Investigation of Cask Drop Analysis Method Considering Interaction With Its Contents for Reprocessed Radioactive Waste Shipping Cask

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INTRODUCTION

In Japan, radioactive wastes owing to the reprocess of the spent fuel will be returned from the U.K. and France in the near future. According to the IAEA regulations for transport, these waste shipping casks shall maintain their integrity during the drop tests. As to these reprocessed waste cask, some of the contents are spaced longitudinally in the cask and there are some gaps between the contents and the cask body. So, the impact phenomena of the contents at the drop test especially at a vertical orientation are very complicated for both the interaction between the contents and between the contents and cask body. It seems to be necessary to develop a method the evaluate the integrity not only of the cask body, but also of its contents. The main object of this study is to establish a method for this kind of the interaction problem. As a first step, we developed a computer code using a lumped−mass model for analysis of free drop tests and examined the accuracy of the proposed code by comparing the test results using a scale model cask.

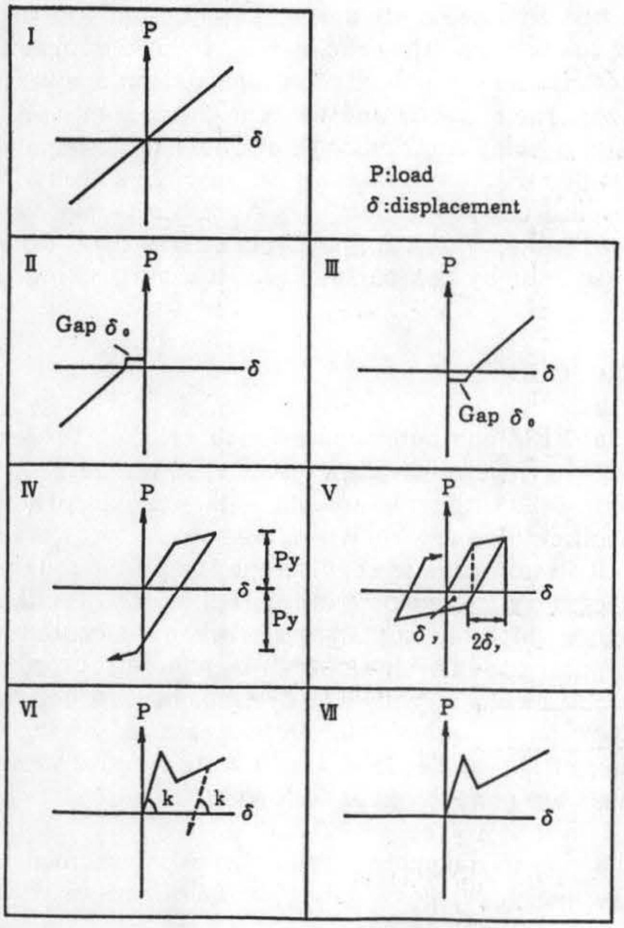
DESCRIPTION OF THE PROPOSED CODE

The drop analysis using 2 or 3 dimensional FEM computer codes (such as the DYNA-3D code) can be uesed for evaluating the behaviour of the cask at the drop impact. These codes have an advantage of predicting the impact behaviour with some accuracy if the material property and the cask specifications are known in advence. However these codes are expensive. A long calculation time is required and is not adequate for parameter survey. So, it seems necessary to develop a simplified method for the drop impact analysis especially for the cask which has some gaps between the contents and cask body. As a first step, a computer code using a one−dimensional lumped−mass model has been developed. The outline of this code was described *Investigation on the Method of Cask Drop Analysis Considering Interaction−Development of Spring−Mass Model*, C. Ito et al., Annual Meeting of the AESJ, 1988. 4. In this code, some characteristics specific to the drop analysis are considered as follows :

(1) A parallel disposition of a spring and a viscous dashpot between masses is assumed.
(2) The plastic deformation of material property, such as elastic−plastic behaviour with isotrophic and kinematic hardening, can be considered.

(3) The viscous damping can be considered. The viscous dashpot causes a reactional force proportional to the relative velocity.
(4) The gaps between the cask body and the contents can be considered.
(5) The rebound of the cask can be simulated.
(6) The gravity acceleration and external enforced acceleration can be considered.
(7) As an initial condition, initial velocity or initial displacement can be treated.
(8) The restart operation is attached.
(9) A mass can be fixed to an arbitary point in space.
(10) In addition to the impact analysis, modal analysis can be performed. Moreover, the law-pass-filter can be applied and the impact response (time history of an acceleration or displacement etc.) can be illustrated using a post-processor.
(11) Integration of equation of motion is based on an explicit numerical scheme called the Runge-Kutta-Gill method.

