NUMERICAL SIMULATION OF STRESS WAVE PROPAGATION FROM UNDERGROUND NUCLEAR EXPLOSIONS*

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ABSTRACT

This paper presents a numerical model of stress wave propagation (SOC) which uses material properties data from a preshot testing program to predict the stress-induced effects on the rock mass involved in a Plowshare application. SOC calculates stress and particle velocity history, cavity radius, extent of brittle failure, and the rock's efficiency for transmitting stress. The calculations are based on an equation of state for the rock, which is developed from preshot field and laboratory measurements of the rock properties.

The field measurements, made by hole logging, determine in situ values of the rock's density, water content, and propagation velocity for elastic waves. These logs also are useful in judging the layering of the rock and in choosing which core samples to test in the laboratory. The laboratory analysis of rock cores includes determination of hydrostatic compressibility to 40 kb, triaxial strength data, tensile strength, Hugoniot elastic limit, and, for the rock near the point of detonation, high-pressure Hugoniot data.

Equation-of-state data are presented for rock from three sites subjected to high explosive or underground nuclear shots, including the Hardhat and Gasbuggy sites. SOC calculations of the effects of these two shots on the surrounding rock are compared with the observed effects. In both cases SOC predicts the size of the cavity quite closely. Results of the Gasbuggy calculations indicate that useful predictions of cavity size and chimney height can be made when an adequate preshot testing program is run to determine the rock's equation of state. Seismic coupling is very sensitive to the low-pressure part of the equation of state, and its successful prediction depends on agreement between the logging data and the static compressibility data. In general, it appears that enough progress has been made in calculating stress wave propagation to begin looking at derived numbers, such as number of cracks per zone, for some insight into the effects on permeability. A listing of the SOC code is appended.

1. INTRODUCTION

The important engineering effects associated with an underground (noncratering) Plowshare application are the increase in permeability of the reservoir rock, the height of the chimney, and the amount of seismic energy generated by the nuclear explosion. A fundamental goal of the Plowshare

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program is to predict these effects when an explosive of known yield is detonated at a given depth in a given medium.

This paper presents results from a numerical technique called SOC which calculates the propagating stress field in the medium surrounding an explosive source and the resultant effects on the medium. We attempt to relate directly predicted changes in the medium, namely fracturing and cavity size, to permeability change and chimney height. Seismic coupling is obtained from the calculated displacement history of a particle in the elastic region.

Part 2 of the paper describes a general numerical approach to stress wave propagation. Part 3 discusses the material properties needed to relate stress to deformation in an equation of state. These properties are obtained by preshot field and laboratory measurements. Part 4 compares SOC numerical solutions with experimental observations for sites where nuclear or high explosive shots were made. The SOC calculations are based on material properties obtained from laboratory tests on selected rock samples. A listing of the SOC code is given in the Appendix.

2. THE NUMERICAL MODEL

A wave is a time-dependent process that transfers energy from point to point in a medium. A wave propagates through a medium because of a feedback loop that exists between the various physical properties of the medium that are changed by the energy deposition.

The cycle followed in calculating stress wave propagation is presented in Fig. 1. We start at the top of the loop, with the applied stress field. The

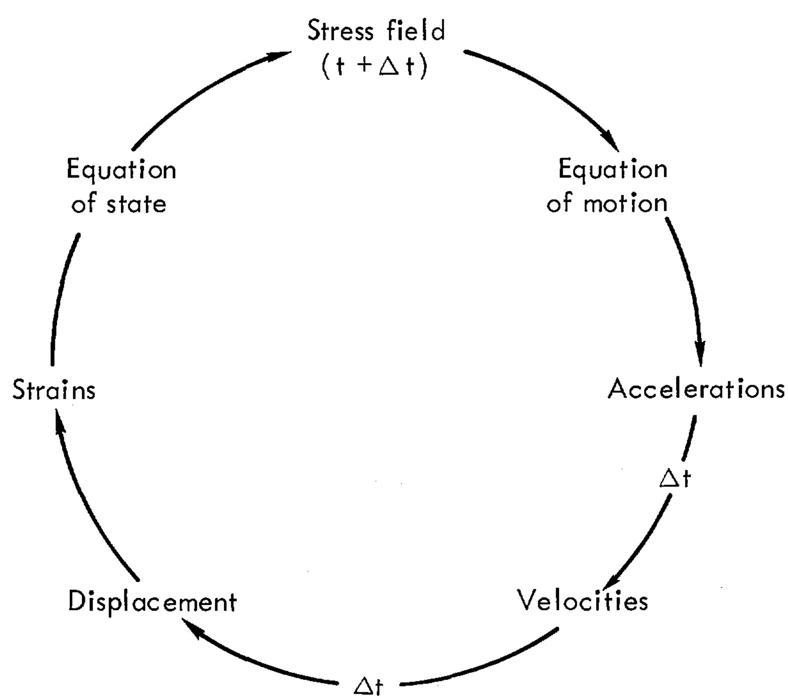

Fig. 1. Cycle of interactions treated in calculating stress wave propagation.

equation of motion provides a functional relation between the stress field and the resulting acceleration of each point in the medium. Accelerations, when allowed to act over a small time increment Δt, produce new velocities; velocities produce displacements, displacements produce strains, and strains produce a new stress field. Time is incremented by Δt and the cycle is repeated. The analysis of this loop is provided by a computer program, SOC, which solves the equations of continuum mechanics for spherical symmetry by finite difference methods.

2.1 Equation of Motion

The fundamental equations of continuum mechanics (conservation of mass, linear momentum, and angular momentum) combine to produce the following equation of motion for spherical symmetry, taken from Keller[1]:

$$\rho \dot{u} = -\left(\frac{\partial P}{\partial R} + \frac{4}{3}\frac{\partial K}{\partial R} + 4\frac{K}{R} + g\right), \tag{1}$$

where ρ is the density, $\dot{u}$ is the particle acceleration, g is a body force used to include gravity effects, and the stress tensor in the spherically symmetric coordinate system is written as the sum of an isotropic tensor and a deviatoric tensor,

$$\begin{bmatrix} T_{RR} & 0 & 0 \\ 0 & T_{\theta\theta} & 0 \\ 0 & 0 & T_{\phi\phi}=T_{\theta\theta} \end{bmatrix} = \begin{bmatrix} -P & 0 & 0 \\ 0 & -P & 0 \\ 0 & 0 & -P \end{bmatrix} + \begin{bmatrix} -\frac{4}{3}K & 0 & 0 \\ 0 & \frac{2}{3}K & 0 \\ 0 & 0 & \frac{2}{3}K \end{bmatrix}. \tag{2}$$

We see from equation (2) that

$$P = -\frac{1}{3}(T_{RR} + 2T_{\theta\theta}),$$
$$K = \frac{T_{\theta\theta} - T_{RR}}{2}. \tag{3}$$

Equation (1) is differenced by establishing a Lagrangian coordinate system (j) in the material. These coordinates move with the material and assume discrete values: 0, 1, 2, . . . , j - 1, j, j + 1, ... This coordinate system divides the material into volume elements or zones, with the mass in each zone remaining constant. At zero time each Lagrangian coordinate (j) has a unique Eulerian coordinate R_j^0; after n cycles, corresponding to a time t^n, the Eulerian coordinate is R_j^n.

Equation (1) is transformed into the Lagrangian (j) coordinate system. Each stress component (Σ) in this equation is a scalar function of position (R) and time (t). If the Eulerian coordinate (R) is considered to be a function of j and t then we can write

$$\frac{\partial \Sigma}{\partial j} = \frac{\partial \Sigma}{\partial R}\frac{\partial R}{\partial j}. \tag{4}$$

Equation (4) is easily solved for $\partial\Sigma/\partial R$.

The time derivative of velocity simplifies considerably in the Lagrangian system since j is independent of time. In the Eulerian system we have

$$\dot{u} = \frac{\partial u}{\partial t} + \frac{dR}{dt}\frac{\partial u}{\partial R}, \tag{5}$$

while in the Lagrangian system we have simply

$$\dot{u} = \frac{\partial u_j}{\partial t}. \tag{6}$$

Using equations (4) and (6), we obtain the following first-order difference approximation to the equation of motion (superscripts denote cycle, subscripts denote Lagrangian coordinate, and $R_j^n - R_{j+1}^n > 0$):

$$u_j^{n+\frac{1}{2}} = u_j^{n-\frac{1}{2}} - \Delta t^n \left(\frac{\Delta P/\Delta j}{\rho(\Delta R/\Delta j)} + \frac{4}{3}\frac{\Delta K/\Delta j}{\rho(\Delta R/\Delta j)} + B + g \right), \tag{7}$$

where

$$\frac{\Delta P}{\Delta j} = P_{j-\frac{1}{2}}^n + Q_{j-\frac{1}{2}}^{n-\frac{1}{2}} - P_{j+\frac{1}{2}}^n - Q_{j+\frac{1}{2}}^{n-\frac{1}{2}},$$

$$\frac{\Delta K}{\Delta j} = K_{j-\frac{1}{2}}^n + QK_{j-\frac{1}{2}}^{n-\frac{1}{2}} - K_{j+\frac{1}{2}}^n - QK_{j+\frac{1}{2}}^{n-\frac{1}{2}},$$

$$2\rho\frac{\Delta R}{\Delta j} = \frac{M_{j-\frac{1}{2}}}{V_{j-\frac{1}{2}}^n}\left(R_{j-1}^n - R_j^n\right) + \frac{M_{j+\frac{1}{2}}}{V_{j+\frac{1}{2}}^n}\left(R_j^n - R_{j+1}^n\right),$$

$$\frac{B}{8} = \frac{K_{j+\frac{1}{2}}^n + QK_{j+\frac{1}{2}}^{n-\frac{1}{2}}}{R_j^n + R_{j+1}^n}\left(\frac{V_{j+\frac{1}{2}}^n}{M_{j+\frac{1}{2}}}\right)(1 - \xi) + \frac{K_{j-\frac{1}{2}}^n + QK_{j-\frac{1}{2}}^{n-\frac{1}{2}}}{R_{j-1}^n + R_j^n}\left(\frac{V_{j-\frac{1}{2}}^n}{M_{j-\frac{1}{2}}}\right)\xi,$$

$$\xi = \frac{R_j^n - R_{j+1}^n}{R_{j-1}^n - R_{j+1}^n}.$$

The following quantities are calculated at the beginning of the problem in the generator (see Appendix 2) and are saved.

$$V_{j+\frac{1}{2}}^0 = \left(R_j^0\right)^3 - \left(R_{j+1}^0\right)^3, \tag{8}$$

$$DV_{j+\frac{1}{2}}^0 = \left(mu_{j+\frac{1}{2}}^0\right)\left(V_{j+\frac{1}{2}}^0\right), \tag{9}$$

$$V_{j+\frac{1}{2}}^0 = DV_{j+\frac{1}{2}}^0 + V_{j+\frac{1}{2}}^0, \tag{10}$$

$$M_{j+\frac{1}{2}} = \rho_{j+\frac{1}{2}}^I V_{j+\frac{1}{2}}^0, \tag{11}$$

where $\rho_{j+\frac{1}{2}}^I$ is the input material density and $mu_{j+\frac{1}{2}}^0$ is the volume compression due to the overburden pressure.

Equation (7) provides a functional relation between the existing stress gradients (which are obtained from the values of stress in each zone and the positions of these zones at time t^n) and the acceleration of each meshpoint. This acceleration when allowed to act over a small time increment Δt^n changes the velocity of each meshpoint (j) to $u_j^{n+\frac{1}{2}}$.

2.2 Strain Calculation

After the motion of the material under the influence of the existing stress field has been calculated from equation (7), we must now find how this motion alters the stress field.

If we assume that the medium is isotropic, then the stress-strain relation (Hooke's law) has the following form for spherical symmetry:

$$\dot{T}_{RR} = \lambda \frac{\dot{V}}{V} + 2\mu \frac{\partial u}{\partial R}, \tag{12}$$

$$\dot{T}_{\theta\theta} = \dot{T}_{\phi\phi} = \lambda \frac{\dot{V}}{V} + 2\mu \frac{u}{R}, \tag{13}$$

where λ and μ are the Lamé constants and V is the volume.

From the conservation of mass we have

$$\frac{\dot{V}}{V} = \frac{\partial u}{\partial R} + 2\frac{u}{R}. \tag{14}$$

The dot represents a time derivative along a particle path. This will allow us to write the stress-strain relation in incremental form where strain changes will be referred to the current configuration of the element.

We use equation (3) to find $\dot{P}$ and $\dot{K}$:

$$\dot{P} = -k\frac{\dot{V}}{V} \left(\text{where } k = \lambda + \frac{2}{3}\mu \text{ is the bulk modulus}\right), \tag{15}$$

$$\dot{K} = \mu\left(\frac{u}{R} - \frac{\partial u}{\partial R}\right). \tag{16}$$

The total volumetric strain is defined as

$$mu = \frac{V^0 - V}{V}, \tag{17}$$

and equation (15) is replaced by

$$P = f(mu, e), \tag{18}$$

where e is the specific internal energy. The determination of f(mu, e) represents a major part of the equation-of-state work, and will be discussed in the equation-of-state section of the paper.

The strain components given by equations (16) and (17) are calculated in the code using time-centered coordinates at $n + \frac{1}{2}$ as follows (all subscripts at $j + \frac{1}{2}$ are deleted):

$$R_j \equiv R_j^{n+\frac{1}{2}} = R_j^n + \frac{1}{2}\Delta t^{n+\frac{1}{2}} u^{n+\frac{1}{2}},$$

$$\Delta R_j^{n+1} = \Delta R_j^n + \Delta t^{n+\frac{1}{2}} u_j^{n+\frac{1}{2}},$$

$$R_j^{n+1} = R_j^0 + \Delta R_j^{n+1},$$

$$\Delta V^{n+\frac{1}{2}} = \Delta t^{n+\frac{1}{2}} \left\{ 3\left[\left(R_{j+1}\right)^2 u_{j+1}^{n+\frac{1}{2}} - \left(R_j\right)^2 u_j^{n+\frac{1}{2}} \right] + \left(\frac{\Delta t^{n+\frac{1}{2}}}{2}\right)^2 \left[\left(u_{j+1}^{n+\frac{1}{2}}\right)^3 - \left(u_j^{n+\frac{1}{2}}\right)^3 \right] \right\}$$

$$= V^n - V^{n+1} ,$$

$$DV^{n+1} = DV^n + \Delta V^{n+\frac{1}{2}} = \left(R_j^0\right)^3 - \left(R_{j+1}^0\right)^3 - V^{n+1} ,$$

$$V^{n+1} = V^0 - DV^{n+1} - DV^0 ,$$

$$V^{n+\frac{1}{2}} = V^{n+1} + \frac{1}{2}\Delta V^{n+\frac{1}{2}} ,$$

$$mu^{n+1} = \frac{DV^{n+1} + DV^0}{V^{n+1}} = \frac{V^0 - V^{n+1}}{V^{n+1}} , \qquad (19)$$

$$\left(\frac{\Delta K}{\mu}\right)^{n+\frac{1}{2}} = -\frac{1}{2}\left(\frac{\Delta V^{n+\frac{1}{2}}}{V^{n+\frac{1}{2}}} + 3\,\frac{\left(u_j^{n+\frac{1}{2}} - u_{j+1}^{n+\frac{1}{2}}\right)\Delta t^{n+\frac{1}{2}}}{R_j - R_{j+1}} \right) . \qquad (20)$$

The last two equations above represent the strain terms that are used in the code to calculate P^{n+1} and K^{n+1} respectively.

2.3 Calculation of Mean Stress (P)

In the code the calculation of mean stress depends on the state of the material. During shock loading, equation (18) becomes

$$P_H^{n+1} = f_H(mu^{n+1}) , \qquad (21)$$

where f_H is determined from hydrostatic compressibility and Hugoniot measurements on core samples.

The calculation during release depends on the maximum internal energy that has been deposited in the zone. If $e_{j+\frac{1}{2}}^{max} > e_v^I$ then P^{n+1} is calculated using a set of gas tables developed by Butkovich[2] in which P is listed as a function of energy with density as the parameter. The quantity e_v^I is the vaporization energy which is related to the difference between the shock-deposited internal energy and the area under the Hugoniot (the shaded area in Fig. 2). The vaporization energy is obtained from the equation in Fig. 2, where P_v is the pressure value for which the shaded area is just equal to the vaporization "waste heat" for the material (2800 cal/g for SiO_2 in this case).

If $e_f^I \leq e^{max} < e_v^I$ where e_f^I is the melt energy, then the pressure on release is calculated by

$$P^{n+1} = P_H^{n+1} + \Gamma\left(e^n - e_H\right),$$

where

P_H^{n+1} is the Hugoniot pressure,
e^n is the internal energy at t^n,

$$e_H = \frac{1}{2} P_H^{n+1} \frac{mu^{n+1}}{1 + mu^{n+1}},$$

$$\Gamma = \Gamma^I \left[\frac{e^{max} - e_f^I}{e_v^I - e_f^I} \right].$$

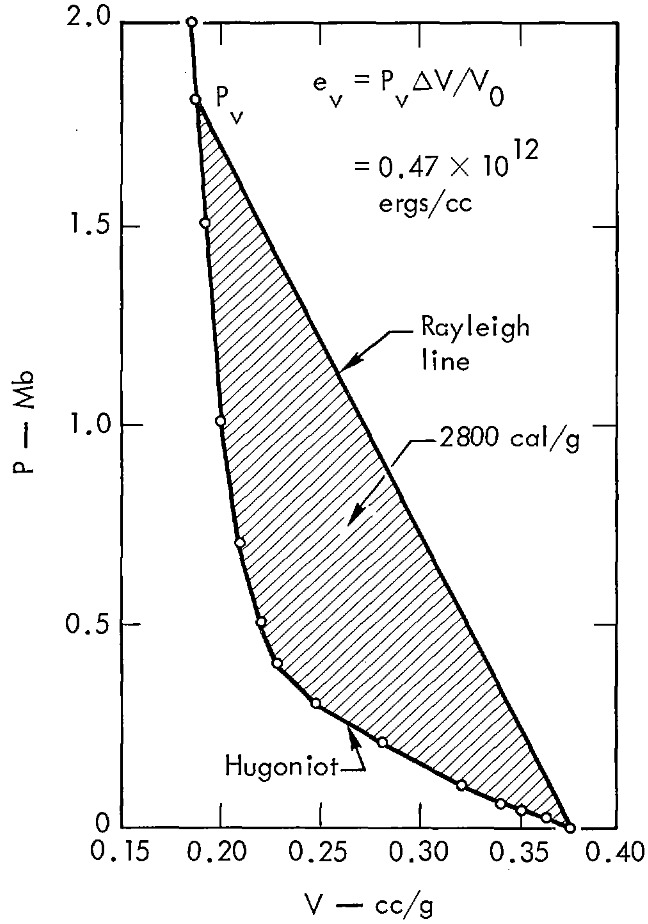

Fig. 2. Calculation of vaporization energy.

The quantity Γ^I is an input quantity specified in the equation of state. In order to assure a reasonable continuity of release paths for e^{max} near e_v^I, the gas tables are merged into the Hugoniot using equation (22). We have found that values of Γ^I between 0.85 and 1 produce an acceptable transition between the Hugoniot and the well-defined part of the gas tables. The melt energy e_f^I is determined the same way as e_v^I (see Fig. 2), except that the "waste heat" value for melting (shaded area between the curves) is less, being 600 cal/g for SiO_2.

If the hydrostatic compressibility data indicate that the material locks in the P-V plane on release (Fig. 3), then the code will accept one input release path in the equation of state. This release path is usually the experimentally determined hydrostatic unloading path from 40 kb (the pressure limit of our apparatus).

The point in the P-mu plane where the experimental loading and unloading hydrostats merge, mu_2^I, is input in the equation of state. If $mu_{j+\frac{1}{2}}^{max} \geq mu_2^I$ then the release path follows the input unloading curve. If

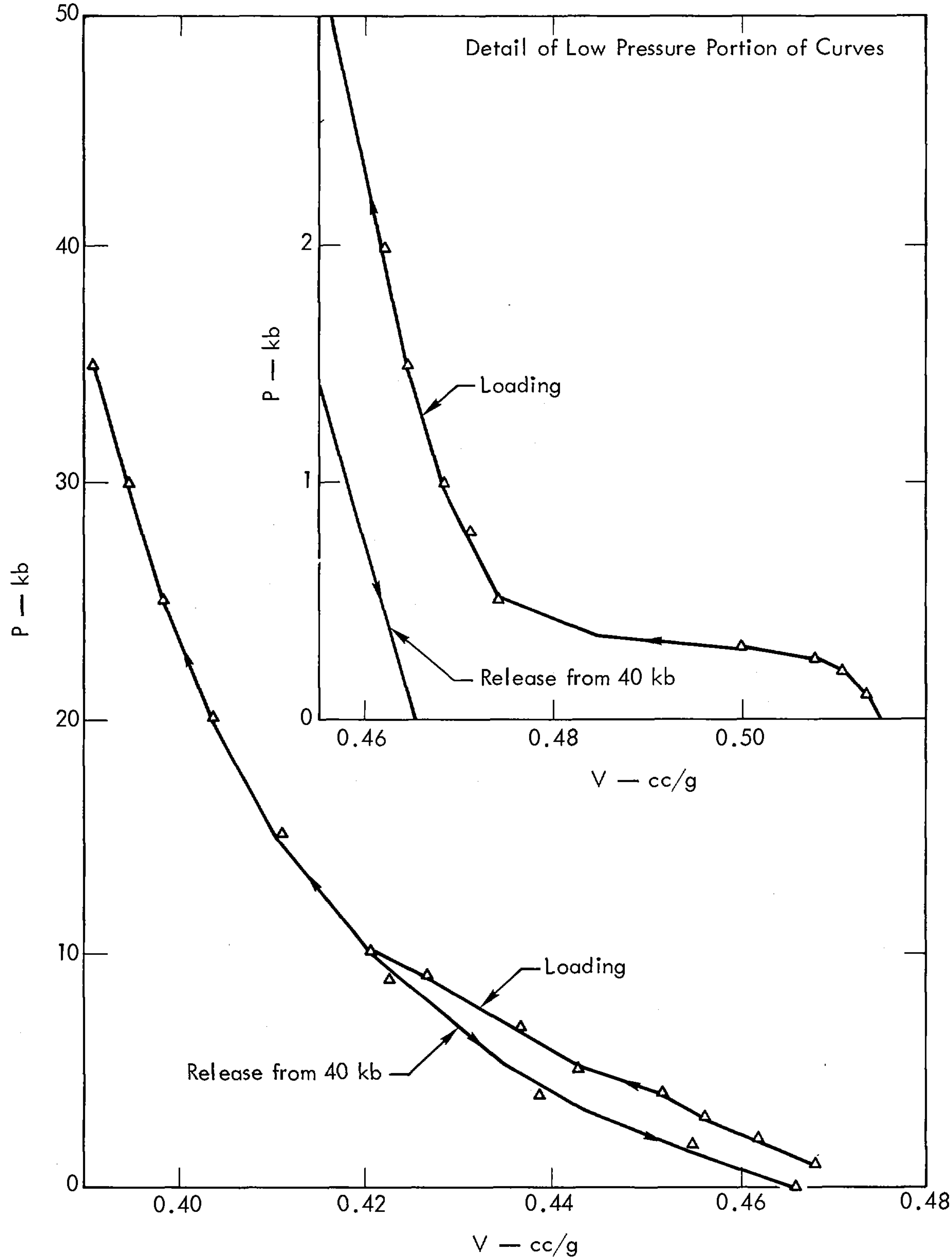

Fig. 3. Compressibility of DF-5A grout.

$mu^{max}_{j+\frac{1}{2}} < mu^{I}_{2}$ then the release path is determined such that

$$\left(\frac{dP}{dmu}\right)^{n+\frac{1}{2}}_{j+\frac{1}{2}} = \left(\frac{dP}{dmu}\right)_L + \frac{mu^{max}_{j+\frac{1}{2}}}{mu^I_2}\left[\left(\frac{dP}{dmu}\right)_u - \left(\frac{dP}{dmu}\right)_L\right], \tag{23}$$

where $(dP/dmu)_L$ and $(dP/dmu)_u$ are the slopes of the loading and unloading hydrostats for $P^n_{j+\frac{1}{2}}$. The pressure on release becomes

$$P^{n+1} = P^n + \left(\frac{dP}{dmu}\right)^{n+\frac{1}{2}} \frac{V^0 \Delta V^{n+\frac{1}{2}}}{V^{n+1}(V^{n+1} + \Delta V^{n+\frac{1}{2}})}. \tag{24}$$

2.4 Calculation of Deviatoric Stress (K)

Equation (20) represents the initial attempt by the code to calculate K^{n+1}:

$$\tilde{K}^{n+1} = K^n + \mu^I \left(\frac{\Delta K}{\mu}\right)^{n+\frac{1}{2}}. \tag{25}$$

The quantity μ^I is the rigidity modulus from the equation of state. At the present time the code accepts either a constant rigidity modulus or a constant Poisson's ratio.

Adjustment of the $\tilde{K}^{n+1}$ calculated in equation (25) is permitted if the zone is undergoing plastic flow or brittle failure. The code uses two strength tables, one for the consolidated and one for the cracked state, a strain rate value K^I_2, and a brittle-ductile transition point P^I_1 in the failure routines. The strength tables will be discussed in the equation-of-state section.

If $P^{n+1} + \frac{1}{3}\tilde{K}^{n+1} \geq P^I_1$ and if $|\tilde{K}^{n+1}| > \left(K^I_2\right)(a)$ then plastic flow develops and

$$K^{n+1} = \left(K^I_2\right)(a)\ \text{sign}\ (\tilde{K}^{n+1}) \text{ for } e^n \leq e^I_f \tag{26}$$

$$= 0 \text{ for } e^n > e^I_f ,$$

where

$$a = \frac{e^I_f - e^n}{e^I_f} .$$

The plastic strain $(\Delta\epsilon_p)$ associated with the adjustment (flow rule) in equation (26) is

$$\Delta\epsilon_p = \frac{|\tilde{K}^{n+1}| - \left(K^I_2\right)(a)}{\mu} . \tag{27}$$

If $P^{n+1} + \frac{1}{3}\tilde{K}^{n+1} < P^I_1$ and if $|\tilde{K}^{n+1}|$ is greater than the value of K allowed by the appropriate strength table, then a crack is allowed to propagate through the zone with a velocity C_V given by Bieniawski[3] as

$$C_v = 1.14 \sqrt{\frac{\mu}{\rho^I\left(3 + \frac{\mu}{k}\right)}} . \tag{28}$$

A crack length C_L and a crack ratio C_R are calculated:

$$C_L^{n+1} = C_1^n + C_v \Delta t^{n+\frac{1}{2}} ,$$

$$C_R = \frac{C_L^{n+1}}{4\left(R_j^{n+1} - R_{j+1}^{n+1}\right)} \leq 1 . \tag{29}$$

A limiting value of K is calculated,

$$K_{Lim} = |\tilde{K}^{n+1}| \left[1 - \frac{C_v C_R}{4\left(R_j^{n+1} - R_{j+1}^{n+1}\right)} \Delta t^{n+\frac{1}{2}}\right] \leq K_2^I . \tag{30}$$

Equation (26) is used to calculate K^{n+1} with K_2^I replaced by K_{Lim}.

The form of equation (30) represents a compromise between a dislocation theory formulation and a Maxwell solid formulation in which the viscosity η is replaced by

$$\eta = \frac{4\mu \Delta R}{C_v C_R} . \tag{31}$$

The relaxation of the deviatoric components of stress during brittle failure has been observed experimentally by Byerlee[4] under quasi-static loading. Ahrens and Duvall[5] have measured the attenuation of the elastic precursor in three quartz rocks in one-dimensional plane geometry and found that on the "elastic" Hugoniot

$$F = -\frac{dK_{Lim}}{dt} \approx 40 \frac{kb}{\mu sec} \tag{32}$$

with a relaxation time of 0.7 μsec. Equation (30) gives

$$-\frac{dK_{Lim}}{dt} = \frac{|\tilde{K}^{n+1}|}{0.7} \tag{33}$$

assuming $C_R = 1$ and $4\Delta R/C_V = 0.7$ μsec. Since the difference between the precursor radial stress and the isothermal hydrostat is about 40 kb for the rocks Ahrens and Duvall considered, then

$$\tilde{K}^{n+1} \approx \left(\frac{3}{4}\right) (40) \text{ kb.}$$

Using this value of $\tilde{K}^{n+1}$ in equation (33) gives 43 kb/μsec for F.

