Proceedings of the 15th International Symposium on the Packaging and Transportation of Radioactive Materials
PATRAM 2007
October 21-26, 2007, Miami, Florida, USA

SIMULATION STUDY OF CONCRETE MATERIAL NUMERIC MODEL IN THE EVALUATION OF STORAGE CASK'S TIPPING OVER EVENT

Norihiro Kageyama
Transnuclear, Ltd.
1-18-16, Shinbashi, Minato-ku, Tokyo 105-0004 JAPAN

Koji Shirai
Central Research Institute of Electric Power Industry
1646 Abiko, Abiko-shi, Chiba-ken 270-1194 JAPAN

Kosuke Nanba
Central Research Institute of Electric Power Industry
1646 Abiko, Abiko-shi, Chiba-ken 270-1194 JAPAN

Takao Shirakura
Transnuclear Tokyo
1-18-16, Shinbashi, Minato-ku, Tokyo 105-0004 JAPAN

Masahiko Ouchi
Transnuclear Tokyo
1-18-16, Shinbashi, Minato-ku, Tokyo 105-0004 JAPAN

ABSTRACT

Recently, at the interim storage facility of spent fuels many metal casks are used in worldwide. Generally, these metal casks are set with vertical position in the interim storage facility. In Japan, some storage casks are designed not to tip-over by the tie-down device, etc. However, in the Standard Review Plan of NRC[1], the evaluation of tipping-over of storage cask is required as a non-mechanistic event consistent with the defense-in-depth policy.

The metal casks are set without shock absorbing covers during storage period, hence, in the tipping over event, the sealing part of the lid may be directly collide to the storage facilities floor. However, there are still uncertainties for the impact behaviours of the metal cask without impact limiters under such severe impact loads.

The dynamic behaviour of the lid during the event greatly influences the sealing performance of the metal cask; therefore it is important to clarify the interaction of the metal cask's lid and the storage facilities floor.

In this study, by using various numeric models for concrete material of the storage facilities floor, analyses of tipping over event of metal cask using dynamic analysis code LS-DYNA have been performed.

The investigated cask has been designed for transport and storage of 52 BWR-type fuel assemblies with double lid structure. The target of collision of the cask is the reinforced concrete floor, and the strength of the concrete is same as a design strength of an interim storage facilities floor. And for the analytical model of the concrete material, following three material numeric models are considered.

(1) Concrete material model developed by CRIEPI considering strain rate dependence and multi-axial fracture
(2) Pseudo tensor concrete material
(3) Isotopic elastic-plastic material
Furthermore, input conditions for them, such as the modification method of material properties and contact conditions for surface of concrete material have been determined from post analysis of a component test of concrete material.

From the comparison with lid behaviours in tipping over event analyses with these material models, we will propose appropriate input conditions for the concrete material model when they are used for the evaluation.

INTRODUCTION

As the electric power demand grows, the amount of spent fuel discharged from nuclear power plant has increased. Therefore, necessity of interim dry storage has risen year by year. For interim dry storage, the metal cask with the metallic lid gasket has been world-widely used to keep high leak-tightness for long-term storage.

Generally, leak-tightness of metallic gasket joints is very sensitive for sliding and opening movements by external impact load. However, there are still uncertainties for the impact behaviours of the metal cask without impact limiters under severe impact loads, such as drop or tipping-over events in interim storage facility. Therefore, it is very important to clarify the dynamic behaviour of the metallic gaskets subjected to sliding and opening movements of the lid structures during impact loads.

Then, in this study, dynamic analyses of tipping-over event have been performed with various concrete material models. And, lid behaviours in these analyses have been compared.

1. EVALUATED CONDITION

Evaluated condition in this study is tipping over event from freestanding condition. The cask is a casting cask for storage and transportation. And the concrete floor is modeled, which simulates the floor of an interim dry storage facility.

