THE COMPUTER CODE SYSTEM CASKETSS FOR THERMAL AND STRUCTURAL ANALYSIS OF PACKAGINGS AND ITS APPLICATIONS

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Abstract

THE COMPUTER CODE SYSTEM CASKETSS FOR THERMAL AND STRUCTURAL ANALYSIS OF PACKAGINGS AND ITS APPLICATIONS.

The paper describes CASKETSS, a modular program system that can be used in packaging evaluation systems when conducting thermal and structural safety analyses. CASKETSS has been developed as an easy to use computer program system and is automated to perform input data preparation and to display graphically the calculation results. The module programs, except the data generation and graphical representation programs, are vectorized in order to save computer time.

1. INTRODUCTION

This paper describes CASKETSS, a modular program system for packaging evaluation program systems for carrying out thermal and structural safety analyses. The main feature of CASKETSS is that it is a system that combines the finite difference, the finite element and the Monte Carlo methods. CASKETSS has been developed as an easy to use computer program system and is automated to perform input data preparation and to display graphically the calculation results. Standardized materials properties, such as thermal and mechanical properties, can also be prepared. The module programs, except the data generation and graphical representation programs, are vectorized in order to save computer time.

In this paper, the methods employed at the Japan Atomic Energy Research Institute (JAERI) to analyse the thermal and structural responses of nuclear material packagings to regulatory and accident environments are described. Four areas are detailed: (1) a pre-processing program used to construct the finite element and the finite difference models of packagings; (2) thermal and structural analysis programs using the finite element, the finite difference and the Monte Carlo methods; (3) a post-processing program for graphical representation and stress evaluation of the calculation results; (4) benchmark calculation results.

The CASKETSS system has been evaluated using such benchmark calculations as fire, truck-impact and drop-impact tests using nuclear fuel packagings. The purposes of the benchmark calculations were to confirm the adequacy of the programs and to ascertain the effect of the material data on the calculations.

The benchmark fire test consisted of an 800°C, 30 min fire, using a ¼-scale model of a spent nuclear fuel packaging. The truck-impact test consisted of a truck, loaded with UO_2 powder packagings, involved in a 50 km/h impact with an unyielding surface. The benchmark drop-impact test consisted of a 9 m drop of a ⅓-scale model of a spent nuclear fuel packaging onto an unyielding surface under various impact conditions, such as vertical, horizontal and corner drops. The calculation results are in good agreement with the experimental data. Another objective of the analysis was to assess the effect of the strain rate of the packaging materials, such as austenitic stainless and carbon steels.

2. PRE-PROCESSING

Input data generation for the finite element and the finite difference models is time consuming and prone to errors. There are two functions of the pre-processing of the computer program, as shown in Fig. 1. The first is model construction (input

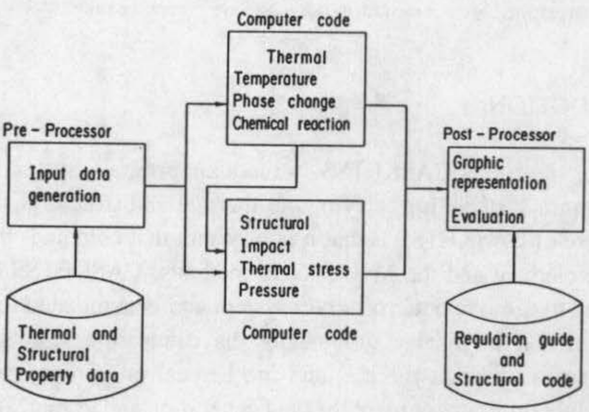

FIG. 1. CASKETSS code system.

data generation), while the second is preparation of material data for analysis objects. The pre-processing computer program PRE-CASKETSS is an interactive, or batch mode, input data generator that provides many features to the analyst. PRE-CASKETSS has three phases: phase-I (two dimensional mesh generation); phase-II (data preparation for packaging material properties); phase-III (generating three-dimensional model data from a two-dimensional model). Input data for the finite difference model are from the finite element model. The materials data library used for the thermal analysis is the standard data library attached to the TRUMP program [1], while the materials data library for structural analysis has been developed at JAERI.

3. COMPUTER PROGRAMS FOR THERMAL ANALYSIS

3.1. Computer programs

The thermal analysis computer programs TRUMP and HEATING6 [2] from Oak Ridge National Laboratory were used. Certain modifications to the programs were made at JAERI, as shown in Table I.