Equation (3) is used to describe the relaxation of the stress deviator during brittle failure. No attempt is made to distinguish between "tensile" or "shear" failure in the crack routine itself.

The internal energy and stability calculations are the standard formulations of Cherry[6] for an adiabatic Lagrangian code using artificial viscosity.

The total energy in the problem (internal, kinetic, and gravitational) is determined at specified times and compared with the input energy. Agreements within 1% or less are considered normal. The listing of the code is given in Appendix 1.

3. DETERMINING AN EQUATION OF STATE FOR THE ROCK AT A PARTICULAR SITE

The equation of state for the rock at a particular site is developed from field logging and from laboratory tests on selected rock samples. Ideally these programs should include the following:

3.1 Logging Program

(1) Density log
(2) Elastic velocity log
    (a) Compressional velocity
    (b) Shear velocity

Hopefully, these logs will permit a judgment concerning both the layering of the medium and the choice of core for laboratory testing.

3.2 Core Tests

(1) Hydrostatic compressibility up to 40 kb
    (a) Loading
    (b) Unloading
(2) Triaxial tests at various confining pressures and saturation levels.
    (a) Consolidated
    (b) Cracked
(3) Tensile strength
(4) Hugoniot elastic limit
(5) High pressure Hugoniot data (loading and release) for the rock near the point of detonation.

The core tests that are now relatively standard are those involving hydrostatic compressibility, triaxial strength, and, to some extent, the shock Hugoniot. Experimental techniques that measure Hugoniot release are still in the developmental stage.

3.3 Hydrostatic Compressibility and Hugoniot Data

Figure 3 shows the measured loading and unloading hydrostatic isotherms for a "locking" solid (DF-5A grout).* This locking feature is typical of most of the dry porous rock encountered at the Nevada Test Site (NTS) and is responsible for the severe seismic decoupling characteristic of the site.

Figure 4 shows the static isotherm along with Hugoniot data for Hardhat granite. The 10-kb offset between the Hugoniot elastic limit (HEL) and the hydrostat is maintained for the

$$P_H^{n+1} = f_H(mu^{n+1})$$

code input (equation(21)).

The Rayleigh line drawn through the HEL intersects the Hugoniot at 320 kb. The slope of the Rayleigh line in the P-V plane is proportional to the

*See Sec. 4.1, "Model Studies."

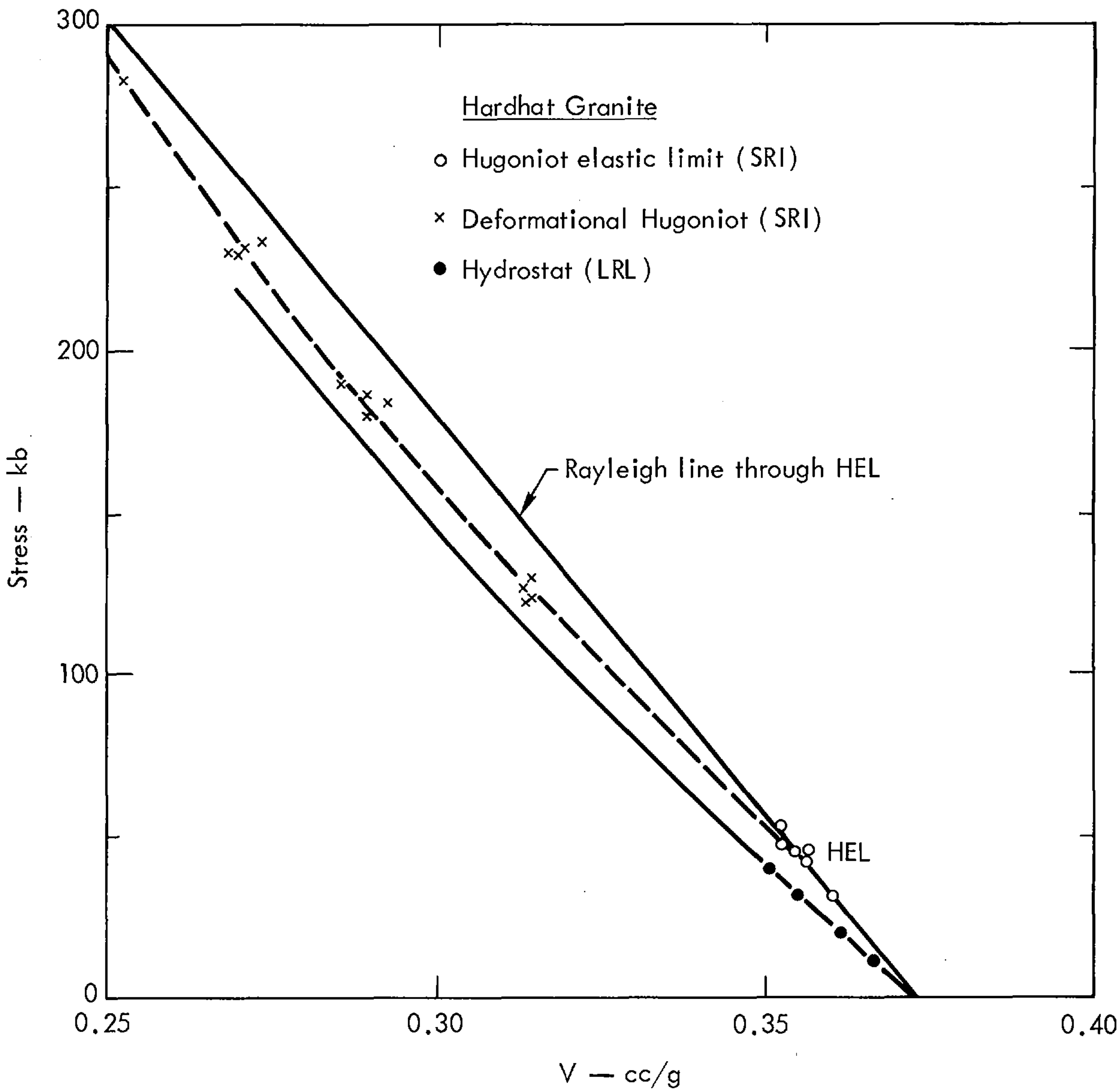

Fig. 4. Hugoniot and compressibility data for Hardhat granite.

square of the shock velocity (u_s):

$$\frac{P - P_0}{V_0 - V} = \left(\rho_0 u_s\right)^2 . \tag{34}$$

For shock states below 320 kb the first arrival corresponds to the Rayleigh line through the HEL (5.9 m/msec) with an amplitude of 45 kb.

3.4 Strength Data

An attempt has been made to develop a failure criterion, in terms of stress invariants, capable of describing the onset of failure in brittle materials. The important stress invariants used are mean stress (P), the second deviatoric invariant (I_{2D}), and the third deviatoric invariant (I_{3D}).

In terms of principal stresses T_{11}, T_{22}, T_{33} (positive for tension), we have

$$P = -\frac{T_{11} + T_{22} + T_{33}}{3},$$

$$I_{2D} = \frac{1}{6}\left(T_{11} - T_{22}\right)^2 + \left(T_{11} - T_{33}\right)^2 + \left(T_{22} - T_{33}\right)^2 \tag{35}$$

$$= \frac{1}{2}\left(T_1^2 + T_2^2 + T_3^2\right),$$

where $T_1 = P + T_{11}$, $T_2 = P + T_{22}$, and $T_3 = P + T_{33}$ are the stress deviators,

$$I_{3D} = T_1 T_2 T_3 .$$

We assume that strength can be expressed in terms of I_{2D}:

$$Y \equiv \left(3I_{2D}\right)^{\frac{1}{2}} .$$

The results of various destructive tests (compression, extension, and hollow torsion) on glass, dolomite, granite, and limestone have been presented by Handin et al.[7] and Mogi.[8] They demonstrated that I_{2D} plotted versus P did not give a consistent failure surface when the test type changed.

Mogi also found that the compression and extension test data are consistent if P is replaced by $\overline{P}$, where

$$\overline{P} = -\frac{T_{11} + T_{33} + bT_{22}}{2}, \tag{36}$$

T_{22} is the intermediate principal stress, and $0 \le b \le 0.1$ depending on the rock type. This suggests that if I_{3D} is combined with P such that

$$\overline{P} = P - a\left(\frac{I_{3D}}{2}\right)^{1/3}, \tag{37}$$

then Mogi's formulation is obtained for b = 0 if a = 0.5.

Figures 5-16 show Y vs P and vs $\overline{P}$, where $\overline{P}$ is given by equation (37) with a = 0.5 and $Y = \left(3I_{2D}\right)^{\frac{1}{2}}$. Each point on a given plot is determined by evaluating the appropriate invariants from the existing stress field at failure. Replacing P by $\overline{P}$ not only improves the consistency of the various tests but well defines the brittle-ductile transition for limestone. It would be easy to improve the consistency even more by allowing "a" to vary with the rock type. However, in our applications the variability of the core obtained from a particular site is more than sufficient to mask changes in "a" with rock type, even if a large variety of strength tests were available.

Equations (2), (35), and (37) give the following relations between Y, $\overline{P}$, and K:

$$Y = 2|K| = |T_{\theta\theta} - T_{RR}| ,$$

$$\overline{P} = P + \frac{K}{3} = -\frac{T_{RR} + T_{\theta\theta}}{2} . \tag{38}$$

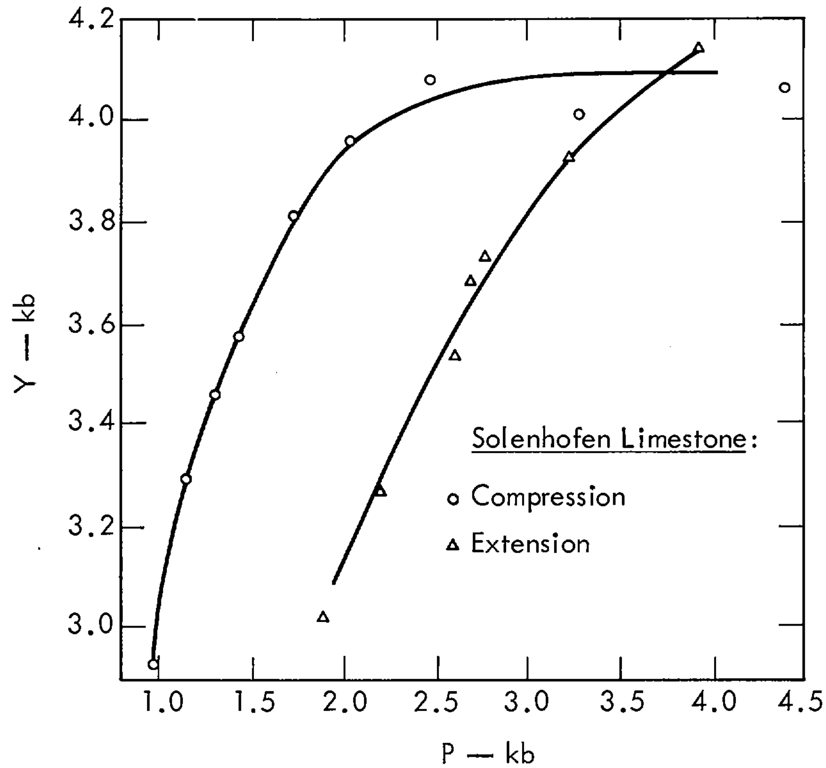

Fig. 5. Yield strength (Y) vs P for Solenhofen limestone (data of Mogi[8]).

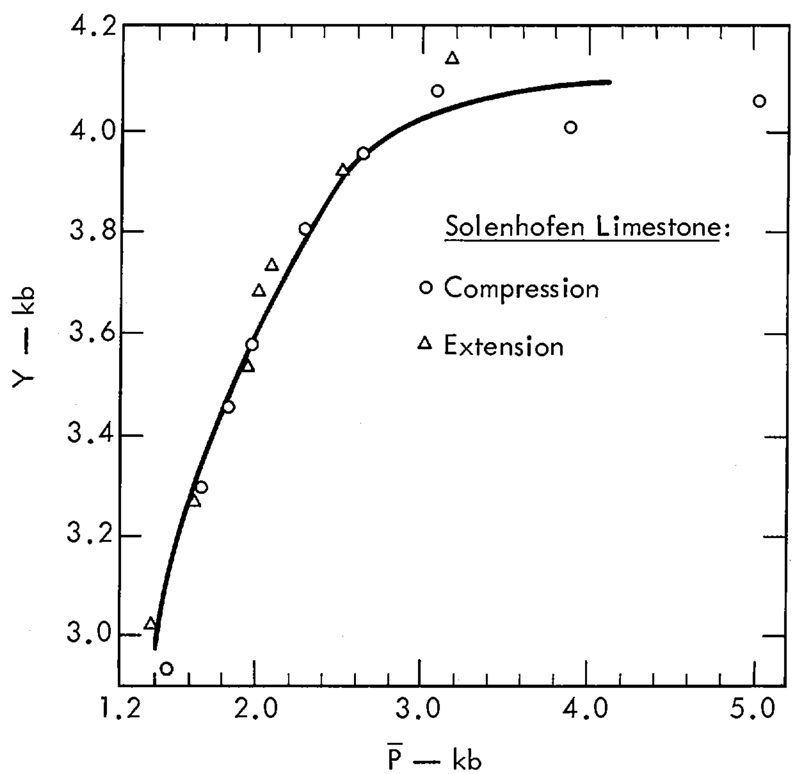

Fig. 6. Y vs $\overline{P}$ for Solenhofen limestone (data of Mogi[8]).

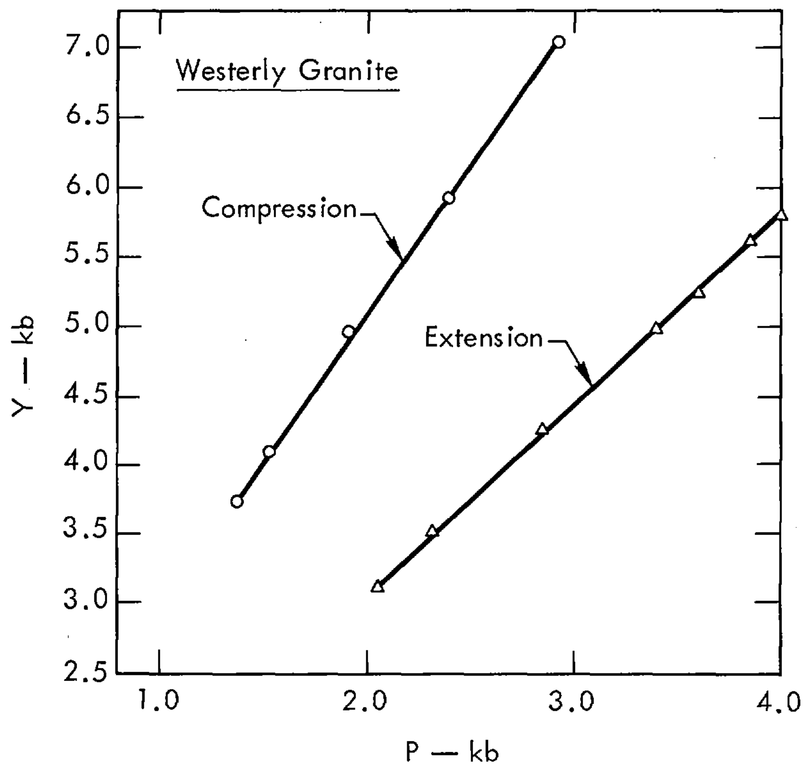

Fig. 7. Y vs P for Westerly granite (data of Mogi[8]).

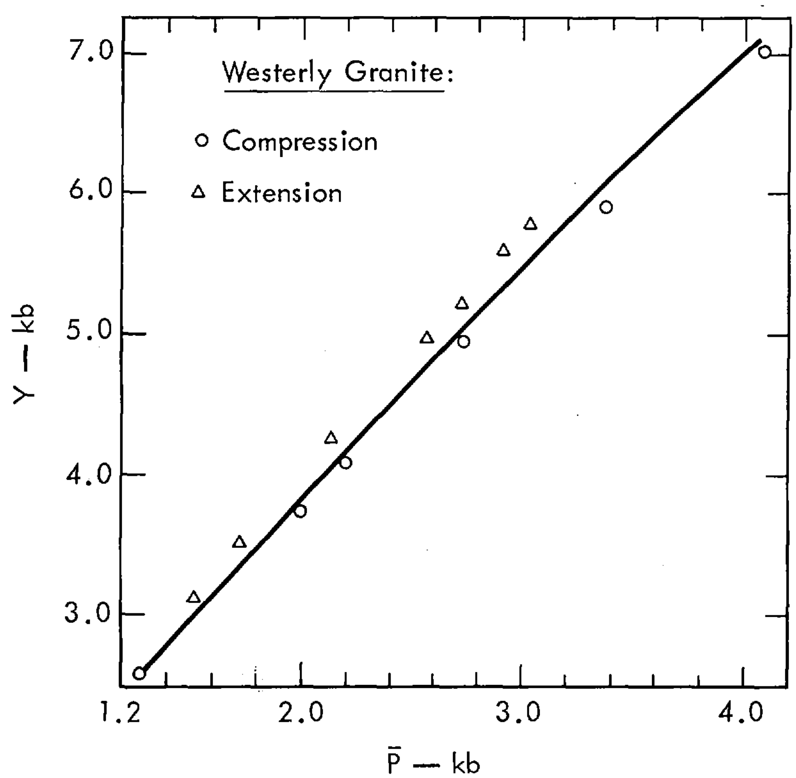

Fig. 8. Y vs $\overline{P}$ for Westerly granite (data of Mogi[8]).

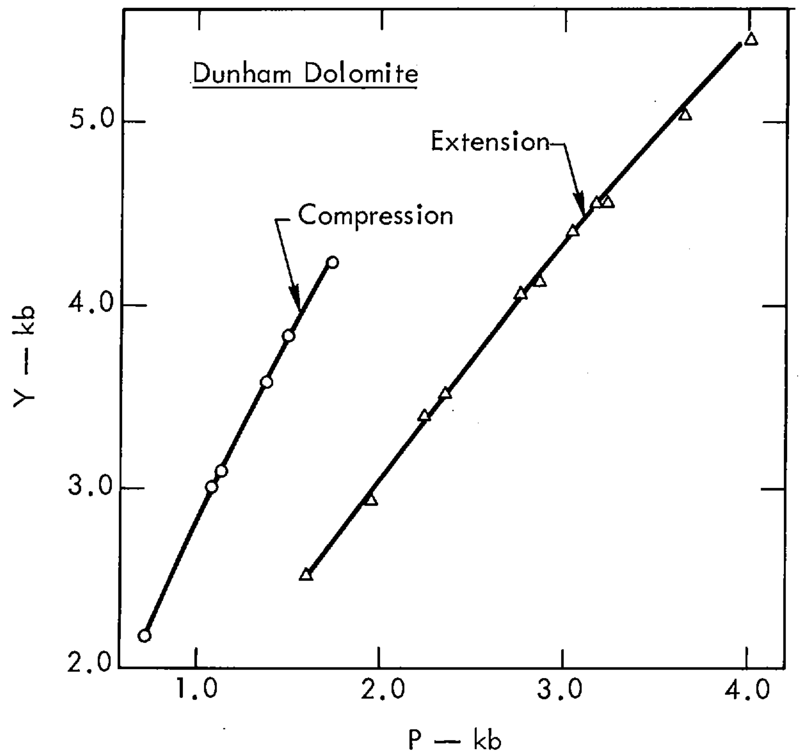

Fig. 9. Y vs P for Dunham dolomite (data of Mogi[8]).

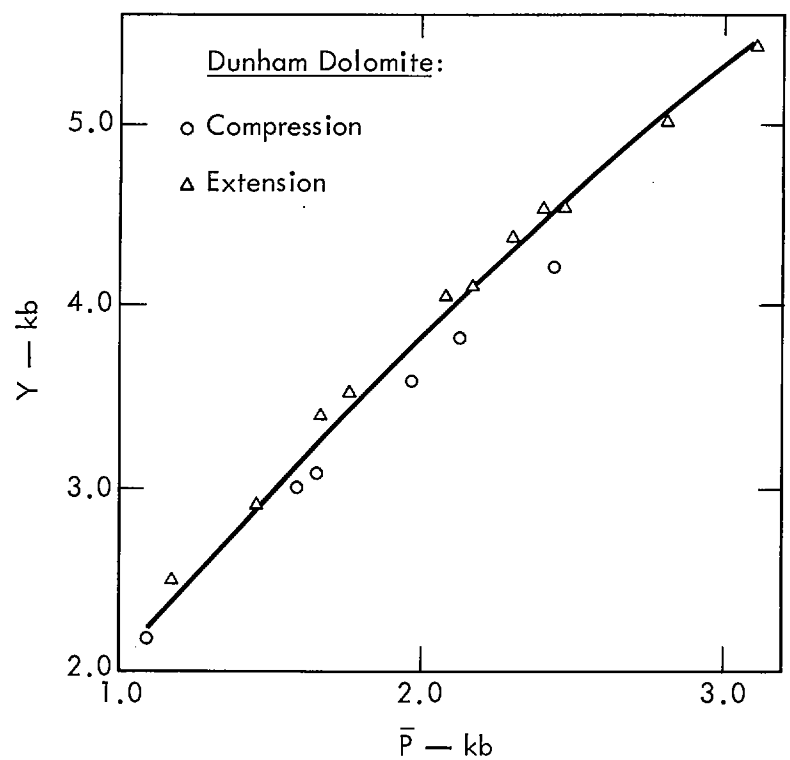

Fig. 10. Y vs $\overline{P}$ for Dunham dolomite (data of Mogi[8]).

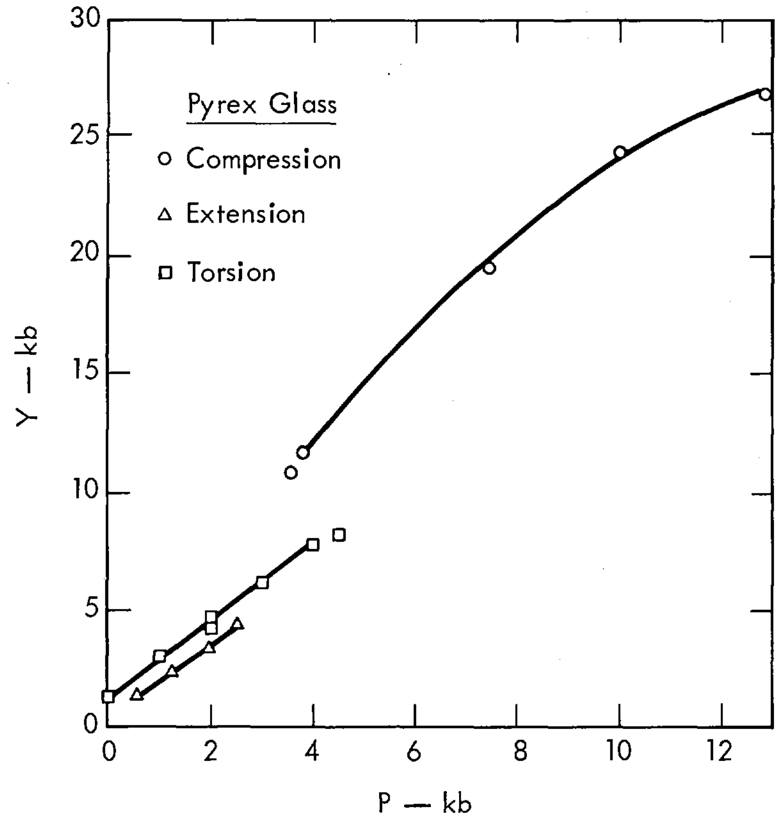

Fig. 11. Y vs P for Pyrex glass (data of Handin et al.[7]).

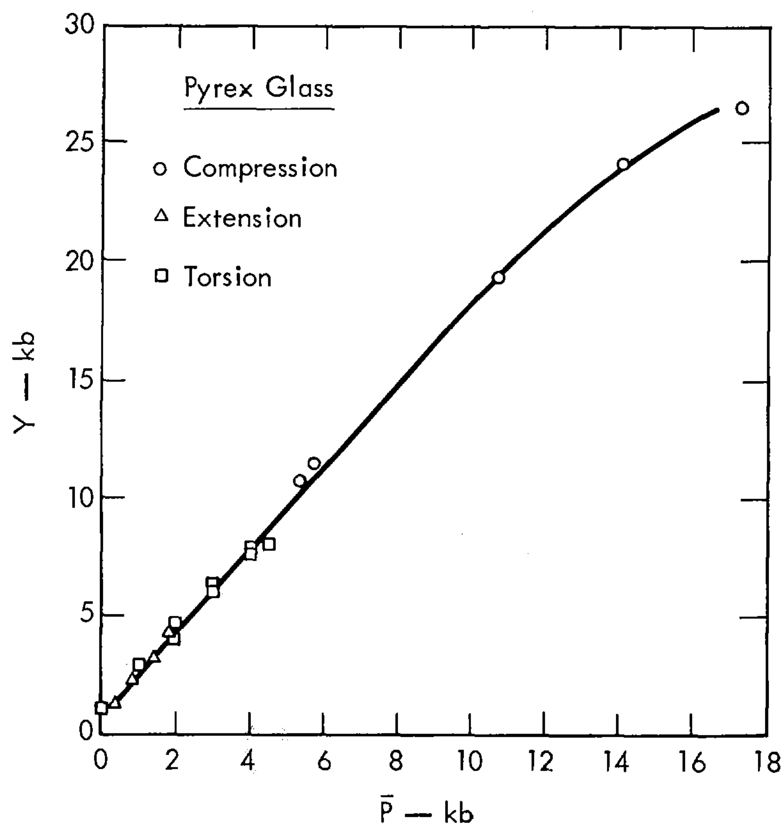

Fig. 12. Y vs $\overline{P}$ for Pyrex glass (data of Handin et al.[7]).

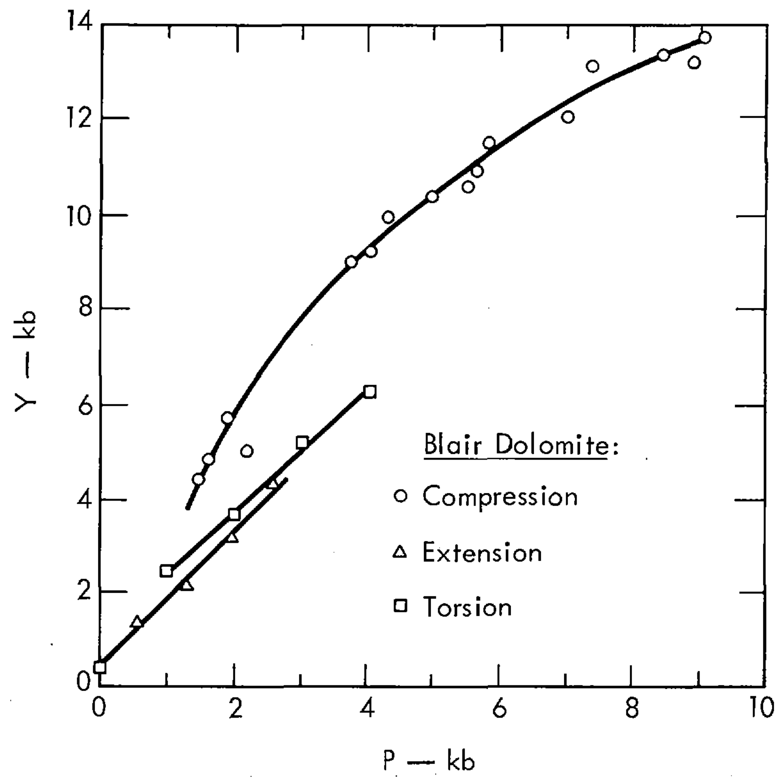

Fig. 13. Y vs P for Blair dolomite (data of Handin et al.[7]).

