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DROP TEST ANALYSIS OF 1/3 SCALE TK TYPE TRANSPORT AND STORAGE CASK

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ABSTRACT

Safety of spent fuel dry storage system using casks is focused on in these days and this system is expected to be strongly increasing. The design of transport and storage cask for BWR spent fuels, named TK-69 and TK-52 were completed for Japanese utilities. Then, the 9m drop tests using 1/3 scale model for TK-69 were performed.

The drop tests were performed with 4 different conditions such as horizontal, vertical, corner and slap-down drop test. The analyses for these conditions are performed with dynamic analysis code LS-DYNA in order to establish suitable analysis method on drop tests for TK type casks.
The results of preliminary analysis for the drop tests show good agreement with experimental results concerning overall reaction of the cask such as maximum acceleration, maximum crush deformation of shock absorbing cover (SAC), etc. However, the analysis results does not express similar deformation mode to the experimental results.

It was suspected that this difference was caused by the different behavior of wood brocks of the SAC in the analysis. Wood block which is installed in the compartments of SAC is normally combined with separated several parts, and these parts may slide each other during the SAC's deforming. Therefore, for simulating the deformation mode of the experimental drop test more accurately, it is necessary that wood blocks should be modeled as similar separated parts, and friction coefficient of contact surface between these parts should be applied to allow sliding. By applying these assumptions to the analysis, the better agreement concerning deformation mode of SAC can be obtained.

Therefore, an existing analysis method is good for the evaluation of overall reaction of 9m drop tests. But if more precise deformation mode of SAC is required, additional consideration mentioned above is necessary. In both analyses, the results have a good agreement with the

experimental drop tests of TK type casks concerning such as the maximum acceleration and the maximum crush deformation of SAC.

INTRODUCTION

Recently, for keeping safety in the operation of nuclear power plants, dry storage system of spent fuel has been came to attract considerable attention. After the Fukushima accident, dry storage system using casks has been recognized as a safer system for storage of spent fuel. Moreover, transport and storage cask will be used for the dry storage system.

From the demand mentioned above, transport and storage cask for BWR spent fuels, named TK-69 and TK-52 for Japanese utilities are jointly designed by Transnuclear, Ltd. and Kobe Steel, Ltd. The 9m drop tests using 1/3 scale model for TK-69 were conducted, in order to verify that this design complies with the transport regulations.

In this study, we performed drop analysis to simulate behavior of the scale model, adding some adjustment to analysis method.

1. OUTLINE OF THE DROP TESTS[1]

1.1 1/3 scale model for the drop tests

For drop test, 1/3 scale model has been designed based on TK-69 cask. Dimension, shape and especially gap around lids are precisely modeled in 1/3 scale.
Main specification of 1/3 scale model is shown in Table 1, and over view is shown in Figure 1.

Table 1. Main specification of 1/3 scale model

Items	Specification
Weight and Dimension	
- Total weight	4.9 tons
- Length / Diameter	1.8 m / ϕ 0.84 m (without SAC) 2.3 m / ϕ 1.2 m (with SAC)
Materials	
- Forged shell and bottom	Low alloy steel
- Neutron shielding	(Light weight concrete)*
- Primary lid and Secondary lid	Low alloy steel
- Tertiary lid	Stainless steel
- Shock absorbing cover	Wood / Stainless steel
- Dummy content	(Carbon steel)*

*: Equivalent material simulating only weight

Figure 1. Overview of 1/3 scale model

1.2 Drop test condition and result

The drop test had been performed with 4 different conditions such as horizontal, vertical, corner and slap-down drop test.
Height of drop was 9m in every condition. And target of the drop test was unyielding flat floor which satisfies the IAEA Safety Standards TS-G-1.1.
Main results of the drop test in each condition are shown in Table 2. This table contains maximum acceleration on each part of the 1/3 scale model and deformation of shock absorbing cover.
In this study, analyses of vertical drop test, representing SAC's behavior under axial compression, and of horizontal and slap down drop test, representing SAC's behavior under radial compression, were performed. In these analysis, the time history of acceleration on the main body of the packaging and maximum deformation of SAC were focused as the indicator of SAC's behavior during drop tests.

