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TROTT COMPUTER PROGRAM FOR
TWO-DIMENSIONAL STRESS WAVE
PROPAGATION

Prepared by

SRI International
333 Ravenswood Avenue
Menlo Park, CA 94025

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US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) TROTT is a Lagrangian finite-difference computer program for calculating two-dimensional stress wave propagation through solid, porous, and composit materials. The stress waves may be caused by impact, detonation of an explosive, or a prescribed velocity. The calculational procedure is the standard leapfrog method of von Neumann and Richtmyer, using artificial viscosity to smooth shock fronts. Quadrilateral or triangular cells are used. The momentum relations are derived by treating		

#20, continued.

the cells as finite elements. Axisymmetric or planar flow can be handled.

The constitutive relations include the standard Mie-Gruneisen equation-of-state and elastic-plastic, work-hardening deviator stress relations. A polytropic gas and detonating flow relations are provided for explosives. Ductile and brittle fracture and shear banding are provided by nucleation and growth models. Porous materials can be represented by a cap plasticity model. A model for layered composites is also present.

The code is constructed for easy insertion of additional material models. The number of extra variables required for each cell for a material model can be specified on an input card.

This manual includes many sample problems, a derivation of the flow equations, and a discussion of material models.

FOREWORD

This volume constitutes Volume III of the three-volume final report to Ballistics Research Laboratory on Contract DAAK11-77-C-0083, SRI Project 6802. Volume I reports on ballistic experiments and calculations, and describes work on the latest version of the SRI brittle fracture subroutine. Volume II is the manual for the one-dimensional wave propagation code SRI PUFF 8.

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1. INTRODUCTION

The TROTT code is a finite-difference computer program for treating two-dimensional stress wave propagation caused by impacts or explosive detonation in either planar or axisymmetric flow. Calculations are made with the Lagrangian form of the equations of motion so that the coordinates move with the materials. Artificial viscosity is used to spread wave fronts over several cells. This manual provides a preliminary description of the algebra of the code and exhibits input for several types of calculations.

The TROTT code was constructed largely as a means for exercising the special material models under construction at SRI. This emphasis is reflected in the special features of the code:

- The code can accommodate complicated material models with large amounts of storage per cell. The insertion procedure for new models and the provision for additional storage for cells are described in Appendices A and B.
- The code is simple and can be easily modified. Input decks are small (see the sample input decks in Appendix C).
- The cell layout is easy and permits flexibility in initializing velocity distributions.
- The code is core-contained.
- The TROTT cells are treated as finite elements for mass and momentum calculations.

Because of the code's simplicity, it runs about three times faster than standard two-dimensional codes. Two additional features are being added to improve the treatment of large deformation problems: elementary slide lines are available and an automatic rezoner has been written but is not in the current version of TROTT. Although the core-contained feature simplifies the code, it also restricts the size of problems that can be treated.

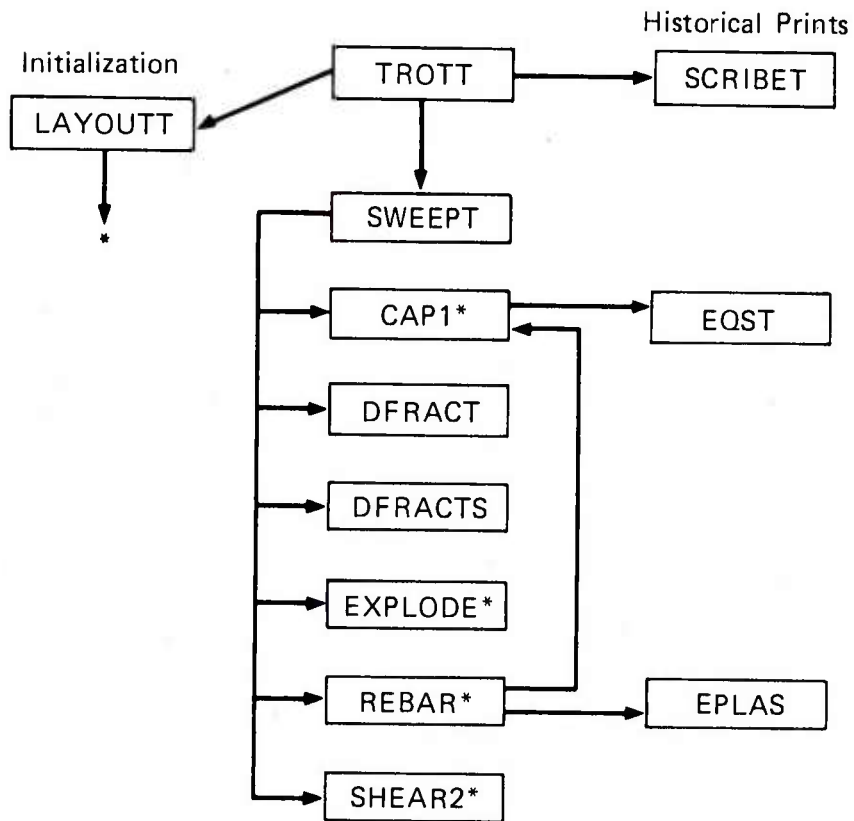
TROTT was derived independently, but it is similar to many other two-dimensional Lagrangian codes. Early codes of this type are HEMP (Ref. 1) and TOODY (Ref. 2). More recent developments are WAVEL (Ref. 3) and STEALTH (Ref. 4). These four are all large codes containing slide lines, rezoning, and buffering of cell variables, but they have difficulty in incorporating new material models with large numbers of variables per cell.

2. ORGANIZATION OF THE CODE

TROTT computes stress waves caused by impact or explosive detonation. The governing equations are numerically integrated by the leapfrog method of von Neumann and Richtmyer (Ref. 5). For the calculations, the material is divided into small cells or continuum elements. The computations proceed by stepping forward in time in small increments. At each increment, calculations are made of stress, velocity, displacement, and so on at each cell and coordinate point.

The primary routines of the program are TROTT (overall control), LAYOUTT (initialization), SWEEPT (propagation calculations for each cell), and SCRIBET (printing historical listings). The flow of program control is illustrated in Figure 1, which shows the relations between the subroutines and the main program. A brief description of the work of each subroutine follows:

- TROTT, the main program, sets the size of the variable storage, calls LAYOUTT for initialization, calls SWEEPT for propagation calculations, writes restart dumps and plot files, sets the time increments, and calls SCRIBET for historical listings.
- LAYOUTT zeroes arrays, reads input, lays out the cells, and initializes cell variables.
- SWEEPT performs a calculation for all cells at a time step at each call. It computes the coordinate velocities from momentum conservation, computes strains, and then either calculates stress or calls a material model subroutine to obtain the stress. This routine also stores variables for the historical listings.
- SCRIBET writes the historical listings at the end of a problem.
- REBAR computes stresses in a layered composite such as reinforced concrete (see Ref. 6).
- CAP1 provides stress and tensile fracture in a porous material with a combined Mohr-Coulomb yield and compaction behavior (see Ref. 6).



*Starred stress-strain routines are also called by LAYOUTT for initialization

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FIGURE 1 FLOW CHART OF TROTT

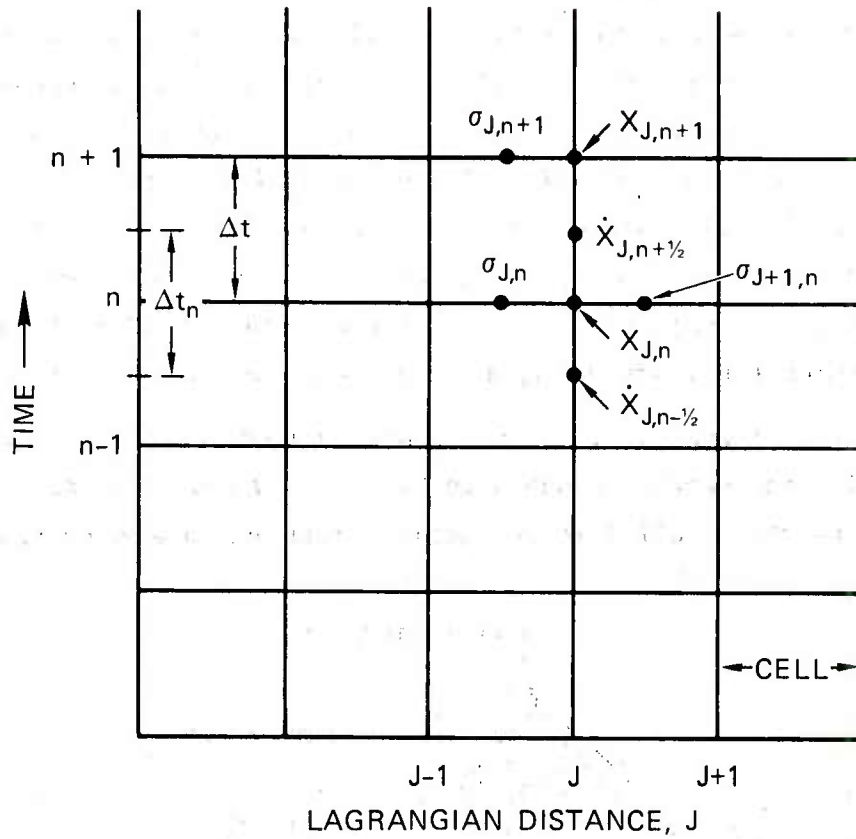
- EPLAS computes stress for a work-hardening elastic-plastic material (see Ref. 6).
- DFRACT computes stress and void growth in material undergoing ductile fracture (see Ref. 7).
- BFRACT provides stress and crack growth in material undergoing brittle fracture (see Refs. 7,8).
- SHEAR2 computes stress and damage for material undergoing shear banding (see Ref. 9).
- DFRACTS computes stress and void growth for static ductile fracture (see Ref. 10).
- EXPLODE provides pressure in explosives (described in Appendix D).

A listing of the program and all subroutines is provided in Appendix E. Appendix F is a glossary of the nomenclature used in the equations of this report and the nomenclature used for input quantities and other major variables in the computer program.

3. PROPAGATION CALCULATIONS: SWEEP

The motion and stresses throughout the material are determined as a function of time in the code. The solution is effected by solving the mass, momentum, and energy conservation relations together with constitutive relations for the material as outlined in this section.

The material is first divided into discrete units or cells. Motions, energies, and other quantities are initialized in cells as required for the particular problem. Then the propagation calculations begin. As a guide in understanding the relationship of the conservation relations, constitutive relations, and the solution procedure, Figure 2 shows the cell quantities on a time-distance plot. For simplicity, Figure 2 contains only one independent spatial direction (Eulerian X or Lagrangian J). Coordinate quantities (location and velocity) are defined only at cell boundaries and at full or half-time increments. All other quantities (such as stress) are determined at cell midpoints and full time increments. The momentum calculation (or $F = Ma$) is used to determine velocity changes. For example, in Figure 2, the stresses $\sigma_{J,n}$ and $\sigma_{J+1,n}$ in adjacent cells at the n^{th} time step determine the forces on the mass centered at point (J,n) . The acceleration of this mass determines the change in velocity $\dot{X}_{J,n-1/2}$ to $\dot{X}_{J,n+1/2}$. From the new velocity, the coordinate position $X_{J,n+1}$ is obtained. With the coordinate positions at time $n+1$ known, the strains and density are also obtainable. Next the stresses such as $\sigma_{J,n+1}$ are calculated from the strains and density, using the constitutive relations. The procedure is continued to the right through each cell for each time increment. This process of stepping forward in time and performing calculations for each cell is repeated until the time has reached the duration of interest. The time step is controlled by the stability and smoothness criteria described in this section. Following the motion calculations, the strain increments are computed.



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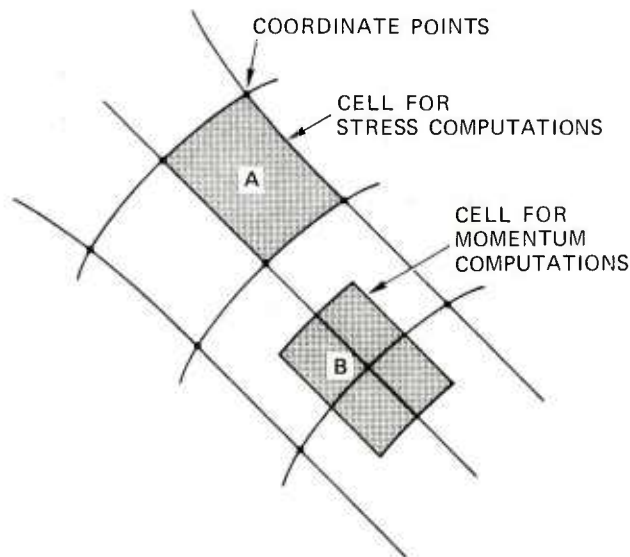
FIGURE 2 FINITE-DIFFERENCE GRID SHOWING LOCATIONS OF VARIABLES USED IN THE MOMENTUM CONSERVATION RELATIONS

3.1 Solution of Conservation Relations

The conservation relations for mass, momentum, and energy are the basic equations governing the wave propagation process. Mass conservation is effected in the code by using Lagrangian cells that maintain a constant mass throughout the problem. Momentum conservation relations are used to obtain the coordinate motions, and energy conservation is the basis of the internal energy calculation. First, momentum conservation is treated here, then the energy computation.

In deriving momentum conservation relations, it is possible to use a discretization of the differential equations of momentum conservation or to consider force balances around a finite element. The following derivation uses the second point of view, a finite element. Therefore, the steps in the calculation are to isolate a volume element for which the acceleration and velocity are computed, compute the forces acting on that element, and compute the mass of the element. Quadrilateral cells, the more common type, are treated first, and then triangular cells.

Two types of quadrilateral cells are defined for the wave propagation calculation. Both are shown in Figure 3, which contains a grid of coordinate points. Cell A is the natural cell surrounded by four



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FIGURE 3 TYPES OF CELLS FOR STRESS AND MOMENTUM COMPUTATIONS

coordinate points. This is the cell for which the strains and stresses, which are homogeneous throughout each cell, are computed. The momentum computation determines the velocity of the coordinate points. For these calculations cell B, containing the mass around a coordinate point, is used. The calculations are broken into four portions corresponding to the parts lying in each of the surrounding stress cells. One typical portion is shown in Figure 4 with the nomenclature and sign conventions that are used in the derivation of momentum conservation or velocity change at point 3. (Stress is positive in tension.) Note that the standard axisymmetric shell is a ring or doughnut, whereas the planar cell is quadrilateral with indefinite thickness in the Z direction.

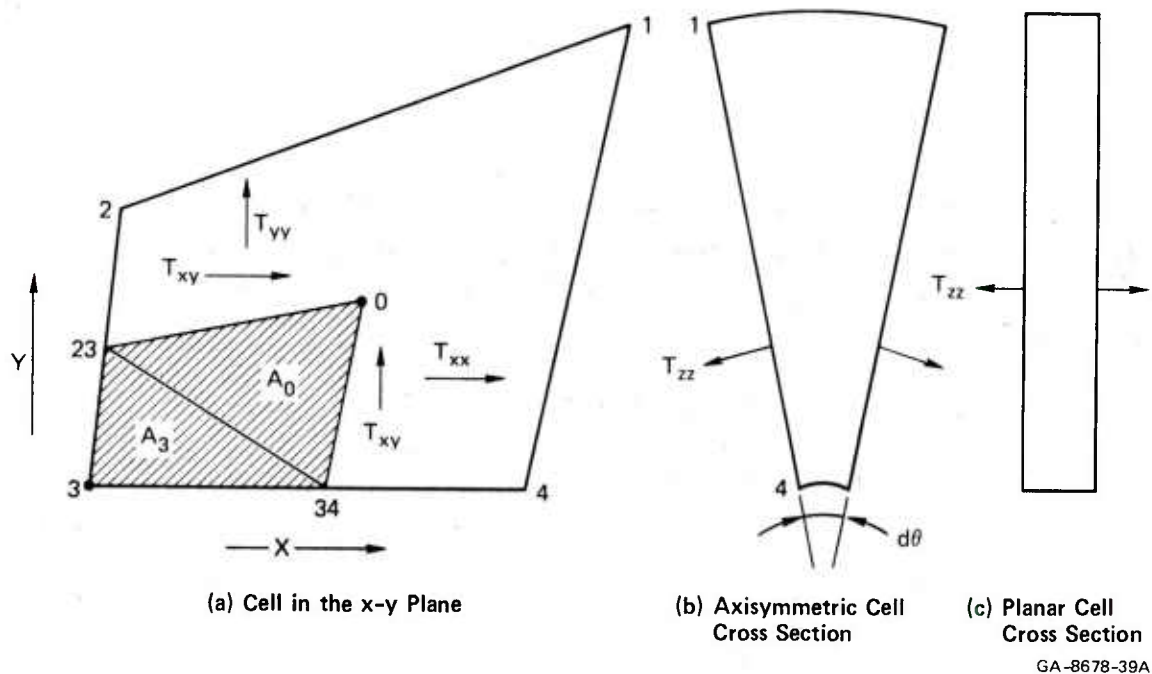


FIGURE 4 STRESS AND COORDINATE NOMENCLATURE FOR AXISYMMETRIC AND PLANAR CELLS

The configuration of the shaded element in Figure 4 is defined in such a way that the x and y coordinates of the point 0 are averages of

the coordinates at the four corners of the stress cell. End views are shown in Figure 4 as a reminder of the three-dimensional character of the elements. For an axisymmetric cell, the areas of the shaded element on which stresses act in the x and y directions are:

$$A_{xx} = \frac{d\theta}{4}(y_2 - y_4) \left(\frac{y_2 + y_4}{2} + y_3 \right) \quad (1)$$

$$A_{yy} = \frac{d\theta}{2} \left[\left(\frac{y_2 + y_3}{2} + y_0 \right) \left(x_0 - \frac{x_2 + x_3}{2} \right) - \left(\frac{y_3 + y_4}{2} + y_0 \right) \left(x_0 - \frac{x_3 + x_4}{2} \right) \right] \quad (2)$$

For planar cells the areas in the x and y directions are:

$$A_{xx} = \frac{1}{2}(y_2 - y_4) \quad (3)$$

$$A_{yy} = \frac{1}{2}(x_4 - x_2) \quad (4)$$

For the axisymmetric case, the area in the x-y plane on which the stress acts is broken into two portions A_0 and A_3 as shown in Figure 4. These portions and the total are:

$$A_0 = \frac{1}{8}[(2x_0 - x_3)(y_2 - y_4) + x_2(y_3 + y_4 - 2y_0) + x_4(2y_0 - y_2 - y_3)] \quad (5)$$

$$A_3 = \frac{1}{8}[x_4(y_2 - y_3) + x_3(y_4 - y_2) + x_2(y_3 - y_4)] \quad (6)$$

$$A_{xy} = A_0 + A_3 \quad (7)$$

Equations (5) and (6) are derived by simplifying the usual general relations for the area of a triangle.

The forces in the x and y directions applied to the small mass represented by the shaded area in Figure 4 are determined by multiplying the

stresses shown in Figure 4 times the areas in Eqs. (1)-(4) and (7). The expressions for the forces are:

$$F_x = T_{xy} A_{yy} + T_{xx} A_{xx} \quad (8)$$

and

$$\begin{aligned} F_y &= T_{yy} A_{yy} + T_{xy} A_{xx} - T_{zz} A_{xy} d\theta \quad (\text{axisymmetric}) \\ &= T_{yy} A_{yy} + T_{xy} A_{xx} \quad (\text{planar}) \end{aligned} \quad (9)$$

For the axisymmetric case, each force term contains the angle $d\theta$, which is left undefined. When force is divided by mass to obtain the velocity change, $d\theta$ is removed. The sign convention for the area computations is such that the product of stress and area is positive in the increasing x and y directions. Because each cell is written with point 3 as the one for which velocity is to be determined, the preceding forces and areas are valid for all quadrilateral cells around the point.

The mass of the small element is determined by multiplying the average density, ρ , of the cell shown in Figure 4 times the volume of the element. The axisymmetric cell mass is as follows:

$$M = \rho \frac{d\theta}{3} \left[A_0 \left(y_0 + y_3 + \frac{y_2 + y_4}{2} \right) + A_3 \left(\frac{y_2 + y_4}{2} + 2y_3 \right) \right] \quad (10)$$

For the planar cells the mass is simply

$$M = \rho A_{xy} \quad (11)$$

Newton's second law is applied to obtain the change in velocity at the coordinate point 3, considering force and mass contributions from four quadrilateral elements around the point. (The index i runs over these elements.)

$$\Delta \dot{x} = \dot{x}_{n+1/2} - \dot{x}_{n-1/2} = \frac{\sum_{i=1}^4 F_{xi} \Delta t_n}{\sum_{i=1}^4 M_i} \quad (12)$$

where $\Delta \dot{x}$ is the change in velocity in the x direction over the time increment Δt_n . A similar relation is used for $\Delta \dot{y}$. The spatial and temporal relationships between the cell variables are shown in Figure 2.

Triangular cells are provided in TROTT by allowing the user to divide some quadrilateral cells into triangles with the orientation shown in Figure 5. The changes in the momentum equations to account for triangular cells are considered here. For the quadrilateral cells in the upper right and lower left corners of Figure 5, only one triangular cell is adjacent to the point 3. Therefore, the stresses, areas, and masses are derived entirely from that cell, and the previously derived equations are used. However, the coordinates of point 0 (Figure 4) are given by

$$x_0 = 1/2(x_2 + x_4) \quad (13)$$

$$y_0 = 1/2(y_2 + y_4)$$

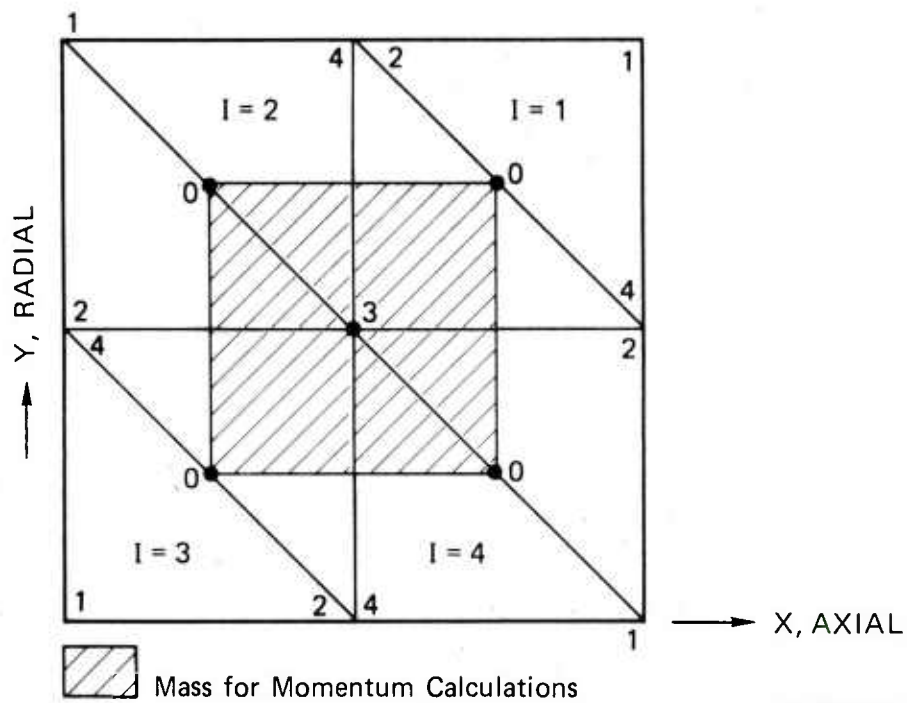
The mass and force contributions of the remaining four triangular cells in the upper left and lower right corners are determined separately and then summed. The area A_{xy} is computed as usual for a triangle:

$$A_{xy} = 1/8 \left[x_4(y_1 - y_3) + x_3(y_4 - y_1) + x_1(y_3 - y_4) \right] \quad (14)$$

for a triangle with vertices at points 1, 3, and 4, and

$$A_{xy} = 1/8 \left[x_1(y_2 - y_3) + x_2(y_3 - y_1) + x_3(y_1 - y_2) \right] \quad (15)$$

for a triangle with vertices at 1, 2, and 3. For this same 1-2-3 triangle, the areas of axisymmetric cells in the x and y directions are



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FIGURE 5 FOUR QUADRILATERAL CELLS DIVIDED INTO TRIANGULAR CELLS, PLUS THE MASS AT POINT 3 USED FOR MOMENTUM CALCULATIONS

$$\begin{aligned}
A_{xx} &= \frac{d\theta}{8}(y_2 - y_1)(y_2 + 2y_3 + y_1) \\
A_{yy} &= \frac{d\theta}{8}(x_1 - x_2)(y_2 + 2y_3 + y_1)
\end{aligned}
\tag{16}$$

For planar cells, the areas are

$$\begin{aligned}
A_{xx} &= 1/2(y_2 - y_1) \\
A_{yy} &= 1/2(x_1 - x_2)
\end{aligned}
\tag{17}$$

Areas for the 1-3-4 triangle are derived by a permutation of indices. Masses of the cells are obtained from an adaptation of Eq. (10) or (11).

Following calculation of the areas and masses of triangular cells, Eq. (12) is used to obtain the new velocity.

3.2 Strain Computation

The strain computations in the two-dimensional wave propagation program are based on the assumption that the strains are uniform throughout each quadrilateral cell of type A shown in Figure 3 and each triangular cell in Figure 5. The required strains are true strains. The strain computations are constructed to meet the following compatibility requirements:

$$\epsilon_x + \epsilon_y = \frac{\Delta A}{A} \tag{18}$$

$$\epsilon_x + \epsilon_y + \epsilon_z = \frac{\Delta V}{V} \tag{19}$$

where

$\epsilon_x, \epsilon_y, \epsilon_z$ = changes in the strain that occur during a time increment

ΔA = change in the cell area A in the x-y plane

ΔV = change in the volume V of the cell.

To ensure that compatibility of strains is enforced, we assume a velocity field (which is unique), rather than a strain field. Strains that are uniform throughout a cell are produced by the following linearly varying velocity field.

$$u = u_0 + u_x x + u_y y \quad (20)$$

$$v = v_0 + v_x x + v_y y \quad (21)$$

where u, v = particle velocity in the x, y directions, respectively.

The strain rates corresponding to these velocities are:

$$\dot{\epsilon}_x = \frac{\partial u}{\partial x} = u_x \quad (22)$$

$$\dot{\epsilon}_y = \frac{\partial v}{\partial y} = v_y \quad (23)$$

$$\dot{\epsilon}_{xy} = \frac{1}{2} \left(\frac{\partial v}{\partial x} + \frac{\partial u}{\partial y} \right) = \frac{1}{2} (v_x + u_y) \quad (24)$$

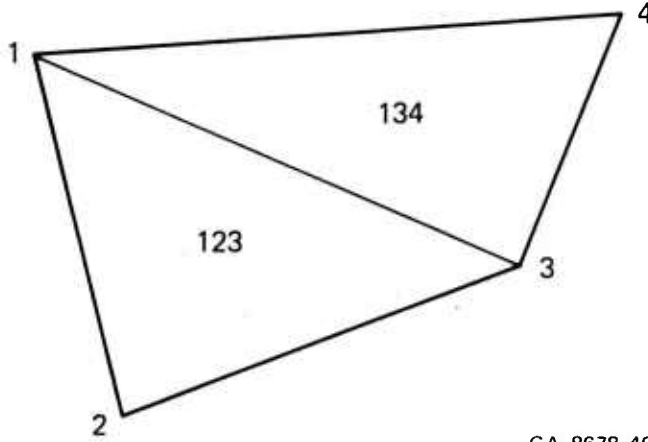
$$\dot{\omega}_{xy} = \frac{1}{2} \left(\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y} \right) = \frac{1}{2} (v_x - u_y) \quad (25)$$

where

$$\dot{\epsilon}_{xy} = \text{tensor shear strain rate}$$

$$\dot{\omega}_{xy} = \text{rotation rate in the } xy \text{ plane.}$$

The velocity fields of Eqs. (20) and (21) can be determined for any triangle if the velocities at the coordinate points are known. Consider for example the triangle in Figure 6 with coordinates 1, 2, and 3 and velocities in the x direction of u_1, u_2 , and u_3 . The velocity field parameters u_0, u_x , and u_y can then be determined from the following three equations:



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FIGURE 6 QUADRILATERAL ELEMENT PRODUCED FROM TWO TRIANGLES

$$\begin{aligned}
 u_1 &= u_0 + u_x x_1 + u_y y_1 \\
 u_2 &= u_0 + u_x x_2 + u_y y_2 \\
 u_3 &= u_0 + u_x x_3 + u_y y_3
 \end{aligned}
 \tag{26}$$

where the x_i, y_i are coordinates of the i^{th} point at some (as yet undetermined) time. Solution of Eqs. (26) gives the following results for u_x and u_y :

$$u_x = \frac{(u_1 - u_2)(y_1 - y_3) - (u_1 - u_3)(y_1 - y_2)}{2A}
 \tag{27}$$

$$u_y = - \frac{(u_1 - u_2)(x_1 - x_3) - (u_1 - u_3)(x_1 - x_2)}{2A}
 \tag{28}$$

where A , the area of the triangle 123 shown in Figure 6, is

$$\begin{aligned}
 2A &= (x_1 - x_2)(y_1 - y_3) - (x_1 - x_3)(y_1 - y_2) \\
 &= x_1(y_2 - y_3) + x_2(y_3 - y_1) + x_3(y_1 - y_2)
 \end{aligned}
 \tag{29}$$

Similarly the strain in the y direction can be determined.

$$v_x = \frac{(v_1 - v_2)(y_1 - y_3) - (v_1 - v_3)(y_1 - y_2)}{2A} \quad (30)$$

$$v_y = - \frac{(v_1 - v_2)(x_1 - x_3) - (v_1 - v_3)(x_1 - x_2)}{2A} \quad (31)$$

The next step is to specify x_i , y_i in Eqs. (27) through (31) in such a way that Eq. (18) is satisfied. This calculation is performed in two steps: first, the requirements are satisfied for each of the two triangles shown in Figure 6 and then the computation is made for the whole quadrilateral. To meet the requirement for triangle 123, the area A of Eq. (29) is taken as the average of the areas at the beginning and end of the time increment, that is,

$$A = \frac{1}{2}(A^0 + A^1) \quad (32)$$

A compatible form for the strain rate in the x direction is given by

$$\dot{\epsilon}_x = \frac{A^0 u_x^0 + A^1 u_x^1}{A^0 + A^1} \quad (33)$$

where values with a superscript 0 are computed with initial values of x and y, and values with a superscript 1 are evaluated with final values of x and y. These final values of coordinates are

$$x_i^1 = x_i^0 + u_i \Delta t \quad (34)$$

$$y_i^1 = y_i^0 + v_i \Delta t$$

Next we test the compatibility in Eq. (18) by substituting A from Eq. (32) (replacing the coordinates in A^1 with their values from Eq. 34), the strains from Eq. (33), and a comparable relation for ϵ_y , and letting $\Delta A = A^1 - A^0$. Then Eq. (18) is satisfied exactly, indicating that the expression for strain in Eq. (33) meets the first compatibility requirement.

For use in the computer program, Eq. (33) takes the form

$$\dot{\epsilon}_x = \frac{u_{12}^m y_{13} - u_{13}^m y_{12}}{A^0 + A^1} \quad (35)$$

and

$$\dot{\epsilon}_y = \frac{v_{13}^m x_{12} - v_{12}^m x_{13}}{A^0 + A^1} \quad (36)$$

for a 1-2-3 triangle, where the doubly subscripted velocities and coordinates have the following meaning

$$u_{ij} = u_i - u_j \quad (37)$$

$$x_{ij}^m = x_i - x_j + 1/2(u_i - u_j)\Delta t \quad (38)$$

The above result is extended to the full quadrilateral by using the following definition of the strain rate

$$\dot{\epsilon}_x = \frac{A_1^{00} u_{1x} + A_1^{11} u_{1x} + A_2^{00} u_{2x} + A_2^{11} u_{2x}}{A_1^0 + A_1^1 + A_2^0 + A_2^1} \quad (39)$$

where subscript 1 refers to the triangle 123 and subscript 2 to triangle 134 in Figure 6. For satisfying Eq. (18) the area A is taken as one-half the denominator in Eq. (39), that is, the average of the areas at the beginning and end of the time increment.

For use in the computer program, Eq. (39) is recast into the following form with the aid of Eqs. (27) - (31), (37) and (38):

$$\dot{\epsilon}_x = \frac{u_{13}^m y_{24}^m - u_{24}^m y_{13}^m}{A^0 + A^1} \quad (40)$$

Similarly

$$\dot{\epsilon}_y = \frac{v_{24}^m x_{13}^m - v_{13}^m x_{24}^m}{A^0 + A^1} \quad (41)$$

$$\dot{\epsilon}_{xy} = \frac{u_{24}^m x_{13}^m - u_{13}^m x_{24}^m + v_{13}^m y_{24}^m - v_{24}^m y_{13}^m}{2(A^0 + A^1)} \quad (42)$$

$$\dot{\omega}_{xy} = \frac{u_{13}^m x_{24}^m - u_{24}^m x_{13}^m + v_{13}^m y_{24}^m - v_{24}^m y_{13}^m}{2(A^0 + A^1)} \quad (43)$$

The requirement given by Eq. (19) is met somewhat more readily in the computer program. The values of $\dot{\epsilon}_x$ and $\dot{\epsilon}_y$ are first determined from Eqs. (40) and (41), and the specific volume change is determined from calculations of the volume before and after a time step. The volume change is from a density calculation, which is in turn based on the mass conservation relations. The mass of an axisymmetric cell is computed from

$$M_s = \int \frac{d\theta}{3} \sum_i A_i \sum_j y_{ij} = \frac{2\pi}{3} \sum_i A_i \sum_i y_{ij} \quad (44)$$

where A_i is the area of the i^{th} triangle in the xy plane and y_{ij} are the radial positions of the vertices. For simplicity, $2\pi/3$ is dropped in the program and the mass is stored in the Z array as

$$Z = \frac{3\pi}{2} M \quad (45)$$

For the planar cells, the mass is simply

$$M = Z = \rho A_{xy} \quad (46)$$

Then during strain calculations, the density is determined by

$$\rho = \frac{Z}{A_{xy}} \quad (47)$$

for example, using Eq. (46). The relative volume change required in Eq. (19) is then

$$\frac{\Delta V}{V} = \frac{2(\rho_1 - \rho_2)}{\rho_1 + \rho_2} \quad (48)$$

where ρ_1 and ρ_2 are densities before and after the current time increment. With $\dot{\epsilon}_x$, $\dot{\epsilon}_y$, and $\Delta V/V$ known, $\dot{\epsilon}_z$ is obtained from Eq. (19), and the volume constraint is satisfied exactly.

3.3 Energy Calculations

The internal energy is computed from the conservation of energy equation at two points. First, an approximate estimate is made just preceding the stress calculation; then a refined value is obtained following the stress calculation.

The conservation of energy expresses the balance between internal energy and strain energy:

$$E = E_o + V \sum_{ij} \sigma_{ij} d\epsilon_{ij} \quad (49)$$

where E, E_o = internal energies at the end and beginning of the time increment

V = specific volume

$\sigma_{ij}, \epsilon_{ij}$ = tensor stress and strain values.

In the TROTT code, the first internal energy calculation immediately follows the determination of density and strain, but the only stresses available are those from the previous time step. In the computation, the stresses σ_{ij} are separated into a pressure and a deviator stress σ'_{ij} . With the introduction of the artificial viscous stress Q , the computer program form of Eq. (49) is

$$E = E_o + V(\sigma'_{xxo} \Delta\epsilon_x + \sigma'_{yyo} \Delta\epsilon_y + \sigma'_{zzo} \Delta\epsilon_z + 2\sigma'_{xyo} \Delta\epsilon_{xy}) - (P_o + Q)(V - V_o) \quad (50)$$

where σ'_{xxo}, P_o , etc., are stresses and pressures from the previous time increment. The sign convention in Eq. (50) reflects the fact that stresses and strains are positive in tension, but pressures are positive in compression.

Following the stress computation, the energy computation is repeated, this time using the linear approximation

$$\frac{\sigma_{ij1} + \sigma_{ij0}}{2} \Delta\epsilon_{ij} = \int \sigma_{ij} d\epsilon_{ij} \quad (51)$$

where σ_{ij1} is stress from the current time. Then Eq. (49) becomes

$$E = E_o + V \left[\frac{\sigma_{xx1} + \sigma_{xxo}}{2} \Delta\epsilon_x + \frac{\sigma_{yy1} + \sigma_{yyo}}{2} \Delta\epsilon_y + \frac{\sigma_{zz1} + \sigma_{zzo}}{2} \Delta\epsilon_z + (\sigma_{xy1} + \sigma_{xyo}) \Delta\epsilon_{xy} \right] - \left(\frac{P + P_o}{2} + Q \right) (V - V_o) \quad (52)$$

The energy approximation in Eq. (50) is used in the subsequent stress calculation. Normally, this energy approximation does not lead to serious errors because the energies are changing gradually in problems treated with TROTT. Very sharp shock fronts at high stresses would not be simulated accurately with the preceding energy calculation. The energy calculation in Eq. (52) is used to obtain the energy, which is stored in the cell array for the next calculational cycle.

3.4 Artificial Viscous Stress

An artificial viscous stress is required in finite-difference wave propagation calculations to smooth out shock waves so that the entire flow field can be treated by the conservation equations of continuous flow. In multidimensional calculations, a triangular artificial viscous stress is also required to combat certain types of cell distortion. Here we describe first the standard artificial viscosity and its implementation in the code.

The artificial viscous stress (Q) is added to the thermodynamic equilibrium stress (σ) from the constitutive relations to produce the nonequilibrium mechanical stress (T). The mechanical stress is therefore the total stress acting between masses and is the appropriate stress for the momentum calculations exhibited earlier. The artificial viscous stress represents real stresses occurring in the nonequilibrium states of a shock front, but the basis for computing Q is artificial because it depends on the computational cell size and on viscosity coefficients that are not derived from physical processes.

In TROTT the usual linear and quadratic forms of artificial viscosity are provided. Both are related to the rate of compression of the material and are zero while the material is extending. For positive density changes, the linear and quadratic stresses are

$$Q_1 = C_1 C_s \sqrt{A_{xy}} \frac{\Delta \rho}{\Delta t} \quad (53)$$

$$Q_2 = \frac{C_o^2 A_{xy}}{\rho} \left(\frac{\Delta \rho}{\Delta t} \right)^2 \quad (54)$$

where

C_1 = coefficient of linear artificial viscosity

C_s = sound speed

C_o = coefficient of quadratic artificial viscosity.

The artificial stress Q is the sum of the linear and quadratic contributions from Eqs. (53) and (54).

The nominal values of the artificial viscosity coefficients are

$$C_1 = 0.15$$

$$C_o^2 = 4.0$$

These values are appropriate for most problems. If sharper definition of shock fronts is required, C_1 could be reduced to as low as 0.05. For more rapid smoothing of wave fronts for quasi-static problems, C_1 could be increased to 0.5.

The triangular artificial viscous stress is used to minimize a type of cell distortion termed hour-glassing (shown in Figure 7). Hour-glassing is a parasitic behavior that is not corrected by the normal momentum, strain, and constitutive relations previously outlined. The motion shown in Figure 7 gives rise to zero values of ϵ_x , ϵ_y , and ϵ_{xy} . Also, stresses in the cell acting on the coordinates would be applied equally to all four coordinates and could not simultaneously pull inward on points 1 and 2, and push out on 3 and 4 to correct the behavior.

The hour-glassing motion in quadrilateral cells represents two additional degrees of freedom that arise because of the averaging process used in calculating the strains (Section 3.2). A triangular cell does not exhibit hour-glassing because the 3 coordinate points have just six

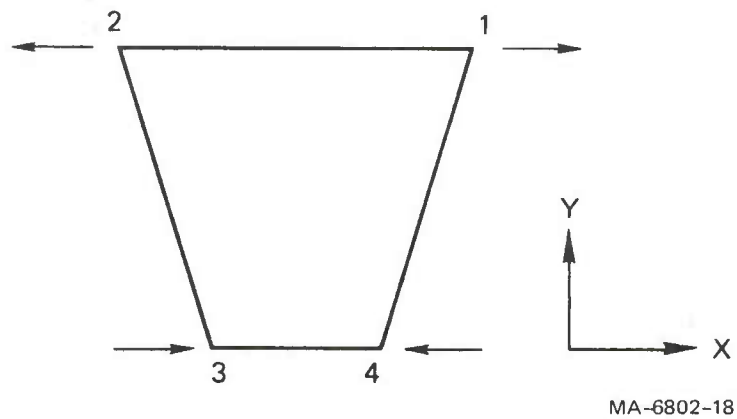


FIGURE 7 A QUADRILATERAL WITH COORDINATE VELOCITIES THAT LEAD TO HOUR-GLASSING

degrees of freedom that can be represented by two rigid body translations, one rotation (ω_{xy}) and three strains. The quadrilateral cell has eight degrees of freedom, but only the same six motions and strains as for the triangular cell are accounted for in the equations that provide the resistance to the motions. The triangular artificial viscosity provides resistance to the hour-glassing motion that arises because of the extra degrees of freedom.

The triangular artificial viscosity is calculated as part of the momentum relations instead of with the other stress calculations. These triangle stresses are computed as a function of the distortion of the triangle 2-3-4 (Figure 5), which is adjacent to point 3, the point of focus of the momentum calculations. From the strain rates in this triangle, the following stresses are computed according to the derivation of Wilkins (Ref. 1):

$$Q_{xx} = T_q \sqrt{A_{xy}} C_s \rho (2\dot{\epsilon}_x - \dot{\epsilon}_y) \quad (55)$$

$$Q_{yy} = T_q \sqrt{A_{xy}} C_s \rho (2\dot{\epsilon}_y - \dot{\epsilon}_x) \quad (56)$$

$$Q_{xy} = 3.0 T_q \sqrt{A_{xy}} C_s \rho \dot{\epsilon}_{xy} \quad (57)$$

where T_q = the dimensionless viscosity coefficient

A_{xy} = the area of the triangle

C_s = the sound speed

ρ = density

$\dot{\epsilon}_x, \dot{\epsilon}_y, \dot{\epsilon}_{xy}$ = strain rates derived as in Section 3.2 for the triangle. Equations (55) to (57) are written so that the Q's are proportional to the appropriate deviator stress, assuming $\dot{\epsilon}_z = 0$.

The triangle Q's are added into the force equations (8) and (9),
to obtain

$$F_x = (T_{xy} + Q_{xy})A_{yy} + (T_{xx} + Q_{xx})A_{xx} \quad (58)$$

for Eq. (8) and a similar result for Eq. (9).

Now we can examine how the triangle Q works to inhibit hour-glassing. These stresses are computed separately for each of the near triangles around the four coordinate points in Figure 7. For instance, with the velocity configuration in Figure 7, Q_{xx} is tensile at points 1 and 2 and compressive at points 3 and 4. Thus, the Q forces tend to counteract the hour-glassing motion. With a coefficient of $T_q = 0.02$, a velocity pattern such as that in Figure 7 will be damped out in about 25 time steps.

3.5 Time Step Control

For the calculations to proceed in a stable manner, the time increment between cycles must be kept smaller than that given by the Courant-Friedrichs-Lewy conditions (Ref. 11). In this criterion the maximum permitted time increment is

$$\Delta t = \frac{\Delta x}{C_e} \quad (59)$$

where Δx = the minimum cell dimension

C_e = the local effective sound speed

In the computer program, the criterion in Eq. (59) is evaluated in five steps.

- (1) Δx is computed as the minimum width for each cell.
- (2) An effective modulus is computed, and from this a local sound speed, C' .

- (3) A natural time step $\Delta t' = \Delta x/C'$ is computed for each cell.
- (4) The minimum of all the time steps $\Delta t'$ is selected.
- (5) The minimum time step is adjusted to account approximately for the triangle artificial viscosity.

The second and fifth steps are described in more detail below.

