Computer Code System for Structural Analysis of Radioactive Materials Transport

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INTRODUCTION

The integrity requirements for transportation and/or storage casks of radioactive materials are defined by Competent Authority(such as domestic regulatory body). Compliance with the integrity requirements of casks shall be demonstrate either by experiments or by analyses. To meet the requirement many computer codes have been develped by research institutes and private companies.

A computer code system CASKET for structural analysis of radioactive material transportation and/or storage casks has been developed by Japan Atomic Energy Research Institute. In order to clarify the accuracy of CASKET, calculation results are compared with experimental results. A part of the CASKET code system has been already reported in PATRAM'92. The present paper is the sequel of the PATRAM'92 paper.

CASKET CODE SYSTEM

The CASKET code system, as shown in Figure 1 consists of four codes and three data libraries, which are drop impact, fin crush, puncture and rocking analysis codes and structural data, fin impact energy absoption data and thermal analysis data libraries. We reported the drop impact analysis, the fin crush analysis and the puncture analysis codes at the previous conference(PATRAM'92) [1]. In this paper we describe the rocking code and its benchmark analyses and the data libraries.

ROCKING CODE

Calculation Model

In the computer code ROCKING, the following two-dimensional model is considered:

(1) a cask is modeled as a rigid body;
(2) the cask has three degrees-of-freedom, two translational displacements, and one rotation around the cask center of gravity;
(3) impact forces are represented by a spring and dashpot model located at impact points;
(4) friction force due to surface sliding between the cask and floor is represented by a non-linear Coulomb element; and
(5) forces of wire ropes work against only as tensile loads.

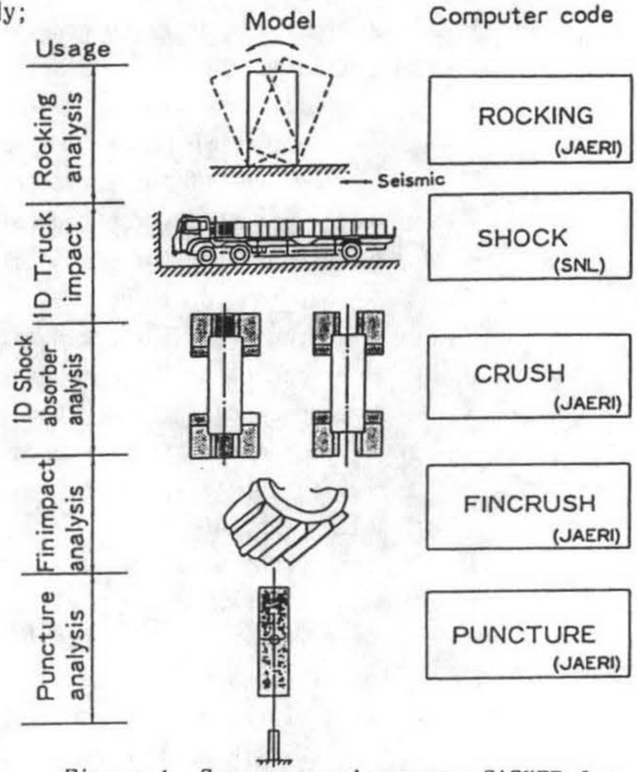


Figure 1 Computer code system CASKET for structural analysis of cask.

Equation of Governing Motion

Let the coordinate system be chosen as shown in Figure 2. The cask has two translational coordinates, ξ and η, and one rotational coordinate θ. Figure 3 shows the forces and moments that act upon the cask. The equations of motion may be written as:

$$m\ddot{\xi} = -m\alpha_{\xi} + F_{\xi A} + F_{\xi B} + F_{\xi C} + F_{\xi D} + R_{\xi} + F_F \quad (1)$$

$$F_{\eta A} + F_{\eta B} + F_{\eta C} + F_{\eta D} = 0 \quad (2)$$

$$m\ddot{z} = -m(\alpha_z + g) + F_{zA} + F_{zB} + F_{zC} + F_{zD} + R_z \quad (3)$$

$$M_{\xi A} + M_{\xi B} + M_{\xi C} + M_{\xi D} = 0 \quad (4)$$

$$I\ddot{\theta} = M_{\eta A} + M_{\eta B} + M_{\eta C} + M_{\eta D} + M_{R\xi} + M_{Rz} + M_F \quad (5)$$

$$M_{zA} + M_{zB} + M_{zC} + M_{zD} = 0 \quad (6)$$

where

a : cask rocking spring half width,
b : radius of cask bottom,
d : cask outer radius,
F_F : friction force between cask and floor,
F_z : z-component of force,
F_{zA} : z-component of force generated by wire rope A,