Table 2. Main results of the drop test of 1/3 scale model

Items	Vertical (Top)	Horizontal	Slap down (5 deg.)	Corner (Top)
Maximum acceleration				
- Primary lid	182 G	152 G	182 G	94 G
- Forged shell	167 G	155 G	177 G	-----
- Dummy content	235 G	161 G	171 G	92 G
- Bottom	166 G	127 G	146 G	67 G
Deformation of SAC				
- Top	70 mm	95 mm	99 mm	198 mm
- Bottom	-----	92 mm	62 mm	-----

2. ANALYSIS MODEL

With taking symmetry of the scale model into consideration, the analysis model was modeled as 1/2 symmetric model. Fig 2 shows overview of the analysis model, and Table 3 and Fig 3 show material properties of each part. Moreover, details of modeling each part are shown below.

2.1 Main Body

The forged shell and the bottom have been modeled with solid elements as real shape. The outer shell has been modeled with shell elements, and the neutron shielding has been considered just as weight with mass elements.

2.2 Lids

Each lid (primary, secondary and tertiary lid) has been modeled with solid elements as real shape. Concerning the bolts for these lids, head of the bolts have been modeled with solid elements and shank of the bolt has been modeled with beam elements. Initial tightening forces for lid bolts have been loaded.

On gasket grooves of primary and secondary lids, and on flange surface of forged shell, reaction force generated by tightening of metallic gasket has been loaded as equivalent surface pressure.

2.3 Shock absorbing cover

Shock absorbing covers are consisted from wood blocks and cover plates. Wood blocks are modeled with solid elements, which are applied material model of considering anisotropy of material property. And cover plates are modeled with shell elements.

2.4 Dummy Content

The dummy content has been modeled with solid elements.

2.5 Floor

Target which is unyielding flat floor has been modeled by "rigid wall".

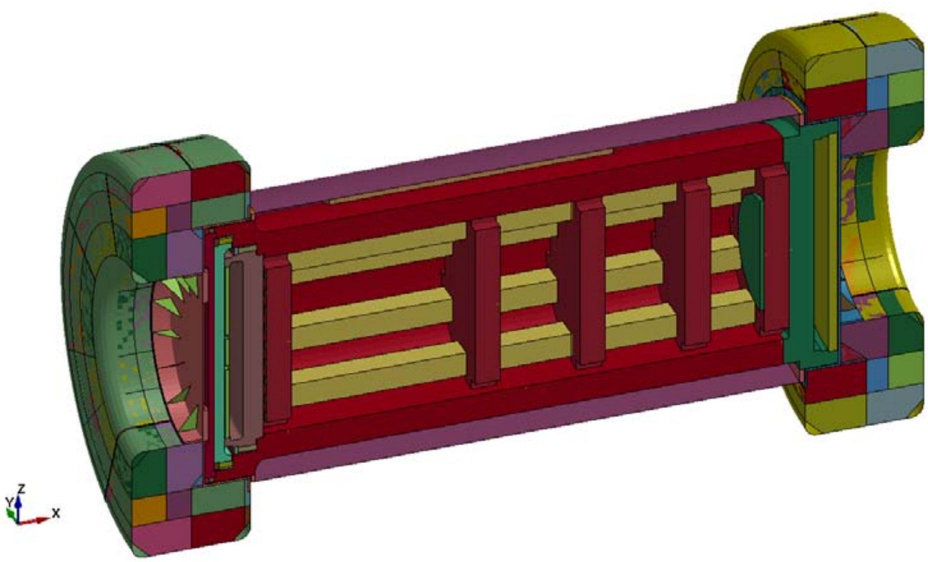


Figure 2. Analysis model

Table 3. Material properties of each part

Material	Part	Density (ton/m^3)	Young Modulus (x10^5MPa)	Poisson's ratio	Yield strength (MPa)	Tangent Modulus (MPa)
Low alloy steel	Main body, Pri. and Sec. lid	7.85	1.92	0.3	207	832
Stainless steel	Tertiary lid	7.93	1.95	0.3	205	734
Alloy steel	Bolts	7.85	1.92	0.3	1030	---
Stainless steel	Shock absorbing cover	7.93	1.95	0.3	(Considering strain rate dependence)	
Wood		0.4	(See Figure 3)			

