157
2-3-77
LA-6642-MS

Informal Report

MASTER

UC-71 413 675

Issued: January 1977

**Comparison of Predicted and Measured
Drop Test Responses of Type B Shipping Containers**

by

J. Counts
J. B. Payne

los alamos
scientific laboratory
of the University of California
LOS ALAMOS, NEW MEXICO 87545

An Affirmative Action/Equal Opportunity Employer

UNITED STATES
ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
CONTRACT W-7405-ENG. 34

This work supported by the US Energy Research and Development
Administration, Transportation Branch, Environmental Control Technology
Division.

Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161
Price. Printed Copy \$3.50 Microfiche \$3.00

This report was prepared as an account of work sponsored
by the United States Government. Neither the United States
nor the United States Energy Research and Development Ad-
ministration, nor any of their employees, nor any of their con-
tractors, subcontractors, or their employees make any
warranty, express or implied, or assumes any legal liability or
responsibility for the accuracy, completeness, or usefulness of
any information, apparatus, product, or process disclosed, or
represents that its use would not infringe privately owned
rights.

by

ABSTRACT

NOTICE

[illegible]

This report describes work done at the Los Alamos Scientific Laboratory (LASL) from October 1, 1975, to September 30, 1976, in support of a program to assure the transportation safety of radioactive materials. The work was sponsored by the Transportation Branch of the Environmental Control Technology Division (ECT) of the U.S. Energy Research and Development Administration (ERDA).

The scope of the LASL effort was to continue the development of a lumped-mass computer code for predicting the dynamic response of Type B shipping containers subjected to impact accident conditions. The principal objective was to substantiate the predictive ability of the code by correlating with full-scale impacting shipping container experiments performed at Oak Ridge National Laboratory (ORNL) and scale model tests conducted by Battelle-Columbus Laboratories (BCL).

1

property descriptions, and a slicing feature that automatically generates a lumped-mass mathematical container model were incorporated with Donham's work by Kern and Merson.² Their work is referred to as IMPAC1. A discussion of the theory of IMPAC1 is given by Fuka in Ref. 3.

The IMPAC1 code was subsequently improved and used to correlate ORNL and LASL experiments. That work is described in Ref. 4 and shows that the code gave reasonable estimates of measured permanent lead deformation. The work discussed in this report was specifically directed toward correlating strain and acceleration-time histories and incorporating an impact limiter capability in the code. The theory and construction of IMPAC2 (an improved version of IMPAC1) including its capabilities, limitations, and spatial and temporal convergence considerations are presented in Ref. 5. This report discusses some aspects of IMPAC2, and describes efforts to correlate ORNL and BCL experiments. The results of these efforts clearly demonstrated the need for a new mathematical model. The elements of a more accurate mathematical shipping container model recommended for future work are presented.

II. IMPAC2: ONE-DIMENSIONAL MODEL

Figure 1a depicts a simplified container impacting in the end-on orientation onto a rigid horizontal target. A lumped-mass mathematical model of the container is shown in Fig. 1b. The code can also accommodate side-on and inclined drops, where the container mass center is directly above the point of initial contact. This discussion is confined to the end-on case to present the salient features of the analysis technique with a minimum of complication. IMPAC2 is discussed in more detail in Ref. 5.

The container is "sliced" into a number of elements specified by the computer code user, and each lump in the model is assigned the mass of the corresponding slice. The code computes an axial stiffness (spring) property for each slice that depends on which of two deformation assumptions is selected.

One deformation assumption included in the code is that welded contact exists between the shielding and the inner and outer shells. Completely welded contact is obviously difficult to attain in practice, and the consequent implication that horizontal plane sections remain plane does not allow a two-dimensional stress state in the shielding. If shielding were a relatively stiff material, such as depleted uranium, welded contact might be a reasonable deformation approximation. However, the second deformation assumption available in the code appears better suited for lead, which is a less stiff and more common shielding material.

This second deformation model assumes that the outer shell behaves as a cylindrical membrane by neglecting bending, axial, and shear effects, as well as its radial inertia. The pressure produced between the inner surface of the outer shell and a lead slice is related to the membrane shell properties by a simple mechanics-of-materials formula. The assumption is then made that the lead retains constant volume during deformation. The constant volume assumption and the pressure produced by the membrane have the effect of adding a strain-dependent stress component to the axial stress-strain relation for the lead. These assumptions, made first by Donham,¹ require the radial strain of any slice to be the negative one-half of its axial strain. Another consequence of assuming constant volume is that the radial deformation and acceleration must depend on the corresponding axial quantities. The outer shell must then experience a radial acceleration that can be computed from the axial acceleration

Fig. 1. Conceptual shipping container and its lumped-mass mathematical model.

of the lead. In a problem of this type, it is common practice to assume that the radial acceleration of the outer shell can be used to obtain an inertial loading. The maximum values of these inertial loads are taken to constitute an equivalent static loading for which the shell stresses are computed. However, as explained in Ref. 5, the radial pressure acting between the outer shell and the lead shielding is a more realistic shell loading than an inertial loading.

