Evaluation of the Impact Behavior of the Contents of Reprocessing Radioactive Waste Shipping Cask Subjected to Drop Impact

K.Shirai, C.Ito and M.Funahashi

Central Research Institute of Electric Power Industry, Chiba, Japan
Maeda Corporation, Tokyo, Japan

INTRODUCTION

Reprocessing radioactive wastes, e.g., the vitrified high level radioactive wastes, will be returned from the U.K. and France in 1995 to Japan. According to the IAEA regulations for transport, the waste shipping casks must maintain their integrity against drop impact. As the contents like canisters for the wastes will be spaced in the cask longitudinally, the severest cask drop orientation seems to be vertical. The impact phenomena at drop test is very complicated for the interaction between the contents and the cask body, it is necessary to evaluate the integrity of both of the cask body and contents.
In our prior study, we developed the one-dimensional spring-mass computer code to evaluate the impact behavior of the contents (Ito et.al 1988 and Shirai et.al 1988, 1989). In this study, to investigate the impact response characteristics of the contents in the cask precisely, we performed laboratory-scale drop tests, and on the basis of the test results, we proposed the construction of the spring-mass model. Moreover, we confirmed the accuracy of the proposed drop analysis method by comparison with a drop test using a full-scale cask for high level wastes.

LABORATORY-SCALE DROP TEST

Description of Test

To evaluate the interaction between the contents and the cask body, drop tests onto an unyielding surface using a scale model cask were performed (Ito et.al 1990). The dimensions and the specifications of the scale model cask are summarized in Fig.1 and Tab.1, respectively. The scale model cask consists of a cask body, four contents and an impact-limiter. The scale model cask

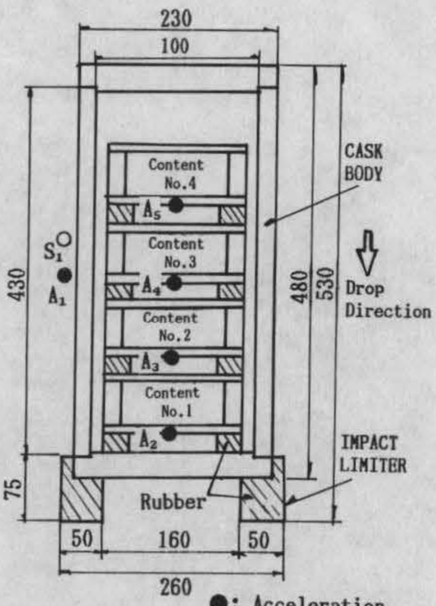

Fig.1 Dimensions of Scale Model Cask

body was a hollow cylinder of approximately 230mm in outer diameter and 430mm in length, and it had a nominal wall thickness of approximately 20mm. The cask body and the contents were made of plastic, and the impact limiter was made of rubber. The material properties for the model cask elements were summarized in Tab.2, and for these values the strain effect was considered. The drop height was settled to 90cm and the drop orientation was vertical. During the drop tests, accelerations and strains were measured at various points as shown in Fig.1.

Drop Test Results

Measured time histories of the accelerometer and strain gauge in the cask body and contents are shown in Fig.2 for the case of the rubber impact limiter. The high frequency components were removed from these time histories by a low pass filter. The strain trace (point S_1) occurring in the cask body was similar to the acceleration of (point A_1). Its maximum peak strain value was nearly equal to that calculated from the force by multiplying the weight above the measuring point by the maximum impact acceleration value. The acceleration response characteristics of the contents were different from that of the cask body considerably. It can be considered that the impact response of the contents will be affected by the interaction between the contents and the cask body, and the above interaction will be characterized by the gap between the contents and the cask body caused by the release of the gravitational force at the moment the drop started.