1.1 Casting cask for storage and transportation[2]

Figure 1 shows overview of the casting cask for this study, and Table 1 shows main specifications of this cask. This cask has been designed as a casting cask for dry storage and transportation of 52 BWR-type fuel assemblies.
This cask has double lid structure and lid gaskets are single type metal gasket made of silver coating material and inconel core spring. For primary and secondary lids, a section diameter of the gasket is 6.0 mm.

1.2 Concrete floor[3]

Size of modeled concrete floor is 4,800mm x 8,000mm x 1,200mm. And D25 reinforcing bars are arranged in 200mm pitch.

Figure 1. Overview of casting cask

Table 1. Main specification of the casting cask

Parts	Material	Weight (ton)
Lid part		
Primary Lid	Stainless steel	3.9
Secondary Lid	Stainless steel	2.2
Bolts	Alloy steel	
Main body		
Body	Ferrum Casting Ductile	73.1
Fins	Ferrum Casting Ductile	
Trunnion	Stainless steel	
Basket		
Lattice plates	Stainless steel with Boron	6.0
Fuel assembly (52 assemblies)		14.6
		Total 100.3

2. MATERIAL MODEL OF CONCRETE

In this study, these three numerical material models are used.

Case1: Concrete material model developed by CRIEPI considering strain rate dependence and multi-axial fracture

Case2: Pseudo tensor concrete material

Case3: Isotopic elastic-plastic material

Material properties are shown in Table 2. These properties have been determined from the results of material tests.

Table 2. Material properties of concrete

Density (kg/m^3)	Shear modulus (MPa)	Bulk modulus (MPa)	Compressive strength (MPa)	Tensile strength (MPa)
2.281×10^3	11919	15706	35.93	2.39

2.1 Concrete material model developed by CRIEPI

Numerical material model of concrete has been developed by CRIEPI (Central Research Institute of Electric Power Industry)[4] as the user subroutine of the LS-DYNA. In this model, strain rate dependence and multi-axial fracture of concrete can be considered.

Moreover, the analysis that reproduces lid behavior during the drop test of another metal storage cask has been done with this material model, and here, it has been confirmed that this analytical result shows good agreement with the drop test result[5].

2.2 Pseudo tensor concrete material

This material model is provided as "*MAT_016" in the LS-DYNA, and in this study, "Mode II Concrete Model Options" of this model has been used.

Based on our pre-internal estimation, by applying twice value of the actual compression strength, this model will show good agreement for the cask collision event. Therefore, in this study, twice value of the Table 2 has been used for this material model.

Actual input data is shown in Table 3.

Table 3. Input data for the Pseudo tensor concrete material

Items	Sign	Value	Remarks
Density	Ro	2.281×10^3 kg/m^3	Table 2
Shear modulus	G	11919MPa	Table 2
Poisson's ratio	PR	0.197	
Compressive Strength	fc	71.8MPa	Twice of actual value*
Tensile strength	σ_F	7.18MPa	fc/10*
Conversion coefficient	a_0	-68.4	$\sigma_F = 1.7(fc^2/-a_0)^{1/3}$
Pressure Hardening Coefficient	a_1	0.333	Constant
Pressure Hardening Coefficient	a_2	0.00464	1/(3・fc)
Cohesion for failed material	a_{0f}	7.18	fc/10
Pressure Hardening Coefficient for failed material	a_{1f}	1.5	Constant
Damage Scaling Factor	b_1	1.25	Constant
Percent reinforcement	PER	0	

*: Assumption based on our pre-internal estimation

2.3 Isotopic elastic-plastic material

This material model is provided as "*MAT_003" in the LS-DYNA, and most popular model used for steel materials. However, difference between tensile strength and compressive strength is not concerned in this model. Therefore, this model is unsuitable for modeling materials like a concrete, because there are ten times or more difference between tensile strength and compression strength.

To this material model, the young modulus is calculated from the shear modulus and bulk modulus of the Table 2, and the compressive strength of Table 2 is used as the yield strength.

