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SAMCR: A Two-Dimensional Dynamic Finite Element Code for the Stress Analysis of Moving CRacks

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FOREWORD

The work reported here was performed at Oak Ridge National Laboratory (ORNL) under the Heavy-Section Steel Technology Program, C. E. Pugh, Program Manager. The program is sponsored by the Office of Nuclear Regulatory Research of the U.S. Nuclear Regulatory Commission (NRC). The technical monitor for the NRC is Milton Vagins.

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ABSTRACT

The mathematical formulation, program structure, and details of required input data are described for SAMCR, a two-dimensional dynamic finite element code for the Stress Analysis of Moving CRacks, which has been developed at the University of Maryland. The code has been shown, through an extensive series of verification analyses, to perform well in modeling dynamic behavior of both uncracked and cracked structures. In particular, the code has been demonstrated to provide useful information regarding run-arrest events in polymeric laboratory samples and large thermally shocked steel cylinders. Complete documentation of the code has been included so that this document can serve as both a technical manual and a user's manual for the code.

CHAPTER 1

INTRODUCTION

SAMCR is a two-dimensional, dynamic, finite-element code for the Stress Analysis of Moving CRacks and has been developed at the University of Maryland under the auspices of the U.S. Nuclear Regulatory Commission and the Oak Ridge National Laboratory Heavy-Section Steel Technology Program. A preliminary version of the code was developed by Dr. J.M. Etheridge of the Naval Surface Weapons Center, Silver Spring, Maryland, who served as a consultant to the University of Maryland. Subsequently the task of code development and enhancement was taken over by Dr. C.W. Schwartz of the University of Maryland. The current version of the code is Version 3.0, and all material contained in this document refers to this version.

This document contains, in addition to the Introduction and Summary chapters, chapters that detail the mathematical formulation of the code and the results from an extensive series of verification and sensitivity analyses. Supplementary appendices provide information on the program organization and variables, details of the required input data and associated formats, a complete listing of Version 3.0 of SAMCR, and the input and abbreviated output for an example problem.

The code formulation is based on the conventional variational formulation of finite element theory using the principle of virtual work. The code employs four-noded isoparametric elements together with explicit time integration and a restraining nodal force model of incremental crack advance to provide a formulation that is both efficient computationally and straightforward mathematically. The code can be used to provide useful information about the Mode I fracture behavior of bodies under a combination of mechanical, thermal, and pressure loadings for materials that permit a linear-elastic fracture mechanics assumption. SAMCR operates in a predictive fracture "application" mode, i.e., the increment of crack extension at each time step is automatically computed based on the calculated stress intensity value K at the crack tip and the user-specified crack tip velocity vs. K constitutive relationship for the fracturing material. The code was developed on a UNIVAC 1100 Series mainframe computer. The code structure has, however, purposely been kept consistent with standard Fortran, so that it should be readily adaptable to other computer systems.

CHAPTER 2

MATHEMATICAL FORMULATION

2.1 Introduction

The mathematical formulation of SAMCR is based on the conventional variational formulation of finite element theory using the principle of virtual work. The major assumptions in the formulation of SAMCR include:

- Symmetric Mode I fracture conditions
- Small strains and small displacements
- Linear behavior
- Mass lumped at nodal points (lumped mass matrix)
- Explicit time integration
- Viscous damping
- Fracture propagation simulated using a crack tip restraining force model and a specified crack speed vs. stress intensity factor constitutive relation
- J-integral formulation for the fracture energy release rate
- Time independent thermal strain fields

2.2 General Formulation of the Finite Element Method

The basic theory underlying the displacement-based finite element method can be found in many standard references. The following discussion will employ the notation in Bathe and Wilson (1976). The fundamental governing equation for a body in equilibrium can be derived either from the principle of virtual work or from Galerkin weighted residual methods:

$$\int_V \bar{\underset{\sim}{\varepsilon}}\, \underset{\sim}{\sigma}\, dV = \int_V \bar{\underset{\sim}{u}}^T \underset{\sim}{f}^b\, dV + \int_S (\bar{\underset{\sim}{u}}^s)^T \underset{\sim}{f}^s\, dS + \sum_i (\bar{U}^i)^T f^i \qquad (2.1)$$

where, for two-dimensional analyses in an orthogonal r-z-θ coordinate system (see Figure 2.1):

$$\bar{\underset{\sim}{\varepsilon}}^T = [\, \bar{\varepsilon}_{rr} \;\; \bar{\varepsilon}_{zz} \;\; \bar{\varepsilon}_{\theta\theta} \;\; \bar{\gamma}_{rz} \,] \qquad (2.2)$$

= virtual strains

$$\underset{\sim}{\sigma}^T = [\, \sigma_{rr} \;\; \sigma_{zz} \;\; \sigma_{\theta\theta} \;\; \tau_{rz} \,] \qquad (2.3)$$

= stresses

$$\bar{\underset{\sim}{u}}^T = [\, \bar{u} \;\; \bar{w} \,] \qquad (2.4)$$

= continuous virtual displacements within body

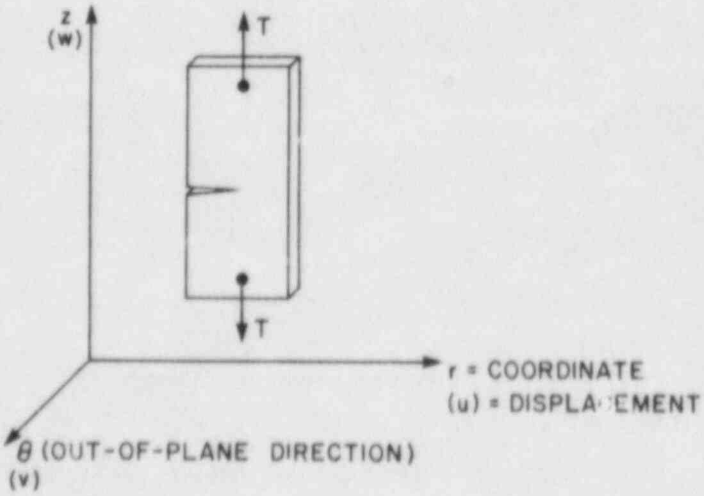


Fig. 2.1. Coordinate system used in SAMCR.

$$(\underset{\sim}{f}^{b})^{T} = [\ f_r \ \ f_z\ ] \tag{2.5}$$

= body forces (inertia forces in a dynamic analysis)

$$(\overline{\underset{\sim}{u}}^{s})^{T} = [\ \overline{u}^{s} \ \ \overline{u}^{w}\ ] \tag{2.6}$$

= continuous virtual displacements on surface of body

$$(\underset{\sim}{f}^{s})^{T} = [\ f_r^{s} \ \ f_z^{s}\ ] \tag{2.7}$$

= surface tractions

$$(\overline{\underset{\sim}{U}}^{i})^{T} = [\ \overline{u}^{i} \ \ \overline{w}^{i}\ ] \tag{2.8}$$

= virtual displacements at applied concentrated load point $\underline{i}$

$$(\underset{\sim}{f}^{i})^{T} = [\ f_r^{i} \ \ f_z^{i}\ ] \tag{2.9}$$

= applied concentrated load $\underline{i}$

In equation (2.1), the integral subscripts V and S denote volume and surface integrals respectively, and the summation is carried out over all applied load points. The quantities with bars are virtual quantities. The underscore '~' denotes matrix or vector quantities, and the superscript 'T' has the usual meaning of the transpose of a matrix or vector quantity.

In the finite element approximation, the body is divided into a set of subregions or elements interconnected at a finite number of nodal points. The displacements and strains within an element $\underline{m}$ are approximated as functions of the displacements of the nodal points by:

$$\underset{\sim}{u}^{(m)} = \underset{\sim}{H}^{(m)}\ \underset{\sim}{U}^{(m)} \tag{2.10}$$

$$\underset{\sim}{\varepsilon}^{(m)} = \underset{\sim}{B}^{(m)}\ \underset{\sim}{U}^{(m)} \tag{2.11}$$

where

$$(\underset{\sim}{U}^{(m)})^T = [\ u^{(m)} \ \ w^{(m)}\ ] \tag{2.12}$$

= continous displacement field in element m

$$(\underset{\sim}{\varepsilon}^{(m)})^T = [\ \varepsilon_{rr}^{(m)} \ \ \varepsilon_{zz}^{(m)} \ \ \varepsilon_{\theta\theta}^{(m)} \ \ \gamma_{rz}^{(m)}\ ] \tag{2.13}$$

= continous strain field in element m

$$(\underset{\sim}{U}^{(m)})^T = [\ u_1 \ \ w_1 \ \ u_2 \ \ w_2 \ \ u_3 \ \ w_3 \ \ u_4 \ \ w_4] \tag{2.14}$$

= nodal point displacements for the 4 nodes connected to element m

$\underset{\sim}{H}^{(m)}$ = matrix of displacement interpolation functions (discussed in subsequent sections)

and $\underset{\sim}{B}^{(m)}$ = matrix relating element strains to nodal displacements (discussed in subsequent sections)

The stress terms in equation (2.1) can be expressed as a function of the strains in element m:

$$\underset{\sim}{\sigma}^{(m)} = \underset{\sim}{C}^{(m)} \underset{\sim}{\varepsilon}^{(m)} \tag{2.15}$$

where

$\underset{\sim}{\sigma}^{(m)}$ = stress vector for element m

and $\underset{\sim}{C}^{(m)}$ = elasticity matrix for element m (detailed in Table 2.1)

After incorporating equations (2.10), (2.11) and (2.15) into (2.1), evaluating the integrals over the volumes and surfaces of the individual elements, and then summing appropriately (i.e. with a proper mapping between local and global degrees of

$$\underset{\sim}{\sigma}^{(m)} = \underset{\sim}{C}^{(m)} \underset{\sim}{\varepsilon}^{(m)}$$

$$\begin{bmatrix} \sigma_{rr} \\ \sigma_{zz} \\ \sigma_{\theta\theta} \\ \tau_{rz} \end{bmatrix} = \frac{E}{(1+\nu)(1-2\nu)} \begin{bmatrix} (1-\nu) & \nu & \nu & 0 \\ \nu & (1-\nu) & \nu & 0 \\ \nu & \nu & (1-\nu) & 0 \\ 0 & 0 & 0 & \frac{(1-2\nu)}{2} \end{bmatrix} \begin{bmatrix} \varepsilon_{rr} \\ \varepsilon_{zz} \\ \varepsilon_{\theta\theta} \\ \gamma_{rz} \end{bmatrix}$$

TABLE 2.1 LINEAR ELASTIC STRESS-STRAIN RELATIONSHIPS

freedom) over all $\underline{n}$ elements:

$$\underset{\sim}{\bar{U}}^{T} \left\{ \sum_{m=1,2}^{n} \int_{V^{(m)}} (\underset{\sim}{B}^{(m)})^{T} \underset{\sim}{C}^{(m)} \underset{\sim}{B}^{(m)} dV^{(m)} \right\} \underset{\sim}{U}$$

$$= \underset{\sim}{\bar{U}}^{T} \left\{ \sum_{m=1,2}^{n} \int_{V^{(m)}} (\underset{\sim}{H}^{(m)})^{T} \underset{\sim}{f}^{b(m)} dV^{(m)} \right\} \qquad (2.16)$$

$$+ \underset{\sim}{\bar{U}}^{T} \left\{ \sum_{m=1,2}^{n} \int_{S^{(m)}} (\underset{\sim}{H}^{s(m)})^{T} \underset{\sim}{f}^{s(m)} dS^{(m)} \right\} + \underset{\sim}{\bar{U}}^{T} \underset{\sim}{F}$$

where

$$\underset{\sim}{H}^{s(m)} = \underset{\sim}{H}^{(m)} \text{ defined over the surface of element } \underline{m}$$

and

$$\underset{\sim}{F}^{T} = [\ f_{1r} f_{1z} \ \ f_{2r} f_{2z} \ \ \ldots\ldots \ \ f_{nr} f_{nz}\ ] \tag{2.17}$$

= vector of applied nodal loads

and all other terms are as defined previously.

Equation (2.16) represents the virtual work expression for the equilibrium of the assemblage of finite elements. If unit virtual displacements are applied to all nodal displacement components in turn, $\underset{\sim}{U}$ becomes the identity matrix and (2.16) can be written as:

$$\underset{\sim}{E} - \underset{\sim}{R}_b = \underset{\sim}{R}_s + \underset{\sim}{F} \tag{2.18}$$

where

$$\underset{\sim}{E} = \{ \sum_{m=1,2}^{n} \int_{V^{(m)}} (\underset{\sim}{B}^{(m)})^{T} \underset{\sim}{C}^{(m)} \underset{\sim}{B}^{(m)} \, dV^{(m)} \} \ \underset{\sim}{U} \tag{2.19}$$

= internal nodal force vector due to the stiffness of the element

$$\underset{\sim}{R}_b = \sum_{m=1,2}^{n} \int_{V^{(m)}} (\underset{\sim}{H}^{(m)})^{T} \underset{\sim}{f}^{b(m)} \, dV^{(m)} \tag{2.20}$$

= nodal body force vector (the dynamic inertial forces in SAMCR)

$$\underset{\sim}{R}_S = \sum_{m=1,2}^{n} \int_{S^{(m)}} (\underset{\sim}{H}^{S(m)})^T \underset{\sim}{f}^{S(m)} \, dS^{(m)} \qquad (2.21)$$

= applied surface pressure nodal load vector

and $\underset{\sim}{F}$ = applied concentrated nodal load vector

Equation (2.18) represents the fundamental governing equation for the equilibrium of the element assemblage and is the basis for the algorithms used in SAMCR.

2.3 Isoparametric Element Formulation

Four-noded quadrilateral isoparametric elements are used in SAMCR. In the isoparametric formulation, the interpolation functions used in $\underset{\sim}{H}^{(m)}$ to relate element displacements to nodal displacements are expressed in terms of the natural a-b coordinate system of the element (see Figure 2.2):

$$u = \sum_{i=1}^{4} h_i \, u_i \qquad (2.22a)$$

$$w = \sum_{i=1}^{4} h_i \, w_i \qquad (2.22b)$$

where

i = local number for element node

u_i, w_i = nodal displacements in global coordinate system

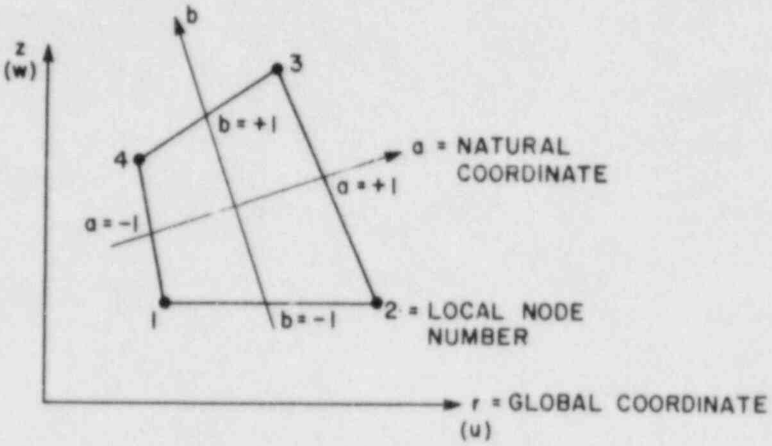


Fig. 2.2. Coordinate system for isoparametric element.

$$h_1 = 1/4\ (1-a)(1-b) \tag{2.23a}$$

$$h_2 = 1/4\ (1+a)(1-b) \tag{2.23b}$$

$$h_3 = 1/4\ (1+a)(1+b) \tag{2.23c}$$

$$h_4 = 1/4\ (1-a)(1+b) \tag{2.23d}$$

In the isoparametric formulation, the same interpolation functions (2.23) are used to express the global coordinates within the element in terms of the nodal coordinate values:

$$r = \sum_{i=1}^{4} h_i\ r_i \tag{2.24a}$$

$$z = \sum_{i=1}^{4} h_i\ z_i \tag{2.24b}$$

in which r_i, z_i are the global coordinates of the element nodes.

In terms of the natural coordinate system and local node numbering scheme for element m, the displacement interpolation relations (2.10):

$$\underset{\sim}{u}^{(m)} = \underset{\sim}{H}^{(m)} \underset{\sim}{U}^{(m)}$$

can be expressed as:

$$\begin{bmatrix} u^{(m)} \\ \\ w^{(m)} \end{bmatrix} = \tfrac{1}{4} \begin{bmatrix} h_1 & 0 & h_2 & 0 & h_3 & 0 & h_4 & 0 \\ \\ 0 & h_1 & 0 & h_2 & 0 & h_3 & 0 & h_4 \end{bmatrix} \begin{bmatrix} u_1 \\ w_1 \\ u_2 \\ w_2 \\ u_3 \\ w_3 \\ u_4 \\ w_4 \end{bmatrix} \qquad (2.25)$$

in which the subscripts on the nodal displacement quantities refer to the local node numbers for element m. Terms in $\underset{\sim}{H}^{(m)}$ corresponding to nodes not connected to the element are zero.

2.4 Element Stiffness Forces

2.4.1 Basic Formulation

The stiffness of each element contributes to the internal element nodal force vector according to the following expression (see also Eq. 2.19):

$$\underset{\sim}{F}^{(m)} = \int_{V^{(m)}} (\underset{\sim}{B}^{(m)})^T \; \underset{\sim}{C}^{(m)} \; \underset{\sim}{B}^{(m)} \; \underset{\sim}{U}^{(m)} \; dV^{(m)} \qquad (2.26)$$

in which $\underset{\sim}{E}^{(m)}$, $\underset{\sim}{U}^{(m)}$ are subvectors corresponding to the degrees of freedom associated with local nodes i=1 to 4, in element $\underline{m}$. Note that in (2.26) the $\underset{\sim}{U}^{(m)}$ vector, a constant, has been brought inside the volume integral.

Because SAMCR uses an explicit time integration scheme starting from known initial conditions (see section 2.9), the global stiffness matrix for the entire system does not need to be calculated. Instead, (2.26) is evaluated for each element in turn and the $\underset{\sim}{E}^{(m)}$ vector for all elements is summed to give the global internal nodal force vector.

Using equations (2.11) and (2.15), equation (2.26) can be expressed as:

$$\underset{\sim}{E}^{(m)} = \int_{V^{(m)}} (\underset{\sim}{B}^{(m)})^T \; \underset{\sim}{\sigma}^{(m)} \; dV^{(m)} \tag{2.27}$$

From (2.10) and (2.11) and the definition of strains, $\underset{\sim}{B}^{(m)}$ can be expressed (in terms of the local element node degrees of freedom) as:

$$\underset{\sim}{B}^{(m)} = \begin{bmatrix} \frac{\partial}{\partial r} & 0 \\ 0 & \frac{\partial}{\partial z} \\ 0 & 0 \\ \frac{\partial}{\partial z} & \frac{\partial}{\partial r} \end{bmatrix} \underset{\sim}{H}^{(m)} \tag{2.28a}$$

or

$$\underset{\sim}{B}^{(m)} = \begin{bmatrix} \frac{\partial h_1}{\partial r} & 0 & \frac{\partial h_2}{\partial r} & 0 & \frac{\partial h_3}{\partial r} & 0 & \frac{\partial h_4}{\partial r} & 0 \\ 0 & \frac{\partial h_1}{\partial z} & 0 & \frac{\partial h_2}{\partial z} & 0 & \frac{\partial h_3}{\partial z} & 0 & \frac{\partial h_4}{\partial z} \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ \frac{\partial h_1}{\partial z} & \frac{\partial h_1}{\partial r} & \frac{\partial h_2}{\partial z} & \frac{\partial h_2}{\partial r} & \frac{\partial h_3}{\partial z} & \frac{\partial h_3}{\partial r} & \frac{\partial h_4}{\partial z} & \frac{\partial h_4}{\partial r} \end{bmatrix} \qquad (2.28b)$$

Note that the third row in $\underset{\sim}{B}^{(m)}$, corresponding to the $\varepsilon_{\theta\theta}$ term in the strain vector, is zero. The $\varepsilon_{\theta\theta}$ term is calculated separately, and its value depends on the type of analysis being performed:

plane stress: $\varepsilon_{\theta\theta} = -\upsilon(\varepsilon_{rr} + \varepsilon_{zz})$ (2.29a)

plane strain: $\varepsilon_{\theta\theta} = 0$ (2.29b)

Since the h_i interpolation fuctions in (2.28b) are functions of the natural coordinates a and b (see Eq. 2.23), the chain rule must be applied to evaluate the derivatives:

$$\begin{bmatrix} \frac{\partial}{\partial a} \\ \\ \frac{\partial}{\partial b} \end{bmatrix} = \underset{\sim}{J}^{(m)} \begin{bmatrix} \frac{\partial}{\partial r} \\ \\ \frac{\partial}{\partial z} \end{bmatrix} \qquad (2.30)$$

in which

$$\underset{\sim}{J}^{(m)} = \begin{bmatrix} \frac{\partial r}{\partial a} & \frac{\partial z}{\partial a} \\ \frac{\partial r}{\partial b} & \frac{\partial z}{\partial b} \end{bmatrix} \tag{2.31}$$

is the Jacobian matrix for element m. The terms in $\underset{\sim}{J}^{(m)}$ can be evaluated using (2.23) and (2.24). Inverting (2.30) produces:

$$\begin{bmatrix} \frac{\partial}{\partial r} \\ \frac{\partial}{\partial z} \end{bmatrix} = \frac{1}{|\underset{\sim}{J}^{(m)}|} \begin{bmatrix} \frac{\partial z}{\partial b} & \frac{-\partial z}{\partial a} \\ \frac{-\partial r}{\partial b} & \frac{\partial r}{\partial a} \end{bmatrix} \begin{bmatrix} \frac{\partial}{\partial a} \\ \frac{\partial}{\partial b} \end{bmatrix} \tag{2.32}$$

in which $|\underset{\sim}{J}^{(m)}|$ is the determinant of $\underset{\sim}{J}^{(m)}$:

$$|\underset{\sim}{J}^{(m)}| = \frac{\partial r}{\partial a}\,\frac{\partial z}{\partial b} - \frac{\partial r}{\partial b}\,\frac{\partial z}{\partial a} \tag{2.33}$$

Using (2.23), (2.24), (2.32), and (2.33), the individual terms in $\underset{\sim}{B}^{(m)}$ (Eq. 2.28b) can be determined. These are given in Table 2.2.

With $\underset{\sim}{B}^{(m)}$ defined, the integral in (2.27) can be evaluated to give the internal nodal force vector for the element. Computationally efficient evaluation of the integral is achieved through use of one-point Gauss quadrature (see for example, Bathe

$$\partial h_1/\partial r = q\ (z_{24} - z_{34}a - z_{23}b)$$

$$\partial h_2/\partial r = q\ (-z_{13} + z_{34}a + z_{14}b)$$

$$\partial h_3/\partial r = q\ (-z_{24} + z_{12}a - z_{14}b)$$

$$\partial h_4/\partial r = q\ (z_{13} - z_{12}a + z_{13}b)$$

$$\partial h_1/\partial z = -q\ (r_{24} - r_{34}a - r_{13}b)$$

$$\partial h_2/\partial z = -q\ (-r_{13} + r_{34}a + r_{14}b)$$

$$\partial h_3/\partial z = -q\ (-r_{24} + r_{12}a - r_{14}b)$$

$$\partial h_4/\partial z = -q\ (r_{13} - r_{12}a + r_{23}b)$$

where

$$q = [\ 8|\underset{\sim}{J}^{(m)}|\ ]^{-1}$$

$$r_{ij} = r_i - r_j$$

$$z_{ij} = z_i - z_j$$

TABLE 2.2 TERMS FOR THE $B^{(m)}$ MATRIX -- EQUATION (2.28b)

and Wilson (1976)), so that

$$\underset{\sim}{E}^{(m)} = 4\ \{\ |\underset{\sim}{J}^{(m)}|\ \underset{\sim}{B}^{(m)}\ \underset{\sim}{\sigma}^{(m)}\ \}_{\substack{a=0\\b=0}} \qquad (2.34)$$

in which the subscripts imply that all matrix terms within the brackets are evaluated at the element center -- i.e. at a=0, b=0 -- before performing the matrix multiplication.

2.4.2 Keystone Mode Stiffness Correction

Exact integration of the terms in (2.27) for the four-node quadrilateral element requires 2 x 2 Gauss quadrature. However, the lower order one-point quadrature scheme is used to obtain good approximations of the integral at a much diminished computational cost, an important consideration given that (2.27) must be integrated for each element, at each time step, in the explicit time integration scheme employed in SAMCR. The computational savings accruing from this reduced order integration are not without penalty however. Reduced integration permits various unrestrained modes of element deformations that would not be possible if exact integration were used. For the four-node isoparametric element, these spurious unrestrained modes are known as "keystone" or "hourglass" deformations because of their characteristic shape, as shown in Figure 2.3. Being unrestrained, these modes will vibrate freely (and possibly in an unstable fashion) during a dynamic analysis unless adequate precautions are taken.

In SAMCR, the approximate stiffness correction proposed by Kosloff and Frazier (1978) is used to eliminate the unrestrained

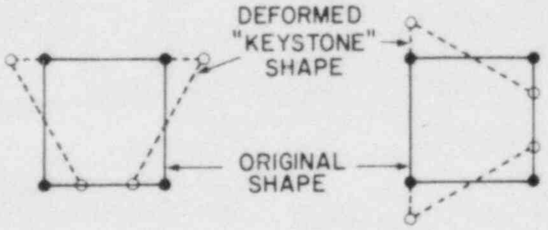


Fig. 2.3. "Keystone" modes of deformation for four-noded isoparametric finite elements.

keystone deformation modes while still permitting use of the simple one-point quadrature scheme. This method is similar to the incompatible displacement model of Wilson et al. (1973). In essence, the keystone modes are treated as pure flexural modes for the element and stiffness terms are derived by relating nodal forces to keystone mode nodal displacements through the analytical solution for the flexural displacement and stress fields in a rectilinear element. These "correction" nodal forces are then added to the nodal forces obtained from (2.27) using one-point quadrature.

The Kosloff and Frazier stiffness correction is preferable to exact integration of (2.27) using 2 x 2 Gauss quadrature for two reasons. First, 2 x 2 Gauss quadrature quadruples the storage requirements and calculation time for the code while the stiffness correction approach adds only a 40% computational overhead with no additional storage. Second, 2 x 2 Gauss quadrature has been found to overestimate the element bending stiffness terms (Wilson et al., 1973) while the Kosloff and Frazier method is based on the correct bending behavior for the element. As an added benefit, the Kosloff and Frazier method is very easy to implement.

Kosloff and Frazier's formulation can be derived as follows. (Kosloff and Frazier's 1978 paper contained several minor errors in their equations; these errors have been corrected here.) Consider the element geometry shown in Figure 2.4 with linearly varying normal tractions on sides $x_1 = \pm \ell_1$. The exact stress and

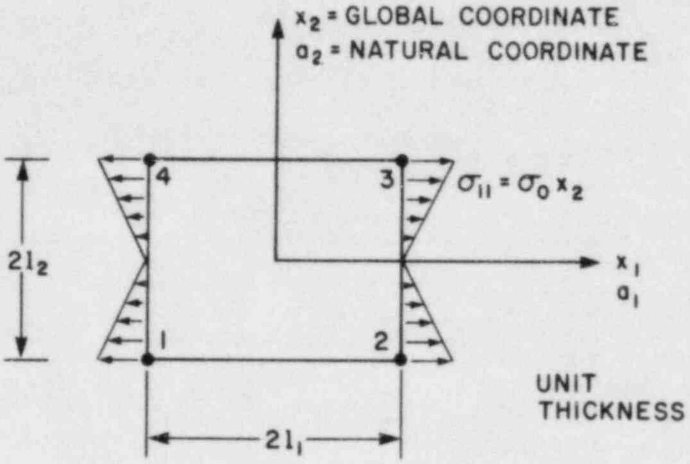


Fig. 2.4. Notation for Kosloff and Frazier's keystone mode stiffness correction.

displacement solutions for the element are:

$$\sigma_{11} = \sigma_0 x_2 \tag{2.35a}$$

$$\sigma_{22} = 0 \tag{2.35b}$$

$$\sigma_{12} = 0 \tag{2.35c}$$

$$u_1 = M^{-1} \sigma_0 x_1 x_2 \tag{2.35d}$$

$$u_2 = 1/2\, M^{-1} \sigma_0 (\ell_1{}^2 - x_1{}^2) \tag{2.35e}$$

where

M = elastic modulus

= E for plane stress

= $E/(1-\nu^2)$ for plane stain

σ_0 = constant with units of force/length^3

The keystone mode nodal displacements in the x_1 direction are obtained by evaluating equation (2.35d) at the element corners:

$$\underset{\sim}{U}_1 = M^{-1} \sigma_0 \ell_1 \ell_2 \underset{\sim}{1} \tag{2.36}$$

where

$\underset{\sim}{1}^T = [\ 1\ -1\ \ 1\ -1\ ]$. Inverting (2.36) gives the value of σ_0 corresponding to a given level of keystone mode deformation:

$$\sigma_0 = \frac{M}{4\ell_1\ell_2}\ \underset{\sim}{1}^T\ \underset{\sim}{U}_1 \qquad (2.37)$$

With σ_0 determined, the normal surface traction σ_{11} can be treated as a known element pressure loading which can be resolved into equivalent nodal forces (see Section 2.7 for details):

$$\underset{\sim}{E}_{k1} = \frac{MV}{48}\ \left\{ \frac{\partial a_1}{\partial x_1} \right\}^2\ \underset{\sim}{1}\ \underset{\sim}{1}^T\ \underset{\sim}{U}_1 \qquad (2.38)$$

in which $\underset{\sim}{E}_{k1}$ represents the keystone mode internal nodal forces in the x_1-direction and V is the element volume.

A similar derivation for σ_{22} surface tractions produces the keystone mode nodal forces in the x_2-direction:

$$\underset{\sim}{E}_{k2} = \frac{MV}{48}\ \left\{ \frac{\partial a_2}{\partial x_2} \right\}^2\ \underset{\sim}{1}\ \underset{\sim}{1}^T\ \underset{\sim}{U}_1 \qquad (2.39)$$

For elements not oriented parallel to the x_1 and x_2 axes, the above equations can be derived for a local x_1', x_2' coordinate system and subsequently transformed to the x_1, x_2 directions. The resulting expression for the keystone mode nodal forces (omitting the intermediate algebra) is:

$$\underset{\sim}{E}_{ki} = \frac{MV}{48} \left\{ \frac{\partial a_1}{\partial x_j}\ \frac{\partial a_1}{\partial x_j} + \frac{\partial a_2}{\partial x_i}\ \frac{\partial a_2}{\partial x_j} \right\}\ \underset{\sim}{1}\ \underset{\sim}{1}^T\ \underset{\sim}{U}_j \qquad (2.40)$$

For nonrectilinear quadrilateral elements, the above scheme must be modified slightly to ensure that the elements pass the standard patch test. As described by Kosloff and Frazier, the $\underset{\sim}{1}^T$ operator must be modified such that: (a) it is orthogonal to the constant strain and rigid body deformation modes for the element, and (b) it degenerates to its previous definition for rectilinear elements. The components d_1, d_2, d_3, and d_4 of the modified $\underset{\sim}{1}^T$ operator are obtained from the solution of the following simultaneous equations:

$$d_4' = 1 \tag{2.40a}$$

$$d_1' + d_2' + d_3' = -1 \tag{2.40b}$$

$$d_1'x_1^1 + d_2'x_1^2 + d_3'x_1^3 = -x_1^4 \tag{2.40c}$$

$$d_1'x_2^1 + d_2'x_2^2 + d_3'x_2^3 = -x_2^4 \tag{2.40d}$$

and

$$d_i = 2\, d_i' \;/\; (\, d_1'^2 + d_2'^2 + d_3'^2 + d_4'^2\,)^{1/2} \tag{2.41}$$

in which x_j^ℓ is the x_j-coordinate of node $\underline{\ell}$. Equations (2.40) represent the orthogonality conditions and (2.41) is a normalization procedure.

The final expressions for the combined $\underset{\sim}{F}_{k1}$ and $\underset{\sim}{F}_{k2}$ keystone mode nodal forces for an arbitrary rectilinear element are given in Table 2.3. These forces must be added to those from (2.34) to obtain the total element stiffness internal nodal forces:

$$\underset{\sim}{F}_s^{(m)} = \underset{\sim}{F}^{(m)} + \underset{\sim}{F}_k^{(m)} \tag{2.42}$$

The total internal nodal force vector due to the element

$$\begin{bmatrix} (E_k)_{r1} \\ (E_k)_{z1} \\ (E_k)_{r2} \\ (E_k)_{z2} \\ (E_k)_{r3} \\ (E_k)_{z3} \\ (E_k)_{r4} \\ (E_k)_{z4} \end{bmatrix} = \frac{MV}{48} \begin{bmatrix} d_1{}^2C_1 & & & & & & & \\ d_1{}^2C_3 & d_1{}^2C_2 & & & & & & \\ d_1d_2C_1 & d_1d_2C_3 & d_2{}^2C_1 & & & \text{(S Y M M E T R I C)} & & \\ d_1d_2C_3 & d_1d_2C_2 & d_2{}^2C_3 & d_2{}^2C_2 & & & & \\ d_1d_3C_1 & d_1d_3C_3 & d_2d_3C_1 & d_2d_3C_3 & d_3{}^2C_1 & & & \\ d_1d_3C_3 & d_1d_3C_2 & d_2d_3C_3 & d_2d_3C_2 & d_3{}^2C_3 & d_3{}^2C_2 & & \\ d_1d_4C_1 & d_1d_4C_3 & d_2d_4C_1 & d_2d_4C_3 & d_3d_4C_1 & d_3d_4C_3 & d_4{}^2C_1 & \\ d_1d_4C_3 & d_1d_4C_2 & d_2d_4C_1 & d_2d_4C_2 & d_3d_4C_3 & d_3d_4C_2 & d_4{}^2C_3 & d_4{}^2C_2 \end{bmatrix} \begin{bmatrix} u_1 \\ w_1 \\ u_2 \\ w_2 \\ u_3 \\ w_3 \\ u_4 \\ w_4 \end{bmatrix}$$

M = elastic modulus (plane stress/strain)

V = element volume = $4A$

d_i = coefficients given in (2.40) and (2.41)

$C_1 = (|\underset{\sim}{J}|)^{-2} \left[\left(\frac{\partial z}{\partial b}\right)^2 + \left(\frac{\partial z}{\partial a}\right)^2\right] = (4A)^{-2} \left[(-z_{14} - z_{23})^2 + (-z_{12} + z_{34})^2\right]$

$C_2 = (|\underset{\sim}{J}|)^{-2} \left[\left(\frac{\partial r}{\partial b}\right)^2 + \left(\frac{\partial r}{\partial a}\right)^2\right] = (4A)^{-2} \left[(-r_{14} - r_{23})^2 + (-r_{12} + r_{34})^2\right]$

$C_3 = -(|\underset{\sim}{J}|)^{-2} \left[\frac{\partial z}{\partial b}\,\frac{\partial r}{\partial b} + \frac{\partial z}{\partial a}\,\frac{\partial r}{\partial a}\right]$

$= -(4A)^{-2} \left[(-z_{14} - z_{23})(-r_{14} - r_{23}) + (-z_{12} + z_{34})(-r_{12} + r_{34})\right]$

$r_{ij} = r_i - r_j$; $z_{ij} = z_i - z_j$; i,j = local element node numbers

$A = |\underset{\sim}{J}|$ and C_1, C_2, C_3 are evaluated at the element center

TABLE 2.3 ELEMENT INTERNAL NODAL FORCES FOR KEYSTONE MODE STIFFNESS CORRECTION stiffness effects is obtained by summing equation (2.42) over all n elements:

$$\underset{\sim}{E} = \sum_{m=1}^{n} \underset{\sim}{E}_s^{(m)} \qquad (2.43)$$

with a proper mapping of local to global degrees of freedom.

2.5 Inertia Forces

As described in Section 2.2, the dynamic inertia forces for element m are included in the nodal body force vector:

$$\underset{\sim}{R}_b^{(m)} = \int_{V^{(m)}} (\underset{\sim}{H}^{(m)})^T \; \underset{\sim}{f}^{b(m)} \; dV^{(m)} \qquad (2.44)$$

In SAMCR, the inertial forces are the only body forces in the system. Using d'Alembert's principle and the second time derivative of (2.10), the inertial body force vector can be expressed as:

$$\underset{\sim}{f}^{b(m)} = - \rho^{(m)} \; \underset{\sim}{H}^{(m)} \; \underset{\sim}{\ddot{U}}^{(m)} \qquad (2.45)$$

in which $\rho^{(m)}$ is the mass density for element m and $\underset{\sim}{\ddot{U}}^{(m)}$ is the vector of nodal accelerations for the nodes connected to element m. Using equations (2.44) and (2.45) and recognizing that $\underset{\sim}{\ddot{U}}^{(m)}$ can be treated as a constant and moved outside the integral:

$$\underset{\sim}{R}_b^{(m)} = - \left\{ \int_V \rho^{(m)} \, (\underset{\sim}{H}^{(m)})^T \, \underset{\sim}{H}^{(m)} \, dV^{(m)} \right\} \underset{\sim}{U}^{(m)} \qquad (2.46)$$

The integral term within the brackets represents the consistent mass matrix for element m:

$$\underset{\sim}{R}_b{}^{(m)} = - \underset{\sim}{M}^{(m)} \; \ddot{\underset{\sim}{U}}^{(m)} \tag{2.47}$$

To minimize the computations at each time step during the explicit time integration, the consistent mass matrix is converted to a lumped mass diagonal matrix by adding the off-diagonal terms to the diagonal terms on a row by row basis. Recognizing that:

$$\sum_{i=1}^{4} h_i = 1 \tag{2.48}$$

the diagonal terms of the lumped mass matrix can be obtained as:

$$m_{ii} = m_{(i+1)(i+1)} = \int_V \rho \, h_\ell \, dV \tag{2.49}$$

in which the subscripts on m denote the row and column number in the element mass matrix and $i = 2\ell-1$, $\ell=1, \ldots 4$. Off-diagonal elements are zero in the lumped mass matrix.

The volume integrals in (2.49) are evaluated exactly using 2 x 2 Gauss quadrature in the natural coordinate system for the element:

$$m_{ii} = m_{(i+1)(i+1)} = \rho \sum_{j=1}^{2} \sum_{k=1}^{2} \alpha_j \, \alpha_k \, (h_\ell)_{jk} \, (|\underset{\sim}{J}|)_{jk} \tag{2.50}$$

where

$\alpha_j = \alpha_k = 1$ = weighting factors

$(h_\ell)_{jk} = h_\ell$ evaluated at $a=a_j$, $b=b_k$

$(|\underset{\sim}{J}|)_{jk} = |\underset{\sim}{J}|$ evaluated at $a=a_j$, $b=b_k$

a_j, b_k = sampling points

$a_1 = b_1 = -a_2 = -b_2 = 0.5773502691$

Performing the operations in (2.50) gives the expressions in Table 2.4 for the terms of the diagonal lumped mass for a plane stress or plane strain element with unit thickness.

$$\underset{\sim}{M} = \begin{bmatrix} m_{11} & 0 & \cdot & \cdot & 0 \\ 0 & m_{22} & & & \\ \cdot & & \cdot & & \cdot \\ & & & \cdot & \\ \cdot & & & \cdot & 0 \\ 0 & \cdot & \cdot & 0 & m_{88} \end{bmatrix}$$

$$m_{11} = m_{22} = \rho\, [\; 3C_1 - C_2 - C_3 \;] \,/\, 24$$

$$m_{33} = m_{44} = \rho\, [\; 3C_1 + C_2 - C_3 \;] \,/\, 24$$

$$m_{55} = m_{66} = \rho\, [\; 3C_1 + C_2 + C_3 \;] \,/\, 24$$

$$m_{77} = m_{88} = \rho\, [\; 3C_1 - C_2 + C_3 \;] \,/\, 24$$

where $C_1 = r_{13}z_{24} - r_{24}z_{13}$

$C_2 = r_{34}z_{12} - r_{12}z_{34}$

$C_3 = r_{23}z_{14} - r_{14}z_{23}$

$r_{ij} = r_i - r_j$

$z_{ij} = z_i - z_j$

TABLE 2.4 ELEMENT LUMPED MASS MATRIX USED IN SAMCR .

With the element mass matrix determined, the inertial nodal forces for the element can be computed from (2.47). The total inertial nodal force vector is obtained by summing (2.47) over all n elements:

$$\underset{\sim}{R}_b = \sum_{m=1}^{n} \underset{\sim}{R}_b^{(m)} \qquad (2.51)$$

As usual, a proper mapping of local to global degrees of freedom is required when performing this summation.

2.6 Viscous Damping Forces

Low levels of viscous damping are often desirable in dynamic analyses for several reasons: (a) to simulate viscoelastic or hysteretic constitutive behavior for the material being analyzed, (b) to smooth discontinuous shock waves that may develop in the analysis, and (c) to reduce the possibility of spurious oscillations and instabilities in the numerical solution. Two viscous damping formulations are incorporated in SAMCR: bulk viscosity for purely volumetric deformation modes and keystone mode viscosity. In both cases, the internal nodal forces due to the viscosity effects are calculated explicitly and added to the internal nodal forces from the element stiffnesses (Section 2.4).

2.6.1 Bulk Viscosity

Due to discontinuous boundary data, solutions to wave propagation problems may develop discontinuous shock waves. These discontinuities create problems in the analysis because the finite element approximation is based on the assumption of smooth variations in the displacement and stress fields.

This problem can be resolved by including an artificial viscosity in the compressive volumetric modes for the element. This bulk viscosity eliminates the mathematical discontinuity by smoothing the shock wave over several elements. Shock waves are thus recognized as very steep but finite gradients in the solution. Some care is required to ensure that the viscous damping terms do not significantly affect the solution at locations other than shock fronts.

In the formulation used in SAMCR, the bulk viscosity effects generate a uniform volumetric pressure, p, given by the following equations (Bertholf and Benzley, 1968):

$$p = \rho A^{1/2} d \left(\frac{1}{\rho}\frac{\partial\rho}{\partial t}\right)\left[B_1^{\,2} A^{1/2} \left(\frac{1}{\rho}\frac{\partial\rho}{\partial t}\right) + B_2 c\right] \text{ for } \frac{1}{\rho}\frac{\partial\rho}{\partial t} > 0 \qquad (2.52a)$$

$$p = 0 \quad \text{for } \frac{1}{\rho}\frac{\partial\rho}{\partial t} < 0 \qquad (2.52b)$$

in which ρ = mass density, A = element area, d = element thickness (equal to 1 in both plane strain and plane stress analyses), c = uniaxial strain sound velocity in the element, and B_1, B_2 = dimensionless viscosity coefficients designed to spread the shock over several elements. Default values of $B_1 = 12.0$ and $B_2 = 0.6$ are used in SAMCR; as a rough guide, the ratio B_1/B_2 should be approximately 20. The mass density rate of change term in (2.52) is calculated from the continuity equation:

$$\frac{1}{\rho}\frac{\partial \rho}{\partial t} + (\dot{\varepsilon}_{rr} + \dot{\varepsilon}_{zz} + \dot{\varepsilon}_{\theta\theta}) = 0 \qquad (2.53)$$

in which $\dot{\varepsilon}_{rr}$, $\dot{\varepsilon}_{zz}$, $\dot{\varepsilon}_{\theta\theta}$ = normal strain rates.

For each element, the internal nodal forces corresponding to the volumetric pressure p are calculated using (2.27) with $\underset{\sim}{\sigma}^T = [-p \quad -p \quad 0 \quad 0]$. (The negative signs are required because compression is positive in Eq. (2.52)). These internal nodal forces are added to the internal nodal forces due to the element stiffness (Section 2.4).

2.6.2 Keystone Mode Viscosity

Keystone mode viscosity effects are treated in a fashion analagous to the keystone mode stiffness correction presented in Section 2.4.2. A linear distribution of normal tractions is applied to the faces of the element; the magnitudes of these tractions are a function of the keystone mode viscosity coefficient and the keystone mode nodal velocities. The resulting internal nodal forces for an element may then be computed using the matrix relations in Table 2.3 with the element nodal displacement vector replaced by the element nodal velocity vector and the scalar multiplicative constant for the coefficient matrix replaced by:

$$\text{constant} = \rho \, (\delta/d) \, c \, B_3 \qquad (2.54)$$

in which ρ = mass density, δ = minimum dimension of element (including diagonals), d = element thickness (assumed equal to 1 for both plane stress and plane strain), c = uniaxial strain sound speed, and B_3 = dimensionless viscosity coefficient. A default value of $B_3 = 0.1$ is used in SAMCR. The keystone mode viscosity internal nodal forces calculated using the above technique are added to the internal nodal forces due to the element stiffness (Section 2.4).

It should be noted that this treatment of keystone mode effects produces a low level of purely artificial viscosity that does not necessarily correlate with any fundamental constitutive properties of the material. The primary purpose of the keystone mode viscosity is to enhance the numerical stability of the dynamic calculations.

2.7 Boundary Conditions

2.7.1 Prescribed Nodal Displacements

As described in Section 2.9, the explicit time integration scheme is based on the calculation of incremental nodal displacements from the nodal accelerations at each time step. Thus, the treatment of prescribed nodal displacement boundary conditions is straightforward; the calculated nodal accelerations in the direction of restraint are set equal to zero at each time step, yielding zero incremental displacements. The displacements at each restrained node remain equal to their initial values.

2.7.2 Applied Nodal Forces

The applied concentrated nodal load vector, $\underset{\sim}{F}$ (2.17), is input at the beginning of the analysis. In the current version of SAMCR, concentrated nodal loads are assumed to be constant with time.

2.7.3 Applied Pressure Loads

The applied surface pressure nodal load vector, $\underset{\sim}{R}_S$ (2.18), is assembled at each time step in SAMCR; thus, pressure loads may be specified as a function of time. As defined in (2.21), $\underset{\sim}{R}_S$ is defined for element $\underline{m}$ as:

$$\underset{\sim}{R}_S = \int_S (\underset{\sim}{H}^S)^T \, \underset{\sim}{f}^S \, dS \tag{2.55}$$

in which $\underset{\sim}{H}^S$ is the subset of $\underset{\sim}{H}$ containing the interpolation function terms for the element side along which the pressure loading $\underset{\sim}{f}^S$ is defined. Without loss of generality, the conditions depicted in Figure 2.5 can be used as an example. A linear normal pressure is acting on the element side between local element nodes 1 and 2. The nodal pressure vector $\underset{\sim}{f}^S$ is then defined as:

$$(\underset{\sim}{f}^S)^T = [\ f_r \quad f_z\ ] \tag{2.56}$$

in which f_r, f_z are the components of the continuous (linear) pressure distribution in the r- and z- directions. the

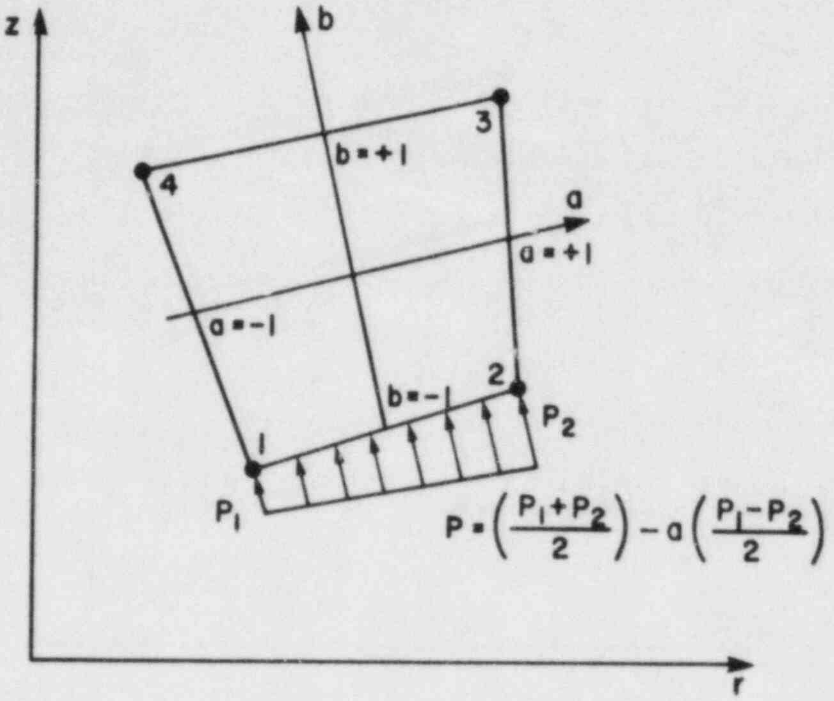


Fig. 2.5. Notation for element pressure loads.

corresponding surface interpolation matrix $\underset{\sim}{H}^S$ is then:

$$\underset{\sim}{H}^S = 1/4 \begin{bmatrix} h_1 & 0 & h_2 & 0 & 0 & 0 & 0 & 0 \\ 0 & h_1 & 0 & h_2 & 0 & 0 & 0 & 0 \end{bmatrix} \quad (2.57)$$

In other words, $\underset{\sim}{H}^S$ is derived from $\underset{\sim}{H}$ by setting equal to zero all terms involving h_3 and h_4, the interpolation functions for nodes 3 and 4, which are not connected to side 1-2. Performing the matrix operations in (2.55) yields:

$$\begin{bmatrix} (R_s)_{r1} \\ (R_s)_{z1} \\ (R_s)_{r2} \\ (R_s)_{z2} \\ (R_s)_{r3} \\ (R_s)_{z3} \\ (R_s)_{r4} \\ (R_s)_{z4} \end{bmatrix} = (1/12) \begin{bmatrix} (z_1-z_2)(4p_1 + 2p_2) \\ (r_2-r_1)(4p_1 + 2p_2) \\ (z_1-z_2)(2p_1 + 4p_2) \\ (r_2-r_1)(2p_1 + 4p_2) \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} \tag{2.58}$$

Expressions for the nodal load vector corresponding to pressure loads on other faces of the element can be derived in a similar manner.

2.7.4 Initial Conditions for Dynamic Calculations

The dynamic calculations in SAMCR require input of the initial nodal displacements and velocities. Initial displacements (and nonzero initial velocities, if required) must be computed using a conventional static finite element code. All analyses at the University of Maryland have employed the finite element program DOASIS (Weiler Research, Inc., Mountain View, CA) for the calculations of the initial conditions. However, any one of the many standard finite element codes available could be adapted for this purpose.