F_{zB} : z -component of force generated by wire rope B,
F_{zC} : z -component of force generated by wire rope C,
F_{zD} : z -component of force generated by wire rope D,
F_{η} : η -component of force,
$F_{\eta A}$: η -component of force generated by wire rope A,
$F_{\eta B}$: η -component of force generated by wire rope B,
$F_{\eta C}$: η -component of force generated by wire rope C,
$F_{\eta D}$: η -component of force generated by wire rope D,
F_{ξ} : ξ -component of force,
$F_{\xi A}$: ξ -component of force generated by wire rope A,
$F_{\xi B}$: ξ -component of force generated by wire rope B,
$F_{\xi C}$: ξ -component of force generated by wire rope C,
$F_{\xi D}$: ξ -component of force generated by wire rope D,
g : gravity constant,
h : half height of cask,
I : mass moment of inertia,
m : mass of cask,
M : moment generated by force F ,
R_z : impact force of z -direction,
R_{ξ} : impact force of ξ -direction,
z : z-coordinate or z -direction displacement,
α_z : vertical floor acceleration,
α_{ξ} : horizontal floor acceleration,
η : η -coordinate or η -direction displacement,
θ : rotational angle,
ν : velocity,
ξ : ξ -coordinate or ξ -direction displacement,
$(\dot{\ }), (\ddot{\ })$: dots denotes time derivatives of ( ).

Friction Force between Cask and Floor and Its Associated Moment

The friction force due to surface sliding is represented by a nonlinear Coulomb element. The equations for the friction force F_F and its associated moment M_F acting on the cask are as follows.

$$F_F = -\mathrm{sign}(\nu)F(\nu) , \tag{7}$$

$$M_F = F_F(-h \cdot \cos\theta - b \cdot \sin\theta) , \tag{8}$$

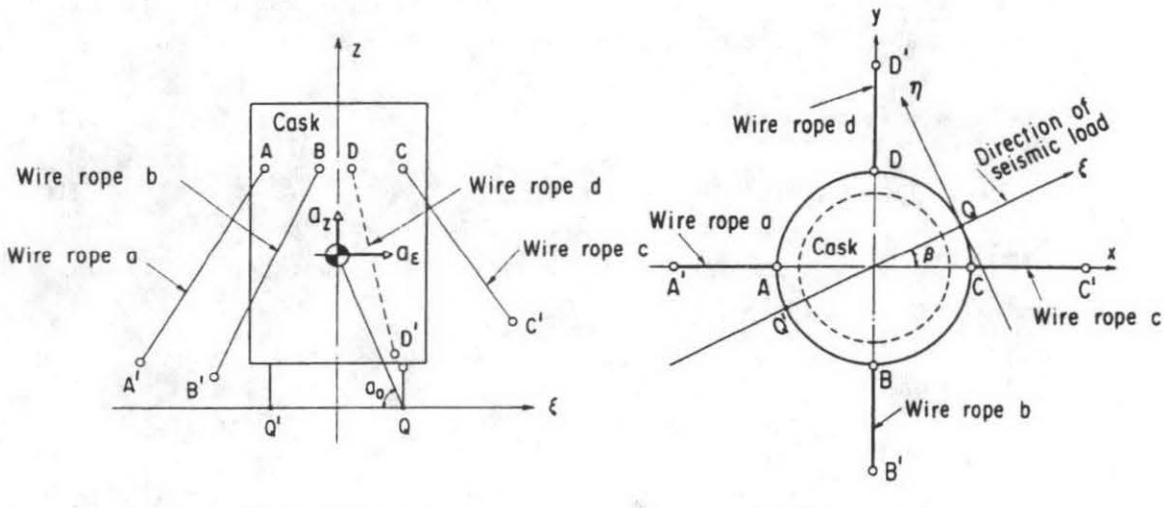
where

$$\nu = \dot{\xi} - (h \cdot \cos\theta + b \cdot \sin\theta)\,\dot{\theta} - \dot{\xi}_0. \tag{9}$$

Where $\dot{\xi}$ and $\dot{\xi}_0$ are horizontal velocity of the center of gravity and support floor, respectively. $F(\nu)$ is a prescribed function for the friction characteristics which are related to the vertical contact force and the coefficients of both statical and dynamical friction.

