Simplified Computer Codes for Cask Impact Analysis

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INTRODUCTION

Shipping casks for radioactive materials are regulatively required to maintain their integrity against the tests where they are dropped onto unyielding surfaces from the determined heights and puncture tests and so on. Analyses of those tests have been carried out using detailed computer codes (such as DYNA2D, DYNA3D, HONDO and PISCES) or simplified computer codes.

Detailed computer codes are suitable for comparing experimental data with analytical results. Simplified computer codes are suitable for design and safety analysis by performing parametric studies.

As mentioned above in safety analysis of cask impacts, four kinds of simplified computer codes as shown in Fig. 1 have been developed in the Japan Atomic Energy Research Institute. They are going to be used for safety analysis of storage casks in the Nuclear Power Engineering Corporation.

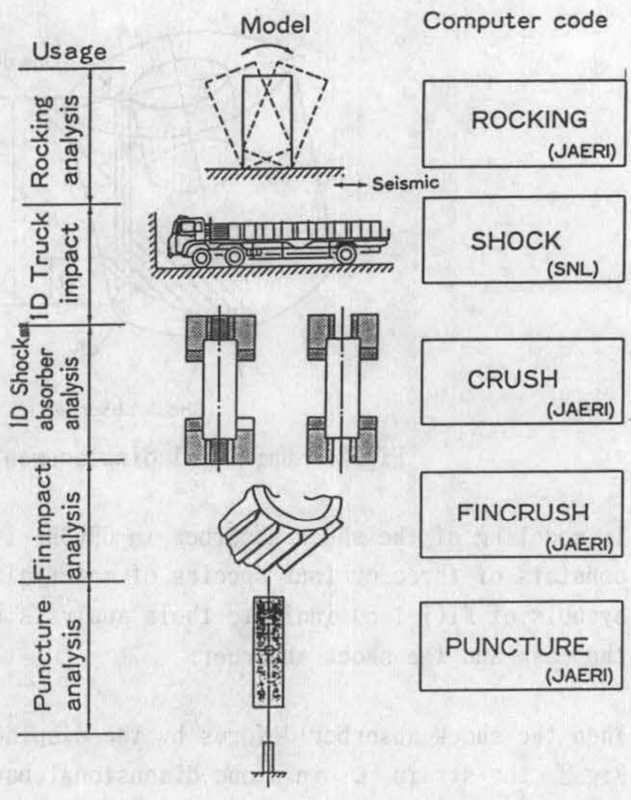

Fig. 1. Simplified analysis computer codes

CRUSH and CRUSH2

The computer code CRUSH is to analyze the accelerations of a cask body and the displacements of a shock absorber statistically for drop impact analysis. CRUSH2 is a revised version of CRUSH which adds stiffness effects of a shock absorber overpack. Calculation method of CRUSH and CRUSH2 are based on a Uni-axial Displacement Method(UDM). Conventionally, the VDM(Volumetric Displacement Method) 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 the material properties, the VDM would have a bit problem in the view of the accuracy of solutions.

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 volumes of the shock absorber can absorb the drop energy.

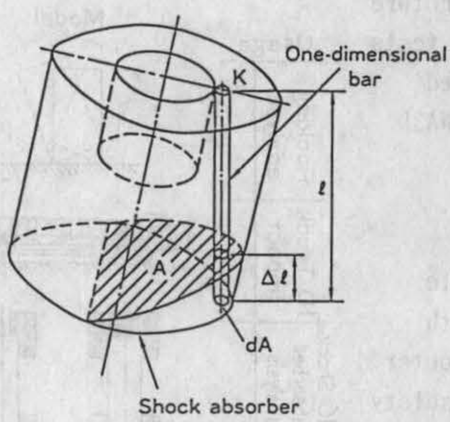

Fig. 2. Uni-axial displacement method

In modeling of the shock absorber in CRUSH, it is assumed that the shock absorber consists of three or four species of materials as shown in Fig. 3. In the figure, the symbols of Ki(i=1~5) indicate their analysis regions determined by the geometries of the cask and the shock absorber.