Tab.1 Specifications of Scale Model Cask

PART	DIMENSION (mm)	MATERIAL	QUANTITY	WEIGHT
Cask Body	Length 430mm Outer Diameter 230mm Wall Thickness 20mm	Plastic	1	About 11.9kg
Cask Body Lid	Outer Diameter 230mm Wall Thickness 30mm	Plastic	2	
Content Body	Length 50mm Outer Diameter 160mm Wall Thickness 20mm	Plastic	4	
Content Lid	Outer Diameter 160mm Wall Thickness 10mm	Plastic	8	About 5.3kg
Content Imapct Plate	Length 20mm Outer Diameter 160mm Wall Thickness 30mm	Rubber	4	
Impact Limiter	Length 50mm Outer Diameter 260mm Wall Thickness 50mm	Rubber	1	About 2.1kg

Tab.2 Material Properties

MATERIAL	DENSITY	POISSON'S RATE	YOUNG'S MODULUS
Plastic	1.17g/cm³	0.33	57000kgf/cm²
Rubber	1.10g/cm³	0.49	320kgf/cm²

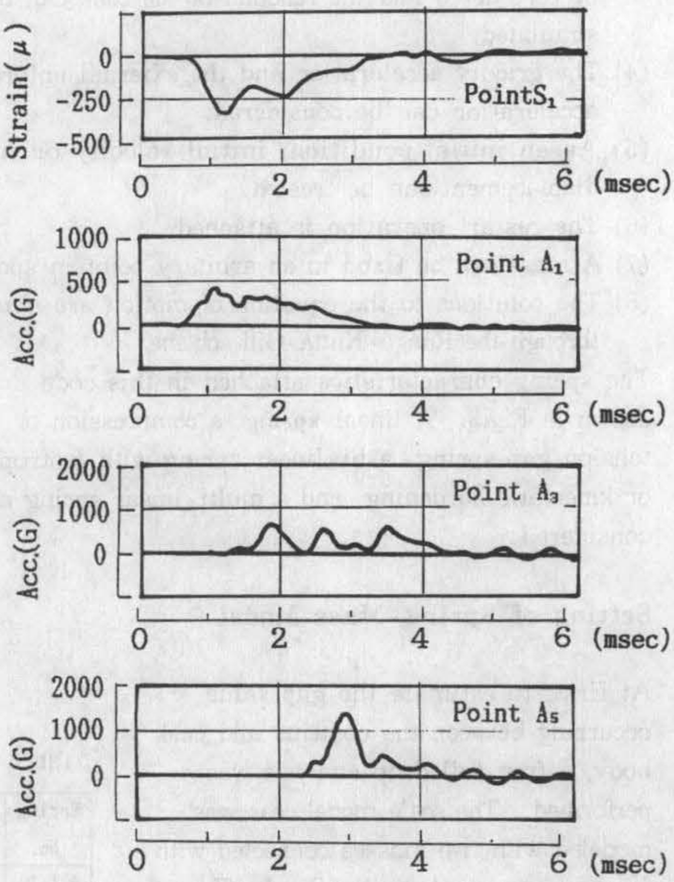

Fig.2 Time History of Acceleration and Strain

DROP ANALYSIS USING SPRING-MASS MODEL

In order to clarify the effect of the gap described above on the impact interaction problem, we applied spring-mass computer code to the drop analysis.

Description of Spring-Mass Computer Code

In this code, some characteristics specific to the drop analysis are considered as follows.

(1) A paralell disposition of a spring and a viscous dashpot between masses is assumed. The viscous dashpot causes a reactional force proportional to the relative velocity.

(2) The plastic deformation of the material's property, such as elastic-plastic behaviour with isotrophic and kinematic hardening, can be considered.

(3) The gap between the cask body and the contents can be considered and the rebound of the cask can be simulated.

(4) The gravity acceleration and the external enforced acceleration can be considered.

(5) As an initial condition, initial velocity or initial displacement can be treated.

(6) The restart operation is attached.

(7) A mass can be fixed to an arbitary point in space.

(8) The solutions to the equation of motion are obtained through the Runge-Kutta-Gill scheme.

The spring characteristics attached in this code are shown in Fig.3. A linear spring, a compression or tension gap spring, a bi-linear spring with isotrophic or kinematic hardening, and a multi-linear spring are considered.

