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Influence of body vibration on deceleration under the slap down drop test

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Abstract

In drop tests, especially under slap down drop test that lid side is suffered the secondary impact, the deceleration is generally higher than that of the horizontal drop test.

Reason for the higher deceleration is explained as follows.

- Increase of the potential energy due to drop condition (height of the center of gravity under slap down drop test is higher than that of horizontal drop test)
- Increase of rotational speed of the package by rebounding of primary impact side

However, in some drop tests, high deceleration value is observed, which cannot be explained by these factors.

In this study, analysis of 9m slap down drop test with a package model is performed, and factors of the deceleration observed under the slap down drop test is considered.

1/3 scale model of a type B package with a mass of 100 metric tonnes and analysis of the 9m slap down drop test using the 1/3 scale model was selected for this study.

- Time history of deceleration, which is obtained directly from the package model, would be similar to the actual drop test result. In addition, the deceleration due to the overall behaviour of the package also can be calculated from reaction force of the target floor. By comparison of these values, the fact is observed that the deceleration on the package model includes some vibration.
- Such significant vibration is shown just after the impacts at each end of the package. By result of eigenvalue analysis for the 1/3 scale model, it is demonstrated that the vibration is caused by oval deformation of the body due to the impact.

Therefore, the high deceleration value with high frequency includes some influence of the vibration, which is caused by the oval deformation.

For the evaluation of the deceleration of drop test, the component of the vibration should be separated since this vibration does not affect to overall behaviour of the package. However, the frequency of this vibration is sometimes close to the cut-off frequency, which is suggested in SSG-26 for a package with a mass of 100 metric tonnes. So, the cut-off frequency should be carefully considered to separate an influence of such vibration.

Introduction

In order to demonstrate suitability for the IAEA regulation concerning to the 9m drop condition, behaviour of a packaging under slap down drop test is focused on. Especially, from the view point of lid bolt's integrity of the packaging, high deceleration value observed after the secondary impact at lid side is important [1] [2].

In this study, detailed evaluation based on an analysis of the 9m slap down drop test using 1/3 scale model, which is modeled a type B package with a mass of 100 metric tonnes, is performed. And factors of this deceleration are considered.

Behaviour of package under slap down drop test

To discuss behaviour of package under slap down drop test, following spent fuel transport package, which is also used for interim storage, is selected as representative. This package has our typical design for dual purpose (transport/storage) package for spent fuel, and the analysis of 9m slap down test has been verified with the 1/3 scale drop test.

Outline of the 1/3 scale model of the package [3]

This dual purpose (transport/storage) package designed as the loading capacity is 69 BWR spent fuel, and actual 9m drop tests have been performed with 1/3 scale model.

Figure 1 and 2 shows cross section and over view of the 1/3 scale model, and main specifications of the 1/3 scale model are shown in Table 1.

As one of the test results, Figure 3 shows time history of deceleration on top and bottom of the body under 9m slap down drop condition. The slap down drop's attitude was that first impact is the bottom side and second impact is the top side. In this case, the inclined angle was set as 5 degree.

