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INFORMAL REPORT

Users Manual for IMPAC1

A Lumped Mass Nonlinear Spring

Computer Program to Analyze

Shipping Containers Subjected to Impact

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by

E. A. Kern
J. L. Merson

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USERS MANUAL FOR IMPACT,
A LUMPED MASS NONLINEAR SPRING COMPUTER PROGRAM
TO ANALYZE SHIPPING CONTAINERS SUBJECTED TO IMPACT

by

E. A. Kern

and

J. L. Merson

ABSTRACT

Information is provided for using a computer program designed for the impact analysis of metal shipping containers. The method of analysis, a description of the program routines, and an explanation of the input and output variables are among the items presented. Also included are a number of sample test cases along with a discussion of the results.

I. INTRODUCTION

The purpose of this report is to provide the user with sufficient information to effectively employ this computer program designed for the impact analysis of shipping containers used to transport radioactive material.

The program has been designed to run on the CDC 6600 and 7600 computers or the IBM 360 and 370 series computers.

The user has a choice of steel, uranium, and lead or any combination thereof for the containers. A lumped mass type approach is employed by the program wherein the container is assumed to consist of a number of masses separated by springs. In the usual case, the container consists of a number of hollow concentric cylinders each of a different material. The user inputs the type of material, height, inner diameter, and outer diameter for these concentric cylinders as well as the angle at which the canister is to strike the surface. Presently, the mechanical properties for these materials are built into the program. The user will have the option of inputting the mechanical properties in the future. The maximum number of lumped masses into which a container may be subdivided is 39. However, this does not appear to be a major drawback, since very good results have been obtained with cylinders which have been divided into 12 layers. Naturally, too few layers could lead to unrealistic results.

Approximately 30 seconds of CDC 7600 computer time were required to analyze impact of a two-foot-long model shipping container. Work has been started on oblique impact which was originally scheduled for FY74.

II. METHOD

The program considers the shipping container to be composed of layers of masses connected by nonlinear springs. The forces exerted by the springs on the masses are determined from the stress-strain characteristics of the shipping container materials. Permanent deformation of the layers into which the container is divided is made equivalent to the permanent deformation of the corresponding springs.

The displacement time history of the lumped masses is determined by dividing the time interval into sufficiently small time increments and assuming a linear variation of acceleration across each of the time increments (See Ref. 1). That is, if $\ddot{X}(t_m)$ equals the acceleration at time t_m , then at any time within the interval t_m, t_{m+1} , the acceleration will be

$$\ddot{X}(t) = \ddot{X}(t_m) + \frac{\ddot{X}(t_{m+1}) - \ddot{X}(t_m)}{t_{m+1} - t_m} (t - t_m) \quad (1)$$

Integrating the above acceleration from t_m to t yields for the velocity

$$\dot{X}(t) = \dot{X}(t_m)(t - t_m) + \frac{[\ddot{X}(t_{m+1}) - \ddot{X}(t_m)](t - t_m)^2}{2(t_{m+1} - t_m)} + \dot{X}(t_m) \quad (2)$$

Performing a second integration yields for the displacement

$$X(t) = \frac{\ddot{X}(t_m)(t - t_m)^2}{2} + \frac{[\ddot{X}(t_{m+1}) - \ddot{X}(t_m)](t - t_m)^3}{6(t_{m+1} - t_m)} + \dot{X}(t_m)(t - t_m) + X(t_m) \quad (3)$$

If the displacements of the masses at time t_{m+1} were known, then the spring forces and hence the forces on the lumped masses could be determined and set equal to the product of the individual masses and the corresponding accelerations, i.e.,

$$F(t_{m+1}) = M \ddot{X}(t_{m+1}) \quad (4)$$

where

$$F(t_{m+1}) = \text{force on the lumped mass at time } t_{m+1}$$

$$M = \text{mass of the lumped mass.}$$

The main objective of the program is to solve the above system of equations (Eqs. 1-4) for the displacement, velocity, and acceleration at time t_{m+1} . An iteration approach must be employed since the acceleration $\ddot{X}(t_{m+1})$ is not known. The approach used successfully in the program is to guess $\ddot{X}(t_{m+1})$. Equations 2-3 can then be solved for $\dot{X}(t_{m+1})$ and $X(t_{m+1})$. With the velocity and displacement known, the spring force can be computed from the stress-strain relationship. The acceleration $\ddot{X}(t_{m+1})$ can then be computed from Eq. (4). This computed acceleration is then compared with the guessed acceleration. If

the difference between the assumed acceleration and the acceleration computed from Eq. 4 is larger than a given tolerance, then the assumed acceleration is set equal to the computed acceleration and another iteration through Eqs. 2-4 is performed.