Here the effective sound speed is determined by summing the stiffness from all factors that contribute to the mechanical stress. The effective modulus for the time increment is given by a sum of ratios of stress increments divided by the strain increments:

$$M_e = \frac{\Delta P + 2Q}{-\frac{\Delta V}{V}} + \max \frac{\frac{2}{3} \Delta \sigma'_i}{\Delta \epsilon'_i} \quad (60)$$

where P = the change in pressure during the increment

Q = the artificial viscous stress

$\Delta V/V$ = the relative volume change

$\Delta \sigma'_i$ = the change in deviator stress in the i^{th} direction

$\Delta \epsilon'_i$ = the deviator strain increment in the i^{th} direction.

The second term on the right-hand side of Eq. (60) is taken as the maximum value in the three principal directions. Because the maximum value of this term is given by the elastic relation, this term can be replaced by $4G/3$, where G is the shear modulus. The factor 2 in the Q term arises because Q is computed at the half time step, providing twice the stiffness that would occur if Q were centered at the full time step. Then the effective sound speed for the cell is

$$(C')^2 = \frac{M_e}{\rho} = \frac{\Delta P + 2Q}{-\Delta V} + \frac{4G}{3\rho} \quad (61)$$

It can be shown (Ref. 12) that Eq. (61) exactly represents the stability condition derived by Herrmann (Ref. 2) for linear and quadratic artificial viscosity. For small strains, C' is taken as the usual longitudinal sound speed.

To account for the additional stiffness associated with the triangle artificial viscosity, a further adjustment is made in the time step obtained using C' .

An approximate adjustment to account for the triangle artificial viscosity is derived by noting the parallel between the expressions for the triangle Q and the linear viscous term (Eqs. 55-57 and Eq. 53). The adjustment for the linear viscosity is given by Herrmann (Ref. 2) as

$$\Delta t = \frac{\Delta x}{C_s} [\sqrt{1 + C_1^2} - C_1] \quad (62)$$

Then we can replace C_1 by $3T_q$ (the factor of 3 occurs because $2\dot{\epsilon}_x - \dot{\epsilon}_y$ in Eq. 55 is three times the deviator strain rate) and neglect the T_q^2 term because T_q is very small. The final form of Eq. (59) is then

$$\Delta t = \min \left(\frac{\Delta x}{C_s} \right) (1 - 3T_q) \quad (63)$$

This time step includes the effects of bulk stiffness, shear stiffness, and the three artificial visious stiffnesses. The foregoing equations are used in TROTT to determine the permissible time increments.

3.6 Slide Lines

A preliminary slide line capability has been incorporated into TROTT to permit slip of one material past another. Although several slide line problems have been run successfully, the coding has not been tested on arbitrarily complex problems. No opening and closing routine is present, no shear is transmitted across the slide line, and the lines are active from the beginning of the calculation (no provision for unzipping during

the calculation). Sliding can occur along lines of constant K or J but not along both simultaneously.

For a slide line between cells, two rows of coordinates are provided, one set for cells on either side. One side is designated the master and the other the slave side. The slave coordinate points are required to slide along the master cell boundaries, and need not coincide with the master coordinate points at any time. Because the slide line shape is determined by the master cells, the master side should be the material with the higher shear modulus and/or higher density. The forces for the momentum computations are computed from the stresses in both master and slave cells to determine the new velocities of the master coordinates. Only the forces on the slave side are used to move the slave coordinates, but then the slave coordinate positions are adjusted to avoid penetration of the master cells. This adjustment is made without testing for momentum conservation, so there may be some momentum loss along the slide line.

The K-slide treatment is designed to handle a slide along a line of nearly constant X, so the slave-side coordinate adjustments are of the X position only. The master coordinates are along $K = KSLIDE - 1$ and the slave coordinates are along $K = KSLIDE$, where KSLIDE is an input quantity. The J-slide case is for sliding along a line of nearly constant Y or radius; adjustments are made in the Y position only. The master coordinates are along $J = JSLIDE$ and the slave coordinates are along $J = JSLIDE - 1$, where JSLIDE is an input quantity. Input information for the slide lines is provided in Section 5 and Appendix C.

4. MATERIAL MODELS

The material models provide the stress as a function of density, strains, internal energy, and other quantities. This section describes common material models or constitutive relations in SWEEPT. If other models are required, they are written as subroutines and called by SWEEPT for stress computations. The switching procedure used to select the appropriate model is also described below.

4.1 Standard Constitutive Models

In the standard material models, the stress tensor is separated into a pressure and a deviator tensor. The pressure is the average stress

$$P = \frac{1}{3} \sum_i \sigma_{ii} \quad (64)$$

and the stress deviator elements are

$$\sigma'_{ij} = \sigma_{ij} - P\delta_{ij} \quad (65)$$

where σ_{ij} are stress tensor elements and δ_{ij} is the Kronecker delta. The pressure is usually given as a function of density and internal energy. The deviator stress is computed by elastic-plastic relations, which may include thermal softening, rate-dependent effects, and work hardening. Since TROTT is intended primarily for mechanical problems at stress levels common in engineering structures, the standard pressure model does not include melting and vaporization, and the deviator model does not include thermal softening. However, these effects could be added in special material models subroutines. The standard pressure and deviator models are presented below.

4.1.1 Standard Pressure Model

The pressure is computed from a simplified form of an equation of state, the locus of all possible thermodynamic equilibrium states for a substance. Each state is a set of values of the thermodynamic quantities: stress tensor, specific volume, entropy, specific internal energy, and temperature. In the simplified equation of state used in TROTT and in most wave propagation codes, the only variables considered are pressure (P) (the deviator components of stress are treated separately), specific volume (V) or density ($\rho = 1/V$), and internal energy (E). The equation of state is then

$$P = P(E,V) \quad (66)$$

which defines a surface or locus of points in energy-pressure-volume space.

An equation of state represents equilibrium states. Therefore, as a material undergoes gradual changes, such as heating or compression, the successive states describe a path on the equation-of-state surface. If the material is compressed by passing through a steady-state shock front, the initial and final states lie on the P-V-E surface. These initial and final states are connected by a straight line, the Rayleigh line, which does not lie on the surface, but above the P-V-E surface. Generally, equations of state describe the material behavior in solid, liquid, and gaseous phases, but the pressure model in TROTT represents only solid states.

The Mie-Grüneisen equation is used in TROTT to determine the pressure.

$$P = P_{REF} + \frac{\Gamma}{V} (E - E_{REF}) \quad (67)$$

where

P_{REF}, E_{REF} = coordinates of a point on some reference curve
at the same specific volume V

Γ = the Grüneisen ratio.

This expression provides a means for extending the information of a known P-V relationship (such as the Hugoniot) to other values of internal energy. Because the Hugoniot is the P-V relation that is most likely to be known, the computations are constructed with the Hugoniot as the reference curve. (The Hugoniot curve used here is the locus of final pressure, energy, and volume points reached by a shock front traveling into material under standard pressure and temperature conditions.) The Hugoniot P-V equation is presumed to be in the form

$$P_H = C\mu + D\mu^2 + S\mu^3 \quad (68)$$

where

$$\mu = \frac{\rho}{\rho_0} - 1 = \frac{V_0}{V} - 1$$

ρ_0, V_0 = the initial solid density and specific volume

C, D, S , = coefficients with the dimensions of pressure

C = the bulk modulus at low pressures.

The internal energy along the Hugoniot is

$$E_H = \frac{1}{2} P_H (V_0 - V) \quad (69)$$

Here the initial internal energy is assumed to be zero and the Hugoniot is concave upward throughout so that the shock follows a single Rayleigh line. Combining Eqs. (67) through (69) provides the pressure relation used in the computer program

$$P = (C\mu + D\mu^2 + S\mu^3) (1 - \Gamma\mu/2) + \Gamma\rho E \quad (70)$$

This calculation is performed following the density and strain computation and the approximate evaluation of E from Eq. (50).

4.1.2 Standard Deviator Stress Model

The deviator stress is the part of the stress tensor that arises because of the material's resistance to shearing deformation. In TROTT the standard model for deviator stress accounts for elastic response and plastic flow according to perfect plasticity. Here the relations are developed in a general form applicable to planar or axisymmetric flow.

Elastic Relations. The elastic relations between deviator stress and strain are cast in the following form

$$\sigma'_{ij} = 2G(\epsilon_{ij}^E - \frac{\delta_{ij}}{3} \Sigma \epsilon_{ii}^E) \quad (71)$$

$$= 2G\epsilon_{ij}^{\prime E} \quad (72)$$

where

σ'_{ij} = the deviator stress

$\epsilon_{ij}^E, \epsilon_{ij}^{\prime E}$ = total and deviatoric elastic strains

δ_{ij} = the Kronecker delta.

The deviator strain is defined as follows (as noted by comparing Eqs. 71 and 72):

$$\epsilon_{ij}^{\prime E} = \epsilon_{ij}^E - \frac{\delta_{ij}}{3} \Sigma \epsilon_{kk}^E \quad (73)$$

In elastic problems, all the strain is elastic, but in plastic cases, the total strain is separated into elastic and plastic components.

$$d\epsilon_{ij} = d\epsilon_{ij}^E + d\epsilon_{ij}^P \quad (74)$$

Plastic Relations. The Reuss or incremental plasticity relations are considered here. Yield occurs when the effective stress reaches the yield strength. The effective stress is defined by

$$\bar{\sigma} = \sqrt{\frac{3}{2} \sigma'_{ij} \sigma'_{ij}} \quad (75)$$

where the repeated subscripts indicate summation. The yield criterion is simply

$$\bar{\sigma} = Y \quad (76)$$

where Y is the yield strength. The Reuss flow rule indicates that the deviator stress in any direction is proportional to the plastic strain in that direction:

$$d\epsilon_{ij}^P = \sigma'_{ij} d\lambda \quad (77)$$

where $d\lambda$ is a proportionality constant. Now Hill (Ref. 13) defines a scalar plastic strain quantity as follows:

$$d\bar{\epsilon}^P = \sqrt{\frac{2}{3} d\epsilon_{ij}^P d\epsilon_{ij}^P} \quad (78)$$

As before, the repeated subscripts indicate summation. When we square Eq. (77) and make use of the definitions of $\bar{\sigma}$ and $d\bar{\epsilon}^P$, then

$$d\bar{\epsilon}^P = \frac{2}{3} \bar{\sigma} d\lambda \quad (79)$$

and

$$d\epsilon_{ij}^P = \sigma'_{ij} \frac{3d\bar{\epsilon}^P}{2\bar{\sigma}} \quad (80)$$

To obtain a solution for an increment of strain, we compute first a nominal stress σ_{ij}^N that would occur if the strain were entirely elastic.

$$\begin{aligned}
\sigma'_{ij}{}^N &= 2G(\epsilon'_{ijo}{}^E + \Delta\epsilon'_{ij}) = 2G(\epsilon'_{ijo}{}^E + \Delta\epsilon'_{ij}{}^E + \Delta\epsilon'_{ij}{}^P) \\
&= 2G(\epsilon'_{ij}{}^E + \Delta\epsilon'_{ij}{}^P)
\end{aligned} \tag{81}$$

where

$$\begin{aligned}
\epsilon'_{ijo}{}^E, \epsilon'_{ij}{}^E &= \text{elastic strains before and after the current strain increment} \\
\Delta\epsilon'_{ij}, \Delta\epsilon'_{ij}{}^E, \Delta\epsilon'_{ij}{}^P &= \text{total, elastic, and plastic strain increments.}
\end{aligned}$$

Through the use of Eqs. (72) and (80), the strains in the third equation of (81) can be replaced by expressions in σ'_{ij} .

$$\sigma'_{ij}{}^N = \sigma'_{ij} \left(1 + \frac{3G\Delta\epsilon'_{ij}{}^P}{\bar{\sigma}} \right) \tag{82}$$

Note that by using Eq. (80) we are relating the plastic strain increment to the stress σ'_{ij} at the end of the time step instead of to the average stress over the step. This approximation is satisfactory for small changes in stress direction. If both sides of Eq. (82) are squared and terms are summed to form a quantity $\bar{\sigma}^N$ in analogy to the definition of $\bar{\sigma}$ in Eq. (75), then we obtain

$$\bar{\sigma}^N = \bar{\sigma} \left(1 + \frac{3G \Delta\bar{\epsilon}^P}{\bar{\sigma}} \right) \tag{83}$$

Combining Eqs. (82) and (83) and using the yield condition (76), gives a solution for σ'_{ij} .

$$\sigma'_{ij} = \sigma'_{ij}{}^N \frac{Y}{\bar{\sigma}^N} \tag{84}$$

The elastic strain can be found from σ'_{ij} and the effective plastic strain is obtained from Eq. (83) with $\bar{\sigma} = Y$.

4.2 Switching for Complex Material Models

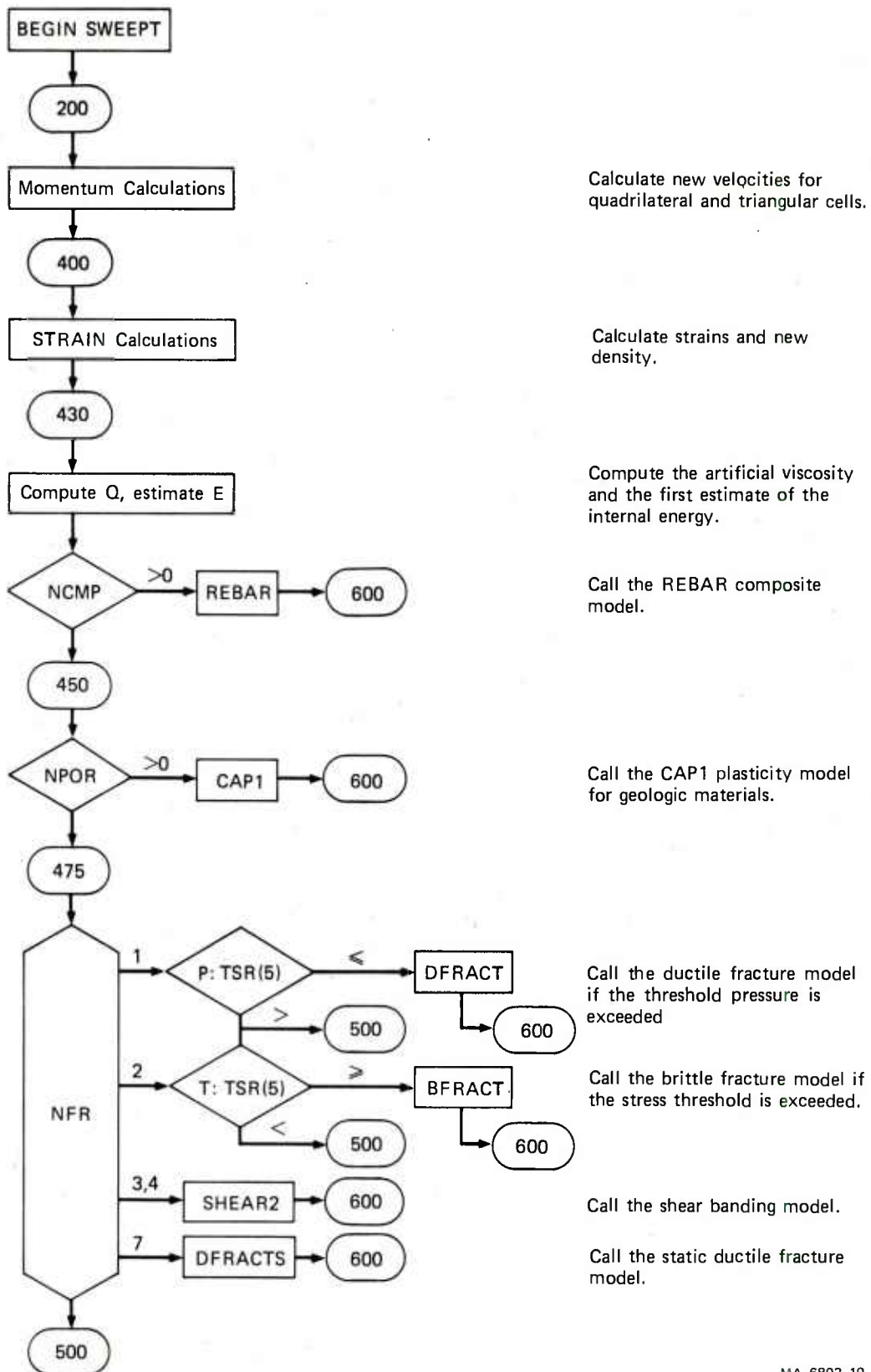
Constitutive or material models may take many forms besides the standard types presented above. Some of the available nonstandard models are introduced here and the portion of SWEEPT calling them in the code is described. Procedures for inserting new models are described in Appendix A.

Our work in porous materials, fracture, composites, and explosives has led us to require the use of very general material models. TROTT and SRI PUFF models were constructed to reflect these requirements. For example, in fracture calculations it should be possible to treat the material with a continuum model up to incipient fracture and then transfer to a fracture model. Composites should be simulated either by a single model or by a combination of models representing the constituents. If pressure and deviator stresses are treated separately for the material, then it should be possible to combine any pressure model with any deviator model. These general requirements have been followed in setting up model types.

At present five model types are accounted for in TROTT:

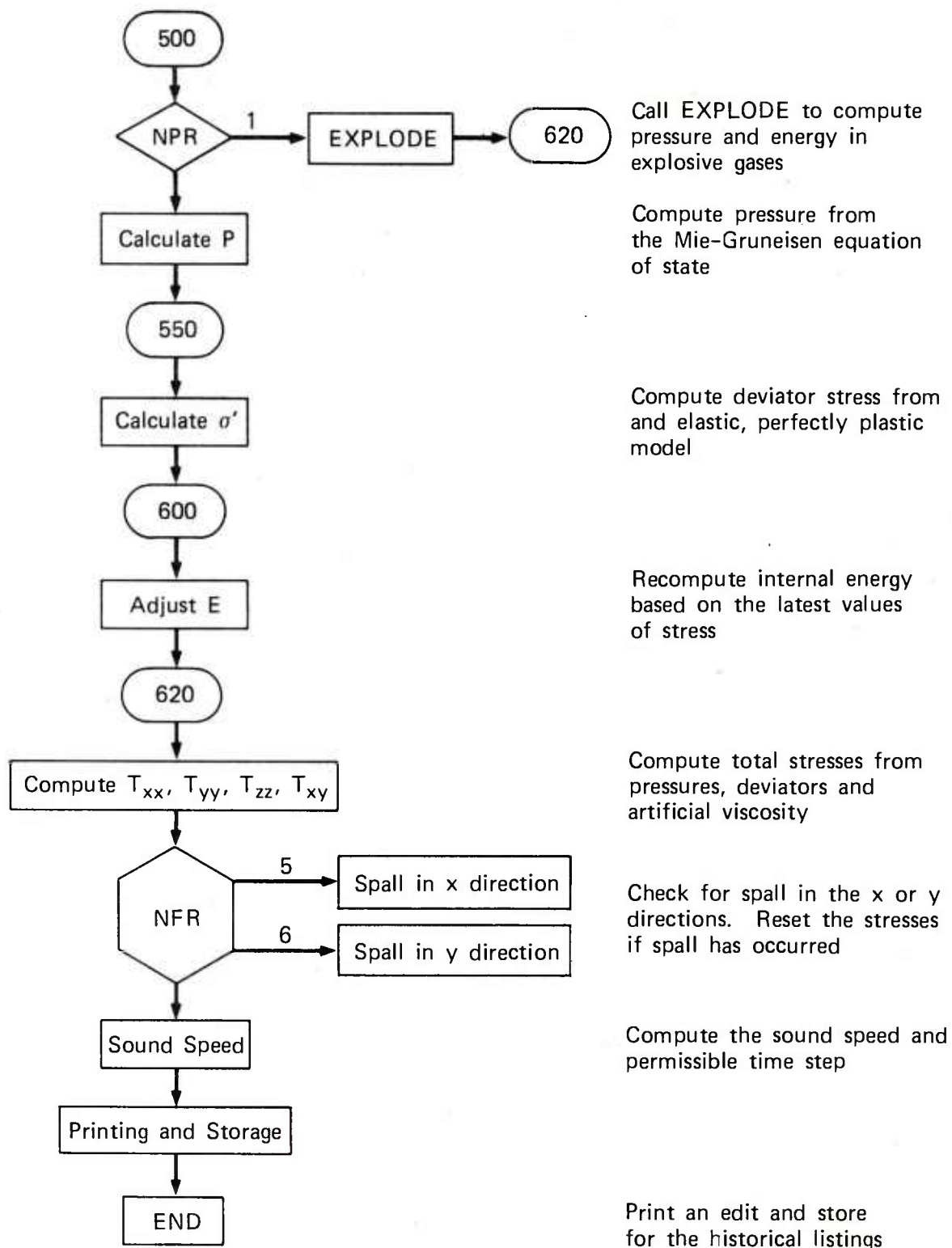
- Composite, for multiconstituent materials. Total stresses are computed.
- Fracture. The models are called after a criterion is reached showing that fracture has begun. Total stresses are computed.
- Porous. Either total stress or pressure is computed, depending on the model. At consolidation, transfer may occur to a continuum model.
- Deviator. Only deviator stresses are computed, so one of these models is used in conjunction with a pressure model.
- Pressure. Only pressure is computed. Explosives are treated under this type.

The subroutine SWEEPT was constructed to serve as a switch between the various subroutines computing pressure, deviator stress, and total stress. The flow chart in Figure 8 emphasizes these stress-switching features. The material models that are currently available are listed



MA-6802-19

FIGURE 8 FLOW CHART FOR SWEEP EMPHASIZING THE PROCEDURE FOR SWITCHING BETWEEN MATERIAL MODELS



MA-6802-20

FIGURE 8 FLOW CHART FOR SWEEP EMPHASIZING THE PROCEDURE FOR SWITCHING BETWEEN MATERIAL MODELS (Concluded)

in the figure and in Section 2. The list in Section 2 also shows where to find more information about each model. The large library of material models associated with the SRI PUFF 8 program may be readily added to TROTT. In fact, of the material model subroutines now in TROTT, only EXPLODE differs from the corresponding routine in PUFF.

4.3 Spall Calculations

In two-dimensional calculations it may be necessary to permit layers of materials to separate during the calculation. An approximate representation of such separation is provided by allowing the stress in the cells along one side of the spall or separation line to reduce to zero in a direction normal to the spall line. Such a separation procedure is provided in TROTT.

Spall is provided for in a cell by representing the material in the cell with a fracture model, labeled by the indicator NFR.

NFR = 5 spall is the x or axial distance
= 6 spall in the y or radial direction

Spall is not permitted in both directions at once. The tensile strength (positive) is read into the TSR array as TSR(M,1) during reading of the material property data.

The spall calculations follow the determination of stress from the usual stress-strain relations and construction of the total stress quantities T_{xx} , T_{yy} , T_{zz} , and T_{xy} . First the possibility of spall is checked by comparing either T_{xx} or T_{yy} (as indicated by NFR) with the spall strength. If the tensile stress exceeds the strength, spall occurs. For this analysis, we assume that the tensile stresses were T_{11} , T_{22} , T_{33} , and T_{12} and that the spall is in the first direction. To produce the spalled state, we apply a compressive stress of $T = -T_{11}$ in the first direction. The conditions of the spall are like those in a uniaxial strain test, because strain occurs only in the first direction. Hence the pressure and deviator stress changes in the spall direction are

$$\Delta P = \frac{C}{C + \frac{4}{3}G} T \quad (85)$$

$$\Delta \sigma' = \frac{\frac{4}{3}G}{C + \frac{4}{3}G} T \quad (86)$$

As usual the deviators in the other directions are

$$\Delta \sigma'_{22} = \Delta \sigma'_{33} = -\frac{1}{2} \Delta \sigma'_{11} \quad (87)$$

Finally, the residual stress state is obtained by adding the effects of this recompression in the spall direction to the existing stresses.

$$T_{11} \rightarrow T_{11} + T = 0$$

$$T_{22} \rightarrow T_{22} + \Delta P + \Delta \sigma'_{22} \quad (88)$$

$$T_{33} \rightarrow T_{33} + \Delta P + \Delta \sigma'_{33}$$

and the shear stress T_{12} is set to zero. The separation calculation is repeated at each cycle so that recombination is permitted at any time.

5. INITIALIZATION

The LAYOUTT subroutine is called at the beginning of each problem to read in all data and initialize the variables. The sequence of operations in LAYOUTT is

- Fill the array storage with initial values, usually zero.
- Read the general running and printing instructions for the problem.
- Read properties for each material.
- Read the grid layout data and construct the layout by initializing all array storage.
- Print the initial layout.

This section describes the general rules governing input and derives the equations for the layout. Several sample input decks are shown in Appendix C. All input information follows these guidelines:

- Each card or group of cards is labeled for ease of identification. For example, equation-of-state lines begin with the identifier "EQST = ". In most cases the identifier is optional and only aids the user in keeping the data in order.
- Each input line is read and then printed immediately in the same format (echo printing) so that the first page of printout looks like the input deck.
- The minimum amount of data is used for each problem. For example, the required data for a material are contained on just two lines. On the first line are indicators that show whether more lines are required because of special models used for the material.

The following subsections describe three sets of data cards that are used for each problem: general running data, materials data, and grid layout. A sample of a complete input deck is shown in Figure 9.

```

NO 16, CONC IMP, 22.34M/S, FULL PROJ., MOMENTUM CHECK
NSTAR 0 NPLCT 999 NOUMP 999 IMAX= 600 IPRIN 100 JPRIN 4 NEXO 600
IJBUNO 2 N8LCK 16 NMTRLS 5 NJED= 8
TS= 2.000E-04 IVTYPE = -1 NV8LK = 1
COSQ= 4.000E+00 CLIN 2.500E-01 TRIQ= 0.020E+00
KSLIOE 0 JSLIOE 0
LIST = KJ/KG KBAR CM M/SEC
CAL = 1.000E-07 1.000E-09 1.000E+00 1.000E-02
JPR = 200 202 300 302 400 402 500 502
JEOT,K,J= 1317 2 1317 3 1317 4 1323 2 1323 3 1323 4 1327 8
          1330 8

IMPACTOR STEEL RHOS= 7.85E0 CFP= 000 OPY = 001 NVAR = 2
EQSTC= 1.5889E12 5.170E12 7.360E10 1.69E0 0.25E0 5.170E13
YIEL0= 1.030E+10 8.188E11

REBAR STEEL RHOS= 7.85E0 CFP= 000 DPY= 001 NVAR= 2
EQSTC= 1.5889E12 5.170E12 7.360E10 1.69E0 0.25E0 5.170E13
YIEL0= 1.030E10 8.188E11

CONCRETE RHOS = 2.85 E0 CFP = 004 OPY = 000 NVAR = 5
EQST = 2.830E+11 0. 1.000E+11 2.000E+00 .25 0.
RHO = 2.22E0 AMU = 2.033E+11
AK = 7.000E+10 AK2 = -.5500E+02 MUP = 5.250E+10 MUP2 = .1250E+03
MC = 1.040E+09-8.300E+08 2.702E+09 2.500E+08 1.000E0
SCRIT = 2.000E+07 OAMG(M) = 1.000E-03
EVP = 0.-1.200E-02-3.500E-02-5.000E-02-2.230E-01
NREG = 4 NPRCAP = 0 P1 = -3.500E+08 W2 = 1.25
P2 = -1.000E+09 OELP = 0.
P2 = -2.400E+09 OELP = 0.
P2 = -3.400E+09 DELP = 0.
P2 = -1.533E+10 DELP = 0.

REBAR RHOS= 2.5015E0 CFP= 100 OPY = 000 NVAR = 13
EQSTC= 1.576E11 0.0 0.0 2.0E0 0.25E0 0.0
FS= 0.05E0 THET= 0.0 IMC= 3 IMS= 2

ALUMINUM RHOS = 2.7 CFP= 000 OPY = 001 NVAR = 2
EQST = 6.670E+11 1.000E+12 1.220E+11 2.04E 0.25E 0.
YIEL0 = 3.210E+09 2.670E+11

(1) K= 16 24 X= 7.62 17.78 17.78 7.62 MAT = 1
J= 1 4 Y= 0. 0. 1.111 1.111
(2) K= 6 8 X= 2.54 3.556 3.556 2.54 MAT = 3
J= 1 4 Y= 0. 0. 1.111 1.111
(3) K= 8 9 X= 3.556 4.064 4.064 3.556 MAT = 4
J= 1 4 Y= 0. 0. 1.111 1.111
(4) K= 9 13 X= 4.064 6.096 6.096 4.064 MAT = 3
J= 1 4 Y= 0. 0. 1.111 1.111
(5) K= 13 14 X= 6.096 6.604 6.604 6.096 MAT = 4
J= 1 4 Y= 0. 0. 1.111 1.111
(6) K= 14 16 X= 6.604 7.62 7.62 6.604 MAT = 3
J= 1 4 Y= 0. 0. 1.111 1.111
(7) K= 6 8 X= 2.54 3.556 3.556 2.540 MAT = 3
J= 4 26 Y= 1.111 1.111 12.7 12.7
(8) K= 8 9 X= 3.556 4.064 4.064 3.556 MAT = 4
J= 4 26 Y= 1.111 1.111 12.7 12.7
(9) K= 9 13 X= 4.064 6.096 6.096 4.064 MAT = 3
J= 4 26 Y= 1.111 1.111 12.7 12.7
(10) K= 13 14 X= 6.096 6.604 6.604 6.096 MAT = 4
J= 4 26 Y= 1.111 1.111 12.7 12.7
(11) K= 14 16 X= 6.604 7.62 7.62 6.604 MAT = 3
J= 4 26 Y= 1.111 1.111 12.7 12.7
(12) K= 1 6 X= 0. 2.54 2.54 0. MAT = 3
J= 14 26 Y= 8.89 6.378 12.7 12.7
(13) K= 24 26 X= 17.78 19.685 19.685 17.78 MAT = 5
J= 1 4 0. 0. 1.111 1.111
(14) K= 24 26 X= 17.78 19.685 19.685 17.78 MAT = 5
J= 4 7 Y= 1.111 1.111 2.475 2.475
(15) K= 24 26 X= 17.78 19.685 19.685 17.78 MAT = 5
J= 7 8 Y= 2.475 2.475 3.1496 3.1496
(16) K= 26 37 X= 19.685 33.02 33.02 19.685 MAT = 5
J= 7 8 Y= 2.475 2.475 3.1496 3.1496
JU= 7/8/9 4 KU = 16 UZERO = -2.234E03

```

GENERAL
RUNNING
DATA

MATERIALS
DATA

CELL AND
COORDINATE
LAYOUT

VELOCITY DATA

FIGURE 9 SAMPLE INPUT DECK FOR CONCRETE IMPACT PROBLEM

5.1 Input of General Running Controls

The first set of data identifies the computation and determine the length of the computation, the printing during and following the computation, the number of materials, and the overall geometry of the problem.

The second line contains NSTART, NPLOT, NDUMP, IMAX, IPRINT, JPRINT, NEXED, and NOBLQ. NSTART is the file number for restarting and is zero for a new problem (see Section 5.4). NPLOT is the frequency in cycles for writing a file containing data for an x,y plot. NDUMP is the frequency in cycles for writing a restart dump (see Section 5.4). IMAX is the maximum number of cycles permitted. IPRINT is the frequency in cycles for printing an edit or for listing the current status of major variables for each cell and coordinate. JPRINT is the number of special groups of edits required. For each group there is a JP1 and JP2, the cycles at which edits will begin and end. Within the range of each group, edits are printed at each cycle. JPRINT is used mainly to study difficulties that arise late in a computation. NEXED indicates the frequency of extra edits listing all the cell variables not normally listed in an edit. NOBLQ is an indicator for an impact of a block onto a smooth, nonmoving boundary (used for oblique ballistic impacts). If NOBLQ is nonzero, the angle of the boundary, ANGLE, is read on a line between the usual second and third lines.

The third line contains IJBUND, NBLOCK, NMTRLS, NJED, IPRIND and NEXTRA. IJBUND determines the geometry and boundary conditions as shown in Table 1. The grid layout information is inserted in the form of NBLOCKS of data, each block describing a quadrilateral in X,Y, space. The number of materials is NMTRLS. The number of historical listings requested in NJED. IPRIND indicates a request for the special print options, KSKIP, KFULL, KPMAX, KPMIN, JPMAX, and JPMIN, which limit the amount of printing in edits. A nonzero NEXTRA calls for a special input of data through the EXTRAT subroutine. If indicated, EXTRAT is called twice: at the end of reading the material data and just before the layout listing.

Table 1

DEFINITIONS OF IJBUND AND IVTYPE

- IJBUND -

Geometry		Boundary Conditions*
<u>Axisymmetric</u>	<u>Planar</u>	
1	-1	Fixed y velocity at J=Jmin and Jmax
2	-2	Fixed y velocity at J=Jmin only
-	-3	All edges free
4	-4	Fixed y velocity at J=Jmin, x velocity at K=Kmin and Kmax
5	-5	Fixed y velocity at J=Jmin and Jmax, x velocity at K=Kmin
9	-9	Special boundary conditions specified by the user as described in Appen- dix G.

Notes: Positive values of IJBUND denote an axisymmetric geometry with x axial, y radial, and z circumferential. Negative IJBUND values denote a plane strain geometry with x and y in the plane and z in third (zero strain) direction.

- IVTYPE -

<u>Value</u>	<u>Meaning</u>
0	No velocity initialization
1	Velocity is initialized for all J up to K = KU with an interface condition at K = KU
2	Velocity is initialized in NVBLK quadrilateral blocks.
-1	Velocity is initialized for all J and from K = KU to Kmax. The interface condition is at KU.

*All minimum and maximum values not mentioned are free.

The fourth line contains the problem stop time TS, the velocity indicators IVTYPE and NVBLK, and KCHEK. IVTYPE is defined in Table 1. NVBLK is the number of quadrilateral blocks used in the velocity initialization for IVTYPE = 2. Initial wave propagation calculations are made from K = 1 to KCHEK, instead of from 1 to KMAX.

The fifth line contains the coefficients for the quadratic, linear, and the triangular artificial viscosities: CQSQ, CLIN, and TRIQ.

The sixth line contains slide line controls (KSLIDE and JSLIDE), a special boundary condition indicator (NBND), and an indicator (ICAL) for the units used in printing the IPRINT listings. KSLIDE and JSLIDE determine the location of slide lines -- only one can be nonzero. NBND is the number of special boundary conditions. For NBND nonzero, NBND lines are read in next containing the special boundary data: IBDK1, IBDK2, IBDJ1, IBDJ2, IBDX, IBDY, XFIX, and YFIX. These parameters and the special boundary conditions are described in Appendix G. A nonzero value of ICAL calls for reading two lines containing calibration information for the IPRINT listings. These additional lines contain the alphanumeric parameters LISTE, LISTS, LISTX, and LISTXD and the constants CALE, CALS, CALX and CALXD, which are defined in Table 2. Each of these parameters is initialized in LAYOUTT with the value given in the table. If the user wishes different units, he should set ICAL to one, and read in the necessary lines. For example, to use kbar as the stress unit, LISTS is read in as KBAR, and CALS is set to 1.E-9. (The internal units of the code are dyne, centimeter, gram and second.)

For nonzero values of JPRINT, the next line is a special line containing JP1 and JP2 values.

The next input lines contain the detailed requests for historical listings of specific variables. Each request is composed of three integers labeled JEDT(I), JEDK(I), and JEDJ(I). JEDT is the type of variable, whereas JEDK and JEDJ are the K,J locations of the cell or coordinate. The types are defined in Table 3 along with some sample input. The type number is used in SWEEP to obtain the required variable from the COM array. For the standard variables, the type number can be

obtained from the equivalence statement for the COM array. For other variables, see the discussion of NVAR and COM in Appendix B. The JED variables must be read in the order in which the K,J coordinates will be encountered in the calculation: JEDT, JEDK, and JEDJ groups must be in order of increasing JEDK, and for groups with the same JEDK, and the JEDJ must be in increasing order. For the same JEDK and JEDJ values, groups with different JEDT can be in any order.

If IPRIND is nonzero, a special print-control line is read at this point, completing the input of general running data.

5.2 Material Properties

Each material is described by data on a series of lines following the general running information. These lines contain

1. Material name, solid density, a series of flags (NCMP, NFR, NPOR, NDS, NPR, NYAM), NVAR, and NTRI.
2. Solid equation-of-state parameters: EQSTC, EQSTD, EQSTE, EQSTG, EQSTH, EQSTS, and PMIN.
3. Special data required for composite, fracture, porous, deviator, or pressure models.
4. Yield data (yield strength, shear modulus, and work-hardening modulus) read in for nonzero values of NYAM.

The parameters mentioned above are all defined in the Glossary, Appendix F. The flags NCMP to NPR show what data are required in the lines under item 3. NYAM controls the reading of item 4. NVAR is the number of extra variables required in addition to the standard 17 (the first 17 listed in Table 3). For example, a material with a yield model requires NVAR = 2. NVAR is described further in Appendix B. NTRI is a flag indicating that all quadrilateral cells of the material are to be divided into triangles.

The input for the special models takes different forms depending on the model. Section 2 lists references to the descriptions of each special model.

Table 2

CONVERSION OF UNITS FOR IPRINT LISTINGS

<u>Parameter</u>	<u>Initialized Value</u>	<u>Quantity Affected</u>	<u>Internal Units</u>
CALE	1.E-7	internal energy	erg/g
CALS	1.E-7	stress, pressure	dyn/cm ²
CALX	1.	X, Y location	cm
CALXD	1.E-2	velocity	cm/sec
LISTE	KJ/KG	internal energy	
LISTS	MPA	stress, pressure	
LISTX	CM	X, Y location	
LISTXD	M/SEC	velocity	

Table 3

TYPE DESIGNATIONS FOR HISTORICAL LISTINGS

JEDT Value	Variable
1	X, Eulerian axial position
2	Y, Eulerian radial position
3	$\dot{X}$ D, $\dot{X}$ or axial velocity
4	$\dot{Y}$ D, $\dot{Y}$ or radial velocity
5	Variable location for triangular cells
6	A, cell area in the x-y plane
7	Z, cell mass (constant)
8	D, cell density
9	SXX, deviator stress in the x direction
10	SYX, deviator stress in the y direction
11	SZZ, deviator stress in the z direction
12	TXY, shear stress on the xy plane
13	TXX, total mechanical stress in the x direction
14	TYX, total mechanical stress in the y direction
15	TZZ, total mechanical stress in the z direction
16	P, pressure
17	E, internal energy
18	H, indicator
19	YY, yield strength
L	COM(L), extra variable
-45	$\bar{\epsilon}, \sqrt{2/9[(\epsilon_x - \epsilon_y)^2 + (\epsilon_y - \epsilon_z)^2 + (\epsilon_x - \epsilon_z)^2 + 6\epsilon_{xy}^2]}$, a scalar deviator strain
-46	Σ EXXH, cumulative strain in the x direction
-47	Σ EYYH, cumulative strain in the y direction
-48	Σ EZZH, cumulative strain in the z direction
-49	Σ EXYH, cumulative strain in the xy direction
-50	Q, artificial viscosity
-51	SXX-P, thermodynamic stress in the x direction
-52	SYX-P, thermodynamic stress in the y direction

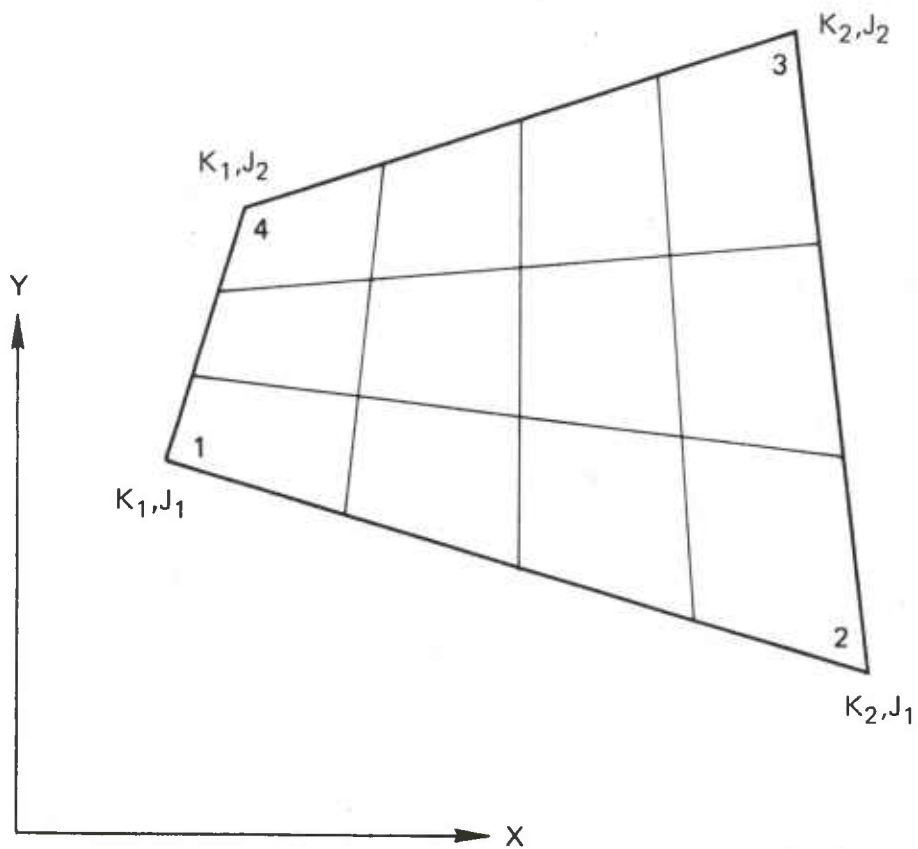
Table 3 (Concluded)

<u>JEDT Value</u>	<u>Variable</u>
-53	SZZ-P, thermodynamic stress in the z direction
-54	Force in the x direction at the K-th row
-55	$-2 \ln (Y_{K,Jmax}/Y_o)$, an areal strain for axisymmetric problems

Sample Input:

T K J *	T K J	T K J	T K J	T K J	T K J	T K J
8 2 5	13 2 5	51 2 5	8 2 7	13 2 7	8 3 4	13 3 4
8 3 6	13 3 6	13 5 2	8 5 2	812 5	1512 5	151213
1413 2	1413 6	1524 2	1424 2			

* The labels T K J indicate JEDT, JEDK and JEDJ. This label line is not included in input.



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FIGURE 10 A QUADRILATERAL BLOCK OF CELLS USED IN THE GRID LAYOUT

5.3 Grid Layout and Velocity Initialization

The grid for the computations is entirely laid out in quadrilateral blocks. For each block the J, K, x, and y values are provided for the four corner points, and the material number in the cells is designated. The information is provided on two input lines as follows:

$K_1, K_2, x_1, x_2, x_3, x_4, MAT$

$J_1, J_2, y_1, y_2, y_3, y_4$

The J and K values are Lagrangian coordinate numbers as shown in Figure 10. The Eulerian coordinates x and y of the four corners are inserted in the counterclockwise order for all cells in the block. From this input, the intermediate x and y coordinate points are computed from the expression

$$x_{K,J} = \frac{[x_1(J_2 - J) + x_4(J - J_1)](K_2 - K) + [x_2(J_2 - J) + x_3(J - J_1)](K - K_1)}{(J_2 - J_1)(K_2 - K_1)} \quad (89)$$

and a similar one for $y_{K,J}$. In the resulting grid, all lines are straight and the increments of x (or y) are equal along any line.

The velocities can be initialized either by designating a single velocity $\dot{x}$ for the moving portion of the object or by designating blocks as in the grid layout. For the single velocity layout, the required information is J_u , K_u , and U_z , where J_u is usually the largest J value (outer radial boundary of the moving object), and K_u is the K value at the interface between moving and nonmoving parts of the object. For $IVTYPE = 1$, $\dot{x}$ velocities are initialized to U_z for $K > K_u$; and for $IVTYPE = -1$, $\dot{x} = U_z$ for $K < K_u$. Along the interface $K = K_u$, the velocity $\dot{x}$ is initialized to a value that preserves the total momentum approximately. For this computation, we obtain the sum M_p of the masses in the projectile cells (from $J = 2$ to J_u) along the interface and the

mass M_T of the corresponding cells along the target. Then the interface velocity $\dot{x}$ initialized along $K = K_u$ is

$$U_{int} = \frac{U_z M_p}{M_p + M_T} \quad (90)$$

If cells are properly matched across the interface so that the crossing time of cells are equal in the x direction, the interface velocity given by Eq. (90) is approximately the velocity reached in a one-dimensional impact. By starting with a good estimate of the velocity U_{int} , we minimize the stress oscillations that usually appear in impact calculations. If the entire layout is to be initialized at the same velocity, as for an oblique impact on a rigid wall, then J_u can be set to zero and K_u is set to zero (for IVTYPE = -1) or KMAX +1 (for IVTYPE = 1).

