Simplified Analysis Computer Programs and Their Adequacy for Radioactive Materials Shipping Casks

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INTROUCTION

In the drop impact analyses for radioactive material shipping casks, it has become possible to perform them in detail using interaction evaluation computer programs, such as DYNA2D, DYNA3D, PISCES and HONDO. However, the considerable cost and calculation time are necessitated to perform such analysis by these computer programs. Therefore, simplified computer programs which are capable of reducing cost and calculation time are needed to perform parameteric survey or sensitivity evaluations in designing a shipping cask and conducting its safety analysis. To meet the above requirements, as shown in Fig. 1, Japan Atomic Energy Research Institute (JAERI) is now under developing some simplified analysis computer programs and Mitsubishi Heavy Industries Ltd, (MHI) has already developed them, respectively.

In the field of the drop impact analysis of shipping casks with shock absorbers, simplified computer programs CRUSH and CASH-II have been developed in JAERI and MHI, respectively. Both CRUSH and CASH-II, though having some differences in detailes each other, are the static calculation computer programs capable of evaluating the maximum acceleration of cask body and the maximum deformation of the shock absorber using the Uniaxial Displacement Method (UDM) which is an improvement on a conventional theory based on the Volumetric Displacement Method (VDM).

CALCULATION METHOD

Conventionally, the VDM has been a usual method to evaluate a large three dimensional deformation. In the VDM, the absorption of drop energy is to be evaluated only by the volumetric quantity loss by the deformation of the shock absorber. This method is therefore considered as an effective means of evaluation provided the material can be treated under a constant compressive stress in any deformation. However, taking into account of the material properties, the VDM would have a bit problema in the view of the accuracy of solution.

The UDM, instead, will execute the evaluation under the assumption that the deformable region consists of an assembly of many one-dimensional bar elements as shown in Fig. 2. All volume of the shock absorber can absorb the drop energy, so that the method makes a benefit of obtaining an accurate results, although the analysis itself gets rather complicated compared with the VDM. CRUSH and CASH-II are computer programs which evaluate statically, for each of drop attitudes, the cask body acceleration and shock absorber deformation in terms of the drop impact using the UDM.

Calculation Model

In modeling of the shock absorber in CRUSH and CASH-II, it is assumed that the shock absorber consists of three or four species of material as shown in Fig. 3. In the figure, the

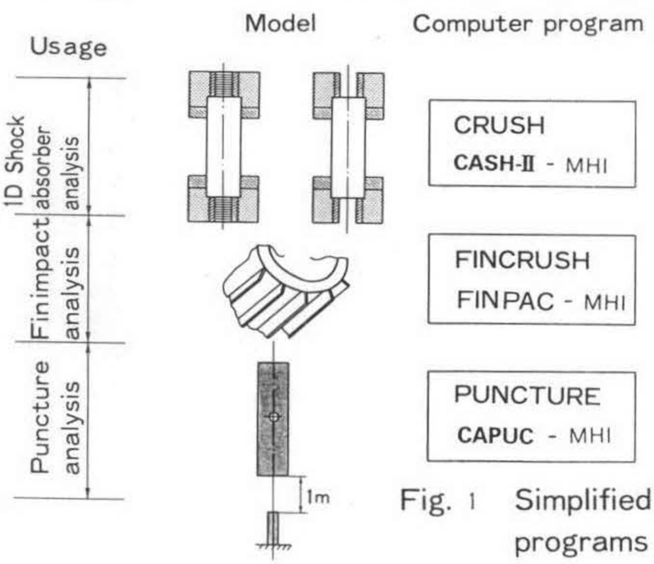

Fig. 1 Simplified analysis computer programs

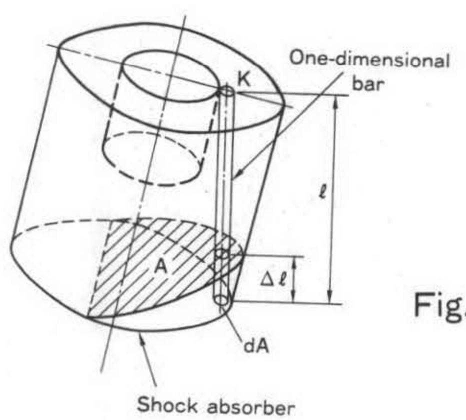

Fig. 2 Uni-axial displacement method

symbols of Ki(i=1-5) indicates boundary condition constants which are estimated by an overpack stiffness and boundary condition of the shock absorber.