2.8 Fracture Modeling

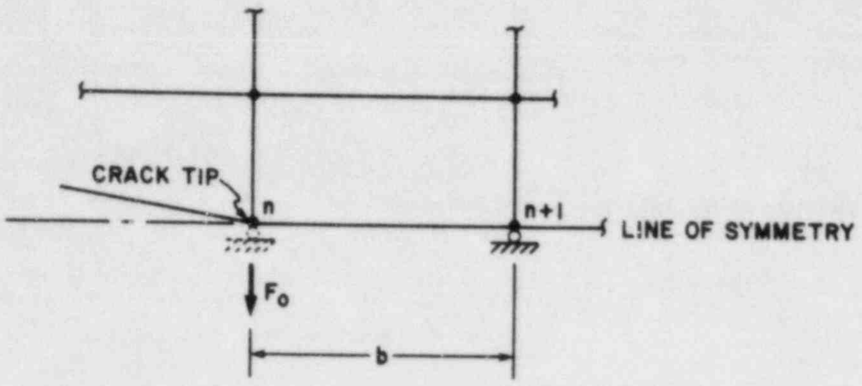
Fracture modeling in SAMCR consists of two major components: (a) simulation of the incremental advance of the crack tip, and (b) calculation of the stress intensity factor at the crack tip, which is used in conjunction with the $\dot{a}$ vs. K fracture constitutive relation to obtain the current crack tip velocity. Each component will be discussed in turn.

2.8.1 Incremental Advance of the Crack Tip

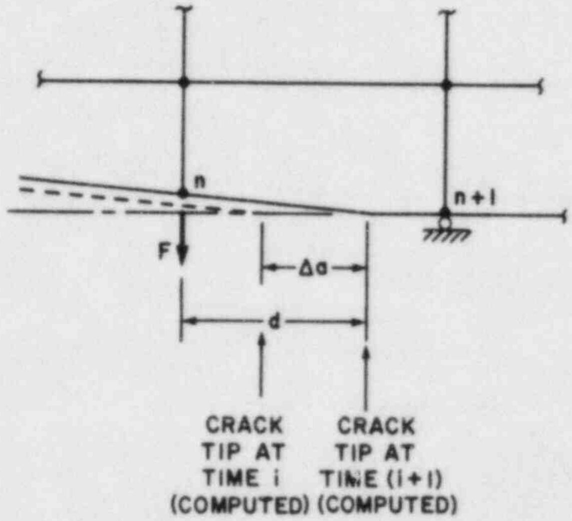
Crack propagation in SAMCR is assumed to occur along the r-axis, an axis of symmetry. Thus, nodes along the crack line ahead of the crack tip are restrained by "roller" boundary conditions (i.e. zero z-displacement); as the crack tip reaches each node in turn, its boundary condition is changed from restrained (in the z-direction) to free.

Because the crack tip will not in general advance from one node to the next in a single time step, a modeling scheme must be devised to simulate an internodal crack tip condition. The modeling scheme employed in SAMCR is the crack tip restraining force approach used previously by several other researchers (e.g. Hodulak, Kobayashi, and Emery, 1980). The simulation of the incremental advance of the crack tip is accomplished as follows (see Figure 2.6):

(a) When the crack tip reaches node n, the z-restraint boundary condition is changed to a free boundary condition (Figure 2.6a). Simultaneously, a nodal



a) CRACK TIP AT NODE n



b) CRACK TIP BETWEEN NODES

Fig. 2.6. Restraining nodal force model for crack advance.

restraining force, F_0, equal to the nodal reaction force prior to release of the z-restraint boundary condition is applied to node n. The net z-displacement at n is zero.

(b) For each subsequent time step, the incremental crack tip advance is calculated as:

$$\Delta a = \dot{a}\,\Delta t \tag{2.59}$$

in which $\dot{a}$ is obtained from the specified $\dot{a}$ vs. K relationship for the material and the known current value for K (see next section for details of K calculation). The computed total crack length is updated using the value of Δa from (2.59).

(c) After each computed increment of crack advance, the crack tip restraining force is modified based on the new tip location, d, relative to the internode spacing, b, (see Figure 2.6b):

$$F = f\ (\ F_o,\ d/b\ ) \tag{2.60a}$$

The current version of SAMCR employs a linear decay of the crack tip restraining force:

$$F = F_o\ [\ 1 - (d/b)\ ] \tag{2.60b}$$

(d) Steps (b) and (c) are repeated for each time step until the computed crack tip location is at the next node <u>n+1</u>, at which point F equals zero; the entire cycle (a)-(d) is then repeated. Note that the time step size for the last increment of crack advance is automatically adjusted to avoid overshooting node <u>n+1</u>.

2.8.2 Stress Intensity Calculation

The stress intensity factor at the crack tip is obtained from a J-integral calculation using concepts from linear elastic fracture mechanics. In the formulation employed in SAMCR, the J-integral is defined as a pure contour integral along the rectangular counterclockwise contour Γ (see Figure 2.7):

$$J = \int_{\Gamma} [W_e + W_k) \, dz - \vec{T} \cdot \frac{\partial \vec{u}}{\partial x}) \, d\Gamma] \qquad (2.61)$$

in which:

$$W_e = 1/2(\sigma_{rr}\varepsilon_{rr} + \sigma_{zz}\varepsilon_{zz} + \tau_{rz}\gamma_{rz}) \qquad (2.62a)$$

= elastic strain energy density (2-D formulation)

$$W_k = 1/2 \, \rho(\dot{u}^2 + \dot{w}^2) \qquad (2.62b)$$

= kinetic energy density

$$\vec{T} = [\sigma_{rr} \; \sigma_{zz} \; \tau_{rz}] \qquad (2.62c)$$

= traction vector

$$\vec{u} = [u \; w] \qquad (2.62d)$$

= displacement vector

For linearly elastic materials, Hooke's law can be employed and the elastic strain energy density can be expressed as:

$$W_e = \frac{(\sigma_{rr} + \sigma_{zz})^2}{2E} + \frac{(1+\nu)(\tau_{rz}^2 - \sigma_{rr}\sigma_{zz})}{E} \qquad (2.63a)$$

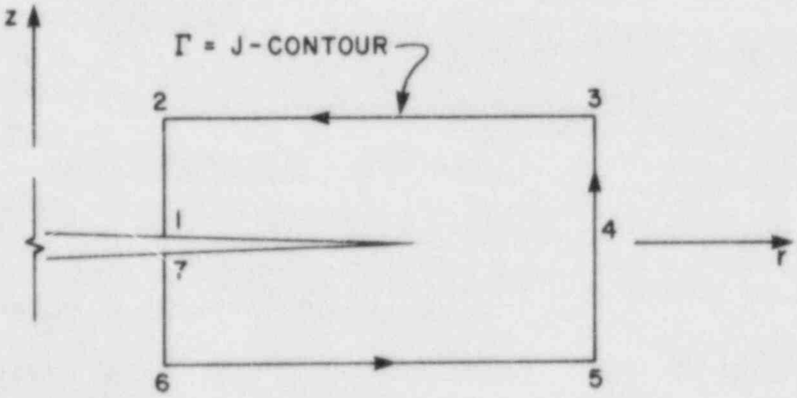


Fig. 2.7. Contour geometry for J-integral calculation.

for plane stress and

$$W_e = \frac{(1-\nu^2)(\sigma_{rr} + \sigma_{zz})^2}{2E} + \frac{(1+\nu)(\tau_{rz}{}^2 - \sigma_{rr}\sigma_{zz})}{E} \quad (2.63b)$$

for plane strain.

From symmetry considerations, only one half of the contour Γ (from points 1 to 4 in Figure 2.7) need be considered in evaluating (2.61); the value of J is equal to twice the value calculated along the half contour. Thus, using (2.62) and (2.63) the integral expression for J (2.61) can be expressed as:

$$\begin{aligned} J = \int_{\Gamma_1} & \frac{\eta(\sigma_{rr} + \sigma_{zz})^2}{2E} + \frac{2(1+\nu)(\tau_{rz}{}^2 - \sigma_{rr}\sigma_{zz})}{E} \\ & + \rho(\dot{u}^2 + \dot{w}^2) - \sigma_{rr}\varepsilon_{rr} - \tau_{rz}\frac{\partial w}{\partial z} \quad |dz| \\ - \int_{\Gamma_2} & 2\tau_{rz}\varepsilon_x + 2\sigma_{zz}\frac{\partial v}{\partial x} \quad |dx| \qquad (2.64) \\ - \int_{\Gamma_3} & \frac{\eta(\sigma_{rr} + \sigma_{zz})^2}{2E} + \frac{2(1+\nu)(\tau_{rz}{}^2 - \sigma_{rr}\sigma_{zz})}{E} \\ & + \rho(\dot{u}^2 + \dot{w}^2) - \sigma_{rr}\varepsilon_{rr} - \tau_{rz}\frac{\partial w}{\partial z} \quad |dz| \end{aligned}$$

in which Γ_1 = contour between points 3 and 4, Γ_2 = contour between points 2 and 3, Γ_3 = contour between points 1 and 2, and $\eta = 1$ for plane stress, $(1-\nu^2)$ for plane strain.

After J is determined using (2.64), it is set equal to the energy release rate G and the stress intensity factor K is calculated from the standard relations:

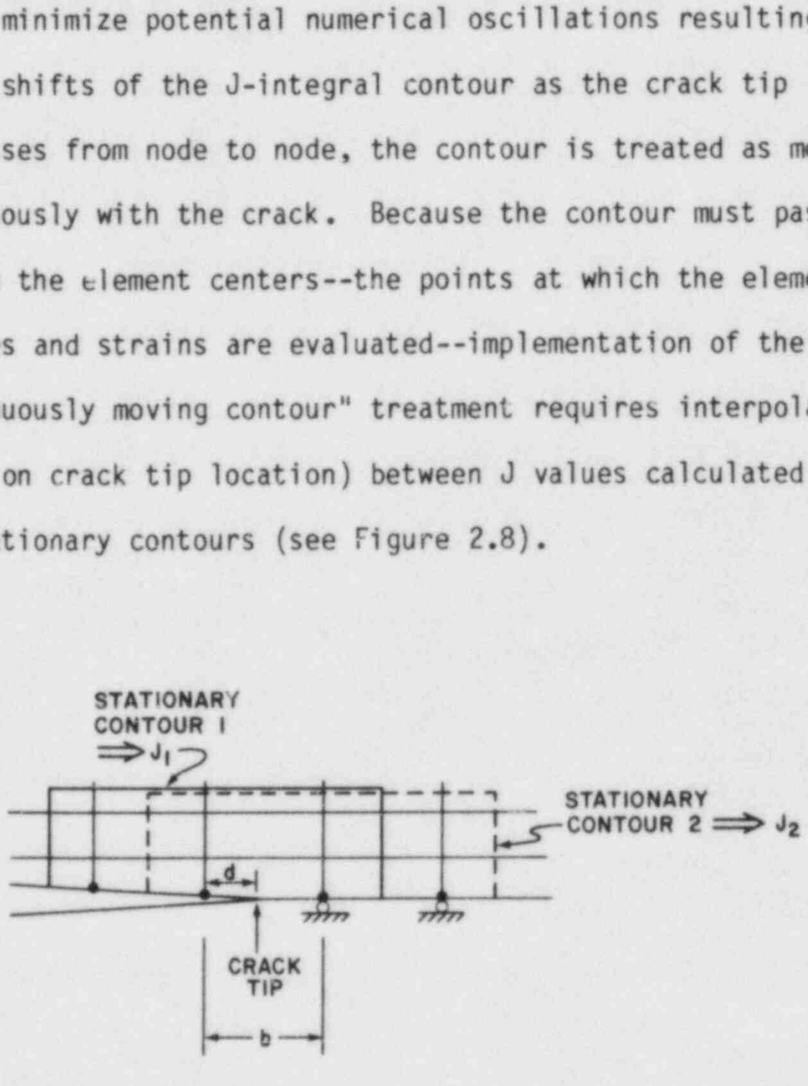
$$K = [\ EG\ ]^{1/2} \quad \text{for plane stress} \tag{2.65a}$$

$$K = [\ EG/(1-\nu^2)\ ]^{1/2} \quad \text{for plane strain} \tag{2.65b}$$

This value of K is used with the prescribed $\dot{a}$ vs. K relation for the material (at a given temperature) to determine the crack tip velocity.

It should be noted here that the J-integral formulation given by (2.61) is in essence a near-field formulation that is strictly valid only for the case of constant-velocity crack propagation, with J being calculated by integrating terms only along the specified contour. For nonconstant velocity situations, a more rigorous formulation for J would include the influence of inertia terms integrated over the area enclosed by the contour (see, for example, Kishimoto et al., 1980). However, the crack tip restraining force scheme used in SAMCR to model crack advance between nodes introduces a local perturbation in the displacement, velocity, and acceleration fields near the crack tip which precludes the accurate computation of the area integral terms. These terms are thus neglected in the J-integral calculation. Consequently, when evaluating J along a contour it is necessary that the contour be close enough to the crack tip so that the area integral terms are negligibly small while at the same time the contour must be sufficiently far enough away that local perturbations of displacements and accelerations near the crack tip restraining force do not affect the calculations. Sensitivity studies have been performed to provide guidelines for proper contour geometry; the results from these studies are presented in Chapter 3.

To minimize potential numerical oscillations resulting from abrupt shifts of the J-integral contour as the crack tip progresses from node to node, the contour is treated as moving continuously with the crack. Because the contour must pass through the element centers--the points at which the element stresses and strains are evaluated--implementation of the "continuously moving contour" treatment requires interpolation (based on crack tip location) between J values calculated for two stationary contours (see Figure 2.8).



$$J = J_1 + \frac{d}{b}(J_2 - J_1)$$

Fig. 2.8. Interpolation scheme for "continously-moving" J-contour.

Finally, since the advance of a real crack front is uniform only in an average sense, with the actual advance being the cumulative result of local incremental cleaving and tearing along microsections of the crack front, it is unreasonable to assume that the average K-value along the entire crack front can change abruptly in very short time periods that are less than the time required for one section of the crack front to communicate with another through shear waves. To reflect this "averaging" of K-values that takes place physically, a smoothing algorithm has been incorporated in SAMCR, with the K-value at any time step being taken as the moving average of the K-values over several preceding time steps.

2.9 Time Integration Algorithm

SAMCR is based on a lumped mass, explicit time integration solution algorithm for the initial value-boundary value dynamic problem. The major advantage of this algorithm is that the total set of equilibrium equations corresponding to the total degrees of freedom in the system does not need to be solved simultaneously at any point during the analysis. This results in a substantial reduction in the amount of computations and the required memory for the program.

The basic equation for the time integration calculations is obtained from (2.18), (2.47) and (2.51):

$$\ddot{\underset{\sim}{U}} = \underset{\sim}{M}^{-1} \left[\underset{\sim}{R}_s + \underset{\sim}{F} - \underset{\sim}{E} \right] = \underset{\sim}{M}^{-1} \underset{\sim}{F}_u \tag{2.66}$$

in which $\underset{\sim}{M}$ is the diagonal lumped mass matrix, $\underset{\sim}{R}_s$ and $\underset{\sim}{F}$ are the applied load vectors (pressure and concentrated), $\underset{\sim}{E}$ is the internal nodal force vector from the element stiffness and viscosity effects, and $\underset{\sim}{F}_u = [\underset{\sim}{R}_S + \underset{\sim}{F} - \underset{\sim}{E}]$ is the unbalanced nodal force vector. The steps in the explicit time integration are:

(1) At time step i, compute $\underset{\sim}{F}_u = \underset{\sim}{R}_S + \underset{\sim}{F} - \underset{\sim}{E}$ based on the current values of the loads, element stresses, and element viscosity forces.

(2) Compute the stress intensity factor, crack tip velocity, and crack advance based on conditions at time step i; modify $\underset{\sim}{F}_u$ to reflect the new value for the crack tip restraining force corresponding to this crack advance.

(3) Using (2.66), compute the nodal accelerations ${}^{(i)}\ddot{\underset{\sim}{U}}$ for time step i.

(4) Compute the nodal velocities for time step i+1:

$$ {}^{(i+1)}\dot{\underset{\sim}{U}} = {}^{(i)}\dot{\underset{\sim}{U}} + {}^{(i+1)}\ddot{\underset{\sim}{U}}\,\Delta t \qquad (2.67) $$

(5) Compute the nodal displacements for time step i+1:

$$ {}^{(i+1)}U = {}^{(i)}U + 0.5\,[\,{}^{(i)}\dot{U} + {}^{(i+1)}\dot{U}\,]\,\Delta t \qquad (2.68) $$

The explicit time integration scheme in SAMCR is only conditionally stable; thus, some care must be exercised in the selection of an appropriate time step. An automatic time step selection algorithm is included in SAMCR. In this algorithm, the critical time step, Δt_{cr}, is evaluated as (Richtmeyer and Morton, 1967):

$$ \Delta t_{cr} = \frac{\delta}{B_2 c + B_1{}^2 \delta \left|\frac{1}{\rho}\frac{\partial\rho}{\partial t}\right| + \left\{\left[B_2 c + B_1{}^2 \delta \left|\frac{1}{\rho}\frac{\partial\rho}{\partial t}\right|\right]^2 + c^2\right\}^{1/2}} \qquad (2.69) $$

in which δ = minimum element dimension, c = uniaxial strain sound speed, ρ = mass density, and B_1, B_2 = bulk viscosity coefficients (see Section 2.6). All elements within the mesh are evaluated to determine the smallest value for Δt_{cr}. The actual time step size for the time integration calculations is taken as 0.9 Δt_{cr}.

2.10 Thermal Effects

The SAMCR code has the ability to predict dynamic fracture propagation behavior for problems with a steady state temperature gradient. Incorporation of thermal effects in SAMCR requires two modifications to the basic mathematical formulation described in the preceding sections. First, in a thermal analysis the initial displacement field will contain a thermal expansion component. In order to calculate the elastic mechanical strains from this initial displacement field, the thermal strains must be subtracted from the total strains:

$$(\varepsilon_{ii})_e = \varepsilon_{ii} - (\varepsilon_{ii})_T \tag{2.70}$$

where ε_{ii} are the total normal strains obtained from the displacement field, $(\varepsilon_{ii})_T$ are the normal thermal strains computed using the standard relation $(\varepsilon_{ii})_T = -\alpha\Delta T$ in which α is the coefficient of thermal expansion and ΔT is the change in temperature from the reference condition, and $(\varepsilon_{ii})_e$ are the elastic normal strains.

The elastic normal strains are used for all stress and J-integral calculations in SAMCR. Because an incremental strain formulation is employed in SAMCR, the thermal strain correction only needs to be applied to the initial displacement condition; incremental strains will contain only the elastic component.

The second modification for thermal effects in SAMCR consists of a specification of the crack tip velocity vs. stress intensity factor constitutive behavior as a function of temperature. This is accomplished by specification of a set of crack tip velocity vs. stress intensity factor curves, each for a given temperature value. Linear interpolation is used to obtain data lying between curves. Details of the temperature vs. crack tip velocity vs. stress intensity factor input specification are given in Section 15 of Appendix II.

2.11 Static Analysis Using Dynamic Relaxation

Static problems can be analyzed using the dynamic relaxation algorithm in SAMCR. Dynamic relaxation simply consists of iteratively performing the conventional dynamic calculations on the unbalanced internal nodal forces in the static problem until the accelerations are negligibly small. Convergence is based on the Euclidean norm of the displacement vector:

$$\frac{\sum_{n=1}^{N} [u_n(j+1) - u_n(j)]^2}{\sum_{n=1}^{N} [u_n(j+1)]^2} \tag{2.71}$$

in which $u_n(j+1)$ are the nodal displacements at iteration cycle j+1, $u_n(j)$ are the nodal displacements at iteration cycle j, and N is the total number of degrees of freedom in the system.

CHAPTER 3

PROGRAM VERIFICATION

3.1 Introduction

An extensive series of verification and sensitivity analyses were performed to evaluate the performance and accuracy of the SAMCR computer code. These analyses can be grouped into four categories:

(a) Comparisons with simple analytical solutions and with other numerical solutions reported in the literature.

(b) Comparisons with photoelastic experimental studies of fracture propagation in Modified Compact Tension specimens (no thermal effects).

(c) Sensitivity studies (based on the MCT specimen geometry).

(d) Comparisons with results from the Oak Ridge Thermal Shock Experiments using A508 steel cylinders.

It should be noted that analyses in categories (b) and (c) are related and were performed, in part, simultaneously.

3.2 Comparisons with Analytical and Other Numerical Solutions

3.2.1 Impulse-Loaded Uncracked Steel Plate

A series of analyses of impulse-loaded uncracked steel plates were performed to verify the basic dynamic algorithms in SAMCR in the absence of any fracture effects. Two finite element meshes were studied: Mesh 1 (Figure 3.1a) consisted of a regular mesh of rectangular quadrilateral elements, while Mesh 2 (Figure 3.1b)

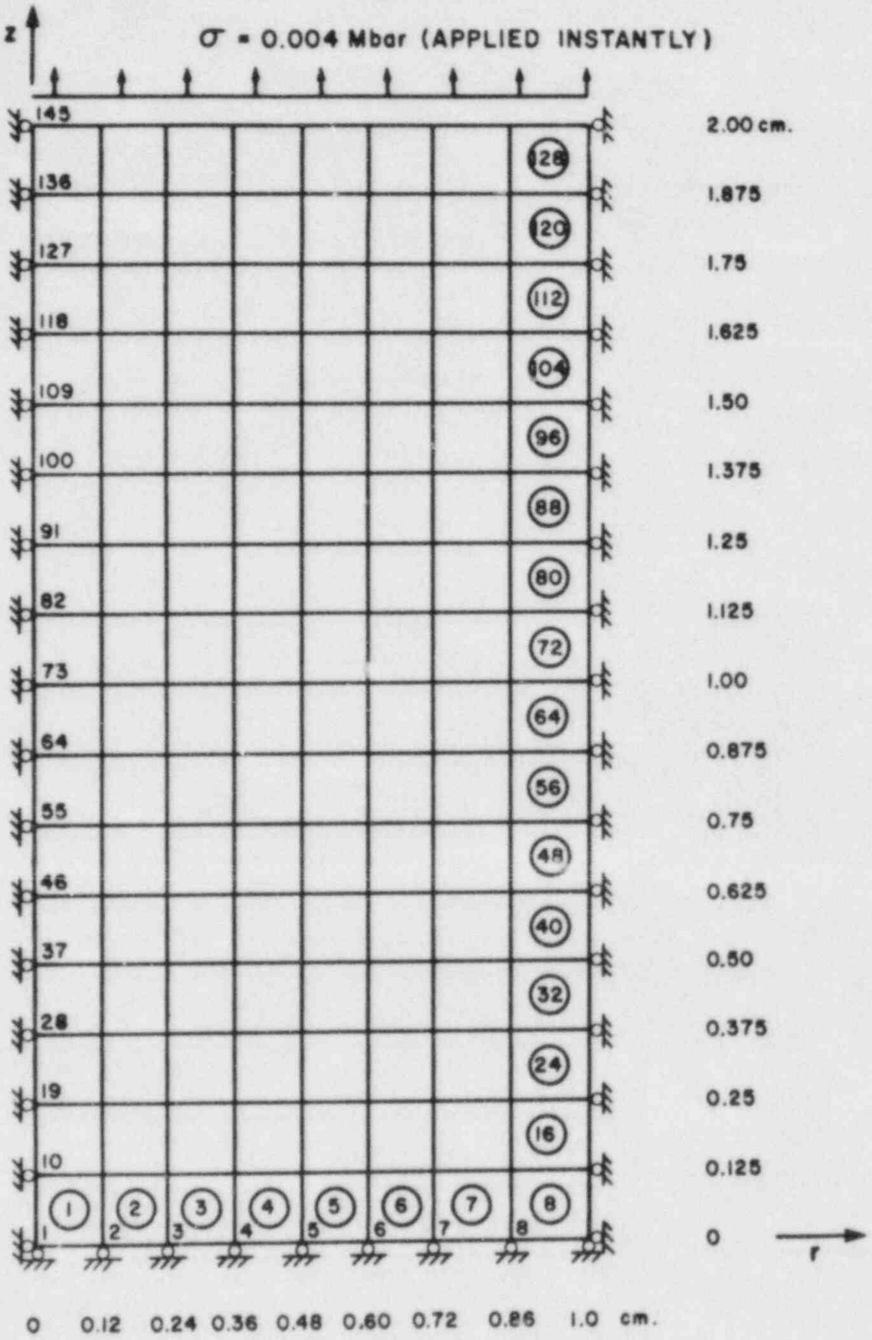


Fig. 3.1(*a*). Mesh 1 (rectangular quadrilateral finite elements) used to model the impulse-loaded uncracked plate.

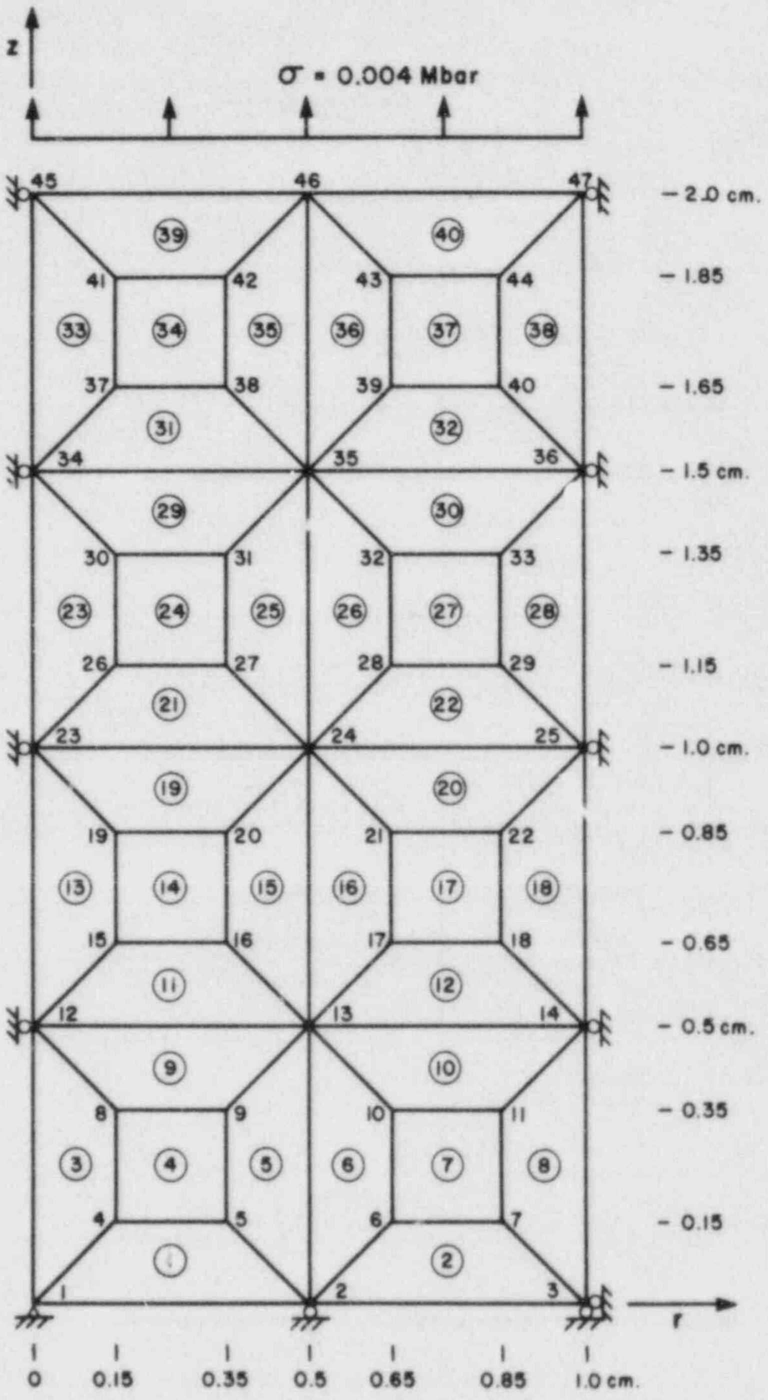


Fig. 3.1(*b*). Mesh 2 (rectangular and trapezoidal finite elements) used to model the impulse-loaded uncracked plate.

consisted of both rectangular and trapezoidal quadrilateral elements. Mesh 2 was devised primarily to test the keystone mode stiffness algorithms in SAMCR. Both meshes were modeled assuming plane strain conditions.

The material properties assumed in these analyses are summarized in Table 3.1. Loading consisted of a 400 MPa uniform tensile stress applied instantaneously to the top of the plate at t=0 and held constant thereafter.

A36 Steel

$E = 200$ GPa

$\nu = 0.3$

$\rho = 0.005$ Gigagrams/m^3

TABLE 3.1 MATERIAL PROPERTIES USED FOR VERIFICATION ANALYSES

As shown in Figure 3.2, the results from these analyses followed the expected sinusoidal variation with time. For both meshes, the computed displacement of the loaded edge and period of the response differed by less than 5% and 1% from the theoretical values, respectively (see Table 3.2). The amplitude of the response decayed slightly with time due to the low (default) levels of viscous damping built into the code. The maximum decay was less than 2% per response cycle in both cases.

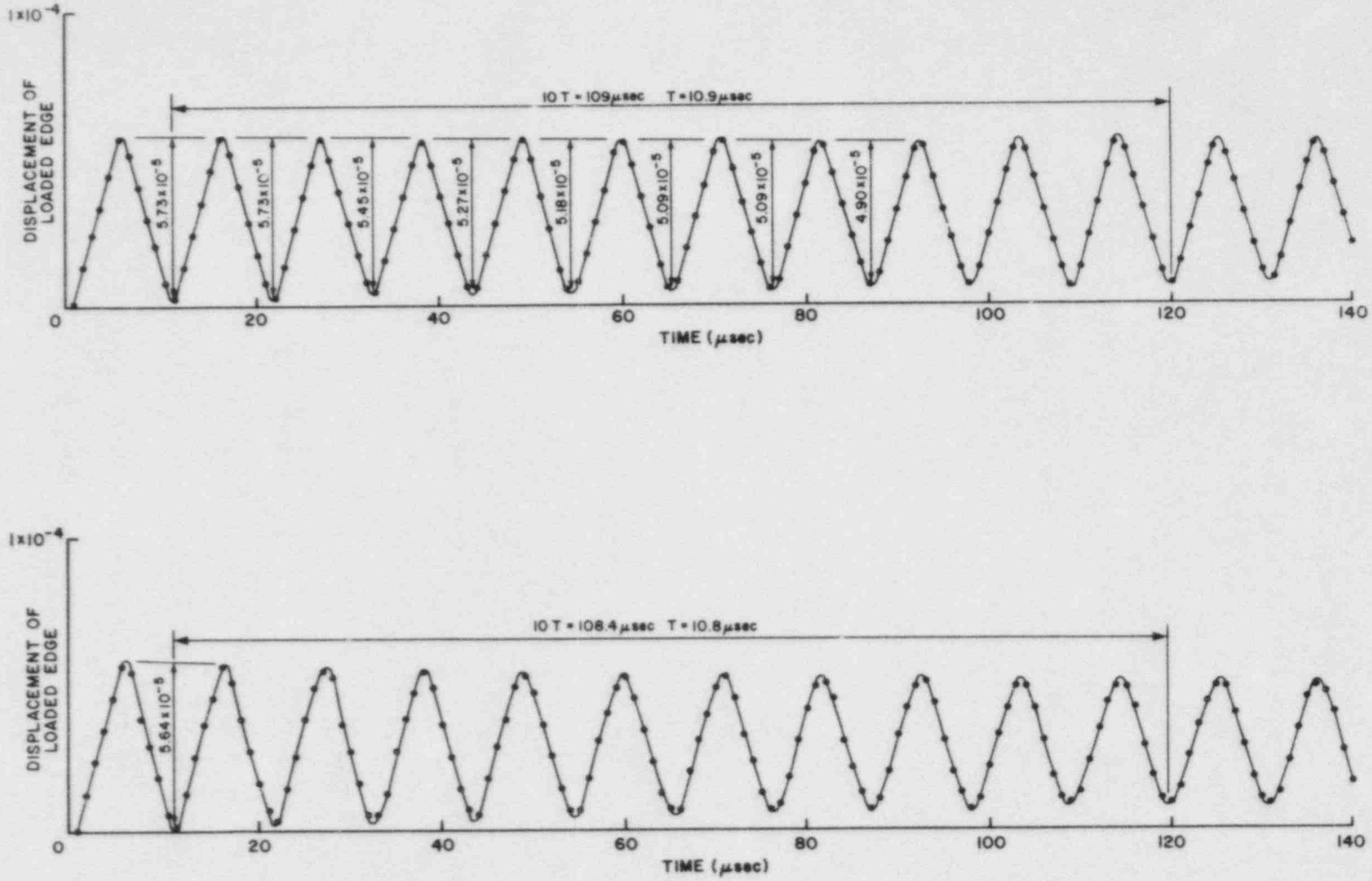


Fig. 3.2. Displacement response of the loaded edge of an impulse-loaded uncracked plate obtained using SAMCR and the finite element meshes shown in Fig. 3.1(*a*) and 3.1(*b*).

	Maximum Displacement of Loaded Edge	Period
Mesh 1	0.0573 mm	10.9 μsec
Mesh 2	0.0564 mm	10.8 μsec
Theoretical	0.0594 mm	10.9 μsec

TABLE 3.2 ANALYSIS RESULTS--IMPULSE-LOADED UNCRACKED STEEL PLATE

3.2.2 Impulse-Loaded Cantilever Beam

In order to test the accuracy of the keystone mode stiffness algorithm under a strong bending deformation field, a cantilever beam subjected to an impulse pressure loading was analyzed. The beam consisted of a single row of finite elements (Figure 3.3) and was modeled assuming plane stress conditions with unit (1 meter) thickness.

The elastic properties used for the cantilever beam were the same as those used for the uncracked plate (Table 3.1). Loading consisted of a 0.8333 MPa uniform pressure applied instantaneously to the top of the beam at t=0 and held constant thereafter. The theoretical static tip deflection of the beam

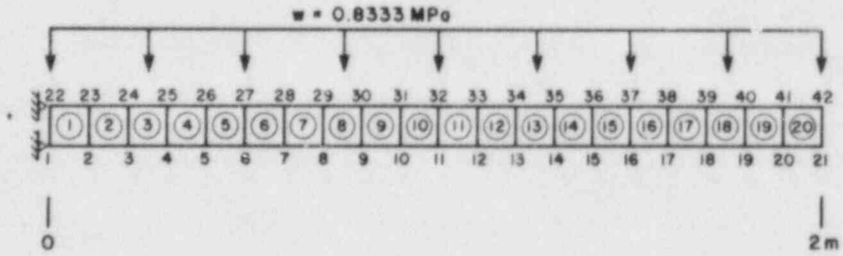


Fig. 3.3. Finite element mesh used to model the cantilever beam problem.

under this load is 0.1 meter; the theoretical maximum dynamic tip deflection is 0.2 meter.

Despite the extreme coarseness of the mesh, the calculated sinusoidal response (see Figure 3.4) was in excellent agreement with theory. The calculated period differed from the theoretical value by 0.26% and the calculated maximum tip deflection differed from the theoretical value by 1.5% (see Table 3.3).

3.2.3 Impulse-Loaded Plate with a Central, Stationary Crack

An impulse-loaded plate with a central, stationary (i.e., non-propagating) crack has been analyzed previously by many researchers, including: Chen (1974), using finite difference

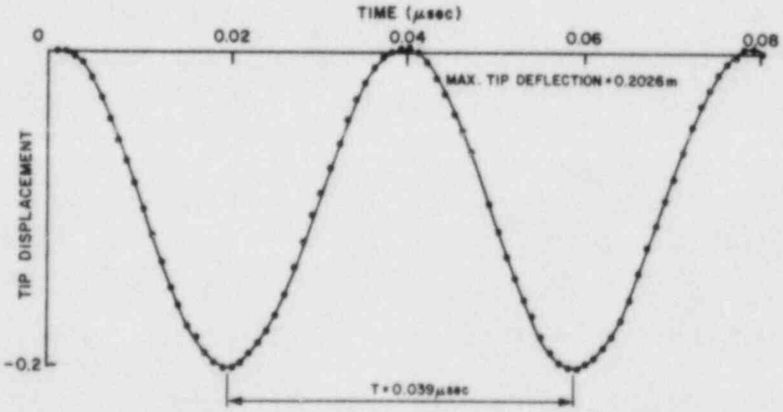


Fig. 3.4. SAMCR results for the tip deflection of the impulse-loaded cantilever beam shown in Fig. 3.3.

	Maximum Tip Deflection	Period
SAMCR	0.203 m	0.0390 sec
Theoretical	0.200 m	0.0391 sec

TABLE 3.3 ANALYSIS RESULTS FOR IMPULSE-LOADED CANTILEVER BEAM

techniques; Anderson et al. (1975), using a singularity element finite element formulation; and Ahmad et al. (1983), using a J-integral finite element formulation. An analytical solution to this problem has also been presented by Thau and Lu (1971), but is valid only for time durations less than the time required for a P-wave to travel across the total crack length.

The problem geometry and the mesh used to model this problem with SAMCR are shown in Figure 3.5. Because of symmetry, only one quadrant of the problem was modeled. Material properties used for this analysis were the same as those given in Table 3.1. Loading consisted of a 400 Mpa tensile stress applied instantaneously to the top of the plate at t=0 and held constant thereafter.

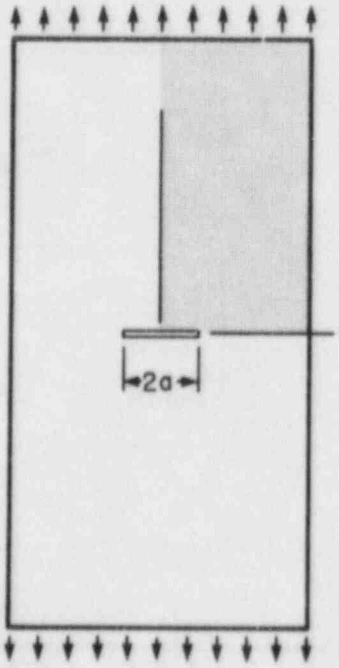


Fig. 3.5(*a*). The geometry of the impulse-loaded plate with a stationary central crack analyzed using SAMCR for comparison with the results from other researchers.

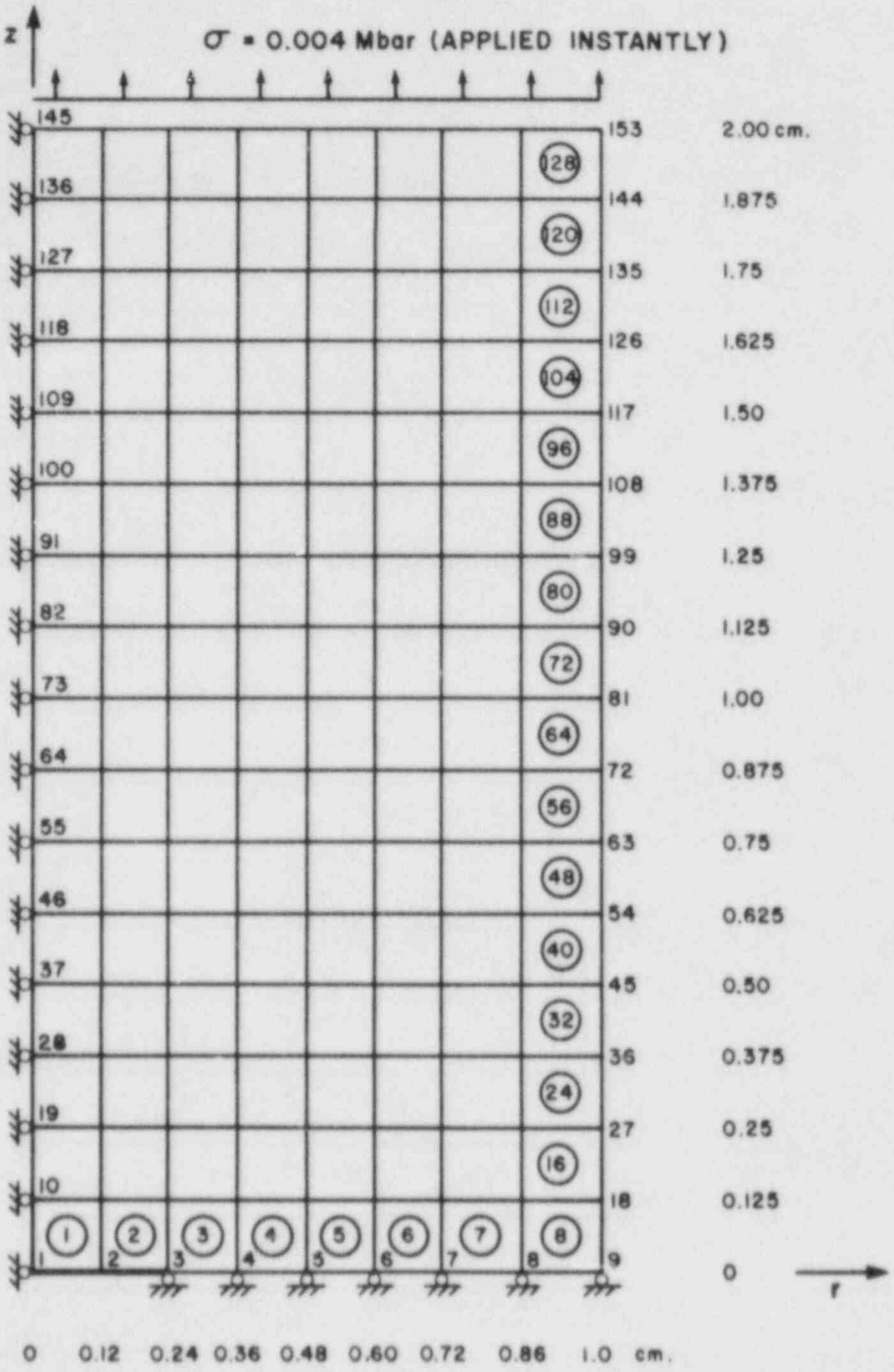


Fig. 3.5(*b*). Finite element mesh used to model one-quarter of the impulse-loaded plate with a stationary central crack.

The K vs. time response from SAMCR, Chen (1974), and Anderson et al. (1975) are compared in Figure 3.6. The agreement among all three sets of data is very good. The maximum K value from SAMCR is approximately 7.5% lower than that from Anderson et al., and approximately 9% lower than that from Chen. The most probable cause for these discrepancies is the relatively coarse mesh (153 nodes and 128 elements) used in the SAMCR analysis. Chen's results are from a finite difference solution with 5000 nodal points, and the analysis by Anderson et al. is based on a singularity element formulation which incorporates the exact solution for the crack tip region.

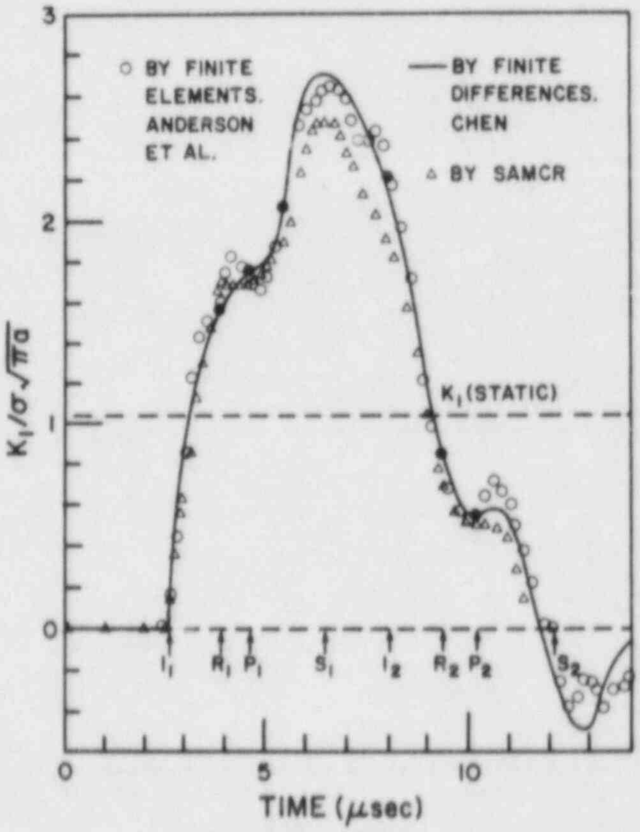
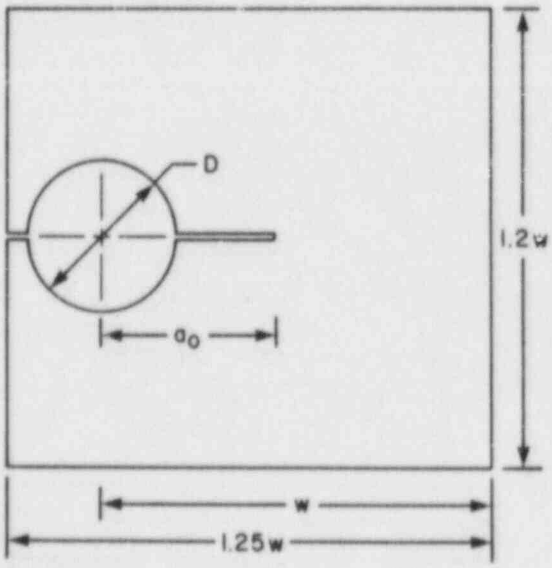


Fig. 3.6. Comparison of results for the problem geometry of Fig. 3.5 obtained by Chen, Anderson, et al., and SAMCR.

3.3 Comparisons with Photoelastic Experimental Results

To evaluate the accuracy of SAMCR for non-stationary crack problems, several analyses of modified compact tension (MCT) Homalite 100 specimens were performed. Photoelastic experimental results for these cases were available for comparison (Irwin et al., 1980).

The geometry of the MCT specimen is shown in Figure 3.7. The initial crack length, a_0/w, equaled 0.44 in all cases and the specimen thickness was 12.7 mm. All specimens were of Homalite 100 with an aluminum split-D pin and wedge arrangement for applying the initial load.



w = 203.2 mm (8.0 inches)
D = 76.2 mm (3.0 inches)
a_0 = 88.9 mm (3.5 inches)

Fig. 3.7. Geometry and dimensions of the Homalite 100 Modified-Compact-Tension specimen used in photoelastic experiments.

The finite element mesh used to analyze the MCT specimens is shown in Figure 3.8. Because of symmetry, only one-half of the specimen was modeled. The aluminum split-D pin was assumed to be a fixed z-displacement boundary condition after application of the wedge load. The split-D pin was also assumed to be perfectly bonded to the Homalite 100, thus neglecting any Hertzian indentation effects. Properties for the Homalite 100 and aluminum are summarized in Table 3.4 and the crack tip velocity vs. stress intensity factor relationship used for Homalite 100 is shown in Figure 3.9. Additional input parameters assumed in the SAMCR analyses included: default viscosity levels; linear crack restraining force decay; J-integral contour parameters NNN=3, NL=2, NL=6 (see Appendix II, Section 13 for an explanation of these variables); no K-smoothing; and no strain-rate effects.

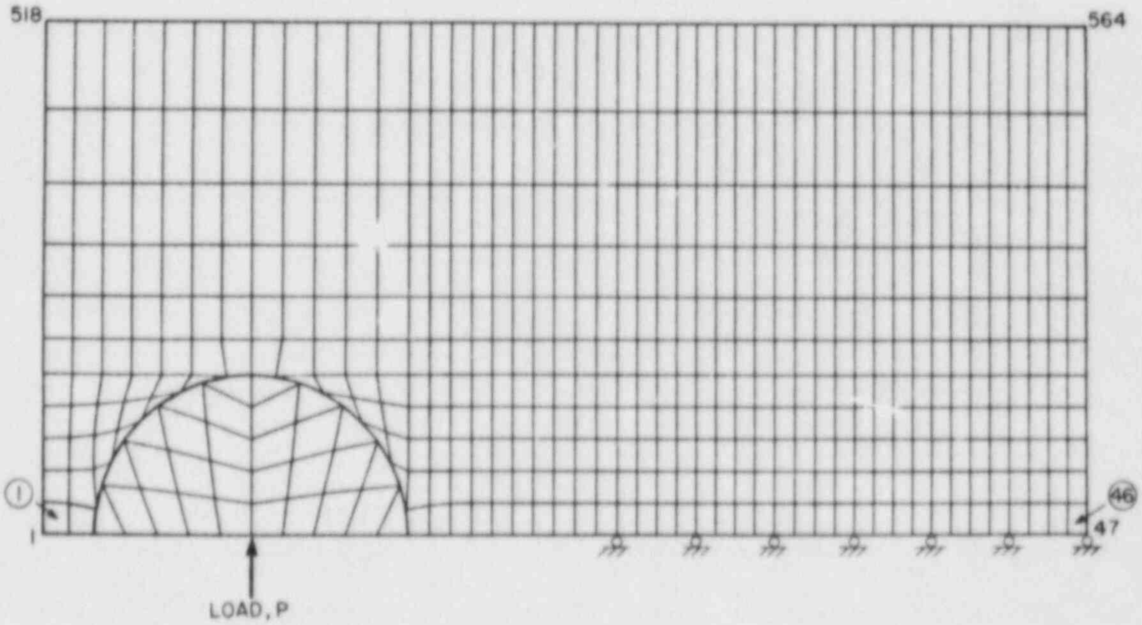


Fig. 3.8. Finite element mesh used to model the upper half of the Homalite 100 MCT specimen for analysis using SAMCR.

