TECHNICAL REPORT SL-87-11

ANALYSIS OF DYNAMIC IN SITU BACKFILL PROPERTY TESTS

Report 3
THE MODIFIED ONED PROGRAM FOR ONE-DIMENSIONAL PLANAR STRESS WAVE PROPAGATION

by

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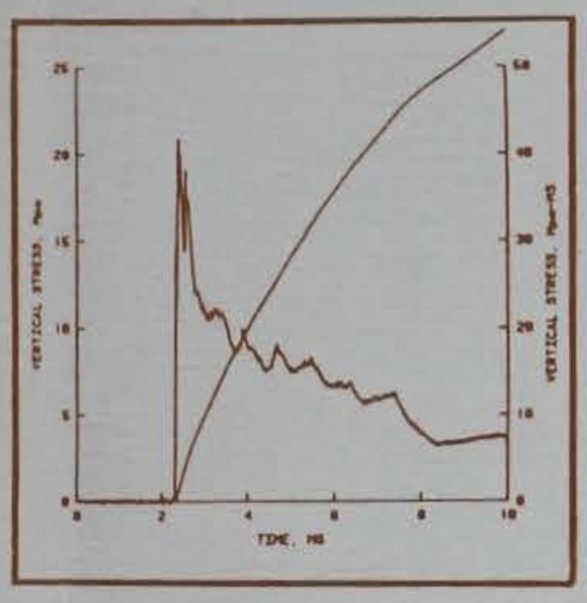


July 1987
Report 3 of a Series

Prepared for US Army Corps of Engineers
Washington, DC 20314-1000

Under Project No. 4A162719AT40, Task AO, Work Unit 024
(Contract No. DACA39-83-K-0002)

Monitored by Structures Laboratory
US Army Engineer Waterways Experiment Station
PO Box 631, Vicksburg, Mississippi 39180-0631

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S) Technical Report SL-87-11
6a. NAME OF PERFORMING ORGANIZATION SRI International 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION USAEWES Structures Laboratory
6c. ADDRESS (City, State, and ZIP Code) 333 Ravenswood Avenue Menlo Park, CA 94025-3493	7b. ADDRESS (City, State, and ZIP Code) PO Box 631 Vicksburg, MS 39180-0631
8a. NAME OF FUNDING/SPONSORING ORGANIZATION US Army Corps of Engineers 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER Contract No. DACA39-83-K-0002
8c. ADDRESS (City, State, and ZIP Code) Washington, DC 20314-1000	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO.: ; PROJECT NO.: 4A162719AT40; TASK NO.: AO; WORK UNIT ACCESSION NO.: 024

11. TITLE (Include Security Classification)
Analysis of Dynamic In Situ Backfill Property Tests; The Modified ONED Program for One-Dimensional Planar Stress Wave Propagation

12. PERSONAL AUTHOR(S)
Seaman, Lynn

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Report 3 of a Series	FROM _____ TO _____	July 1987	102

16. SUPPLEMENTARY NOTATION
Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)	
FIELD	GROUP	SUB-GROUP	Artificial viscosity	Plane stress wave propagation
			Explosive loadings	Porous material models
			Large deformations	Shock waves

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

ONED is a small one-dimensional stress wave propagation computer program for simulating explosive loading on layers of soil. The method of artificial viscosity is used with an explicit computational technique. Materials treated can be solids, porous solids, gases, and explosives. The loading causing the waves can be provided either as a pressure history or by the detonation of an explosive layer. The materials are represented by three-dimensional models with separate treatments for the pressure and deviatoric stresses. The pressure for the porous material is given by loading and unloading curves defined by varying moduli. The deviator stress model describes elastic and plastic behavior with either a Mises or a Coulomb friction yield limit. The detonation of an explosive is provided by either a polytropic gas relation or a tabular isentrope.

This version of ONED is an amplification of an earlier version used at the US Army Engineer Waterways Experiment Station for many years. The main changes are the conversion to

(Continued)

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL	22b. TELEPHONE (Include Area Code) / 22c. OFFICE SYMBOL

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

19. ABSTRACT (Continued).

an explicit computational scheme, use of artificial viscosity, provision for large deformations, addition of explosive detonations, and use of separable material model routines.

PREFACE

The work described herein was performed by SRI International for the US Army Engineer Waterways Experiment Station (WES) under Contract No. DACA39-83-K-0002. It was sponsored by the Office, Chief of Engineers, US Army, as a part of Project 4A162719AT40, Task A0, Work Unit 024, "Ground Shock Prediction Techniques for Earth and Earth-Structure Systems." Technical Monitor for OCE was Mr. R. L. Wight.

Dr. Lynn Seaman was the Principal Investigator for this study. Dr. Joseph S. Zelasko, Geomechanics Division (GD), Structures Laboratory (SL), was the WES Contracting Officer's Representative. Dr. J. G. Jackson, Jr., was Chief, GD, and Mr. Bryant Mather was Chief, SL.

COL Dwayne G. Lee, CE, is Commander and Director of WES. Dr. Robert W. Whalin is Technical Director.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Continued)

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
degrees (angle)	0.01745329	radians
dynes per square centimeter	0.1	pascals
ergs	0.1	microjoules
feet	0.3048	meters
grams per cubic centimeter	1,000	kilograms per cubic meter
inches	25.4	millimeters
kips (force)	4.448222	kilonewtons
kips (force) per square inch	6.894757	megapascals
pounds (force) per square inch	6.894757	kilopascals
pounds (mass)	0.4535924	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic meter

ANALYSIS OF DYNAMIC IN SITU BACKFILL PROPERTY TESTS

THE MODIFIED ONED PROGRAM FOR ONE-DIMENSIONAL PLANAR STRESS WAVE PROPAGATION

I INTRODUCTION

The ONED code is a computer program for calculating one-dimensional plane stress wave propagation through a column of soil and other materials in response to detonation of an explosive. The materials may be porous solids, solids, gases, or explosives. The stress waves being computed are initialized by detonation of an explosive or by prescription of a pressure history at the top boundary. Computations are made with the Lagrangian form of the equations of motion so that the coordinates move with the materials. An artificial viscosity is used to smear wave fronts over several computational cells.

A. Background

The present ONED code is a revision of a code that has been in regular use at the U. S. Army Engineer Waterways Experiment Station (WES) for many years. The first version of the ONED code was developed at WES around 1966 for predicting ground motion. In 1971, Radhakrishnan and Rohani documented the code[1] and it has remained in essentially the same form until the present revision.

The earlier version of ONED is a small-strain, small-displacement, finite-element type of program with an implicit solution scheme. Shock fronts were treated by a weak-shock approximation. A single constitutive relation was provided: a variable-modulus, one-dimensional form that closely represented measured uniaxial strain soil properties.

B. New Features

The following modifications were made to produce the current version of ONED:

(1) The solution procedure was revised to provide an explicit technique, and the time sequencing of the displacement,

velocity, acceleration, and stress calculations were adjusted so that they provide an accurate centering of the finite difference equations for momentum conservation.

(2) The treatment of strain and density was modified to represent a large displacement formulation.

(3) The calculation of an artificial viscosity was added with both a quadratic and a linear term in $d\rho/dt$, the rate of change of density with time.

(4) The subroutines that handle the stress-strain calculation were isolated so that these subroutines can be transported to other organizations and codes and so that other stress-strain routines can be readily added.

(5) A three-dimensional model for porous material was constructed.

The following models were added:

(6) Models for deviator stress, a Mie-Grüneisen model for solids, and polytropic and tabular isentrope models for explosives.

In addition some changes were made in the input and output, and the treatment of geostatic stress has been modified.

C. Scope

This report contains a discussion of the theoretical bases for the equations used in ONED, application of the theory to analysis of typical problems, details of implementation, and sample problems. The essential theory for one-dimensional wave propagation is given in Chapter II and the constitutive relations (stress-strain relations) in Chapter III. The

processes associated with initializing the material properties and the cell layout are described in Chapter IV. Sample input files are listed in Appendix A, followed by a glossary of all important parameters in Appendix B. The code is intended for modification and amplification by adding new stress-strain relations: guidelines for inserting new relations are described in Appendix C.

Appendix D is a listing of ONED and its subroutines. Internally the code uses the cgs system of units, but there are provisions for inserting some of the data in the SI or English systems. Some printout can also be obtained in the other systems.

II PROPAGATION CALCULATIONS (Subroutine CMPUTE)

The motion and stresses throughout the material are determined as a function of time in the code. The solution is obtained by integrating the mass and momentum conservation relations together with constitutive relations for the material. This section presents the conservation relations and their general solutions.

In the solution procedure, the material is first divided into discrete units or cells. Velocities, stresses, and other quantities are initialized in cells as required for the particular problem. Then a time step is taken and the motions and stresses are calculated for each cell using the conservation and constitutive relations. 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 used is controlled by stability and smoothness criteria in the code. The stability considerations are described in this section.

A. Solution Procedure for Wave Propagation Equations

The ONED program is based on the solution of the Lagrangian equations governing one-dimensional planar motion of a continuous medium. The solution technique is called the method of artificial viscosity because of the introduction of viscous forces to permit a continuous-flow computation in regions of high stress gradients. Such regions are interpreted as locations of shock fronts although no discontinuities occur in the computed flow field. With this artificial viscosity method, the equations of continuous flow can be used everywhere, and no special equations are required for shock fronts. ONED uses the leapfrog method of von Neumann and Richtmyer[2] to integrate the flow equations. The following paragraphs introduce the governing differential equations for planar flow. These equations are changed to an integral form for solution in the program.

The one-dimensional planar Lagrangian differential equations to be solved are

$$\left(\frac{\partial V}{\partial t}\right)_H = -\frac{1}{D_o}\left(\frac{\partial R}{\partial H}\right)_t + g \quad ; \qquad \text{(momentum)} \qquad (1)$$

$$\left(\frac{\partial X}{\partial t}\right)_H = V \qquad \text{(velocity)} \qquad (2)$$

$$\left(\frac{\partial D}{\partial t}\right)_H = -\frac{D^2}{D_o}\left(\frac{\partial V}{\partial X}\right)_t \text{ or equivalently}$$

$$\left(\frac{\partial X}{\partial H}\right)_t = D_o/D \qquad \text{(mass)} \qquad (3)$$

where

H = Lagrangian coordinate location (original position in laboratory coordinates)

X = Eulerian coordinate location (current position in laboratory coordinates)

t = time

V = particle velocity

D, D_o = current and original density

R = total mechanical stress

g = acceleration of gravity.

These equations relate velocity to the coordinate motion and provide for conservation of momentum and mass. In addition to these differential equations, there is an equation of state (or constitutive relation) that is a relationship between stress or pressure quantities and the density, history of loading, and so forth.

$$R = F(D, \ldots) \qquad \text{(equation of state)}$$

$$= P + \sigma' + Q \tag{4}$$

The total mechanical stress (in the direction of propagation), R, is composed of the pressure P, the deviator stress σ' in the direction of propagation, and an artificial viscous stress, Q.

In the code the four preceding equations are solved simultaneously by dividing the material into small elements. Then the quantities X, V, D, R, and so forth, are evaluated only at the discrete positions and times shown in Figure 1. The coordinate location X is obtained at integral values of j and n, the velocity is at j and n + 1/2, and all other quantities pertain to the midcell (j+1/2, n) points. Here the cells are treated as constant strain finite elements (each cell has a constant value of all three principal strains throughout its volume).

The discrete values of the flow quantities are obtained from Eqs. (1) through (3), using the nomenclature of Figure 1. Here it is convenient to solve for quantities in the order D, R, V, and X. The density is obtained from conservation of mass by dividing the stored value of the cell mass, Z, by the thickness. The first form of Eq. (3) is not used here because it can give erroneous results for large density changes; instead, the second form of Eq. (3) is used:

$$D^n_{j+1/2} = \frac{Z_{j+1/2}}{X^n_{j+1} - X^n_j} \tag{5}$$

The velocity is obtained by a discretization of Eq. (1), or equivalently, by using "force equals mass times acceleration" and considering a mass pertaining to the jth coordinate point.

$$V^{n+1/2}_j = V^{n-1/2}_j - \frac{R^n_{j+1/2} - R^n_{j-1/2}}{1/2\left(Z_{j+1/2} + Z_{j-1/2}\right)} \Delta t^n + g\Delta t^n \tag{6}$$

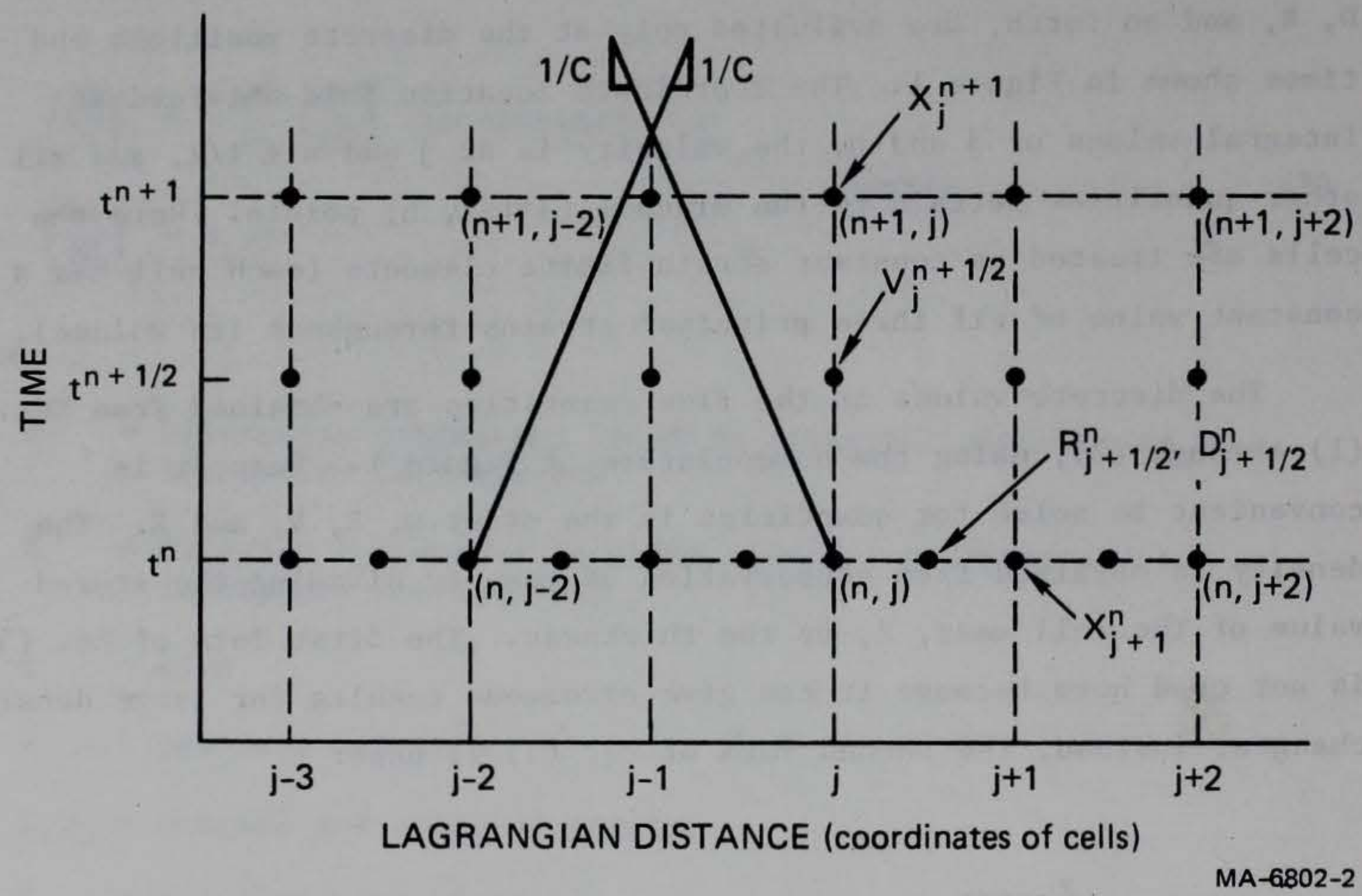


FIGURE 1 GRID FOR DEPICTING COORDINATES AND TIME INCREMENTS

Here $\Delta t^n = t^{n+1/2} - t^{n-1/2}$ is the time step centered at the nth time.

Finally, the Eulerian position of the coordinate is computed from Eq. (2)

$$X_j^{n+1} = X_j^n + V_j^{n+1/2} \Delta t^{n+1/2} \tag{7}$$

where $\Delta t^{n+1/2} = t^{n+1} - t^n$. The computations proceed from top to bottom (or from left to right in Figure 1), one cell and coordinate at a time, updating the flow quantities to the new time $t^{n+1/2}$ or t^{n+1}, as appropriate. This process is continued until the bottom boundary is reached. Then computations resume at the top for the next time increment.

The foregoing integration method is essentially the leapfrog method of von Neumann and Richtmyer[2]. With this approach, the derivatives in the equations of mass and momentum are correctly centered. That is, each of the conservation relations is replaced by a numerical approximation in which all terms pertain to the same point in time and space. For example, in the momentum Eq. (6), $\partial V/\partial t$ and $\partial R/\partial Z$ are both centered precisely at (n,j), and therefore, the solution scheme is of second order although no numerical approximations to $\partial^2 V/\partial t^2$ or $\partial^2 R/\partial Z^2$ are needed.

In the code, the names of quantities are essentially those given above in the discretized equations. The coordinate quantities are VEL(J) $= V^{n+1/2}$ and X(J) $= X_j^{n+1}$, and the cell quantities are of the form RMECH(J) $= R_{j+1/2}^n$. The time step is DT $= \Delta t^{n+1/2}$. Hence the coordinate point and the cell to the right are both labeled J, and the midcell quantities at n and the coordinate quantities at n+1/2 or n+1 are stored in the arrays. Boundaries between materials are treated in the same fashion as coordinates within a material except that an extra coordinate is provided to permit separation of the layers.

B. Artificial Viscous Stress

The artificial viscous stress is required in finite difference wave propagation calculations to smooth shock waves so that the entire flow field can be treated by the conservation equations of continuous flow, Eqs. (1) through (3). The artificial viscous stress (Q) is the difference between the nonequilibrium mechanical stress (R) and the equilibrium thermodynamic stress (σ) given by the constitutive relations. Hence Q represents real stresses occurring in the nonequilibrium states of the shock front. However, the basis for computing Q is artificial, depending on the computational cell size and on viscosity coefficients, which are not related to real physical processes.

In the modified ONED, the usual linear and quadratic viscous stress forms are provided. The linear form is computed by the equation

$$Q = - C_L C_s \rho \Delta V \tag{8}$$

where C_L = dimensionless coefficient of linear artificial viscosity, C_s = sound speed, and $\Delta V = V_{j+1} - V_j$, the velocity difference across the cell. The linear artificial viscosity is similar in form and operation to the standard linear viscosity models used to represent material behavior. However, here the coefficient C_L is chosen to provide enough damping to minimize oscillations in the calculations and not to represent the real material viscosity. Useful values for C_L are in the range of 0.05 to 0.50.

The quadratic artificial viscous stress proposed originally by von Neumann and Richtmyer[2] has the form

$$Q = C_Q \rho (\Delta V)^2 \tag{9}$$

where C_Q = the dimensionless viscosity coefficient, and $\Delta V = V_{j+1} - V_j$, as before. The quadratic viscous stress is permitted to act only on compressive waves. For normal values of C_Q of 3 or 4, the shock front is rapidly spread over three to four cells and then maintains essentially a

constant thickness as the wave propagates. Because of the quadratic nature of the expression for Q, very little damping occurs outside the shock front. In contrast, the linear viscosity tends to continue to erode the wave fronts as long as they propagate.

Normally, both linear and quadratic artificial viscous stresses are used, so the artificial viscous stress Q is the sum of the linear and quadratic terms from Eqs. (8) and (9). The quadratic viscosity quickly establishes the shock front thickness. The linear viscosity damps the small oscillations that would otherwise occur near the shock front, but is given a small enough coefficient so that the wave front is not seriously eroded.

C. 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 condition (see Reference 3, p. 262). This criterion is simply

$$\Delta t \leq \frac{\Delta X}{C_e} \tag{10}$$

where ΔX is the cell size and C_e is the local effective sound speed (defined later).

The criterion means that the time step cannot be so large that the new points are outside the characteristic domain of dependence of the previous points. Referring to Figure 1, the new point (n+1, j-1), for which the variables are computed from values at (n, j-2), (n, j-1), and (n, j), must lie within the domain of dependence or range of waves from those points. This domain is contained between lines with speeds of C_e. A physical interpretation of the requirement is that a wavelet cannot be allowed to proceed from one coordinate point to beyond another in one time step because this would allow a material point to be affected by conditions at material points outside the true domain of dependence.

This simple criterion is modified to provide for added safety (the step used in ONED is 80% of the time step at the limit of stability) and to allow for the effect of artificial viscosity.

Artificial viscosity stiffens the material and therefore increases the apparent sound speed, reducing the allowable time step. For linear and quadratic viscosity coefficients (C_L and C_Q), Herrmann et al. (Reference 4, p. 37) derived a reduction factor to be applied to the time step. As shown in Reference 5, the effect of the artificial viscosity can be accounted for by computing an effective sound speed C_e and effective modulus M_e as follows:

$$C_e^2 = \frac{M_e}{\rho} = \frac{\Delta P + 2Q}{\Delta\rho} + \frac{4G}{3\rho} \tag{11}$$

where ΔP and $\Delta\rho$ are the changes in pressure and density during the current time step, and G is the shear modulus.

III CONSTITUTIVE RELATIONS

The constitutive relations provide the stress as a function of density, strains, and other quantities. This section describes the common constitutive relations and outlines the available constitutive models.

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

$$P = 1/3 \sum_i \sigma_{ii} \tag{12}$$

and the stress deviator elements are

$$\sigma'_{ij} = \sigma_{ij} - P\delta_{ij} \tag{13}$$

where σ_{ij} are stress tensor elements and δ_{ij} is the Kronecker delta. The pressure is usually presented as a function of density and internal energy. The deviator stress is calculated by elastic-plastic relations.

A. Pressure Model for a Solid (Subroutine EQST)

The pressure is computed from a pressure density relation for each material. The pressure-density relation used here is the Hugoniot for shock compaction given as the following series:

$$P_H = C\mu + D\mu^2 + S\mu^3 \tag{14}$$

where

$\mu = \frac{\rho}{\rho_o} - 1$

C = bulk modulus

D,S = coefficients with the units of moduli

ρ,ρ_o = current and initial densities.

For the present calculations, we are neglecting the internal energy changes occurring in shock compaction because ONED is intended only for stresses up to a few kilobars. Thus, the Hugoniot is also being used as the unloading isentrope.

B. Deviator Stress Model (a Part of Subroutine CMPUTE)

The deviator stress is the part of the stress tensor that arises because of the resistance of the material to shearing deformation. In ONED, the standard model for deviator stresses accounts for elastic response and plastic flow. The yield strength that governs plastic flow can be either of the Mises or Coulomb types. First some general definitions are given and then the equations that are special to each yield type.

The elastic relations between stress and strain are cast in the following form:

$$\sigma'_{ij} = 2G\left(\varepsilon^E_{ij} - \frac{\delta_{ij}}{3}\sum_{\ell}\varepsilon^E_{\ell\ell}\right) \tag{15}$$

$$P = C\Sigma\varepsilon_{ii} \tag{16}$$

Here, σ'_{ij} and ε^E_{ij} are the deviatoric stress and elastic strain in the ij direction, G is the shear modulus, δ_{ij} is the Kronecker delta, P is pressure, and C is the bulk modulus. For the elastic case, $\varepsilon_{ij} = \varepsilon^E_{ij}$, all the strain is elastic. However, Eqs. (15) and (16) are also applicable to the plastic case where the strain increments are separated into elastic and plastic components:

$$d\varepsilon_{ij} = d\varepsilon^E_{ij} + d\varepsilon^P_{ij} \tag{17}$$

where $d\varepsilon_{ij}$ is the total strain increment and $d\varepsilon^p_{ij}$ is the plastic strain increment. For convenience, the terms in the parentheses of Eq. (15) can be named a deviator strain, defined as follows:

$$\varepsilon'^E_{ij} = \varepsilon^E_{ij} - \frac{\delta_{ij}}{3} \sum_{\ell} \varepsilon^E_{\ell\ell} \tag{18}$$

Then Eq. (15) becomes

$$\sigma'_{ij} = 2G\, \varepsilon'^E_{ij} \tag{19}$$

The Mises or Reuss plasticity relations or "incremental plasticity with an associated flow rule" are considered here first[6]. Modifications to treat Coulomb friction are described later. Yield occurs when the effective stress reaches the yield strength. The effective stress is

$$\bar{\sigma} = \sqrt{\frac{3}{2}\left(\sigma'_{ij}\,\sigma'_{ij}\right)} \tag{20}$$

where the repeated subscripts indicate summation. The yield criterion is

$$\bar{\sigma} = Y \tag{21}$$

where Y is the current yield strength. The Reuss flow rule indicates that the deviator stress in any direction is proportional to the plastic deviator strain in that direction (because the Reuss material sustains no plastic volume strain $\Sigma\, d\varepsilon^p_{ii} = o$). Hence,:

$$d\varepsilon'^p_{ij} = \sigma'_{ij}\, d\lambda \tag{22}$$

where $d\lambda$ is a proportionality constant. Now we define a scalar effective plastic strain quantity as follows:

$$d\bar{\varepsilon}^p = \sqrt{\frac{2}{3}\, d\varepsilon'^p_{ij}\, d\varepsilon'^p_{ij}} \tag{23}$$

As before, the repeated subscripts indicate summation. Now we square Eq. (22) and make use of the definitions of $\bar{\sigma}$ and $d\bar{\varepsilon}^p$. Then

$$d\bar{\varepsilon}^p = \frac{2}{3}\,\bar{\sigma}\,d\lambda \tag{24}$$

Combining this definition with Eq. (22), we find that

$$d\varepsilon'^p_{ij} = \sigma'_{ij}\,\frac{3d\bar{\varepsilon}^p}{2\bar{\sigma}} \tag{25}$$

To obtain a solution for an increment of strain, we compute first the stress that would occur if the strain were entirely elastic, that is,

$$\sigma'^N_{ij} = 2G\left(\varepsilon'^E_{ijo} + \Delta\varepsilon'_{ij}\right) = 2G\left(\varepsilon'^E_{ij} + \Delta\varepsilon'^p_{ij}\right) \tag{26}$$

where

ε'^E_{ijo} = the elastic deviator up to the current strain step

$\Delta\varepsilon'_{ij}$ = the total deviator strain increment

ε'^E_{ij} = the elastic deviator strain after the current increment

$\Delta\varepsilon'^p_{ij}$ = the plastic strain increment.

The second equality in Eq. (26) is obtained by using Eq. (17) to decompose $\Delta\varepsilon'_{ij}$ and by adding $\varepsilon^E_{ijo} + \Delta\varepsilon'^E_{ij}$ to obtain ε'^E_{ij}. Quantities ε'^E_{ij} and $\Delta\varepsilon^p_{ij}$ can both be replaced by stress quantities through the use of Eqs. (19) and (25). Then,

$$\sigma'^N_{ij} = \sigma'_{ij}(1 + 3G\Delta\bar{\varepsilon}^p/\bar{\sigma}) \tag{27}$$

If both sides of Eq. (27) are squared and a quantity $\bar{\sigma}^N$ is introduced in analogy to the definition of $\bar{\sigma}$, then we obtain

$$\bar{\sigma}^N = \bar{\sigma}(1 + 3G\Delta\bar{\varepsilon}^p/\bar{\sigma}) \tag{28}$$

Here, $\bar{\sigma} = Y$. Combining Eqs. (27) and (28) yields a solution for σ'_{ij}:

$$\sigma'_{ij} = \sigma'^{N}_{ij} \frac{\bar{\sigma}}{\bar{\sigma}^{N}} \tag{29}$$

Then, the elastic strain can be obtained from Eq. (19) and the effective plastic strain from Eq. (28):

$$\Delta\bar{\varepsilon}^{P} = \frac{\bar{\sigma}^{N} - \bar{\sigma}}{3G} \tag{30}$$

Finally, each component of plastic strain is found from Eq. (22) using $d\lambda$ obtained from Eq. (24).

The preceding process can be adapted to hardening plasticity where Y is not a constant. The equations are appropriate for steps from one plastic Mises state to another or from an elastic state to a plastic state.

The Coulomb plasticity model is quite different from the preceding Mises model. The yield strength is a function of normal stress on the plane of yield (a Tresca formulation); hence, the pressure as well as the deviator stresses are involved in yielding. No changes in pressure or volume occur during yielding so this is a Coulomb-without-dilatation model and hence, the flow law is non-associated. The fundamental Coulomb relation provides a shear yield stress τ_c as a function of cohesion c, normal stress σ_N, and the angle of internal friction ϕ:

$$\tau_c = c + \sigma_N \tan \phi \tag{31}$$

Following Terzaghi,[7] this expression is transformed to

$$\sigma_1 = 2c \sqrt{N_\phi} + \sigma_3 N_\phi \tag{32}$$

where $N_\phi = \tan^2(45° + \phi/2)$, σ_1 is the stress in the direction of propagation, and $\sigma_2 = \sigma_3$ is the lateral stress. A second yield condition, with σ_1 and σ_3 interchanged in Eq. (32), is obtained for the case where σ_3 is the most compressive stress. To solve for the yield limit on σ_1' (σ_{1y}'), we replace σ_1 and σ_3 by deviator stresses and pressure and use Eqs. (12) and (13) to obtain

$$\sigma_1' + \sigma_2' + \sigma_3' = 0 \qquad (\sigma_2 = \sigma_3)$$

$$\sigma_3' = -\frac{1}{2}\sigma_1' \tag{33}$$

Using Eq. (33) in Eq. (32), we obtain the yield limit

$$\sigma_{1y}' = \frac{2c\sqrt{N_\phi} + P(N_\phi - 1)}{1 + N_\phi/2} \tag{34}$$

for σ_1 more compressive than σ_3, and

$$\sigma_{1y}' = -\frac{2c\sqrt{N_\phi} + P(N_\phi - 1)}{1/2 + N_\phi} \tag{35}$$

for σ_3 more compressive than σ_1.

The input quantities for the yield model are the yield strength (Y) for the Mises model or 2c and tan ϕ for the Coulomb model. Because of the different natures of the two models, they cannot be combined. The one that is to be used is determined in the code by whether tan ϕ is nonzero. The deviator stress model is used with either solid or porous models for pressure.