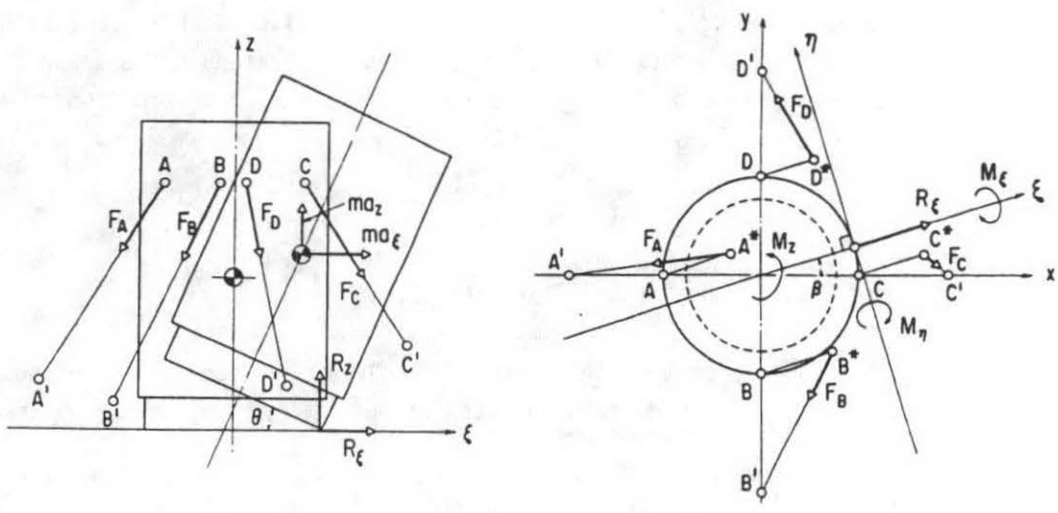
$$F(\nu) = m \cdot g(\mu_d + \mu_s), \tag{10}$$

Where μ_d and μ_s are the coefficients of dynamical amd statical frictions, respectively.



(a) Vertical view (b) Plan view

Figure 2 Coordinate system.



(a) Vertical view (b) Plan view

Figure 3 Forces and moments acting on a cask.

Vertical Impact Force and Its Associated Moment

The force acting on the interface between the cask and the floor is derived in the term of deformation of a spring dashpot unit. When the gap is closing, the spring deformation γ and its time rate $\dot{\gamma}$ are

$$\gamma = 0.5(z_o - \{z + h(1 - \cos\theta) - b \cdot \sin\theta\}) , \tag{11}$$

$$\dot{\gamma} = 0.5 [\dot{z}_o - \{\dot{z} + h \cdot \sin\theta - b \cdot \cos\theta\} \dot{\theta}] , \tag{12}$$

where b is the cask rocking spring half width. z_o and $\dot{z}_o$ are the vertical displacement and velocity of the floor, respectively. The vertical impact force R_z and its associated moment M_{Rz} acting on the cask are as follows. If $\gamma > 0$

$$R_z = -(K_z \cdot \gamma + C_z \cdot \dot{\gamma}) , \tag{13}$$

$$M_{Rz} = -R_z (h \cdot \cos\theta - a \cdot \sin\theta) . \tag{14}$$

where K_z and C_z are the vertical boundary spring and damping coefficients, respectively. If $\gamma \leqq 0$

$$R_z = 0, \tag{15}$$

$$M_{Rz} = 0. \tag{16}$$

Lower Corner Impact Force and Its Associated Moment

The force acting on the cask lower corner as a results of the impact is derived by deformation of a spring dashpot unit, which is located on the lower corner of the cask. During impact against the lower corner, spring deformation τ and its time rate $\dot{\tau}$ of the cask are follows.

$$\tau = \xi + h \cdot \sin\theta - b(1 - \cos\theta) - \xi_o - \delta, \tag{17}$$

$$\dot{\tau} = \dot{\xi} + (h \cdot \cos\theta - b \cdot \sin\theta) \dot{\theta} - \dot{\xi}_o , \tag{18}$$

where δ is the gap between the cask and its lower boundary wall. The boundary wall impact force R_ℓ and its associated moment $M_{R\ell}$ acting on the cask are as follows. If $\tau > 0$

$$R_\ell = -(K_\ell \cdot \tau + C_\ell \cdot \dot{\tau}) , \tag{19}$$

$$M_{R\ell} = R_\ell (h \cdot \cos\theta - b \cdot \sin\theta) , \tag{20}$$

where K_ℓ and C_ℓ are the horizontal boundary spring and damping coefficients, respectively. If $\tau \leqq 0$

$$R_\ell = 0, \quad (21)$$

$$M_{R\ell} = 0. \quad (22)$$

Force Due to Wire Rope

A tensile force due to a wire rope is as follows:

$$F = \sigma \cdot A, \quad (23)$$

where

F : tensile force of wire rope,

σ : tensile stress of wire rope,

$$\sigma = E \cdot \Delta L / L, \quad (24)$$

A : sectional area of wire rope,

E : Young's modulus,

ΔL : elongation of wire rope,

L : wire rope length.