Homalite 100

$E = 3.59$ GPa

$\nu = 0.35$

$\rho = 0.0012$ Gigagrams/m^3

Aluminum

$E = 100$ GPa

$\nu = 0.31$

$\rho = 0.0027$ Gigagrams/m^3

TABLE 3.4 MATERIAL PROPERTIES FOR MCT ANALYSES

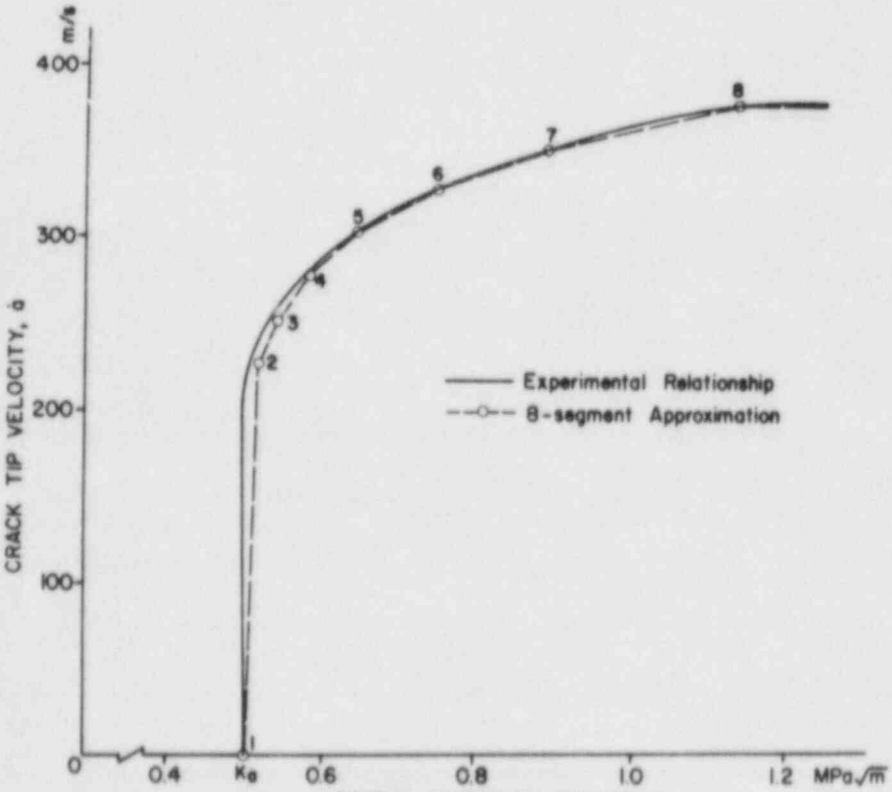


Fig. 3.9. The experimentally determined ȧ-K relationship for Homalite 100 and the approximation used in SAMCR.

The three cases analyzed corresponded to low, intermediate, and high values of initial stress intensity factor, K_0. The experimentally measured loads and load-line crack opening displacements for the three experiments are summarized in Table 3.5.

TEST NO	PIN LOAD	PIN DISPLACEMENT	OFF-PIN DISPLACEMENT*
P-9	0.51 kN	0.41 mm	0.29 mm
P-7	0.56 kN	0.47 mm	0.32 mm
P-10	0.65 kN	0.53 mm	0.37 mm

* - Measured along the load-line, halfway between the crack line and the edge of the specimen. Provides a measure of the degree of Hertzian indentation.

TABLE 3.5 SUMMARY OF LOAD AND DISPLACEMENT DATA FOR MCT ANALYSES

The analysis results for all three tests were quite similar and only the lowest K_0 test (Test P9) will be discussed in detail. Figures 3.10a, 3.10b, and 3.10c show, respectively, K versus time, crack extension versus time, and energies versus time for Test P9 over a time span of 500 microseconds. The results compared well with the experimental measurements superposed in Figures 3.10a and 3.10b. Some minor differences merit further comment. The computed K-values (Figure 3.10a) dropped quickly from the initiation level but not quite as rapidly as the expermental data. At the other end of the propagation phase, arrest did not occur as a single event but rather as a series of

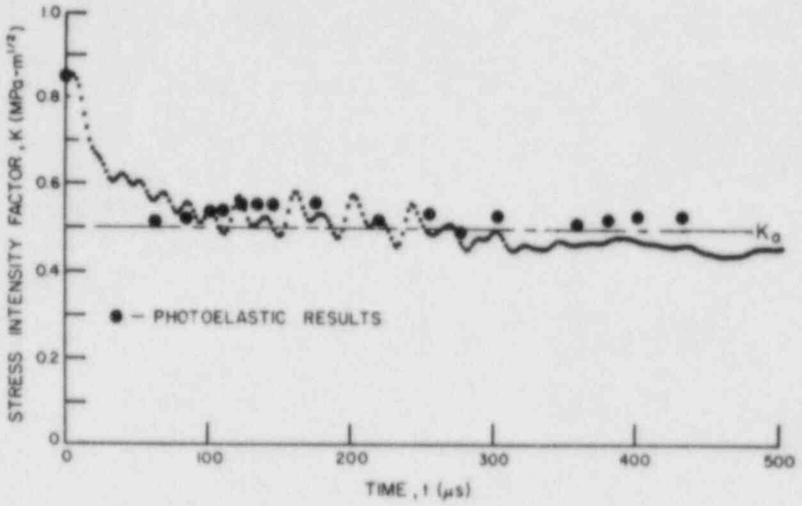


Fig. 3.10(*a*). SAMCR predicted and experimentally determined values for stress intensity as a function of time for Test P-9.

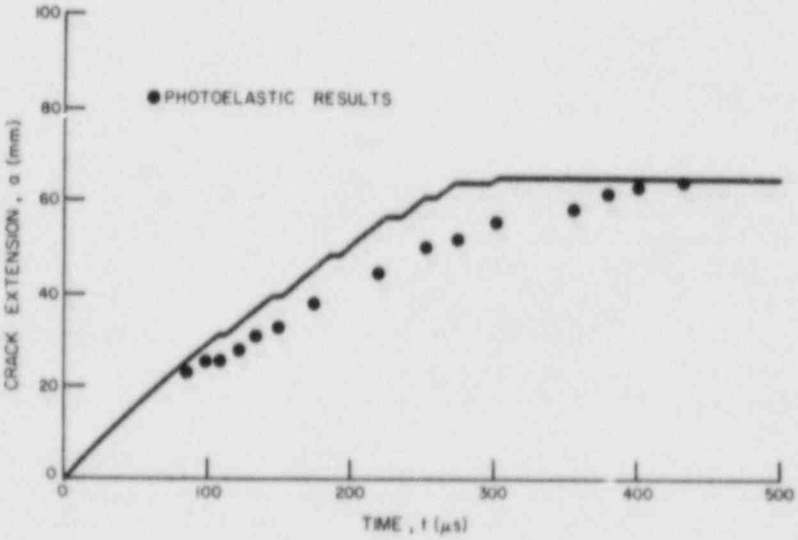


Fig. 3.10(*b*). SAMCR predicted and experimentally determined crack extension as a function of time for Test P-9.

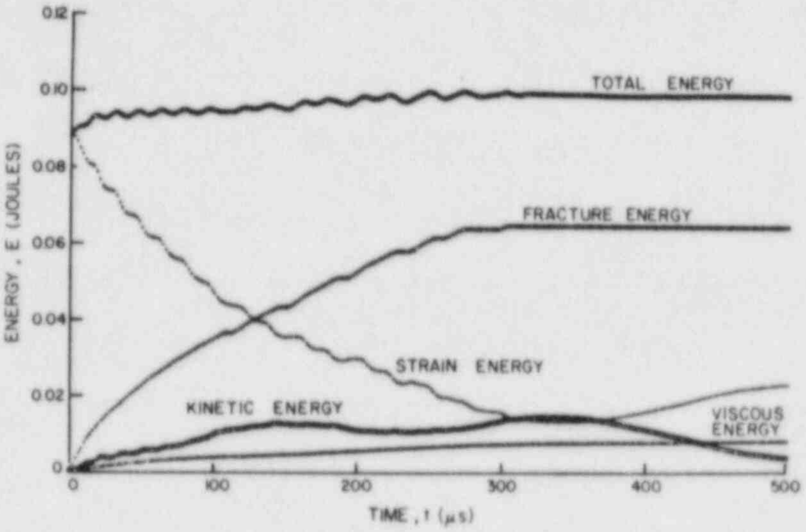


Fig. 3.10(*a*). SAMCR calculated strain, fracture, kinetic, viscous and total energies as a function of time for Test P-9.

short run-arrest segments, followed by a much longer arrest which was typically of 150-200 microsecond duration in a computational time span of 500 microseconds. Table 3.6 summarizes the comparisons between predicted and observed crack extension for the three tests analyzed. Predicted crack jumps differed from the measured values by less than 7% in all three cases.

TEST NO	OBSERVED CRACK JUMP	PREDICTED CRACK JUMP	RATIO*
P-9	67.3 mm	65.5 mm	97.5%
P-7	79.5 mm	74.2 mm	93.4%
P-10	86.1 mm	89.9 mm	104.0%

* - Ratio = Predicted Crack Jump / Observed Crack Jump

TABLE 3.6 COMPARISON OF OBSERVED AND PREDICTED CRACK JUMPS FOR WEDGE-LOADED HOMALITE 100 MCT SPECIMENS

3.4 Sensitivity Studies

Embedded in the SAMCR algorithms are several purely analytical parameters governing the details of the calculation procedures. These parameters, which are largely independent of the particular problem being analyzed, include: (a) the geometry of the J-integral contour; (b) the form of the crack tip restraining force decay function; (c) the level of viscous damping; and (d) the degree of "smoothing" performed on the computed K vs. time data. In order to study the influence of these parameters on the analytical results, a set of sensitivity analyses were performed using the MCT geometry and the material properties described in the preceding section.

3.4.1 J-Contour Geometry

As described in Appendices I and II, the J-contour geometry in SAMCR is defined by three parameters (see Figure II.3): NNN, the number of elements from the crack tip to the leading vertical leg of the contour; NT, the number of elements to the upper hotizontal leg of the contour; and NL, the number of elements to the lagging vertical leg of the contour. Two contour geometries were considered, with both analyses continued until crack arrest. The contour geometries, crack jumps and arrest times from the two analyses are summarized in Table 3.7. The differences between the two sets of analayses were found to be negligible. Contour 2 (NNN=NT=NL=3) exhibited slightly higher levels of oscillation in the computed K vs. time response than did Contour 1.

CONTOUR	NNN	NT	NL	Δa*	Δt
1	3	2	6	74.2 mm	394 μs
2	3	3	3	74.4 mm	402 μs

* - Experimentally measured value = 79.5 mm

TABLE 3.7 INFLUENCE OF J-CONTOUR GEOMETRY ON PREDICTED CRACK JUMP AND RUN-ARREST TIME FOR TEST P-9

In addition to the J-contour shape, the contour size might also be expected to influence the analysis results. As described in Chapter 2, the J-integral formulation used in SAMCR is in essence a near-field formulation that is strictly valid only for the case of constant-velocity situations. A more rigorous formulation for J would include the influence of inertia terms integrated over the area enclosed by the contour (see, for examaple, Kishimoto et al., 1980). However, the crack tip restraining force modeling scheme that is used in SAMCR to model crack advance between nodes introduces a local perturbation near the crack tip which precludes the accurate computation of the area integral terms. Consequently, these terms are neglected in the code formulation. Thus, when evaluating J along a contour, it is necessary that the contour used be small enough that the area integral terms are negligibly small while, at the same time, the contour must be placed far enough away so that any perturbations of the local stresses and strains by the restraining force do not affect the calculations.

The influence of J-contour size was studied by calculating J along several different contours at different times in the dynamic analysis of an MCT test. The results from this study are shown in Figure 3.11, where the distance of the contour from the crack tip is expressed in terms of an equivalent contour radius, which is defined as the radius of a circular contour having the same length as the actual rectangular contour used. As expected, the calculated J-value was found to be insensitive to contour geometry during the beginning and late phases of the analysis when the crack had either zero velocity or was moving with a nonzero but near-constant speed. Only during the intermediate

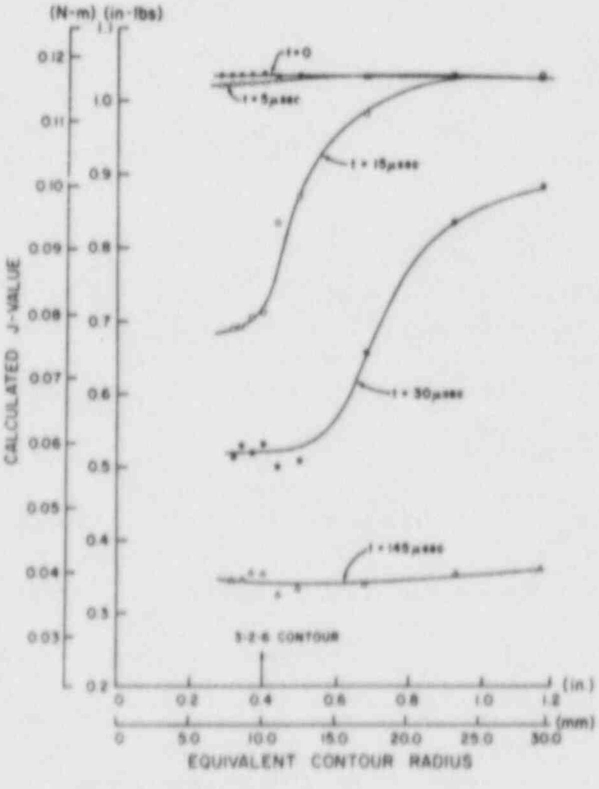


Fig. 3.11. SAMCR calculated J-values as a function of equivalent contour radius at several different times during the analysis of crack propagation in a Homalite 100 MCT specimen.

phase, ranging from 5 microseconds to about 40 microseconds after crack initiation, did the J-value show large sensitivity to contour size. However, even during this phase, values of equivalent contour radius less than about 10 mm gave reasonably contour-independent values for J, suggesting that this is the upper limit on contour size when using the near-field approximation. All contours used in our dynamic analyses to date have stayed within this upper bound.

3.4.2 Crack-Tip Restraining Force Relationship

In the crack tip restraining force model for incremental crack growth employed in SAMCR, the product of the restraining force and the nodal velocity is essentially the energy release rate of the fracture process. Consequently, the rate at which the restraining force is released can be expected to influence the calculated J value. The MCT test geometry was therefore reanalyzed using four different crack force decay relationships. Figure 3.12 shows the calculated K values from each of these relationships as the crack traversed one element in the finite element mesh. The data are from late in the dynamic event when the crack was moving at a near-constant velocity and the K values would be expected to show little change with crack length. The results shown in Figure 3.12 indicate that the exact form of the crack force decay function does in fact influence the calculated K value to a significant degree. The linear force decay relationship, which we have used in the past and are continuing to

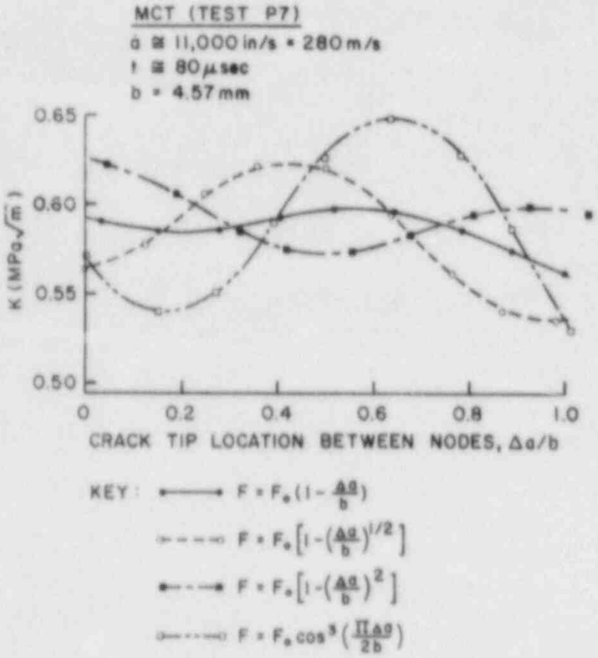


Fig. 3.12. The influence of the crack force decay relationship on the computed K-value as the crack propagated across one element in the finite element mesh used to analyze an MCT specimen.

use, gives the best results, while a cosine-cubed relationship seems to be the least desirable.

3.4.3 Viscosity Effects

Small amounts of viscous damping in the bulk and keystone deformation modes improve the numerical stability of the dynamic computations. To study the influence of this parameter on the numerical results, the MCT geometry was re-analyzed at low, medium, and high damping levels. Corresponding values for the viscosity coefficients B1, B2, and B3 are given in Table 3.8. Computed values of crack jump and arrest time with each set of coefficients are also summarized in Table 3.8. At the low viscosity level, the analysis was numerically unstable. For the

VISCOSITY	B1	B2	B3	Δa*	Δt
Low	1.2	0.06	0.002	- Unstable	-
Medium	4.0	0.20	0.033	73.4 mm	344 μs
High	12.0	0.60	0.100	74.2 mm	392 μs

* - Experimentally measured value = 79.5 mm

TABLE 3.8 INFLUENCE OF VISCOSITY LEVEL ON PREDICTED CRACK JUMP AND RUN-ARREST TIME FOR TEST P-9

remaining two cases, increasing the viscosity produced a negligible increase in crack jump and a somewhat larger increase in the time to arrest. As would be expected, the higher viscosity level gave a less oscillatory K vs. time response.

3.4.4 Effect of K-Smoothing

Since the advance of a real crack front is uniform only in an average sense, with the actual advance being the cumulative result of local incremental cleaving and tearing along microsections of the crack front, it is unreasonable to assume that the average K value along the entire crack front can change abruptly in very short time periods that are less than the time required for one section of the crack front to communicate with another through shear waves. However, in the dynamic calculations for the propagating crack problem, significant changes in K can occur between individual time steps. To reflect the "averaging" of K values that takes placed physically, a smoothing algorithm has been incorporated into SAMCR, with the K value at any time step being taken as the average of the K values over several preceding time steps. Results from re-analysis of the MCT test geometry showed that, for a polymeric material such as Homalite 100, smoothing over five time steps (2.5 microseconds) gave the best results with less oscillations in the K vs. t data, little change in the predicted crack jump, and no degradation of the dynamic response at crack initiation. Smoothing over a much larger number of steps tended to "overdamp" the system.

3.5 Comparisons with ORNL Thermal Shock Tests

The test conditions pertaining to several of the run-arrest events observed in ORNL Thermal Shock Experiments TSE5, TSE5A, and TSE6 were modeled using SAMCR. Attention was focused on the 2nd event in TSE5, the 3rd and 4th events in TSE5A, and the 2nd event in TSE6. A 180° segment of the test cylinder was modeled in each case, with the crack oriented along the positive branch of the x-axis. The finite element meshes used are shown in Figure 3.13a (TSE5 and TSE5A) and Figure 3.13b (TSE6). The change in mesh between the TSE5-series and TSE6 was necessitated by the smaller wall thickness in the latter.

Input data pertaining to the radial temperature distribution and initial crack depth for each event was obtained from Drs. Cheverton and Pugh at ORNL. The static finite element program, DOASIS, was used to generate the initial displacement and thermal strain distribution in the cylinder wall prior to each dynamic event. The temperature transient associated with a particular event was assumed to remain unchanged during the run-arrest

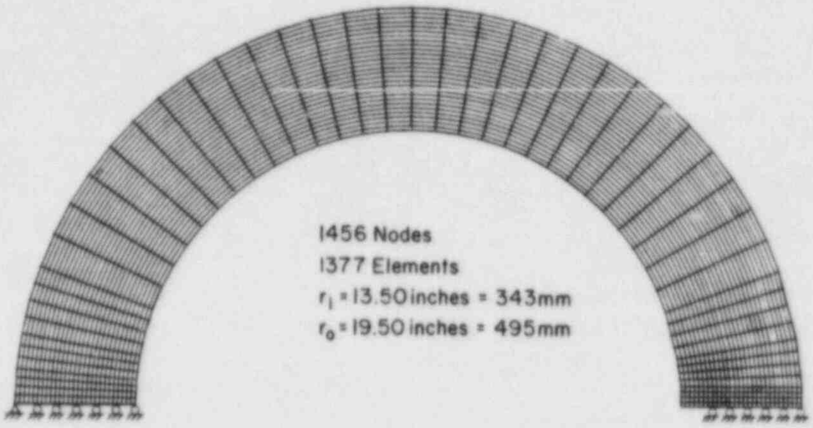


Fig. 3.13(*a*). Finite element mesh used to model one-half of the thermal shock cylinder used in ORNL experiments TSE5 and TSE5A.

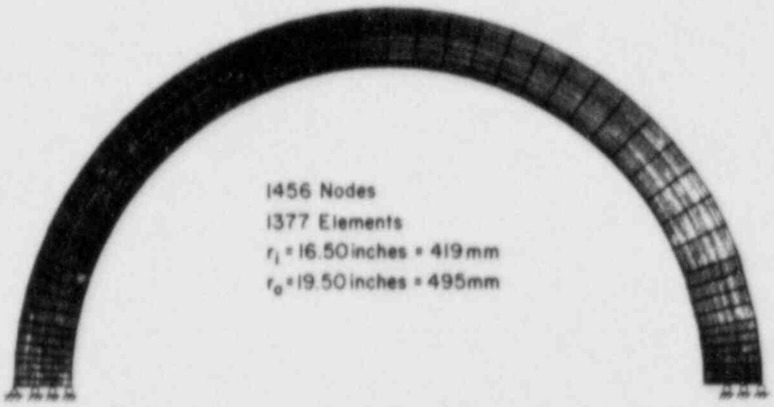


Fig. 3.13(*b*). Finite element mesh used to model one-half of the thermal shock cylinder used in ORNL experiment TSE6.

segment. The variation with temperature of the arrest toughness, K_{Ia}, of A508 steel was modeled by the dashed curve shown in Figure 3.14. The data in Figure 3.14 represent a compilation of the static analysis test results from the TSE experiments and the mean values obtained from the A533B steel tested in the Coop Program on Crack Arrest Testing. The last piece of input data required by SAMCR, namely the relationship between crack tip stress intensity factor, K, and crack speed, $\dot{a}$, was obtained from

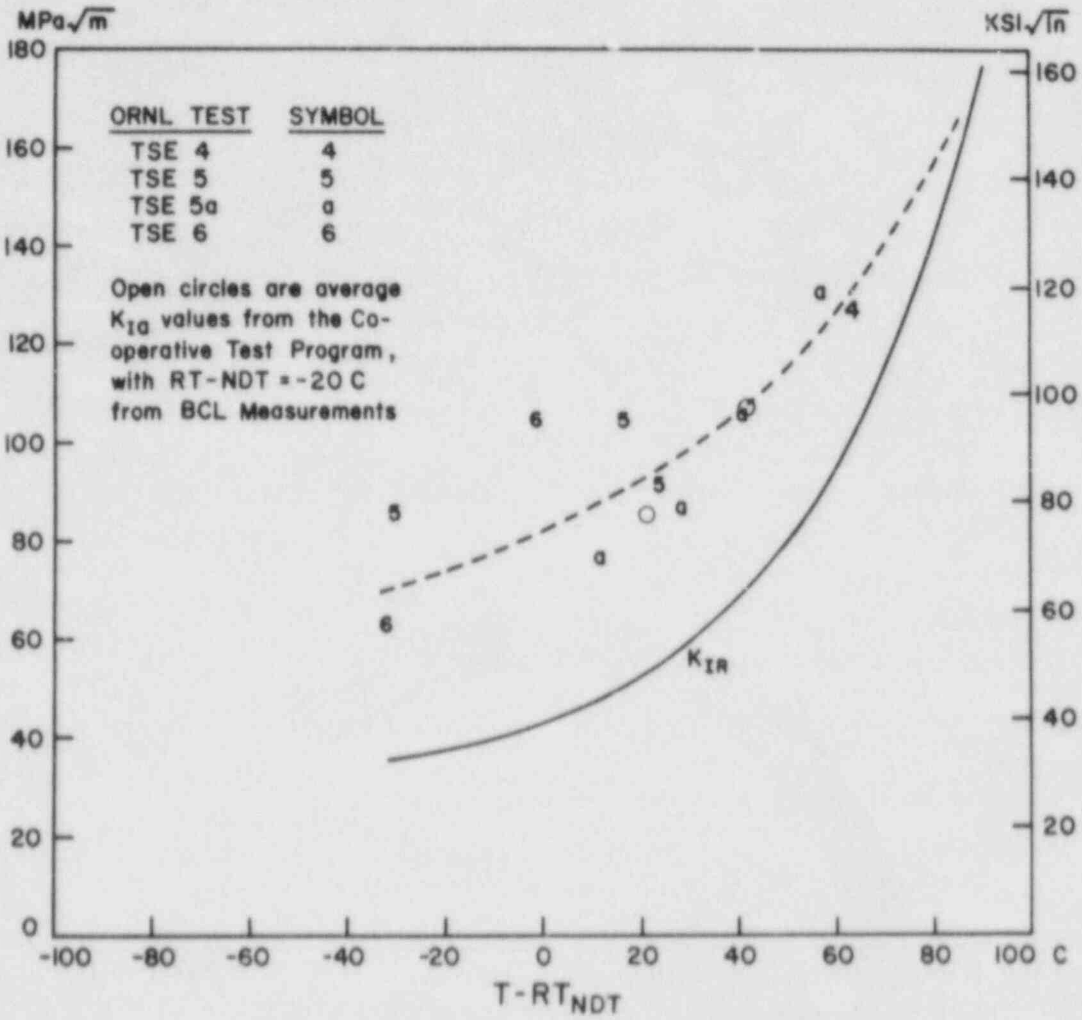


Fig. 3.14. Crack arrest fracture toughness as a function of crack tip temperature for A508 and A533B steels, based on static analysis of the ORNL TSE experiments and the Coop Test Program results.

Rosenfield, et al., 1982, where it is suggested that

$$K(\dot{a}, T) = K_{Ia}(T) \cdot f(\dot{a}) \tag{3.1}$$

where

$$\begin{aligned} f(\dot{a}) &= 1, \quad \dot{a} < 340 \text{ m/s} \\ &= (828 + 2.45\dot{a})/(2000 - \dot{a}), \quad \dot{a} > 340 \text{ m/s} \end{aligned} \tag{3.2}$$

is a reasonable assumption for RPV steels. A plot of $f(\dot{a})$ vs. $\dot{a}$ is shown in Figure 3.15.

A comparison of the experimental and SAMCR-predicted crack jumps for each event analyzed is presented in Table 3.9. A better picture of the predicted crack extension behavior is, however, obtained from an examination of Figures 3.16a, 3.16b, and 3.16c, which show, respectively, crack extension vs. time, stress intensity factor vs. time, and computed energies vs. time from the analysis results for the 2nd jump in TSE5. The crack is seen (Figure 3.16a) starting out with a relatively large velocity, which decreases at about 50 μs and remains nearly constant thereafter until crack arrest occurs. As with the MCT

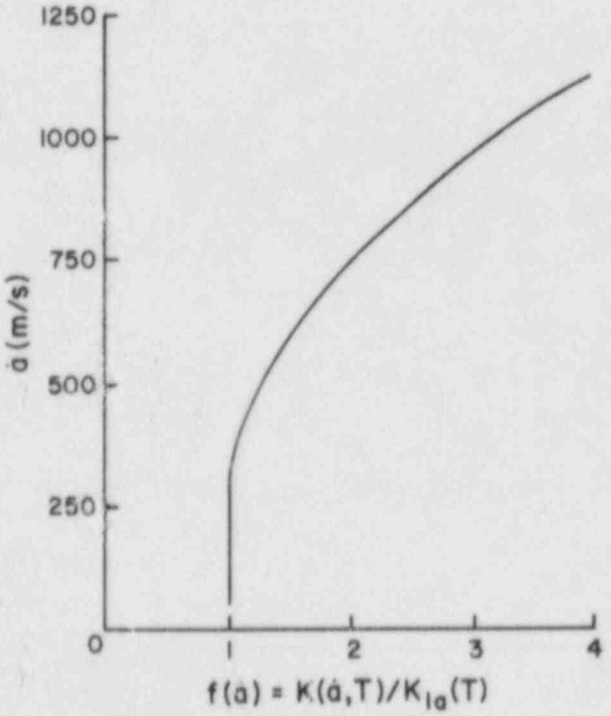


Fig. 3.15. The relationship between crack speed and crack tip stress intensity factor assumed for A508 steel (after Rosenfield, et al., 1982).

TSE EVENT	EXPERIMENTAL CRACK JUMP	PREDICTED CRACK JUMP	RUN-ARREST TIME	AVERAGE CRACK VELOCITY
TSE5 Jump 2	65.5 mm	77.9 mm	473 μs	165 m/s
TSE5A Jump 3	18.3 mm	16.3 mm	368 μs	44 m/s
TSE5A Jump 4	33.0 mm	39.4 mm	454 μs	87 m/s
TSE6* Jump 2	50.3 mm	47.2+mm	460 μs	103 m/s

* - Analysis of TSE6, Jump 2, was halted when the forward leg of the J-contour passed outside the finite element mesh. Crack velocity at this time was 4 m/s.

TABLE 3.9 COMPARISON OF PREDICTED AND OBSERVED CRACK JUMPS IN ORNL THERMAL SHOCK EXPERIMENTS TSE5, TSE5A, & TSE6

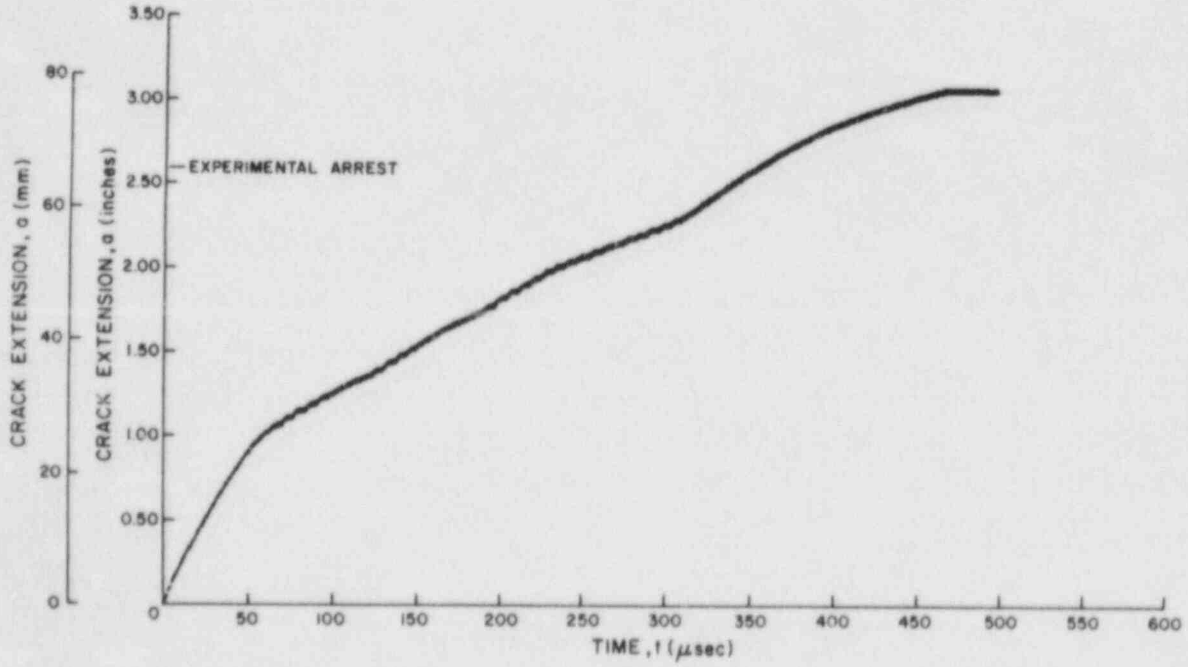


Fig. 3.16(*a*). SAMCR predicted crack extension as a function of time for the 2nd jump in ORNL experiment TSE5.

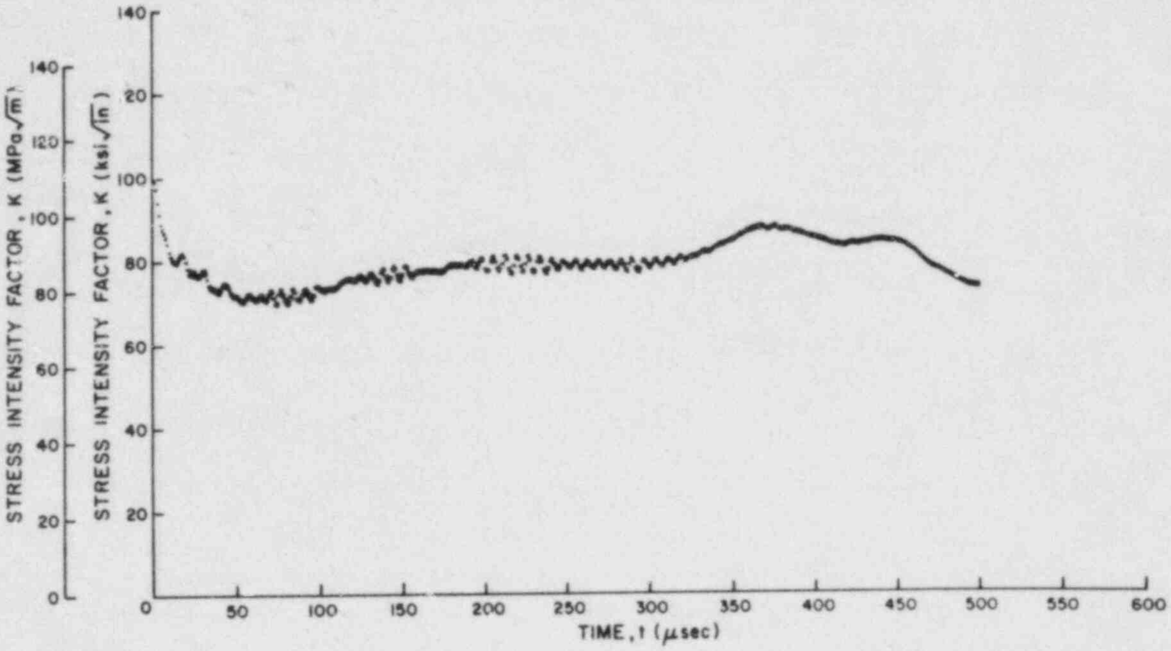


Fig. 3.16(*b*). SAMCR predicted crack tip stress intensity factor as a function of time for the 2nd jump in ORNL experiment TSE5.

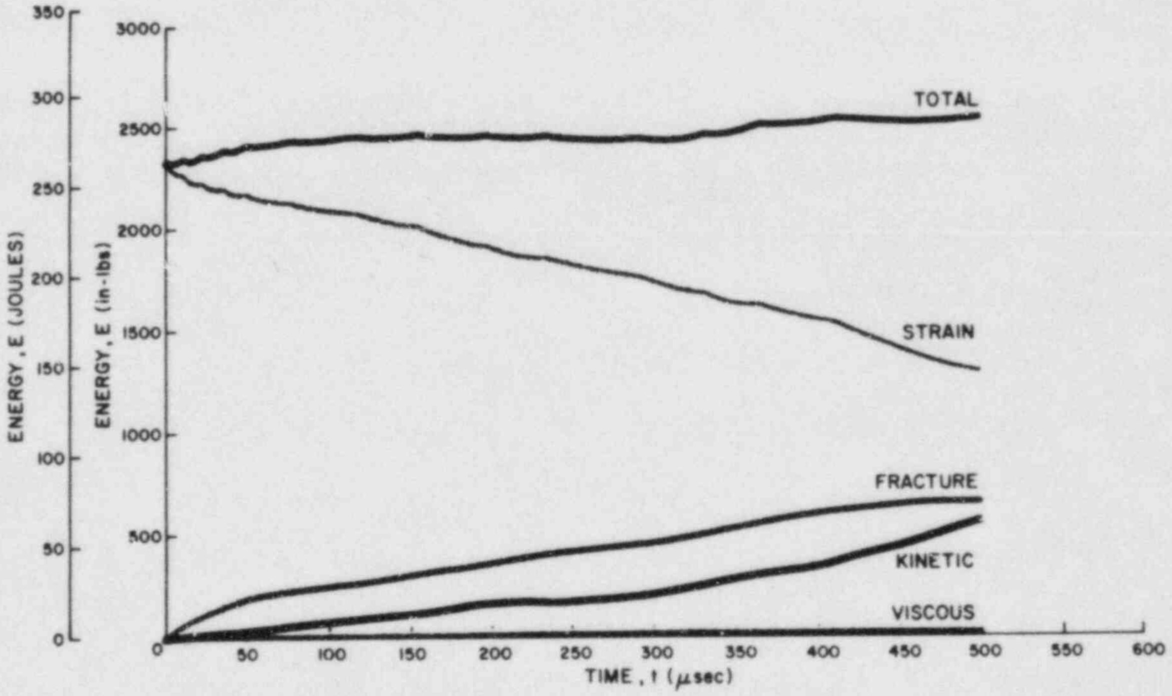


Fig. 3.16(*c*). SAMCR calculated strain, fracture, kinetic, viscous and total energies as a function of time for TSE5 Jump 2.

analyses discussed in Section 3.3, there are numerous short segments of run-arrest to be seen within the overall crack extension history. This is more readily understood by an examination of Figure 3.16b in conjunction with Figure 3.15. The computed dynamic K-value falls sharply at first, but then follows a gradually rising trend before peaking at about 375 μs, after which it begins to fall. This is consistent with the static K_I vs. crack depth behavior calculated for this transient by Cheverton, et al. (1979). However, in the dynamic analysis, this behavior in the computed K-value has the effect of keeping K just above or just below the threshold K_{Ia} value. From Figure 3.15, it is then obvious that the crack speed will vary somewhat discontinously between a value of approximately 350 m/s and zero. This is confirmed by the predicted instantaneous crack speed vs. time data.

The large initial velocity is also a consequence of the constitutive relation specified in Figure 3.15. The steadily increasing nature of the $\dot{a}$-K relationship defined by equation (3.2) allows large crack speeds (in excess of 10% of shear wave speed) during the early stages of the analysis, even though the K-value is falling. A large segment of the total crack extension therefore occurs during this period. The difference between predicted and observed crack jump (78 mm vs. 66 mm) is thus closely linked to the nature of the $\dot{a}$-K relationship that has been used, and about which little is known. The overall picture of a slowly advancing crack which does not exhibit large dynamic effects over most of its propagation history is in agreement with the low kinetic energy levels shown in Figure 3.16c, and with expectations of what would happen in a large structure such as the test cylinder.

Figures 3.17 and 3.18 are plots of crack extension vs. time for the 4th jump in TSE5A and the 2nd jump in TSE6, respectively. In neither instance does one see the large initial velocities of Figure 3.16a. This is probably due to differences in K-levels for these jumps and/or different crack tip temperatures, which placed these events lower down on the $\dot{a}$-K curve at initiation. An observation worthy of note in Figure 3.18 (TSE6, jump 2) is the indication in the computations of an intermediate arrest for 40 μs, after the crack had jumped about 36 mm. This is consistent with the COD and fracture surface observations made by Cheverton (1981) for this test. Unfortunately, the analysis for this event was halted at 460μs after initiation, when the crack depth became large enough for the leading edge of the J-integral contour to pass outside of the finite element mesh being used. The crack had extended 47.2 mm from its starting position at that time, and was moving with a very low velocity (of the order of 4 metres/sec). By comparison with other TSE analyses, it could therefore be expected to arrest without penetrating the cylinder wall much further.

It should be pointed out here that the small internodal spacing in the r-direction required to accurately model the thermal gradients, when combined with the size of the cylinder,

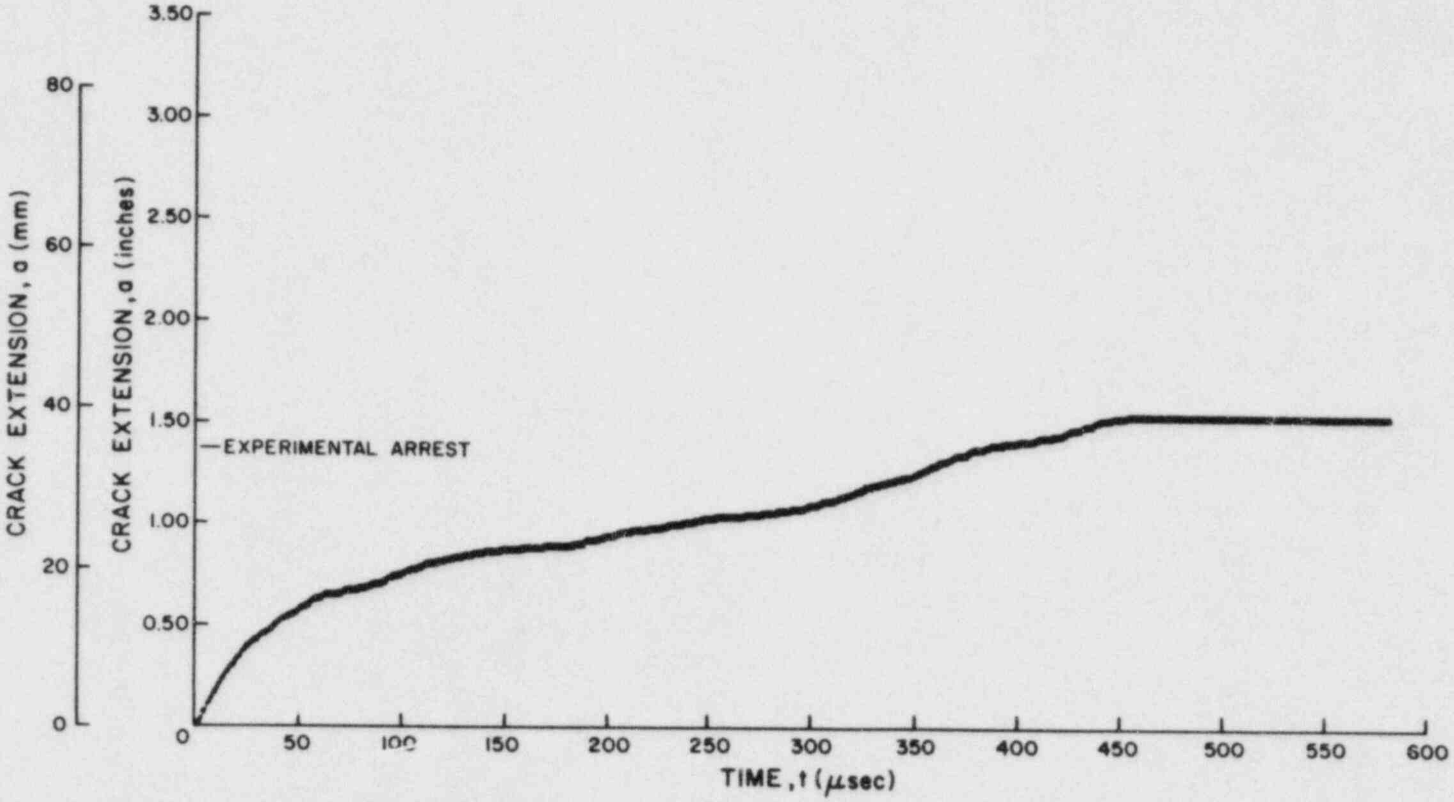


Fig. 3.17. SAMCR predicted crack extension as a function of time for the 4th jump in ORNL experiment TSE5A.

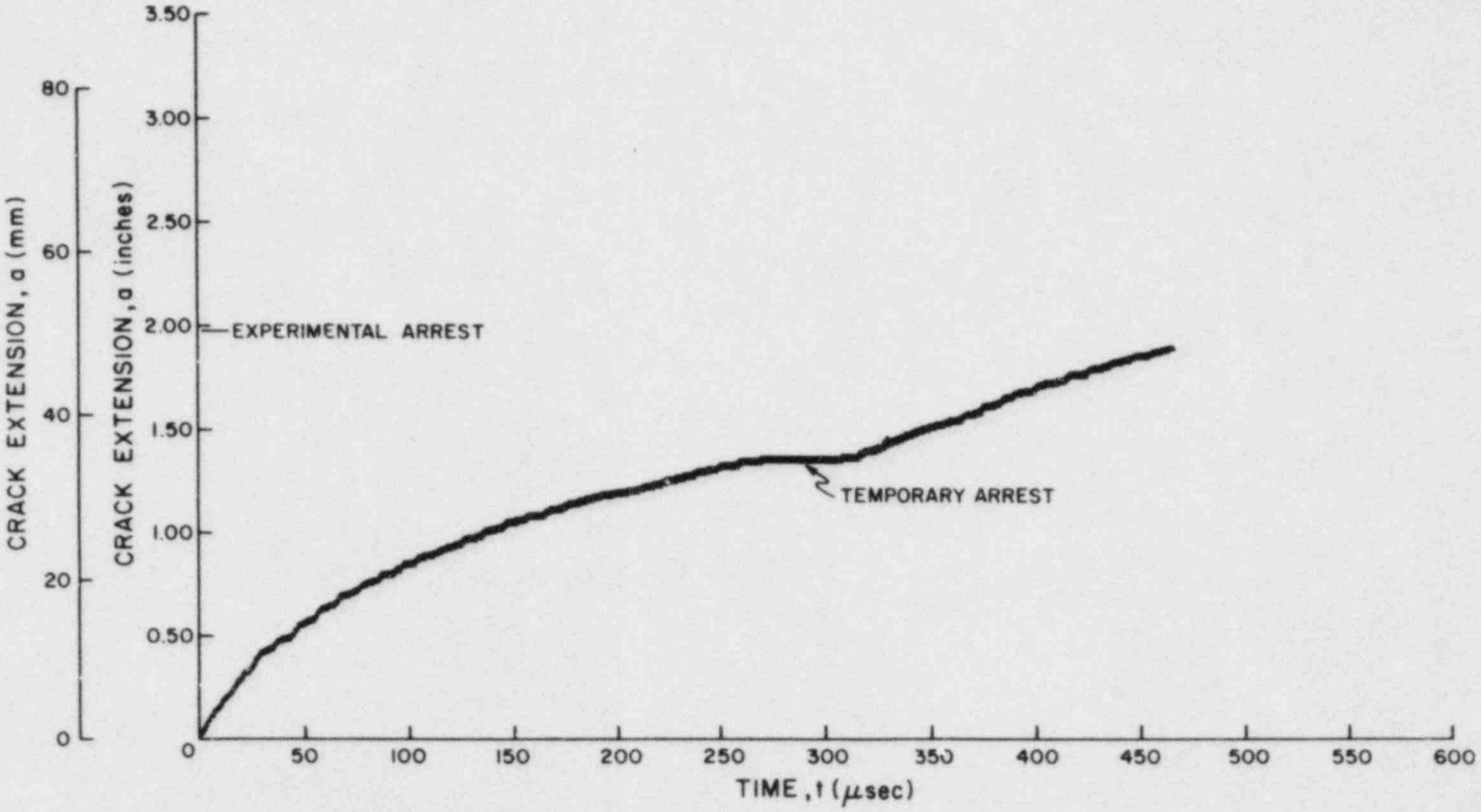


Fig. 3.18. SAMCR predicted crack extension as a function of time for the 2nd jump in ORNL experiment TSE6.

required the use of approximately 1400 nodal points to model the thermal shock problem. The consequent increase in computational time over some of the other analyses that have been performed with SAMCR was therefore very large. The time step size used was typically of the order of 0.2 μs, and a computation over 400 or 500μs thus extended over 1000 or more time steps. The restart option that is built into the code proved to be ideally suited for efficient execution of such long-term analyses.

CHAPTER 4

SUMMARY

The mathematical formulation, program structure, and details of required input data have been described for the SAMCR code. The code has been shown, through an extensive series of verification analyses, to perform well in modelling dynamic behavior of both uncracked and cracked structures. In particular, the code has been demonstrated to provide useful information regarding run-arrest events in polymeric laboratory samples and large thermally shocked steel cylinders. Complete documentation of the code has been included so that this document can serve as both a technical manual and a user's manual for the code.

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APPENDIX I

PROGRAM ORGANIZATION FOR SAMCR

I.1 Introduction

SAMCR (Stress Analysis of Moving CRacks) is a general purpose finite element code for the analysis of rapid fracture propagation and arrest under Mode I conditions. SAMCR operates in a predictive fracture "application" mode: the increment of crack extension at each time step is automatically computed based on the calculated stress intensity value K at the crack tip and the user-specified crack tip velocity vs. K constitutive relationship for the fracturing material.

The major features of SAMCR are:

- Efficient explicit finite element formulation based on four-node isoparametric quadrilateral elements
- Crack advance calculations based on a crack tip restraining force model
- J-integral formulation for calculation of the dynamic stress intensity factor K
- Flexibility in the specification of the crack tip velocity vs. K fracture constitutive relationship
- Thermal effects, both for thermal strains and for the crack tip velocity vs. K constitutive relationship
- Energy calculations (strain, fracture, kinetic, and dissipated/damping) as a monitor of solution accuracy
- Automatic time step selection
- "Static" analysis using dynamic relaxation
- Analysis restart option

SAMCR is written in Fortran V and executes entirely in core. Although SAMCR was developed on a Univac 1100 series computer, it can be readily implemented on any mainframe scientific computer with a minimum of recoding. The program is modular in structure, permitting easy modification if desired.

The dynamic calculations in SAMCR require input of the initial nodal displacements and velocities. Initial displacements (and nonzero initial velocities, if required) must be computed using a conventional static finite element code. All analyses at the University of Maryland have employed the finite element program DOASIS (Weiler Research, Inc., Mountain View, CA) for the calculation of the initial conditions. However, any of the many standard finite element codes available could be adapted for this purpose.

I.2 Program Size

Because of the explicit dynamic formulation in SAMCR, there is no need to form the entire global stiffness matrix during the analysis. Thus, the major storage requirement of the finite element method is absent. This, together with the compact storage of initial and computed data, results in a program possessing large capacity and flexibility compared to implicit dynamic finite element schemes.

All of the major subscripted variables in SAMCR are stored sequentially without gaps as a vector in blank COMMON storage. This efficient scheme provides two benefits: (a) this size of the program storage can be changed by altering the dimensions of a single array (COMMON A(NDIMA)), and (b) optimum use is made of available core storage. This master storage array is partitioned into individual data arrays by a set of pointers, defined in Table I.1.

The dimension NDIMA required for the master storage array A for a given problem can be calculated using the following formula:

```
NDIMA = 19*NUMNP*ITWO + NUMEL*(5+9*ITWO)
        + NUMMAT*(1+31*ITWO) + NUMPC*(2+3*ITWO)
        + 2*NUMLP*ITWO + NUMNP*ITWO*ITEMP          (I-1)
```

in which the right-side variables are defined in the footnote to Table I.1 (Note: ITEMP=1 for thermal analyses only and is zero otherwise).