C. Model for Porous Material (Subroutine SSONED)

For simulating the soil response to wave propagation and representation of both vertical and horizontal stress histories, it is necessary to have a multidimensional soil model. As a preliminary step toward such a model, we developed a simple isotropic model with separate treatments for the pressure and deviatoric stresses. The deviatoric stresses follow the standard elastic-plastic behavior with a Coulomb yield criterion, as described above. The pressure follows the segmented loading and unloading paths given in the original version of ONED.[1] A possible pressure-strain diagram for the SSONED model is shown in Figure 2. In the figure, SL's are volume strains and EL's are bulk moduli.

During loading, the pressure is computed from the relation

$$P = P_i + E_i (\varepsilon - \varepsilon_i) \tag{36}$$

where

$P_i = P(i,M)$ = pressure at i^{th} node of the loading diagram

$E_i = EL(i, M)$ = the modulus for the strain interval from i to i + 1

$\varepsilon_i = SL(i, M)$ = the volumetric strain at the beginning of the interval

$\varepsilon = \rho / \rho_o - 1$, where ρ and ρ_o are the current and initial density.

In the computer subroutine there is first a search to find the strain interval appropriate to ε; this search determines i. Then the pressure is computed from Eq. 36.

The unloading process is also given by a segmented path as shown in Figure 2. However, it is necessary to provide for unloading from any point on the loading curve. Therefore, procedures are provided for shifting the unloading curve to any current position on the loading curve.

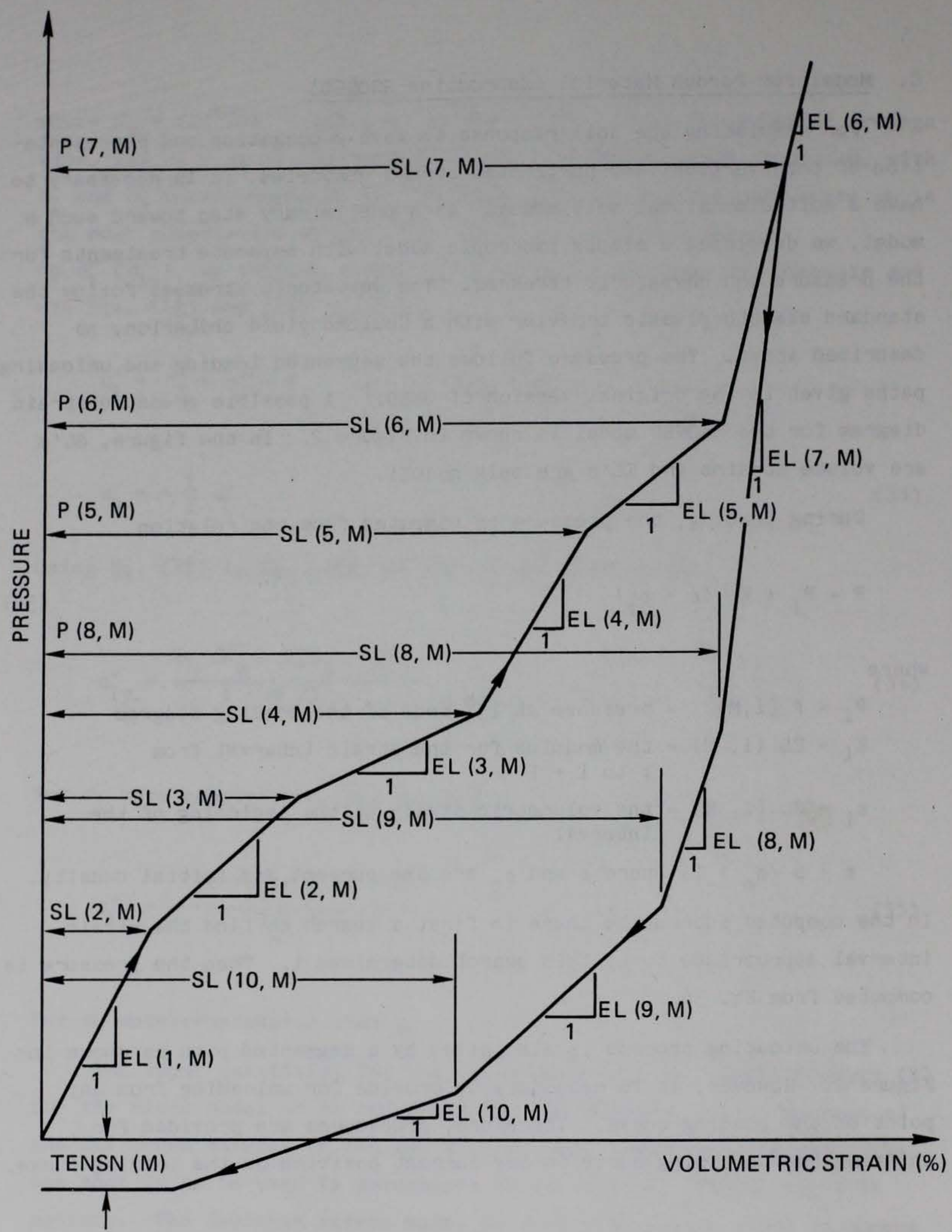


FIGURE 2 DEFINITION OF MODULUS AND STRAIN VALUES ON LOADING AND UNLOADING CURVES FOR THE SSONED MODEL

Three possibilities have been provided for prescribing the unloading curve:

(1) The unloading curve is simply shifted horizontally to the strain at which the unloading begins.

(2) The stresses on the unloading curve are reduced in proportion to the stress at which unloading begins, but the unloading moduli are unchanged. Then the curve is shifted to the strain at which the unloading begins.

(3) The stresses on the unloading curve are reduced as in version 2, but the moduli are modified to preserve the strain increment amplitudes. Then the curve is shifted to the strain at which the unloading begins.

These three unloading processes, illustrated in Figure 3, are provided in the current model to facilitate testing of a variety of stress-strain possibilities.

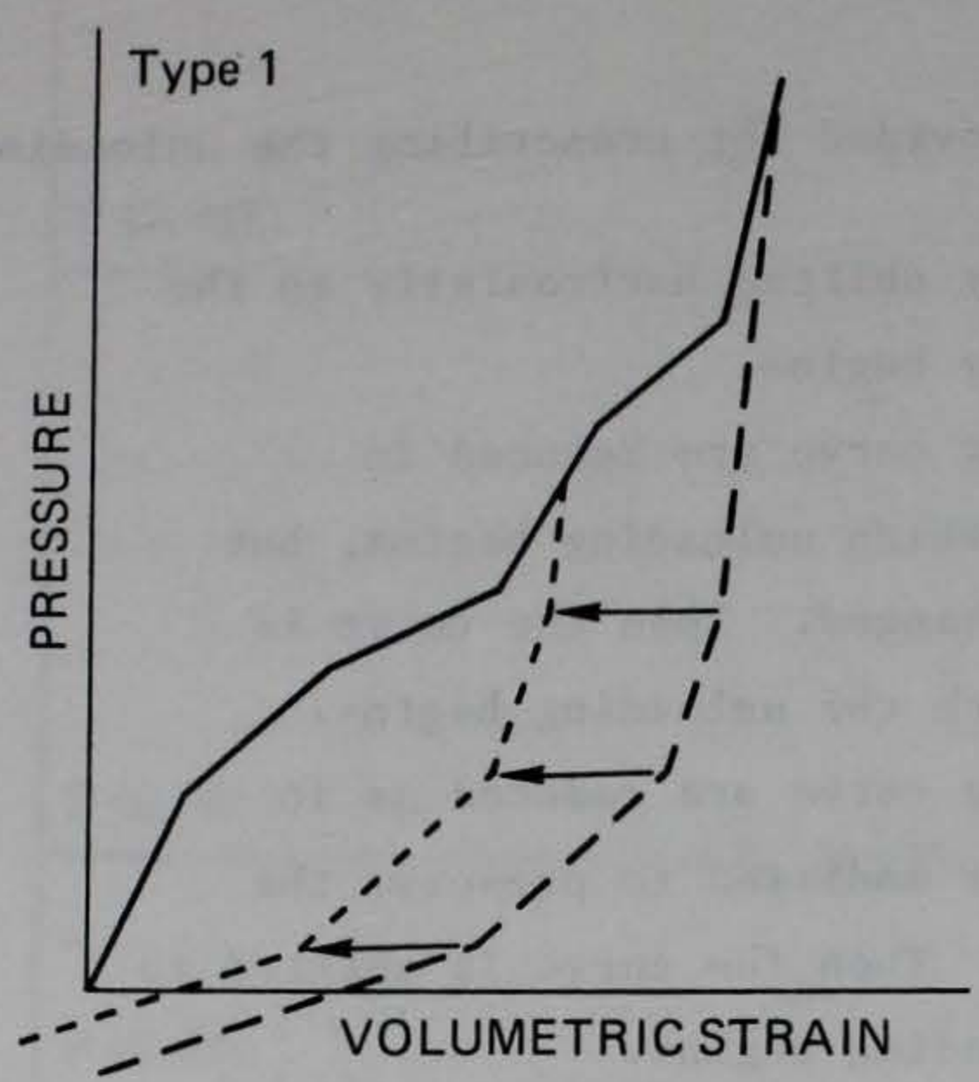
For all three unloading paths, we use the following expression for pressure:

$$P = P_i + E_i (\varepsilon_Q - \varepsilon_i) \tag{37}$$

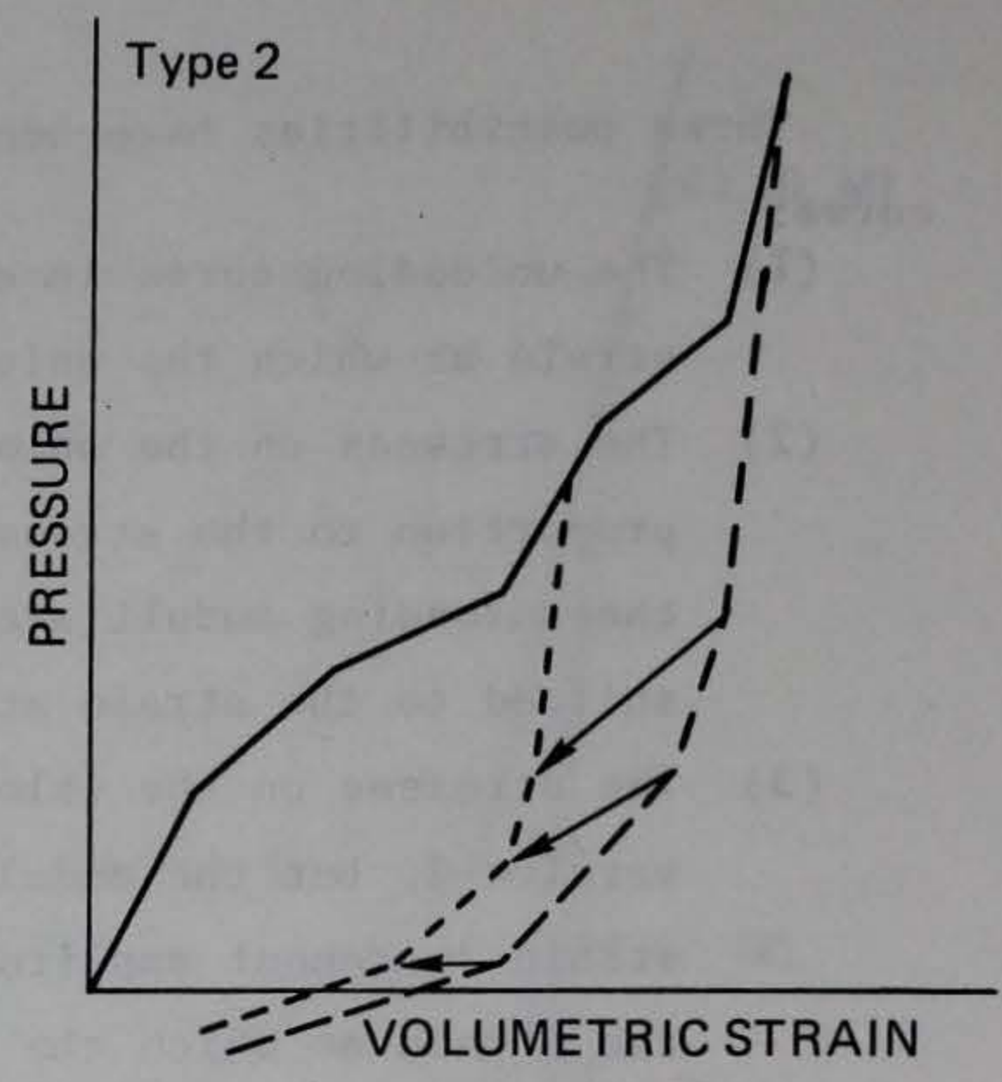
where ε_Q is a pseudo strain and the other quantities are the same as those in Eq. 36. The next task is to determine ε_Q for all three loading types.

For type 1 unloading, we see in Figure 3a that the strain at a pressure of P_{max} on the unloading curve is

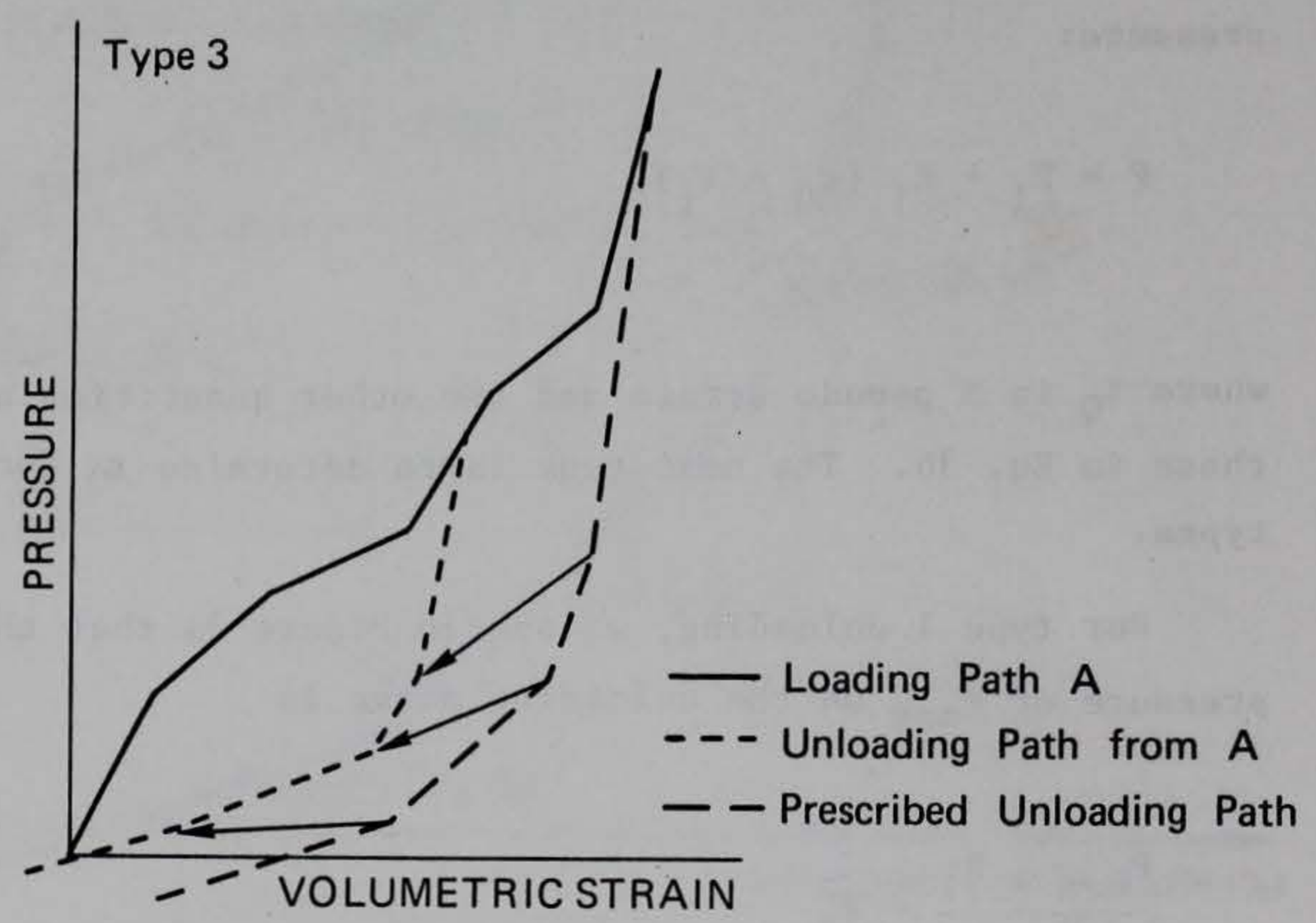
$$\frac{P_{max} - P_i}{E_i} + \varepsilon_i \tag{38}$$



(a) Shift Only



(b) Stresses Reduced Proportionately, Moduli Unchanged



(c) Stresses Reduced Proportionately, Strain Increments Unchanged

JA-6391-58A

FIGURE 3 THREE DESCRIPTIONS OF THE UNLOADING PROCESS PROVIDED BY THE SSONED MODEL

where P_{max} is the highest pressure reached before the current unloading and P_i is the pressure at an unloading node just above P_{max}. The strain at P_{max} is ε_{max}. Then the appropriate pseudo strain is

$$\varepsilon_Q = \varepsilon + \frac{P_{max} - P_i}{E_i} + \varepsilon_i - \varepsilon_{max} \tag{39}$$

This expression is also satisfactory for unloading from pressures above the provided peak and for continuing into tension.

For type 2 unloading the peak point $(P_k \varepsilon_k)$ of the provided loading curve governs. The unloading curve is constructed by reducing the pressures at nodes and the strain increments by the ratio P_{max}/P_k. The pseudo strain ε_Q is readily obtained by computing the incremental reduction from ε_k:

$$\varepsilon_Q = \varepsilon_k + \frac{P_k}{P_{max}} (\varepsilon - \varepsilon_{max}) \tag{40}$$

where ε_k is the volumetric strain at the peak point of the provided loading curve.

With type 3 unloading the strain increment sizes are preserved. Therefore, the expression is like that in Eq. 40, but without the ratio factor

$$\varepsilon_Q = \varepsilon_k + \varepsilon - \varepsilon_{max} \tag{41}$$

With these special definitions of the pseudo strain, all three unloading types can be treated in a common fashion.

It is advisable to plot the loading curve and unloading curves from several nodes to decide whether the behavior is reasonable. Under some circumstances the unloading curves can cross the loading curves or otherwise provide for physically unreasonable behavior.

D. Model for an Explosive (Subroutine EXPLODE)

At the time of detonation, the chemical energy of an explosive is transformed into internal energy. This energy places the state for the material at a point on the equation-of-state surface termed the "constant-volume explosion" state. Subsequent motions of the material usually allow it to expand along the unloading isentrope that passes through the constant-volume explosion point.

For the ONED calculations, a very simple procedure is available for representing explosions. Only the isentrope must be provided. Then, at the beginning of the calculation, the pressure in the explosive jumps to the constant-volume explosion point on the isentrope. Subsequent rarefaction waves in the explosive allow the pressure to reduce along the isentrope in a natural fashion. The isentrope can be provided in two ways: with the analytical form for a polytropic gas or as a series of pressure-volume points.

The polytropic gas has the following expression for an isentrope:

$$PV^{\gamma} = \text{constant} = P_{CJ}\, V_{CJ}^{\gamma} \tag{42}$$

where γ is the gas constant = $\Gamma + 1$, and P_{CJ} and V_{CJ} are the pressure and specific volume at the Chapman-Jouguet point. The input quantities used to define the pressure-volume isentrope are the chemical energy Q and the Grüneisen ratio Γ. From these two quantities and the initial density ρ_o, the detonation velocity D_x and quantities at the C-J point can all be determined.

$$D_x = \sqrt{2Q(\gamma + 1)(\gamma - 1)} \tag{43}$$

$$P_{CJ} = 2Q(\gamma - 1)\, \rho_o \tag{44}$$

$$V_{CJ} = \frac{\gamma}{\rho_o(\gamma + 1)} \tag{45}$$

$$E_{CJ} = \frac{2Q\gamma}{\gamma + 1} \tag{46}$$

$$u_{CJ} = \sqrt{\frac{2Q(\gamma - 1)}{\gamma + 1}} \tag{47}$$

where E_{CJ} and u_{CJ} are internal energy and particle velocity, respectively. The quantities P_{CJ}, V_{CJ}, and D_x are computed in the subroutine EXPLODE during initialization. Then Eq. (42) is used to determine the pressure during calls by CMPUTE. The parameters of the C-J point are convenient for characterizing the explosives because these data are usually available; however, the C-J state is not normally reached in constant-volume explosion calculations.

The sound speed on the isentrope is given by

$$C = \sqrt{\gamma P/\rho} \tag{48}$$

The sound speed is computed at each call to aid in the time-step calculation.

IV INITIALIZATION

The READIT subroutine is called once at the beginning of each problem to read in all the data and initialize the COMMON storage. The sequence of major operations conducted by this subroutine is

- Call ZERO to zero the main arrays.
- Read general running instructions for the problem.
- Read properties for each material.
- Lay out a coordinate grid over all the materials.
- Initialize the coordinate and cell arrays, including the geostatic stress.
- Print initial coordinate and cell values.

A sample input file is shown in Figure 4. All the input quantities are provided by the user in free-field format, except for the first three lines of comments and the title. The input quantities are generally in English units; lengths in feet or inches, density in pounds per cubic foot, pressure in psi, and time in seconds. The exception is the Q or chemical energy of explosives in erg/g. The input quantities are explained in the next subsections, and some guidance for selecting values is provided. Please refer to the Glossary (Appendix B) for definitions of the terms.

A. Input of General Control Information

The first group of data identifies the computation and controls the type of simulation, the amount of printing and plotting, and the numbers of layers of materials.

The first three lines describe the computation. The first two lines should begin after column 5. The third line contains an identifying

```
      FIRST TRIAL OF MODIFIED ONED WITH DATA, USING ZELASKO'S INPUT FOR
      DISKO 2, MODIFIED FORM TO FIT THE SRI ONED.
    1 DISKO 2 FOR WES, ONED TRIAL WITH AN EXPLOSIVE LAYER
998, 0, 0.0035, 10, 1.  NOCOMP, BOTTOM BOUNDARY INDICATOR, TEND, NSTOP, GACC
6, 0, 0, 0, 5, 0,          NLAYRS, MISP, NSP, MATTEN, NMTRLS, NFORCE
11, 1,3,0,0,0,0,0, 1, 1, 1, 1, 0.005  NNODE,KNTROL(7),NHIST,MVT,NSV,KVEL,TND
1.333, 2.9, 3.3, 3.8, 3.9, 4.0, 4.44, 5.44, 6.44, 7.44, 8.44 DEPTHS FOR HIST.
1000., 0.0, 60., 0., 0., 0., 0.    SK (7)

'CLAY',128.,0.05, 4., 0.,1,0,0,2    GAM,DAMP,TENSN, POR,PR,SOL,VAR  FOR CLAY
0., 0., 0.    SHMOD, YIELD, TANPHI
3, 1, 'MODU',  'STRA', 6.914627E4, 1.   KFIN, NTYPE, LPRESS, LDENS, PUNIT, DUNIT
39750., 993750., 993750.      CLAY BERM MODEL, MODULI
100., 0., STRAINS

'PLYWUD',42.,0.05,4., 0.,1,0,0,2    GAM, DAMP, TENSN, POR, PR, SOL, VAR
0., 0., 0.    SHMOD, YIELD, TANPHI
8, 1, 'MODU',  'STRA', 6.914627E4, 1.   KFIN, NTYPE, LPRESS, LDENS, PUNIT, DUNIT
65000., 16000., 8000., 18000., 21500., 30000., 2.E5, 2.E5, PLYWOOD, MODULI
1.0, 2.5, 7., 9.5, 12.75, 100., 0.0,    STRAINS

'FOAM',1.25, 0.05, 4., 1.5, 1,0,0,2  GAM,DAMP,TENSN, POR,PR,SOL,VAR FOR FOAM
0., 0., 0.    SHMOD, YIELD, TANPHI
10, 1, 'MODU',  'STRA', 6.914627E4, 1. KFIN, NTYPE, LPRESS, LDENS, PUNIT, DUNIT
72.73, 1891., 41., 1654., 7.5E4, 7.5E4, 75000., 40000., 14000., 14000.,FOAM, MOD
55., 92.0, 3260., 4892.,   5000., 5100., 5064., 5058.,5052., STRAINS.

'SAND',106.3, 0.1, 4.,0.0,1,0,0,2   GAM,DAMP,TENSN, POR,PR,SOL,VAR FOR SAND
1.36E+9, 1.0E+4, 0.274    SHMOD, YIELD, TANPHI
7,3,'P','D',1.,1.0          SSONED:    KFIN,NTYPE,LPRESS,LDENS,PUNIT,DUNIT
4.E7, 7.E7, 1.7E8, 4.5E8, 1.E9, 0.,  FLUME SAND, P, DYN/CM^2 (K=2.92E9)
1.7268, 1.7458, 1.793, 1.893, 2.065, 2.023       DENSITIES, G/CM^3

'EXPL1', 2.7406, 0.05, 4.,0.0, 0, 1, 0, 0 GAM,DAMP,TENSN, POR,PR,SOL,VAR (EXPL)
0., 0., 0.    SHMOD, YIELD, TANPHI
'POLY', 4.5E10, 0.2     Q AND GAMMA

'OVERBDN',  95.035, 0.1, 4., 0.0, 1,0,0,2 GAM, DAMP, TENSN, POR, PR, SOL, NVAR
1.36E+9, 1.0E+4, 0.274    SHMOD, YIELD, TANPHI
10,1,'P','D',1.E7,1.0          SSONED:    KFIN,NTYPE,LPRESS,LDENS,PUNIT,DUNIT
 8., 39., 69., 122., 230., 400., 100., 30., 0., SAND OVERBDN MODEL, PRESS., MPA
 1.603,1.792,1.904,2.031,2.176,2.343,2.290,2.256,2.207 DENSITIES

2.6667,  3.0, 0, 6     SAND OVERBURDEN
3.0417,  1.0, 0, 5     EXPLOSIVE
3.7917,  1.0, 0, 1     CLAY LAYER    DB, SPL, NSP, M
3.8547,  1.0, 0, 2     PLYWOOD LAYER
3.9387,  0.5, 0, 3     FOAM
9.9387   1.0, 0, 4     SAND TEST BED
```

Comments and Title

General Running Controls

Clay Properties

Plywood Properties

Polyurethane Foam Properties

Sand Properties

Explosive

Overburden Soil

Layers and Cells

Notes: The blank lines between materials were introduced for readibility.
They must not appear in the input file.

JA-6391-59

FIGURE 4 SAMPLE INPUT FOR AN ONED SIMULATION OF WAVE PROPAGATION THROUGH LAYERS OF CLAY, PLYWOOD, FOAM, AND SAND (DISKO-2)

number in column 5 and is alphanumeric thereafter. This third line is printed as a title with the remainder of the output.

The fourth line contains the parameters NOCOMP, LB, TEND, NSTOP, and GACC. NOCOMP controls the plotting process. For a calculation with NOCOMP greater than or equal to 999, the input stops and the results from a previous run are plotted. LB gives the boundary condition at the bottom of the last layer. LB is zero for a free boundary and 1 for a rigid boundary: neither condition represents the continuum of material below a test region. Therefore, sufficient distance should be provided below the region of interest so that no waves reflected from the bottom can return to the region of interest during the calculation time. TEND is the termination time of the calculation and NSTOP is the total number of time increments. The program halts when either of these stop parameters is reached. GACC is an indicator for the geostatic stress; a nonzero value causes initialization of a geostatic stress and use of a gravity loading throughout the computation.

The fifth line contains NLAYRS, MISP, NSP, MATTEN, NMTRLS, and NFORCE; these control layering, materials, and loading. NLAYRS is the number of layers, and MISP and NSP are indicators controlling the method of computing the cell sizes in each layer. MATTEN is an indicator that can allow ONED to approximate spherical attenuation and dispersion. NMTRLS is the number of materials; the number of materials need not correspond with the number of layers. NFORCE is the number of pressure-time points in the loading history; NFORCE = 0 is used for an explosive loading in which the explosion process is simulated.

The sixth line provides a series of plot and print controls: NNODE, KNTROL(7), NHIST, MVT, NSV, KVEL, and TNDPLT. NNODE is the number of nodes or cells at which histories are required, and KNTROL (7 parameters) controls the types of plots generated for each of those nodes. NHIST is the frequency for listing the array values at these nodes (the listing occurs every NHIST time steps). See Appendix B for KVEL and TNDPLT.

The seventh line contains the depths (in feet) at which the plots and printouts are required. There are NNODE of these depths.

The eighth line contains the scale factors SK(7) for the requested plots.

B. Material Property Input

In the present version of ONED, the information for the materials and for the layers is inserted separately. Therefore, although a material appears in several layers, it is only necessary to insert its properties once. Conversely, a material may appear in the data input but not be used for any layer.

For each material two lines of data are read by READIT. The first of these lines gives NAME, GAM, DAMPL, DAMPQ, TENSN, NPOR, NPR, NSOL, and NVAR. NAME is an eight-letter alphanumeric identifier for the material and GAM is its initial density in pounds per cubic foot. DAMPL is the coefficient of linear artificial viscosity. A value of 0.05 is appropriate for an elastic solid, but larger values, such as 0.15 to 0.5, should be used for porous materials. DAMPQ is the coefficient of quadratic artificial viscosity. A value of 4 is used for solids, but values up to 100 can be used for porous materials. The appropriate values of the viscous coefficients for each material and stress level are determined by trial calculations. The "best" values of DAMPL and DAMPQ allow the calculation to meet two criteria:

- Slight oscillations occur in the stress and velocity histories near the shock fronts and do not occur elsewhere.

- During a shock loading at a point in the material, the series of total stress, specific volume (RMECH,1/DENS) points from the initial state to the shocked state approximate a straight line in stress-volume space.

Excessive damping eliminates oscillations, increases the rise time of shock fronts, and causes a stress-volume curve that is convex upward. Too little damping will cause serious oscillations in the histories and may even cause cell distortions that can halt the calculation.

TENSN is the tensile strength. For TENSN set to zero, no strength criterion is used (i.e., infinite tension stress is allowed).

NPOR, NPR, and NSOL are a set of indicators for the type of material model to be used. Currently, only one material model of each type is provided:

NPOR = 1: porous model, subroutine SSONED

NPR = 1: explosive model, subroutine EXPLODE

NSOL = 1: solid model, subroutine EQST.

As more models are generated and inserted, they can be designated by NPOR = 2, NPR = 2, and so forth. Separate designators are used for each type of model so that combined models can be used. A combined model could describe a porous material that compacts to a solid or an explosive that begins as a solid.

