# AVAILABLE DATA ON SHOCK-ABSORBING MATERIALS

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## Abstract

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The paper presents a survey of available data on shock-absorbing materials in order to collect information for possible later adaptation of the plastic deformation codes. Shock-absorbing materials and structures can be used as part of a transport container structure or part of truck equipment. Several materials can be used as shock absorbers. An extensive survey of the literature has provided a great, deal of information on these products. It appears, however, that many properties are still not available, or are not accurately known, especially in the case of natural products. So, further investigation has been carried out to define the required experimental procedures necessary to measure the missing properties. Three codes were selected: EURDYN, PLEXUS and SAMCEF. For code evaluation, a schematic container model has been considered to serve as a benchmark for the evaluation of plastic deformation. For shock calculation, the container was hypothetically dropped from a height of 9 m. The EURDYN computer code, developed at the Commission of the European Communities' Joint Research Centre at Ispra (Italy), was selected first since it was especially designed to handle dynamic (particularly plastic) problems. The SAMCEF computer code was developed at the University of Liège. As this code could not readily calculate the benchmark, since only a visco-plastic flow model was available for steel, such a model was added to it. Contact with the CEA, France, led to the replacement of MARC by the PLEXUS code, which is part of the CASTEM system developed at CEA Département d'études mécaniques et thermiques. The results obtained using the SAMCEF program confirm those obtained with EURDYN. The PLEXUS results are more or less in between. It is concluded that the three tested codes gave qualitatively consistent results and confirmed experimental results.

This study intends to evaluate current knowledge, as well as future developments, with the aim of designing and constructing a shock-absorbing structure with a high safety factor. Such a device can be used as part of the transport container, its structure, or as part of the truck equipment. With this objective, two main tasks have been undertaken:

(1) Collection of data from the available literature to be used for the further adaptation of the codes for plastic-deformation behaviour.
(2) Evaluation of a container drop using finite-element codes.

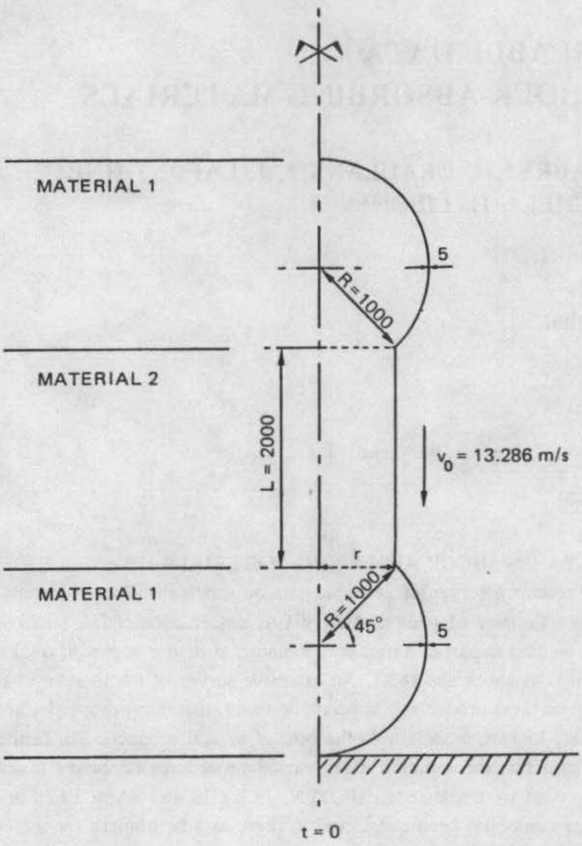

*FIG. 1. Schematic container model shown in initial position.*

## COLLECTION OF DATA

Based on the regulatory procedures defined in the IAEA Transport Regulations, an exhaustive inventory of all of the materials currently available that can withstand the test procedures mentioned earlier has been drawn up. All of the necessary information has been subdivided into three categories: the physical and mechanical properties and the fire-proof features. At the same time, a classification of shock-absorbing materials as a function of their nature has been developed. Classes one, two, three and four represent, respectively, vegetable, mineral, organic and soft-metal materials as well as metallic structures.