I.3 Activity Test

For problems in which stresses are generated at one point in a body and subsequently propagate through the rest of the body, large portions of the finite element mesh may be stress free during the beginning stages of the analysis. An activity test checks the stress conditions for each element during the calculations; if the element is stress-free, then it is skipped during the element stiffness computation phase of the explicit dynamic calculations. Two benefits result from this: (a) the time spent in the element stiffness computations is saved, and (b) the critical time step is based only on those elements that are currently active. This latter point can result in

POINTER	ARRAY	LENGTH*	DESCRIPTION
N1	R	NUMNP*ITWO	r-coordinates for nodes
N2	Z	NUMNP*ITWO	z-coordinates for nodes
N3	CODE	NUMNP*ITWO	boundary condition codes
N4	IX	5*NUMEL	element connectivity data
N5	MTYPE	NUMMAT	material model number
N6	RO	NUMMAT*ITWO	material densities
N7	EE	30*NUMMAT*ITWO	material properties
N8	INI	NUMPC	pressure load connectivity
N9	JNJ	NUMPC	pressure load connectivity
N10	PI	NUMPC*ITWO	pressure load scaling factors
N11	PJ	NUMPC*ITWO	pressure load scaling factors
N12	T	NUMPC*ITWO	arrival times for pressure loads
N13	P	2*NUMLP*ITWO	pressure load history data
N14	U	NEQ*ITWO	current nodal displacements
N15	V	NEQ*ITWO	current nodal velocities
N16	A	NEQ*ITWO	current nodal accelerations
N17	E	NEQ*ITWO	internal nodal load vector
N18	MS	NUMNP*ITWO	mass matrix
N19	SIG	4*NUMEL*ITWO	element stresses
N20	EPS	5*NUMEL*ITWO	element strains
N21	ELOAD	NEQ*ITWO	applied concentrated load vector

TABLE I.1 ALLOCATION OF STORAGE IN MASTER ARRAY 'A'

POINTER	ARRAY	LENGTH*	DESCRIPTION
N22	ULAST	NEQ*ITWO	previous nodal displacements
N23	VLAST	NEQ*ITWO	previous nodal velocities
N24	TEMP	NUMNP*ITWO	nodal temperatures
NEND			end of array 'A'

* NUMNP = number of nodal points
NUMEL = number of elements
NUMMAT = number of material types
NUMPC = number of pressure loads
NUMLP = number of points defining load history
NEQ = number of equations (NEQ=2*NUMNP)
ITWO = 1 for single precision
= 2 for double precision

TABLE I.1 ALLOCATION OF STORAGE IN MASTER ARRAY 'A' -- CONTD

significant computational savings for problems in which the stress pulse propagates from coarse to fine regions of the mesh.

If at any point during the analysis the activity test indicates that all elements are stress free, the analysis is halted.

I.4 Input and Output Files

In addition to the standard card/keyboard input (Unit=5) and printer output (Unit=6) units, SAMCR requires several auxiliary input and output files during the data input and analysis execution phases. The unit numbers and contents of these files are summarized in Table I.2. Scratch file NTAPE (Unit=4)

UNIT	DESCRIPTION
4	Scratch file containing SAMCR-generated card-image listing of input data
5	System input device (card reader/keyboard)
6	System printer
7	Data from mesh generation program (see subroutine DATAIN for details of required contents and formats)
9	Results from "static" analysis by dynamic relaxation (see subroutine CONVRG for details of contents and formats)
10	Analysis results (unformatted -- intended as input to plotter routines; see Appendix II, Section 11 for details)
11	Crack data (for details see Appendix II, Section 11; also subroutine ROLOUT)
12	Edited nodal point analysis results (for details see Appendix II, Section 11; also subroutine DATOUT)
13	Restart output file (unformatted; see subroutine RSTOUT for details)
14	Restart input file (unformatted; see subroutine RSTIN for details)

TABLE I.2 INPUT AND OUTPUT UNITS USED IN SAMCR

contains a SAMCR-generated card image listing of the input data deck. Details of the characteristics of the other I/O files (contents, formats, etc.) are given in at appropriate points in Appendix II.

I.5 Subprograms in SAMCR

SAMCR is divided into three major functional modules. The main program (SAMCR) dimensions the master storage array A, sets the single/double precision flag ITWO, and passes control to subroutine CRACK. Subroutine CRACK controls the data input phase and initializes the analysis, including the settings of all array pointers (Table I.1), before passing control to subroutine SOLVE. Subroutine SOLVE controls the step-by-step calculations for the dynamic analysis.

The organization of the subprogram calls in SAMCR is summarized in Figure I.1. The functions of each of the

```
                RUNNING CRACK PROGRAM 'SAMCR'
                       (VERSION 3.0)
                      PROCEDURE CALLS



MAIN  →  CRACK  →  SECOND /
                   DATE /
                   DATAIN /
                   ROLIN /
                   RSTIN  →  ENERGY /
                   RSTOUT /
                   SOLVE  →  LOAD /
                             MASS /
                             INTSTR /
                             STRESS /
                             FORCE /
                             JINTGL /
                             INVEL  →  INTPL /
                             CRKFOR /
                             ENERGY /
                             CONVRG /
                             DATOUT /
                             ROLOUT /
                             RSTOUT /
                             NEWUV /
                             STRAIN /
                             VEL  →  INTPL /
                             TERM
< STOP >


→  calls
/  calls only system routines
```

Fig. I.1. Subroutine call map for SAMCR.

subprograms are briefly described below:

CONVRG	checks convergence of dynamic relaxation algorithm for static analysis; writes results from static analysis to Unit 9
CRACK	calls data input subprograms; sets array pointers; sets up problem before passing control to SOLVE
CRKFOR	calculates crack tip restraining force
DATAIN	reads analysis input data from card image file NTAPE; prints summary of input data
DATE	calls Univac Fortran-V library routine ERTRAN to obtain current date and time
DATOUT	prints edited nodal point and element stress data during analysis; writes same information to Unit 12
ENERGY	calculates fracture and kinetic energies at each time step
FORCE	calculates element nodal forces due to element stiffness and viscosity; computes new time step; computes element strain and viscous dissipated energies
INTPL	interpolation routine for fracture constitutive relation data stored as piecewise linear segments
INTSTR	computes initial elastic strains for each element at first time step in analysis
INVEL	computes initial crack tip velocity at first time step in analysis
JINTGL	evaluates J-integral at each time step
LOAD	assembles system applied load vector at each time step
MASS	assembles diagonal (lumped mass) system mass matrix at beginning of analysis
NEWUV	updates nodal displacements and velocities using explicit time integration algorithms

ROLIN	reads crack input data from card image file NTAPE; prints summary of input data
ROLOUT	prints crack and energy parameters during analysis; writes same information to Unit 11
RSTIN	reads unformatted analysis restart information from Unit 14
RSTOUT	writes unformatted analysis restart information to Unit 13
SAMCR	(Main Program) dimensions master storage array; sets single/double precision flag; passes control to CRACK
SECOND	calls Univac Fortran-V routine ERTRAN to obtain current time of day; converts time of day to seconds
SOLVE	control subprogram during step-by-step analysis phase
STRAIN	computes element strains at second and subsequent time steps during analysis
STRESS	computes element stresses at each time step during analysis
TERM	checks for crack tip overshoot of next node during next time step
VEL	computes instantaneous crack tip velocity at second and subsequent time steps during analysis

The only Univac library subroutine referenced in the program is the time-and-date routine ERTRAN, called by subroutines DATE and SECOND.

The major variables appearing as subroutine arguments in SAMCR are as follows:

A	master storage array (subprogram CRACK)
A	nodal acceleration vector

B	nodal load vector for applied pressure loads (equivalent to vector E below)
CODE	array containing boundary condition codes for each nodal point
E	internal nodal load vector for system (computed in subprogram FORCE)
EE	array containing material property data for all materials
ELOAD	nodal load vector for applied concentrated loads
EPS	array containing element strain vectors
EPSDOT	average maximum strain rate for near-tip elements
IERROR	input data error flag
IX	array containing connectivity data and material property set number for elements
INI, JNJ	arrays containing connectivity information for applied pressure loads
IWRT	flag controlling output to printer, Unit 11, and Unit 12
MS	lumped mass matrix (stored as vector)
MTYPE	array containing material model number for element
N	loop variable used in subprogram SOLVE; equals element number
NDUMP	restart dump number to be read during restart analysis
P	array containing pressure, time data pairs defining time history for applied loads
PI, PJ	arrays containing scaling factors for applied pressure loads
R	array containing radial/x-coordinates for nodal points
RO	array containing material density for each material type
SIG	array containing element stress vectors
T	array containing arrival times for pressure loads

TEMP	array containing nodal temperature values
TT	current time
U	current nodal displacement vector
ULAST	nodal displacement vector for preceding time step
V	current nodal velocity vector
VLAST	nodal velocity vector for preceding time step
Z	array containing z-coordinates for nodal points

Additional detailed information regarding the program subroutines and variables may be found in the comment statements in the program listing.

I.6 COMMON Variables in SAMCR

Unlabeled (Blank) COMMON

A	master storage array (see Section I.2)

COMMON Block BK1

NUMMAT	number of material types
NUMNP	number of nodal points
NUMEL	number of elements
NUMPC	number of element sides subjected to pressure loads
NUMLP	number of time points defining loading history
HED(16)	analysis title information
RA	flag for analysis type .EQ.-1.0: plane strain .EQ. 1.0: plane stress
NTAPE	unit number for scratch file used for storing card image listing of input data

NEQ	number of equations (NEQ=2*NUMNP)
MESH	flag for input of mesh data from Unit 7 .EQ.0: mesh data input on cards .NE.0: mesh data read from Unit 7
IRSTRT	flag controlling restart option .EQ.0: no read or write of restart data .EQ.1: write restart data to Unit 13 during analysis .EQ.-1: read restart data from Unit 14 and write new restart data to Unit 13 during analysis
ITEMP	flag controlling input of nodal temperature data .EQ.0: no input of nodal temperatures .EQ.1: input nodal temperatures

COMMON Block BK2

EPZ(5)	not used
D(4)	strain rate vector
C(4,4)	elastic constitutive matrix
DF	not used
KLIN	not used
DT1	last time step increment
DT2	next time step increment
WRZ	not used

COMMON Block BK3

NDSOUT(160)	array of nodal points for edited output of nodal quantities
NSTOUT(160)	array of element numbers for edited output of stresses
NUMDS	number of nodal points in edited ouput of nodal quantities
NUMST	number of elements in edited output of stresses
TIO1(5)	array containing starting times for output to printer (Unit 6), Unit 10, Unit 11, Unit 12, and Unit 13, respectively

TIO2(5)	array containing ending times for output; similar to TIO1(5)
TIO3(5)	array containing time intervals between output; similar to TIO1(5)

COMMON Block BK5

I1,I2,I3,I4,I5,I6,I7,I8	global indices of the eight degrees of freedom (equation numbers) for an element

COMMON Block BK6

NNN	number of elements from crack tip to leading leg of J-integral contour
NODENO	element number for element containing crack tip
NN	number of elements in one row of mesh
CJINT	J-integral value
HK	crack tip stress intensity factor
CDOT	crack tip velocity
ADOTK(10,17,2)	temperature-stress intensity-crack tip velocity data for fracture constitutive relation
SIFRST	crack reinitiation fracture toughness
KK	number of stress intensity vs. crack tip velocity data pairs used to specify fracture constitutive relation at each temperature
KT	number of temperatures at which stress intensity vs. crack tip velocity data are specified
DXX	intraelement crack tip advance
DX	global crack tip advance
X	crack tip position
NS	time step counter
NSTEP	time step limit
NT	number of elements between crack tip and upper leg of J-integral contour

NL	number of elements between crack tip and lagging leg of J-integral contour
DYNMOD	reference dynamic modulus for J-to-K conversion
NSRPTS	number of data pairs used to define strain rate dependency of J-to-K conversion
STRNRT(8)	strain rate points defining strain rate dependency of J-to-K conversion
EDMULT(8)	multiplicative factors defining strain rate dependency of J-to-K conversion (EDYN = EDMULT(I)*DYNMOD)
NAVG	number of time steps to be used in K-smoothing algorithm

COMMON Block BK7

E0	initial value for crack tip restraining force
F0	current value for crack tip restraining force
DDX	predicted intraelement crack advance (used to determine if crack tip will reach next node during the next time step
NBETA	flag indicating whether crack tip will reach next node during next time step

COMMON Block BK8

BETA1	exponent in crack tip restraining force decay relation

COMMON Block BK9

RDT	reduction factor for automatically-selected time step increment
B1, B2, B3	dynamic viscosity constants

COMMON Block BK10

TT	current time
EFRAC	fracture energy

STRENG	strain energy
HKNENG	kinetic energy
VISENG	dissipated viscous energy

COMMON Block BK11

ISTAT	flag for static analysis by dynamic relaxation
NITER	iteration limit for dynamic relaxation algorithm
TOL	convergence tolerance for dynamic relaxation
VISC1, VISC2, VISC3	viscosity constants for use in dynamic relaxation algorithm (compare with B1, B2, B3 in COMMON Block BK9)

COMMON Block BK12

FBFB	sum of squares of nodal forces from 1-point element stiffness integration
QBQB	sum of squares of nodal forces from bulk viscosity effects
FKFK	sum of squares of nodal forces from keystone mode stiffness terms
QKQK	sum of squares of nodal forces from keystone mode viscosities

COMMON Block BK13

ITWO	flag for single/double precision .EQ.1: single precision .EQ.2: double precision
NDIMA	dimension of unlabeled COMMON master storage array A
N1-N24	pointers to start of individual data arrays in master storage array A (see Table I.1 for details)

APPENDIX II

INPUT DATA DESCRIPTION

In this chapter, the input data required for analyzing running crack problems with SAMCR are described in detail. Each input record or group of records is identified by a title, the format used on the card, the names and meanings of the variables, and notes clarifying proper usage.

The input formats and variable names follow the standard Fortran conventions:

Character (alphanumeric) data are entered using an "A" format.

Integer number values are entered using an "I" format. Integer numeric values may begin with an optional "+" or "-" sign and must be right-justified in their fields. Integer variable names begin with the letters I,J,K,L,M, and N.

Real number values are entered using either an "F" or "E" format. A leading "+" or "-" sign is optional. Real number values entered using the "E" format must be right-justified in their fields. It should be noted that the decimal point location specified on the input data overrides the decimal point on the format specification. Real variables begin with any letter other than I,J,K,L,M, or N.

All data in this section refers to Version 3.0 of SAMCR.

1. ANALYSIS TITLE (16A5)

columns	variable	note	entry
1-80	HED(16)		Analysis title

2. ANALYSIS RESTART INFORMATION (2I5)

columns	variable	note	entry
1-5	IRSTRT	(1)	Flag for reading/writing restart data .EQ.0: no read/write of restart data .EQ.1: write restart data to Unit 13 .EQ.-1: read restart data from Unit 14 and write new restart data to Unit 13
6-10	NDUMP	(1)	Dump number to be used for restart from Unit 14

Note:

(1) Analysis restart data is written (unformatted) to Unit 13 at intervals specified in Record Group 10. For a restarted analysis (IRSTRT.EQ.-1), most input and system variable data are read from Unit 14; thus, most of the input data in this Chapter are skipped. In particular, input record groups 3, 4,5,6,7,8,9,13,14, and 15 are skipped and record groups 10,11, and 12 are retained.

3. ANALYSIS CONTROL DATA (6I5,F10.0,3I5)

If IRSTRT.EQ.-1 on Record 2, skip this section.

columns	variable	note	entry
1-5	NUMMAT		Number of material types
6-10	NUMNP	(1)	Number of nodal points
11-15	NUMEL	(1)	Number of elements
16-20	NUMPC	(1)	Number of pressure loads

21-25	NUMLP	(1)	Number of time points used to describe pressure loading history
26-30	KLIN		Strain flag. Not used in current version of program; set equal to zero.
31-40	RA	(2)	Flag indicating analysis type .EQ.-1.0: plane strain analysis .EQ. 1.0: plane stress analysis
41-45	MESH	(3)	Mesh generation flag .NE.0: nodal point, element, and load data are to be read as part of input stream .EQ.0: nodal point, element, and load data are to be read from Unit 7
46-50	ISTAT		Flag indicating static/dynamic analysis .EQ.0: dynamic fracture analysis .NE.0: "static" analysis using dynamic relaxation algorithm
51-55	ITEMP		Flag indicating temperature-dependent analysis .EQ.0: no temperture effects considered; nodal temperatures not read .EQ.1: temperature effects considered; nodal temperatures read (see Record group 6)

Notes:

(1) Need not be supplied if provided by mesh generation program.

(2) For an axisymmetric analysis, RA.EQ.0.0; however, axisymmetric analyses are not fully implemented in the current version (Version 3.0) of SAMCR. For both plane stress and plane strain analyses, all element thicknesses are assumed equal to 1.

(3) If mesh generation program is used to create nodal point, element, and pressure load data, this information must be stored on Unit 7 (tape or disk file) in a form suitable for reading by subprogram DATAIN (see program listing for details).

4. DYNAMIC RELAXATION CONTROL PARAMETERS (I5,5X,4F10.0)

If IRSTRT.EQ.-1 on Record 2 or ISTAT.EQ.0 on Record 3, skip this section. Otherwise, input the "static" analysis dynamic relaxation parameters on this record in the following format:

columns	variable	note	entry
1-5	NITER		Maximum number of iterations to be performed
11-20	TOL	(1)	Convergence tolerance (Default = 1.0E-4)
21-30	VISC1	(2)	Bulk viscosity coefficient B1 (Default = 1.2E+2)
31-40	VISC2	(2)	Bulk viscosity coefficient B2 (Default = 0.06E+2)
41-50	VISC3	(2)	Keystone mode viscosity coefficient B3 (Default = 0.01E+02)

Notes:

(1) Convergence is based on the Euclidean norm of the nodal displacement vector; see Chapter 2 for more details.

(2) Viscosity coefficient values for dynamic relaxation algorithm only; see Chapter 2 for more details.

5. MATERIAL PROPERTY INFORMATION

If IRSTRT.EQ.-1 on Record 2, skip this section.

5.1 Material Number (2I5,F10.0)

columns	variable	note	entry
1-5	N		Material property set identification number
6-10	MTYPE(N)	(1)	Material model number; set equal to 1
11-20	RO(N)		Mass density of material

5.2 Material Title (16A5)

columns	variable	note	entry
1-80			Alphanumeric title to describe material

5.3 Material Property Data (6 records, each 5F10.0)

columns	variable	note	entry
first record:			
1-10	EE(1,1,N)		Young's modulus
second record:			
1-10	EE(1,2,N)		Poisson's ratio
third record:			
1-10	EE(1,3,N)	(2)	Coefficient of thermal expansion
fourth record:			
1-10	EE(1,4,N)	(3)	Reference temperature for thermal strain calculations

fifth and sixth records are blank (but must be present)

Notes:

(1) Current program version supports only linearly elastic material behavior.

(2) Required only if ITEMP.NE.0 on Record 3. If ITEMP.EQ.0, input a blank record.

(3) The reference temperature is the temperature at which the thermal strains are equal to zero. The reference temperature should be the same for all material property sets (and thus for all elements). The reference temperature is required only if ITEMP.NE.0 on Record 3. If ITEMP.EQ.0, input a blank record.

6. NODAL POINT DATA (I5,6F10.0)

If IRSTRT.EQ.-1 on Record 2 or MESH.EQ.0 on Record 3, skip this section. Otherwise, input one record for each nodal point using the following format:

columns	variable	note	entry
1-5	N		Nodal point number
6-15	CODE(N)	(1)	Boundary condition code
16-25	R(N)		R- (or x-) coordinate
26-35	Z(N)		Z-coordinate
36-45	U1	(2)	R- (or x-) direction boundary condition value
46-55	U2	(2)	Z-direction boundary condition value
56-65	TEMP(N)		Nodal temperature (not read if ITEMP.EQ.0 on Record 3)

Notes:

(1) The boundary condition codes are specified as follows:

CODE(N)	Interpretation
0.0	Neither nodal displacement nor nodal force value specified
1.0	Prescribed r- (or x-) direction displacement
2.0	Prescribed z-direction displacement
3.0	Prescribed r- (or x-) and z-direction displacements
-1.0	Prescribed z-direction nodal load
-2.0	Prescribed r- (or x-) direction nodal load
-3.0	Prescribed r- (or x-) and z-direction nodal loads
Other	CODE(N) equals the angle in degrees between the positive r-direction and the direction of motion along a sliding boundary. Angles must be greater than or equal to zero.

Note that CODE(N).EQ.0.0 is equivalent to CODE(N).EQ.-3.0 with U1=U2=0.0.

(2) In the current version of SAMCR, prescribed displacements are always taken as equal to their initial values (see record group 9) and the values of U1 and U2 are ignored. For the case of prescribed nodal loads, U1 and U2 are the magnitudes of the loads in their respective directions. Concentrated nodal loads input in this section may <u>not</u> be functions of time.

7. ELEMENT CONNECTIVITY DATA (6I5,F10.0)

If IRSTRT.EQ.-1 on Record 2 or MESH.EQ.0 on Record 3, skip this section. Otherwise, input one record for each element using the following format:

columns	variable	note	entry
1-5	M		Element number
6-10	IX(1,M)	(1)	Global node number of element nodal point I
11-15	IX(2,M)	(1)	Global node number of element nodal point J
16-20	IX(3,M)	(1)	Global node number of element nodal point K
21-25	IX(4,M)	(1)	Global node number of element nodal point L
26-30	IX(5,M)		Material property set number assigned to this element
31-40	HM1		Not used

Notes:

(1) The element nodal numbering scheme used in SAMCR is illustrated in Figure II.1. The element mesh must conform to the following requirements:

(a) The fracture is assumed to propagate along the + r-axis. This axis must be a line of symmetry for the problem (Mode I fracture propagation) and must be modeled with roller supports.

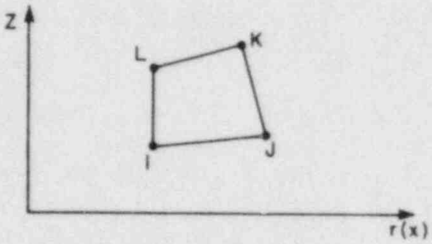

Fig. II.1. Node numbering scheme used for finite elements in SAMCR.

(b) Element numbers must increase sequentially along each row parallel to the r-axis (at least for those elements included in the J-integral contour--see Section 13 in this Appendix).

(c) The increment in element numbers between the rows of elements described in (b) must be uniform and constant (at least for those elements included in the J-integral contour).

See Figure II.3 and Section 13 in this Appendix for a more detailed description of the required mesh layout in the vicinity of the crack tip.

8. PRESSURE LOAD DATA

If IRSTRT.EQ.-1 on Record 2, skip this section.

8.1 Element Pressure Loads (2I5,3F10.0)

Not required if MESH.EQ.0 on Record 3. If MESH.NE.0, input NUMPC records (NUMPC specified on Record 3) using the following format:

columns	variable	note	entry
1-5	INI	(1)	Global node number for beginning of pressure load
6-10	JNJ	(1)	Global node number for end of pressure load
11-20	PI	(1)	Multiplier for pressure intensity at node I

21-30	PJ	(1)	Multiplier for pressure intensity at node J
31-40	T	(2)	Arrival time of pressure loading

8.2 Load History Data (2F10.0)

As specified on Record 3, NUMLP pressure-time data pairs must be input in ascending order. Each record contains one data pair using the following format:

columns	variable	note	entry
1-10	P(1,M)	(3)	Time value at data point M
11-20	P(2,M)	(4)	Pressure value at data point M

Notes:

(1) As shown in Figure II.2, the element must be on the left as one progresses from node INI to node JNJ. Surface tensile pressures are input as negative pressures.

(2) For time values less than T, the pressure intensity is zero.

(3) The pressure value is taken as zero before the first time value and after the last time value.

(4) The actual pressure magnitude is P(2,K)*PI for node INI and P(2,K)*PJ for node INJ.

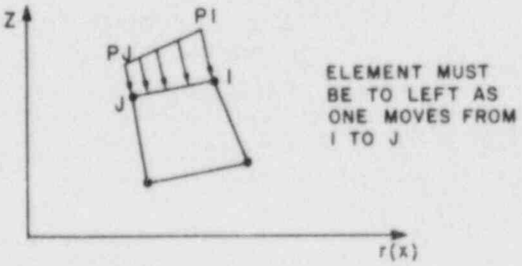

Fig. II.2. Node numbering scheme used for pressure loads in SAMCR.

9. INITIAL CONDITIONS

If IRSTRT.EQ.-1 on Record 2, skip this section.

9.1 Multiplier for Initial Displacements (F12.6)

columns	variable	note	entry
1-12	RATIO	(1)	Multiplier for initial displacements

9.2 Initial Nodal Displacements (I5,15X,E16.7,5X,E16.7)

columns	variable	note	entry
1-5	NODE		Node number
21-36	U(J1)	(1)	R- (or x-) direction initial displacement
42-57	U(J2)	(1)	Z-direction initial displacement

(Repeat as necessary until all NUMNP initial displacement pairs have been input.)

9.3 Initial Nodal Velocities (I5,2E10.0,I5)

columns	variable	note	entry
1-5	N		Node number
6-15	V(2*N-1)		R- (or x-) direction initial velocity
16-25	V(2*N)		Z-direction initial velocity
26-30	ND	(2)	Node increment for automatic generation of initial velocities (Default = 1)

(Repeat as necessary until all NUMNP initial velocity pairs have been input or generated.)

Notes:

(1) Actual initial displacements are computed as U(I) = RATIO * U(I). R- and z-direction displacements are stored sequentially in array U: J1 = 2*NODE-1 and J2 = 2*NODE.

(2) Nodal velocity data for a series of nodes N, N+1*ND, N+2*ND, etc. may be generated from two records given in sequence:

Record 1: N, V(2*N-1), V(2*N), ND
Record 2: M, V(2*M-1), V(2*M), MD

The first generated node is N+1*ND; the second generated node is N+2*ND; etc. Generation continues until node number M-ND is established. The node number difference M-N must be evenly divisible by ND. The default value for ND is 1.

The velocity values for each generated node are computed using linear interpolation between the appropriate values specified for nodes N and M.

Nodal velocity data may be input in any sequence. However, node NUMNP must appear last in the list.

10. OUTPUT TIME CONTROL DATA (2 or 3 records, each 6E10.0)

If IRSTRT.EQ.-1 on Record 2, the data provided in this section will override the values read from the analysis restart file (Unit 14). If zero values are input on the following records, the old values from the analysis restart file will be used.

columns	variable	note	entry
first record:			
1-10	TIO1(1)		Initial time for printed output
11-20	TIO2(1)	(1)	Final time for printed output
21-30	TIOD(1)	(2)	Time interval between printed output
31-40	TIO1(2)		Initial time for output to Unit 10 (unformatted plot file)
41-50	TIO2(2)	(3)	Final time for output to Unit 10
51-60	TIOD(2)	(2)	Time interval between output to Unit 10

second record:

1-10	TIO1(3)	(4)	Initial time for output to Unit 11 (crack data)
11-20	TIO2(3)		Final time for output to Unit 11
21-30	TIOD(3)	(2)	Time interval between output to Unit 11
31-40	TIO1(4)	(5)	Initial time for output to Unit 12 (edited nodal point and element data)
41-50	TIO2(4)		Final time for output to Unit 12
51-60	TIOD(4)	(2)	Time interval between output to Unit 12

third record (read only in IRSTRT.NE.0)

1-10	TIO1(5)	(6)	Initial time for output to Unit 13 (restart data)
11-20	TIO2(5)		Final time for output to Unit 13
21-30	TIOD(5)	(2)	Time interval between output to Unit 13

Notes:

(1) If the current time during the analysis exceeds TIO2(1), execution is halted.

(2) A value of zero for the time interval will result in data output at every time step between TIO1 and TIO2 during the analysis.

(3) Unit 10 contains unformatted analysis results suitable for subsequent input to a post-processing plotting routine. The sequence of write statements used to generate this file is of the form:

At the beginning of program execution:

```
   WRITE(10) HED,NUMEL,NUMNP
   WRITE(10) (R(I),I=1,NUMNP),(Z(I),I=1,NUMNP),
  +          ((IX(I,J),J=1,NUMEL),I=1,5)
```

At each specified time interval:

```
WRITE(10) TT
WRITE(10) (U(I),I=1,NEQ),(V(I),I=1,NEQ),(A(I),I=1,NEQ)
WRITE(10) ((SIG(I,J),J=1,NUMEL),I=1,4)
WRITE(10) ((EPS(I,J),J=1,NUMEL),I=1,4)
```

in which: HED = problem title
NUMEL = number of elements
NUMNP = number of nodal points
NEQ = number of equations
R,Z = r- and z- nodal coordinates
IX = element connectivity
TT = current time
U,V,A = nodal displacements, velocities, and accelerations
SIG = element stresses
EPS = element strains

(4) Unit 11 contains crack and energy data from the analysis. The write statement used to generate this file at each specified time interval is of the form:

```
      WRITE(11,300) TT,X,CDOT,CJINT,HK,EO,FO,DDX,EFRAC,STREN2,
     +              HKNENG,VISEN2,TOTENG
  300 FORMAT(13E10.4)
```

in which: TT = time
X = crack tip location
CDOT = crack tip velocity
CJINT = J-integral value
HK = stress intensity factor
EO = initial magnitude of crack restraining force
FO = current magnitude of crack restraining force
DDX = intraelement crack advance
EFRAC = fracture energy (cumulative)
STREN2 = strain energy
HKNENG = kinetic energy
VISEN2 = viscous (dissipated) energy (cumulative)
TOTENG = total energy

It should be noted that the energy values represent the complete energies for the problem, including symmetry about the crack line.

(5) Unit 12 contains edited nodal data. The write statement used to generate this file at each specified interval for each node I listed in NDSOUT(I) is of the form:

```
    WRITE(12,150) NCOUNT,TT,N,UR(I),UZ(I),VR(I),VZ(I),
   +              AR(I),AZ(I)
150 FORMAT(I6,E10.4,I4,6E10.4)
```

in which: NCOUNT = line number
TT = time
N = node number
UR(I),UZ(I) = nodal displacements
VR(I),VZ(I) = nodal velocities
AR(I),AZ(I) = nodal accelerations

(6) Unit 13 contains the unformatted data needed for an analysis restart. This data consists of all labeled COMMON blocks in order, followed by the master storage array A in unlabeled COMMON. See subroutine RSTOUT for a more detailed description.

11. NODAL AND ELEMENT DATA OUTPUT CONTROL

The following cards are used to specify the edited list of nodes and elements for output of displacements, velocities, accelerations, and stresses to the printer and Unit 12.

If IRSTRT.EQ.-1 on Record 2, the data provided in this section will override the values read from the analysis restart file (Unit 14). If zero values are input on the following records, the old values from the analysis restart file will be used.

11.1 Number of Nodes and Elements in Lists (2I5)

columns	variable	note	entry
1-5	NUMDS	(1)	Number of nodes listed on Record 12.2 (below)
6-10	NUMST	(1)	Number of elements listed on Record 12.3 (below)

11.2 Nodes for Output (multiple records, each 16I5)

columns	variable	note	entry
1-5	NDSOUT(1)		Node number at which output is desired
6-10	NDSOUT(2)		Node number at which output is desired
.			
.			
.			
76-80	NDSOUT(16)		Node number at which output is desired

(Repeat as required to input NUMDS node numbers)

11.3 Elements for Output (multiple records, each 16I5)

columns	variable	note	entry
1-5	NSTOUT(1)		Element number at which output is desired
6-10	NSTOUT(2)		Element number at which output is desired
.			
.			
.			
76-80	NSTOUT(16)		Element number at which output is desired

(Repeat as required to input NUMST element numbers)

Note:

(1) If NUMDS (NUMST) is set equal to zero, output will be generated for all nodes (elements). The maximum value for NUMDS, NUMST is 160.

12. DYNAMIC ANALYSIS CONTROL DATA

If IRSTRT.EQ.-1 on Record 2, the data provided in this section will override the values read from the analysis restart file (Unit 14). If zero values are input on the following records, the old values from the analysis restart file will be used.

columns	variable	note	entry
1-5	NSTEP		Limit for number of time steps to be performed
6-15	RDT	(1)	Adjustment factor for time step size (Default = 1.0)
16-25	B1		First bulk viscosity coefficient (Default = 12.0)
26-35	B2		Second bulk viscosity coefficient (Default = 0.6)
36-45	B3		Keystone mode viscosity coefficient (Default = 0.1)

Note:

(1) Time step size is automatically selected during the analysis. (See Chapter 2 for details on the selection algorithm). The automatically selected value may be modified as follows:

DELTAT = RDT * DELTAT

RDT should be restricted to the range of 0 to 1.

13. J-INTEGRAL CONTOUR GEOMETRY (F10.0,5I5)

If IRSTRT.EQ.-1 on Record 2, skip this section.

columns	variable	note	entry
1-10	X	(1)	R- (x-) coordinate for initial crack tip location
11-15	NODENO	(2)	Element number for element just behind initial crack tip location
16-20	NNN	(2)	Number of elements from crack tip to leading edge of J-integral contour (Default = 3)

21-25	NT	(2)	Number of elements between crack tip and upper leg of J-integral contour (Default = 2)
26-30	NL	(2)	Number of elements between crack tip and lagging leg of J-integral contour (Default = 6)
31-35	NN	(3)	Number of elements in one row of mesh

Notes:

(1) The crack is assumed to propagate along the positive r-axis.

(2) See Figure II.3 for a detailed description of the J-integral contour geometry notation. The horizontal and vertical legs of the J-integral contour must be parallel to the r- and z-axes, respectively. The contour legs are assumed to run through the centers of the elements.

(3) Elements must be numbered in rows parallel to the crack path with increasing element numbers in the direction of crack propagation. The increment in element numbers between rows must be uniform and constant for all elements within the J-contour.

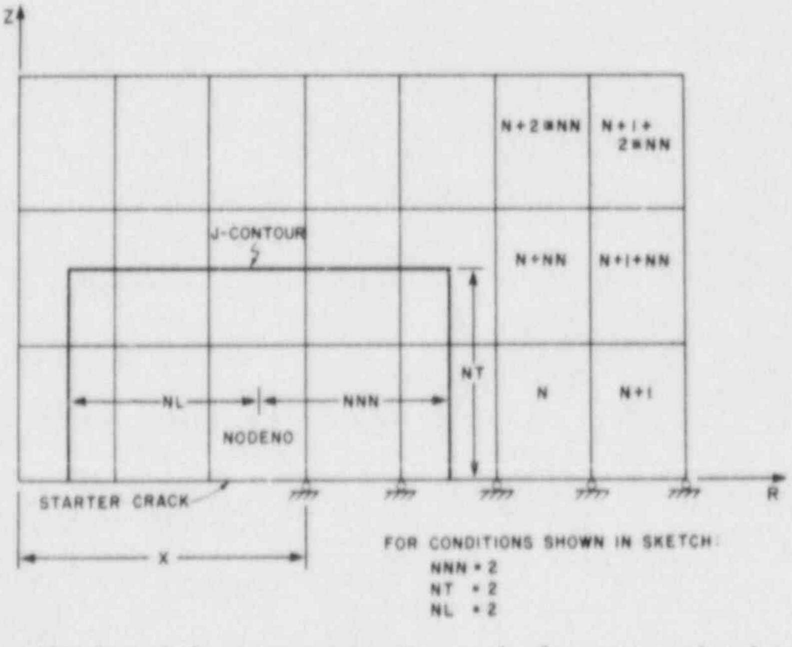

Fig. II.3. J-Contour geometry and element numbering scheme used in SAMCR.

14. DYNAMIC MODULUS VALUE FOR STRESS INTENSITY FACTOR COMPUTATION

If IRSTRT.EQ.-1 on Record 2, skip this section.

14.1 Dynamic Modulus (F15.6,I5)

columns	variable	note	entry
1-15	DYNMOD	(1)	Reference value for dynamic
16-20	NSRPTS	(2)	Number of strain rate points used to describe strain rate dependency of dynamic modulus; see Records 13.2 and 13.3 below.

14.2 Strain Rate Values for Dynamic Modulus Calculation (8E10.0)

Skip this subsection if NSRPTS.EQ.0.

column	variable	note	entry
1-10	STRNRT(1)	(2)	Strain rate value used to describe strain rate dependency of dynamic modulus
11-20	STRNRT(2)	(2)	
. . .			
71-80	STRNRT(8)	(2)	

14.3 Dynamic Modulus Multiplication Factors (8E10.0)

Skip this subsection if NSRPTS.EQ.0.

column	variable	note	entry
1-10	EDMULT(1)	(2)	Multiplication factor for dynamic modulus corresponding to STRNRT(1)
11-20	EDMULT(2)	(2)	Multiplication factor for dynamic modulus corresponding to STRNRT(2)
. . .			
71-80	EDMULT(8)	(2)	Multiplication factor for dynamic modulus corresponding to STRNRT(8)

Notes:

(1) DYNMOD is the reference value for the dynamic modulus EDYN; EDYN is used for computing the stress intensity factor, K, from the J-integral value. For strain rate dependent materials (e.g., polymers), the dynamic modulus is modified as described in Note (2) below.

(2) For strain rate dependent materials, the reference dynamic modulus DYNMOD may be modified as follows:

EDYN = EDMULT * DYNMOD

in which EDYN is the dynamic modulus used to compute the stress intensity factor, K, and EDMULT is a strain rate correction factor. The strain rate dependency relation is specified by NSRPTS data pairs of STRNRT(I),EDMULT(I); values between these points are computed using linear interpolation. Data must be input in ascending order.

If NSRPTS.EQ.0, then EDYN = DYNMOD.

15. FRACTURE CONSTITUTIVE PROPERTIES

If IRSTRT.EQ.-1 on Record 2, skip this section.

15.1 Control Data (3I5,F10.0)

columns	variable	note	entry
1-5	KK	(1)	Number of stress intensity vs. crack tip velocity data pairs per temperature value
6-10	KT	(2)	Number of temperature values at which stress intensity vs. crack tip velocity data are specified (Default = 1)
11-15	NAVG	(3)	Number of time steps used for stress intensity smoothing algorithm (Default = 1)
16-25	SIFRST	(4)	Stress intensity factor multiplier for fracture reinitiation (Default = 1)

15.2 Temperature-Stress Intensity-Crack Tip Velocity Data

For each of KT temperature values, enter KK stress intensity vs. crack tip velocity data pairs using the following format:

columns	variable	note	entry
first record (F10.0)			
1-10	ADOTK(1,1,1)	(5)	Temperature for stress intensity vs. crack tip velocity data
second record (8F10.0)			
1-10	ADOTK(1,2,1)	(5)	First stress intensity value
11-20	ADOTK(1,3,1)	(5)	Second stress intensity value
.			
.			
.			
71-80	ADOTK(1,9,1)	(5)	Eighth stress intensity value
third record (8F10.0--required only if KK.GT.8)			
1-10	ADOTK(1,10,1)	(5)	Ninth stress intensity value
.			
.			
.			
fourth record (8F10.0)			
1-10	ADOTK(1,2,2)	(5)	First crack tip velocity value (corresponds to first stress intensity value)
11-20	ADOTK(1,3,2)	(5)	Second crack tip velocity value
.			
.			
.			
71-80	ADOTK(1,9,2)	(5)	Eighth crack tip velocity value
fifth record (8F10.0--required only if KK.GT.8)			
1-10	ADOTK(1,10,2)	(5)	Ninth crack tip velocity value
.			
.			
.			

(Repeat first through fifth records of this group until data sets for KT temperature values have been input.)

Notes:

(1) KK may not exceed 16. The number of stress intensity vs. crack tip velocity data pairs must be the same for all temperatures.

(2) KT may not exceed 10.

(3) The current value for the crack tip stress intensity factor K may be computed as a moving average of the calculated K values for the preceding NAVG time steps. This "smoothed" value for K is then used to determine the crack tip velocity at the current time step. NAVG may not exceed 50.

(4) After the fracture has arrested for some "threshold" time interval, the K value needed for reinitiation may be greater than the K value at arrest:

$$K_{\text{reinitiation}} = \text{SIFRST} * K_{\text{arrest}}$$

The threshold time interval after which the fracture is assumed to have arrested is set at 100 microseconds in subroutine VEL.

(5) The temperature-stress intensity-crack tip velocity constitutive data for the fracturing material is described as a set of curves, with each curve specifying the stress intensity vs. crack tip velocity characteristics of the material at a specified temperature, as shown in Figure II.4. The temperature-stress intensity-crack tip velocity data is stored in array ADOTK(L,M,N) using the following scheme:

ADOTK(L,1,1) = Temperature value for curve L

ADOTK(L,M,1) = Stress intensity values for curve L (M = 2, KK+1)

ADOTK(L,M,2) = Crack tip velocity values for curve L (M = 2, KK+1)

All data must be input in ascending order.

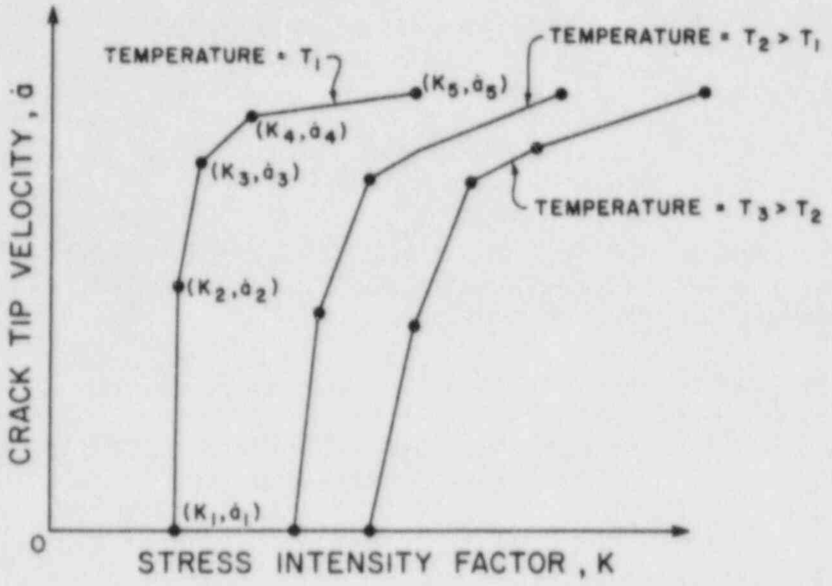

Fig. II.4. A sample input to SAMCR of crack speed as a function of crack tip stress intensity factor and crack tip temperature.

APPENDIX III

ABBREVIATED INPUT AND OUTPUT FOR A SAMPLE PROBLEM

(ANALYSIS OF HOMALITE 100 MCT TEST P-9)