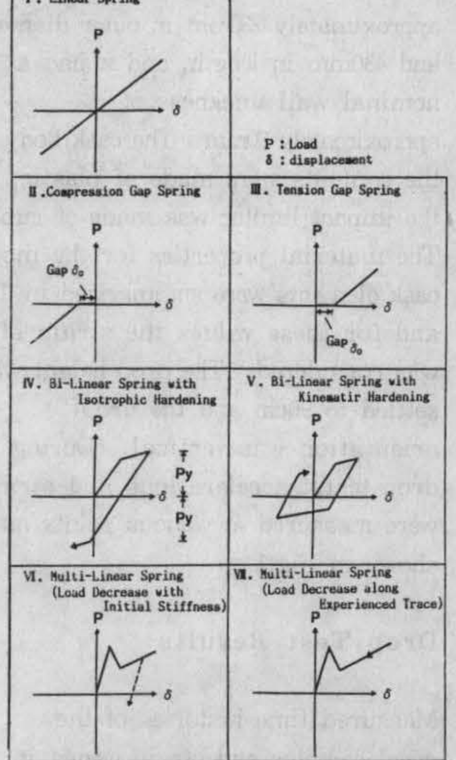

Fig. 3 Spring Characteristics

Setting of Spring-Mass Model

At first, to estimate the gap value occurring between the contents and cask body, a free-fall drop analysis was performed. The scale model cask was modeled with five masses connected with four springs as shown in Fig.4. The spring constant stiffness and the damping coefficient were calculated

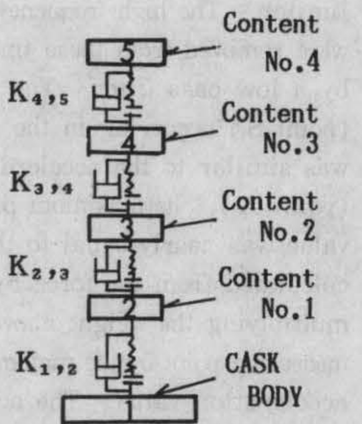

Fig. 4 Spring-Mass Model for Free-Fall Drop Analysis

Tab. 3 Analysis Parameters for Free-Fall Model

Spring No.	Spring Type	Spring Constant K (Mdyne/cm)	Damping Coefficient C (Mdyne·s/cm)	Initial Displacement (cm)
K1, 2	SP-2	1.454×10^{5}	1.3710	-3.628×10^{-5}
K2, 3	SP-2	1.454×10^{5}	1.3710	-6.349×10^{-5}
K3, 4	SP-2	1.454×10^{5}	1.3710	-8.163×10^{-5}
K4, 5	SP-2	1.454×10^{5}	1.3710	-9.070×10^{-5}

using the following equation (1).

$$K = \frac{\pi^2 \cdot m \cdot V^2}{4 \cdot H^2} \qquad C = 2h \cdot \sqrt{K \cdot m} \cdots\cdots\cdots (1)$$

H : Length of content
V : Wave propagation velocity through content
m : Mass of content
h : Damping constant

Tab. 4 Results of Free-Fall Drop Analysis

Mass No.	Displacement(cm) t=0.0	Displacement(cm) t=0.4286	Gap Value (cm)
m_1	0.0	90.000	---
m_2	3.628×10^{-5}	89.957	0.043
m_3	6.349×10^{-5}	89.910	0.047
m_4	8.163×10^{-5}	89.859	0.051
m_5	9.070×10^{-5}	89.829	0.030

The spring constant stiffness was defined to satisfy two conditions of one-forth of the natural period of the content and the wave propagation time through the content. The damping constant was settled to 0.07. For initial conditions, the deformation due to the gravitational force was applied to each spring of the free-fall model. The analysis parameters and the analysis results are summarized in Tab.3 and Tab.4, respectively. It was found that the gap occurring at each spring after a 90cm free-fall was about 0.5mm. Subsequently, a drop analysis of the scale model cask was performed. Fig.5 shows the spring-mass model. The analysis parameters are summarized in Tab.5. The cask body and the impact limiter were divided to nine masses, and the content and unyielding surface were modeled for two masses and one mass, respectively. The load-deflection characteristic for each spring was based upon the stress-strain curve using the following equation (2).

$$P = \sigma \cdot A = f(\varepsilon) \cdot A = f(\delta / L) \cdot A \cdots\cdots (2)$$

L : Length of each element of the cask
A : Cross section area of each element of the cask