At this time, there is no analytical or experimental evidence to evaluate the accuracy of this pseudo-static technique, but there is some thought that it is conservative. However, it is not reasonable to assume such a margin of safety unless the actual stresses in the system are known. Consequently, it is felt that a more accurate mathematical container model must be developed. It should be noted that because of the membrane assumption for the outer shell, the one-dimensional model cannot predict the real shell motion history. This is the most important inadequacy of the one-dimensional model, as weld and closure stresses cannot be correctly evaluated. A later section of this report will present a discussion of some results from the one-dimensional model and indicate needed additional features.

The lumped spring-mass model results in a system of simultaneous, nonlinear, ordinary differential equations that are solved by an iterative technique. Solutions from this iterative technique have been found to compare well with those of an independent (a computer code for nonlinear differential equation solution) method in regions of space and time for which container stresses are monotonically increasing. The independent method did not employ the unloading feature that is available in IMPAC2. Consequently, the independent method could not be used to verify the solution at positions and times involving unloading. However, the check on the solution during loading did show that the number of slices must be increased to attain convergence. Spatial and temporal convergence are discussed in more detail in Ref. 5.

The material property descriptions available with the code are representative of a variety of container structural materials, and other material descriptions can be incorporated in the code if desired. However, the mechanical properties of lead can be elusive. A cursory examination of the literature will reveal that these properties are very sensitive to chemical content, temperature, and the state of stress. Temperature effects are particularly important because containers having radioactive contents will be at elevated temperatures. "Properties" as used above implies more than just a number of pertinent independent values. It means a constitutive relationship that can be used to accurately compute the mechanical variables as functions of time. Predictions made with the one-dimensional model should use lead properties that correspond to those of a desired experimental container model. Because lead properties are difficult to determine, close correlation, especially with regard to acceleration, cannot always be expected.

The permanent lead slump values measured in impacting shipping container experiments performed by ORNL and BCL have been computed to acceptable accuracy with the one-dimensional model.⁴ The results do not appear to be extremely sensitive to the assumed lead properties. It has been shown elsewhere that permanent lead deformation can be reasonably estimated in one-dimensional impact situations without complete consideration of the inertia distribution, although the complete motion was not considered.⁶

The inner shell shown in Fig. 1 is included in the one-dimensional model only by adding the mass of each shell segment to the corresponding slice. This inner shell represents the shielded radioactive material container. In many

instances, the inner shell and its contents could have sufficient mass and stiffness to markedly influence the behavior of the main containment structure. It will therefore be included in greater detail in the more accurate model.

III. PREDICTED RESPONSES

Figure 2 shows the axial acceleration-time history calculated for a position in the lead approximately 0.36 m above the impact end of an ORNL-tested full-scale container. The accelerations were calculated with a one-dimensional model of the 21 005-kg full-scale container, with and without a balsa wood impact limiter 0.438 m long and 0.794 m in diameter. Both configurations were dropped end-on from 9.14 m onto an armor-plate-covered concrete target. Use of the impact limiter resulted in a calculated reduction in peak acceleration from 1212 g's to 647 g's during the initial pulse. The computed oscillations following the initial pulse, which are not felt to be accurately calculated, exist because the initial kinetic energy is not entirely dissipated by plastic action in the lead and impact limiter. The remaining kinetic and elastic strain energy produce the subsequent vibrations. An actual container would have much smaller magnitudes for these oscillations because of other energy dissipating mechanisms not included in the model.

The ORNL acceleration records⁷ for the test involving the impact limiter are still being studied, and correlations are not available at this time. Figure 3 is a reproduction of the measured experimental acceleration record from the ORNL test without the impact limiter. The initial part of the calculated pulse shown in Fig. 2 for this case is shown by dots on Fig. 3, adjusted to the scale of Fig. 3. The heavy container actually causes the impact target to penetrate the soil for some distance, and this has been observed in high-speed photographs of drop tests on that target. A plausible interpretation of the experimentally determined response shown in Fig. 3 is that during Phase I the container is decelerated slightly by the initial penetration of the target into the soil. The effective soil resistance then increases until it is extremely stiff at the beginning of Phase II, and the container responds to an essentially unyielding surface. Phase III of the curve then reflects the combined effect of target rebound and container response.