NOTE: Card images for all required input data are given first, followed by the output generated

```
                                   CARD IMAGES
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890


EXAMPLE PROBLEM:  MCT TEST P-9
    0    0
    2  658  598    0    0    0       1.0    1    0    0
    1    1  112.0E-6
HOMALITE 100 MATERIAL PROPERTIES:
520000.0
0.35



    2    1  2.524E-4
ALUMINUM PIN MATERIAL PROPERTIES:
  15.0E+06
0.31



    1   .000000   .000000   .000000    .00000    .00000
    2   .000000   .250000   .000000    .00000    .00000
    3   .000000   .500000   .000000    .00000    .00000
    4   .000000   .800000   .000000    .00000    .00000
    5   .000000  1.100000   .000000    .00000    .00000
    6   .000000  1.400000   .000000    .00000    .00000
    7   .000000  1.700000   .000000    .00000    .00000
    8  3.000000  2.000000   .000000    .00000   0.00000
    9   .000000  2.300000   .000000    .00000    .00000
   10   .000000  2.600000   .000000    .00000    .00000
   11   .000000  2.900000   .000000    .00000    .00000
   12   .000000  3.200000   .000000    .00000    .00000
   13   .000000  3.500000   .000000    .00000    .00000
   14   .000000  3.722222   .000000    .00000    .00000
   15   .000000  3.944444   .000000    .00000    .00000
   16   .000000  4.166667   .000000    .00000    .00000
   17   .000000  4.388889   .000000    .00000    .00000
   18   .000000  4.611111   .000000    .00000    .00000
   19   .000000  4.833333   .000000    .00000    .00000
   20   .000000  5.055555   .000000    .00000    .00000
   21   .000000  5.277778   .000000    .00000    .00000
   22  2.000000  5.500000   .000000    .00000    .00000
   23  2.000000  5.680000   .000000    .00000    .00000
   24  2.000000  5.860000   .000000    .00000    .00000
   25  2.000000  6.040000   .000000    .00000    .00000
   26  2.000000  6.220000   .000000    .00000    .00000
   27  2.000000  6.400000   .000000    .00000    .00000
   28  2.000000  6.580000   .000000    .00000    .00000
```

```
                                   CARD IMAGES
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   29  2.000000  6.760000   .000000    .00000    .00000
   30  2.000000  6.940000   .000000    .00000    .00000
   31  2.000000  7.120000   .000000    .00000    .00000
   32  2.000000  7.299999   .000000    .00000    .00000
   33  2.000000  7.479999   .000000    .00000    .00000
   34  2.000000  7.659999   .000000    .00000    .00000
   35  2.000000  7.839999   .000000    .00000    .00000
   36  2.000000  8.019999   .000000    .00000    .00000
   37  2.000000  8.199999   .000000    .00000    .00000
   38  2.000000  8.379999   .000000    .00000    .00000
   39  2.000000  8.559999   .000000    .00000    .00000
   40  2.000000  8.739999   .000000    .00000    .00000
   41  2.000000  8.919999   .000000    .00000    .00000
   42  2.000000  9.099999   .000000    .00000    .00000
   43  2.000000  9.279999   .000000    .00000    .00000
   44  2.000000  9.459999   .000000    .00000    .00000
   45  2.000000  9.639999   .000000    .00000    .00000
   46  2.000000  9.819999   .000000    .00000    .00000
   47  2.000000 10.000000   .000000    .00000    .00000
   48   .000000   .000000   .300000    .00000    .00000
   49   .000000   .254948   .282490    .00000    .00000
   50   .000000   .518468   .234652    .00000    .00000
   51   .000000   .573415   .463526    .00000    .00000
   52   .000000   .939457   .435234    .00000    .00000
   53   .000000  1.297940   .395733    .00000    .00000
   54   .000000  1.650552   .349448    .00000    .00000
   55   .000000  2.000000   .300000    .00000    .00000
   56   .000000  2.349448   .349448    .00000    .00000
   57   .000000  2.702060   .395733    .00000    .00000
   58   .000000  3.060542   .435234    .00000    .00000
   59   .000000  3.426585   .463526    .00000    .00000
   60   .000000  3.481532   .234652    .00000    .00000
   61   .000000  3.716655   .280299    .00000    .00000
   62   .000000  3.942540   .293260    .00000    .00000
   63   .000000  4.165926   .297381    .00000    .00000
   64   .000000  4.388568   .298865    .00000    .00000
   65   .000000  4.610960   .299467    .00000    .00000
   66   .000000  4.833259   .299739    .00000    .00000
   67   .000000  5.055520   .299873    .00000    .00000
   68   .000000  5.277763   .299948    .00000    .00000
   69   .000000  5.500000   .300000    .00000    .00000
   70   .000000  5.680000   .300000    .00000    .00000
   71   .000000  5.860000   .300000    .00000    .00000
   72   .000000  6.040000   .300000    .00000    .00000
   73   .000000  6.219999   .300000    .00000    .00000
   74   .000000  6.400000   .300000    .00000    .00000
```

```
                                   CARD IMAGES
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

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   76   .000000  6.760000   .300000    .00000    .00000
   77   .000000  6.939999   .300000    .00000    .00000
   78   .000000  7.119999   .300000    .00000    .00000
   79   .000000  7.299999   .300000    .00000    .00000
   80   .000000  7.479999   .300000    .00000    .00000
   81   .000000  7.659999   .300000    .00000    .00000
   82   .000000  7.839999   .300000    .00000    .00000
   83   .000000  8.019999   .300000    .00000    .00000
   84   .000000  8.199999   .300000    .00000    .00000
   85   .000000  8.379999   .300000    .00000    .00000
   86   .000000  8.559999   .300000    .00000    .00000
   87   .000000  8.739999   .300000    .00000    .00000
   88   .000000  8.919999   .300000    .00000    .00000
   89   .000000  9.099999   .300000    .00000    .00000
   90   .000000  9.279999   .300000    .00000    .00000
   91   .000000  9.459999   .300000    .00000    .00000
   92   .000000  9.639999   .300000    .00000    .00000
   93   .000000  9.819999   .300000    .00000    .00000
   94   .000000 10.000000   .300000    .00000    .00000
   95   .000000   .000000   .600000    .00000    .00000
   96   .000000   .251325   .595310    .00000    .00000
   97   .000000   .500000   .600000    .00000    .00000
   98   .000000   .663490   .680986    .00000    .00000
   99   .000000   .786475   .881678    .00000    .00000
  100   .000000  1.201751   .798249    .00000    .00000
  101   .000000  1.604267   .702060    .00000    .00000
  102   .000000  2.000000   .600000    .00000    .00000
  103   .000000  2.395733   .702060    .00000    .00000
  104   .000000  2.798249   .798249    .00000    .00000
  105   .000000  3.213525   .881678    .00000    .00000
  106   .000000  3.336510   .680986    .00000    .00000
  107   .000000  3.500000   .600000    .00000    .00000
  108   .000000  3.720324   .593283    .00000    .00000
  109   .000000  3.943133   .595362    .00000    .00000
  110   .000000  4.165931   .597399    .00000    .00000
  111   .000000  4.388496   .598610    .00000    .00000
  112   .000000  4.610903   .599266    .00000    .00000
  113   .000000  4.833224   .599615    .00000    .00000
  114   .000000  5.055501   .599806    .00000    .00000
  115   .000000  5.277755   .599919    .00000    .00000
  116   .000000  5.500000   .600000    .00000    .00000
  117   .000000  5.680000   .600000    .00000    .00000
  118   .000000  5.860000   .600000    .00000    .00000
  119   .000000  6.039999   .600000    .00000    .00000
  120   .000000  6.219999   .600000    .00000    .00000
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                                   CARD IMAGES
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  122   .000000  6.580000   .600000    .00000    .00000
  123   .000000  6.759999   .600000    .00000    .00000
  124   .000000  6.939999   .600000    .00000    .00000
  125   .000000  7.119999   .600000    .00000    .00000
  126   .000000  7.299999   .600000    .00000    .00000
  127   .000000  7.479999   .600000    .00000    .00000
  128   .000000  7.659999   .600000    .00000    .00000
  129   .000000  7.839999   .600000    .00000    .00000
  130   .000000  8.019999   .600000    .00000    .00000
  131   .000000  8.199999   .600000    .00000    .00000
  132   .000000  8.379999   .600000    .00000    .00000
  133   .000000  8.559999   .600000    .00000    .00000
  134   .000000  8.739998   .600000    .00000    .00000
  135   .000000  8.919998   .600000    .00000    .00000
  136   .000000  9.099998   .600000    .00000    .00000
  137   .000000  9.279998   .600000    .00000    .00000
  138   .000000  9.459999   .600000    .00000    .00000
  139   .000000  9.639999   .600000    .00000    .00000
  140   .000000  9.819999   .600000    .00000    .00000
  141   .000000 10.000000   .600000    .00000    .00000
  142   .000000   .000000   .900000    .00000    .00000
  143   .000000   .250353   .898749    .00000    .00000
  144   .000000   .500000   .900000    .00000    .00000
  145   .000000   .716086   .970033    .00000    .00000
  146   .000000   .939340  1.060660    .00000    .00000
  147   .000000  1.118322  1.213526    .00000    .00000
  148   .000000  1.564766  1.060543    .00000    .00000
  149   .000000  2.000000   .900000    .00000    .00000
  150   .000000  2.435234  1.060543    .00000    .00000
  151   .000000  2.881678  1.213526    .00000    .00000
  152   .000000  3.060660  1.060660    .00000    .00000
  153   .000000  3.283914   .970033    .00000    .00000
  154   .000000  3.500000   .900000    .00000    .00000
  155   .000000  3.721508   .897473    .00000    .00000
  156   .000000  3.943739   .897504    .00000    .00000
  157   .000000  4.166170   .898242    .00000    .00000
  158   .000000  4.388581   .898912    .00000    .00000
  159   .000000  4.610932   .899369    .00000    .00000
  160   .000000  4.833234   .899650    .00000    .00000
  161   .000000  5.055504   .899818    .00000    .00000
  162   .000000  5.277756   .899923    .00000    .00000
  163   .000000  5.500000   .900000    .00000    .00000
  164   .000000  5.680000   .900000    .00000    .00000
  165   .000000  5.860000   .900000    .00000    .00000
  166   .000000  6.039999   .900000    .00000    .00000
```

```
                                   CARD IMAGES
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  168   .000000  6.400000   .900000    .00000    .00000
  169   .000000  6.579999   .900000    .00000    .00000
  170   .000000  6.759999   .900000    .00000    .00000
  171   .000000  6.939999   .900000    .00000    .00000
  172   .000000  7.119999   .900000    .00000    .00000
  173   .000000  7.299999   .900000    .00000    .00000
  174   .000000  7.479999   .900000    .00000    .00000
  175   .000000  7.659999   .900000    .00000    .00000
  176   .000000  7.839999   .900000    .00000    .00000
  177   .000000  8.019999   .900000    .00000    .00000
  178   .000000  8.199999   .900000    .00000    .00000
  179   .000000  8.379999   .900000    .00000    .00000
  180   .000000  8.559999   .900000    .00000    .00000
  181   .000000  8.739998   .900000    .00000    .00000
  182   .000000  8.919998   .900000    .00000    .00000
  183   .000000  9.099998   .900000    .00000    .00000
  184   .000000  9.279998   .900000    .00000    .00000
  185   .000000  9.459999   .900000    .00000    .00000
  186   .000000  9.639999   .900000    .00000    .00000
  187   .000000  9.819999   .900000    .00000    .00000
  188   .000000 10.000000   .900000    .00000    .00000
  189   .000000   .000000  1.200000    .00000    .00000
  190   .000000   .250088  1.199687    .00000    .00000
  191   .000000   .500000  1.200000    .00000    .00000
  192   .000000   .761513  1.238487    .00000    .00000
  193   .000000  1.029967  1.283914    .00000    .00000
  194   .000000  1.319014  1.336510    .00000    .00000
  195   .000000  1.536475  1.426585    .00000    .00000
  196   .000000  2.000000  1.200000    .00000    .00000
  197   .000000  2.463525  1.426585    .00000    .00000
  198   .000000  2.680986  1.336510    .00000    .00000
  199   .000000  2.970033  1.283914    .00000    .00000
  200   .000000  3.238487  1.238487    .00000    .00000
  201   .000000  3.500000  1.200000    .00000    .00000
  202   .000000  3.721969  1.199103    .00000    .00000
  203   .000000  3.944145  1.198940    .00000    .00000
  204   .000000  4.166427  1.199153    .00000    .00000
  205   .000000  4.388727  1.199428    .00000    .00000
  206   .000000  4.611012  1.199649    .00000    .00000
  207   .000000  4.833276  1.199798    .00000    .00000
  208   .000000  5.055525  1.199892    .00000    .00000
  209   .000000  5.277765  1.199954    .00000    .00000
  210   .000000  5.500000  1.200000    .00000    .00000
  211   .000000  5.680000  1.200000    .00000    .00000
  212   .000000  5.860000  1.200000    .00000    .00000
```

```
                                   CARD IMAGES
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  214   .000000  6.220000  1.200000    .00000    .00000
  215   .000000  6.399999  1.200000    .00000    .00000
  216   .000000  6.579999  1.200000    .00000    .00000
  217   .000000  6.759999  1.200000    .00000    .00000
  218   .000000  6.939999  1.200000    .00000    .00000
  219   .000000  7.120000  1.200000    .00000    .00000
  220   .000000  7.299999  1.200000    .00000    .00000
  221   .000000  7.479999  1.200000    .00000    .00000
  222   .000000  7.659999  1.200000    .00000    .00000
  223   .000000  7.839999  1.200000    .00000    .00000
  224   .000000  8.019999  1.200000    .00000    .00000
  225   .000000  8.199999  1.200000    .00000    .00000
  226   .000000  8.379999  1.200000    .00000    .00000
  227   .000000  8.559999  1.200000    .00000    .00000
  228   .000000  8.739999  1.200000    .00000    .00000
  229   .000000  8.919999  1.200000    .00000    .00000
  230   .000000  9.099998  1.200000    .00000    .00000
  231   .000000  9.279999  1.200000    .00000    .00000
  232   .000000  9.459999  1.200000    .00000    .00000
  233   .000000  9.639999  1.200000    .00000    .00000
  234   .000000  9.819999  1.200000    .00000    .00000
  235   .000000 10.000000  1.200000    .00000    .00000
  236   .000000   .000000  1.500000    .00000    .00000
  237   .000000   .250000  1.500000    .00000    .00000
  238   .000000   .500000  1.500000    .00000    .00000
  239   .000000   .800000  1.500000    .00000    .00000
  240   .000000  1.100000  1.500000    .00000    .00000
  241   .000000  1.400000  1.500000    .00000    .00000
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  243   .000000  2.000000  1.500000    .00000    .00000
  244   .000000  2.234652  1.481532    .00000    .00000
  245   .000000  2.600000  1.500000    .00000    .00000
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  247   .000000  3.200000  1.500000    .00000    .00000
  248   .000000  3.500000  1.500000    .00000    .00000
  249   .000000  3.722222  1.500000    .00000    .00000
  250   .000000  3.944444  1.500000    .00000    .00000
  251   .000000  4.166667  1.500000    .00000    .00000
  252   .000000  4.388889  1.500000    .00000    .00000
  253   .000000  4.611111  1.500000    .00000    .00000
  254   .000000  4.833333  1.500000    .00000    .00000
  255   .000000  5.055555  1.500000    .00000    .00000
  256   .000000  5.277778  1.500000    .00000    .00000
  257   .000000  5.500000  1.500000    .00000    .00000
  258   .000000  5.680000  1.500000    .00000    .00000
```

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                                    CARD IMAGES
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    260   .000000  6.040000  1.500000     .00000     .00000
    261   .000000  6.220000  1.500000     .00000     .00000
    262   .000000  6.400000  1.500000     .00000     .00000
    263   .000000  6.580000  1.500000     .00000     .00000
    264   .000000  6.760000  1.500000     .00000     .00000
    265   .000000  6.940000  1.500000     .00000     .00000
    266   .000000  7.120000  1.500000     .00000     .00000
    267   .000000  7.299999  1.500000     .00000     .00000
    268   .000000  7.479999  1.500000     .00000     .00000
    269   .000000  7.659999  1.500000     .00000     .00000
    270   .000000  7.839999  1.500000     .00000     .00000
    271   .000000  8.019999  1.500000     .00000     .00000
    272   .000000  8.199999  1.500000     .00000     .00000
    273   .000000  8.379999  1.500000     .00000     .00000
    274   .000000  8.559999  1.500000     .00000     .00000
    275   .000000  8.739999  1.500000     .00000     .00000
    276   .000000  8.919999  1.500000     .00000     .00000
    277   .000000  9.099999  1.500000     .00000     .00000
    278   .000000  9.279999  1.500000     .00000     .00000
    279   .000000  9.459999  1.500000     .00000     .00000
    280   .000000  9.639999  1.500000     .00000     .00000
    281   .000000  9.819999  1.500000     .00000     .00000
    282   .000000 10.000000  1.500000     .00000     .00000
    283   .000000   .000000  1.875000     .00000     .00000
    284   .000000   .250000  1.875000     .00000     .00000
    285   .000000   .500000  1.875000     .00000     .00000
    286   .000000   .800814  1.874770     .00000     .00000
    287   .000000  1.102387  1.874325     .00000     .00000
    288   .000000  1.406566  1.873144     .00000     .00000
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    296   .000000  3.722222  1.875000     .00000     .00000
    297   .000000  3.944444  1.875000     .00000     .00000
    298   .000000  4.166666  1.875000     .00000     .00000
    299   .000000  4.388889  1.875000     .00000     .00000
    300   .000000  4.611111  1.875000     .00000     .00000
    301   .000000  4.833333  1.875000     .00000     .00000
    302   .000000  5.055555  1.875000     .00000     .00000
    303   .000000  5.277778  1.875000     .00000     .00000
    304   .000000  5.500000  1.875000     .00000     .00000
```

```
                                   CARD IMAGES
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12345678901234567890123456789012345678901234567890123456789012345678901234567890

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  306   .000000  5.860000  1.875000    .00000    .00000
  307   .000000  6.040000  1.875000    .00000    .00000
  308   .000000  6.220000  1.875000    .00000    .00000
  309   .000000  6.399999  1.875000    .00000    .00000
  310   .000000  6.580000  1.875000    .00000    .00000
  311   .000000  6.760000  1.875000    .00000    .00000
  312   .000000  6.940000  1.875000    .00000    .00000
  313   .000000  7.119999  1.875000    .00000    .00000
  314   .000000  7.299999  1.875000    .00000    .00000
  315   .000000  7.479999  1.875000    .00000    .00000
  316   .000000  7.659999  1.875000    .00000    .00000
  317   .000000  7.839999  1.875000    .00000    .00000
  318   .000000  8.019999  1.875000    .00000    .00000
  319   .000000  8.199999  1.875000    .00000    .00000
  320   .000000  8.379999  1.875000    .00000    .00000
  321   .000000  8.559999  1.875000    .00000    .00000
  322   .000000  8.739999  1.875000    .00000    .00000
  323   .000000  8.919999  1.875000    .00000    .00000
  324   .000000  9.099999  1.875000    .00000    .00000
  325   .000000  9.279999  1.875000    .00000    .00000
  326   .000000  9.459999  1.875000    .00000    .00000
  327   .000000  9.639999  1.875000    .00000    .00000
  328   .000000  9.819999  1.875000    .00000    .00000
  329   .000000 10.000000  1.875000    .00000    .00000
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  331   .000000   .250000  2.250000    .00000    .00000
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  334   .000000  1.102167  2.249387    .00000    .00000
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  341   .000000  3.199129  2.249754    .00000    .00000
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  343   .000000  3.722222  2.250000    .00000    .00000
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  345   .000000  4.166666  2.250000    .00000    .00000
  346   .000000  4.388889  2.250000    .00000    .00000
  347   .000000  4.611111  2.250000    .00000    .00000
  348   .000000  4.833333  2.250000    .00000    .00000
  349   .000000  5.055555  2.250000    .00000    .00000
  350   .000000  5.277778  2.250000    .00000    .00000
```

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                                                CARD IMAGES
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

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    353   .000000  5.860000  2.250000    .00000    .00000
    354   .000000  6.040000  2.250000    .00000    .00000
    355   .000000  6.220000  2.250000    .00000    .00000
    356   .000000  6.399999  2.250000    .00000    .00000
    357   .000000  6.580000  2.250000    .00000    .00000
    358   .000000  6.760000  2.250000    .00000    .00000
    359   .000000  6.939999  2.250000    .00000    .00000
    360   .000000  7.119999  2.250000    .00000    .00000
    361   .000000  7.299999  2.250000    .00000    .00000
    362   .000000  7.479999  2.250000    .00000    .00000
    363   .000000  7.659999  2.250000    .00000    .00000
    364   .000000  7.839999  2.250000    .00000    .00000
    365   .000000  8.019999  2.250000    .00000    .00000
    366   .000000  8.199999  2.250000    .00000    .00000
    367   .000000  8.379999  2.250000    .00000    .00000
    368   .000000  8.559999  2.250000    .00000    .00000
    369   .000000  8.739999  2.250000    .00000    .00000
    370   .000000  8.919999  2.250000    .00000    .00000
    371   .000000  9.099998  2.250000    .00000    .00000
    372   .000000  9.279998  2.250000    .00000    .00000
    373   .000000  9.459998  2.250000    .00000    .00000
    374   .000000  9.639999  2.250000    .00000    .00000
    375   .000000  9.819999  2.250000    .00000    .00000
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    377   .000000   .000000  2.625000    .00000    .00000
    378   .000000   .250000  2.625000    .00000    .00000
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    380   .000000   .800502  2.624858    .00000    .00000
    381   .000000  1.101136  2.624679    .00000    .00000
    382   .000000  1.401876  2.624470    .00000    .00000
    383   .000000  1.702092  2.624409    .00000    .00000
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    388   .000000  3.199498  2.624858    .00000    .00000
    389   .000000  3.500000  2.625000    .00000    .00000
    390   .000000  3.722222  2.625000    .00000    .00000
    391   .000000  3.944444  2.625000    .00000    .00000
    392   .000000  4.166666  2.625000    .00000    .00000
    393   .000000  4.388889  2.625000    .00000    .00000
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    395   .000000  4.833333  2.625000    .00000    .00000
    396   .000000  5.055555  2.625000    .00000    .00000
```

```
                                  CARD IMAGES
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12345678901234567890123456789012345678901234567890123456789012345678901234567890

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  398   .000000  5.500000  2.625000    .00000    .00000
  399   .000000  5.680000  2.625000    .00000    .00000
  400   .000000  5.860000  2.625000    .00000    .00000
  401   .000000  6.040000  2.625000    .00000    .00000
  402   .000000  6.219999  2.625000    .00000    .00000
  403   .000000  6.399999  2.625000    .00000    .00000
  404   .000000  6.580000  2.625000    .00000    .00000
  405   .000000  6.759999  2.625000    .00000    .00000
  406   .000000  6.939999  2.625000    .00000    .00000
  407   .000000  7.119999  2.625000    .00000    .00000
  408   .000000  7.299999  2.625000    .00000    .00000
  409   .000000  7.479999  2.625000    .00000    .00000
  410   .000000  7.659999  2.625000    .00000    .00000
  411   .000000  7.839999  2.625000    .00000    .00000
  412   .000000  8.019999  2.625000    .00000    .00000
  413   .000000  8.199999  2.625000    .00000    .00000
  414   .000000  8.379999  2.625000    .00000    .00000
  415   .000000  8.559999  2.625000    .00000    .00000
  416   .000000  8.739999  2.625000    .00000    .00000
  417   .000000  8.919999  2.625000    .00000    .00000
  418   .000000  9.099999  2.625000    .00000    .00000
  419   .000000  9.279999  2.625000    .00000    .00000
  420   .000000  9.459999  2.625000    .00000    .00000
  421   .000000  9.639999  2.625000    .00000    .00000
  422   .000000  9.819999  2.625000    .00000    .00000
  423   .000000 10.000000  2.625000    .00000    .00000
  424   .000000   .000000  3.000000    .00000    .00000
  425   .000000   .250000  3.000000    .00000    .00000
  426   .000000   .500000  3.000000    .00000    .00000
  427   .000000   .800000  3.000000    .00000    .00000
  428   .000000  1.100000  3.000000    .00000    .00000
  429   .000000  1.400000  3.000000    .00000    .00000
  430   .000000  1.700000  3.000000    .00000    .00000
  431   .000000  2.000000  3.000000    .00000    .00000
  432   .000000  2.300000  3.000000    .00000    .00000
  433   .000000  2.600000  3.000000    .00000    .00000
  434   .000000  2.900000  3.000000    .00000    .00000
  435   .000000  3.200000  3.000000    .00000    .00000
  436   .000000  3.500000  3.000000    .00000    .00000
  437   .000000  3.722222  3.000000    .00000    .00000
  438   .000000  3.944444  3.000000    .00000    .00000
  439   .000000  4.166667  3.000000    .00000    .00000
  440   .000000  4.388889  3.000000    .00000    .00000
  441   .000000  4.611111  3.000000    .00000    .00000
  442   .000000  4.833333  3.000000    .00000    .00000
```

```
                                   CARD IMAGES
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

  443   .000000  5.055555  3.000000    .00000    .00000
  444   .000000  5.277778  3.000000    .00000    .00000
  445   .000000  5.500000  3.000000    .00000    .00000
  446   .000000  5.680000  3.000000    .00000    .00000
  447   .000000  5.860000  3.000000    .00000    .00000
  448   .000000  6.040000  3.000000    .00000    .00000
  449   .000000  6.220000  3.000000    .00000    .00000
  450   .000000  6.400000  3.000000    .00000    .00000
  451   .000000  6.580000  3.000000    .00000    .00000
  452   .000000  6.760000  3.000000    .00000    .00000
  453   .000000  6.940000  3.000000    .00000    .00000
  454   .000000  7.120000  3.000000    .00000    .00000
  455   .000000  7.299999  3.000000    .00000    .00000
  456   .000000  7.479999  3.000000    .00000    .00000
  457   .000000  7.659999  3.000000    .00000    .00000
  458   .000000  7.839999  3.000000    .00000    .00000
  459   .000000  8.019999  3.000000    .00000    .00000
  460   .000000  8.199999  3.000000    .00000    .00000
  461   .000000  8.379999  3.000000    .00000    .00000
  462   .000000  8.559999  3.000000    .00000    .00000
  463   .000000  8.739999  3.000000    .00000    .00000
  464   .000000  8.919999  3.000000    .00000    .00000
  465   .000000  9.099999  3.000000    .00000    .00000
  466   .000000  9.279999  3.000000    .00000    .00000
  467   .000000  9.459999  3.000000    .00000    .00000
  468   .000000  9.639999  3.000000    .00000    .00000
  469   .000000  9.819999  3.000000    .00000    .00000
  470   .000000 10.000000  3.000000    .00000    .00000
  471   .000000   .000000  3.450000    .00000    .00000
  472   .000000   .250000  3.450000    .00000    .00000
  473   .000000   .500000  3.450000    .00000    .00000
  474   .000000   .800000  3.450000    .00000    .00000
  475   .000000  1.100000  3.450000    .00000    .00000
  476   .000000  1.400000  3.450000    .00000    .00000
  477   .000000  1.700000  3.450000    .00000    .00000
  478   .000000  2.000000  3.450000    .00000    .00000
  479   .000000  2.300000  3.450000    .00000    .00000
  480   .000000  2.600000  3.450000    .00000    .00000
  481   .000000  2.900000  3.450000    .00000    .00000
  482   .000000  3.200000  3.450000    .00000    .00000
  483   .000000  3.500000  3.450000    .00000    .00000
  484   .000000  3.722222  3.450000    .00000    .00000
  485   .000000  3.944444  3.450000    .00000    .00000
  486   .000000  4.166666  3.450000    .00000    .00000
  487   .000000  4.388889  3.450000    .00000    .00000
  488   .000000  4.611111  3.450000    .00000    .00000
```

```
                                        CARD IMAGES
          1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

   489    .000000  4.833333  3.450000    .00000    .00000
   490    .000000  5.055555  3.450000    .00000    .00000
   491    .000000  5.277778  3.450000    .00000    .00000
   492    .000000  5.500000  3.450000    .00000    .00000
   493    .000000  5.680000  3.450000    .00000    .00000
   494    .000000  5.860000  3.450000    .00000    .00000
   495    .000000  6.040000  3.450000    .00000    .00000
   496    .000000  6.220000  3.450000    .00000    .00000
   497    .000000  6.399999  3.450000    .00000    .00000
   498    .000000  6.580000  3.450000    .00000    .00000
   499    .000000  6.760000  3.450000    .00000    .00000
   500    .000000  6.940000  3.450000    .00000    .00000
   501    .000000  7.119999  3.450000    .00000    .00000
   502    .000000  7.299999  3.450000    .00000    .00000
   503    .000000  7.479999  3.450000    .00000    .00000
   504    .000000  7.659999  3.450000    .00000    .00000
   505    .000000  7.839999  3.450000    .00000    .00000
   506    .000000  8.019999  3.450000    .00000    .00000
   507    .000000  8.199999  3.450000    .00000    .00000
   508    .000000  8.379999  3.450000    .00000    .00000
   509    .000000  8.559999  3.450000    .00000    .00000
   510    .000000  8.739999  3.450000    .00000    .00000
   511    .000000  8.919999  3.450000    .00000    .00000
   512    .000000  9.099999  3.450000    .00000    .00000
   513    .000000  9.279999  3.450000    .00000    .00000
   514    .000000  9.459999  3.450000    .00000    .00000
   515    .000000  9.639999  3.450000    .00000    .00000
   516    .000000  9.819999  3.450000    .00000    .00000
   517    .000000 10.000000  3.450000    .00000    .00000
   518    .000000   .000000  3.900000    .00000    .00000
   519    .000000   .250000  3.900000    .00000    .00000
   520    .000000   .500000  3.900000    .00000    .00000
   521    .000000   .800000  3.900000    .00000    .00000
   522    .000000  1.100000  3.900000    .00000    .00000
   523    .000000  1.400000  3.900000    .00000    .00000
   524    .000000  1.700000  3.900000    .00000    .00000
   525    .000000  2.000000  3.900000    .00000    .00000
   526    .000000  2.300000  3.900000    .00000    .00000
   527    .000000  2.600000  3.900000    .00000    .00000
   528    .000000  2.900000  3.900000    .00000    .00000
   529    .000000  3.200000  3.900000    .00000    .00000
   530    .000000  3.500000  3.900000    .00000    .00000
   531    .000000  3.722222  3.900000    .00000    .00000
   532    .000000  3.944444  3.900000    .00000    .00000
   533    .000000  4.166666  3.900000    .00000    .00000
   534    .000000  4.388889  3.900000    .00000    .00000
```

```
                                      CARD IMAGES
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

  535   .000000  4.611111  3.900000    .00000    .00000
  536   .000000  4.833333  3.900000    .00000    .00000
  537   .000000  5.055555  3.900000    .00000    .00000
  538   .000000  5.277778  3.900000    .00000    .00000
  539   .000000  5.500000  3.900000    .00000    .00000
  540   .000000  5.680000  3.900000    .00000    .00000
  541   .000000  5.860000  3.900000    .00000    .00000
  542   .000000  6.040000  3.900000    .00000    .00000
  543   .000000  6.220000  3.900000    .00000    .00000
  544   .000000  6.399999  3.900000    .00000    .00000
  545   .000000  6.580000  3.900000    .00000    .00000
  546   .000000  6.760000  3.900000    .00000    .00000
  547   .000000  6.939999  3.900000    .00000    .00000
  548   .000000  7.119999  3.900000    .00000    .00000
  549   .000000  7.299999  3.900000    .00000    .00000
  550   .000000  7.479999  3.900000    .00000    .00000
  551   .000000  7.659999  3.900000    .00000    .00000
  552   .000000  7.839999  3.900000    .00000    .00000
  553   .000000  8.019999  3.900000    .00000    .00000
  554   .000000  8.199999  3.900000    .00000    .00000
  555   .000000  8.379999  3.900000    .00000    .00000
  556   .000000  8.559999  3.900000    .00000    .00000
  557   .000000  8.739999  3.900000    .00000    .00000
  558   .000000  8.919999  3.900000    .00000    .00000
  559   .000000  9.099998  3.900000    .00000    .00000
  560   .000000  9.279998  3.900000    .00000    .00000
  561   .000000  9.459998  3.900000    .00000    .00000
  562   .000000  9.639999  3.900000    .00000    .00000
  563   .000000  9.819999  3.900000    .00000    .00000
  564   .000000 10.000000  3.900000    .00000    .00000
  565   .000000   .000000  4.350000    .00000    .00000
  566   .000000   .250000  4.350000    .00000    .00000
  567   .000000   .500000  4.350000    .00000    .00000
  568   .000000   .800000  4.350000    .00000    .00000
  569   .000000  1.100000  4.350000    .00000    .00000
  570   .000000  1.400000  4.350000    .00000    .00000
  571   .000000  1.700000  4.350000    .00000    .00000
  572   .000000  2.000000  4.350000    .00000    .00000
  573   .000000  2.300000  4.350000    .00000    .00000
  574   .000000  2.600000  4.350000    .00000    .00000
  575   .000000  2.900000  4.350000    .00000    .00000
  576   .000000  3.200000  4.350000    .00000    .00000
  577   .000000  3.500000  4.350000    .00000    .00000
  578   .000000  3.722222  4.350000    .00000    .00000
  579   .000000  3.944444  4.350000    .00000    .00000
  580   .000000  4.166666  4.350000    .00000    .00000
```

```
                                   CARD IMAGES
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

  581   .000000  4.388889  4.350000    .00000    .00000
  582   .000000  4.611111  4.350000    .00000    .00000
  583   .000000  4.833333  4.350000    .00000    .00000
  584   .000000  5.055555  4.350000    .00000    .00000
  585   .000000  5.277778  4.350000    .00000    .00000
  586   .000000  5.500000  4.350000    .00000    .00000
  587   .000000  5.680000  4.350000    .00000    .00000
  588   .000000  5.860000  4.350000    .00000    .00000
  589   .000000  6.040000  4.350000    .00000    .00000
  590   .000000  6.219999  4.350000    .00000    .00000
  591   .000000  6.399999  4.350000    .00000    .00000
  592   .000000  6.580000  4.350000    .00000    .00000
  593   .000000  6.759999  4.350000    .00000    .00000
  594   .000000  6.939999  4.350000    .00000    .00000
  595   .000000  7.119999  4.350000    .00000    .00000
  596   .000000  7.299999  4.350000    .00000    .00000
  597   .000000  7.479999  4.350000    .00000    .00000
  598   .000000  7.659999  4.350000    .00000    .00000
  599   .000000  7.839999  4.350000    .00000    .00000
  600   .000000  8.019999  4.350000    .00000    .00000
  601   .000000  8.199999  4.350000    .00000    .00000
  602   .000000  8.379999  4.350000    .00000    .00000
  603   .000000  8.559999  4.350000    .00000    .00000
  604   .000000  8.739999  4.350000    .00000    .00000
  605   .000000  8.919999  4.350000    .00000    .00000
  606   .000000  9.099999  4.350000    .00000    .00000
  607   .000000  9.279999  4.350000    .00000    .00000
  608   .000000  9.459999  4.350000    .00000    .00000
  609   .000000  9.639999  4.350000    .00000    .00000
  610   .000000  9.819999  4.350000    .00000    .00000
  611   .000000 10.000000  4.350000    .00000    .00000
  612   .000000   .000000  4.800000    .00000    .00000
  613   .000000   .250000  4.800000    .00000    .00000
  614   .000000   .500000  4.800000    .00000    .00000
  615   .000000   .800000  4.800000    .00000    .00000
  616   .000000  1.100000  4.800000    .00000    .00000
  617   .000000  1.400000  4.800000    .00000    .00000
  618   .000000  1.700000  4.800000    .00000    .00000
  619   .000000  2.000000  4.800000    .00000    .00000
  620   .000000  2.300000  4.800000    .00000    .00000
  622   .000000  2.900000  4.800000    .00000    .00000
  623   .000000  3.200000  4.800000    .00000    .00000
  624   .000000  3.500000  4.800000    .00000    .00000
  625   .000000  3.722222  4.800000    .00000    .00000
  626   .000000  3.944444  4.800000    .00000    .00000
  627   .000000  4.166667  4.800000    .00000    .00000
```

```
                                   CARD IMAGES
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

  628   .000000  4.388889  4.800000    .00000    .00000
  629   .000000  4.611111  4.800000    .00000    .00000
  630   .000000  4.833333  4.800000    .00000    .00000
  631   .000000  5.055555  4.800000    .00000    .00000
  632   .000000  5.277778  4.800000    .00000    .00000
  633   .000000  5.500000  4.800000    .00000    .00000
  634   .000000  5.680000  4.800000    .00000    .00000
  635   .000000  5.860000  4.800000    .00000    .00000
  636   .000000  6.040000  4.800000    .00000    .00000
  637   .000000  6.220000  4.800000    .00000    .00000
  638   .000000  6.400000  4.800000    .00000    .00000
  639   .000000  6.580000  4.800000    .00000    .00000
  640   .000000  6.760000  4.800000    .00000    .00000
  641   .000000  6.940000  4.800000    .00000    .00000
  642   .000000  7.120000  4.800000    .00000    .00000
  643   .000000  7.299999  4.800000    .00000    .00000
  644   .000000  7.479999  4.800000    .00000    .00000
  645   .000000  7.659999  4.800000    .00000    .00000
  646   .000000  7.839999  4.800000    .00000    .00000
  647   .000000  8.019999  4.800000    .00000    .00000
  648   .000000  8.199999  4.800000    .00000    .00000
  649   .000000  8.379999  4.800000    .00000    .00000
  650   .000000  8.559999  4.800000    .00000    .00000
  651   .000000  8.739999  4.800000    .00000    .00000
  652   .000000  8.919999  4.800000    .00000    .00000
  653   .000000  9.099999  4.800000    .00000    .00000
  654   .000000  9.279999  4.800000    .00000    .00000
  655   .000000  9.459999  4.800000    .00000    .00000
  656   .000000  9.639999  4.800000    .00000    .00000
  657   .000000  9.819999  4.800000    .00000    .00000
  658   .000000 10.000000  4.800000    .00000    .00000
    1    1    2   49   48    1      .000
    2    2    3   50   49    1      .000
    3    3    4   51   50    2      .000
    4    4    5   52   51    2      .000
    5    5    6   53   52    2      .000
    6    6    7   54   53    2      .000
    7    7    8   55   54    2      .000
    8    8    9   56   55    2      .000
    9    9   10   57   56    2      .000
   10   10   11   58   57    2      .000
   11   11   12   59   58    2      .000
   12   12   13   60   59    2      .000
   13   13   14   61   60    1      .000
   14   14   15   62   61    1      .000
   15   15   16   63   62    1      .000
```

```
                                   CARD IMAGES
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

   16   16   17   64   63    1      .000
   17   17   18   65   64    1      .000
   18   18   19   66   65    1      .000
   19   19   20   67   66    1      .000
   20   20   21   68   67    1      .000
   21   21   22   69   68    1      .000
   22   22   23   70   69    1      .000
   23   23   24   71   70    1      .000
   24   24   25   72   71    1      .000
   25   25   26   73   72    1      .000
   26   26   27   74   73    1      .000
   27   27   28   75   74    1      .000
   28   28   29   76   75    1      .000
   29   29   30   77   76    1      .000
   30   30   31   78   77    1      .000
   31   31   32   79   78    1      .000
   32   32   33   80   79    1      .000
   33   33   34   81   80    1      .000
   34   34   35   82   81    1      .000
   35   35   36   83   82    1      .000
   36   36   37   84   83    1      .000
   37   37   38   85   84    1      .000
   38   38   39   86   85    1      .000
   39   39   40   87   86    1      .000
   40   40   41   88   87    1      .000
   41   41   42   89   88    1      .000
   42   42   43   90   89    1      .000
   43   43   44   91   90    1      .000
   44   44   45   92   91    1      .000
   45   45   46   93   92    1      .000
   46   46   47   94   93    1      .000
   47   48   49   96   95    1      .000
   48   49   50   97   96    1      .000
   49   50   51   98   97    1      .000
   50   51   52   99   98    2      .000
   51   52   53  100   99    2      .000
   52   53   54  101  100    2      .000
   53   54   55  102  101    2      .000
   54   55   56  103  102    2      .000
   55   56   57  104  103    2      .000
   56   57   58  105  104    2      .000
   57   58   59  106  105    2      .000
   58   59   60  107  106    1      .000
   59   60   61  108  107    1      .000
   60   61   62  109  108    1      .000
   61   62   63  110  109    1      .000
```

```
                                    CARD IMAGES
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

   62   63   64  111  110    1      .000
   63   64   65  112  111    1      .000
   64   65   66  113  112    1      .000
   65   66   67  114  113    1      .000
   66   67   68  115  114    1      .000
   67   68   69  116  115    1      .000
   68   69   70  117  116    1      .000
   69   70   71  118  117    1      .000
   70   71   72  119  118    1      .000
   71   72   73  120  119    1      .000
   72   73   74  121  120    1      .000
   73   74   75  122  121    1      .000
   74   75   76  123  122    1      .000
   75   76   77  124  123    1      .000
   76   77   78  125  124    1      .000
   77   78   79  126  125    1      .000
   78   79   80  127  126    1      .000
   79   80   81  128  127    1      .000
   80   81   82  129  128    1      .000
   81   82   83  130  129    1      .000
   82   83   84  131  130    1      .000
   83   84   85  132  131    1      .000
   84   85   86  133  132    1      .000
   85   86   87  134  133    1      .000
   86   87   88  135  134    1      .000
   87   88   89  136  135    1      .000
   88   89   90  137  136    1      .000
   89   90   91  138  137    1      .000
   90   91   92  139  138    1      .000
   91   92   93  140  139    1      .000
   92   93   94  141  140    1      .000
   93   95   96  143  142    1      .000
   94   96   97  144  143    1      .000
   95   97   98  145  144    1      .000
   96   98   99  146  145    1      .000
   97   99  100  147  146    2      .000
   98  100  101  148  147    2      .000
   99  101  102  149  148    2      .000
  100  102  103  150  149    2      .000
  101  103  104  151  150    2      .000
  102  104  105  152  151    2      .000
  103  105  106  153  152    1      .000
  104  106  107  154  153    1      .000
  105  107  108  155  154    1      .000
  106  108  109  156  155    1      .000
  107  109  110  157  156    1      .000
```

```
                                        CARD IMAGES
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

  108  110  111  158  157    1      .000
  109  111  112  159  158    1      .000
  110  112  113  160  159    1      .000
  111  113  114  161  160    1      .000
  112  114  115  162  161    1      .000
  113  115  116  163  162    1      .000
  114  116  117  164  163    1      .000
  115  117  118  165  164    1      .000
  116  118  119  166  165    1      .000
  117  119  120  167  166    1      .000
  118  120  121  168  167    1      .000
  119  121  122  169  168    1      .000
  120  122  123  170  169    1      .000
  121  123  124  171  170    1      .000
  122  124  125  172  171    1      .000
  123  125  126  173  172    1      .000
  124  126  127  174  173    1      .000
  125  127  128  175  174    1      .000
  126  128  129  176  175    1      .000
  127  129  130  177  176    1      .000
  128  130  131  178  177    1      .000
  129  131  132  179  178    1      .000
  130  132  133  180  179    1      .000
  131  133  134  181  180    1      .000
  132  134  135  182  181    1      .000
  133  135  136  183  182    1      .000
  134  136  137  184  183    1      .000
  135  137  138  185  184    1      .000
  136  138  139  186  185    1      .000
  137  139  140  187  186    1      .000
  138  140  141  188  187    1      .000
  139  142  143  190  189    1      .000
  140  143  144  191  190    1      .000
  141  144  145  192  191    1      .000
  142  145  146  193  192    1      .000
  143  146  147  194  193    1      .000
  144  147  148  195  194    2      .000
  145  148  149  196  195    2      .000
  146  149  150  197  196    2      .000
  147  150  151  198  197    2      .000
  148  151  152  199  198    1      .000
  149  152  153  200  199    1      .000
  150  153  154  201  200    1      .000
  151  154  155  202  201    1      .000
  152  155  156  203  202    1      .000
  153  156  157  204  203    1      .000
```

```
                                   CARD IMAGES
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

  154  157  158  205  204    1      .000
  155  158  159  206  205    1      .000
  156  159  160  207  206    1      .000
  157  160  161  208  207    1      .000
  158  161  162  209  208    1      .000
  159  162  163  210  209    1      .000
  160  163  164  211  210    1      .000
  161  164  165  212  211    1      .000
  162  165  166  213  212    1      .000
  163  166  167  214  213    1      .000
  164  167  168  215  214    1      .000
  165  168  169  216  215    1      .000
  166  169  170  217  216    1      .000
  167  170  171  218  217    1      .000
  168  171  172  219  218    1      .000
  169  172  173  220  219    1      .000
  170  173  174  221  220    1      .000
  171  174  175  222  221    1      .000
  172  175  176  223  222    1      .000
  173  176  177  224  223    1      .000
  174  177  178  225  224    1      .000
  175  178  179  226  225    1      .000
  176  179  180  227  226    1      .000
  177  180  181  228  227    1      .000
  178  181  182  229  228    1      .000
  179  182  183  230  229    1      .000
  180  183  184  231  230    1      .000
  181  184  185  232  231    1      .000
  182  185  186  233  232    1      .000
  183  186  187  234  233    1      .000
  184  187  188  235  234    1      .000
  185  189  190  237  236    1      .000
  186  190  191  238  237    1      .000
  187  191  192  239  238    1      .000
  188  192  193  240  239    1      .000
  189  193  194  241  240    1      .000
  190  194  195  242  241    1      .000
  191  195  196  243  242    2      .000
  192  196  197  244  243    2      .000
  193  197  198  245  244    1      .000
  194  198  199  246  245    1      .000
  195  199  200  247  246    1      .000
  196  200  201  248  247    1      .000
  197  201  202  249  248    1      .000
  198  202  203  250  249    1      .000
  199  203  204  251  250    1      .000
```

```
                                   CARD IMAGES
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

  200  204  205  252  251    1      .000
  201  205  206  253  252    1      .000
  202  206  207  254  253    1      .000
  203  207  208  255  254    1      .000
  204  208  209  256  255    1      .000
  205  209  210  257  256    1      .000
  206  210  211  258  257    1      .000
  207  211  212  259  258    1      .000
  208  212  213  260  259    1      .000
  209  213  214  261  260    1      .000
  210  214  215  262  261    1      .000
  211  215  216  263  262    1      .000
  212  216  217  264  263    1      .000
  213  217  218  265  264    1      .000
  214  218  219  266  265    1      .000
  215  219  220  267  266    1      .000
  216  220  221  268  267    1      .000
  217  221  222  269  268    1      .000
  218  222  223  270  269    1      .000
  219  223  224  271  270    1      .000
  220  224  225  272  271    1      .000
  221  225  226  273  272    1      .000
  222  226  227  274  273    1      .000
  223  227  228  275  274    1      .000
  224  228  229  276  275    1      .000
  225  229  230  277  276    1      .000
  226  230  231  278  277    1      .000
  227  231  232  279  278    1      .000
  228  232  233  280  279    1      .000
  229  233  234  281  280    1      .000
  230  234  235  282  281    1      .000
  231  236  237  284  283    1      .000
  232  237  238  285  284    1      .000
  233  238  239  286  285    1      .000
  234  239  240  287  286    1      .000
  235  240  241  288  287    1      .000
  236  241  242  289  288    1      .000
  237  242  243  290  289    1      .000
  238  243  244  291  290    1      .000
  239  244  245  292  291    1      .000
  240  245  246  293  292    1      .000
  241  246  247  294  293    1      .000
  242  247  248  295  294    1      .000
  243  248  249  296  295    1      .000
  244  249  250  297  296    1      .000
  245  250  251  298  297    1      .000
```

```
                                   CARD IMAGES
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

  246  251  252  299  298    1      .000
  247  252  253  300  299    1      .000
  248  253  254  301  300    1      .000
  249  254  255  302  301    1      .000
  250  255  256  303  302    1      .000
  251  256  257  304  303    1      .000
  252  257  258  305  304    1      .000
  253  258  259  306  305    1      .000
  254  259  260  307  306    1      .000
  255  260  261  308  307    1      .000
  256  261  262  309  308    1      .000
  257  262  263  310  309    1      .000
  258  263  264  311  310    1      .000
  259  264  265  312  311    1      .000
  260  265  266  313  312    1      .000
  261  266  267  314  313    1      .000
  262  267  268  315  314    1      .000
  263  268  269  316  315    1      .000
  264  269  270  317  316    1      .000
  265  270  271  318  317    1      .000
  266  271  272  319  318    1      .000
  267  272  273  320  319    1      .000
  268  273  274  321  320    1      .000
  269  274  275  322  321    1      .000
  270  275  276  323  322    1      .000
  271  276  277  324  323    1      .000
  272  277  278  325  324    1      .000
  273  278  279  326  325    1      .000
  274  279  280  327  326    1      .000
  275  280  281  328  327    1      .000
  276  281  282  329  328    1      .000
  277  283  284  331  330    1      .000
  278  284  285  332  331    1      .000
  279  285  286  333  332    1      .000
  280  286  287  334  333    1      .000
  281  287  288  335  334    1      .000
  282  288  289  336  335    1      .000
  283  289  290  337  336    1      .000
  284  290  291  338  337    1      .000
  285  291  292  339  338    1      .000
  286  292  293  340  339    1      .000
  287  293  294  341  340    1      .000
  288  294  295  342  341    1      .000
  289  295  296  343  342    1      .000
  290  296  297  344  343    1      .000
  291  297  298  345  344    1      .000
```

```
                                   CARD IMAGES
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

  292  298  299  346  345    1      .000
  293  299  300  347  346    1      .000
  294  300  301  348  347    1      .000
  295  301  302  349  348    1      .000
  296  302  303  350  349    1      .000
  297  303  304  351  350    1      .000
  298  304  305  352  351    1      .000
  299  305  306  353  352    1      .000
  300  306  307  354  353    1      .000
  301  307  308  355  354    1      .000
  302  308  309  356  355    1      .000
  303  309  310  357  356    1      .000
  304  310  311  358  357    1      .000
  305  311  312  359  358    1      .000
  306  312  313  360  359    1      .000
  307  313  314  361  360    1      .000
  308  314  315  362  361    1      .000
  309  315  316  363  362    1      .000
  310  316  317  364  363    1      .000
  311  317  318  365  364    1      .000
  312  318  319  366  365    1      .000
  313  319  320  367  366    1      .000
  314  320  321  368  367    1      .000
  315  321  322  369  368    1      .000
  316  322  323  370  369    1      .000
  317  323  324  371  370    1      .000
  318  324  325  372  371    1      .000
  319  325  326  373  372    1      .000
  320  326  327  374  373    1      .000
  321  327  328  375  374    1      .000
  322  328  329  376  375    1      .000
  323  330  331  378  377    1      .000
  324  331  332  379  378    1      .000
  325  332  333  380  379    1      .000
  326  333  334  381  380    1      .000
  327  334  335  382  381    1      .000
  328  335  336  383  382    1      .000
  329  336  337  384  383    1      .000
  330  337  338  385  384    1      .000
  331  338  339  386  385    1      .000
  332  339  340  387  386    1      .000
  333  340  341  388  387    1      .000
  334  341  342  389  388    1      .000
  335  342  343  390  389    1      .000
  336  343  344  391  390    1      .000
  337  344  345  392  391    1      .000
```

```
                                   CARD IMAGES
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

  338  345  346  393  392    1      .000
  339  346  347  394  393    1      .000
  340  347  348  395  394    1      .000
  341  348  349  396  395    1      .000
  342  349  350  397  396    1      .000
  343  350  351  398  397    1      .000
  344  351  352  399  398    1      .000
  345  352  353  400  399    1      .000
  346  353  354  401  400    1      .000
  347  354  355  402  401    1      .000
  348  355  356  403  402    1      .000
  349  356  357  404  403    1      .000
  350  357  358  405  404    1      .000
  351  358  359  406  405    1      .000
  352  359  360  407  406    1      .000
  353  360  361  408  407    1      .000
  354  361  362  409  408    1      .000
  355  362  363  410  409    1      .000
  356  363  364  411  410    1      .000
  357  364  365  412  411    1      .000
  358  365  366  413  412    1      .000
  359  366  367  414  413    1      .000
  360  367  368  415  414    1      .000
  361  368  369  416  415    1      .000
  362  369  370  417  416    1      .000
  363  370  371  418  417    1      .000
  364  371  372  419  418    1      .000
  365  372  373  420  419    1      .000
  366  373  374  421  420    1      .000
  367  374  375  422  421    1      .000
  368  375  376  423  422    1      .000
  369  377  378  425  424    1      .000
  370  378  379  426  425    1      .000
  371  379  380  427  426    1      .000
  372  380  381  428  427    1      .000
  373  381  382  429  428    1      .000
  374  382  383  430  429    1      .000
  375  383  384  431  430    1      .000
  376  384  385  432  431    1      .000
  377  385  386  433  432    1      .000
  378  386  387  434  433    1      .000
  379  387  388  435  434    1      .000
  380  388  389  436  435    1      .000
  381  389  390  437  436    1      .000
  382  390  391  438  437    1      .000
  383  391  392  439  438    1      .000
```

```
                                   CARD IMAGES
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

  384  392  393  440  439    1      .000
  385  393  394  441  440    1      .000
  386  394  395  442  441    1      .000
  387  395  396  443  442    1      .000
  388  396  397  444  443    1      .000
  389  397  398  445  444    1      .000
  390  398  399  446  445    1      .000
  391  399  400  447  446    1      .000
  392  400  401  448  447    1      .000
  393  401  402  449  448    1      .000
  394  402  403  450  449    1      .000
  395  403  404  451  450    1      .000
  396  404  405  452  451    1      .000
  397  405  406  453  452    1      .000
  398  406  407  454  453    1      .000
  399  407  408  455  454    1      .000
  400  408  409  456  455    1      .000
  401  409  410  457  456    1      .000
  402  410  411  458  457    1      .000
  403  411  412  459  458    1      .000
  404  412  413  460  459    1      .000
  405  413  414  461  460    1      .000
  406  414  415  462  461    1      .000
  407  415  416  463  462    1      .000
  408  416  417  464  463    1      .000
  409  417  418  465  464    1      .000
  410  418  419  466  465    1      .000
  411  419  420  467  466    1      .000
  412  420  421  468  467    1      .000
  413  421  422  469  468    1      .000
  414  422  423  470  469    1      .000
  415  424  425  472  471    1      .000
  416  425  426  473  472    1      .000
  417  426  427  474  473    1      .000
  418  427  428  475  474    1      .000
  419  428  429  476  475    1      .000
  420  429  430  477  476    1      .000
  421  430  431  478  477    1      .000
  422  431  432  479  478    1      .000
  423  432  433  480  479    1      .000
  424  433  434  481  480    1      .000
  425  434  435  482  481    1      .000
  426  435  436  483  482    1      .000
  427  436  437  484  483    1      .000
  428  437  438  485  484    1      .000
  429  438  439  486  485    1      .000
```

```
                                   CARD IMAGES
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

  430  439  440  487  486    1      .000
  431  440  441  488  487    1      .000
  432  441  442  489  488    1      .000
  433  442  443  490  489    1      .000
  434  443  444  491  490    1      .000
  435  444  445  492  491    1      .000
  436  445  446  493  492    1      .000
  437  446  447  494  493    1      .000
  438  447  448  495  494    1      .000
  439  448  449  496  495    1      .000
  440  449  450  497  496    1      .000
  441  450  451  498  497    1      .000
  442  451  452  499  498    1      .000
  443  452  453  500  499    1      .000
  444  453  454  501  500    1      .000
  445  454  455  502  501    1      .000
  446  455  456  503  502    1      .000
  447  456  457  504  503    1      .000
  448  457  458  505  504    1      .000
  449  458  459  506  505    1      .000
  450  459  460  507  506    1      .000
  451  460  461  508  507    1      .000
  452  461  462  509  508    1      .000
  453  462  463  510  509    1      .000
  454  463  464  511  510    1      .000
  455  464  465  512  511    1      .000
  456  465  466  513  512    1      .000
  457  466  467  514  513    1      .000
  458  467  468  515  514    1      .000
  459  468  469  516  515    1      .000
  460  469  470  517  516    1      .000
  461  471  472  519  518    1      .000
  462  472  473  520  519    1      .000
  463  473  474  521  520    1      .000
  464  474  475  522  521    1      .000
  465  475  476  523  522    1      .000
  466  476  477  524  523    1      .000
  467  477  478  525  524    1      .000
  468  478  479  526  525    1      .000
  469  479  480  527  526    1      .000
  470  480  481  528  527    1      .000
  471  481  482  529  528    1      .000
  472  482  483  530  529    1      .000
  473  483  484  531  530    1      .000
  474  484  485  532  531    1      .000
  475  485  486  533  532    1      .000
```

```
                                   CARD IMAGES
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

  476  486  487  534  533    1      .000
  477  487  488  535  534    1      .000
  478  488  489  536  535    1      .000
  479  489  490  537  536    1      .000
  480  490  491  538  537    1      .000
  481  491  492  539  538    1      .000
  482  492  493  540  539    1      .000
  483  493  494  541  540    1      .000
  484  494  495  542  541    1      .000
  485  495  496  543  542    1      .000
  486  496  497  544  543    1      .000
  487  497  498  545  544    1      .000
  488  498  499  546  545    1      .000
  489  499  500  547  546    1      .000
  490  500  501  548  547    1      .000
  491  501  502  549  548    1      .000
  492  502  503  550  549    1      .000
  493  503  504  551  550    1      .000
  494  504  505  552  551    1      .000
  495  505  506  553  552    1      .000
  496  506  507  554  553    1      .000
  497  507  508  555  554    1      .000
  498  508  509  556  555    1      .000
  499  509  510  557  556    1      .000
  500  510  511  558  557    1      .000
  501  511  512  559  558    1      .000
  502  512  513  560  559    1      .000
  503  513  514  561  560    1      .000
  504  514  515  562  561    1      .000
  505  515  516  563  562    1      .000
  506  516  517  564  563    1      .000
  507  518  519  566  565    1      .000
  508  519  520  567  566    1      .000
  509  520  521  568  567    1      .000
  510  521  522  569  568    1      .000
  511  522  523  570  569    1      .000
  512  523  524  571  570    1      .000
  513  524  525  572  571    1      .000
  514  525  526  573  572    1      .000
  515  526  527  574  573    1      .000
  516  527  528  575  574    1      .000
  517  528  529  576  575    1      .000
  518  529  530  577  576    1      .000
  519  530  531  578  577    1      .000
  520  531  532  579  578    1      .000
  521  532  533  580  579    1      .000
```

```
                                   CARD IMAGES
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

  522  533  534  581  580    1      .000
  523  534  535  582  581    1      .000
  524  535  536  583  582    1      .000
  525  536  537  584  583    1      .000
  526  537  538  585  584    1      .000
  527  538  539  586  585    1      .000
  528  539  540  587  586    1      .000
  529  540  541  588  587    1      .000
  530  541  542  589  588    1      .000
  531  542  543  590  589    1      .000
  532  543  544  591  590    1      .000
  533       545  592  591    1      .000
  534  545  546  593  592    1      .000
  535  546  547  594  593    1      .000
  536  547  548  595  594    1      .000
  537  548  549  596  595    1      .000
  538  549  550  597  596    1      .000
  539  550  551  598  597    1      .000
  540  551  552  599  598    1      .000
  541  552  553  600  599    1      .000
  542  553  554  601  600    1      .000
  543  554  555  602  601    1      .000
  544  555  556  603  602    1      .000
  545  556  557  604  603    1      .000
  546  557  558  605  604    1      .000
  547  558  559  606  605    1      .000
  548  559  560  607  606    1      .000
  549  560  561  608  607    1      .000
  550  561  562  609  608    1      .000
  551  562  563  610  609    1      .000
  552  563  564  611  610    1      .000
  553  565  566  613  612    1      .000
  554  566  567  614  613    1      .000
  555  567  568  615  614    1      .000
  556  568  569  616  615    1      .000
  557  569  570  617  616    1      .000
  558  570  571  618  617    1      .000
  559  571  572  619  618    1      .000
  560  572  573  620  619    1      .000
  561  573  574  621  620    1      .000
  562  574  575  622  621    1      .000
  563  575  576  623  622    1      .000
  564  576  577  624  623    1      .000
  565  577  578  625  624    1      .000
  566  578  579  626  625    1      .000
  567  579  580  627  626    1      .000
```

```
                                   CARD IMAGES
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

  568  580  581  628  627    1      .000
  569  581  582  629  628    1      .000
  570  582  583  630  629    1      .000
  571  583  584  631  630    1      .000
  572  584  585  632  631    1      .000
  573  585  586  633  632    1      .000
  574  586  587  634  633    1      .000
  575  587  588  635  634    1      .000
  576  588  589  636  635    1      .000
  577  589  590  637  636    1      .000
  578  590  591  638  637    1      .000
  579  591  592  639  638    1      .000
  580  592  593  640  639    1      .000
  581  593  594  641  640    1      .000
  582  594  595  642  641    1      .000
  583  595  596  643  642    1      .000
  584  596  597  644  643    1      .000
  585  597  598  645  644    1      .000
  586  598  599  646  645    1      .000
  587  599  600  647  646    1      .000
  588  600  601  648  647    1      .000
  589  601  602  649  648    1      .000
  590  602  603  650  649    1      .000
  591  603  604  651  650    1      .000
  592  604  605  652  651    1      .000
  593  605  606  653  652    1      .000
  594  606  607  654  653    1      .000
  595  607  608  655  654    1      .000
  596  608  609  656  655    1      .000
  597  609  610  657  656    1      .000
  598  610  611  658  657    1      .000
26.68
    1                    .1013878-05          .3174001-03
    2                    .9739806-06          .3061132-03
    3                    .5821444-06          .2950779-03
    4                    .5189122-06          .2808821-03
    5                    .4470567-06          .2665719-03
    6                    .3734076-06          .2522781-03
    7                    .2874422-06          .2379339-03
    8                    .0000000             .2243447-03
    9                   -.2970964-06          .2086354-03
   10                   -.3848791-06          .1936693-03
   11                   -.4638829-06          .1786231-03
   12                   -.5344473-06          .1635795-03
   13                   -.6115325-06          .1482603-03
   14                   -.3565306-06          .1352917-03
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                                   CARD IMAGES
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

   15                    .8169379-06          .1219204-03
   16                    .2367452-05          .1086906-03
   17                    .4106627-05          .9544717-04
   18                    .5938907-05          .8194659-04
   19                    .7865051-05          .6797608-04
   20                    .9826270-05          .5224955-04
   21                    .1270457-04          .3560416-04
   22                    .1893385-04          .0000000
   23                    .2568233-04          .0000000
   24                    .3127667-04          .0000000
   25                    .3553805-04          .0000000
   26                    .3909679-04          .0000000
   27                    .4217806-04          .0000000
   28                    .4490988-04          .0000000
   29                    .4736304-04          .0000000
   30                    .4958378-04          .0000000
   31                    .5160425-04          .0000000
   32                    .5344856-04          .0000000
   33                    .5513580-04          .0000000
   34                    .5668193-04          .0000000
   35                    .5810095-04          .0000000
   36                    .5940578-04          .0000000
   37                    .6060893-04          .0000000
   38                    .6172296-04          .0000000
   39                    .6276098-04          .0000000
   40                    .6373711-04          .0000000
   41                    .6466690-04          .0000000
   42                    .6556780-04          .0000000
   43                    .6645971-04          .0000000
   44                    .6736560-04          .0000000
   45                    .6831222-04          .0000000
   46                    .6933095-04          .0000000
   47                    .7045895-04          .0000000
   48                    .1470955-04          .3173388-03
   49                    .1392061-04          .3058284-03
   50                    .1169240-04          .2942349-03
   51                    .2261555-04          .2916376-03
   52                    .2126364-04          .2742639-03
   53                    .1932805-04          .2571482-03
   54                    .1699548-04          .2403856-03
   55                    .1463845-04          .2236546-03
   56                    .1711858-04          .2062567-03
   57                    .1932877-04          .1885569-03
   58                    .2130620-04          .1706112-03
   59                    .2279772-04          .1520524-03
   60                    .1136991-04          .1492661-03
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                                   CARD IMAGES
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

   61                    .1537136-04          .1349067-03
   62                    .1764452-04          .1212740-03
   63                    .1958112-04          .1078887-03
   64                    .2161430-04          .9454114-04
   65                    .2392291-04          .8099587-04
   66                    .2668272-04          .6676091-04
   67                    .3014224-04          .5168659-04
   68                    .3472942-04          .3251606-04
   69                    .3590057-04          .1690537-04
   70                    .3514918-04          .7182720-05
   71                    .3677284-04          .4480618-05
   72                    .3925658-04          .2949518-05
   73                    .4184617-04          .2007520-05
   74                    .4434962-04          .1333696-05
   75                    .4670231-04          .8193563-06
   76                    .4889143-04          .4041983-06
   77                    .5091946-04          .5575400-07
   78                    .5279452-04         -.2465565-06
   79                    .5452625-04         -.5165855-06
   80                    .5612462-04         -.7645011-06
   81                    .5759954-04         -.9982935-06
   82                    .5896087-04         -.1224682-05
   83                    .6021860-04         -.1449659-05
   84                    .6138305-04         -.1678871-05
   85                    .6246516-04         -.1917890-05
   86                    .6347678-04         -.2172428-05
   87                    .6443101-04         -.2448533-05
   88                    .6534251-04         -.2752770-05
   89                    .6622799-04         -.3092411-05
   90                    .6710663-04         -.3475653-05
   91                    .6800068-04         -.3911861-05
   92                    .6893609-04         -.4411945-05
   93                    .6994346-04         -.4988560-05
   94                    .7105886-04         -.5656782-05
   95                    .2863753-04          .3170425-03
   96                    .2858748-04          .3055953-03
   97                    .2902604-04          .2946107-03
   98                    .3301009-04          .2873915-03
   99                    .4267193-04          .2815283-03
  100                    .3871157-04          .2617433-03
  101                    .3412321-04          .2424702-03
  102                    .2927115-04          .2233794-03
  103                    .3438460-04          .2038133-03
  104                    .3923154-04          .1837456-03
  105                    .4348975-04          .1628556-03
  106                    .3365914-04          .1566756-03
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                                   CARD IMAGES
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

  107                    .3065596-04         .1468084-03
  108                    .3203177-04         .1335198-03
  109                    .3387371-04         .1202200-03
  110                    .3578228-04         .1069535-03
  111                    .3781218-04         .9363252-04
  112                    .4005881-04         .8006955-04
  113                    .4253011-04         .6612513-04
  114                    .4510489-04         .5120202-04
  115                    .4647106-04         .3686361-04
  116                    .4707985-04         .2423535-04
  117                    .4720373-04         .1641884-04
  118                    .4699775-04         .1047936-04
  119                    .4755261-04         .7126635-05
  120                    .4865797-04         .4885172-05
  121                    .5005726-04         .3306353-05
  122                    .5158965-04         .2114724-05
  123                    .5315876-04         .1172199-05
  124                    .5470956-04         .3954709-06
  125                    .5621071-04        -.2669499-06
  126                    .5764501-04        -.8497288-06
  127                    .5900380-04        -.1377629-05
  128                    .6028380-04        -.1869566-05
  129                    .6148530-04        -.2340931-05
  130                    .6261125-04        -.2805037-05
  131                    .6366660-04        -.3274067-05
  132                    .6465816-04        -.3759756-05
  133                    .6559447-04        -.4273903-05
  134                    .6648587-04        -.4828806-05
  135                    .6734470-04        -.5437671-05
  136                    .6818554-04        -.6114989-05
  137                    .6902558-04        -.6876975-05
  138                    .6988503-04        -.7742056-05
  139                    .7078770-04        -.8731351-05
  140                    .7176153-04        -.9869881-05
  141                    .7283993-04        -.1118656-04
  142                    .4250544-04         .3164149-03
  143                    .4266636-04         .3050573-03
  144                    .4300053-04         .2939647-03
  145                    .4660925-04         .2842859-03
  146                    .5129308-04         .2742616-03
  147                    .5874689-04         .2656726-03
  148                    .5150207-04         .2442525-03
  149                    .4388249-04         .2231993-03
  150                    .5192282-04         .2017349-03
  151                    .5960102-04         .1794997-03
  152                    .5226445-04         .1705932-03
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                                   CARD IMAGES
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12345678901234567890123456789012345678901234567890123456789012345678901234567890

  153                    .4879037-04          .1579748-03
  154                    .4650088-04          .1454180-03
  155                    .4774804-04          .1322636-03
  156                    .4919466-04          .1191982-03
  157                    .5076740-04          .1061318-03
  158                    .5242857-04          .9300785-04
  159                    .5413053-04          .7978866-04
  160                    .5576214-04          .6639854-04
  161                    .5694398-04          .5325499-04
  162                    .5764167-04          .4082460-04
  163                    .5769673-04          .2983975-04
  164                    .5744273-04          .2240782-04
  165                    .5723551-04          .1649778-04
  166                    .5709774-04          .1185111-04
  167                    .5729464-04          .8489224-05
  168                    .5780490-04          .5958157-05
  169                    .5854845-04          .4003397-05
  170                    .5944587-04          .2441891-05
  171                    .6043380-04          .1156332-05
  172                    .6146582-04          .6641638-07
  173                    .6250924-04         -.8839916-06
  174                    .6354181-04         -.1736088-05
  175                    .6454892-04         -.2521516-05
  176                    .6552173-04         -.3265875-05
  177                    .6645571-04         -.3990996-05
  178                    .6734984-04         -.4716492-05
  179                    .6820595-04         -.5460873-05
  180                    .6902841-04         -.6242401-05
  181                    .6982397-04         -.7079788-05
  182                    .7060173-04         -.7992849-05
  183                    .7137324-04         -.9003087-05
  184                    .7215272-04         -.1013435-04
  185                    .7295735-04         -.1141347-04
  186                    .7380772-04         -.1287111-04
  187                    .7472821-04         -.1454217-04
  188                    .7574682-04         -.1646936-04
  189                    .5615284-04          .3156201-03
  190                    .5638289-04          .3043645-03
  191                    .5669438-04          .2931748-03
  192                    .5884527-04          .2814277-03
  193                    .6153235-04          .2692763-03
  194                    .6475410-04          .2560241-03
  195                    .6923020-04          .2455100-03
  196                    .5847955-04          .2230593-03
  197                    .6971935-04          .2002228-03
  198                    .6550874-04          .1895117-03
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                                   CARD IMAGES
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12345678901234567890123456789012345678901234567890123456789012345678901234567890

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  200                    .6218998-04          .1592482-03
  201                    .6144905-04          .1442054-03
  202                    .6240514-04          .1313287-03
  203                    .6345553-04          .1184768-03
  204                    .6457611-04          .1056672-03
  205                    .6570585-04          .9289656-04
  206                    .6676060-04          .8018706-04
  207                    .6759412-04          .6769711-04
  208                    .6811793-04          .5565065-04
  209                    .6821942-04          .4441233-04
  210                    .6796286-04          .3436114-04
  211                    .6757086-04          .2728954-04
  212                    .6711973-04          .2125403-04
  213                    .6675784-04          .1627243-04
  214                    .6652861-04          .1219382-04
  215                    .6650386-04          .8928637-05
  216                    .6668220-04          .6285800-05
  217                    .6703334-04          .4117364-05
  218                    .6751830-04          .2303793-05
  219                    .6809986-04          .7552308-06
  220                    .6874645-04         -.5969703-06
  221                    .6943295-04         -.1805974-05
  222                    .7014026-04         -.2914153-05
  223                    .7085454-04         -.3956510-05
  224                    .7156640-04         -.4963141-05
  225                    .7227030-04         -.5961052-05
  226                    .7296391-04         -.6975525-05
  227                    .7364781-04         -.8031217-05
  228                    .7432519-04         -.9153077-05
  229                    .7500176-04         -.1036718-04
  230                    .7568565-04         -.1170152-04
  231                    .7638757-04         -.1318685-04
  232                    .7712089-04         -.1485754-04
  233                    .7790206-04         -.1675246-04
  234                    .7875107-04         -.1891622-04
  235                    .7969225-04         -.2139750-04
  236                    .6959741-04          .3147946-03
  237                    .6983062-04          .3036191-03
  238                    .7008687-04          .2923890-03
  239                    .7051238-04          .2788618-03
  240                    .7109762-04          .2652633-03
  241                    .7183662-04          .2515076-03
  242                    .7200313-04          .2343707-03
  243                    .7300526-04          .2229444-03
  244                    .7225686-04          .2114891-03
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                                   CARD IMAGES
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  245                    .7308206-04          .1929850-03
  246                    .7359221-04          .1770135-03
  247                    .7438713-04          .1603428-03
  248                    .7529916-04          .1433030-03
  249                    .7599421-04          .1306763-03
  250                    .7670194-04          .1180950-03
  251                    .7739323-04          .1056032-03
  252                    .7802330-04          .9324688-04
  253                    .7852088-04          .8111193-04
  254                    .7881780-04          .6932702-04
  255                    .7884560-04          .5808788-04
  256                    .7859306-04          .4761973-04
  257                    .7808830-04          .3814159-04
  258                    .7755414-04          .3131333-04
  259                    .7698153-04          .2529410-04
  260                    .7643129-04          .2007843-04
  261                    .7597197-04          .1563414-04
  262                    .7563600-04          .1186794-04
  263                    .7544737-04          .8694355-05
  264                    .7540610-04          .6006114-05
  265                    .7549827-04          .3707668-05
  266                    .7570332-04          .1715908-05
  267                    .7599936-04         -.3837692-07
  268                    .7636591-04         -.1612847-05
  269                    .7678538-04         -.3055912-05
  270                    .7724352-04         -.4409083-05
  271                    .7772943-04         -.5708901-05
  272                    .7823538-04         -.6988565-05
  273                    .7875656-04         -.8279292-05
  274                    .7929087-04         -.9611420-05
  275                    .7983867-04         -.1101543-04
  276                    .8040263-04         -.1252290-04
  277                    .8098767-04         -.1416741-04
  278                    .8160086-04         -.1598549-04
  279                    .8225146-04         -.1801758-04
  280                    .8295088-04         -.2030927-04
  281                    .8371262-04         -.2291216-04
  282                    .8455258-04         -.2588549-04
  283                    .8620367-04          .3138587-03
  284                    .8640110-04          .3027449-03
  285                    .8661076-04          .2914837-03
  286                    .8689562-04          .2777959-03
  287                    .8723993-04          .2639344-03
  288                    .8761868-04          .2497668-03
  289                    .8787659-04          .2349914-03
  290                    .8854765-04          .2214900-03
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                                   CARD IMAGES
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

  291                    .8874875-04          .2076574-03
  292                    .8948474-04          .1916560-03
  293                    .9014247-04          .1755206-03
  294                    .9078477-04          .1590969-03
  295                    .9137870-04          .1424946-03
  296                    .9176774-04          .1302124-03
  297                    .9210417-04          .1180089-03
  298                    .9236518-04          .1059488-03
  299                    .9251758-04          .9410977-04
  300                    .9252539-04          .8258357-04
  301                    .9235219-04          .7148692-04
  302                    .9197972-04          .6095184-04
  303                    .9140878-04          .5111754-04
  304                    .9067282-04          .4211149-04
  305                    .8999221-04          .3548893-04
  306                    .8927893-04          .2949874-04
  307                    .8857591-04          .2414487-04
  308                    .8791907-04          .1940343-04
  309                    .8734201-04          .1523943-04
  310                    .8686419-04          .1159289-04
  311                    .8649706-04          .8402893-05
  312                    .8624217-04          .5601788-05
  313                    .8609403-04          .3124376-05
  314                    .8604289-04          .9098252-06
  315                    .8607715-04         -.1096981-05
  316                    .8618507-04         -.2945675-05
  317                    .8635578-04         -.4681109-05
  318                    .8657998-04         -.6344326-05
  319                    .8685019-04         -.7973585-05
  320                    .8716086-04         -.9605345-05
  321                    .8750829-04         -.1127524-04
  322                    .8789069-04         -.1301902-04
  323                    .8830800-04         -.1487345-04
  324                    .8876178-04         -.1687727-04
  325                    .8925511-04         -.1907223-04
  326                    .8979261-04         -.2150407-04
  327                    .9038033-04         -.2422375-04
  328                    .9102600-04         -.2728915-04
  329                    .9173947-04         -.3076797-04
  330                    .1027220-03          .3131128-03
  331                    .1028742-03          .3020007-03
  332                    .1030340-03          .2907123-03
  333                    .1032358-03          .2769434-03
  334                    .1034652-03          .2629731-03
  335                    .1037193-03          .2487869-03
  336                    .1040293-03          .2343794-03
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                                   CARD IMAGES
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12345678901234567890123456789012345678901234567890123456789012345678901234567890

  337                    .1044860-03          .2201085-03
  338                    .1048554-03          .2055066-03
  339                    .1053614-03          .1900633-03
  340                    .1058576-03          .1742326-03
  341                    .1062703-03          .1581520-03
  342                    .1065669-03          .1419676-03
  343                    .1066877-03          .1300359-03
  344                    .1067158-03          .1182090-03
  345                    .1066364-03          .1065649-03
  346                    .1064325-03          .9518301-04
  347                    .1060868-03          .8415126-04
  348                    .1055880-03          .7356300-04
  349                    .1049336-03          .6351545-04
  350                    .1041361-03          .5410159-04
  351                    .1032219-03          .4540108-04
  352                    .1024223-03          .3891828-04
  353                    .1015983-03          .3295914-04
  354                    .1007772-03          .2752630-04
  355                    .9998563-04          .2260966-04
  356                    .9924607-04          .1818355-04
  357                    .9857734-04          .1421500-04
  358                    .9799177-04          .1066023-04
  359                    .9749654-04          .7472228-05
  360                    .9709377-04          .4600951-05
  361                    .9678173-04          .1996351-05
  362                    .9655608-04         -.3903223-06
  363                    .9641099-04         -.2605682-05
  364                    .9634015-04         -.4693996-05
  365                    .9633741-04         -.6697366-05
  366                    .9639726-04         -.8656128-05
  367                    .9651505-04         -.1060940-04
  368                    .9668715-04         -.1259575-04
  369                    .9691089-04         -.1465390-04
  370                    .9718452-04         -.1682354-04
  371                    .9750710-04         -.1914620-04
  372                    .9787838-04         -.2166625-04
  373                    .9829858-04         -.2443191-04
  374                    .9876835-04         -.2749645-04
  375                    .9928838-04         -.3091936-04
  376                    .9985814-04         -.3476787-04
  377                    .1192682-03          .3125789-03
  378                    .1193749-03          .3014219-03
  379                    .1194917-03          .2900881-03
  380                    .1196371-03          .2762655-03
  381                    .1197964-03          .2622393-03
  382                    .1199800-03          .2480064-03
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                                   CARD IMAGES
         1         2         3         4         5         6         7         8
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  384                    .1204836-03          .2189903-03
  385                    .1207323-03          .2041166-03
  386                    .1210009-03          .1888282-03
  387                    .1212190-03          .1732458-03
  388                    .1213345-03          .1574913-03
  389                    .1213041-03          .1416965-03
  390                    .1211665-03          .1300780-03
  391                    .1209212-03          .1185906-03
  392                    .1205585-03          .1073078-03
  393                    .1200705-03          .9630530-04
  394                    .1194522-03          .8566016-04
  395                    .1187031-03          .7544975-04
  396                    .1178297-03          .6574849-04
  397                    .1168468-03          .5662384-04
  398                    .1157776-03          .4813172-04
  399                    .1148683-03          .4174470-04
  400                    .1139403-03          .3581042-04
  401                    .1130150-03          .3033098-04
  402                    .1121096-03          .2529870-04
  403                    .1112425-03          .2069768-04
  404                    .1104287-03          .1650305-04
  405                    .1096803-03          .1268444-04
  406                    .1090057-03          .9205552-05
  407                    .1084105-03          .6027112-05
  408                    .1078972-03          .3107642-05
  409                    .1074661-03          .4048008-06
  410                    .1071158-03         -.2123768-05
  411                    .1068439-03         -.4519900-05
  412                    .1066475-03         -.6824652-05
  413                    .1065234-03         -.9078280-05
  414                    .1064687-03         -.113204[illegible]-04
  415                    .1064804-03         -.1359038-04
  416                    .1065560-03         -.1592763-04
  417                    .1066928-03         -.1837235-04
  418                    .1068883-03         -.2096623-04
  419                    .1071393-03         -.2375336-04
  420                    .1074422-03         -.2678127-04
  421                    .1077925-03         -.3010214-04
  422                    .1081851-03         -.3377341-04
  423                    .1086141-03         -.3785769-04
  424                    .1359231-03          .3122457-03
  425                    .1359864-03          .3010104-03
  426                    .1360625-03          .2896138-03
  427                    .1361579-03          .2757466-03
  428                    .1362529-03          .2616781-03
```

```
                                   CARD IMAGES
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

  429                    .1363464-03          .2474035-03
  430                    .1364388-03          .2329070-03
  431                    .1365223-03          .2181719-03
  432                    .1365804-03          .2031920-03
  433                    .1365838-03          .1879852-03
  434                    .1364989-03          .1725998-03
  435                    .1362877-03          .1571185-03
  436                    .1359170-03          .1416577-03
  437                    .1355236-03          .1302992-03
  438                    .1350192-03          .1190923-03
  439                    .1343982-03          .1081034-03
  440                    .1336581-03          .9740021-04
  441                    .1327999-03          .8705039-04
  442                    .1318287-03          .7711895-04
  443                    .1307547-03          .6766618-04
  444                    .1295933-03          .5874482-04
  445                    .1283651-03          .5039715-04
  446                    .1273376-03          .4407694-04
  447                    .1262970-03          .3816100-04
  448                    .1252584-03          .3265067-04
  449                    .1242369-03          .2754033-04
  450                    .1232464-03          .2281731-04
  451                    .1222998-03          .1846299-04
  452                    .1214079-03          .1445283-04
  453                    .1205796-03          .1075794-04
  454                    .1198216-03          .7345529-05
  455                    .1191386-03          .4180159-05
  456                    .1185335-03          .1224451-05
  457                    .1180079-03         -.1560076-05
  458                    .1175622-03         -.4212468-05
  459                    .1171958-03         -.6771903-05
  460                    .1169077-03         -.9277423-05
  461                    .1166965-03         -.1176779-04
  462                    .1165604-03         -.1428151-04
  463                    .1164973-03         -.1685696-04
  464                    .1165046-03         -.1953271-04
  465                    .1165784-03         -.2234804-04
  466                    .1167139-03         -.2534366-04
  467                    .1169042-03         -.2856288-04
  468                    .1171398-03         -.3205288-04
  469                    .1174085-03         -.3586645-04
  470                    .1176954-03         -.4006287-04
  471                    .1561152-03          .3120688-03
  472                    .1561394-03          .3007133-03
  473                    .1561721-03          .2892342-03
  474                    .1562011-03          .2752970-03
```

```
                                   CARD IMAGES
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

  475                    .1562048-03          .2611732-03
  476                    .1561736-03          .2468507-03
  477                    .1560980-03          .2323195-03
  478                    .1559652-03          .2175774-03
  479                    .1557561-03          .2026362-03
  480                    .1554469-03          .1875275-03
  481                    .1550097-03          .1723073-03
  482                    .1544168-03          .1570578-03
  483                    .1536438-03          .1418848-03
  484                    .1529444-03          .1307677-03
  485                    .1521312-03          .1198180-03
  486                    .1512028-03          .1090945-03
  487                    .1501605-03          .9865683-04
  488                    .1490095-03          .8856320-04
  489                    .1477583-03          .7886847-04
  490                    .1464192-03          .6962231-04
  491                    .1450080-03          .6086701-04
  492                    .1435438-03          .5263591-04
  493                    .1423332-03          .4636890-04
  494                    .1411143-03          .4046715-04
  495                    .1398997-03          .3493135-04
  496                    .1387019-03          .2975675-04
  497                    .1375330-03          .2493326-04
  498                    .1364043-03          .2044540-04
  499                    .1353260-03          .1627329-04
  500                    .1343068-03          .1239256-04
  501                    .1333543-03          .8775364-05
  502                    .1324745-03          .5390756-05
  503                    .1316720-03          .2205470-05
  504                    .1309502-03         -.8155199-06
  505                    .1303113-03         -.3708460-05
  506                    .1297568-03         -.6510284-05
  507                    .1292869-03         -.9258173-05
  508                    .1289016-03         -.1198918-04
  509                    .1286000-03         -.1473989-04
  510                    .1283803-03         -.1754612-04
  511                    .1282400-03         -.2044282-04
  512                    .1281752-03         -.2346400-04
  513                    .1281799-03         -.2664301-04
  514                    .1282456-03         -.3001325-04
  515                    .1283596-03         -.3360982-04
  516                    .1285047-03         -.3747201-04
  517                    .1286581-03         -.4164909-04
  518                    .1765874-03          .3120623-03
  519                    .1765854-03          .3005817-03
  520                    .1765850-03          .2890335-03
```