The spring characteristics attached in this code are shown in Fig. 1. A linear spring, a compression or tension gap spring, a bi-linear spring with isotrophic-kinematic hardening, and a multi-linear spring are considered.



I Linear Spring

II Compression Gap Spring

III Tension Gap Spring

IV Bi-Linear Spring with Isotrophic Hardening

V Bi-Linear Spring with Kinematic Hardening

VI Multi-Linear Spring (Load Decrease with Initial Stiffness)

VII Multi-Linear Spring (Load Decrease along Experienced Trace)

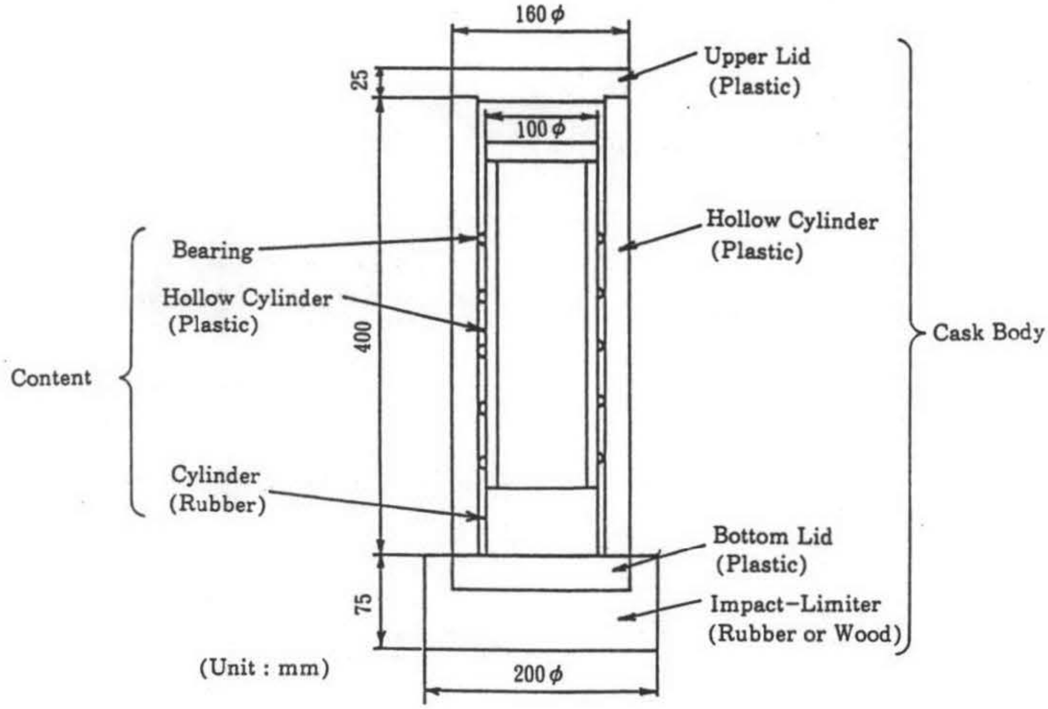
Fig. 1 Characteristics of Spring

DROP TEST USING A SCALE MODEL

Test Method

In order to evaluate the interaction between the contents and the cask body and the accuracy of the proposed code, the free drop tests using a scale model cask onto the unyielding surface were performed. The outline of these drop tests were described in Investigation on *the Method of Cask Drop Analysis Considering Interaction –Drop Test Using Small Model–*, K. Shirai et al., Fall Meetting of the AESJ, 1988. 10. Referring to the full scale cask, about one–tenth of the full scale cask was fabricated. The outline of the model cask was shown in Fig. 2.