3.2. Finite difference programs

TRUMP and HEATING6 are based on the finite difference method, since finite difference programs are faster than those based on the finite element model. Nevertheless, calculations of a three-dimensional model need much more computer time than a two-dimensional model. Thus TRUMP and HEATING6 were modified to vectorized programs and are currently used in vectorized form for execution on the FACOM VP-100 computer system.

3.3. Monte Carlo method

The Monte Carlo method is used to calculate the heat transfer of dry-type casks.

4. PROGRAMS FOR STRUCTURAL ANALYSIS

4.1 Computer programs

Programs for structural analysis, such as DYNA2D [3], DYNA3D [4], IMPAC2 [5], SHOCK [6] and SAP-IV [7], were introduced from Lawrence Livermore National Laboratory, Los Alamos National Laboratory, Sandia National Laboratories and the University of California. Some modifications were made at JAERI, as shown in Table I.

TABLE I. THE CASKETSS PROGRAM SYSTEM FOR THERMAL AND STRUCTURAL ANALYSIS AND PRE- AND POST-PROCESSING

Use	Thermal analysis JAERI version (modify from original program)
Thermal analysis program	CASKETSS-TRUMP Vectorized program for FACOM VP-100 Variable memory allocation Finned geometry option Generalized tabulated data handling for temperature and time dependent material properties Coupled to stress analysis program SAP-IV Coupled to pre-processing program for input data generation Coupled to post-processing program for graphical representation of calculation results
	CASKETSS-HEATING6 Vectorized program for FACOM VP-100 Coupled to stress analysis program SAP-IV Coupled to pre-processing program for input data generation Coupled to post-processing program for graphical representation of calculation results
	Structural analysis
Structural analysis program	CASKETSS-DYNA2D, CASKETSS-DYNA3D Added to treatment of strain and strain rate dependent material data Vectorized program for FACOM VP-100
	CASKETSS-IMPAC2 Added to post-processing program for graphical representation of calculation results
	CASKETSS-SHOCK Added to post-processing program for graphical representation of calculation results
	CASKETSS-SAP-IV Vectorized program for FACOM VP-100
	Pre- and post-processing
Pre-processing program	PRE-CASKETSS Input data generation for finite element and finite difference programs Two- and three-dimensional geometries Material data preparation
Post-processing program	POST-CASKETSS Graphical representation of calculation results for finite element and finite difference programs Colour graphics Two- and three-dimensional geometries

4.2. Non-linear dynamic response analysis

The DYNA2D and DYNA3D programs were used at JAERI to analyse the structural behaviour of nuclear packagings subjected to regulatory conditions. These programs are explicit two- or three-dimensional finite element programs which calculate the large deformation dynamic response of inelastic solids.

4.3. Simplified dynamic response analysis

Impact analysis of a 9 m drop of a three-dimensional cask model consumes a great deal of computer time. In such cases, simplified dynamic analysis programs are useful. For this reason, IMPAC2 and SHOCK were introduced into the CASKETSS program system.

4.4. Linear stress analysis program

The three-dimensional stress analysis program SAP-IV was used for stress analysis under fire-test or water-immersion conditions.

5. POST-PROCESSING PROGRAM

POST-CASKETSS has three modular progams for post-processing of two- and three-dimensional packaging analysis data produced from TRUMP, HEATING6, DYNA2D and DYNA3D. This program permits interactive or batch-mode display in terms of two- or three-dimensional geometries. The drawing capability includes undeformed and deformed model, node and element numbering, hidden line and also includes retention only of the boundary of the model. The user controls the colours used in the display of the model. Live contours on the line drawings and colour fringes on the continuous tone drawings are used. By using the animation capabilities of the program system, a film showing the time dependent behaviour of the model can be obtained.

POST-CASKETSS is used to produce X versus Y or time plots, where X and Y are nodal, element or other quantities selected by the user. Stress, strain and energy versus time plots are produced as results. Variables, such as the principal values of stress and strain effective stress and strain, are evaluated and plotted by the program system.

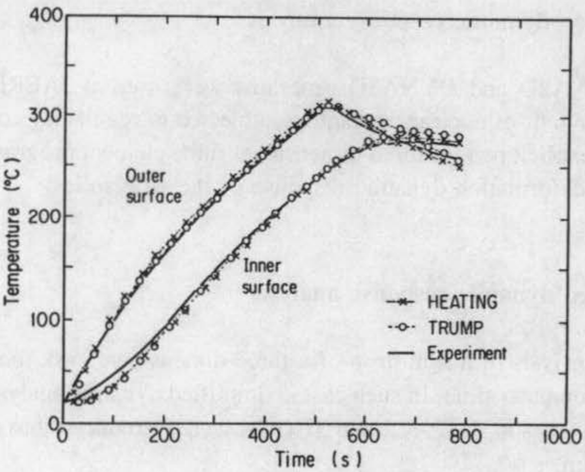

FIG. 2. Comparison of temperature histories among computer codes.