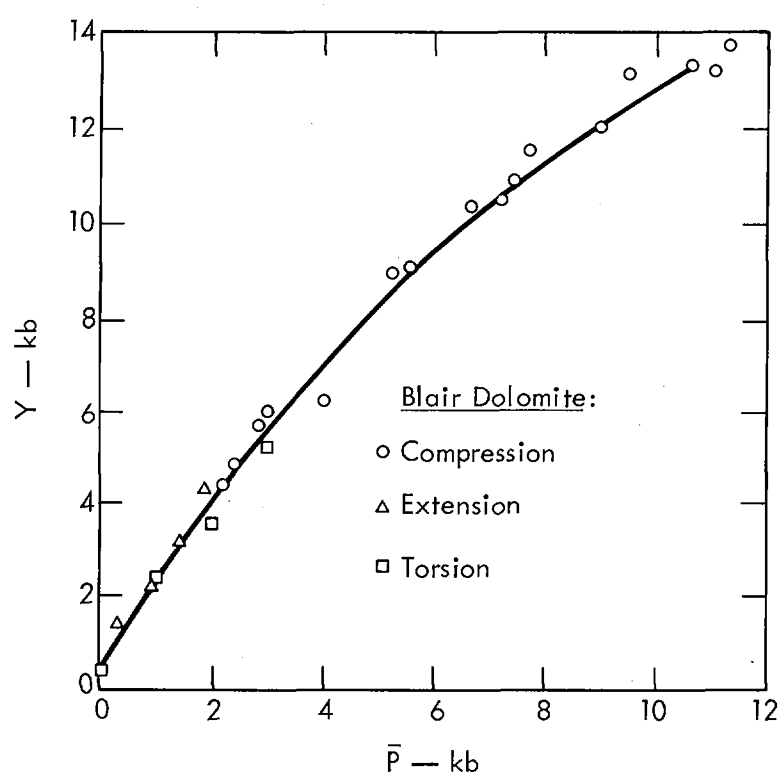

Fig. 14. Y vs $\overline{P}$ for Blair dolomite (data of Handin et al.[7]).

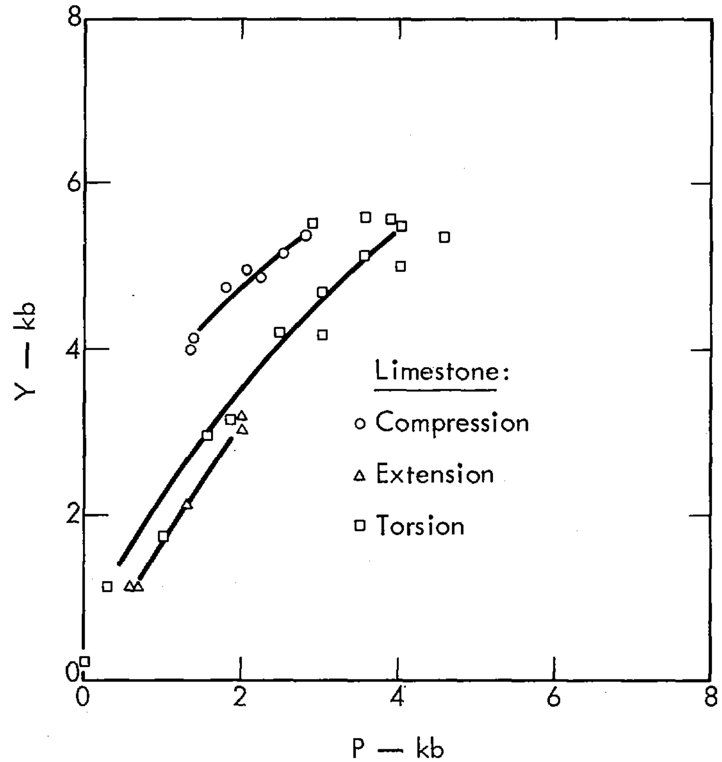

Fig. 15. Y vs P for limestone (data of Handin et al.[7]).

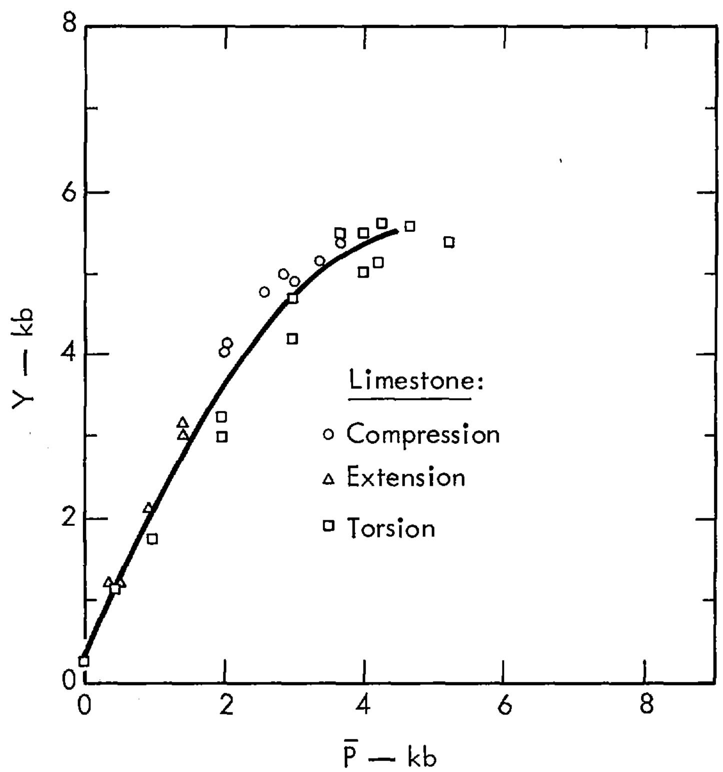

Fig. 16. Y vs $\overline{P}$ for limestone (data of Handin et al.[7]).

The failure criterion in the code is a table of Y/2 vs $\overline{P}$. The table is determined from triaxial compression test data, the tensile strength, and the Hugoniot elastic limit, where Y/2 and $\overline{P}$ are evaluated for each test.

4. COMPARISON OF CALCULATIONS AND EXPERIMENTAL RESULTS

4.1 Model Studies

Model studies were done in which a charge of high explosive and a number of pressure transducers at various distances from the charge were imbedded in a large block of grout which was allowed to set and harden. When the charge was detonated in the hardened grout, the resultant stress history was determined from the pressure transducer data.

The grout was a special mix called DF-5A, developed by the U.S. Army Corps of Engineers. It was poured into an approximately cubical form 60 cm on a side, with the top side given a slight cylindrical curvature to facilitate study of its free surface behavior by shadowgraph photography. A 4-cm-diam spherical charge of LX-04 high explosive was placed 14 cm below this free surface. Ten pressure transducers sensitive to radial stress were placed at distances between 4.5 and 14 cm from the charge. The transducers were all at least 10 cm below the free surface, and most of them were below the level of the charge. For the experiment, the entire form was buried in sand or gravel with only the free surface protruding.

The explosive was detonated and the free surface velocity was measured with a streaking camera in "shadowgraph" configuration. The cylindrical free surface simplified this measurement. Pressure transducers were 1.25-cm-diam, 0.5-mm-thick Z-cut tourmaline disks (Hearst et al.[9]). A characteristic of the DF-5A grout is the presence of voids due to air in the mix, a desirable feature both for transducer bonding and for producing the "locking solid" behavior characteristic of porous rocks.

The purpose of the experiment was to compare the experimental results with the code solutions. These calculations were performed using the material properties furnished from laboratory tests on grout samples. Figure 3 shows the loading and unloading hydrostats measured for the grout. Figure 17 shows the strength data obtained from triaxial compression tests. We regard the wet strength as the equilibrium strength and attempt to compensate for the difference between the wet and dry materials by including a strain rate term (K_2^I, equation (31)) of 4 kb in the equation of state. A Poisson's ratio of about 0.2 was obtained from ultrasonic measurements on grout cylinders. The equation of state of LX-04 has been published by Wilkins.[10]

Figures 18, 19, and 20 compare calculated and measured radial stress histories at 6.5, 7.5, and 9 cm. At 7.5 and 9 cm the calculated peak radial stress is high and the shock arrives too fast. Figure 21 compares calculated and measured peak radial stress versus radial distance. Again the high calculated value is apparent. The calculated free surface (spall) velocity was 60 m/sec compared to an observed value of 53 m/sec, rather encouraging agreement considering this measurement is the easiest to obtain and probably the most reliable part of the experimental effort.

In view of the complexity of the grout equation of state, the agreement between calculation and experiment is considered to be good, at least encouraging enough to warrant improvement in the stress-history measurement techniques (too many gauge failures now occur) and to ask for a detailed study of the variability of the grout material properties.

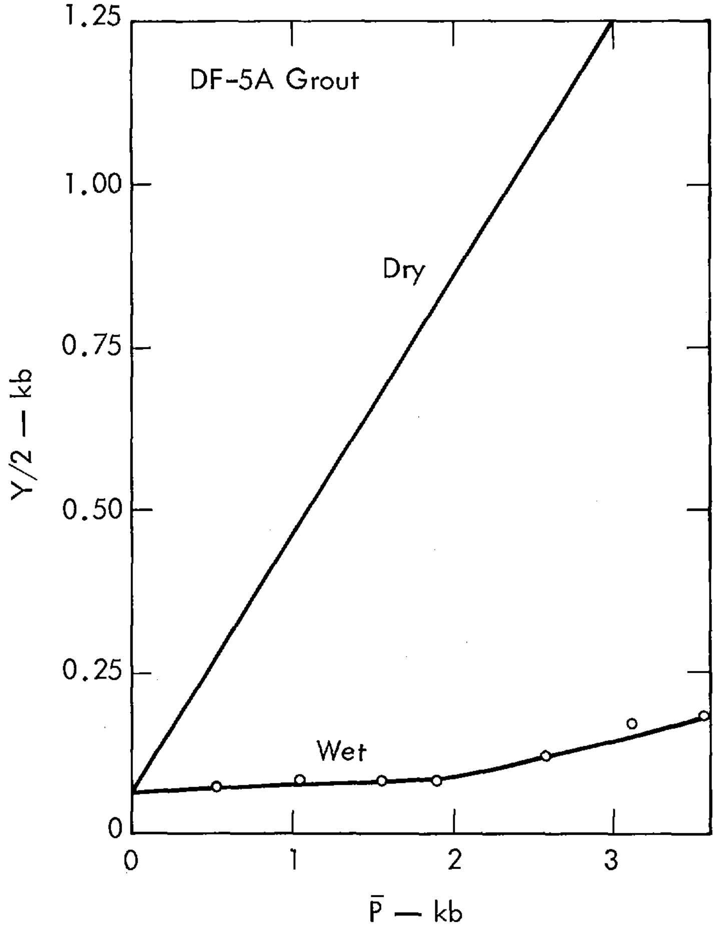

Fig. 17. Strength of DF-5A grout.

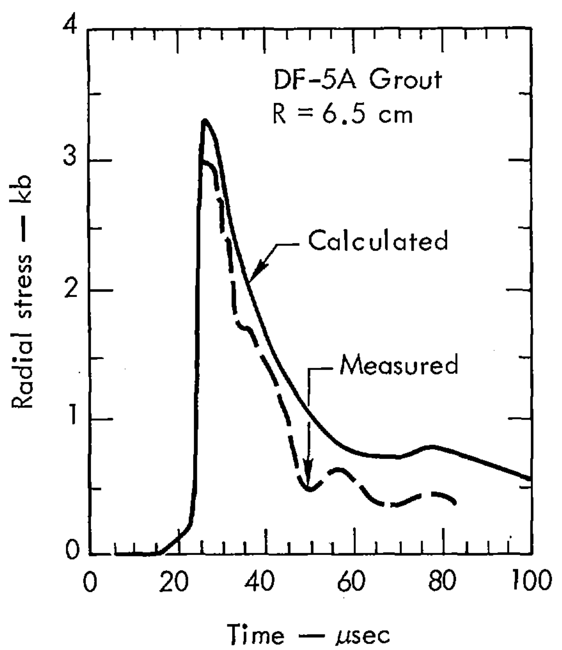

Fig. 18. Stress history in DF-5A grout 6.5 cm from high explosive detonation.

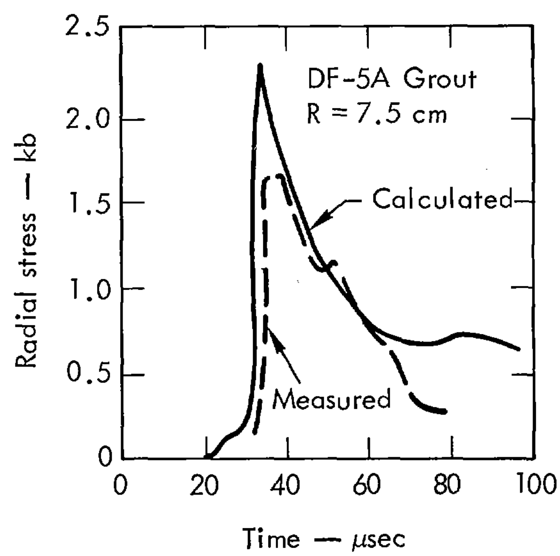

Fig. 19. Stress history in DF-5A grout 7.5 cm from high explosive detonation.

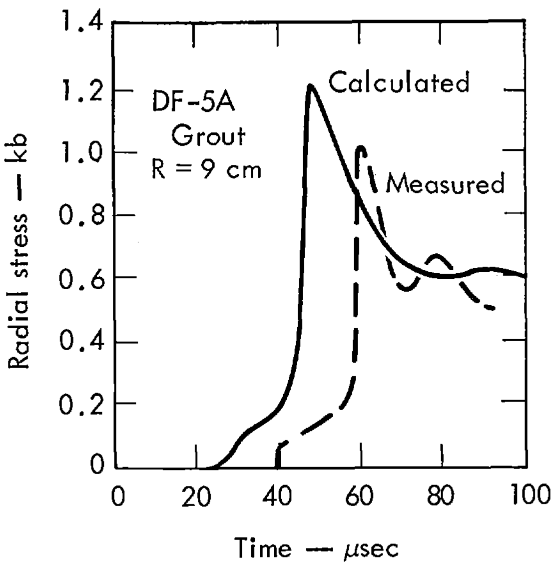

Fig. 20. Stress history in DF-5A grout 9 cm from high explosive detonation.

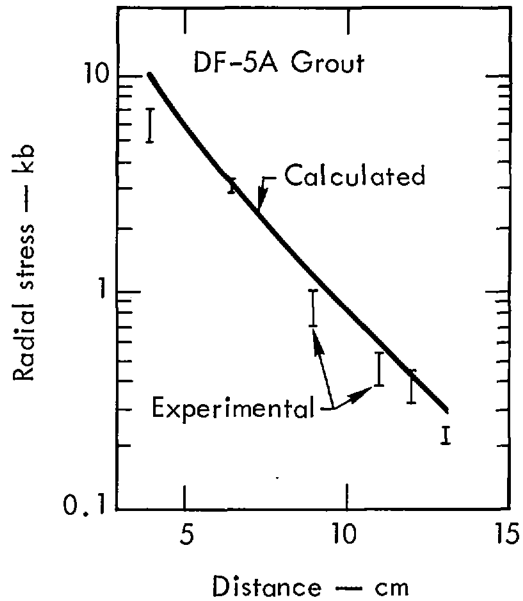

Fig. 21. Peak radial stress in DF-5A grout vs distance from high explosive detonation.

4.2 Hardhat Granite

The Hardhat Event was a 5-kt contained nuclear explosion at a depth of 290 m in granite at NTS. Figure 4 shows the static isotherm along with Hugoniot data obtained from granite cores taken at the Hardhat site. The 10-kb offset between the HEL and the static isotherm is maintained for the code input. Figure 22 gives the granite strength (Y/2 vs $\overline{P}$) for various states of the test sample. The strength data that give best agreement between calculation and observation are the wet, precracked values. In order to make these strength data consistent with the HEL data of Fig. 4, a strain rate term $\left(K_2^I\right.$, equation (30)$\left.\right)$ of 7.5 kb was included in the equation of state. This value corresponds to the 10-kb offset between the static isotherm and the HEL. A Poisson's ratio of about 0.28 was obtained from ultrasonic laboratory measurements.

The calculation was begun by uniformly distributing 5 kt of internal energy in a sphere of radius 3.15 m at normal density (2.67 g/cc) and using the appropriate gas tables for this region (SiO_2 + 1% H_2O, Butkovich[2]). Code calculations show that the mass of rock vaporized is proportional to the yield, and for silicate rocks approximately 70×10^6 g/kt is vaporized. The value 3.15 m corresponds to the radius of vaporization for the 5-kt source.

Figure 23 shows calculated and observed peak radial stress versus scaled radius. Figures 24, 25, 26, and 27 show calculated radial stress versus distance at 4, 16, 24, and 40 msec. A striking feature of this sequence is the emergence of the precursor (P) and the decay of the main shock.

Figures 28 and 29 show calculated and measured radial stress versus time at 62 and 120 m. The experimental stress-history data do not exhibit the strong precursor obtained from the calculations. This may be due, in part, to the weak grouting material used for an impedance match between the transducer and the granite formation.

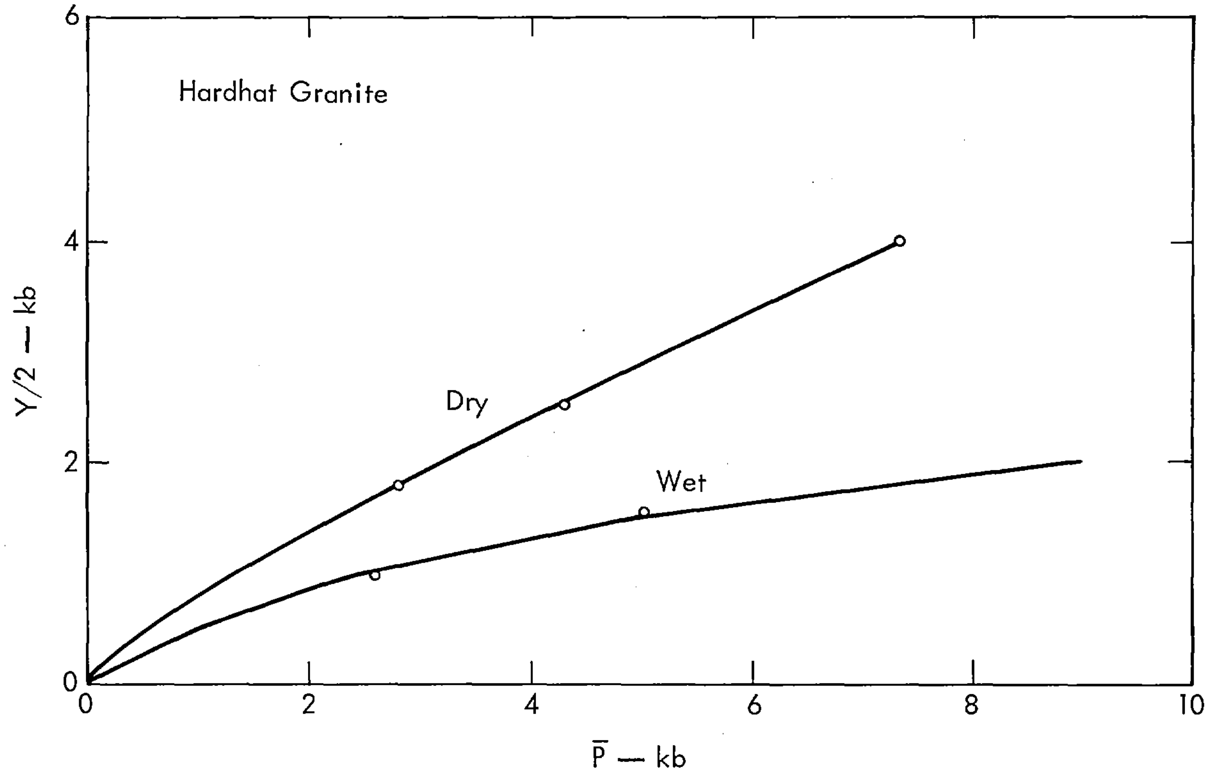

Fig. 22. Strength of Hardhat granite.

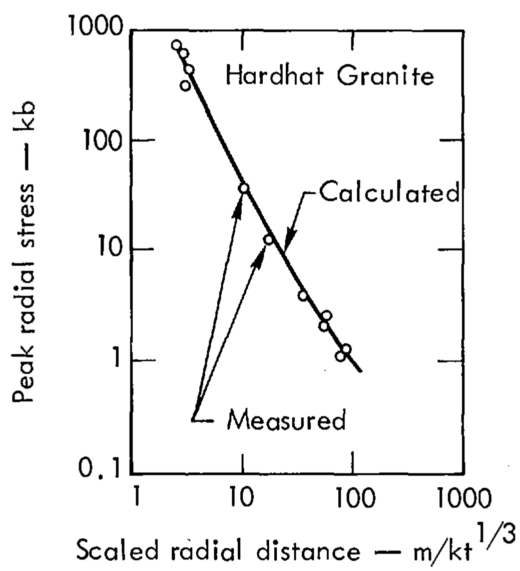

Fig. 23. Calculated and observed peak radial stress in Hardhat granite as a function of scaled distance from a nuclear shot.

The calculation gives a final cavity radius (corresponding to the initial gas-rock interface at 3.15-m radius) of 20.4 m. The measured Hardhat cavity radius is 19 m. Figure 30 gives the calculated and observed reduced

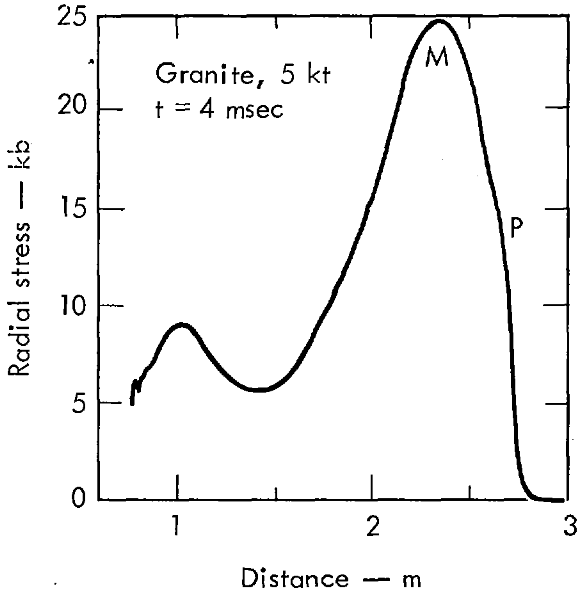

Fig. 24. Calculated radial stress vs distance, 4 msec after a 5-kt shot in Hardhat granite.

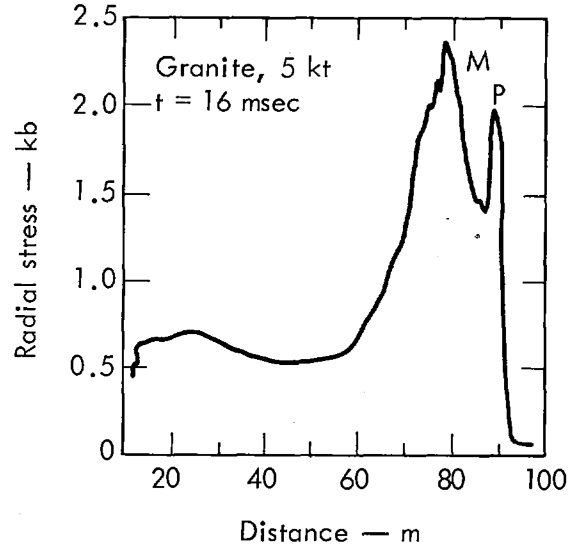

Fig. 25. Calculated radial stress vs distance, 16 msec after a 5-kt shot in Hardhat granite.

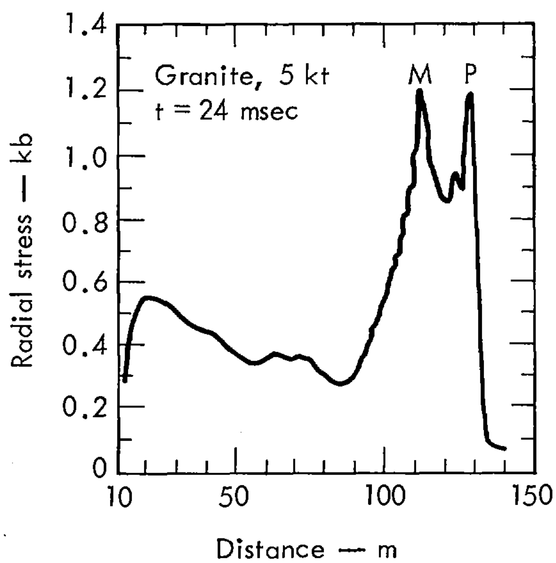

Fig. 26. Calculated radial stress vs distance, 24 msec after a 5-kt shot in Hardhat granite.

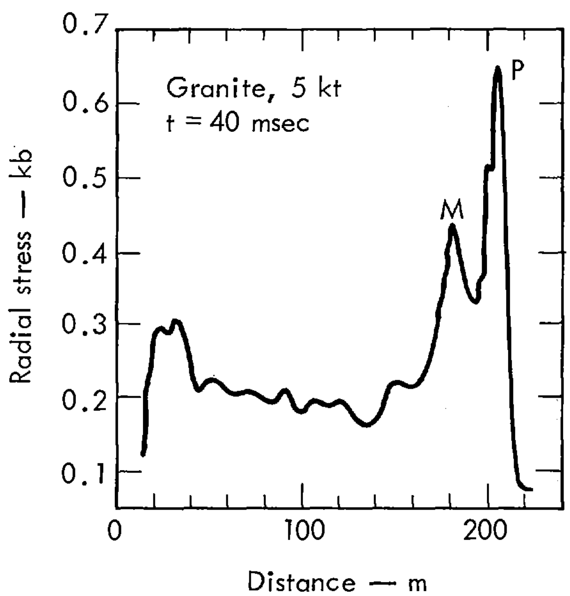

Fig. 27. Calculated radial stress vs distance, 40 msec after a 5-kt shot in Hardhat granite.

displacement potential (RDP) obtained from displacement versus time for a particle in the "elastic" region.

The RDP is a measure of the seismic efficiency of the medium. For a spherical outgoing elastic wave whose displacement is S_R we can write

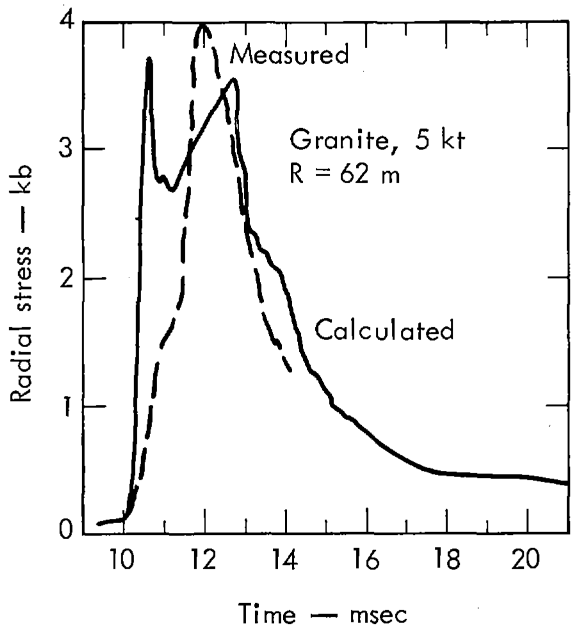

Fig. 28. Calculated and measured stress history in Hardhat granite, 62 m from a 5-kt shot.