This procedure is continued until the assumed and computed accelerations are within a sufficiently small tolerance of one another. The iterative approach just described must be employed in the program simultaneously for all the lumped masses since the forces and displacements of the lumped masses are dependent on each other.

The forces exerted by the springs on the masses are determined from the stress-strain relationships associated with the container materials. Steel, uranium, and lead are the three container material choices currently in the program. Following is a description of the assumed stress-strain characteristics for these three materials. These stress-strain characteristics were assumed in order to check the capability of the computer program, and are not necessarily the most accurate representation of the mechanical properties.

The stress-strain characteristics assumed for steel are as shown in Fig. 1 where true stress is plotted as a function of engineering strain. Force is computed from the product of stress and the actual cross-sectional area, where the actual cross-sectional area is computed by taking into account both the permanent and elastic deformation of the material, assuming the elastic deformation to be negligible.

As seen from Fig. 1, the stress-strain characteristics for steel are approximated by two straight lines. The first line has a slope equal to the modulus of elasticity and the second line limits the stress to a constant maximum value. For steel, both the modulus of elasticity and the maximum stress are available to the user as inputs.

Fig. 1. Stress-Strain Characteristics for Steel.

Fig. 2. Stress-Strain Characteristics for Uranium.

The stress-strain characteristics for uranium have been taken from Ref. 2 and are shown in Fig. 2.

The linear portion of the curve which is valid up to a stress of 46,000 psi corresponding to a strain of 0.00184615 has a slope equal to the modulus of elasticity for uranium, which for this case is taken to be 26×10^6 psi. A cubic spline interpolation technique is employed in the program to obtain an analytic representation of the nonlinear portion of the stress-strain curve in Fig. 2. The points through which this curve passes are given in Table I. At the current time the stress-strain characteristics for uranium cannot be altered by user input.

TABLE I

STRESS-STRAIN CHARACTERISTICS FOR URANIUM

Engineering Strain	0.00184	0.005	0.01	0.02	0.04	0.06	0.08	0.10	0.15	0.20
True Stress (10^3 psi)	48.0	60.49	71.08	83.57	98.38	108.33	116.09	122.56	135.52	145.35

The stress-strain characteristics for lead are represented by the following equation (Ref. 1).

$$\sigma = 6740. (1 + .004\dot{\epsilon}^2) \epsilon^{.44}$$

where

σ = engineering stress (psi)

ϵ = engineering strain

$\dot{\epsilon}$ = engineering strain rate .

This particular equation for stress gives excellent agreement with experimental deflection results for thirty-foot-lead-cylinder drop tests. The analytically predicted maximum deformation is within a few percent of the experimentally measured deformation. However, this equation predicts stresses which seem inordinately large for the higher strain rates experienced during impact.

The stress-strain characteristics for both tension and compression are modeled in the program. As an example, consider the stress-strain time history shown in Fig. 3 for uranium during a typical computer simulation of a shipping container drop test.

Fig. 3. Stress-Strain Time History .

Upon impact of the container upon the rigid surface, the uranium element is first placed in compression. This is represented in Fig. 3 by the path from point 0 to point 1. At point 1, the element reaches its maximum compression and moves from compression into tension along the path 1-2. At point 2, the element reaches maximum tension and then moves along path 2-3 to a state of zero stress at point 3. If at

any point on the entire path 0-3, for example point a, we form the triangle abc, where the line ab is perpendicular to the horizontal axis and the line ac has a slope equal to the modulus of elasticity, then the area enclosed by the triangle is equal to the elastic distortion energy per unit volume. The distance along the horizontal axis from point 0 to point c is equal to the permanent deformation per unit length corresponding to point a. At the end of the drop at point 3, the distance from point 0 to point 3 represents the final permanent deformation per unit length.