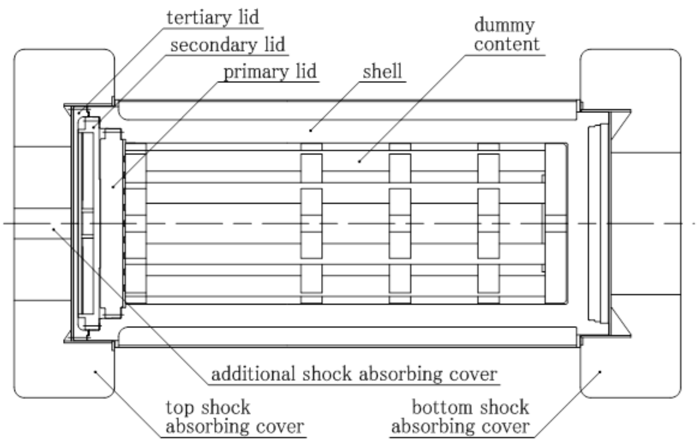

Figure 1 Cross section of 1/3 scale model

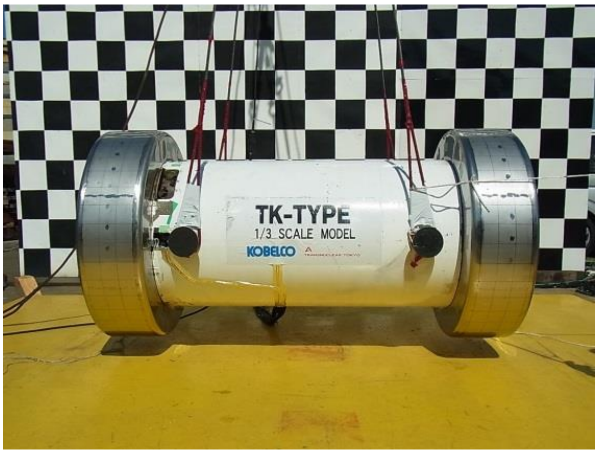

Figure 2 Over view of 1/3 scale model

Table 1 Main specification of 1/3 scale model

Parts	Material	Weight (kg)
Shell **Neutron shielding** **Outer shell**	Low alloy steel Light weight concrete* Carbon steel*	2850
Primary lid	Low alloy steel	185
Secondary lid	Low alloy steel	135
Tertiary lid	Stainless steel	85
Shock absorbing cover	Stainless steel and Redwood	200 (top) 200 (bottom)
Dummy content**	Carbon steel	980
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* Equivalent material simulating only the weight

** Modeled to simulate the weight and the center of gravity

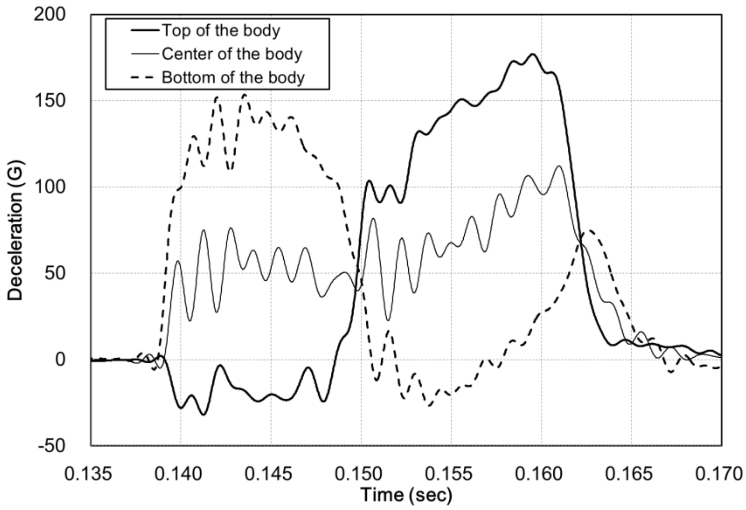

Figure 3 Time history of deceleration (9m slap down drop test result)

Results of 9m slap down drop analysis [4]

For detailed evaluation of behaviour of the package, FEM analysis of a 9m slap down drop has been performed. Figure 4 shows over view of the analysis model.

Figure 5 shows time history of decelerations obtained from the 9m slap down drop analysis. Drop conditions of this analysis (inclined angle and drop attitude) are set as same as the drop test using the 1/3 scale model.

The decelerations on the top and bottom of the body shown in the Figure 5 are obtained from accelerometers set on the FEM analysis model. As shown in Figure 6, these decelerations match the decelerations of the drop test result, which are shown in Figure 3.

Moreover, reaction force on the target floor, which is set as a target of the drop analysis, can be obtained. And from time history of the reaction force, deceleration can be converted by using loaded weight to the target floor. The conversion is performed with following equation.

$$\text{(Deceleration based on reaction force)} = \frac{\text{(Reaction force on the rigid floor)}}{\text{(Total weight of the model) / 2}}$$

Accuracy loaded weight to the target floor is not clear under the slap down drop condition, so, in this study, it is assumed that the half of the total weight is loaded. As mentioned below, the deceleration calculated with this assumption matches actual behaviour of the analysis model.

As shown in Figure 4, maximum deceleration is observed under second impact (on top of the body), and the value is over 250 G. The deceleration value is obtained from the 1/3 model, so it is corresponds to 83 G of an actual packaging.