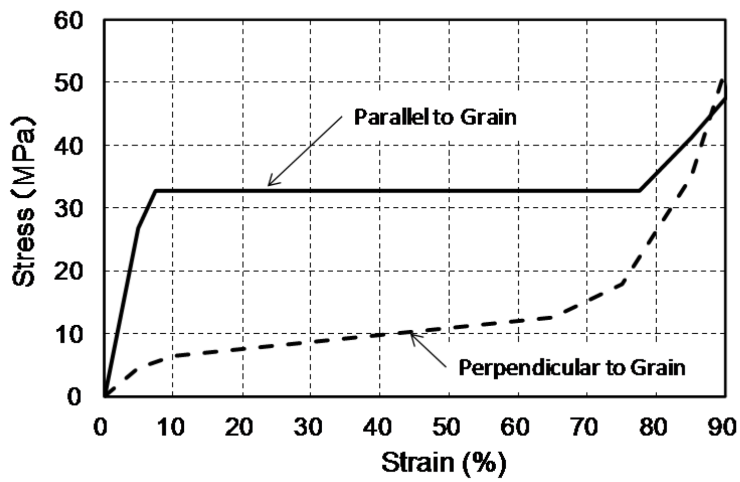


Figure 3. Material properties of wood
(Stress - strain curve is defined based on the proceeding of PATRAM 2007[2])

4. ANALYSIS CONDITION

4.1 Analysis code

3 dimensional dynamic analysis code LS-DYNA Ver. 971[3] was used for this analysis.

4.2 Analysis condition

In these drop analyses, drop tests with 1/3 scale model of TK-69 cask have been performed. Initial velocity 13.3 m/sec has been applied to whole of analysis model, as equivalent to 9 m free drop. These analyses have been starting from just before the collision.

4.3 Consideration of wood block

Inside of shock absorbing cover of the 1/3 scale model, woods are consisted of several blocks in each compartment which is separated by cover plates.
Therefore, in these drop analysis, wood blocks are modeled as combination of several small blocks in each compartment, and following 2 cases of contact conditions has been applied.

- Case 1:
    Friction between wood blocks and cover plates is considered.
- Case 2:
    Friction between wood blocks and cover plates in crushed zone is ignored. (See Figure 4)

The "Case 1" is normal contact condition for wood blocks of SAC, in drop analysis.
However, under 9 m free drop condition, wood blocks in the crushed zone of SAC are crushed into pieces. In this case, resistance force against deformation of SAC by wood blocks is decreased. Therefore, in the "Case 2", to simulate this decrease of the resistance force, friction between wood blocks and cover plates in the crushed zone is ignored.

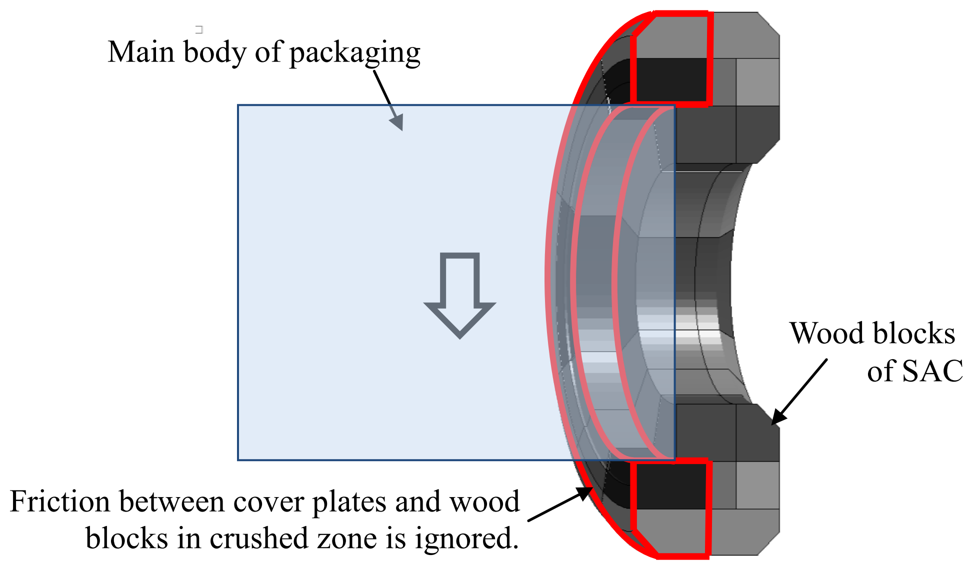


Figure 4. Example of contact conditions in analysis "Case 2" (horizontal drop test)