Calculation Equations

When the shock absorber deforms by the displacement $\Delta\ell$ in a corner drop as shown in Fig. 2, the strain ε of an one-dimensional bar is

$$\varepsilon = \frac{\Delta\ell}{\ell} . \tag{1}$$

The force f of the one-dimensional bar is

$$f = K\,\sigma\,(\varepsilon)\;dA . \tag{2}$$

where ℓ, σ and dA are the length, stress and area of the one-dimensional bar. K is the boundary condition cosatant. The total force of the shock absorber is

$$F = \int_A f\;dA . \tag{3}$$

The dissipated energy $E(\delta)$ can also be obtained by using equation similar to above Eq. (3)

$$E(\delta) = \int_0^{\delta} F\;d\ell . \tag{4}$$

Therefore when a cask whose weight of W is dropped from a height H with an oblique angle θ, the maximum displacement of the shock absorber δ and the maximum acceleration of the cask body α are given as follows.

$$E(\delta) = \gamma \cdot W \cdot H , \tag{5}$$

$$\alpha = F(\delta)/M . \tag{6}$$

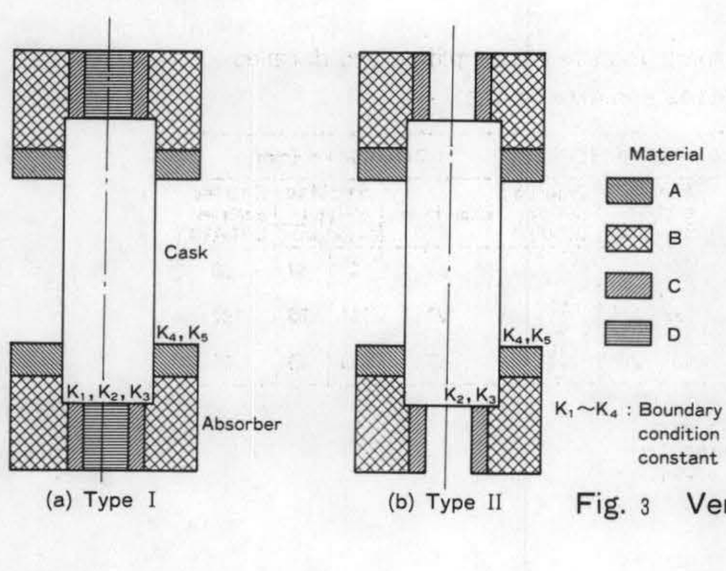

Fig. 3 Vertical drop model

Where γ is ratio of the energy absorbed in the primary impact to the total energy absorbed in the primary and secondary impacts. M is mass of the cask.

BENCHMARK CALCULATIONS

Comparison between Simplified Calculation and Experiment

In order to demonstrate the adequacy of the simplified computer programs, the benchmark calculations using the experimental results of the 1/4 scale model of NUPAC 125B cask as shown in Fig. 4, have been performed.

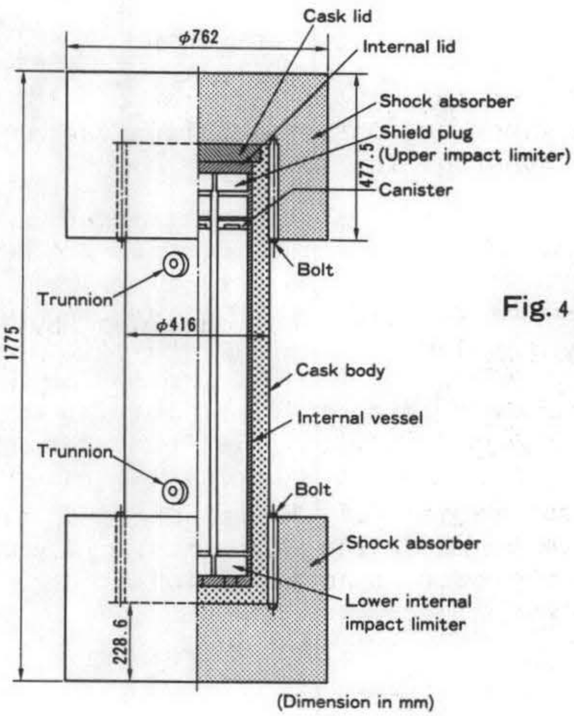

Fig. 4 Shipping cask-NUPAC 125B (¼ scale model)

Table 1 Comparison between simplified and detailed analyses and experiment

Attitude	Acceleration (G)				Deformation (mm)			
	Experiment	Simplified analysis		Detailed analysis	Experiment	Simplified analysis		Detailed analysis
		CRUSH	CASH-II	DYNA3D		CRUSH	CASH-II	DYNA3D
Vertical	200	179	189	271* (200)**	51	52	57	50
Corner	106	125	115	130 (85)	127	151	183	132
Horizontal	180	183	204	216 (160)	61	63	73	64

* Value of low pass filter is 600 Hz.

** Mean value $= \frac{\text{Impact velocity}}{\text{Rebound time}}$.

(NUPAC 125 B cask ¼ scale model).

