The Effect of Secondary Impact on a Spent Fuel Shipping Cask Subjected to Slant-Angle Drop Tests

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Abstract

According to the IAEA Regulations, any cask for large radioactive sources must be able to withstand the free drop test from a height of 9m onto a rigid target. The regulations require that the cask withstand a drop in an orientation for which maximum damage is expected. Conventionally, either the vertical, the horizontal or the corner drop has been assumed to be the orientation of maximum damage. However, if any arbitrary orientation such as the slant-angle drop is or could be more severe than other orientation, the safety assessment for that case should be done.

Recently, it is suggested by many researchers that, depending upon test condition, the secondary impact under slant-angle drop test can result in severe damage compared with other cases.

To clarify this point, we conducted a series of drop tests with a 1/4 scale model of the spent fuel shipping cask and also carried out dynamic structural analysis by use of DYNA-3D Code. It is concluded ultimately, that the horizontal drop condition is more severe than the slant-angle drop test, from the viewpoint of safety evaluation for container-body itself.

1. Introduction

The present regulatory hypothetical accident conditions such as "9m free drop test" and "1m penetration test" pose the most severe requirements on cask design, and those tests impose to conduct in the orientation so as to suffer the maximum damage in respect of the safety features of the specimen to be tested. For free drop test, either the vertical, the horizontal or the corner drop (cask center of gravity directly above the impacting corner) condition has been considered to cause the maximum damage.

However, recently some researchers 1)-3) pointed out that, depending upon container geometry, the low-angle secondary impact condition can be more severe than the above-mentioned conditions. If this suggestion is true, the safety analysis for secondary impact must be essential in cask design.

To make a thorough investigation of this matter, we conducted a series of drop tests with a 1/4 scale model of the spent fuel shipping cask under the condition of inclination (at 5, 10 and 20 degree-angle of the longitudinal axis of cask-model to the target surface), and also carried out dynamic structural analysis by use of DYNA-3D Code in the condition of inclination (at 0 to 30 degree-angles including the same angles as tested).

This paper describes the result of the dynamic structural analysis as well as the test results which obtained certain conclusions on the most nfluenced drop-angle in connection with the safety of cask-model.

2. Outline of Analysis and Drop-tests

In case of the large scale nuclear container such as a spent fuel shipping cask, usually, shock absorbers are equipped at both its ends to limit the shock caused by any accident during the transportation or handling. Hence, at the time when such a type of cask is being designed, it allows to be considered as a full-fabricated packaging including shock absorbers.

In this study, therefore, a cask model with shock absorbers, as shown in Fig. 1 and Fig. 2, is employed to examine. The extent of damage given by the secondary impact to the structural integrity of cask is depending upon the angle of inclination as well as the design of cask-body and shock absorbers.

For the parameters on the cask design among those factors, however, almost the familiar types of structures are used in general, as far as the existing spent fuel shipping casks are concerned. Therefore, we designed to deal with only the effect of the angle of inclination in this study.

For the analysis, a fairly simplified 3D-FEM (Three Dimensional Finite Element Method) model was used and meshed into 2250 elements (3115 nodal points) as shown as Fig. 3, and a dynamic nonlinear 3D-FEM computer code, DYNA-3D was used.

As the analytical conditions, it is assumed that the above-mentioned model is dropped from a height of 9m onto a rigid flat floor in the orientations of 0, 5, 10, 20, and 30 degree-angles with the initial velocity of 13.28 m/s at the moment of contact with the floor. A number of dynamic response data such as the time histories of displacements, velocities, accelerations, strains and stresses at some selected points on the model, and the diagrams of sectional deformation of the model were obtained during the time between the beginning of the primary impact and the end of the secondary impact.

And additional assumptions, that the surface of shock absorbing material (Balsa) in contact with cask body is separable and only the outer shell's contacting part with the cask body is fixed were used to simulate the gap generating phenomenon of balsa filled in shock absorbers.