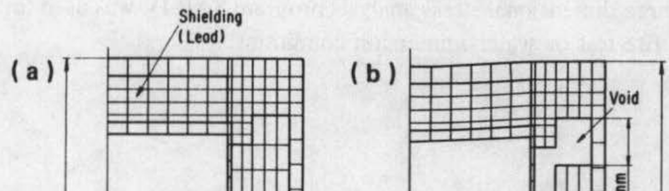

FIG. 3. Comparison between (a) analytical (before impact) and (b) experimental (after impact) results for cask after drop impact.

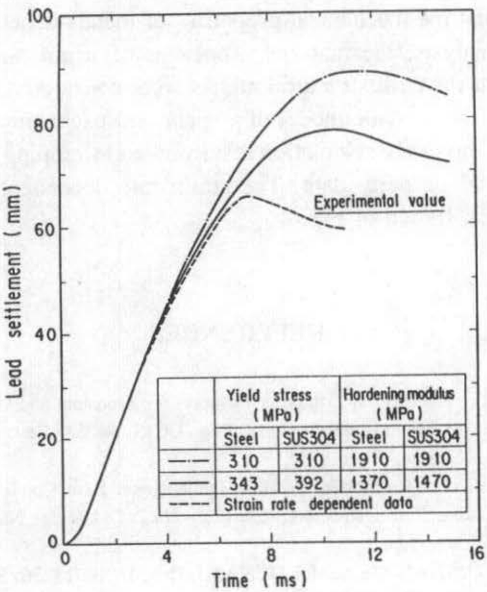

FIG. 4. Effect of materials properties on lead settlement on impact.

6. BENCHMARK CALCULATIONS

6.1. Thermal analysis

The benchmark thermal analysis problem involved a furnace test of a packaging which was conducted by the Fire Defence Research Institute using a ¼-scale model of a spent nuclear fuel packaging. Figure 2 shows analytical results of the temperature histories of the model packaging as compared with the test results. It is concluded from the benchmark results that the TRUMP and HEATING6 programs are able to calculate temperature distribution rapidly and accurately.

6.2. Structural analysis

The benchmark structural analysis test was a 9 m drop test of a ⅓-scale model of lead shielding packagings without shock absorbers. The packaging model used for the drop test was of three-layer sandwich structure, as shown in Fig. 3. Each layer consisted of carbon steel (outer shell), stainless steel (inner shell) and lead shielding (intermediate). The scale model was dropped from a height of 9 m onto a solid, essentially unyielding, surface while in a vertical position.

It is known that the mechanical properties of metals depend on the strain rate. In the drop test analysis, the material properties of strain rate dependent elastic-plastic behaviour of the cask structural metals were considered. Figure 3 shows the deformed shape of the ⅓-scale model of a spent fuel packaging after a 9 m vertical drop test. Figure 4 shows the calculation results of lead slumping compared with variation of the material property data. The strain rate dependent data are useful for accurate analysis, as shown in Fig. 4.

REFERENCES

[1] EDWARDS, A.L., TRUMP: A Computer Program for Transient and Steady-State Temperature Distribution in Multi-Dimensional Systems, Rep. UCRL-14754, Rev. 3, Lawrence Livermore National Lab., Livermore, CA (1972).

[2] ELROD, D.C., et al, HEATING6: A Multi-Dimensional Heat Conduction Analysis of Finite Difference Formation, Rep. ORNL/NUREG/CSD-2/V2, Oak Ridge National Lab., Oak Ridge, TN (1982).

[3] HALLQUIST, J.O, User's Manual for DYNA2D, Rep. UCID-18756, Rev. 1, Lawrence Livermore Lab., Livermore, CA (1982).

[4] HALLQUIST, J.O., User's Manual for DYNA3D and DYNAP, Rep. UCID-19156, Lawrence Livermore Lab., Livermore CA (1981).

[5] KERN, E.A., MERSON, J.L., User's Manual for IMPAC2, Rep. LA-5344-MS, Los Alamos Scientific Lab., Los Alamos, NM (1973)

[6] GABRIELSON, V.K., REESE, R.T., SHOCK Code User's Manual, Rep. SCL-DR-69-98, Sandia National Labs, Livermore, CA (1969).

[7] BATHE, K.J., et al., SAP-IV: A Structural Analysis Program for Static and Dynamic Response of Linear System, Rep. EERC-73-11, Earthquake Engineering Research Centre, University of California, Berkeley, CA (1973).