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

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

The force f of the one-dimensional bar is

$$f = K\,\sigma(\varepsilon)\,dA\ .$$

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

$$F = \int_A f\,dA\ .$$

The dissipated energy $E(\delta)$ can also be obtained by using an eqation similar to the above :

$$E(\delta) = \int_0^{\delta} F\,d\ell\ .$$

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

$$E(\delta) = \gamma\cdot W\cdot H \quad \text{and}$$

$$\alpha = F(\delta)/M$$

where γ is the 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.

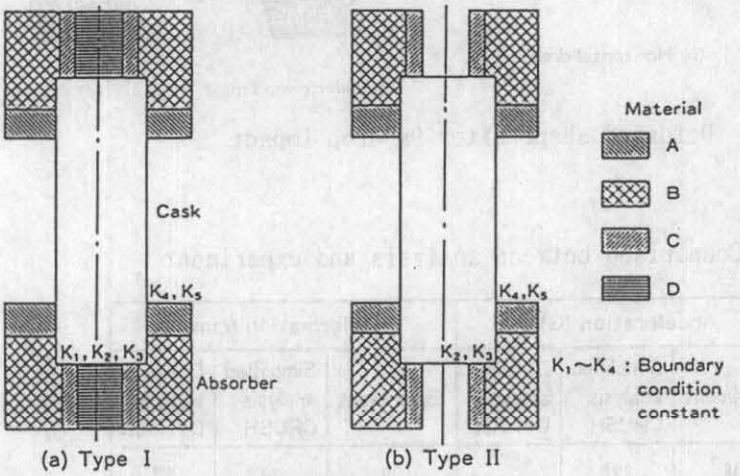

Fig. 3. Vertical drop model

In order to demenstrate the adequacy of the simplified computer code, benchmark calculations using the experimental results of the 1/3 scale PIE (Post Irradiation Experiment) cask as shown in Fig. 4 have been performed.

The relation among the results obtained by experiments, the simplified computer code CRUSH and the detailed computer code DYNA3D are shown in Fig. 5 and Table 1. The results obtained by use of CRUSH agree with both the experiments and the results of DYNA3D.

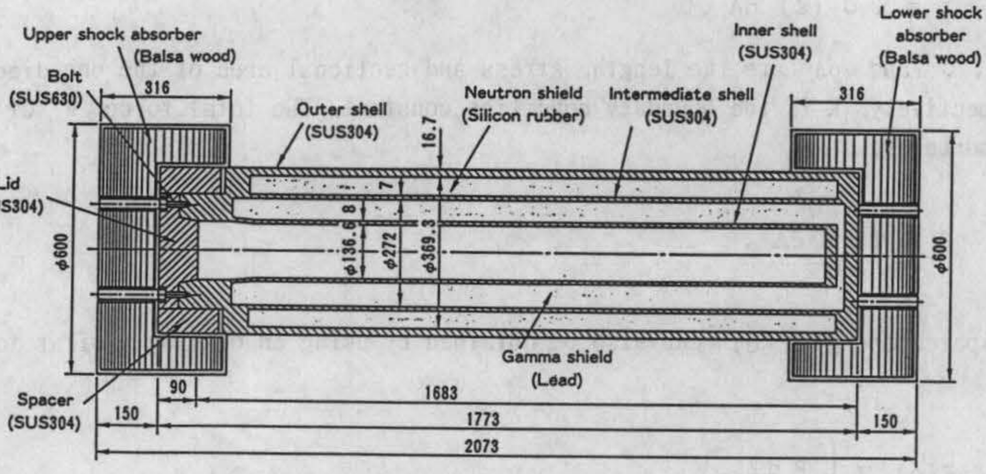

Fig. 4 Shipping cask for PIE(1/3 scale model)