NVAR is the number of extra variables provided for each cell of the material. The extra variables are stored in the COM array. The first extra variable for the Jth cell is at location L = LVAR(J); that is, at COM(L). Of the current models, SSONED requires two extra variables and the others require none. If histories of nonarray quantities are desired for any model, a simple coding change can allow storage of these in the COM array for later printing and plotting.

The second line read by READIT contains the shear modulus SHMOD, yield strength YIELD, and tan ϕ TANPHI. These parameters control the deviator stress model used. SHMOD and YIELD are input in dyn/cm^2.

The remainder of the material properties for each model are read by that model subroutine.

1. Input for the Porous Model SSONED

The input required for the porous model SSONED defines the pressure-volume relations to be used for loading and unloading. Three lines or more are read to provide the necessary properties.

The first line contains a series of control parameters needed for interpreting the remaining input: KFIN, NTYPE, LPRESS, LDENS, PUNIT, DUNIT. KFIN is the number of pressure-strain segments used to define the loading and unloading curves. The pressure-strain curves can be entered

using pressures or moduli, and strain or density. In each case only KFIN-1 values are required: the first pressure and strain values are taken to be zero, the initial density is GAM, and there are only KFIN-1 intervals for moduli.

NTYPE gives the type of unloading process as described in Section III and shown in Figure 3.

The indicators LPRESS, LDENS, PUNIT, and DUNIT control the interpretation of the pressure-strain values read in next. LPRESS and LDENS are labels with the possible values "D", "M", "P", and "S"; these indicate whether density, modulus, pressure, or strain quantities will be read in. PUNIT and DUNIT are conversion factors to transform pressures and moduli to dyn/cm^2 and densities to g/cm^3.

The next lines contain the values defining the pressure-strain path during loading and unloading for the porous material. The meaning of these quantities is indicated in Figure 3.

2. Input for the Explosive Model EXPLODE

The model for an explosive can be prescribed in two ways. In the first method the explosive products are a polytropic gas specified by the standard polytropic gas equation. The only required input quantities are Q and Γ. All other properties of the material can be found from Eqs. 42 through 48. The single line read by EXPLODE contains LABEL, Q, and Γ. LABEL is an alphanumeric label of three letters.

The second means of specifying an explosive is to provide a pressure-volume series to define the unloading isentrope for the explosive products. To indicate the use of the pressure-volume series, the LABEL parameter is 'TAB' for a tabular equation of state. In this case Q and Γ have no meaning. Following this line, are a series of lines read by EOSTAB (the tabular equation-of-state subroutine), which is called by EXPLODE.

The first line read by EOSTAB contains IMAX, LABEL, and TYPE. IMAX is the number of pressure-volume (or pressure-density) values in the

series defining the isentrope. LABEL is an alphanumeric label indicating whether densities or volumes are being presented. The default value is 'DENSITY'. If volumes are used, read in 'VOLUME'. TYPE determines whether the interpolation between successive points in the series is linear or logarithmic. Logarithmic interpolation should be used, so TYPE should be set to 'LOG'.

Subsequent lines of the input for EOSTAB contain pairs of density (or volume) and pressure. The units for these are g/cm^3 (or cm^3/g) and dyn/cm^2 because properties for explosives are usually given in these units. The points can be inserted in order of ascending or descending pressure; the subroutine determines which order is being used.

3. Input for the Solid Model, EQST

The solid model EQST requires parameters to define the Hugoniot curve. These quantities are RHO, EQSTC, EQSTD, and EQSTS, which are given in a single line. These correspond to ρ_o , C, D, and S of Eq. (14).

The EXPLODE model can also be used to represent a nonexplosive gas, such as air. Figure A-2 shows a sample of this treatment. The Q is simply chosen so that the pressure from Eq. (42) is the desired ambient value.

C. Layering

The dimensions and sequencing of the layers and cells are provided next in a series of lines, one line per layer. NLAYRS, the total number of layers including gaps, was read in under the general control information. For each of these layers the user specifies the layer thickness, the material of the layer, and the method for dividing the layer into cells. The layer thickness is provided by the depth of the bottom of the layer in feet. The material number for the layer is M, meaning that it was the Mth material described. For a gap, M = 0.

The cell sizes are given by a combination of three parameters: MISP, NSP, and SPL. Uniform cell sizes can be specified in two ways:

(1) MISP = 0, SPL = cell size in inches.

(2) MISP = 2, NSP = the number of equal size cells.

If nonuniform cell sizes are desired, MISP can be set to 1 and NSP to the number of cells. Then the cell size for each cell is read into the SP() array.

For accurate calculations the cells should be laid out with care. The following rules are suggested as means for obtaining good results:

- A single cell can be used to represent the presence of a material, but it can provide no information about the wave shape within that material and very little information on the travel time through the material. Five cells in a material can define the presence of the material and its dimensions, but give little information about the wave reverberations within that material. Twenty cells will provide the reverberations also in the material. For judging the appropriate cell sizes and numbers for a problem, it is often necessary to perform a preliminary calculation and examine the resulting wave shapes. For more sharply defined wave fronts, the number of cells should be increased.

- For porous materials, more cells should be provided than would normally be necessary for a solid material.

- Rise times of stress waves are equal to about four traverse times for the cells. Hence, the definition of the stress history can be used as a basis for defining acceptable cell sizes.

- The cell sizes in adjacent layers should be matched so that the propagation times across cells are approximately the same. This propagation time is given by

$$\Delta T = \Delta X/C \tag{49}$$

where ΔX is the cell thickness and C is the nominal sound speed. For a porous material, many possible definitions are available for the sound speed. Here the appropriate value of C is that associated with the main compaction wave. Hence, given the stress-strain relation and an estimate of the peak stress, we can determine the location of the Rayleigh line. From this line, we can find the sound speed C.

$$C^2 = \frac{P/\rho_o}{1 - \rho_o/\rho} \tag{50}$$

In some cases of large compaction it may be necessary to perform a preliminary calculation and revise the cell sizing based on the results of this first calculation.

For nonuniform cells, the sizes should not be allowed to change more than about 5% between cells within a single material.

D. Geostatic Stress Initialization

In the revised ONED the geostatic stress is initialized in detail and the gravity effect is maintained throughout the calculation. The geostatic effect is indicated by providing a nonzero value of GACC. Then READIT computes the overburden for each cell at its center, assuming that X increases in the downward direction. With the overburden stress GEOSTR, READIT computes the strain caused in the cell to reach the overburden stress in the cell. For computing the geostatic stress, READIT calls the various stress-strain subroutines. The strain results in a changed density. The changed density modifies the overburden so the geostatic stress is determined by iteration in each cell. The number of iteration trials is output by the code (see next section). Thus, the initialized material shows a gradually increasing density with depth. The geostatic stress is presumed to affect the pressure only and not the deviatoric stress.

V PRINTED OUTPUT: READIT, HISTRY, SCRIBE, CMPUTE, AND VALMAX

Several types of printed output are provided during and at the conclusion of a calculation. During the reading of the input, the input values are printed by READIT with some additional comments. The material property subroutines read their own input and provide printout. After the input is read, a layout listing is given by READIT. During the calculation, several listings of the layout with current cell variables are made by HISTRY (on a call from CMPUTE) and from CMPUTE. A VALMAX listing of maximum values is made at the end of the calculation. The SCRIBE subroutine is called by ONED to print historical listings of all requested variables.

Samples of the output are presented for simulations of the DISKO-1 event[8]. Three sets of input for the problem are given in Figures A-1 through A-3.

The input of the general control information in Figure A-2 is reflected in the listing of the quantities in Figure 5 from READIT. These parameters are also defined in the Glossary in Appendix B.

Listings of two sets of data for porous materials are shown in Figure 6. The first three lines in each set are written in READIT and reflect the information read by READIT. These lines are common to all types of material models. The next lines are written by SSONED and are specific to porous materials. The first of these contains the control parameters and indicators for SSONED: KFIN, the number of pressure-strain points on the loading and unloading path; NTYPE, the type of unloading requested (see Figure 3); LPRESS and LDENS, labels for the specified values on the paths; and the calibration factors PUNIT and DUNIT. To the right on the line are MAT, THE MATERIAL NUMBER, AND RHOS, the initial density in g/cm^3. The next two to four lines contain the pressure (or modulus) and strain (or density) values on the loading and unloading path. Finally there are six lines in which the pressures,

```
ONED: A ONE-DIMENSIONAL WAVE PROPAGATION SOLUTION IN PIECEWISE LINEAR HYSTERETIC MATERIAL

TEST OF SRI ONED TO SIMULATE THE DISKO-1 EVENT, FINAL SET OF DATA
[B6391.ONED]DISKO1E.OND IS DATA, [*.*]RONED.COM, [*.*]MONED.EXE
   DISKO 1 FOR WES, ONED SIMULATION OF THE EXPLOSIVE LAYER.

PROBLEM NUMBER    1


COMPUTATION CONTROLS

NOCOMP  =  998        PLOT AT INPUT SCALE FACTORS
LB      =    0        INFINITE BOTTOM BOUNDARY
TEND    =   4.000E-03 END OF PROBLEM TIME (SEC)
NSTOP   =  400        TOTAL NUMBER OF STEPS
GACC    =   9.815E+02 ACC OF GRAVITY FOR GEOSTATIC EFFECT


INPUT CONTROLS

NLAYRS  =    4        NUMBER OF LAYERS
MISP    =    0        SPACING CONST W/IN EACH LAYER
MATTEN  =    0        ALPHA(I) = 1 FOR EVERY NODE
NMTRLS  =    4        NUMBER OF MATERIALS
NFORCE  =    0        NUMBER OF PRESSURE-TIME PTS.


OUTPUT CONTROLS

KNTROL1 =    1        STRESS - TIME PLOT
KNTROL2 =    3        PART. VEL. - TIME PLOT
NHIST   =  100        GROUND MOTIONS PRINTED EVERY 'NHIST' TIME INCREMENTS
MVT     =    1        MAX VALUE TABLE PRINTED
NNODE   =    7        NUMBER OF OUTPUT NODES
TNDPLT  =   0.0040    END OF PLOT TIME (SEC)
KVEL    =    1        OUTPUT PARTICLE VELOCITIES IN M  /SEC


SCALE FACTORS ARE     1000.0      0.0      60.0      0.0      0.0      0.0      0.0
```

FIGURE 5 LISTING FROM READIT OF GENERAL CONTROL INFORMATION USED IN ONED SIMULATION OF DISKO-1 USING AN EXPLICIT TREATMENT OF THE EXPLOSIVE LAYER

JA-6391-60

```
          MATERIAL NUMBER   1
MATERIAL IS SAND     DENS= 106.30000 DAMPL,Q= 1.000E-01 4.000E+00 TENSN= 0.000E+00 NPOR= 1 NPR= 0 NSOL= 0 NVAR= 2
SHMOD= 1.360E+09 YIELD= 1.000E+04 TANPHI= 2.740E-01
KFIN=  7 NTYPE=  3 LPRESS= PRES LDENS= DENS PUNIT= 1.00000E+00 DUNIT= 1.00000E+00 MAT=  1 RHOS= 1.70277E+00 FROM -SSONED-
   4.000E+07 7.000E+07 1.700E+08 4.500E+08 1.000E+09 0.000E+00
   1.727E+00 1.746E+00 1.793E+00 1.893E+00 2.065E+00 2.023E+00
      MAT'L = 1          -------------------------- LOADING AND UNLOADING --------------------------
      PT    =                 1          2          3          4          5          6          7
      STRAIN (%) =     0.0000     1.4114     2.5273     5.2992    11.1720    21.2732    18.8067
      DENS(G/CM3)=  1.702767  1.726800  1.745800  1.793000  1.893000  2.065000  2.023000
      PRESS(PSI) = 0.000E+00 5.801E+02 1.015E+03 2.466E+03 6.527E+03 1.450E+04 0.000E+00
      MODULI (PSI) =    4.110E+04 3.899E+04 5.232E+04 6.915E+04 7.897E+04 5.880E+05 0.000E+00


          MATERIAL NUMBER   4
MATERIAL IS OVERBDN  DENS=  95.03500 DAMPL,Q= 1.000E-01 4.000E+00 TENSN= 0.000E+00 NPOR= 1 NPR= 0 NSOL= 0 NVAR= 2
SHMOD= 1.360E+09 YIELD= 1.000E+04 TANPHI= 2.740E-01
KFIN= 10 NTYPE=  1 LPRESS= PRES LDENS= DENS PUNIT= 1.00000E+07 DUNIT= 1.00000E+00 MAT=  2 RHOS= 1.52232E+00 FROM -SSONED-
   8.000E+00 3.900E+01 6.900E+01 1.220E+02 2.300E+02 4.000E+02 1.000E+02 3.000E+01
   0.000E+00
   1.603E+00 1.792E+00 1.904E+00 2.031E+00 2.176E+00 2.343E+00 2.290E+00 2.256E+00
   2.207E+00
      MAT'L = 4          -------------------------- LOADING AND UNLOADING --------------------------
      PT    =                 1          2          3          4          5          6          7          8          9         10
      STRAIN (%) =     0.0000     5.2999    17.7152    25.0724    33.4150    42.9399    53.9100    50.4285    48.1950    44.9763
      DENS(G/CM3)=  1.522318  1.603000  1.792000  1.904000  2.031000  2.176000  2.343000  2.290000  2.256000  2.207000
      PRESS(PSI) = 0.000E+00 1.160E+03 5.656E+03 1.001E+04 1.769E+04 3.336E+04 5.801E+04 1.450E+04 4.351E+03 0.000E+00
      MODULI (PSI) =    2.189E+04 3.621E+04 5.914E+04 9.214E+04 1.645E+05 2.248E+05 1.250E+06 4.546E+05 1.352E+05 0.000E+00
```

FIGURE 6 LISTING OF MATERIAL PROPERTY INFORMATION FOR POROUS MATERIALS: THREE LINES FROM READIT AND THE REMAINDER FROM SSONED

JA-6391-61

moduli, strains, and densities are listed in a standard array. This listing is intended to assist users in catching errors in the prescription of the path.

Sample output of the material data for gaseous material is shown in Figure 7. As for porous materials, the first three lines are standard data written by READIT. The next two lines are written by EXPLODE. The first line contains a label "POL" for polytropic and two numerical values: Q and Γ (explosive energy in erg/g and the Grüneisen ratio). The last line, starting with "CONST.VOL...." lists the chemical energy Q, Chapman-Jouguet (C-J) detonation pressure, specific volume at the C-J point, Grüneisen ratio, and the square of the detonation velocity.

The layering information is listed by READIT with the cell layout data, as shown in Figure 8. The input quantities (see Figure 4) are DB, the distance in feet to the bottom of the layer; SPL, the cell size in inches; NSP, the number of cells; and the material number M. The cell listing contains the cell number J, the node position X in cm, the cell size SPL in cm, the density in g/cm^3, the stress σ_1 (geostatic) in dyn/cm^2, the cell mass per unit area in g/cm^2, tensile strength in dyn/cm^2, material number M, the material name, and the location in the COM array of extra variables. The number of trials used in the iteration to compute the geostatic stress is listed on the right. In this listing, it is apparent that there is a zero-mass cell at the end of each layer. This unused cell permits double nodes to occur at interfaces between materials. The double nodes permit a simple separation process between layers and also allows the user to initialize the layout with a gap between layers.

A second listing of this layout information is provided in the upper part of Figure 9. This listing is like the layout given in the earlier version of ONED. Also in Figure 9 is a short listing of the cells or nodes at which historical information is requested.

During a calculation, two types of snapshot listings are provided to show stresses and other quantities in the cells and nodes at certain times. Both are triggered when NSTEP is a multiple of NHIST. Samples of

```
          MATERIAL NUMBER   2
MATERIAL IS EXPL1     DENS=   2.74060 DAMPL,Q= 5.000E-02 4.000E+00 TENSN= 0.000E+00 NPOR= 0 NPR= 1 NSOL= 0 NVAR= 0
SHMOD= 0.000E+00 YIELD= 0.000E+00 TANPHI= 0.000E+00
POL   4.500E+10 2.000E-01
  CONST.VOL.EXPLOSION WITH ENERGY= 4.500E+10 ERG/G, PCJ = 7.902E+08 VCJ = 1.24248E+01 GRUN = 2.00000E-01 SPEED2= 3.960E+10

          MATERIAL NUMBER   3
MATERIAL IS AIR       DENS=   0.07295 DAMPL,Q= 5.000E-02 4.000E+00 TENSN= 0.000E+00 NPOR= 0 NPR= 1 NSOL= 0 NVAR= 0
SHMOD= 0.000E+00 YIELD= 0.000E+00 TANPHI= 0.000E+00
POL   2.139E+09 4.000E-01
  CONST.VOL.EXPLOSION WITH ENERGY= 2.139E+09 ERG/G, PCJ = 2.000E+06 VCJ = 4.99222E+02 GRUN = 4.00000E-01 SPEED2= 4.107E+09
```

FIGURE 7 LISTING OF MATERIAL PROPERTY INFORMATION FOR EXPLOSIVES AND GASES: THREE LINES FROM READIT AND TWO FROM EXPLODE

JA-6391-62

LISTING OF THE LAYOUT
DISKO 1 FOR WES, ONED SIMULATION OF THE EXPLOSIVE LAYER. 20-JAN-86

J	X	SPL	DENSITY	SIG1	CELMAS	TENS	M	NAME	LVAR	TRIALS
1	0.000E+00	2.540E+00	1.522320	1.898E+03	3.867E+00	0.000E+00	4	OVERBD	1	3
2	2.540E+00	2.540E+00	1.522324	5.693E+03	3.867E+00	0.000E+00	4	OVERBD	3	3
3	5.081E+00	2.540E+00	1.522328	9.489E+03	3.867E+00	0.000E+00	4	OVERBD	5	3
	Omitted in the Figure									
31	7.621E+01	2.540E+00	1.522435	1.158E+05	3.867E+00	0.000E+00	4	OVERBD	61	3
32	7.875E+01	2.540E+00	1.522439	1.196E+05	3.867E+00	0.000E+00	4	OVERBD	63	3
33	8.129E+01	2.540E+00	0.000000	0.000E+00	0.000E+00	0.000E+00	0	OVERBD	0	0

LISTING OF THE LAYOUT
DISKO 1 FOR WES, ONED SIMULATION OF THE EXPLOSIVE LAYER. 20-JAN-86

J	X	SPL	DENSITY	SIG1	CELMAS	TENS	M	NAME	LVAR	TRIALS
34	8.129E+01	3.810E-01	0.043900	1.215E+05	1.673E-02	0.000E+00	2	EXPL1	0	1
35	8.167E+01	3.810E-01	0.043900	1.215E+05	1.673E-02	0.000E+00	2	EXPL1	0	1
36	8.205E+01	3.810E-01	0.043900	1.215E+05	1.673E-02	0.000E+00	2	EXPL1	0	1
	Omitted in the Figure									
43	8.472E+01	3.810E-01	0.043900	1.216E+05	1.673E-02	0.000E+00	2	EXPL1	0	1
44	8.510E+01	3.810E-01	0.000000	0.000E+00	0.000E+00	0.000E+00	0	EXPL1	0	0

LISTING OF THE LAYOUT
DISKO 1 FOR WES, ONED SIMULATION OF THE EXPLOSIVE LAYER. 20-JAN-86

J	X	SPL	DENSITY	SIG1	CELMAS	TENS	M	NAME	LVAR	TRIALS
45	8.510E+01	7.620E+00	0.001168	1.216E+05	8.904E-03	0.000E+00	3	AIR	0	1
46	9.272E+01	7.620E+00	0.000000	0.000E+00	0.000E+00	0.000E+00	0	AIR	0	0

LISTING OF THE LAYOUT
DISKO 1 FOR WES, ONED SIMULATION OF THE EXPLOSIVE LAYER. 20-JAN-86

J	X	SPL	DENSITY	SIG1	CELMAS	TENS	M	NAME	LVAR	TRIALS
47	9.272E+01	1.016E+00	1.702840	1.225E+05	1.730E+00	0.000E+00	1	SAND	65	3
48	9.374E+01	1.016E+00	1.702841	1.242E+05	1.730E+00	0.000E+00	1	SAND	67	3
49	9.475E+01	1.016E+00	1.702842	1.259E+05	1.730E+00	0.000E+00	1	SAND	69	3
	Omitted in the Figure									
296	3.457E+02	1.016E+00	1.703094	5.453E+05	1.730E+00	0.000E+00	1	SAND	563	3
297	3.467E+02	1.016E+00	0.000000	0.000E+00	0.000E+00	0.000E+00	0	SAND	0	0

FIGURE 8 PARTIAL LISTING OF THE LAYER, NODE, AND CELL INFORMATION FROM READIT FOR THE ONED SIMULATION OF DISKO-1 WITH AN EXPLICIT TREATMENT OF THE EXPLOSIVE LAYER

JA-6391-63

DISKO 1 FOR WES, ONED SIMULATION OF THE EXPLOSIVE LAYER. 20-JAN-87

LAYER PROPERTIES

LAYER NUMBER	NODES	BOTTOM (FT)	GAMMA (PCF)	PCRIT (%)	SPACING (IN)	TENSION (PSI)
1	1 - 33	2.6670	95.04	0.10	1.0001	0.000E+00
2	34 - 44	2.7920	2.74	0.05	0.1500	0.000E+00
3	45 - 46	3.0420	0.07	0.05	3.0000	0.000E+00
4	47 - 298	11.3750	106.30	0.10	0.4000	0.000E+00

OUTPUT DESIRED AT

DEPTH(ft)	NODE
3.1420	50
3.5420	62
4.5420	92
5.5420	122
6.5420	152
7.5420	182
8.5420	212

FIGURE 9 LISTING OF THE LAYOUT AND DEPTHS AT WHICH HISTORIES ARE REQUESTED FOR THE ONED SIMULATION OF DISKO-1 WITH AN EXPLICIT TREATMENT OF THE EXPLOSIVE LAYER

JA-6391-64

both these snapshot listings are shown in Figures 10 and 11. The listed quantities in Figure 10 include position X in cm, velocity VEL in cm/s, the mechanical stress RMECH in the direction of propagation in dyn/cm^2, thermodynamic stress SIG1 in dyn/cm^2, the artificial viscous stress DSTRS in dyn/cm^2, the pressure in dyn/cm^2, the density DENS in g/cm^3, the sound speed SSPEED in cm/s, the deviator stress SIGDEV in the direction of propagation in dyn/cm^2, and the yield strength Y in dyn/cm^2.

The second snapshot listing, shown in Figure 11, is similar to that obtained in the original version of ONED. This listing provides most of the same quantities, but only for the requested nodes and cells. The applied pressure at the surface, the mechanical stress RMECH, thermodynamic stress SIG1 and the damping stress are in psi. The compressive strain is in percent, acceleration in g's, particle velocity in m/s or in/s (depending on the setting of the indicator KVEL), and the node location in cm or inches (depending on KVEL).

At the end of the calculation, a summary is given of the maximum values that have occurred at all depths. Such a summary is shown in Figure 12. The listed quantities include the depth to the node, the mechanical stress RMECH, the velocity, coordinate position, strain in the cell, and acceleration. The depth, velocity, position, and acceleration pertain to the node J, and the other quantities refer to the following cell. In each case the time at which the maximum quantity occurred is also shown.

The final listing shows a history of some quantities at the requested nodes. A portion of one of these listings from SCRIBE (part of HISTRY) is given in Figure 13. The quantities are RMECH in psi, the acceleration in g's, the velocity in m/s, position in in., strain in percent, impulse in dyn-s/cm^2, and the stress in the first and second principal directions in MPa. The impulse is obtained as the integral of stress RMECH over time at the cell:

$$I = \int_{o}^{t_n} R \, dt \tag{51}$$

DISKO 1 FOR WES, ONED SIMULATION OF THE EXPLOSIVE LAYER. 23-JAN-86

SNAPSHOT AT NSTEP = 400, TIME = 1.03428E-03

J	MAT	L	X CM	VEL CM/SEC	RMECH DYN/CM2	SIG1 DYN/CM2	DSTRS DYN/CM2	PRESS DYN/CM2	DENS G/CM3	SSPEED CM/SEC	SIGDEV DYN/CM2	Y DYN/CM2
1	4	1	8.44917E-07	3.96159E-04	6.043E+02	6.043E+02	5.664E-05	1.298E+00	1.522321	8.552E+04	6.030E+02	1.000E+04
J = 2 to 31 were omitted from the Figure. MAT 4 is the Overburden.												
32	4	63	7.67864E+01	-1.68039E+03	5.639E+07	5.639E+07	0.000E+00	4.755E+07	1.647572	8.220E+04	8.839E+06	1.000E+04
33	0	0	7.91338E+01	-1.48328E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000000	0.000E+00	0.000E+00	0.000E+00
34	2	0	7.91338E+01	-1.48328E+03	6.816E+07	6.816E+07	0.000E+00	6.816E+07	0.010444	8.850E+04	0.000E+00	0.000E+00
J = 35 to 43 were omitted from the Figure. MAT 2 is Primacord Explosive.												
42	2	0	9.12713E+01	2.20655E+03	8.352E+07	8.340E+07	1.207E+05	8.340E+07	0.012357	9.000E+04	0.000E+00	0.000E+00
43	2	0	9.26249E+01	1.74489E+03	8.489E+07	8.474E+07	1.450E+05	8.474E+07	0.012522	9.012E+04	0.000E+00	0.000E+00
44	0	0	9.39606E+01	1.21503E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000000	0.000E+00	0.000E+00	0.000E+00
45	3	0	9.39606E+01	1.21503E+03	8.488E+07	8.488E+07	6.415E+01	8.488E+07	0.029140	6.386E+04	0.000E+00	0.000E+00
46	0	0	9.42661E+01	1.19526E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000000	0.000E+00	0.000E+00	0.000E+00
47	1	65	9.42661E+01	1.19526E+03	8.963E+07	8.941E+07	2.253E+05	7.764E+07	1.802557	1.533E+05	1.177E+07	1.000E+04
J = 48 to 60 were omitted from the Figure. MAT 1 is Flume Sand. J = 62 is at the 6" gage depth.												
61	1	93	1.07948E+02	1.04290E+03	8.239E+07	8.239E+07	0.000E+00	6.032E+07	1.757782	1.552E+05	2.207E+07	1.000E+04
62	1	95	1.08932E+02	1.05206E+03	7.892E+07	7.892E+07	0.000E+00	5.758E+07	1.755109	1.553E+05	2.134E+07	1.000E+04
63	1	97	1.09918E+02	1.12735E+03	8.410E+07	8.403E+07	6.937E+04	6.136E+07	1.754481	1.554E+05	2.267E+07	1.000E+04
64	1	99	1.10904E+02	1.07618E+03	8.910E+07	8.910E+07	0.000E+00	6.502E+07	1.754007	1.554E+05	2.408E+07	1.000E+04
J = 65 to 87 were omitted from the Figure.												
88	1	147	1.34627E+02	1.55218E+03	1.395E+08	1.395E+08	0.000E+00	1.006E+08	1.760313	1.551E+05	3.886E+07	1.000E+04
89	1	149	1.35610E+02	1.60514E+03	1.267E+08	1.259E+08	8.149E+05	9.082E+07	1.755626	1.553E+05	3.510E+07	1.000E+04
90	1	151	1.36595E+02	1.33766E+03	1.115E+08	1.115E+08	0.000E+00	8.105E+07	1.751037	1.555E+05	3.049E+07	1.000E+04
91	1	153	1.37583E+02	1.44746E+03	1.254E+08	1.252E+08	2.069E+05	9.030E+07	1.755382	1.553E+05	3.490E+07	1.000E+04
J = 92 is at the 18" gage depth.												
92	1	155	1.38569E+02	1.34110E+03	9.586E+07	9.476E+07	1.106E+06	6.953E+07	1.745022	1.558E+05	2.523E+07	1.000E+04
93	1	157	1.39560E+02	1.00945E+03	8.500E+07	8.500E+07	0.000E+00	6.320E+07	1.741659	1.559E+05	2.180E+07	1.000E+04
94	1	159	1.40554E+02	1.23000E+03	1.088E+08	1.088E+08	0.000E+00	7.853E+07	1.749813	1.556E+05	3.031E+07	1.000E+04
95	1	161	1.41543E+02	1.24849E+03	9.271E+07	9.162E+07	1.088E+06	6.608E+07	1.743317	1.559E+05	2.554E+07	1.000E+04
96	1	163	1.42535E+02	9.18443E+02	6.433E+07	6.322E+07	1.116E+06	4.559E+07	1.730343	1.565E+05	1.762E+07	1.000E+04
97	1	165	1.43535E+02	5.72848E+02	3.717E+07	3.645E+07	7.259E+05	2.628E+07	1.718559	1.570E+05	1.016E+07	1.000E+04
98	1	167	1.44541E+02	2.91633E+02	1.758E+07	1.731E+07	2.667E+05	1.248E+07	1.710266	1.574E+05	4.830E+06	1.000E+04
99	1	169	1.45553E+02	1.24673E+02	7.249E+06	7.186E+06	6.293E+04	5.178E+06	1.705878	1.576E+05	2.008E+06	1.000E+04
100	1	171	1.46567E+02	4.78922E+01	2.904E+06	2.892E+06	1.132E+04	2.081E+06	1.704017	1.577E+05	8.112E+05	1.000E+04
101	1	173	1.47582E+02	1.86556E+01	1.354E+06	1.352E+06	1.913E+03	9.701E+05	1.703349	1.577E+05	3.819E+05	1.000E+04
102	1	175	1.48598E+02	8.85777E+00	8.363E+05	8.358E+05	5.134E+02	5.978E+05	1.703126	1.577E+05	2.380E+05	1.000E+04
103	1	177	1.49614E+02	4.85159E+00	5.449E+05	5.447E+05	2.562E+02	4.171E+05	1.703017	1.577E+05	1.276E+05	1.000E+04
104	1	179	1.50630E+02	2.32672E+00	3.676E+05	3.675E+05	1.123E+02	3.097E+05	1.702953	1.577E+05	5.782E+04	1.000E+04
105	1	181	1.51646E+02	9.56769E-01	2.781E+05	2.781E+05	4.507E+01	2.558E+05	1.702920	1.577E+05	2.228E+04	1.000E+04
106	1	183	1.52662E+02	3.16232E-01	2.392E+05	2.391E+05	1.698E+01	2.327E+05	1.702906	1.577E+05	6.427E+03	1.000E+04
107	1	185	1.53678E+02	5.38749E-02	2.260E+05	2.260E+05	3.357E+00	2.254E+05	1.702902	1.577E+05	6.372E+02	1.000E+04
108	1	187	1.54694E+02	0.00000E+00	2.261E+05	2.261E+05	0.000E+00	2.261E+05	1.702902	1.577E+05	-2.068E-07	1.000E+04

Note: Remainder of Listing is beyond the wave front.