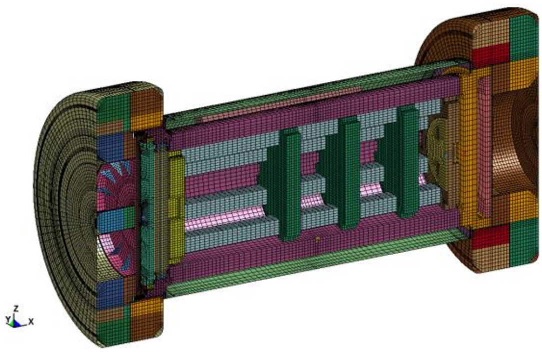

Figure 4 FEM analysis model for the 1/3 drop test

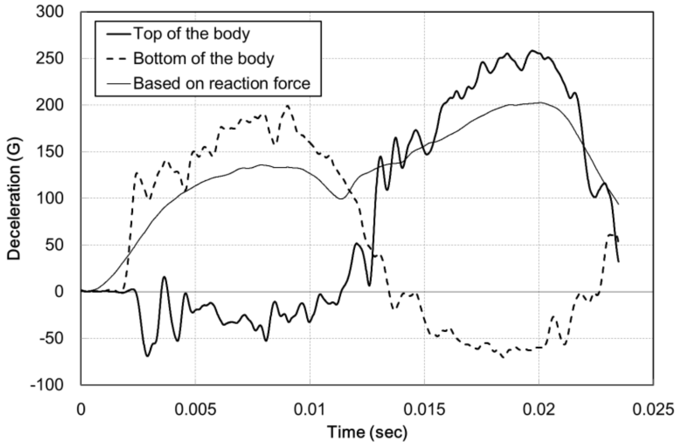

Figure 5 Time history of deceleration (9m slap down drop analysis)

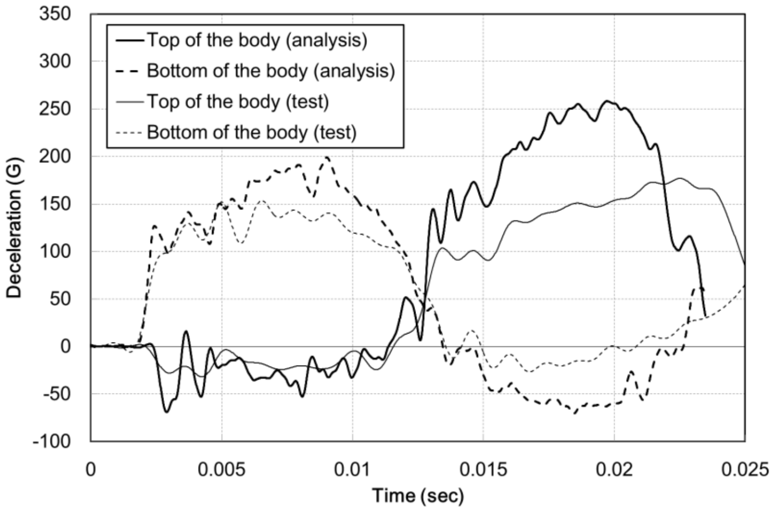

Figure 6 Comparison of deceleration between analytical result and actual test (9m slap down drop)

Detailed evaluation of the behaviour

By evaluating in detail the time history of deceleration, 3 factors included in the deceleration are considered.

- Deceleration based on reaction force
- Rotational movement of the package
- Vibration on the package

Assumption: Reaction force from the target floor

In the time history of deceleration under the 9m slap down drop, some rotational movement due to the partial collision of the model is included in addition to deceleration based on reaction force. In the Figure 5, the rotational movement is shown as opposite direction's deceleration on the opposite of the collision side.

This rotational movement does not affect to interaction between the package model and the target floor. Therefore, if the rotational movement is subtracted as shown in Figure 7, the time history of the deceleration match the deceleration based on reaction force. The time history is obtained by subtracting the time history of the 'Bottom of the body' from the 'Top of the body' in the Figure 5.

It also shows that the assumption of the conversion, which is mentioned above, is appropriate. In the slap down drop, loaded force to the target floor is almost same to the half of the total weight of the package.