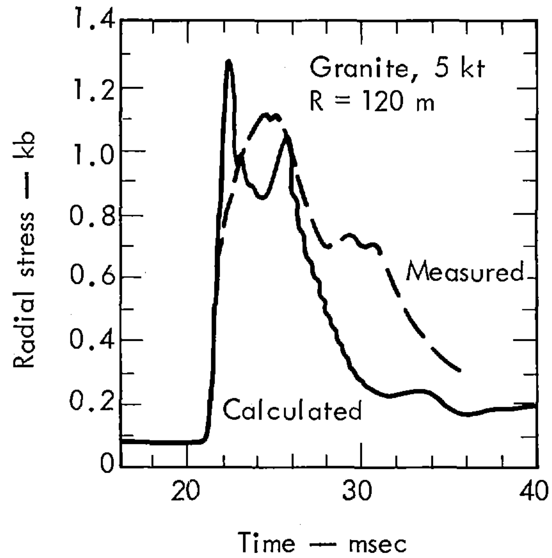

Fig. 29. Calculated and measured stress history in Hardhat granite, 120 m from a 5-kt shot.

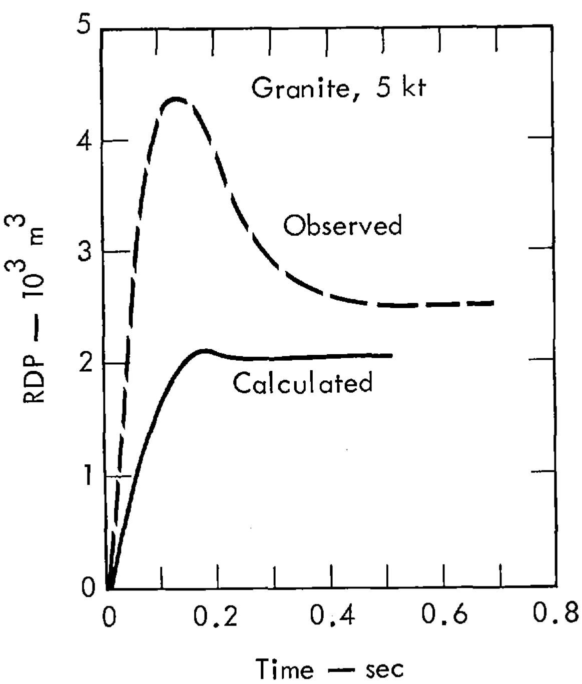

Fig. 30. Calculated and observed reduced displacement potential (RDP) for a 5-kt shot in Hardhat granite.

$$S_R = \frac{\partial}{\partial R}\left[\frac{f(t - R/V_P)}{R}\right] ; \qquad (39)$$

we define the RDP as:

$$\mathrm{RDP} = f(t - R/V_P),$$

where

$$V_P = \sqrt{\frac{k + \frac{4}{3}\mu}{\rho}} .$$

The RDP, obtained by integrating equation (39), gives the source function that determines the displacement of a particle at any point in the elastic region. The source function should scale from one shot to another by multiplying the RDP by the ratio of the yields involved.

The calculated and observed steady-state values of RDP agree. The early time disagreement could be due to the surface reflection returning to the instrument 60 msec from the onset of the direct wave (Werth and Herbst [11]). No calculation incorporating reasonable changes in the equation of state has been able to produce the observed overshoot in RDP.

Figure 31 shows the number of times a zone has cracked versus distance for the Hardhat calculation. This number is saved by the code for each

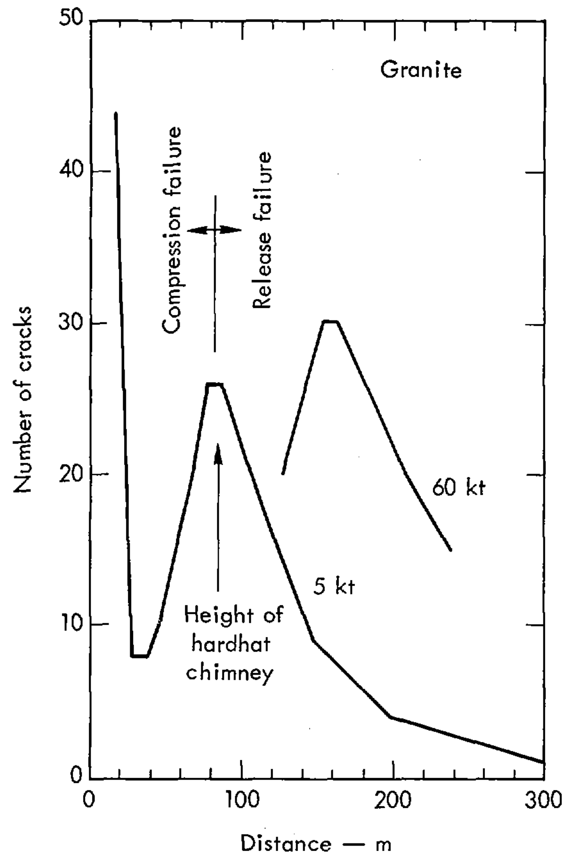

Fig. 31. Calculated number of cracks produced in Hardhat granite vs distance from the shot.

zone and increased by 1 each time the material strength is exceeded. The number can only be increased after the deviatoric component of stress (K) relaxes to half the value allowed by the strength table and after C_R (equation (29)) equals 1. At this point the relaxation of K (equation (30)) ceases and equation (25) is used to obtain K^{n+1} ($K^{n+1} = \tilde{K}^{n+1}$). This scheme for exiting from the crack routine emphasizes release failure (where $\tilde{K}^{n+1}$ calculated from equation (25) is less than K^n) over compression failure. This number has its largest value (44) at the cavity boundary due to the divergence there as the cavity expands, falls to a minimum value of 8 between 30 and 40 m where compression failure is the controlling mechanism, and then increases to a maximum of 26 between 80 and 90 m. This maximum is due to zone failure changing from compression (failure at the shock front) to release (failure behind the shock front) at $R \approx 90$ m. It is interesting that the observed height of the Hardhat chimney falls within this maximum.

Additional calculations for larger yields show that the maximum not only increases but the shape broadens as indicated by the 60-kt plot given in Fig. 31. This suggests that as the yield increases the bulking of the rock, as it collapses into the cavity, should eventually become the controlling factor in determining chimney height.

The crack number, assuming it is calculated correctly, should be related to permeability changes in the medium. Apparently permeability is both difficult and expensive to measure. However, Fig. 31 suggests that permeability should reach a minimum between 30 and 40 m from the cavity for 5 kt. This zone of low permeability might serve a useful purpose in some applications by helping to limit the spread of gas-borne radioactivity from the cavity; however, unless it is removed by chimney collapse, it might severely limit the effectiveness of reservoir stimulation.

4.3 Gasbuggy

Gasbuggy was an experiment in nuclear stimulation of a gas-bearing formation in Rio Arriba County, New Mexico, sponsored jointly by the U.S. Atomic Energy Commission, the El Paso Natural Gas Company, and the U.S. Bureau of Mines. A 25-kt nuclear explosive was detonated 1280 m underground, in the Lewis shale formation 12 m below the gas-bearing Pictured Cliffs sandstone. The objective was to evaluate the effectiveness of the nuclear explosion in increasing the permeability of the Pictured Cliffs formation and thus improving the recovery of gas from it.

The best experimental measurements, in terms of stress wave propagation, were obtained by Sandia Laboratories (Perret[12]) in a deep borehole

457 m from the emplacement hole. This part of the experiment was funded by the Advanced Research Projects Agency (ARPA).

Logging data near the emplacement hole and in the ARPA instrument hole indicate that the compressional velocity in the Lewis shale ranges from 4.75 to 3.87 m/msec and the density varies from 2.4 to 2.6 g/cc. Figure 32 shows the loading and unloading static compressibility data for the Lewis shale. The loading data give a bulk modulus of about 160 kb (curve A) and an initial density of 2.61 g/cc. Using a Poisson's ratio of 0.3 (obtained from the shear velocity log) we obtain a compressional velocity of about 3 m/msec, a value that is not consistent with the logging data.

In order to obtain a reasonable value for the compressional velocity we have found it necessary to ignore all the loading compressibility data below 3 kb on the basis that these data are probably influenced heavily by both the release of overburden pressure (0.3 kb) on the core and the coring technique itself. The loading compressibility curve B shown in Fig. 32 was accordingly assumed for the Lewis shale. This curve, having a bulk modulus of 215 kb, gives a compressional velocity of 3.5 m/msec, in fair agreement with the logging data.

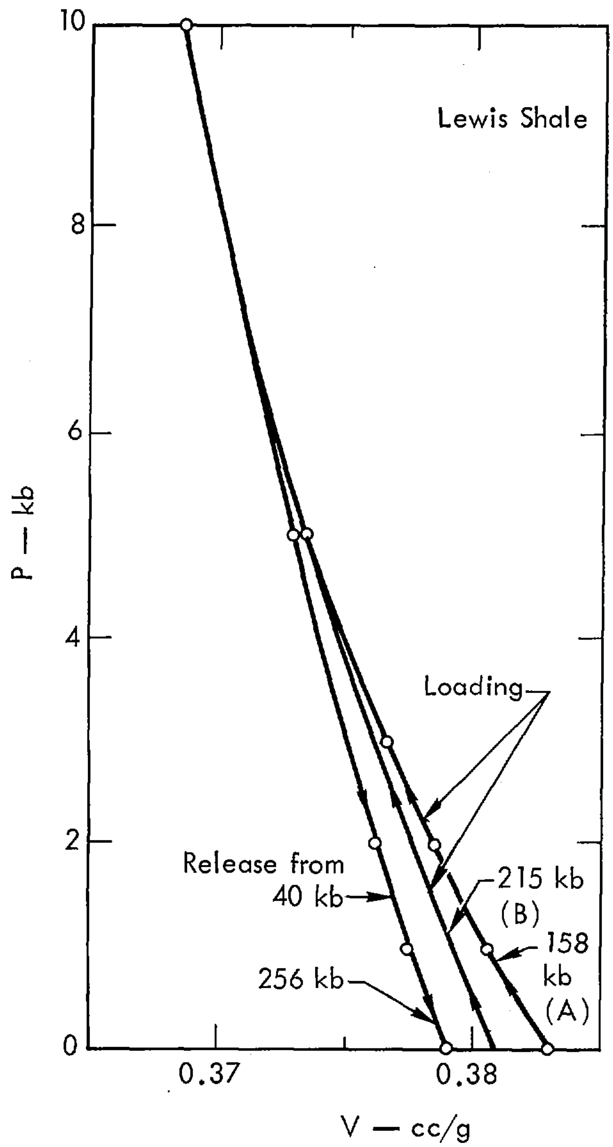

Fig. 32. Compressibility of Lewis shale, the formation in which the Gasbuggy explosive was located.

This change in compressibility curves severely affects the seismic coupling. The effect is due entirely to the attenuation of the stress wave by the pressure release calculation (equation (24)) in the code. As indicated in Fig. 32, the measured static release path from 40 kb has a slope of 256 kb, corresponding to a rarefaction speed of about 3.7 m/msec. These rarefactions overtake the slower moving (3.0 m/msec) compression front and continuously decrease its stress and particle velocity.

Figure 33 shows measured and calculated displacement versus time at 467 m from the 25-kt source. The difference between the two calculations is obtained by changing the compressibility curve from A to B as discussed above (Fig. 32). The sensitivity of this part of the calculation to changes in the "locking" portion of the equation of state seems dramatic until one considers the magnitude of the changes that are being made in the only material attenuation mechanism operative in the code (rarefaction velocity compared to shock velocity).

Figure 34 gives the measured and calculated RDP corresponding to the displacement of Fig. 33. We see

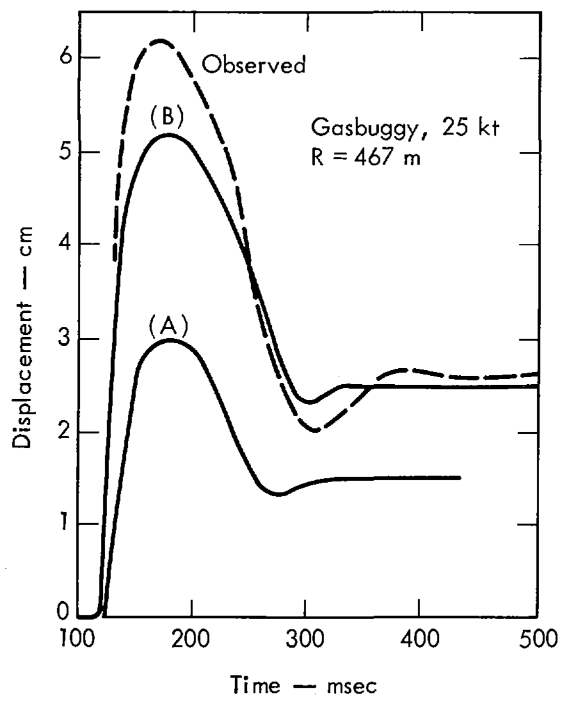

Fig. 33. Calculated and observed displacement history in Lewis shale 467 m from the 25-kt Gasbuggy shot.

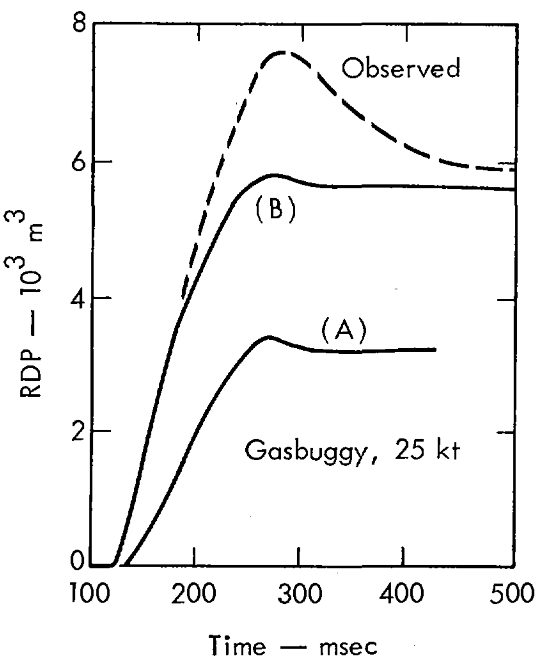

Fig. 34. Calculated and observed reduced displacement potential (RDP) for Gasbuggy shot.

that with compressibility curve B twice as much energy is coupled into the elastic region as with curve A. These calculations indicate that a detailed equation-of-state effort is required before a seismic coupling calculation can be attempted. Even then, since the low pressure part of the equation of state seems to control the coupling, we may not be able to predict this parameter with confidence. The key issue would seem to be obtaining agreement between the sonic logs and the static compressibility data. The Gasbuggy experiment represented the first time such severe disagreement existed between the field and laboratory data.

Calculations indicating severity of fracture (similar to those for Hardhat, Fig. 31) have been performed for the Gasbuggy environment. Figure 35 shows the geological layering for the site. Figure 36 shows the compressibility curves for the Lewis shale, the Pictured Cliffs sandstone, and the Fruitland coal. Figure 37 shows the strength curves used in the calculations.

Figure 38 shows calculations of number of cracks per zone vs distance from the shot point for paths vertically upward through the various layers (layered calculation) and also for paths outward into the sandstone (Pictured Cliffs calculation). As noted preshot, the coal seam located between 100 and 112 m above the shot point reduces the fracturing at this distance, which corresponds to the measured height of the Gasbuggy chimney. This highly compressible coal seam also sends a rarefaction into the Pictured Cliffs formation, and the fracture number is increased accordingly. The observed postshot casing failures and gas entries are also consistent with the calculated data of Fig. 38.

The calculated cavity radius was 26.3 m for the layered calculation and 25.8 m for the Pictured Cliffs calculation. These values compare closely with the 25.4-m value inferred from flow tests.

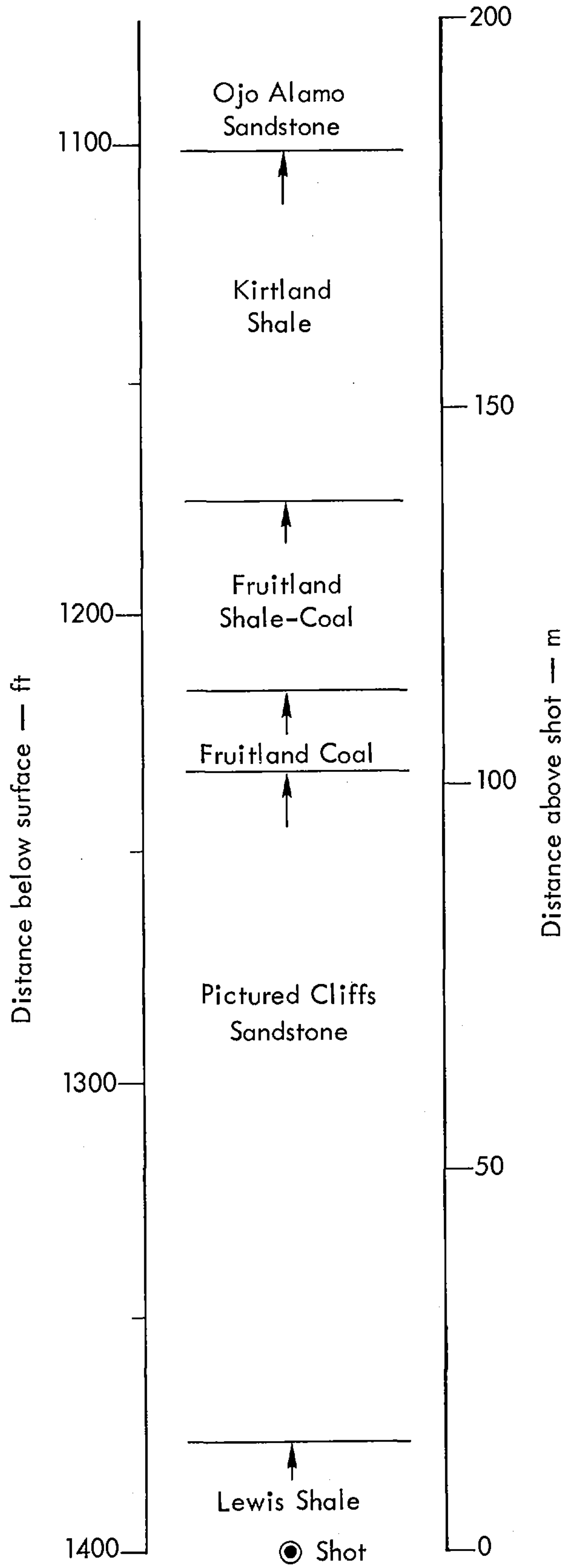

Fig. 35. Geological layering at Gasbuggy site.

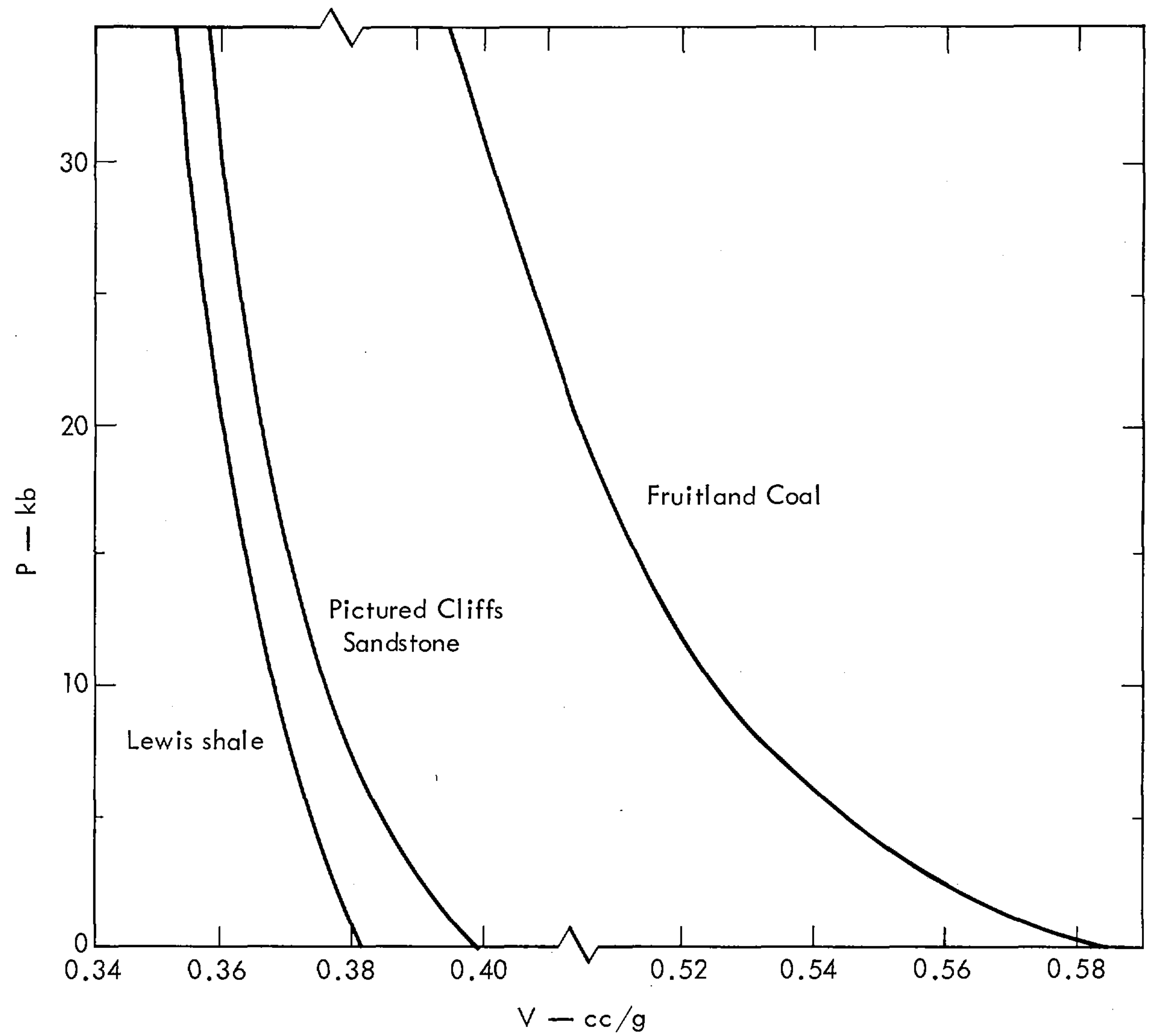

Fig. 36. Compressibility of Gasbuggy rocks.

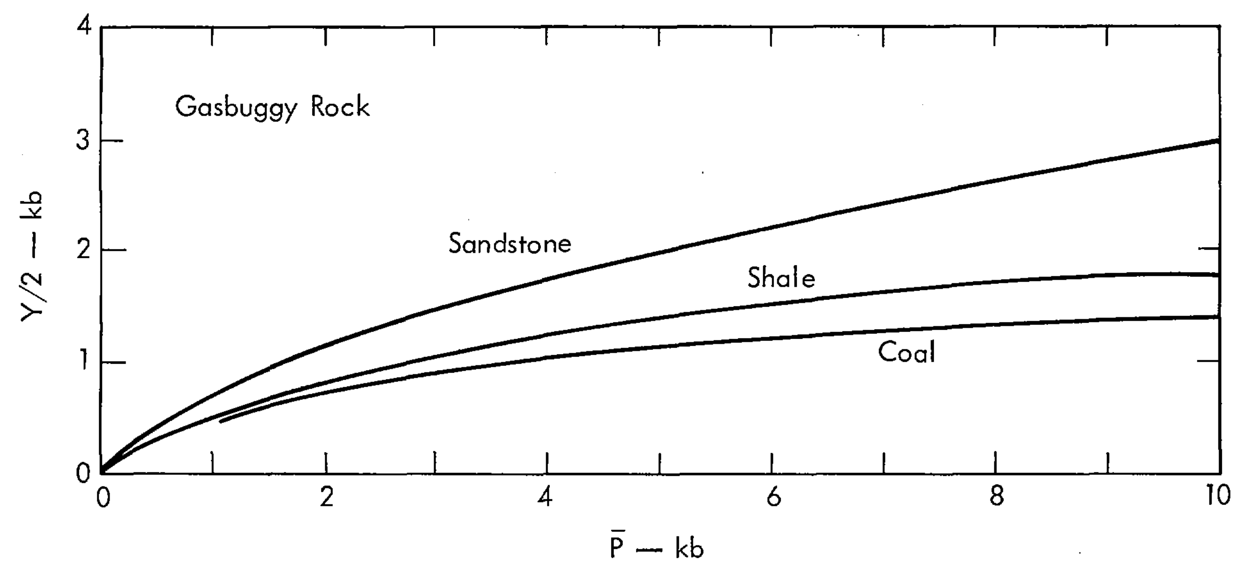

Fig. 37. Strength of Gasbuggy rocks.

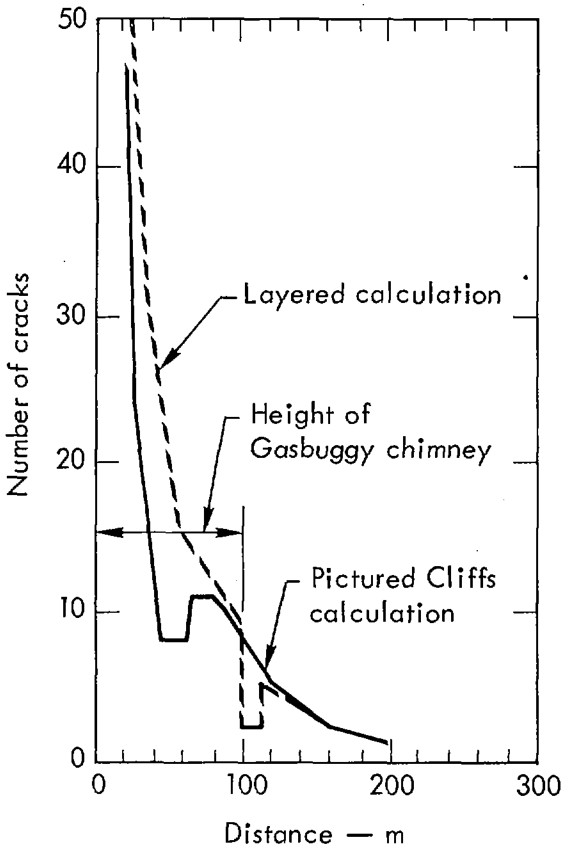

Fig. 38. Calculated number of cracks vs distance from the Gasbuggy shot, for paths upward through the various layers and outward through the Pictured Cliffs sandstone.

5. CONCLUSIONS

A numerical model of stress wave propagation has been presented. We have included a listing of the SOC code (see Appendix) and have given a discussion of the material properties required to obtain a prediction of the stress-induced effects on the rock mass involved in an application. These effects include chimney height, seismic coupling, and permeability change. The seismic coupling parameter was shown to be primarily dependent on the low pressure part (<3 kb) of the equation of state. For high yields the controlling factor for chimney height should be cavity volume.

Future effort is required in the areas of Hugoniot release (especially for a fluid-saturated environment), laboratory strength measurements, and failure criteria. A significant improvement in the equation of state would result if the in situ rigidity modulus could be measured directly.

The preshot calculations for the Gasbuggy experiment indicate that useful predictions of cavity radius and chimney height can be made when an adequate effort is made to obtain equation-of-state data for the rock involved.

In general the code seems to be doing well enough in predicting stress wave propagation that we can begin looking at derived numbers — such as number of cracks per zone — for some insight into predicting stress-induced changes in permeability.