In the second type of velocity initialization, the user provides the velocity distribution by quadrilateral blocks (NVBLK of them) as in the grid initialization. The velocities at all points in the block are then initialized so that there is a linear variation of velocity with distance whenever possible. The equation used for the velocity interpolation is

$$\begin{aligned} \dot{x}_{K,J} = & \left[\frac{\dot{x}_{K1,J1}(x_{K2,J1} - x_{K,J1}) + \dot{x}_{K2,J1}(x_{K,J2} - x_{K1,J1})}{(x_{K2,J1} - x_{K1,J1})(y_{K,J2} - y_{K,J1})} \right] (y_{K,J2} - y_{K,J}) \\ & + \left[\frac{\dot{x}_{K2,J2}(x_{K,J2} - x_{K1,J2}) + \dot{x}_{K1,J2}(x_{K2,J2} - x_{K,J2})}{(x_{K2,J2} - x_{K1,J2})(y_{K,J2} - y_{K,J1})} \right] (y_{K,J} - y_{K,J1}) \end{aligned} \quad (91)$$

A similar equation is used for the velocity in the y direction, $\dot{y}$. The resulting velocity distribution is linear with distance along straight K and J lines in the block.

5.4 Restart Procedure

For long calculations it is convenient to be able to perform the computations in several sections. At the end of each section of the calculation, the program is stopped, all the information on the current status is stored, and the computed results are examined. Then changes are made in the input as required, the stored information is read in again and the calculation is restarted.

In preparation for a restart the parameter NDUMP is set to the frequency in cycles at which a restart file should be written. At cycles which are multiples of NDUMP and at the last cycle, a restart record is written onto file 9 in TROTT. The restart record contains the COM, LVAR and MM arrays plus the parameters JMAX, JMIN, KMAX, KMIN, and TYME. The programmer must save file 9 at the end of the calculation.

To restart from the stored information, NSTART is set to the number of the record to be used for restarting. The restart records are read from file 1; therefore, the programmer must prepare for the restart by assigning the name "file 1" to the restart file. New restart records will be written on file 9 as before. For a restart, the input deck includes the General Running Data and Materials Data labeled in Fig. 9. Hence these data may be changed for the restart. KCHEK should be inserted equal to KMAX in the restart deck, although it may have been left at zero in the initial deck. We have used restarts to change yield strength or other model parameters which have not yet been used in the previous calculation.

Following the materials data the restart record is read into the usual arrays. At this time additional changes may be made by calling a user-written subroutine, EXTRAT. (NEXTRA is set to a positive number to trigger this call.) This subroutine can be constructed to modify any of the COMMON variables. For example, distorted cells in the ejecta region of a crater can be eliminated and fracture quantities can be inserted arbitrarily.

When the restarted calculations begin, the time step is set back to 10^{-12} sec as for any new calculation.

5.5 Matching Array Size to Problem Size

The number of coordinates in the J and K directions and the total number of variables available may be readily altered to match the size of a problem. The variables controlling these dimensions are all set in TROTT: JXX and KXX are the number of coordinates in the J and K directions, and JSIZE is the size of the COM array which contains the variables for each cell and coordinate. To change array sizes, these three variables are set in TROTT and the dimension statements for COM, XL, YL, MM, IZ and LVAR are set appropriately. No changes are required in the subroutines unless JXX exceeds 100: then the XDTEMP family of arrays are redimensioned in SWEEP.

6. PRINTED OUTPUT

Several types of printed output are provided during and at the conclusion of a calculation. During the reading of input, the input lines are printed by LAYOUTT. Some material property subroutines read their own input and provide printout. At the conclusion of the input, a listing is given by LAYOUTT of the cell and coordinate layout. During the calculation SWEEPT makes several listings of the layout with current cell variables. At the end of the calculation, SCRIBET is called to produce a historical listing of all the variables requested. In addition, there are error messages and special printing from some material models. Samples of these listings are given here.

6.1 Input and Layout Listings

As the input is read by LAYOUTT, an echo print is made of each line. The input lines shown in Figure 9 (Section 5) are printed as in Figure 11. The listing in Figure 11 is the same as Figure 9 except for the addition of the date, gaps to separate material property groups, the sound speed listing (SP =) following material properties data, and the appended data "IN = 5 CAP." The latter note indicates that these data were read by the subroutine CAP1 from the input file TAPE 5.

Following the reading of all data and initialization of arrays by LAYOUTT, a listing (as in Figure 12) is made of some variables and array quantities that are used for each cell and coordinate. J and K are the Lagrangian coordinates, M is the material number, and LVAR shows the location in the COM array at which information for the coordinate begins. The Eulerian positions are X and Y. The area, density, and mass (A,D,Z) refer to the cell defined by the coordinates at (J,K), (J-1,K), (J,K-1), and (J-1, K-1). The initial yield strength, X and Y velocities, and the internal energy are also listed.

```

OATE = 77/07/09.
ND 20: CONC IMP: 92.35M/S, SANOIA R00 IMPACT SIMULATION
NSTAR 0 NPLUT 999 NDUMP 400 IMAX= 400 IPRIN 50 JPRIN 0 NEXED 400 -0
IJRUN 1 NBLUC 21 NMTRL 5 NJEO= 1 -0
YS= .100E-02 IVTYPE = -1 NVBLK = 1
CQSQ= .400E+01 CLIN .250E+00 TRIQ= .200E-01
JEDT,K,J= 1321 2

IMPACTOR STEEL RHOS= .785E+01 CFP= 000 DPY= 001 NVAR= 2 NTRI= 1
EQSTC= .159E+13 .517E+13 .736E+11 .169E+01 .250E+00 .517E+14-0.
YIELD= .103E+11 .819E+12-0.

REBAR STEEL RHOS= .785E+01 CFP= 000 DPY= 001 -0 -0
EQSTC= .159E+13 .517E+13 .736E+11 .169E+01 .250E+00 .517E+14-0.
YIELD= .103E+11 .819E+12-0.

CONCRETE RHOS= .285E+01 CFP= 001 DPY= 000 NCON= 5
EQST= .243E+12 0. .100E+12 .200E+01 .250E+00 0. -0.
RMD= .222E+01 AMU= .203E+12
AK= 1.000E+10 AK2= -5.500E+01 MUP= 5.250E+10 MUP2= 1.250E+02 IN= 5 CAP
MC= 1.040E+09-8.300E+08 2.702E+09 2.500E+08 1.000E+00 IN= 5 CAP
SCRIT= 2.000E+07 DAMG(M)= 1.000E-03 IN= 5 CAP
EVP= 0. -1.200E-04-3.500E-02-5.000E-02-2.230E-01 IN= 5 CAP
NREG= 4 NPRECAP= 0 P1= -3.500E+08 W2= 1.250E+00 IN= 5 CAP
P2= -1.000E+09 OELP= 0. IN= 5 CAP
P2= -2.400E+09 DELP= 0. IN= 5 CAP
P2= -3.400E+09 OELP= 0. IN= 5 CAP
P2= -1.533E+10 OELP= 0. IN= 5 CAP

REBAR RHOS= .250E+01 CFP= 100 DPY= 000 NVAR= 13
EQSTC= .158E+12 0. 0. .200E+01 .250E+00 0. -0.
FS= .650E-01 TMET= 0. 1MC= 3 1MS= 2

ALUMINUM RHOS= .270E+01 CFP= 000 DPY= 001 NVAR= 2
EQST= .667E+12 .100E+13 .122E+12 .204E+01 .250E+00 0. -0.
YIELD= .321E+10 .267E+12-0.
SP= 5.845E+05 5.845E+05 4.994E+05 5.170E+05 6.155E+05 0.
(1) K= 20 68 X= 45.72000 137.16000 137.16000 45.72000 MAT= 1
J= 1 2 Y= 0.00000 0.00000 1.27000 1.27000
(2) K= 1 3 X= 0.00000 3.81000 3.81000 0.00000 MAT= 3
J= 1 4 Y= 0.00000 0.00000 3.81000 3.81000
(3) K= 3 4 X= 3.81000 6.35000 6.35000 3.81000 MAT= 4
J= 1 4 Y= 0.00000 0.00000 3.81000 3.81000
(4) K= 4 17 X= 6.35000 39.37000 39.37000 6.35000 MAT= 3
J= 1 4 Y= 0.00000 0.00000 3.81000 3.81000
(5) K= 17 18 X= 39.37000 41.91000 41.91000 39.37000 MAT= 4
J= 1 4 Y= 0.00000 0.00000 3.81000 3.81000
(6) K= 18 20 X= 41.91000 45.72000 45.72000 41.91000 MAT= 3
J= 1 4 Y= 0.00000 0.00000 3.81000 3.81000
(7) K= 1 3 X= 0.00000 3.81000 3.81000 0.00000 MAT= 3
J= 4 8 Y= 3.81000 3.81000 11.43000 11.43000
(8) K= 3 4 X= 3.81000 6.35000 6.35000 3.81000 MAT= 4
J= 4 8 Y= 3.81000 3.81000 11.43000 11.43000
(9) K= 4 17 X= 6.35000 39.37000 39.37000 6.35000 MAT= 3
J= 4 8 Y= 3.81000 3.81000 11.43000 11.43000
(10) K= 17 18 X= 39.37000 41.91000 41.91000 39.37000 MAT= 4
J= 4 8 Y= 3.81000 3.81000 11.43000 11.43000
(11) K= 18 20 X= 41.91000 45.72000 45.72000 41.91000 MAT= 3
J= 4 8 Y= 3.81000 3.81000 11.43000 11.43000
(12) K= 1 3 X= 0.00000 3.81000 3.81000 0.00000 MAT= 3
J= 8 12 Y= 11.43000 11.43000 21.59000 21.59000
(13) K= 3 4 X= 3.81000 6.35000 6.35000 3.81000 MAT= 4
J= 8 12 Y= 11.43000 11.43000 21.59000 21.59000
(14) K= 4 17 X= 6.35000 39.37000 39.37000 6.35000 MAT= 3
J= 8 12 Y= 11.43000 11.43000 21.59000 21.59000
(15) K= 17 18 X= 39.37000 41.91000 41.91000 39.37000 MAT= 4
J= 8 12 Y= 11.43000 11.43000 21.59000 21.59000
(16) K= 18 20 X= 41.91000 45.72000 45.72000 41.91000 MAT= 3
J= 8 12 Y= 11.43000 11.43000 21.59000 21.59000
(17) K= 1 3 X= 0.00000 3.81000 3.81000 0.00000 MAT= 3
J= 12 19 Y= 21.59000 21.59000 48.26000 48.26000
(18) K= 3 4 X= 3.81000 6.35000 6.35000 3.81000 MAT= 4
J= 12 19 Y= 21.59000 21.59000 48.26000 48.26000
(19) K= 4 17 X= 6.35000 39.37000 39.37000 6.35000 MAT= 3
J= 12 19 Y= 21.59000 21.59000 48.26000 48.26000
(20) K= 17 18 X= 39.37000 41.91000 41.91000 39.37000 MAT= 4
J= 12 19 Y= 21.59000 21.59000 48.26000 48.26000
(21) K= 18 20 X= 41.91000 45.72000 45.72000 41.91000 MAT= 3
J= 12 19 Y= 21.59000 21.59000 48.26000 48.26000
JU= 2 20 UZERO= -9235.440

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FIGURE 11 LISTING OF INPUT PROVIDED BY LAYOUTT FOR CONCRETE IMPACT CALCULATION

Y	K	M	LVAR	X	Y	A	D	Z	YIELD	XU	YD	E
1	1	0	1	0.00000	0.00000	0.00000	0.00000	0.00000	0.	0.	0.	0.
2	1	0	5	1.27000	0.00000	0.00000	0.00000	0.00000	0.	0.	0.	0.
3	3	0	9	2.54000	0.00000	0.00000	0.00000	0.00000	0.	0.	0.	0.
4	1	0	13	3.81000	0.00000	0.00000	0.00000	0.00000	0.	0.	0.	0.
5	1	0	17	5.08000	0.00000	0.00000	0.00000	0.00000	0.	0.	0.	0.
6	1	0	21	6.35000	0.00000	0.00000	0.00000	0.00000	0.	0.	0.	0.
7	1	0	25	7.62000	0.00000	0.00000	0.00000	0.00000	0.	0.	0.	0.
8	1	0	29	8.89000	0.00000	0.00000	0.00000	0.00000	0.	0.	0.	0.
9	1	0	33	10.16000	0.00000	0.00000	0.00000	0.00000	0.	0.	0.	0.
10	1	0	37	11.43000	0.00000	0.00000	0.00000	0.00000	0.	0.	0.	0.
11	1	0	41	12.70000	0.00000	0.00000	0.00000	0.00000	0.	0.	0.	0.
12	1	0	45	13.97000	0.00000	0.00000	0.00000	0.00000	0.	0.	0.	0.
13	1	0	49	15.24000	0.00000	0.00000	0.00000	0.00000	0.	0.	0.	0.
14	1	0	53	16.51000	0.00000	0.00000	0.00000	0.00000	0.	0.	0.	0.
15	1	0	57	17.78000	0.00000	0.00000	0.00000	0.00000	0.	0.	0.	0.
16	1	0	61	19.05000	0.00000	0.00000	0.00000	0.00000	0.	0.	0.	0.
17	1	0	65	20.32000	0.00000	0.00000	0.00000	0.00000	0.	0.	0.	0.
18	1	0	69	21.59000	0.00000	0.00000	0.00000	0.00000	0.	0.	0.	0.
19	1	0	73	22.86000	0.00000	0.00000	0.00000	0.00000	0.	0.	0.	0.
20	1	0	77	24.13000	0.00000	0.00000	0.00000	0.00000	0.	0.	0.	0.
21	2	0	81	25.40000	0.00000	0.00000	0.00000	0.00000	0.	0.	0.	0.
22	2	0	85	26.67000	0.00000	0.00000	0.00000	0.00000	0.	0.	0.	0.
23	2	0	89	27.94000	0.00000	0.00000	0.00000	0.00000	0.	0.	0.	0.
24	2	0	93	29.21000	0.00000	0.00000	0.00000	0.00000	0.	0.	0.	0.
25	2	0	97	30.48000	0.00000	0.00000	0.00000	0.00000	0.	0.	0.	0.
26	2	0	101	31.75000	0.00000	0.00000	0.00000	0.00000	0.	0.	0.	0.
27	2	0	105	33.02000	0.00000	0.00000	0.00000	0.00000	0.	0.	0.	0.
28	2	0	109	34.29000	0.00000	0.00000	0.00000	0.00000	0.	0.	0.	0.
29	2	0	113	35.56000	0.00000	0.00000	0.00000	0.00000	0.	0.	0.	0.
30	2	0	117	36.83000	0.00000	0.00000	0.00000	0.00000	0.	0.	0.	0.
31	2	0	121	38.10000	0.00000	0.00000	0.00000	0.00000	0.	0.	0.	0.
32	2	0	125	39.37000	0.00000	0.00000	0.00000	0.00000	0.	0.	0.	0.
33	2	0	129	40.64000	0.00000	0.00000	0.00000	0.00000	0.	0.	0.	0.
34	2	0	133	41.91000	0.00000	0.00000	0.00000	0.00000	0.	0.	0.	0.
35	2	0	137	43.18000	0.00000	0.00000						

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6.2 Periodic Edits

At specified times in the calculation, listings are made of the major cell and coordinate variables at the time. A sample listing is given in Figure 13 for all the cells in K rows 15, 16, and 17 at cycle 200. The listing is requested by a nonzero value of IPRINT. Then the listing occurs every IPRINT cycles. Locations are given in centimeters, stresses (positive in tension) and pressure (positive in compression) are given in megapascals $= 10^7$ dynes/cm² = 0.01 kbar, internal energy is given in j/kg, density in g/cm³, artificial viscous stress in MPa, sound speed squared in (km/sec)², and velocity in m/sec. The indicator H shows the path taken by the material for some material models; the meaning depends on the model.

For special material models, many variables may be used that are not listed in the usual edit in Figure 13. These extra variables beginning with the yield strength, COM(19), are given in the "extra edit," a sample of which is shown in Figure 14. The meaning of the individual variables must be traced through the call statement in SWEEP to the material model subroutine as outlined in Appendix A. These extra edits are requested by a nonzero value of NEXED. The listing is provided by TROTT every NEXED cycles.

6.3 Historical Listings

Histories are provided for all COM array quantities and for many other variables through the specification of JEDT, JEDX and JEDJ as outlined in Section 5. A history is a list of values of the variable at each time step. During a calculation, the requested variables are stored at each cycle on tape 4. At the conclusion of the calculation, the subroutine SCRIBET is called by TROTT to read tape 4 and print the histories. A brief portion of a history is given in Figure 15. The listing consists of the cycle number N, time in microseconds, and the requested variables. For the standard variables the histories are identified by titles such as TZZ(12,5) for total stress in the Z direction in the cell at K=12, J=5. For extra variables the K,J values and the JEDT number are given to identify the history.

COLUMN K= 15, N= 200, TIME= 2147E-03, X= 34.2719, Y= 0.0000									
J	X	Y	TXM	TYM	TZM	TXW	P	E	D
1	34.2703	1.2767	8.3333	8.3333	0.0000	0.0000	-8.3333	.0	2.215329
2	34.2719	2.5418	-9.4880	13.1364	2.8420	0.0000	-0.085	.0	2.219889
3	34.2769	3.8115	-9.4880	4.199	-3.6711	0.0000	1.9400	.0	2.220296
4	34.2771	5.1197	-15.2432	4.8856	3.6711	0.0000	1.6682	.0	2.220520
5	34.2792	7.6213	-7.1503	3.2135	6.7585	0.0000	2.5449	.0	2.220785
6	34.2794	9.5287	-6.2274	1.0837	2.3358	0.0000	1.7747	.0	2.220244
7	34.2819	11.4319	-4.7633	-5.5300	1.8025	0.0000	1.7719	.0	2.220551
8	34.2844	13.3723	-2.7109	-1.3380	1.597	0.0000	1.7719	.0	2.220551
9	34.2844	16.3115	-2.5531	-1.2828	1.597	0.0000	1.7719	.0	2.220551
10	34.2844	19.2518	-1.5432	-4.929	2.5566	0.0000	1.7719	.0	2.220551
11	34.2860	21.5915	-2.0033	-4.219	1.6171	0.0000	1.7719	.0	2.220551
12	34.2860	24.5318	-1.2146	-2.443	2.6073	0.0000	1.7719	.0	2.220551
13	34.2873	25.4016	-1.0824	-5.676	1.6571	0.0000	1.7719	.0	2.220551
14	34.2891	29.2113	-0.8824	-7.056	1.6571	0.0000	1.7719	.0	2.220551
15	34.2897	33.0211	-0.764	-8.694	1.6571	0.0000	1.7719	.0	2.220551
16	34.2901	36.8308	-0.7132	-10.435	1.6571	0.0000	1.7719	.0	2.220551
17	34.2900	40.6405	-0.732	-12.176	1.6571	0.0000	1.7719	.0	2.220551
18	34.2900	44.4503	-0.732	-13.917	1.6571	0.0000	1.7719	.0	2.220551
19	34.2900	48.2600	-0.732	-15.658	1.6571	0.0000	1.7719	.0	2.220551
K= 15, F= 9.5282E-06, M= 1.452E-10, YBAR= 2.413E-01									
COLUMN K= 16, N= 200, TIME= 2147E-03, X= 36.1818, Y= 0.0000									
J	X	Y	TXM	TYM	TZM	TXW	P	E	D
1	36.1816	1.2600	-6.924	-28.4696	1.4302	0.0000	19.4490	.0	2.225104
2	36.1802	2.5445	-38.4911	8.3333	0.0000	0.0000	-8.3333	.0	2.221679
3	36.1825	3.8169	-13.4281	-8.5317	12.5414	0.0000	10.5397	.0	2.221411
4	36.1858	5.1170	-12.2751	-5.9919	9.9387	0.0000	4.5738	.0	2.221380
5	36.1860	7.6262	-6.6431	-5.9919	6.4736	0.0000	1.4529	.0	2.220454
6	36.1860	9.5274	-1.5270	-3.026	1.1175	0.0000	2.9400	.0	2.220903
7	36.1860	11.4331	-2.0570	-3.026	3.6330	0.0000	1.929	.0	2.220295
8	36.1823	13.3715	-1.1362	-1.3318	1.4507	0.0000	1.929	.0	2.220373
9	36.1823	16.3117	-2.4264	-5.862	3.6330	0.0000	1.929	.0	2.220373
10	36.1823	19.2519	-1.3166	-3.894	1.9351	0.0000	1.929	.0	2.220158
11	36.1823	21.5915	-1.3166	-5.862	1.9351	0.0000	1.929	.0	2.220158
12	36.1823	24.5318	-1.3166	-5.862	1.9351	0.0000	1.929	.0	2.220158
13	36.1823	26.4012	-1.3166	-5.862	1.9351	0.0000	1.929	.0	2.220158
14	36.1823	29.2112	-1.3166	-5.862	1.9351	0.0000	1.929	.0	2.220158
15	36.1823	33.0208	-1.3166	-5.862	1.9351	0.0000	1.929	.0	2.220158
16	36.1823	36.8306	-1.3166	-5.862	1.9351	0.0000	1.929	.0	2.220158
17	36.1823	40.6404	-1.3166	-5.862	1.9351	0.0000	1.929	.0	2.220158
18	36.1823	44.4502	-1.3166	-5.862	1.9351	0.0000	1.929	.0	2.220158
19	36.1823	48.2600	-1.3166	-5.862	1.9351	0.0000	1.929	.0	2.220158
K= 16, F= 1.253E-09, M= 2.135E-10, YBAR= 2.413E-01									
COLUMN K= 17, N= 200, TIME= 2147E-03, X= 38.2268, Y= 0.0000									
J	X	Y	TXM	TYM	TZM	TXW	P	E	D
1	38.3352	1.2992	-3.6540	-3.6540	0.0000	0.0000	0.0000	.0	2.217546
2	38.3346	2.5483	-37.2866	-39.9267	21.3181	0.0000	20.0326	.0	2.226787
3	38.3354	3.8140	-30.5595	-18.4709	11.4583	0.0000	10.4494	.0	2.222412
4	38.3394	5.1264	-29.4889	-1.6825	11.1062	0.0000	8.9055	.0	2.221433
5	38.3394	7.6235	-14.5553	-17.6205	3.3763	0.0000	8.9055	.0	2.221868
6	38.3394	9.5291	-5.200	-11.2537	21.8249	0.0000	1.9428	.0	2.222603
7	38.3321	11.4315	-1.711	-6.2454	0.7993	0.0000	1.9428	.0	2.222603
8	38.3321	13.3717	-3.254	-3.0192	5.3706	0.0000	1.9428	.0	2.220387
9	38.3321	15.3113	-2.3559	-3.0192	1.9025	0.0000	1.9428	.0	2.220105
10	38.3321	17.2514	-1.6451	-5.862	1.9025	0.0000	1.9428	.0	2.220105
11	38.3321	19.1914	-1.6451	-5.862	1.9025	0.0000	1.9428	.0	2.220105
12	38.3321	21.1314	-1.6451	-5.862	1.9025	0.0000	1.9428	.0	2.220105
13	38.3321	23.0714	-1.6451	-5.862	1.9025	0.0000	1.9428	.0	2.220105
14	38.3321	25.0114	-1.6451	-5.862	1.9025	0.0000	1.9428	.0	2.220105
15	38.3321	26.9514	-1.6451	-5.862	1.9025	0.0000	1.9428	.0	2.220105
16	38.3321	28.8914	-1.6451	-5.862	1.9025	0.0000	1.9428	.0	2.220105
17	38.3321	30.8314	-1.6451	-5.862	1.9025	0.0000	1.9428	.0	2.220105
18	38.3321	32.7714	-1.6451	-5.862	1.9025	0.0000	1.9428	.0	2.220105
19	38.3321	34.7114	-1.6451	-5.862	1.9025	0.0000	1.9428	.0	2.220105
K= 17, F= 0.6403, M= 0.072									

FIGURE 13 PORTION OF AN EDIT LISTING WRITTEN BY SWEET

DATE = 77/08/04. OSC-4 OIL SHALE (2ND 40 GAL/TON SHOT), NO DAMAGE. RUN C
 NSCRIB8= 1. HISTORIES, TIME IN MUSEC, STRESS IN DYN/CM2, VELOCITY IN CM/SEC, DENSITY IN G/CM3

N	TIME	DT	DELTIM	TZZ(12, 5)	TYY(13, 2)	TYY(13, 6)	TYY(24, 2)	TZZ(24, 5)	TYY(24, 6)	TZZ(24, 13)
51	1.720E+01	3.852E-07	1.076E+01	-6.858E+08	-8.702E+07	-2.182E+09	-1.662E+09	-2.149E+04	1.664E+06	-4.615E+06
52	1.755E+01	3.485E-07	4.703E+00	-6.227E+08	-8.869E+07	-2.101E+09	-1.629F+09	0.	1.547E+06	-5.017E+06
53	1.789E+01	3.455E-07	4.688E+00	-5.453E+08	-8.878E+07	-2.027E+09	-1.620E+09	0.	1.454E+06	-5.17E+06
54	1.824E+01	3.453F-07	4.751E+00	-4.618E+08	-8.714E+07	-1.959E+09	-1.628E+09	0.	1.373E+06	-5.217E+06
55	1.859E+01	3.450E-07	4.697E+00	-3.808E+08	-8.365E+07	-1.896E+09	-1.642E+09	0.	1.184E+06	-5.248E+06
56	1.894E+01	3.781F-07	4.655E+00	-3.034E+08	-7.774E+07	-1.832E+09	-1.647F+09	0.	7.384E+05	-5.243E+06
57	1.932E+01	3.626E-07	4.714E+00	-2.469E+08	-6.976E+07	-1.775E+09	-1.641F+09	0.	2.337E+05	-5.236E+06
58	1.967E+01	3.504E-07	4.742E+00	-2.116E+08	-6.013E+07	-1.725E+09	-1.624F+09	-2.235E+05	4.187E+04	-5.183E+06
59	2.002E+01	3.447E-07	4.759E+00	-1.951E+08	-4.900E+07	-1.680E+09	-1.593E+09	-1.094E+06	-2.542E+05	-5.052E+06
60	2.038E+01	3.579E-07	4.769E+00	-1.941E+08	-3.661E+07	-1.637E+09	-1.597E+09	-6.675E+05	-2.113E+06	-6.719E+06
61	2.073E+01	3.583F-07	4.682E+00	-2.241E+08	-2.469E+07	-1.597E+09	-1.492E+09	0.	-6.017E+06	-7.884E+06
62	2.109E+01	3.549E-07	4.693E+00	-2.091E+08	-1.033E+07	-1.560E+09	-1.434E+09	0.	-1.093E+07	-1.045E+07
63	2.144E+01	3.529E-07	4.705E+00	-2.325E+08	4.651E+06	-1.527E+09	-1.375E+09	-4.074E+07	-1.843E+07	-1.645E+07
64	2.180E+01	3.541F-07	4.705E+00	-2.312E+08	2.086E+07	-1.496E+09	-1.331E+09	-1.198E+08	-3.427E+07	-2.689E+07
65	2.219E+01	3.934E-07	4.794E+00	-2.214E+08	4.005E+07	-1.464E+09	-1.289E+09	-1.177E+08	-6.308E+07	-4.233E+07
66	2.252E+01	3.279F-07	4.774E+00	-2.051E+08	5.678E+07	-1.439E+09	-1.262E+09	-1.052E+08	-8.973E+07	-6.513E+07
67	2.286E+01	3.457F-07	4.717E+00	-1.803E+08	7.431E+07	-1.416E+09	-1.244E+09	-1.052E+08	-1.171E+08	-1.077E+08
68	2.302E+01	3.379F-07	4.735E+00	-1.515E+08	9.268E+07	-1.394E+09	-1.232E+09	-1.205E+08	-1.469E+08	-1.649E+08
69	2.359E+01	3.863F-07	4.803E+00	-1.176E+08	1.134E+08	-1.372E+09	-1.224E+09	-1.470E+10	-2.109E+08	-2.401E+08
70	2.394E+01	3.509E-07	4.704E+00	-9.016E+07	1.318E+08	-1.353E+09	-1.219E+09	-1.410E+10	-2.732E+08	-4.660E+08
71	2.429E+01	3.477E-07	4.704E+00	-6.909E+07	1.494E+08	-1.336E+09	-1.214E+09	-1.314E+10	-2.732E+08	-4.660E+08
72	2.463E+01	3.434E-07	4.715E+00	-5.576E+07	1.661E+08	-1.322E+09	-1.208E+09	-1.207E+10	-7.551E+08	-8.226E+08
73	2.497E+01	3.382E-07	4.669E+00	-5.009E+07	1.813E+08	-1.308E+09	-1.198E+09	-1.076E+09	-1.076E+09	-1.076E+09
74	2.530E+01	3.324F-07	4.744E+00	-5.371E+07	1.965E+08	-1.297E+09	-1.188E+09	-9.914E+09	-1.451E+09	-1.241E+09
75	2.563E+01	3.264E-07	4.759E+00	-6.142E+07	2.101E+08	-1.286E+09	-1.175E+09	-8.942E+09	-1.846E+09	-1.485E+09
76	2.600E+01	3.739F-07	1.102E+01	-7.126E+07	2.248E+08	-1.276E+09	-1.158E+09	-7.993E+09	-2.319E+09	-1.803E+09
77	2.636E+01	3.602E-07	4.748E+00	-7.880E+07	2.382E+08	-1.267E+09	-1.142E+09	-7.193E+09	-2.719E+09	-1.803E+09
78	2.672E+01	3.581E-07	4.763E+00	-8.239F+07	2.510E+08	-1.259E+09	-1.126E+09	-6.514E+09	-3.188E+09	-2.493E+09
79	2.708E+01	3.563E-07	4.792E+00	-8.161E+07	2.632E+08	-1.252E+09	-1.112E+09	-5.941E+09	-3.497E+09	-2.849E+09
80	2.745E+01	3.753E-07	4.800E+00	-7.662E+07	2.699F+08	-1.246E+09	-1.099E+09	-5.427E+09	-3.686E+09	-3.212E+09
81	2.780E+01	3.540E-07	4.804E+00	-7.011E+07	2.600E+08	-1.242E+09	-1.089E+09	-5.011E+09	-3.721E+09	-3.507E+09
82	2.815E+01	3.453E-07	4.807E+00	-6.392E+07	2.816E+08	-1.238E+09	-1.080E+09	-4.658E+09	-3.638E+09	-3.728E+09
83	2.854E+01	3.933E-07	4.836E+00	-5.775E+07	2.874E+08	-1.235E+09	-1.071E+09	-4.305E+09	-3.447E+09	-3.884E+09
84	2.892E+01	3.723E-07	4.786E+00	-5.486E+07	2.920E+08	-1.233E+09	-1.064F+09	-4.011E+09	-3.136E+09	-3.916E+09
85	2.931E+01	3.971E-07	4.860E+00	-5.829E+07	2.960E+08	-1.232E+09	-1.056F+09	-3.732E+09	-2.715E+09	-3.862E+09
86	2.970E+01	3.851E-07	4.842E+00	-6.723E+07	2.988F+08	-1.232E+09	-1.047F+09	-3.492E+09	-2.282E+09	-3.718E+09
87	3.008E+01	3.864F-07	4.842E+00	-7.966E+07	3.009F+08	-1.231E+09	-1.039F+09	-3.277E+09	-1.848E+09	-3.476E+09
88	3.045E+01	3.667F-07	4.827E+00	-9.450E+07	3.024F+08	-1.241E+09	-1.030F+09	-3.096E+09	-1.527E+09	-3.186E+09
89	3.084E+01	3.883E-07	4.835E+00	-1.137E+08	3.036E+08	-1.246E+09	-1.021E+09	-2.924E+09	-1.235E+09	-2.854E+09
90	3.123E+01	3.915E-07	4.858E+00	-1.352E+08	3.048E+08	-1.251E+09	-1.013F+09	-2.770E+09	-1.025E+09	-2.529E+09
91	3.161E+01	3.817E-07	4.833E+00	-1.577E+08	3.065E+08	-1.255E+09	-1.004F+09	-2.636E+09	-8.985E+08	-2.529E+09
92	3.197E+01	3.597E-07	4.833E+00	-1.805E+08	3.084E+08	-1.260E+09	-9.956F+08	-2.522E+09	-8.411E+08	-2.042E+09
93	3.236E+01	3.927F-07	4.916E+00	-2.086E+08	3.123F+08	-1.266E+09	-9.835E+08	-2.404E+09	-8.355E+08	-1.877E+09
94	3.271E+01	3.476F-07	4.858E+00	-2.360E+08	3.165E+08	-1.268E+09	-9.697F+08	-2.318E+09	-8.355E+08	-1.782E+09
95	3.309E+01	3.799F-07	4.858E+00	-2.683E+08	3.224F+08	-1.272E+09	-9.519E+08	-2.227E+09	-8.437E+08	-1.723E+09
96	3.344E+01	3.487F-07	4.894E+00	-3.066E+08	3.283E+08	-1.276E+09	-9.338F+08	-2.150E+09	-8.346E+08	-1.699E+09
97	3.384E+01	3.954F-07	4.901E+00	-3.415E+08	3.350E+08	-1.280E+09	-9.121E+08	-2.069E+09	-7.970E+08	-1.691E+09
98	3.423E+01	3.960F-07	4.894E+00	-3.873E+08	3.417E+08	-1.284E+09	-8.906F+08	-1.994E+09	-7.256E+08	-1.699E+09
99	3.457E+01	3.413F-07	4.831E+00	-4.298E+08	3.474E+08	-1.287E+09	-8.734E+08	-1.935E+09	-6.418E+08	-1.642E+09
100	3.493E+01	3.551E-07	4.887E+00	-4.758E+08	3.529F+08	-1.290E+09	-8.585E+08	-1.877E+09	-5.413E+08	-1.644E+09

FIGURE 15 PORTION OF A HISTORICAL LISTING WRITTEN BY SCRIBET

6.4 Miscellaneous Messages

Several error messages and a STOP message are provided by TROTT. Also several material model subroutines may print information about the current state of material in a cell.

The STOP message lists values of the stop criteria and the current values of variables that are compared with the criteria (see Figure 16). In the sample case the stop occurred as the result of an error that caused NSCRIB to be set to 1.

When excessive grid distortion occurs, cells may get so tangled that the cells areas become negative. When a negative area is computed, a message like that shown in Figure 16 is printed and NSCRIB is set to 1. Then at the completion of the time step, TROTT terminates the calculation with the usual historical listings.

STOP MESSAGE

STOP CRITERIA - IMAX = 375 TS = 6.000E-05 DT LESS THAN 1.E-12 NSCRIB = 1 CALTIM = 3.605E+02 SECONDS
 CURRENT VALUES - N = 258 TYME = 4.742E-05 DT = 9.969E-08 NSCRIB = 1

ERROR MESSAGES

POINTS 214 K,J= 17 3 A124,A234= 1.151E+00-2.261E-01 XNW,XTEMP(J),XTEMP(J-1)= 1.732E+01 1.628E+01 1.818E+01
 XKMJM,YNW,YTEMP(J)= 1.641E+01 4.996E+00 3.622E+00 YTEMP(J-1),YKMJM= 5.020E+00 3.841E+00
 POINTS 214 K,J= 17 4 A124,A234= 6.104E-01-1.241E-01 XNW,XTEMP(J),XTEMP(J-1)= 1.697E+01 1.590E+01 1.628E+01
 XKMJM,YNW,YTEMP(J)= 1.641E+01 4.673E+00 3.935E+00 YTEMP(J-1),YKMJM= 3.622E+00 3.841E+00
 POINTS 234 K,J= 17 5 A124,A234= 1.152E-01-1.408E-02 XNW,XTEMP(J),XTEMP(J-1)= 1.676E+01 1.581E+01 1.590E+01
 XKMJM,YNW,YTEMP(J)= 1.641E+01 4.776E+00 3.980E+00 YTEMP(J-1),YKMJM= 3.935E+00 3.841E+00

FIGURE 16 MISCELLANEOUS MESSAGES FROM THE TROTT PROGRAM

Appendix A

INSERTION PROCEDURE FOR MATERIAL MODELS

As new material models are generated, they can be added to TROTT for performing wave propagation calculations. The appendix describes the procedure for inserting material model subroutines and provides a sample case.

A wave propagation code normally has four main categories of operations: reading the input data, initializing a finite difference grid, performing calculations for each time increment at each grid point, and printing the computed information. A material model subroutine may be involved in all or some of these operations. Call statements must be provided in TROTT at appropriate locations to accomplish these tasks. Also the new subroutine should be provided with separate sections for each operation and an indicator to show which operation to perform. For example, in SHEAR2 the formal parameter NCALL indicates the operation required, as follows:

```
NCALL = 0 Initialize the routine and read data for one material
        1 Read data for one material
        2 Calculate stresses and damage
        3 Calculate stresses and damage, and print results
        4 Print results only.
```

The calls for NCALL = 0 and 1 are in LAYOUTT. There, NCALL is LSHB, a parameter that is initially zero. After the first call, LSHB is set to 1. For NCALL = 2 and 3, the call statement is in SWEEP. Other calling strategies are also possible. For example, BFRAC is initialized on the first call from SWEEP; there are no other calls. EXPLODE is called from LAYOUTT to read data and then called for each cell during the

layout to initialize array variables. During propagation calculation, EXPLODE is also called by SWEEPT.

At the point of insertion of the call statement, four elements are provided.

- (1) The appropriate branching statements are needed to switch to the new model when it is required. For SHEAR2, it was decided to treat the model as a fracture routine and designate it by $NFR(M) = 3$. Then the available branching statements in LAYOUTT and SWEEPT were amplified to include one more branch.
- (2) Variables must be initialized, calibrated, or given sign changes just preceding the call statement.
- (3) The call statement is provided.
- (4) Some variables may need to be reset following the calculations in the routine. Then a jump is provided to the appropriate section of SWEEPT or LAYOUTT to continue the calculation.

Items (2), (3), and (4) are discussed further below following introduction of a call statement.

A sample call statement for SHEAR2 is listed here as it appears in SWEEPT (the same call can be used in LAYOUTT).

```
CALL SHEAR2 (NCALL, IN, MAT, K, J, IH(LM), SXXW, SYYW, TXYW,  
PW, COM(LM+24), DW, D(LM), DT, EW, E(LM), COM(LM+21), EMELT,  
COM(LM+22), EXXH, EYYH, EXYH, F, YY(LM) COM(LM+23), TH(LM),  
-ALFA, ESC, COM(LM+25))
```

Because SHEAR2 represents a fairly complex case, this call statement will be discussed in detail.

The initialization of NCALL for use in LAYOUTT was described above. For SWEEPT, NCALL (LS is the name used in SWEEPT) is initialized just before the call statement. NCALL is set to 2 normally, but it is set to 3 on cycles when an edit listing will occur. The parameter IN is the file containing input data. Normally IN is 5. MAT is the material number. The coordinate numbers J and K indicate the cell being treated; they are used for printout only. The deviator stress components SXXW,

SYW, TXYW are positive in tension, whereas the pressure PW is positive in compression. If necessary, sign and magnitude changes can be made in the stresses just preceding the call statement. The current and previous density and energy values are DW, D(LM), EW, and E(LM). The strain increments EXXH, EYYH, EXYH are also positive in tension. For SHEAR2 the standard equation-of-state constants are contained in the ESC array as follows:

```

ESC(MAT,1) = initial density, g/cm3
ESC(MAT,2) = bulk modulus, dyn/cm2
ESC(MAT,3) = D, S; the second and third coefficients of the
ESC(MAT,4) = Hugoniot series expansion for pressure, dyn/cm2
ESC(MAT,5) = shear modulus, dyn/cm2
ESC(MAT,9) = Grüneisen's ratio.

```

All the cell quantities are stored in a single large array called COM. The particular locations assigned to cell J,K begin at LM = LVAR(K,J). IH(LM) = indicator, D(LM), E(LM), YY(LM) = yield strength, and TH(LM) = rotation are all in this array. Quantities COM(LM+24), etc., are also in the array. This allocation of space in the COM array is discussed further in Appendix B.

Following insertion of a new material model, it is a good plan to run a simple problem with frequent edits to determine whether the routine is performing satisfactorily.

Appendix B

COORDINATE AND CELL VARIABLES

All the cell and coordinate variables are stored in a single large one-dimensional array called COM(). The array locations that pertain to each cell or coordinate are identified by an auxiliary array, LVAR(K,J). Extra array locations may be provided for a cell through the use of the indicator NVAR(M). Quadrilateral cells may be divided into triangular cells with the use of NTRI(M). Operations with these four variables are described below.

The standard 17 variables associated with cells and coordinates are listed in Table B.1. These variables are equivalenced to the COM array for convenience in identifying them. For example,

$$\begin{aligned}X(L) &= \text{COM}(L) \\Y(L) &= \text{COM}(L + 1) \\XD(L) &= \text{COM}(L + 2) \\Z(L) &= \text{COM}(L + 6) \\P(L) &= \text{COM}(L + 15)\end{aligned}$$

Thus all the variables associated with a particular cell or coordinate are stored one after the other in the COM array. The starting location, L, for the set is given by the LVAR array. Thus for the point K, J, the starting point is $L = \text{LVAR}(K, J)$. To find a value such as $P_{K,J}$, two steps are required:

$$\begin{aligned}L &= \text{LVAR}(K, J) \\P_{K,J} &= P(L)\end{aligned}$$

In the layout, cells are numbered according to the highest number coordinates around the cell. That is, for cell K, J the coordinates are (K-1, J-1), (K-1, J), (K, J-1), and (K, J). Therefore, in a normal layout

Table B.1

STANDARD VARIABLES FOR EACH COORDINATE AND CELL

<u>No.</u>	<u>Name</u>	<u>Definition</u>
1	X	Eulerian position in the x direction, cm
2	Y	Eulerian position in the y direction, cm
3	XD	Particle velocity in the x direction, cm/sec
4	YD	Particle velocity in the y direction, cm/sec
5	M	Material number (normally unused)
6	A	Cell area in the xy plane, cm^2
7	Z	Cell mass in planar problems, g/cm; $1.5/\pi$ times cell mass in axisymmetric problems, g
8	D	Cell density, g/cm^3
9	SXX	Deviator stress in x direction, dyn/cm^2
10	SYX	Deviator stress in y direction
11	SZZ	Deviator stress in z direction, dyn/cm^2
12	TXY	Shear stress on xy plane, dyn/cm^2
13	TXX	Total stress in x direction, dyn/cm^2
14	TYX	Total stress in y direction, dyn/cm^2
15	TZZ	Total stress in z direction, dyn/cm^2
16	P	Pressure, dyn/cm^2
17	E	Internal energy, erg/g

there are some coordinates, such as (1,1) that are not associated with a cell. For these only four variables (X, Y, XD, and YD) are needed. For the usual cell and coordinate combination, 17 variables are allocated. For material models that require more variables, an input variable NVAR is set to the additional number required. In summary, the number of variables allocated are:

Coordinate only	4 variables
Standard cell and coordinate	17 variables
Special cell and coordinate	17 + NVAR(M)

The LVAR array is initialized in such a way that the COM array is just filled, with no gaps remaining between variable sets for each cell. The NVAR(M) input variable is required for all but simple elastic materials. Yield and explosive models require two extra variables. The numbers required for some special models are listed in Table B.2.

Triangular cells may be used instead of quadrilateral cells for any material. The triangular cells are stiffer than quadrilateral cells and hence tend to resist distortion in regions of high shear flow. Because they resist shear distortion partially by a density change, the pressures in such cells often vary wildly. Hence it is advisable to use the triangular cells only where absolutely necessary and not to use a pressure-sensitive material model for the cell material.

The triangular cell feature is initiated by setting NTRI = 1 for the material. Then each standard quadrilateral cell K, J is divided into two triangular cells with coordinates

(K, J), (K, J-1), (K-1, J)

and

(K, J-1), (K-1, J), (K-1, J-1).

A larger storage array is required for this special double cell. There are four (coordinates), 13 (cell), 12 (second cell), plus 2 x NVAR variables for a quadrilateral cell treated as two triangular cells.

Table B.2

EXTRA VARIABLES REQUIRED FOR SPECIAL MODELS

<u>Model</u>	<u>NVAR</u>
CAP1	5
REBAR	12
SHEAR2	Variable, minimum 13
BFRAC3	23
EXPLODE	2
DFRACT	6
DFRACTS	5

To obtain historical information from triangular cells, the storage process must be traced to locate the variable of interest. For example, the request for pressure in both triangles at cell K=10, J=20 would read

161020

L1020

where 16 is the number for pressure in Table B.1 and $L = 17 + NVAR + 16 - 5$, in which 17 is the standard number for the coordinate and the first triangular cell, NVAR is for the extra variables in the first cell, $16 - 5$ is for the location of the pressure variable for the second triangular cell. This request for historical input is also described in Section 5 and Table 2.

For large or oddly shaped problems, it may be necessary to redimension some of the arrays. These arrays are COM, XL, YL, MM, IZ, and LVAR in TROTT; XDTEMP and YDTEMP in SWEEP; and the array size constants JSIZE, JXX, and KXX in TROTT. JXX and KXX must be greater than or equal to the number of coordinates in the J and K directions, and must equal the dimension of the arrays XL, YL, MM, IZ, and LVAR. JSIZE is the length of the COM array. XDTEMP and YDTEMP must be dimensioned to be at least as long as JXX.

Appendix C

SAMPLE INPUT DECKS

This appendix provides some sample input decks and supplements the input description in Section 5. Several data decks are provided to illustrate the main features of TROTT and the range of problems that can be treated. General guidelines for constructing the decks are listed below:

- The data fields are usually in multiples of 5 or 10 characters.
- The first column is reserved for indicators and is normally blank.
- Columns 2 through 10 are usually labels only.
- Any number of decks can be run, one following the other with no separators between decks.

Problems of planar and cylindrical geometry can be run by appropriate use of the indicator IJBUND (see Table 1 in Section 5). The activation is usually prescribed either by velocities or a detonation. Sample problems with these geometries and activation mechanisms are provided in the following figures.

Figure C.1 contains an input deck for a one-dimensional simulation of a plate impact problem in lexan. Only one cell in the J direction is used. The second lexan material is treated by the NAG brittle fracture model.

A two-dimensional simulation of an impact of a rod onto an oblique plate is initialized by the data deck in Figure C.2. The rod is treated as a plate and the target is simply a rigid boundary at 45° . Triangular cells are used for the row of cells along the impact plane.