III. AVAILABILITY AND MACHINE DEPENDENCE

The program is available in two versions, one for the CDC 6600 and CDC 7600, and one for IBM 360 and IBM 370. The program has actually been run on the following machines and systems:

CDC 7600, Los Alamos Scientific Laboratory (LASL) modified CDC RUN FØRTRAN
compiler, LASL CRØS operating system
CDC 6600, LASL RUN FØRTRAN compiler, LASL modified SCØPE operating system
IBM 360/50, FØRTRAN G, DØS, 128K bytes memory

The CDC and IBM decks are identical except for the following:

1. Control cards for the proper system are used.
2. CDC deck requires a program card omitted for IBM.
3. On the CDC machine, data for each case is preceded by \$DATA and followed by \$END. For IBM, these cards are &DATA and &END (or +DATA and +END when 026 character set is used).
4. IBM 360/50 deck includes a function ASIN which uses the system function ARSIN. This may not be needed on larger IBM systems.

Input and Output File Definition

Input and output files are defined in the subroutines INIT, SECVØL, PRTPLT, and in the main program. In each case, the definitions are in the form of assignment statements which are among the first executable statements in the routines, defining INFL, ØUTFL, and the debugging output files IBUGFL and IBUGF1. In the deck provided, all input is from file 1 and output is to file 3, which are the card reader and printer on LASL's IBM 360. Another IBM convention is input from file 5 and output to file 6. On the CDC systems, these files may have any number, provided they are properly defined on the program card.

Input is in the form

READ(INFL,DATA),

where INFL is a variable which defines the input file, and DATA is a namelist name.

All output is of the form WRITE (unit, name) or WRITE (unit, format) variable list, that is,

$$\text{WRITE} \left(\left\{ \begin{array}{l} \text{IØUTFL} \\ \text{IBUGFL} \\ \text{IBUGF1} \end{array} \right\}, \text{name} \right)$$

or

$$\text{WRITE} \left(\left\{ \begin{array}{l} \text{IØUTFL} \\ \text{IBUGFL} \\ \text{IBUGF1} \end{array} \right\}, \text{format number} \right) \text{variable list.}$$

System Routines

External routines which are used by the program and expected to be found in the system library include the following:

I/Ø routines
STØP
END
SQRT
SIN

System Routines (Cont.)

COS

TAN

ASIN (in the IBM 360/50 deck a function ASIN is included, which uses the system routine ARSIN)

IV. INPUT

Input to the program is by means of the FORTRAN namelist feature. A standard FORTRAN namelist with the label DATA is used for inputting to the program. The namelist data must be preceded by a \$DATA card and end with a \$END card on the CDC machines, or &DATA and &END on the IBM 360. All cards in the namelist data deck including the \$DATA and the \$END cards must leave a blank in the first column of each card.

There is included in the program a set of default values which will be used for those variables which the user does not specify. The variables which can be specified fall into three categories:

- (1) Those specifying method of computation and output
- (2) Those specifying geometry
- (3) Those specifying materials

Following is a summary of the possible inputs to the program. The two possible modes for the variables in this input list are real (R) and integer (I).

Computation and Output Control Variables

- NELEM - Number of elements or masses to be used. May not exceed 39.
Default = 12 (I)
- TDELTA - Time interval at which calculations are initially done. Default = $1. \times 10^{-5}$ (R) sec (If the solution does not converge, a smaller time increment is automatically chosen in the computer program).
- INCPRT - Number of initial time intervals between printed output. Default = 500 (I)
- STOPT - Time at which calculation is to end. Default = $1. \times 10^{-2}$ (R) sec
- KEEP - If this variable is set to 1, values from previous case will be used instead of normal default values. Default = 0 (I)
- LAST - If LAST = 0, when present case is completed, data for another case will be read. If LAST = 1, present case is considered to be last case, and no more data are read. If LAST = 0 and no more data are provided, job will abort with an error message from the system indicating an attempt to read past an end of file. Default = 1 (I)
- IPLTOT - Control of amount of output generated. If IPLTOT = 0, no plotting is done. Default = 0 (I)

Geometry Variables

The geometry of the container can be specified by either of two methods, or by a combination of them. If the container is composed of concentric cylinders, the user can specify the radii of the cylinders, their heights, and the impact angle, and the program will determine the radii and thicknesses of NELEM sets of five concentric rings of equal thickness sliced parallel to the impact plane.