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C       VERSION CURRENT OCTOBER 1969
        CLICHE COMMON
COMMON WHICH CAN VARY WITH TIME
        COMMON NC, JN, LN, TT, IR, LX, ENI, RN(1202), DRMX(1202), VMX(1202
       1), PX(1202), GMX(1202), SIGR(1202), SIGT(1202), XMU(1202), AM(1202
       2), C1(1202), DR(1202), DV(1202), DVO(1202), EO(1202), ISV(1202),
       3 P(1202), Q(1202), GK(1202), TK(1202), VN(1202), VO(1202), AMU(120
       42), E(1202), I(1202), R(1202), V(1202), TC(12), TIC(12), RPL(25),
       5 DT, DTH, DTN, DTPR, EPP, ETOT, FDT, HDT1, IL, IPI, IPO, ITCX,
       6 IRANK, NCD, PJM, PTS, GXT, RJH, STR, SXN, TPR, HDTH, TTS
COMMON WHICH REMAINS THE SAME FOR DURATION OF PROBLEM
        COMMON DPLOT, IEPLOT, IRPLOT, IHEAD(8), GR, DXT, PLOD(100), GAS(27
       12R), PT(400), FMU(400), DPM(400), PTC(200), FMC(200), DPC(200),
       2 FK(200), FP(200), DFK(200), CK(200), CP(200), CKP(200), AK(10),
       3 VI(10), RM(10), AMZ(10), AM1(10), AM2(10), GXK(10), PZO(10), P1(1
       40), P2(10), GSL(10), GCT(10), SE(10), EF(10), FV(10), GSI(10),
       5 IT(10), ITT(10), IP(10), RB(11), RHO(11), GK(10), CF, CCN, HCCN,
       6 IRZ, REZF, IWRT(4), PPR(61), TP(61), IVR, IALF
COMMON WHICH IS USED FOR GENERAL CALCULATION BUT NOT SAVED
        COMMON ABF(4004), ABA(4004), ABB(4004), BF(200), EN(11), OCH(11),
       1 FMC(11), EDP(6), EDT(6), EDTL(6), ING(25), FNG(25), ION(4), PRI,
       2 IC(2), MO(2), ID(8), A, ABS, AMC, AME, AMP1, B, BAPK, C, CKL, CRC
       3, CTC, CZO, CAVR, CRTI, CVEL, CVRC, D, DP, DU, DEC, DR1, DR2, DRH,
       4 DRS, DTV, DV1, DVK, EW, EOV, EKL, ETA, ETW, EJTH, EROU, FA, FST,
       5 FSTM, FSTR, G1, G2, GAM, GLN, GM1, GMU, IBX, III, IIJ, IPR, IPDT,
       6 ITER, ITOT, ITIME, ITOTL, ITSTP, J, K, L, LL, LP, M, N, NN, NP,
       7 NCYC, OFF, PCT, PL3, PL4, PQ1, PQ2, PBAR, QO, QS, QKS, QSAV, R21,
       8 R22, RDR, RH1, RH2, ROR, RZ1, RADT, RH21, RH22, RMV1, RMV2, SK,
       9 SLC, SLE, SLP, SMU, SDSP, SLP1, STAB, TV, TAR, TBR, TER, TK1
        COMMON TK2, TQ1, TQ2, TRR, TERK, VCC, VDV, VM1, VM2, VN1, VNH,
       1 VOL1, VOL2, WT, YN1, RIX(10), GW, F, S, AD, AF, DA, DB, DC, DD,
       2 KIM, ZETA, LIL
        EQUIVALENCE (YN1, RIX(1))
        EQUIVALENCE (ION(4),PRI)
        EQUIVALENCE (ING,FNG)
        END CLICHE
        USE COMMON
C       READ 6B AND WRITE 6A
        CALL REGST
        N=.LOC.ABF(1)
        J=.LOC.ZETA
        N=J-N
        DO 1 LIL=1,N
        ABF(LIL)=0.
      1 CONTINUE
        CALL REWIND (16)
        CALL CLOCK (MO(1), MO(2))
        CRTI=1.
        NCYC=J=5
        L=16
      2 BUFFER IN (16,1) (DPLOT,IALF)
      3 IF (UNIT,16,M) 3, ,219,219
        CALL REDEOF (16)
        J=
      4 BUFFER IN (16,1) (NC,TTS)
      5 IF (UNIT,16,M) 5, ,220,220
        BACKSPACE FILE 16
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      CALL BSPACE (16)
      CALL FSPACE (16)
      READ INPUT TAPE 2, 950, (ID(J), J=1,8)
      READ INPUT TAPE 2, 951, GW, ITIME, A, STR
      STP=100.*STR
      CALL ASSIGN (7,0,10HSOCPLOTBUF,40200)
C     SET UP RUNNING TIME
      IF (ITIME) ,7,7
      IF (IBANK) 6, ,6
      IBANK=-ITIME
    6 ITIME=IBANK
    7 IBX=1
      TTS=MAX1F(GW*1000.,TTS)
CHECK FOR RIGHT TAPE
      DO 8 J=1,8
      IF (IHEAD(J)-ID(J)) ,8,
      WRITE OUTPUT TAPE 3, 954, (IHEAD(J), J=1,8)
      CALL ERROR (0.)
    8 CONTINUE
      K=6
      IF (A) , ,9
      CALL WRSO
      GO TO 10
    9 CALL REDEOF (6)
      CALL BSPACE (6)
   10 CALL WRST
      CALL WRTEOF (6)
      CALL BSPACE (6)
      CALL BANDP (ION(1), ION(3))
      B=ION(2)
      B=B/PRI
      A=B-40.
      ION(1)=A
      IF (ITIME) , ,11
      ITIME=ION(1)
      GO TO 12
   11 ITIME=XMINOF(ION(1), ITIME)
   12 ITOTL=B
      IF (NC) 13, ,13
CYCLE 1 CONSTANTS INITIALIZED
      CALL BANDP (ION(1), ION(3))
      A=ION(2)
      A=A/PRI
      ITOT=A
      ITOT=ITOTL-ITOT
      GO TO 15
CHECK CLOCK FOR TIME STOP - INCREMENT COUNTER
C     EVERY 20 CYCLES GOES TO 10 INSTEAD OF 11
   13 ITSTP=0
      CALL BANDP (ION(1), ION(3))
      A=ION(2)
      A=A/PRI
      ITOT=A
      ITOT=ITOTL-ITOT
   14 ITSTP=ITSTP+1
CALCULATE DELTA T
      A=1.1*DTH
      B=(SQRTI(SXN))/3.
      B=MIN1F(B,A)
      DT=.5*(B+DTH)
```

```
      DTH=B
CHECK FOR PRESSURE PROFILE
   15 IF (IPO-2) 20,16,
C     OUTER PRESSURE PROFILE
      L=1
      GO TO 17
C     INNER PRESSURE PROFILE
   16 L=LX
   17 TK(L)=0.
   18 A=DIMF(TP(IPI+1),TT)
      IF (A) 19, ,19
      IPI=IPI+1
      IF (TP(IPI+1)) , ,18
      IPO=1
      GO TO 20
   19 A=TT-TP(IPI)
      B=TP(IPI+1)-TP(IPI)
      P(L)=PPR(IPI)+(PPR(IPI+1)-PPR(IPI))*A/B
      EPP=EPP+(PJM*HDT1+P(L)*DTN)*V(L-1)*CCN*(3.*RJH*RJH+FDT*V(L-1)*V(L-
     11))
      ETOT=EPP+ENI
CYCLE CONSTANT INITIALIZATION
   20 PCT=BARK=0.
      TT=TT+DTH
      HDT1=.5*DT
      HDTH=.5*DTH
      DTN=DTH-HDT1
      FDT=HDTH*HDTH
      L=IR
      SXN=DXT
      QXT=ABSF(QXT)
      VCC=1.0E-3*QXT/SQRTI(AK(L)*RHO(L+1))
      VCC=MIN1F(VCC,1.0E-8)
      QXT=1.
      PQ1=P(JN)+Q(JN)
      TQ1=TK(JN)+QK(JN)
      IF (I(JN)) ,21,
      DR1=DR(JN-1)-DR(JN)+RN(JN-1)-RN(JN)
      R21=DR(JN-1)+DR(JN)+RN(JN-1)+RN(JN)
      VOL1=VN(JN)-DVO(JN)
      VM1=(VOL1-DV(JN))/AM(JN)
      TK1=TQ1*VM1/R21
      RMV1=DR1/VM1
      RH1=R(JN-1)+V(JN-1)*HDTH
      RH21=RH1*RH1*V(JN-1)
CALCULATION OF J-LINES BEGINS HERE
   21 DO 144 J=JN,LN
      GAM=0.
      IIT=(I(J)-1)/100+1
      EO(J)=E(J)
      VO(J)=V(J)
CALCULATE EQUATIONS OF MOTION
      IF (R(J)) 218,27,
      PQ2=P(J+1)+Q(J+1)
      TQ2=TK(J+1)+QK(J+1)
      IF (I(J+1)) ,28,
      DR2=DR(J)-DR(J+1)+RN(J)-RN(J+1)
      R22=DR(J)+DR(J+1)+RN(J)+RN(J+1)
      VOL2=VN(J+1)-DVO(J+1)
      VM2=(VOL2-DV(J+1))/AM(J+1)
```

```
      TK2=TQ2*VM2/R22
      RMV2=DR2/VM2
      IF (I(J)) ,29,
      ROR=(TK2*DR1+TK1*DR2)/(DR1+DR2)
      RDR=.5*(RMV1+RMV2)
   22 A=(PQ1-PQ2)/RDR
      IF (V(J)) ,23,
      VCC=1.E-20
   23 DV1=DT*(1.333333333*(TQ1-TQ2)/RDR+A+8.*ROR+GR)
      V(J)=V(J)-DV1
      IF (ABSF(V(J))-VCC) 30,30,
   24 C=DTH*V(J)
      RH2=R(J)+.5*C
      RH22=RH2*RH2*V(J)
      DR(J)=DR(J)+C
      R(J)=RN(J)+DR(J)
      DRS=R(J-1)-R(J)
      IF (I(J)) ,113,
   25 C=(V(J)-V(J-1))*(V(J)*(V(J-1)+V(J))+V(J-1)*V(J-1))
      C=DTH*(3.*(RH22-RH21)+FDT*C)
      DV(J)=DV(J)+C
      VN1=VOL1-DV(J)
      VNH=VN1+.5*C
      D=(DV(J)+DVO(J))/VN1
      AMP1=D+1.
      EDV=C/VN(J)
      DVK=C/VNH
      ETA=VN(J)/VNH
      VDV=VN(J)*C/(VN1*(VN1+C))
      DU=V(J-1)-V(J)
      DRH=RH1-RH2
      IF (DU) ,26,26
      ERDU=ETA*DU*RHO(L+1)
      QSAV=ERDU*DU
   26 TER=3.*DTH*DU/DRH
      TERK=DVK+TER
      IF (III-3) 31,31,
      IF (I(J)-400) 116,125,125
C     CALCULATE BOUNDARY CONDITIONS
   27 RH2=RH22=0.
      GO TO 25
   28 RDR=.5*RMV1
      ROR=TK1
      GO TO 22
   29 RDR=.5*RMV2
      ROR=TK2
      GO TO 22
C     CALCULATIONS MADE WHEN LITTLE OR NO ACTIVITY EXISTS
   30 V(J)=0.
      IF (V(J-1)) 24, ,24
      RH2=R(J)
      RH22=0.
      IF (III-3) 113,113,
      IF (III-4) ,24,
      C=DR1*(R(J-1)*R2)+R(J)*R(J))
      PCT=C*P(J)+PCT
      GO TO 113
C     CALCULATE SLOPE AND PRESSURE FOR I LESS THAN 300
   31 N=IT(L)+1
      NP=IP(L)+1
```

```
      PL =SLP=SMU=0.
      IF (XMU(J)-2.*GCT(L)*AM2(L)) ,47,47
      IF (XMU(J)) 56, ,
      IF (D-XMU(J)) 32, ,
      XMU(J)=D
      GO TO 42
   32 IF (XMU(J)-AM1(L)) 42,42,
      IF (III-2) 34, ,
      IF (P(J)) , ,34
      IF (XMU(J)-AM2(L)) 33, ,
      XMU(J)=.98*AM2(L)
   33 XMU(J)=-XMU(J)
      GO TO 56
   34 IF (XMU(J)-AM2(L)) ,48,48
      IF (D-.95*XMU(J)) ,42,42
C - SPECIAL UNLOADING SCHEME - A -
      IF (D-AM1(L)) , ,35
      SLP=AK(L)
      GO TO 41
   35 DO 36 K=NP,NP+38
      IF (P(J)-PT(K)) 37,37,
      IF (FMU(K+1)-FMU(K)) 37,37,
   36 CONTINUE
      K=NP+38
   37 SLE=DPM(K)
      DO 38 K=N,N+18
      IF (P(J)-PTC(K)) 39,39,
      IF (FMC(K+1)-FMC(K)) , ,38
      SLC=SLE
      GO TO 40
   38 CONTINUE
      K=N+18
   39 SLC=DPC(K)
   40 SLP1=SLE+XMU(J)*(SLC-SLE)/AM2(L)
      SLP=SLP1-AM1(L)*(SLP1-AK(L))/D
   41 PL3=P(J)+SLP*VDV
      GO TO 65
CALCULATE ELASTIC P-MU TABLE - B -
   42 ABS=D
      CALL PSUB
      GO TO 65
      ENTRY PSUB
      DO 44 K=NP,NP+38
      IF (ABS-FMU(K)) ,45,43
      PL3=PT(K-1)+(ABS-FMU(K-1))*DPM(K)
      GO TO 46
   43 IF (FMU(K+1)-FMU(K)) 45,45,
   44 CONTINUE
      K=NP+38
   45 PL3=PT(K)+(ABS-FMU(K))*DPM(K)
   46 SLP=DPM(K)
      RETURN PSUB
CALCULATE CRUSHED P-MU TABLE
   47 XMU(J)=MAX1F(D,XMU(J))
   48 SLP=AK(L)*.01
      ABS=D
      DO 51 K=N-1,N+18
      IF (D-FMC(K)) 49, ,50
      PL3=PTC(K)
      SLP=DPC(K)
```

```
      GO TO 52
   49 IF (K-N) 52, ,
      PL3=PTC(K-1)+(D-FMC(K-1))*DPC(K)
      SLP=DPC(K)
      GO TO 52
   50 IF (FMC(K+1)-FMC(K)) , ,51
      CALL PSUB
      GO TO 52
   51 CONTINUE
      CALL PSUB
   52 IF (D-.985*XMU(J)) ,65,65
      ABS=XMU(J)
      PL4=PL3
      SLP1=SLP
      CALL PSUB
      GAM=.5*PL3*XMU(J)/(1.+XMU(J))
      GAM=GXK(L)*(GAM-EF(L))/(EV(L)-EF(L))
      IF (GAM) , ,53
      PL3=PL4
      SLP=SLP1
      GO TO 65
   53 GAM=MIN1F(GAM,GXK(L))
      ABS=D
      IF (D) , ,54
      PL4=GSL(L)*D
      PL3=SLP=0.
      SLP1=GSL(L)
      GO TO 55
   54 CALL PSUB
   55 DP=GAM*(E(J)-.5*PL3*D/AMP1)
      PL4=PL4+DP
      SLP=SLP1+.5*GAM*((PL4+P(J))/ETA-(.5*(D+AMU(J))*SLP+PL3/ETA))/ETA
      PL3=PL4
      IF (SLP) ,65,65
      SLP=.01*AK(L)
      GO TO 65
C     CALCULATE S.L.S.
   56 IF (D-AMZ(L)) , ,57
      PL3=0.
      SLP=AK(L)
      GO TO 65
   57 DO 58 K=N,N+18
      IF (P(J)-PTC(K)) 62, ,
      IF (FMC(K+1)-FMC(K)) 59,59,
   58 CONTINUE
   59 DO 60 K=NP,NP+38
      IF (P(J)-PT(K)) 61, ,
      IF (FMU(K+1)-FMU(K)) 61,61,
   60 CONTINUE
      K=NP+38
   61 ABS=FMU(K-1)+(P(J)-PT(K-1))/DPM(K)
      SLP=DPM(K)
      GO TO 63
   62 ABS=FMC(K-1)+(P(J)-PTC(K-1))/DPC(K)
      SLP=DPC(K)
   63 IF (D-ABS) ,64,64
      IF (ABS-AMZ(L)) ,64,
      SLP=(D-AMZ(L))*SLP/(ABS-AMZ(L))
   64 PL3=P(J)+SLP*VDV
      IF (PL3)  ,65,65
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```
      PL3=0.
C - EXIT -
   65 IF (E(J)-EF(L)) ,66,66
      IF (GAM) 67,67,
      C1(J)=ISV(J)=0.
   66 SK=SMU=0.
      GO TO 103
   67 WT=(EF(L)-ABSF(E(J)))/EF(L)
      IF (PL3+TK(J)/3.-P1(L)) ,68,68
      IF (PL3) 69,69,
      IF (III-2) 70,79,79
   68 C1(J)=ISV(J)=0.
      IF (III-2) 70, ,
      I(J)=I(J)-200
      III=1
      GO TO 70
   69 IF (III-2) 70, ,
      ISV(J)=-XABSF(ISV(J))
      PL3=SK=QKS=SMU=C1(J)=0.
      QS=QSAV
      SLP=AK(L)
      SDSP=SQRTI(AK(L)/RHO(L+1))
      GO TO 104
CALCULATIONS FOR I(J) LESS THAN 100
   70 IF (RM(L)) , ,71
      AME=SLP*SE(L)*WT
      GO TO 72
   71 AME=RM(L)*WT
   72 SMU=AME
      IF (AME/SLP-1.501) 73,73,
      I(J)=I(J)+500
      WRITE OUTPUT TAPE 3, 975, AME, SLP, D, PL3, 1
      CALL ERROR (1.)
   73 SK=TK(J)-.5*AME*TERK
      ABS=PL3+SK/3.
      DO 76 K=N,N+18
      IF (ABS-EP(K)) ,74,75
      EKL=EK(K-1)+(ABS-EP(K-1))*DEK(K)
      GO TO 77
   74 EKL=EK(K)+(ABS-EP(K))*DEK(K)
      GO TO 77
   75 IF (EP(K+1)) 76, ,76
      IF (EP(K)) ,74,74
   76 CONTINUE
      K=N+18
      EKL=EK(K)+(ABS-EP(K))*DEK(K)
   77 EKL=EKL*WT
      EKL=MAX1F(0.,EKL)
      IF (PL3+SK/3.-P1(L)) 78, ,
      EKL=P2(L)*WT
      IF (SK-EKL) 103,103,
      SK=SIGNF(EKL,SK)
      GO TO 103
   78 IF (ABSF(SK)-EKL) 103, ,
      I(J)=I(J)+200
      III=3
      C1(J)=0.
      ISV(J)=1
CALCULATIONS FOR I(J) GREATER THAN 100
   79 IF (RM(L)) , ,80
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```
      AMC=SLP*SE(L)*WT
      GO TO 81
   80 AMC=RM(L)*WT
   81 GW=(D-AMZ(L))/(PZO(L)-AMZ(L))
      GW=MIN1F(1.,GW)
      IF (GW) , ,82
      C1(J)=SK=SMU=0.
      ISV(J)=-XABSF(ISV(J))
      GO TO 103
   82 AMC=SMU=GW*AMC
      IF (AMC/SLP-1.501) 83,83,
      I(J)=I(J)+500
      WRITE OUTPUT TAPE 3, 976, AME, SLP, D, PL3
      CALL ERROR (1.)
   83 ABS=PL3+TK(J)/3.
      DO 86 K=N,N+18
      IF (ABS-CP(K)) ,84,85
      CKL=CK(K-1)+(ABS-CP(K-1))*CKP(K)
      GO TO 87
   84 CKL=CK(K)+(ABS-CP(K))*CKP(K)
      GO TO 87
   85 IF (CP(K+1)) 86, ,86
      IF (CP(K)) ,84,84
   86 CONTINUE
      K=N+18
      CKL=CK(K)+(ABS-CP(K))*CKP(K)
   87 CKL=CKL*WT*GW
      CKL=MAX1F(0.,CKL)
      IF (ISV(J)) , ,89
      SK=TK(J)-.5*AMC*TERK
      IF (ABSF(SK)-CKL) 103, ,
      C1(J)=0.
      ISV(J)=XABSF(ISV(J))+1
CRACK EQUATIONS
   89 IF (ISV(J)-1) , ,91
      IF (RM(L)) , ,90
      AME=SLP*SE(L)*WT
      IF (AME/SLP-1.501) 92,92,
      I(J)=I(J)+500
      WRITE OUTPUT TAPE 3, 975, AME, SLP, D, PL3, 2
      CALL ERROR (1.)
   90 AME=RM(L)*WT
      GO TO 92
   91 AME=AMC
   92 CZO=.1*DRS
      CTC=CZO+C1(J)
      CTC=MIN1F(CTC,DRS)
      AME=AMC+(1.-CTC/DRS)*(AME-AMC)
      CVEL=1.14*SQRTI(AME/(RHO(L+1)*(3.+AME/SLP)))
      PL4=CKL
      C1(J)=C1(J)+CVEL*DTH
      CRC=.25*C1(J)/DRS
      IF (CRC-1.) 94, ,
      CRC=1.
      IF (ABSF(TK(J))-.5*CKL) 93,93,
      C1(J)=C1(J)-CVEL*DTH
      GO TO 94
   93 ISV(J)=-XABSF(ISV(J))
      C1(J)=0.
   94 SK=TK(J)-.5*AME*TERK
```

```
      GW=P2(L)*WT
      CKL=ABSF(SK)*(1.-CVEL*CRC*DTH/DRS*.25)*WT
      IF (XABSF(ISV(J))-2) 95,95,
      CKL=MIN1F(CKL,PL4)
      GO TO 96
   95 CKL=MIN1F(CKL,GW)
   96 CKL=MAX1F(0.,CKL)
      IF (ABSF(SK)-CKL) 102,102,
      SK=SIGNF(CKL,SK)
  102 SMU=AME
CALCULATE Q
  103 SDSP=SQRTI((SLP+1.33333333*SMU)/RHO(L+1))
      IF (DU) ,104,104
      QS=QSAV-VI(L)*SDSP*ERDU
      QKS=-.5*VI(L)*SMU/SLP*RHO(L+1)*ETA*SDSP*DRH/DTH*TERK
      QKS=MIN1F(QKS,.5*WT*P2(L))
CALCULATE ENERGY
  104 IF (QS-GK(L)) ,105,105
      QS=0.
  105 PBAR=(PL3+QS)*DTN+PG1*HDT1
      IF (I(J)-390) , ,106
      BARK=(SK+QKS)*DTN+TG1*HDT1
  106 DEC=(PBAR*EDV-.6666666666*BARK*(EDV+TER/ETA))/DTH
      E(J)=E(J)+DEC
      IF (I(J)-390) , ,111
      IF (RHO(L+1)*AMP1-10.) , ,107
      IF (D-.985*XMU(J)) ,111,111
      IF (E(J)-EV(L)) 111, ,
  107 IF (III-2) ,108,109
      I(J)=I(J)+400
      GO TO 110
  108 I(J)=I(J)+300
      GO TO 110
  109 I(J)=I(J)+200
  110 III=5
CALCULATE STABILITY
  111 DU=MIN1F(0.,DU)
      FA=4.*DU
      TV=2.*VI(L)
      STAB=(DRS*DRS)/(FA*FA+(TV*TV+1.)*SDSP*SDSP)
      AMU(J)=D
      P(J)=PL3
      TK(J)=SK
      QK(J)=QKS
      Q(J)=QS
      IF (STAB) 112,112,
      IF (SXN-STAB) 112,112,
      SXN=STAB
      RADT=R(J)
  112 IF (I(J)-390) 113,113,
      PCT=(VOL1-DV(J))*P(J)+PCT
CLEAR OUT AND SHIFT FOR NEXT J-LINE
  113 D=AMP1=PL3=SK=QS=QKS=BARK=QSAV=DRS=0.
      IF (QXT) 115, ,
      IF (QXT-Q(J)) , ,114
      QXT=Q(J)
      GO TO 115
  114 IF (Q(J+1)) 115,115,
      IF (J-JN-10) 115,115,
      QXT=-QXT
```

```
  115 DR1=DR2
      R21=R22
      VOL1=VOL2
      VM1=VM2
      TQ1=TQ2
      TK1=TK2
      RMV1=RMV2
      PQ1=PQ2
      RH1=RH2
      RH21=RH22
CHECK FOR REGION BOUNDARY
      IF (RN(J)-RB(L+1)) , ,144
      LL=L
      L=L+1
      GO TO 144
CALCULATE H.E.
  116 IF (C1(J)) , ,119
      DTV=TT*RM(L)-RN(J)+RN(LX-2)
      IF (DTV) 114, ,
      DTV=.4*DTV/(RN(J-1)-RN(J))
      IF (DTV-1.) 117, ,
      DTV=1.
      C1(J)=1.
  117 QO=AMZ(L)+1.
      SLP=QO*D/(AMP1*AMZ(L))
      IF (D) 119, ,
      IF (SLP-1.) 118,118,
      C1(J)=1.
  118 PL3=SLP*DTV*RHO(L+1)*RM(L)*RM(L)*AMZ(L)/QO
      SLP=PZO(L)/AMZ(L)
      GO TO 124
  119 N=IP(L)+1
      DO 122 K=N,N+18
      IF (D-FMU(K)) ,120,121
      PL3=PT(K-1)+(D-FMU(K-1))*DPM(K)
      GO TO 123
  120 PL3=PT(K)
      GO TO 123
  121 IF (PT(K+1)) ,120,
  122 CONTINUE
      K=N+38
      PL3=PT(K)
  123 SLP=DPM(K)
  124 SDSP=SQRTI(SLP/RHO(L+1))
      IF (DU) ,105,105
      QS=QSAV-VI(L)*SDSP*ERDU
      GO TO 104
CALCULATE GAS
  125 N=ITT(L)
      IF (GSI(L)-100.) ,138,
CALCULATE LONG GAS TABLE
      IF (DU) ,126,126
      SLP=P(J)/(E(J)*AMP1)*(E(J)+PQ1/AMP1)
      QS=QSAV-VI(L)*SQRTI(SLP/RHO(L+1))*DU*ETA*RHO(L+1)
  126 ETW=E(J)+(P(J)+QS)*EDV
      EW=ETW/RHO(L+1)
      GMU=AMP1*RHO(L+1)
      GLN=LOGF(GMU)
      DO 134 K=N,N+9
      IF (GAS(K)-GMU) 133, ,
```

```
  127 M=(K-N+1)*64+20+N
      DO 131 NN=N+20,N+83
      IF (GAS(NN)-EW) 130,130,
      IF (NN-N-20) , ,129
  128 G2=GAS(M)
      G1=GAS(M-64)
      GO TO 132
  129 G2=EW-GAS(NN-1)
      G1=GAS(M-65)+G2*GAS(M+576)
      G2=GAS(M-1)+G2*GAS(M+640)
      GO TO 132
  130 IF (GAS(NN+1)) ,128,
      M=M+1
  131 CONTINUE
      GM1=.667
      GO TO 137
  132 IF (K-N) 136, ,136
      GM1=G2
      GO TO 137
  133 IF (GAS(K+1)-GAS(K)) 126,126,
  134 CONTINUE
  135 N=K
      GO TO 127
  136 GM1=G1+(G2-G1)*(GLN-GAS(K+9))/(GAS(K+10)-GAS(K+9))
  137 PL3=GM1*EW*GMU
      EJTW=(.5*(P(J)+PL3)+QS)*EDV+E(J)
      PL3=GM1*AMP1*EJTW
      SLP=GM1*(EJTW+(PL3+QS)/ETA)
      SMU=0.
      GO TO 103
CALCULATE SHORT P-V GAS TABLES
  138 DO 141 K=N+1,N+69
      IF (D-GAS(K+70)) 140, ,139
      PL3=GAS(K)
      K=K+1
      GO TO 143
  139 PL3=GAS(K-1)+(D-GAS(K+69))*GAS(K+140)
      GO TO 143
  140 IF (GAS(K+1)) ,142,
  141 CONTINUE
      K=N+68
  142 PL3=GAS(K)+(D-GAS(K+70))*GAS(K+140)
  143 SDSP=SQRTI(GAS(K+140)/RHO(L+1))
      SLP=GAS(K+140)
      SMU=0.
      IF (DU) ,105,105
      QS=QSAV-VI(L)*SDSP*ERDU
      GO TO 104
  144 CONTINUE
CYCLE END - DO REZONING, PLOTTING AND EDITING
      III=IIJ=2
      IF (NC) , ,149
CYCLE 1 CALCULATIONS
      DO 145 J=JN,LN
      IF (V(J)) 146, ,146
  145 CONTINUE
  146 A=J-5
      A=MAX1F(1.,A)
      JN=A
      DO 147 N=1,L
```