```

DUPLICATE PUFF RUN 1033-51 IMPACT IN LEXAN FOR D. SHOCKEY
NSTAR 0 NPL0T 999 NDUMP 999 IMAX= 100 IPRIN 10 JPRIN 1
IJBUND -1 NBL0CK 3 NMTRLS 3 NJED= 16
TS = 15.00E-06 IVTYPE = 1 NVBLK = 0
COSQ = 4.0 CLIN = 0.1 TRIQ = 0.
KSLIDE 0 JSLIDE 0
JPR = 96 100
JEDT,K,J= -510202 -510402 -510602 -510802 -511402 -511602 -511802
          -512002 -512102 -512202 -512302 -512402 -512502 -512602
          -512802 -513002

LEXAN      RHOS = 1.20 CFP= 000 DPY= 000 NVAR = 0 NTRI = 0
EQST = 4.720E+10-1.330E+11 1.000E+11 1.30 .25 3.500E+12

LEXAN      RHOS = 1.20 CFP= 060 DPY= 000 NVAR = 2 NTRI = 0
EQST = 4.720E+10-1.330E+11 1.000E+11 1.30 .25 3.500E+12
TSR = -1.000E+07

LEXAN FRACTURE RHOS = 1.2 CFP = 020 DPY= 001 NVAR = 26 NTRI = 0
EQST = 4.720E+10-1.330E+11 1.000E+11 1.3 .25 3.500E+12
BFR = -5.000E-04 3.600E+07 .002 3.500E+10-1.670E+09-1.410E+08 .02
BFR 2 -1.670E+09 0. .25 1.0 .20 4.0
YIELD = 1.000E+11 2.000E+10

K = 1 10 X = 0. .2745 .2745 0. MAT = 1
J = 1 2 Y = 0. 0. .03 .03
K = 10 11 X = .2745 .305 .305 .2745 MAT = 2
J = 1 2 Y = 0. 0. .03 .03
K = 11 33 X = .305 .963 .963 .305 MAT= 3
J = 1 2 Y = 0. 0. .03 .03
JU = 11 KU = 11 UZERO = 1.522E+04
7/8/9

```

FIGURE C.1 SIMULATION OF A ONE-DIMENSIONAL PLANAR IMPACT OF LEXAN PLATES UNDERGOING BRITTLE FRACTURE

OBLIQUE PLATE IMPACT WITH BFRACT, 45 DEG., UZERO=1.E+05 CM/SEC
 NSTAR 0 NPLOT 999 NDUMP 999 IMAX 0 IPRIN 200 JPRIN 1 NOBLQ 1
 ANGLE = 45.
 IJBUND -3 NBLCK 4 NMTRLS 3 NJED = 13
 TS = 1.000E-04 IVTYPE = -1 NVBLK = 1
 CQSQ = .4000E+01 CLIN = .1000E+00 TRIQ = .1000E+00
 KSLIDE 0 JSLIDE 0
 JP1,JP2 = 1 5
 JEDT,K,J = -5110 2 -5110 6 -5115 2 -5115 6 -5120 2 -5120 6 -5125 2
 -5125 6 -5130 2 -5130 3 -5130 4 -5130 5 -5130 6

 ARMCO FRACTURE RHCS = .7850E+01 CFP= 020 DPY = 001 NVAR = 23
 EQST = .1590E+13 .517E+13 .736E+11 .169E+01 .250E+00 .517E+14
 BFR 1 = -.550E-03 -.100E+09 .500E-04 .400E+13 -.300E+10 -.5270E+10
 BFR 2 = -.300E+10 0. .250E+00 .500E+00 .400E+00 .300E+01
 YIELD = .550E+10 .819E+12
 ARMCO IRON RHCS = .7850E+01 CFP= 000 DPY = 001 NVAR = 2 NTRI = 1
 EQST = .1590E+13 .517E+13 .736E+11 .169E+01 .250E+00 .517E+14
 YIELD = .550E+10 .819E+12

 ARMCO IRON RHCS = .7850E+01 CFP= 000 DPY = 001 NVAR = 2
 EQST = .1590E+15 .517E+13 .736E+11 .169E+01 .250E+00 .517E+14
 YIELD = .550E+10 2.380E+14

 K = 1 29 X = 0. 6.72 6.72 0. MAT = 1
 J = 1 6 Y = 0. 0. 1.20 1.2
 K = 29 30 X = 6.72 6.86 7.1 6.72 MAT = 2
 J = 1 2 Y = 0. 0. .24 .24
 K = 29 30 X = 6.72 7.1 7.1 6.72 MAT = 2
 J = 2 5 Y = .24 .24 .96 .96
 K = 29 30 X = 6.72 7.1 6.86 6.72 MAT = 2
 J = 5 6 Y = .96 .96 1.2 1.2
 JU = 0 KU = 0 UZERO = 1.000E+05
 7/8/9

FIGURE C.2 IMPACT OF AN ARMCO IRON PLATE ONTO A RIGID WALL AT 45°, WITH
 TRIANGULAR CELLS IN THE REGION OF IMPACT

A planar problem with just two cells is illustrated in Figure C.3. The calculation was made to examine coefficients to use for the triangular artificial viscosity. The velocity initialization shows the method for laying out velocities by quadrilateral blocks.

Figures C.4, C.5, and C.6 contain decks for impacts of cylinders along their common axes. Figure C.4 simulates a simple impact of two cylinders to test radial motion of the free cylindrical walls.

Radial motions are also of interest in the impact prescribed by the deck in Figure C.5. The simulation includes a PMMA flyer plate on the front of an aluminum projectile described in geometric detail. The target is a disk of zinc sulfide inside an aluminum guard ring; both disks are encased in lexan. The lexan housing is also inside a separable lexan guard ring. The special spall features of materials 2 and 4 (CFP = 050 or 060) permit spallation along radial and circumferential surfaces.

Impact of a steel cylinder (with a 2.5-inch diameter aluminum projectile) onto a reinforced concrete target is simulated with the data deck in Figure C.6. The concrete is treated by a cap plasticity model and the reinforcing steel layers by a composite model.

Explosions activate the problems in Figures C.7, C.8, and C.9. The deck in Figure C.7 simulates a detonation running along the axis of a small PETN charge in a cylinder of oil shale. The calculation was made to examine radial stresses at planes where stress gages had been located in the corresponding experiment.

Figure C.8 is the input deck for a contained fragmenting round experiment. The motion is caused by a running detonation in PETN down the axis of the fragmenting steel cylinder, which is being treated by the shear band model (CFP = 030). Radial motion of the round is presented by surrounding the round with cylinders of PMMA, steel, and lead, in that order. Problems with the large distortions at the outer ends of the fragmenting steel cylinder are avoided by making the outermost rows of cells triangular instead of quadrilateral.

```

HOURGLASSING SAMPLE TO TEST TRIQ EFFECTIVENESS
NSTAR 0 NPL0T 999 NDUMP 999 IMAX 50 IPRIN 1
IJBUND -3-NBLOCK 1 NMTRLS 1 NJED= 5
TS = 1.000E-04 IVTYPE = 2 NVBLK = 2
CQSQ = 4.E CLIN = 0.1E TRIQ = 0.03E0
KSLIDE 0 JSLIDE 0
JED = 3 2 1 3 2 2 -51 2 2 3 2 3 -51 2 3

IMPACTOR STEEL RHOS= 7.85E CFP= 000 DPY = 001 NVAR = 2
EQSTC= 1.5889E12 5.170E12 7.360E10 1.69E0 0.25E0 5.170E+13
YIELD= 1.222E10 8.188E11

K = 1 2 X = 0. 1. 1. 0. MAT = 1
J = 1 3 Y = 0. 0. 2. 2.
K = 1 2 XDOT = -10000. 10000. 10000. -10000.
J = 1 3 YDOT = 0. 0. 0. 0.
K = 1 2 XDOT = 10000. -10000.
J = 2 2 YDOT = 0. 0.
7/8/9

```

FIGURE C-3 TEST OF THE DAMPING PROVIDED BY THE TRIANGLE ARTIFICIAL VISCOSITY TO COMBAT HOURGLASSING MOTIONS

```

CYLINDRICAL IMPACT FOR TESTING LATERAL MOTION
NSTAR 0 NPL0T 999 NDUMP 999 IMAX 100 IPRIN 10
IJBUND 2 NBLOCK 2 NMTRLS 1 NJED= 40
TS = 1.000E-04 IVTYP = 1 NVBLK = 0
CQSQ = 4.E CLIN = 0.1E TRIQ = 0.01
KSLIDE 0 JSLIDE 0
JEDT=K,J=
    4 5 1      4 5 4      4 6 1      4 6 2      -46 6 2      -47 6 2      -48 6 2
   -49 6 2    -50 6 2    -51 6 2    -52 6 2    -53 6 2      9 6 2      10 6 2
    11 6 2     12 6 2     16 6 2    -46 6 4    -47 6 4    -48 6 4    -49 6 4
   -50 6 4    -51 6 4    -52 6 4    -53 6 4      9 6 4     10 6 4     11 6 4
    12 6 4     16 6 4      4 6 4    -53 7 2    -53 7 3    -53 7 4    -53 8 2
   -53 8 3    -53 8 4    -53 9 2    -53 9 3    -53 9 4

IMPACTOR STEEL      RHOS=      7.85E0 CFP= 000 DPY = 001 NVAR = 2
EQSTC= 1.5889E12 5.170E12 7.360E10 1.69E0 0.25E0 5.170E13
YIELD= 1.222E10 8.188E11

K = 1 6 X = 0. 1. 1. 0. MAT = 1
J = 1 5 Y = 0. 0. 0.8 0.8
K = 6 11 X = 1.0 2.0 2.0 1.0 MAT = 1
J = 1 4 Y = 0. 0. 0.6 0.6
JU = 4 KU = 6 UZERO = 1.000E+04
7/8/9

```

FIGURE C-4 IMPACT OF TWO STEEL CYLINDERS ALONG THEIR AXIS TO STUDY RADIAL INERTIA EFFECTS

ZINC SULFIDE /GUARD RING IMPACT FOR Y. GUPTA, 4928-4

NSTAR 0 NPL0T 999 NOUMP 999 IMAX= 100 IPRIN 10 JPRIN 0 NOBLQ 0

IJBUND 2 NBLOCK 30 NMTRL 6 NJEO= 30

TS = 20.00E+06 IVTYPE = 1 NVBLK = 0

COSQ = 4. CLIN = 0.1 TRIG = 0.1

KSLIOE 0 JSLIOE 0

JEOT,K,J=

-5115 2	-5215 2	-5315 2	-5118 2	-5218 2	-5318 2	-5118 5
-5218 5	-5318 5	-5119 3	-5219 3	-5319 3	-5121 2	-5221 2
-5321 2	-5121 5	-5221 5	-5321 5	-5123 3	-5223 3	-5323 3
-5124 4	-5224 4	-5324 4	-5125 2	-5225 2	-5325 2	-5128 2
-5228 2	-5328 2					

PMMA-8KB (BARKER) RHQS = 1.184 CFP= 000 OPY = 001 NVAR = 2 NTRI = 0

EQST = 5.750E+10 4.050E+11 1.000E+10 1. .25 3.640E+11

YIELD = 2.000E+09 2.280E+10 2.850E+09

PMMA-8KB (BARKER) RHQS = 1.184 CFP= 050 OPY= 001 NVAR = 2 NTRI = 0

EQST = 5.750E+10 4.050E+11 1.000E+10 1. .25 3.640E+11

TSR = 1.000E+07

YIELD = 2.000E+09 2.280E+10 2.850E+09

LEXAN RHQS = 1.200 CFP= 000 OPY= 001 NVAR = 2 NTRI = 0

EQST = 4.750E+10-1.330E+11 1.000E+11 1.300 .25 3.500E+12

YIELD = 2.000E+09 1.000E+10

LEXAN RHQS = 1.200 CFP= 060 DPY= 001 NVAR = 2 NTRI = 0

EQST = 4.750E+10-1.330E+11 1.000E+11 1.300 .25 3.500E+12

TSR = 1.000E+07

YIELD = 2.000E+09 1.000E+10

AL6061-T6 RHQS = 2.707 CFP = 000 OPY = 001 NVAR = 2 NTRI = 0

EQST = 6.670E+11 1.000E+12 1.220E+11 2.04 .25 0.

YIELD = 3.210E+09 2.670E+11 3.790E+10

ZNS RHQS = 4.079 CFP= 000 OPY = 001 NVAR = 2 NTRI = 0

EQST = .7190E+12 0. 2.037E+11 2. .25 0.

YIELD = 10.00E+09 .3180E+12

K = 1 5 X = 0. 10.16 10.16 0. MAT = 5

J = 13 14 Y = 3.81 3.81 5.08 5.08

K = 5 9 X = 10.16 15.24 15.24 10.16 MAT = 5

J = 13 14 Y = 3.81 3.81 5.08 5.08

K = 9 11 X = 15.24 16.66875 16.66875 15.24 MAT = 5

J = 1 13 Y = 0. 0. 4.60375 3.81

K = 9 11 X = 15.24 16.66875 16.66875 15.24 MAT = 5

J = 13 14 Y = 3.81 4.60375 5.08 5.08

K = 11 12 X = 16.66875 17.6022 17.27 16.66875 MAT = 5

J = 13 14 Y = 4.60375 4.60375 5.08 5.08

K = 12 13 X = 17.6022 17.6911 17.6911 17.6022 MAT = 1

J = 1 12 Y = 0. 0. 3.89 3.89

K = 12 13 X = 17.6022 17.6911 17.6022 17.6022 MAT = 1

J = 12 13 Y = 3.89 3.89 4.92125 4.60375

K = 12 13 X = 17.6022 17.6022 17.6022 17.27 MAT = 5

J = 13 14 Y = 4.60375 4.92125 5.08 5.08

K = 13 14 X = 17.6911 17.78 17.78 17.6911 MAT = 2

J = 1 12 Y = 0. 0. 3.89 3.89

K = 13 14 X = 17.6911 17.78 17.78 17.6022 MAT = 2

J = 12 13 Y = 3.89 3.89 4.92125 4.92125

K = 13 14 X = 17.6022 17.78 17.78 17.8022 MAT = 5

J = 13 14 Y = 4.92125 4.92125 5.08 5.08

K = 14 17 X = 17.78 18.0848 18.0848 17.78 MAT = 3

J = 1 5 Y = 0. 0. 1.5875 1.5875

K = 14 17 X = 17.78 18.0848 18.0848 17.78 MAT = 3

J = 5 9 Y = 1.5875 1.5875 2.8575 2.8575

K = 14 17 X = 17.78 18.0848 18.0848 17.78 MAT = 3

J = 9 12 Y = 2.8575 2.8575 3.9113 3.89

K = 14 17 X = 17.78 18.0848 18.0848 17.78 MAT = 4

J = 12 13 Y = 3.89 3.9113 4.92125 4.92125

K = 14 17 X = 17.78 18.0848 18.0848 17.78 MAT = 3

J = 13 14 Y = 4.92125 4.92125 5.08 5.08

K = 14 17 X = 17.78 18.0848 18.0848 17.78 MAT = 3

J = 14 17 Y = 5.08 5.08 8.89 8.89

K = 17 25 X = 18.0848 19.333 19.333 18.0848 MAT = 6

J = 1 5 Y = 0. 0. 1.5875 1.5875

K = 17 25 X = 18.0848 19.333 19.333 18.0848 MAT = 5

J = 5 9 Y = 1.5875 1.5875 2.8575 2.8575

K = 17 25 X = 18.0848 19.333 19.333 18.0848 MAT = 3

J = 9 12 Y = 2.8575 2.8575 3.9986 3.9113

K = 17 25 X = 18.0848 19.333 19.333 18.0848 MAT = 4

J = 12 13 Y = 3.9113 3.9986 4.92125 4.92125

K = 17 25 X = 18.0848 19.333 19.333 18.0848 MAT = 3

J = 13 14 Y = 4.92125 4.92125 5.08 5.08

K = 17 25 X = 18.0848 19.333 19.333 18.0848 MAT = 3

J = 14 17 Y = 5.08 5.08 8.89 8.89

K = 25 33 X = 19.333 21.6093 21.6093 19.333 MAT = 3

J = 1 5 Y = 0. 0. 1.5875 1.5875

K = 25 33 X = 19.333 21.6093 21.6093 19.333 MAT = 3

J = 5 9 Y = 1.5875 1.5875 2.8575 2.8575

K = 25 33 X = 19.333 21.6093 21.6093 19.333 MAT = 3

J = 9 12 Y = 2.8575 2.8575 4.1578 3.9986

K = 25 33 X = 19.333 21.6093 21.6093 19.333 MAT = 4

J = 12 13 Y = 3.9986 4.1578 4.92125 4.92125

K = 25 33 X = 19.333 21.6093 21.6093 19.333 MAT = 3

J = 13 14 Y = 4.92125 4.92125 5.08 5.08

K = 25 33 X = 19.333 21.6093 21.6093 19.333 MAT = 3

J = 14 17 Y = 5.08 5.08 8.89 8.89

K = 33 36 X = 21.6093 26.6893 26.6893 21.6093 MAT = 5

J = 14 17 Y = 5.08 5.08 8.89 8.89

JU = 14 KU = 14 UZERO = 1.901E+03

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FIGURE C-5 IMPACT OF A PMMA FLYER PLATE ONTO A ZINC SULFIDE DISK WITH AN ALUMINUM GUARD RING AND ENCAPSULATED IN LEXAN

NO 16, CONC IMP, 22.34M/S, FULL PROJ., MOMENTUM CHECK
 NSTAR 0 NPL0T 999 NDUMP 999 IMAX= 600 IPRIN 100 JPRIN 4 NEXED 600
 IJBUND 2 NBLOCK 16 NMTRLS 5 NJED= 8
 TS= 2.000E-04 IVTYPE = -1 NVBLK = 1
 CQSQ= 4.000E+00 CLIN 2.500E-01 TRIQ= 0.020E+00
 KSLIDE 0 JSLIDE 0
 JPR = 200 202 300 302 400 402 500 502
 JEDT,K,J= 1317 2 1317 3 1317 4 1323 2 1323 3 1323 4 1327 8
 1330 8

IMPACTOR STEEL RHOS= 7.85E0 CFP= 000 DPY = 001 NVAR = 2
 EQSTC= 1.5889E12 5.170E12 7.360E10 1.69E0 0.25E0 5.170E13
 YIELD= 1.030E+10 8.188E11

REBAR STEEL RHOS= 7.85E0 CFP= 000 DPY= 001 NVAR= 2
 EQSTC= 1.5889E12 5.170E12 7.360E10 1.69E0 0.25E0 5.170E13
 YIELD= 1.030E10 8.188E11

CONCRETE RHOS = 2.85 E0 CFP = 004 DPY = 000 NVAR = 5
 EQST = 2.830E+11 0. 1.000E+11 2.000E+00 .25 0.
 RH0 = 2.22E0 AMU = 2.033E+11
 AK = 7.000E+10 AK2 = -.5500E+02 MUP = 5.250E+10 MUP2 = .1250E+03
 MC = 1.040E+09-8.300E+08 2.702E+09 2.500E+08 1.000E0
 SCRIT = 2.000E+07 DAMG(M) = 1.000E-03
 EVP = 0. -1.200E-02-3.500E-02-5.000E-02-2.230E-01
 NREG = 4 NPRCAP = 0 P1 = -3.500E+08 W2 = 1.25
 P2 = -1.000E+09 DELP = 0.
 P2 = -2.400E+09 DELP = 0.
 P2 = -3.400E+09 DELP = 0.
 P2 = -1.533E+10 DELP = 0.

REBAR RHOS= 2.5015E0 CFP= 100 DPY = 000 NVAR = 13
 EQSTC= 1.576E11 0.0 0.0 2.0E0 0.25E0 0.0
 FS= 0.05E0 THET= 0.0 IMC= 3 IMS= 2

ALUMINUM RHOS = 2.7 CFP= 000 DPY = 001 NVAR = 2
 EQST = 6.670E+11 1.000E+12 1.220E+11 2.04E 0.25E 0.
 YIELD = 3.210E+09 2.670E+11

(1)	K=	16	24	X=	7.62	17.78	17.78	7.62	MAT =	1
	J=	1	4	Y=	0.	0.	1.111	1.111		
(2)	K=	6	8	X=	2.54	3.556	3.556	2.54	MAT =	3
	J=	1	4	Y=	0.	0.	1.111	1.111		
(3)	K=	8	9	X=	3.556	4.064	4.064	3.556	MAT =	4
	J=	1	4	Y=	0.	0.	1.111	1.111		
(4)	K=	9	13	X=	4.064	6.096	6.096	4.064	MAT =	3
	J=	1	4	Y=	0.	0.	1.111	1.111		
(5)	K=	13	14	X=	6.096	6.604	6.604	6.096	MAT =	4
	J=	1	4	Y=	0.	0.	1.111	1.111		
(6)	K=	14	16	X=	6.604	7.62	7.62	6.604	MAT =	3
	J=	1	4	Y=	0.	0.	1.111	1.111		
(7)	K=	6	8	X=	2.54	3.556	3.556	2.540	MAT =	3
	J=	4	26	Y=	1.111	1.111	12.7	12.7		
(8)	K=	8	9	X=	3.556	4.064	4.064	3.556	MAT =	4
	J=	4	26	Y=	1.111	1.111	12.7	12.7		
(9)	K=	9	13	X=	4.064	6.096	6.096	4.064	MAT =	3
	J=	4	26	Y=	1.111	1.111	12.7	12.7		
(10)	K=	13	14	X=	6.096	6.604	6.604	6.096	MAT =	4
	J=	4	26	Y=	1.111	1.111	12.7	12.7		
(11)	K=	14	16	X=	6.604	7.62	7.62	6.604	MAT =	3
(1)	J=	4	26	Y=	1.111	1.111	12.7	12.7		
(12)	K=	1	6	X=	0.	2.54	2.54	0.	MAT =	3
	J=	14	26	Y=	8.89	6.378	12.7	12.7		
(13)	K=	24	26	X=	17.78	19.685	19.685	17.78	MAT =	5
	J=	1	4	Y=	0.	0.	1.111	1.111		
(14)	K=	24	26	X=	17.78	19.685	19.685	17.78	MAT =	5
	J=	4	7	Y=	1.111	1.111	2.475	2.475		
(15)	K=	24	26	X=	17.78	19.685	19.685	17.78	MAT =	5
	J=	7	8	Y=	2.475	2.475	3.1496	3.1496		
(16)	K=	26	37	X=	19.685	33.02	33.02	19.685	MAT =	5
	J=	7	8	Y=	2.475	2.475	3.1496	3.1496		
	JU=		4	KU =	16	UZERO =	-2.234E03			

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FIGURE C-6 IMPACT OF A CYLINDRICAL STEEL PROJECTILE ONTO A REINFORCED CONCRETE WALL

```

OSC-4 OIL SHALE(2ND 40GAL/TON SHOT), NO DAMAGE, RUN C
NSTAR 0 NPL0T 999 NDUMP 50 IMAX= 200 IPRIN 25
IJBUN= 2 NBL0C= 12 NMTRL 2 NJED= 14
TS = 5.000E-05 IVTYPE = 0 NVBLK = 0 KCHEK = 6
COSQ = 4.000E0 CLIN = 1.000E-01 TRIQ = 3.000E-02
KSLIDE 0 JSLIDE 0
JEDT,K,J= 1512 5 151213 1413 2 1413 6 1424 2 1524 5 1424 6
           152413 142413 1437 2 1537 6 1437 7 153713

PETN RHOS = 5.390E-01 CFP = 000 DPY = 010 NVAR = 2
EQST = 1.000E0 0. 1.000E0 9.300E-01 9.300E-01
NTYPE = 12 QEXPL = 3.000E+10 5.000E0 0. 5.000E-01

OIL SHALE (40G/T) RHOS = 2.000E0 CFP = 000 DPY = 001 NVAR = 2
EQST = 1.120E+11 1.120E+12 1.000E+11 1.240E0 2.500E-01-6.820E+11
YIELD = 1.000E+09 6.850E+10