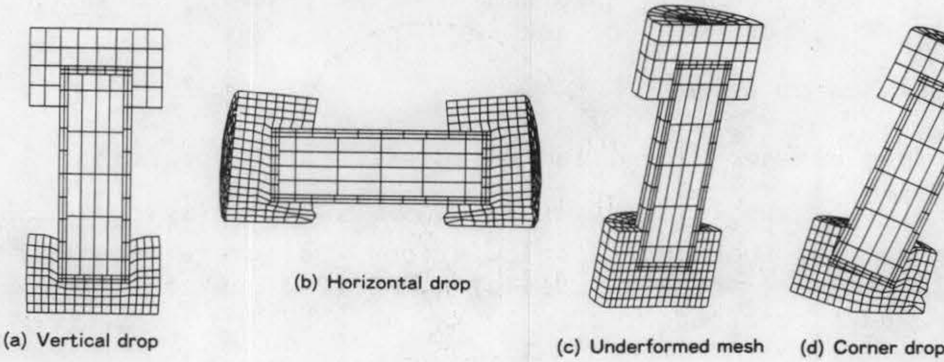

Fig. 5 Deformed shape after 9m drop impact (NUPAC 125B cask 1/4 scale model)

Figure 5 is the deformed shape of the cask after 9m drop impact to obtained by the detailed computer program DYNA3D. The comparison among the results obtained by the experiments, the simplified computer programs CRUSH and CASH-II and the detailed computer program DYNA3D is shown in Table 1. The relation among the oblique angle, the acceleration and deformation obtained by CRUSH are shown in Figs. 6 and 7. According to Table 1 and Figs. 6 and 7, the results by the simplified computer programs CRUSH and CASH-II agree with both the experimental results and that of the results of the detailed computer program.

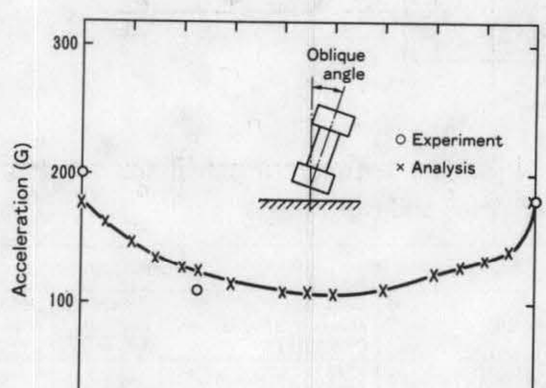

Fig. 6 Comparison between simplified analysis and experiment on acceleration

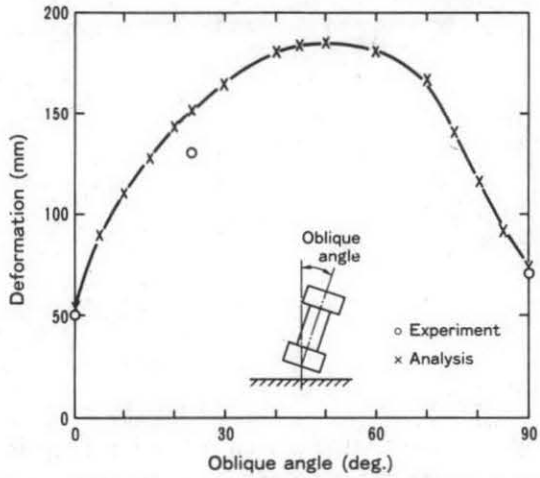

Fig. 7 Comparison between simplified analysis and experiment on deformation

The comparison between the results obtained by the simplified computer programs and the experimental results of various casks with respect to the acceleration and the deformation are shown in Figs. 8 and 9. It is clear that the CRUSH and CASH-II acceleration values multiplied by a constant of 1.2 as a dynamic factor conservatively agree with the experimental results, while the calculated deformations indicate the conservative values suitable for designing safer shock absorbers.

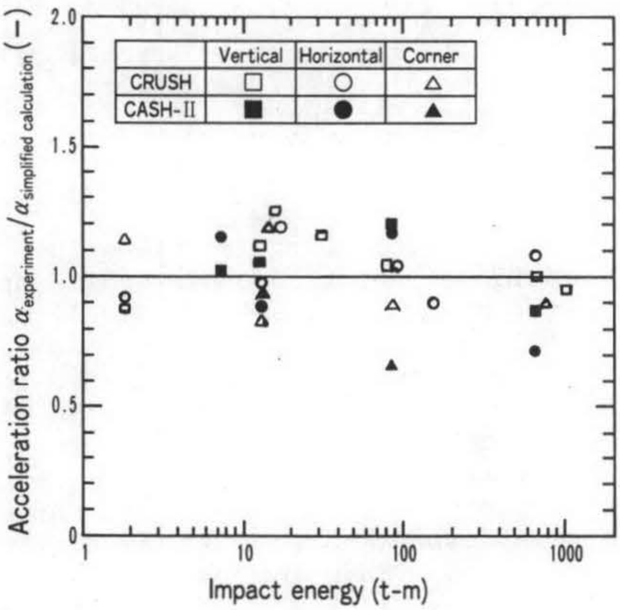

Fig. 8 Comparison detween simplified calculation and experiment on impact acceleration.