The drop tests were conducted by use of the drop test facility from the height of 9m onto the target with a steel plate (50mm thick), in the orientation of 5, 10, and 20 degree-angles of the longitudinal axis of cask model with the target surface, respectively, in a posture of falling the lid-side first.

In order to evaluate the behaviour of test-models during impact, the measurements of acceleration and dynamic strain at some selected positions of the models as well as the measurements of deformation of the shock absorbers caused by impact were carried out.

Besides the high speed camera photographing and film motion analysing were also carried out to obtain the kinematic behaviour of the models during impact.

3. Results and Discussions

Several results were obtained in regard to the safety of cask body, as follows.

3.1 Deformation

The example diagram of final deformation at the section of the shock absorbers caused by impact are shown in Fig. 4 and Fig. 5. The values in brackets in those figures are experimental results observed after the drop tests. It can be seen from those figures that the damage to shock absorbers at the secondary end (bottom-side) was greater than that at the initial end (lid-side) in all cases and the analysed values of deformation coincide nearly with the experimental values shown in brackets.

The example aspect of deformation at the section observed after the drop tests are shown in Fig. 6. Compared with the analysed diagram, the main features of deformation are roughly similar to analysed results, except that the fracture or the partial buckling in stainless outer-shell are experimentally observed after drop tests.

3.2 Deceleration

The example diagram of the deceleration at the selected point near the bottom of cask body are shown in Fig. 7. As seen in Fig. 7, the maximum value of the deceleration at the secondary end (bottom-side) are higher than that at the initial end (lid-side) and the highest deceleration at the secondary end occurs at the 5 to 10 degree-angle.

The values of the deceleration near the bottom of cask body are shown in Table 1. As seen in Table 1, the experimental values are smaller than the analysed values in all cases and the similar tendency are obtained with experimental and analysed values both of the deceleration.

3.3 Stress

For the maximum values of stress which directly affect the safety of cask body, the analysed diagram of strain at the outer-shell's center of cask body are shown in Fig. 8. As seen in Fig. 8, the analysed values of strain increased with a decrease in the angle of cask-inclination and the highest values of strain occur at 0 degree-angle, i.e. a horizontal orientation.

So it is considered that the analysed values of stress increased with a decrease in the angle of cask-inclination and the highest values of stress occur at 0 degree-angle, i.e. a horizontal orientation.

The experimental results of stress which are calculated from experimental strain data at the outer-shell's center of cask body are 18.4 kg/mm^2, 15.7 kg/mm^2 respectively at 5, 20 degree-angle, and slightly greater than the analysed value (16.5 kg/mm^2, 14.5 kg/mm^2).

4. Conclusions

Certain conclusions were obtained on the most influenced drop-angle in regard to the safety of cask, as follows.

1) It was shown that the damage to shock absorbers at the secondary end was slightly greater than that at the initial end in both the experimental and analytical results. In addition in every case the maximum value of the deceleration at the secondary end was higher than that at the initial end.

From analytical results it is found that the highest decelerations occur at 5 to 10 degree-angle.

2) However, for the maximum values of stress which directly affect the safety of cask body, it was shown that the analysed values of stress increased with a decrease in the angle of cask-inclination, and the worst impact orientation was 0 degree-angle, i.e., a horizontal orientation (model's longitudinal axis parallel to target surface).

Therefore, from the viewpoint of safety evaluation for container-body, it is concluded that the horizontal drop test is a more severe condition that the slant-angle drop test.