Benchmark Test

To demonstrate the adequacy of ROCKING code, benchmark calculations using experimental results(carried out in Central Research Institute of Electric Power Industry)[2] of a 1/3 scale model of spent fuel cask as shown in Figure 4 have been performed.

The rocking analysis of the model cask was performed under constant sinusoidal excitation. Figure 5 shows the maximum rotational angles in comparison with the experimental results. According to Figure 5, analytical results of ROCKING code agree with the experimental ones.

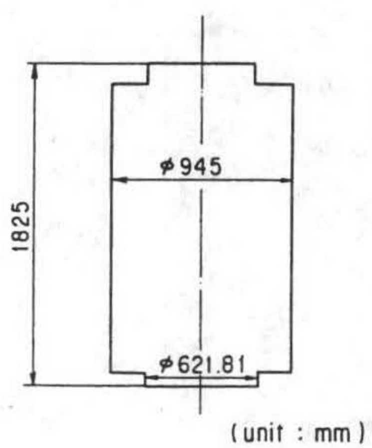


Figure 4 Analysis model.

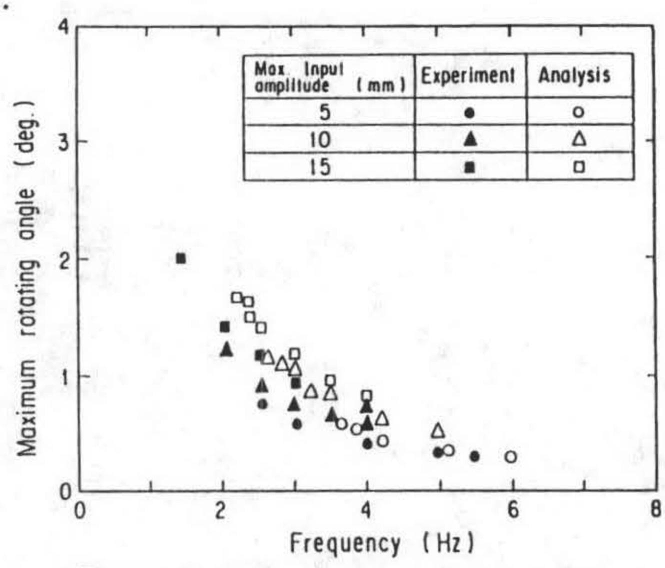


Figure 5 Maximum rotating angie response.

Figure 6 shows cask rocking motion at 3 Hz sinusoidal excitation.

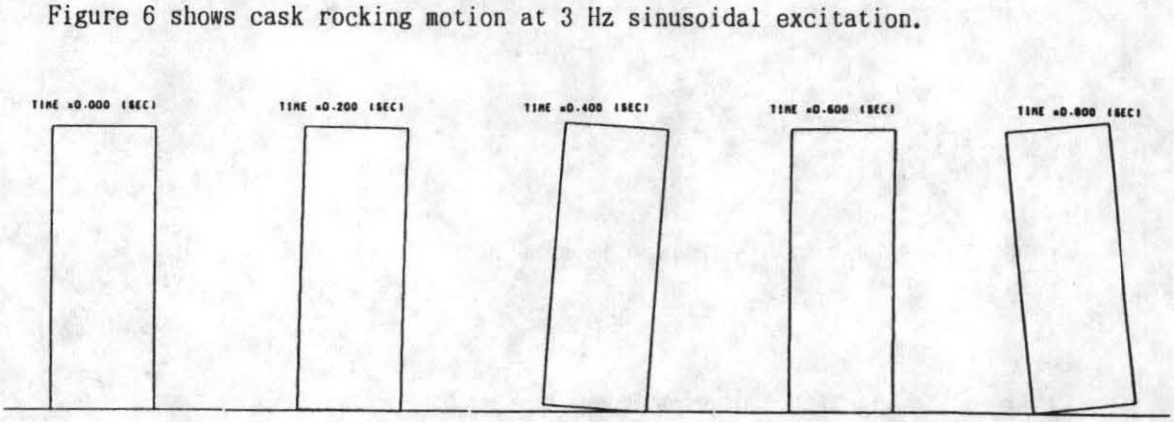


Fig. 6 Cask rocking motion.