```
      IF (RN(JN)-RB(N+1)) ,148,148
  147 CONTINUE
  148 IR=N
      NC=III=1
      GO TO 169
  149 NC=NC+1
      IF (JN-1) 153,153,
      IF (V(JN+4)) 150, ,150
      IF (V(JN+3)) ,153,
  150 JN=JN-1
      DO 151 N=1,10
      IF (RN(JN)-RB(N+1)) ,152,152
  151 CONTINUE
  152 IR=N
  153 IF (IRZ) ,164,
CALCULATE DEZONE
      IF (NC-200) 164,164,
      RZ1=REZF*(R(JN)-R(JN+1))
      DO 163 J=JN,LN
      IF (R(J)) 164,164,
      IF (IVR-1) ,154,
      IF (I(J-1)) 155, ,155
  154 IF (1.5*RN(J)-R(J)) , ,163
  155 A=R(J-1)-R(J)
      IF (A-RZ1) , ,163
      IF (A/R(J)-.04) , ,163
      IF (R(J)-R(J+1)-R(J-2)+R(J-1)) , ,156
      IF (I(J+1)-400) , ,156
      IF (R(J+1)) ,156,
      K=J+1
      GO TO 157
  156 K=J
  157 IF (XMU(K)) 158, ,
      IF (XMU(K-1)),159,159
      XMU(K)=XMU(K-1)
      GO TO 159
  158 IF (XMU(K-1)) 159, ,
      XMU(K-1)=XMU(K)
CHECK REGION BOUNDS - DEZONING CAN OCCUR
  159 DO 160 N=1,10
      IF (RN(K-1)-RB(N)) ,163,161
  160 CONTINUE
  161 IF (I(K-1)) ,163,
C - WEIGHTING OF VARIABLES
      LX=LX-1
      LN=LN-1
      A=VN(K)+VN(K-1)
      B=VN(K)-DV(K)-DVO(K)
      C=VN(K-1)-DV(K-1)-DVO(K-1)
      GW=B+C
      E(K)=(E(K)*VN(K)+E(K-1)*VN(K-1))/A
      EO(K)=(EO(K)*VN(K)+EO(K-1)*VN(K-1))/A
      TK(K)=(TK(K)*B+TK(K-1)*C)/GW
      P(K)=(P(K)*B+P(K-1)*C)/GW
      XMU(K)=(XMU(K)*B+XMU(K-1)*C)/GW
      DVO(K)=DVO(K)+DVO(K-1)
      DV(K)=DV(K)+DV(K-1)
      AMU(K)=(DV(K)+DVO(K))/GW
      VN(K)=A
      AM(K)=AM(K)+AM(K-1)
```

```
      C1(K)=0.
      ISV(K)=-XABSF(ISV(K))
C - DEZONE
      DO 162 N=K,LN+2
      R(N-1)=R(N)
      DR(N-1)=DR(N)
      V(N-1)=V(N)
      AMU(N-1)=AMU(N)
      P(N-1)=P(N)
      TK(N-1)=TK(N)
      QK(N-1)=QK(N)
      Q(N-1)=Q(N)
      E(N-1)=E(N)
      I(N-1)=I(N)
      RN(N-1)=RN(N)
      XMU(N-1)=XMU(N)
      C1(N-1)=C1(N)
      ISV(N-1)=ISV(N)
      AM(N-1)=AM(N)
      VN(N-1)=VN(N)
      DRMX(N-1)=DRMX(N)
      VMX(N-1)=VMX(N)
      SIGR(N-1)=SIGR(N)
      SIGT(N-1)=SIGT(N)
      QMX(N-1)=QMX(N)
      PX(N-1)=PX(N)
      DV(N-1)=DV(N)
      DVO(N-1)=DVO(N)
      EO(N-1)=EO(N)
      VO(N-1)=VO(N)
  162 CONTINUE
      GO TO 164
  163 CONTINUE
CHECK FOR STOP TIME, EDIT OR PLOT TIME
  164 IF (ITIME) 165,165,
      IF (ITIME-ITOT) 166, ,
  165 IF (TTS-TT) 166, ,
      IF (STR) 167,167,
      IF (RN(JN)-STR) , ,167
  166 III=IIJ=1
      IBANK=0
      OFF=1.
      GO TO 172
  167 IF (TPR-TT) , ,168
      TPR=TPR+DTPR
      III=1
  168 IF (TC(ITCX+2)-TT) , ,169
      IF (TIC(ITCX+2))169,169,
      DTPR=TIC(ITCX+2)
      TPR=DTPR+TC(ITCX+2)
      ITCX=ITCX+1
  169 IF (DPLOT) 170,170,
      IF (TT-PTS) 170, ,
      IIJ=1
CHECK SENSE SWITCH 1
  170 IF (SENSE SWITCH 1) ,171
      III=IIJ=1
      OFF=-1.
  171 IF (III-1) ,172,
      IF (IIJ-1) 188, ,188
```

```
  172 DO 173 J=JN,LN
      IF (I(J)-390) 173,173,
      CAVR=R(J-1)
      GO TO 174
  173 CONTINUE
      CAVR=0.
      GO TO 175
  174 CVRC=PCT/(CAVR*CAVR*CAVR)
  175 IF (III-1) 180, ,180
C - EDIT
      IF (NCYC) ,176,
      WRITE OUTPUT TAPE 3, 956, (IHEAD(N), N=1,7), (IWRT(N), N=1,4),
     1 MO(1), MO(2)
      NCYC=0
      GO TO 177
  176 WRITE OUTPUT TAPE 3, 957, (IHEAD(N), N=1,8), (IWRT(N), N=1,4)
  177 WRITE OUTPUT TAPE 3, 958, NC, DT, DTH, TT, RADT
      DO 178 J=JN-1,LN
      I(J)=XSIGNF(I(J),ISV(J))
  178 CONTINUE
      WRITE OUTPUT TAPE 3, 959, ((J-1), DR(J), R(J), V(J), AMU(J), P(J),
     1 Q(J), TK(J), QK(J), E(J), I(J), J=JN,LN+1)
      DO 179 J=JN-1,LN
      I(J)=XABSF(I(J))
  179 CONTINUE
CALCULATE ENERGY EDIT OR PLOT
  180 DO 181 J=1,51
      EN(J)=BF(J)=0.
  181 CONTINUE
      K=1
      M=I(2)
      FST=VN(1)*EO(1)
      DO 182 J=1,LN
      FSTR=VN(J+1)*EO(J+1)
      FSTM=AM(J)+AM(J+1)
      A=FSTM*V(J)*VO(J)
      B=FST+FSTR
      FST=FSTR
      GW=DR(J)*GR*FSTM
      EN(K)=EN(K)+A
      OCH(K)=OCH(K)+B
      BF(K)=BF(K)+GW
      M=M/100+1
      EDP(M)=EDP(M)+A
      EDT(M)=EDT(M)+B
      BF(M+11)=BF(M+11)+GW
      M=I(J+1)
      IF (RN(J)-RB(K+1)) , ,182
      EN(K)=EN(K)*CF
      OCH(K)=HCCN*OCH(K)
      BF(K)=HCCN*BF(K)
      ENC(K)=EN(K)+OCH(K)+BF(K)
      K=K+1
  182 CONTINUE
      DO 183 N=1,K-1
      EN(K)=EN(K)+EN(N)
      OCH(K)=OCH(K)+OCH(N)
      BF(K)=BF(K)+BF(N)
  183 CONTINUE
      ENC(K)=EN(K)+OCH(K)+BF(K)
```

```
      DO 184 M=1,5
      EDP(M)=EDP(M)*CF
      EDT(M)=EDT(M)*HCCN
      BF(M+11)=BF(M+11)*HCCN
      EDP(6)=EDP(6)+EDP(M)
      EDT(6)=EDT(6)+EDT(M)
      BF(17)=BF(17)+BF(M+11)
      EDTL(M)=EDP(M)+EDT(M)+BF(M+11)
  184 CONTINUE
      EDTL(6)=EDP(6)+EDT(6)+BF(17)
      IF (III-1) 188, ,188
      WRITE OUTPUT TAPE 3, 952
      WRITE OUTPUT TAPE 3, 960, (EN(L), OCH(L), BF(L), ENC(L), L=1,K)
      WRITE OUTPUT TAPE 3, 953
      WRITE OUTPUT TAPE 3, 960, (EDP(L), EDT(L), BF(L+11),EDTL(L),L=1,6)
      IF (ETOT) 185, ,185
      ETOT=ENI=EDTL(6)
  185 WRITE OUTPUT TAPE 3, 961, ETOT
      IF (CAVR) , ,186
      WRITE OUTPUT TAPE 3, 962
      GO TO 187
  186 WRITE OUTPUT TAPE 3, 963, CVRC
  187 A=ETOT-EDTL(6)
      IF (A) ,188,
CHECK ENERGY
      IF (ABSF(A/ETOT)-.5) 188,188,
      OFF=1.
      ITJ=1
      WRITE OUTPUT TAPE 3, 964
C - DO R PLOT IF TIME
  188 IF (IL-25) , ,190
      IF (TT-RPL(IL)) 190, ,
      IF (CRTI-1.) 189, ,
      CALL CRTID (2HAV,1,0)
      CALL FRAME
      CRTI=0.
  189 CALL RPLOT
      IL=IL+1
COMPUTE MAX. VALUES FOR PLOT
  190 IF (IRPLOT) 192,192,
      DO 191 J=JN,LN
      DRMX(J)=MAX1F(DRMX(J),DR(J))
      VMX(J)=MAX1F(VMX(J),V(J))
      QMX(J)=MAX1F(QMX(J),Q(J))
      PX(J)=MAX1F(PX(J),P(J))
      A=P(J)-.6666666666*TK(J)
      B=P(J)+1.333333333*TK(J)
      SIGR(J)=MAX1F(SIGR(J),B)
      SIGT(J)=MAX1F(SIGT(J),A)
  191 CONTINUE
  192 RJH=R(LX-1)-V(LX-1)*HDTH
      PJM=P(LX)
CHECK FOR TERMINATING
      L=1
      IF (OFF) 214, ,213
CALCULATE DUMP TIME ON 6A (TAPE OR DISK)
      IF (NC-NCD) 193, ,
      K=6
      CALL WRST
      CALL WRTEOF (6)
```

```
      CALL BSPACE (6)
      NCD=NCD+1000
  193 IF (ITOT-IPDT-900) 195, ,
      IPDT=ITOT
      IF (DPLOT) 194,194,
      ABF(IBX)=-1000.
      CALL PLTOUT
  194 K=16
      CALL WRST
      BACKSPACE FILE 16
      CALL BSPACE (16)
C   CHECK FOR PLOT DATA
  195 IF (IIJ-1) 212, ,212
      PTS=PTS+DPLOT
      DO 196 J=JN,LN
      IF (Q(J)) 196,196,
      IF (Q(J)-Q(J-1)) ,196,196
      C=RN(J-1)
      GO TO 197
  196 CONTINUE
      C=0.
  197 N=III=1
      M=0
      DO 203 J=JN,LN
  198 IF (N-25) , ,204
      IF (RN(J)-PLOD(N)) ,200,203
      IF (RN(J-1)-PLOD(N)) 201,199,
      IF (RN(J)+RN(J-1)-2.*PLOD(N)) ,200,200
  199 ING(N)=J-1
      GO TO 202
  200 ING(N)=J
      GO TO 202
  201 ING(N)=0
      N=N+1
      GO TO 198
  202 M=M+1
      N=N+1
  203 CONTINUE
  204 IF (IBX-3815) 208,208,
      K=7*(M+2+IEPLOT)
      IF (IBX-4004+K) 208, ,
C - PLOT BUFFER FULL - WRITE ON 6B
      ABF(IBX)=-1000.
      IF (IPB-10) ,207,207
      BUFFER OUT (7,1) (ABF,ABF(4004))
  205 IF (UNIT,7,K) 205,206, ,
      WRITE OUTPUT TAPE 3, 977
  206 IPB=IPB+1
      IBX=1
      GO TO 208
  207 CALL PLTOUT
      IPB=0
      K=16
      CALL WRST
      BACKSPACE FILE 16
      CALL BSPACE (16)
      CALL FSPACE (16)
      IBX=1
C - STORE PLOT DATA IN BUFFER
  208 ABF(IBX)=-1.
```

```
      ARF(IBX+1)=TT
      ARF(IBX+2)=CAVR
      ARF(IBX+3)=CVRC
      ARF(IBX+4)=C
      ARF(IBX+5)=M
      IBX=IBX+7
      DO 209 N=1,25
      IF (ING(N)) 209,209,
      J=ING(N)
      ARF(IBX-1)=PLOD(N)
      ARF(IBX)=DR(J)
      ARF(IBX+1)=V(J)
      A=TSV(J)
      ARF(IBX+2)=SIGNF(CI(J),A)
      ARF(IBX+3)=AMU(J)
      ARF(IBX+4)=P(J)
      ARF(IBX+5)=TK(J)
      IBX=IBX+7
  209 CONTINUE
      IF (IEPLOT) 211,211,
      ARF(IBX-1)=-100.
      ARF(IBX)=ETOT
      DO 210 N=1,6
      ARF(IBX+1)=EDTL(N)
      IBX=IBX+1
  210 CONTINUE
      IBX=IBX+1
      GO TO 212
  211 ARF(IBX-1)=-10.
  212 IF (ITSTP-20) 14,13,13
  213 L=2
CALCULATE BALANCE OF REAL TIME IN ACCOUNT (NEG. RUNNING TIME) AND RESET
  214 IF (IBANK) 215,215,
      IBANK=IBANK-ITOT
  215 III=2
C - EMPTY PLOT BUFFER ONTO 6B BEFORE TERMINATION
      IF (DPLOT) 216,216,
      CALL PLTOUT
C - WRITE FINAL DUMP ON 6B
  216 K=16
      CALL WRST
      K=6
      CALL PLOTE
      CALL WRST
      CALL WRTEOF (6)
      CALL UNLOAD (6)
      CALL CLOCK (IC(1),IC(2))
      WRITE OUTPUT TAPE 3, 966, ITOT, IC(1),IC(2)
      WRITE OUTPUT TAPE 3, 967
      CALL OOND3A(3)
      CALL OOND3A(61)
      IF (L-1) ,217,
      READ INPUT TAPE 2, 971, L
      IF (L-8) 217, ,217
C - CALL PLOT
      CALL CHAIN (5,5)
C - UNLOAD TAPES - CALL EXIT - NO PLOT
  217 CALL UNLOAD (16)
      CALL EXIT
CREATE EXIT IF RADIUS NEGATIVE
```

```
  218 WRITE OUTPUT TAPE 3, 968, J-1
      CALL ERROR (1.)
C - TAPE READ ROUTINES
  219 CALL TSTR
      GO TO (221,2,2,2), IJ
  220 CALL TSTR
      GO TO (221,4,4,4), IJ
  221 WRITE OUTPUT TAPE 3, 972
      PRINT 972
      CALL OOND3A(3)
      CALL OOND3A(61)
      CALL EXIT
C     MAIN CODE TAPE SUBROUTINES
      ENTRY TSTO
      CALL BSPACE (K)
      DO 900 M=1,(5-N)
      CALL WRBLNK (K)
  900 CONTINUE
      N=N-1
      RETURN TSTO
      ENTRY WRSO
      N=5
  901 BUFFER OUT (K,1) (DPLOT,IALF)
  902 IF (UNIT,K,M) 902,904, ,
      CALL TSTO
      IF (N-1) 901, ,901
      WRITE OUTPUT TAPE 3, 908, K
      IF (K-6) 903, ,903
      RETURN WRSO
  903 CALL OOND3A(3)
      CALL OOND3A(61)
      CALL EXIT
  904 CALL WRTEOF (K)
      RETURN WRSO
      ENTRY WRST
      N=5
  905 BUFFER OUT (K,1) (NC,TTS)
  906 IF (UNIT,K,M) 906,907, ,
      N=N-1
      IF (N-1) 905, ,905
  907 RETURN WRST
      ENTRY TSTR
      CALL BSPACE (L)
      J=J-1
      RETURN TSTR
C     FORMAT STATEMENTS
  908 FORMAT ( 7H1 TAPE ,I3,38H IS BAD, PLEASE REPLACE IT AND RESTART)
  950 FORMAT (8A10)
  951 FORMAT (E7.0,I7,2E7.0)
  952 FORMAT (///35H ENERGY TOTALS PER ORIGINAL REGIONS)
  953 FORMAT (///33H ENERGY TOTALS PER MATERIAL STATE)
  954 FORMAT (60H TAPE 6B AND CARD I.D. ARE NOT THE SAME, PROBLEM TERMIN
     1IATED///22H  TAPE IS FOR PROBLEM ,8A10)
  956 FORMAT (1H1/8H SOC II ,7A10,4A10//, 9H STARTED ,1A8, 4H ON ,1A8/)
  957 FORMAT (1H1/8A10,4A10)
  958 FORMAT (///43H N CYCLE    DELTA T(N)  DELTA T(N+.5)  TIME//1X,I6,
     11X,3E14.5//42H  DELTA T CONTROLLED BY ZONE WITH RADIUS =,E14.5)
  959 FORMAT (///120H   J    DELTA R     RADIUS      VELOCITY     MU
     1     PRESSURE     SHOCK        K R-THETA   K SHOCK     ENERGY      ST
     2ATE//(1X,I4,9E12.5,I7))
```

```
960 FORMAT (//69H   KINETIC ENERGY    INTERNAL ENERGY   GRAVITY
   1     TOTAL ENERGY//(4E18.10))
961 FORMAT (///17H ENERGY INPUT IS ,E18.10)
962 FORMAT (///35H THIS IS A PRESSURE PROFILE PROBLEM)
963 FORMAT (///36H VOLUME WEIGHTED CAVITY PRESSURE IS ,F12.5)
964 FORMAT (18H  BAD ENERGY CHECK/)
966 FORMAT (26H PROBLEM TERMINATED AFTER ,I6,8H SECONDS///13H THE TIME
   1 IS ,1A8,13H THE MACHINE ,1A8)
967 FORMAT (1H1)
968 FORMAT (1H1///19H NEGATIVE R AT J = ,I4,14H CHECK PROBLEM)
971 FORMAT (I1)
972 FORMAT  (65H 3 BAD READS OF 68, CHECK TAPE AND UNIT, THEN RESTART
   1THIS JOB    )
973 FORMAT (60H  ERROR IN THIS PROBLEM.  DO NOT TRY TO CONTINUE OR RES
   1TART.)
974 FORMAT (1H1///47H SLOPE LESS THAN OR EQUAL TO ZERO.  CHECK INPUT//
   1//117H CYCLE DELTA T(N)  DELTA T(N+.5)  J    STATE    P(N+1)
   2SLOPE         MU(N+1)        P(N)            MU(N)           MU MAX//1X,I6,
   32F12.5,2I6,5E13.5,E12.5)
975 FORMAT (1H1///30H MU-E/SLOPE GREATER THAN 1.501///60H      MU-E
   1      SLOPE          MU N+1          PRESSURE     LOC.//4F14.5,I1)
976 FORMAT (1H1///30H MU-C/SLOPE GREATER THAN 1.501///60H      MU-C
   1      SLOPE          MU N+1          PRESSURE          //4F14.5)
977 FORMAT (45H  BAD DISK WRITE, MAY BE SOME BAD PLOT POINTS)
    END
```

```
*       LIST 8
*       CARDS COLUMN
*       FORTRAN             RPLOT
        SUBROUTINE RPLOT
        USE COMMON
        A=R(JN)
        DO 1 J=JN,LN
        IF (I(J)-390) 1, ,
        B=R(J-1)
        LP=J-1
        GO TO 2
    1   CONTINUE
        B=R(LN)
        LP=LN
    2   YN1=GW=V(J)
        F=S=P(JN)
        AD=AF=TK(JN)
        DA=DB=EO(JN)=P(JN)+1.3333333*TK(JN)
        DC=DD=VO(JN)=P(JN)-.66666667*TK(JN)
        DO 3 J=JN+1,LP
        YN1=MAX1F(YN1,V(J))
        GW=MIN1F(GW,V(J))
        F=MAX1F(F,P(J))
        S=MIN1F(S,P(J))
        AD=MAX1F(AD,TK(J))
        AF=MIN1F(AF,TK(J))
        VO(J)=P(J)-.66666667*TK(J)
        EO(J)=P(J)+1.3333333*TK(J)
        DA=MAX1F(DA,EO(J))
        DB=MIN1F(DB,EO(J))
        DC=MAX1F(DC,VO(J))
        DD=MIN1F(DD,VO(J))
    3   CONTINUE
        K=LP-JN+1
        DO 12 J=1,10,2
        IF (RIX(J)-RIX(J+1)) 12,12,
        CALL SETCH (10.,2.,0,0,0,0)
        GO TO (4,5,6,8,9), J/2+1
    4   WRITE OUTPUT TAPE 100, 450, (IHEAD(N), N=1,8), TT
        L= JN+12020
        GO TO 7
    5   WRITE OUTPUT TAPE 100, 451, (IHEAD(N), N=1,8), TT
        L= JN
        GO TO 7
    6   WRITE OUTPUT TAPE 100, 452, (IHEAD(N), N=1,8), TT
        L=JN+3606
    7   CALL MAPG(B, A, RIX(J+1), RIX(J))
        CALL TRACE (R(JN), P(L), K)
        GO TO 11
    8   WRITE OUTPUT TAPE 100, 453, (IHEAD(N), N=1,8), TT
        L=JN
        GO TO 10
    9   WRITE OUTPUT TAPE 100, 454, (IHEAD(N), N=1,8), TT
        L=JN+8414
   10   CALL MAPG (B, A, RIX(J+1), RIX(J))
        CALL TRACE (R(JN), EO(L), K)
   11   CALL FRAME
   12   CONTINUE
        RETURN
  450   FORMAT (8A10/30H VELOCITY VERSUS RADIUS AT T = ,E12.5)
```

```
451 FORMAT (8A10/30H PRESSURE VERSUS RADIUS AT T = ,E12.5)
452 FORMAT (8A10/31H K-R THETA VERSUS RADIUS AT T = ,E12.5)
453 FORMAT (8A10/30H RADIAL STRESS VERSUS R AT T = ,E12.5)
454 FORMAT (8A10/34H TANGENTIAL STRESS VERSUS R AT T = ,E12.5)
    END
```

```
*       LIST8
*       CARDS COLUMN
*       FORTRAN                 PLTO
        SUBROUTINE PLTOUT
        USE COMMON
        CALL REWIND (7)
        BUFFER IN (7,1)  (ABA(1),ABA(4004))
        M=4005
        J=1
        DO 7 N=1,IPB
    1   IF (UNIT,7,K) 1,2,,
        WRITE OUTPUT TAPE 3, 901
    2   IF (N-IPB) ,3,3
        BUFFER IN (7,1)  (ABA(M),ABA(M+4003))
    3   BUFFER OUT (16,1)  (ABA(J),ABA(J+4003))
    4   IF (UNIT,16,K) 4,5,,
        WRITE OUTPUT TAPE 3, 900
    5   IF (N-IPB) ,8,8
        IF (M-1) , ,6
        M=4005
        J=1
        GO TO 7
    6   M=1
        J=4005
    7   CONTINUE
    8   CALL REWIND (7)
        BUFFER OUT (16,1)  (ABF(1), ABF(4004))
    9   IF (UNIT,16,K) 9,10,,
        WRITE OUTPUT TAPE 3, 900
   10   CALL WRTEOF (16)
        RETURN
  900   FORMAT (51H BAD TAPE READ/WRITE, PLOT MAY HAVE SOME BAD POINTS)
  901   FORMAT (51H BAD DISK READ/WRITE, PLOT MAY HAVE SOME BAD POINTS)
        END
```

```
*       CARDS COLUMN
*       LIST 8
*       FORTRAN
        SUBROUTINE BANDP (IBA,ITL)
        USE COMMON
C
C       CALL BANDP(A,B)
C       STORES ASCII USER NUMBER IN A(1)
C       STORES NUMBER OF SECONDS IN BANK ACCOUNT IN A(2)  INTEGER
C       STORES TL IN B(1) INTEGER SECONDS
C       STORES PRIORITY IN B(2)  FLOATING PT
C
        COMMON /GOBCOM/ GCOM
        ADDRESS ZETA
        DIMENSION IBA(2), ITL(2)
        ZETA=0
        KIM = (24018.SHL.48).UN.((.LOC.ERROR) .SHL.30) .UN.(.LOC.IBA(1))
        GCOM=(10048.SHL.18).UN.(.LOC.KIM)
        GO TO ZETA
 ERROR  GO TO OK
        GO TO ERROR
  OK    IBA(2) =IBA(2) / 1000000
        KIM =(24038.SHL.48).UN.((.LOC.ERR) .SHL.30 ) .UN.(.LOC.ITL(1))
        GCOM=(10048.SHL.18).UN.(.LOC.KIM)
        GO TO ZETA
  ERR    GO TO THRU
        GO TO ERR
  THRU  ITL(1)= ITL(1) / 1000000
        RETURN
        END
```

```
*     LIST 8
*     CARDS COLUMN
*     FORTRAN              ERROR
      SUBROUTINE ERROR (ERR)
      USE COMMON
      CALL UNLOAD (16)
      CALL UNLOAD (6)
      IF (CRTI) 1, ,1
      CALL PLOTE
    1 IF (ERR) 3,3,
      WRITE OUTPUT TAPE 3, 100, NC, DT, DTH, TT, RADT
      DO 2 J=JN,LN
      I(J)=XSIGNF(I(J),ISV(J))
    2 CONTINUE
      WRITE OUTPUT TAPE 3, 101, (J-1, DR(J), R(J), V(J), AMU(J), P(J),
     1 Q(J), TK(J), QK(J), E(J), I(J), J=JN,LN+1)
    3 CALL COND3A (3)
      CALL COND3A (61)
      CALL EXIT
  100 FORMAT (18H1   ERROR PRINTOUT///43H N CYCLE    DELTA T(N)  DELTA T
     1(N+.5)   TIME///X,I6,1X,3E14.5//42H  DELTA T CONTROLLED BY ZONE WIT
     2H RADIUS =,E14.5)
  101 FORMAT (///120H  J    DELTA R      RADIUS      VELOCITY        MU
     1     PRESSURE      SHOCK         K R-THETA    K SHOCK      ENERGY     ST
     2ATE//(1X,I4,9E12.5,I7))
      END
```

```
*       LIST 8
*       CARDS COLUMN
*       FORTRAN              GEN
        CLICHE GENCOM
        COMMON NC(2), JN, LN, TT, IR, LX, ENI, RN(1202), HH(8414), IH(8414
      1),   AM(1202), C1(1202), DR(1202), DV(1202), DVO(2404), ISV(1202),
      2 P(1202), Q(1202), GK(1202), TK(1202), VN(1202), VO(1202), AMU(120
      32), E(1202), I(1202), R(1202), V(1202), TC(12), TIC(12), RPL(25),
      4 DT, DTH, DTN, DTPR, FPP, ETOT, FDT, HDT1, IL, IPI, IPO, ITCX,
      5 IRANK, NCD, PJM, PTS, GXT, RJH, STR, SXN, TPR, HDTH, TTS
COMMON CONSTANT FOR RUN
        COMMON DP, IE, IX, IDX(8), GR, DXT, PL(100), GAS(2728), PT(400),
      1 PM(400), PD(400), CP(200), CM(200), CD(200), PK(200), PR(200),
      2 DK(200), SS(200), SP(200), SD(200), AK(10), VI(10), RM(10), AMZ(1
      30), AM1(10), AM2(10), XK(10), PZO(10), P1(10), P2(10), SKQ(10),
      4 R(10), SE(10), EF(10), EV(10), SI(10), IT(10), ITT(10), IP(10),
      5 RR(11), RHO(11), GK(10), CF, CCN, HCCN, IRZ, REZF, IW(4), PPR(61)
      6, TP(61), IVR, IALF
COMMON USED IN GENERATION ONLY
        COMMON ITL(10), IAM(100), DNC, GI(11), EN(11), IZ(11), IES(11),
      1 FNC(11), GL(11), J, K, L, M, N, JJ, INN, ICLK, MACH, A, D, F, G,
      2 TKT(80), IM, IC(9), H(16), HP(40), HM(40), HD(40), HC(20), HCM(20
      3), HCD(20), HE(20), HK(20), HDD(20), HGAM(20), HPRE(20), HDP(20),
      4 HG(10), HGL(10), HGE(64), HGG(640), HGD(640), HGDE(64), ZP(400),
      5 ZM(200),KX, II, NN, NO, MP, IN, AST, JL, LLP, AAA, YY1, YY2, ZZ1,
      6 ZZ2, KL, ZZ, YY, LLG, BA, X, KG, DX, KE, NNN, IS, IV
        EQUIVALENCE (HH,IH)
        EQUIVALENCE (IC(1), IM)
        EQUIVALENCE (NC(2), JN)
        ENDCLICHE
        USE GENCOM
        CALL REGST
        CALL CRTID (2HAV,1)
        CALL FRAME
        N=.LOC.NC
        J=.LOC.KE
        NNN=J-N
        DO 1 IS=1,NNN
        NC(IS)=0
      1 CONTINUE
        CALL CLOCK (ICLK, MACH)
        IVR=IPO=IPI=LN=LX=INN=1
        READ INPUT TAPE 2, 900, (IDX(N), N=1,8), DP, DTPR, F, J, IX, IE,
       1 K, IRZ, L
        READ INPUT TAPE 2, 901, RR(1), TTS, DX, IR, M, A, IV, REZF
        IF (REZF) , ,2
        REZF=.2
      2 IF (IR-J) , ,3
        II=J
        GO TO 4
      3 II=IR
      4 READ INPUT TAPE 2, 902, (RR(N   GK(N), EN(N), IZ(N), IES(N), TC(N)
       1, TIC(N), N=2,II+1)
        IALF=3
        IPO=K+IPO
        RR(1)=RR(1)*100.
        DO 5 N=2,II+1
        RR(N)=RR(N)*100.
        TC(N)=TC(N)*1000.
        TIC(N)=TIC(N)*1000.
```