Any geometry may be defined by giving the radii and thicknesses of concentric rings.

The results of the automatic slicing can be overridden with entered radii and thicknesses. This may be helpful in the event that the results of automatic slicing are known from an earlier run, and minor changes are desired.

- CYL RAD - An array of 5 radii of concentric right cylinders to be used by the automatic slicing option. CYLRAD (5) is the outer radius. If CYLRAD (5) is non-zero, the slicing option is invoked. If fewer than 5 radii are needed, the inner ones should be set to zero. Default = 0., 0., 0., 0., 0. (R) in. (See Fig. 4.)

Fig. 4. Input Variables for Slicing Concentric Cylinders.

Geometry Variables (Cont.)

- HEIGHT - An array of five heights of concentric cylinders for use by the automatic slicer. HEIGHT (5) is the height of the outer cylinder. If fewer than five heights are needed, the inner ones should be set to zero. Default = 0., 0., 0., 0., 0. (R) in. (See Fig. 4)
- ANGLE - The angle of impact in degrees for use by the automatic slicing option. Angle between the longitudinal axis and the impact plane. (R) degrees. (See Fig. 4)
- RADIUS - An array 5 x 40 containing the radii of five rings of material in each of NELEM layers. This input is not required if automatic slicing option is used. Radius will override the automatic slicing if it is given. Default is a function of ANGLE and NELEM. A solid cylinder with a radius of 2 and height equal to 24 is tilted at the specified ANGLE (default = 90) and sliced into NELEM sections (default = 12) (R) in. (See Fig. 5)
- THICK - An array containing the thicknesses of each of NELEM layers. Thickness is not needed if automatic slicing is used. If it is given, it will override the thicknesses generated by the automatic slicing option. Default is a function of ANGLE and NELEM, and is arrived at by slicing a solid cylinder 24 inches high. (R) in. (See Fig. 5)

Fig. 5. Variables for Sliced Disks.

Material Variables

Up to five material shells may be specified. Currently, steel, uranium, and lead can be chosen for these shells. For each, the following properties are defined; density, modulus of elasticity, maximum stress in the elastic range, type of calculation to be done. The user may use materials as specified in Table II.

Currently, the physical properties of lead and uranium, as shown in Table II, are fixed in the program. For steel (MAT(I) = 4HSST1) the properties may be overridden by specifying the variables EMØDUL, DENSTY, and STRSMX.

MAT - An array of five names of materials, to be chosen from column 2 (name) of Table II. MAT (5) defines the properties of the outer shell of the canister, MAT (4) those of the next, etc.

If a name is entered which is not in Table II, it is ignored. Default MAT (5) = 4HLEAD (I)

EMØDUL - Modulus of elasticity of each of 5 shells. Default = 0., 0., 0., 0., 1.2E6. (R) psi

DENSTY - Weight density of each of 5 shells. Default = 0., 0., 0., 0., 0.4096. (R) pounds/in.³

STRSMX - Maximum stress in elastic range, of interest to the user only if calculation is for steel.

(R) psi

The input of data is handled by the subroutines, INIT, SECVØL, AELPSE, and CØRECT.

TABLE II
MATERIAL PROPERTIES

<u>Material</u>	<u>Name</u>	<u>Type</u> ^a	<u>Modulus of Elasticity psi</u>	<u>Maximum Stress psi</u>	<u>Weight Density lbs/in.³</u>
Steel	SST1	1	30 x 10 ⁶	55 x 10 ³	0.2830
Lead	LEAD	2	1.2 x 10 ⁶	5 x 10 ³	0.4096
Uranium	URAN	3	26 x 10 ⁶	160 x 10 ³	0.6807
Void	VØID	4	0		0

^aUsed internally by the program

V. SUBROUTINES

Program IMPAC1 is the main driver for the overall program. The major iteration loop, embodied by Eqs. (1-4), and the computation of the permanent deformation are also contained in IMPAC1. The subroutine dependency chart which shows how the subroutines interact with one another and the main program, is given in Fig. 6.

The stress-strain characteristics for the various container materials are modeled in subroutine RESGEN. From inputs of strain and strain rate, subroutine RESGEN computes the lumped mass forces and elastic energy.