FIGURE 10 LISTING OF STRESSES, VELOCITIES, AND OTHER PROPERTIES AT CYCLE 400, 1.03 ms FROM DISKO-1 SIMULATION WITH ONED, USING AN EXPLICIT TREATMENT OF THE EXPLOSIVE LAYOUT

JA-6391-99

DISKO 1 FOR WES, ONED SIMULATION OF THE EXPLOSIVE LAYER. 20-JAN-87

TIME	SURFACE STRESS PSI	NODE NO.	APPLIED STRESS PSI	REACTION STRESS PSI	DAMPING STRESS PSI	STRAIN PERCENT	ACCEL G'S	PARTICLE VELOCITY M/S	POSITION IN
6.474E-04	0.00								
		50	972.83	971.68	1.15	3.93064	8468.844	11.784	38.080
		62	1908.41	1908.41	0.00	3.77272	-9397.986	14.595	42.703
		92	2.88	2.88	0.00	0.00702	0.000	0.000	54.503
		122	3.62	3.62	0.00	0.00882	0.000	0.000	66.503
		152	4.36	4.36	0.00	0.01061	0.000	0.000	78.502
		182	5.10	5.10	0.00	0.01241	0.000	0.000	90.502
		212	5.84	5.84	0.00	0.01421	0.000	0.000	102.501

FIGURE 11 SNAPSHOT LISTING OF STRESSES, VELOCITIES, AND OTHER PROPERTIES AT THE REQUESTED NODES AT CYCLE 300 FROM THE DISKO-1 SIMULATION WITH ONED, USING AN EXPLICIT TREATMENT OF THE EXPLOSIVE LAYOUT

JA-6391-100

DISKO 1 FOR WES, ONED SIMULATION OF THE EXPLOSIVE LAYER. 20-JAN-87
SUMMARY OF MAXIMUM VALUES

NODE NO.	DEPTH FT.	REACTION VALUE (MPA)	STRESS TIME (SEC)	VELOCITY VALUE (M/S)	VELOCITY TIME (SEC)	DISPLACEMENT VALUE (IN)	DISPLACEMENT TIME (SEC)	STRAIN VALUE (%)	STRAIN TIME (SEC)	ACCELERATION VALUE (G'S)	ACCELERATION TIME
Nodes 1 - 16 were omitted from the Figure Overburden is contained in cells 1 to 32.											
17	1.3335	6.94	1.035E-03	-9.043	1.035E-03	-0.027	1.035E-03	3.216E+00	1.035E-03	-8.169E+03	1.035E-03
18	1.4168	9.38	1.035E-03	-14.234	1.035E-03	-0.058	1.035E-03	4.445E+00	1.035E-03	-8.371E+03	9.738E-04
19	1.5002	10.03	1.016E-03	-17.124	1.035E-03	-0.100	1.035E-03	4.793E+00	1.020E-03	-8.584E+03	9.047E-04
20	1.5835	10.06	9.657E-04	-17.409	9.895E-04	-0.146	1.035E-03	4.808E+00	9.698E-04	-8.839E+03	8.366E-04
21	1.6669	9.99	9.534E-04	-17.300	9.364E-04	-0.190	1.035E-03	4.772E+00	9.575E-04	-9.173E+03	7.648E-04
22	1.7502	10.43	9.272E-04	-17.548	9.408E-04	-0.234	1.035E-03	4.982E+00	9.272E-04	-9.641E+03	6.958E-04
23	1.8336	11.00	8.810E-04	-18.516	9.000E-04	-0.280	1.035E-03	5.254E+00	8.810E-04	-1.035E+04	6.324E-04
24	1.9169	11.11	8.366E-04	-19.156	8.542E-04	-0.326	1.035E-03	5.305E+00	8.409E-04	-1.123E+04	5.712E-04
25	2.0002	11.60	7.994E-04	-19.281	8.242E-04	-0.376	1.035E-03	5.512E+00	7.994E-04	-1.201E+04	5.140E-04
26	2.0836	12.74	6.991E-04	-19.764	5.281E-04	-0.426	1.035E-03	5.977E+00	7.024E-04	1.267E+04	5.618E-04
27	2.1669	13.73	7.431E-04	-21.639	4.782E-04	-0.480	1.035E-03	6.337E+00	7.431E-04	1.655E+04	5.106E-04
28	2.2503	13.97	4.154E-04	-22.618	4.327E-04	-0.536	1.035E-03	6.361E+00	6.991E-04	-1.764E+04	6.031E-04
29	2.3336	14.71	3.733E-04	-23.248	3.931E-04	-0.591	1.035E-03	6.358E+00	6.618E-04	-1.666E+04	2.128E-04
30	2.4170	16.92	2.982E-04	-24.727	3.352E-04	-0.647	1.035E-03	7.130E+00	2.982E-04	-2.335E+04	1.567E-04
31	2.5003	18.96	1.299E-04	-26.314	1.545E-04	-0.706	1.035E-03	8.166E+00	2.406E-04	-3.865E+04	2.323E-04
32	2.5837	26.87	6.911E-05	-35.864	1.006E-04	-0.773	1.035E-03	9.775E+00	8.227E-05	-5.971E+04	5.188E-05
33	2.6670	0.00	1.035E-03	-54.919	4.587E-05	-0.849	1.035E-03	0.000E+00	1.035E-03	-2.002E+05	1.044E-07
The preceding cell is unused: 33 represents a node only. The next cells contain explosive.											
34	2.6670	38.18	1.000E-12	-54.919	4.587E-05	-0.849	1.035E-03	-8.542E+01	1.504E-04	-2.002E+05	1.044E-07
35	2.6795	38.18	2.297E-07	-220.015	1.879E-04	0.694	1.484E-04	-8.264E+01	1.316E-04	-1.701E+06	1.524E-04
36	2.6920	38.18	1.037E-06	414.680	1.053E-04	1.368	1.445E-04	-7.956E+01	1.133E-04	1.894E+06	3.866E-05
37	2.7045	38.18	2.711E-06	621.674	9.093E-05	1.871	1.370E-04	-7.563E+01	9.767E-05	2.169E+06	3.610E-05
38	2.7170	38.18	5.064E-06	826.401	7.994E-05	2.221	1.316E-04	-7.489E+01	1.027E-03	2.494E+06	3.086E-05
39	2.7295	38.18	2.711E-06	998.172	7.159E-05	2.457	1.265E-04	-7.416E+01	1.009E-03	2.874E+06	2.505E-05
40	2.7420	38.18	1.349E-06	1123.381	6.647E-05	2.626	1.248E-04	-7.477E+01	8.721E-04	-4.588E+06	6.989E-05
41	2.7545	38.18	3.801E-07	1249.056	6.375E-05	2.754	1.214E-04	-7.550E+01	8.857E-04	-1.438E+07	6.594E-05
42	2.7670	74.54	6.401E-05	1311.246	5.511E-05	2.857	1.182E-04	-7.635E+01	2.777E-04	-3.804E+07	6.430E-05
43	2.7795	172.82	6.353E-05	1323.457	3.610E-05	3.113	1.035E-03	-7.850E+01	2.733E-04	-8.240E+07	6.353E-05
44	2.7920	0.00	1.035E-03	1396.479	1.338E-05	3.489	1.035E-03	0.000E+00	1.035E-03	-1.480E+08	6.320E-05
The preceding cell is unused: 44 represents a node only. The next cell contains air.											
45	2.7920	311.25	6.320E-05	1396.479	1.338E-05	3.489	1.035E-03	3.257E+04	6.320E-05	-1.480E+08	6.320E-05
46	3.0420	0.00	1.035E-03	59.499	6.705E-05	0.609	1.035E-03	0.000E+00	1.035E-03	3.521E+06	6.335E-05
The preceding cell is unused. The next cells contain soil - the test bed.											
47	3.0420	38.99	7.994E-05	59.499	6.705E-05	0.609	1.035E-03	7.648E+00	8.110E-05	3.521E+06	6.335E-05
48	3.0753	32.36	9.767E-05	37.337	8.965E-05	0.587	1.035E-03	6.678E+00	1.334E-04	1.372E+05	7.346E-05
49	3.1087	28.60	1.149E-04	32.407	1.069E-04	0.568	1.035E-03	6.092E+00	1.524E-04	9.061E+04	9.223E-05
50	3.1420	26.65	1.334E-04	29.874	1.248E-04	0.551	1.035E-03	5.769E+00	1.334E-04	7.567E+04	1.069E-04
A new title occurs at this line.											
51	3.1753	25.66	1.524E-04	28.598	1.426E-04	0.535	1.035E-03	5.617E+00	1.524E-04	7.278E+04	1.231E-04
Nodes 52 to 60 are omitted for the Figure. Node 62 is at the 6" gage depth in the Flume sand.											
61	3.5086	20.55	3.435E-04	23.603	3.352E-04	0.396	1.035E-03	4.692E+00	3.435E-04	6.230E+04	3.142E-04
62	3.5420	19.84	3.619E-04	22.860	3.539E-04	0.383	1.035E-03	4.547E+00	3.619E-04	5.993E+04	3.352E-04
63	3.5753	19.11	3.818E-04	22.109	3.733E-04	0.371	1.035E-03	4.404E+00	3.818E-04	5.775E+04	3.539E-04
64	3.6086	18.42	3.988E-04	21.362	3.903E-04	0.359	1.035E-03	4.267E+00	4.016E-04	5.560E+04	3.733E-04
65	3.6420	17.79	4.211E-04	20.679	4.098E-04	0.348	1.035E-03	4.142E+00	4.211E-04	5.320E+04	3.931E-04
66	3.6753	17.23	4.386E-04	20.054	4.298E-04	0.337	1.035E-03	4.022E+00	4.417E-04	5.085E+04	4.126E-04
Nodes 67 to 77 are omitted here.											
78	4.0753	14.46	8.632E-04	16.788	8.542E-04	0.210	1.035E-03	3.477E+00	8.632E-04	3.166E+04	6.583E-04
79	4.1086	14.40	8.857E-04	16.744	8.765E-04	0.200	1.035E-03	3.464E+00	8.857E-04	3.046E+04	6.790E-04
Nodes 80 to 90 are omitted here. Node 92 is at the 18" gage depth.											
91	4.5086	12.56	1.035E-03	14.757	1.027E-03	0.064	1.035E-03	3.094E+00	1.035E-03	2.169E+04	1.009E-03
92	4.5419	11.07	9.856E-04	13.521	1.035E-03	0.052	1.035E-03	2.799E+00	9.895E-04	2.141E+04	1.031E-03
93	4.5753	11.00	1.009E-03	13.247	1.001E-03	0.042	1.035E-03	2.785E+00	1.009E-03	1.830E+04	9.698E-04
94	4.6086	10.94	1.031E-03	13.156	1.024E-03	0.033	1.035E-03	2.772E+00	1.031E-03	1.778E+04	9.895E-04
95	4.6419	9.34	1.035E-03	12.550	1.035E-03	0.022	1.035E-03	2.401E+00	1.035E-03	1.733E+04	1.009E-03
96	4.6753	6.51	1.035E-03	9.283	1.035E-03	0.013	1.035E-03	1.640E+00	1.035E-03	1.689E+04	1.031E-03
97	4.7086	3.79	1.035E-03	5.821	1.035E-03	0.007	1.035E-03	9.448E-01	1.035E-03	1.566E+04	1.035E-03
98	4.7419	1.80	1.035E-03	2.981	1.035E-03	0.003	1.035E-03	4.509E-01	1.035E-03	1.068E+04	1.035E-03
99	4.7753	0.74	1.035E-03	1.280	1.035E-03	0.001	1.035E-03	1.876E-01	1.035E-03	5.402E+03	1.035E-03
100	4.8086	0.30	1.035E-03	0.493	1.035E-03	0.000	1.035E-03	7.534E-02	1.035E-03	2.206E+03	1.035E-03
The remainder of the listing is omitted for the Figure.											

FIGURE 12 PARTIAL LISTING OF THE MAXIMUM VALUE TABLE FOR THE ONED SIMULATION OF DISKO-1 WITH EXPLICIT TREATMENT OF THE EXPLOSIVE

JA-6391-101

DISKO 1 FOR WES, ONED SIMULATION OF THE EXPLOSIVE LAYER. 20-JAN-87

HISTORIES AT NODE NO. 62

NS	TIME SEC	RMECH MPA	ACC G'S	VELOCITY M/SEC	POSITION IN	STRAIN (%)	IMPULSE DYN-S/CM^2	SIGMA-1 MPA	SIGMA-2 MPA
166	2.201E-04	1.633E-02	5.159E+01	4.678E-03	4.250E+01	5.551E-03	3.285E+01	1.633E-02	1.543E-02
167	2.216E-04	1.669E-02	5.844E+01	5.522E-03	4.250E+01	5.628E-03	3.310E+01	1.669E-02	1.558E-02
168	2.231E-04	1.711E-02	6.608E+01	6.484E-03	4.250E+01	5.717E-03	3.335E+01	1.710E-02	1.575E-02
Time steps 169 to 200 are omitted for the Figure.									
201	3.105E-04	2.423E+00	2.636E+04	4.723E+00	4.251E+01	5.914E-01	3.732E+02	2.324E+00	1.352E+00
202	3.142E-04	3.077E+00	3.158E+04	5.892E+00	4.251E+01	7.458E-01	4.667E+02	2.931E+00	1.705E+00
203	3.176E-04	3.807E+00	3.686E+04	7.172E+00	4.251E+01	9.166E-01	5.756E+02	3.602E+00	2.096E+00
204	3.208E-04	4.610E+00	4.219E+04	8.531E+00	4.251E+01	1.103E+00	7.025E+02	4.333E+00	2.521E+00
205	3.238E-04	5.502E+00	4.887E+04	1.001E+01	4.251E+01	1.308E+00	8.502E+02	5.139E+00	2.990E+00
206	3.267E-04	6.466E+00	5.410E+04	1.159E+01	4.251E+01	1.534E+00	1.022E+03	6.003E+00	3.493E+00
207	3.296E-04	7.505E+00	5.781E+04	1.323E+01	4.251E+01	1.783E+00	1.220E+03	6.931E+00	4.033E+00
208	3.324E-04	8.632E+00	5.986E+04	1.491E+01	4.252E+01	2.055E+00	1.447E+03	7.944E+00	4.622E+00
209	3.352E-04	9.825E+00	5.993E+04	1.657E+01	4.252E+01	2.346E+00	1.704E+03	9.029E+00	5.254E+00
210	3.380E-04	1.121E+01	5.799E+04	1.816E+01	4.252E+01	2.652E+00	1.993E+03	1.033E+01	6.009E+00
211	3.408E-04	1.283E+01	5.318E+04	1.961E+01	4.252E+01	2.963E+00	2.318E+03	1.189E+01	6.917E+00
212	3.435E-04	1.436E+01	4.535E+04	2.082E+01	4.252E+01	3.270E+00	2.680E+03	1.342E+01	7.810E+00
213	3.461E-04	1.576E+01	3.644E+04	2.178E+01	4.253E+01	3.562E+00	3.075E+03	1.488E+01	8.660E+00
214	3.487E-04	1.699E+01	2.613E+04	2.246E+01	4.253E+01	3.831E+00	3.501E+03	1.622E+01	9.441E+00
215	3.513E-04	1.803E+01	1.425E+04	2.282E+01	4.253E+01	4.067E+00	3.956E+03	1.741E+01	1.013E+01
216	3.539E-04	1.884E+01	1.429E+03	2.286E+01	4.253E+01	4.265E+00	4.438E+03	1.839E+01	1.070E+01
217	3.566E-04	1.942E+01	-1.156E+04	2.256E+01	4.254E+01	4.415E+00	4.945E+03	1.915E+01	1.114E+01
218	3.592E-04	1.976E+01	-2.392E+04	2.195E+01	4.254E+01	4.511E+00	5.475E+03	1.963E+01	1.142E+01
219	3.619E-04	1.984E+01	-3.479E+04	2.103E+01	4.254E+01	4.547E+00	6.023E+03	1.981E+01	1.153E+01
220	3.647E-04	1.958E+01	-4.334E+04	1.987E+01	4.254E+01	4.519E+00	6.582E+03	1.958E+01	1.139E+01
The new heading was omitted here.									
221	3.675E-04	1.883E+01	-4.824E+04	1.854E+01	4.254E+01	4.425E+00	7.138E+03	1.883E+01	1.096E+01
222	3.704E-04	1.762E+01	-4.789E+04	1.719E+01	4.255E+01	4.274E+00	7.664E+03	1.762E+01	1.025E+01
223	3.733E-04	1.611E+01	-4.202E+04	1.600E+01	4.255E+01	4.086E+00	8.143E+03	1.611E+01	9.372E+00
224	3.761E-04	1.449E+01	-3.168E+04	1.511E+01	4.255E+01	3.885E+00	8.573E+03	1.449E+01	8.433E+00
225	3.789E-04	1.294E+01	-1.863E+04	1.459E+01	4.255E+01	3.692E+00	8.957E+03	1.294E+01	7.532E+00
226	3.818E-04	1.161E+01	-4.871E+03	1.446E+01	4.255E+01	3.526E+00	9.303E+03	1.161E+01	6.755E+00
227	3.846E-04	1.061E+01	7.725E+03	1.467E+01	4.255E+01	3.402E+00	9.618E+03	1.061E+01	6.177E+00
228	3.874E-04	1.005E+01	1.755E+04	1.516E+01	4.256E+01	3.332E+00	9.913E+03	1.005E+01	5.847E+00
229	3.903E-04	9.950E+00	2.342E+04	1.581E+01	4.256E+01	3.320E+00	1.020E+04	9.950E+00	5.790E+00
230	3.931E-04	1.030E+01	2.465E+04	1.651E+01	4.256E+01	3.362E+00	1.049E+04	1.027E+01	5.997E+00

FIGURE 13 PARTIAL LISTING OF THE HISTORIES FOR NODE 62 (6-in.-GAGE DEPTH) FROM ONED SIMULATION OF DISKO-1 WITH AN EXPLICIT TREATMENT OF THE EXPLOSIVE LAYER

JA-6391-102

where t_n is the current time. The quantities SIGMA-1 AND SIGMA-2 are the stresses in the direction of propagation and orthogonal to that direction, respectively.

In cases where the wave propagation is caused by a pressure history instead of a detonation, the history is read and printed by READIT during initialization. A sample of the pressure history listing (THIST, PHIST) is shown in Figure 14. This pressure history was obtained from a GUINSY calculation[9] of the DISKO-1 stress gage records. The input for this case is given in Figure A-3.

Some of the data printed in the preceding figures are also available for plotting. The SCRIBE listings of this histories have been stored on file 7 and can be plotted. Also the maximum value table in Figure 12 is available on file 7, following the SCRIBE data.

DISKO 1 FOR WES, ONED SIMULATION WITH PRESSURES FROM GUINSY20-JAN-86

FORCE HISTORY ON FIRST NODE

TIME	PRESS	TIME	PRESS	TIME	PRESS	TIME	PRESS	TIME	PRESS
0.000E+00	0.000E+00	2.000E-06	2.326E+02	4.000E-06	4.651E+02	6.000E-06	6.977E+02	1.000E-05	8.335E+02
1.400E-05	9.678E+02	1.700E-05	1.100E+03	2.100E-05	1.229E+03	2.500E-05	1.354E+03	2.900E-05	1.477E+03
3.300E-05	1.595E+03	3.700E-05	1.711E+03	4.000E-05	1.825E+03	4.400E-05	1.938E+03	4.800E-05	2.051E+03
5.200E-05	2.164E+03	5.600E-05	2.278E+03	5.900E-05	2.393E+03	6.300E-05	2.514E+03	6.700E-05	2.636E+03
7.100E-05	2.762E+03	7.500E-05	2.894E+03	7.900E-05	3.028E+03	8.200E-05	3.167E+03	9.400E-05	2.914E+03
1.040E-04	2.697E+03	1.130E-04	2.512E+03	1.230E-04	2.354E+03	1.330E-04	2.217E+03	1.420E-04	2.097E+03
1.520E-04	1.991E+03	1.640E-04	1.896E+03	1.740E-04	1.811E+03	1.840E-04	1.733E+03	1.930E-04	1.660E+03
2.030E-04	1.592E+03	2.130E-04	1.530E+03	2.220E-04	1.471E+03	2.340E-04	1.418E+03	2.440E-04	1.370E+03
2.540E-04	1.329E+03	2.630E-04	1.295E+03	2.730E-04	1.271E+03	2.830E-04	1.257E+03	2.900E-04	1.297E+03
2.970E-04	1.355E+03	3.020E-04	1.428E+03	3.090E-04	1.510E+03	3.170E-04	1.600E+03	3.240E-04	1.691E+03
3.290E-04	1.782E+03	3.360E-04	1.867E+03	3.430E-04	1.945E+03	3.510E-04	2.015E+03	3.550E-04	2.075E+03
3.630E-04	2.126E+03	3.700E-04	2.169E+03	3.750E-04	2.211E+03	3.820E-04	2.255E+03	4.030E-04	2.130E+03
4.250E-04	2.003E+03	4.470E-04	1.877E+03	4.680E-04	1.756E+03	4.890E-04	1.641E+03	5.110E-04	1.533E+03
5.320E-04	1.434E+03	5.540E-04	1.343E+03	5.750E-04	1.260E+03	5.970E-04	1.185E+03	6.180E-04	1.117E+03
6.390E-04	1.054E+03	6.610E-04	9.964E+02	6.830E-04	9.424E+02	7.040E-04	8.910E+02	7.250E-04	8.420E+02
7.460E-04	7.950E+02	7.680E-04	7.499E+02	7.900E-04	7.078E+02	8.110E-04	6.696E+02		

OUTPUT DESIRED AT

DEPTH(ft)	NODE
0.1000	4
0.2500	8
0.5000	16
1.5000	46
1.6700	51
1.8300	55
2.5000	76
3.5000	106
4.5000	136
5.5000	166

FIGURE 14 LISTING FROM READIT OF THE FORCE HISTORY AND OF THE LOCATIONS WHERE PRINTED AND PLOTTED OUTPUT IS DESIRED: ONED SIMULATION OF DISKO-1 USING THE PRESSURE HISTORY FROM GUINSY

JA-6391-103

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Appendix A

SAMPLE INPUT FOR ONED

This appendix provides sample input files and supplements the input description in Section IV. The input files show sample problems in which either a surface pressure history or an explosive detonation drives the waves. Material properties characteristic of solids, porous materials, explosives, and air are provided.

Figures A-1 through A-3 show three treatments of the DISKO-1 event[8]. In Figure A-1, the loading is applied by an average pressure history from the blast pressure gages, and in Figure A-2 by detonation of the explosive layer. The explosive is treated as a polytropic gas. Figure A-3 contains another input for DISKO-1 in which the loading is a pressure history derived from a Lagrangian analysis performed using the GUINSY code[9]. In Figure A-4 is an input file for a synthetic problem containing several layers of porous and solid materials, an explosive, and a gap. The gap is simply an empty layer; it closes during the calculation. The isentrope (pressure-volume curve) for the explosive is provided by a table of volume and pressure values.

```
      TEST OF SRI ONED TO SIMULATE THE DISKO-1 EVENT, FINAL SET OF DATA
      [B6391.ONED]DISKO1BL.OND IS DATA, [*.*]RONED.COM, [*.*]MONED.EXE
    1 DISKO 1 FOR WES, ONED SIMULATION WITH PRESSURES FROM BLAST GAGES.
998, 0, 0.004, 400, 1.  NOCOMP, BOTTOM BOUNDARY INDICATOR, TEND, NSTOP, GACC
1, 0, 0, 0, 1,  139,          NLAYRS, MISP, NSP, MATTEN, NMTRLS, NFORCE
10, 1,3,0,0,0,0,0, 100, 1, 1, 1, 0.004  NNODE,KNTROL(7),NHIST,MVT,NSV,KVEL,TND
0.1, 0.25, 0.5, 1.5, 1.67, 1.83, 2.5, 3.5, 4.5, 5.5  DEPTHS FOR HIST. (FT)
1000., 0.0, 60., 0., 0., 0., 0.    SK (7)
'SAND',106.3, 0.1, 4.,0.0,1,0,0,2   GAM,DAMP,TENSN, POR,PR,SOL,VAR FOR SAND
1.36E+9, 1.0E+4, 0.274    SHMOD, YIELD, TANPHI
7,3,'P','D',1.,1.0          SSONED:    KFIN,NTYPE,LPRESS,LDENS,PUNIT,DUNIT
4.E7, 7.E7, 1.7E8, 4.5E8, 1.E9, 0.,  FLUME SAND, P, DYN/CM^2 (K=2.92E9)
1.7268, 1.7458, 1.793, 1.893, 2.065, 2.023        DENSITIES, G/CM^3
8.333    0.4, 0, 1  DB(DIST TO BOT, FT), SPL(CELL SIZE,IN), NSP(# CELL), MAT #
  0.000E+00  0.000E+00
  2.000E-06  1.896E+03
  4.000E-06  2.136E+03
  6.000E-06  2.336E+03
  8.000E-06  2.515E+03
  1.000E-05  2.664E+03
  1.200E-05  2.794E+03
  1.400E-05  2.894E+03
  1.600E-05  2.984E+03
  1.800E-05  3.053E+03
  2.000E-05  3.293E+03
  2.200E-05  3.503E+03
  2.400E-05  3.692E+03
  2.600E-05  3.832E+03
  2.800E-05  3.922E+03
  3.000E-05  3.961E+03
  3.200E-05  3.951E+03
  3.400E-05  3.892E+03
  3.600E-05  3.822E+03
  3.800E-05  3.743E+03
  4.000E-05  3.662E+03
  4.200E-05  3.572E+03
  4.400E-05  3.482E+03
  4.600E-05  3.393E+03
  4.800E-05  3.313E+03
  5.000E-05  3.234E+03
  5.200E-05  3.163E+03
  5.400E-05  3.093E+03
  5.600E-05  3.034E+03
  5.800E-05  2.973E+03
  6.000E-05  2.914E+03
  6.200E-05  2.863E+03
  6.400E-05  2.824E+03
     Lines were omitted for the Figure.
  1.550E-03  6.775E+02
  1.590E-03  6.865E+02
  1.660E-03  6.945E+02
  1.720E-03  7.374E+02
  1.780E-03  7.235E+02
  1.000E-02  7.235E+02
```

FIGURE A-1 INPUT FILE FOR ONED SIMULATION OF DISKO-1 USING THE PRESSURE HISTORY FROM THE BLAST PRESSURE GAGES

JA-6391-104

```
      TEST OF SRI ONED TO SIMULATE THE DISKO-1 EVENT, FINAL SET OF DATA
      [B6391.ONED]DISKO1E.OND IS DATA, [*.*]RONED.COM, [*.*]MONED.EXE
    1 DISKO 1 FOR WES, ONED SIMULATION OF THE EXPLOSIVE LAYER.
998, 0, 0.004, 400, 1.  NOCOMP, BOTTOM BOUNDARY INDICATOR, TEND, NSTOP, GACC
4, 0, 0, 0, 4,  0,          NLAYRS, MISP, NSP, MATTEN, NMTRLS, NFORCE
7, 1,3,0,0,0,0,0, 100, 1, 1, 1, 0.004  NNODE,KNTROL(7),NHIST,MVT,NSV,KVEL,TND
3.142, 3.542, 4.542, 5.542, 6.542, 7.542, 8.542   DEPTHS FOR HIST. (FT)
1000., 0.0, 60., 0., 0., 0., 0.    SK (7)
'SAND',106.3, 0.1, 4.,0.0,1,0,0,2   GAM,DAMP,TENSN, POR,PR,SOL,VAR FOR SAND
1.36E+9, 1.0E+4, 0.274    SHMOD, YIELD, TANPHI
7,3,'P','D',1.,1.0          SSONED:    KFIN,NTYPE,LPRESS,LDENS,PUNIT,DUNIT
4.E7, 7.E7, 1.7E8, 4.5E8, 1.E9, 0.,  FLUME SAND, P, DYN/CM^2 (K=2.92E9)
1.7268, 1.7458, 1.793, 1.893, 2.065, 2.023        DENSITIES, G/CM^3
'EXPL1', 2.7406, 0.05, 4.,0.0, 0, 1, 0, 0 GAM,DAMP,TENSN, POR,PR,SOL,VAR (EXPL)
0., 0., 0.    SHMOD, YIELD, TANPHI
'POLY', 4.5E10, 0.2     Q AND GAMMA
'AIR', .072946, 0.05, 4.,0.0, 0, 1, 0, 0 GAM,DAMP,TENSN, POR,PR,SOL,VAR FOR AIR
0., 0., 0.    SHMOD, YIELD, TANPHI
'POLY', 2.139E9, 0.4     Q AND GAMMA
'OVERBDN',  95.035, 0.1, 4., 0.0, 1,0,0,2 GAM, DAMP, TENSN, POR, PR, SOL, NVAR
1.36E+9, 1.0E+4, 0.274    SHMOD, YIELD, TANPHI
10,1,'P','D',1.E7,1.0          SSONED:    KFIN,NTYPE,LPRESS,LDENS,PUNIT,DUNIT
 8., 39., 69., 122., 230., 400., 100., 30., 0., SAND OVERBDN MODEL, PRESS., MPA
 1.603,1.792,1.904,2.031,2.176,2.343,2.290,2.256,2.207 DENSITIES
2.667    1.0  0, 4  32 INCHES OF SAND OVERBURDEN
2.792    0.15 0, 2  1.5 INCHES OF PRIMACORD-AIR MIXTURE
3.042    3.0  0, 3  3.0 INCHES OF AIR (REPRESENTING A MIXTURE OF FOAM AND AIR)
11.375   0.4  0, 1  100 INCHES OF FLUME SAND
```