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                                   CARD IMAGES
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

  521                    .1765600-03          .2750531-03
  522                    .1764891-03          .2609105-03
  523                    .1763550-03          .2465848-03
  524                    .1761407-03          .2320667-03
  525                    .1758266-03          .2173601-03
  526                    .1753899-03          .2024849-03
  527                    .1748058-03          .1874796-03
  528                    .1740491-03          .1724037-03
  529                    .1730966-03          .1573384-03
  530                    .1719294-03          .1423836-03
  531                    .1709193-03          .1314438-03
  532                    .1697834-03          .1206793-03
  533                    .1685225-03          .1101443-03
  534                    .1671415-03          .9989134-04
  535                    .1656486-03          .8997246-04
  536                    .1640551-03          .8043601-04
  537                    .1623759-03          .7132530-04
  538                    .1606284-03          .6267687-04
  539                    .1588327-03          .5451894-04
  540                    .1573575-03          .4828411-04
  541                    .1558774-03          .4238890-04
  542                    .1544050-03          .3683389-04
  543                    .1529529-03          .3161466-04
  544                    .1515332-03          .2672224-04
  545                    .1501574-03          .2214304-04
  546                    .1488363-03          .1785937-04
  547                    .1475796-03          .1384956-04
  548                    .1463956-03          .1008839-04
  549                    .1452917-03          .6547724-05
  550                    .1442736-03          .3196882-05
  551                    .1433459-03          .3169838-08
  552                    .1425116-03         -.3067570-05
  553                    .1417728-03         -.6050429-05
  554                    .1411301-03         -.8980908-05
  555                    .1405831-03         -.1189435-04
  556                    .1401305-03         -.1482537-04
  557                    .1397698-03         -.1780717-04
  558                    .1394975-03         -.2087090-04
  559                    .1393089-03         -.2404481-04
  560                    .1391975-03         -.2735361-04
  561                    .1391541-03         -.3081777-04
  562                    .1391654-03         -.3445355-04
  563                    .1392108-03         -.3827484-04
  564                    .1392585-03         -.4229653-04
  565                    .1973179-03          .3121143-03
  566                    .1973116-03          .3005482-03
```

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                                   CARD IMAGES
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

  567                    .1973014-03          .2889611-03
  568                    .1972625-03          .2749692-03
  569                    .1971732-03          .2608387-03
  570                    .1970086-03          .2465423-03
  571                    .1967405-03          .2320702-03
  572                    .1963376-03          .2174291-03
  573                    .1957668-03          .2026420-03
  574                    .1949949-03          .1877498-03
  575                    .1939906-03          .1728124-03
  576                    .1927273-03          .1579070-03
  577                    .1911867-03          .1431333-03
  578                    .1898595-03          .1323325-03
  579                    .1883721-03          .1217128-03
  580                    .1867287-03          .1113196-03
  581                    .1849370-03          .1012028-03
  582                    .1830084-03          .9140977-04
  583                    .1809582-03          .8198490-04
  584                    .1788056-03          .7296752-04
  585                    .1765729-03          .6439059-04
  586                    .1742849-03          .5627992-04
  587                    .1724091-03          .5006334-04
  588                    .1705298-03          .4416866-04
  589                    .1686625-03          .3859562-04
  590                    .1668227-03          .3334027-04
  591                    .1650252-03          .2839421-04
  592                    .1632844-03          .2374497-04
  593                    .1616140-03          .1937622-04
  594                    .1600260-03          .1526784-04
  595                    .1585316-03          .1139646-04
  596                    .1571400-03          .7735797-05
  597                    .1558590-03          .4257066-05
  598                    .1546943-03          .9294619-06
  599                    .1536497-03         -.2279354-05
  600                    .1527272-03         -.5402740-05
  601                    .1519266-03         -.8474503-05
  602                    .1512456-03         -.1152830-04
  603                    .1506802-03         -.1459690-04
  604                    .1502244-03         -.1771141-04
  605                    .1498703-03         -.2090016-04
  606                    .1496086-03         -.2418739-04
  607                    .1494287-03         -.2759151-04
  608                    .1493186-03         -.3112264-04
  609                    .1492647-03         -.3477968-04
  610                    .1492499-03         -.3854580-04
  611                    .1492480-03         -.4238608-04
  612                    .2181822-03          .3121392-03
```

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                                   CARD IMAGES
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

  613                    .2181864-03          .3005429-03
  614                    .2182068-03          .2889403-03
  615                    .2182425-03          .2749504-03
  616                    .2182595-03          .2608425-03
  617                    .2182141-03          .2465894-03
  618                    .2180576-03          .2321827-03
  619                    .2177388-03          .2176302-03
  620                    .2172049-03          .2029560-03
  621                    .2164036-03          .1882009-03
  622                    .2152859-03          .1734224-03
  623                    .2138089-03          .1586962-03
  624                    .2119401-03          .1441052-03
  625                    .2102920-03          .1334581-03
  626                    .2084171-03          .1229833-03
  627                    .2063190-03          .1127320-03
  628                    .2040074-03          .1027489-03
  629                    .2014979-03          .9307792-04
  630                    .1988122-03          .8375941-04
  631                    .1959773-03          .7482936-04
  632                    .1930251-03          .6631787-04
  633                    .1899921-03          .5824770-04
  634                    .1875019-03          .5204611-04
  635                    .1850062-03          .4614769-04
  636                    .1825274-03          .4055313-04
  637                    .1800877-03          .3525848-04
  638                    .1777092-03          .3025597-04
  639                    .1754128-03          .2553404-04
  640                    .1732185-03          .2107746-04
  641                    .1711444-03          .1686761-04
  642                    .1692069-03          .1288283-04
  643                    .1674198-03          .9098737-05
  644                    .1657946-03          .5488553-05
  645                    .1643400-03          .2023673-05
  646                    .1630616-03         -.1325964-05
  647                    .1619620-03         -.4591352-05
  648                    .1610402-03         -.7803861-05
  649                    .1602919-03         -.1099463-04
  650                    .1597087-03         -.1419382-04
  651                    .1592787-03         -.1742981-04
  652                    .1589856-03         -.2072799-04
  653                    .1588087-03         -.2410938-04
  654                    .1587236-03         -.2758857-04
  655                    .1587018-03         -.3117087-04
  656                    .1587132-03         -.3484809-04
  657                    .1587293-03         -.3859282-04
  658                    .1587319-03         -.4234685-04
```

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                                   CARD IMAGES
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

    1       0.0       0.0    1
  658       0.0       0.0
       0.0   10.0E-6    5.0E-6       0.0       0.0       0.0
       0.0   10.0E-6    5.0E-6       0.0   10.0E-6    1.0E-6
   18   15
    8   22   24   26   28   30   32   34   36   38   40   42   44  243  337  431
  525  619
   26   27   28   29   30   52   53   54   55   56   98   99  100  101  102
   50       1.0
       5.5   21    3    2    6   46
       705000.0    0
    8    1    1       1.0
      70.0
     455.0     460.0     485.0     525.0     585.0     680.0     805.0    1035.0
       0.0    9500.0   10000.0   11000.0   12000.0   13000.0   14000.0   15000.0
```

```
EXAMPLE PROBLEM:  MCT TEST P-9

                  NUMBER OF MATERIALS---------   2

                  NUMBER OF NODAL POINTS------ 658

                  NUMBER OF ELEMENTS---------- 598

                  NUMBER OF PRESSURE CARDS----   0

                  NUMBER OF LOAD POINTS-------   0

                  FINITE STRAIN--------------- NO

                  RADIUS INCREMENT------------ .100+01

                  RESTART OPTION--------------   0

                  NODAL TEMPERATURE FLAG------   0

S A M C R                                                         S A M C R
S A M C R                                                         S A M C R
S A M C R                                                         S A M C R
S A M C R                    VERSION 3.0                          S A M C R
S A M C R                                                         S A M C R
S A M C R                                                         S A M C R
S A M C R                                                         S A M C R
S A M C R                                                         S A M C R
S A M C R                RELEASED JAN   1 1984                    S A M C R
S A M C R                                                         S A M C R
S A M C R                                                         S A M C R
S A M C R                                                         S A M C R
S A M C R                                                         S A M C R
S A M C R        DOUBLE PRECISION FOR UNIVAC 1100 COMPUTERS       S A M C R
S A M C R                                                         S A M C R
S A M C R                                                         S A M C R
S A M C R                                                         S A M C R
S A M C R                                                         S A M C R
S A M C R         LATEST CHANGES INCORPORATED IN DEC  1983        S A M C R
S A M C R                                                         S A M C R
S A M C R                                                         S A M C R
S A M C R                                                         S A M C R
S A M C R                                                         S A M C R
S A M C R           THIS PROBLEM WAS EXECUTED ON 021084           S A M C R
S A M C R                                                         S A M C R
S A M C R                                                         S A M C R
S A M C R                                                         S A M C R
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STORAGE ALLOCATIONS

     STORAGE AVAILABLE IN A---------- 50000

     STORAGE NEEDED FOR SOLUTION----- 37569

     UNUSED STORAGE IN A------------- 12431
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```
MATERIAL NUMBER  1

     TYPE NO.=   1

     DENSITY =     .112000-03

HOMALITE 100 MATERIAL PROPERTIES:

        .520+06        .000           .000           .000           .000
        .350+00        .000           .000           .000           .000
        .000           .000           .000           .000           .000
        .000           .000           .000           .000           .000
        .000           .000           .000           .000           .000
        .000           .000           .000           .000           .000


MATERIAL NUMBER  2

     TYPE NO.=   1

     DENSITY =     .252400-03

ALUMINUM PIN MATERIAL PROPERTIES:

        .150+08        .000           .000           .000           .000
        .310+00        .000           .000           .000           .000
        .000           .000           .000           .000           .000
        .000           .000           .000           .000           .000
        .000           .000           .000           .000           .000
        .000           .000           .000           .000           .000
```

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                                  NODAL POINT COORDINATES AND CONCENTRATED FORCES

  NP    CODE    R-COOD      R-FORCE     Z-COOD      Z-FORCE           NP    CODE    R-COOD      R-FORCE     Z-COOD      Z-FORCE

   1      .0    .0000       .0000       .0000       .0000             51      .0    .5734+00    .0000       .4635+00    .0000
   2      .0    .2500+00    .0000       .0000       .0000             52      .0    .9395+00    .0000       .4352+00    .0000
   3      .0    .5000+00    .0000       .0000       .0000             53      .0    .1298+01    .0000       .3957+00    .0000
   4      .0    .8000+00    .0000       .0000       .0000             54      .0    .1651+01    .0000       .3494+00    .0000
   5      .0    .1100+01    .0000       .0000       .0000             55      .0    .2000+01    .0000       .3000+00    .0000
   6      .0    .1400+01    .0000       .0000       .0000             56      .0    .2349+01    .0000       .3494+00    .0000
   7      .0    .1700+01    .0000       .0000       .0000             57      .0    .2702+01    .0000       .3957+00    .0000
   8     3.0    .2000+01    .0000       .0000       .0000             58      .0    .3061+01    .0000       .4352+00    .0000
   9      .0    .2300+01    .0000       .0000       .0000             59      .0    .3427+01    .0000       .4635+00    .0000
  10      .0    .2600+01    .0000       .0000       .0000             60      .0    .3482+01    .0000       .2347+00    .0000
  11      .0    .2900+01    .0000       .0000       .0000             61      .0    .3717+01    .0000       .2803+00    .0000
  12      .0    .3200+01    .0000       .0000       .0000             62      .0    .3943+01    .0000       .2933+00    .0000
  13      .0    .3500+01    .0000       .0000       .0000             63      .0    .4166+01    .0000       .2974+00    .0000
  14      .0    .3722+01    .0000       .0000       .0000             64      .0    .4389+01    .0000       .2989+00    .0000
  15      .0    .3944+01    .0000       .0000       .0000             65      .0    .4611+01    .0000       .2995+00    .0000
  16      .0    .4167+01    .0000       .0000       .0000             66      .0    .4833+01    .0000       .2997+00    .0000
  17      .0    .4389+01    .0000       .0000       .0000             67      .0    .5056+01    .0000       .2999+00    .0000
  18      .0    .4611+01    .0000       .0000       .0000             68      .0    .5278+01    .0000       .2999+00    .0000
  19      .0    .4833+01    .0000       .0000       .0000             69      .0    .5500+01    .0000       .3000+00    .0000
  20      .0    .5056+01    .0000       .0000       .0000             70      .0    .5680+01    .0000       .3000+00    .0000
  21      .0    .5278+01    .0000       .0000       .0000             71      .0    .5860+01    .0000       .3000+00    .0000
  22     2.0    .5500+01    .0000       .0000       .0000             72      .0    .6040+01    .0000       .3000+00    .0000
  23     2.0    .5680+01    .0000       .0000       .0000             73      .0    .6220+01    .0000       .3000+00    .0000
  24     2.0    .5860+01    .0000       .0000       .0000             74      .0    .6400+01    .0000       .3000+00    .0000
  25     2.0    .6040+01    .0000       .0000       .0000             75      .0    .6580+01    .0000       .3000+00    .0000
  26     2.0    .6220+01    .0000       .0000       .0000             76      .0    .6760+01    .0000       .3000+00    .0000
  27     2.0    .6400+01    .0000       .0000       .0000             77      .0    .6940+01    .0000       .3000+00    .0000
  28     2.0    .6580+01    .0000       .0000       .0000             78      .0    .7120+01    .0000       .3000+00    .0000
  29     2.0    .6760+01    .0000       .0000       .0000             79      .0    .7300+01    .0000       .3000+00    .0000
  30     2.0    .6940+01    .0000       .0000       .0000             80      .0    .7480+01    .0000       .3000+00    .0000
  31     2.0    .7120+01    .0000       .0000       .0000             81      .0    .7660+01    .0000       .3000+00    .0000
  32     2.0    .7300+01    .0000       .0000       .0000             82      .0    .7840+01    .0000       .3000+00    .0000
  33     2.0    .7480+01    .0000       .0000       .0000             83      .0    .8020+01    .0000       .3000+00    .0000
  34     2.0    .7660+01    .0000       .0000       .0000             84      .0    .8200+01    .0000       .3000+00    .0000
  35     2.0    .7840+01    .0000       .0000       .0000             85      .0    .8380+01    .0000       .3000+00    .0000
  36     2.0    .8020+01    .0000       .0000       .0000             86      .0    .8560+01    .0000       .3000+00    .0000
  37     2.0    .8200+01    .0000       .0000       .0000             87      .0    .8740+01    .0000       .3000+00    .0000
  38     2.0    .8380+01    .0000       .0000       .0000             88      .0    .8920+01    .0000       .3000+00    .0000
  39     2.0    .8560+01    .0000       .0000       .0000             89      .0    .9100+01    .0000       .3000+00    .0000
  40     2.0    .8740+01    .0000       .0000       .0000             90      .0    .9280+01    .0000       .3000+00    .0000
  41     2.0    .8920+01    .0000       .0000       .0000             91      .0    .9460+01    .0000       .3000+00    .0000
  42     2.0    .9100+01    .0000       .0000       .0000             92      .0    .9640+01    .0000       .3000+00    .0000
  43     2.0    .9280+01    .0000       .0000       .0000             93      .0    .9820+01    .0000       .3000+00    .0000
  44     2.0    .9460+01    .0000       .0000       .0000             94      .0    .1000+02    .0000       .3000+00    .0000
  45     2.0    .9640+01    .0000       .0000       .0000             95      .0    .0000       .0000       .6000+00    .0000
  46     2.0    .9820+01    .0000       .0000       .0000             96      .0    .2513+00    .0000       .5953+00    .0000
  47     2.0    .1000+02    .0000       .0000       .0000             97      .0    .5000+00    .0000       .6000+00    .0000
  48      .0    .0000       .0000       .3000+00    .0000             98      .0    .6635+00    .0000       .6810+00    .0000
  49      .0    .2549+00    .0000       .2825+00    .0000             99      .0    .7865+00    .0000       .8817+00    .0000
  50      .0    .5185+00    .0000       .2347+00    .0000            100      .0    .1202+01    .0000       .7982+00    .0000
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                               NODAL POINT COORDINATES AND CONCENTRATED FORCES

 NP    CODE    R-COOD     R-FORCE     Z-COOD     Z-FORCE            NP    CODE    R-COOD     R-FORCE     Z-COOD     Z-FORCE

101     .0    .1604+01    .0000     .7021+00    .0000            151     .0    .2882+01    .0000     .1214+01    .0000
102     .0    .2000+01    .0000     .6000+00    .0000            152     .0    .3061+01    .0000     .1061+01    .0000
103     .0    .2396+01    .0000     .7021+00    .0000            153     .0    .3284+01    .0000     .9700+00    .0000
104     .0    .2798+01    .0000     .7982+00    .0000            154     .0    .3500+01    .0000     .9000+00    .0000
105     .0    .3214+01    .0000     .8817+00    .0000            155     .0    .3722+01    .0000     .9975+00    .0000
106     .0    .3337+01    .0000     .6810+00    .0000            156     .0    .3944+01    .0000     .8975+00    .0000
107     .0    .3500+01    .0000     .6000+00    .0000            157     .0    .4166+01    .0000     .8982+00    .0000
108     .0    .3720+01    .0000     .5933+00    .0000            158     .0    .4389+01    .0000     .8989+00    .0000
109     .0    .3943+01    .0000     .5954+00    .0000            159     .0    .4611+01    .0000     .8994+00    .0000
110     .0    .4166+01    .0000     .5974+00    .0000            160     .0    .4833+01    .0000     .8996+00    .0000
111     .0    .4388+01    .0000     .5986+00    .0000            161     .0    .5056+01    .0000     .8998+00    .0000
112     .0    .4611+01    .0000     .5993+00    .0000            162     .0    .5278+01    .0000     .8999+00    .0000
113     .0    .4833+01    .0000     .5996+00    .0000            163     .0    .5500+01    .0000     .9000+00    .0000
114     .0    .5056+01    .0000     .5998+00    .0000            164     .0    .5680+01    .0000     .9000+00    .0000
115     .0    .5278+01    .0000     .5999+00    .0000            165     .0    .5860+01    .0000     .9000+00    .0000
116     .0    .5500+01    .0000     .6000+00    .0000            166     .0    .6040+01    .0000     .9000+00    .0000
117     .0    .5680+01    .0000     .6000+00    .0000            167     .0    .6220+01    .0000     .9000+00    .0000
118     .0    .5860+01    .0000     .6000+00    .0000            168     .0    .6400+01    .0000     .9000+00    .0000
119     .0    .6040+01    .0000     .6000+00    .0000            169     .0    .6580+01    .0000     .9000+00    .0000
120     .0    .6220+01    .0000     .6000+00    .0000            170     .0    .6760+01    .0000     .9000+00    .0000
121     .0    .6400+01    .0000     .6000+00    .0000            171     .0    .6940+01    .0000     .9000+00    .0000
122     .0    .6580+01    .0000     .6000+00    .0000            172     .0    .7120+01    .0000     .9000+00    .0000
123     .0    .6760+01    .0000     .6000+00    .0000            173     .0    .7300+01    .0000     .9000+00    .0000
124     .0    .6940+01    .0000     .6000+00    .0000            174     .0    .7480+01    .0000     .9000+00    .0000
125     .0    .7120+01    .0000     .6000+00    .0000            175     .0    .7660+01    .0000     .9000+00    .0000
126     .0    .7300+01    .0000     .6000+00    .0000            176     .0    .7840+01    .0000     .9000+00    .0000
127     .0    .7480+01    .0000     .6000+00    .0000            177     .0    .8020+01    .0000     .9000+00    .0000
128     .0    .7660+01    .0000     .6000+00    .0000            178     .0    .8200+01    .0000     .9000+00    .0000
129     .0    .7840+01    .0000     .6000+00    .0000            179     .0    .8380+01    .0000     .9000+00    .0000
130     .0    .8020+01    .0000     .6000+00    .0000            180     .0    .8560+01    .0000     .9000+00    .0000
131     .0    .8200+01    .0000     .6000+00    .0000            181     .0    .8740+01    .0000     .9000+00    .0000
132     .0    .8380+01    .0000     .6000+00    .0000            182     .0    .8920+01    .0000     .9000+00    .0000
133     .0    .8560+01    .0000     .6000+00    .0000            183     .0    .9100+01    .0000     .9000+00    .0000
134     .0    .8740+01    .0000     .6000+00    .0000            184     .0    .9280+01    .0000     .9000+00    .0000
135     .0    .8920+01    .0000     .6000+00    .0000            185     .0    .9460+01    .0000     .9000+00    .0000
136     .0    .9100+01    .0000     .6000+00    .0000            186     .0    .9640+01    .0000     .9000+00    .0000
137     .0    .9280+01    .0000     .6000+00    .0000            187     .0    .9820+01    .0000     .9000+00    .0000
138     .0    .9460+01    .0000     .6000+00    .0000            188     .0    .1000+02    .0000     .9000+00    .0000
139     .0    .9640+01    .0000     .6000+00    .0000            189     .0    .0000       .0000     .1200+01    .0000
140     .0    .9820+01    .0000     .6000+00    .0000            190     .0    .2501+00    .0000     .1200+01    .0000
141     .0    .1000+02    .0000     .6000+00    .0000            191     .0    .5000+00    .0000     .1200+01    .0000
142     .0    .0000       .0000     .9000+00    .0000            192     .0    .7615+00    .0000     .1238+01    .0000
143     .0    .2504+00    .0000     .8987+00    .0000            193     .0    .1030+01    .0000     .1284+01    .0000
144     .0    .5000+00    .0000     .9000+00    .0000            194     .0    .1319+01    .0000     .1337+01    .0000
145     .0    .7161+00    .0000     .9700+00    .0000            195     .0    .1536+01    .0000     .1427+01    .0000
146     .0    .9393+00    .0000     .1061+01    .0000            196     .0    .2000+01    .0000     .1200+01    .0000
147     .0    .1118+01    .0000     .1214+01    .0000            197     .0    .2464+01    .0000     .1427+01    .0000
148     .0    .1565+01    .0000     .1061+01    .0000            198     .0    .2681+01    .0000     .1337+01    .0000
149     .0    .2000+01    .0000     .9000+00    .0000            199     .0    .2970+01    .0000     .1284+01    .0000
150     .0    .2435+01    .0000     .1061+01    .0000            200     .0    .3238+01    .0000     .1238+01    .0000
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                                           NODAL POINT COORDINATES AND CONCENTRATED FORCES

 NP     CODE    R-COOD      R-FORCE     Z-COOD      Z-FORCE         NP     CODE    R-COOD      R-FORCE     Z-COOD      Z-FORCE