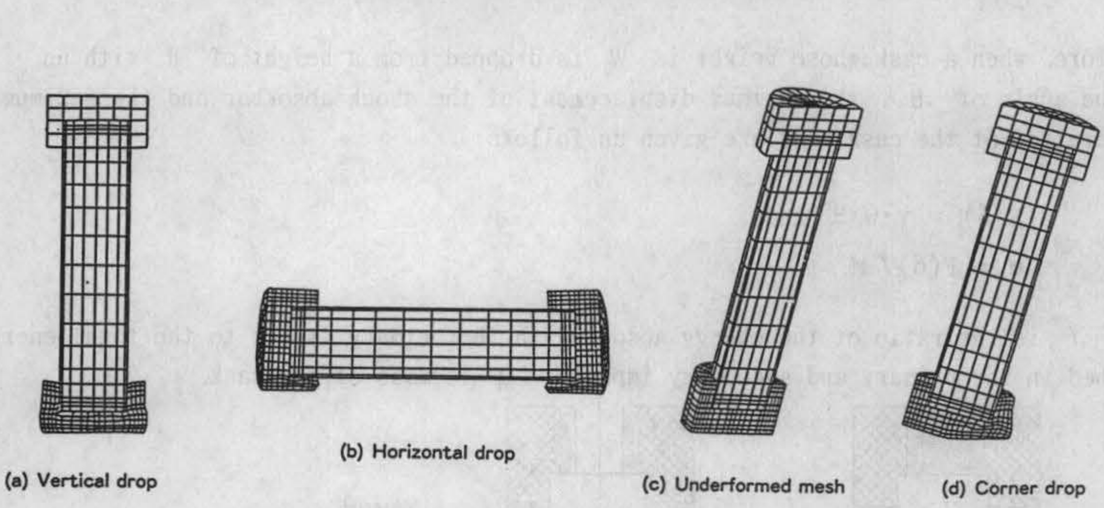

Fig. 5 Deformed shape after 9m drop impact

Table 1 Comparison between analysis and experiment

Attitude	Acceleration (G)			Deformation (mm)		
	Experiment	Simplified analysis CRUSH	Detailed analysis DYNA3D	Experiment	Simplified analysis CRUSH	Detailed analysis DYNA3D
Vertical	408	326	457* (335)**	29	28	27
Corner	259	218	261 (140)	51	85	84
Horizontal	417	353	459 (331)	24	30	25

* Value of low pass filter is 600 Hz.

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

PUNCTURE

The computer code PUNCTURE is to analyze statically the acceleration and displacement of a cask body or a shock absorber for dropping the cask onto a round steel bar.

When the cask is dropped onto a mild steel bar in a puncture test, the kinematic energy of the cask is absorbed into deformations of both the cask body and the mild steel bar, provided the puncture does not occur. The deformation generated on the cask body can be evaluated based on the fact that loads generated on the cask and the mild steel bar are equal to each other. In this evaluation, the plastic theory of bending of a circular plate having a multi-layer construction(e.g., steel-lead-steel) is used, which has been developed by extending Onat's theory.

When a distributed load is applied to a three-layer circular plate rigidly clamped at its edges as shown in Fig. 6, the relationship between the center displacement and the load can be given by

$$P^* = \begin{cases} 1 + \alpha_1 U + \alpha_2 U^2 & U \leq U^* \\ \beta_1 + \beta_2 U + \beta_3 / U & U \geq U^* \end{cases}$$

where

P* : P/Pℓ
U : δ/t*
U* : (1 + ℓn(R/ρ))/2
P : load
Pℓ : limit load
δ : center displacement
t' : equivalent plate thickness
R : radius of the plate
ρ : discontinuity radius of the velocity curvature
a : radius of the loaded area

$$\alpha_1 = \frac{1 + 2\ell_n R/\rho}{(2 + \ell_n R/\rho)(1 + \ell_n R/\rho)}$$

$$\alpha_2 = \frac{2(1 + 3\ell_n R/\rho)}{3(2 + \ell_n R/\rho)(1 + \ell_n R/\rho)^2}$$

$$\beta_1 = \frac{3 + \ell_n R/\rho}{2(2 + \ell_n R/\rho)}$$

$$\beta_2 = \frac{2(1 + 2\ell_n R/\rho)}{(2 + \ell_n R/\rho)(1 + \ell_n R/\rho)}$$