FIGURE A-2 INPUT FILE FOR THE ONED SIMULATION OF DISKO-1 USING THE EXPLICIT TREATMENT OF THE EXPLOSIVE LAYER

JA-6391-105

```
      TEST OF SRI ONED TO SIMULATE THE DISKO-1 EVENT, FINAL SET OF DATA
      [B6391.ONED]DISKO1P.OND IS DATA, [*.*]RONED.COM, [*.*]MONED.EXE
    1 DISKO 1 FOR WES, ONED SIMULATION WITH PRESSURES FROM GUINSY CALC. 7/10/85
998, 0, 0.004, 400, 1.  NOCOMP, BOTTOM BOUNDARY INDICATOR, TEND, NSTOP, GACC
1, 0, 0, 0, 1,  79,          NLAYRS, MISP, NSP, MATTEN, NMTRLS, NFORCE
10, 1,3,0,0,0,0,0, 100, 1, 1, 1, 0.004  NNODE,KNTROL(7),NHIST,MVT,NSV,KVEL,TND
0.1, 0.25, 0.5, 1.5, 1.67, 1.83, 2.5, 3.5, 4.5, 5.5  DEPTHS FOR HIST. (FT)
1000., 0.0, 60., 0., 0., 0., 0.    SK (7)
'SAND',106.3, 0.1, 4.,0.0,1,0,0,2   GAM,DAMP,TENSN, POR,PR,SOL,VAR FOR SAND
1.36E+9, 1.0E+4, 0.274    SHMOD, YIELD, TANPHI
7,3,'P','D',1.,1.0          SSONED:    KFIN,NTYPE,LPRESS,LDENS,PUNIT,DUNIT
4.E7, 7.E7, 1.7E8, 4.5E8, 1.E9, 0.,  FLUME SAND, P, DYN/CM^2 (K=2.92E9)
1.7268, 1.7458, 1.793, 1.893, 2.065, 2.023        DENSITIES, G/CM^3
8.333    0.4, 0, 1  DB(DIST TO BOT, FT), SPL(CELL SIZE,IN), NSP(# CELL), MAT #
  0.000E+00  0.000E+00
  2.000E-06  2.326E+02
  4.000E-06  4.651E+02
  6.000E-06  6.977E+02
  1.000E-05  8.335E+02
  1.400E-05  9.678E+02
  1.700E-05  1.100E+03
  2.100E-05  1.229E+03
  2.500E-05  1.354E+03
  2.900E-05  1.477E+03
  3.300E-05  1.595E+03
  3.700E-05  1.711E+03
  4.000E-05  1.825E+03
  4.400E-05  1.938E+03
  4.800E-05  2.051E+03
  5.200E-05  2.164E+03
  5.600E-05  2.278E+03
  5.900E-05  2.393E+03
  6.300E-05  2.514E+03
  6.700E-05  2.636E+03
  7.100E-05  2.762E+03
  7.500E-05  2.894E+03
  7.900E-05  3.028E+03
  8.200E-05  3.167E+03
  9.400E-05  2.914E+03
  1.040E-04  2.697E+03
  1.130E-04  2.512E+03
  1.230E-04  2.354E+03
  1.330E-04  2.217E+03
     Lines were omitted here for the figure
  7.900E-04  7.078E+02
  8.110E-04  6.696E+02
  1.000E-02  6.696E+02
```

FIGURE A-3 INPUT FILE FOR THE ONED SIMULATION OF DISKO-1 WITH THE PRESSURE HISTORY CONSTRUCTED BY GUINSY FROM THE STRESS GAGE RECORDS

JA-6391-106

```
      TEST OF SRI ONED TO SIMULATE A FICTITIOUS SITUATION TO DEMONSTRATE
      THE TREATMENT OF SOLIDS, POROUS MATLS, TABULAR ISENTROPE, AND A GAP.
    1 ONED SIMULATION OF SIX LAYER PROBLEM, INCLUDING A GAP
998, 0, 0.004, 400, 1.  NOCOMP, BOTTOM BOUNDARY INDICATOR, TEND, NSTOP, GACC
6, 0, 0, 0, 5,  0,          NLAYRS, MISP, NSP, MATTEN, NMTRLS, NFORCE
7, 1,3,0,0,0,0,0, 100, 1, 1, 1, 0.004  NNODE,KNTROL(7),NHIST,MVT,NSV,KVEL,TND
3.142, 3.542, 4.542, 5.542, 6.542, 7.542, 8.542   DEPTHS FOR HIST. (FT)
1000., 0.0, 60., 0., 0., 0., 0.    SK (7)

'SAND',106.3, 0.1, 4.,0.0,1,0,0,2   GAM,DAMP,TENSN, POR,PR,SOL,VAR FOR SAND
1.36E+9, 1.0E+4, 0.274    SHMOD, YIELD, TANPHI
7,3,'P','D',1.,1.0          SSONED:    KFIN,NTYPE,LPRESS,LDENS,PUNIT,DUNIT
4.E7, 7.E7, 1.7E8, 4.5E8, 1.E9, 0.,  FLUME SAND, P, DYN/CM^2 (K=2.92E9)
1.7268, 1.7458, 1.793, 1.893, 2.065, 2.023        DENSITIES, G/CM^3

'STEEL',489.8, 0.1, 4.,0.0, 0,0,1,2 GAM,DAMP;Q,TENSN, POR,PR,SOL,VAR -----
1.344E+10, 7.034E+11, 0.   SHMOD(DYN/CM2), YIELD(DYN/CM2), TANPHI
2.203E7, 7.477E7, 8.E8 EQSTC, EQSTD, EQSTS FOR STEEL

'EXPL1', 2.7406, 0.05, 4.,0.0, 0, 1, 0, 0 GAM,DAMP,TENSN, POR,PR,SOL,VAR (EXPL)
0., 0., 0.    SHMOD, YIELD, TANPHI
'POLY', 4.5E10, 0.2     Q AND GAMMA

'ANFO', 48.8, 0.05, 4.,0.0, 0, 1, 0, 0 GAM,DAMP,TENSN, POR,PR,SOL,VAR (EXPL)
0., 0., 0.    SHMOD, YIELD, TANPHI
'TAB', 4.5E10, 0.2     Q AND GAMMA   -NOT USED-
10, 'VOLUME',     'LOG'          IMAX, LABEL, TYPE FOR TABULAR EQ. OF STATE
9.142E-01, 6.500E+10, 1.5322E00, 1.871E+10, 2.568E+00, 5.932E+09
4.304E+00, 2.060E+09, 7.214E+00, 7.790E+08, 1.2091E01, 3.174E+08
2.0265E01, 1.372E+08, 3.3966E01, 6.200E+07, 5.6928E01, 3.100E+07
1.000E+02, 1.530E+07

'PLYWUD',42.,0.05,4., 0.,1,0,0,2    GAM, DAMP, TENSN, POR, PR, SOL, VAR
0., 0., 0.    SHMOD, YIELD, TANPHI
8, 1, 'MODU',   'STRA', 6.914627E4, 1.   KFIN, NTYPE, LPRESS, LDENS, PUNIT, DUNIT
65000., 16000., 8000., 18000., 21500., 30000., 2.E5, 2.E5, PLYWOOD, MODULI
1.0, 2.5, 7., 9.5, 12.75, 100., 0.0,    STRAINS

2.667    1.0  0, 2  32 INCHES OF STEEL (OVERBURDEN)
2.792    0.15 0, 3  1.5 INCHES OF EXPL1 (PRIMACORD-AIR MIXTURE)
3.042    3.0  0, 4  3.0 INCHES OF ANFO
3.1045   0.75 0, 5  3/4 INCH OF PLYWOOD
3.1253   0.25 0, 0  1/4 INCH GAP
11.4587   0.4  0, 1  100 INCHES OF FLUME SAND
```

Notes: The blank lines between materials were introduced for readibility.
They must not appear in the input file.

FIGURE A-4 INPUT FILE FOR A SYNTHETIC PROBLEM WITH A SOLID, A GAP, A POROUS MATERIAL, AND AN EXPLOSIVE REQUIRING A TABULAR ISENTROPE

JA-6391-107

Appendix B

GLOSSARY OF TERMS USED IN THE PROGRAM

ACC(J)	Acceleration of the Jth node, cm/s^2.
ALPHA(J)	Ratio of area at top to area at node J (attenuation factor).
BETA	Array containing problem title, input.
CELMAS(J)	Mass of material in cell J between nodes J and J+1, g/cm^2.
COM(L)	Array containing extra variables for each cell. Used with the NVAR(M) and LVAR(J) arrays.
DAMPL(M)	Coefficient for the linear artificial viscosity term, input, dimensionless.
DAMPQ(M)	Coefficient for the quadratic artificial viscosity term, initialized at 4.0, dimensionless.
DENS(J)	Density of the Jth cell, g/cm^3.
DENSCAL	Conversion factor for changing densities from pcf to g/cm^3: 0.0160185 g/cm^3/(pcf).
DEP()	Depth in feet at which historical information is requested, input.
DISTCAL	Conversion factor for changing distances from inches to cm: 2.54 cm/in.
DT	Time step for each computational cycle, computed in the program, sec.
DUNIT	Unit conversion factor to transform the input values of density to g/cm^3. (Used for SSONED input)
EL(i,M)	An array of moduli for loading and unloading in a porous material treated by SSONED. EL(i,M) is used in the strain interval from SL(i,M) to SL(i+1,M).
ELMOD(M)	Longitudinal elastic modulus for each material, computed in the program, dyn/cm^2.
EQSTC(M)	Bulk modulus used with the solid model, EQST. Input in psi.

EQSTD(M) Second coefficient in the series expansion for bulk modulus used in EQST. Input in psi.

EQSTG(M) Gruneisen ratio = $\Gamma = \gamma - 1$ where γ is the polytropic exponent for an explosive, input to EXPLODE, dimensionless.

EQSTS(M) Third coefficient in the series expansion for bulk modulus used in EQST. Input in psi.

FL(i,M) An array of pressures for the loading and unloading curves used in SSONED. FL(i,M) is the pressure at the strain SL(i,M) in dyn/cm^2.

G Acceleration of gravity, 981.456 cm/s^2.

GACC Indicator for initializing the geostatic stress option and using a gravity effect throughout the calculation, input, dimensionless at input. When GACC is read in with a nonzero value, it is reset to G = 981.456 cm/s^2.

GAM(M) Initial density for each material, input, lb/ft^3

KNT Index used with the KNTROL() array to indicate plots desired. If KNT = 0, no plotting occurs.

KNTROL() Indicator array for the type of plots required:

= 0 for no plots. KNT is set to zero.
= 1 for stress - time plot.
= 2 for acceleration - time plot.
= 3 for particle velocity - time plot.
= 4 for node location - time plot.
= 5 for strain - time plot.
= 6 for impulse - time plot.
= 7 for average strain - time plot.

KVEL Input indicator to control units for printing particle velocity: 0 for in./s, > 0 for m/s.

LB Indicator for the boundary condition at the bottom of the last layer:

= 0 means free boundary
= 1 means rigid boundary

LDENS Label with the same meaning as LPRESS.

LPRESS Label for type of quantities to be used for pressure-strain relation for SSONED. Four labels are provided: "D" for density, "S" for strain, "M" for modulus, and "P" for pressure. (Only the first character is interpreted.)

LVAR(J) A locator array for the Jth cell providing the starting position for extra variables in the COM array. For L = LVAR(J), the first variable is at COM(L).

MASSCAL Conversion factor to change masses from pounds to grams: 2.204624E-3 lb/g.

MAT(J) Material number of the Jth cell, dimensionless.

MATTEN Indicator for the use of the attenuation factors, ALPHA(J), input. 0 for no attenuation; > 0 for use of the attenuation factors.

MISP Indicator used to control cell spacing (input):
= 0 uniform spacing given by SPL.
= 1 cell spacing is read in for each layer.
> 1 and NSP > 0, uniform cell sizes and NSP is the number of cells.

MVT Parameter controlling printing of the maximum value table, input. Zero value omits printing.

N Total number of nodes in the problem.

NAME(M) Four-letter title for each material, input.

NFORCE Number of pressure-time points in the loading function, input.

NHIST Frequency for snapshot listings of current status of the requested cells and nodes, input.

NLAYRS Number of layers used in the input. A gap counts as a layer.

NMTRLS Number of materials to be read in for the calculation, input.

NNODE Number of nodes or cells at which output is required, input.

NOCOMP Parameter controlling plot scales:
< 998 means compute and plot at computed scales.
= 998 means compute and plot at input scales.
> 998 means plot at input scales, no computation.

NOUT() Array containing the numbers of cells or nodes at which historical data are requested.

NPOR(M) Indicator for a porous material, input; nonzero means SSONED is to be called.

NPR(M)	Indicator for a pressure model for a material, here used for an explosive, input: nonzero means EXPLODE is to be called.
NSOL(M)	Indicator for a solid model, input: nonzero means EQST is to be called.
NSP	Number of cells in each layer (input). Used either with MISP = 1 for nonuniform layout or MISP = 2 for a uniform layout.
NSTEP	Current count of the computational cycle for the problem.
NSTOP	Number of computational cycles at which problem will be stopped, input, dimensionless.
NSV	Parameter controlling saving of a plot tape for future plotting, input.
NTYPE(M)	Indicator for type of unloading process used in SSONED. Input to SSONED. See Section III.C.
NVAR(M)	Number of extra variables in the COM array to be provided for each cell of the material.
NVELCAL	Label used with velocity output to indicate either in./s or m/s.
PHIST()	Array containing the pressures for the applied pressure on the top boundary, input in psi.
PRESCAL	Conversion factor for changing pressure or stress in psi to dyn/cm^2: 6.914627E4 $dyn/cm^2/psi$.
PUNIT	Unit conversion factor to transform from the input values of modulus and pressure to dyn/cm^2 (used for SSONED input).
PRESS(J)	Pressure in the Jth cell, dyn/cm^2.
QEXPL(M)	Chemical energy of an explosive, input in erg/g.
RHO(M)	Initial density of the material, g/cm^3.
RMECH(J)	Mechanical stress in the Jth cell, dyn/cm^2.
SAVDMX()	A two-dimensional array for the maximum mechanical stress, acceleration, particle velocity, position, and strain that occur at the Jth cell and node during the computation.
SHMOD(M)	Shear modulus for each material, input, dyn/cm^2.

SIGI(J)	Thermodynamic stress in the direction of propagation, dyn/cm^2.
SL(i,M)	Strain array describing loading and unloading curves for a porous material treated by SSONED. These curves are subdivided into a number of strain intervals: the SL(i,M) bound these intervals.
SSPEED(J)	Sound speed in the Jth cell, cm/s.
TANPHI(M)	Tangent of the coefficient of friction for a yield strength model with Coulomb friction, input, dimensionless.
TEND	Stop time for the calculation, input, s.
TENSIL(J)	Tensile strength of the Jth cell, dyn/cm^2.
TENSN(M)	Tensile strength of the material, input, psi. A zero value is interpreted as infinite strength.
THIST()	Array containing the times of the pressure history applied to the top boundary, input in s.
TIME	Current problem time during a calculation, s.
TMAX()	A two-dimensional array containing the times at which the maxima SAVDMX occur.
TNDPLT	Duration of plotting time, input, s.
VEL(J)	Particle velocity of the Jth node, cm/s.
VELCAL	Conversion for changing particle velocity in in./s to cm/s.
X(J)	Position of the Jth node, cm.
Y(J)	Yield strength of the Jth cell, dyn/cm^2.
YIELD(M)	Yield strength of the material, input in dyn/cm^2.

Appendix C

INSERTION PROCEDURE

As new material models are generated, they can be added to ONED for performing wave propagation calculations. This appendix describes the procedure for inserting material model subroutines.

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 ONED 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 SSONED the formal parameter NCALL indicates the operation required, as follows:

NCALL = 0	Initialize the routine and read data for one material
1	Calculate pressure

The CALL for NCALL = 0 is in READIT. For NCALL = 1, the CALL statement is in CMPUTE.

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. SSONED was treated as a porous model and designated by NPOR(M) = 1. Then branching statements in READIT and CMPUTE were written to route the computation to SSONED.

(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 READIT or CMPUTE to continue the calculation.

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

A sample of the calling procedure for SHEAR2 is listed here because it encompasses most of the problems that might be encountered in an insertion. SHEAR2 is a stress-strain relation describing elastic-plastic behavior with shear banding. It was written for two-dimensional calculations and hence employs most of the stress and strain tensor components. The pressure is positive in compression in SHEAR2, but the stress is positive in tension. Twenty-five extra variables (from the COM array) are required by SHEAR2. In addition, most of the basic material properties are transmitted to SHEAR2 in an array called ESC. Thus, it is necessary to dimension ESC and to fill it with properties before the CALL. Thus, the first step is the dimension statement:

```
DIMENSION ESC(20,20)
```

The first subscript indicates the material parameter, and the second subscript is the material number. The array could be filled with a set of statements as follows:

```
IF (ESC(1,M)  .GT. 0.) GO TO 25
ESC(2,M) = RHO(M)
ESC(2,M) = EQSTC(M)
ESC(3,M) = EQSTD(M)
ESC(4,M) = EQSTS(M)
ESC(5,M) = SHMOD(M)
ESC(9,M) = Grüneisen ratio
```

Note that the Hugoniot coefficients (used in EQST) must be provided to CMPUTE before this equivalencing can work. In the example that follows, the stress, strain, and other variables must be prepared for the CALL to SHEAR2. The first of the preparatory statements defines NCALL, which is 2 for the usual stress calculation, but 3 for a stress calculation plus a request that SHEAR2 print its shear banding quantities.

```
NCALL = 2

If (NHIST .GT. 0 .AND. MOD(N,NHIST) .EQ. 0) NCALL = 3
```

The input file is set to 5, although it is not used here.

```
INPUT = 5
```

An integer indicator is used with SHEAR2. It may be reset within the subroutine.

```
IH3 = COM(L)
```

The deviator stresses are initialized with the sign convention that stress is positive in tension.

```
SX  = - SIGDEV

SY  = - 0.5*SIGDEV

SZ  = SY

TXY = 0.
```

The strain increments are initialized to be positive in tension, also.

```
EX  = -2.*(DENS(J)-DOLD)/(DENS(J)+DOLD)

EY  = 0.

EZ  = 0.

EXY = 0.
```

The rotation quantities are set at zero because there is no rotation in ONED.

```
ROT  = 0.

DROT = 0.
```

The melt energy should be initialized in erg/g. F is the thermal strength reduction factor.

```
EMELT = 1.E10

F     = 1.

CALL SHEAR2 (NCALL, INPUT, MATL, J, J, IH3, SX, SY, SZ,
1  TXY, PRESS(J), COM(L+1), DENS(J), DOLD, DT, EH, EOLD,
2  COM(L+2), EMELT, COM(L+3), EX, EY, EZ, EXY, F, Y(J),
3  COM(L+4), ROT, DROT, ESC, COM(L+5) )
```

In the CALL statement, J appears twice because the statement is for a two-dimensional code. DENS(J) and DOLD are the new density and the density at the previous cycle, DT is the time step, and EH and EOLD are the new internal energy and the internal energy at the previous cycle. The use of the COM array is illustrated in the CALL. The first member of the array for the Jth cell, COM(L), was used earlier for IH3. Now the next four members of the array are used to represent individual variables. The last of the formal parameters, COM(L+5), is just the first of a set of 20 variables used in one group by SHEAR2. After the CALL statement, the stress and IH3 are returned to their standard locations:

SIGDEV = -SX

COM(L) = IH3

Before insertion into ONED, any new subroutine should be thoroughly tested by itself. For example, SSONED was tested with a one-page program called TSS, which was written for these tests. TSS first calls SSONED (in the same way that READIT would) to read and initialize variables. Then TSS calls SSONED in a 50-step loop (like CMPUTE would) to compute pressure. In this loop density changes were provided that caused several cycles of loading, unloading, and reloading. The resulting pressure-density path was plotted to verify that the correct path was followed.

Following insertion of a new material model into ONED, it is a good plan to run a simple problem with NHIST set to 5 or 10 to determine whether the routine is performing satisfactorily.

Appendix D

LISTING OF ONED AND ITS SUBROUTINES

The following listing contains all the subroutines used with ONED, listed in alphabetical order after the main program. Included are ONED, the COMMON block used with all the routines, CMPUTE, EOSTAB, EQST, EXPLODE, GRAFONED, HISTRY, PLOTIT, READIT, and SSONED. HISTRY contains a number of ENTRYs, which make them also appear as subroutine CALLS in the other routines. These ENTRYs are FORCI, PLOTSC, RECORD, SCRIBE, UPDATE, VALMAX, and ZERO.