```
    5 CONTINUE
      DP=DP*1000.
      DTPR=DTPR*1000.
      F=F*1000.
      TTS=TTS*1000.
      DX=DX*1000.
      CCN=4.18879
      HCCN=.5*CCN
      CF=.25*CCN
      QXT=1.
      DTH=1.E-3
      DT=HDT1=.5E-3
      HDTH=FDT=DTN=0.
      DXT=DX*DX*9.
      IF (DP) ,7,
      DO 6 K=1,25,5
      READ INPUT TAPE 2, 903, (C1(N), N=K,K+4)
      IF (C1(K+4)) 7,7,
    6 CONTINUE
    7 IF (F) 11, ,12
      DO 8 K=1,25,5
      READ INPUT TAPE 2, 903,(RPL(N), N=K,K+4)
      IF (RPL(K+4)) 9,9,
    8 CONTINUE
    9 DO 10 K=1,25
      RPL(K)=RPL(K)*1000.
   10 CONTINUE
      GO TO 14
   11 F=TTS/25.
   12 RPL(1)=F
      DO 13 K=2,25
      RPL(K)=RPL(K-1)+F
   13 CONTINUE
   14 CALL ZONER
      K=0
      DO 21 N=1,IR
      R(K+1)=RN(K+1)=RB(N)
      IF (IZ(N+1)) ,15,15
      LN=LN-IZ(N+1)
      GO TO 16
   15 LN=LN+IZ(N+1)
   16 ENC(N+1)=EN(N+1)*4.186E7/(CCN*(RB(N)**IALF-RB(N+1)**IALF))
      DO 20 K=K+1,LN-1
      IF (GL(N+1)) , ,17
      F=RN(K)*RN(K)*RN(K)
      F=F-GI(N+1)
      IF (F-.1) 18,18,
      F=F**.33333333
      RN(K+1)=R(K+1)=F
      GO TO 18
   17 RN(K+1)=R(K+1)=(RN(K)-GI(N+1))
      GI(N+1)=GI(N+1)/GL(N+1)
   18 I(K+1)=IES(N+1)
      E(K+1)=ENC(N+1)
      IF (L) 19, ,19
      AMU(K+1)=GK(N+1)
      GO TO 20
   19 V(K+1)=GK(N+1)
   20 CONTINUE
      K=K-1
```

```
21 CONTINUE
   R(K+1)=RN(K+1)=RB(N)
   IF (DP) ,42,
   NN=IR+1
   K=1
22 IF (C1(K)) 23,23,
   C1(K)=C1(K)*100.
   K=K+1
   IF (K-25) 22,22,35
23 IF (IES(NN)-400) 24, ,
   NN=IR
24 JJ=27-K-NN
   F=RN(1)
   IF (JJ) 25,25,
   G=JJ
   F=(RB(1)-RB(NN))/G
25 G=PL(1)=RB(NN)
   JJ=26-K
   DO 34 N=1,JJ
   DO 28 II=1,K
   IF (C1(II)) , ,26
   C1(II)=G
   K=K+1
   GO TO 29
26 IF (G-C1(II)) ,32,28
   NO=K=K+1
27 C1(NO)=C1(NO-1)
   NO=NO-1
   IF (NO-II) , ,27
   C1(II)=G
   GO TO 29
28 CONTINUE
29 IF (K-25) , ,35
   IF (G-RB(NN)) 30, ,30
   NN=NN-1
   G=PL(1)
30 IF (G+F-RB(NN)) ,32,31
   G=G+F
   GO TO 34
31 PL(1)=G
   G=RB(NN)
   GO TO 34
32 F=RN(1)
   NO=27-K-NN+1
   IF (NO) 33,33,
   G=NO
   F=(RB(1)-RB(NN))/G
33 G=PL(1)=RB(NN)+F
   NN=NN-1
34 CONTINUE
35 JJ=25
   NN=1
   IF (C1(JJ)) , ,36
   C1(JJ)=C1(JJ-1)
   C1(JJ-1)=.5*(C1(JJ)-C1(JJ-2))+C1(JJ-2)
36 DO 39 N=1,LN
   IF (C1(JJ)-RN(N)) 39,37,
   IF (2.*C1(JJ)-RN(N)-RN(N-1)) 37,37,
   PL(NN)=RN(N-1)
   GO TO 38
```

```
37 PL(NN)=RN(N)
38 NN=NN+1
   JJ=JJ-1
   IF (JJ) 40,40,
39 CONTINUE
40 DO 41 JJ=1,25
   C1(JJ)=0.
41 CONTINUE
   F=TTS/DP
   IF (F-9600.) 42,42,
   DP=TTS/9600.
42 LX=LX+LN
   NO=M
   INN=1
   DO 50 N=1,NO
   CALL MATRD
   IF (H(16)-100.) ,43,
   CALL GASRD
   GO TO 48
43 DO 45 K=1,70,3
   READ INPUT TAPE 2, 906, (HG(JJ), HG(JJ+70), JJ=K,K+2)
   DO 44 JJ=K,K+2
   IF (JJ-1) 44,44,
   IF (HG(JJ+70)-HG(JJ+69)) , ,44
   IF (HG(JJ+70)) ,46,
   WRITE OUTPUT TAPE 3, 955, IM
   DNC=1.
   GO TO 48
44 CONTINUE
45 CONTINUE
46 DO 47 K=1,JJ
   IF (HG(K+70)) ,47,
   HG(K+70)=1./(HG(K+70)*H)-1.
   IF (K-1) 47,47,
   F=HG(K+70)-HG(K+69)
   IF (F) ,48,
   HG(K+140)=(HG(K)-HG(K-1))/F
47 CONTINUE
48 DO 49 K=1,1690
   IH(INN)=IC(K)
   INN=INN+1
49 CONTINUE
50 CONTINUE
   II=JJ=NN=MP=1
   DO 66 K=1,IR
   N=IES(K+1)
51 IF (N-100) 52,52,
   N=N-100
   GO TO 51
52 IF (IAM(N)) 64, ,64
   IAM(N)=K
   DO 53 IN=1,M*1690,1690
   IF (IH(IN)-N) ,54,
53 CONTINUE
   WRITE OUTPUT TAPE 3, 957, N
   DNC=1.
   GO TO 66
54 DO 55 NO=1,1690
   IC(NO)=IH(IN)
   IN=IN+1
```

```
55 CONTINUE
   IN=1
   DO 56 NO=K,K+169,10
   AK(NO)=H(IN)
   IN=IN+1
56 CONTINUE
   RHO(K+1)=AK(K)
   IF (IES(K+1)-400) , ,57
   IF (IES(K+1)-389) 57,57,
   ENC(K+1)=EF(K)*AK(K)*4.186E-2
57 IN=1
   DO 58 NO=MP,MP+39
   PT(NO)=HP(IN)
   PM(NO)=HM(IN)
   PD(NO)=HD(IN)
   IN=IN+1
58 CONTINUE
   IN=1
   DO 59 NO=NN,NN+19
   CP(NO)=HC(IN)
   CM(NO)=HCM(IN)
   CD(NO)=HCD(IN)
   PK(NO)=HE(IN)
   PR(NO)=HK(IN)
   DK(NO)=HDD(IN)
   SS(NO)=HGAM(IN)
   SP(NO)=HPRE(IN)
   SD(NO)=HDP(IN)
   IN=IN+1
59 CONTINUE
   NO=IN=1
   IF (HG(NO)-HG(NO+1)) ,61,
   DO 60 INN=JJ,JJ+1363
   GAS(INN)=HG(NO)
   NO=NO+1
60 CONTINUE
   ITT(K)=JJ
   JJ=JJ+1364
   GO TO 62
61 ITT(K)=0
62 DO 63 INN=II,II+7
   IKT(INN)=IC(IN+1)
   IN=IN+1
63 CONTINUE
   IP(K)=MP
   IT(K)=NN
   ITL(K)=II
   MP=MP+40
   NN=NN+20
   II=II+8
   GO TO 66
64 IN=IAM(N)
   IP(K)=IP(IN)
   IT(K)=IT(IN)
   ITL(K)=ITL(IN)
   ITT(K)=ITT(IN)
   INN=K
   DO 65 NO=IN,IN+169,10
   AK(INN)=AK(NO)
   INN=INN+10
```

```
65 CONTINUE
   RHO(K+1)=AK(K)
   IF (IES(K+1)-400) , ,66
   IF (IES(K+1)-389) 66,66,
   ENC(K+1)=EF(K)*AK(K)*4.186E-2
66 CONTINUE
   N=2
   DO 68 IN=1,LN
   IF (ENC(N)) 67,67,
   E(IN)=ENC(N)
67 IF (RN(IN)-RB(N)) 68, ,68
   N=N+1
68 CONTINUE
   IF (IPO-1) ,72,
   DO 70 N=1,60,4
   READ INPUT TAPE 2, 907, (HH(K), K=1,8)
   K=1
   DO 69 IN=N,N+3
   TP(IN)=HH(K)*1000.
   PPR(IN)=HH(K+1)
   K=K+2
69 CONTINUE
   IF (TP(IN-1)) ,71,
70 CONTINUE
71 IF (TP) ,72,
   TT=TP
72 WRITE OUTPUT TAPE 3, 958, ICLK, MACH
   IF (IRZ) ,73,
   IW(1)=(10HSPHERE     )
   GO TO 74
73 IW(1)=(10HSPHERE NOT)
74 IW(2)=(10H REZONED  )
   IF (IV) ,75,
   IW(3)=(10H HORIZONTA)
   IW(4)=(10HL         )
   GO TO 76
75 IW(3)=(10H VERTICAL )
   IW(4)=(10H          )
76 DO 77 N=2,IR
   IF (IES(N)-389) 77,77,
   IF (IES(N)-400) , ,77
   EN(N)=ENC(N)*(RB(N-1)**IALF-RB(N)**IALF)*CCN/4.186E7
77 CONTINUE
   WRITE OUTPUT TAPE 3, 959, (IDX(N), N=1,8), (IW(N), N=1,4)
   WRITE OUTPUT TAPE 3, 963, (RB(1), TTS, DX, A, REZF)
   IF (L) ,78,
   WRITE OUTPUT TAPE 3, 964
   V(1)=D
   GO TO 79
78 WRITE OUTPUT TAPE 3, 965
   AMU(1)=D
79 WRITE OUTPUT TAPE 3, 966, (RB(N), RHO(N), GK(N), EN(N), ENC(N),
  1 IZ(N), IES(N), GL(N), N=2,IR+1)
   IF (DP) ,80,
   WRITE OUTPUT TAPE 3, 967, DP, (PL(N), N=1,25)
80 WRITE OUTPUT TAPE 3, 995, (RPL(K), K=1,25)
   IL=1
   IF (IX) ,81,
   WRITE OUTPUT TAPE 3, 968
81 IF (IE) ,82,
```

```
      WRITE OUTPUT TAPE 3, 969
   82 WRITE OUTPUT TAPE 3, 970, DTPR
      IF (J) 83,83,
      WRITE OUTPUT TAPE 3, 971, (TC(N), TTC(N), N=2,J+1)
   83 DO 164 N=1,100
      AST=0.
      IF (IAM(N)) ,164,
      II=IAM(N)
      K=ITL(II)
      J=JL=IP(II)
      L=IT(II)
      D=AK(II)
      IF (D) , ,84
      DNC=1.
      WRITE OUTPUT TAPE 3, 996, N
   84 IF (PT(J)) , ,85
      J=J+1
      GO TO 84
   85 AK(II)=PD(J)
      DO 88 J=JL,JL+39
      IF (PM(J)) 86, ,86
      IF (J-JL) ,86,
      IF (PM(J-1)) 86, ,
      ZP(J)=0.
      J=J-1
      GO TO 89
   86 F=PM(J)+1.
      IF (F) 87, ,87
      ZP(J)=0.
      GO TO 88
   87 ZP(J)=1./(D*F)
   88 CONTINUE
   89 IF (N-89) 94,94,
      CALL SETCH (10.,2.,0,0,0,0)
      WRITE OUTPUT TAPE 100, 949, (IDX(LLP), LLP=1,8), N
      LLP=J-JL
      CALL MAPGLL (ZP(J), ZP(JL+1), PT(JL+1), PT(J))
      CALL TRACE (ZP(JL+1), PT(JL+1), LLP)
      CALL FRAME
      WRITE OUTPUT TAPE 3, 972, (IKT(J), J=K,K+7), N, D, RM(II), AMZ(II)
     1, PZO(II), EF(II)
      WRITE OUTPUT TAPE 3, 975
      IF (ZP(JL)) 90, ,90
      WRITE OUTPUT TAPE 3, 976, PT(JL), PM(JL), PD(JL)
      GO TO 91
   90 WRITE OUTPUT TAPE 3, 977, PT(JL), ZP(JL), PM(JL),PD(JL)
   91 DO 93 J=JL+1,JL+39
      IF (PD(J)-PD(J-1)) ,92,92
      IF (PD(J)) ,92,
      WRITE OUTPUT TAPE 3, 800, PT(J), ZP(J), PM(J), PD(J)
      AST=1.
      GO TO 93
   92 WRITE OUTPUT TAPE 3, 977, PT(J), ZP(J), PM(J), PD(J)
   93 CONTINUE
      GO TO 138
   94 WRITE OUTPUT TAPE 3, 973, (IKT(J), J=K,K+7), N, D, (AK(J), J=II,
     1 II+149,10)
      IF (PT(JL)-PT(JL+1)) 95, ,
      WRITE OUTPUT TAPE 3, 974
      GO TO 138
```

```
 95 DO 97 J=JL,JL+39
    IF (ZP(J+1)) , ,97
 96 CALL SETCH (10.,2.,0,0,0,0)
    WRITE OUTPUT TAPE 100, 961, (IDX(LLP), LLP=1,8), N
    CALL MAPG (ZP(J), ZP(JL), PT(JL), PT(J))
    LLP=J-JL+1
    CALL TRACE (ZP(JL), PT(JL), LLP)
    CALL FRAME
    GO TO 98
 97 CONTINUE
    J=JL+39
    GO TO 96
 98 IF (CP(L)-CP(L+1)) ,118,118
    DO 99 J=L,L+19
    IF (CP(J)-CP(J+1)) ,100,100
 99 CONTINUE
100 IF (CM(J)-AM2(II)) ,104,104
    WRITE OUTPUT TAPE 3, 951, AM2(II), N, CM(J)
    AM2(II)=CM(J)
    DO 103 LLP=1,IR
    AAA=IES(LLP)
101 IF (AAA-100) 102, ,
    AAA=AAA-100
    GO TO 101
102 IF (AAA-N) 103, ,103
    AM2(LLP)=AM2(II)
103 CONTINUE
104 DO 107 LLP=L,L+39
    IF (PM(LLP)-CM(J)) 107,106,
105 J=J-1
    IF (J-L) , ,104
    WRITE OUTPUT TAPE 3, 950
    DNC=1.
    GO TO 108
106 IF (PT(LLP)-CP(J)) 105,108,105
107 CONTINUE
108 DO 111 J=L,L+19
    IF (CM(J)) 109, ,109
    IF (L-J) ,109,
    IF (CM(J-1)) 109, ,
    ZM(J)=0.
    GO TO 111
109 F=CM(J)+1.
    IF (F) 110, ,110
    ZM(J)=0.
    GO TO 111
110 ZM(J)=1./(D*F)
111 CONTINUE
    CALL SETCH (10.,2.,0,0,0,0)
    WRITE OUTPUT TAPE 100, 952, (IDX(LLP), LLP=1,8), N
    LLP=JL
112 IF (PT(LLP)-.04) ,113,113
    LLP=LLP+1
    IF (PT(LLP)) 112, ,112
    LLP=LLP-1
113 MP=LLP
    LLP=L
114 IF (CP(LLP)-.04) , ,115
    LLP=LLP+1
    IF (CP(LLP)) 114, ,114
```

```
      LLP=LLP-1
  115 YY1=MIN1F(ZP(MP), ZM(LLP))
      YY2=MAX1F(ZP(JL), ZM(L))
      ZZ1=MIN1F(PT(JL), CP(L))
      ZZ2=MAX1F(PT(MP), CP(LLP))
      LLP=LLP-L+1
      MP=MP-JL+1
      CALL MAPG (YY1, YY2, ZZ1, ZZ2)
      CALL TRACE (ZP(JL), PT(JL), MP)
      CALL TRACEC (1HC,ZM(L),CP(L),LLP)
      CALL FRAME
      DO 117 J=L,L+19
      IF (ZM(J+1)) , ,117
  116 LLP=J-L+1
      CALL SETCH (10.,2.,0,0,0,0)
      WRITE OUTPUT TAPE 100, 962, (IDX(LLP), LLP=1,8), N
      LLP=J-L+1
      CALL MAPG (ZM(J),ZM(L),CP(L),CP(J))
      CALL TRACE (ZM(L), CP(L), LLP)
      CALL FRAME
      GO TO 125
  117 CONTINUE
      J=L+19
      GO TO 116
  118 CALL FRAME
      IF (PZO(II)) 119, ,119
      DNC=1.
      WRITE OUTPUT TAPE 3, 994, N
  119 IF (EF(II)) 120, ,120
      DNC=1.
      WRITE OUTPUT TAPE 3, 997, N
  120 WRITE OUTPUT TAPE 3, 978
      IF (ZP(JL)) 121, ,121
      WRITE OUTPUT TAPE 3, 976, PT(JL), PM(JL), PD(JL)
      GO TO 122
  121 WRITE OUTPUT TAPE 3, 977, PT(JL), ZP(JL), PM(JL), PD(JL)
  122 DO 124 J=JL+1,JL+39
      IF (PD(J)-PD(J-1)) ,123,123
      IF (PD(J)) ,123,
      WRITE OUTPUT TAPE 3, 800, PT(J), ZP(J), PM(J), PD(J)
      AST=1.
      GO TO 124
  123 WRITE OUTPUT TAPE 3, 977, PT(J), ZP(J), PM(J), PD(J)
  124 CONTINUE
      GO TO 138
  125 IF (PZO(II)) 126, ,126
      DNC=1.
      WRITE OUTPUT TAPE 3, 994, N
  126 IF (EF(II)) 127, ,127
      DNC=1.
      WRITE OUTPUT TAPE 3, 997, N
  127 WRITE OUTPUT TAPE 3, 998
      KL=L
      DO 135 J=JL,JL+19
      IF (J-JL) , ,130
      IF (ZP(J)) 128, ,128
      IF (ZM(KL)) 129, ,129
      WRITE OUTPUT TAPE 3, 981, PT(J), PM(J),PD(J), CP(KL), CM(KL), CD(K
     1L)
      GO TO 135
```

```
128 IF (ZM(KL)) 130, ,130
    WRITE OUTPUT TAPE 3, 999, PT(J), ZP(J), PM(J), PD(J), CP(KL),CM(KL
   1), CD(KL)
    GO TO 135
129 WRITE OUTPUT TAPE 3, 954, PT(J), PM(J), PD(J), CP(KL), ZM(KL),
   1CM(KL), CD(KL)
    GO TO 135
130 IF (PD(J)-PD(J-1)) ,132,132
    IF (PD(J)) ,132,
    IF (CD(KL)-CD(KL-1)) ,131,131
    IF (CD(KL)) ,131,
    WRITE OUTPUT TAPE 3, 801, PT(J), ZP(J), PM(J), PD(J), CP(KL), ZM(
   1 KL), CM(KL), CD(KL)
    AST=1.
    GO TO 134
131 WRITE OUTPUT TAPE 3, 802, PT(J), ZP(J), PM(J), PD(J), CP(KL),
   1 ZM(KL), CM(KL), CD(KL)
    AST=1.
    GO TO 134
132 IF (CD(KL)-CD(KL-1)) ,133,133
    IF (CD(KL)) ,133,
    WRITE OUTPUT TAPE 3, 803, PT(J), ZP(J), PM(J), PD(J), CP(KL),
   1 ZM(KL), CM(KL), CD(KL)
    AST=1.
    GO TO 134
133 WRITE OUTPUT TAPE 3, 993, PT(J), ZP(J), PM(J), PD(J), CP(KL),
   1 ZM(KL), CM(KL), CD(KL)
134 KL=KL+1
135 CONTINUE
    DO 137 J=JL+20,JL+39
    IF (PD(J)-PD(J-1)) ,136,136
    IF (PD(J)) ,136,
    WRITE OUTPUT TAPE 3, 800, PT(J), ZP(J), PM(J), PD(J)
    AST=1.
    GO TO 137
136 WRITE OUTPUT TAPE 3, 977, PT(J), ZP(J), PM(J), PD(J)
137 CONTINUE
138 IF (AST-1.) 139, ,
    WRITE OUTPUT TAPE 3, 804
139 WRITE OUTPUT TAPE 3, 1000
    IF (PR(L)-PR(L+1)) ,145,145
    WRITE OUTPUT TAPE 3, 980
    DK(L)=0.
    WRITE OUTPUT TAPE 3, 982, (PK(J), PR(J), DK(J), J=L,L+19)
    YY=ZZ=PK(L)
    DO 143 J=L+1,L+19
    YY=MIN1F(YY,PK(J))
    ZZ=MAX1F(ZZ,PK(J))
    IF (PR(J)) 143, ,143
    IF (PR(J+1)) 143, ,143
    J=J-1
140 IF (YY-ZZ) ,146,
    CALL SETCH (10.,2.,0,0,0,0)
    WRITE OUTPUT TAPE 100, 953, (IDX(LLP), LLP=1,8), N
    LLP=J-L+1
    YY1=PR(L)
    IF (PK(L)-PK(L+1)) 141, ,141
    YY1=PR(L+1)-(PR(L+1)-PR(L))/100.
141 ZZ1=PR(J)
    IF (PK(J-1)-PK(J)) 142, ,142
```

```
    ZZ1=PR(J-1)+(PR(J)-PR(J-1))/100.
142 CALL MAPG (YY1, ZZ1, YY, ZZ)
    CALL TRACE (PR(L), PK(L), LLP)
    GO TO 144
143 CONTINUE
    J=L+19
    GO TO 140
144 K=K+1
    GO TO 146
145 WRITE OUTPUT TAPE 3, 983
146 IF (SP(L)-SP(L+1)) 147, ,
    CALL FRAME
    GO TO 151
147 IF (K) 148, ,148
    WRITE OUTPUT TAPE 3, 1000
148 WRITE OUTPUT TAPE 3, 984, (SS(J), SP(J), SD(J), J=L,L+19)
    IF (YY-ZZ) ,147,
    DO 150 J=L+1,L+19
    IF (SP(J)) 150, ,150
    IF (SP(J+1)) 150, ,150
    J=J-1
149 LLP=J-L+1
    CALL TRACEC (1HC,SP(L),SS(L),LLP)
    CALL FRAME
    GO TO 151
150 CONTINUE
    J=L+19
    GO TO 149
151 L=ITT(II)
    IF (L) 157,157,
    IF (SI(II)-100.) 158, ,158
    WRITE OUTPUT TAPE 3, 985, D
    DO 154 J=L,L+69
    IF (GAS(J+70)) 152, ,152
    IF (GAS(J+71)) 152, ,152
    HG(J)=GAS(J)=GAS(J+140)=0.
    GO TO 154
152 F=GAS(J+70)+1.
    IF (F) 153, ,153
    HG(J)=0.
    WRITE OUTPUT TAPE 3, 976, GAS(J), GAS(J+70), GAS(J+140)
    GO TO 154
153 HG(J)=1./(D*F)
    WRITE OUTPUT TAPE 3, 977, GAS(J), HG(J), GAS(J+70), GAS(J+140)
154 CONTINUE
    DO 156 J=L,L+69
    IF (GAS(J+1)) , ,156
155 CALL SETCH (10.,2.,0,0,0,0)
    WRITE OUTPUT TAPE 100, 956, (IDX(LLP), LLP=1,8), N
    LLP=J-L+1
    CALL MAPGLL (GAS(J),GAS(L),HG(L),HG(J))
    CALL TRACE (GAS(L), HG(L), LLP)
    CALL FRAME
    GO TO 164
156 CONTINUE
    J=L+69
    GO TO 155
157 WRITE OUTPUT TAPE 3, 986
    GO TO 164
158 WRITE OUTPUT TAPE 3, 987, N
```

```
      WRITE OUTPUT TAPE 3, 988, (GAS(J), J=L,L+9), (GAS(J), J=L+10,L+19)
      WRITE OUTPUT TAPE 3, 989, (GAS(J),GAS(J+64),GAS(J+128),GAS(J+192),
     1GAS(J+256),GAS(J+320),GAS(J+384),GAS(J+448),GAS(J+512),GAS(J+576),
     2GAS(J+640), J=L+20,L+83)
      F=GAS(L+84)
      DO 159 J=L+85,L+639
      IF (GAS(J)) 159,159,
      F=MIN1F(F,GAS(J))
  159 CONTINUE
      CALL MAPGSL (F,5.,GAS(L+20),10000.)
      J=0
      DO 160 LLP=L+20,L+83
      IF (GAS(LLP)) 161,161,
      J=J+1
  160 CONTINUE
      J=64
  161 DO 162 LLP=L,L+9
      IF (GAS(LLP)) 163,163,
      LLG=(LLP-L+1)*64+20+L
      CALL TRACE (GAS(LLG), GAS(L+20), J)
  162 CONTINUE
  163 CALL SETCH (10.,2.,0,0,0,0)
      WRITE OUTPUT TAPE 100, 960, (IDX(J), J=1,8), N
      CALL FRAME
  164 CONTINUE
      CALL PLOTE
      IF (IPO-2) 167,165,
      IF (IPO-3) , ,167
      WRITE OUTPUT TAPE 3, 990
      GO TO 166
  165 WRITE OUTPUT TAPE 3, 991
  166 WRITE OUTPUT TAPE 3, 992, (TP(N), PPR(N), N=1,60)
  167 DO 172 N=1,IR
      L=LLP=IP(N)+1
  168 IF (PT(L)) , ,169
      L=L+1
      GO TO 168
  169 AK(N)=PD(L)
      DO 170 L=LLP,LLP+38
      IF (PM(L)-AM1(N)) 170, ,
      GL(N)=PD(L)
      GO TO 171
  170 CONTINUE
      GL(N)=PD(L)
  171 GK(N)=0.
      IF (IES(N+1)-389) , ,172
      SF(N)=1.5*(1.-2.*SF(N))/(1.+SE(N))
  172 CONTINUE
      CALL INIT
C     FORMAT STATEMENTS RELATING TO READING TAPE 2
  800 FORMAT (2X, 4E14.5,1H*)
  801 FORMAT (2X, 2(4E14.5, 1H*))
  802 FORMAT (2X, 4E14.5,1H*, 4F14.5)
  803 FORMAT (2X, 4E14.5, 1X, 4F14.5,1H*)
  804 FORMAT (57H * - DENOTES PHASE CHANGE IN LOADING AND UNLOADING CURV
     1ES)
  900 FORMAT (8A10/3E9.0,I2,2(2X,I1),1X,I1,6X,I1,11X,I1)
  901 FORMAT (3E9.0,I2,2X,I2,3X,F7.0,I1,6X,E6.0)
  902 FORMAT (2E9.0,E8.0,I5,I3,2X,2E7.0)
  903 FORMAT (5E10.0)
```