The model cask consists of a cask body, a single content in the body, and an impact–limiter at the bottom of the body. The cask body was a hollow cylinder of approximately 160mm in the outer diameter and 400mm in length. It had a nominal wall thickness of approximately 20mm. A number of bearings were attached to the surface of the content to prevent the friction and rocking motion between the cask body and content. The weight of the cask body was 6. 5kgf and the weight of the content was ranged from 1. 26 to 2. 43kgf. The cask body and content were made of plastic, and the impact limiter was made of various kinds of wood or rubber. Before testing, the cask body and the content were instrumented with many accelerometers and strain gauges. The data from these transducers were sent to a recording system and



Weight
Cask Body : 6. 5 kgf
Content : 1. 26 2. 43 kgf
Impact–Limiter: 2. 0 kgf(Rubber)
0. 2 kgf(Wood)

Fig. 2 Outline of the Model Cask

reproduced on the synchroscope through the wave memory. The measuring system is shown in Fig. 3. In order to obtain mechanical properties of the material used in the model cask, dynamic compression material tests were performed. The method of the material tests is shown in Fig. 4. The test specimen, which was 100mm in diameter and 50mm in height, was attached at the bottom of the steel cylinder. The cylinder was dropped from a 90cm height onto the unyielding surface. By integrating the measured acceleration using the following equations, the load−deflection curves of the test specimen were obtained and transformed to the stress−strain curves.

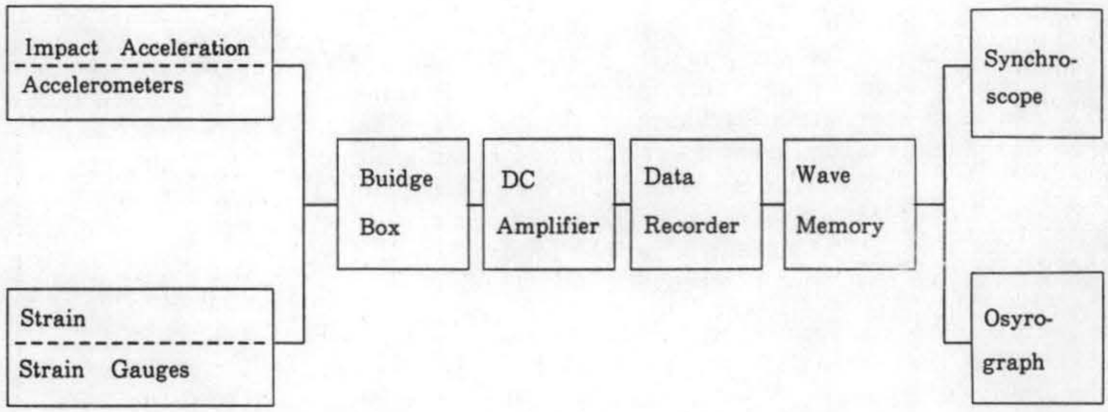


Fig. 3 Measuring System

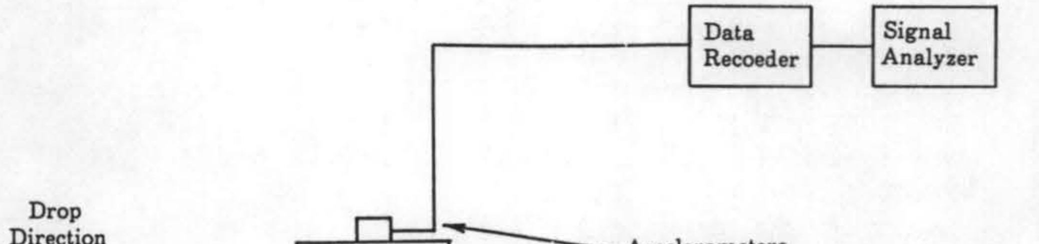


Fig. 4 Outline of the Dynamic Compression Material Test

load : $P(t) = a(t) \cdot W$ W : Weight of cylinder

Deflection : $\delta(t) = \int_0^{t1} [V_0 - \int_0^{t1} a(t)\,dt]\,dt$ a(t) : Measured acceleration

V_0 : Initial velocity

As the rubber was somewhat of a viscoelastic material, the cyclic dynamic material tests ware performed additionally to obtain the equivalent viscous damping constant.