A damping coefficient of the dashpot was calculated from following equation (3).

$$C = 2h \cdot K_i \frac{m_i \cdot m_j}{m_i + m_j} \cdots\cdots\cdots\cdots\cdots (3)$$

K_i : Initial stiffness of spring K_{ij}

Tab. 5 Analysis Parameters for Drop Imapct Model

Spring No.	Spring Type	Spring Constant K(Mdyne/cm)	Damping Coefficient C(Mdyne·s/cm)	Initial Gap (cm)
K1,2	SP-2	1.903×10^{4}	1.262	0.000
K2,3 ~K9,10	SP-5	1.495×10^{6}	0.195	----
K2,11	SP-1	1.242×10^{6}	1.796	
K11,12 K13,14 K15,16 K17,18	SP-2	2.000×10^{4}	0.519	0.043, 0.047 0.051, 0.030
K12,13 K14,15 K16,18 K18,19	SP-5	1.072×10^{6}	0.943	----
K19,20	SP-2	1.000×10^{5}	0.395	3.0

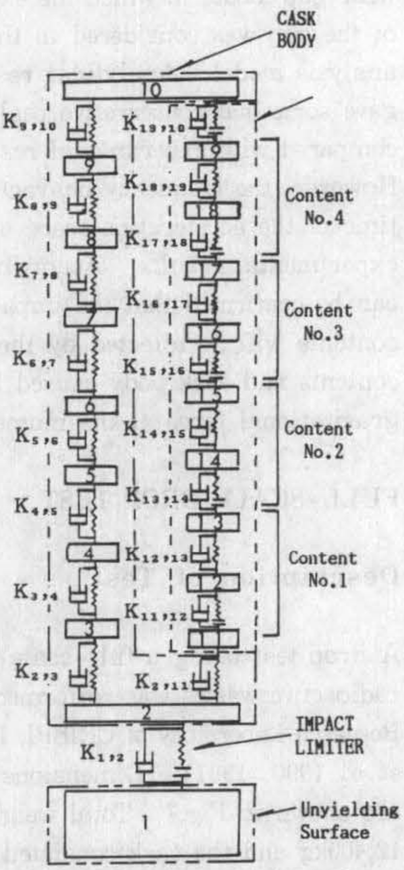

Fig.5 Spring-Mass Model for Drop Impact Analysis

A damping constant h was assumed to be 2.5% for plastic and 7% for rubber. For initial conditions, an initial velocity (-420cm/sec) was given to the masses except a mass representing the unyielding surface.

Comparison between Test Results and Drop Analysis

To evaluate the effect of the existence of the gap on the impact response, the drop analysis used a without-gap model and a with-gap model. The comparison of acceleration-time history between two models is shown in Fig.6. Fig.6(a) shows the case of a without-gap model in which the existence of the gap between the contents and cask body was ignored. In the analytical results, the acceleration frequency characteristics occurring in each content were similar and different from experimental results. Fig.6(b) shows the case of with-gap model in which the existence of the gap was considered in the analysis model. Analytical results gave somewhat conservative peak values compared with experimental results. However, the frequency characteristics and the rising time of the acceleration trace agreed approximately with experimental results. According to these results, it can be confirmed that the impact behavior of the contents will be affected by the gap between the contents and cask body caused by the release of gravitational force at the moment the drop starts.