$$\beta_3 = \frac{1 + \ell_n R/\rho)}{12(2 + \ell_n R/\rho)}$$

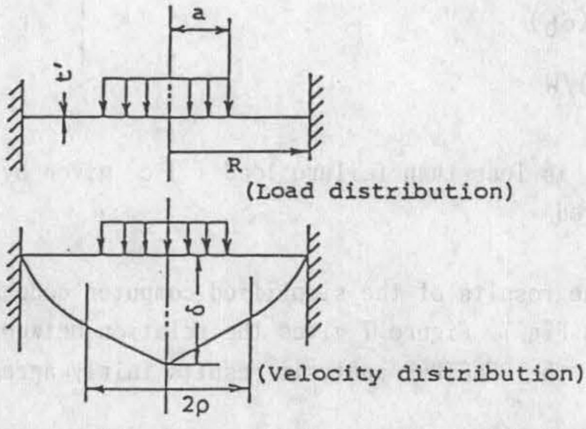

Fig. 6. Analysis model of a multi-layer plate with distributed load

In converting the three-layer plate into an equivalent single layer plate, the equivalent plate thickness t' and equivalent stress σ_f' are related by

$$\left.\begin{aligned} t' &= 4M_p/N_p \\ \sigma_f' &= N_p/t' \end{aligned}\right\}$$

where

M_p : section yield moment of the 3-layer plate (per unit width)
N_p : section yield load of the 3-layer plate (per unit width)

On an assumption that the plug failure occurs in the three layers, the failure load Pc is given by

$$P_c \geq \pi d\,(\tau_1 t_1 + \tau_2 t_2 + \tau_3 t_3)$$

where

d : diameter of the mild steel bar
t_1, t_2, t_3 : plate thickness of each layer
τ_1, τ_2, τ_3 : failure shear stress in each layer

Now the relation between the load Pb and the displacement δ_b of the mild steel bar is assumed to be

$$Pb = Pb(\delta_b)$$

In the case when the cask whose weight is W is dropped from a height of H onto the mild steel bar, the maximum displacement of the cask δ^*, that of the bar δ^*_b and the maximum acceleration of the cask G^* are given by

$$\left.\begin{aligned} W \cdot H &= \int_0^{\delta^*} P(\delta)\,d\delta + \int_0^{\delta_b^*} P_b(\delta_b)\,d\delta_b \\ P(\delta) &= P_b(\delta_b) \\ G^* &= P(\delta^*)/W \end{aligned}\right\}$$

If the value of $P(\delta^*)$ is less than failure load Pc given by the above equation, the cask is not punctured.

A comparison between the results of the simplified computer code PUNCTURE and the LLNL experiments is shown in Fig. 7. Figure 7 gives the relation between the load and displacement. As shown above, the PUNCTURE analysis results fairly agree with those from the LLNL experiments.