References

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D. J. Nolan, et al. (TN N.Y.): "Analysis Method for the Design of Transport Packaging Shock Absorbing End Covers", Proc. 7th PATRAM, New Orleans ('83)

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Table 1 Effect of slant-angle on deceleration at upper surface near the bottom

Slant-angle [$\theta°$]	Deceleration [G]	
	Analysed value	Experimental value
5	287	261
10	290	269
20	265	181

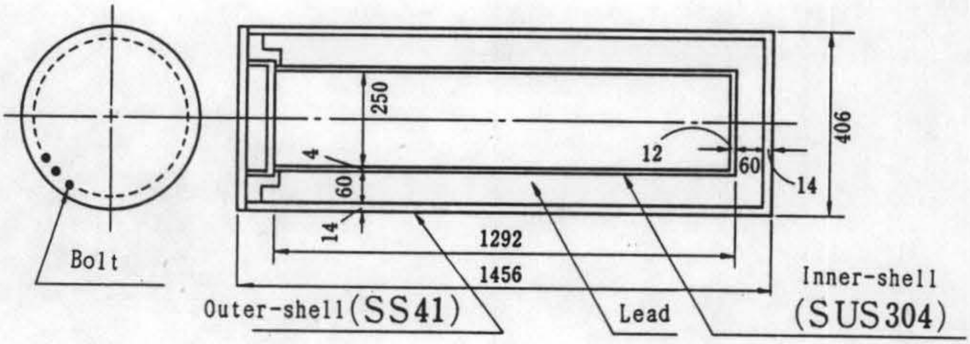


Fig. 1 1/4 scale cask model

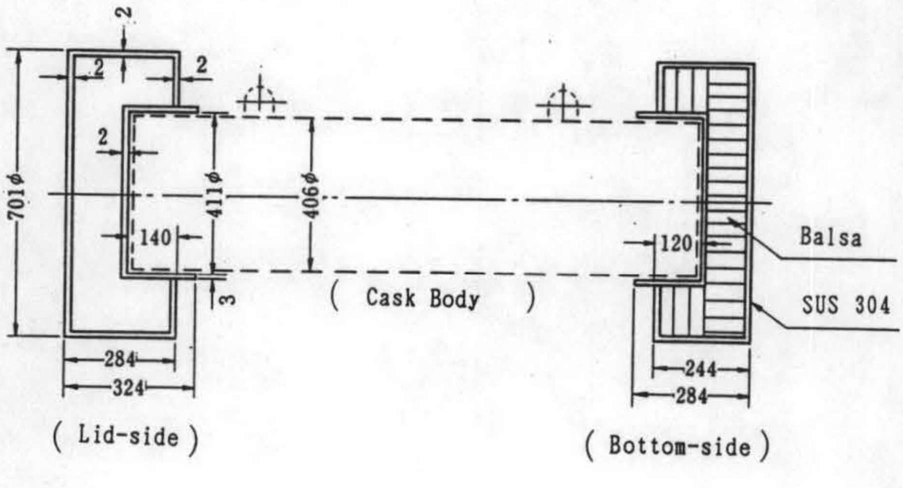


Fig. 2 Shock absorbers

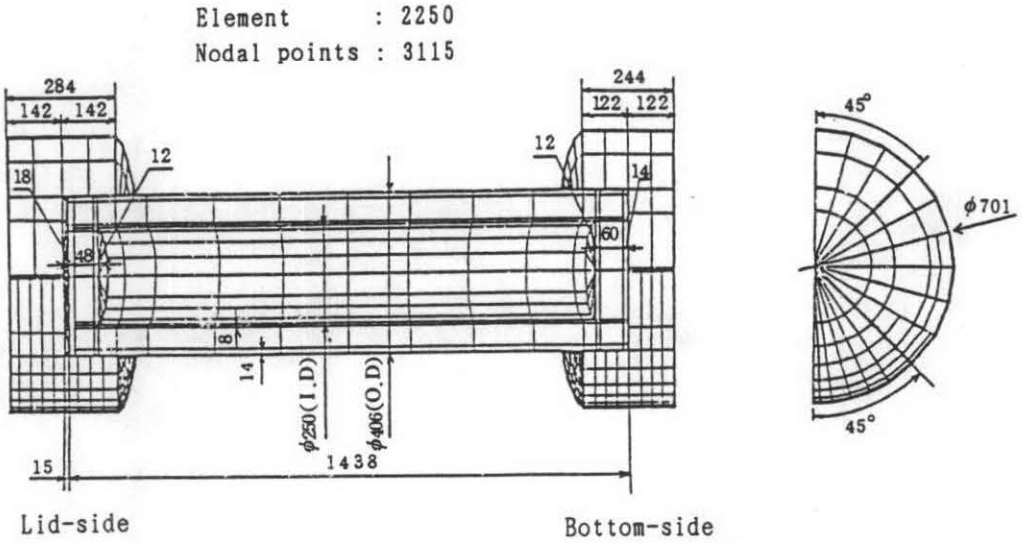
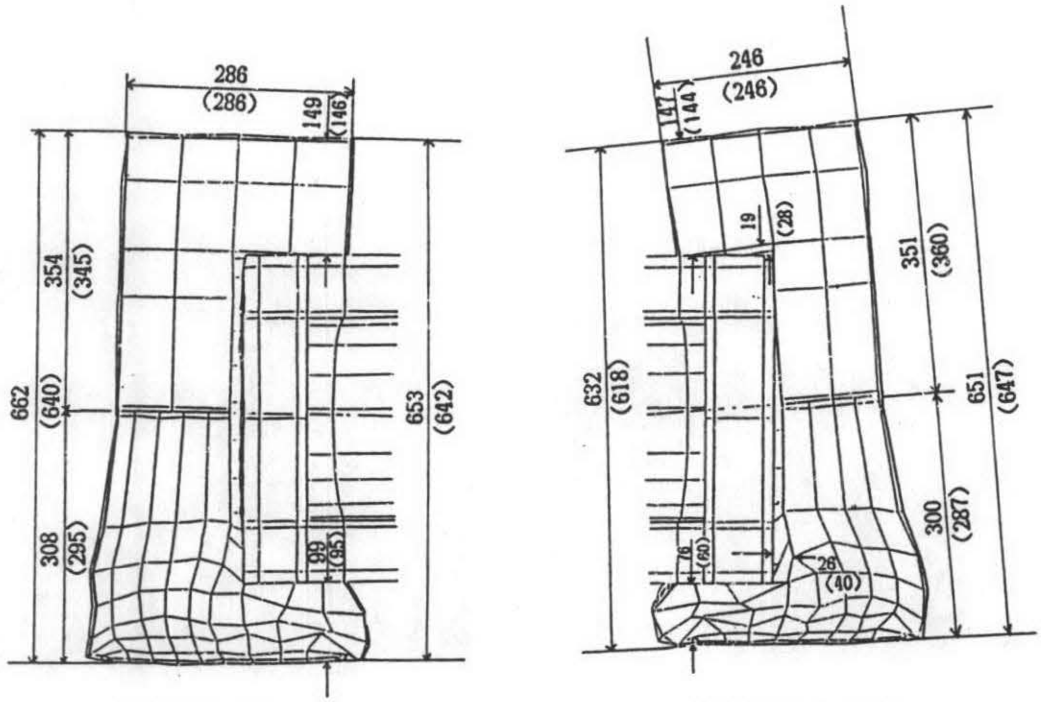
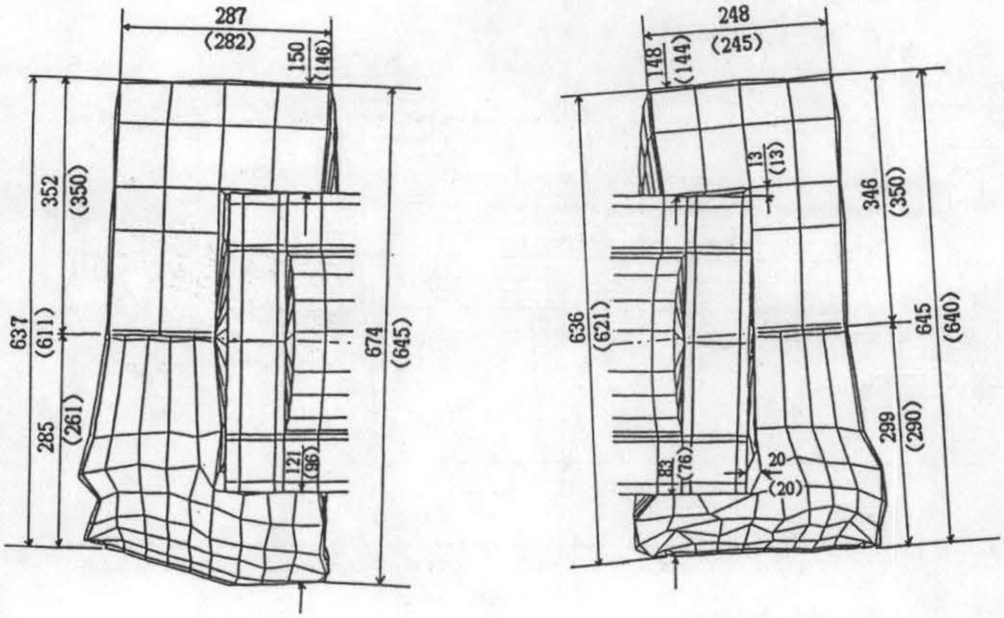