5. ANALYSIS RESULTS

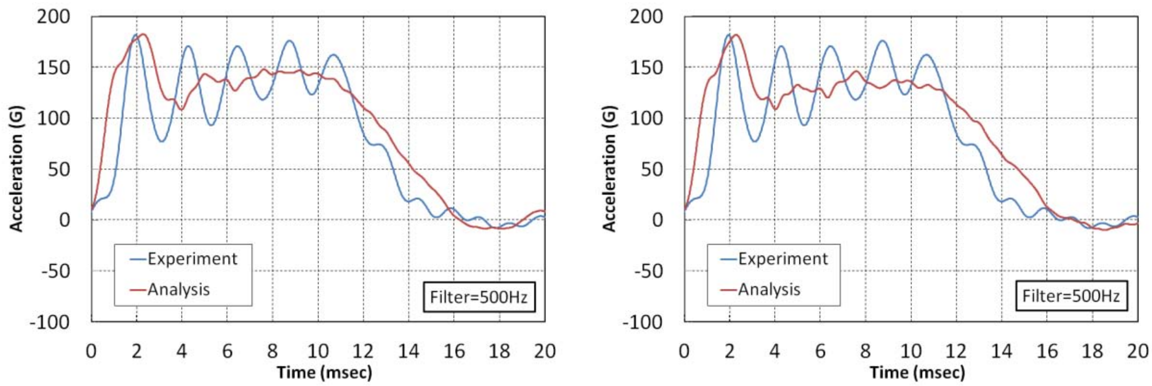
5.1 Acceleration

Figure 5 to 7 show the time histories of acceleration in vertical, horizontal and slap down drop test. In these figures, red lines show results of the analysis and blue lines show results of the experiment.
Concerning vertical drop test (Figure 5), there is no significant difference in maximum acceleration between the analysis results of Case 1 and Case 2, and these analysis results show good agreement with the experimental result.
On the other hand, concerning horizontal and slap down drop test (Figure 6 and 7), maximum acceleration of the analysis result of Case 1 is higher than the experimental result, and the analysis result of Case 2 shows good agreement with the experimental result.

5.2 SAC's deformation

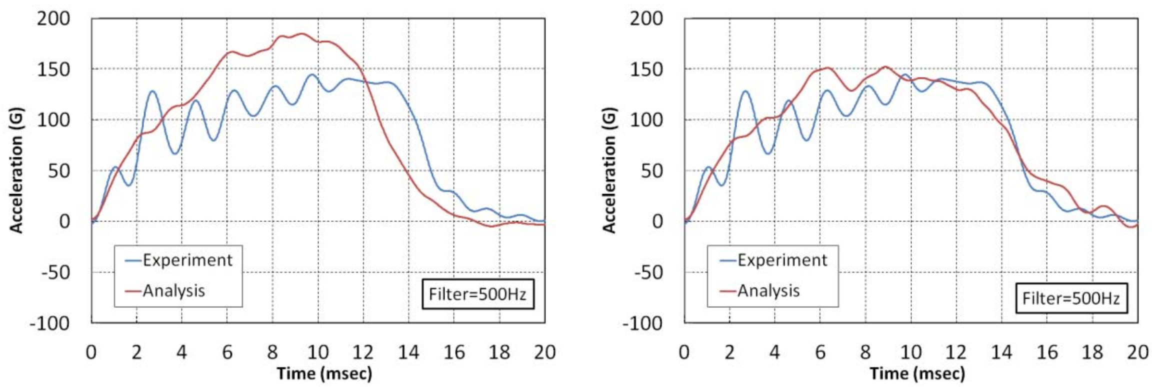
Table 4 shows the SAC's deformations after drop test compared with the experimental results in vertical, horizontal and slap down drop test.