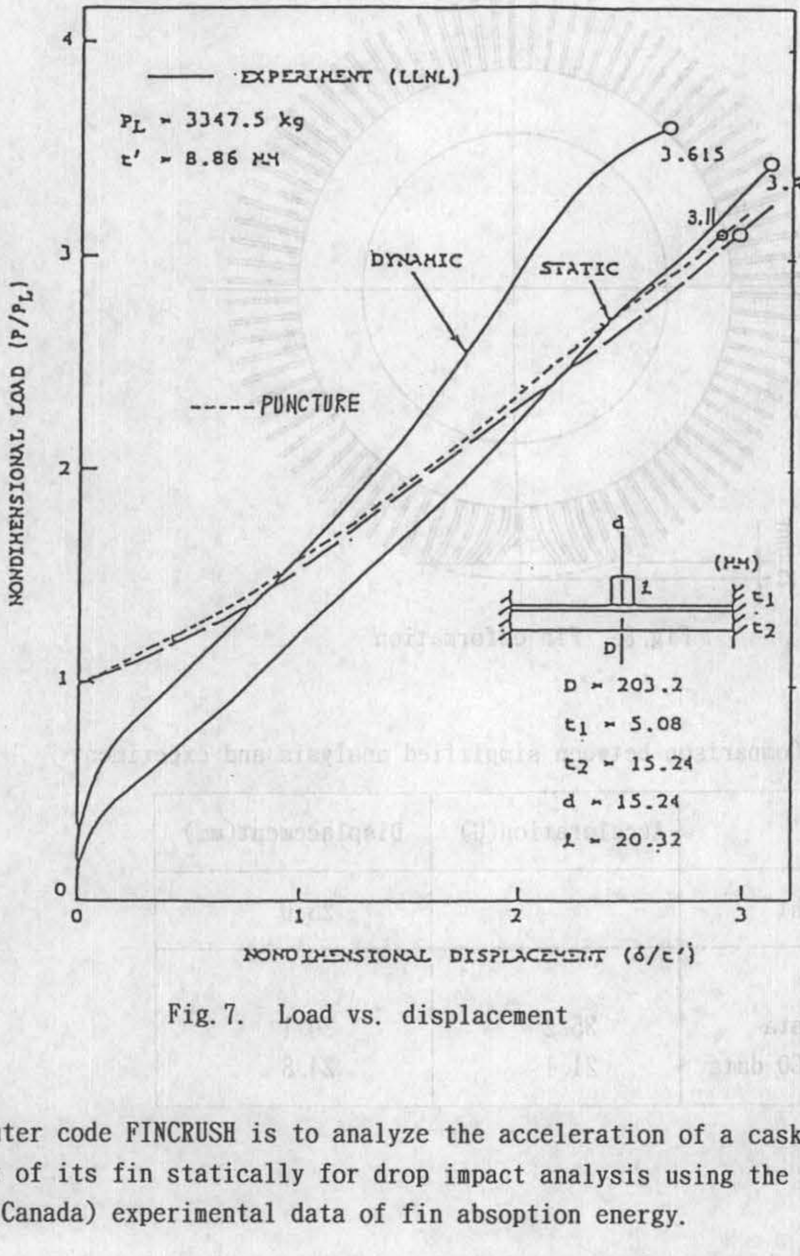

Fig. 7. Load vs. displacement

FINCRUSH

The computer code FINCRUSH is to analyze the acceleration of a cask body and the displacement of its fin statically for drop impact analysis using the ORNL(USA) and MONSERCO(Canada) experimental data of fin absoption energy.

A comparison between the FINCRUSH analysis and the JAERI experiments is shown in Fig. 8 and Table 2. Table 2 gives the maximum acceleration of a cask body and the maximum displacement of fin. As shown above, the FINCRUSH analysis results fairly agree with these from the JAERI experiments. Differences between the ORNL data and the MONSERCO data are shown in Table 2.

ROCKING

The computer code ROCKING is to analyze the dynamic response and tip over under seismic disturbance for storage casks.

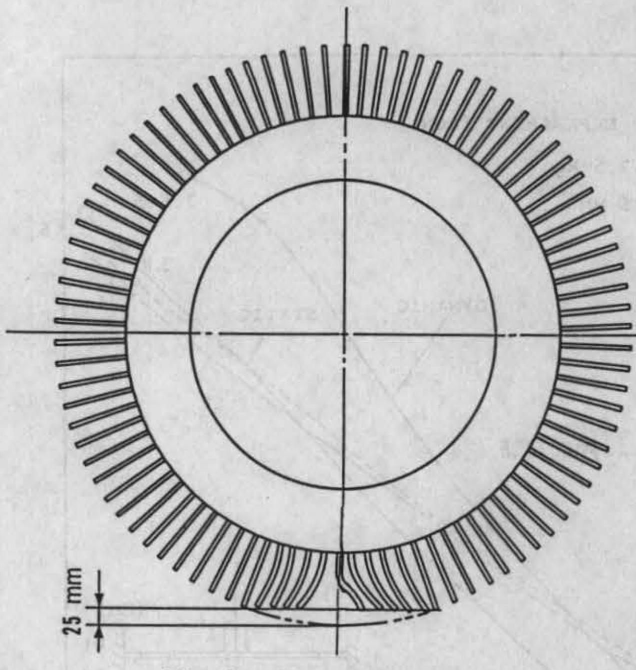

Fig. 8. Fin deformation

Table 2. Comparison between simplified analysis and experiment

	Acceleration(G)	Displacement(mm)
Experiment	–	25.0
Analysis		
ORNL data	25.2	20.1
MONSERCO data	21.1	24.8

CONCLUSIONS

In regard to the evaluation of the acceleration and deformation of casks, the simplified computer codes make analyses economical and decrease input and calculation time. The results obtained by the simplified computer codes have enough adequacy for their practical use.

REFERENCES

Larder, R. A. and Arther, D., 1978, UCRL-52638.
Onat, E. T. and Haythornthwaite, R. M., 1955, ASME J. Appl. Mech. Vol. 23.