201      .0    .3500+01    .0000       .1200+01    .0000           251      .0    .4167+01    .0000       .1500+01    .0000
202      .0    .3722+01    .0000       .1199+01    .0000           252      .0    .4389+01    .0000       .1500+01    .0000
203      .0    .3944+01    .0000       .1199+01    .0000           253      .0    .4611+01    .0000       .1500+01    .0000
204      .0    .4166+01    .0000       .1199+01    .0000           254      .0    .4833+01    .0000       .1500+01    .0000
205      .0    .4389+01    .0000       .1199+01    .0000           255      .0    .5056+01    .0000       .1500+01    .0000
206      .0    .4611+01    .0000       .1200+01    .0000           256      .0    .5278+01    .0000       .1500+01    .0000
207      .0    .4833+01    .0000       .1200+01    .0000           257      .0    .5500+01    .0000       .1500+01    .0000
208      .0    .5056+01    .0000       .1200+01    .0000           258      .0    .5680+01    .0000       .1500+01    .0000
209      .0    .5278+01    .0000       .1200+01    .0000           259      .0    .5860+01    .0000       .1500+01    .0000
210      .0    .5500+01    .0000       .1200+01    .0000           260      .0    .6040+01    .0000       .1500+01    .0000
211      .0    .5680+01    .0000       .1200+01    .0000           261      .0    .6220+01    .0000       .1500+01    .0000
212      .0    .5860+01    .0000       .1200+01    .0000           262      .0    .6400+01    .0000       .1500+01    .0000
213      .0    .6040+01    .0000       .1200+01    .0000           263      .0    .6580+01    .0000       .1500+01    .0000
214      .0    .6220+01    .0000       .1200+01    .0000           264      .0    .6760+01    .0000       .1500+01    .0000
215      .0    .6400+01    .0000       .1200+01    .0000           265      .0    .6940+01    .0000       .1500+01    .0000
216      .0    .6580+01    .0000       .1200+01    .0000           266      .0    .7120+01    .0000       .1500+01    .0000
217      .0    .6760+01    .0000       .1200+01    .0000           267      .0    .7300+01    .0000       .1500+01    .0000
218      .0    .6940+01    .0000       .1200+01    .0000           268      .0    .7480+01    .0000       .1500+01    .0000
219      .0    .7120+01    .0000       .1200+01    .0000           269      .0    .7660+01    .0000       .1500+01    .0000
220      .0    .7300+01    .0000       .1200+01    .0000           270      .0    .7840+01    .0000       .1500+01    .0000
221      .0    .7480+01    .0000       .1200+01    .0000           271      .0    .8020+01    .0000       .1500+01    .0000
222      .0    .7660+01    .0000       .1200+01    .0000           272      .0    .8200+01    .0000       .1500+01    .0000
223      .0    .7840+01    .0000       .1200+01    .0000           273      .0    .8380+01    .0000       .1500+01    .0000
224      .0    .8020+01    .0000       .1200+01    .0000           274      .0    .8560+01    .0000       .1500+01    .0000
225      .0    .8200+01    .0000       .1200+01    .0000           275      .0    .8740+01    .0000       .1500+01    .0000
226      .0    .8380+01    .0000       .1200+01    .0000           276      .0    .8920+01    .0000       .1500+01    .0000
227      .0    .8560+01    .0000       .1200+01    .0000           277      .0    .9100+01    .0000       .1500+01    .0000
228      .0    .8740+01    .0000       .1200+01    .0000           278      .0    .9280+01    .0000       .1500+01    .0000
229      .0    .8920+01    .0000       .1200+01    .0000           279      .0    .9460+01    .0000       .1500+01    .0000
230      .0    .9100+01    .0000       .1200+01    .0000           280      .0    .9640+01    .0000       .1500+01    .0000
231      .0    .9280+01    .0000       .1200+01    .0000           281      .0    .9820+01    .0000       .1500+01    .0000
232      .0    .9460+01    .0000       .1200+01    .0000           282      .0    .1000+02    .0000       .1500+01    .0000
233      .0    .9640+01    .0000       .1200+01    .0000           283      .0    .0000       .0000       .1875+01    .0000
234      .0    .9820+01    .0000       .1200+01    .0000           284      .0    .2500+00    .0000       .1875+01    .0000
235      .0    .1000+02    .0000       .1200+01    .0000           285      .0    .5000+00    .0000       .1875+01    .0000
236      .0    .0000       .0000       .1500+01    .0000           286      .0    .8008+00    .0000       .1875+01    .0000
237      .0    .2500+00    .0000       .1500+01    .0000           287      .0    .1102+01    .0000       .1874+01    .0000
238      .0    .5000+00    .0000       .1500+01    .0000           288      .0    .1407+01    .0000       .1873+01    .0000
239      .0    .8000+00    .0000       .1500+01    .0000           289      .0    .1720+01    .0000       .1869+01    .0000
240      .0    .1100+01    .0000       .1500+01    .0000           290      .0    .2000+01    .0000       .1875+01    .0000
241      .0    .1400+01    .0000       .1500+01    .0000           291      .0    .2280+01    .0000       .1869+01    .0000
242      .0    .1765+01    .0000       .1482+01    .0000           292      .0    .2593+01    .0000       .1873+01    .0000
243      .0    .2000+01    .0000       .1500+01    .0000           293      .0    .2898+01    .0000       .1874+01    .0000
244      .0    .2235+01    .0000       .1482+01    .0000           294      .0    .3199+01    .0000       .1875+01    .0000
245      .0    .2600+01    .0000       .1500+01    .0000           295      .0    .3500+01    .0000       .1875+01    .0000
246      .0    .2900+01    .0000       .1500+01    .0000           296      .0    .3722+01    .0000       .1875+01    .0000
247      .0    .3200+01    .0000       .1500+01    .0000           297      .0    .3944+01    .0000       .1875+01    .0000
248      .0    .3500+01    .0000       .1500+01    .0000           298      .0    .4167+01    .0000       .1875+01    .0000
249      .0    .3722+01    .0000       .1500+01    .0000           299      .0    .4389+01    .0000       .1875+01    .0000
250      .0    .3944+01    .0000       .1500+01    .0000           300      .0    .4611+01    .0000       .1875+01    .0000
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                                       NODAL POINT COORDINATFS AND CONCENTRATED FORCES

  NP    CODE    R-COOD      R-FORCE     Z-COOD      Z-FORCE           NP    CODE    R-COOD      R-FORCE     Z-COOD      Z-FORCE

 301     .0    .4833+01     .0000      .1875+01     .0000            351     .0    .5500+01     .0000      .2250+01     .0000
 302     .0    .5056+01     .0000      .1875+01     .0000            352     .0    .5680+01     .0000      .2250+01     .0000
 303     .0    .5278+01     .0000      .1875+01     .0000            353     .0    .5860+01     .0000      .2250+01     .0000
 304     .0    .5500+01     .0000      .1875+01     .0000            354     .0    .6040+01     .0000      .2250+01     .0000
 305     .0    .5680+01     .0000      .1875+01     .0000            355     .0    .6220+01     .0000      .2250+01     .0000
 306     .0    .5860+01     .0000      .1875+01     .0000            356     .0    .6400+01     .0000      .2250+01     .0000
 307     .0    .6040+01     .0000      .1875+01     .0000            357     .0    .6580+01     .0000      .2250+01     .0000
 308     .0    .6220+01     .0000      .1875+01     .0000            358     .0    .6760+01     .0000      .2250+01     .0000
 309     .0    .6400+01     .0000      .1875+01     .0000            359     .0    .6940+01     .0000      .2250+01     .0000
 310     .0    .6580+01     .0000      .1875+01     .0000            360     .0    .7120+01     .0000      .2250+01     .0000
 311     .0    .6760+01     .0000      .1875+01     .0000            361     .0    .7300+01     .0000      .2250+01     .0000
 312     .0    .6940+01     .0000      .1875+01     .0000            362     .0    .7480+01     .0000      .2250+01     .0000
 313     .0    .7120+01     .0000      .1875+01     .0000            363     .0    .7660+01     .0000      .2250+01     .0000
 314     .0    .7300+01     .0000      .1875+01     .0000            364     .0    .7840+01     .0000      .2250+01     .0000
 315     .0    .7480+01     .0000      .1875+01     .0000            365     .0    .8020+01     .0000      .2250+01     .0000
 316     .0    .7660+01     .0000      .1875+01     .0000            366     .0    .8200+01     .0000      .2250+01     .0000
 317     .0    .7840+01     .0000      .1875+01     .0000            367     .0    .8380+01     .0000      .2250+01     .0000
 318     .0    .8020+01     .0000      .1875+01     .0000            368     .0    .8560+01     .0000      .2250+01     .0000
 319     .0    .8200+01     .0000      .1875+01     .0000            369     .0    .8740+01     .0000      .2250+01     .0000
 320     .0    .8380+01     .0000      .1875+01     .0000            370     .0    .8920+01     .0000      .2250+01     .0000
 321     .0    .8560+01     .0000      .1875+01     .0000            371     .0    .9100+01     .0000      .2250+01     .0000
 322     .0    .8740+01     .0000      .1875+01     .0000            372     .0    .9280+01     .0000      .2250+01     .0000
 323     .0    .8920+01     .0000      .1875+01     .0000            373     .0    .9460+01     .0000      .2250+01     .0000
 324     .0    .9100+01     .0000      .1875+01     .0000            374     .0    .9640+01     .0000      .2250+01     .0000
 325     .0    .9280+01     .0000      .1875+01     .0000            375     .0    .9820+01     .0000      .2250+01     .0000
 326     .0    .9460+01     .0000      .1875+01     .0000            376     .0    .1000+02     .0000      .2250+01     .0000
 327     .0    .9640+01     .0000      .1875+01     .0000            377     .0    .0000        .0000      .2625+01     .0000
 328     .0    .9820+01     .0000      .1875+01     .0000            378     .0    .2500+00     .0000      .2625+01     .0000
 329     .0    .1000+02     .0000      .1875+01     .0000            379     .0    .5000+00     .0000      .2625+01     .0000
 330     .0    .0000        .0000      .2250+01     .0000            380     .0    .8005+00     .0000      .2625+01     .0000
 331     .0    .2500+00     .0000      .2250+01     .0000            381     .0    .1101+01     .0000      .2625+01     .0000
 332     .0    .5000+00     .0000      .2250+01     .0000            382     .0    .1402+01     .0000      .2624+01     .0000
 333     .0    .8009+00     .0000      .2250+01     .0000            383     .0    .1702+01     .0000      .2624+01     .0000
 334     .0    .1102+01     .0000      .2249+01     .0000            384     .0    .2000+01     .0000      .2625+01     .0000
 335     .0    .1404+01     .0000      .2249+01     .0000            385     .0    .2298+01     .0000      .2624+01     .0000
 336     .0    .1706+01     .0000      .2248+01     .0000            386     .0    .2598+01     .0000      .2624+01     .0000
 337     .0    .2000+01     .0000      .2250+01     .0000            387     .0    .2899+01     .0000      .2625+01     .0000
 338     .0    .2294+01     .0000      .2248+01     .0000            388     .0    .3199+01     .0000      .2625+01     .0000
 339     .0    .2596+01     .0000      .2249+01     .0000            389     .0    .3500+01     .0000      .2625+01     .0000
 340     .0    .2898+01     .0000      .2249+01     .0000            390     .0    .3722+01     .0000      .2625+01     .0000
 341     .0    .3199+01     .0000      .2250+01     .0000            391     .0    .3944+01     .0000      .2625+01     .0000
 342     .0    .3500+01     .0000      .2250+01     .0000            392     .0    .4167+01     .0000      .2625+01     .0000
 343     .0    .3722+01     .0000      .2250+01     .0000            393     .0    .4389+01     .0000      .2625+01     .0000
 344     .0    .3944+01     .0000      .2250+01     .0000            394     .0    .4611+01     .0000      .2625+01     .0000
 345     .0    .4167+01     .0000      .2250+01     .0000            395     .0    .4833+01     .0000      .2625+01     .0000
 346     .0    .4389+01     .0000      .2250+01     .0000            396     .0    .5056+01     .0000      .2625+01     .0000
 347     .0    .4611+01     .0000      .2250+01     .0000            397     .0    .5278+01     .0000      .2625+01     .0000
 348     .0    .4833+01     .0000      .2250+01     .0000            398     .0    .5500+01     .0000      .2625+01     .0000
 349     .0    .5056+01     .0000      .2250+01     .0000            399     .0    .5680+01     .0000      .2625+01     .0000
 350     .0    .5278+01     .0000      .2250+01     .0000            400     .0    .5860+01     .0000      .2625+01     .0000
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NODAL POINT COORDINATES AND CONCENTRATED FORCES

NP	CODE	R-COOD	R-FORCE	Z-COOD	Z-FORCE	NP	CODE	R-COOD	R-FORCE	Z-COOD	Z-FORCE
401	.0	.6040+01	.0000	.2625+01	.0000	451	.0	.6580+01	.0000	.3000+01	.0000
402	.0	.6220+01	.0000	.2625+01	.0000	452	.0	.6760+01	.0000	.3000+01	.0000
403	.0	.6400+01	.0000	.2625+01	.0000	453	.0	.6940+01	.0000	.3000+01	.0000
404	.0	.6580+01	.0000	.2625+01	.0000	454	.0	.7120+01	.0000	.3000+01	.0000
405	.0	.6760+01	.0000	.2625+01	.0000	455	.0	.7300+01	.0000	.3000+01	.0000
406	.0	.6940+01	.0000	.2625+01	.0000	456	.0	.7480+01	.0000	.3000+01	.0000
407	.0	.7120+01	.0000	.2625+01	.0000	457	.0	.7660+01	.0000	.3000+01	.0000
408	.0	.7300+01	.0000	.2625+01	.0000	458	.0	.7840+01	.0000	.3000+01	.0000
409	.0	.7480+01	.0000	.2625+01	.0000	459	.0	.8020+01	.0000	.3000+01	.0000
410	.0	.7660+01	.0000	.2625+01	.0000	460	.0	.8200+01	.0000	.3000+01	.0000
411	.0	.7840+01	.0000	.2625+01	.0000	461	.0	.8380+01	.0000	.3000+01	.0000
412	.0	.8020+01	.0000	.2625+01	.0000	462	.0	.8560+01	.0000	.3000+01	.0000
413	.0	.8200+01	.0000	.2625+01	.0000	463	.0	.8740+01	.0000	.3000+01	.0000
414	.0	.8380+01	.0000	.2625+01	.0000	464	.0	.8920+01	.0000	.3000+01	.0000
415	.0	.8560+01	.0000	.2625+01	.0000	465	.0	.9100+01	.0000	.3000+01	.0000
416	.0	.8740+01	.0000	.2625+01	.0000	466	.0	.9280+01	.0000	.3000+01	.0000
417	.0	.8920+01	.0000	.2625+01	.0000	467	.0	.9460+01	.0000	.3000+01	.0000
418	.0	.9100+01	.0000	.2625+01	.0000	468	.0	.9640+01	.0000	.3000+01	.0000
419	.0	.9280+01	.0000	.2625+01	.0000	469	.0	.9820+01	.0000	.3000+01	.0000
420	.0	.9460+01	.0000	.2625+01	.0000	470	.0	.1000+02	.0000	.3000+01	.0000
421	.0	.9640+01	.0000	.2625+01	.0000	471	.0	.0000	.0000	.3450+01	.0000
422	.0	.9820+01	.0000	.2625+01	.0000	472	.0	.2500+00	.0000	.3450+01	.0000
423	.0	.1000+02	.0000	.2625+01	.0000	473	.0	.5000+00	.0000	.3450+01	.0000
424	.0	.0000	.0000	.3000+01	.0000	474	.0	.8000+00	.0000	.3450+01	.0000
425	.0	.2500+00	.0000	.3000+01	.0000	475	.0	.1100+01	.0000	.3450+01	.0000
426	.0	.5000+00	.0000	.3000+01	.0000	476	.0	.1400+01	.0000	.3450+01	.0000
427	.0	.8000+00	.0000	.3000+01	.0000	477	.0	.1700+01	.0000	.3450+01	.0000
428	.0	.1100+01	.0000	.3000+01	.0000	478	.0	.2000+01	.0000	.3450+01	.0000
429	.0	.1400+01	.0000	.3000+01	.0000	479	.0	.2300+01	.0000	.3450+01	.0000
430	.0	.1700+01	.0000	.3000+01	.0000	480	.0	.2600+01	.0000	.3450+01	.0000
431	.0	.2000+01	.0000	.3000+01	.0000	481	.0	.2900+01	.0000	.3450+01	.0000
432	.0	.2300+01	.0000	.3000+01	.0000	482	.0	.3200+01	.0000	.3450+01	.0000
433	.0	.2600+01	.0000	.3000+01	.0000	483	.0	.3500+01	.0000	.3450+01	.0000
434	.0	.2900+01	.0000	.3000+01	.0000	484	.0	.3722+01	.0000	.3450+01	.0000
435	.0	.3200+01	.0000	.3000+01	.0000	485	.0	.3944+01	.0000	.3450+01	.0000
436	.0	.3500+01	.0000	.3000+01	.0000	486	.0	.4167+01	.0000	.3450+01	.0000
437	.0	.3722+01	.0000	.3000+01	.0000	487	.0	.4389+01	.0000	.3450+01	.0000
438	.0	.3944+01	.0000	.3000+01	.0000	488	.0	.4611+01	.0000	.3450+01	.0000
439	.0	.4167+01	.0000	.3000+01	.0000	489	.0	.4833+01	.0000	.3450+01	.0000
440	.0	.4389+01	.0000	.3000+01	.0000	490	.0	.5056+01	.0000	.3450+01	.0000
441	.0	.4611+01	.0000	.3000+01	.0000	491	.0	.5278+01	.0000	.3450+01	.0000
442	.0	.4833+01	.0000	.3000+01	.0000	492	.0	.5500+01	.0000	.3450+01	.0000
443	.0	.5056+01	.0000	.3000+01	.0000	493	.0	.5680+01	.0000	.3450+01	.0000
444	.0	.5278+01	.0000	.3000+01	.0000	494	.0	.5860+01	.0000	.3450+01	.0000
445	.0	.5500+01	.0000	.3000+01	.0000	495	.0	.6040+01	.0000	.3450+01	.0000
446	.0	.5680+01	.0000	.3000+01	.0000	496	.0	.6220+01	.0000	.3450+01	.0000
447	.0	.5860+01	.0000	.3000+01	.0000	497	.0	.6400+01	.0000	.3450+01	.0000
448	.0	.6040+01	.0000	.3000+01	.0000	498	.0	.6580+01	.0000	.3450+01	.0000
449	.0	.6220+01	.0000	.3000+01	.0000	499	.0	.6760+01	.0000	.3450+01	.0000
450	.0	.6400+01	.0000	.3000+01	.0000	500	.0	.6940+01	.0000	.3450+01	.0000

NODAL POINT COORDINATES AND CONCENTRATED FORCES

NP	CODE	R-COOD	R-FORCE	Z-COOD	Z-FORCE	NP	CODE	R-COOD	R-FORCE	Z-COOD	Z-FORCE
501	.0	.7120+01	.0000	.3450+01	.0000	551	.0	.7660+01	.0000	.3900+01	.0000
502	.0	.7300+01	.0000	.3450+01	.0000	552	.0	.7840+01	.0000	.3900+01	.0000
503	.0	.7480+01	.0000	.3450+01	.0000	553	.0	.8020+01	.0000	.3900+01	.0000
504	.0	.7660+01	.0000	.3450+01	.0000	554	.0	.8200+01	.0000	.3900+01	.0000
505	.0	.7840+01	.0000	.3450+01	.0000	555	.0	.8380+01	.0000	.3900+01	.0000
506	.0	.8020+01	.0000	.3450+01	.0000	556	.0	.8560+01	.0000	.3900+01	.0000
507	.0	.8200+01	.0000	.3450+01	.0000	557	.0	.8740+01	.0000	.3900+01	.0000
508	.0	.8380+01	.0000	.3450+01	.0000	558	.0	.8920+01	.0000	.3900+01	.0000
509	.0	.8560+01	.0000	.3450+01	.0000	559	.0	.9100+01	.0000	.3900+01	.0000
510	.0	.8740+01	.0000	.3450+01	.0000	560	.0	.9280+01	.0000	.3900+01	.0000
511	.0	.8920+01	.0000	.3450+01	.0000	561	.0	.9460+01	.0000	.3900+01	.0000
512	.0	.9100+01	.0000	.3450+01	.0000	562	.0	.9640+01	.0000	.3900+01	.0000
513	.0	.9280+01	.0000	.3450+01	.0000	563	.0	.9820+01	.0000	.3900+01	.0000
514	.0	.9460+01	.0000	.3450+01	.0000	564	.0	.1000+02	.0000	.3900+01	.0000
515	.0	.9640+01	.0000	.3450+01	.0000	565	.0	.0000	.0000	.4350+01	.0000
516	.0	.9820+01	.0000	.3450+01	.0000	566	.0	.2500+00	.0000	.4350+01	.0000
517	.0	.1000+02	.0000	.3450+01	.0000	567	.0	.5000+00	.0000	.4350+01	.0000
518	.0	.0000	.0000	.3900+01	.0000	568	.0	.8000+00	.0000	.4350+01	.0000
519	.0	.2500+00	.0000	.3900+01	.0000	569	.0	.1100+01	.0000	.4350+01	.0000
520	.0	.5000+00	.0000	.3900+01	.0000	570	.0	.1400+01	.0000	.4350+01	.0000
521	.0	.8000+00	.0000	.3900+01	.0000	571	.0	.1700+01	.0000	.4350+01	.0000
522	.0	.1100+01	.0000	.3900+01	.0000	572	.0	.2000+01	.0000	.4350+01	.0000
523	.0	.1400+01	.0000	.3900+01	.0000	573	.0	.2300+01	.0000	.4350+01	.0000
524	.0	.1700+01	.0000	.3900+01	.0000	574	.0	.2600+01	.0000	.4350+01	.0000
525	.0	.2000+01	.0000	.3900+01	.0000	575	.0	.2900+01	.0000	.4350+01	.0000
526	.0	.2300+01	.0000	.3900+01	.0000	576	.0	.3200+01	.0000	.4350+01	.0000
527	.0	.2600+01	.0000	.3900+01	.0000	577	.0	.3500+01	.0000	.4350+01	.0000
528	.0	.2900+01	.0000	.3900+01	.0000	578	.0	.3722+01	.0000	.4350+01	.0000
529	.0	.3200+01	.0000	.3900+01	.0000	579	.0	.3944+01	.0000	.4350+01	.0000
530	.0	.3500+01	.0000	.3900+01	.0000	580	.0	.4167+01	.0000	.4350+01	.0000
531	.0	.3722+01	.0000	.3900+01	.0000	581	.0	.4389+01	.0000	.4350+01	.0000
532	.0	.3944+01	.0000	.3900+01	.0000	582	.0	.4611+01	.0000	.4350+01	.0000
533	.0	.4167+01	.0000	.3900+01	.0000	583	.0	.4833+01	.0000	.4350+01	.0000
534	.0	.4389+01	.0000	.3900+01	.0000	584	.0	.5056+01	.0000	.4350+01	.0000
535	.0	.4611+01	.0000	.3900+01	.0000	585	.0	.5278+01	.0000	.4350+01	.0000
536	.0	.4833+01	.0000	.3900+01	.0000	586	.0	.5500+01	.0000	.4350+01	.0000
537	.0	.5056+01	.0000	.3900+01	.0000	587	.0	.5680+01	.0000	.4350+01	.0000
538	.0	.5278+01	.0000	.3900+01	.0000	588	.0	.5860+01	.0000	.4350+01	.0000
539	.0	.5500+01	.0000	.3900+01	.0000	589	.0	.6040+01	.0000	.4350+01	.0000
540	.0	.5680+01	.0000	.3900+01	.0000	590	.0	.6220+01	.0000	.4350+01	.0000
541	.0	.5860+01	.0000	.3900+01	.0000	591	.0	.6400+01	.0000	.4350+01	.0000
542	.0	.6040+01	.0000	.3900+01	.0000	592	.0	.6580+01	.0000	.4350+01	.0000
543	.0	.6220+01	.0000	.3900+01	.0000	593	.0	.6760+01	.0000	.4350+01	.0000
544	.0	.6400+01	.0000	.3900+01	.0000	594	.0	.6940+01	.0000	4350+01	.0000
545	.0	.6580+01	.0000	.3900+01	.0000	595	.0	.7120+01	.0000	.4350+01	.0000
546	.0	.6760+01	.0000	.3900+01	.0000	596	.0	.7300+01	.0000	.4350+01	.0000
547	.0	.6940+01	.0000	.3900+01	.0000	597	.0	.7480+01	.0000	.4350+01	.0000
548	.0	.7120+01	.0000	.3900+01	.0000	598	.0	.7660+01	.0000	.4350+01	.0000
549	.0	.7300+01	.0000	.3900+01	.0000	599	.0	.7840+01	.0000	.4350+01	.0000
550	.0	.7480+01	.0000	.3900+01	.0000	600	.0	.8020+01	.0000	.4350+01	.0000

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                                         NODAL POINT COORDINATES AND CONCENTRATED FORCES

   NP    CODE    R-COOD      R-FORCE    Z-COOD      Z-FORCE          NP    CODE    R-COOD      R-FORCE    Z-COOD      Z-FORCE

  601     .0    .8200+01    .0000      .4350+01    .0000            651     .0    .8740+01    .0000      .4800+01    .0000
  602     .0    .8380+01    .0000      .4350+01    .0000            652     .0    .8920+01    .0000      .4800+01    .0000
  603     .0    .8560+01    .0000      .4350+01    .0000            653     .0    .9100+01    .0000      .4800+01    .0000
  604     .0    .8740+01    .0000      .4350+01    .0000            654     .0    .9280+01    .0000      .4800+01    .0000
  605     .0    .8920+01    .0000      .4350+01    .0000            655     .0    .9460+01    .0000      .4800+01    .0000
  606     .0    .9100+01    .0000      .4350+01    .0000            656     .0    .9640+01    .0000      .4800+01    .0000
  607     .0    .9280+01    .0000      .4350+01    .0000            657     .0    .9820+01    .0000      .4800+01    .0000
  608     .0    .9460+01    .0000      .4350+01    .0000            658     .0    .1000+02    .0000      .4800+01    .0000
  609     .0    .9640+01    .0000      .4350+01    .0000
  610     .0    .9820+01    .0000      .4350+01    .0000
  611     .0    .1000+02    .0000      .4350+01    .0000
  612     .0    .0000       .0000      .4800+01    .0000
  613     .0    .2500+00    .0000      .4800+01    .0000
  614     .0    .5000+00    .0000      .4800+01    .0000
  615     .0    .8000+00    .0000      .4800+01    .0000
  616     .0    .1100+01    .0000      .4800+01    .0000
  617     .0    .1400+01    .0000      .4800+01    .0000
  618     .0    .1700+01    .0000      .4800+01    .0000
  619     .0    .2000+01    .0000      .4800+01    .0000
  620     .0    .2300+01    .0000      .4800+01    .0000
  621     .0    .2600+01    .0000      .4800+01    .0000
  622     .0    .2900+01    .0000      .4800+01    .0000
  623     .0    .3200+01    .0000      .4800+01    .0000
  624     .0    .3500+01    .0000      .4800+01    .0000
  625     .0    .3722+01    .0000      .4800+01    .0000
  626     .0    .3944+01    .0000      .4800+01    .0000
  627     .0    .4167+01    .0000      .4800+01    .0000
  628     .0    .4389+01    .0000      .4800+01    .0000
  629     .0    .4611+01    .0000      .4800+01    .0000
  630     .0    .4833+01    .0000      .4800+01    .0000
  631     .0    .5056+01    .0000      .4800+01    .0000
  632     .0    .5278+01    .0000      .4800+01    .0000
  633     .0    .5500+01    .0000      .4800+01    .0000
  634     .0    .5680+01    .0000      .4800+01    .0000
  635     .0    .5860+01    .0000      .4800+01    .0000
  636     .0    .6040+01    .0000      .4800+01    .0000
  637     .0    .6220+01    .0000      .4800+01    .0000
  638     .0    .6400+01    .0000      .4800+01    .0000
  639     .0    .6580+01    .0000      .4800+01    .0000
  640     .0    .6760+01    .0000      .4800+01    .0000
  641     .0    .6940+01    .0000      .4800+01    .0000
  642     .0    .7120+01    .0000      .4800+01    .0000
  643     .0    .7300+01    .0000      .4800+01    .0000
  644     .0    .7480+01    .0000      .4800+01    .0000
  645     .0    .7660+01    .0000      .4800+01    .0000
  646     .0    .7840+01    .0000      .4800+01    .0000
  647     .0    .8020+01    .0000      .4800+01    .0000
  648     .0    .8200+01    .0000      .4800+01    .0000
  649     .0    .8380+01    .0000      .4800+01    .0000
  650     .0    .8560+01    .0000      .4800+01    .0000
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ELEMENT DEFINITIONS

ELEMENT	I	J	K	L	MATERIAL	ELEMENT	I	J	K	L	MATERIAL
1	1	2	49	48	1	51	52	53	100	99	2
2	2	3	50	49	1	52	53	54	101	100	2
3	3	4	51	50	2	53	54	55	102	101	2
4	4	5	52	51	2	54	55	56	103	102	2
5	5	6	53	52	2	55	56	57	104	103	2
6	6	7	54	53	2	56	57	58	105	104	2
7	7	8	55	54	2	57	58	59	106	105	2
8	8	9	56	55	2	58	59	60	107	106	1
9	9	10	57	56	2	59	60	61	108	107	1
10	10	11	58	57	2	60	61	62	109	108	1
11	11	12	59	58	2	61	62	63	110	109	1
12	12	13	60	59	2	62	63	64	111	110	1
13	13	14	61	60	1	63	64	65	112	111	1
14	14	15	62	61	1	64	65	66	113	112	1
15	15	16	63	62	1	65	66	67	114	113	1
16	16	17	64	63	1	66	67	68	115	114	1
17	17	18	65	64	1	67	68	69	116	115	1
18	18	19	66	65	1	68	69	70	117	116	1
19	19	20	67	66	1	69	70	71	118	117	1
20	20	21	68	67	1	70	71	72	119	118	1
21	21	22	69	68	1	71	72	73	120	119	1
22	22	23	70	69	1	72	73	74	121	120	1
23	23	24	71	70	1	73	74	75	122	121	1
24	24	25	72	71	1	74	75	76	123	122	1
25	25	26	73	72	1	75	76	77	124	123	1
26	26	27	74	73	1	76	77	78	125	124	1
27	27	28	75	74	1	77	78	79	126	125	1
28	28	29	76	75	1	78	79	80	127	126	1
29	29	30	77	76	1	79	80	81	128	127	1
30	30	31	78	77	1	80	81	82	129	128	1
31	31	32	79	78	1	81	82	83	130	129	1
32	32	33	80	79	1	82	83	84	131	130	1
33	33	34	81	80	1	83	84	85	132	131	1
34	34	35	82	81	1	84	85	86	133	132	1
35	35	36	83	82	1	85	86	87	134	133	1
36	36	37	84	83	1	86	87	88	135	134	1
37	37	38	85	84	1	87	88	89	136	135	1
38	38	39	86	85	1	88	89	90	137	136	1
39	39	40	87	86	1	89	90	91	138	137	1
40	40	41	88	87	1	90	91	92	139	138	1
41	41	42	89	88	1	91	92	93	140	139	1
42	42	43	90	89	1	92	93	94	141	140	1
43	43	44	91	90	1	93	95	96	143	142	1
44	44	45	92	91	1	94	96	97	144	143	1
45	45	46	93	92	1	95	97	98	145	144	1
46	46	47	94	93	1	96	98	99	146	145	1
47	48	49	96	95	1	97	99	100	147	146	2
48	49	50	97	96	1	98	100	101	148	147	2
49	50	51	98	97	1	99	101	102	149	148	2
50	51	52	99	98	2	100	102	103	150	149	2

ELEMENT DEFINITIONS

ELEMENT	I	J	K	L	MATERIAL	ELEMENT	I	J	K	L	MATERIAL
101	103	104	151	150	2	151	154	155	202	201	1
102	104	105	152	151	2	152	155	156	203	202	1
103	105	106	153	152	1	153	156	157	204	203	1
104	106	107	154	153	1	154	157	158	205	204	1
105	107	108	155	154	1	155	158	159	206	205	1
106	108	109	156	155	1	156	159	160	207	206	1
107	109	110	157	156	1	157	160	161	208	207	1
108	110	111	158	157	1	158	161	162	209	208	1
109	111	112	159	158	1	159	162	163	210	209	1
110	112	113	160	159	1	160	163	164	211	210	1
111	113	114	161	160	1	161	164	165	212	211	1
112	114	115	162	161	1	162	165	166	213	212	1
113	115	116	163	162	1	163	166	167	214	213	1
114	116	117	164	163	1	164	167	168	215	214	1
115	117	118	165	164	1	165	168	169	216	215	1
116	118	119	166	165	1	166	169	170	217	216	1
117	119	120	167	166	1	167	170	171	218	217	1
118	120	121	168	167	1	168	171	172	219	218	1
119	121	122	169	168	1	169	172	173	220	219	1
120	122	123	170	169	1	170	173	174	221	220	1
121	123	124	171	170	1	171	174	175	222	221	1
122	124	125	172	171	1	172	175	176	223	222	1
123	125	126	173	172	1	173	176	177	224	223	1
124	126	127	174	173	1	174	177	178	225	224	1
125	127	128	175	174	1	175	178	179	226	225	1
126	128	129	176	175	1	176	179	180	227	226	1
127	129	130	177	176	1	177	180	181	228	227	1
128	130	131	178	177	1	178	181	182	229	228	1
129	131	132	179	178	1	179	182	183	230	229	1
130	132	133	180	179	1	180	183	184	231	230	1
131	133	134	181	180	1	181	184	185	232	231	1
132	134	135	182	181	1	182	185	186	233	232	1
133	135	136	183	182	1	183	186	187	234	233	1
134	136	137	184	183	1	184	187	188	235	234	1
135	137	138	185	184	1	185	189	190	237	236	1
136	138	139	186	185	1	186	190	191	238	237	1
137	139	140	187	186	1	187	191	192	239	238	1
138	140	141	188	187	1	188	192	193	240	239	1
139	142	143	190	189	1	189	193	194	241	240	1
140	143	144	191	190	1	190	194	195	242	241	1
141	144	145	192	191	1	191	195	196	243	242	2
142	145	146	193	192	1	192	196	197	244	243	2
143	146	147	194	193	1	193	197	198	245	244	1
144	147	148	195	194	2	194	198	199	246	245	1
145	148	149	196	195	2	195	199	200	247	246	1
146	149	150	197	196	2	196	200	201	248	247	1
147	150	151	198	197	2	197	201	202	249	248	1
148	151	152	199	198	1	198	202	203	250	249	1
149	152	153	200	199	1	199	203	204	251	250	1
150	153	154	201	200	1	200	204	205	252	251	1

ELEMENT DEFINITIONS

ELEMENT	I	J	K	L	MATERIAL	ELEMENT	I	J	K	L	MATERIAL
201	205	206	253	252	1	251	256	257	304	303	1
202	206	207	254	253	1	252	257	258	305	304	1
203	207	208	255	254	1	253	258	259	306	305	1
204	208	209	256	255	1	254	259	260	307	306	1
205	209	210	257	256	1	255	260	261	308	307	1
206	210	211	258	257	1	256	261	262	309	308	1
207	211	212	259	258	1	257	262	263	310	309	1
208	212	213	260	259	1	258	263	264	311	310	1
209	213	214	261	260	1	259	264	265	312	311	1
210	214	215	262	261	1	260	265	266	313	312	1
211	215	216	263	262	1	261	266	267	314	313	1
212	216	217	264	263	1	262	267	268	315	314	1
213	217	218	265	264	1	263	268	269	316	315	1
214	218	219	266	265	1	264	269	270	317	316	1
215	219	220	267	266	1	265	270	271	318	317	1
216	220	221	268	267	1	266	271	272	319	318	1
217	221	222	269	268	1	267	272	273	320	319	1
218	222	223	270	269	1	268	273	274	321	320	1
219	223	224	271	270	1	269	274	275	322	321	1
220	224	225	272	271	1	270	275	276	323	322	1
221	225	226	273	272	1	271	276	277	324	323	1
222	226	227	274	273	1	272	277	278	325	324	1
223	227	228	275	274	1	273	278	279	326	325	1
224	228	229	276	275	1	274	279	280	327	326	1
225	229	230	277	276	1	275	280	281	328	327	1
226	230	231	278	277	1	276	281	282	329	328	1
227	231	232	279	278	1	277	283	284	331	330	1
228	232	233	280	279	1	278	284	285	332	331	1
229	233	234	281	280	1	279	285	286	333	332	1
230	234	235	282	281	1	280	286	287	334	333	1
231	236	237	284	283	1	281	287	288	335	334	1
232	237	238	285	284	1	282	288	289	336	335	1
233	238	239	286	285	1	283	289	290	337	336	1
234	239	240	287	286	1	284	290	291	338	337	1
235	240	241	288	287	1	285	291	292	339	338	1
236	241	242	289	288	1	286	292	293	340	339	1
237	242	243	290	289	1	287	293	294	341	340	1
238	243	244	291	290	1	288	294	295	342	341	1
239	244	245	292	291	1	289	295	296	343	342	1
240	245	246	293	292	1	290	296	297	344	343	1
241	246	247	294	293	1	291	297	298	345	344	1
242	247	248	295	294	1	292	298	299	346	345	1
243	248	249	296	295	1	293	299	300	347	346	1
244	249	250	297	296	1	294	300	301	348	347	1
245	250	251	298	297	1	295	301	302	349	348	1
246	251	252	299	298	1	296	302	303	350	349	1
247	252	253	300	299	1	297	303	304	351	350	1
248	253	254	301	300	1	298	304	305	352	351	1
249	254	255	302	301	1	299	305	306	353	352	1
250	255	256	303	302	1	300	306	307	354	353	1

ELEMENT DEFINITIONS

ELEMENT	I	J	K	L	MATERIAL
301	307	308	355	354	1
302	308	309	356	355	1
303	309	310	357	356	1
304	310	311	358	357	1
305	311	312	359	358	1
306	312	313	360	359	1
307	313	314	361	360	1
308	314	315	362	361	1
309	315	316	363	362	1
310	316	317	364	363	1
311	317	318	365	364	1
312	318	319	366	365	1
313	319	320	367	366	1
314	320	321	368	367	1
315	321	322	369	368	1
316	322	323	370	369	1
317	323	324	371	370	1
318	324	325	372	371	1
319	325	326	373	372	1
320	326	327	374	373	1
321	327	328	375	374	1
322	328	329	376	375	1
323	330	331	378	377	1
324	331	332	379	378	1
325	332	333	380	379	1
326	333	334	381	380	1
327	334	335	382	381	1
328	335	336	383	382	1
329	336	337	384	383	1
330	337	338	385	384	1
331	338	339	386	385	1
332	339	340	387	386	1
333	340	341	388	387	1
334	341	342	389	388	1
335	342	343	390	389	1
336	343	344	391	390	1
337	344	345	392	391	1
338	345	346	393	392	1
339	346	347	394	393	1
340	347	348	395	394	1
341	348	349	396	395	1
342	349	350	397	396	1
343	350	351	398	397	1
344	351	352	399	398	1
345	352	353	400	399	1
346	353	354	401	400	1
347	354	355	402	401	1
348	355	356	403	402	1
349	356	357	404	403	1
350	357	358	405	404	1
351	358	359	406	405	1
352	359	360	407	406	1
353	360	361	408	407	1
354	361	362	409	408	1
355	362	363	410	409	1
356	363	364	411	410	1
357	364	365	412	411	1
358	365	366	413	412	1
359	366	367	414	413	1
360	367	368	415	414	1
361	368	369	416	415	1
362	369	370	417	416	1
363	370	371	418	417	1
364	371	372	419	418	1
365	372	373	420	419	1
366	373	374	421	420	1
367	374	375	422	421	1
368	375	376	423	422	1
369	377	378	425	424	1
370	378	379	426	425	1
371	379	380	427	426	1
372	380	381	428	427	1
373	381	382	429	428	1
374	382	383	430	429	1
375	383	384	431	430	1
376	384	385	432	431	1
377	385	386	433	432	1
378	386	387	434	433	1
379	387	388	435	434	1
380	388	389	436	435	1
381	389	390	437	436	1
382	390	391	438	437	1
383	391	392	439	438	1
384	392	393	440	439	1
385	393	394	441	440	1
386	394	395	442	441	1
387	395	396	443	442	1
388	396	397	444	443	1
389	397	398	445	444	1
390	398	399	446	445	1
391	399	400	447	446	1
392	400	401	448	447	1
393	401	402	449	448	1
394	402	403	450	449	1
395	403	404	451	450	1
396	404	405	452	451	1
397	405	406	453	452	1
398	406	407	454	453	1
399	407	408	455	454	1
400	408	409	456	455	1

ELEMENT DEFINITIONS

ELEMENT	I	J	K	L	MATERIAL	ELEMENT	I	J	K	L	MATERIAL
401	409	410	457	456	1	451	460	461	508	507	1
402	410	411	458	457	1	452	461	462	509	508	1
403	411	412	459	458	1	453	462	463	510	509	1
404	412	413	460	459	1	454	463	464	511	510	1
405	413	414	461	460	1	455	464	465	512	511	1
406	414	415	462	461	1	456	465	466	513	512	1
407	415	416	463	462	1	457	466	467	514	513	1
408	416	417	464	463	1	458	467	468	515	514	1
409	417	418	465	464	1	459	468	469	516	515	1
410	418	419	466	465	1	460	469	470	517	516	1
411	419	420	467	466	1	461	471	472	519	518	1
412	420	421	468	467	1	462	472	473	520	519	1
413	421	422	469	468	1	463	473	474	521	520	1
414	422	423	470	469	1	464	474	475	522	521	1
415	424	425	472	471	1	465	475	476	523	522	1
416	425	426	473	472	1	466	476	477	524	523	1
417	426	427	474	473	1	467	477	478	525	524	1
418	427	428	475	474	1	468	478	479	526	525	1
419	428	429	476	475	1	469	479	480	527	526	1
420	429	430	477	476	1	470	480	481	528	527	1
421	430	431	478	477	1	471	481	482	529	528	1
422	431	432	479	478	1	472	482	483	530	529	1
423	432	433	480	479	1	473	483	484	531	530	1
424	433	434	481	480	1	474	484	485	532	531	1
425	434	435	482	481	1	475	485	486	533	532	1
426	435	436	483	482	1	476	486	487	534	533	1
427	436	437	484	483	1	477	487	488	535	534	1
428	437	438	485	484	1	478	488	489	536	535	1
429	438	439	486	485	1	479	489	490	537	536	1
430	439	440	487	486	1	480	490	491	538	537	1
431	440	441	488	487	1	481	491	492	539	538	1
432	441	442	489	488	1	482	492	493	540	539	1
433	442	443	490	489	1	483	493	494	541	540	1
434	443	444	491	490	1	484	494	495	542	541	1
435	444	445	492	491	1	485	495	496	543	542	1
436	445	446	493	492	1	486	496	497	544	543	1
437	446	447	494	493	1	487	497	498	545	544	1
438	447	448	495	494	1	488	498	499	546	545	1
439	448	449	496	495	1	489	499	500	547	546	1
440	449	450	497	496	1	490	500	501	548	547	1
441	450	451	498	497	1	491	501	502	549	548	1
442	451	452	499	498	1	492	502	503	550	549	1
443	452	453	500	499	1	493	503	504	551	550	1
444	453	454	501	500	1	494	504	505	552	551	1
445	454	455	502	501	1	495	505	506	553	552	1
446	455	456	503	502	1	496	506	507	554	553	1
447	456	457	504	503	1	497	507	508	555	554	1
448	457	458	505	504	1	498	508	509	556	555	1
449	458	459	506	505	1	499	509	510	557	556	1
450	459	460	507	506	1	500	510	511	558	557	1

ELEMENT DEFINITIONS

ELEMENT	I	J	K	L	MATERIAL
501	511	512	559	558	1
502	512	513	560	559	1
503	513	514	561	560	1
504	514	515	562	561	1
505	515	516	563	562	1
506	516	517	564	563	1
507	518	519	566	565	1
508	519	520	567	566	1
509	520	521	568	567	1
510	521	522	569	568	1
511	522	523	570	569	1
512	523	524	571	570	1
513	524	525	572	571	1
514	525	526	573	572	1
515	526	527	574	573	1
516	527	528	575	574	1
517	528	529	576	575	1
518	529	530	577	576	1
519	530	531	578	577	1
520	531	532	579	578	1
521	532	533	580	579	1
522	533	534	581	580	1
523	534	535	582	581	1
524	535	536	583	582	1
525	536	537	584	583	1
526	537	538	585	584	1
527	538	539	586	585	1
528	539	540	587	586	1
529	540	541	588	587	1
530	541	542	589	588	1
531	542	543	590	589	1
532	543	544	591	590	1
533	544	545	592	591	1
534	545	546	593	592	1
535	546	547	594	593	1
536	547	548	595	594	1
537	548	549	596	595	1
538	549	550	597	596	1
539	550	551	598	597	1
540	551	552	599	598	1
541	552	553	600	599	1
542	553	554	601	600	1
543	554	555	602	601	1
544	555	556	603	602	1
545	556	557	604	603	1
546	557	558	605	604	1
547	558	559	606	605	1
548	559	560	607	606	1
549	560	561	608	607	1
550	561	562	609	608	1

ELEMENT	I	J	K	L	MATERIAL
551	562	563	610	609	1
552	563	564	611	610	1
553	565	566	613	612	1
554	566	567	614	613	1
555	567	568	615	614	1
556	568	569	616	615	1
557	569	570	617	616	1
558	570	571	618	617	1
559	571	572	619	618	1
560	572	573	620	619	1
561	573	574	621	620	1
562	574	575	622	621	1
563	575	576	623	622	1
564	576	577	624	623	1
565	577	578	625	624	1
566	578	579	626	625	1
567	579	580	627	626	1
568	580	581	628	627	1
569	581	582	629	628	1
570	582	583	630	629	1
571	583	584	631	630	1
572	584	585	632	631	1
573	585	586	633	632	1
574	586	587	634	633	1
575	587	588	635	634	1
576	588	589	636	635	1
577	589	590	637	636	1
578	590	591	638	637	1
579	591	592	639	638	1
580	592	593	640	639	1
581	593	594	641	640	1
582	594	595	642	641	1
583	595	596	643	642	1
584	596	597	644	643	1
585	597	598	645	644	1
586	598	599	646	645	1
587	599	600	647	646	1
588	600	601	648	647	1
589	601	602	649	648	1
590	602	603	650	649	1
591	603	604	651	650	1
592	604	605	652	651	1
593	605	606	653	652	1
594	606	607	654	653	1
595	607	608	655	654	1
596	608	609	656	655	1
597	609	610	657	656	1
598	610	611	658	657	1

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                                              INITIAL NODAL DISPLACEMENTS

   NP        R-DISP          Z-DISP        NP        R-DISP          Z-DISP        NP        R-DISP          Z-DISP

    1       .2705-04        .8468-02       51       .6034-03        .7781-02      101       .9104-03        .6469-02
    2       .2599-04        .8167-02       52       .5673-03        .7317-02      102       .7810-03        .5960-02
    3       .1553-04        .7873-02       53       .5157-03        .6861-02      103       .9174-03        .5438-02
    4       .1384-04        .7494-02       54       .4534-03        .6413-02      104       .1047-02        .4902-02
    5       .1193-04        .7112-02       55       .3906-03        .5967-02      105       .1160-02        .4345-02
    6       .9963-05        .6731-02       56       .4567-03        .5503-02      106       .8980-03        .4180-02
    7       .7669-05        .6348-02       57       .5157-03        .5031-02      107       .8179-03        .3917-02
    8       .0000           .5986-02       58       .5684-03        .4552-02      108       .8546-03        .3562-02
    9      -.7927-05        .5566-02       59       .6082-03        .4057-02      109       .9038-03        .3207-02
   10      -.1027-04        .5167-02       60       .3033-03        .3982-02      110       .9547-03        .2854-02
   11      -.1238-04        .4766-02       61       .4101-03        .3599-02      111       .1009-02        .2498-02
   12      -.1426-04        .4364-02       62       .4708-03        .3236-02      112       .1069-02        .2136-02
   13      -.1632-04        .3956-02       63       .5224-03        .2878-02      113       .1135-02        .1764-02
   14      -.9512-05        .3610-02       64       .5767-03        .2522-02      114       .1203-02        .1366-02
   15       .2180-04        .3253-02       65       .6383-03        .2161-02      115       .1240-02        .9835-03
   16       .6316-04        .2900-02       66       .7119-03        .1781-02      116       .1256-02        .6466-03
   17       .1096-03        .2547-02       67       .8042-03        .1379-02      117       .1259-02        .4381-03
   18       .1585-03        .2186-02       68       .9266-03        .8675-03      118       .1254-02        .2796-03
   19       .2098-03        .1814-02       69       .9578-03        .4510-03      119       .1269-02        .1901-03
   20       .2622-03        .1394-02       70       .9378-03        .1916-03      120       .1298-02        .1303-03
   21       .3390-03        .9499-03       71       .9811-03        .1195-03      121       .1336-02        .8821-04
   22       .5052-03        .0000          72       .1047-02        .7869-04      122       .1376-02        .5642-04
   23       .6852-03        .0000          73       .1116-02        .5356-04      123       .1418-02        .3127-04
   24       .8345-03        .0000          74       .1183-02        .3558-04      124       .1460-02        .1055-04
   25       .9482-03        .0000          75       .1246-02        .2186-04      125       .1500-02       -.7122-05
   26       .1043-02        .0000          76       .1304-02        .1078-04      126       .1538-02       -.2267-04
   27       .1125-02        .0000          77       .1359-02        .1488-05      127       .1574-02       -.3676-04
   28       .1198-02        .0000          78       .1409-02       -.6578-05      128       .1608-02       -.4988-04
   29       .1264-02        .0000          79       .1455-02       -.1378-04      129       .1640-02       -.6246-04
   30       .1323-02        .0000          80       .1497-02       -.2040-04      130       .1670-02       -.7484-04
   31       .1377-02        .0000          81       .1537-02       -.2663-04      131       .1699-02       -.8735-04
   32       .1426-02        .0000          82       .1573-02       -.3267-04      132       .1725-02       -.1003-03
   33       .1471-02        .0000          83       .1607-02       -.3868-04      133       .1750-02       -.1140-03
   34       .1512-02        .0000          84       .1638-02       -.4479-04      134       .1774-02       -.1288-03
   35       .1550-02        .0000          85       .1667-02       -.5117-04      135       .1797-02       -.1451-03
   36       .1585-02        .0000          86       .1694-02       -.5796-04      136       .1819-02       -.1631-03
   37       .1617-02        .0000          87       .1719-02       -.6533-04      137       .1842-02       -.1835-03
   38       .1647-02        .0000          88       .1743-02       -.7344-04      138       .1865-02       -.2066-03
   39       .1674-02        .0000          89       .1767-02       -.8251-04      139       .1889-02       -.2330-03
   40       .1701-02        .0000          90       .1790-02       -.9273-04      140       .1915-02       -.2633-03
   41       .1725-02        .0000          91       .1814-02       -.1044-03      141       .1943-02       -.2985-03
   42       .1749-02        .0000          92       .1839-02       -.1177-03      142       .1134-02        .8442-02
   43       .1773-02        .0000          93       .1866-02       -.1331-03      143       .1138-02        .8139-02
   44       .1797-02        .0000          94       .1896-02       -.1509-03      144       .1147-02        .7843-02
   45       .1823-02        .0000          95       .7640-03        .8459-02      145       .1244-02        .7585-02
   46       .1850-02        .0000          96       .7627-03        .8153-02      146       .1368-02        .7317-02
   47       .1880-02        .0000          97       .7744-03        .7860-02      147       .1567-02        .7088-02
   48       .3925-03        .8467-02       98       .8807-03        .7668-02      148       .1374-02        .6517-02
   49       .3714-03        .8160-02       99       .1138-02        .7511-02      149       .1171-02        .5955-02
   50       .3120-03        .7850-02      100       .1033-02        .6983-02      150       .1385-02        .5382-02
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INITIAL NODAL DISPLACEMENTS