(1) K = 1 7 X = 0. 4.826 4.826 0. MAT = 2
    J = 1 2 Y = 0. 0. .292 .292
    K = 7 41 X = 4.826 24.384 24.384 4.826 MAT = 1
    J = 1 2 Y = 0. 0. .292 .292
    K = 41 47 X = 24.384 29.21 29.21 24.384 MAT = 2
    J = 1 2 Y = 0. 0. .292 .292
(1) K = 1 7 X = 0. 4.826 4.826 0. MAT = 2
    J = 2 7 Y = .292 .292 1.78 1.78
    K = 7 41 X = 4.826 24.384 24.384 4.826 MAT = 2
    J = 2 7 Y = .292 .292 1.78 1.78
    K = 41 47 X = 24.384 29.21 29.21 24.384 MAT = 2
    J = 2 7 Y = .292 .292 1.78 1.78
(1) K = 1 7 X = 0. 4.826 4.826 0. MAT = 2
    J = 7 10 Y = 1.78 1.78 3.03 3.03
    K = 7 41 X = 4.826 24.384 24.384 4.826 MAT = 2
    J = 7 10 Y = 1.78 1.78 3.03 3.03
    K = 41 47 X = 24.384 29.21 29.21 24.384 MAT = 2
    J = 7 10 Y = 1.78 1.78 3.03 3.03
(1) K = 1 7 X = 0. 4.826 4.826 0. MAT = 2
    J = 10 20 Y = 3.03 3.03 8.73 8.73
    K = 7 41 X = 4.826 24.384 24.384 4.826 MAT = 2
    J = 10 20 Y = 3.03 3.03 8.73 8.73
    K = 41 47 X = 24.384 29.21 29.21 24.384 MAT = 2
    J = 10 20 Y = 3.03 3.03 8.73 8.73
7/8/9

```

FIGURE C-7 RUNNING DETONATION ALONG THE AXIS OF A CYLINDER OF OIL SHALE
Array sizes should be reset with $KXX \geq 47$, $JXX \geq 20$, and $JSIZE \geq 17000$.

FRAGMENTING ROUND - SHOT NO. 2, RHOS(PETN)=1.2
 NSTAR 0 NPL0T 5 NDUMP 999 IMAX= 50 IPRIN 5
 IJBUN 2 NBL0C 7 NMTRL 6 NJED 0
 TS = 60.00E-06 IVTYPE = 0 NVBLK = 0 KCHEK = 6
 COSQ = 4, CLIN = 0.1 TRIQ = .05
 KSLIDE 0 JSLIDE 0

PETN RHOS = 1.2 CFP = 000 DPY= 010 NVAR = 2
 EQST = 1. 0. 1.45 1.45
 NTYPE = 2 Q = 3.580E+10 1.3 0. 2.

4340STEEL (SHEAR2) RHOS = 7.85 CFP = 030 DPY= 001 NVAR= 63
 EQST = 1.589E+12 5.170E+12 7.360E+10 1.69 .25 5.170E+13
 SH2 30. .2 .011 .001 5. .07 .07
 1.4 3.000E-08 3.000E+08 6. .2 .17 7.000E+09
 SIZE = 0 0 0 0 0 0 0
 YIELD = 1.120E+10 8.190E+11

PMMA-8KB (BARKER) RHOS = 1.184 CFP= 000 DPY= 001 NVAR = 2
 EQST = 7.000E+10 4.050E+11 1.000E+10 1. .25 3.640E+11
 YIELD = 1.000E+06 1.950E+10

4140STEEL RHOS = 7.85 CFP = 000 DPY= 001 NVAR= 2
 EQST = 1.589E+12 5.170E+12 7.360E+10 1.69 .25 5.170E+13
 YIELD = 6.000E+09 8.190E+11

LEAD (KOHN) RHOS = 11.355 CFP = 000 DPY = 000
 EQST = 5.008E+11 4.986E+11 9.155E+09 2.2 .25 2.019E+12

4340STEEL (SHEAR2) RHOS = 7.85 CFP = 030 DPY= 001 NVAR = 63 NTRI = 1
 EQST = 1.589E+12 5.170E+12 7.360E+10 1.69 .25 5.170E+13
 SH2 30. .2 .011 .001 5. .07 .07
 1.4 3.000E-08 3.000E+08 6. .2 .17 7.000E+09
 SIZE = 0 0 0 0 0 0 0
 YIELD = 1.120E+10 8.190E+11

K =	1	17	X =	1.905	13.335	15.24	0. MAT =	1
J =	1	2	Y =	0.	0.	2.28	2.28	
K =	3	16	X =	1.905	14.288	14.288	1.905 MAT =	2
J =	2	5	Y =	2.280	2.280	3.42	3.42	
K =	1	3	X =	0.	1.905	1.905	0. MAT =	6
J =	2	5	Y =	2.28	2.28	3.42	3.42	
K =	16	17	X =	14.288	15.24	15.24	14.288 MAT =	6
J =	2	5	Y =	2.28	2.28	3.42	3.42	
K =	1	17	X =	0.	15.24	15.24	0. MAT =	3
J =	5	6	Y =	3.42	3.42	4.69	4.69	
K =	1	17	X =	0.	15.24	15.24	0. MAT =	4
J =	6	8	Y =	4.69	4.69	10.16	10.16	
K =	1	17	X =	0.	15.24	15.24	0. MAT =	5
J =	8	10	Y =	10.16	10.16	12.7	12.7	

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FIGURE C-8 RUNNING DETONATION OF PETN IN A STEEL FRAGMENTING CYLINDER
 CONTAINED IN CYLINDER OF PMMA, 4340 STEEL, AND LEAD

HF-1 FRAG ROUND WITH RUNNING DETONATION

NSTAR 0 NPL0T 20 NDUMP 999 IMAX= 200 IPRIN 20

IJBUND 2 NBLOCK 18 NMTRLS 3 NJED=

TS = 115.0E-06 IVTYPE= 0 NVBLK = 0 KCHEK = 12

COSQ= 4.0 CLIN = 0.1 TRIQ= .05

KSLIDE 0 JSLIDE 0

HF-1 RHOS = 7.85E0 CFP= 030 DPY= 002 NVAR = 64
 EQST= 1.589E+12 5.170E+12 7.360E+10 1.69E0 0.25E0 5.170E+13
 SH2 3.000E+01 .2000E+00 1.100E-02 1.000E-03 0.17 0.070E+00 0.070E+00
 1.4 3.000E-08 3.000E+08 6. .2 .17 7.000E+09
 NSIZE 0 0 0 8 0 0 0
 YIELD = 1.030E+10 8.190E+11

PBXN-106 RHOS = 1.634 CFP = 000 DPY = 010 NVAR = 2
 EQST = 1. 0. 2.0 2.0 0.
 NTYPE = 2 QEXPL = 3.900E+10 53.87 0. 2.0

CH6 RHOS = 1.774 CFP = 000 DPY = 010 NVAR = 2
 EQST = 1. 0. 1.7 1.7 0.
 NTYPE = 2 QEXPL = 5.811E+10 54.10 0. 2.0

1	K=	1	4	X =	0.	2.54	3.81	0.	MAT =	1
	J=	1	7	Y =	0.	0.	5.08	4.572		
2	K=	4	12	X =	3.048	12.7	12.7	3.81	MAT =	1
	J=	4	7	Y =	2.108	4.318	6.35	5.08		
3	K=	4	12	X =	2.54	12.7	12.7	3.048	MAT =	2
	J=	1	4	Y =	0.	0.	4.318	2.108		
4	K=	12	29	X =	12.7	33.02	33.02	12.7	MAT =	1
	J=	4	7	Y =	4.318	4.318	6.35	6.35		
5	K=	12	29	X =	12.7	33.02	33.02	12.7	MAT =	2
	J=	1	4	Y =	0.	0.	4.318	4.318		
6	K=	29	43	X =	33.02	51.05	51.05	33.02	MAT =	1
	J=	4	7	Y =	4.318	1.651	4.064	6.350		
7	K=	29	43	X =	33.02	51.05	51.05	33.02	MAT =	2
	J=	1	4	Y =	0.	0.	1.651	4.318		
8	K=	43	46	X =	51.05	54.10	54.10	51.05	MAT =	1
	J=	4	7	Y =	1.651	1.651	3.505	4.064		
9	K=	43	46	X =	51.05	54.10	54.10	51.05	MAT =	3
	J=	1	4	Y =	0.	0.	1.651	1.651		
10	K=	46	47	X =	54.1	55.218	55.218	54.1	MAT =	1
	J=	2	7	Y =	0.5503333	0.	3.4086	3.505		
11	K=	46	47	X =	54.1	54.659	55.218	54.1	MAT =	1
	J=	1	2	Y =	0.	0.	0.	0.5503333		
12	K=	47	50	X =	55.218	58.572	58.572	55.218	MAT =	1
	J=	2	7	Y =	0.	0.	3.119	3.4086		
13	K=	50	51	X =	58.572	59.69	59.69	58.572	MAT =	1
	J=	3	7	Y =	0.6238	0.	3.023	3.119		
14	K=	50	51	X =	58.572	59.131	59.69	58.572	MAT =	1
	J=	2	3	Y =	0.	0.	0.	0.6238		
15	K=	51	56	X =	59.69	66.04	66.04	59.69	MAT =	1
	J=	3	7	Y =	0.	0.	1.448	3.023		
16	K=	56	57	X =	66.04	67.31	67.31	66.04	MAT =	1
	J=	4	7	Y =	0.362	0.	1.137	1.448		
17	K=	56	57	X =	66.04	66.675	67.31	66.04	MAT =	1
	J=	3	4	Y =	0.	0.	0.	0.362		
18	K=	57	58	X =	67.31	68.58	68.58	67.31	MAT =	1
	J=	4	7	Y =	0.	0.	0.8255	1.137		

7/8/9

FIGURE C-9 SIMULATION OF A FRAGMENTING ROUND OF STANDARD MILITARY SHAPE

Array sizes should be reset with KXX $\geq$ 58, JXX $\geq$ 7, and JSIZE $\geq$ 19000.

Detonation of a standard military shell is simulated with the deck in Figure C.9. Material 3 is detonated first, then the detonation runs through the secondary explosive (material 2). The steel HF-1 is simulated by the shear band model so that a fragment size distribution is obtained at the end of the calculation. Note that three of the quadrilateral cells (blocks 11, 14, and 17) are laid out in the shape of triangles.

Most of the data decks shown can be run with the array dimensions shown in the listings: $KXX = 40$, $JXX = 30$, and $JSIZE = 15000$. However, for problems in Figs. C-7 and C-9, these dimensions must be augmented as shown in the figure subtitles. Matching array dimensions to problem size is further discussed in Section 5.5.

Appendix D

CALCULATIONS FOR EXPLOSIVES

This appendix outlines a simple detonation theory based on standard references such as Taylor.* Then the types of detonation provided in TROTT, the input required, and the algebra of the code calculations are described.

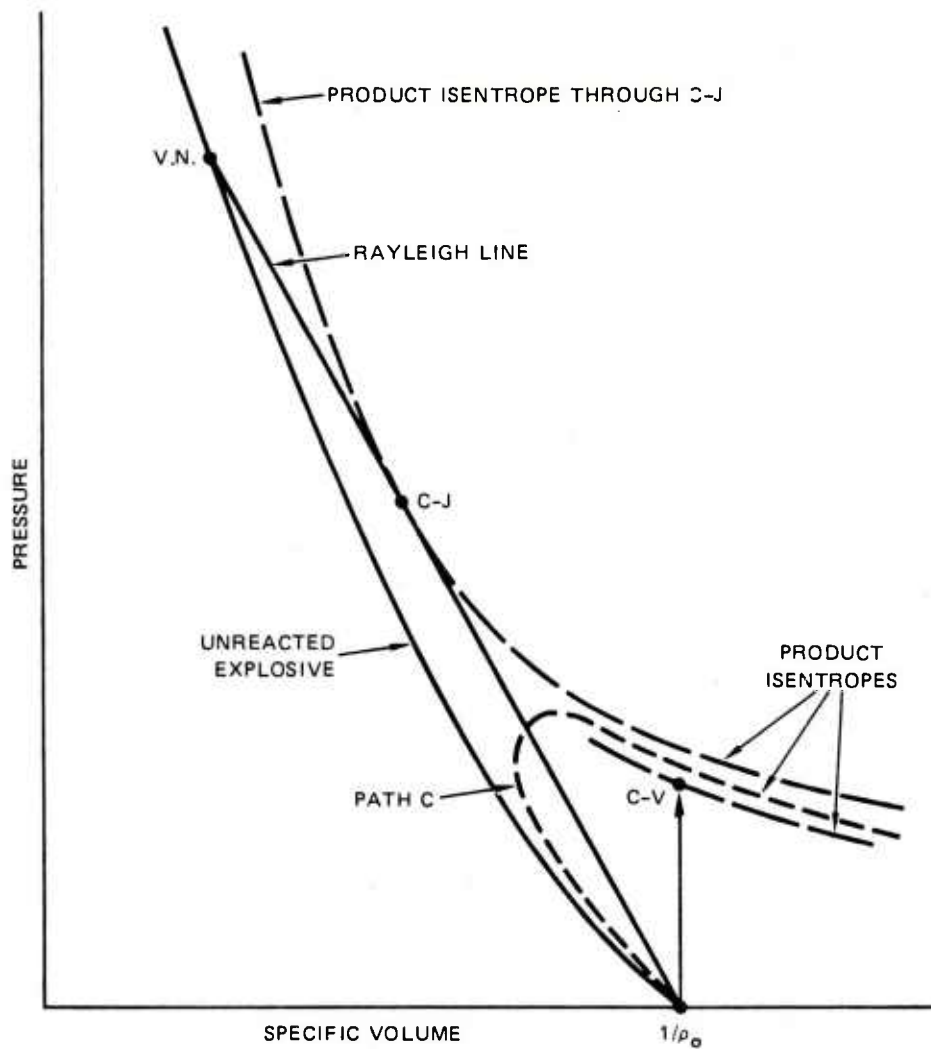
Background on Detonation Processes

Three substances are involved in a detonation process: the unreacted explosive, the reacting explosive, and the product gases. Here we will presume that the unreacted explosive and the product gases can be represented by equations of state with the pressure-volume isentropes shown in Figure D.1. During detonation, the chemical energy in the explosive is transformed to internal energy and the state point moved from the unreacted curve to the product curve of Figure D.1. In Chapman-Jouguet detonation theory, the reaction occurs within the shock front. In a steady detonation, the material follows a Rayleigh line from the initial density to a point of tangency on the products curve as shown. The point of tangency is the Chapman-Jouguet or C-J point. The pressure, volume, and energy at this point are labeled P_{CJ} , V_{CJ} , and E_{CJ} . If the product gases are assumed to follow a polytropic gas equation of state, that is,

$$PV^\gamma = \text{constant} \quad (D.1)$$

Then relations for the detonation velocity (D_x), P_{CJ} , E_{CJ} , and the particle velocity (u_{CJ}) can be derived. These are all derived from the polytropic gas relations, Hugoniot jump conditions, energy conservation, and the condition of tangency at the CJ point.

* J. Taylor, Detonation in Condensed Explosives (Clarendon Press, Oxford 1952).



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FIGURE D.1 PRESSURE-VOLUME PATHS FOLLOWED IN DETONATION PROCESS

$$D_x = \sqrt{2Q_x (\gamma + 1) (\gamma - 1)} \quad (D.2)$$

$$P_{CJ} = 2Q_x (\gamma - 1) \rho_o \quad (D.3)$$

$$V_{CJ} = \frac{\gamma}{\rho_o (\gamma + 1)} \quad (D.4)$$

$$E_{CJ} = \frac{2Q_x \gamma}{\gamma + 1} \quad (D.5)$$

$$u_{CJ} = \sqrt{\frac{2Q_x (\gamma - 1)}{\gamma + 1}} \quad (D.6)$$

where Q_x = the energy of the explosive
 ρ_o = the initial density.

the polytropic gas exponent is related to the Grüneisen ratio as follows

$$\gamma = \Gamma + 1 \quad (D.7)$$

For many common explosives, γ values range from 2.5 to 3.0. This exponent describes the product gas isentrope adequately down to a few kilobars. For lower pressures, the apparent γ value decreases gradually to about 1.5 at ambient conditions.

Besides the Chapman-Jouguet process, several other detonation processes may occur in explosives. Von Neumann suggested that in a steady-state running detonation, the pressure in the shock rises to the point V.N. in Figure D.1 and then reduces gradually to C-J as the chemical reaction occurs. Path C is typical of computed pressure-volume paths followed during the buildup to a steady-state detonation. Here the chemical reaction is occurring during the loading by the stress wave. If the explosion occurs without a change in volume, the vertical path to the constant-volume point C-V is followed. The Chapman-Jouguet,

von Neumann, constant-volume, and various gradual detonation processes have all been used to represent explosive phenomena. Only the Chapman-Jouguet and constant-volume processes are currently available in TROTT.

The detonation type used in the calculation should match as nearly as possible the explosive behavior and geometry being considered. For example, if a block of explosive next to a plate is detonated at a point on the block opposite the plate, the detonation front will reach the plate as a plane wave; this process should be simulated as a running detonation. If the detonation occurs such that the wave front sweeps past the plate, however, a constant-volume explosion may give a better representation of the impulse applied to the plate. In some problems the stress histories in the explosive are not important (as in the impact of an explosively driven flyer plate); then a constant-volume calculation will adequately represent the impulse applied by the explosive.

Computation of Detonation Processes with the Subroutine EXPLODE

The Chapman-Jouguet and constant-volume detonation processes are incorporated into the EXPLODE subroutine. This routine may be called to perform three different functions: reading input, initializing cells, and computing the pressure for the running detonation.

The input for an explosive calculation includes $NTYPE$, Q_x , X_D , Y_D , and b , and is read during the first call to EXPLODE from LAYOUTT. $NTYPE$ indicates the type of detonation:

- $NTYPE = 1$ Constant volume explosion
- $= 2$ Detonation along a line of constant x .
- $= 3$ Detonation along a line of constant y .
- $= 4$ Detonation from a point.

X_D and Y_D designate the initiation lines or points for a running detonation. The parameter b is the number of cells over which a detonation front is spread: nominal values of b are 2 to 4.

At the second call to EXPLODE, the energy and density of cells containing explosive are initialized. This call is made from LAYOUTT during the cell layout process. For a constant-volume explosion, the internal energy is equated to Q_x , and $F_B = FBURN$ (the detonated fraction) is set to 1.0 to show that detonation has taken place.

For a running detonation, only cells near the detonation point or line are initialized at the second call to EXPLODE. The reacted fraction FBURN of a cell is computed based on the distance of the cell midpoint from the initiation point or line.

$$F_B = 1 - \frac{|\bar{Z} - Z_D|}{b\Delta Z} \quad (D.8)$$

where $\bar{Z}$ = the cell midpoint

Z_D = the initiation point

ΔZ = the cell length in the direction of propagation.

For the line initiations, the Z quantities are interpreted as the appropriate X or Y values. For a point detonation, $\bar{Z} - Z_D$ is the diagonal distance

$$\bar{Z} - Z_D = \sqrt{(X - X_D)^2 + (Y - Y_D)^2} \quad (D.9)$$

and ΔZ is the diagonal cell length

$$\Delta Z = \frac{\sqrt{[(\bar{X} - X_D)\Delta X]^2 + [(\bar{Y} - Y_D)\Delta Y]^2}}{\bar{Z} - Z_D} \quad (D.10)$$

where ΔX and ΔY are the cell dimensions. From Eq. (D.8) it appears that the cell midpoint must be within a distance of $b\Delta Z$ of the initiation point for any initiation to occur. For $F_B > 0$, the pressure, density, and internal energy are augmented to represent a point along the C-J detonation path in Figure D.1. Hence

$$P = P_{CJ} F_B \quad (D.11)$$

$$\rho = \frac{\rho_o}{1 + F_B (V_{CJ} \rho_o - 1)} \quad (D.12)$$

$$E = Q_x + (E_{CJ} - Q_x) F_b \quad (D.13)$$

This energy calculation appears adequate, although it is not justified analytically.

The third call to EXPLODE is made in SWEEP7. The purpose of the call is to compute pressure and energy during and following the reaction process. First, the time t_B to begin burning is computed.

$$t_B = \frac{|z - z_D| - b\Delta Z}{D_X} \quad (D.14)$$

The fraction detonated is then

$$F_B = \frac{(t - t_B) D_X}{b\Delta Z} \quad (D.15)$$

where t is the current problem time. Because of the absolute value sign in Eq. (D.14), the detonation can proceed in either direction from the initiation point or line. Given the detonated fraction F_B , the pressure and energy are computed both from the usual poly-tropic gas relations and as fractions of the C-J values. The pressure and energy values for the cell are taken as the maxima from these two calculations.

Appendix E

LISTING OF TROTT PROGRAM

The listing of the TROTT program includes the primary routines TROTT, LAYOUTT, SWEEPT, and SCRIBET plus some of the material model subroutines that may be used with TROTT. Listed here are EQST, EPLAS, REBAR, and EXPLODE. Other material models that may be used with TROTT are listed in Volume II of the final report, the manual for SRI PUFF 8.

PROGRAM TROTT

	PROGRAM TROTT (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE1=1000,	TROTT	2
	1 TAPE2,TAPE3,TAPE4,TAPE7=TAPE1,TAPE8=TAPE2,TAPE9=1000)	TROTT	3
C		TROTT	4
C	PROGRAM FOR 2-DIMENSIONAL PLANAR OR AXISYMMETRIC WAVE PROPAGATION	TROTT	5
C	WITHOUT SLIDE LINES OR VERY LARGE DEFORMATION. LAGRANGIAN, ARTIFI	TROTT	6
C	VISCOSITY CODE WITH TRIANGLE Q. INTEGRATION BASED ON LEAPFROG SCHE	TROTT	7
C	AND CONSTANT STRAIN QUADRILATERAL FINITE ELEMENTS.	TROTT	8
C		TROTT	9
C	WRITTEN MARCH 1976 BY L.SEAMAN.	TROTT	10
		TROTT	11
	COMMON/EQS/EQSTC(6),EQSTD(6),EQSTE(6),EQSTG(6),EQSTH(6),EQSTN(6),	EQSCOM	2
	1 EQSTS(6),RHO(6),RHOS(6),YC(6),YAD(6),MU(6),ESC(6,20),CLIN,CQSQ,	EQSCOM	3
	2 TRIQ,AMAT(6,4),SP(6),Q2(6),PMIN(6)	EQSCOM	4
	COMMON/NSCRB/SJ(60),NJED,NJKED,NKED,N,TIMEZ,DISCPT(20),JEDJ(60),	NSCRBCOM	2
	1 JEDK(60),JEDT(60),NAME(60)	NSCRBCOM	3
	COMMON/GEN/LZ(1),IJBUND, JMAX,JMIN,KMAX,KMIN,UZERO,CALTIM,	TROTTCOM	2
	1 DELTIM,DT,DTN,TS,TYME,NSTART,NPLOT,NDUMP,IMAX,IPRINT	TROTTCOM	3
	2 ,KSKIP,KFULL,KPMAX,KPMIN,JPMAX,JPMIN,JSLIDE,KSLIDE	TROTTCOM	4
	3 ,NSCRIB,DTW,NEXED,NBLQ,TANTH,JPRINT,JPR,JP1(20),JP2(20),KCHECK	TROTTCOM	5
	4 ,NBND,IBDJ1(6),IBDJ2(6),IBDK1(6),IBDK2(6),IBDX(6),IBDY(6),	TROTTCOM	6
	5 XF1X(6),YF1X(6)	TROTTCOM	7
	COMMON/CAL/ LISTE,LISTS,LISTX,LISTXD,CALE,CALS,CALX,CALXD	TROTTCOM	8
	COMMON/IND/NCMP(6),NFR(6),NFOR(6),NDS(6),NPR(6),NVAR(6),NTRI(6)	TROTTCOM	9
	COMMON/TSR/TSR(6,21),BFR(6,20)	TROTTCOM	10
	REAL MU	TROTT	15
	DIMENSION X(1),Y(1),XD(1),YD(1),M(1),A(1),Z(1),D(1),SXX(1),SYY(1),	TROTT	16
	1 SZZ(1),TXY(1),TXX(1),TYY(1),TZZ(1),P(1),E(1),TH(1),FS(1),DSTL(1)	TROTT	17
	2 ,SRS(1),ZEV(1),TEVP(1),YY(1),ROLD(1),IH(1),ENM(1),ENT(1),	TROTT	18
	3 ICOM(1),CLB(1),CL1(1),CN(1),FF(1)	TROTT	19
	EQUIVALENCE (COM,ICOM),(COM(1),X),(COM(2),Y),(COM(3),XD),	TROTT	20
	1 (COM(4),YD),(COM(5),M),(COM(6),A),(COM(7),Z),(COM(8),D),(COM(9),	TROTT	21
	2 SXX),(COM(10),SYY),(COM(11),SZZ),(COM(12),TXY),(COM(13),TXX),	TROTT	22
	3 (COM(14),TYY),(COM(15),TZZ),(COM(16),P),(COM(17),E),(COM(18),	TROTT	23
	4 IH),(COM(19),YY),(COM(20),TH),(COM(21),ZEV),(COM(22),TEVP),	TROTT	24
	5 (COM(23),FS),(COM(24),DSTL),(COM(25),ROLD),(COM(26),SRS),	TROTT	25
	6 (COM(22),ENM),(COM(23),ENT),(COM(23),CLB),(COM(28),CL1),(COM(33)	TROTT	26
	7 ,CN),(COM(21),FF)	TROTT	27
C		TROTT	28
C	COMMON AREAS WHICH MUST BE REDIMENSIONED TO MATCH PROBLEM SIZE	TROTT	29
	COMMON/T/COM(15000)	TROTT	30
	DIMENSION XL(40,30),YL(40,30),MM(40,30),IZ(40,30),LVAR(40,30)	TROTT	31
	DATA (NAME(1),I=1,55)/3H X,3H Y,3H XD,3H YD,3(3H),3H D,	TROTT	32
	1 3HDSX,3HDSY,3HDSZ,3HTXY,3HTXX,3HTYY,3HTZZ,3H P,3H E,3H IH,	TROTT	33
	2 3H YY,3H TH,3H21*,3H22*,3H23*,3H24*,3H25*,3H26*,3H27*,3H28*,	TROTT	34
	3 3H29*,3H30*,3H31*,3H32*,3H33*,3H34*,3H35*,3H36*,3H37*,3H38*,	TROTT	35
	4 3H39*,3H40*,5(3H),3H EX,3H EY,3H EZ,3HEXY,3H Q,3H SX,3H SY,	TROTT	36
	5 3H SZ,3HSTS,3HSTN/	TROTT	37
C	ALSO SET JSIZE, JXX, KXX	TROTT	38
C	IF JXX EXCEEDS 100, RESET DIMENSION OF XTEMP IN SWEEP	TROTT	39
	JSIZE=15000	TROTT	40
	JXX=30	TROTT	41
	KXX=40	TROTT	42
	JK=JXX*KXX	TROTT	43
C		TROTT	44
	DISCPT(1)=5H DAT	TROTT	45
	DISCPT(2)=5HE =	TROTT	46
	CALL DATE(DISCPT(3))	TROTT	47
	DISCPT(4)=SHIFT(DISCPT(3),30)	TROTT	48
10	CALL SECOND(TIMEZ)	TROTT	49
C	*****	TROTT	50
C	INITIALIZATION IN LAYOUT	TROTT	51
C		TROTT	52
	CALL LAYOUT(JSIZE,JXX,KXX,XL,YL,MM,IZ,LVAR)	TROTT	53
C		TROTT	54
	NC=3	TROTT	55
	IF (NPLOT .LT. 900) GO TO 180	TROTT	56
80	IF (IMAX .EQ. 0) GO TO 10	TROTT	57
	WRITE (4) DISCPT,JEDT,JEDK,JEDJ	TROTT	58
	N=0	TROTT	59
	NSCRIB=0	TROTT	60
	NC=1	TROTT	61
	TIM=TIMEZ	TROTT	62
	DT=1.E-12	TROTT	63
	DTN=DT	TROTT	64

PROGRAM TROTT (Continued)

100	N=N+1	TROTT	65
	CALL SECOND(TNOW)	TROTT	66
	CALTIM=TNOW-TIMEZ	TROTT	67
	DELTIM=TNOW-TIM	TROTT	68
	TIM=TNOW	TROTT	69
	TYME=TYME+DT	TROTT	70
	IF (TYME .GE. TS .OR. N .GE. IMAX) IPRINT=N	TROTT	71
C*****		TROTT	72
C	C O M P U T A T I O N S IN SWEEP	TROTT	73
C		TROTT	74
	CALL SWEEP(JSIZE,JXX,KXX,XL,YL,MM,IZ,LVAR)	TROTT	75
C		TROTT	76
	TG=TYME *1.E6	TROTT	77
C*****		TROTT	78
C	WRITE TAPE4 FOR SCRIBE HISTORIES AND PLOT HISTORIES	TROTT	79
	WRITE (4) N,TG,DT,DELTIM,(SJ(1), I=1,NJED)	TROTT	80
	IF (NEXED .EQ. 0) GO TO 150	TROTT	81
C*****		TROTT	82
C	WRITE THE EXTRA EDIT	TROTT	83
	IF (MOD(N,NEXED) .EQ. 0) GO TO 140	TROTT	84
	IF (JPRINT .EQ. 0) GO TO 150	TROTT	85
	IF (N .LT. JP1(JPR) .OR. N .GT. JP2(JPR)) GO TO 150	TROTT	86
140	PRINT 1140,N,TYME	TROTT	87
	DO 148 K=1,KMAX	TROTT	88
	PRINT 1142,K	TROTT	89
	DO 148 J=2,JMAX	TROTT	90
	IF (MM(K,J) .LE. 0) GO TO 148	TROTT	91
	LM=LVAR(K,J)	TROTT	92
	MAT=MM(K,J)	TROTT	93
	IF (NVAR(MAT) .LE. 1) GO TO 148	TROTT	94
	NV1=LM+18	TROTT	95
	NV2=NVAR(MAT)+LM+17	TROTT	96
	PRINT 1145,J,(COM(1),I=NV1,NV2)	TROTT	97
148	CONTINUE	TROTT	98
	IF (NC .GT. 1) GO TO 205	TROTT	99
150	CONTINUE	TROTT	100
C*****		TROTT	101
C	DUMP FOR RESTART	TROTT	102
	IF (NDUMP .NE. 0 .AND. MOD(N,NDUMP) .EQ. 0)WRITE(9)(COM(1),I=1,	TROTT	103
	1 JSIZE),(LVAR(1),I=1,JK),(MM(1),I=1,JK),JMAX,JMIN,KMAX,KMIN,TYME	TROTT	104
C		TROTT	105
C	WRITE PLOT FILE	TROTT	106
	IF (N .EQ. JP2(JPR)) JPR=JPR+1	TROTT	107
C		TROTT	108
C	CHECK STOP CRITERIA	TROTT	109
	IF (NSCRIB .GT. 0) GO TO 200	TROTT	110
	IF (TYME .GE. TS) GO TO 200	TROTT	111
	IF (N .GE. IMAX) GO TO 200	TROTT	112
	IF (MOD(N,NPLOT) .NE. 0) GO TO 195	TROTT	113
C*****		TROTT	114
C	WRITE TAPE 3 FOR X-Y PLOTS	TROTT	115
180	DO 190 K=1,KMAX	TROTT	116
	JMIN=0	TROTT	117
	DO 185 J=1,JMAX	TROTT	118
	IF (LVAR(K,J) .EQ. -1) GO TO 190	TROTT	119
	IF (LVAR(K,J) .EQ. 0) GO TO 185	TROTT	120
	IF (JMIN .EQ. 0) JMIN = J	TROTT	121
	LM=LVAR(K,J)	TROTT	122
	XL(K,J)=X(LM)	TROTT	123
	YL(K,J)=Y(LM)	TROTT	124
	IZ(K,J)=IH(LM)	TROTT	125
185	CONTINUE	TROTT	126
190	CONTINUE	TROTT	127
	WRITE (3) N,TYME,((XL(K,J),YL(K,J), IZ(K,J), J=1,JMAX),K=1,KMAX)	TROTT	128
195	CONTINUE	TROTT	129
	IF (NC-2) 197,210,80	TROTT	130
C		TROTT	131
C	SET TIME STEP FOR NEXT CYCLE	TROTT	132
197	DTN=DT	TROTT	133
	DT=AMIN1(0.9*DTW,AMAX1(1.2*DT,0.035*DTW))	TROTT	134
	DTN=0.5*(DT+DTN)	TROTT	135
	IF (DT .GT. 1.E-12) GO TO 100	TROTT	136
C		TROTT	137
C	PREPARE FOR HISTORICAL LISTING AT END OF COMPUTATION	TROTT	138
200	CALL SECOND(TNOW)	TROTT	139

PROGRAM TROTT (Concluded)

C*****	***** TROTT	140
C FINAL DUMP FOR RESTART	TROTT	141
IF (NDUMP .NE. 0 .AND. MOD(N,NDUMP) .NE. 0)WRITE(9)(COM(1),I=1,	TROTT	142
1 JSIZE),(LVAR(1),I=1,JK),(MM(1),I=1,JK),JMAX,JMIN,KMAX,KMIN,TYME	TROTT	143
NC=2	TROTT	144
CALTIM=TNOW-TIMEZ	TROTT	145
IF (NEXED .GT. 0) GO TO 140	TROTT	146
205 CONTINUE	TROTT	147
IF (NPL0T .LT. 900) GO TO 180	TROTT	148
210 PRINT 1200,IMAX,TS,CALTIM,N,TYME,DT,NSCRIB	TROTT	149
IF (NJED .LE. 0) GO TO 250	TROTT	150
DO 225 I=1,NJED	TROTT	151
JT=JEDT(I)	TROTT	152
IF (JT .LT. -40) JEDT(I)=NAME(-JT)	TROTT	153
IF (JT .GT. 0 .AND. JT .LE. 20) JEDT(I)=NAME(JT)	TROTT	154
IF (JT .GT. 20) ENCODE(3,1250,JEDT(I)) JT	TROTT	155
1250 FORMAT(A3)	TROTT	156
225 CONTINUE	TROTT	157
250 CONTINUE	TROTT	158
CALL SECOND(TNOW)	TROTT	159
CALTIM=TNOW-TIMEZ	TROTT	160
CALL SCRIBET	TROTT	161
GO TO 10	TROTT	162
1140 FORMAT (//21H EXTRA EDIT AT CYCLE 14,7H, TYME=1PE10.3)	TROTT	163
1142 FORMAT (3X,1HJ,10X,9HCOLUMN K= 14)	TROTT	164
1145 FORMAT (1X,13,1P10E12.3/(1X,10E12.3))	TROTT	165
1200 FORMAT(// * STOP CRITERIA - IMAX =*,14,4X,*TS =*,1PE10.3,	TROTT	166
- * DT LESS THAN 1.E-12 NSCRIB = 1*,4X,*CALTIM =*,1PE10.3,	TROTT	167
- * SECONDS*/ * CURRENT VALUES - N=*,14,* TYME =*,1PE10.3,	TROTT	168
- * DT = *,1PE10.3,* NSCRIB =*,12)	TROTT	169
END	TROTT	170

SUBROUTINE EPLAS

	SUBROUTINE EPLAS(J,I,M,SR3,PS,DES,ESC,D,Y)	EPLAS	2
	DIMENSION ESC(6,20),DES(4),SR3(4)	EPLAS	3
C	I X,Z,Y,XZ	EPLAS	4
C	DES(1) DEVIATOR STRAIN INCREMENTS	EPLAS	5
C	SR3(1) DEVIATOR STRESSES	EPLAS	6
C	ESC(M,1)=RHOO ESC(M,2)=C ESC(M,3)=D ESC(M,4)=S ESC(M,5)=SHEAR MOD	EPLAS	7
C	ESC(1,6)= WORK HARDENING MODULUS	EPLAS	8
C	D DENSITY AFTER STRAIN	EPLAS	9
C	Y YIELD	EPLAS	10
C	Y=ESC(M,7)	EPLAS	11
	U=D/ESC(M,1)-1.	EPLAS	12
C	COMPUTE NEW PRESSURE	EPLAS	13
	PS= ESC(M,2)*U+ESC(M,3)*U**2+ESC(M,4)*U**3	EPLAS	14
	DEPSM=(DES(1)+DES(2)+DES(3))/3.	EPLAS	15
C	COMPUTE STRESSES IF STRAINS ARE ELASTIC	EPLAS	16
	SR3(1)=SR3(1)+2.*ESC(M,5)*(DES(1)-DEPSM)	EPLAS	17
	SR3(2)=SR3(2)+2.*ESC(M,5)*(DES(2)-DEPSM)	EPLAS	18
	SR3(3)=SR3(3)+2.*ESC(M,5)*(DES(3)-DEPSM)	EPLAS	19
	SR3(4)=SR3(4)+2.*ESC(M,5)*DES(4)	EPLAS	20
	SR3EFF=SQRT(3./2.*(SR3(1)**2+SR3(2)**2+SR3(3)**2+2.*SR3(4)**2))	EPLAS	21
C	TEST FOR YIELD	EPLAS	22
	IF (SR3EFF.LE. Y) GO TO 30	EPLAS	23
C	COMPUTE YIELD WITH WORK HARDENING	EPLAS	24
	Y=Y+ESC(M,6)*(SR3EFF-Y)/(2*ESC(M,5)+ESC(M,6))	EPLAS	25
C	COMPUTE STRESSES IF STRAINS ARE PLASTIC	EPLAS	26
	SR3(1)=SR3(1)*Y/SR3EFF	EPLAS	27
	SR3(2)=SR3(2)*Y/SR3EFF	EPLAS	28
	SR3(3)=SR3(3)*Y/SR3EFF	EPLAS	29
	SR3(4)=SR3(4)*Y/SR3EFF	EPLAS	30
30	CONTINUE	EPLAS	31
	RETURN	EPLAS	32
	END	EPLAS	33

SUBROUTINE EQST

SUBROUTINE EQST(E,D,P,M)	EQST	2
COMMON/EQS/EQSTC(6),EQSTD(6),EQSTE(6),EQSTG(6),EQSTH(6),EQSTN(6),	EQSCOM	2
1 EQSTS(6),RHG(6),RHOS(6),YC(6),YAD(6),MU(6),ESC(6,20),CLIN,CQSQ,	EQSCOM	3
2 TRIQ,AMAT(6,4),SP(6),Q2(6),PMIN(6)	EQSCOM	4
EMU=D/RHOS(M)-1.	EQST	4
PH=EMU*(EQSTC(M)+EMU*(EQSTD(M)+EMU*EQSTS(M)))	EQST	5
P=PH*(1.-0.5*EQSTG(M)*(1.-RHOS(M)/D))+EQSTG(M)*RHOS(M)*E	EQST	6
RETURN	EQST	7
END	EQST	8

SUBROUTINE EXPLODE

	SUBROUTINE EXPLODE (NCALL, IN, M, E, D, DOLD, P, Q, FBURN, X, DX, Y, DY, J, K,	EXPLODE	2
	1 TIME)	EXPLODE	3
C		EXPLODE	4
C	INITIALIZATION DEFINITIONS	EXPLODE	5
C	X, Y CELL CENTERS	EXPLODE	6
C	DX, DY CELL DIMENSIONS	EXPLODE	7
C	TIME = TBURN, TIME WHEN DETONATION REACHES CELL	EXPLODE	8
C	DEFINITIONS FOR SWEEP COMPUTATIONS	EXPLODE	9
C	X = TBURN, DETONATION TIME	EXPLODE	10
C	DX = CELL DIMENSION	EXPLODE	11
C	TIME = PROBLEM TIME	EXPLODE	12
	COMMON/EQS/EQSTC(6), EQSTD(6), EQSTE(6), EQSTG(6), EQSTH(6), EQSTN(6),	EXPLODE	13
1	EQSTS(6), RH0(6), RHOS(6), YC(6), YAD(6), MU(6), ESC(6, 20), CLIN, CQSQ,	EXPLODE	14
2	TRIQ, AMAT(6, 4), SP(6), G2(6), PMIN(6)	EXPLODE	15
	DIMENSION DET(6), DIST(6), ECJ(6), PCJ(6), QEXPL(6), VCJ(6), XDET(6),	EXPLODE	16
1	YDET(6), NTYPE(6)	EXPLODE	17
	IF (NCALL-2) 100, 200, 300	EXPLODE	18
C		EXPLODE	19
C	READ DATA AND INITIALIZE MATERIAL VARIABLES (NCALL=1)	EXPLODE	20
C		EXPLODE	21
100	READ (IN, 1000) A1, A2, NTYPE(M), A3, A4, QEXPL(M), XDET(M), YDET(M),	EXPLODE	22
1	DIST(M)	EXPLODE	23
	PRINT 1500, A1, A2, NTYPE(M), A3, A4, QEXPL(M), XDET(M), YDET(M),	EXPLODE	24
1	DIST(M)	EXPLODE	25
	PRINT 1001, IN	EXPLODE	26
	DET(M)=SQRT(2.*QEXPL(M)*EQSTG(M)*(EQSTG(M)+2.))	EXPLODE	27
	E=DET(M)	EXPLODE	28
	VCJ(M)=(EQSTG(M)+1.)/((EQSTG(M)+2.)*RH0(M))	EXPLODE	29
	ECJ(M)=2.*((EQSTG(M)+1.)*QEXPL(M)/(EQSTG(M)+2.))	EXPLODE	30
	PCJ(M)=2.*RH0(M)*QEXPL(M)*EQSTG(M)	EXPLODE	31
	PRINT 1501, DET(M), VCJ(M), ECJ(M), PCJ(M)	EXPLODE	32
	RETURN	EXPLODE	33
C		EXPLODE	34
C	INITIALIZE CELL VARIABLES (NCALL=2)	EXPLODE	35
C		EXPLODE	36
200	NTYP=NTYPE(M)-(NTYPE(M)/10)*10	EXPLODE	37
	GO TO (210, 220, 230, 240) NTYP	EXPLODE	38
C	CONSTANT VOLUME EXPLOSION (NTYPE=1)	EXPLODE	39
210	E=QEXPL(M)	EXPLODE	40
	FBURN=1.	EXPLODE	41
	RETURN	EXPLODE	42
C	DETONATION ALONG A LINE OF CONSTANT -X- (NTYPE=2)	EXPLODE	43
220	DZ=ABS(DX)*DIST(M)	EXPLODE	44
	TBURN=(ABS(X-XDET(M))-DZ)/DET(M)	EXPLODE	45
	IF (TBURN .GE. 0.) GO TO 280	EXPLODE	46
	FBURN=AMIN1(1., -TBURN*DET(M)/DZ)	EXPLODE	47
	GO TO 250	EXPLODE	48
C	DETONATION ALONG A LINE OF CONSTANT -Y- (NTYPE=3)	EXPLODE	49
230	DZ=ABS(DY)*DIST(M)	EXPLODE	50
	TBURN=(ABS(Y-YDET(M))-DZ)/DET(M)	EXPLODE	51
	IF (TBURN .GE. 0.) GO TO 280	EXPLODE	52
	FBURN=AMIN1(1., -TBURN*DET(M)/DZ)	EXPLODE	53
	GO TO 250	EXPLODE	54
C	DETONATION FROM A POINT (NTYPE=4)	EXPLODE	55
240	XH=X	EXPLODE	56
	YH=Y	EXPLODE	57
	ZH=SQRT((XH-XDET(M))**2+(YH-YDET(M))**2)	EXPLODE	58
	IF (ZH .LT. 1.E-4) GO TO 248	EXPLODE	59
	DZ=DIST(M)*SQRT(((XH-XDET(M))*DX)**2+((YH-YDET(M))*DY)**2)/ZH	EXPLODE	60
	TBURN=(ZH-DZ)/DET(M)	EXPLODE	61
	IF (TBURN .GE. 0.) GO TO 280	EXPLODE	62
	FBURN=AMIN1(1., -TBURN*DET(M)/DZ)	EXPLODE	63
	GO TO 250	EXPLODE	64
248	FBURN=1.	EXPLODE	65
250	IF (NTYPE(M) .GT. 10) GO TO 270	EXPLODE	66
	E=QEXPL(M)+(ECJ(M)-QEXPL(M))*FBURN	EXPLODE	67
	D=RH0(M)/(1.-FBURN*(1.-VCJ(M)*RH0(M)))	EXPLODE	68
	P=PCJ(M)*FBURN	EXPLODE	69
260	PRINT 1555, K, J, FBURN, TBURN, XH, E, D, P	EXPLODE	70
1555	FORMAT (* K, J=*2I4, * FBURN=*F6.4, * TBURN=*1PE11.3, * XH=*E11.3,	EXPLODE	71
1	* E=*E11.3, * D=*E11.3, * P=*E11.3)	EXPLODE	72
	GO TO 280	EXPLODE	73
270	E=QEXPL(M)*FBURN	EXPLODE	74
	P=EQSTG(M)*D*E	EXPLODE	75