3. ANALYTICAL MODEL

In consideration of the symmetry of the cask, the analytical model was modeled as 1/2 plane symmetric model. Fig 2 shows overview of the analytical model, and Table 4 shows material properties of each part. Moreover, details of modeling each part are shown below.

3.1 Main Body

The body, the bottom, and the fin on the body side have been modeled with solid elements as real shape.

3.2 Lid

The primary lid and the secondary lid have 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 stress 291MPa have been loaded for all bolts.

On gasket grooves of primary and secondary lids, and on flange surface of body, reaction force generated by tightening of metallic gasket(800N/mm) has been loaded as equivalent surface pressure.

3.3 Contents

The basket has been modeled with solid elements, and weight of 52 fuel elements has been loaded on the basket with mass elements.

3.4 Concrete floor

Concrete part of the concrete floor has been models with solid elements, and reinforcing bars have been modeled with beam elements whose nodes have been jointed to the concrete part.

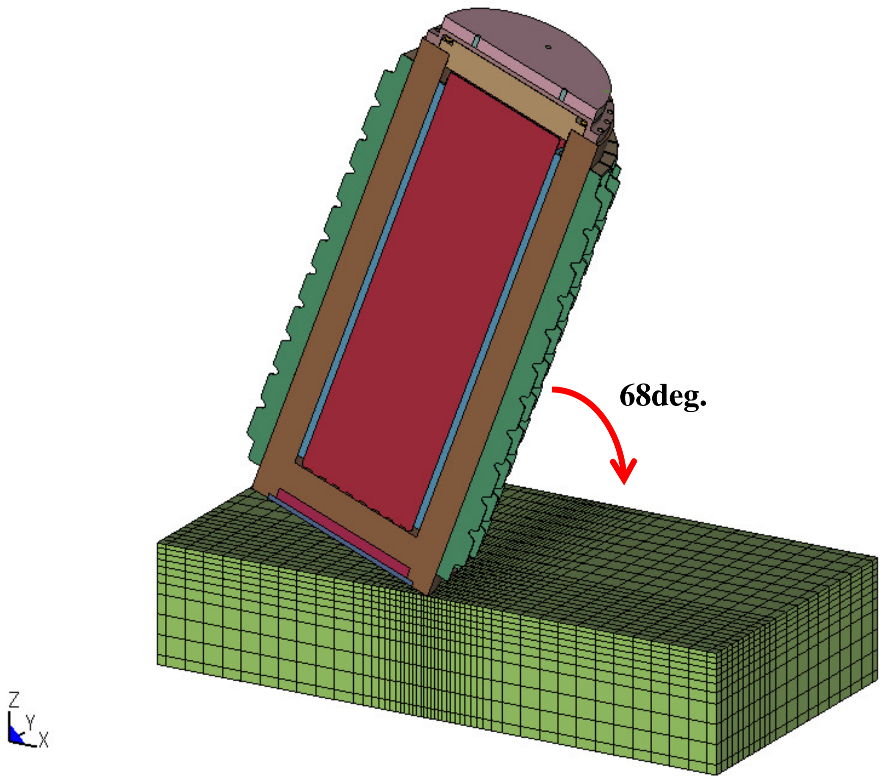

Figure 2. Analytical model

Table 4. Material properties for steel materials

Material	**Part**	**Density (ton/m^3)**	**Young Modulus (x10^{5}MPa)**	**Poisson's ratio**	**Yield strength (MPa)**	**Hardness Modulus (MPa)**
Ferrum Casting Ductile	Body, Fin	7.85	1.60	0.28	210	800
Stainless steel	Lid	7.85	1.95	0.3	206	975
Alloy steel	Bolts	7.85	2.06	0.3	883	1030
Stainless steel with boron	Basket	7.85	2.05	0.3	206	1025
Steel	Reinforcing bar	7.8	2.06	0.3	295	2060

4. ANALYTICAL CONDITION

As the analytical condition, tipping over event from freestanding condition has been considered. Based on the center of gravity position of this cask, maximum rotational angle is 68 degree in the tipping over event (see Fig. 2). Therefore, rotational speed when the cask collides to the floor is 1.89 rad/sec.