Test Results

Drop tests were conducted at a height of 90cm. An example of the test results is shown in Fig. 5. In these cases, the hard rubber and soft wood were used as a impact-limiter material. The strain trace which occurred was similar to the one of the acceleration of the cask body at each measuring point. Its maximum peak strain value was nearly equal to the one that was calculated from the force by multiplying the weight above the measuring point by the maximum impact acceleration. Between each strain trace, there was somewhat of a delay of the trigger time. Its delay time was about 100 μsec and equal to the time required for the elastic-wave to propagate between the measuring points. When hard rubber was used as an impact-limiter material, the maximum value of the acceleration of the cask body and the content was 400G and 650G, respectively and in the case of soft wood the maximum value of the acceleration of the cask body and the content was 300G and 550G, respectively.
To investigate the acceleration which occurred in the content, the free drop test of the content only was performed. Its maximum acceleration value was 600G, nearly equal to the value which occurred in the content in the drop test using the scale model cask. So, owing to the existence of the gap between the cask body and content, the material of the impact-limiter did not have any considerable influence on the behaviour of the content.

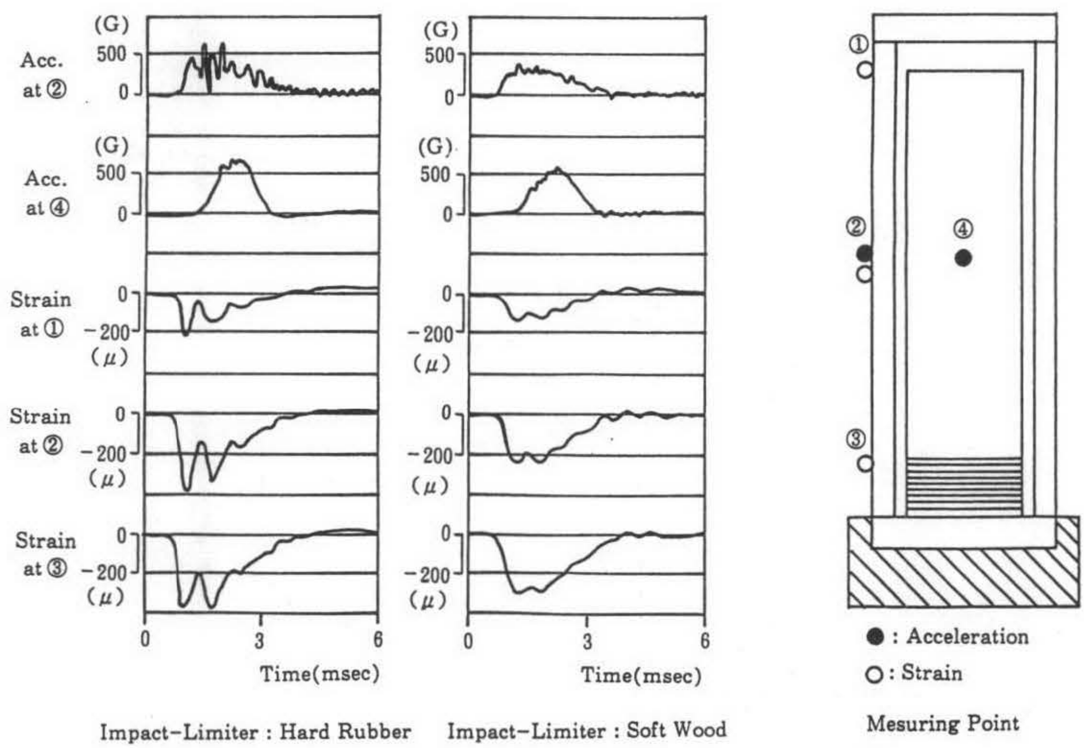


Fig. 5 Test Results

DROP ANALYSIS

Drop analysis using the proposed code were performed. In this analysis, the cask was modeled using a number of masses, springs, and dashpots, as shown in Fig. 6. The cask body and impact-limiter were divided using five lumped masses and two inferential masses. These inferential masses were attached to improve the accuracy of the analysis in a high frequency domain. The content or unyielding surface was modeled for one lumped-mass. A mass for unyielding surface was fixed and was assummed to have an infinite weight. Lumped-masses were connected to one another by springs and dashpots each other. A damping coefficient of the dashpot was calculated from following equation.

$$C = 2\,h\sqrt{k\,\frac{m\,i + m\,j}{m\,i + m\,j}}$$

k : an initial stiffness of spring Kij

h : a damping constant

A damping constant h was assumed to be 2.5% for plastic and wood, and for rubber 7% was used reffering to the cyclic dynamic material tests performed in *Drop Tests Using a Scale Model.* As to an initial condition, an initial velocity was given to the lumped -masses except a mass for unyielding surface. The load-deflection characteristics for each member of the cask was based upon the stress-strain curves obtained in the dynamic material tests described in *Drop Tests Using a Scale Model.*