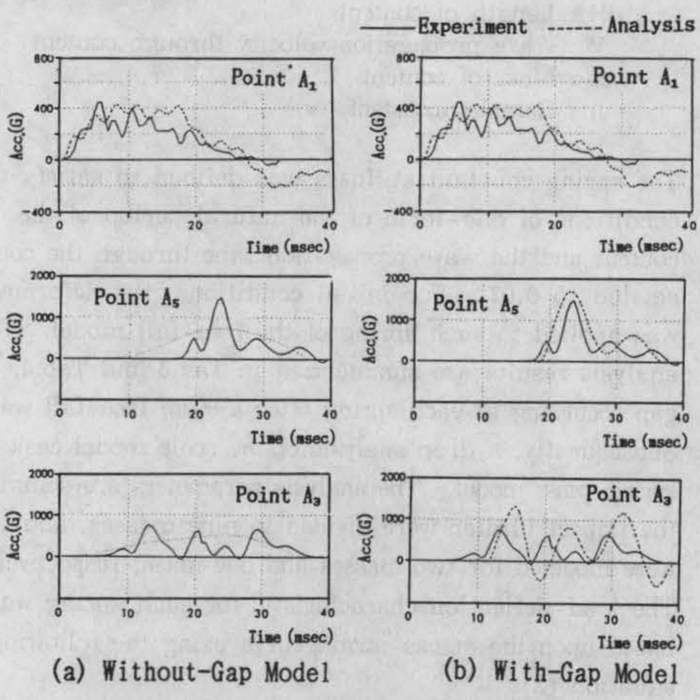

Fig.6 Comparison between Test Results and Analytical Results

FULL-SCALE DROP TEST

Description of Test

A drop test using a full-scale cask for high level radioactive wastes was performed at the Yokosuka Research Laboratory of CRIEPI, Kanagawa, Japan (Shirai et.al 1990, 1991). Dimensions of the full-scale cask are shown in Fig.7. Total weight of the cask was 12,400kg and the cask consisted of the cask body, a basket with two canistors filled up with cold glass, a spacer and an impact limiter. The test conditions are

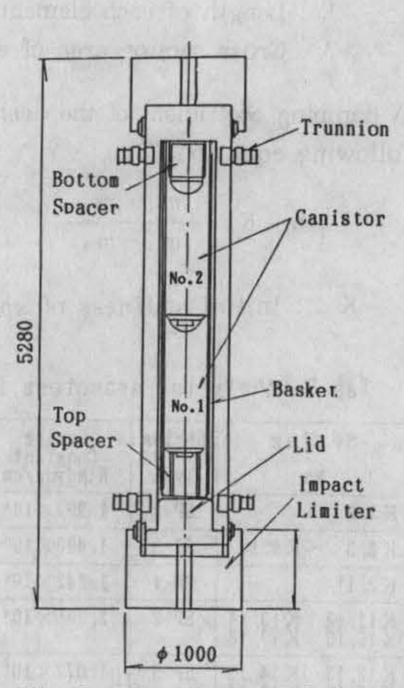

Fig.7 Dimensions of Full Scale Cask

summarized in Tab.6. The drop orientation was vertical, and the drop height was 9m. To evaluate the impact force on the cask and the contents, accelerations were measured at various points in the cask body and contents.

Tab. 6 Test Condition

Content	Two Cold Canistors
Weight	12,400 kg
Orientation	Vertical
Target	Unyileding Surface
Drop Height	9.0 m

Drop Analysis

The analysis model are shown in Fig.8. Essentialy, the load-deflection curve was obtained using equation (3). However.