5. COMPARISON OF RESULTS

Fig. 3.1 to 3.3 show time histories of the primary lid's slide. In these graphs, "plus displacement" means that the lid gets close to the main body, and "minus displacement" means displacement of another direction.

In all results, maximum sliding displacement is shown at lower side (90 deg.). On the other hand, displacement of opposite side is quite smaller than that. Therefore, it is thought that an ovaling deformation of the main body has been main cause of such lid displacements.

And maximum amount of lid sliding is almost same of the Case 1 and the Case 2. However, the result of the Case 3 shows that maximum amount of lid sliding is larger and the response is earlier than Case 1. It is expected that the concrete material of the Case 3 is harder than the actual concrete, and the analytical result is too much conservative to lid behaviour.

Table 5. shows summary of lid behaviour during tipping over event.

It is shown that it is similar tendencies about the secondary lid, because the flange surfaces of the primary and secondary lid are both in one plane.

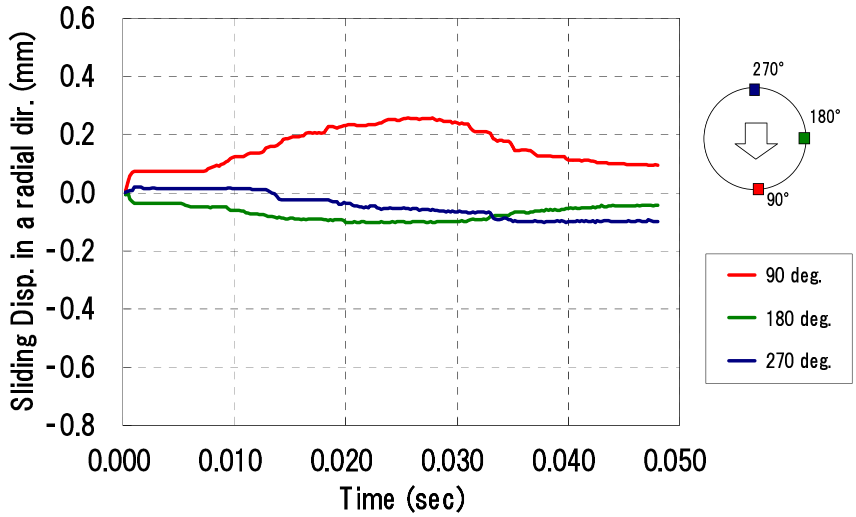

Fig. 3.1 Time history of the primary lid's slide (Case 1)

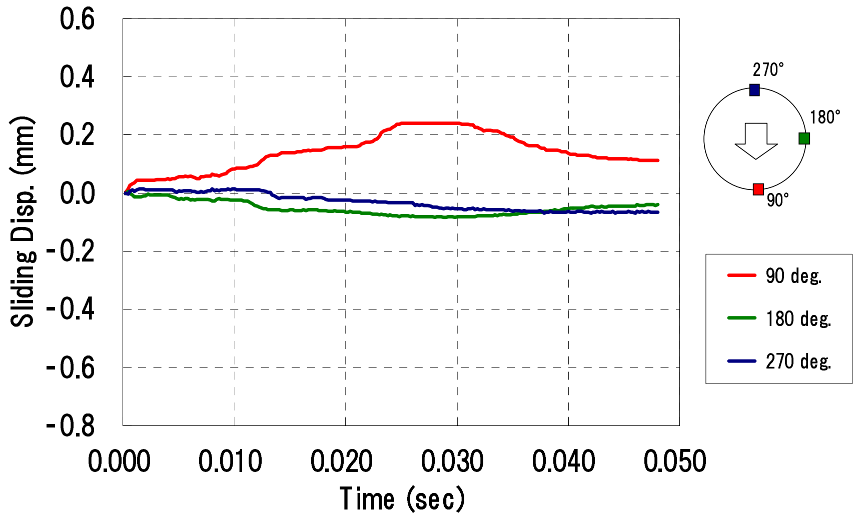

Fig. 3.2 Time history of the primary lid's slide (Case 2)