Subroutines URSTRS, SPLN1 and SPLN2 provide the cubic spline interpolation over the nonlinear portion of the stress-strain characteristics for uranium. Subroutine SPLN1 computes the required cubic coefficients at the beginning of the run and subroutine SPLN2 uses these coefficients for cubic interpolation. SPLN1 and SPLN2 are controlled via subroutine URSTRS, which in turn is called from subroutine RESGEN.

Subroutine PRITPLT provides the printing and plotting output capability for the program. PRITPLT is called from program IMPAC1. The plotting portion of PRITPLT is system dependent and is operational on the LASL CDC 7600 and CDC 6600. This system uses the Stromberg Carlson 4020 film plotter and is intentionally omitted in the IBM 360 program version, so that the IBM 360 user may use his own system's plotting capability.

Fig. 6. Subroutine Dependency Chart.

Subroutine INIT

This routine was designed to permit great flexibility to the user and still not force him to enter massive amounts of data if his wishes were simple. Five approaches were used to accomplish these ends.

1. The user may approximate any arbitrary geometry by a stack of circular cylindrical disks and define other controls as timing intervals, number of masses, and output options.
2. The user may accept the default values included in the program. In general, the use of default values of "method"-type variables will give satisfactory results. The default values for geometry and materials are useful for program testing purposes.
3. The properties of the materials which may be analyzed are described in Table II, and are entered by naming the material. Those properties for steel may be modified.
4. If the container being analyzed is made up of right circular cylinders, its geometry can be specified by entering the total radii and heights of the cylinders, and allowing the program to determine the radii and thicknesses of the individual masses.
5. If multiple cases are being analyzed in a single run, values defined for one case may be kept and used as the default values for the next, requiring the user to enter only that data which is to be changed.

The gross flow of INIT is as follows:

1. Input and output files are defined.
2. Input variables are initialized so that those for which input is received can be recognized.
3. The data are read and the input data are printed out.
4. Default values are set. This section is omitted if the user has set KEEP = 1, and if it is not the first case being processed.
5. Several "method"-type variables are accepted and substituted into the internal variables from which they will be used.

6. If CYLRAD (5) is non-zero, the automatic slicing function is performed, and radii, thickness, and areas are set.
7. Physical properties of named materials are set.
8. Individual variables are accepted, which may override those set in steps 6 and 7. The actual values used in the computer program, both input and default, are then printed out.

Subroutine SECVOL

This subroutine performs the major part of the automatic slicing when that option is taken. It is also used in setting default values of radii and thicknesses. If the impact angle is not 90° then it calls AELPSE, which calculates areas of cross sections of a cylinder cut at an angle, and CORRECT, which recalculates the volume of a section of the cylinder in that area where the normal calculation does not apply because of a corner. SECVOL is called successively for each cylinder of the container, with arguments passed in the array SECARG in common. On the first call for a case, the elevation of the highest point of the cylinder is calculated, and this height is used to calculate the thickness of slices for all cylinders.

The slice containing the bottom corner of each inner cylinder is treated separately. After the areas of each inner slice are determined, the array is shifted upward such that the slices are aligned properly. The areas are returned to INIT, and the effective radii which would yield those areas if the sections were circular are determined.

The angle of impact on which calculations are based is limited to 0° to 90° inclusive.

VI. OUTPUT

The output from the program appears in tabular form for a given time. The number of computation intervals between printouts can be set by the user through the input integer variable INCPRT. Each page of the output is initiated with the column headings. Following is an explanation of these headings.

MASS	- Indicates the container layer (The first container layer corresponds to the second row of output or MASS = 2).
AREA	- Area (in. ²) of the layer.
THICKNESS	- Layer thickness (in.).
RADIUS	- Layer radius (in.).
DISPLACEMENT	- Layer displacement (in.) from equilibrium (positive downward).
LOWER RESIST	- "Spring" force (lbf) acting on the lower surface of each layer (positive upward).
STRESS5	- Stress (psi) in the fifth or outer ring of each layer (compressive stress is negative).
STRESS4	- Stress (psi) in the fourth ring of each layer (compressive stress is negative).
STORED ENERGY	- The sum of the kinetic and elastic energies for each layer. (lbf - in.). The first entry in this column is the sum total of the remaining entries in that column.
VELOCITY	- Velocity (in./sec) of each layer (positive downward).
YIELD DISTANCE	- Permanent deformation (in.) of each layer (positive for compression).