## SURVEY OF THE CODES

A schematic container model (Fig. 1), comprising a cylindrical container connected to two spherical shells, has been proposed to serve as a benchmark for the

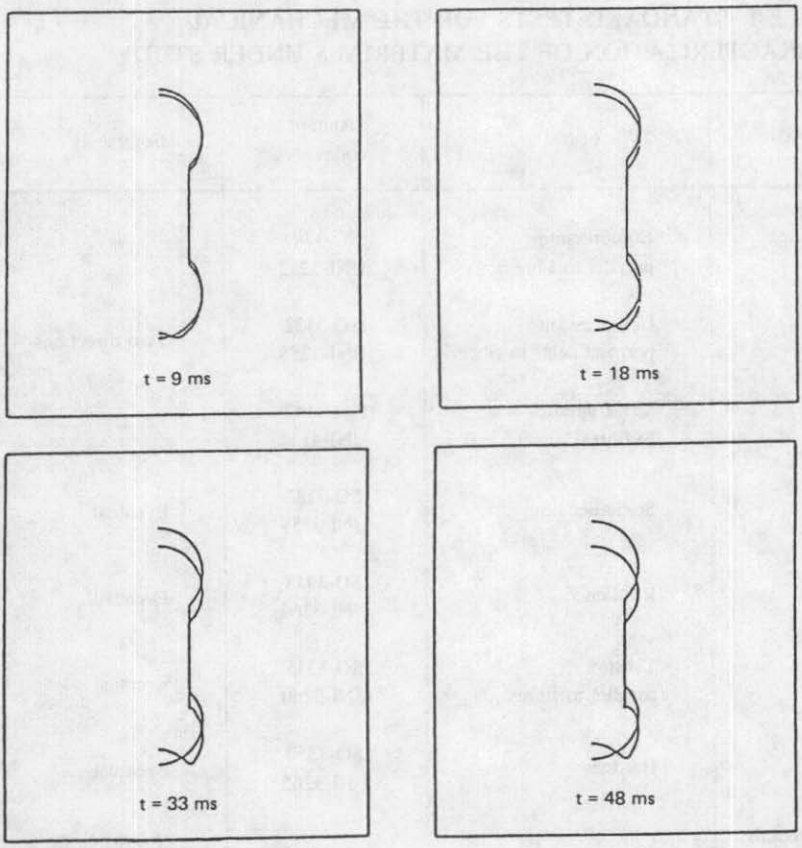

*FIG. 2. Shell shapes at various points in time.*

evaluation of the plastic deformation codes. The cylindrical container represents a container filled with material with an average density of 4 g/cm$^3$. The spherical shell is assumed to be made of a perfectly elastic, nearly rigid material. Three codes were selected: EURDYN, PLEXUS and SAMCEF. For code evaluation, the schematic container model was used as a benchmark for the evaluation of plastic deformation.

For shock calculation, the container was hypothetically dropped from a height of 9 m along the direction of its cylinder axis on a flat, unyielding surface. The EURDYN computer code, developed at the Commission of the European Communities' Joint Research Centre, at Ispra (Italy), was selected first for evaluation because it is especially designed to handle dynamic (particularly plastic) problems. Indeed, EURDYN uses an explicit integration versus time scheme, which makes it quite efficient to run short deformation evaluations, such as absorber collapses. In the framework of this project, the EURDYN code was first run at Ispra and was, at a later

TABLE I. STANDARD TESTS FOR THE MECHANICAL CHARACTERIZATION OF THE MATERIALS UNDER STUDY

| Material | Type of test | Standard codes | Comments |
|---|---|---|---|
| **Wood** | | | |
| 1 | Compression parallel to fibres | ISO-3787<br>UNI-3252 | |
| 2 | Compression perpendicular to fibres | ISO-3132<br>UNI-3258 | Two directions |
| 3 | Shear parallel to fibres | ISO-3147<br>UNI-4144 | |
| 4 | Static bending | ISO-3133<br>UNI-3259 | Eventual |
| 5 | Resilience | ISO-3348<br>UNI-3264 | Eventual |
| 6 | Tension parallel to fibres | ISO-3345<br>UNI-3260 | Eventual |
| 7 | Hardness | ISO-3350<br>UNI-3265 | Eventual |
| **Honeycomb** | | | |
| 8 | Tension on component material | ISO/R190<br>UNI-556 | If possible for every material thickness considered |

stage, implemented at Belgonucléaire, Brussels. Several runs have confirmed the correct transfer.