Fig. 3 3D-FEM model



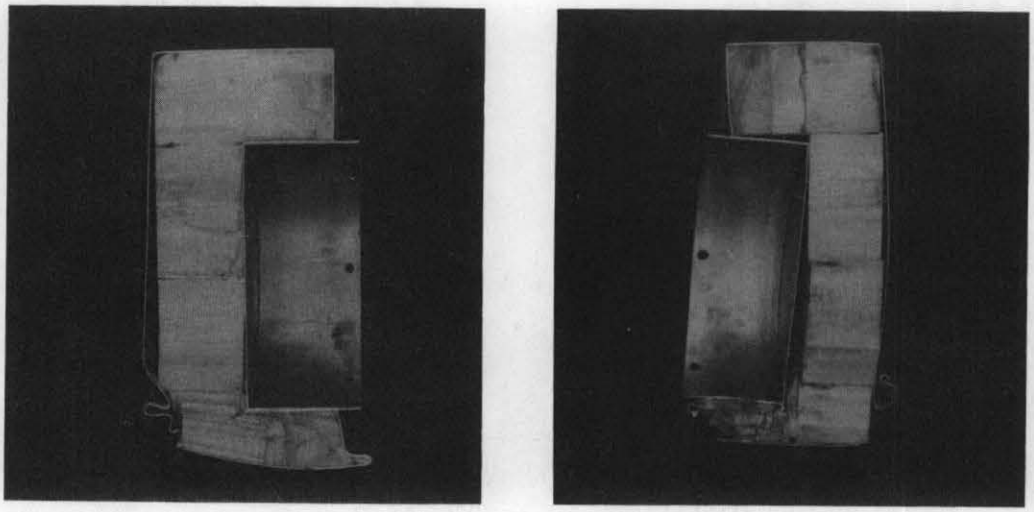
(a) Lid-side (b) Bottom-side

Fig. 4 Final deformation at the section of the shock absorbers (5 degree)



(a) Lid-side (b) Bottom-side

Fig. 5 Final deformation at the section of the shock absorbers (20 degree)



(a) Lid-side (b) Bottom-side

Fig. 6 Aspect of deformation at the section observed after the drop tests (20 degree)