GRAFONED calls an SRI graphing routine called GRAPH4. A user will need to replace these CALLs in GRAFONED by CALLs appropriate to the graphics software at his computer.

```
      PROGRAM ONED                                                      ONED   1
C       ONE-DIMENSIONAL WAVE PROPAGATION PROGRAM FOR PLANAR FLOW.       ONED   2
C BASED ON ONED154 OF WES.  PROGRAMMERS ROHANI AND DAVIS. REVISED BY    ONED   3
C RADHAKRISHNAN, SEPT.69.MODIFIED BY SEAMAN IN SEPTEMBER 1984 TO INCLUDEONED   4
C AN EXPLICIT LEAP-FROG SOLUTION SCHEME WITH ARTIFICIAL VISCOSITY, LARGEONED   5
C DEFORMATIONS, AND SEPARATE SUBROUTINES WITH STRESS-STRAIN RELATIONS   ONED   6
C FOR SOILS, SOLIDS, AND EXPLOSIVES.                                    ONED   7
C                                                                       ONED   8
C       MAIN PROGRAM CALLS ROUTINES READIT, CMPUTE AND PLOTIT.          ONED   9
C                                                                       ONED  10
C       TIME SEQUENCING                                                 ONED  11
C         STRESS, ACCEL, POSITION, STRAIN ARE AT TIME AND TIME+DT       ONED  12
C         VELOCITY IS DEFINED AT TIME+DT/2                              ONED  13
C       ORDER OF CALCULATIONS IS:                                       ONED  14
C         ACCEL, VELOCITY, POSITION, STRESS                             ONED  15
C                                                                       ONED  16
      INCLUDE '$DISK3:[SEAMAN.ONED]ONEDCOM.FOR'                         ONED  17
C                                                                       ONED  18
      ITAPE = 0                                                         ONED  19
   10 REWIND 7                                                          ONED  20
C ****      READIT READS, DIGESTS, AND OUTPUTS THE INPUT DATA  ****     ONED  21
      CALL READIT                                                       ONED  22
      IF (NOCOMP .EQ. 999) GO TO 30                                     ONED  23
C ****   CMPUTE COMPUTES AND PRINTS THE GROUND MOTIONS AND STRESSES AND ONED  24
C       RECORDS THE INFORMATION ON TAPE FOR PLOTIT              ****    ONED  25
      CALL CMPUTE                                                       ONED  26
      READ (5,950,END=22) ID                                            ONED  27
      GO TO 24                                                          ONED  28
   22 ID = 0                                                            ONED  29
C       IF ID = 0, END OF RUN; OTHERWISE, ANOTHER SET OF DATA FOLLOWS.  ONED  30
   24 IF (KNT .LE. 0) GO TO 55                                          ONED  31
   30 REWIND 7                                                          ONED  32
C ****  PLOTIT USES THE DATA FROM THE TAPE GENERATED IN CMPUTE TO       ONED  33
C       GENERATE A PLOT TAPE OF THE GROUND MOTIONS AND STRESSES  ****   ONED  34
C       CALL PLOTIT                                                     ONED  35
      ITAPE = 1                                                         ONED  36
      IF (NSV .EQ. 0) GO TO 55                                          ONED  37
C       SAVE TAPE BY ADDING SUITABLE CODING AT THIS POINT               ONED  38
   55 IF (KNT .EQ. 0) WRITE (6,934)                                     ONED  39
      CALL SCRIBE                                                       ONED  40
      IF (ID .EQ. 0) GO TO 70                                           ONED  41
      WRITE (6,965)                                                     ONED  42
      GO TO 10                                                          ONED  43
   70 WRITE (6,970)                                                     ONED  44
      STOP ' ONED, NORMAL END'                                          ONED  45
C               FORMAT STATEMENTS                                       ONED  46
  934 FORMAT (// 9X,20H NO PLOTS WERE MADE   )                          ONED  47
  950 FORMAT (78X,I2)                                                   ONED  48
  965 FORMAT (// 9X,16H END OF PROBLEM   )                              ONED  49
  970 FORMAT (// 9X,12H END OF RUN   )                                  ONED  50
      END                                                               ONED  51
```

```
C       [SEAMAN.ONED]ONEDCOM.FOR                                          COM    1
      IMPLICIT REAL*8 (A-H,O-Z)                                           COM    2
      PARAMETER (NON = 300)                                               COM    3
      CHARACTER*8 NAME                                                    COM    4
      COMMON G,GACC,NOCOMP,FORCE,NMTRLS,NSTEP,NSTOP                       COM    5
      COMMON /ID/ BETA(12),IDENT                                          COM    6
      COMMON /PLOT/ DEP(20),KNTROL(7),KNT,NOUT(20),NSV,SK(7),TNDPLT       COM    7
      COMMON /TIME/ DT,TIME,TEND                                          COM    8
      COMMON /PROP/ DAMPL(6),DAMPQ(6),ELMOD(6),GAM(6),NAME(6),NPR(6),     COM    9
     @  NPOR(6),NSOL(6),NVAR(6),RHO(6),SHMOD(6),SQRTNP(6),TANPHI(6),      COM   10
     @  YIELD(6)                                                          COM   11
      COMMON /LAYER/ LB,N,NSP                                             COM   12
      COMMON /EDIT/ KVEL,LCOUNT,LPRNT,MVT,NHIST,NNODE                     COM   13
      COMMON /TENS/ TENSN(6),NTENSN(6)                                    COM   14
      COMMON /ARRAY/ ACC(NON),ALPHA(NON),CELMAS(NON),DENS(NON),           COM   15
     @  PRESS(NON),RMECH(NON),SIG1(NON),SSPEED(NON),TENSIL(NON),          COM   16
     @  VEL(NON),X(NON),Y(NON),MAT(NON)                                   COM   17
      COMMON /MAX/ SAVDMX(5,NON),TMAX(5,NON)                              COM   18
      COMMON /COM/ LVAR(NON),COM(5000)                                    COM   19
      COMMON /CALIB/ DENSCAL, DISTCAL, PRESCAL, VELCAL, AVELCAL,          COM   20
     @ NVELCAL                                                            COM   21
      COMMON /FORC/ NFORCE,PHIST(900),THIST(900)                          COM   22
```

```
      SUBROUTINE CMPUTE                                                 CMPT   1
C   "CMPUTE" CONTAINS THE MAIN TIME-STEPPING LOOP OVER ALL CELLS,       CMPT   2
C            COMPUTES ACCEL., VELOCITY, DISPL., AND CALLS THE           CMPT   3
C             STRESS-STRAIN SUBROUTINES TO COMPUTE STRESS.              CMPT   4
C            DETERMINES THE TIME STEP SIZE,                             CMPT   5
C            CALLS "FORCI" TO COMPUTE DRIVING STRESS ON FIRST NODE,     CMPT   6
C            CALLS "HISTRY" FOR LISTING OF VALUES AT CERTAIN TIMES,     CMPT   7
C            CALLS "UPDATE" TO STORE MAXIMUM VALUES OF VARIABLES,       CMPT   8
C            CALLS "VALMAX" TO PRINT THE MAXIMUM VALUES, AND            CMPT   9
C            CALLS "RECORD" TO STORE HISTORICAL DATA FOR PRINTING.      CMPT  10
C                                                                       CMPT  11
C        - - -  DEFINITIONS  - - -                                      CMPT  12
C        ACC(I)   = ACCELERATION AT NODE  I, (IN/SEC^2)                 CMPT  13
C        ALPHA(I)= ATTENUATION FACTOR TO APPROXIMATE MULTI-DIM FLOW     CMPT  14
C        CELMAS(I)= MASS OF CELL  I  BETWEEN NODES I AND I+1,(G/CM^2)   CMPT  15
C        DENS(I) = DENSITY OF CELL  I  BETWEEN NODES I AND I+1,(G/CM^3) CMPT  16
C        RMECH(I)= MECHANICAL STRESS IN CELL  I, (DYN/CM^2)             CMPT  17
C        SIG1(I) = THERMODYNAMIC STRESS IN CELL  I, (DYN/CM^2)          CMPT  18
C        SSPEED(I) = SOUND SPEED IN CELL  I, (CM/SEC)                   CMPT  19
C        VEL(I)   = VELOCITY AT NODE  I, (CM/SEC)                       CMPT  20
C        X(I)     = POSITION OF NODE  I, (CM)                           CMPT  21
C        Y(I)     = CURRENT YIELD STRENGTH OF NODE I, (DYN/CM^2)        CMPT  22
C                                                                       CMPT  23
C        NPRNT AND NHIST CONTROL WHEN GROUND MOTIONS ARE (ARE NOT) PRINTECMPT  24
C                                                                       CMPT  25
      INCLUDE '[SEAMAN.ONED]ONEDCOM.FOR'                                CMPT  26
C                                                                       CMPT  27
C **********                                                  ***********CMPT  28
      TIME = 0.                                                         CMPT  29
      FORCE = 0.                                                        CMPT  30
      SAFETY = 0.8                                                      CMPT  31
      NPRNT = NHIST - 1                                                 CMPT  32
C       BEGIN LOOP OVER TIME STEPS                                      CMPT  33
      DT = 1.E-12                                                       CMPT  34
      DTOLD = DT                                                        CMPT  35
      NSTEP = 0                                                         CMPT  36
  100 NSTEP = NSTEP+1                                                   CMPT  37
      TIME = TIME+DT                                                    CMPT  38
      DTHALF = 0.5*(DT+DTOLD)                                           CMPT  39
      DTMIN = 1000.                                                     CMPT  40
C       CALL "FORCI" TO OBTAIN THE DRIVING STRESS ON NODE 1.            CMPT  41
      IF (NFORCE .GT. 0) CALL FORCI                                     CMPT  42
C *********                                                   *******   CMPT  43
C                                                                       CMPT  44
C       COMPUTE ACCELERATION, VELOCITY AND POSITION                     CMPT  45
C                                                                       CMPT  46
C *********                                                   *******   CMPT  47
      ACC(1) = (FORCE-RMECH(1))/(0.5*CELMAS(1)) + GACC                  CMPT  48
      VOLD = VEL(1)                                                     CMPT  49
      XOLD = X(1)                                                       CMPT  50
      VEL(1) = VEL(1)+DTHALF*ACC(1)                                     CMPT  51
      X(1) = X(1)+VEL(1)*DT                                             CMPT  52
C *********                                                   *******   CMPT  53
C       LOOP OVER ALL NODES FOR ACC, VEL, POSITION                      CMPT  54
C *********                                                   *******   CMPT  55
      ISPALL = 0                                                        CMPT  56
      DO 200 J=2,N                                                      CMPT  57
C       REAR BOUNDARY CONDITIONS, LB=1 MEANS RIGID, LB=0 MEANS FREE     CMPT  58
      IF (J .GE. N .AND. LB .EQ. 1) GO TO 200                           CMPT  59
      IF (J .GE. N .AND. LB .EQ. 0) GO TO 160                           CMPT  60
C       TEST FOR INTERFACE CONDITIONS                                   CMPT  61
  120 IF (MAT(J-1) .NE. 0 .AND. MAT(J) .NE. 0) GO TO 160                CMPT  62
```

```
C       TEST FOR RIGHT SIDE OF INTERFACE, MAT(J-1) = 0                    CMPT  63
      IF (MAT(J-1) .EQ. 0) GO TO 155                                      CMPT  64
C       TEST CONDITIONS ON LEFT SIDE OF INTERFACE, MAT(J) = 0             CMPT  65
      IF (X(J+1)-X(J) .GT. 1.E-8) GO TO 160                               CMPT  66
C       COMBINED INTERFACE, COMPUTED FOR J = NODE ON LEFT                 CMPT  67
      ACC(J) = (RMECH(J-1)-RMECH(J+1))/(0.5*(CELMAS(J-1)+CELMAS(J+1)))    CMPT  68
     @  + GACC                                                            CMPT  69
      VEL(J) = (CELMAS(J-1)*VEL(J)+CELMAS(J+1)*VEL(J+1))/                 CMPT  70
     @  (CELMAS(J-1)+CELMAS(J+1)) + DTHALF*ACC(J)                         CMPT  71
      IF (ABS(VEL(J)) .LE. 1.) VEL(J) = 0.                                CMPT  72
      X(J) = X(J)+VEL(J)*DT                                               CMPT  73
      ACC(J+1) = ACC(J)                                                   CMPT  74
      VEL(J+1) = VEL(J)                                                   CMPT  75
      X(J+1) = X(J)                                                       CMPT  76
      ISPALL = 1                                                          CMPT  77
      GO TO 200                                                           CMPT  78
C       RIGHT SIDE OF INTERFACE                                           CMPT  79
  155 IF (ISPALL .EQ. 1) GO TO 200                                        CMPT  80
C *********                                                   *******     CMPT  81
C       STANDARD ROUTE FOR INTERIOR NODE OR SPALLED NODE                  CMPT  82
  160 ACC(J) = (RMECH(J-1)-RMECH(J))/(0.5*(CELMAS(J-1)+CELMAS(J))) +GACCCMPT  83
      VEL(J) = VEL(J)+ACC(J)*DTHALF                                       CMPT  84
      IF (ABS(VEL(J)) .LE. 0.01) VEL(J) = 0.                              CMPT  85
      X(J) = X(J)+VEL(J)*DT                                               CMPT  86
      ISPALL = 0                                                          CMPT  87
  200 CONTINUE                                                            CMPT  88
C                                                                         CMPT  89
C *********                                                   *******     CMPT  90
C       LOOP OVER EACH CELL TO COMPUTE STRAIN AND STRESS                  CMPT  91
C *********                                                   *******     CMPT  92
C                                                                         CMPT  93
      IF (NHIST .GT. 0 .AND. MOD(NSTEP,NHIST) .EQ. 0)                     CMPT  94
     @  WRITE (6,1644) BETA,NSTEP,TIME                                    CMPT  95
 1644 FORMAT (/10X,12A6/' SNAPSHOT AT NSTEP =',I4,', TIME =',1PE12.5/     CMPT  96
     @  8H   J MAT,5X,1HL,11X,1HX,9X,3HVEL,5X,5HRMECH,6X,4HSIG1,          CMPT  97
     @ 5X,5HDSTRS,5X,5HPRESS,6X,4HDENS,4X,6HSSPEED,4X,6HSIGDEV,9X,1HY/    CMPT  98
     @  24X,2HCM,6X,6HCM/SEC,3X,7HDYN/CM2,3X,7HDYN/CM2,3X,7HDYN/CM2,      CMPT  99
     @  3X,7HDYN/CM2,5X,5HG/CM3,4X,6HCM/SEC,3X,7HDYN/CM2,3X,7HDYN/CM2)    CMPT 100
      DO 650 J = 1,N                                                      CMPT 101
      RMOLD = RMECH(J)                                                    CMPT 102
      DOLD = DENS(J)                                                      CMPT 103
      SOLD = SIG1(J)                                                      CMPT 104
      POLD = PRESS(J)                                                     CMPT 105
      DSTRS = 0.                                                          CMPT 106
      SPEED = SSPEED(J)                                                   CMPT 107
      L = LVAR(J)                                                         CMPT 108
      SIGDEV = SIG1(J)-PRESS(J)                                           CMPT 109
      IF (MAT(J) .LE. 0 .OR. J .EQ. N) GO TO 648                          CMPT 110
      MATL = MAT(J)                                                       CMPT 111
      DENS(J) = CELMAS(J)/(X(J+1)-X(J))                                   CMPT 112
C *********                                                   *******     CMPT 113
C                 CONSTITUTIVE RELATIONS                                  CMPT 114
C *********                                                   *******     CMPT 115
C                   MODELS FOR PRESSURE                                   CMPT 116
C *********                                                   *******     CMPT 117
C           POROUS MATERIAL:  THE -SSONED- MODEL                          CMPT 118
      IF (NPOR(MATL) .EQ. 0) GO TO 260                                    CMPT 119
      CALL SSONED(2,J,NSTEP,MATL,DENS(J),DOLD,PRESS(J),COM(L),            CMPT 120
     @  TENSIL(J),COM(L+1),SPEED2)                                        CMPT 121
      GO TO 450                                                           CMPT 122
C *********                                                   *******     CMPT 123
C                EXPLOSIVE                                                CMPT 124
```

```
  260 IF (NPR(MATL) .EQ. 0) GO TO 280                                   CMPT 125
      CALL EXPLODE(2,J,NSTEP,MATL,DENS(J),PRESS(J),SPEED2)              CMPT 126
      GO TO 600                                                         CMPT 127
C *********                                                   *******   CMPT 128
C          MIE-GRUENEISEN MODEL FOR A SOLID                             CMPT 129
  280 IF (NSOL(MATL) .EQ. 0) GO TO 450                                  CMPT 130
      CALL EQST(2,J,NSTEP,MATL,PRESS(J),DENS(J),SPEED2)                 CMPT 131
C *********                                                   *******   CMPT 132
C                DEVIATOR STRESS MODELS                                 CMPT 133
C *********                                                   *******   CMPT 134
C        ELASTIC, PLASTIC, WITH COULOMB-TRESCA YIELD STRENGTH           CMPT 135
 450  IF (Y(J) .EQ. 0. .AND. TANPHI(MATL) .EQ. 0.) GO TO 590            CMPT 136
      IF (TANPHI(MATL) .EQ. 0.) GO TO 500                               CMPT 137
      PLIMIT = -Y(J)*SQRTNP(MATL)/(SQRTNP(MATL)**2-1.)                  CMPT 138
      IF (PRESS(J) .LE. PLIMIT) GO TO 590                               CMPT 139
      DEPS = 2.*(DENS(J)-DOLD)/(DENS(J)+DOLD)                           CMPT 140
      SIGDEV = SIGDEV+1.333*SHMOD(MATL)*DEPS                            CMPT 141
      IF (SIGDEV .GT. 0.) SIGDEV = MIN(SIGDEV,(Y(J)*SQRTNP(MATL) +      CMPT 142
     @  PRESS(J)*(SQRTNP(MATL)**2-1.))/(1.+0.5*SQRTNP(MATL)**2))        CMPT 143
      IF (SIGDEV .LT. 0.) SIGDEV = MAX(SIGDEV,-(Y(J)*SQRTNP(MATL) +     CMPT 144
     @  PRESS(J)*(SQRTNP(MATL)**2-1.))/(0.5+SQRTNP(MATL)**2))           CMPT 145
      GO TO 600                                                         CMPT 146
C        DEVIATOR MODEL: ELASTIC, PLASTIC WITH CONSTANT YIELD STRENGTH  CMPT 147
  500 DEPS = 2.*(DENS(J)-DOLD)/(DENS(J)+DOLD)                           CMPT 148
      SIGDEV = SIGDEV+1.333*SHMOD(MATL)*DEPS                            CMPT 149
      SIGDEV = SIGN(MIN(ABS(SIGDEV),0.666667*Y(J)),SIGDEV)               CMPT 150
      GO TO 600                                                         CMPT 151
  590 SIGDEV = 0.                                                       CMPT 152
  600 SIG1(J) = PRESS(J)+SIGDEV                                         CMPT 153
      SSPEED(J) = SQRT(SPEED2+1.333*SHMOD(MATL)/DENS(J))                CMPT 154
C *********                                                   *******   CMPT 155
C        ARTIFICIAL VISCOUS STRESS                                      CMPT 156
      DELTAV = VEL(J+1)-VEL(J)                                          CMPT 157
      IF (DELTAV .GT. 0.) GO TO 635                                     CMPT 158
      DSTRS = RHO(MATL)*DELTAV*(-DAMPL(MATL)*SQRT(ABS(PRESS(J)/DENS(J)))CMPT 159
     @  + DAMPQ(MATL)*DELTAV)                                           CMPT 160
C *********                                                   *******   CMPT 161
C        SOUND SPEED                                                    CMPT 162
  635 SPEED = SSPEED(J)                                                 CMPT 163
      IF (ABS(DENS(J)-DOLD) .LT. 1.E-4) GO TO 640                       CMPT 164
      EFFMOD = (SIG1(J)-SOLD+2.*DSTRS)/(DENS(J)-DOLD)                   CMPT 165
      IF (EFFMOD .GT. SPEED**2) SPEED = SQRT(EFFMOD)                    CMPT 166
C *********                                                   *******   CMPT 167
C        COMPUTE NATURAL TIME STEP FOR EACH CELL                        CMPT 168
  640 DTNAT = (X(J+1)-X(J)+DT*(VEL(J+1)-VEL(J)))/(SPEED+MAX(VEL(J),0.D0)CMPT 169
     @  - MIN(VEL(J+1),0.D0))                                           CMPT 170
      IF (DTNAT .GT. DTMIN) GO TO 645                                   CMPT 171
      DTMIN = DTNAT                                                     CMPT 172
      JTS = J                                                           CMPT 173
      DXJTS = X(J+1)-X(J)                                               CMPT 174
      SPJTS = SPEED                                                     CMPT 175
  645 RMECH(J) = SIG1(J)+DSTRS                                          CMPT 176
  648 IF (NHIST .GT. 0 .AND. MOD(NSTEP,NHIST) .EQ. 0)                   CMPT 177
     @  WRITE (6,1645) J, MAT(J), L, X(J), VEL(J), RMECH(J), SIG1(J),   CMPT 178
     @    DSTRS, PRESS(J), DENS(J), SSPEED(J), SIGDEV,Y(J)             CMPT 179
 1645 FORMAT (I4,I4,I6,1P2E12.5,4E10.3,0PF10.6,1P3E10.3)                CMPT 180
  650 CONTINUE                                                          CMPT 181
C *********                                                   *******   CMPT 182
C        SET TIME STEP FOR NEXT CYCLE                                   CMPT 183
      DTOLD = DT                                                        CMPT 184
      DT = MIN(SAFETY*DTMIN,TEND-TIME,MAX(1.2*DT,0.035*SAFETY*DTMIN))   CMPT 185
      IF (NHIST .GT. 0 .AND. MOD(NSTEP,NHIST) .EQ. 0)                   CMPT 186
```

```
     @  WRITE (6,1655) NSTEP, DT, DTMIN, TIME, JTS, DXJTS, SPJTS        CMPT 187
 1655 FORMAT (' CMP TIME, NSTEP=',I4,' DT,DTMIN,TIME=',1P3E12.5,' JTS=',CMPT 188
     @  I4,' DX,SPEED AT JTS=',2E10.3)                                  CMPT 189
C *********                                                  *******    CMPT 190
C       PRINT SNAPSHOT EDIT OF VALUES AT CURRENT TIME                   CMPT 191
      IF (NHIST .LE. 0) GO TO 701                                       CMPT 192
      NPRNT = NPRNT + 1                                                 CMPT 193
      IF (NPRNT .LT. NHIST) GO TO 701                                   CMPT 194
      NPRNT = 0                                                         CMPT 195
      CALL HISTRY                                                       CMPT 196
C       WRITE HISTORICAL DATA TO TAPE 7 FOR PLOTTING                    CMPT 197
  701 IF (KNT .GE. 1 .OR. NSTEP .EQ. 1) CALL RECORD                     CMPT 198
C       STORE MAXIMUM VALUES FOR CURRENT CYCLE                          CMPT 199
      CALL UPDATE                                                       CMPT 200
      IF (TIME .LT. TEND .AND. NSTEP .LT. NSTOP) GO TO 100              CMPT 201
      END FILE 7                                                        CMPT 202
C *********                                                  *******    CMPT 203
C       PRINT MAX VALUES OF STRESS, ACC, VEL, POSITION, STRAIN          CMPT 204
      CALL VALMAX                                                       CMPT 205
      END FILE 7                                                        CMPT 206
      REWIND 7                                                          CMPT 207
      IF (KNT .LE. 0) RETURN                                            CMPT 208
      IF (NOCOMP .EQ. 998) RETURN                                       CMPT 209
C       WRITE PLOTTING SCALES                                           CMPT 210
C *********                                                  *******    CMPT 211
      CALL PLOTSC                                                       CMPT 212
      RETURN                                                            CMPT 213
      END                                                               CMPT 214
```

```
      SUBROUTINE EOSTAB (NCALL,IN,M,DN,ENGN,PRESN)
C       TABULAR ISENTROPE TO BE USED FOR EXPLOSIVE GASES
      IMPLICIT REAL*8 (A-H,O-Z)
C
C             CURRENT REVISION - AUGUST, 1984
C
      DIMENSION D(30,6),ENG(30,6),PRES(30,6),EX(30,6),MAXN(6),
     @  PRINV(30),TYPE(6),VORD(30)
      CHARACTER*8 LABEL,TYPE
C
      IF (NCALL .GT. 0) GO TO 200
C
C         INITIALIZE AND READ DATA   #####  NCALL = 0  #######
C
      READ (IN,*) IMAX,LABEL,TYPE(M)
      MAXN(M) = IMAX
      IF (LABEL .EQ. 'VOLUME') GO TO 10
      LABEL = 'DENSITY'
   10 IF (TYPE(M) .EQ. 'LOG') GO TO 20
      TYPE(M) = 'LINEAR'
   20 WRITE (6,9010) IMAX,LABEL,TYPE(M),IN
      READ (IN,*) (VORD(I),PRES(I,M), I=1,IMAX)
      WRITE (6,9030) (VORD(I),PRES(I,M), I=1,IMAX)
      IF (LABEL .NE. 'VOLUME') GO TO 31
C         TRANSFORMATION OF VOLUME TO DENSITY
      DO 30 I=1,IMAX
   30 VORD(I)=1./VORD(I)
   31 IF (VORD(1) .GT. VORD(2)) GO TO 38
C       INVERT ORDER OF DENSITY VALUES TO GIVE LARGEST VALUES FIRST
      DO 32 I = 1,IMAX
   32 PRINV(I) = PRES(I,M)
      DO 35 I = 1,IMAX
      IS = IMAX+1-I
      PRES(I,M) = PRINV(IS)
   35 D(I,M) = VORD(IS)
      GO TO 45
C       PLACE DENSITY AND PRESSURE IN MAIN ARRAYS
   38 DO 40 I = 1,IMAX
   40 D(I,M) = VORD(I)
   45 IM1=IMAX-1
      WRITE (6,1045) (PRES(I,M),D(I,M),I=1,IMAX)
 1045 FORMAT (' 45 EOSTAB P,D=',1P6E10.3/(10X,6E10.3))
C       COMPUTE DP/DRHO OR POLYTROPIC EXPONENT
      DO 50 I=1,IM1
   50 EX(I,M)=(PRES(I+1,M)-PRES(I,M))/(D(I+1,M)-D(I,M))
      IF (TYPE(M) .NE. 'LOG') GO TO 80
      DO 65 I=1,IM1
      IF (PRES(I,M) .LE. 0. .OR. PRES(I+1,M) .LE. 0.) GO TO 65
      EX(I,M)=LOG(PRES(I+1,M)/PRES(I,M))/LOG(D(I+1,M)/D(I,M))
   65 CONTINUE
   80 CONTINUE
      WRITE (6,1080) (EX(I,M),I=1,IMAX)
 1080 FORMAT (' 80 EOSTAB EX=',1P6E10.3/(10X,6E10.3))
      RETURN
C *****                                                 *****
C-----CALCULATE PRESSURE          ####  NCALL = 1  ####
C *****                                                 *****
C       IT - ARRAY SUBSCRIPT OF LEFT LIMIT OF INTERVAL BEING CHECKED
  200 IT = MAXN(M) - 1
C       CHECK IF INPUT DENSITY IS LESS THAN ANY VALUE IN INTERVAL
C        CONTAINING LOWEST DENSITY
      IF (DN .LT. D(IT,M)) GO TO 275
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```
      IT=1                                                              ETAB  63
C       CHECK IF INPUT DENSITY IS GREATER THAN ANY VALUE IN INTERVAL    ETAB  64
C        CONTAINING HIGHEST DENSITY                                     ETAB  65
      IF (DN .GT. D(IT,M)) GO TO 275                                    ETAB  66
      IM2 = MAXN(M) - 1                                                 ETAB  67
      DO 240 I=1,IM2                                                    ETAB  68
      IT=MAXN(M)-I+1                                                    ETAB  69
      IF (DN .LT. D(IT,M)) GO TO 275                                    ETAB  70
  240 CONTINUE                                                          ETAB  71
  275 IF (TYPE(M) .EQ. 'LOG') GO TO 290                                 ETAB  72
  280 PRESN = PRES(IT,M)+(DN-D(IT,M))*EX(IT,M)                          ETAB  73
      GO TO 300                                                         ETAB  74
  290 IF (PRES(IT,M) .LE. 0. .OR. PRES(IT+1,M) .LE. 0.) GO TO 280       ETAB  75
      PRESN = PRES(IT,M)*(DN/D(IT,M))**EX(IT,M)                         ETAB  76
  300 CONTINUE                                                          ETAB  77
      RETURN                                                            ETAB  78
C                                                                       ETAB  79
 9010 FORMAT (' IMAX=',I3,' LABEL=',A8,' TYPE=',A8,2X,4H,IN=,I1,        ETAB  80
     @  7H -EOST- )                                                     ETAB  81
 9030 FORMAT (' V OR D, P=',1P6E10.3/(11X,6E10.3))                      ETAB  82
      END                                                               ETAB  83
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      SUBROUTINE EQST (LS, J, N, M, P, D, SPEED2)                       EQST   1
C       PRESSURE FROM P = C*MU + D*MU^2 + S*MU^3                        EQST   2
      IMPLICIT REAL*8(A-H,O-Z)                                          EQST   3
C                                                                       EQST   4
      COMMON /CALIB/ DENSCAL, DISTCAL, PRESCAL, VELCAL                  EQST   5
C                                                                       EQST   6
      DIMENSION EQSTC(6),EQSTD(6),EQSTS(6),RHO(6)                       EQST   7
      IF (LS .GT. 0) GO TO 100                                          EQST   8
C       INITIALIZATION PORTION                                          EQST   9
      READ (5,*) EQSTC(M), EQSTD(M), EQSTS(M)                           EQST  10
      WRITE (6,1002) M, EQSTC(M), EQSTD(M), EQSTS(M)                    EQST  11
 1002 FORMAT (' EOS DATA FOR M=',I2,': C, D, S=',1P8E10.3)              EQST  12
      RHO(M) = D                                                        EQST  13
      EQSTC(M) = EQSTC(M)*PRESCAL                                       EQST  14
      EQSTD(M) = EQSTD(M)*PRESCAL                                       EQST  15
      EQSTS(M) = EQSTS(M)*PRESCAL                                       EQST  16
      SPEED2 = EQSTC(M)/RHO(M)                                          EQST  17
      WRITE (6,1093) RHO(M), EQSTC(M), EQSTD(M), EQSTS(M), SPEED2       EQST  18
 1093 FORMAT (' EOS CALIB. DATA: RHO, C, D, S=',1P4E10.3,' SP2=',E10.3) EQST  19
      RETURN                                                            EQST  20
C       COMPUTE PRESSURE                                                EQST  21
  100 EMU = D/RHO(M)-1.                                                 EQST  22
      P = EMU*(EQSTC(M)+EMU*(EQSTD(M)+EMU*EQSTS(M)))                    EQST  23
      SPEED2 = (EQSTC(M)+2.*EMU*EQSTD(M)+3.*EMU**2*EQSTS(M))/RHO(M)     EQST  24
      RETURN                                                            EQST  25
      END                                                               EQST  26
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      SUBROUTINE EXPLODE (NCALL, J, N, M, D, P, SPEED2)
      IMPLICIT REAL*8 (A-H,O-Z)
C
C        THIS SUBROUTINE FOR EXPLOSIONS HAS TWO FUNCTIONS AND
C        IS DIVIDED INTO TWO PARTS:
C          1.  INITIALIZE THE MATERIAL VARIABLES AT THE TIME OF READING
C              MATERIAL PROPERTIES.
C          2.  COMPUTE PRESSURE IN THE EXPLOSIVE PRODUCTS DURING THE
C              CALCULATION.
C       SPECIAL FEATURES:
C         * TABULAR EQUATION OF STATE BY LABELLING -QEXPL- WITH 'TAB'
C           IN THE TITLE OF THE INPUT LINE
C
      COMMON /CALIB/ DENSCAL, DISTCAL, PRESCAL, VELCAL
C
      DIMENSION RHO(3),MTRANS(6),PCJ(3),QEXPL(3),TAB(3),VCJ(3)
      DIMENSION EQSTG(3)
      CHARACTER*3 LABEL
C
      DATA MAT/0/
      IN=5
      IF (NCALL .GT. 1) GO TO 300
C        NCALL = 1 TO INIT MAT PROP, 2 TO CALC PRESS.
C ********
C          INITIALIZE MATERIAL VARIABLES
C ********
      MAT = MAT+1
      MTRANS(M) = MAT
      READ (IN,*) LABEL,QEXPL(MAT),EQSTG(MAT)
      WRITE (6,9010) LABEL,QEXPL(MAT),EQSTG(MAT)
      RHO(MAT) = D
      TAB(MAT) = 0.
      SPEED2 = 2.*QEXPL(MAT)*EQSTG(MAT)*(EQSTG(MAT)+2.)
      VCJ(MAT)=(EQSTG(MAT)+1.)/((EQSTG(MAT)+2.)*RHO(MAT))
      PCJ(MAT)=2.*RHO(MAT)*QEXPL(MAT)*EQSTG(MAT)
      WRITE (6,9020) QEXPL(MAT),PCJ(MAT),VCJ(MAT),EQSTG(MAT),SPEED2
      IF (LABEL .NE. 'TAB') RETURN
C
C*****PREPARE FOR TABULAR EQUATION OF STATE FOR PRODUCTS
      CALL EOSTAB (0,IN,MAT,RHO(MAT),E)
      TAB(MAT) = 1.
      RETURN
C
C ********
C          COMPUTE DETONATION PROCESS
C ********

  300 MAT = MTRANS(M)
      IF (TAB(MAT) .EQ. 1.) GO TO 350
      P = PCJ(MAT)*(VCJ(MAT)*D)**(EQSTG(MAT)+1.)
      SPEED2 = (EQSTG(MAT)+1.)*P/D
      RETURN
C
C*****TABULAR EQUATION OF STATE
  350 CALL EOSTAB(1,5,MAT,D,E,P)
      SPEED2 = 3.*P/D
      RETURN
C
 9010 FORMAT(1X,A3,2X,1P2E10.3)
 9020 FORMAT(3X,'CONST.VOL.EXPLOSION WITH ENERGY='1PE10.3,
     @  ' ERG/G, PCJ =' E10.3,' VCJ ='E12.5,' GRUN =',E12.5,' SPEED2=',
     @  1PE10.3)
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```
      SUBROUTINE GRAFONED(TIME,SS,ST1,ST2,NST,NNODE,IDAT,BETA)