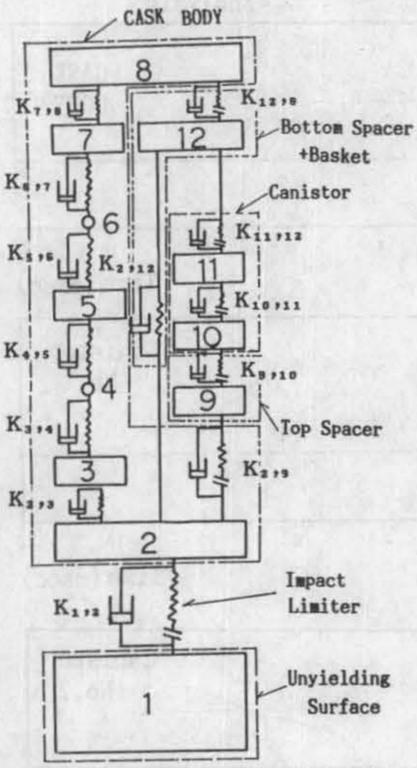

Fig. 8 Spring-Mass Model of Full Scale Cask

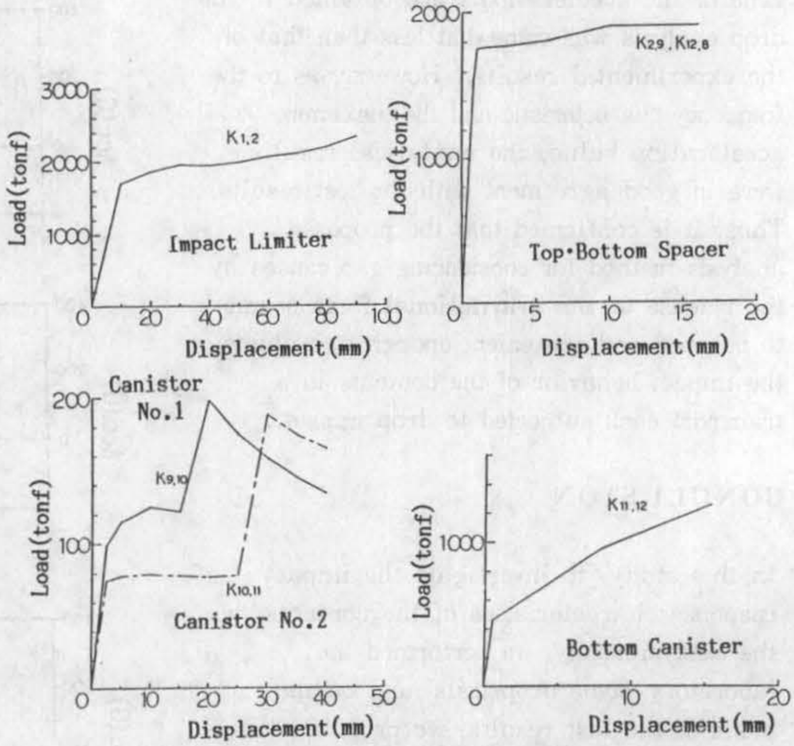

Fig. 9 Load-Deflection Curve of Each Member of Cask

Tab. 7 Analysis Parameters of Full Scale Cask Model

Mass No.	Mass Part	Mass (ton)
m1	Unyielding Surface	1.0×10^5
m2	Impact Limiter+Lid	1.340
m3 | m7	Cask Body	Total 7.475
m8	Bottom Plate + Impact Limiter	1.727
m9	Top Spacer	0.150
m10	Canistor No.1	0.480
m11	Canistor No.2	0.480
m12	Bottom Spacer + Basket	0.752

Spring No.	Spring Part	Spring Type	Spring Constant K(N/cm)	Damping Coefficient C(N·s/cm)	Initial Gap (cm)
K1,2	Impact Limiter	SP-7	1.737×10^5	7.786	0.000
K2,3 K3,4 K4,5 K5,6 K6,7 K7,8	Cask Body	SP-4	8.454×10^6	47.500	----
K2,12	Basket	SP-2	1.891×10^5	4.876	0.000
K2,9	Top Spacer	SP-7	1.980×10^6	8.265	0.556
K9,10	Canistor No.1	SP-7	4.082×10^4	1.092	0.054
K10,11	Canistor No.2	SP-7	3.061×10^4	1.388	0.095
K11,12	Bottom Canistor	SP-7	9.490×10^5	8.510	2.300
K12,8	Bottom Spacer	SP-7	1.980×10^6	16.449	0.140

as to the member of the cask which has a complicated shape and seems to be deformed considerably at drop impact, the load-deflection characteristic was examined by static structural analysis using NIKE-2D FEM code. Fig.9 shows the load-deflection curve of each member of the cask. For initial conditions, an initial velocity (1328cm/sec) and the initial gap obtained from free-drop analysis were given to the masses and springs, respectively. The analysis parameters are summarized in Tab.7. In Fig.10, the test results and the analytical results were compared as to the acceleration-time history at the cask body and canistors. The rising time of the acceleration trace obtained in the drop analysis was somewhat less than that of the experimental results. However, as to the frequency characteristic and the maximum acceleration value, the analytical results were in good agreement with the test results. Thus, it is confirmed that the proposed analysis method for considering gap caused by the release of the gravitational force seems to be good and convenient enough to evaluate the impact behavior of the contents in a transport cask subjected to drop impact.