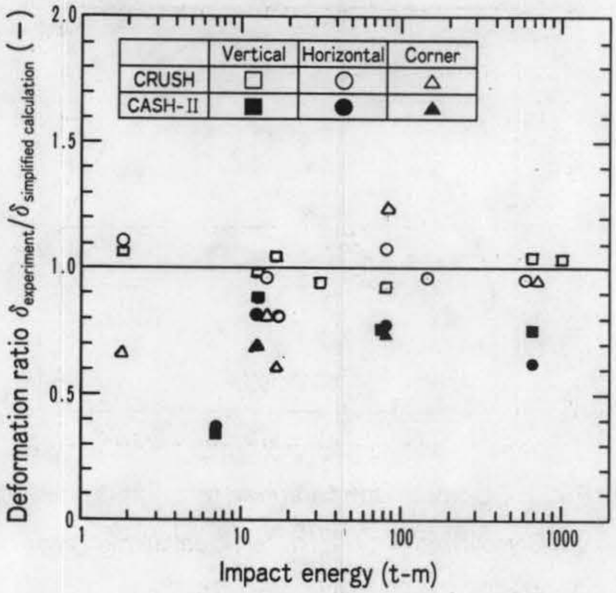

Fig. 9 Comparison between simplified calculation and experiment on shock absorber deformation.

Comparison between Detailed Calculation and Experiment

The comparison between the results obtained by the detailed computer programs (DYNA2D, DYNA3D) and the experimental results of the cask drop tests are shown in Figs. 10 and 11. These figures indicate that the results by the detailed computer programs fall within nearly the same deviation range as that of the simplified computer programs.

CONCLUSIONS

In regard to the evaluation of the acceleration of cask body and the deformation of shock absorber on the drop impact, two simplified computer programs CRUSH and CASH-II make to analyze economical and by shortening input and calculation time to about 1/50 or less as compared with other detailed computer programs to analyze dynamic interactions. The results obtained by the simplified computer programs have an enough adequacy for their practical use, and can be effectively used by multiplying safer (dynamic) factors which have been determined based on the previous extensive experiments and comparative studies with other computer programs. CRUSH and CASH-II are further being utilized satisfactorily in safety analysis and designing not only spent fuel transport casks but also those for various radioactive transport casks.

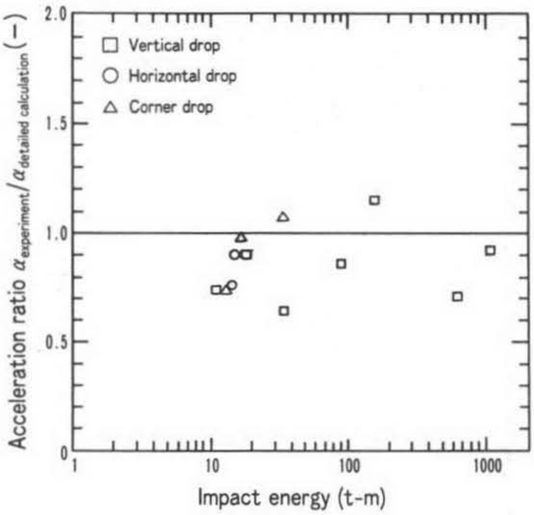

Fig.10 Comparison between detailed calculation and experiment on impact acceleration.

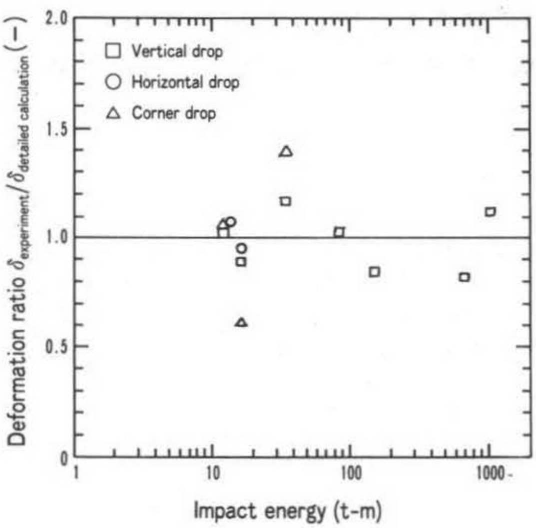

Fig.11 Comparison between detailed calculation and experiment on shock absorber deformation.

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