In all drop test conditions, the value of analysis results of Case 1 are smaller than those of Case 2, and the analysis results of Case 2 are better than those of Case 1 in the view of agreement with the experiment results.



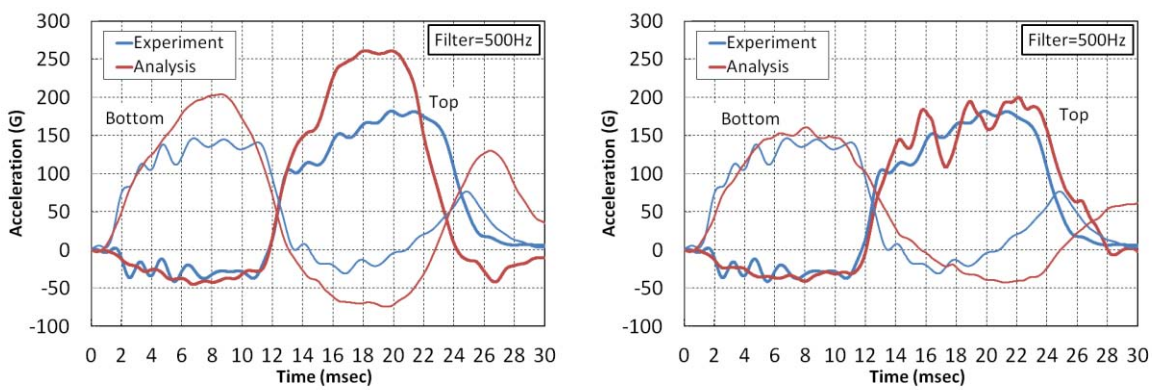
(Case 1) (Case 2)

Figure 5. Comparison of acceleration on the primary lid in vertical drop



(Case 1) (Case 2)

Figure 6. Comparison of acceleration on the center of the main body in horizontal drop



(Case 1) (Case 2)

Figure 7. Comparison of acceleration on the primary lid and on bottom of the main body in slap down drop

Table 4. Comparison of SAC's deformation after drop test

Condition	Part	Deformation (mm)		
		Experiment	Case 1	Case 2
Vertical drop	Top SAC	70	65.9 (-5.9%)	68.3 (-2.4%)
Horizontal drop	Top SAC	95	87.4 (-8.0%)	96.7 (+1.8%)
	Bottom SAC	92	82.2 (-10.7%)	86.6 (-5.9%)
Slap down drop	Top SAC	99	75.3* (-34.1%)	100.2* (+1.2%)
	Bottom SAC	62	55.6* (-10.3%)	67.0* (+8.1%)

*: Deformation value at the termination of analysis

6. DISCUSSION

In horizontal and slap down drop test, analysis results of the "Case 2" have a good agreement with the experiment results, especially concerning time history of acceleration. This shows that behavior of wood blocks mainly affects result of accelerations, and the adjustment of analysis conditions around wood blocks in crushed zone of SAC is available to obtain an analysis result agreed with an experiment result.

However, in the analysis of slap down drop test, behavior after second impact (after 18msec, see the result of Case 2 in Figure 7) is not sufficiently agree with the experiment result.

Moreover, maximum accelerations in vertical drop test of "Case 1" and "Case 2" are almost same, and both results show a good agreement with the experiment result. These accelerations are shown in just after the collision. In this period, because the deformation of SAC is still small, sliding of wood blocks against cover plates might be not occurred. Therefore, the adjustment of analysis conditions around wood blocks in crushed zone of SAC is not related to the result of maximum acceleration in vertical drop test.

7. CONCLUSION

As a conclusion, in this drop analysis with adjustment of friction coefficient on wood blocks in SAC, the result have a good agreement with the experiment drop tests of TK type casks concerning such as the maximum acceleration and the maximum crush deformation of SAC.

And as a next step, it is necessary to adjust the other analysis conditions for after second impact of slap down test, and corner drop test.

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[3] Livermore Software Technology Corporation, LS-DYNA Version 971.