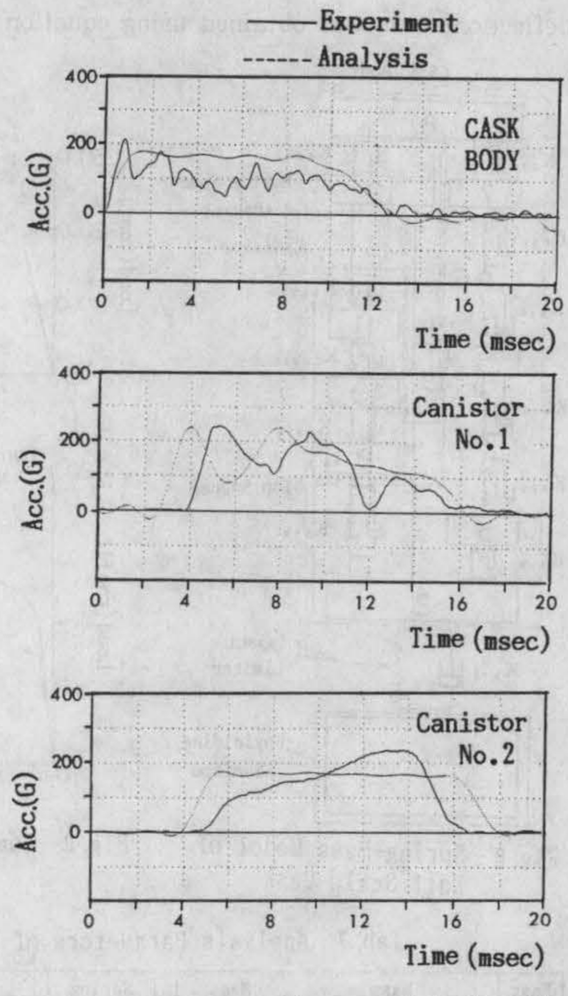

Fig.10 Compariosn between Tets Results and Analytical Results

CONCLUSION

In this study, to investigate the impact response characteristics of the contents in the cask precisely, we performed the laboratory-scale drop tests, and on the basis of the test results, we proposed the construction of the spring-mass model and confirmed the accuracy of the proposed drop analysis method by comparison with drop test using a full-scale cask for high level wastes. Following the results of the drop tests and analysis, the outline of the contents and results is summarized below.

1) The drop tests onto the unyielding surface using a scale model containing several contents were performed and the effect of the interaction between the contents and the cask body on the impact response experimentally.

2) The above interaction can be characterized by the gap between the contents and the cask body caused by the release of the gravitational force at the moment the drop started. So, we proposed the analysis method for considering gap using spring-mass model by comparing the laboratory-scale drop test results.

3) We applied the proposed analysis method to a drop test using a full-scale cask for high level wastes, and it was found that this method seems to be good and convenient enough to evaluate the impact behavior of the contents in a transport cask subjected to drop impact.

REFERENCES

Ito.C, Shirai.K and K.Kono : Investigation on the Method of Cask Drop Analysis Considering Interaction-Development of Spring-Mass Model, Annual Meeting of the AESJ, 1988.4 (in Japanese).

Ito.C, Shirai.K and M.Funahashi : Investigation on the Method of Cask Drop Analysis Considering Interaction-Drop Test Using Small Model (Part 2), Fall Meeting of the AESJ, 1990.10 (in Japanese).

Shirai.K, Ito.C and K.Kono : Investigation on the Method of Cask Drop Analysis Considering Interaction-Drop Test Using Small Model, Fall Meeting of the AESJ, 1988.10 (in Japanese).

Shirai.K, Ito.C and K.Kono : Investigation of Cask Drop Analysis Method Considering Interaction with its Contents for Reprocessed Radioactive Waste Shipping Cask, PATRAM'89.

Shirai.K, Ito.C and M.Funahashi : Investigation on the Method of Cask Drop Analysis Considering Interaction-Application for Drop Impact of Full Scale Model, Fall Meeting of the AESJ, 1990.10 (in Japanese).

Shirai K. and C.Ito : Investigation on Integrity of Transport Cask for Returnable Vitrified Residues Subjected to Drop Impact-Establishment of Cask Drop Analysis Method Considering Interaction with its Contents, CRIEPI Rep. No.U91016, 1991.7 (in Japanese).