The close correlation between the calculated and experimental accelerations in Phase II of Fig. 3 is encouraging, but could be fortuitous. Realistic correlation and interpretation of experimental results such as these will require a mathematical shipping container model that includes a deformable target as well as an impact limiter.

Figure 4 shows the calculated acceleration-time history at a point near the upper surface of the lead shielding for a one-dimensional mathematical model of a 1986-kg BCL 1/2-scale physical model. The balsa wood impact limiter was 0.33 m long by 0.38 m in diameter, and ambient temperature was assumed. The impact limiter reduced the peak acceleration of the initial pulse from 2250 g's to 330 g's. Again, the oscillatory behavior following the initial pulse exists because all of the energy has not been dissipated by an appropriate mechanism in the mathematical model.

Fig. 2. Calculated acceleration-time histories 0.36 m above the impact end of the 21 005-kg container tested at ORNL.

Fig. 3. Measured and calculated acceleration-time histories for the 21 005-kg container (ORNL).

Fig. 4. Calculated acceleration-time histories at the upper end of the BCL 1/2-scale, 1986-kg model at ambient temperature.

Fig. 5. New container model elements.

IV. NEW MATHEMATICAL MODEL

Figure 5 is a conceptual sketch of the structural elements included in the new mathematical model of a shipping container subjected to an end-on drop. Axial symmetry is assumed, and the problem will be two-dimensional. Existing mathematical solutions for the response of the cylindrical shells and their end-plates, including inertia, will be used to piece the elements together and provide continuity of slopes and deflections. These elements will then be coupled with the shielding material.

The two-dimensional behavior of the lead or other shielding material will be ascertained by using complex wave codes to determine the deformation pattern in this relatively simple model. From these wave codes and other techniques a judicious model for the lead behavior at elevated temperatures will be developed that, when coupled with the solutions for the other structural elements, will more accurately represent actual container impact response. The possibility of treating lead as a compressible liquid at 170°C is also being considered. Essential features of the impacting container will be incorporated so that experimental results, particularly strain gage records from the shells and plates, can be used to substantiate the analysis.

There is a growing tendency to use impact limiters in the design of shipping containers, and the new model will include such energy absorbing elements. The relationship of real targets, such as pavement, to the essentially unyielding surface will be studied by including these elements in the model. This feature is represented symbolically by the target and spring in Fig. 5.

The analytical method proposed for this program is only one of several ways to analyze shipping container impact problems. It would be useful if other programs consider finite element techniques and closed-form or asymptotic mathematical solutions. The important and complicated problems of container response will probably never yield their complete solution to one method, and an exchange of results and ideas from several techniques would be valuable.

Substantiating experiments for this part of the program have been planned with BCL, where simple models will be tested at several temperatures, both with and without impact limiters. The purpose of these experiments is to test the two-dimensional mathematical model, and using a physical model that is relatively free of structural complexities, ascertain if all pertinent physical phenomena have been properly included. These experiments will enable the analytical assumptions to be modified as required.

REFERENCES

1. B. J. Donham, "Prediction of Maximum Damage to Shielded Shipping Containers," Los Alamos Scientific Laboratory report LA-4649 (June 1971).
2. E. A. Kern and J. L. Merson, "Users Manual for IMPAC1 - A Lumped Mass Non-linear Spring Computer Program to Analyze Shipping Containers Subjected to Impact," Los Alamos Scientific Laboratory report LA-5344-MS (August 1973).
3. L. R. Fuka, "THEORY OF IMPAC1 - Analysis of Impact Loaded Radioactive Material Shipping Containers," Los Alamos Scientific Laboratory report LA-5334-MS (July 1973).

4. J. Counts and J. B. Payne, "Evaluation of Analysis Methods for Type B Shipping Container Impact Problems," Los Alamos Scientific Laboratory report LA-6640-MS (January 1977).
5. J. Counts and J. B. Payne, "IMPAC2 - A Lumped-Mass Nonlinear Spring Computer Program to Analyze Type B Shipping Container Impact Problems," Los Alamos Scientific Laboratory report LA-6643-MS (January 1977).
6. W. Johnson, Impact Strength of Materials, (Edward Arnold, London, 1972), p. 236.
7. R. D. Seagren, Oak Ridge National Laboratory, personal communication, July 1976.