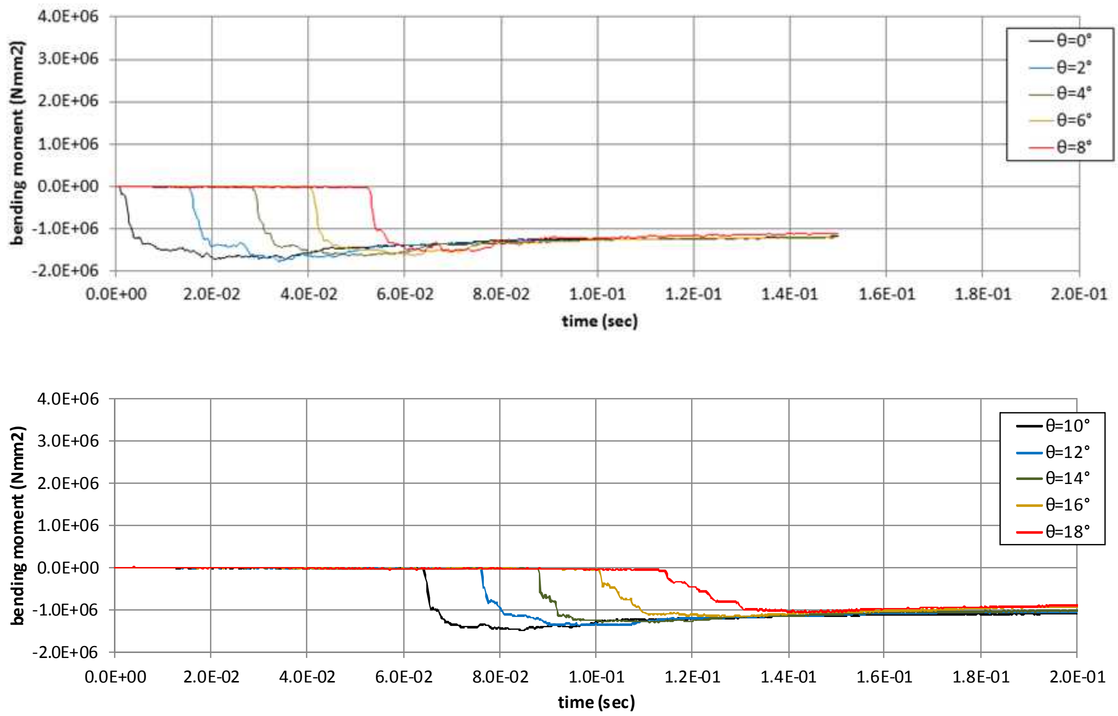


Figure 8(1). Time history of the bending moment for the bolt of the primary lid

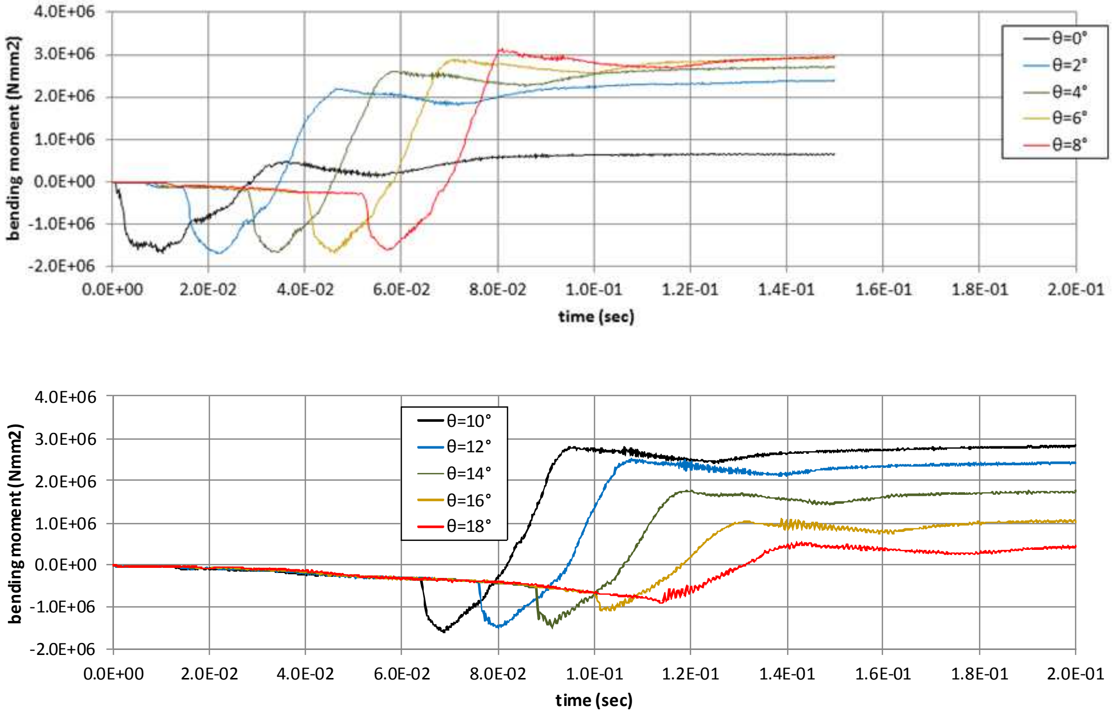


Figure 8(2). Time history of the bending moment for the bolt of the secondary lid

5. Conclusions

It was found that the drop attitude angle that produced the maximum damage was different for each evaluation item. Therefore, it was concluded that slap-down drops need to be studied with multiple angles of attitude for evaluating the structural integrity of the package.

6. References

[1] IAEA Safety Standards, "Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material (2012 Edition)", Specific Safety Guide No. SSG-26

[2] Thomas Quercetti, et al., "Comparison of Experimental Results from Drop Testing of a Spent Fuel Package Design Using a Full-scale Prototype Model and a Reduced-scale Model", 15th International Symposium on the Packaging and Transportation of Radioactive Materials (PATRAM), (2007)

[3] Tadashi Kimura, et al., "EVALUATION ON STRUCTURAL INTEGRITY OF "MSF" TRANSPORT AND STORAGE CASK BASED ON RESULTS OF DROP TEST", 15th International Symposium on the Packaging and Transportation of Radioactive Materials (PATRAM), (2007)

[4] Takeshi YOKOYAMA, et al., "Integrity Assessment of Dual-Purpose Metal CASK after Long Term Interim Storage Seal Performance under Transport Conditions", 14th International Symposium on the Packaging and Transportation of Radioactive Materials (PATRAM), # 076, (2004)