SUBROUTINE EXPLODE (Concluded)

280	GO TO 260	EXPLODE	76
	TIME=TBURN	EXPLODE	77
	DX=DZ	EXPLODE	78
	RETURN	EXPLODE	79
C		EXPLODE	80
C	COMPUTE DETONATION PROCESS (NCALL=3)	EXPLODE	81
C		EXPLODE	82
300	IF (FBURN .GT. 0.999) GO TO 310	EXPLODE	83
	NTYP=NTYPE(M)-(NTYPE(M)/10)*10	EXPLODE	84
	IF (NTYP .GT. 1) GO TO 320	EXPLODE	85
C	PRESSURE IN EXPLOSION PRODUCTS	EXPLODE	86
310	P=EQSTG(M)*D*E	EXPLODE	87
	RETURN	EXPLODE	88
320	TBURN=X	EXPLODE	89
	FB=AMIN1(1.,AMAX1((TIME-TBURN)*DET(M)/DX,	EXPLODE	90
1	(1.-RHO(M)/D)/(1.-VCJ(M)*RHO(M)),FBURN))	EXPLODE	91
	IF (FB .LT. 0.4) RETURN	EXPLODE	92
352	HDV=0.5*(1./DOLD-1./D)	EXPLODE	93
	POLD=P	EXPLODE	94
	P=EQSTG(M)*D*(E+POLD*HDV+QEXPL(M)*(FB-FBURN)+Q*2.*HDV)/	EXPLODE	95
1	(1.-EQSTG(M)*HDV*D)	EXPLODE	96
	E=E+(P+POLD)*HDV+QEXPL(M)*(FB-FBURN)+2.*Q*HDV	EXPLODE	97
	IF (NTYPE(M) .GT. 10) GO TO 360	EXPLODE	98
	P=AMAX1(P,PCJ(M)*FB)	EXPLODE	99
	E=AMAX1(E,ECJ(M)*FB)	EXPLODE	100
360	FBURN=FB	EXPLODE	101
	IF (FB .GE. 0.999) PRINT 1350,K,J,D	EXPLODE	102
	RETURN	EXPLODE	103
1000	FORMAT (2A5,110,2A5,5E10.3)	EXPLODE	104
1001	FORMAT (1H+,79X,12H IND= , IN=12,10H -EXPLODE-)	EXPLODE	105
1350	FORMAT (27H DETONATION COMPLETED AT K=13,3H J=13,9H DENSITY=	EXPLODE	106
1	1PE10.3)	EXPLODE	107
1500	FORMAT(2A5,110,2A5,1P5E10.3)	EXPLODE	108
1501	FORMAT (10X,33HFROM EXPLODE, DET, VCJ, ECJ, PCJ=1P4E10.3)	EXPLODE	109
	END	EXPLODE	110

SUBROUTINE LAYOUTT

	SUBROUTINE LAYOUTT(JSIZE,JXX,KXX,XL,YL,MM,IZ,LVAR)	LAYOUTT	2
C		LAYOUTT	3
C	ROUTINE READS IN DATA FOR EACH PROBLEM AND LAYS OUT COORDINATE ARR	LAYOUTT	4
C		LAYOUTT	5
	COMMON/GEN/LZ(1),IJBUND, JMAX,JMIN,KMAX,KMIN,UZER0,CALTIM,	TROTTCOM	2
1	DELTIM,DT,DTN,TS,TYME,NSTART,NPLOT,NDUMP,IMAX,IPRINT	TROTTCOM	3
2	,KSKIP,KFULL,KPMAX,KPMIN,JPMAX,JPMIN,JSIDE,KSLIDE	TROTTCOM	4
3	,NSCRIB,DTW,NEXED,NOBLQ,TANTH,JPRINT,JPR,JP1(20),JP2(20),KCHEK	TROTTCOM	5
4	,NBND,IBDJ1(6),IBDJ2(6),IBDK1(6),IBDK2(6),IBDX(6),IBDY(6),	TROTTCOM	6
5	XFIX(6),YFIX(6)	TROTTCOM	7
	COMMON/CAL/ LISTE,LISTS,LISTX,LISTXD,CALE,CALS,CALX,CALXD	TROTTCOM	8
	COMMON/IND/NCMP(6),NFR(6),NFOR(6),NDS(6),NPR(6),NVAR(6),NTRI(6)	TROTTCOM	9
	COMMON/TSR/TSR(6,21),BFR(6,20)	TROTTCOM	10
	COMMON/NSCRB/SJ(60),NJED,NJKED,NKED,N,TIMEZ,DISCPT(20),JEDJ(60),	NSCRBCOM	2
1	JEDK(60),JEDT(60),NAME(60)	NSCRBCOM	3
	COMMON/EQS/EQSTC(6),EQSTD(6),EQSTE(6),EQSTG(6),EQSTH(6),EQSTN(6),	EQSCOM	2
1	EQSTS(6),RHO(6),RHOS(6),YAD(6),MU(6),ESC(6,20),CLIN,CQSQ,	EQSCOM	3
2	TRIQ,AMAT(6,4),SP(6),G2(6),PMIN(6)	EQSCOM	4
	REAL MU	LAYOUTT	9
	COMMON/T/COM(1000)	LAYOUTT	10
	DIMENSION XA(4),YA(4),XL(KXX,JXX),YL(KXX,JXX),MM(KXX,JXX),IZ(KXX,	LAYOUTT	11
1	JXX),LVAR(KXX,JXX)	LAYOUTT	12
	DIMENSION X(1),Y(1),XD(1),YD(1),M(1),A(1),Z(1),D(1),SXX(1),SYY(1),	LAYOUTT	13
1	SZZ(1),TXY(1),TXX(1),TTY(1),TZZ(1),P(1),E(1),TH(1),FS(1),DSTL(1)	LAYOUTT	14
2	,SRS(1),ZVP(1),TEVP(1),YY(1),ROLD(1),IH(1),ENM(1),ENT(1),	LAYOUTT	15
3	ICOM(1),CLB(1),CL1(1),CN(1)	LAYOUTT	16
	EQUIVALENCE (COM,ICOM),(COM(1),X),(COM(2),Y),(COM(3),XD),	LAYOUTT	17
1	(COM(4),YD),(COM(5),M),(COM(6),A),(COM(7),Z),(COM(8),D),(COM(9),	LAYOUTT	18
2	SXX),(COM(10),SYY),(COM(11),SZZ),(COM(12),TXY),(COM(13),TXX),	LAYOUTT	19
3	(COM(14),TTY),(COM(15),TZZ),(COM(16),P),(COM(17),E),(COM(18),	LAYOUTT	20
4	IH),(COM(19),YY),(COM(20),TH),(COM(21),ZVP),(COM(22),TEVP),	LAYOUTT	21
5	(COM(23),FS),(COM(24),DSTL),(COM(25),ROLD),(COM(26),SRS),	LAYOUTT	22
6	(COM(27),ENM),(COM(28),ENT),(COM(29),CLB),(COM(30),CL1),(COM(31),	LAYOUTT	23
7	,CN),(COM(32),FF)	LAYOUTT	24
	DATA LISTE,LISTS,LISTX,LISTXD,CALE,CALS,CALX,CALXD/5HKJ/KG,3HGPA	LAYOUTT	25
1	,2HCM,5HM/SEC,1.E-7,1.E-7,1.,1.E-2/	LAYOUTT	26
C		LAYOUTT	27
C	XA(1)=XL(K1,J1), XA(2)=XL(K2,J1),XA(3)=XL(K2,J2),XA(4)=XL(K1,J2)	LAYOUTT	28
C		LAYOUTT	29
	DO 102 I=1,JSIZE	LAYOUTT	30
102	COM(I)=0.	LAYOUTT	31
	JK=JXX*KXX	LAYOUTT	32
	DO 104 I=1,JK	LAYOUTT	33
	XL(I)=-999.	LAYOUTT	34
	YL(I)=-999.	LAYOUTT	35
	MM(I)=0	LAYOUTT	36
104	LVAR(I)=0	LAYOUTT	37
	DO 106 I=1,237	LAYOUTT	38
106	EQSTC(I)=0.	LAYOUTT	39
	DO 107 I=1,246	LAYOUTT	40
107	TSR(I)=0.	LAYOUTT	41
	DO 108 I=1,36	LAYOUTT	42
108	NCMP(I)=0	LAYOUTT	43
	DO 109 I=1,245	LAYOUTT	44
109	SJ(I)=0.	LAYOUTT	45
	DO 111 I=1,66	LAYOUTT	46
111	LZ(I)=0	LAYOUTT	47
	KMAX=KXX	LAYOUTT	48
	JMAX=JXX	LAYOUTT	49
	READ 1100,(DISCPT(I), I=5,20)	LAYOUTT	50
	IF (EOF(5)) 105,110	LAYOUTT	51
105	PRINT 1001	LAYOUTT	52
	STOP 2020	LAYOUTT	53
110	PRINT 1000	LAYOUTT	54
	PRINT 1100,(DISCPT(I), I=1,4)	LAYOUTT	55
	PRINT 1100,(DISCPT(I), I=5,20)	LAYOUTT	56
	READ 1105,A1,NSTART,A2,NPLOT,A3,NDUMP,A4,IMAX,A5,	LAYOUTT	57
1	IPRINT,A6,JPRINT,A7,NEXED,A8,NOBLQ	LAYOUTT	58
	PRINT 1105,A1,NSTART,A2,NPLOT,A3,NDUMP,A4,IMAX,A5,	LAYOUTT	59
1	IPRINT,A6,JPRINT,A7,NEXED,A8,NOBLQ	LAYOUTT	60
	IF (NOBLQ.EQ. 0) GO TO 115	LAYOUTT	61
	READ 1104,A1,A2,ANGLE	LAYOUTT	62
	PRINT 1104,A1,A2,ANGLE	LAYOUTT	63
	TANTH=TAN(ANGLE/57.2957795)	LAYOUTT	64

SUBROUTINE LAYOUTT (Continued)

115	CONTINUE		LAYOUTT	65
C		IJBUND DEFINITION	LAYOUTT	66
C	BOUNDARY CONDITION	AXISYMMETRIC	LAYOUTT	67
C	FIXED YVEL AT JMAX, JMIN	1	LAYOUTT	68
C	FIXED YVEL AT JMIN ONLY	2	LAYOUTT	69
C	FREE EDGES	-	LAYOUTT	70
C	FIXED YVEL AT JMIN	4	LAYOUTT	71
C	FIXED XVEL AT KMAX, KMIN		LAYOUTT	72
C	FIXED YVEL AT JMIN, JMAX,	5	LAYOUTT	73
C	FIXED XVEL AT KMIN		LAYOUTT	74
C	FIXED YMIN, XMIN	6	LAYOUTT	75
C		IVTYPE DEFINITION	LAYOUTT	76
C	1 INITIALIZE X VELOCITY UP TO KU, SET INTERFACE		LAYOUTT	77
C	VELOCITY AT KU		LAYOUTT	78
C	-1 INITIALIZE X VELOCITY FROM KU TO KMAX, SET		LAYOUTT	79
C	INTERFACE VELOCITY AT KU		LAYOUTT	80
C	2 INITIALIZE X AND Y VELOCITIES BY BLOCKS, INTERPOLATING IN		LAYOUTT	81
C	X AND Y. NO INTERFACE PROVISION		LAYOUTT	82
C	IPRIND CAUSES A CARD TO BE READ WHICH SETS SPECIAL PRINT OPTIONS		LAYOUTT	83
C	KSKIP SKIPS K COLUMNS IN THE PRINTOUT		LAYOUTT	84
C	KFULL GIVES FULL K LISTING AMONGST SKIPPED K LISTINGS		LAYOUTT	85
C	KPMAX AND KPMIN SET THE MAXIMUM AND MINIMUM K ROWS TO BE PRINTED		LAYOUTT	86
C	JPMAX AND JPMIN SET THE MAXIMUM AND MINIMUM J COLUMNS TO BE		LAYOUTT	87
C	PRINTED		LAYOUTT	88
	KSKIP =1		LAYOUTT	89
	KFULL=1		LAYOUTT	90
	KPMAX=KMAX		LAYOUTT	91
	KPMIN=KMIN=1		LAYOUTT	92
	JPMAX=JMAX		LAYOUTT	93
	JPMIN=JMIN=1		LAYOUTT	94
	READ 1106, A1, A2, IJBUND, A3, A4, NBLCK, A5, A6, NMTRLS, A7, A8, NJED		LAYOUTT	95
1	, A9, A10, IPRIND, A11, A12, NEXTRA		LAYOUTT	96
	PRINT 1106, A1, A2, IJBUND, A3, A4, NBLCK, A5, A6, NMTRLS, A7, A8, NJED		LAYOUTT	97
1	, A9, A10, IPRIND, A11, A12, NEXTRA		LAYOUTT	98
	READ 1108, A1, A2, TS, A3, A4, IVTYPE, A5, A6, NVBLK, A7, A8, KCHEK		LAYOUTT	99
	PRINT 1108, A1, A2, TS, A3, A4, IVTYPE, A5, A6, NVBLK, A7, A8, KCHEK		LAYOUTT	100
	READ 1104, A1, A2, CQSQ, A3, A4, CLIN, A5, A6, TRIQ		LAYOUTT	101
	PRINT 1104, A1, A2, CQSQ, A3, A4, CLIN, A5, A6, TRIQ		LAYOUTT	102
	READ 1106, A1, A2, KSLIDE, A3, A4, JSLIDE, A5, A6, NBND, A7, A8, ICAL		LAYOUTT	103
	PRINT 1106, A1, A2, KSLIDE, A3, A4, JSLIDE, A5, A6, NBND, A7, A8, ICAL		LAYOUTT	104
	IF (NBND .LE. 0) GO TO 135		LAYOUTT	105
	DO 133 I=1, NBND		LAYOUTT	106
	READ 1133, A1, A2, IBDK1(I), IBDK2(I), A3, A4, IBDJ1(I), IBDJ2(I), A5, A6,		LAYOUTT	107
1	IBDX(I), IBDY(I), XFIX(I), YFIX(I)		LAYOUTT	108
	PRINT 1133, A1, A2, IBDK1(I), IBDK2(I), A3, A4, IBDJ1(I), IBDJ2(I), A5, A6,		LAYOUTT	109
1	IBDX(I), IBDY(I), XFIX(I), YFIX(I)		LAYOUTT	110
133	CONTINUE		LAYOUTT	111
135	IF (ICAL .LE. 0) GO TO 140		LAYOUTT	112
	READ 1109, A1, A2, LISTE, LISTS, LISTX, LISTXD		LAYOUTT	113
	PRINT 1109, A1, A2, LISTE, LISTS, LISTX, LISTXD		LAYOUTT	114
	READ 1107, A1, A2, CALE, CALS, CALX, CALXD		LAYOUTT	115
	PRINT 1107, A1, A2, CALE, CALS, CALX, CALXD		LAYOUTT	116
140	CONTINUE		LAYOUTT	117
	IF (JPRINT .EQ. 0) GO TO 145		LAYOUTT	118
	READ 1112, A1, A2, (JP1(I), JP2(I), I=1, JPRINT)		LAYOUTT	119
	PRINT 1112, A1, A2, (JP1(I), JP2(I), I=1, JPRINT)		LAYOUTT	120
	JPR=1		LAYOUTT	121
145	IF (NJED .EQ. 0) GO TO 155		LAYOUTT	122
	N1=1		LAYOUTT	123
150	N2=MINO(N1+6, NJED)		LAYOUTT	124
	IF (N2 .LE. 60) READ 1125, A1, A2, (JEDT(I), JEDK(I), JEDJ(I),		LAYOUTT	125
-	I=N1, N2)		LAYOUTT	126
	IF (N2 .GT. 60) READ 1110, A1		LAYOUTT	127
	PRINT 1125, A1, A2, (JEDT(I), JEDK(I), JEDJ(I), I=N1, N2)		LAYOUTT	128
	N1=N2+1		LAYOUTT	129
	IF (N2 .LT. NJED) GO TO 150		LAYOUTT	130
155	NJED=MINO(NJED, 98)		LAYOUTT	131
	NJKED=NJED		LAYOUTT	132
	IF (IPRIND .LE. 0) GO TO 160		LAYOUTT	133
	READ 1111, A1, A2, KSKIP, A3, A4, KFULL, A5, A6, KPMAX, A7, A8, KPMIN,		LAYOUTT	134
1	A9, A10, JPMAX, A11, A12, JPMIN		LAYOUTT	135
	PRINT 1111, A1, A2, KSKIP, A3, A4, KFULL, A5, A6, KPMAX, A7, A8, KPMIN,		LAYOUTT	136
1	A9, A10, JPMAX, A11, A12, JPMIN		LAYOUTT	137
160	LSHB=0		LAYOUTT	138
	DO 200 L=1, NMTRLS		LAYOUTT	139

SUBROUTINE LAYOUTT (Continued)

READ 1130, (AMAT(L,I), I=1,4), A1,A2,RHOS(L),A3,A4,NCMP(L),	LAYOUTT	140
1 NFR(L),NPOR(L),A5,A6,NDS(L),NPR(L),NYAM,A7,A8,NVAR(L),A9,A10,	LAYOUTT	141
2 NTRI(L)	LAYOUTT	142
RHO(L)=RHOS(L)	LAYOUTT	143
PRINT 1002	LAYOUTT	144
PRINT 1130, (AMAT(L,I), I=1,4), A1,A2,RHOS(L),A3,A4,NCMP(L),	LAYOUTT	145
1 NFR(L),NPOR(L),A5,A6,NDS(L),NPR(L),NYAM,A7,A8,NVAR(L),A9,A10,	LAYOUTT	146
2 NTRI(L)	LAYOUTT	147
READ 1107, A1,A2,EQSTC(L),EQSTD(L),EQSTE(L),EQSTG(L),	LAYOUTT	148
- EQSTH(L),EQSTS(L),PMIN(L)	LAYOUTT	149
PRINT 1107,A1,A2,EQSTC(L),EQSTD(L),EQSTE(L),EQSTG(L),	LAYOUTT	150
- EQSTH(L),EQSTS(L),PMIN(L)	LAYOUTT	151
IF (NCMP(L) .GT. 0) CALL REBAR(-1,5,1,1,L,N,IH,RHO(L),DOLD,SSP,SY,	LAYOUTT	152
1SZ,TSY,E,P,DEX,DEY,DEZ,DEXY,F,THETA,DTHETA,ESC,FS,DSTL,SRS,ZEVP,	LAYOUTT	153
2 TEVP,YC(L),ROLD,IPRINT)	LAYOUTT	154
IF (NFR(L) .EQ. 0) GO TO 180	LAYOUTT	155
NFRM=NFR(L)	LAYOUTT	156
GO TO (170,170,175,175,170,170,170) NFRM	LAYOUTT	157
170 CONTINUE	LAYOUTT	158
READ 1107,A1,A2,(TSR(L,I),I=1,7)	LAYOUTT	159
PRINT 1107,A1,A2,(TSR(L,I),I=1,7)	LAYOUTT	160
IF (NFR(L) .NE. 2 .AND. NFR(L) .NE. 7) GO TO 180	LAYOUTT	161
READ 1107,A1,A2,(TSR(L,I),I=8,14)	LAYOUTT	162
PRINT 1107,A1,A2,(TSR(L,I),I=8,14)	LAYOUTT	163
GO TO 180	LAYOUTT	164
175 CALL SHEAR2(LSHB,5,L,1,1,IH,SX,SY,SXY,P,A1,DH,DOLD,A2,E,A3,A4,	LAYOUTT	165
1 A5,A6,EX,EY,EXY,F,A7,A8,A9,A10,A11,A12)	LAYOUTT	166
LSHB=1	LAYOUTT	167
IF (NFR(L) .EQ. 4) GO TO 170	LAYOUTT	168
180 IF (NPOR(L) .EQ. 0) GO TO 190	LAYOUTT	169
READ 1104, A1, A2, RHO(L), A3, A4, MU(L)	LAYOUTT	170
PRINT 1104,A1, A2, RHO(L), A3, A4, MU(L)	LAYOUTT	171
IF (NPOR(L) .EQ. 4) GO TO 185	LAYOUTT	172
CALL POREQST(0,5,L,SP(L),RHO(L),A2,A3,A4,A5,A6,A7,A8,A9,A10,	LAYOUTT	173
1 EQSTC(L),EQSTD(L),EQSTG(L),EQSTS(L),A11,A12,A13)	LAYOUTT	174
GO TO 190	LAYOUTT	175
185 CONTINUE	LAYOUTT	176
CALL CAP1(-1,5,L,N,IH,DH,DOLD,E,EX,EY,EZ,EXY,SX,SY,SZ,SXY,ZEVP,	LAYOUTT	177
1 K,J,TEVP)	LAYOUTT	178
190 CONTINUE	LAYOUTT	179
IF (NDS(L) .EQ. 7) CALL EP(0,L,N)	LAYOUTT	180
IF (NPR(L) .EQ. 1) CALL EXPLODE(1,5,L,SP(L),D(1),DOLD,P(1),Q,	LAYOUTT	181
1 COM(19),X(1),DX,Y(1),DY,J,K,O.)	LAYOUTT	182
IF (NYAM .EQ. 0) GO TO 195	LAYOUTT	183
READ 1107, A1,A2, YC(L), MU(L),YAD(L)	LAYOUTT	184
PRINT 1107,A1,A2, YC(L), MU(L),YAD(L)	LAYOUTT	185
195 IF (SP(L) .EQ. 0.) SP(L)=SQRT((EQSTC(L)+1.33333*MU(L))/RHO(L))	LAYOUTT	186
IF (NCMP(L) .GT. 0) SP(L)=SSP	LAYOUTT	187
ESC(L,1)=RHO(L)	LAYOUTT	188
ESC(L,2)=EQSTC(L)	LAYOUTT	189
ESC(L,3)=EQSTD(L)	LAYOUTT	190
ESC(L,4)=EQSTS(L)	LAYOUTT	191
ESC(L,5)=MU(L)	LAYOUTT	192
ESC(L,6)=YAD(L)	LAYOUTT	193
ESC(L,7)=RHOS(L)	LAYOUTT	194
ESC(L,9)=EQSTG(L)	LAYOUTT	195
ESC(L,10)=YC(L)	LAYOUTT	196
200 G2(L)=2.*MU(L)	LAYOUTT	197
C	LAYOUTT	198
C CALL FOR ADDED DATA	LAYOUTT	199
IF (NEXTA .GT. 0) CALL EXTRAT(1)	LAYOUTT	200
C	LAYOUTT	201
C ***** CELL LAYOUT *****	LAYOUTT	202
PRINT 1800,SP	LAYOUTT	203
1800 FORMAT(* SP=* 1P6E10.3)	LAYOUTT	204
IF (NSTART .GE. 1) GO TO 500	LAYOUTT	205
C	LAYOUTT	206
NSTDY=4	LAYOUTT	207
NSTD=13	LAYOUTT	208
DO 250 NB=1,NBLOCK	LAYOUTT	209
READ 1030, A1,A2,K1,K2,A3,A4,(XA(I),I=1,4),A5,A6,MAT	LAYOUTT	210
PRINT 1030,A1,A2,K1,K2,A3,A4,(XA(I),I=1,4),A5,A6,MAT	LAYOUTT	211
READ 1030, A1,A2,J1,J2,A3,A4,(YA(I),I=1,4)	LAYOUTT	212
PRINT 1030, A1,A2,J1,J2,A3,A4,(YA(I),I=1,4)	LAYOUTT	213
DJDK=(J2-J1)*(K2-K1)	LAYOUTT	214

SUBROUTINE LAYOUTT (Continued)

	D0 210 K=K1,K2	LAYOUTT	215
	D0 210 J=J1,J2	LAYOUTT	216
	IF (XL(K,J) .EQ. -999.) XL(K,J)=((XA(1)*(J2-J)+XA(4)*(J-J1))*(K2-K)	LAYOUTT	217
	+ (XA(2)*(J2-J)+XA(3)*(J-J1))*(K-K1))/DJDK	LAYOUTT	218
	IF (YL(K,J) .EQ. -999.) YL(K,J)=((YA(1)*(J2-J)+YA(4)*(J-J1))*(K2-K)	LAYOUTT	219
	+ (YA(2)*(J2-J)+YA(3)*(J-J1))*(K-K1))/DJDK	LAYOUTT	220
	IF (K .GT. K1 .AND. J .GT. J1) MM(K,J)=MAT	LAYOUTT	221
210	CONTINUE	LAYOUTT	222
250	CONTINUE	LAYOUTT	223
	LVAR=1	LAYOUTT	224
	JM=1	LAYOUTT	225
	D0 300 K=1,KMAX	LAYOUTT	226
	D0 280 J=1,JMAX	LAYOUTT	227
	IF (J .GT. 1 .AND. LVAR(K,J-1) .GT. 0) LVAR(K,J)=-1	LAYOUTT	228
	IF (XL(K,J) .EQ. -999. .OR. YL(K,J) .EQ. -999.) GO TO 280	LAYOUTT	229
	KM=K	LAYOUTT	230
	JM=MAX0(JM,J)	LAYOUTT	231
	LVAR(K,J)=LVAR	LAYOUTT	232
	X(LVAR)=XL(K,J)	LAYOUTT	233
	Y(LVAR)=YL(K,J)	LAYOUTT	234
	IH(LVAR)=2	LAYOUTT	235
	MAT=MM(K,J)	LAYOUTT	236
	IF (MAT .EQ. 0) GO TO 260	LAYOUTT	237
	A124=0.5*(XL(K,J-1)*(YL(K,J)-YL(K-1,J))	LAYOUTT	238
	-XL(K,J)*(YL(K,J-1)-YL(K-1,J))+XL(K-1,J)*(YL(K,J-1)-YL(K,J)))	LAYOUTT	239
	A234=0.5*(XL(K,J-1)*(YL(K-1,J)-YL(K-1,J-1))+XL(K-1,J)*	LAYOUTT	240
	-(YL(K-1,J-1)-YL(K,J-1))+XL(K-1,J-1)*(YL(K,J-1)-YL(K-1,J)))	LAYOUTT	241
	XZ=0.25*(XL(K,J)+XL(K,J-1)+XL(K-1,J)+XL(K-1,J-1))	LAYOUTT	242
	YZ=0.25*(YL(K,J)+YL(K,J-1)+YL(K-1,J)+YL(K-1,J-1))	LAYOUTT	243
	D(LVAR)=RH0(MAT)	LAYOUTT	244
	IF (YC(MAT) .NE. 0.) YY(LVAR)=YC(MAT)	LAYOUTT	245
	IF (NPR(MAT) .NE. 1) GO TO 255	LAYOUTT	246
	DX=X(LVAR)-XL(K-1,J)	LAYOUTT	247
	CALL EXPLODE(2,5,MAT,E(LVAR),D(LVAR),D0LD,P(LVAR),Q,COM(18+	LAYOUTT	248
	1 LVAR),XZ,DX,YZ,Y(LVAR)-YL(K,J-1),J,K,COM(LVAR+19))	LAYOUTT	249
	COM(LVAR+20)=DX	LAYOUTT	250
255	CONTINUE	LAYOUTT	251
	IF (NTRI(MAT) .EQ. 0) GO TO 258	LAYOUTT	252
	M(LVAR)=LVAR+NSTD+NSTD+NVAR(MAT)-5	LAYOUTT	253
	LVAR2=M(LVAR)	LAYOUTT	254
	D(LVAR2)=RH0(MAT)	LAYOUTT	255
	IF (NPR(MAT) .NE. 1) GO TO 256	LAYOUTT	256
	DX=X(LVAR)-XL(K-1,J)	LAYOUTT	257
	CALL EXPLODE(2,5,MAT,E(LVAR2),D(LVAR2),D0LD,P(LVAR2),Q,COM(18+	LAYOUTT	258
	1 LVAR2),XZ,DX,YZ,Y(LVAR)-YL(K,J-1),J,K,COM(LVAR2+19))	LAYOUTT	259
	COM(LVAR2+20)=DX	LAYOUTT	260
256	CONTINUE	LAYOUTT	261
	A(LVAR)=A124	LAYOUTT	262
	A(LVAR2)=A234	LAYOUTT	263
	Z(LVAR)=D(LVAR)*A(LVAR)	LAYOUTT	264
	Z(LVAR2)=D(LVAR2)*A(LVAR2)	LAYOUTT	265
	IF (IJBUND .GT. 0) Z(LVAR)=D(LVAR2)*A124*(YL(K,J)+YL(K-1,J)+	LAYOUTT	266
	1 YL(K,J-1))	LAYOUTT	267
	IF (IJBUND .GT. 0) Z(LVAR2)=D(LVAR2)*A234*(YL(K-1,J)+YL(K-1,J-1)+	LAYOUTT	268
	1 YL(K,J-1))	LAYOUTT	269
	IF (YC(MAT) .NE. 0.) YY(LVAR2)=YC(MAT)	LAYOUTT	270
	LVAR=LVAR2	LAYOUTT	271
	GO TO 260	LAYOUTT	272
258	A(LVAR)=A124+A234	LAYOUTT	273
	Z(LVAR)=D(LVAR)*A(LVAR)	LAYOUTT	274
C	Z IS COMPUTED AS 1.5/PI TIMES ACTUAL NUMBER FOR AXISYMMETRIC CASE	LAYOUTT	275
	IF (IJBUND .GT. 0) Z(LVAR)=D(LVAR)*(A124*(YL(K,J)+YL(K-1,J)+	LAYOUTT	276
	1 YL(K,J-1))+A234*(YL(K-1,J)+YL(K-1,J-1)+YL(K,J-1)))	LAYOUTT	277
260	CONTINUE	LAYOUTT	278
	LVAR=LVAR+NSTD	LAYOUTT	279
	IF (MAT .NE. 0) LVAR=LVAR+NVAR(MAT)+NSTD	LAYOUTT	280
280	CONTINUE	LAYOUTT	281
300	CONTINUE	LAYOUTT	282
	KMAX=KM	LAYOUTT	283
	JMAX=JM	LAYOUTT	284
C		LAYOUTT	285
C	***** INITIALIZE VELOCITIES IN ONE BLOCK	LAYOUTT	286
C		LAYOUTT	287
	IF (IVTYPE .GT. 1) GO TO 350	LAYOUTT	288
	IF (IVTYPE .EQ. 0) GO TO 450	LAYOUTT	289

SUBROUTINE LAYOUTT (Continued)

READ 1032,A1,A2,JU,A3,A4,KU,A5,A6,UZER0	LAYOUTT	290
PRINT 1032,A1,A2,JU,A3,A4,KU,A5,A6,UZER0	LAYOUTT	291
AMASS=0.	LAYOUTT	292
BMASS=0.	LAYOUTT	293
UZINT=UZER0	LAYOUTT	294
D0 310 J=2,JU	LAYOUTT	295
IF (MM(KU,J) .LE. 0 .OR. MM(KU+1,J) .LE. 0) G0 TO 310	LAYOUTT	296
MA=MM(KU,J)	LAYOUTT	297
MB=MM(KU+1,J)	LAYOUTT	298
AMASS=AMASS+RH0(MA)*(XL(KU,J)-XL(KU-1,J))	LAYOUTT	299
BMASS=BMASS+RH0(MB)*(XL(KU+1,J)-XL(KU,J))	LAYOUTT	300
310 CONTINUE	LAYOUTT	301
IF (AMASS+BMASS .GT. 0 .AND. IVTYPE .EQ. -1) UZINT=UZER0*BMASS/	LAYOUTT	302
1 (AMASS+BMASS)	LAYOUTT	303
IF (AMASS+BMASS .GT. 0 .AND. IVTYPE .EQ. 1) UZINT=UZER0*AMASS/	LAYOUTT	304
1 (AMASS+BMASS)	LAYOUTT	305
D0 325 K=1,KMAX	LAYOUTT	306
D0 325 J=1,JMAX	LAYOUTT	307
IF (LVAR(K,J) .LE. 0) G0 TO 320	LAYOUTT	308
LM=LVAR(K,J)	LAYOUTT	309
IF (K .GT. KU .AND. IVTYPE .EQ. -1) XD(LM)=UZER0	LAYOUTT	310
IF (K .LT. KU .AND. IVTYPE .EQ. 1) XD(LM)=UZER0	LAYOUTT	311
IF (J .LE. JU .AND. K .EQ. KU) XD(LM)=UZINT	LAYOUTT	312
320 CONTINUE	LAYOUTT	313
325 CONTINUE	LAYOUTT	314
IF (KCHK .NE. 0) G0 TO 450	LAYOUTT	315
KCHK=KMAX	LAYOUTT	316
IF (IVTYPE .EQ. 1) KCHK=KU+3	LAYOUTT	317
G0 TO 450	LAYOUTT	318
C	LAYOUTT	319
C ***** INITIALIZE X AND Y VELOCITIES IN SEVERAL BLOCKS	LAYOUTT	320
350 CONTINUE	LAYOUTT	321
D0 400 NB=1,NVBLK	LAYOUTT	322
READ 1031,A1,A2,K1,K2,A3,A4,(XA(1),I=1,4)	LAYOUTT	323
PRINT 1031,A1,A2,K1,K2,A3,A4,(XA(1),I=1,4)	LAYOUTT	324
READ 1031,A1,A2,J1,J2,A3,A4,(YA(1),I=1,4)	LAYOUTT	325
PRINT 1031,A1,A2,J1,J2,A3,A4,(YA(1),I=1,4)	LAYOUTT	326
KCHK=MAX0(KCHK,K1+2,K2+2)	LAYOUTT	327
IF (K1 .LT. K2) G0 TO 370	LAYOUTT	328
IF (J1 .LT. J2) G0 TO 360	LAYOUTT	329
C INITIALIZE VELOCITY AT ONE POINT	LAYOUTT	330
LM=LVAR(K1,J1)	LAYOUTT	331
XD(LM)=XA(1)	LAYOUTT	332
YD(LM)=YA(1)	LAYOUTT	333
G0 TO 400	LAYOUTT	334
C INITIALIZE VELOCITY AT SEVERAL J VALUES, ONE K	LAYOUTT	335
360 DY=YL(K1,J2)-YL(K1,J1)	LAYOUTT	336
IF (ABS(DY) .LE. 1.E-06) G0 TO 390	LAYOUTT	337
D0 365 J=J1,J2	LAYOUTT	338
LM=LVAR(K1,J)	LAYOUTT	339
XD(LM)=(XA(1)*(YL(K1,J2)-YL(K1,J))+XA(2)*(YL(K1,J)-YL(K1,J1)))/DY	LAYOUTT	340
365 YD(LM)=(YA(1)*(YL(K1,J2)-YL(K1,J))+YA(2)*(YL(K1,J)-YL(K1,J1)))/DY	LAYOUTT	341
G0 TO 400	LAYOUTT	342
C INITIALIZE VELOCITY AT SEVERAL K VALUES, ONE J	LAYOUTT	343
370 IF (J1 .LT. J2) G0 TO 380	LAYOUTT	344
DX=XL(K2,J1)-XL(K1,J1)	LAYOUTT	345
IF (ABS(DX) .LE. 1.E-06) G0 TO 390	LAYOUTT	346
D0 375 K=K1,K2	LAYOUTT	347
LM=LVAR(K,J1)	LAYOUTT	348
XD(LM)=(XA(1)*(XL(K2,J1)-XL(K,J1))+XA(2)*(XL(K,J1)-XL(K1,J1)))/DX	LAYOUTT	349
375 YD(LM)=(YA(1)*(XL(K2,J1)-XL(K,J1))+YA(2)*(XL(K,J1)-XL(K1,J1)))/DX	LAYOUTT	350
G0 TO 400	LAYOUTT	351
C INITIALIZE VELOCITY FOR SEVERAL J AND K VALUES	LAYOUTT	352
C INTERPOLATION IS LINEAR IN J DIRECTION AND ON BOUNDARIES OF BLOCK	LAYOUTT	353
380 IF (ABS((XL(K2,J1)-XL(K1,J1))*(YL(K1,J2)-YL(K1,J1))*(XL(K2,J2)-	LAYOUTT	354
1 XL(K1,J2))*(YL(K2,J2)-YL(K2,J1))) .LE. 1.E-25) G0 TO 390	LAYOUTT	355
D0 385 K=K1,K2	LAYOUTT	356
D0 385 J=J1,J2	LAYOUTT	357
LM=LVAR(K,J)	LAYOUTT	358
XD(LM)=((XA(1)*(XL(K2,J1)-XL(K,J1))+XA(2)*(XL(K,J1)-XL(K1,J1)))	LAYOUTT	359
1 /(XL(K2,J1)-XL(K1,J1))*(YL(K,J2)-YL(K,J)) + (XA(3)*(XL(K,J2)	LAYOUTT	360
2 -XL(K1,J2))+XA(4)*(XL(K2,J2)-XL(K,J2)))/(XL(K2,J2)-XL(K1,J2))	LAYOUTT	361
3 *(YL(K,J)-YL(K,J1))/(YL(K,J2)-YL(K,J1))	LAYOUTT	362
385 YD(LM)=((YA(1)*(XL(K2,J1)-XL(K,J1))+YA(2)*(XL(K,J1)-XL(K1,J1)))	LAYOUTT	363
1 /(XL(K2,J1)-XL(K1,J1))*(YL(K,J2)-YL(K,J)) + (YA(3)*(XL(K,J2)	LAYOUTT	364

SUBROUTINE LAYOUTT (Continued)

2	-XL(K1,J2))+YA(4)*(XL(K2,J2)-XL(K,J2))/(XL(K2,J2)-XL(K1,J2))	LAYOUTT	365
3	*(YL(K,J)-YL(K,J1))/(YL(K,J2)-YL(K,J1))	LAYOUTT	366
	GO TO 400	LAYOUTT	367
390	D0 395 K=K1,K2	LAYOUTT	368
	D0 395 J=J1,J2	LAYOUTT	369
	LM=LVAR(K,J)	LAYOUTT	370
	AK1=AJ1=0.5	LAYOUTT	371
	IF (K1 .NE. K2) AK1=(K-K1)/(K2-K1)	LAYOUTT	372
	AK2=1.-AK1	LAYOUTT	373
	IF (J1 .NE. J2) AJ1=(J-J1)/(J2-J1)	LAYOUTT	374
	AJ2=1.-AJ1	LAYOUTT	375
	XD(LM)=(XA(1)*AK2+XA(2)*AK1)*AJ2+(XA(3)*AK1+XA(4)*AK2)*AJ1	LAYOUTT	376
395	YD(LM)=(YA(1)*AK2+YA(2)*AK1)*AJ2+(YA(3)*AK1+YA(4)*AK2)*AJ1	LAYOUTT	377
400	CONTINUE	LAYOUTT	378
C		LAYOUTT	379
C		LAYOUTT	380
C	CALL FOR ADDED DATA	LAYOUTT	381
450	IF (NEXTRA .GT. 0) CALL EXTRAT(2)	LAYOUTT	382
C	***** PRINT INITIAL LAYOUT	LAYOUTT	383
C		LAYOUTT	384
	PRINT 1250,DISCPT	LAYOUTT	385
	ZERO=0.	LAYOUTT	386
	D0 470 K=1,KMAX	LAYOUTT	387
	D0 460 J=1,JMAX	LAYOUTT	388
	LM=LVAR(K,J)	LAYOUTT	389
	IF (LM .LE. 0) GO TO 460	LAYOUTT	390
	IF (MM(K,J) .GT. 0) GO TO 455	LAYOUTT	391
	PRINT 1280,J,K,MM(K,J),LM,X(LM),Y(LM),ZERO,ZERO,ZERO,ZERO,XD(LM),	LAYOUTT	392
	1 YD(LM),ZERO	LAYOUTT	393
	GO TO 460	LAYOUTT	394
455	MAT=MM(K,J)	LAYOUTT	395
	YYY=0.	LAYOUTT	396
	IF (YC(MAT) .NE. 0) YYY=YY(LM)	LAYOUTT	397
	PRINT 1280,J,K,MAT,LM,X(LM),Y(LM),A(LM),D(LM),Z(LM),YYY,XD(LM),	LAYOUTT	398
	1 YD(LM),E(LM)	LAYOUTT	399
460	CONTINUE	LAYOUTT	400
470	CONTINUE	LAYOUTT	401
	RETURN	LAYOUTT	402
C		LAYOUTT	403
C	*****INITIALIZE VALUES FROM A RESTART FILE	LAYOUTT	404
C		LAYOUTT	405
500	NST= NSTART-1	LAYOUTT	406
	IF(NST .EQ. 0) GO TO 515	LAYOUTT	407
	D0 510 I=1,NST	LAYOUTT	408
	READ (1) A1	LAYOUTT	409
510	CONTINUE	LAYOUTT	410
515	READ (1) (COM(I),I=1,JSIZE),(LVAR(I),I=1,JK),(MM(I),I=1,JK),JMAX,	LAYOUTT	411
	1 JMIN,KMAX,KMIN,TYME	LAYOUTT	412
C		LAYOUTT	413
C	CALL FOR ADDED DATA	LAYOUTT	414
	IF (NEXTRA .GT. 0) CALL EXTRAT(3)	LAYOUTT	415
	IF (KCHK .EQ. 0) KCHK=KMAX	LAYOUTT	416
	PRINT 1290	LAYOUTT	417
	D0 490 K=1,KMAX	LAYOUTT	418
	D0 480 J=1,JMAX	LAYOUTT	419
	LM=LVAR(K,J)	LAYOUTT	420
	IF(LM .LE. 0) GO TO 480	LAYOUTT	421
	PRINT 2000,K,J,P(LM),SXX(LM),SYY(LM),SZZ(LM),TXY(LM)	LAYOUTT	422
1290	FORMAT(4X,1HK,4X,1HJ,9X,1HP,7X,3HSXX,7X,3HSYY,7X,3HSZZ,7X,3HTXY)	LAYOUTT	423
2000	FORMAT(2I5,1P5E10.3)	LAYOUTT	424
480	CONTINUE	LAYOUTT	425
490	CONTINUE	LAYOUTT	426
	GO TO 450	LAYOUTT	427
C	***** FORMATS *****	LAYOUTT	428
C		LAYOUTT	429
1000	FORMAT(1H1)	LAYOUTT	430
1001	FORMAT(43H0EOF ON INPUT, FOUND BY LAYOUTT, NORMAL END)	LAYOUTT	431
1002	FORMAT(1H0)	LAYOUTT	432
1030	FORMAT(2A5,2I5,2A5,4F10.5,A5,A4,I1)	LAYOUTT	433
1031	FORMAT(2A5,2I5,2A5,4F10.2)	LAYOUTT	434
1032	FORMAT(2A5,I10,2A5,I10,2A5,F10.3)	LAYOUTT	435
1100	FORMAT(16A5)	LAYOUTT	436
1104	FORMAT(4(2A5,E10.3))	LAYOUTT	437
1105	FORMAT(8(A6,I4))	LAYOUTT	438

SUBROUTINE LAYOUTT (Concluded)

1106	FORMAT (8(A4,A3,I3))	LAYOUTT	439
1107	FORMAT(2A5,7E10.3)	LAYOUTT	440
1108	FORMAT(2A5,E10.3,2A5,I10,2(2A5,I10))	LAYOUTT	441
1109	FORMAT (2A5,7A10)	LAYOUTT	442
1110	FORMAT(2A5,7I10)	LAYOUTT	443
1111	FORMAT (8(A5,A3,I2))	LAYOUTT	444
1112	FORMAT(2A5,14I5/(16I5))	LAYOUTT	445
1125	FORMAT(2A5,7(I6,2I2))	LAYOUTT	446
1130	FORMAT(6A5,E10.3,A5,A2,3I1,A5,A2,3I1,(A5,A3,I2,A5,A3,I2))	LAYOUTT	447
1250	FORMAT (1H1,20X,20A5//4X,*J*,4X,*K*,4X,*M*,* LVAR*,11X,*X*,11X,	LAYOUTT	448
	1 1HY,11X,1HA,11X,1HD,11X,1HZ,7X,5HYIELD,10X,2HXD,10X,2HYD,11X,	LAYOUTT	449
	2 1HE)	LAYOUTT	450
1280	FORMAT (4I5,5F12.6,1P4E12.3)	LAYOUTT	451
1133	FORMAT (2A5,2I5,2A5,2I5,2A5,I9,I1,2E10.4)	LAYOUTT	452
	END	LAYOUTT	453

SUBROUTINE REBAR

	SUBROUTINE REBAR(LL, IN, JC, IC, M, N, IH, DH, DOLD, SX, SY, SZ, TXY, E, P,	REBAR	2
	1 DEX, DEY, DEZ, DEXY, F, THETA, DTHETA, ESC, FS, DSTL, SRS,	REBAR	3
	2 ZEVP, TEVP, Y, ROLD, IPRINT)	REBAR	4
C	SR1 AND SR3 ARE OLD AND NEW STRESSES ON STEEL.	REBAR	5
C	SR2 AND SR4 ARE OLD AND NEW STRESSES ON CONCRETE.	REBAR	6
C	ALL STRESSES ARE DEVIATORS EXCEPT SRS ARRAY	REBAR	7
C	STRESSES ARE POSITIVE IN TENSION, PRESSURE IS POSITIVE IN COMP.	REBAR	8
C	STRAINS ARE POSITIVE IN TENSION	REBAR	9
C	PLANE OF REBARS IS INITIALLY NORMAL TO THE X DIRECTION	REBAR	10
C	THETA IS OLD VALUE OF ROTATION ANGLE, POSITIVE TOWARDS Y	REBAR	11
C	DTHETA IS INCREMENT OF THETA ON CURRENT CYCLE	REBAR	12
	DIMENSION SR(4), SRS(4), SR1(4), SR2(4), DEC(4), DES(4), DE(4), SR3(4),	REBAR	13
	1 SR4(4), THET(6), IMC(6), IMS(6), FSTEEL(6), ESC(6, 20)	REBAR	14
	IF (LL .GE. 0) GO TO 15	REBAR	15
	READ 1004, A1, FSTEEL(M), A2, THET(M), A3, IMC(M), A4, IMS(M)	REBAR	16
	PRINT 1004, A1, FSTEEL(M), A2, THET(M), A3, IMC(M), A4, IMS(M)	REBAR	17
1004	FORMAT(A10, E10.3, A10, E10.3, A10, I10, A10, I10)	REBAR	18
	LS=0	REBAR	19
	MC=IMC(M)	REBAR	20
	MS=IMS(M)	REBAR	21
	SX=SQRT((FSTEEL(M)*(ESC(MS, 2)+1.33*ESC(MS, 5)))+(1.-FSTEEL(M))*	REBAR	22
	1 (ESC(MC, 2)+1.33*ESC(MC, 5)))/(FSTEEL(M)*ESC(MS, 1)+(1.-FSTEEL(M))*	REBAR	23
	2 ESC(MC, 1)))	REBAR	24
	DH=FSTEEL(M)*ESC(MS, 1)+(1.-FSTEEL(M))*ESC(MC, 1)	REBAR	25
	Y=ESC(MS, 10)	REBAR	26
	RETURN	REBAR	27
15	IF(ROLD .NE. 0.) GO TO 18	REBAR	28
	MC=IMC(M)	REBAR	29
	MS=IMS(M)	REBAR	30
	FS=FSTEEL(M)	REBAR	31
	THETA=THET(M)	REBAR	32
	DSTL=ESC(MS, 1)	REBAR	33
	ROLD=ESC(MC, 1)	REBAR	34
18	CONTINUE	REBAR	35
	MC=IMC(M) \$ MS=IMS(M)	REBAR	36
	NTRY=1	REBAR	37
	RHOS=ESC(MC, 7)	REBAR	38
	EQSTC=ESC(MC, 2)	REBAR	39
	GRUN=ESC(MC, 9)	REBAR	40
	AMU=ESC(MC, 5)	REBAR	41
	CRIT=1.E7	REBAR	42
	TEVPSV=TEVP	REBAR	43
	ZEVP=ZEVP	REBAR	44
	YSV=Y	REBAR	45
	IHSV=IH	REBAR	46
	IPRINT=0	REBAR	47
	FS1=FS=(DOLD-ROLD)/(DSTL-ROLD)	REBAR	48
	COS2TH=COS(2.*THETA)	REBAR	49
	SIN2TH=SIN(2.*THETA)	REBAR	50
C	ROTATE STRAIN INCREMENTS TO AXIS OF REBARS	REBAR	51
	SIN2TH1=SIN2TH+DTHETA*COS2TH \$ COS2TH1=COS2TH-SIN2TH*DTHETA	REBAR	52
	DE(1)=(DEX+DEY+(DEX-DEY)*COS2TH1)/2.+DEXY*SIN2TH1	REBAR	53
	DE(2)=(DEX+DEY-(DEX-DEY)*COS2TH1)/2.-DEXY*SIN2TH1	REBAR	54
	DE(3)=DEZ	REBAR	55
	DE(4)=- (DEX-DEY)*SIN2TH1/2.+DEXY*COS2TH1	REBAR	56
C	ROTATE STRESSES TO AXIS OF REBARS	REBAR	57
	SR(1)=(SX+SY+(SX-SY)*COS2TH)/2.+TXY*SIN2TH	REBAR	58
	SR(2)=(SX+SY-(SX-SY)*COS2TH)/2.-TXY*SIN2TH	REBAR	59
	SR(3)=SZ	REBAR	60
	SR(4)=- (SX-SY)*SIN2TH/2.+TXY*COS2TH	REBAR	61
	RL=0. \$ RR=1.	REBAR	62
	IF (IPRINT .EQ. 1) PRINT 1120, (SR(I), I=1, 4), SX, SY, SZ, TXY, COS2TH,	REBAR	63
	1 SIN2TH	REBAR	64
C	*****	REBAR	65
C	BEGINNING OF COMPUTATIONAL LOOP FOR EACH STRAIN INCREMENT	REBAR	66
120	PS=FS1=-(SRS(1)+SRS(2)+SRS(3))/3.	REBAR	67
	FS=FS1	REBAR	68
	PC=PC1=(P-PS1*FS)/(1.-FS)	REBAR	69
	DO 170 I=1, 4	REBAR	70
	SR1(I)=SRS(I)+PS1	REBAR	71
	IF (I .EQ. 4) SR1(4)=SRS(4)	REBAR	72
	SR2(I)=(SR(I)-SR1(I)*FS)/(1.-FS)	REBAR	73
170	DEC(I)=DES(I)=DE(I)*RR	REBAR	74
	DES(I)=DEC(I)*ESC(MC, 2)/ESC(MS, 2)	REBAR	75

SUBROUTINE REBAR (Continued)

DEC(1)=(DE(1)*RR-DES(1)*FS)/(1.-FS)	REBAR	76
18D NC=0	REBAR	77
C *****	REBAR	78
C BEGINNING OF ITERATION LOOP	REBAR	79
2DD NC=NC+1	REBAR	80
DO 210 I=1,4	REBAR	81
SR3(I)=SR1(I)	REBAR	82
210 SR4(I)=SR2(I)	REBAR	83
TEVP=TEVPSV	REBAR	84
ZEVP=ZEVPSV	REBAR	85
Y=YSV	REBAR	86
IH=IHSV	REBAR	87
PS=PS1 \$ PC=PC1	REBAR	88
RX=SR4(1)-PC \$ RY=SR4(2)-PC \$ RZ=SR4(3)-PC \$ RXY=SR4(4)	REBAR	89
DEST=(DEC(1)+DEC(2)+DEC(3))/3.	REBAR	90
RH=ROLD*(2.-DEST)/(2.+DEST)	REBAR	91
IF (IPRINT .EQ. 1) PRINT 1DD2,RH,ROLD,RX,RY,RZ,RXY,ZEVP,TEVP	REBAR	92
CALL CAP1(LS,IN,MC,N,IH,RH,ROLD,E,DEC(1),DEC(2),DEC(3),DEC(4),	REBAR	93
1 RX,RY,RZ,RXY,ZEVP,IC,JC,TEVP)	REBAR	94
IF (IPRINT .EQ. 1) PRINT 1DD3,RH,ROLD,RX,RY,RZ,RXY,ZEVP,TEVP	REBAR	95
PC=(RX+RY+RZ)/3.	REBAR	96
SR4(1)=RX+PC \$ SR4(2)=RY+PC \$ SR4(3)=RZ+PC \$ SR4(4)=RXY	REBAR	97
DEST=(DES(1)+DES(2)+DES(3))/3.	REBAR	98
D=DSTL*(2.-DEST)/(2.+DEST)	REBAR	99
CALL EPLAS(JC,IC,MS,SR3,PS,DES,ESC,D,Y)	REBAR	100
SCTEST=SR4(1)-PC \$ SSTEEST=SR3(1)-PS	REBAR	101
IF (IPRINT .EQ. 1) PRINT 1DD1,NC,DES(1),DEC(1),PC,PS,(SR1(I),I=1,4	REBAR	102
1),(SR2(I),I=1,4),(SR3(I),I=1,4),(SR4(I),I=1,4),SCTEST,SSTEEST	REBAR	103
IF (ABS(SR4(1)-PC-SR3(1)+PS) .LT. CRIT) GO TO 290	REBAR	104
DEZA=DES(1) \$ DSZA=SR4(1)-SR3(1) -PC+PS	REBAR	105
IF (NC .EQ. 1) GO TO 25D	REBAR	106
IF (NC .LT. 12) GO TO 26D	REBAR	107
IF (NTRY .LT. 5) GO TO 45D	REBAR	108
C ABORT PROVISION	REBAR	109
PRINT 1240,JC,IC,N,PS,PC,SSTEEST,SCTEST,SR1,SR2,SR3,SR4,DES,DEC	REBAR	110