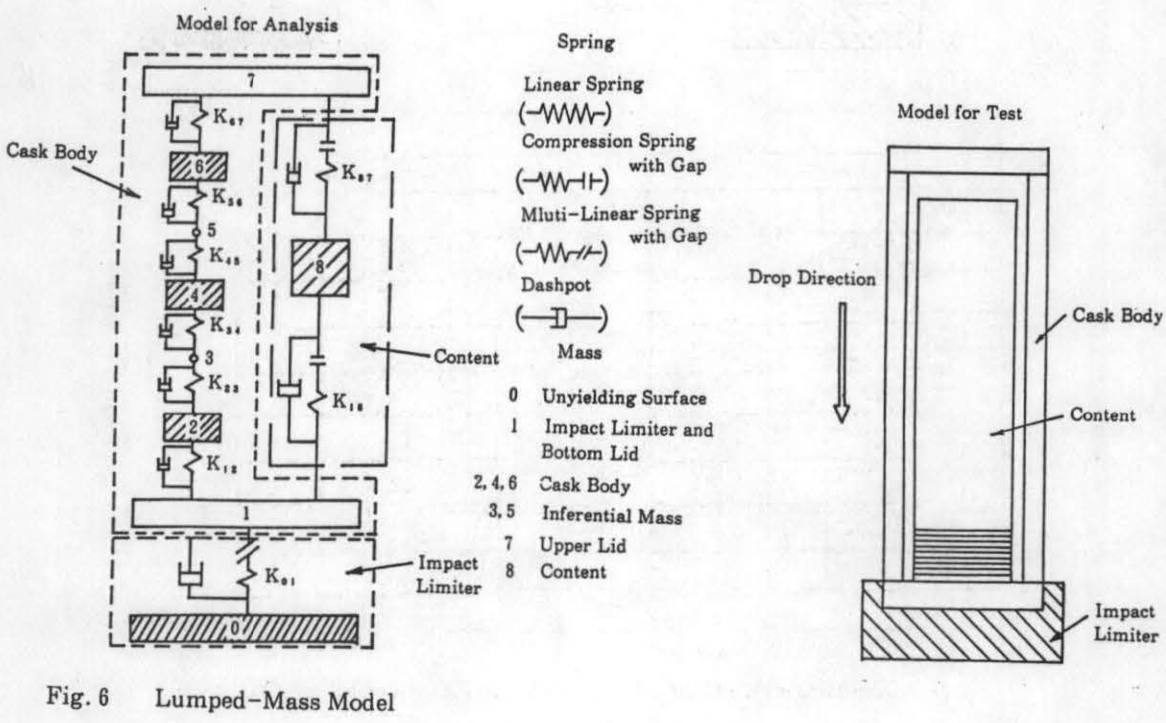
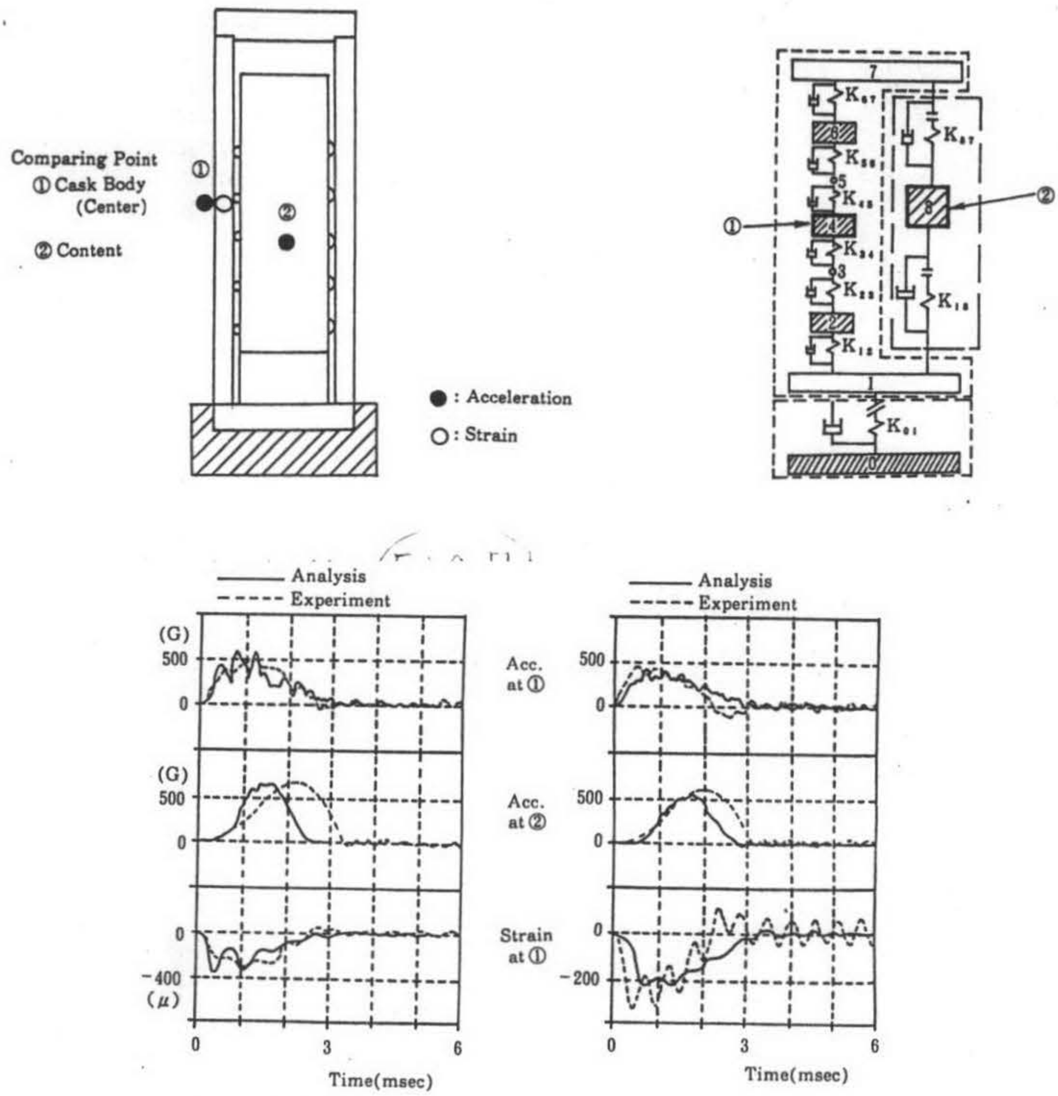