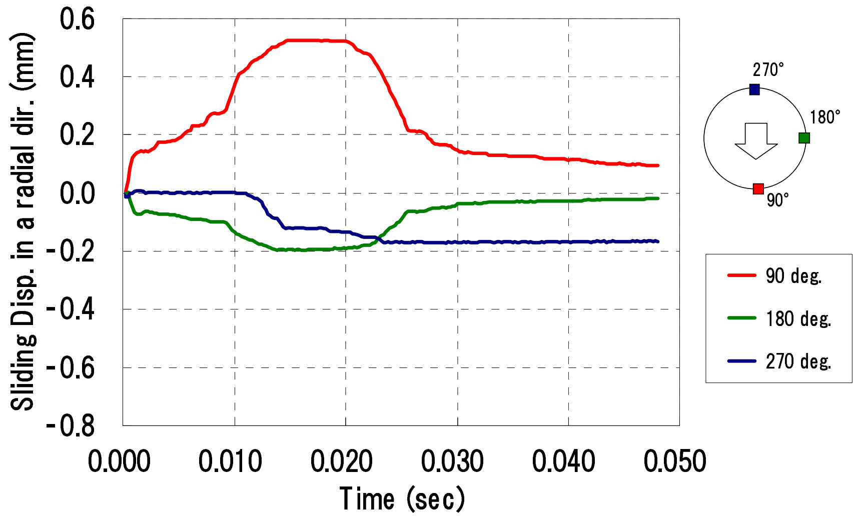

Fig. 3.3 Time history of the primary lid's slide (Case 3)

Table 5. Summary of the lid behaviour

Items	Case1	Case2	Case3
Primary Lid			
Acceleration	About 40.3G	About 43.3G	About 58.2G
Max. Sliding Disp.	0.257mm	0.240mm	0.525mm
Max. Opening Disp.	0.017mm	0.018mm	0.023mm
Secondary Lid			
Max. Sliding Disp.	0.341mm	0.380mm	0.706mm
Max. Opening Disp.	0.034mm	0.038mm	0.035mm

CONCLUSIONS

1) The pseudo tensor concrete material model shows good agreement to the concrete model developed by CRIEPI, by applying twice value of compression strength of concrete.
2) Analytical result using the isotopic elastic-plastic material model is too much conservative, because difference between tensile strength and compressive strength is not considered in this material model

REFERENCES

[1] U. S. Nuclear Regulatory Commission, Standard Review Plan for Dry Cask Storage Systems, NUREG-1536, 1997

[2] C. Ito, et al., Establishment of Cask Storage Method for Storing Spent Fuel -Evaluation Integrity of Cask at Postulated Mishandling Drop-, Abiko Research Laboratory Rep.No.U92035, CRIEPI, Japan, 1992

[3] Evaluation of Instantaneous Leakage from Metal Cask under Drop Accident -Drop Tests by Full-scale Metal Cask-, Civil Engineering Research Laboratory Rep.No.N06004, CRIEPI, Japan, 2006

[4] K. Shirai, et al., Impact Analysis of Reinforced Concrete Structure by Finite Element Method, Abiko Research Laboratory Rep.No.U93053, CRIEPI, Japan, 1993

[5] Evaluation of Instantaneous Leakage from Metal Cask under Drop Accident -Evaluation of Containment during Handing Accident with Numerical Analysis-, Civil Engineering Research Laboratory Rep.No.N06005, CRIEPI, Japan, 2006