1240 FORMAT(1X,* ABORT IN REBAR FOR NTRY EQUALS 5 FOR J=*,I5,* I=*,I5,	REBAR	111
1 * ON CYCLE *,I5,/,1X,* PS=*,E10.3,* PC=*,E10.3,* SSTEEST=*,E10.3,	REBAR	112
2 * SCTEST=*,E10.3/,* SR1=*,4E10.3,* SR2=*,4E10.3,/,* SR3=*,4E10.3,	REBAR	113
3 * SR4=*,4E10.3,/,* DES=*,4E10.3,* DEC=*,4E10.3)	REBAR	114
GO TO 32D	REBAR	115
C PREPARATION FOR SECOND ITERATION	REBAR	116
25D DES(1)=DES(1)+(SR4(1)-PC-SR3(1)+PS)/(ESC(MC,2)*FS/(1.-FS)+ESC(MS,2	REBAR	117
1))	REBAR	118
DEC(1)=(DE(1)*RR -DES(1)*FS)/(1.-FS)	REBAR	119
GO TO 28D	REBAR	120
C REGULA FALSI BRANCHES	REBAR	121
26D IF (NC .EQ. 2) GO TO 262	REBAR	122
IF (DSZC .GT. 0.) GO TO 265	REBAR	123
IF (DSZB .LT. D.) GO TO 262	REBAR	124
IF (DSZA .GT. D.) GO TO 265	REBAR	125
262 DES(1)=DEZA+(DEZB-DEZA)/(DSZB-DSZA)*(-DSZA)	REBAR	126
IF (NC .EQ. 6 .OR. NC .EQ. 1D) DES(1)=D.5*(DEZA+DEZB)	REBAR	127
GO TO 27D	REBAR	128
265 DES(1)=DEZA+(DEZC-DEZA)/(DSZC-DSZA)*(-DSZA)	REBAR	129
IF (NC .EQ. 6 .OR. NC .EQ. 10) DES(1)=D.5*(DEZA+DEZC)	REBAR	130
270 DEC(1)=(DE(1)*RR -DES(1)*FS)/(1.-FS)	REBAR	131
IF (NC .GT. 2) GO TO 275	REBAR	132
IF (DSZA .LT. DSZB) 283,279	REBAR	133
275 IF (DSZA .GT. DSZB .OR. DSZA .LT. DSZC) GO TO 277	REBAR	134
IF (DSZA .LT. 0.) 283,280	REBAR	135
277 IF (DSZB .LT. 0. .AND. DSZA .GT. DSZB) GO TO 279	REBAR	136
IF (DSZC .GT. 0. .AND. DSZA .GT. DSZC) 282,200	REBAR	137
279 DSZC=DSZB \$ DEZC=DEZB	REBAR	138
28D DSZB=DSZA \$ DEZB=DEZA \$ GO TO 20D	REBAR	139
282 DSZB=DSZC \$ DEZB=DEZC	REBAR	140
283 DSZC=DSZA \$ DEZC=DEZA \$ GO TO 20D	REBAR	141
C *****	REBAR	142
C END OF ITERATION LOOP, RESET FOR NEXT STRAIN INCREMENT	REBAR	143
290 DO 295 I=1,4	REBAR	144
SR1(I)=SR3(I)	REBAR	145
295 SR2(I)=SR4(I)	REBAR	146
IHSV=IH	REBAR	147
YSV=Y	REBAR	148
TEVPSV=TEVP	REBAR	149
ZEVPSV=ZEVP	REBAR	150

SUBROUTINE REBAR (Concluded)

	FS=FS*(1.+DES(1))/(FS*(1.+DES(1))+(1.-FS)*(1.+DEC(1)))	REBAR	151
	DSTL=D	REBAR	152
	ROLD=RH	REBAR	153
	PS1=PS \$ PC1=PC	REBAR	154
	RL=RL+RR	REBAR	155
	IF (RL .LT. .999) GO TO 180	REBAR	156
C	ENDING ROUTINE	REBAR	157
320	CONTINUE	REBAR	158
	DO 330 I=1,4	REBAR	159
	SR(I)=SR4(I)*(1.-FS)+SR3(I)*FS	REBAR	160
330	SRS(I)=SR3(I)-PS	REBAR	161
	SRS(4)=SR3(4)	REBAR	162
	THETA2=(THETA+DTHETA)*2.	REBAR	163
	SIN2TH1=SIN(THETA2) \$ COS2TH1=COS(THETA2)	REBAR	164
	SX=(SR(1)+SR(2)+(SR(1)-SR(2))*COS2TH1)/2.-SR(4)*SIN2TH1	REBAR	165
	SY=(SR(1)+SR(2)-(SR(1)-SR(2))*COS2TH1)/2.+SR(4)*SIN2TH1	REBAR	166
	SZ=SR(3)	REBAR	167
	TXY=+(SR(1)-SR(2))/2.*SIN2TH1+SR(4)*COS2TH1	REBAR	168
	IF (IPRINT .EQ. 1) PRINT 1120,(SR(I),I=1,4),SX,SY,SZ,txy,COS2TH1,	REBAR	169
	1 SIN2TH1	REBAR	170
	P=PC*(1.-FS)+PS*FS	REBAR	171
	RETURN	REBAR	172
C	PROVISION TO CUT STRAIN INCREMENTS	REBAR	173
450	NTRY=NTRY+1	REBAR	174
	IF (NTRY .EQ. 5) IPRINT=1	REBAR	175
	RR=RR/3.	REBAR	176
	GO TO 120	REBAR	177
1001	FORMAT(1X,* NC=*15,* DES(1),DEC(1)=*, 1P2E10.3,* PC=*,E10.3,* PS=*	REBAR	178
	1,E10.3,/,1X,* SR1=*,4E10.3,* SR2=*,4E10.3,/,1X,* SR3=*,4E10.3,	REBAR	179
	2* SR4=*,4E10.3/,1X,* (CONCRETE STRESS) SR4(1)-PC=*,E12.5,* (STEEL	REBAR	180
	3STRESS) SR3(1)-PS=*,E12.5)	REBAR	181
1002	FORMAT(* BEFORE CAP,RH,ROLD=*1P2E10.3,	REBAR	182
	1 * RX,RY,RZ,RXY=*4E10.3,* ZEVP,TEVP=*2E10.3)	REBAR	183
1003	FORMAT (* AFTER CAP, RH,ROLD=*1P2E10.3,	REBAR	184
	1 * RX,RY,RZ,RXY=*4E10.3,* ZEVP,TEVP=*2E10.3)	REBAR	185
1120	FORMAT(* SR1,SR2,SR3,SR4=*4E10.3/* SX,SY,SZ,txy=*4E'0.3/* COS2TH,	REBAR	186
	1 SIN2TH=*2E10.3)	REBAR	187
	END	REBAR	188

SUBROUTINE SCRIBET

SUBROUTINE SCRIBET	SCRIBET	2
COMMON/NSCRB/SJ(60),NJED,NJKED,NKED,N,TIMEZ,DISCPT(20),JEDJ(60),	NSCRBCOM	2
1 JEDK(60),JEDT(60),NAME(60)	NSCRBCOM	3
DIMENSION R(1)	SCRIBET	4
EQUIVALENCE (R,SJ)	SCRIBET	5
REWIND 4	SCRIBET	6
READ (4) A1	SCRIBET	7
NSCRIBE=N1=1	SCRIBET	8
N2=MINO(N1+7,NJKED)	SCRIBET	9
DO 30 NP=1,N	SCRIBET	10
READ (4) NN,T,DT,DELTIM,(R(1), I=1,NJKED)	SCRIBET	11
IF (MOD(NN,50) .EQ. 1) PRINT 1001, DISCPT,NSCRIBE,(JEDT(1),	SCRIBET	12
1 JEDK(1),JEDJ(1), I=N1,N2)	SCRIBET	13
PRINT 1100, NN,T,DT,DELTIM,(R(1), I=N1,N2)	SCRIBET	14
30 CONTINUE	SCRIBET	15
GO TO 120	SCRIBET	16
50 N2=MINO(N1+9,NJKED)	SCRIBET	17
READ (4) A1	SCRIBET	18
DO 100 NP=1,N	SCRIBET	19
READ (4) NN,T,DT,DELTIM,(R(1), I=1,NJKED)	SCRIBET	20
IF (MOD(NN,50) .EQ. 1) PRINT 1000,DISCPT,NSCRIBE,(JEDT(1),JEDK(1),	SCRIBET	21
1 JEDJ(1),I=N1,N2)	SCRIBET	22
PRINT 1100, NN,T,(R(1),I=N1,N2)	SCRIBET	23
100 CONTINUE	SCRIBET	24
120 REWIND 4	SCRIBET	25
N1=N2+1	SCRIBET	26
NSCRIBE=NSCRIBE+1	SCRIBET	27
IF (N2 .LT. NJKED) GO TO 50	SCRIBET	28
CALL SECOND(TIMNOW)	SCRIBET	29
CALTIM=TIMNOW-TIMEZ	SCRIBET	30
PRINT 1200, CALTIM	SCRIBET	31
RETURN	SCRIBET	32
1000 FORMAT (1H1,20A5,/9H NSCRIBE=13,31H, HISTORIES, TIME IN MUSEC, STR	SCRIBET	33
1 51HESS IN DYN/CM2, VELOCITY IN CM/SEC,DENSITY IN G/CM3//4X,1HN,	SCRIBET	34
2 7X,4HTIME,10(1X,A3,1H(12,1H,12,1H))//)	SCRIBET	35
1001 FORMAT(1H1,20A5/9H NSCRIBE=13,31H, HISTORIES, TIME IN MUSEC, STR	SCRIBET	36
1 51HESS IN DYN/CM2, VELOCITY IN CM/SEC,DENSITY IN G/CM3//4X,1HN,	SCRIBET	37
2 7X,4HTIME,9X,2HDT,5X,6HDELTIM,8(1X,A3,1H(12,1H,12,1H))//)	SCRIBET	38
1100 FORMAT(15,1PE11.3,10E11.3)	SCRIBET	39
1200 FORMAT(* CALTIM=*F8.3,* SEC*)	SCRIBET	40
END	SCRIBET	41

SUBROUTINE SWEEP

	SUBROUTINE SWEEP(JSIZE,JXX,KXX,XL,YL,MM,IZ,LVAR)	SWEPT	2
C		SWEPT	3
C	ROUTINE PERFORMS COMPUTATIONS FOR EACH CELL AT EACH CYCLE.	SWEPT	4
C	COMPUTATIONS ARE MADE FOR VELOCITY (FROM MOMENTUM CONSERVATION),	SWEPT	5
C	STRAIN AND DENSITY CHANGES (MASS CONSERVATION), ENERGY (ENERGY	SWEPT	6
C	CONSERVATION) AND STRESS (CONSTITUTIVE EQUATIONS AND EQUATIONS OF	SWEPT	7
C	STATE).	SWEPT	8
C	SELECTED VALUES ARE STORED FOR HISTORIES.	SWEPT	9
C	STRESSES ARE POSITIVE IN TENSION, PRESSURE POSITIVE IN COMP	SWEPT	10
C	SXX, ETC ARE DEVIATORS, TXX, ETC ARE TOTAL STRESSES	SWEPT	11
C		SWEPT	12
	COMMON/EQS/EQSTC(6),EQSTD(6),EQSTE(6),EQSTG(6),EQSTH(6),EQSTN(6),	EQSCOM	2
1	EQSTS(6),RHO(6),RHOS(6),YC(6),YAD(6),MU(6),ESC(6,20),CLIN,CQSQ,	EQSCOM	3
2	TRIQ,AMAT(6,4),SP(6),G2(6),PMIN(6)	EQSCOM	4
	COMMON/NSCRB/SJ(60),NJED,NJKED,NKED,N,TIMEZ,DISCPT(20),JEDJ(60),	NSCRBCOM	2
1	JEDK(60),JEDT(60),NAME(60)	NSCRBCOM	3
	COMMON/GEN/LZ(1),IJBUND, JMAX,JMIN,KMAX,KMIN,UZER0,CALTIM,	TROTTCOM	2
1	DELTIM,DT,DTN,TS,TYME,NSTART,NPLOT,NDUMP,IMAX,IPRINT	TROTTCOM	3
2	,KSKIP,KFULL,KPMAX,KPMIN,JPMAX,JPMIN,JSLIDE,KSLIDE	TROTTCOM	4
3	,NSCRIB,DTW,NEXED,N0BLQ,TANTH,JPRINT,JPR,JP1(20),JP2(20),KCHEK	TROTTCOM	5
4	,NBND,IBDJ1(6),IBDJ2(6),IBDK1(6),IBDK2(6),IBDX(6),IBDY(6),	TROTTCOM	6
5	XFIX(6),YFIX(6)	TROTTCOM	7
	COMMON/CAL/ LISTE,LISTS,LISTX,LISTXD,CALE,CALS,CALX,CALXD	TROTTCOM	8
	COMMON/IND/NCMP(6),NFR(6),NFOR(6),NDS(6),NPR(6),NVAR(6),NTRI(6)	TROTTCOM	9
	COMMON/TSR/TSR(6,21),BFR(6,20)	TROTTCOM	10
	COMMON/T/COM(1000)	SWEPT	16
	DIMENSION XA(4),YA(4),XL(KXX,JXX),YL(KXX,JXX),MM(KXX,JXX),IZ(KXX,	SWEPT	17
1	JXX),LVAR(KXX,JXX)	SWEPT	18
	REAL MU	SWEPT	19
	DIMENSION X(1),Y(1),XD(1),YD(1),M(1),A(1),Z(1),D(1),SXX(1),SYY(1),	SWEPT	20
1	SZZ(1),TXY(1),TXX(1),TYX(1),TZZ(1),P(1),E(1),TH(1),FS(1),DSTL(1)	SWEPT	21
2	,SRS(1),ZVFP(1),TEVP(1),YY(1),ROLD(1),IH(1),ENM(1),ENT(1),	SWEPT	22
3	ICOM(1),CLB(1),CL1(1),CN(1),FF(1)	SWEPT	23
	EQUIVALENCE (COM,ICOM),(COM(1),X),(COM(2),Y),(COM(3),XD),	SWEPT	24
1	(COM(4),YD),(COM(5),M),(COM(6),A),(COM(7),Z),(COM(8),D),(COM(9),	SWEPT	25
2	SXX),(COM(10),SYY),(COM(11),SZZ),(COM(12),TXY),(COM(13),TXX),	SWEPT	26
3	(COM(14),TYX),(COM(15),TZZ),(COM(16),P),(COM(17),E),(COM(18),	SWEPT	27
4	IH),(COM(19),YY),(COM(20),TH),(COM(21),ZVFP),(COM(22),TEVP),	SWEPT	28
5	(COM(23),FS),(COM(24),DSTL),(COM(25),ROLD),(COM(26),SRS),	SWEPT	29
6	(COM(22),ENM),(COM(23),ENT),(COM(23),CLB),(COM(28),CL1),(COM(33)	SWEPT	30
7	,CN),(COM(21),FF)	SWEPT	31
	DIMENSION XTEMP(100),YTEMP(100),XDTEMP(100),YDTEMP(100),LCON(100)	SWEPT	32
	DATA LCON/100*0/	SWEPT	33
	JE=1	SWEPT	34
	F=1.	SWEPT	35
	IF (N.EQ. 1) LSFRAC=0	SWEPT	36
	IF (N.EQ. 1) SINTH=SIN(N0BLQ/57.2957795)	SWEPT	37
	IF (N.EQ. 1) COSTH=COS(N0BLQ/57.2957795)	SWEPT	38
	IF (N.EQ. 1) LCON(1)=1	SWEPT	39
	IHEAD=1	SWEPT	40
	IPR=0	SWEPT	41
	IF (MOD(N,IPRINT).EQ. 0) GO TO 100	SWEPT	42
	IF (JPRINT.EQ. 0) GO TO 110	SWEPT	43
100	IF (N.LT. JP1(JPR).OR. N.GT. JP2(JPR)) GO TO 110	SWEPT	44
110	IHEAD=2	SWEPT	45
	CONTINUE	SWEPT	46
	DTSQM=1.	SWEPT	47
	DO 950 K=1,KMAX	SWEPT	48
	KHEAD=2	SWEPT	49
	DO 920 J=1,JMAX	SWEPT	50
	LVAR=LVAR(K,J)	SWEPT	51
	IF (LVARM.LE. 0) GO TO 780	SWEPT	52
	DW=0.	SWEPT	53
	TXXW=0.	SWEPT	54
	TYYW=0.	SWEPT	55
	TZZW=0.	SWEPT	56
	TXYW=0.	SWEPT	57
	SXXW=0.	SWEPT	58
	SYYW=0.	SWEPT	59
	SZZW=0.	SWEPT	60
	EW=0.	SWEPT	61
	PW=0.	SWEPT	62
	Q=0.	SWEPT	63
	SPSQ=0.	SWEPT	64

SUBROUTINE SWEEP (Continued)

C *****	*****	SWEPT	65
C *****	BEGIN MOMENTUM CALCULATIONS	SWEPT	66
C *****	*****	SWEPT	67
	XDNH=XD(LVARM)	SWEPT	68
	YDNH=YD(LVARM)	SWEPT	69
	FX=0.	SWEPT	70
	FY=0.	SWEPT	71
	XMOM=0.	SWEPT	72
	AMASS=0.	SWEPT	73
	L3=LVARM	SWEPT	74
C		SWEPT	75
C *****	FIND COORDINATES OF CELLS AROUND POINT (K,J)	SWEPT	76
C		SWEPT	77
	DO 360 I=1,4	SWEPT	78
	ITRI=0	SWEPT	79
	DMASS=0.	SWEPT	80
	GO TO (230,240,250,260) I	SWEPT	81
C		SWEPT	82
C XXXX	I=1, UPPER RIGHT HAND QUADRANT XXXX	SWEPT	83
230	IF(K.EQ. KMAX .OR. J.EQ. JMAX)GO TO 360	SWEPT	84
	IF (J.EQ. JSLIDE-1) GO TO 360	SWEPT	85
	IF (K.EQ. KSLIDE-1) GO TO 235	SWEPT	86
	IF (MM(K+1,J+1) .LE. 0) GO TO 360	SWEPT	87
	L1=LVAR(K+1,J+1)	SWEPT	88
	L2=LVAR(K,J+1)	SWEPT	89
	L4=LVAR(K+1,J)	SWEPT	90
	LM=L1	SWEPT	91
	MAT=MM(K+1,J+1)	SWEPT	92
	GO TO 270	SWEPT	93
C	K-SLIDE CASE	SWEPT	94
235	IF (LCON(J) .EQ. 0) GO TO 360	SWEPT	95
	L4=L3	SWEPT	96
	L1=L2=LVAR(K,J+1)	SWEPT	97
	GO TO 262	SWEPT	98
C		SWEPT	99
C XXXX	I=2, UPPER LEFT HAND QUADRANT XXXX	SWEPT	100
240	IF(K.EQ. 1 .OR. J.EQ. JMAX)GO TO 360	SWEPT	101
	IF (J.EQ. JSLIDE-1) GO TO 360	SWEPT	102
	IF (K.EQ. KSLIDE) GO TO 360	SWEPT	103
	IF (MM(K,J+1) .LE. 0) GO TO 360	SWEPT	104
	L1=LVAR(K-1,J+1)	SWEPT	105
	L2=LVAR(K-1,J)	SWEPT	106
	L4=LVAR(K,J+1)	SWEPT	107
	LM=L4	SWEPT	108
	MAT=MM(K,J+1)	SWEPT	109
	IF (K.EQ. KSLIDE-1) XMOM=XMOM+0.25*Z(LM)*XD(L3)	SWEPT	110
	GO TO 270	SWEPT	111
C		SWEPT	112
C XXXX	I=3, LOWER LEFT QUADRANT	SWEPT	113
250	IF(K.EQ. 1 .OR. J.EQ. 1) GO TO 360	SWEPT	114
	IF (J.EQ. JSLIDE) GO TO 255	SWEPT	115
	IF (K.EQ. KSLIDE) GO TO 360	SWEPT	116
	IF (MM(K,J) .LE. 0) GO TO 360	SWEPT	117
	L1=LVAR(K-1,J-1)	SWEPT	118
	L2=LVAR(K,J-1)	SWEPT	119
	L4=LVAR(K-1,J)	SWEPT	120
	LM=L3	SWEPT	121
	MAT=MM(K,J)	SWEPT	122
	IF (K.EQ. KSLIDE-1) XMOM=XMOM+0.25*Z(LM)*XD(L3)	SWEPT	123
	GO TO 270	SWEPT	124
C	J-SLIDE CASE	SWEPT	125
255	L2=L3	SWEPT	126
	L1=L4=LVAR(K-1,J)	SWEPT	127
	XSTAR=0.75*X(L3)+0.25*X(L4)	SWEPT	128
	GO TO 267	SWEPT	129
C		SWEPT	130
C ****	I=4, LOWER RIGHT QUADRANT	SWEPT	131
260	IF(K.EQ. KMAX .OR. J.EQ. 1)GO TO 360	SWEPT	132
	IF (J.EQ. JSLIDE) GO TO 265	SWEPT	133
	IF (K.EQ. KSLIDE-1) GO TO 262	SWEPT	134
	IF (MM(K+1,J) .LE. 0) GO TO 360	SWEPT	135
	L1=LVAR(K+1,J-1)	SWEPT	136
	L2=LVAR(K+1,J)	SWEPT	137
	L4=LVAR(K,J-1)	SWEPT	138
	LM=L2	SWEPT	139

SUBROUTINE SWEEP (Continued)

	MAT=MM(K+1,J)	SWEEP	140
	GO TO 270	SWEEP	141
C	K-SLIDE CASE	SWEEP	142
262	IF (LCOM(J) .EQ. 0) GO TO 360	SWEEP	143
	L2=L3	SWEEP	144
	L1=L4=LVAR(K,J-1)	SWEEP	145
	JS=LCOM(J)	SWEEP	146
	LX=LVAR(KSLIDE,JS)	SWEEP	147
	IF (JS .EQ. 1) JS=2	SWEEP	148
	LM=LVAR(KSLIDE+1,JS)	SWEEP	149
	DMASS=0.25*Z(LM)	SWEEP	150
	XMOM=XMOM+XD(LX)*DMASS	SWEEP	151
	GO TO 270	SWEEP	152
C	J-SLIDE CASE	SWEEP	153
265	L4=L3	SWEEP	154
	L1=L2=LVAR(K+1,J)	SWEEP	155
	XSTAR=0.75*X(L3)+0.25*X(L2)	SWEEP	156
267	L=LVAR(1,JSLIDE-1)	SWEEP	157
	IF (XSTAR .LT. X(L)) GO TO 360	SWEEP	158
	KS=1	SWEEP	159
268	KS=KS+1	SWEEP	160
	IF (KS .GE. KMAX) GO TO 360	SWEEP	161
	L=LVAR(KS,JSLIDE-1)	SWEEP	162
	IF (L .LT. 0) GO TO 360	SWEEP	163
	IF (XSTAR .GT. X(L)) GO TO 268	SWEEP	164
	LM=L	SWEEP	165
	DMASS=0.25*Z(LM)	SWEEP	166
	XMOM=XMOM+XD(LM)*DMASS	SWEEP	167
	GO TO 300	SWEEP	168
C	*****	SWEEP	169
C	COMPUTE AREAS, MASSES, FORCES ACTING ON COORDINATE (K,J)	SWEEP	170
C	*****	SWEEP	171
270	IF (M(LM) .EQ. 0) GO TO 300	SWEEP	172
	LMS=LM	SWEEP	173
C		SWEEP	174
C	***** TRIANGULAR CELLS	SWEEP	175
	QXX=QYY=QXY=0.	SWEEP	176
	IF (I .EQ. 2 .OR. I .EQ. 4) GO TO 275	SWEEP	177
	ITRI=-1	SWEEP	178
	XO2=X(L2)+X(L4)	SWEEP	179
	YO2=Y(L2)+Y(L4)	SWEEP	180
	IF (I .EQ. 1) LM=M(LM)	SWEEP	181
	GO TO 305	SWEEP	182
C		SWEEP	183
C	TRIANGULAR CELL WITH POINTS 1,3,4	SWEEP	184
275	ITRI=1	SWEEP	185
	AXY=(X(L4)*(Y(L1)-Y(L3))+X(L3)*(Y(L4)-Y(L1))+X(L1)*(Y(L3)-Y(L4)))/8.	SWEEP	186
	A3=4.*AXY	SWEEP	187
	IF (I .EQ. 4) LM=M(LMS)	SWEEP	188
	IF (IJBUND .GT. 0) GO TO 280	SWEEP	189
	AXX=(Y(L1)-Y(L4))/2.	SWEEP	190
	AYY=(X(L4)-X(L1))/2.	SWEEP	191
	TZZAXY=0.	SWEEP	192
	IF (DMASS .NE. 0.) GO TO 330	SWEEP	193
	DMASS=D(LM)*AXY	SWEEP	194
	GO TO 330	SWEEP	195
280	AXX=(Y(L1)-Y(L4))*(Y(L1)+2.*Y(L3)+Y(L4))/8.	SWEEP	196
	AYY=(X(L4)-X(L1))*(Y(L1)+2.*Y(L3)+Y(L4))/8.	SWEEP	197
	TZZAXY=TZZ(LM)*AXY	SWEEP	198
	IF (DMASS .NE. 0.) GO TO 330	SWEEP	199
	DMASS=D(LM)*AXY*(0.666667*Y(L3)+(Y(L1)+Y(L4))/6.)	SWEEP	200
	GO TO 330	SWEEP	201
C		SWEEP	202
C	TRIANGULAR CELL WITH POINTS 1,2,3	SWEEP	203
285	ITRI=2	SWEEP	204
	AXY=(X(L1)*(Y(L2)-Y(L3))+X(L2)*(Y(L3)-Y(L1))+X(L3)*(Y(L1)-Y(L2)))/8.	SWEEP	205
	A3=4.*AXY	SWEEP	206
	LM=LMS	SWEEP	207
	IF (I .EQ. 2) LM=M(LMS)	SWEEP	208
	IF (IJBUND .GT. 0) GO TO 290	SWEEP	209
	AXX=(Y(L2)-Y(L1))/2.	SWEEP	210
	AYY=(X(L1)-X(L2))/2.	SWEEP	211
	TZZAXY=0.	SWEEP	212
		SWEEP	213
		SWEEP	214

SUBROUTINE SWEEP (Continued)

	DMASS=D(LM)*AXY	SWEPT	215
	GO TO 330	SWEPT	216
290	AXX=(Y(L2)-Y(L1))*(Y(L2)+2.*Y(L3)+Y(L1))/8.	SWEPT	217
	AYY=(X(L1)-X(L2))*(Y(L2)+2.*Y(L3)+Y(L1))/8.	SWEPT	218
	TZZAXY=TZZ(LM)*AXY	SWEPT	219
	DMASS=D(LM)*AXY*(0.666667*Y(L3)+(Y(L1)+Y(L2))/6.)	SWEPT	220
	GO TO 330	SWEPT	221
C		SWEPT	222
C *****	QUADRILATERAL CELLS	SWEPT	223
300	X02=0.5*(X(L1)+X(L2)+X(L3)+X(L4))	SWEPT	224
	Y02=0.5*(Y(L1)+Y(L2)+Y(L3)+Y(L4))	SWEPT	225
305	A0=(X02-X(L3))*(Y(L2)-Y(L4))+X(L2)*(Y(L3)+Y(L4)-Y02)+X(L4)	SWEPT	226
	-*(Y02-Y(L2)-Y(L3))	SWEPT	227
	A3=X(L4)*(Y(L2)-Y(L3))-X(L3)*(Y(L2)-Y(L4))+X(L2)*(Y(L3)-Y(L4))	SWEPT	228
	AXY=(A0+A3)/8.	SWEPT	229
	IF (1JBUND .GT. 0) GO TO 320	SWEPT	230
	AXX=(Y(L2)-Y(L4))/2.	SWEPT	231
	AYY=(X(L4)-X(L2))/2.	SWEPT	232
	TZZAXY=0.	SWEPT	233
	IF (DMASS .NE. 0.) GO TO 330	SWEPT	234
	DMASS=D(LM)*AXY	SWEPT	235
	GO TO 330	SWEPT	236
320	AXX=(Y(L2)-Y(L4))*(Y(L2)+2.*Y(L3)+Y(L4))/8.	SWEPT	237
	AYY=((Y(L2)-Y(L4))*(X02-X(L3))+(X(L4)-X(L2))*(Y02+Y(L3))-X(L2)*	SWEPT	238
1	Y(L2)+X(L4)*Y(L4))/8.	SWEPT	239
	IF (DMASS .NE. 0.) GO TO 330	SWEPT	240
	DMASS=D(LM)*(A0*((Y(L2)+Y(L4)+Y02)/2.+Y(L3))+A3*((Y(L2)+Y(L4))/	SWEPT	241
	-2.+2.*Y(L3)))/24.	SWEPT	242
	TZZAXY=TZZ(LM)*AXY	SWEPT	243
C	STRAINS EDXX, EDYY, AND EDXY ARE POSITIVE IN TENSION	SWEPT	244
330	QXX=QYY=QXY=0.	SWEPT	245
	IF (J .EQ. JSLIDE .AND. (1.EQ.3 .OR. 1.EQ.4)) GO TO 340	SWEPT	246
	IF (K .EQ. KSLIDE-1 .AND. (1 .EQ. 1 .OR. 1 .EQ. 4)) GO TO 340	SWEPT	247
	IF (TRIQ .EQ. 0. .OR. A3 .LT. 0.1*AXY) GO TO 340	SWEPT	248
	EDXX=((XD(L2)-XD(L3))*(Y(L2)-Y(L4))-(XD(L2)-XD(L4))*(Y(L2)-	SWEPT	249
1	Y(L3)))/A3	SWEPT	250
	EDYY=-((YD(L2)-YD(L3))*(X(L2)-X(L4))-(YD(L2)-YD(L4))*(X(L2)-	SWEPT	251
	-X(L3)))/A3	SWEPT	252
	EDXY=(-(XD(L2)-XD(L3))*(X(L2)-X(L4))+(XD(L2)-XD(L4))*(X(L2)-	SWEPT	253
1	X(L3))+(YD(L2)-YD(L3))*(Y(L2)-Y(L4))-(YD(L2)-YD(L4))*(Y(L2)-	SWEPT	254
2	Y(L3)))/A3	SWEPT	255
C	TRIANGLE Q STRESSES QXX, QYY, AND QXY ARE POSITIVE IN TENSION	SWEPT	256
	COEF=SQRT(A3)*SP(MAT)*D(LM)*TRIQ	SWEPT	257
	QXX=COEF*(2.*EDXX-EDYY)	SWEPT	258
	QYY=COEF*(2.*EDYY-EDXX)	SWEPT	259
	QXY=3.*COEF*EDXY	SWEPT	260
340	FX=FX+(TX(LM)+QXX)*AXX+(TX(LM)+QXY)*AYY	SWEPT	261
	FY=FY+(TY(LM)+QXY)*AXX+(TY(LM)+QYY)*AYY-TZZAXY	SWEPT	262
	AMASS=AMASS+DMASS	SWEPT	263
	IF (ITRI .EQ. 1) GO TO 285	SWEPT	264
360	CONTINUE	SWEPT	265
C		SWEPT	266
C ****	COMPUTE POSITIONS AND VELOCITIES AT -K,J-	SWEPT	267
C		SWEPT	268
	LM=LVAR(K,J)	SWEPT	269
	1JBABS=1ABS(1JBUND)	SWEPT	270
	IF (1JBABS .NE. 9) GO TO 344	SWEPT	271
	IB=0	SWEPT	272
	DO 342 NB=1,NBND	SWEPT	273
	IF (J .LT. 1BDJ1(NB) .OR. J .GT. 1BDJ2(NB)) GO TO 342	SWEPT	274
	IF (K .LT. 1BDK1(NB) .OR. K .GT. 1BDK2(NB)) GO TO 342	SWEPT	275
	IF (1BDY(NB) .EQ. 0) GO TO 345	SWEPT	276
	IF (1BDY(NB) .LE. 1) GO TO 347	SWEPT	277
	IB=NB	SWEPT	278
	GO TO 345	SWEPT	279
342	CONTINUE	SWEPT	280
	GO TO 345	SWEPT	281
344	IF (J .EQ. JMAX .AND. (1JBABS.EQ.1 .OR. 1JBABS.EQ.5)) GO TO 347	SWEPT	282
	IF (J .EQ. 1 .AND. 1JBUND .NE. -3) GO TO 347	SWEPT	283
	IF (1JBUND .EQ. 2 .AND. Y(LM) .EQ. 0.) GO TO 347	SWEPT	284
345	YDNH=YD(LM)+DTN*FY/AMASS	SWEPT	285
347	YNW=Y(LM)+YDNH*DT	SWEPT	286
	IF (IB .EQ. 0) GO TO 349	SWEPT	287
	IF (1BDY(IB) .EQ. 2) YNW=AMIN1(YNW,YFIX(IB))	SWEPT	288
	IF (1BDY(IB) .EQ. 3) YNW=AMAX1(YNW,YFIX(IB))	SWEPT	289

SUBROUTINE SWEEP (Continued)

349	IF (1JBUND .GT. 0) YNW=AMAX1(YNW,0.)	SWEEP	290
	YDNH=(YNW-Y(LM))/DT	SWEEP	291
	IF (1JBABS .NE. 9) GO TO 354	SWEEP	292
	IB=0	SWEEP	293
	DO 352 NB=1,NBND	SWEEP	294
	IF (J .LT. 1BDJ1(NB) .OR. J .GT. 1BDJ2(NB)) GO TO 352	SWEEP	295
	IF (K .LT. 1BDK1(NB) .OR. K .GT. 1BDK2(NB)) GO TO 352	SWEEP	296
	IF (1BDX(NB) .EQ. 0) GO TO 356	SWEEP	297
	IF (1BDX(NB) .LE. 1) GO TO 357	SWEEP	298
	IB=NB	SWEEP	299
	GO TO 356	SWEEP	300
352	CONTINUE	SWEEP	301
	GO TO 356	SWEEP	302
354	IF (K .EQ. 1 .AND. (1JBABS .EQ. 4 .OR. 1JBABS .EQ. 5 .OR.	SWEEP	303
	1 1JBABS .EQ. 6)) GO TO 357	SWEEP	304
	IF (K .EQ. KMAX .AND. 1JBABS .EQ. 4) GO TO 357	SWEEP	305
356	XDNH=XD(LM)+DTN*FX/AMASS	SWEEP	306
357	IF (K .EQ. KSLIDE-1 .AND. LCON(J) .NE. 0) XDNH=XMOM/AMASS+DTN*FX/	SWEEP	307
	1 AMASS	SWEEP	308
	XNW=X(LM)+XDNH*DT	SWEEP	309
	IF (IB .EQ. 0) GO TO 362	SWEEP	310
	IF (1BDX(IB) .EQ. 2) XNW=AMIN1(XNW,XFIX(IB))	SWEEP	311
	IF (1BDX(IB) .EQ. 3) XNW=AMAX1(XNW,XFIX(IB))	SWEEP	312
362	CONTINUE	SWEEP	313
C		SWEEP	314
C	ADJUST XNW AND XDNH FOR SLIDE LINE	SWEEP	315
C	(CALC ON KSLIDE-1, ADJUST KSLIDE)	SWEEP	316
	IF (K .NE. KSLIDE) GO TO 375	SWEEP	317
	JS=1	SWEEP	318
	LMR=LVAR(KSLIDE-1,JS)	SWEEP	319
	IF (YNW .GT. Y(LMR)) GO TO 355	SWEEP	320
	IF (J .GE. JMAX) GO TO 355	SWEEP	321
	LMJ1=LVAR(K,J+1)	SWEEP	322
	IF (LMJ1 .LE. 0) GO TO 355	SWEEP	323
	IF (Y(LMJ1) .LT. Y(LMR)) GO TO 370	SWEEP	324
355	JS=JS+1	SWEEP	325
	IF (JS .EQ. JMAX+1) GO TO 365	SWEEP	326
	LMRT=LVAR(KSLIDE-1,JS)	SWEEP	327
	IF (LMRT .LE. 0) GO TO 365	SWEEP	328
	LML=LMR	SWEEP	329
	LMR=LMRT	SWEEP	330
	IF (YNW .GT. Y(LMR)) GO TO 355	SWEEP	331
358	XCONT=X(LML)+(YNW-Y(LML))*(X(LMR)-X(LML))/(Y(LMR)-Y(LML))	SWEEP	332
	IF (XNW .GT. XCONT+0.001) GO TO 370	SWEEP	333
	XNW=XCONT	SWEEP	334
	IF (LCON(JS) .NE. 0) XDNH=XD(LML)+(YNW-Y(LML))*(XD(LMR)-XD(LML))/	SWEEP	335
	1 (Y(LMR)-Y(LML))	SWEEP	336
	LCON(JS)=J	SWEEP	337
	GO TO 375	SWEEP	338
365	IF (J .EQ. 1) GO TO 375	SWEEP	339
	LMJ=LVAR(K,J-1)	SWEEP	340
	IF (Y(LMJ) .LE. Y(LMR)) GO TO 358	SWEEP	341
	GO TO 375	SWEEP	342
370	LCON(J)=0	SWEEP	343
375	CONTINUE	SWEEP	344
C		SWEEP	345
C	***** ADJUST YNW AND YDNH FOR SLIDE LINE	SWEEP	346
	IF (J .NE. JSLIDE-1) GO TO 394	SWEEP	347
	KS=1	SWEEP	348
	LMR=LVAR(KS,JSLIDE)	SWEEP	349
	IF (XNW .GT. X(LMR)) GO TO 380	SWEEP	350
	IF (K .GE. KMAX) GO TO 380	SWEEP	351
	LMJ1=LVAR(K+1,J)	SWEEP	352
	IF (LMJ1 .LE. 0) GO TO 380	SWEEP	353
	IF (X(LMJ1) .LT. X(LMR)) GO TO 394	SWEEP	354
	YCONT=Y(LMR)+(XNW-X(LMR))*(Y(LMJ1)-Y(LMR))/(X(LMJ1)-X(LMR))	SWEEP	355
	IF (YNW .LT. YCONT) GO TO 394	SWEEP	356
	YNW=YCONT	SWEEP	357
	YDNH=YD(LMR)+(XNW-X(LMR))*(YD(LMJ1)-YD(LMR))/(X(LMJ1)-X(LMR))	SWEEP	358
	GO TO 394	SWEEP	359
380	KS=KS+1	SWEEP	360
	IF (KS .EQ. KMAX+1) GO TO 386	SWEEP	361
	LMRT=LVAR(KS,JSLIDE)	SWEEP	362
	IF (LMRT .LE. 0) GO TO 386	SWEEP	363
	LML=LMR	SWEEP	364

SUBROUTINE SWEEP (Continued)

	LMR=LMRT	SWEPT	365
	IF (XNW.GT. X(LMR)) GO TO 380	SWEPT	366
383	YCONT=Y(LML)+(XNW-X(LML))*(Y(LMR)-Y(LML))/(X(LMR)-X(LML))	SWEPT	367
	IF (YNW.LT. YCONT) GO TO 394	SWEPT	368
	YNW=YCONT	SWEPT	369
	YDNH=YD(LML)+(XNW-X(LML))*(YD(LMR)-YD(LML))/(X(LMR)-X(LML))	SWEPT	370
	PRINT 1394,N,K,J,YNW,YDNH	SWEPT	371
1394	FORMAT(* N=*13,* K,J=*213,* YNW,YDNH=*2F13.6)	SWEPT	372
	GO TO 394	SWEPT	373
386	IF (K.EQ. 1) GO TO 394	SWEPT	374
	LMJ=LVAR(K-1,J)	SWEPT	375
	IF (X(LMJ).LE. X(LMR)) GO TO 383	SWEPT	376
C		SWEPT	377
C	***** ADJUST XNW, YNW FOR OBLIQUE IMPACT ON FIXED PLANE	SWEPT	378
394	CONTINUE	SWEPT	379
	IF (NOBLQ.EQ. 0) GO TO 396	SWEPT	380
	IF (K.NE. KMAX.AND. J.NE. 1) GO TO 396	SWEPT	381
	LL=LVAR(KMAX,1)	SWEPT	382
	IF (XNW.LT. X(LL)+(YNW-Y(LL))*TANTH) GO TO 396	SWEPT	383
	IF (XDNH.EQ. 0.AND. YDNH.EQ. 0) GO TO 396	SWEPT	384
	DDT=(X(LL)-X(LM)+(Y(LM)-Y(LL))*TANTH)/(XDNH-YDNH*TANTH)	SWEPT	385
	XNW=X(LM)+XDNH*DDT	SWEPT	386
	YNW=Y(LM)+YDNH*DDT	SWEPT	387
	DTI=(XNW-X(LM))/XDNH	SWEPT	388
	VT=XDNH*SINTH+YDNH*COSTH	SWEPT	389
	XDNH=VT*SINTH	SWEPT	390
	YDNH=VT*COSTH	SWEPT	391
	XNW=XNW+XDNH*(DT-DTI)	SWEPT	392
	YNW=YNW+YDNH*(DT-DTI)	SWEPT	393
396	CONTINUE	SWEPT	394
	IF (MM(K,J).EQ. 0) GO TO 750	SWEPT	395
C		SWEPT	396
C	**** COMPUTE NEW AREA AND VOLUME FOR CELL -K,J-	SWEPT	397
C		SWEPT	398
	A124=XTEMP(J-1)*(YNW-YTEMP(J))-XNW*(YTEMP(J-1)-YTEMP(J))+	SWEPT	399
	1 XTEMP(J)*(YTEMP(J-1)-YNW)	SWEPT	400
	LM=LVAR(K,J)	SWEPT	401
	LMM=LVAR(K-1,J-1)	SWEPT	402
	LKM=LVAR(K,J-1)	SWEPT	403
	LMJ=LVAR(K-1,J)	SWEPT	404
	A234=XTEMP(J-1)*(YTEMP(J)-YKJM)+XTEMP(J)*(YKJM-YTEMP(J-1))+	SWEPT	405
	1 XKJM*(YTEMP(J-1)-YTEMP(J))	SWEPT	406
	ITRI=0	SWEPT	407
	IF (M(LM).EQ. 0) GO TO 420	SWEPT	408
	LMS=LM	SWEPT	409
	ITRI=1	SWEPT	410
C	TRIANGLE WITH POINTS 1,2,4	SWEPT	411
	AW=A124/2.	SWEPT	412
	IF (AW.GT.0.) GO TO 400	SWEPT	413
	IF (AW.LE. 0.) PRINT 93,K,J,A124,A234,XNW,XTEMP(J),XTEMP(J-1),	SWEPT	414
	1 XKJM,YNW,YTEMP(J),YTEMP(J-1),YKJM	SWEPT	415
93	FORMAT(* POINTS 124 K,J=*213,* A124,A234=*1P2E10.3,* XNW,XTEMP(J)	SWEPT	416
	1,XTEMP(J-1)=*3E10.3/* XKJM,YNW,YTEMP(J)=*1P3E10.3,* YTEMP(J-1),*	SWEPT	417
	2 *YKJM=*2E10.3)	SWEPT	418
	NSCRIB = 1	SWEPT	419
	GO TO 920	SWEPT	420
400	CONTINUE	SWEPT	421
	DW=Z(LM)/AW	SWEPT	422
	IF (IJBUND.GT. 0) DW=2.*Z(LM)/(A124*(YTEMP(J-1)+YNW+YTEMP(J)))	SWEPT	423
	DTA=DT/(AW+A(LM))	SWEPT	424
	YH12=(Y(LM)+YNW-YTEMP(J)-Y(LMJ))/2.	SWEPT	425
	YH14=(Y(LM)+YNW-YTEMP(J-1)-Y(LKM))/2.	SWEPT	426
	XDH12=XDNH-XDTEMP(J)	SWEPT	427
	XDH14=XDNH-XDTEMP(J-1)	SWEPT	428
	XH12=(X(LM)+XNW-XTEMP(J)-X(LMJ))/2.	SWEPT	429
	XH14=(X(LM)+XNW-XTEMP(J-1)-X(LKM))/2.	SWEPT	430
	YDH12=YDNH-YDTEMP(J)	SWEPT	431
	YDH14=YDNH-YDTEMP(J-1)	SWEPT	432
	DELX=A124**2/(AMAX1(XH12**2+YH12**2,XH14**2+YH14**2,(XTEMP(J)-	SWEPT	433
	1 XTEMP(J-1))*2+(YTEMP(J)-YTEMP(J-1))*2))	SWEPT	434
	EVOL=2.*(D(LM)-DW)/(D(LM)+DW)	SWEPT	435
	EXXH=DTA*(XDH12*YH14-XDH14*YH12)	SWEPT	436
	EYYH=DTA*(YDH14*XH12-YDH12*XH14)	SWEPT	437
	EXYH=DTA*(XDH14*XH12-XDH12*XH14+YDH12*YH14-YDH14*YH12)/2.	SWEPT	438
	EZZH=EVOL-EXXH-EYYH	SWEPT	439

SUBROUTINE SWEEP (Continued)

C	CLOCKWISE ROTATION	SWEPT	440
	ALFA=DTA*(XDH12*XH14-XDH14*XH12+YDH12*YH14-YDH14*YH12)/2.	SWEPT	441
	GO TO 430	SWEPT	442
C	TRIANGLE WITH POINTS 2,3,4	SWEPT	443
405	ITR1=2	SWEPT	444
	LM=M(LMS)	SWEPT	445
	AW=A234/2.	SWEPT	446
	IF (AW.GT.0.) GO TO 410	SWEPT	447
	IF (AW.LE.0.) PRINT 94,K,J,A124,A234,XNW,XTEMP(J),XTEMP(J-1),	SWEPT	448
	1 XKMJM,YNW,YTEMP(J),YTEMP(J-1),YKMJM	SWEPT	449
94	FORMAT(* POINTS 234 K,J=*213,* A124,A234=*1P2E10.3,* XNW,XTEMP(J)	SWEPT	450
	1,XTEMP(J-1)=*3E10.3/* XKMJM,YNW,YTEMP(J)=*1P3E10.3,* YTEMP(J-1),*	SWEPT	451
	2 *YKMJM=*2E10.3)	SWEPT	452
	NSCRIB = 1	SWEPT	453
	GO TO 920	SWEPT	454
410	CONTINUE	SWEPT	455
	DW=Z(LM)/AW	SWEPT	456
	IF (IJBUND.GT.0) DW=2.*Z(LM)/(A234*(YKMJM+YTEMP(J-1)+YTEMP(J)))	SWEPT	457
	DTA=DT/(AW+A(LM))	SWEPT	458
	YH23=(YTEMP(J)+Y(LMJ))/2.-YHMM	SWEPT	459
	YH24=(YTEMP(J)+Y(LMJ)-YTEMP(J-1)-Y(LKM))/2.	SWEPT	460
	XH23=(XTEMP(J)+X(LMJ))/2.-XHMM	SWEPT	461
	XH24=(XTEMP(J)+X(LMJ)-XTEMP(J-1)-X(LKM))/2.	SWEPT	462
	XDH23=XDTEMP(J)-XD(LMM)	SWEPT	463
	XDH24=XDTEMP(J)-XDTEMP(J-1)	SWEPT	464
	YDH23=YDTEMP(J)-YD(LMM)	SWEPT	465
	YDH24=YDTEMP(J)-YDTEMP(J-1)	SWEPT	466
	DELX=AMIN1(DELX,A234**2/(AMAX1(XH23**2+YH23**2,XH24**2+YH24**2,	SWEPT	467
	1 (XHMM-X(LKM))**2+(YHMM-Y(LKM))**2))	SWEPT	468
	EVOL=2.*(D(LM)-DW)/(D(LM)+DW)	SWEPT	469
	EXXH=DTA*(XDH23*YH24-XDH24*YH23)	SWEPT	470
	EYYH=DTA*(YDH24*XH23-YDH23*XH24)	SWEPT	471
	EXYH=DTA*(XDH24*XH23-XDH23*XH24+YDH23*YH24-YDH24*YH23)/2.	SWEPT	472
	EZZH=EVOL-EXXH-EYYH	SWEPT	473
	ALFA=DTA*(XDH23*XH24-XDH24*XH23+YDH23*YH24-YDH24*YH23)/2.	SWEPT	474
	GO TO 430	SWEPT	475
420	AW=0.5*(A124+A234)	SWEPT	476
	IF (AW.GT.0.) GO TO 425	SWEPT	477
	IF (AW.LE.0.) PRINT 95,K,J,A124,A234,XNW,XTEMP(J),XTEMP(J-1),	SWEPT	478
	1 XKMJM,YNW,YTEMP(J),YTEMP(J-1),YKMJM	SWEPT	479
95	FORMAT(* K,J=*213,* A124,A234=*2E10.3,* XNW,XTEMP(J),XTEMP(J-1)=*	SWEPT	480
	1 3E10.3/* XKMJM,YNW,YTEMP(J)=*3E10.3,* YTEMP(J-1),YKMJM=*2E10.3)	SWEPT	481
	NSCRIB = 1	SWEPT	482
	GO TO 920	SWEPT	483
425	CONTINUE	SWEPT	484
	DW=Z(LM)/AW	SWEPT	485
	IF (IJBUND.GT.0) DW=2.*Z(LM)/(A124*(YTEMP(J-1)+YNW+YTEMP(J))+	SWEPT	486
	1 A234*(YKMJM+YTEMP(J-1)+YTEMP(J)))	SWEPT	487
C		SWEPT	488
C	**** COMPUTE STRAINS	SWEPT	489
C		SWEPT	490
	DTA=DT/(AW+A(LM))	SWEPT	491
	XH13=(X(LM)+XNW)/2.-XHMM	SWEPT	492
	XH42=(XTEMP(J-1)+X(LKM)-XTEMP(J)-X(LMJ))/2.	SWEPT	493
	YH13=(Y(LM)+YNW)/2.-YHMM	SWEPT	494
	YH42=(YTEMP(J-1)+Y(LKM)-YTEMP(J)-Y(LMJ))/2.	SWEPT	495
	XDH13=XDNH-XD(LMM)	SWEPT	496
	XDH42=XDTEMP(J-1)-XDTEMP(J)	SWEPT	497
	YDH13=YDNH-YD(LMM)	SWEPT	498
	YDH42=YDTEMP(J-1)-YDTEMP(J)	SWEPT	499
C	CALCULATE THE SHORTEST DISTANCE BETWEEN TWO SIDES OF	SWEPT	500
C	THE CALCULATIONAL CELL USING VECTOR DOT PRODUCTS	SWEPT	501
C		SWEPT	502
C	DEFINE COORDINATES OF CELL	SWEPT	503
C		SWEPT	504
	X1=0.5*(X(LM)+XNW)	SWEPT	505
	X2=0.5*(XTEMP(J)+X(LM))	SWEPT	506
	X3=XHMM	SWEPT	507
	X4=0.5*(XTEMP(J-1)+X(LKM))	SWEPT	508
	Y1=0.5*(Y(LM)+YNW)	SWEPT	509
	Y2=0.5*(YTEMP(J)+Y(LMJ))	SWEPT	510
	Y3=YHMM	SWEPT	511
	Y4=0.5*(YTEMP(J-1)+Y(LKM))	SWEPT	512
C		SWEPT	513
C	VECTOR V43 = (X4-X3)I + (Y4-Y3)J	SWEPT	514

SUBROUTINE SWEEP (Continued)

C	V34 = -V43	SWEPT	515
C	V41 = (X4-X1)I + (Y4-Y1)J	SWEPT	516
C	V14 = -V41	SWEPT	517
C	V12 = (X1-X2)I + (Y1-Y2)J	SWEPT	518
C	V21 = -V12	SWEPT	519
C	V23 = (X2-X3)I + (Y2-Y3)J	SWEPT	520
C	V32 = -V23	SWEPT	521
C		SWEPT	522
C	CALCULATE THE MAGNITUDE SQUARED OF THE VECTORS	SWEPT	523
C		SWEPT	524
	XMAG43=(X4-X3)**2+(Y4-Y3)**2	SWEPT	525
	XMAG41=(X4-X1)**2+(Y4-Y1)**2	SWEPT	526
	XMAG12=(X1-X2)**2+(Y1-Y2)**2	SWEPT	527
	XMAG23=(X2-X3)**2+(Y2-Y3)**2	SWEPT	528
C		SWEPT	529
C	CALCULATE THE DOT PRODUCT	SWEPT	530
C		SWEPT	531
	D432=-((X4-X3)*(X3-X2)+(Y4-Y3)*(Y3-Y2))	SWEPT	532
	D321=-((X3-X2)*(X2-X1)+(Y3-Y2)*(Y2-Y1))	SWEPT	533
	D214=-((X2-X1)*(X1-X4)+(Y2-Y1)*(Y1-Y4))	SWEPT	534
	D143=-((X1-X4)*(X4-X3)+(Y1-Y4)*(Y4-Y3))	SWEPT	535
C		SWEPT	536
C	CHECK TO SEE IF PROJECTION LIES INSIDE CELL	SWEPT	537
C		SWEPT	538
	IF (D432 .LE. 0.0) D432=0.0	SWEPT	539
	IF (D321 .LE. 0.0) D321=0.0	SWEPT	540
	IF (D214 .LE. 0.0) D214=0.0	SWEPT	541
	IF (D143 .LE. 0.0) D143=0.0	SWEPT	542
	D432=D432**2	SWEPT	543
	D321=D321**2	SWEPT	544
	D214=D214**2	SWEPT	545
	D143=D143**2	SWEPT	546
C		SWEPT	547
C	NOW FIND MIN. DISTANCE	SWEPT	548
C		SWEPT	549