      CHARACTER*10 DISCPT(10),IDAT
      CHARACTER*80 LABEL(3)
      DIMENSION TIME(1),SS(1),ST1(1),ST2(1),IAR(7)
      REAL*8 KK,BETA(12)
C
C       GRAPHS DATA FROM ONED
C         STRESS 1 VS TIME
C         STRESS 2 VS TIME
C         STRESS 1 VS STRAIN
C
C     INITIALIZE
C
      IAR(1)=-1
      IAR(2)=1
      IAR(3)=0
      IAR(4)=0
      IAR(5)=0
      IAR(6)=0
      IAR(7)=5
C
      XMIN=0.
      XMAX=0.
      YMIN=0.
      YMAX=0.
C
      LABEL(1) = IDAT
      ENCODE (42,1000,LABEL(1)(11:52)) BETA(1),BETA(2),BETA(3),
     @   BETA(4),BETA(5),BETA(6),BETA(7)
1000  FORMAT (7A6)
C
      LABEL(2) = 'TIME -- *SEC$'
      LABEL(3) = 'PRINCIPAL STRESS 1  (MPa), NODE'
      ENCODE (3,1010,LABEL(3)(32:34)) NNODE
1010  FORMAT (I3)
      CALL GRAPH4 (TIME,ST1,NST,1,XMAX,XMIN,YMAX,YMIN,LABEL,IAR)
C
      LABEL(3) = 'PRINCIPAL STRESS 2  (MPa), NODE'
      ENCODE (3,1010,LABEL(3)(32:34)) NNODE
      CALL GRAPH4 (TIME,ST2,NST,1,XMAX,XMIN,YMAX,YMIN,LABEL,IAR)
C
      LABEL(2) = 'STRAIN  (*PERCENT$)'
      LABEL(3) = 'PRINCIPAL STRESS 1  (MPa), NODE'
      ENCODE (3,1010,LABEL(3)(32:34)) NNODE
      CALL GRAPH4 (SS,ST1,NST,1,XMAX,XMIN,YMAX,YMIN,LABEL,IAR)
      RETURN
      END
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      SUBROUTINE HISTRY                                                 HIST   1
C   THE HISTRY SUBROUTINE CONTAINS A SERIES OF SEPARATE SUBROUTINES     HIST   2
C   CALLED FOR PRINTING AND STORAGE OPERATIONS.                         HIST   3
C       - -  ACTIONS OF THE SUBROUTINES - -                             HIST   4
C      "ZERO"   INITIALIZES VALUES OF THE ARRAYS                        HIST   5
C      "HISTRY" PRINTS THE GROUND MOTIONS AT SELECTED TIMES             HIST   6
C      "RECORD" STORES ON TAPE 7 THE VARIABLES AT SELECTED NODES        HIST   7
C      "SCRIBE" PRINTS THE HISTORIES OF THE VARIABLES AT SELECTED NODESHIST   8
C      "UPDATE" UPDATES THE MAX VALUE TABLE                             HIST   9
C      "VALMAX" PRINTS THE MAXIMUM VALUE TABLE                          HIST  10
C      "FORCI"  INTERPOLATES THE PRESSURE-TIME INPUT VALUES TO          HIST  11
C        DETERMINE THE SURFACE STRESS AT EACH TIME INCREMENT            HIST  12
C      "PLOTSC" COMPUTES THE SCALE FACTORS FOR THE PLOTS                HIST  13
C                                                                       HIST  14
      INCLUDE '[SEAMAN.ONED]ONEDCOM.FOR'                                HIST  15
C                                                                       HIST  16
      DIMENSION AA(20), RIMP(20), RR(20), RROLD(20), SS(20),            HIST  17
     @  ST1(20), ST2(20), VV(20), XX(20)                                HIST  18
      DIMENSION XSAVE(20), DSAVE(20), XZERO(900)                        HIST  19
      CHARACTER*10 IDAT                                                 HIST  20
      DATA ITIME/0/                                                     HIST  21
C       ********************************************                    HIST  22
      CALL DATE(IDAT)                                                   HIST  23
C       ENTRY HISTRY                                                    HIST  24
C  - HISTRY - PRINTS A SNAPSHOT OF THE STATUS OF STRESS AND OTHER VALUESHIST  25
C             AT THE REQUESTED NODES AT PERIODIC CALLS FROM -CMPUTE-.   HIST  26
C             THE CALL TO HISTRY IS AT CYCLES THAT ARE A MULTIPLE OF    HIST  27
C             NHIST.                                                    HIST  28
      LCOUNT = LCOUNT+1                                                 HIST  29
C      IF (LCOUNT-LPRNT) 210,205,205                                    HIST  30
  205 WRITE (6,1018) BETA                                               HIST  31
      WRITE (6,1019) NVELCAL                                            HIST  32
      LCOUNT = 0                                                        HIST  33
      RPSI = FORCE/PRESCAL                                              HIST  34
  210 WRITE (6,1021)TIME,RPSI                                           HIST  35
      DO 215 J=1,NNODE                                                  HIST  36
      KJ = NOUT(J)                                                      HIST  37
      QA = RMECH(KJ)*ALPHA(KJ)/PRESCAL                                  HIST  38
      RA = SIG1(KJ)*ALPHA(KJ)/PRESCAL                                   HIST  39
      DAMPF = QA-RA                                                     HIST  40
      MATL = MAT(KJ)                                                    HIST  41
      ST = (DENS(KJ)/RHO(MATL)-1.)*100.                                 HIST  42
      VELOC = VEL(KJ)*AVELCAL                                           HIST  43
      AG = ACC(KJ)/G                                                    HIST  44
      XIN = X(KJ)/2.54                                                  HIST  45
  215 WRITE (6,1023)KJ,QA,RA,DAMPF,ST,AG,VELOC,XIN                      HIST  46
      RETURN                                                            HIST  47
C       ****************************************                        HIST  48
      ENTRY RECORD                                                      HIST  49
C  - RECORD - SAVES CURRENT VALUES AT THE REQUESTED NODES FOR LATER     HIST  50
C             PRINTING BY -SCRIBE-.  RECORD IS CALLED AT EACH CYCLE     HIST  51
C             BY -CMPUTE-.                                              HIST  52
C      GLOSSARY OF VALUES STORED ON TAPE 7 FOR HISTORIES                HIST  53
C                                                                       HIST  54
C      RR = RMECH(J)  MECHANICAL STRESS                                 HIST  55
C      AA = ACC(J)/G  ACCELERATION IN G'S                               HIST  56
C      VV = VEL(J)  PARTICLE VELOCITY                                   HIST  57
C      XX = POSITION                                                    HIST  58
C      RIMP = IMPULSE                                                   HIST  59
C      SS = REACTION STRAIN                                             HIST  60
C      ST1 = THERMODYNAMIC STRESS IN FIRST (AXIAL) DIRECTION.           HIST  61
C      ST2 = THERMODYNAMIC STRESS IN SECOND (LATERAL) DIRECTION.        HIST  62
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C       SAVDMX(1,I)...(5,I) ARE RESPECTIVELY THE MAXIMUM VALUES OF      HIST  63
C         STRESS, ACCELERATION, PARTICLE VELOCITY, DISPLACEMENT AND     HIST  64
C         STRAIN AT I.                                                  HIST  65
C       TMAX(1,I)...TMAX(5,I) ARE THE TIMES CORRESPONDING TO THE MAX'S. HIST  66
C       SK(1)...SK(7) ARE THE SCALE FACTORS FOR PLOTTING THE ABOVE VS   HIST  67
C         TIME.                                                         HIST  68
      TOPSTRS = FORCE*1.E-7                                             HIST  69
      IF (NSTEP .GT. 1) GO TO 220                                       HIST  70
C       -DO 218-                                                        HIST  71
      DO 218 J = 1,NNODE                                                HIST  72
      KJ = NOUT(J)                                                      HIST  73
      DSAVE(J) = DENS(KJ)                                               HIST  74
      XSAVE(J) = X(KJ)                                                  HIST  75
  218 CONTINUE                                                          HIST  76
      DO 219 J = 1,N                                                    HIST  77
  219 XZERO(J) = X(J)                                                   HIST  78
C       PREPARE FIRST RECORD ON TAPE 7                                  HIST  79
C 'NNODE' IS THE NUMBER OF OUTPUT NODES, 'NOUT' GIVES THE CELL NO.S OF  HIST  80
C  THE OUTPUT NODES, 'BETA' IS THE PROBLEM DESCRIPTION, 'NSTEP' IS THE  HIST  81
C  NUMBER OF CYCLES, AND 'N' IS THE NUMBER OF CELLS.                    HIST  82
      NEND = 10000                                                      HIST  83
      WRITE (7) NNODE, NOUT, BETA, NEND, N                              HIST  84
  220 CONTINUE                                                          HIST  85
C       -DO 280-                                                        HIST  86
      DO 280 J=1,NNODE                                                  HIST  87
      KJ = NOUT(J)                                                      HIST  88
C       CONVERT STRESS FROM DYN/CM^2 TO MPA                             HIST  89
      RR(J)   = RMECH(KJ)*ALPHA(KJ)*1.E-7                               HIST  90
      ST1(J)  = SIG1(KJ)*1.E-7                                          HIST  91
      ST2(J)  = (1.5*PRESS(KJ)-0.5*SIG1(KJ))*1.E-7                      HIST  92
      RIMP(J)= RIMP(J)+(RR(J)+RROLD(J))/2.*DT*1.E7                      HIST  93
      IF (J .EQ. 1) WRITE (6,1224) J,KJ,RIMP(J),RR(J),RROLD(J),DT       HIST  94
 1224 FORMAT (' 224 HIST J,KJ=',2I4,' RIMP,RR=',1P2E10.3,' RROLD,DT=',  HIST  95
     1  2E10.3)                                                        HIST  96
      RROLD(J) = RR(J)                                                  HIST  97
      MATL = MAT(KJ)                                                    HIST  98
      SS(J) = (DENS(KJ)/RHO(MATL)-1.)*100.                              HIST  99
      AA(J) = ACC(KJ)/G                                                 HIST 100
      VV(J) = VEL(KJ)*AVELCAL                                           HIST 101
  280 XX(J) = X(KJ)/DISTCAL                                             HIST 102
      WRITE (7) TIME,TOPSTRS,(RR(J),AA(J),VV(J),XX(J),SS(J),RIMP(J),    HIST 103
     @  ST1(J),ST2(J),J=1,NNODE)                                        HIST 104
  290 RETURN                                                            HIST 105
C       ***********************************************                 HIST 106
      ENTRY SCRIBE                                                      HIST 107
C  - SCRIBE - IS CALLED AT THE END OF A CALCULATION TO PRINT THE        HIST 108
C             HISTORICAL DATA STORED ON TAPE 7 BY -RECORD-.  THE        HIST 109
C             CALL IS FROM -ONED-.                                      HIST 110
      DO 305 I = 1,NNODE                                                HIST 111
      REWIND 7                                                          HIST 112
      READ (7) NSPACE                                                   HIST 113
      IF (I .EQ. 1) WRITE (6,1299) BETA,NOUT(I),NVELCAL                 HIST 114
      IF (I .GT. 1) WRITE (6,1300) BETA,NOUT(I),NVELCAL                 HIST 115
      DO 300 NS = 1,NSTEP                                               HIST 116
      READ (7) TIME,TOPSTRS,(RR(J),AA(J),VV(J),XX(J),SS(J),RIMP(J),     HIST 117
     @  ST1(J),ST2(J),J=1,NNODE)                                        HIST 118
      IF (I .EQ. 1) WRITE (6,1301) NS,TIME,TOPSTRS,RR(I),AA(I),         HIST 119
     @  VV(I),XX(I),SS(I),RIMP(I),ST1(I),ST2(I)                         HIST 120
      IF (I .GT. 1) WRITE (6,1301) NS,TIME,RR(I),AA(I),VV(I),XX(I),     HIST 121
     @  SS(I),RIMP(I),ST1(I),ST2(I)                                     HIST 122
      IF (MOD(NS,55) .EQ. 0 .AND. I .EQ. 1) WRITE (6,1299) BETA,        HIST 123
     @  NOUT(I), NVELCAL                                                HIST 124
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      IF (MOD(NS,55) .EQ. 0 .AND. I .GT. 1) WRITE (6,1300) BETA,
     @  NOUT(I), NVELCAL
  300 CONTINUE
  305 CONTINUE
 1299 FORMAT (1H1,10X,12A6/
     @  24H  HISTORIES AT NODE NO. ,I3/4X,2HNS,8X,4HTIME,
     @  2X,10HTOP STRESS,7X,5HRMECH,9X,3HACC,4X,8HVELOCITY,4X,
     @  8HPOSITION,6X,6HSTRAIN,5X,7HIMPULSE,5X,7HSIGMA-1,5X,7HSIGMA-2/
     @  15X,3HSEC,9X,3HMPA,9X,3HMPA,9X,3HG'S,6X,A2,4H/SEC,10X,2HIN,
     @  9X,3H(%),2X,10HDYN-S/CM^2,9X,3HMPA,9X,3HMPA)
 1300 FORMAT (1H1,10X,12A6/
     @  24H  HISTORIES AT NODE NO. ,I3/4X,2HNS,8X,4HTIME,
     @  7X,5HRMECH,9X,3HACC,4X,8HVELOCITY,4X,8HPOSITION,6X,6HSTRAIN,
     @  5X,7HIMPULSE,5X,7HSIGMA-1,5X,7HSIGMA-2/
     @  15X,3HSEC,9X,3HMPA,9X,3HG'S,6X,A2,4H/SEC,10X,2HIN,
     @  9X,3H(%),2X,10HDYN-S/CM^2,9X,3HMPA,9X,3HMPA)
 1301 FORMAT (I6,1P10E12.3)
      RETURN
C       ***********************************************
      ENTRY UPDATE
C  - UPDATE - IS CALLED TO UPDATE THE MAXIMUM VALUE TABLE AT EACH CYCLE.
C             THESE VALUES ARE STORED AT THE REQUESTED NODES.  UPDATE
C             IS CALLED BY -CMPUTE-.
      IF (MVT) 319,317,319
  317 IF (KNT) 500,500,318
  318 NSTRT = NOUT(1)
      NFINSH = NOUT(1)+1
      GO TO 320
  319 NSTRT = 1
      NFINSH = N
  320 DO 365 I = NSTRT,NFINSH
      IF (ABS(RMECH(I)) .LT. ABS(SAVDMX(1,I))) GO TO 325
      SAVDMX(1,I) = RMECH(I)
      TMAX(1,I) = TIME
  325 IF (ABS(ACC(I)) .LT. ABS(SAVDMX(2,I))) GO TO 330
      SAVDMX(2,I) = ACC(I)
      TMAX(2,I) = TIME
  330 IF (ABS(VEL(I)) .LT. ABS(SAVDMX(3,I))) GO TO 335
      SAVDMX(3,I) = VEL(I)
      TMAX(3,I) = TIME
  335 IF (ABS(X(I)-XZERO(I)) .LT. ABS(SAVDMX(4,I))) GO TO 340
      SAVDMX(4,I) = X(I)-XZERO(I)
      TMAX(4,I) = TIME
  340 MATL = MAT(I)
      IF (ABS(DENS(I)-RHO(MATL)) .LT. ABS(SAVDMX(5,I))) GO TO 365
      SAVDMX(5,I) = DENS(I)-RHO(MATL)
      TMAX(5,I) = TIME
  365 CONTINUE
      RETURN
C       ***********************************************
      ENTRY VALMAX
C  - VALMAX - PRINTS THE TABLE OF MAXIMUM VALUES OF STRESS,
C             ACCELERATION, VELOCITY, DISPLACEMENT, AND STRAIN,
C             AND FOR ALL NODES AND CELLS.
C             THE CALL IS FROM -CMPUTE-.
      IF (MVT .EQ. 0) GO TO 420
      LCOUNT = 50
      DO 410 I=1,N
C       MODIFY THE MAXIMUM VALUES WITH CALIBRATION FACTORS
      SAVDMX(1,I) = SAVDMX(1,I)*ALPHA(I)*1.E-7
      SAVDMX(2,I) = SAVDMX(2,I)/G
      SAVDMX(3,I) = SAVDMX(3,I)*AVELCAL
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      SAVDMX(4,I) = SAVDMX(4,I)/DISTCAL                                 HIST 187
      MATL = MAT(I)                                                     HIST 188
      IF (MATL .EQ. 0 .OR. RHO(MATL) .EQ. 0.) MATL=MAT(I-1)             HIST 189
      SAVDMX(5,I) = SAVDMX(5,I)/RHO(MATL)*100.                          HIST 190
      LCOUNT = LCOUNT+1                                                 HIST 191
      IF (LCOUNT-50) 408,406,406                                        HIST 192
  406 LCOUNT = 0                                                        HIST 193
      WRITE (6,1014) BETA                                               HIST 194
      WRITE (6,1015) NVELCAL                                            HIST 195
  408 CONTINUE                                                          HIST 196
      XFT = XZERO(I)/30.48                                              HIST 197
      WRITE (6,1017),I,XFT, SAVDMX(1,I),TMAX(1,I), SAVDMX(3,I),         HIST 198
     @  TMAX(3,I), SAVDMX(4,I), TMAX(4,I), SAVDMX(5,I), TMAX(5,I),      HIST 199
     @  SAVDMX(2,I),TMAX(2,I)                                           HIST 200
      WRITE (7) I,CELMAS(I),(SAVDMX(J,I),TMAX(J,I),J=1,5)               HIST 201
  410 CONTINUE                                                          HIST 202
      WRITE (7) NNODE, NOUT, BETA, NSTEP, N                             HIST 203
  420 RETURN                                                            HIST 204
C                                                                       HIST 205
C      ***********************************************                  HIST 206
      ENTRY PLOTSC                                                      HIST 207
C  - PLOTSC -   DETERMINE THE SCALE FACTORS FOR PLOTTING                HIST 208
C               THIS ROUTINE HAS NOT BEEN UPDATED OR TESTED.            HIST 209
C                                                                       HIST 210
  430 K1 = NOUT(1)                                                      HIST 211
      DO 440 J=1,6                                                      HIST 212
      TEMX = ABS(SAVDMX(J,K1))                                          HIST 213
      IF (J .EQ. 6) TEMX = RRM                                          HIST 214
      IF (TEMX-16.) 431,435,435                                         HIST 215
  431 IF (TEMX-1.6) 432,433,433                                         HIST 216
  432 SKF = 0.1                                                         HIST 217
      GO TO 438                                                         HIST 218
  433 SKF = 1.0                                                         HIST 219
      GO TO 438                                                         HIST 220
  435 IF (TEMX-160.) 436,437,437                                        HIST 221
  436 SKF = 10.                                                         HIST 222
      GO TO 438                                                         HIST 223
  437 IF (TEMX-1600.) 4371,4372,4372                                    HIST 224
 4371 SKF = 100.                                                        HIST 225
      GO TO 438                                                         HIST 226
 4372 SKF = 1000.                                                       HIST 227
  438 ISK = TEMX/4./SKF+1.                                              HIST 228
      SKI = ISK                                                         HIST 229
      SK(J) = SKI*SKF                                                   HIST 230
  440 WRITE (6,1440),J,SK(J)                                            HIST 231
      SK(7) = SK(5)                                                     HIST 232
      WRITE (6,1440),7,SK(7)                                            HIST 233
      RETURN                                                            HIST 234
C       ***********************************************                 HIST 235
      ENTRY ZERO                                                        HIST 236
C  - ZERO - SETS THE MAIN ARRAYS TO ZERO DURING INITIALIZATION.  -ZERO- HIST 237
C           IS CALLED BY -READIT-.                                      HIST 238
      LPRNT = 55/(NNODE+1)                                              HIST 239
      LCOUNT = LPRNT                                                    HIST 240
      DO 455 I=1,N                                                      HIST 241
      RMECH(I)   = 0.                                                   HIST 242
      CELMAS(I)  = 0.                                                   HIST 243
      ACC(I)     = 0.                                                   HIST 244
      VEL(I)     = 0.                                                   HIST 245
      DO 455 J=1,5                                                      HIST 246
      SAVDMX(J,I) = 0.                                                  HIST 247
      TMAX(J,I) = 0.                                                    HIST 248
```

```
  455 CONTINUE                                                          HIST 249
      DO 460 J=1,NNODE                                                  HIST 250
      RROLD(J) = 0.                                                     HIST 251
  460 RIMP(J) = 0.                                                      HIST 252
  500 RETURN                                                            HIST 253
C       ***********************************************                 HIST 254
      ENTRY FORCI                                                       HIST 255
C  - FORCI - IS CALLED BY -CMPUTE- TO PROVIDE THE PRESSURE AT THE       HIST 256
C            TOP BOUNDARY AT EACH TIME STEP.  -FORCI- INTERPOLATES      HIST 257
C            BETWEEN VALUES OF THE PRESSURE HISTORY.                    HIST 258
C                                                                       HIST 259
      IF (ITIME .GT. 0) GO TO 45                                        HIST 260
C       ACQUIRE FIRST TWO POINTS                                        HIST 261
   10 TLAST = THIST(1)                                                  HIST 262
      PLAST = PHIST(1)*PRESCAL                                          HIST 263
      ITIME = 2                                                         HIST 264
      GO TO 35                                                          HIST 265
C       ACQUIRE THE NEXT POINT                                          HIST 266
   30 IF (ITIME .GE. NFORCE) GO TO 50                                   HIST 267
      TLAST = TNOW                                                      HIST 268
      PLAST = PNOW                                                      HIST 269
      ITIME = ITIME+1                                                   HIST 270
   35 TNOW = THIST(ITIME)                                               HIST 271
      PNOW = PHIST(ITIME)*PRESCAL                                       HIST 272
C       TEST FOR VERTICAL SLOPE                                         HIST 273
      DELTAT = TNOW-TLAST                                               HIST 274
      IF (DELTAT .LT. 1.E-12) GO TO 30                                  HIST 275
C       CALCULATE SLOPE                                                 HIST 276
      SLOPE = (PNOW-PLAST)/DELTAT                                       HIST 277
   45 IF (TNOW .LT. TIME .AND. ITIME .LT. NFORCE) GO TO 30              HIST 278
C       COMPUTE FORCE ON TOP SURFACE                                    HIST 279
   50 FORCE = PLAST+SLOPE*(TIME-TLAST)                                  HIST 280
      RETURN                                                            HIST 281
C                                                                       HIST 282
C       FORMATS                                                         HIST 283
 1014 FORMAT (1H1,10X,12A6/23X,                                         HIST 284
     @  25HSUMMARY OF MAXIMUM VALUES // 2X,4HNODE, 3X,                  HIST 285
     @  5HDEPTH,4X,16HREACTION  STRESS,10X,8HVELOCITY,11X,              HIST 286
     @  12HDISPLACEMENT,11X,6HSTRAIN,12X,12HACCELERATION,10X /          HIST 287
     @  2X,3HNO.,5X,3HFT.,5(6X,5HVALUE,6X,4HTIME))                      HIST 288
 1015 FORMAT (19X,5H(MPA),6X,5H(SEC),4X,1H(,A2,3H/S),6X,5H(SEC),6X,     HIST 289
     @  4H(IN),6X,5H(SEC),6X,5H( % ),6X,5H(SEC),6X,5H(G'S),             HIST 290
     @  6X,5H(SEC))                                                     HIST 291
 1017 FORMAT (2X,I3,F10.4,F10.2,2(1PE11.3,0PF10.3),1P5E11.3)            HIST 292
 1018 FORMAT (//10X,12A6/                                               HIST 293
     @  10X,50HTIME   SURFACE    NODE  APPLIED REACTION  DAMPING        HIST 294
     @ 42H   STRAIN        ACCEL  PARTICLE  POSITION / 18X,             HIST 295
     @  41HSTRESS       NO.  STRESS  STRESS    STRESS,24X,8HVELOCITY)   HIST 296
 1019 FORMAT (20X,3HPSI,13X,3HPSI,6X,3HPSI,7X,3HPSI,4X,7HPERCENT,7X,    HIST 297
     @  3HG'S,7X,A2,2H/S,6X,2HIN)                                       HIST 298
 1021 FORMAT (2X,1PE12.3,0PF10.2)                                       HIST 299
 1023 FORMAT (27X,I5,3F9.2,F10.5,F12.3,F10.3,F10.3)                     HIST 300
 1440 FORMAT (//9X,14H SCALE FACTOR,I1,8H EQUALS ,F6.1)                 HIST 301
      END                                                               HIST 302
```

```
      PROGRAM PLOTIT
C       PROGRAM TO PLOT HISTORIES FROM -ONED-
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION BETA(12), NOUT(20)
      DIMENSION AA(20), RIMP(20), RR(20), RROLD(20), SS(20),
     @  ST1(20), ST2(20), VV(20), XX(20)
      CHARACTER*10 IDAT
      REAL*4 PTIME(800),PSS(800),PST1(800),PST2(800)
C
C       INITIALIZE PLOTTING PARAMETERS
      CALL GINITL(0)
      WRITE(95,7216)
 7216 FORMAT ('SET VIEWPORT 1 (-.95 .95 -.95 .95)')
C       CALL DATE FOR THE CALCULATION
      CALL DATE(IDAT)
C       READ THE NUMBER OF NODES (NNODE) AND NUMBER OF CYCLES (NSTEP)
      READ (7) NNODE, NOUT, BETA, NSTEP, N
      WRITE (6,1001) NNODE, NOUT, BETA, NSTEP, N
 1001 FORMAT (' NNODE=',I3/' NOUT=',20I3/' BETA=',12A6/' NSTEP=',I5/
     @  ' NUMBER OF CELLS, N=',I4)
C  ---------------------------------------------------------------------
C       FIND NUMBER OF COMPUTATIONAL STEPS: NSTEP
      DO 400 I = 1,NSTEP
      IEND = I-1
      READ (7,END=405,ERR=405) N1
  400 CONTINUE
  405 NSTEP = IEND-N
C  ---------------------------------------------------------------------
C       BEGIN MAJOR LOOP OVER EACH OUTPUT NODE
      DO 610 J = 1,NNODE
      REWIND 7
      READ (7) NSPACE
      NST = 0
C       BEGIN LOOP OVER EACH TIME STEP FOR EACH NODE
      DO 600 I = 1,NSTEP
      NST = NST+1
      READ (7,ERR=605,END=605) TIME,TOPSTRS,(RR(JJ),AA(JJ),VV(JJ),
     @  XX(JJ),SS(JJ),RROLD(JJ),ST1(JJ),ST2(JJ),JJ=1,NNODE)
      PTIME(NST) = TIME
      PSS(NST) = SS(J)
      PST1(NST) = ST1(J)
      PST2(NST) = ST2(J)
  600 CONTINUE
      GO TO 608
  605 NSTEP = NST-1
      WRITE (6,1002) NSTEP
 1002 FORMAT (' NSTEP =',I4)
  608 CONTINUE
      CALL GRAFONED(PTIME,PSS,PST1,PST2,NST,NOUT(J),IDAT,BETA)
  610 CONTINUE
      CALL GPLOT(.0,.0,999)
      END
```

```
      SUBROUTINE READIT                                                 READ   1
C       "READIT" READS THE INPUT DATA, EXCEPT FOR FORCE HISTORY AND     READ   2
C       SOME MATERIALS DATA, LAYS OUT THE CELLS, AND FILLS THE ARRAYS.  READ   3
C                                                                       READ   4
      INCLUDE '[SEAMAN.ONED]ONEDCOM.FOR'                                READ   5
C                                                                       READ   6
      CHARACTER*10 IDAT                                                 READ   7
      DIMENSION NFIRST(30),NLAST(30),SP(300),SPMAT(6)                   READ   8
      DATA   G,   DENSCAL,   PRESCAL, VELCAL, DISTCAL/                  READ   9
     @ 981.456, 0.0160185,  6.8948E4,   2.54,    2.54/                 READ  10
C                                                                       READ  11
C       ***  CALL -ZERO- TO INITIALIZE THE ARRAYS    ****              READ  12
      CALL ZERO                                                         READ  13
      CIN3 = 3456.                                                      READ  14
      CALL DATE(IDAT)                                                   READ  15
      WRITE (6,1000)                                                    READ  16
C                                                                       READ  17
C ***    READ THE IDENT NUMBER AND TITLE FOR THE CALCULATION  ***       READ  18
      DO 100 K=1,2                                                      READ  19
      READ  (5,1008) BETA                                               READ  20
  100 WRITE (6,1008) BETA                                               READ  21
      READ  (5,1001) IDENT, BETA                                        READ  22
      WRITE (6,1002) BETA                                               READ  23
      WRITE (6,1003) IDENT                                              READ  24
      DECODE (10,1008,IDAT) BETA(11),BETA(12)                           READ  25
C ***                                                          ***      READ  26
      READ (5,*) NOCOMP, LB, TEND, NSTOP, GACC                          READ  27
      WRITE (6,1005)                                                    READ  28
      IF (NOCOMP .LT. 998) WRITE (6,1006) NOCOMP                        READ  29
      IF (NOCOMP .EQ. 998) WRITE (6,1060) NOCOMP                        READ  30
      IF (NOCOMP .GT. 998) WRITE (6,1007) NOCOMP                        READ  31
      IF (LB .NE. 0) WRITE (6,1011) LB                                  READ  32
      IF (LB .EQ. 0) WRITE (6,1012) LB                                  READ  33
      WRITE (6,1014) TEND, NSTOP                                        READ  34
      IF (GACC .NE. 0.) GACC = G                                        READ  35
      WRITE (6,1015) GACC                                               READ  36
C ***                                                          ***      READ  37
      READ (5,*) NLAYRS, MISP, NSP, MATTEN, NMTRLS, NFORCE              READ  38
      WRITE (6,1020)                                                    READ  39
      WRITE (6,1021) NLAYRS                                             READ  40
      IF (MISP .LE. 0) WRITE (6,1022) MISP                              READ  41
      IF (MISP .EQ. 1) WRITE (6,1023) MISP                              READ  42
      IF (MISP .GE. 2) WRITE (6,1024) MISP, NSP                         READ  43
      IF (MATTEN .LE. 0) WRITE (6,1025) MATTEN                          READ  44
      IF (MATTEN .GE. 1) WRITE (6,1028) MATTEN                          READ  45
      WRITE (6,1029) NMTRLS,NFORCE                                      READ  46
C ***                                                          ***      READ  47
      READ (5,*) NNODE, KNTROL, NHIST, MVT, NSV, KVEL, TNDPLT           READ  48
      WRITE (6,1031)                                                    READ  49
      IF (KNTROL(1) .GT. 0) GO TO 131                                   READ  50
      WRITE (6,1032)                                                    READ  51
      GO TO 139                                                         READ  52
  131 DO 138 I = 1,7                                                    READ  53
      IF (KNTROL(I) .EQ. 0) GO TO 139                                   READ  54
      KNT = I                                                           READ  55
      IF (KNTROL(I) .EQ. 1) WRITE (6,1033) KNT,KNTROL(I)                READ  56
      IF (KNTROL(I) .EQ. 2) WRITE (6,1035) KNT,KNTROL(I)                READ  57
      IF (KNTROL(I) .EQ. 3) WRITE (6,1036) KNT,KNTROL(I)                READ  58
      IF (KNTROL(I) .EQ. 4) WRITE (6,1037) KNT,KNTROL(I)                READ  59
      IF (KNTROL(I) .EQ. 5) WRITE (6,1038) KNT,KNTROL(I)                READ  60
      IF (KNTROL(I) .EQ. 6) WRITE (6,1039) KNT,KNTROL(I)                READ  61
      IF (KNTROL(I) .EQ. 7) WRITE (6,1040) KNT,KNTROL(I)                READ  62
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  138 CONTINUE                                                          READ  63
  139 IF (NHIST .LE. 0) WRITE (6,1042) NHIST                            READ  64
      IF (NHIST .GE. 1) WRITE (6,1043) NHIST                            READ  65
      IF (MVT .EQ. 0) WRITE (6,1045) MVT                                READ  66
      IF (MVT .NE. 0) WRITE (6,1044) MVT                                READ  67
      WRITE (6,1046) NNODE                                              READ  68
      IF (TNDPLT .LT. TEND) TNDPLT = TEND                               READ  69
      WRITE (6,1153) TNDPLT                                             READ  70
      NVELCAL = ' M'                                                    READ  71
      AVELCAL = 0.01                                                    READ  72
      IF (KVEL .NE. 0) GO TO 147                                        READ  73
      NVELCAL = 'IN'                                                    READ  74
      AVELCAL = 1./VELCAL                                               READ  75
  147 WRITE (6,1154) KVEL,NVELCAL                                       READ  76
C ***                                                           ***     READ  77
      READ (5,*) (DEP(L),L=1,NNODE)                                     READ  78
      IF (NOCOMP .LT. 998) GO TO 150                                    READ  79
C ***                                                           ***     READ  80
  148 READ (5,*) SK                                                     READ  81
      WRITE (6,1048) SK                                                 READ  82
      IF (NOCOMP .GE. 999) RETURN                                       READ  83
C                                                                       READ  84