Restrictions

A given container currently can be subdivided by the program into a maximum of 39 layers. Test runs indicate, however, that reasonable results are obtainable for an average canister (length = 24", diameter = 4") by subdividing the canister into 12 layers. Increasing the number of layers will increase the accuracy of final result, but this will only be achieved with an increase in the overall computation time. In general, doubling the number of layers will more than double the required computation time since more iterations for the actual acceleration are required as the number of layers is increased.

The choice of container materials is currently limited to three; stainless steel, lead, uranium, and also an air void. The stress-strain characteristics of stainless steel, which includes the modulus of elasticity and the maximum stress, can be varied with user inputs, whereas the characteristics for lead and uranium are presently fixed in the program.

VII. EXAMPLES OF USAGE

Following are the FORTRAN namelist inputs for several typical examples. Column 1 of all the cards appearing in the namelist deck must be left blank. The comments appearing after the "*" mark on each line of data have been included only for clarification purposes and should not appear in the actual namelist data deck.

Case 1: Thirty-foot drop of a solid lead cylinder (24-in. long, 4-in. diameter) at a 90° impact angle. This is the default case so only the \$DATA and \$END cards required by all namelist data decks need be included, i.e., the data deck for this case will be

```
$DATA
$END
```

Case 2: Thirty-foot drop of a hollow lead cylinder at a 90° impact angle. The geometry for this cylinder is shown in Fig. 7. The namelist input data will be as follows:

```
$DATA
CYLRAD (4) = 1., 2.,          *Cylinder radii (in.)
HEIGHT (4) = 20., 24.,       *Cylinder heights (in.)
$END
```

Case 3: Thirty-foot drop of a steel-jacketed lead cylinder at a 90° impact angle, as shown in Fig. 8. The FORTRAN namelist input for this case is as follows:

```
$DATA
HEIGHT (3) = 8., 10., 12.,   *Cylinder heights (in.)
CYLRAD (3) = .875, 1.875, 2., *Cylinder radii (in.)
MAT (4) = 4HLEAD, 4HSSSTL,   *Cylinder materials
$END
```

Fig. 7. Hollow Lead Cylinder.

Fig. 8. Steel-Jacketed Lead Cylinder.

Fig. 9. Steel-Jacketed Uranium Cylinder.

Fig. 10. Steel-Jacketed Solid Lead Cylinder.

Case 4: Forty-foot drop of a steel-jacketed uranium cylinder with an impact angle of 60° , as shown in Fig. 9. The data for this case will be:

```

&DATA
CYLRAD (3) = .875,1.875,2.,
HEIGHT (3) = 20., 22., 24.,
MAT (4) = 4HURAN, 4HSST1,
STRSX (5) = 60.E3,
EMODUL (5) = 29.6E6,
VEL = 608.768,
ANGLE = 60.,
NELEN = 24,

STOPT = .005,
TDELTA = 1.E-6,
INCPRT = 500,

&END

```

*Cylinder radii (in.)
 *Cylinder heights (in.)
 *Cylinder materials
 *Maximum stress for steel (psi)
 *Modulus of elasticity for steel (psi)
 *Impact velocity (in./sec)
 *Impact angle (deg)
 *Number of layers into which cylinder is divided
 *Run stopping time (sec)
 *Computation interval (sec)
 *Number of computation intervals per print interval

Case 5: Drop-test of a steel-jacketed solid lead cylinder at 90° impact angle, as shown in Fig. 10. It is desired to consider the sub-cases where this cylinder is dropped from altitudes of 10', 20', 30', and 40'. This is accomplished through use of the LAST and KEEP inputs in the following manner.

```

&DATA
CYLRAD (4) = 1.375, 1.5,
HEIGHT (4) = 10., 12.,
MAT (4) = 4HLEAD, 4HSST1,
VEL = 304.38,
STOPT = .002,
TDELTA = 1.E-6,
LAST = 0,
&END
&DATA
KEEP = 1,
VEL = 430.46,
&END
&DATA
KEEP = 1,

```

*Cylinder radii (in.)
 *Cylinder heights (in.)
 *Cylinder materials
 *Impact velocity (in./sec - 10-ft drop)
 *Termination time (sec)
 *Computation interval (sec)
 *Another case is to be run
 *Do not reinitialize default values
 *Impact velocity (in./sec - 20-ft drop)
 *Do not reinitialize default values

VEL	= 527.2,	*Impact velocity (in./sec - 30-ft drop)
&END		
&DATA		
KEEP	= 1,	*Do not reinitialize default values
VEL	= 608.77 ,	*Impact velocity (in./sec - 40-ft drop)
LAST	= 1,	*This is the last case
&END		

VIII. DISCUSSION OF TEST CASE RESULTS

Following is a discussion of the results of the five test cases presented in the previous section. Some of the runs were made using different computation intervals (TDELTA) in order to determine how this parameter affects the required computer time.