```
  906 FORMAT (6E12.5)
  907 FORMAT (8E7.0)
C     FORMAT STATEMENTS RELATING TO OUTPUT ON TAPE 3
  949 FORMAT (28X,8A10,/35X,37H H.E.  P VERSUS V        FOR MATERIAL ,I3)
  950 FORMAT (///68H THE LOADING AND UNLOADING TABLES DO NOT MERGE. CORR
     1ECT AND RESTART.)
  951 FORMAT (////13H  THE MU-2 = ,E12.5,14H FOR MATERIAL ,I2,29H BUT TH
     1E LAST TABLE ENTRY IS ,E12.5,24H THE CODE HAS CHANGED IT)
  952 FORMAT (28X,8A10,/35X,49HP VERSUS V LOADING AND UNLOADING    FOR M
     1ATERIAL ,I2)
  953 FORMAT (28X,8A10,/35X,49HK VERSUS P CONSOLIDATED AND CRUSHED FOR M
     1ATERIAL ,I2)
  954 FORMAT (2X,E14.5,14H     INFINITE  ,6E14.5)
  955 FORMAT (32H P-V GAS TABLE OUT OF ORDER FOR ,I3)
  956 FORMAT (28X,8A10,/35X,29H P VERSUS V GAS FOR MATERIAL ,I2)
  957 FORMAT (22H NO DATA FOR MATERIAL , I3,32H CAN BE LOCATED.  INPUT E
     1RROR    )
  958 FORMAT (34H1       SOC GENERATOR        STARTED , 1A8, 4H ON , 1A8//)
  959 FORMAT (8A10,4A10)
  960 FORMAT (28X,8A10,/35X,45H E IN 10**12 ERGS/GM VS GAMMA-1 FOR MATER
     1IAL ,I2)
  961 FORMAT (28X,8A10,/35X,37HP VERSUS V LOADING        FOR MATERIAL ,I2)
  962 FORMAT (28X,8A10,/35X,37HP VERSUS V UNLOADING      FOR MATERIAL ,I2)
  963 FORMAT (//90H     OUTER RADIUS     STOP TIME       DT MAX        OVERBU
     1RDEN  REZONE FACTOR                        //4X,4(E12.5,2X),E12.5)
  964 FORMAT(//105H     INNER RADII      RHO ZERO       VELOCITY     ENERGY (
     1KT)      ENERGY (DEN)    N   EOS      RADIUS FACTOR       )
  965 FORMAT(//105H     INNER RADII      RHO ZERO      MU ZERO       ENERGY (
     1KT)      ENERGY (DEN)    N   EOS      RADIUS FACTOR       )
  966 FORMAT (1X,5E14.5,I6,I5,F18.5)
  967 FORMAT (///35H PLOT AGAINST TIME AT INTERVALS OF ,E12.5,24H FOR TH
     1E FOLLOWING RADII//(5E14.5))
  968 FORMAT (///17H PLOT PEAK VALUES)
  969 FORMAT (///17H PLOT EDIT VALUES)
  970 FORMAT (//23H INITIAL DELTA PRINT = ,E12.5////)
  971 FORMAT (46H      CHANGE TIME    NEW POINT AND EDIT INTERVAL/(E16.5,
     1E25.5))
  972 FORMAT (1H1/8A10//10H MATERIAL ,I3//82H          RHO ZERO        D
     1           MU (C.J.)       P (C.J.)        E (ZERO)           /(2X,5E14.5
     2))
  973 FORMAT (1H1/8A10//10H MATERIAL ,I3//114H        RHO ZERO        K
     1    VISCOSITY        R M          MU - 0         MU - 1         MU - 2
     2    GAMMA                     /2X,8E13.5/114H      P - 0          P - 1
     3    P - 2          GAMMA SLOPE GAMMA CONST.  SIGMA             EF
     4    EV                      /2X,8E13.5)
  974 FORMAT (///33H NO P-MU TABLES FOR THIS MATERIAL)
  975 FORMAT (//20H            H. E. CURVE //58H           P              V
     1           MU               DP/DMU)
  976 FORMAT (2X,E14.5,14H     INFINITE  ,2E14.5)
  977 FORMAT (2X, 4E14.5)
  978 FORMAT (//20H          LOADING CURVE//58H            P              V
     1           MU               DP/DMU)
  979 FORMAT (///30H UNLOADING TABLE FOR MATERIAL ,I3/57H          P
     1           V                MU              DP/DMU)
  980 FORMAT (//24H  CONSOLIDATED K-P TABLE//42H             K
     1P               DK/DP/)
  981 FORMAT (2X,E14.5,14H     INFINITE  ,3E14.5,14H     INFINITE  ,2E14.5
     1)
  982 FORMAT (2X, 3E14.5)
  983 FORMAT (/36H NO K PSI=1 TABLES FOR THIS MATERIAL)
```

```
984 FORMAT (///19H  CRUSHED K-P TABLE//39H            K                P
   1       DK/DP//(2X,3E14.5))
985 FORMAT (74H1          P              V                  MU            DP/DMU
   1 MU FOR DENSITY OF ,E14.5//)
986 FORMAT (///32H NO GAS TABLES FOR THIS MATERIAL)
987 FORMAT (28H1   GAS TABLES FOR MATERIAL , I3/)
988 FORMAT (/118H                   RHO 1       RHO 2       RHO 3       RHO 4
   1    RHO 5       RHO 6       RHO 7       RHO 8       RHO 9       RHO 10/
   210X,10E11.4/118H                LOG RHO     LOG RHO     LOG RHO     LOG R
   3HO    LOG RHO     LOG RHO     LOG RHO     LOG RHO     LOG RHO     LOG R
   4HO/10X,10E11.4)
989 FORMAT (/118H  ENERGY    GAMMA-1     GAMMA-1     GAMMA-1     GAMMA-1
   1    GAMMA-1     GAMMA-1     GAMMA-1     GAMMA-1     GAMMA-1     GAMMA-1/
   2(F10.3,10E11.4))
990 FORMAT (24H1 OUTER PRESSURE PROFILE//)
991 FORMAT (24H1 INNER PRESSURE PROFILE//)
992 FORMAT (24H          TIME            P/(2E14.5))
993 FORMAT (2X, 4E14.5, 1X, 4F14.5)
994 FORMAT(/26H  P-ZERO IS 0 FOR MATERIAL, I2,20H CORRECT AND RESTART)
995 FORMAT(/54H  INTERVALS AT WHICH PLOTS VERSUS RADIUS WILL BE TAKEN/
   1 //(5E14.5))
996 FORMAT (/42H  RHO IS LESS THAN OR = TO 0 FOR MATERIAL ,I2,24H
   1CORRECT AND RESTART)
997 FORMAT(/25H  EF IS ZERO FOR MATERIAL, I2, 20H CORRECT AND RESTART)
998 FORMAT (///93H                          LOADING CURVE
   1                                  UNLOADING CURVE//109H        P
   2    V              MU              DP/DMU          P              V
   3     MU             DP/DMU)
999 FORMAT (2X,5E14.5,14H    INFINITE  ,2E14.5)
1000 FORMAT (1H1)
    END
```

```
*       LIST 8
*       CARDS COLUMN
*       FORTRAN              INIT
        SUBROUTINE INIT
        USE GENCOM
        L=J=2
        IF (IV) 3, ,3
        GR=.98E-9
        IF (I(2)-300) , ,5
        P(1)=0.
        P(2)=P(1)+.5*GR*RHO(2)*(R(1)-R(2))
        J=3
      1 IF (I(J)-300) , ,5
        P(J)=RHO(L)*(RN(J-2)-RN(J-1))
        IF (RN(J)-RB(L)) , ,2
        L=L+1
      2 P(J)=P(J-1)+.5*GR*(P(J)+RHO(L)*(RN(J-1)-RN(J)))
        J=J+1
        IF (J-LN) 1,1,5
      3 IF (A) ,6,
        J=1
        A=1.E-6*A
      4 IF (I(J)-300) , ,5
        P(J)=A
        J=J+1
        IF (I(J)) ,5,
        IF (J-LN) 4,4,
      5 J=L=2
      6 IF (I(J)-389) , ,10
        N=IP(L-1)+1
        DO 8 K=N,N+39
        IF (P(J)-PT(K)) , ,7
        AMU(J)=PM(K)+(P(J)-PT(K))/PD(K)
        GO TO 28
      7 IF (PT(K+1)-PT(K)) 9,9,
      8 CONTINUE
        K=N+39
      9 AMU(J)=PM(K)+(P(J)-PT(K))/PD(K)
        GO TO 28
     10 IF (I(J)-400) , ,11
        AMU(LX-1)=AMZ(L-1)
        GO TO 30
     11 IF (E(J)) ,28,
        N=ITT(L-1)
        IF (SI(L-1)-100.) 16, ,16
        DO 15 K=N,N+69
        IF (AMU(J)-GAS(K+70)) 14, ,12
        P(J)=GAS(K)
        GO TO 28
     12 IF (K-N)  ,13,
        K=K-1
     13 P(J)=GAS(K)+(AMU(J)-GAS(K+70))*GAS(K+141)
        GO TO 28
     14 IF (GAS(K+1)) , ,15
        P(J)=GAS(K)+(AMU(J)-GAS(K+70))*GAS(K+140)
        GO TO 28
     15 CONTINUE
        GO TO 28
     16 A=E(J)/RHO(L)
        BA=(AMU(J)+1.)*RHO(L)
```

```
      X=LOGF(BA)
      DO 24 K=N,N+9
      IF (GAS(K)-BA) 23, ,
   17 NN=(K-N+1)*64+20+N
      DO 21 II=N+20,N+83
      IF (GAS(II)-A) 20,18,
      IF (II-N-20) , ,19
   18 A=GAS(NN)
      BA=GAS(NN-64)
      GO TO 22
   19 A=A-GAS(II-1)
      BA=GAS(NN-65)+A*GAS(NN+576)
      A=GAS(NN-1)+A*GAS(NN+640)
      GO TO 22
   20 IF (GAS(II+1)) 18,18,
      NN=NN+1
   21 CONTINUE
      X=.67
      GO TO 27
   22 IF (K-N) 26, ,26
      X=A
      GO TO 27
   23 IF (GAS(K+1)-GAS(K)) 25,25,
   24 CONTINUE
      K=N+9
   25 N=K
      GO TO 17
   26 X=BA+(A-BA)*(X-GAS(K+9))/(GAS(K+10)-GAS(K+9))
   27 P(J)=X*E(J)*(AMU(J)+1.)
   28 IF (RN(J)-RB(L)) , ,29
      L=L+1
   29 J=J+1
      IF (J-LN) 6,6,
   30 DO 31 J=2,LN
      A=RN(J-1)+RN(J)
      DV(J)=(RN(J-1)-RN(J))*(A*A-RN(J-1)*RN(J))
      DVO(J)=AMU(J)*DV(J)
      VN(J)=DVO(J)+DV(J)
      DV(J)=0.
      IF (I(J)-100) 31,31,
      ISV(J)=-1
      DR(J)=0.
   31 CONTINUE
      N=2
      AM=AM(LX)=0.
      DO 32 J=2,LN
      AM(J)=RHO(N)*VN(J)
      IF (RB(N)-RN(J)) 32, ,32
      N=N+1
   32 CONTINUE
      WRITE OUTPUT TAPE 3, 993, (IDX(N), N=1,8), (IW(N), N=1,4), ((J-1),
     1 RN(J), AM(J), VN(J), DVO(J), AMU(J), P(J), E(J), I(J), J=1,LX)
      JN=IR=1
      TPR=DTPR
      DO 33 J=1,8414
      HH(J)=0.
   33 CONTINUE
      J=K=1
      DO 35 N=1,LN
      IF (RN(N)-PL(J)) 34, ,34
```

```
      PL(J+25)=AK(K)
      PL(J+50)=SE(K)*AK(K)
      PL(J+75)=RHO(K+1)
      J=J+1
      IF (J-25) , ,36
   34 IF (RN(N)-RB(K+1)) 35, ,35
      K=K+1
   35 CONTINUE
      RJH=R(LX-1)
      PJM=P(LX)
   36 CALL REWIND (16)
      N=5
   37 BUFFER OUT (16,1) (DP,IALF)
   38 IF (UNIT,16,K) 38,40, ,
      CALL TCSTO
      GO TO (39,37,37,37), N
   39 WRITE OUTPUT TAPE 3, 994
      PRINT 994
      CALL UNLOAD (16)
      CALL CLOCK (K,L)
      WRITE OUTPUT TAPE 3, 995, K, L
      CALL OOND3A(61)
      CALL OOND3A(3)
      CALL EXIT
   40 CALL WRTEOF (16)
      N=5
   41 BUFFER OUT (16,1) (DNC,TTS)
   42 IF (UNIT,16,K) 42,43, ,
      CALL TCSTO
      GO TO (39,41,41,41), N
   43 IF (DNC-1.) ,44,
      WRITE OUTPUT TAPE 3, 999
      PRINT 999
      GO TO 45
   44 WRITE OUTPUT TAPE 3, 997
      PRINT 997
   45 CALL UNLOAD (16)
      CALL OOND3A(3)
      CALL OOND3A(61)
      CALL EXIT
      ENTRY TCSTO
      CALL BSPACE (16)
      DO 46 K=1,6-N
      CALL WRBLNK (16)
   46 CONTINUE
      N=N-1
      RETURN TCSTO
  908 FORMAT (I1)
  993 FORMAT (24H1     OVERBURDEN PRINTOUT///,8A10,4A10///110H     J    R-ZE
     1RO           MASS              VOLUME           DELTA V          MU
     2PRESSURE        ENERGY           STATE/(1X,I4,7E14.7,I7))
  994 FORMAT (38H 6B IS NOT GOOD, REPLACE IT AND HIT GO)
  995 FORMAT (15H TAPE 6B BAD AT,1A8,4H ON ,1A6)
  996 FORMAT (20H TAPE 6B REPLACED AT,1A8,4H ON ,1A6)
  997 FORMAT (50H1 ERROR IN GENERATOR INPUT, CORRECT AND REGENERATE)
  999 FORMAT (20H GENERATION COMPLETE)
 1000 FORMAT (1H1)
      END
*     LIST 8
*     CARDS COLUMN
```

```
*       FORTRAN            MATRD
        SUBROUTINE MATRD
        USE GENCOM
        READ INPUT TAPE 2, 904, (TC(K), K=2,9), IM, (H(K), K=1,7)
        READ INPUT TAPE 2, 905, (H(K), K=8,16)
        DO 1 K=1,40,4
        READ INPUT TAPE 2, 906, (HP(IN), HM(IN), IN=K,K+3)
        IF (HP(K+3)) , ,1
        IF (HP(K+2)) 1,2,2
      1 CONTINUE
      2 DO 8 IN=1,40
        IF (IN-1) 4, ,4
        HD(IN)=0.
        IF (HM(IN+1)-HM(IN)) ,8,8
        DO 3 K=1,40
        IF (HM(K)) ,8,
        HM(K)=1./(HM(K)*H)-1.
        IF (ABSF(HM(K))-1.E-5) , ,3
        HM(K)=0.
      3 CONTINUE
        GO TO 8
      4 F=HM(IN)-HM(IN-1)
        IF (F) ,5,7
        IF (HP(IN)) ,5,
        WRITE OUTPUT TAPE 3, 951, IM
        DNC=1.
      5 DO 6 K=IN,40
        HP(K)=HM(K)=HD(K)=0.
      6 CONTINUE
        GO TO 9
      7 HD(IN)=(HP(IN)-HP(IN-1))/F
      8 CONTINUE
      9 DO 10 K=1,20,4
        READ INPUT TAPE 2, 906, (HC(IN), HCM(IN), IN=K,K+3)
        IF (HC(K+3)) 11,11,
     10 CONTINUE
     11 IF (HCM(1)-HCM(2)) 13, ,13
        DO 12 K=1,60
        HC(K)=0.
     12 CONTINUE
        GO TO 20
     13 DO 19 K=1,20
        IF (K-1) 15, ,15
        HCD(K)=0.
        IF (HCM(K+1)-HCM(K)) ,19,19
        DO 14 IN=1,20
        IF (HCM(IN)) ,19,
        HCM(IN)=1./(HCM(IN)*H)-1.
        IF (ABSF(HCM(IN))-1.E-5) , ,14
        HCM(IN)=0.
     14 CONTINUE
        GO TO 19
     15 F=HCM(K)-HCM(K-1)
        IF (F) ,16,18
        IF (HC(K)) ,16,
        WRITE OUTPUT TAPE 3, 952, IM
        DNC=1.
     16 DO 17 IN=K,20
        HC(IN)=HCM(IN)=HCD(IN)=0.
     17 CONTINUE
```

```
      GO TO 20
   18 HCD(K)=(HC(K)-HC(K-1))/F
   19 CONTINUE
   20 DO 25 K=1,20,4
      READ INPUT TAPE 2, 906, (HE(IN), HK(IN), IN=K,K+3)
      DO 24 IN=K,K+3
      IF (IN-1) ,24,
      HDD(IN)=0.
      F=HK(IN)-HK(IN-1)
      IF (F) ,21,23
      IF (HK(IN)) ,21,
      WRITE OUTPUT TAPE 3, 953, IM
      DNC=1.
   21 DO 22 K=IN,20
      HE(K)=HK(K)=HDD(K)=0.
   22 CONTINUE
      GO TO 26
   23 HDD(IN)=(HE(IN)-HE(IN-1))/F
   24 CONTINUE
   25 CONTINUE
   26 DO 31 K=1,20,4
      READ INPUT TAPE 2, 906, (HGAM(IN), HPRE(IN), IN=K,K+3)
      DO 30 IN=K,K+3
      IF (IN-1) ,30,
      HDP(IN)=0.
      F=HPRE(IN)-HPRE(IN-1)
      IF (F) ,27,29
      IF (HPRE(IN)) ,27,
      WRITE OUTPUT TAPE 3, 954, IM
      DNC=1.
   27 DO 28 K=IN,20
      HPRE(K)=HGAM(K)=HDP(K)=0.
   28 CONTINUE
      GO TO 32
   29 HDP(IN)=(HGAM(IN)-HGAM(IN-1))/F
   30 CONTINUE
   31 CONTINUE
   32 RETURN
  904 FORMAT (8A10/I2,2E8.0,2E7.0,3E8.0)
  905 FORMAT (9E7.0)
  906 FORMAT (8E7.0)
  951 FORMAT (///40H THERE IS A MU OUT OF ORDER IN MATERIAL ,I3,14H LOAD
     1ING CURVE)
  952 FORMAT (///40H THERE IS A MU OUT OF ORDER IN MATERIAL ,I3,16H UNLO
     1ADING CURVE)
  953 FORMAT (///71H A PRESSURE IS OUT OF ORDER IN THE CONSOLIDATED K-P
     1 TABLE FOR MATERIAL ,I3)
  954 FORMAT (///65H A PRESSURE IS OUT OF ORDER IN THE CRUSHED K-P TABLE
     1 FOR MATERIAL ,I3)
      END
*     LIST 8
*     CARDS COLUMN
*     FORTRAN             ZONER
      SUBROUTINE ZONER
      USE GENCOM
      K=IR+1
      DO 1 IN=1,11
      GT(IN)=0.
      GL(IN)=1.
    1 CONTINUE
```

```
      IZ(1)=IES(1)=0
      DO 14 INN=1,IR+1
      IF (IZ(K)) 3,2,
      F=IZ(K)
      GI(K)=(RB(K-1)-RB(K))/F
      GL(K)=1.
      IF (IZ(K-1)) ,13,13
      K=K-1
      GL(K)=1.001
      CALL FINDR
      GO TO 13
    2 IF (GI(K+1)) 20,20,
      G=RB(K-1)-RB(K)
      F=G/GI(K+1)
      IZ(K)=F
      F=IZ(K)
      GI(K)=G/F
      GL(K)=1.
      GO TO 13
    3 NO=K-1
      IF (IZ(K)+1) 7, ,20
      IF (NO-1) 20,5,
      DO 4 IN=1,K-1
      IF (IZ(NO)) ,5,6
      NO=NO-1
    4 CONTINUE
      GO TO 20
    5 F=LOGF(1.+.05*(RB(NO)-RB(NO+1))/GI(NO+2))
      F=F/LOGF(1.05)+1.
      IZ(NO+1)=-F
      GL(K)=1.05
      CALL FINDR
      GO TO 13
    6 F=IZ(NO)
      GI(NO)=GI(NO+1)=((RB(NO-1)-RB(NO))/F)
      GL(NO)=1.
    7 DO 12 IN=NO+1,K
      IF (IZ(IN)) 8, ,20
      G=RB(IN-1)-RB(IN)
      F=G/GI(IN)
      IZ(IN)=F
      F=IZ(IN)
      GI(IN)=GI(IN+1)=G/F
      GL(IN)=1.
      GO TO 12
    8 GL(K)=1.001
      IF (IES(IN)-400) , ,11
      IF (IZ(IN)+1) 10, ,20
      F=RB(IN-1)-RB(IN)+GI(IN+1)
      IF (GI(IN+1)) , ,9
      F=LOGF(GI(IN-1)/(1.05*GI(IN-1)-.05*(F+GI(IN-1))))/LOGF(1.05)+1.
      IZ(IN)=-F
      GL(IN)=1.05
      CALL FINDR
      GO TO 12
    9 GL(IN)=(F-GI(IN+1))/(F-GI(IN-1))
      F=LOGF(GI(IN-1)/GI(IN+1))/LOGF(GL(IN))+1.
      IZ(IN)=-F
   10 CALL FINDR
      GO TO 12
```

```
   11 IF (IZ(IN)+1) 10, ,20
      X=(RB(IN-1)+GI(IN-1))**IALF
      F=RB(IN-1)**IALF
      X=F/(X-F)+1.
      IZ(IN)=-X
      X=-IZ(IN)
      GL(IN)=0.
      GI(IN)=F/X
   12 CONTINUE
      K=NO
   13 IF (K-1) 15, ,
      IF (GI(K)) 14,14,
      K=K-1
      GO TO 13
   14 CONTINUE
   15 NO=0
      DO 19 K=2,10
      IF (RB(K-1)) 19,19,
      NO=XABSF(IZ(K))+NO
      IF (IZ(K)-1) 19, ,19
      IF (IES(K)-IES(K-1)) ,16,
      IF (IES(K)-IES(K+1)) 19, ,19
      IZ(K+1)=IZ(K+1)-1
      NO=NO-1
      RB(K+1)=RB(K)
      GI(K+1)=GI(K)
      IN=K
      GO TO 17
   16 IZ(K)=IZ(K-1)-1
      GL(K)=GL(K-1)
      GI(K)=GI(K-1)
      IN=K-1
   17 DO 18 JJ=IN,IR+1
      RB(JJ)=RB(JJ+1)
      RHO(JJ)=RHO(JJ+1)
      EN(JJ)=EN(JJ+1)
      IZ(JJ)=IZ(JJ+1)
      IES(JJ)=IES(JJ+1)
      GK(JJ)=GK(JJ+1)
      GI(JJ)=GI(JJ+1)
      GL(JJ)=GL(JJ+1)
   18 CONTINUE
      IR=IR-1
      IF (K-IR-1) 19, ,
      IF (NO-1200) , ,21
      RETURN
   19 CONTINUE
      IF (NO-1200) , ,21
      RETURN
   20 DNC=1.
      WRITE OUTPUT TAPE 3, 951
      RETURN
   21 DNC=1.
      WRITE OUTPUT TAPE 3, 952, NO
      RETURN
  951 FORMAT (33H ZONING ERROR - NO SPECIFIED SIZE)
  952 FORMAT (I5,53H ZONES CALCULATED, MAX. NO. IS 1200, FIX AND RESUBMI
     1T)
      END
*     LIST 8
```

```
*       FORTRAN              FINDR
        SUBROUTINE FINDR
        USE GENCOM
        IF (IES(K)-400) , ,1
        F=RB(K-1)-RB(K)+GI(K+1)
        G=GI(K+1)
        GO TO 2
    1   F=RB(K-2)-RB(K)
        GI(K)=GI(K-1)=G=RB(K-2)-RB(K-1)
    2   JJ=-IZ(K)+1
        IVR=2
        DV(2)=JJ
        DV(3)=LOGF(F/G)
        DV(4)=GL(K)
        DV(5)=G/F
        DO 3 JJ=1,1000
        GL(K)=EXPF((DV(3)+LOGF(DV(4)-1.+DV(5)))/DV(2))
        IF (ABSF(GL(K)-DV(4))-1.E-7) 4,4,
        DV(4)=GL(K)
    3   CONTINUE
        IZ(K)=-IZ(K)
        GL(K)=1.
        F=IZ(K)
        GI(K)=(RB(K-1)-RB(K))/F
        RETURN
    4   IF (IES(K)-400) 5, ,
        GL(K)=1./GL(K)
        RETURN
    5   IF (GL(K)-1.1) 6,6,
        WRITE OUTPUT TAPE 3, 950, GL(K)
        DNC=1.
    6   GI(K)=((RB(K-1)-RB(K)+GI(K+1))*(GL(K)-1.)+GI(K+1))/GL(K)
        RETURN
  950   FORMAT (92H   THE R CALCULATED IS GREATER THAN 1.1, EXECUTION OF T
       1HIS PROBLEM DELETED, CHECK INPUT - R=,E12.5)
        END
```

```
*       CARDS COLUMN
*       FORTRAN              GASRD
        SUBROUTINE GASRD
        USE GENCOM
        READ INPUT TAPE 2, 907, (HG(K), K=1,10)
        IF (HG(1)) 16,16,
        DO 3 K=1,63,8
        READ INPUT TAPE 2, 906, (HGE(IN), IN=K,K+7)
        DO 1 IN=K,K+7
        HGDE(IN)=HGE(IN)-HGE(IN-1)
      1 CONTINUE
        IF (HGE(K+7)) , ,3
        DO 2 IN=K+8,64
        HGE(IN)=HGDE(IN)=0.
      2 CONTINUE
        GO TO 4
      3 CONTINUE
      4 KG=1
        DO 8 K=1,10
        IF (HG(K)) 9,9,
        HGL(K)=LOGF(HG(K))
        KE=1
        DO 6 IN=KG,KG+62,8
        READ INPUT TAPE 2, 906, (HGG(NO), NO=IN,IN+7)
        IF (HGE(KE+7)) , ,6
        DO 5 NO=IN+8,KG+63
        HGG(NO)=HGD(NO)=0.
      5 CONTINUE
        GO TO 7
      6 KE=KE+8
      7 KG=KG+64
      8 CONTINUE
      9 KG=K
        IF (H(16)) ,13,13
        NO=1
        DO 12 K=1,KG-1
        NNN=1
        DO 10 IN=NO,NO+63
        HGG(IN)=HGG(IN)/(HG(K)*HGE(NNN))
        NNN=NNN+1
        IF (HGE(NNN)) 11,11,
     10 CONTINUE
     11 NO=NO+64
     12 CONTINUE
     13 DO 15 K=2,64
        IF (HGE(K)) 18,18,
        DO 14 IN=K,64*(KG-1),64
        HGD(IN)=(HGG(IN)-HGG(IN-1))/HGDE(K)
     14 CONTINUE
     15 CONTINUE
        RETURN
     16 DO 17 K=1,1364
        HG(K)=0.
     17 CONTINUE
     18 RETURN
    906 FORMAT (8E7.0)
    907 FORMAT (10E7.0)
        END
*       LIST 8
*       CARDS COLUMN
```