C       INPUT MATERIAL PROPERTIES FOR EACH MATERIAL                     READ  85
C                                                                       READ  86
  150 NSTEP = 0                                                         READ  87
      J = 0                                                             READ  88
      DO 300 M = 1, NMTRLS                                              READ  89
      DAMPQ(M) = 4.                                                     READ  90
      LS = 0                                                            READ  91
C ***                                                           ***     READ  92
      READ (5,*) NAME(M),GAM(M),DAMPL(M),DAMPQ(M),TENSN(M),NPOR(M),     READ  93
     @  NPR(M),NSOL(M),NVAR(M)                                          READ  94
      WRITE (6,1158) M,NAME(M),GAM(M),DAMPL(M),DAMPQ(M),TENSN(M),       READ  95
     @  NPOR(M),NPR(M),NSOL(M),NVAR(M)                                  READ  96
      TENSN(M) = -ABS(TENSN(M))                                         READ  97
      IF (TENSN(M) .NE. 0.) NTENSN(M) = 1                               READ  98
      READ (5,*) SHMOD(M),YIELD(M),TANPHI(M)                            READ  99
      WRITE (6,1160) SHMOD(M),YIELD(M),TANPHI(M)                        READ 100
       SQRTNP(M) = SQRT(1.+TANPHI(M)**2)+TANPHI(M)                      READ 101
      RHO(M) = GAM(M)*DENSCAL                                           READ 102
      TENSN(M) = TENSN(M)*PRESCAL                                       READ 103
      IF (GAM(M) .EQ. 0.) GO TO 300                                     READ 104
      IF (NPOR(M) .EQ. 0) GO TO 190                                     READ 105
      CALL SSONED(LS,J,NSTEP,M,RHO(M),RHO(M),P,EMAX,TENSN(M),PMAX,      READ 106
     @  SPMAT(M))                                                       READ 107
      GO TO 290                                                         READ 108
  190 IF (NPR(M) .EQ. 0) GO TO 210                                      READ 109
      CALL EXPLODE(LS,J,NSTEP,M,RHO(M),P,SPMAT(M))                      READ 110
      GO TO 290                                                         READ 111
  210 IF (NSOL(M) .EQ. 0) GO TO 300                                     READ 112
      CALL EQST(LS,J,NSTEP,M,P,RHO(M),SPMAT(M))                         READ 113
C       COMPUTE SOUND SPEED FROM SOUND-SPEED-SQUARED FROM PRESSURE      READ 114
C         RELATIONS AND SHEAR MODULUS                                   READ 115
  290 SPMAT(M) = SQRT(SPMAT(M) + 1.333*SHMOD(M)/RHO(M))                 READ 116
  300 CONTINUE                                                          READ 117
C       END OF LOOP TO READ IN MATERIAL PROPERTIES                      READ 118
      NCEL = 1                                                          READ 119
      TOP = 0.                                                          READ 120
      LAST = 0                                                          READ 121
      LVMAX = 1                                                         READ 122
      X(1) = 0.                                                         READ 123
      GEOSTR = 0.                                                       READ 124
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      DO 600 NL = 1,NLAYRS                                              READ 125
C ***                                                          ***    READ 126
      READ (5,*) DB, SPL, NSP, M                                        READ 127
      THICK = DB-TOP                                                    READ 128
      IF (THICK .GT. 0.) GO TO 310                                      READ 129
      WRITE (6,1312) DB, TOP, THICK                                     READ 130
 1312 FORMAT (' STOP IN READIT, NEGATIVE LAYER THICKNESS.  BOTTOM OF '  READ 131
     @  /' CURRENT LAYER, DB =',F12.6,' BOTTOM OF PREVIOUS LAYER =',    READ 132
     @  F12.6,/' THICKNESS =',F12.6)                                    READ 133
      STOP 'READIT, NEGATIVE THICKNESS'                                 READ 134
  310 IF (M .GT. 0) GO TO 315                                           READ 135
      WRITE (6,1315) THICK                                              READ 136
 1315 FORMAT (/'          GAP IN THE LAYERS = ',F12.6,' FEET',/)       READ 137
      X(LAST+1) = DB*12.*DISTCAL                                        READ 138
      GO TO 600                                                         READ 139
  315 CONTINUE                                                          READ 140
      TOP = DB                                                          READ 141
      IF (GAM(M) .EQ. 0.) NSP = 1                                       READ 142
      IF (MISP .EQ. 1) GO TO 330                                        READ 143
C       UNIFORM SIZES FOR CELLS                                         READ 144
      IF (MISP .GT. 0 .AND. NSP .GT. 0) SPL = THICK*12./NSP             READ 145
      NSP = THICK*12./SPL+0.5                                           READ 146
      SPL = THICK*12./NSP*DISTCAL                                       READ 147
      SP(1) = SPL                                                       READ 148
      GO TO 340                                                         READ 149
C ***    FOR MISP = 1: INPUT VARIABLE NODE SPACING                 ***  READ 150
  330 READ (5,*) (SP(I),I=1,NSP)                                        READ 151
      DO 335 I = 1,NSP                                                  READ 152
  335 SP(I) = SP(I)*DISTCAL                                             READ 153
  340 NFIRST(NL) = LAST+1                                               READ 154
      NLAST(NL) = LAST+NSP                                              READ 155
      LAST = NLAST(NL)+1                                                READ 156
      NFST = NFIRST(NL)                                                 READ 157
      NLST = NLAST(NL)                                                  READ 158
      I = 0                                                             READ 159
      LS = 2                                                            READ 160
      WRITE (6,1343) BETA                                               READ 161
 1343 FORMAT (//' LISTING OF THE LAYOUT'/10X,12A6)                      READ 162
      WRITE (6,1344)                                                    READ 163
 1344 FORMAT (4X,1HJ,10X,1HX,8X,3HSPL,4X,7HDENSITY,7X,4HSIG1,5X,        READ 164
     @  6HCELMAS,7X,4HTENS,3H  M,3X,4HNAME,6H  LVAR,3X,6HTRIALS)        READ 165
      NLST1 = NLST+1                                                    READ 166
      DENSLST = RHO(M)                                                  READ 167
      DO 560 J = NFST,NLST1                                             READ 168
      ITRY = 0                                                          READ 169
      IF (J .EQ. NLST1) GO TO 550                                       READ 170
      I = I+1                                                           READ 171
      IF (MISP .EQ. 1) SPL = SP(I)                                      READ 172
      X(J+1) = X(J)+SPL                                                 READ 173
      DENS(J) = DENSLST                                                 READ 174
      SSPEED(J) = SPMAT(M)                                              READ 175
      SPEED2 = SPMAT(M)**2                                              READ 176
      Y(J) = YIELD(M)                                                   READ 177
      MAT(J) = 0                                                        READ 178
      IF (GAM(M) .EQ. 0.) GO TO 540                                     READ 179
C       MODIFY INITIAL DENSITY FOR GEOSTATIC STRESS                     READ 180
      IF (GACC .EQ. 0.) GO TO 425                                       READ 181
      IF (NPR(M) .NE. 1) DENS(J) = DENS(J) +                            READ 182
     @  DENS(J)*SPL*GACC/SPEED2                                         READ 183
  400 ITRY = ITRY+1                                                     READ 184
      GEOEST = GEOSTR + 0.5*DENS(J)*SPL*GACC                            READ 185
C       GET STRESS FROM THE EQUATIONS OF STATE FOR EACH MATERIAL        READ 186
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      IF (NPOR(M) .EQ. 0) GO TO 410                                     READ 187
      PRESS(J) = 0.                                                     READ 188
      EMAX = 0.                                                         READ 189
      PMAX = 0.                                                         READ 190
      CALL SSONED(LS,J,NSTEP,M,DENS(J),DENS(J),PRESS(J),EMAX,TENSN(M),  READ 191
     @  PMAX,SPEED2)                                                    READ 192
      GO TO 420                                                         READ 193
  410  IF (NPR(M) .EQ. 0) GO TO 415                                     READ 194
      PRESS(J) = GEOEST                                                 READ 195
      SIG1(J) = PRESS(J)                                                READ 196
      GO TO 425                                                         READ 197
  415 IF (NSOL(M) .EQ. 0) GO TO 420                                     READ 198
      CALL EQST(LS,J,NSTEP,M,PRESS(J),DENS(J),SPEED2)                   READ 199
  420 SIG1(J) = PRESS(J)                                                READ 200
C      WRITE (6,1422) NL,J,ITRY,GEOEST,SIG1(J),DENS(J),SPEED2,DDENS     READ 201
C 1422 FORMAT (' GEOST READIT, NL,J,ITRY=',3I3,' GEOEST,SIG1=',1P2E17.10READ 202
C     @  ' D=',E15.8,' SP2=',E10.3,' DDENS=',E10.3)                     READ 203
      IF (ABS(SIG1(J) - GEOEST) .LT. 1.E-6*GEOEST .AND. ITRY .GT. 1)    READ 204
     @  GO TO 425                                                       READ 205
      TRY = 0.5*ITRY                                                    READ 206
      DENSOLD = DENS(J)                                                 READ 207
      DENS(J) = DENS(J)+MIN(1.D0,TRY)*(GEOEST-SIG1(J))*                 READ 208
     @  (DENS(J)-RHO(M))/SIG1(J)                                        READ 209
      DDENS = DENS(J) - DENSOLD                                         READ 210
      IF (ITRY .LT. 20) GO TO 400                                       READ 211
      WRITE (6,1349) NL,J,GEOEST,SIG1(J),RHO(M),DENS(J)                 READ 212
      STOP 'READIT, 424'                                                READ 213
  425 CELMAS(J) = SPL*DENS(J)                                           READ 214
      RMECH(J) = SIG1(J)                                                READ 215
      ALPHA(J) = 1.                                                     READ 216
      MAT(J) = M                                                        READ 217
      TENSIL(J) = TENSN(M)                                              READ 218
      DENSLST = DENS(J)                                                 READ 219
      GEOSTR = GEOSTR+CELMAS(J)*GACC                                    READ 220
  540 IF (NVAR(M) .EQ. 0) GO TO 550                                     READ 221
      LVAR(J) = LVMAX                                                   READ 222
      LVMAX = LVMAX+NVAR(M)                                             READ 223
  550 WRITE (6,1542) J,X(J),SPL,DENS(J),SIG1(J),CELMAS(J),TENSIL(J),    READ 224
     @  MAT(J),NAME(M),LVAR(J),ITRY                                     READ 225
 1542 FORMAT (I5,1P2E11.3,0PF11.6,1P3E11.3,I3,2X,A6,I5,I4)              READ 226
C        END LOOP OVER EACH J WITHIN A LAYER                            READ 227
  560 CONTINUE                                                          READ 228
      SPL = SP(1)                                                       READ 229
      X(NLST+2) = X(NLST+1)                                             READ 230
      MAT(NLST+1) = 0                                                   READ 231
C        END LOOP OVER EACH LAYER                                       READ 232
  600 CONTINUE                                                          READ 233
      NLAST(NLAYRS) = NLAST(NLAYRS)+1                                   READ 234
      N = LAST                                                          READ 235
      CELMAS(N) = CELMAS(N-1)                                           READ 236
      RMECH(N) = RMECH(N-1)+CELMAS(N)*GACC                              READ 237
      WRITE (6,1603) N,RMECH(N)                                         READ 238
 1603 FORMAT (' LAST NODE N,RMECH(N)=',I5,1PE12.5)                      READ 239
C                                                                       READ 240
      WRITE (6,4101) BETA                                               READ 241
      DO 610 NL=1,NLAYRS                                                READ 242
      J = NFIRST(NL)                                                    READ 243
      M = MAT(J)                                                        READ 244
      JEND = NLAST(NL)+1                                                READ 245
      DB = X(JEND)/12./DISTCAL                                          READ 246
      SPL = (X(J+1)-X(J))/DISTCAL                                       READ 247
      TENS = TENSN(M)/PRESCAL                                           READ 248
```

```
      WRITE (6,4102) NL,NFIRST(NL),JEND,DB,GAM(M),DAMPL(M),
     @  SPL,TENS
  610 CONTINUE
C
C       SPATIAL ATTENUATION FACTORS
C
      IF (MATTEN .LE. 1) GO TO 720
C ***                                                          ***
      READ (5,*) (ALPHA(I),I=1,N)
      DO 700 I = 1,N
  700 CELMAS(I) = CELMAS(I)/ALPHA(I)
      WRITE (6,4202) (ALPHA(I),I=1,N)
C ***********                                          **********
C       READ IN THE FORCE HISTORY
  720 IF (NFORCE .LE. 0) GO TO 750
      WRITE (6,1720) BETA
      READ (5,*) (THIST(I),PHIST(I),I=1,NFORCE)
      WRITE (6,1004) (THIST(I),PHIST(I),I=1,NFORCE)
C
C       COMPUTE PROPERTIES AT EACH NODE
C
  750 CONTINUE
C
C       DETERMINE FOR WHICH CELLS OUTPUT IS REQUIRED
C
      WRITE (6,4600)
      DO 860 L = 1,NNODE
      DEPTH = DEP(L)*12.*DISTCAL
      DO 840 J = 2,N
      IF (DEPTH .GT. X(J)) GO TO 840
      NOUT(L) = J-1
      IF (MAT(J-1) .EQ. 0) NOUT(L) = J-2
      GO TO 850
  840 CONTINUE
  850 WRITE (6,4601) DEP(L),NOUT(L)
  860 CONTINUE
C
C       OUTPUT NODAL PROPERTIES
C
      RETURN
C
C                    FORMAT STATEMENTS
C
 1000 FORMAT (1H1 // 9X,41H ONED: A ONE-DIMENSIONAL WAVE PROPAGATION,
     @ 49H SOLUTION IN PIECEWISE LINEAR HYSTERETIC MATERIAL //)
 1001 FORMAT (I5,1X,12A6)
 1002 FORMAT (10X,12A6)
 1003 FORMAT (/9X, 15H PROBLEM NUMBER, I5 //)
 1004 FORMAT (5(7X,4HTIME,6X,5HPRESS)/(1P10E11.3))
 1005 FORMAT (// 9X, 22H COMPUTATION CONTROLS  /)
 1006 FORMAT (9X,10H NOCOMP  =,I5,7X,31H PLOT AT COMPUTED SCALE FACTORS)
 1007 FORMAT (9X,10H NOCOMP  =,I5,7X,30H PLOT AT INPUT SCALE FACTORS  /
     @  29X,46H USE SCRATCH TAPE (CALCULATIONS NOT REQUIRED)    )
 1008 FORMAT (12A6)
 1011 FORMAT (9X,10H LB      =,I5,7X,24H RIGID BOTTOM BOUNDARY  )
 1012 FORMAT (9X,10H LB      =,I5,7X,26H INFINITE BOTTOM BOUNDARY  )
 1014 FORMAT (9X,10H TEND    =,1PE12.3,27H END OF PROBLEM TIME (SEC) ,
     @       /9X,10H NSTOP   =,I5,7X,24H TOTAL NUMBER OF STEPS  )
 1015 FORMAT (9X,10H GACC    =,1PE12.3,20H ACC OF GRAVITY FOR ,
     @ 16HGEOSTATIC EFFECT)
 1020 FORMAT (//// 9X,16H INPUT CONTROLS   /)
 1021 FORMAT (9X,10H NLAYRS  =,I5,7X,18H NUMBER OF LAYERS   )
```

```
1022 FORMAT (9X,10H MISP     =,I5,7X,30H SPACING CONST W/IN EACH LAYER) READ 311
1023 FORMAT (9X,10H MISP     =,I5,7X,30H SPACING VARIABLE - MUST INPUT) READ 312
1024 FORMAT (9X,10H MISP     =,I5,7X,26H SPACING COMPUTED FOR EACH,     READ 313
    @ 8H LAYER. ,I2,18H SPACES PER LAYER   )                            READ 314
1025 FORMAT (9X,10H MATTEN   =,I5,7X,28H ALPHA(I) = 1 FOR EVERY NODE  ) READ 315
1028 FORMAT (9X,10H MATTEN   =,I5,7X,30H ALPHA(I) IS INPUT FOR EA NODE) READ 316
1029 FORMAT (9X,10H NMTRLS   =,I5,7X,20H NUMBER OF MATERIALS/           READ 317
    @        9X,10H NFORCE   =,I5,7X,29H NUMBER OF PRESSURE-TIME PTS.)  READ 318
1031 FORMAT (//// 9X,17H OUTPUT CONTROLS  /)                            READ 319
1032 FORMAT (9X,15H KNTROL1 =    0,7X,10H NO PLOTS  )                   READ 320
1033 FORMAT (9X,7H KNTROL,I1,2H =,I5,8X,20HSTRESS - TIME PLOT  )        READ 321
1035 FORMAT (9X,7H KNTROL,I1,2H =,I5,8X,24HACCELERATION - TIME PLOT)    READ 322
1036 FORMAT (9X,7H KNTROL,I1,2H =,I5,8X,24HPART. VEL. - TIME PLOT  )    READ 323
1037 FORMAT (9X,7H KNTROL,I1,2H =,I5,8X,24HDISPLACEMENT - TIME PLOT)    READ 324
1038 FORMAT (9X,7H KNTROL,I1,2H =,I5,8X,24HSTRAIN - TIME PLOT      )    READ 325
1039 FORMAT (9X,7H KNTROL,I1,2H =,I5,8X,24HIMPULSE - TIME          )    READ 326
1040 FORMAT (9X,7H KNTROL,I1,2H =,I5,8X,24HAVG STRAIN - TIME PLOT  )    READ 327
1042 FORMAT (9X,10H NHIST    =,I5,7X,27H GROUND MOTIONS NOT PRINTED)    READ 328
1043 FORMAT (9X,10H NHIST    =,I5,7X,29H GROUND MOTIONS PRINTED EVERY,  READ 329
    @  25H 'NHIST' TIME INCREMENTS  )                                   READ 330
1044 FORMAT (9X,10H MVT      =,I5,7X,24H MAX VALUE TABLE PRINTED )      READ 331
1045 FORMAT (9X,10H MVT      =,I5,7X,28H MAX VALUE TABLE NOT PRINTED)   READ 332
1046 FORMAT (9X,10H NNODE    =,I5,7X,24H NUMBER OF OUTPUT NODES   )     READ 333
1048 FORMAT (/// 9X,19H SCALE FACTORS ARE  ,7F10.1 )                    READ 334
1060 FORMAT (9X,10H NOCOMP   =,I5,7X,28H PLOT AT INPUT SCALE FACTORS)   READ 335
1153 FORMAT (9X,10H TNDPLT   =,F9.4,3X,24H END OF PLOT TIME (SEC)  )    READ 336
1154 FORMAT (9X,10H KVEL     =,I5,7X,27H OUTPUT PARTICLE VELOCITIES,    READ 337
    @  3H IN,A4,4H/SEC)                                                 READ 338
1158 FORMAT (//10X,' MATERIAL NUMBER ',I3/                              READ 339
    @  ' MATERIAL IS ',A8,' DENS=',F10.5,' DAMPL,Q=',1P2E10.3,          READ 340
    @  ' TENSN=',E10.3,' NPOR=',I2,' NPR=',I2,' NSOL=',I2,' NVAR='I2)   READ 341
1160 FORMAT (' SHMOD=',1PE10.3,' YIELD=',E10.3,' TANPHI=',E10.3)        READ 342
1349 FORMAT (' STOP IN READIT, UNABLE TO INITIALIZE AT GEOSTATIC ',     READ 343
    @  'STRESS',/' NL,J=',2I4,' GEOEST,SIG1=',1P2E10.3,' RHO,DENS=',    READ 344
    @  2E12.5)                                                          READ 345
C                                                                       READ 346
1720 FORMAT (//10X,12A6/'          FORCE HISTORY ON FIRST NODE')        READ 347
4101 FORMAT (1H1,12A6,                                                  READ 348
    @  /30X,18H LAYER PROPERTIES  ///4X,5HLAYER,24X,6HBOTTOM,           READ 349
    @  5X,5HGAMMA,5X,15HPCRIT   SPACING,3X,7HTENSION/9H   NUMBER,9X,    READ 350
    @  5HNODES,12X,4H(FT),6X,5H(PCF),5X,5H( % ),5X,4H(IN),5X,5H(PSI)//)READ 351
4102 FORMAT (5X,I2,9X,I3,3H - ,I3,4X,F10.4,2F10.2,F10.4,E11.3)          READ 352
4103 FORMAT (//4X,5HLAYER,18X,26H LOADING  MODULI  ( PSI ) ,28X,        READ 353
    @  28H UNLOADING  MODULI  ( PSI ) /3X,6HNUMBER,6X,3H1ST,7X,3H2ND,   READ 354
    @  7X,3H3RD,7X,3H4TH,7X,3H5TH,7X,3H6TH,12X,3H1ST,7X,3H2ND,7X,3HERD,READ 355
    @  7X,3H4TH/)                                                       READ 356
4104 FORMAT (5X,I2,3X,6F10.1,5X,4F10.1)                                 READ 357
4105 FORMAT (//4X,5HLAYER,5X,41HSTRAINS AT KNEES OF LOADING CURVES ( % READ 358
    @  ,15X,43H% OF MAX STRESS AT KNEES OF UNLOADING CURVE /3X,         READ 359
    @  6HNUMBER,6X,3H1ST,7X,3H2ND,7X,3H3RD,7X,3H4TH,7X,3H5TH,22X,3H2ND,READ 360
    @ 7X,3H3RD,7X,3H4TH /)                                              READ 361
4106 FORMAT (5X,I2,3X,5F10.3,15X,3F10.3)                                READ 362
4202 FORMAT (/// 40X,30H SPATIAL  ATTENUATION  FACTORS//(10X,10F10.4)) READ 363
4600 FORMAT (///10X,18H OUTPUT DESIRED AT /5X,9HDEPTH(ft),13X,4HNODE /)READ 364
4601 FORMAT (2X,F10.4,13X,I5)                                           READ 365
     END                                                                READ 366
```

```
      SUBROUTINE SSONED (LS, J, N, M, D, DOLD, P, EMAX, TENSIL, PMAX,
     @  SPEED2)
      IMPLICIT REAL*8(A-H,O-Z)
C       ADAPTATION OF STANDARD VARIABLE MODULUS MODEL USED AT WES
C       EXPANDED FOR MULTI-DIMENSIONAL PROBLEMS
C   DEFINITION OF NTYPE FOR TREATMENT OF UNLOADING PROCESSES
C       NTYPE = 1, UNLOADING CURVE TRANSLATES, MODULI AND STRESS ARE
C                  UNCHANGED.
C       NTYPE = 2, UNLOADING CURVE IS MODIFIED IN PROPORTION TO THE
C                  PEAK STRESS REACHED, MODULI ARE UNCHANGED.
C       NTYPE = 3, UNLOADING CURVE IS MODIFIED IN PROPORTION TO THE
C                  PEAK STRESS REACHED, STRAIN INCREMENTS ARE UNCHANGED.
C   EL(I,M) PERTAINS TO THE STRAIN INTERVAL FROM I TO I+1.
      DIMENSION EL(10,6),FL(10,6),SL(10,6),RHOS(6),KPEAK(6),KFIN(6)
      DIMENSION MTRANS(6),NTYPE(6),DORSTR(10),PORMOD(10)
      DATA MAT/0/
      DATA PRESCAL/6.8948E4/
      CHARACTER*4 LPRESS,LDENS
C
C ******        INITIALIZATION                          ********
      NPRNT = 1
      IF (LS .GT. 0) GO TO 100
      MAT = MAT+1
      MTRANS(M) = MAT
      RHOS(MAT) = D
      READ (5,*) KFIN(MAT),NTYPE(MAT),LPRESS,LDENS,PUNIT,DUNIT
      KFINM = KFIN(MAT)
      IP = 0
      ID = 0
      IF (LPRESS.EQ.'PRES' .OR. LPRESS.EQ.'PRE' .OR. LPRESS.EQ.'PR'
     @  .OR. LPRESS .EQ. 'P') IP = 1
      IF (LDENS.EQ.'PRES' .OR. LDENS.EQ.'PRE' .OR. LDENS.EQ.'PR'
     @  .OR. LDENS .EQ. 'P') IP = 1
      IF (LPRESS.EQ.'DENS' .OR. LPRESS.EQ.'DEN' .OR. LPRESS.EQ.'DE'
     @  .OR. LPRESS .EQ. 'D') ID = 1
      IF (LDENS.EQ.'DENS' .OR. LDENS.EQ.'DEN' .OR. LDENS.EQ.'DE'
     @  .OR. LDENS .EQ. 'D') ID = 1
      IF (IP .EQ. 1) LPRESS = 'PRES'
      IF (ID .EQ. 1) LDENS = 'DENS'
      IF (PUNIT .EQ. 0.) PUNIT = PRESCAL
      IF (DUNIT .EQ. 0.) DUNIT = 1.
      WRITE (6,1001) KFINM,NTYPE(MAT),LPRESS,LDENS,PUNIT,DUNIT,MAT,
     @  RHOS(MAT)
      KMAX = KFINM
      IF (LPRESS .EQ. 'PRES') KMAX = KFINM-1
      READ (5,*) (PORMOD(I),I=1,KMAX)
      WRITE (6,1005) (PORMOD(I),I=1,KMAX)
      READ (5,*) (DORSTR(I),I=2,KFINM)
      WRITE (6,1005) (DORSTR(I),I=2,KFINM)
      FL(1,MAT) = 0.
      DORSTR(1) = RHOS(MAT)
      DO 30 I = 1,KFINM
      EL(I,MAT) = PORMOD(I)
      IF (I .EQ. 1) GO TO 30
      FL(I,MAT) = PORMOD(I-1)
      SL(I,MAT) = DORSTR(I)*DUNIT
      IF (LDENS .EQ. 'DENS') SL(I,MAT) = (DORSTR(I)*DUNIT/RHOS(MAT)-1.)*
     @  100.
      DORSTR(I) = RHOS(MAT)*(0.01*SL(I,MAT)+1.)
      IF (LPRESS .NE. 'PRES')
     @  FL(I,MAT) = FL(I-1,MAT)+EL(I-1,MAT)*(SL(I,MAT)-SL(I-1,MAT))/100.
      IF (SL(I,MAT) .LT. SL(I-1,MAT) .AND. KPEAK(MAT) .EQ. 0)
```

```
     @  KPEAK(MAT) = I-1                                                SS1D  63
      IF (LPRESS .EQ. 'PRES')                                           SS1D  64
     @  EL(I-1,MAT) = (FL(I,MAT)-FL(I-1,MAT))/(SL(I,MAT)-SL(I-1,MAT))   SS1D  65
     @  *100.                                                           SS1D  66
   30 CONTINUE                                                          SS1D  67
C        CALIBRATE MODULI AND PRESSURES ON THE HYDROSTAT (TO DYN/CM2)   SS1D  68
      DO 55 I = 1,KFINM                                                 SS1D  69
      EL(I,MAT) = EL(I,MAT)*PUNIT                                       SS1D  70
      FL(I,MAT) = FL(I,MAT)*PUNIT                                       SS1D  71
   55 CONTINUE                                                          SS1D  72
C        PUT PRESSURES AND MODULI IN PSI UNITS                          SS1D  73
      DO 60 I = 1,KFINM                                                 SS1D  74
      EL(I,MAT) = EL(I,MAT)/PRESCAL                                     SS1D  75
   60 FL(I,MAT) = FL(I,MAT)/PRESCAL                                     SS1D  76
C        PRINT THE SET OF STRAINS, DENSITIES, PRESSURES, AND MODULI     SS1D  77
      WRITE (6,1040) M,(I,I=1,KFINM)                                    SS1D  78
      WRITE (6,1045) (SL(I,MAT),I=1,KFINM)                              SS1D  79
      WRITE (6,1060) (DORSTR(I),I=1,KFINM)                              SS1D  80
      WRITE (6,1050) (FL(I,MAT),I=1,KFINM)                              SS1D  81
      WRITE (6,1055) (EL(I,MAT),I=1,KFINM)                              SS1D  82
C        PUT PRESSURES AND MODULI BACK INTO DYN/CM2                     SS1D  83
      DO 65 I = 1,KFINM                                                 SS1D  84
      EL(I,MAT) = EL(I,MAT)*PRESCAL                                     SS1D  85
      FL(I,MAT) = FL(I,MAT)*PRESCAL                                     SS1D  86
   65 SL(I,MAT) = SL(I,MAT)*0.01                                        SS1D  87
      SPEED2 = EL(1,MAT)/RHOS(MAT)                                      SS1D  88
 1001 FORMAT (' KFIN=',I3,' NTYPE=',I3,' LPRESS= ',A4,                  SS1D  89
     @  ' LDENS= ',A4,' PUNIT=',1PE12.5,' DUNIT=',E12.5,                SS1D  90
     @  ' MAT=',I3,' RHOS=',1PE12.5,' FROM -SSONED-')                   SS1D  91
 1005 FORMAT (3X,1P8E10.3)                                              SS1D  92
 1040 FORMAT (6X,8H MAT'L =,I2,9X,26(1H-),23H LOADING AND UNLOADING ,   SS1D  93
     @  26(1H-)/6X,9H PT     = ,6X,10I10)                               SS1D  94
 1045 FORMAT (6X,13H STRAIN (%) =,10F10.4)                              SS1D  95
 1050 FORMAT (6X,13H PRESS(PSI) =,1P10E10.3)                            SS1D  96
 1055 FORMAT (6X,15H MODULI (PSI) =,3X,1P10E10.3)                       SS1D  97
 1060 FORMAT (6X,13H DENS(G/CM3)=,10F10.6)                              SS1D  98
      RETURN                                                            SS1D  99
C *********                                          *********          SS1D 100
C        COMPUTE PRESSURE                                               SS1D 101
C *********                                          *********          SS1D 102
  100 MAT = MTRANS(M)                                                   SS1D 103
      NPRNT = 1                                                         SS1D 104
      KLOAD = 0                                                         SS1D 105
      KFINM = KFIN(MAT)                                                 SS1D 106
      KPEKM = KPEAK(MAT)                                                SS1D 107
      KPEKP1 = KPEAK(MAT)+1                                             SS1D 108
      KPEKM2 = KPEAK(MAT)-2                                             SS1D 109
      KFINM1 = KFINM-1                                                  SS1D 110
      POLD = P                                                          SS1D 111
      EPS = D/RHOS(MAT)-1.                                              SS1D 112
      IF (EPS .LT. EMAX) GO TO 190                                      SS1D 113
C *********                                          *********          SS1D 114
C        VIRGIN LOADING CURVE                                           SS1D 115
      DO 120 IL = 1,KPEKM2                                              SS1D 116
      IF (EPS .LT. SL(IL+1,MAT)) GO TO 150                              SS1D 117
  120 CONTINUE                                                          SS1D 118
      IL = KPEKM-1                                                      SS1D 119
      EMAX = EPS                                                        SS1D 120
  150 P = FL(IL,MAT)+EL(IL,MAT)*(EPS-SL(IL,MAT))                        SS1D 121
      PMAX = MAX(P,PMAX)                                                SS1D 122
      EMAX = MAX(EMAX,EPS)                                              SS1D 123
      STFACT = 1.                                                       SS1D 124
```

```
      KLOAD = 1                                                         SS1D 125
C **********                                            ***********     SS1D 126
C       UNLOADING AND RELOADING ROUTE (AND SOUND SPEED^2 FOR ALL CASES) SS1D 127
  190 GO TO (200,250,300) NTYPE(MAT)                                    SS1D 128
C       PSEUDO STRAIN FOR TYPE 1 UNLOADING                - TYPE 1 -    SS1D 129
  200 DO 210 IP = KPEKP1,KFINM                                          SS1D 130
      IF (PMAX .GE. FL(IP,MAT)) GO TO 220                               SS1D 131
  210 CONTINUE                                                          SS1D 132
      IP = KFINM+1                                                      SS1D 133
  220 CONTINUE                                                          SS1D 134
      DEPSH = -(FL(IP-1,MAT)-PMAX)/EL(IP-1,MAT) -EMAX +SL(IP-1,MAT)     SS1D 135
      EPSUDO = EPS+DEPSH                                                SS1D 136
      GO TO 350                                                         SS1D 137
C       PSEUDO STRAIN FOR TYPE 2 UNLOADING                - TYPE 2 -    SS1D 138
  250 EPSUDO = EPS                                                      SS1D 139
      IF (PMAX .GT. 0.)                                                 SS1D 140
     @  EPSUDO = SL(KPEKM,MAT)+FL(KPEKM,MAT)/PMAX*(EPS-EMAX)            SS1D 141
      GO TO 350                                                         SS1D 142
C       PSEUDO STRAIN FOR TYPE 3 UNLOADING                - TYPE 3 -    SS1D 143
  300 EPSUDO = SL(KPEKM,MAT) + EPS-EMAX                                 SS1D 144
      STFACT = PMAX/FL(KPEKM,MAT)                                       SS1D 145
C       COMMON ROUTE FOR PRESSURE AND SOUND SPEED SQUARED               SS1D 146
  350 DO 360 I = KPEKM,KFINM1                                           SS1D 147
      IF (EPSUDO .GT. SL(I+1,MAT)) GO TO 380                            SS1D 148
  360 CONTINUE                                                          SS1D 149
      I = KFINM                                                         SS1D 150
  380 IF (KLOAD .EQ. 0) P = (FL(I,MAT)+EL(I,MAT)*(EPSUDO-SL(I,MAT)))*   SS1D 151
     @  STFACT                                                          SS1D 152
      SPEED2 = EL(I,MAT)/D                                              SS1D 153
      IF (ABS(D-DOLD) .GT. 1.E-6) SPEED2 = (P-POLD)/(D-DOLD)            SS1D 154
      IF (SPEED2 .GT. 0.) GO TO 385                                     SS1D 155
C      WRITE (6,1390) J,N,KLOAD,I,SPEED2,P,POLD,D,DOLD                  SS1D 156
C 1390 FORMAT (' J,N=',2I4,' K,I=',2I3,' SP=',1PE10.3,' P,PO=',2E10.3,  SS1D 157
C     @  ' D,DO=',2E12.5)                                               SS1D 158
      SPEED2 = EL(I,MAT)/D                                              SS1D 159
      GO TO 387                                                         SS1D 160
  385 IF (NPRNT .EQ. 0) GO TO 390                                       SS1D 161
  387 CONTINUE                                                          SS1D 162
C      IF (KLOAD .GT. 0) WRITE (6,1153) J,N,I,IL,MAT,D,EPS,EMAX,P,PMAX, SS1D 163
C     @  SPEED2                                                         SS1D 164
C      IF (KLOAD .EQ. 0) WRITE (6,1382) J,N,I,MAT,D,EPS,EMAX,EPSUDO,P,  SS1D 165
C     @  PMAX,SPEED2                                                    SS1D 166
  390 IF (P .GT. TENSIL) RETURN                                         SS1D 167
  400 P = TENSIL                                                        SS1D 168
      SPEED2 = EL(KFINM,MAT)/D                                          SS1D 169
      RETURN                                                            SS1D 170
C 1153 FORMAT (' SS J,N,I,IL,MAT=',5I4,' D=',1PE12.5,' E,EMAX=',1P2E10.3SS1D 171
C     @  ' P,PMAX=',2E10.3,' SP=',E10.3)                                SS1D 172
C 1382 FORMAT (' SS-UN J,N,I,MAT=',4I4,' D=',1PE12.5,' E,EMAX,ESUD=',   SS1D 173
C     @  3E10.3,' P,PMAX=',2E10.3,' SP=',E10.3)                         SS1D 174
      END                                                               SS1D 175
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