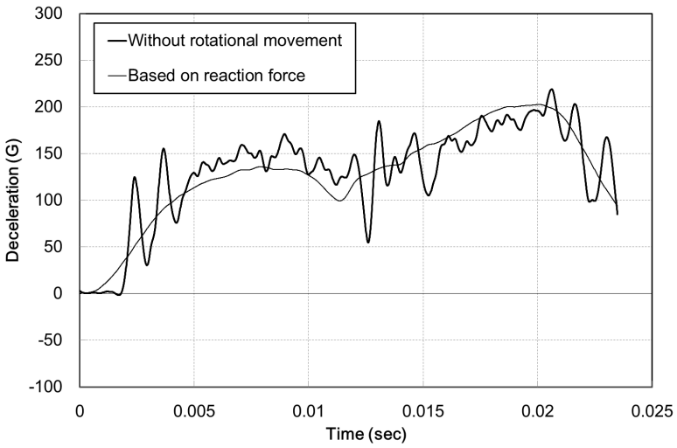

Figure 7 Time history of deceleration without rotational acceleration

Vibration included in the time-history of deceleration

As can be seen from the waveform of the Figure 7, the time history of deceleration 'without rotational movement', which is obtained from accelerometers on the body, includes some vibrations. Figure 8 clearly shows these vibrations as the time history of deceleration. This time history is obtained with subtracting from the time history of 'without rotational movement' in the Figure 7 by the time history of 'based on reaction force'. The maximum deceleration of the vibrations is around

70 G, and significant vibrations are generated just after each impact.

In order to find the cause of the vibrations, a frequency analysis of the vibrations is conducted with FFT (Fast Fourier Transform) method, and the result is shown in Figure 9. Resolution of the FFT is about 50 Hz, and the result of frequency range is 0 through about 1000 Hz.

As shown in the Figure 9, dominant frequencies other than fundamental responses, shown in below 100 Hz, are appeared in about 750 Hz through 950 Hz. In this frequency range, frequency of vibrations caused by oval deformation of the body, which is obtained from result of an eigenvalue analysis in Figure 10, is included.

Therefore, the vibrations shown in the Figure 8 include the vibrations caused by oval deformation of the body. Because such vibration does not affect to overall substantial behaviour of the package, acceleration caused by the vibration should be separated from the time history of deceleration, such as shown in Figure 5.

In particular, such vibration should be eliminated by choosing appropriate cut-off frequency of filtering. As suggested in IAEA SSG-26, the cut-off frequency should be 100-200 Hz for a package with a mass of 100 metric tons, and this cut-off frequency should be multiplied by a factor $(100/m)^{1/3}$ for smaller packages with a mass of metric tonnes. Mass of the 1/3 scale model used for this study is about 4.6 tons, so the factor $(100/m)^{1/3}$ is calculated as about 2.8. Therefore, the suggested cut-off frequency for the 1/3 scale model is 280-560 Hz.

If a filter of cut-off frequency 500 Hz is applied to the time history of deceleration shown in the Figure 5, by comparison between Figure 11.1 and 11.2, it can be seen that some vibrations on the time history are eliminated.