The SAMCEF computer code was developed at the University of Liège. As that code could not readily calculate the benchmark, and since only a visco-plastic flow model was available for steel, such a model was added to it. Convergence towards a dynamic equilibrium state was obtained at every step using a Newton–Raphson iterative process, including contact conditions at ground level (with velocity and acceleration reset to zero).

The MARC computer code was to have been a candidate for shock calculations. However, it was apparent that extensive computing time and engineering efforts would be required owing to the intrinsic complexities of the code. Furthermore, since MARC was developed in the United States of America only limited expert support would be available in Europe to run such a program, with code-source modifications

TABLE II. TESTS OF THE BEHAVIOUR UNDER 'IMPULSIVE' LOADING OF THE MATERIALS CONSIDERED

| Material | Type of load | | Type of test | Specimen (mm) | Notes |
|---|---|---|---|---|---|
| Wood | Static | 1 | Compression parallel to fibres | Cubic (s = 150 mm) | |
| | | 2 | Compression perpendicular to fibres | Cubic (s = 150 mm) | |
| | Dynamic | 3 | Impact parallel to fibres | Cubic (s = 150 mm) | Two drop hammer weights |
| | | 4 | Impact perpendicular to fibres | Cubic (s = 150 mm) | Two drop hammer weights |
| | | 5 | Impact perpendicular to fibres | Cubic (s = 150 mm) | Two drop hammer weights |
| | | 6 | Impact parallel to fibres | Prismatic (h/s = 1.5) | |
| | | 7 | Impact parallel to fibres | Prismatic (h/s = 2) | |
| | Static | 8 | Compression parallel to cell axis | Cubic (s = 100 mm) | Two wall thicknesses and two cell dimensions (eventual) |
| | | 9 | Compression perpendicular to cell axis | Cubic (s = 100 mm) | Two directions |
| | | 10 | Impact parallel to cell axis | Cubic (s = 100 mm) | Two wall thicknesses and two cell dimensions |

TABLE II. (cont.)

| Material | Type of load | | Type of test | Specimen (mm) | Notes |
|---|---|---|---|---|---|
| Honeycomb | | | | | |
| | Dynamic | 11 | Impact perpendicular to cell axis | Cubic (s = 100 mm) | Two directions |
| | | 12 | Impact parallel to cell axis | Prismatic (h/s = 1.5) | |
| | | 13 | Impact parallel to cell axis | Prismatic (h/s = 2) | |

practically unfeasible. As a result, MARC was replaced by the PLEXUS code, which is part of the CASTEM system developed at CEA Département d'études mécaniques et thermiques.

A typical deformation sequence for the structure, together with the undeformed structure, was drawn every 3 ms (Fig. 2). It is of interest to note that all three codes showed the same mechanism of deformation, in two stages:

(1) In the first stage, only that part of the spherical shell that collides with the floor undergoes any significant deformation, the deformation being described as an inversion of the shell curvature. The deformed shape can be viewed as the intersection of two spheres of nearly the same radius, a sphere moving downwards and a sphere moving upwards. The already deformed material is on the second sphere, while the as yet undeformed part belongs to the first one. The process of energy absorption occurs mostly at the intersection of the two spheres, in a ring-shaped zone. As the impact continues, the radius of the ring-shaped zone increases, the second stage being reached when this radius is more or less equal to the cylindrical shell radius.

(2) In the second stage another process comes into play. The connection between the cylindrical shell and the spherical shell undergoes a large deformation. According to the EURDYN results, this deformation leads to a failure 48 ms after the start of impact. By that time, 50% of the kinetic energy has been absorbed.

The above-mentioned results were used to evaluate the acceleration of the structure. These values are less than 15g (g = acceleration of gravity).

Another aspect of this study is that many of the materials properties researched during data collection were not actually available, or were not known. Thus, a procedure was established to determine what tests would be required for the characterization of materials as energy absorbers. Four materials were considered, namely oak, balsa wood, redwood and honeycomb structures.

For the calculation of a radioactive material transport package four characteristics are required:

- Unequivocal material identification parameters,
- Standard mechanical characteristics,
- Dynamic mechanical characteristics,
- Energy-absorption capability for absorption 'efficiency' of the materials.

Tables I and II summarize all of the necessary tests.