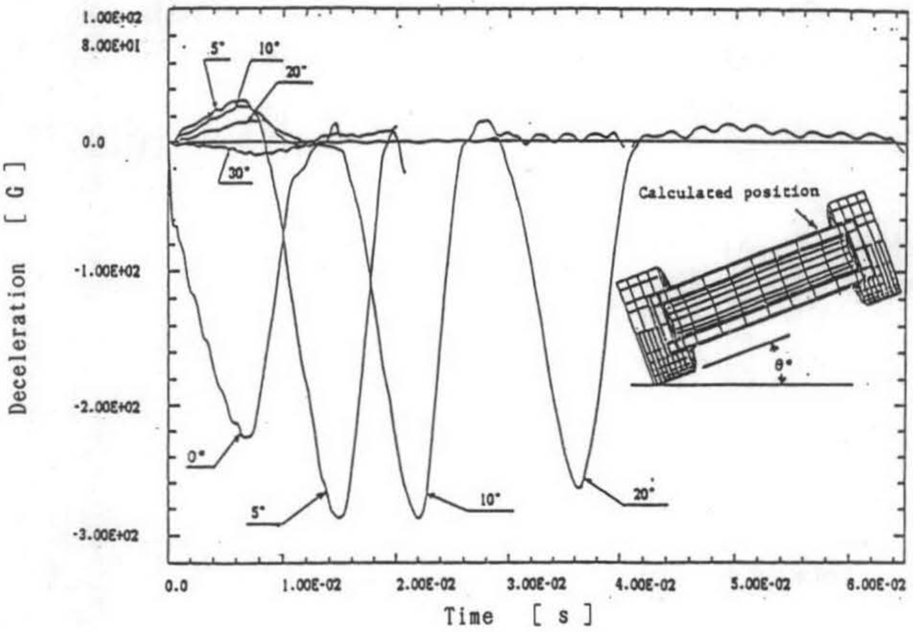


Fig. 7 Effect of slant-angle on deceleration at upper surface near the bottom

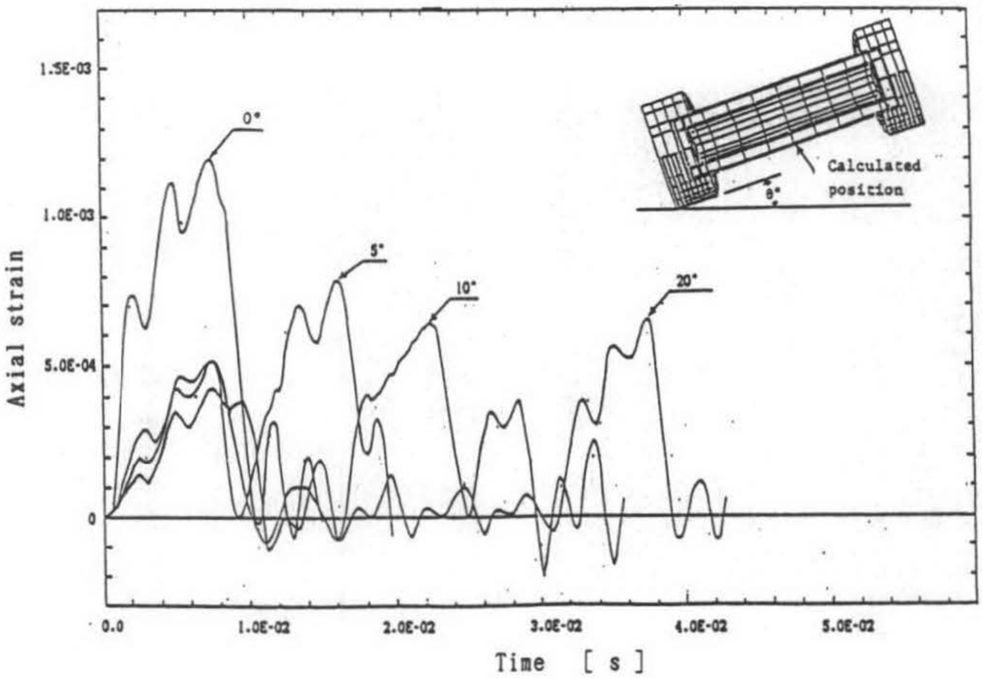


Fig. 8 Effect of slant-angle on axial strain at center of lower surface