STRUCTURAL DATA LIBRARY

Four kinds of material data: mild steel, stainless steel, lead, and wood are stored. These materials are main structural elements of casks. Structural data, such as the coefficient of thermal expansion, the modulus of longtudinal elasticity, the modulus of transverse elasticity, the Poisson's ratio, and stress-strain relationship, have been tabulated against temperature or strain rate. Figure 7 shows a typical example of stress-strain curves of a mild steel which depends on strain and strain-rate.

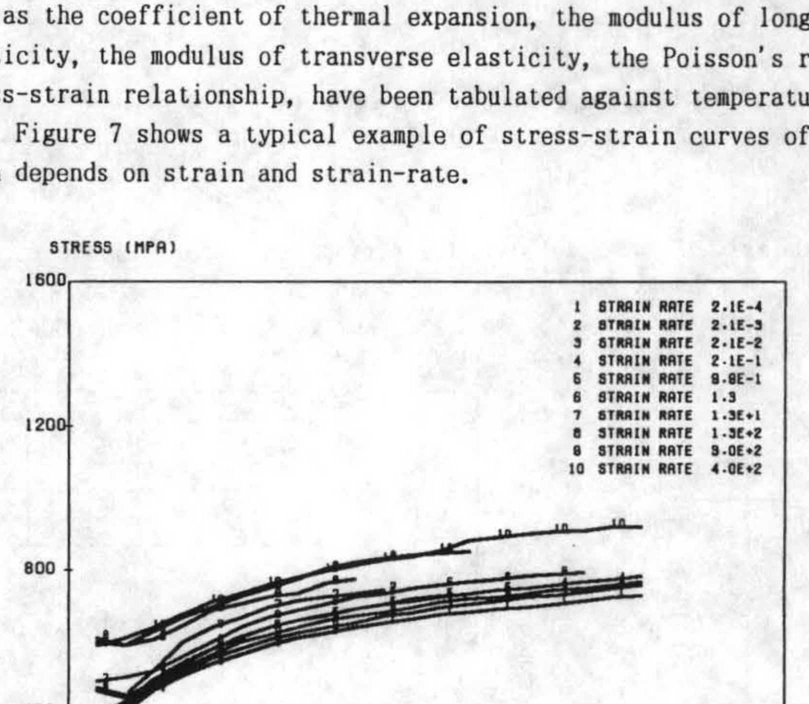


Figure 7 Stress-strain curve of mild steel.

FIN DATA LIBRARY

Two kinds of fin energy absorption data, ORNL data (data obtained by Oak Ridge National Laboratory in USA) and MONSERCO data (MONSER Co. in Canada) are stored in the library. Figure 8 shows a typical example of fin energy absorption data compared with ORNL data and MONSERCO data.

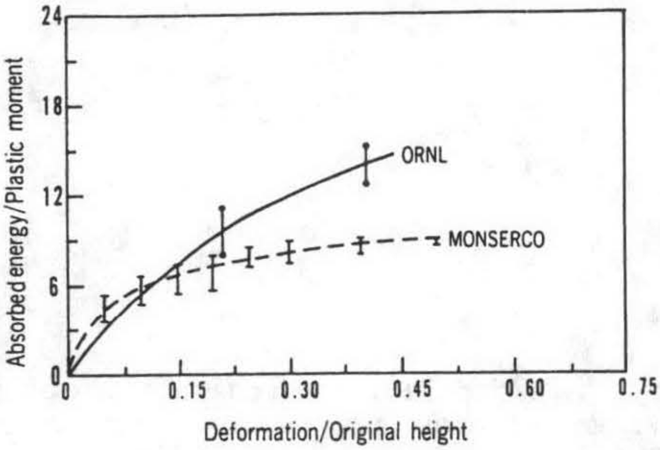


Figure 8 Absorbed energy vs. deformation ratio.

THERMAL ANALYSIS DATA LIBRARY

More than 1000 data are stored in the thermal analysis data library. Thermal analysis data, heat conductivity, heat capacity, density, melting point, latent heat and so on have been tabulated.

CONCLUSIONS

A computer code system for cask structural analyses has been developed. Validity tests for the code system CASKET has been performed using the experimental results. Good agreement was obtained between analytical and experimental results.

REFERENCES

(1) Ikushima, T.,et al., *Simplified Computer Codes for Cask Impact Analysis,* 10th International Conference on the Packaging and Transportation of Radioactive Materials, pp.1419-1426, Japan (1992).

(2) Shirai, K., Ito, C. and Ryu, H., *Development of Seismic Response Analysis Code of Cask,* 10th International Conference on the Packaging and Transportation of Radioactive Materials, pp.1427-1434, Japan (1992).