Fig. 6 Lumped-Mass Model

COMPARISON BETWEEN TEST RESULTS AND DROP ANALYSIS

In order to evaluate the accuracy of the proposed code, the test results of the free drop tests and calculated results for the acceleration and strain were compared. Fig. 7 shows a comparison for the two cases. Fig. 7 (a) shows the case in which the impact −limiter was made of elastic material (hard rubber). Though a little time delay exists, the acceleration and strain traces obtained in the analysis were in satisfactory agreement with the experimental results. Fig. 7 (b) shows the case in which the impact −limiter was made of plastic−elastic material (soft wood). The analytical results gave somewhat conservative values (about 1 ~ 1.3 times higher at pesk) compared with the experimental results. According to these results, the accuracy of the proposed code and the applicability of the method for evaluating the load−deflection constants determined from stress−strain curves (taking into account the dynamic behaviour of the material) seemed to be confirmed.



(a) Impact−Limiter : Hard Rubber

(b) Impact−Limiter : Soft Wood

Fig. 7 Comparison between Test Results and Drop Analysis

CONCLUSION

The computer code using a lumped-mass model for analyses of free drop tests (especially for vertical orientation) considering the interaction with its contents was developed. Drop tests using a scale model cask were performed to examine the accuracy of the code and the applicability of the method to evaluate the load-deflection characteristics. The comparison between the test results and calculated results for acceleration and strain showed that the calculated results gave a somewhat conservative value compared with the test results. From these results, it could be concluded that dynamic time-history analysis using this code could be used to estimate test results accurately (about 1 ~ 1. 3 times higher at peak). Based on this results, the accuracy of the proposed code will be improved by performing free drop tests using scale models which contain several contents in near future.

REFERENCES

C. Ito, et al. , *Investigation on the Method of Cask Drop Analysis Considering Interaction -Development of Spring-Mass Model*, Annual Meeting of the AESJ, 1988. 4.

K. Shirai, et al. , *Investigation on the Method of Cask Drop Analysis Considering Interaction-Drop Test Using Small Model*, Fall Meeting of the AESJ, 1988. 10.