	DELX=AMIN1(XMAG43-D432/XMAG23 ,	SWEPT	550
1	XMAG23-D432/XMAG43 ,	SWEPT	551
2	XMAG23-D321/XMAG12 ,	SWEPT	552
3	XMAG12-D321/XMAG23 ,	SWEPT	553
4	XMAG12-D214/XMAG41 ,	SWEPT	554
5	XMAG41-D214/XMAG12 ,	SWEPT	555
6	XMAG41-D143/XMAG43 ,	SWEPT	556
7	XMAG43-D143/XMAG41)	SWEPT	557
	EVOL=2.*(D(LM)-DW)/(D(LM)+DW)	SWEPT	558
	EXXH=DTA*(YDH42*YH13-YH42*YDH13)	SWEPT	559
	EYYH=-DTA*(YDH42*XH13-YH42*YDH13)	SWEPT	560
	EXYH=0.5* DTA*(YDH42*YH13-YH42*YDH13-XDH42*XH13+XH42*YDH13)	SWEPT	561
	EZZH=EVOL-EXXH-EYYH	SWEPT	562
	ALFA=0.5*DTA*(-YDH42*YH13+YH42*YDH13-XDH42*XH13+XH42*YDH13)	SWEPT	563
430	MAT=MM(K,J)	SWEPT	564
C		SWEPT	565
C	COMPUTE ARTIFICIAL VISCOUS STRESS	SWEPT	566
C		SWEPT	567
	DELD = DW-D(LM)	SWEPT	568
	IF (ABS(DELD) .LT. 1.E-8 .AND. E(LM) .LT. 1.) GO TO 690	SWEPT	569
	IF (DELD .GT. 0.)	SWEPT	570
	1Q=DELD/DT*(SP(MAT)*CLIN*SQRT(AW)+CQSQ*AW*DELD/DW/DT)	SWEPT	571
C		SWEPT	572
C	COMPUTE ESTIMATE OF INTERNAL ENERGY	SWEPT	573
C		SWEPT	574
	DELZ=(SXX(LM)*EXXH+SYX(LM)*EYYH+SZZ(LM)*EZZH+2.*TXY(LM)*EXYH)/DW	SWEPT	575
	EW=E(LM)+DELZ-(P(LM)+Q)*(1./DW-1./D(LM))	SWEPT	576
C		SWEPT	577
C	STRESS FROM COMPOSITE MODEL	SWEPT	578
C		SWEPT	579
	IF (NCMP(MAT) .EQ. 0) GO TO 450	SWEPT	580
	SXXW=SXX(LM)	SWEPT	581
	SYW=SYX(LM)	SWEPT	582
	SZZW=SZZ(LM)	SWEPT	583
	TXYW=TXY(LM)	SWEPT	584
	PW=P(LM)	SWEPT	585
	CALL REBAR(0,5,J,K,MAT,N,IH(LM),DW,D(LM),SXXW,SYW,SZZW,TXYW,EW,PW	SWEPT	586
1	, EXXH,EYYH,EZZH,EXYH,F,TH(LM),-ALFA,ESC,FS(LM),DSTL(LM),SRS(LM),	SWEPT	587
2	ZEVP(LM),TEVP(LM),YY(LM),ROLD(LM),IPR)	SWEPT	588
	TH(LM)=TH(LM)-ALFA	SWEPT	589

SUBROUTINE SWEEP (Continued)

C	GO TO 600	SWEEP	590
C	STRESS FROM POROUS MODEL	SWEEP	591
C		SWEEP	592
450	IF (NFOR(MAT) .EQ. 0) GO TO 475	SWEEP	593
	IF (NFOR(MAT) .EQ. 4) GO TO 455	SWEEP	594
	CALL POREQST(1,5,MAT,SP(MAT),DW,D(LM),EW,E(LM),F,PW,CZJ,CWJ,IH(LM)	SWEEP	595
	1 ,DPDE,EQSTC(MAT),EQSTD(MAT),EQSTG(MAT),EQSTS(MAT),MU(MAT),	SWEEP	596
	2 RHOS(MAT),YAD(MAT),NDS(MAT),NPR(MAT),J)	SWEEP	597
	GO TO 550	SWEEP	598
455	CONTINUE	SWEEP	599
	SX=SXX(LM)-P(LM)	SWEEP	600
	SY=SYI(LM)-P(LM)	SWEEP	601
	SZ=SZZ(LM)-P(LM)	SWEEP	602
	TXYW=TXI(LM)	SWEEP	603
	CALL CAP1(1,5,MAT,N,IH(LM),DW,D(LM),EW,EXXH,EYYH,EZZH,EXYH,	SWEEP	604
	1 SX,SY,SZ,XYW,ZEVP(LM),K,J,TEVP(LM))	SWEEP	605
	PW=-(SX+SY+SZ)/3.	SWEEP	606
	SXXW=SX+PW	SWEEP	607
	SYIY=SY+PW	SWEEP	608
	SZZW=SZ+PW	SWEEP	609
	GO TO 600	SWEEP	610
C		SWEEP	611
C	STRESS FROM FRACTURE MODEL	SWEEP	612
C		SWEEP	613
475	IF (NFR(MAT) .EQ. 0) GO TO 500	SWEEP	614
	NFRM=NFR(MAT)	SWEEP	615
	GO TO (477,485,490,490,500,500,495)NFRM	SWEEP	616
C		SWEEP	617
C	DUCTILE FRACTURE	SWEEP	618
C		SWEEP	619
477	IF (P(LM) .GT. TSR(MAT,5) .AND. IH(LM) .EQ. 2) GO TO 500	SWEEP	620
	SXXW=SXX(LM)	SWEEP	621
	SYIY=SYI(LM)	SWEEP	622
	SZZW=SZZ(LM)	SWEEP	623
	TXYW=TXI(LM)	SWEEP	624
	PW=P(LM)	SWEEP	625
	CALL DFRAC(SXXW,SYIY,SZZW,XYW,+EXXH,+EYYH,+EZZH,+EXYH,PW,	SWEEP	626
	1 ENI(LM),ENT(LM),DW,D(LM),DT ,E(LM),EW,EQSTC(MAT),EQSTG(MAT),	SWEEP	627
	2 MU(MAT),RHOS(MAT),TSR,YY(LM),YD(MAT),F,MAT,ALFA)	SWEEP	628
	IH(LM)=3	SWEEP	629
	GO TO 600	SWEEP	630
C		SWEEP	631
C	BRITTLE FRACTURE	SWEEP	632
C		SWEEP	633
485	IF (AMAX1(TXX(LM),TYI(LM),TZZ(LM)) +Q .LT. -TSR(MAT,5)	SWEEP	634
	1 .AND. IH(LM) .EQ. 2) GO TO 500	SWEEP	635
	IH(LM)=1	SWEEP	636
	SXXW=SXX(LM)	SWEEP	637
	SYIY=SYI(LM)	SWEEP	638
	SZZW=SZZ(LM)	SWEEP	639
	TXYW=TXI(LM)	SWEEP	640
	TXIY=-TXI(LM)	SWEEP	641
	PW=P(LM)	SWEEP	642
	LS=LSFRACT	SWEEP	643
	IF (MOD(N,IPRINT) .EQ. 0 .AND. LS .NE. 0) LS=2	SWEEP	644
	CALL FRAG(LS,5,MAT,J,K,N,IH(LM),EQSTC(MAT),DW,D(LM),DT,EW,E(LM),	SWEEP	645
	1 EXXH,EYYH,EXYH,F,FF(LM),MU(MAT),EQSTG(MAT),RHOS(MAT),TH(LM),	SWEEP	646
	2 -ALFA,PW,SXXW,SYIY,XYW,YY(LM),TSR,CLB(LM),CL1(LM),CN(LM),	SWEEP	647
	3 COM(LM+37))	SWEEP	648
	LSFRACT=1	SWEEP	649
	TH(LM)=TH(LM)-ALFA	SWEEP	650
	SZZW=-SXXW-SYIY	SWEEP	651
	GO TO 600	SWEEP	652
C		SWEEP	653
C	SHEAR BAND MODEL	SWEEP	654
C		SWEEP	655
490	SXXW=SXX(LM)	SWEEP	656
	SYIY=SYI(LM)	SWEEP	657
	SZZW=SZZ(LM)	SWEEP	658
	TXYW=TXI(LM)	SWEEP	659
	PW=P(LM)	SWEEP	660
	EMELT=0.1*EQSTE(MAT)	SWEEP	661
	LS = 2	SWEEP	662
	IF (MOD(N,IPRINT) .EQ. 0) LS = 3	SWEEP	663
		SWEEP	664

SUBROUTINE SWEEP (Continued)

	CALL SHEAR2(LS,5,MAT,K,J,IH(LM),SXXW,SYW,TXYW,PW,COM(L+24),DW,	SWEPT	665
	1 D(LM),DT,EW,E(LM),COM(LM+21),EMELT,COM(LM+22),EXXH,EYH,EXYH,	SWEPT	666
	2 F,YY(LM),COM(LM+23),TH(LM),-ALFA,ESC,COM(LM+25))	SWEPT	667
	SZZW=-SXXW-SYW	SWEPT	668
	TH(LM)=TH(LM)-ALFA	SWEPT	669
	GO TO 600	SWEPT	670
C	STATIC FRACTURE MODEL	SWEPT	671
C		SWEPT	672
495	LS=LSFRACT	SWEPT	673
	IF (IHEAD .GT. 1 .AND. LS .NE. 0) LS=2	SWEPT	674
	SXXW=SXX(LM)	SWEPT	675
	SYW=SY(LM)	SWEPT	676
	SZZW=SZZ(LM)	SWEPT	677
	TXYW=TXY(LM)	SWEPT	678
	PW=P(LM)	SWEPT	679
	CALL DFRAC(LS,J,K,N,IH(LM),MAT,SXXW,SYW,SZZW,TXYW,PW,EXXH,EYH,	SWEPT	680
	1 EZZH,EXYH,DW,D(LM),YY(LM),EW,E(LM),COM(LM+19),TSR,ESC)	SWEPT	681
	LSFRACT=1	SWEPT	682
	GO TO 600	SWEPT	683
C		SWEPT	684
C	MODELS FOR PRESSURE	SWEPT	685
C		SWEPT	686
500	CONTINUE	SWEPT	687
	NPRM=NPR(MAT)+1	SWEPT	688
	GO TO (520,510) NPRM	SWEPT	689
C		SWEPT	690
C	PRESSURE FROM EXPLOSION	SWEPT	691
C		SWEPT	692
510	CONTINUE	SWEPT	693
	CALL EXPLODE(3,5,MAT,EW,DW,D(LM),PW,Q,COM(18+LM),COM(19+LM),	SWEPT	694
	1 COM(20+LM),YNW,YNW-Y(LKM),J,K,TYME)	SWEPT	695
	GO TO 550	SWEPT	696
520	CONTINUE	SWEPT	697
C		SWEPT	698
C	PRESSURE FROM MIE-GRUNEISEN	SWEPT	699
C		SWEPT	700
	EMU=DW/RHO(MAT)-1.	SWEPT	701
	PHUG=+EMU*(EQSTC(MAT)+EMU*(EQSTD(MAT)+EMU*EQSTS(MAT)))	SWEPT	702
	PW=PHUG*(1.-EQSTG(MAT)*EMU/2.)+EQSTG(MAT)*DW*EW	SWEPT	703
C		SWEPT	704
C	MODELS FOR DEVIATOR STRESS	SWEPT	705
C		SWEPT	706
550	CONTINUE	SWEPT	707
	IF (NDS(MAT) .EQ. 7) GO TO 560	SWEPT	708
	IF (YC(MAT) .LE. 0.) GO TO 600	SWEPT	709
	EAVG=EVOL/3.	SWEPT	710
	BETA=2.*TXY(LM)*ALFA	SWEPT	711
	SXXW=SXX(LM)+G2(MAT)*(EXXH-EAVG)+BETA	SWEPT	712
	SYW=SY(LM)+G2(MAT)*(EYH-EAVG)-BETA	SWEPT	713
	SZZW=SZZ(LM)+G2(MAT)*(EZZH-EAVG)	SWEPT	714
	TXYW=TXY(LM)+G2(MAT)*EXYH+(SY(LM)-SXX(LM))*ALFA	SWEPT	715
	SJ2=SXXW**2+SYW**2+SZZW**2+2.*TXYW**2	SWEPT	716
	YYY=0.666667*YY(LM)**2	SWEPT	717
	IF (SJ2 .LE. YYY) GO TO 600	SWEPT	718
	CY=SQRT(YYY/SJ2)	SWEPT	719
	SXXW=CY*SXXW	SWEPT	720
	SYW=CY*SYW	SWEPT	721
	SZZW=CY*SZZW	SWEPT	722
	TXYW=CY*TXYW	SWEPT	723
	GO TO 600	SWEPT	724
560	SXXW=SXX(LM)	SWEPT	725
	SYW=SY(LM)	SWEPT	726
	SZZW=SZZ(LM)	SWEPT	727
	TXYW=TXY(LM)	SWEPT	728
	CALL EP(1,MAT,N,SXXW,SYW,SZZW,TXYW,YY(LM),EXXH,EYH,EZZH,EXYH,	SWEPT	729
	1 MU(MAT),COM(LM+19))	SWEPT	730
C		SWEPT	731
C	ADJUST INTERNAL ENERGY	SWEPT	732
C		SWEPT	733
600	IF (NPR(MAT) .EQ. 1) GO TO 620	SWEPT	734
	EW=E(LM)+0.5*((SXX(LM)+SXXW)*EXXH+(SY(LM)+SYW)*EYH+(SZZ(LM)+	SWEPT	735
	1 SZZW)*EZZH+2.*(TXY(LM)+TXYW)*EXYH)/DW-((P(LM)+PW)/2.+Q)*(1./DW-	SWEPT	736
	2 1./D(LM))	SWEPT	737
C		SWEPT	738
C	COMPUTE TOTAL STRESS	SWEPT	739

SUBROUTINE SWEEP (Continued)

C		SWEEP	740
620	TXXW=SXXW-PW-Q	SWEEP	741
	TTYW=SYW-PW-Q	SWEEP	742
	TZZW=SZZW-PW-Q	SWEEP	743
C		SWEEP	744
C	SEPARATION FOR GUARD RING OR IMPACT PLANE	SWEEP	745
C		SWEEP	746
	IF (NFR(MAT) .NE. 5 .AND. NFR(MAT) .NE. 6) GO TO 690	SWEEP	747
	IF (NFR(MAT) .EQ. 6) GO TO 650	SWEEP	748
	IF (TXXW .LE. TSR(MAT,1)) GO TO 690	SWEEP	749
	P1=TXXW*EQSTC(MAT)/(EQSTC(MAT)+1.333*MU(MAT))	SWEEP	750
	DSX=1.333*TXXW*MU(MAT)/(EQSTC(MAT)+1.333*MU(MAT))	SWEEP	751
	TXXW=TXXW-DSX-P1	SWEEP	752
	TTYW=TTYW-P1+DSX/2.	SWEEP	753
	TZZW=TZZW-P1+DSX/2.	SWEEP	754
	PW=-(TXXW+TTYW+TZZW)/3.	SWEEP	755
	TTYW=0.	SWEEP	756
	GO TO 680	SWEEP	757
650	IF (TTYW .LE. TSR(MAT,1)) GO TO 690	SWEEP	758
	P1=TTYW*EQSTC(MAT)/(EQSTC(MAT)+1.333*MU(MAT))	SWEEP	759
	DSY=1.333*TTYW*MU(MAT)/(EQSTC(MAT)+1.333*MU(MAT))	SWEEP	760
	TXXW=TXXW-P1+DSY/2.	SWEEP	761
	TTYW=TTYW-P1-DSY	SWEEP	762
	TZZW=TZZW-P1+DSY/2.	SWEEP	763
	PW=-(TXXW+TTYW+TZZW)/3.	SWEEP	764
	TTYW=0.	SWEEP	765
680	IF (IH(LM) .EQ. 1) GO TO 690	SWEEP	766
	IH(LM)=1	SWEEP	767
	PRINT 1680,K,J	SWEEP	768
1680	FORMAT(* SEPARATION AT CELL K,J =*214)	SWEEP	769
C		SWEEP	770
C	COMPUTE SOUND SPEED AND TIME STEP	SWEEP	771
C		SWEEP	772
690	EMOD=0.	SWEEP	773
	SPSQ=SP(MAT)**2	SWEEP	774
	IF (ABS(DW-D(LM)) .LT. 1.E-4) GO TO 700	SWEEP	775
	EMOD=PW/(DW/RHO(MAT)-1.)+2.*Q*DW/(DW-D(LM))+1.33*MU(MAT)	SWEEP	776
	SPSQ=AMAX1(EMOD/D(LM),0.2*SPSQ)	SWEEP	777
700	DTSQ=DELX/SPSQ	SWEEP	778
	IF (DTSQ .GE. DTSQM) GO TO 750	SWEEP	779
	KT=K	SWEEP	780
	JT=J	SWEEP	781
	DELXT=DELX	SWEEP	782
	DTSQT=DTSQ	SWEEP	783
	SPSQT=SPSQ	SWEEP	784
	DTSQM=DTSQ	SWEEP	785
C		SWEEP	786
C	***** MAJOR PRINTOUT	SWEEP	787
C		SWEEP	788
750	GO TO (780,755,760) IHEAD	SWEEP	789
755	PRINT 1755,N,TYME,DT,CALTIM,KT,JT,DELXT,DTSQT,SPSQT,LISTX,	SWEEP	790
	1 LISTXD,LISTS,LISTE	SWEEP	791
	IHEAD=3	SWEEP	792
	GO TO 761	SWEEP	793
760	GO TO (765,761,780) KHEAD	SWEEP	794
761	IF (MOD(N,KFULL) .EQ. 0) GO TO 763	SWEEP	795
	KHEAD=3	SWEEP	796
	IF (K .GT. KPMAX .OR. K .LT. KPMIN) GO TO 780	SWEEP	797
	IF (MOD(K-KPMIN,KSKIP) .NE. 0) GO TO 780	SWEEP	798
763	ZX=XNW*CALX	SWEEP	799
	ZY=YNW*CALX	SWEEP	800
	ZXD=XDNH*CALXD	SWEEP	801
	ZYD=YDNH*CALXD	SWEEP	802
	PRINT 1756,K,N,TYME,ZX,ZY,ZXD,ZYD	SWEEP	803
	KHEAD=1	SWEEP	804
	GO TO 780	SWEEP	805
765	IF (I .GT. JPMAX .OR. J .LT. JPMIN) GO TO 780	SWEEP	806
	ZX=XNW*CALX	SWEEP	807
	ZY=YNW*CALX	SWEEP	808
	ZXX=TXXW*CALX	SWEEP	809
	ZYY=TTYW*CALX	SWEEP	810
	ZZZ=TZZW*CALX	SWEEP	811
	ZXY=TTYW*CALX	SWEEP	812
	ZE=EW*CALX	SWEEP	813
	ZP=PW*CALX	SWEEP	814
	ZQ=Q*CALX	SWEEP	815

SUBROUTINE SWEEP (Continued)

ZSP=SPSQ*1.E-10	SWEEP	816
ZXD=XDNH*CALXD	SWEEP	817
ZYD=YDNH*CALXD	SWEEP	818
ICOND=0	SWEEP	819
IF (MM(K,J) .GT. 0 .AND. NVAR(MAT) .GE. 2) ICOND=IH(LM)	SWEEP	820
PRINT 1760,J,ZX,ZY,ZXX,ZYY,ZZZ,ZXY,ZP,ZE,DW,ZQ,ZSP,ZXD,ZYD,ICOND	SWEEP	821
1 ,AMAT(MAT,1)	SWEEP	822
780 CONTINUE	SWEEP	823
IF (ITRI .EQ. 1) GO TO 795	SWEEP	824
IF (K .EQ. 1) GO TO 790	SWEEP	825
IF (J .EQ. 1) GO TO 785	SWEEP	826
LMM=LVAR(K-1,J-1)	SWEEP	827
IF (LMM .LE. 0) GO TO 785	SWEEP	828
X(LMM)=XKMJM	SWEEP	829
Y(LMM)=YKMJM	SWEEP	830
785 CONTINUE	SWEEP	831
LMJ=LVAR(K-1,J)	SWEEP	832
IF (LMJ .LE. 0) GO TO 790	SWEEP	833
XHMM=(X(LMJ)+XTEMP(J))/2.	SWEEP	834
YHMM=(Y(LMJ)+YTEMP(J))/2.	SWEEP	835
XKMJM=XTEMP(J)	SWEEP	836
YKMJM=YTEMP(J)	SWEEP	837
XD(LMJ)=XDTEMP(J)	SWEEP	838
YD(LMJ)=YDTEMP(J)	SWEEP	839
790 IF (LVARM .LE. 0) GO TO 920	SWEEP	840
XTEMP(J)=XNW	SWEEP	841
YTEMP(J)=YNW	SWEEP	842
XDTEMP(J)=XDNH	SWEEP	843
YDTEMP(J)=YDNH	SWEEP	844
IF (MM(K,J) .EQ. 0) GO TO 800	SWEEP	845
795 LM=LVAR(M)	SWEEP	846
IF (ITRI .EQ. 2) LM=M(LM)	SWEEP	847
D(LM)=DW	SWEEP	848
E(LM)=EW	SWEEP	849
SXX(LM)=SXXW	SWEEP	850
SYY(LM)=SYYW	SWEEP	851
SZZ(LM)=SZZW	SWEEP	852
TXY(LM)=TXYW	SWEEP	853
TXX(LM)=TXXW	SWEEP	854
TTY(LM)=TTYW	SWEEP	855
TZZ(LM)=TZZW	SWEEP	856
P(LM)=PW	SWEEP	857
IF (ITRI .EQ. 1) GO TO 405	SWEEP	858
800 IF (K .NE. JEDK(JE) .OR. J .NE. JEDJ(JE)) GO TO 920	SWEEP	859
IF (JEDT(JE) .LT. 0) GO TO 820	SWEEP	860
LM=LVAR(K,J)	SWEEP	861
LL=LM+JEDT(JE)-1	SWEEP	862
SJ(JE)=X(LL)	SWEEP	863
IF (JEDT(JE) .EQ. 18) SJ(JE)=IH(LM)	SWEEP	864
810 JE=JE+1	SWEEP	865
GO TO 800	SWEEP	866
820 JJ=IABS(JEDT(JE))-40	SWEEP	867
GO TO (841,842,843,844,845,846,847,848,849,850,851,852,853,	SWEEP	868
1 854,855)JJ	SWEEP	869
841 CONTINUE	SWEEP	870
842 CONTINUE	SWEEP	871
843 CONTINUE	SWEEP	872
844 CONTINUE	SWEEP	873
845 SJ(JE)=0.47140*SQRT((EXXH-EYYH)**2+(EYYH-EZZH)**2+(EZZH-EXXH)**2	SWEEP	874
1 +6.*EXYH**2)+SJ(JE)	SWEEP	875
GO TO 810	SWEEP	876
846 SJ(JE)=EXXH+SJ(JE)	SWEEP	877
GO TO 810	SWEEP	878
847 SJ(JE)=EYYH+SJ(JE)	SWEEP	879
GO TO 810	SWEEP	880
848 SJ(JE)=EZZH+SJ(JE)	SWEEP	881
GO TO 810	SWEEP	882
849 SJ(JE)=EXYH+SJ(JE)	SWEEP	883
GO TO 810	SWEEP	884
850 SJ(JE)=Q	SWEEP	885
GO TO 810	SWEEP	886
851 SJ(JE)=SXXW-PW	SWEEP	887
GO TO 810	SWEEP	888
852 SJ(JE)=SYYW-PW	SWEEP	889
GO TO 810	SWEEP	890

SUBROUTINE SWEEP (Concluded)

853	SJ(JE)=SZZW-PW	SWEEP	891
	GO TO 810	SWEEP	892
854	EF=0.	SWEEP	893
	NP=1	SWEEP	894
	IF (1JBUND ,GT. 0)NP=2	SWEEP	895
	KK=MAX0(K-1,1)	SWEEP	896
	LM1=LVAR(KK,1)	SWEEP	897
	DO 8545 JST=2,JMAX	SWEEP	898
	LM2=LVAR(KK,JST)	SWEEP	899
	LMS=LVAR(K,JST)	SWEEP	900
	EF=EF+TX(X(LMS)*(Y(LM2)**NP-Y(LM1)**NP)	SWEEP	901
8545	LM1=LM2	SWEEP	902
	SJ(JE)=EF/Y(LM2)**NP	SWEEP	903
	GO TO 810	SWEEP	904
855	LM1=LVAR(K,JMAX)	SWEEP	905
	IF(N.EQ. 1) RAD0=Y(LM1)	SWEEP	906
	SJ(JE)=-2.*ALOG(Y(LM1)/RAD0)	SWEEP	907
	GO TO 810	SWEEP	908
920	CONTINUE	SWEEP	909
	IF (K.EQ. 1) GO TO 940	SWEEP	910
	LMJ=LVAR(K-1,JMAX)	SWEEP	911
	IF (LMJ.LE. 0) GO TO 940	SWEEP	912
	X(LMJ)=XKMJM	SWEEP	913
	Y(LMJ)=YKMJM	SWEEP	914
940	KK=K	SWEEP	915
	IF (K.LT. KCHEK .OR. K.EQ. KMAX) GO TO 950	SWEEP	916
	DO 945 J=1,JMAX	SWEEP	917
	LMJ=LVAR(K,J)	SWEEP	918
	IF (LMJ.LE. 0) GO TO 945	SWEEP	919
	IF (ABS(XD(LMJ)).GT. 1. .OR. ABS(YD(LMJ)).GT. 1.) GO TO 948	SWEEP	920
945	CONTINUE	SWEEP	921
	GO TO 960	SWEEP	922
948	KCHEK=MIN0(K+1,KMAX)	SWEEP	923
	GO TO 960	SWEEP	924
950	CONTINUE	SWEEP	925
960	CONTINUE	SWEEP	926
	DO 980 J=1,JMAX	SWEEP	927
	LMJ=LVAR(KK,J)	SWEEP	928
	IF(LMJ.LE. 0)GO TO 980	SWEEP	929
	X(LMJ)=XTEMP(J)	SWEEP	930
	Y(LMJ)=YTEMP(J)	SWEEP	931
	XD(LMJ)=XDTEMP(J)	SWEEP	932
	YD(LMJ)=YDTEMP(J)	SWEEP	933
980	CONTINUE	SWEEP	934
	DTW=SQRT(DTSQM)*(1.-3.*TRI0)	SWEEP	935
	RETURN	SWEEP	936
C *****	FORMATS	SWEEP	937
C		SWEEP	938
1755	FORMAT (15H0 EDIT AT CYCLE14,7H, TYME=E10.4,12H SECS, DT =E10.4,	SWEEP	939
	1 9H, CALTIM=1PE10.3/31H TIME STEP CONTROL AT KT, JT=214,	SWEEP	940
	2 18H DELX, DTSQ, SPSQ=1P3E13.5/ 11H X, Y IN ,A3,12F, XD, YD IN	SWEEP	941
	3 A6,14H, STRESSES IN A7,7H, E IN A7,29H, D IN M0/M3, SP IN (KM/SE	SWEEP	942
	4C)2)	SWEEP	943
1756	FORMAT(10H COLUMN K=13,4H, N=14,7H, TIME= E10.4,4H, X=F8.4,4H, Y=	SWEEP	944
	1 F8.4,38X,11HXDNH, YDNH=2F9.3/ 3H J7X,1HX7X,1HY7X,4FTXXW7X,	SWEEP	945
	2 4HTYYW7X,4HTZZW7X,4HTXYW10X,1HP6X,1HE9X,1HD10X,1HQ5X,4HSPSQ5X,	SWEEP	946
	3 4HXDNH5X,4HYDNH2X,1HH)	SWEEP	947
1760	FORMAT (13,2F8.4,5F11.4,F7.1,F10.6,F11.4,3F9.3,13,A4)	SWEEP	948
	END	SWEEP	949

Appendix F

GLOSSARY

The nomenclature for this manual is given in two groups. First, symbols used in the derivations are listed, followed by the input quantities and other major variables in the computer program.

Nomenclature of Text

A	Cell area, cm^2
A_{xx}	Area of cell facing the x direction, cm^2
A_{xy}	Area of cell in the xy plane, cm^2
A_{yy}	Area of cell facing the y direction, cm^2
A_0, A_3	Area of two triangular portions of a quadrilateral cell, cm^2
b	Number of cells over which a detonation front is spread.
C, D, S	Coefficients in the series expansion for Hugoniot pressure, dyn/cm^2
C'	Effective sound speed considering only bulk and shear moduli, cm/sec
C_e	Effective sound speed for determining the time step, cm/sec
C_s	Sound speed, cm/sec
C_0	Coefficient of quadratic artificial viscosity relation
C_1	Coefficient of linear artificial viscosity relation
D_x	Detonation velocity, cm/sec
E	Internal energy, erg/g
E_{CJ}	Internal energy at the C-J point, erg/g
E_H	Internal energy on the Hugoniot, erg/g
F_B	Detonated fraction of an explosive
F_x	Force in the x direction, dyn
F_y	Force in the y direction, dyn
G	Shear modulus, dyn/cm^2
J	Lagrangian position (radial for axisymmetric geometry)
K	Lagrangian position (axial for axisymmetric geometry)

M	Material number; or cell mass
M_e	Effective modulus for determining the time step, dyn/cm^2
n	Time step number
P	Pressure, dyn/cm^2
P_{CJ}	Pressure at the C-J point, dyn/cm^2
P_H	Hugoniot pressure, dyn/cm^2
Q	Artificial viscous stress, dyn/cm^2
Q_x	Chemical energy of the explosive, erg/g
Q_{xx} , Q_{yy} , Q_{xy}	Triangular artificial viscosity stresses, dyn/cm^2
T	Total mechanical stress, dyn/cm^2
T_q	Coefficient of triangular artificial viscosity relation
T_{xx}	Total stress in the x direction, dyn/cm^2
T_{xy}	Shear stress on the xy plane, dyn/cm^2
T_{yy}	Total stress in the y direction, dyn/cm^2
T_{zz}	Total stress in the z direction, dyn/cm^2
t	Time in the problem, sec
Δt	Time increment, sec
u	Particle velocity in the x direction, cm/sec
u_{CJ}	Particle velocity at the C-J point, cm/sec
u_0 , u_x , u_y	Constants in the series expansion for particle velocity in the x direction
V	Specific volume, cm^3/g
V_{CJ}	Specific volume at the C-J point, cm^3/g
v	Particle velocity in the y direction, cm/sec
v_0 , v_x , v_y	Constants in the series expansion for particle velocity in the y direction

x	Coordinate location in x direction, cm (axial for axisymmetric geometry)
$\dot{x}$	Particle velocity in the x direction, cm/sec
X_D, Y_D	Coordinates of the initiation point of an explosive, cm
y	Coordinate location in y direction, cm, (radial for axisymmetric geometry); or yield strength, dyn/cm ²
$\dot{y}$	Particle velocity in the y direction, cm/sec
Z	Quantity stored as the cell mass: for planar cells, Z is the mass in g/cm; for axisymmetric cells, Z is the $1.5/\pi$ times the mass in g.
$\bar{Z}$	Cell midpoint used in explosive calculations, cm
Z_D	Initiation point for a detonation, cm
Γ	Grüneisen ratio
γ	Polytropic gas exponent
γ_{xy}	Engineering shear strain
δ_{ij}	Kronecker delta: $\delta = 1$ for $i = j$; otherwise, $\delta = 0$
ϵ_{ij}	Tensor strain component
ϵ'_{ij}	Deviator strain
ϵ'^E_{ij}	Elastic deviator strain
$\bar{\epsilon}^p$	$\sqrt{\frac{2}{3} \epsilon^p_{ij} \epsilon^p_{ij}}$, equivalent plastic strain
ϵ^p_{ij}	Plastic strain tensor
ϵ_x	Strain in the x direction
ϵ_y	Strain in the y direction
ϵ_z	Strain in the z direction
θ	Angle in a circumferential direction

λ	Proportionality factor used in plastic flow stress-strain relation, cm^2/dyn
μ	$\rho/\rho_0 - 1$, strain
ρ	Cell density, g/cm^3
ρ_0	Initial density, g/cm^3
σ	Stress, dyn/cm^2
σ_{ij}	Tensor stress component, dyn/cm^2
σ'_{ij}	Deviator stress, dyn/cm^2
$\bar{\sigma}$	$\sqrt{\frac{3}{2} \sigma'_{ij} \sigma'_{ij}}$, effective stress, dyn/cm^2
σ_{ij}^N	Stress component computed on an elastic basis, dyn/cm^2
$\bar{\sigma}^N$	$\sqrt{\frac{3}{2} \sigma_{ij}^N \sigma_{ij}^N}$, effective stress computed on an elastic basis, dyn/cm^2
ω_{xy}	Rotation in the xy plane, positive counterclockwise

Nomenclature of TROTT

A()	Area of cell in the xy plane, cm^2
ALFA	Incremental cell rotation, positive clockwise
ANGLE	Angle of boundary for an oblique impact, deg
BFR()	Material properties array used for fracture models
CALE, CALS, CALX, CALXD	Calibration factors for transforming energy, stress, distance and velocity respectively from the internal c.g.s. system to form the IPRINT listings in the units described by the names LISTE, LISTS, LISTX AND LISTXD.
CALTIM	Computation time from start of reading input, sec
CLIN	C_1 ; coefficient of linear artificial viscosity
COM()	One-dimensional array containing all cell and coordinate variables
CQSQ	C_0^2 ; coefficient of quadratic artificial viscosity
D()	Cell density, g/cm^3
DELTIM	Computation time for a time increment, sec
DT	Time increment, sec
DTN	One-half the current and previous time increments, sec
E()	Internal energy, erg/g
EQSTC(), EQSTD(), EQSTS()	C, D, S; coefficients in series expansion for Hugoniot pressure dyn/cm^2
EQSTE ()	Sublimation energy, erg/g (unusec)
EQSTG()	Γ ; Grüneisen's ratio
EQSTH()	Gas Grüneisen's ratio (unused)
ESC()	Large array for equation-of-state constants. See Appendix A for definitions

G2()	2G; twice the shear modulus, dyn/cm ²
IBDJ1(), IBDJ2()	Range of J values designating a special boundary condition
IBDK1(), IBDK2()	Range of K values designating a special boundary condition
IBDX(), IBDY()	Indicators for displacement boundary condition control on the X or Y locations. The values mean: 0 Free, no control 1 No velocity change 2 X (or Y) is kept $\leq$ XFIX (or YFIX) 3 X (or Y) is kept $\geq$ XFIX (or YFIX)
ICAL	Indicator for special controls on the units used for IPRINT listings
IH()	Indicator array used with some material models
IJBUND	Geometry and boundary indicator, see Table 1 in Section 5
IMAX	Maximum number of cycles for a run, or for the increment in a restarted run
IPRIND	An indicator for reading print options KSKIP, KFULL, KPMAX, KPMIN, JPMAX, and JPMIN to alter the normal edit listings
IPRINT	Frequency in computational cycles at which edit listings of cell and coordinate variables are requested
IVTYPE	Velocity initialization indicator, see Table 1 in Section 5
J	Lagrangian coordinate
JEDJ(), JEDK(), JEDT()	J, K, and variable type values in a historical listing request. See Table 2 in Section 5
JMAX	Maximum J value in the layout

JPMAX,	Maximum and minimum J values for which edit listings
JPMIN	are given when the cycle is not a multiple of KFULL
JPRINT	Print indicator for obtaining edit listings at every cycle from JP1 to JP2. JPRINT is the number of groups of JP1 and JP2
JP1(),	Minimum and maximum computational cycles for which edit
JP2()	listings are requested at each cycle
JSIZE	Dimension of the COM array, set in TROTT (Section 5.5)
JSLIDE	Indicator for a slide line between J rows JSLIDE-1 and JSLIDE with master cells on the JSLIDE side
JU	Maximum J value initialized at the velocity UZERO
JXX	Maximum number of J values permitted, set in TROTT
J1, J2	Range of J values for a quadrilateral set of cells
K	Lagrangian coordinate
KCHEK	Maximum value of K treated in the wave propagation calculations
KFULL	Frequency in computational cycles at which a full edit listing is given
KMAX	Maximum K value in the layout
KPMAX,	Maximum and minimum K values for which edit listings are
KPMIN	given when the cycle is not a multiple of KFULL
KSKIP	Frequency in K values at which K columns are printed in an edit listing
KSLIDE	Indicator for a slide line between K rows KSLIDE-1 and KSLIDE with master cells on the KSLIDE-1 side
KU	Interface K value for a projectile impact. If IVTYPE = 1, rows 1 to KU are given an initial velocity. For IVTYPE = -1, rows KU to KMAX are given an initial velocity

KXX	Maximum number of K values permitted, set in TROTT
K1, K2	Range of K values for a quadrilateral set of cells
LISTE, LISTS,	Alphanumeric names for the units used in IPRINT
LISTX,	listings for energy, stress, distance, and velocity,
LISTXD	respectively
LVAR()	Two-dimensional array containing locations in COM to begin data for each cell and coordinate
M, MAT, MM	Material number
MU()	Shear modulus, dyn/cm^2
NBLOCK	Number of quadrilateral blocks used in providing the x,y geometric data
NBND	Number of special boundary groups, used only for IJBUND = ± 9 . See Appendix G
NCMP()	Composite material indicator; nonzero means that the REBAR subroutine is used
NDS()	Deviator stress model indicator (not used)
NDUMP	Frequency in computational cycles at which a restart dump is written to Tape 9
NEXED	Frequency in computational cycles at which listings are requested of all values in the COM array not in a normal edit
NEXTRA	Indicator for reading extra data through the EXTRAT subroutine
NFR()	Fracture model indicator as follows:
	0 no fracture model
	1 ductile fracture, DFRACT
	2 brittle fracture, BFRACT(3)
	3 SHEAR2 shear band model

	4	SHEAR2 shear band model
	5	simple tensile fracture in the X direction
	6	simple tensile fracture in the Y direction
	7	static ductile fracture, DFRAC1S
NJED		Number of historical listings requested
NMTRL5		Number of materials
NOBLQ		Indicator for an impact on a fixed oblique wall to be impacted by the material laid out
NPLOT		Frequency in computational cycles at which data for XY plots are written to Tape 3
NPOR()		Porous material model indicator; nonzero means that CAP1 is used
NPR()		Pressure model indicator; zero means Mie-Grüneisen and 1 is for explosives
NSTART		Number of the restart file to be used for a restart problem, zero for an original run (read from Tape 1)
NTRI()		Indicator for separating each quadrilateral cell of the material into two triangular cells
NVAR()		Number of additional variables (beyond the usual 17) to be assigned to each cell of the material
NVBLK		Number of quadrilateral blocks used in initializing the velocities
NYAM		Indicator for yielding; nonzero values permit initialization of yield strength and shear modulus
P()		Pressure, dyn/cm^2
Q		Artificial viscous stress, dyn/cm^2
RHO()		ρ ; initial density, g/cm^3
RHOS()		ρ_0 ; initial solid density, g/cm^3
SP()		Sound speed, cm/sec

SXX()	Deviator stress in the x direction, dyn/cm ²
SYX()	Deviator stress in the y direction, dyn/cm ²
SZZ()	Deviator stress in the z direction, dyn/cm ²
TANTH	Tangent of angle of fixed oblique wall
TH()	Cell rotation, positive counterclockwise
TRIQ	T _q ; coefficient of triangular artificial viscosity
TS	Input stop time, sec
TSR()	Material properties array available for special models
TXX()	Total stress in the x direction, dyn/cm ²
TXY()	Shear stress on the xy plane, dyn/cm ²
TYME	Problem time, sec
TYX()	Total stress in the y direction, dyn/cm ²
TZZ()	Total stress in the z direction, dyn/cm ²
UZERO	U _z ; initial velocity of an impactor, cm/sec
X()	Eulerian position in the x direction, cm
XA, YA	Eulerian coordinate positions or velocities for a quadrilateral set of cells, read in counterclockwise order starting with point of smallest K, J values
XFIX()	X value used with special boundary conditions, cm
XD()	Particle velocity in the x direction, cm/sec
Y()	Eulerian position in the y direction, cm
YAD()	Work-hardening modulus, dyn/cm ²
YC()	Y; initial yield strength, dyn/cm ²
YD()	Particle velocity in the y direction cm/sec
YFIX()	Y value used with special boundary conditions, cm
YY()	Yield strength for a cell, dyn/cm ²
Z()	Mass of a cell, g/cm or g

Appendix G

SPECIAL BOUNDARY CONDITIONS

In addition to the standard boundary conditions specified by IJBUND = ± 1 to ± 5 , special kinematic conditions can be applied at individual points or along K or J lines. These conditions can be adjusted to fix a point in the X or Y directions, to maintain its X or Y velocity, or to keep the point within specified bounds.

The special boundary conditions are provided for IJBUND = ± 9 (negative for planar and positive for axisymmetric). The input parameter NBND then gives the number of special boundary conditions to be provided. For each boundary condition, values of IBDJ1, IBDJ2, IBDK1, and IBDK2 give the range of J and K values affected. Note that a range in only one (J or K) is permissible; otherwise, the boundary condition would affect interior points. Along the boundary IBDY and IBDX specify how the X and Y directions are to be treated:

- IBDX or IBDY = 0 No control, free boundary
- 1 No change in velocity permitted
 - 2 X (or Y) is required to be $\leq$ XFIX (or YFIX)
 - 3 X (or Y) is required to be $\geq$ XFIX (or YFIX)

The other two quantities XFIX and YFIX provide maximum or minimum values of the X and Y locations. For example, the radii along the axis of symmetry can be kept on the axis by specifying IBDY = 1 (Y is radial).

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