Case 1: Thirty-foot drop of a solid lead cylinder (24-in. long, 4-in. diameter). This is the default case with the cylinder divided into 12 layers. In order to obtain some comparisons on how the number of layers influences the final results, this same case was also run with 6, 18, and 24 layers. The results are summarized in the following table.

TABLE III
COMPARISON OF EFFECT OF NUMBER OF LAYERS

Number of Layers	Final Time (sec)		Maximum Deformation (in.)	Final Deformation (in.)	Computer Time (CDC 7600) (sec)	
	TDELTA =	TDELTA =			TDELTA =	TDELTA =
	10 ⁻⁷ sec	10 ⁻⁵ sec			10 ⁻⁷ sec	10 ⁻⁵ sec
6	0.01	0.01	1.5631	1.4742	119.3	35
12	0.012	0.01	1.4916	1.4057	267.5	49
18	0.008	0.01	1.4668	1.3772	287.1	90
24	0.01	0.01	1.4543	1.3708	504.5	246

Experimental test drops of solid lead cylinders (Ref. 1) of the type considered in this test case showed a final permanent deformation of about 1.57 in. The final deformations appearing in the above table average about ten percent lower than the experimental value. A better agreement with the experimental results could be achieved by reducing the stress in the lead stress-strain model used in the program. Of the three cases summarized in Table III, the six-layer case approximated the experimental results the closest. This does not necessarily suggest that six layers should be employed for all the canister drop cases, but it does indicate that for most cases, reasonable results can be achieved with relatively few layers. The 24-layer case does not differ appreciably from the 12-layer case, making it difficult to justify the increased computer time for the larger number of layers.

Case 2: Thirty-foot drop of a hollow lead cylinder at 90° impact angle. The objective in this test case was to check out the automatic slicing feature of the program. The maximum displacement for this case was 1.508 in., and this displacement occurred at a time of 0.0045 seconds. At the final time of 0.01 seconds the deformation was 1.419 in. The run required 225 seconds of CDC 7600 computer time for the 10⁻⁷ sec computation interval and 9 seconds for the 10⁻⁵ sec interval.

Case 3: Thirty-foot drop of a steel-jacketed lead cylinder at 90° impact angle. The main purpose for this test case was to establish the capability of the program to handle canisters composed of more than one material. The maximum deformation was 0.1369 in. and occurred at 0.0005 seconds. At the final time of 0.01

seconds, the final deformation was 0.1262 in. This case required 337 sec of CDC 7600 computer time for the 10^{-7} sec computation interval and 52 sec for the 10^{-5} sec computation interval.

Case 4: Forty-foot drop of a steel-jacketed uranium cylinder with an impact angle of 60° . The main purpose of this case was to check out the automatic slicing feature of the program for canisters with oblique angle impacts. Also, some variations from the program default values with regard to the properties of steel, the drop height, the number of canister layers, the stopping time, printing interval, and computation interval were included to indicate some features of the input flexibility. Maximum displacement for this case was 0.6354 in. at a time of 0.0018 seconds. A total of 78 seconds of 7600 computer time was required to achieve the final time of 0.005 seconds using a computation interval of 10^{-6} sec.

Case 5: Drop-test of a steel-jacketed solid lead cylinder at 90° impact angle. The main purpose of this test case was to check out the multiple-case capability of the program using the LAST and KEEP input options. Four different drop tests, corresponding to 10-, 20-, 30-, and 40-foot drops, were run to stopping times of 0.002 seconds. Computer time for this case, using a computation interval of 10^{-6} sec, was 170.74 sec. With a computation interval of 10^{-5} sec, the computer time was reduced to 50 seconds.

Additional information concerning the theory of impact may be obtained by consulting Ref. 3.

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