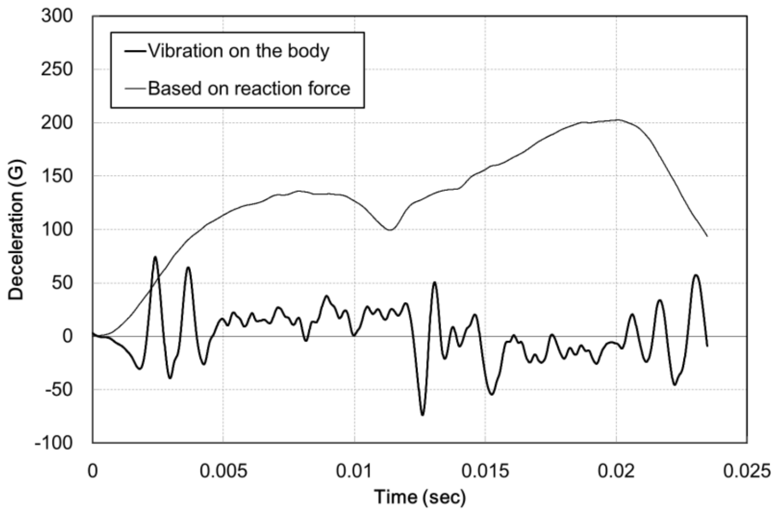

Figure 8 Vibration included in the time history of deceleration

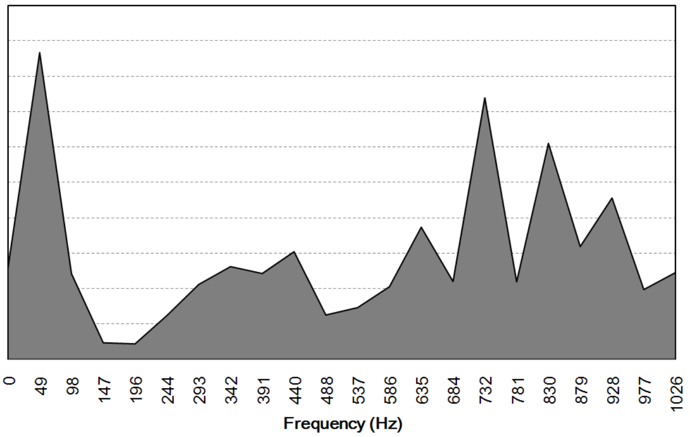

Figure 9 Frequency analysis of the vibration on the body

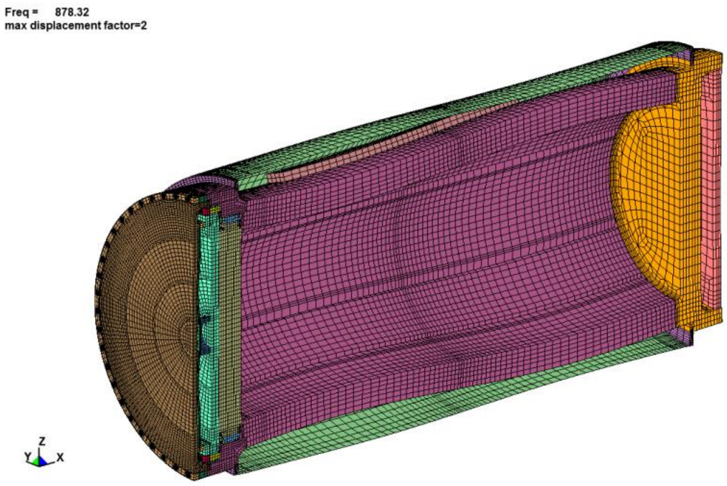

Figure 10 Oval deformation mode of the body on 878 Hz

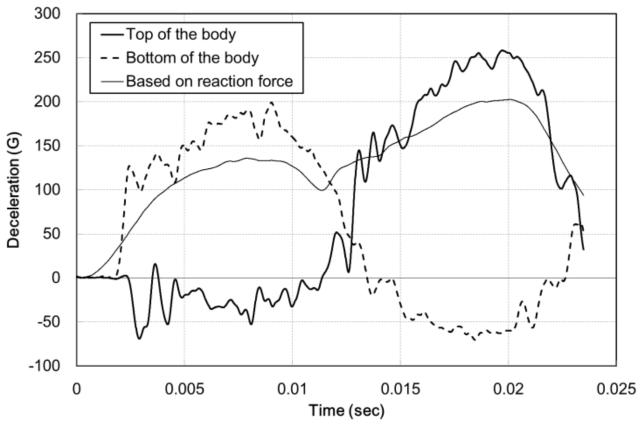

Figure 11.1 Time history of deceleration (filtered at 1000 Hz, same as Figure 5)

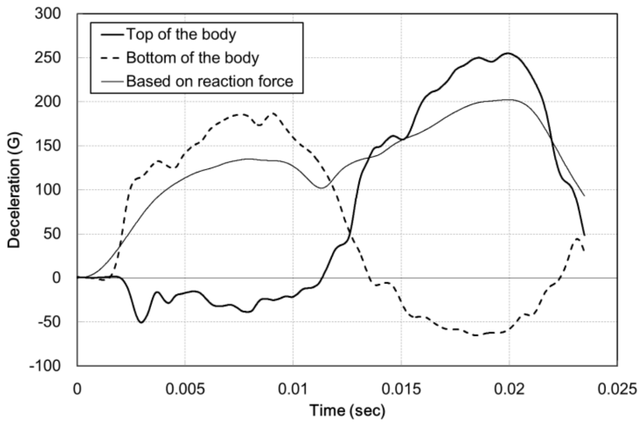

Figure 11.2 Time history of deceleration (filtered at 500 Hz)

Conclusions

From the FEM analysis results of the 9m slap down drop using the 1/3 scale model, 3 factors included in the deceleration are considered.

First one is deceleration based on reaction force. For conversion from reaction force on the target floor, half of the total weight can be used. Second one is rotational movement. The rotational movement is appeared as opposite direction’s deceleration on the time history of deceleration. Third one is vibration. It can be eliminated appropriately with cut-off frequency suggested in IAEA SSG-26.

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