NP	R-DISP	Z-DISP	NP	R-DISP	Z-DISP	NP	R-DISP	Z-DISP
151	.1590-02	.4789-02	201	.1639-02	.3847-02	251	.2065-02	.2817-02
152	.1394-02	.4551-02	202	.1665-02	.3504-02	252	.2082-02	.2488-02
153	.1302-02	.4215-02	203	.1693-02	.3161-02	253	.2095-02	.2164-02
154	.1241-02	.3880-02	204	.1723-02	.2819-02	254	.2103-02	.1850-02
155	.1274-02	.3529-02	205	.1753-02	.2478-02	255	.2104-02	.1550-02
156	.1313-02	.3180-02	206	.1781-02	.2139-02	256	.2097-02	.1270-02
157	.1354-02	.2832-02	207	.1803-02	.1806-02	257	.2083-02	.1018-02
158	.1399-02	.2481-02	208	.1817-02	.1485-02	258	.2069-02	.8354-03
159	.1444-02	.2129-02	209	.1820-02	.1185-02	259	.2054-02	.6748-03
160	.1488-02	.1772-02	210	.1813-02	.9168-03	260	.2039-02	.5357-03
161	.1519-02	.1421-02	211	.1803-02	.7281-03	261	.2027-02	.4171-03
162	.1538-02	.1089-02	212	.1791-02	.5671-03	262	.2018-02	.3166-03
163	.1539-02	.7961-03	213	.1781-02	.4341-03	263	.2013-02	.2320-03
164	.1533-02	.5978-03	214	.1775-02	.3253-03	264	.2012-02	.1602-03
165	.1527-02	.4402-03	215	.1774-02	.2382-03	265	.2014-02	.9892-04
166	.1523-02	.3162-03	216	.1779-02	.1677-03	266	.2020-02	.4578-04
167	.1529-02	.2265-03	217	.1788-02	.1099-03	267	.2028-02	-.1024-05
168	.1542-02	.1590-03	218	.1801-02	.6147-04	268	.2037-02	-.4303-04
169	.1562-02	.1068-03	219	.1817-02	.2015-04	269	.2049-02	-.8153-04
170	.1586-02	.6515-04	220	.1834-02	-.1593-04	270	.2061-02	-.1176-03
171	.1612-02	.3085-04	221	.1852-02	-.4818-04	271	.2074-02	-.1523-03
172	.1640-02	.1772-05	222	.1871-02	-.7775-04	272	.2087-02	-.1865-03
173	.1668-02	-.2358-04	223	.1890-02	-.1056-03	273	.2101-02	-.2209-03
174	.1695-02	-.4632-04	224	.1909-02	-.1324-03	274	.2115-02	-.2564-03
175	.1722-02	-.6727-04	225	.1928-02	-.1590-03	275	.2130-02	-.2939-03
176	.1748-02	-.8713-04	226	.1947-02	-.1861-03	276	.2145-02	-.3341-03
177	.1773-02	-.1065-03	227	.1965-02	-.2143-03	277	.2161-02	-.3780-03
178	.1797-02	-.1258-03	228	.1983-02	-.2442-03	278	.2177-02	-.4265-03
179	.1820-02	-.1457-03	229	.2001-02	-.2766-03	279	.2194-02	-.4807-03
180	.1842-02	-.1665-03	230	.2019-02	-.3122-03	280	.2213-02	-.5419-03
181	.1863-02	-.1889-03	231	.2038-02	-.3518-03	281	.2233-02	-.6113-03
182	.1884-02	-.2132-03	232	.2058-02	-.3964-03	282	.2256-02	-.6906-03
183	.1904-02	-.2402-03	233	.2078-02	-.4470-03	283	.2300-02	.8374-02
184	.1925-02	-.2704-03	234	.2101-02	-.5047-03	284	.2305-02	.8077-02
185	.1947-02	-.3045-03	235	.2126-02	-.5709-03	285	.2311-02	.7777-02
186	.1969-02	-.3434-03	236	.1857-02	.8399-02	286	.2318-02	.7412-02
187	.1994-02	-.3880-03	237	.1863-02	.8101-02	287	.2328-02	.7042-02
188	.2021-02	-.4394-03	238	.1870-02	.7801-02	288	.2338-02	.6664-02
189	.1498-02	.8421-02	239	.1881-02	.7440-02	289	.2345-02	.6270-02
190	.1504-02	.8120-02	240	.1897-02	.7077-02	290	.2362-02	.5909-02
191	.1513-02	.7822-02	241	.1917-02	.6710-02	291	.2368-02	.5540-02
192	.1570-02	.7508-02	242	.1921-02	.6253-02	292	.2387-02	.5113-02
193	.1642-02	.7184-02	243	.1948-02	.5948-02	293	.2405-02	.4683-02
194	.1728-02	.6831-02	244	.1928-02	.5643-02	294	.2422-02	.4245-02
195	.1847-02	.6550-02	245	.1950-02	.5149-02	295	.2438-02	.3802-02
196	.1560-02	.5951-02	246	.1963-02	.4723-02	296	.2448-02	.3474-02
197	.1860-02	.5342-02	247	.1985-02	.4278-02	297	.2457-02	.3148-02
198	.1748-02	.5056-02	248	.2009-02	.3823-02	298	.2464-02	.2827-02
199	.1693-02	.4649-02	249	.2028-02	.3486-02	299	.2468-02	.2511-02
200	.1659-02	.4249-02	250	.2046-02	.3151-02	300	.2469-02	.2203-02

INITIAL NODAL DISPLACEMENTS

NP	R-DISP	Z-DISP	NP	R-DISP	Z-DISP	NP	R-DISP	Z-DISP
301	.2464-02	.1907-02	351	.2754-02	.1211-02	401	.3015-02	.8092-03
302	.2454-02	.1626-02	352	.2733-02	.1038-02	402	.2991-02	.6750-03
303	.2439-02	.1364-02	353	.2711-02	.8793-03	403	.2968-02	.5522-03
304	.2419-02	.1124-02	354	.2689-02	.7344-03	404	.2946-02	.4403-03
305	.2401-02	.9468-03	355	.2668-02	.6032-03	405	.2926-02	.3384-03
306	.2382-02	.7870-03	356	.2648-02	.4851-03	406	.2908-02	.2456-03
307	.2363-02	.6442-03	357	.2630-02	.3793-03	407	.2892-02	.1608-03
308	.2346-02	.5177-03	358	.2614-02	.2844-03	408	.2879-02	.8291-04
309	.2330-02	.4066-03	359	.2601-02	.1994-03	409	.2867-02	.1080-04
310	.2318-02	.3093-03	360	.2590-02	.1228-03	410	.2858-02	-.5666-04
311	.2308-02	.2242-03	361	.2582-02	.5326-04	411	.2851-02	-.1206-03
312	.2301-02	.1495-03	362	.2576-02	-.1041-04	412	.2845-02	-.1821-03
313	.2297-02	.8336-04	363	.2572-02	-.6952-04	413	.2842-02	-.2422-03
314	.2296-02	.2427-04	364	.2570-02	-.1252-03	414	.2841-02	-.3020-03
315	.2297-02	-.2927-04	365	.2570-02	-.1787-03	415	.2841-02	-.3626-03
316	.2299-02	-.7859-04	366	.2572-02	-.2309-03	416	.2843-02	-.4249-03
317	.2304-02	-.1249-03	367	.2575-02	-.2831-03	417	.2847-02	-.4902-03
318	.2310-02	-.1693-03	368	.2580-02	-.3361-03	418	.2852-02	-.5594-03
319	.2317-02	-.2127-03	369	.2586-02	-.3910-03	419	.2858-02	-.6337-03
320	.2325-02	-.2563-03	370	.2593-02	-.4489-03	420	.2867-02	-.7145-03
321	.2335-02	-.3008-03	371	.2601-02	-.5108-03	421	.2876-02	-.8031-03
322	.2345-02	-.3473-03	372	.2611-02	-.5781-03	422	.2886-02	-.9011-03
323	.2356-02	-.3968-03	373	.2623-02	-.6518-03	423	.2898-02	-.1010-02
324	.2368-02	-.4503-03	374	.2635-02	-.7336-03	424	.3626-02	.8331-02
325	.2381-02	-.5088-03	375	.2649-02	-.8249-03	425	.3628-02	.8031-02
326	.2396-02	-.5737-03	376	.2664-02	-.9276-03	426	.3630-02	.7727-02
327	.2411-02	-.6463-03	377	.3182-02	.8340-02	427	.3633-02	.7357-02
328	.2429-02	-.7281-03	378	.3185-02	.8042-02	428	.3635-02	.6982-02
329	.2448-02	-.8209-03	379	.3188-02	.7740-02	429	.3638-02	.6601-02
330	.2741-02	.8354-02	380	.3192-02	.7371-02	430	.3640-02	.6214-02
331	.2745-02	.8057-02	381	.3196-02	.6997-02	431	.3642-02	.5821-02
332	.2749-02	.7756-02	382	.3201-02	.6617-02	432	.3644-02	.5421-02
333	.2754-02	.7389-02	383	.3207-02	.6232-02	433	.3644-02	.5015-02
334	.2760-02	.7016-02	384	.3215-02	.5843-02	434	.3642-02	.4605-02
335	.2767-02	.6638-02	385	.3221-02	.5446-02	435	.3636-02	.4192-02
336	.2776-02	.6253-02	386	.3228-02	.5038-02	436	.3626-02	.3779-02
337	.2788-02	.5872-02	387	.3234-02	.4622-02	437	.3616-02	.3476-02
338	.2798-02	.5483-02	388	.3237-02	.4202-02	438	.3602-02	.3177-02
339	.2811-02	.5071-02	389	.3236-02	.3780-02	439	.3586-02	.2884-02
340	.2824-02	.4649-02	390	.3233-02	.3470-02	440	.3566-02	.2599-02
341	.2835-02	.4219-02	391	.3226-02	.3164-02	441	.3543-02	.2323-02
342	.2843-02	.3788-02	392	.3217-02	.2863-02	442	.3517-02	.2058-02
343	.2846-02	.3469-02	393	.3203-02	.2569-02	443	.3489-02	.1805-02
344	.2847-02	.3154-02	394	.3187-02	.2285-02	444	.3458-02	.1567-02
345	.2845-02	.2843-02	395	.3167-02	.2013-02	445	.3425-02	.1345-02
346	.2840-02	.2539-02	396	.3144-02	.1754-02	446	.3397-02	.1176-02
347	.2830-02	.2245-02	397	.3117-02	.1511-02	447	.3370-02	.1018-02
348	.2817-02	.1963-02	398	.3089-02	.1284-02	448	.3342-02	.8711-03
349	.2800-02	.1695-02	399	.3065-02	.1114-02	449	.3315-02	.7348-03
350	.2778-02	.1443-02	400	.3040-02	.9554-03	450	.3288-02	.6088-03

INITIAL NODAL DISPLACEMENTS

NP	R-DISP	Z-DISP	NP	R-DISP	Z-DISP	NP	R-DISP	Z-DISP
451	.3263-02	.4926-03	501	.3558-02	.2341-03	551	.3824-02	.8457-07
452	.3239-02	.3856-03	502	.3534-02	.1438-03	552	.3802-02	-.8184-04
453	.3217-02	.2870-03	503	.3513-02	.5884-04	553	.3782-02	-.1614-03
454	.3197-02	.1960-03	504	.3494-02	-.2176-04	554	.3765-02	-.2396-03
455	.3179-02	.1115-03	505	.3477-02	-.9894-04	555	.3751-02	-.3173-03
456	.3162-02	.3267-04	506	.3462-02	-.1737-03	556	.3739-02	-.3955-03
457	.3148-02	-.4162-04	507	.3449-02	-.2470-03	557	.3729-02	-.4761-03
458	.3137-02	-.1124-03	508	.3439-02	-.3199-03	558	.3722-02	-.5568-03
459	.3127-02	-.1807-03	509	.3431-02	-.3933-03	559	.3717-02	-.6415-03
460	.3119-02	-.2475-03	510	.3425-02	-.4681-03	560	.3714-02	-.7298-03
461	.3113-02	-.3140-03	511	.3421-02	-.5454-03	561	.3713-02	-.8222-03
462	.3110-02	-.3810-03	512	.3420-02	-.6260-03	562	.3713-02	-.9192-03
463	.3108-02	-.4497-03	513	.3420-02	-.7108-03	563	.3714-02	-.1021-02
464	.3108-02	-.5211-03	514	.3422-02	-.8008-03	564	.3715-02	-.1128-02
465	.3110-02	-.5962-03	515	.3425-02	-.8967-03	565	.5264-02	.8327-02
466	.3114-02	-.6762-03	516	.3429-02	-.9998-03	566	.5264-02	.8019-02
467	.3119-02	-.7621-03	517	.3433-02	-.1111-02	567	.5264-02	.7709-02
468	.3125-02	-.8552-03	518	.4711-02	.8326-02	568	.5263-02	.7336-02
469	.3132-02	-.9569-03	519	.4711-02	.8020-02	569	.5261-02	.6959-02
470	.3140-02	-.1069-02	520	.4711-02	.7711-02	570	.5256-02	.6578-02
471	.4165-02	.8326-02	521	.4711-02	.7338-02	571	.5249-02	.6192-02
472	.4166-02	.8023-02	522	.4709-02	.6961-02	572	.5238-02	.5801-02
473	.4167-02	.7717-02	523	.4705-02	.6579-02	573	.5223-02	.5406-02
474	.4167-02	.7345-02	524	.4699-02	.6192-02	574	.5202-02	.5009-02
475	.4168-02	.6968-02	525	.4691-02	.5799-02	575	.5176-02	.4611-02
476	.4167-02	.6586-02	526	.4679-02	.5402-02	576	.5142-02	.4213-02
477	.4165-02	.6198-02	527	.4664-02	.5002-02	577	.5101-02	.3819-02
478	.4161-02	.5805-02	528	.4644-02	.4600-02	578	.5065-02	.3531-02
479	.4156-02	.5406-02	529	.4618-02	.4198-02	579	.5026-02	.3247-02
480	.4147-02	.5003-02	530	.4587-02	.3799-02	580	.4982-02	.2970-02
481	.4136-02	.4597-02	531	.4560-02	.3507-02	581	.4934-02	.2700-02
482	.4120-02	.4190-02	532	.4530-02	.3220-02	582	.4883-02	.2439-02
483	.4099-02	.3785-02	533	.4496-02	.2939-02	583	.4828-02	.2187-02
484	.4081-02	.3489-02	534	.4459-02	.2665-02	584	.4771-02	.1947-02
485	.4059-02	.3197-02	535	.4420-02	.2400-02	585	.4711-02	.1718-02
486	.4034-02	.2911-02	536	.4377-02	.2146-02	586	.4650-02	.1502-02
487	.4006-02	.2632-02	537	.4332-02	.1903-02	587	.4600-02	.1336-02
488	.3976-02	.2363-02	538	.4286-02	.1672-02	588	.4550-02	.1178-02
489	.3942-02	.2104-02	539	.4238-02	.1455-02	589	.4500-02	.1030-02
490	.3906-02	.1858-02	540	.4198-02	.1288-02	590	.4451-02	.8895-03
491	.3869-02	.1624-02	541	.4159-02	.1131-02	591	.4403-02	.7576-03
492	.3830-02	.1404-02	542	.4120-02	.9827-03	592	.4356-02	.6335-03
493	.3797-02	.1237-02	543	.4081-02	.8435-03	593	.4312-02	.5170-03
494	.3765-02	.1080-02	544	.4043-02	.7129-03	594	.4269-02	.4073-03
495	.3733-02	.9320-03	545	.4006-02	.5908-03	595	.4230-02	.3041-03
496	.3701-02	.7939-03	546	.3971-02	.4765-03	596	.4192-02	.2064-03
497	.3669-02	.6652-03	547	.3937-02	.3695-03	597	.4158-02	.1136-03
498	.3639-02	.5455-03	548	.3906-02	.2692-03	598	.4127-02	.2480-04
499	.3610-02	.4342-03	549	.3876-02	.1747-03	599	.4099-02	-.6081-04
500	.3583-02	.3306-03	550	.3849-02	.8529-04	600	.4075-02	-.1441-03

```
                                          INITIAL NODAL DISPLACEMENTS

  NP         R-DISP          Z-DISP       NP         R-DISP          Z-DISP       NP         R-DISP          Z-DISP

 601       .4053-02      -.2261-03       651       .4250-02      -.4650-03
 602       .4035-02      -.3076-03       652       .4242-02      -.5530-03
 603       .4020-02      -.3894-03       653       .4237-02      -.6432-03
 604       .4008-02      -.4725-03       654       .4235-02      -.7361-03
 605       .3999-02      -.5576-03       655       .4234-02      -.8316-03
 606       .3992-02      -.6453-03       656       .4234-02      -.9297-03
 607       .3987-02      -.7361-03       657       .4235-02      -.1030-02
 608       .3984-02      -.8304-03       658       .4235-02      -.1130-02
 609       .3982-02      -.9279-03
 610       .3982-02      -.1028-02
 611       .3982-02      -.1131-02
 612       .5821-02       .8328-02
 613       .5821-02       .8018-02
 614       .5822-02       .7709-02
 615       .5823-02       .7336-02
 616       .5823-02       .6959-02
 617       .5822-02       .6579-02
 618       .5818-02       .6195-02
 619       .5809-02       .5806-02
 620       .5795-02       .5415-02
 621       .5774-02       .5021-02
 622       .5744-02       .4627-02
 623       .5704-02       .4234-02
 624       .5655-02       .3845-02
 625       .5611-02       .3561-02
 626       .5561-02       .3281-02
 627       .5505-02       .3008-02
 628       .5443-02       .2741-02
 629       .5376-02       .2483-02
 630       .5304-02       .2235-02
 631       .5229-02       .1996-02
 632       .5150-02       .1769-02
 633       .5069-02       .1554-02
 634       .5003-02       .1389-02
 635       .4936-02       .1231-02
 636       .4870-02       .1082-02
 637       .4805-02       .9407-03
 638       .4741-02       .8072-03
 639       .4680-02       .6812-03
 640       .4621-02       .5623-03
 641       .4566-02       .4500-03
 642       .4514-02       .3437-03
 643       .4467-02       .2428-03
 644       .4423-02       .1464-03
 645       .4385-02       .5399-04
 646       .4350-02      -.3538-04
 647       .4321-02      -.1225-03
 648       .4297-02      -.2082-03
 649       .4277-02      -.2933-03
 650       .4261-02      -.3787-03
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```
                                     INITIAL NODAL VELOCITIES

         NP      R-VEL         Z-VEL        NP      R-VEL         Z-VEL        NP      R-VEL         Z-VEL
                             **ALL NODAL POINT INITIAL VELOCITIES ARE ZERO**
```

```
PRINTED OUTPUT PARAMETERS

     START OUTPUT AT-----   0.00

     STOP OUTPUT AT------   1.00-05

     STEP OUTPUT AT------   5.00-06

     NODAL POINTS TO BE PRINTED       18

     ELEMENT STRESSES TO BE PRINTED   15

PLOT TAPE (UNIT 10) OUTPUT PARAMETERS

     START OUTPUT AT-----   0.00

     STOP OUTPUT AT------   0.00

     STEP OUTPUT AT------   0.00

UNIT 11 OUTPUT PARAMETERS

     START OUTPUT AT-----   0.00

     STOP OUTPUT AT------   1.00-05

     STEP OUTPUT AT------   5.00-06

UNIT 12 OUTPUT PARAMETERS

     START OUTPUT AT-----   0.00

     STOP OUTPUT AT------   1.00-05

     STOP OUTPUT AT------   1.00-06
```

```
                              DYNAMIC FRACTURE ANALYSIS DATA


NUMBER OF TIME STEPS (NSTEP)                              50

TIME STEP ADJUSTMENT FACTOR (RDT)                   1.000000

DYNAMIC VISCOSITY COEFFICIENTS:

              B1     1.20000+01

              B2     6.00000-01

              B3     1.00000-01

INITIAL CRACK TIP LOCATION:

               X    5.5000

          NODENO        21

J-INTEGRAL CONTOUR GEOMETRY:

             NNN    3

              NT    2

              NL    6

              NN   46

REFERENCE DYNAMIC MODULUS (DYNMOD)                7.05000+05

NUMBER OF TIME STEPS FOR K-SMOOTHING (NAVG)                1

REINITIATION STRESS INTENSITY MULTIPLIER (SIFRST)   1.000000
```

```
TEMPERATURE VS. ADOT VS. K DATA:

 TEMP:   .70000+02
    K:   .45500+03   .46000+03   .48500+03   .52500+03   .58500+03   .68000+03   .80500+03   .10350+04

 ADOT:   .00000      .95000+04   .10000+05   .11000+05   .12000+05   .13000+05   .14000+05   .15000+05
```

```
CYCLE=    0      CURRENT TIME=  0.000000         LAST TIME STEP=  4.178975-07      NEXT TIME STEP=  4.178975-07


TIME T=    .000
NODAL POINT R-DISPLACEMENT  Z-DISPLACEMENT    R-VELOCITY       Z-VELOCITY  R-ACCELERATION  Z-ACCELERATION  NODAL POINT
       8          .0000          .5986-02          .0000            .0000           .0000           .0000          8
      22          .5052-03       .0000             .0000            .0000         -.4139+03        .1827+07        22
      24          .8345-03       .0000             .0000            .0000          .4858+01        .0000           24
      26          .1043-02       .0000             .0000            .0000         -.1430+02        .0000           26
      28          .1198-02       .0000             .0000            .0000         -.3839+02        .0000           28
      30          .1323-02       .0000             .0000            .0000         -.7459+01        .0000           30
      32          .1426-02       .0000             .0000            .0000         -.2812+02        .0000           32
      34          .1512-02       .0000             .0000            .0000         -.9900+01        .0000           34
      36          .1585-02       .0000             .0000            .0000          .4142+02        .0000           36
      38          .1647-02       .0000             .0000            .0000         -.2123+02        .0000           38
      40          .1701-02       .0000             .0000            .0000          .6829+01        .0000           40
      42          .1749-02       .0000             .0000            .0000         -.1311+02        .0000           42
      44          .1797-02       .0000             .0000            .0000         -.3017+01        .0000           44
     243          .1948-02       .5948-02          .0000            .0000          .9289+06       -.3131+06       243
     337          .2788-02       .5872-02          .0000            .0000          .8587+03        .1770+03       337
     431          .3642-02       .5821-02          .0000            .0000          .9132+01        .1577+03       431
     525          .4691-02       .5799-02          .0000            .0000          .2241+03        .1710+03       525
     619          .5809-02       .5806-02          .0000            .0000          .3547+03        .1741+03       619

          EL.NO        SIG-R        SIG-Z        SIG-T       TAU-RZ      SIG-MAX      SIG-MIN   ANGLE    EL.NO
             26     .2761+03     .1739+03     .6661-15     .3253+02     .2856+03     .1644+03   16.24       26
             27     .2432+03     .1349+03     .8882-15     .2661+02     .2493+03     .1287+03   13.09       27
             28     .2152+03     .1036+03     .4441-15     .2251+02     .2195+03     .9923+02   10.99       28
             29     .1908+03     .7743+02     .4441-15     .1955+02     .1941+03     .7415+02    9.51       29
             30     .1693+03     .5485+02     .3331-15     .1732+02     .1719+03     .5229+02    8.42       30
             52    -.4204+02    -.7862+02     .0000        .9020+02     .3170+02    -.1524+03   39.27       52
             53     .1036+02    -.2554+03    -.1110-15     .7330+02     .2924+02    -.2742+03   14.44       53
             54     .2319+02    -.2558+03     .2220-15    -.9319+02     .5146+02    -.2841+03  -16.87       54
             55     .2637+01    -.7002+02     .2776-16    -.1178+03     .8954+02    -.1569+03  -36.43       55
             56     .7464+02    -.6877+01     .0000       -.1010+03     .1428+03    -.7506+02  -34.01       56
             98     .8409+02    -.7202+02     .1249-15     .5973+02     .1043+03    -.9225+02   18.71       98
             99     .9032+02    -.1616+03     .1110-15     .2184+02     .9220+02    -.1635+03    4.92       99
            100     .1151+03    -.1552+03     .1665-15    -.6521+02     .1301+03    -.1701+03  -12.88      100
            101     .1369+03    -.6543+02    -.8327-16    -.1254+03     .1968+03    -.1254+03  -25.55      101
            102     .2494+03     .8423+02    -.2220-15    -.1574+03     .3446+03    -.1095+02  -31.16      102

X=  .550000+01 CDOT=  .138593+05 CJINT=  .879465+00 HK=  .787415+03 E0=  .191841+03 F0=  .185668+03 DDX=  .579178-02 NBETA= 0

ENERGIES:  FRACTURE=  .000000    STRAIN=  .143526+01 KINETIC=  .000000    DISSIPATED=  .000000    TOTAL=  .143526+01

RMSFB=  1.46776+01  RMSQB=  0.00000     RMSFK=  1.71964+00 RMSQK=  0.00000
```

```
CYCLE=   12      CURRENT TIME=  5.128646-06      LAST TIME STEP=  4.178507-07      NEXT TIME STEP=  4.178756-07


TIME T=    .513-05
NODAL POINT R-DISPLACEMENT  Z-DISPLACEMENT     R-VELOCITY       Z-VELOCITY  R-ACCELERATION  Z-ACCELERATION  NODAL POINT
       8       .0000           .5986-02         .0000             .0000           .0000            .0000           8
      22       .5056-03        .8768-04         .3127+00          .4291+02        .1471+06         .1088+08       22
      24       .8351-03        .0000            .5143+00          .0000           .2854+06         .0000          24
      26       .1043-02        .0000            .1770-01          .0000           .2816+05         .0000          26
      28       .1198-02        .0000            .2018-03          .0000           .4701+03         .0000          28
      30       .1323-02        .0000            .1026-03          .0000           .5264+02         .0000          30
      32       .1426-02        .0000            .1034-03          .0000           .7111+02         .0000          32
      34       .1512-02        .0000            .1046-03          .0000           .5359+02         .0000          34
      36       .1585-02        .0000            .1369-03          .0000           .3203+02         .0000          36
      38       .1647-02        .0000            .1223-03          .0000           .7866+02         .0000          38
      40       .1701-02        .0000            .1515-03          .0000           .4884+02         .0000          40
      42       .1749-02        .0000            .1275-03          .0000           .7494+02         .0000          42
      44       .1797-02        .0000            .1482-03          .0000           .5894+02         .0000          44
     243       .1951-02        .5947-02         .2313+00          .2225-02       -.2699+06         .1526+06      243
     337       .2788-02        .5873-02         .4778-02          .1207-01        .1700+04         .3618+04      337
     431       .3642-02        .5821-02         .3546-04          .1139-02        .1197+02         .3739+03      431
     525       .4691-02        .5799-02         .1629-02          .8571-03        .3983+03         .1680+03      525
     619       .5809-02        .5806-02         .1897-02          .8545-03        .3824+03         .1509+03      619


          EL.NO        SIG-R       SIG-Z        SIG-T        TAU-RZ       SIG-MAX      SIG-MIN   ANGLE    EL.NO
             26      .2760+03    .1739+03     .6660-15     .3252+02     .2855+03     .1644+03   16.24       26
             27      .2432+03    .1349+03     .8882-15     .2661+02     .2493+03     .1287+03   13.09       27
             28      .2152+03    .1036+03     .4441-15     .2251+02     .2195+03     .9923+02   10.99       28
             29      .1908+03    .7743+02     .4441-15     .1956+02     .1941+03     .7415+02    9.51       29
             30      .1693+03    .5485+02     .3331-15     .1732+02     .1719+03     .5229+02    8.42       30
             52     -.5594+02   -.7587+02     .1128-16     .9675+02     .3136+02    -.1632+03   42.06       52
             53      .2212+02   -.2549+03    -.1128-15     .7748+02     .4231+02    -.2751+03   14.61       53
             54      .3507+02   -.2576+03     .2047-15    -.9662+02     .6409+02    -.2867+03  -16.72       54
             55     -.2569+02   -.8198+02     .3123-16    -.1279+03     .7712+02    -.1848+03  -38.79       55
             56      .5233+02    .2972+02    -.6939-17    -.7908+02     .1209+03    -.3886+02  -40.93       56
             98      .8387+02   -.5491+02     .1164-15     .5944+02     .1058+03    -.7689+02   20.29       98
             99      .9077+02   -.1566+03     .1128-15     .2772+02     .9384+02    -.1597+03    6.32       99
            100      .1084+03   -.1653+03     .1648-15    -.7065+02     .1255+03    -.1824+03  -13.65      100
            101      .1314+03   -.5914+02    -.7633-16    -.1115+03     .1828+03    -.1105+03  -24.75      101
            102      .1463+03    .1416+02    -.2047-15    -.1245+03     .2212+03    -.6070+02  -31.02      102

X=  .557104+01 CDOT=  .138116+05 CJINT=  .866192+00 HK=  .781451+03 EO=  .191841+03 FO=  .109981+03 DDX=  .768072-01 NBETA= 0

ENERGIES:  FRACTURE=  .622650-01 STRAIN=  .140137+01 KINETIC=  .670129-02 DISSIPATED=  .107572-02 TOTAL=  .147141+01

RMSFB=  1.44074+01  RMSQB=  2.68438-01  RMSFK=  1.59723+00 RMSQK=  8.63540-02
```

```
CYCLE=   24      CURRENT TIME=  1.014323-05      LAST TIME STEP=  4.178851-07      NEXT TIME STEP=  4.178855-07

TIME T=    .101-04
NODAL POINT R-DISPLACEMENT  Z-DISPLACEMENT     R-VELOCITY        Z-VELOCITY  R-ACCELERATION  Z-ACCELERATION  NODAL POINT
       8          .0000           .5986-02       .0000              .0000          .0000              .0000            8
      22          .5091-03        .4074-03       .9785+00           .7554+02       .6239+04           .2422+06        22
      24          .8394-03        .0000          .4368+00           .0000         -.8035+06           .0000           24
      26          .1044-02        .0000          .7077+00           .0000          .2760+06           .0000           26
      28          .1198-02        .0000          .6766-01           .0000          .5529+05           .0000           28
      30          .1323-02        .0000          .3068-02           .0000          .3483+04           .0000           30
      32          .1426-02        .0000          .6148-03           .0000          .2225+03           .0000           32
      34          .1512-02        .0000          .6020-03           .0000          .1618+03           .0000           34
      36          .1585-02        .0000          .6328-03           .0000          .1730+03           .0000           36
      38          .1647-02        .0000          .6593-03           .0000          .1512+03           .0000           38
      40          .1701-02        .0000          .6192-03           .0000          .1681+03           .0000           40
      42          .1749-02        .0000          .6514-03           .0000          .1524+03           .0000           42
      44          .1797-02        .0000          .6016-03           .0000          .1465+03           .0000           44
     243          .1950-02        .5948-02      -.1284+00          -.9532-01       .4227+05           .3462+05       243
     337          .2788-02        .5873-02       .1288-01           .2993-01       .2487+04           .3374+04       337
     431          .3642-02        .5821-02       .2332-03           .4691-02       .9513+02           .1244+04       431
     525          .4691-02        .5799-02       .3448-02           .1744-02       .2968+03           .1923+03       525
     619          .5809-02        .5806-02       .3747-02           .1575-02       .3540+03           .1362+03       619

           EL.NO       SIG-R       SIG-Z       SIG-T       TAU-RZ      SIG-MAX      SIG-MIN   ANGLE     EL.NO
              26     .2729+03    .1730+03    .6605-15    .3241+02    .2825+03    .1634+03   16.48        26
              27     .2422+03    .1346+03    .8864-15    .2657+02    .2484+03    .1284+03   13.14        27
              28     .2149+03    .1035+03    .4435-15    .2251+02    .2193+03    .9915+02   11.00        28
              29     .1908+03    .7742+02    .4440-15    .1956+02    .1941+03    .7414+02    9.52        29
              30     .1693+03    .5485+02    .3330-15    .1732+02    .1719+03    .5229+02    8.42        30
              52    -.6695+02   -.7812+02    .1214-16    .9820+02    .2582+02   -.1709+03   43.37        52
              53     .1390+02   -.2554+03   -.1050-15    .7931+02    .3552+02   -.2770+03   15.25        53
              54     .2528+02   -.2556+03    .2108-15   -.9679+02    .5540+02   -.2857+03  -17.29        54
              55    -.3313+02   -.7818+02    .3209-16   -.1146+03    .6112+02   -.1724+03  -39.44        55
              56     .5623+02    .8402-01   -.5204-17   -.7759+02    .1107+03   -.5435+02  -35.05        56
              98     .7194+02   -.6007+02    .1171-15    .5743+02    .9343+02   -.8156+02   20.51        98
              99     .6508+02   -.1580+03    .1197-15    .2295+02    .6742+02   -.1603+03    5.81        99
             100     .7804+02   -.1527+03    .1634-15   -.5849+02    .9202+02   -.1667+03  -13.44       100
             101     .1089+03   -.5880+02   -.7242-16   -.1042+03    .1588+03   -.1087+03  -25.59       101
             102     .1425+03    .1046+02   -.1995-15   -.1313+03    .2235+03   -.7052+02  -31.65       102

X=  .563959+01 CDOT=  .134256+05 CJINT=  .762535+00 HK=  .733204+03 EO=  .191841+03 FO=  .370883+02 DDX=  .145201+00 NBETA= 0

ENERGIES:  FRACTURE=  .118745+00 STRAIN=  .132955+01 KINETIC=  .265975-01 DISSIPATED=  .582801-02 TOTAL=  .148072+01

RMSFB=  1.40625+01  RMSQB=  3.38633-01  RMSFK=  1.57790+00 RMSQK=  1.25155-01

                                  .425+03 CPU SECONDS WERE USED FOR S A M C R
```

APPENDIX IV

FORTRAN V COMPUTER CODE LISTING

RUNNING CRACK PROGRAM 'SAMCR'

(VERSION 3.0)

RELEASED JANUARY 1, 1984

NOTE: Listing for main program SAMCR is given first, followed by listings for program subroutines in alphabetical order according to subroutine name

RUNNING CRACK PROGRAM 'SAMCR'
(VERSION 3.0)
PROCEDURE CALLS

```
MAIN  →→  CRACK  →→  SECOND /
                     DATE /
                     DATAIN /
                     ROLIN /
                     RSTIN  →→  ENERGY /
                     RSTOUT /
                     SOLVE  →→  LOAD /
                                MASS /
                                INTSTR /
                                STRESS /
                                FORCE /
                                JINTGL /
                                INVEL  →→  INTPL /
                                CRKFOR /
                                ENERGY /
                                CONVRG /
                                DATOUT /
                                ROLOUT /
                                RSTOUT /
                                NEWUV /
                                STRAIN /
                                VEL  →→  INTPL /
                                TERM
< STOP >
```

→→ calls
/   calls only system routines

FIGURE IV.1 SUBROUTINE CALL MAP FOR SAMCR

PROGRAM LISTING -- SAMCR (VERSION 3.0) -- RELEASED JANUARY 1 1984

```
C        PROGRAM SAMCR
C
C      ALLOCATES MASTER ARRAY STORAGE
C      CALLS MASTER SUBROUTINE 'CRACK'
C         A      = MASTER STORAGE ARRAY (BLANK COMMON
C         NDIMA = DIMENSION OF 'A' IN WORDS
C         ITWO  = DOUBLE PRECISION FLAG
C               = 1 ===> SINGLE PRECISION
C               = 2 ===> DOUBLE PRECISION
C
       COMMON/BK13/ITWO,NDIMA,N1,N2,N3,N4,N5,N6,N7,N8,N9,N10,N11,N12,
     +             N13,N14,N15,N16,N17,N18,N19,N20,N21,N22,N23,N24
       COMMON A(65000)
       NDIMA=65000
       ITWO=2
       CALL CRACK
C
       STOP
       END
```

```
      SUBROUTINE CONVRG(A,U,NS)
C
C  SUBROUTINE TO CHECK CONVERGENCE OF DYNAMIC RELAXATION FOR STATIC
C  (NON-FRACTURE PROPAGATION) ANALYSIS, USING ALGORITHM FROM SECTION 2.11
C  IN SCHWARTZ ET AL., 1984.  SEE APPENDIX I IN SAME REPORT FOR
C  DESCRIPTIONS OF SUBROUTINE ARGUMENTS AND LABELED COMMON BLOCKS.
C
C  IF NS.EQ.NITER.OR.ERROR.LE.TOL, ITERATION IS HALTED, RESULTS ARE
C  PRINTED, AND EXECUTION OF PROGRAM STOPS
C
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON/BK1/NUMMAT,NUMNP,NUMEL,NUMPC,NUMLP,HED(16),RA,NTAPE,NEQ,
     +           MESH,IRSTRT,ITEMP
      COMMON/BK11/ISTAT,NITER,TOL,VISC1,VISC2,VISC3
      DIMENSION A(1),U(1)
      DATA ANORM0,ANORM1,ANORM2/3*0.0D0/
C
      IF (NS.NE.NITER) GO TO 10
      WRITE(6,1000)
      WRITE(9,1010) NITER
      GO TO 100
C
 10   ANORM2=0.0
      DO 20 I=1,NEQ
 20   ANORM2=ANORM2+A(I)*A(I)
      ANORM2=SQRT(ANORM2)
      IF (ANORM0.GT.0.0) GO TO 30
      ANORM0=ANORM2
      ANORM1=ANORM2
      RETURN
C
 30   ERROR=ABS((ANORM2-ANORM1)/ANORM1)
      IF (ERROR.LT.TOL) GO TO 90
      ANORM1=ANORM2
      RETURN
C
 90   WRITE(6,1000)
      WRITE(9,1020) NS
 100  WRITE(9,1030) ANORM0,ANORM2
      WRITE(9,1040) ERROR
      WRITE(9,1050)
      WRITE(9,1060) (A(I),I=1,NEQ)
      WRITE(9,1070)
      DO 110 I=1,NUMNP
         J1=2*I-1
         J2=2*I
         WRITE(9,1080) I,U(J1),U(J2)
 110  CONTINUE
C
      STOP
```

```
C
 1000 FORMAT('1STATIC ANALYSIS BY DYNAMIC ITERATION',////)
 1010 FORMAT(' FAILURE TO REACH CONVERGENCE AFTER',I5,' ITERATIONS')
 1020 FORMAT(' CONVERGENCE REACHED AFTER',I5,' ITERATIONS')
 1030 FORMAT(/,T5,'INITIAL LENGTH OF ACCELERATION VECTOR=',1PE12.5,//,
     +        T5,'FINAL   LENGTH OF ACCELERATION VECTOR=',E12.5)
 1040 FORMAT(/,T5,'RELATIVE ERROR AT CONVERGENCE=',1PE12.5)
 1050 FORMAT(/,' FINAL NODAL ACCELERATION VECTOR ',/)
 1060 FORMAT(8E10.4)
 1070 FORMAT(/,' FINAL NODAL DISPLACEMENT VECTOR ',/)
 1080 FORMAT(I5,15X,E16.7,5X,E16.7)
C
      END
```

```
      SUBROUTINE CRACK
C
C  CALLS DATA INPUT SUBROUTINES; SETS ARRAY POINTERS;
C  SETS UP PROBLEM BEFORE PASSING CONTROL TO 'SOLVE'
C
      IMPLICIT REAL*8 (A-H,O-Z)
      REAL T1,T2,TT5
C
      COMMON/BK1/NUMMAT,NUMNP,NUMEL,NUMPC,NUMLP,HED(16),RA,NTAPE,NEQ,
     +           MESH,IRSTRT,ITEMP
      COMMON/BK2/EPZ(5),D(4),C(4,4),DF,KLIN,DT1,DT2,WRZ
      COMMON/BK11/ISTAT,NITER,TOL,VISC1,VISC2,VISC3
      COMMON/BK13/ITWO,NDIMA,N1,N2,N3,N4,N5,N6,N7,N8,N9,N10,N11,N12,
     +            N13,N14,N15,N16,N17,N18,N19,N20,N21,N22,N23,N24
      COMMON A(1)
      REAL A
C
      NTAPE = 4
C
C  REWIND PLOT AND RESTART UNITS
C
      REWIND 10
      REWIND 13
C
C  READ AND WRITE OF CARD IMAGES
C
      REWIND NTAPE
   10 MPRINT=0
      WRITE(6,130)
      WRITE (6,140)
   20 READ(5,110,END=50) HED
      WRITE (6,150) HED
      WRITE (NTAPE,110) HED
      MPRINT=MPRINT+1
      IF (MPRINT.LT.50) GO TO 20
      WRITE (6,140)
      GO TO 10
   50 REWIND NTAPE
C
C  READ AND WRITE OF HEADING
C
      IERROR=1
      READ (NTAPE,110) HED
      WRITE (6,160) HED
      CALL SECOND (T1)
C
C  READ AND WRITE OF CONTROL PARAMETERS
C
      READ(NTAPE,115) IRSTRT,NDUMP
      IF (IRSTRT.NE.-1) GO TO 55
         WRITE(6,165)
         CALL RSTIN(NDUMP,0,IERROR)
         IF (IERROR.EQ.0) GO TO 90
         GO TO 65
   55 READ (NTAPE,120) NUMMAT,NUMNP,NUMEL,NUMPC,NUMLP,KLIN,RA,MESH,
```

```
     +                  ISTAT,ITEMP
      IF (RA.NE.0.0) GO TO 65
C      ***AXISYMMETRIC ANALYSIS NOT FULLY IMPLEMENTED
         WRITE(6,290)
         STOP
   65 IF (KLIN.EQ.0) J4=4H  NO
      IF (KLIN.NE.0) J4=4H YES
      WRITE (6,260) NUMMAT,NUMNP,NUMEL,NUMPC,NUMLP,J4,RA,IRSTRT,
     +              ITEMP
C
C  PRINT 'SAMCR' PROGRAM TITLE BLOCK
C
      CALL DATE (IDATE)
      DO 60 I=1,27
         IF (I.EQ.5) WRITE (6,180)
         IF (I.EQ.10) WRITE (6,190)
         IF (I.EQ.15.AND.ITWO.EQ.1) WRITE(6,200)
         IF (I.EQ.15.AND.ITWO.EQ.2) WRITE(6,205)
         IF (I.EQ.20) WRITE (6,210)
         IF (I.EQ.25) WRITE (6,220) IDATE
         WRITE (6,170)
   60 CONTINUE
C
      IF (IRSTRT EQ.-1) GO TO 84
C
C  INPUT DATA FOR NON-RESTART ANALYSIS
C
C
C  ALLOCATE STORAGE FOR DATA:  SET ARRAY POINTERS
C  (SEE TABLE I.1 IN SCHWARTZ ET AL. 1984 FOR DEFINITION OF POINTERS)
C
      NEQ=2*NUMNP
      N1=1
      N2=N1+NUMNP*ITWO
      N3=N2+NUMNP*ITWO
      N4=N3+NUMNP*ITWO
      N5=N4+5*NUMEL
      N6=N5+NUMMAT
      N7=N6+NUMMAT*ITWO
      N8=N7+30*NUMMAT*ITWO
      N9=N8+NUMPC
      N10=N9+NUMPC
      N11=N10+NUMPC*ITWO
      N12=N11+NUMPC*ITWO
      N13=N12+NUMPC*ITWO
      N14=N13+2*NUMLP*ITWO
      N15=N14+NEQ*ITWO
      N16=N15+NEQ*ITWO
      N17=N16+NEQ*ITWO
      N18=N17+NEQ*ITWO
      N19=N18+NUMNP*ITWO
      N20=N19+4*NUMEL*ITWO
      N21=N20+5*NUMEL*ITWO
      N22=N21+NEQ*ITWO
      N23=N22+NEQ*ITWO
      N24=N23+NEQ*ITWO
```

```
    NEND=N24+NUMNP*ITWO*ITEMP
    NXX=NDIMA-NEND
    WRITE (6,240) NDIMA,NEND,NXX
C
C  CHECK FOR STORAGE OVERFLOW
C
    IF (-NXX) 70,70,100
 70 DO 80 I=N16,N24
 80 A(I)=0.0
C
C  READ AND WRITE OF INPUT DATA:  MATERIAL PROPERTY, NODAL
C  POINT,LOAD DATA AND INITIAL DISPLACEMENTS, VELOCITIES
C
    CALL DATAIN (A(N1),A(N2),A(N3),A(N4),A(N5),A(N6),A(N7),A(N8),
   +             A(N9),A(N10),A(N11),A(N12),A(N13),A(N14),A(N15),
   +             A(N21),A(N24),IERROR)
C
C  CHECK FOR DATA ERROR
C
    IF (IERROR.EQ.0) GO TO 90
C
C  READ AND WRITE CRACK INPUT DATA
C
    CALL ROLIN(IERROR)
    IF (IERROR.EQ.0) GO TO 90
    GO TO 88
C
C  INPUT DATA FOR RESTART ANALYSIS
C
  84 CALL RSTIN(NDUMP,1,IERROR)
  88 WRITE (6,250)
C
C  FORM TOTAL STIFFNESS AND MASS MATRICES AND SOLVE STEP-BY-STEP
C
    CALL SOLVE (A(N1),A(N2),A(N3),A(N4),A(N5),A(N6),A(N7),A(N8),A(N9),
   +A(N10),A(N11),A(N12),A(N13),A(N14),A(N15),A(N16),A(N17),A(N18),
   +A(N19),A(N20),A(N21),A(N22),A(N23),A(N24))
C
C  WRITE RESTART FILE AT END OF ANALYSIS
C
    IF (IRSTRT.NE.0) CALL RSTOUT
C
C
    CALL SECOND (T2)
    TT5=T2-T1
    WRITE (6,230) TT5
    RETURN
C
C  INPUT ERROR EXIT
C
 90 WRITE(6,260)
    RETURN
C
C  STORAGE OVERFLOW EXIT
C
```

```
  100  WRITE (6,270)
       RETURN
C
  110  FORMAT (16A5)
   115 FORMAT(2I5)
  120  FORMAT (6I5,E10.0,3I5)
  130  FORMAT(1H1,35X,11HCARD IMAGES)
  140  FORMAT (1H0,8X,2H10,8X,2H20,8X,2H30,8X,2H40,8X,2H50,8X,2H60,8X,2H7
      108X,2H80/81H 123456789012345678901234567890123456789012345678901234567890123
      24567890123456789012345678901234567890/1H0)
  150  FORMAT (1H ,16A5)
  160  FORMAT(1H1,20X,16A5)
  165  FORMAT(1H0,47X,24H<<< RESTART ANALYSIS >>>)
C
C      *********  VERSION ID FORMAT BLOCK  *********
C
  170  FORMAT (1H ,20X,9HS A M C R,62X,9HS A M C R)
  180  FORMAT (1H+,53X,11HVERSION 3.0)
 190   FORMAT (1H+,47X,22H RELEASED JAN   1 1984)
 200   FORMAT (1H+,39X,42HSINGLE PRECISION FOR UNIVAC 1100 COMPUTERS)
 205   FORMAT (1H+,39X,42HDOUBLE PRECISION FOR UNIVAC 1100 COMPUTERS)
 210   FORMAT (1H+,40X,40HLATEST CHANGES INCORPORATED IN DEC  1983)
  220  FORMAT (1H+,42X,29HTHIS PROBLEM WAS EXECUTED ON ,A6 )
C
C      **********  END VERSION ID FORMATS  *********
C
  230  FORMAT (1H0,36X,E10.3,36H CPU SECONDS WERE USED FOR S A M C R)
  240  FORMAT (20H1STORAGE ALLOCATIONS/1H0,5X,32HSTORAGE AVAILABLE IN A--
      1--------,I8/1H0,5X,32HSTORAGE NEEDED FOR SOLUTION-----,I8/1H0,5X,3
      22HUNUSED STORAGE IN A-------------,I8/)
  250  FORMAT (1H1)
  260  FORMAT (1H0,39X,28HNUMBER OF MATERIALS---------I4/1H0,39X,28HNUMBE
      1R OF NODAL POINTS------I4/1H0,39X,28HNUMBER OF ELEMENTS----------I
      24/1H0,39X,28HNUMBER OF PRESSURE CARDS----I4/1H0,39X,28HNUMBER OF L
      3OAD POINTS-------I4/1H0,39X,28HFINITE STRAIN---------------A4/1H0,
      439X,28HRADIUS INCREMENT------------,E9.3/,
      51H0,39X,28HRESTART OPTION--------------,I4/,
      61H0,39X,28HNODAL TEMPERATURE FLAG------,I4/)
   270 FORMAT('OSTORAGE NEEDED EXCEEDS ROOM IN MASTER STORAGE ARRAY;',/,
      +       ' CALCULATIONS TERMINATED.')
  280  FORMAT('0INPUT ERROR--PROGRAM STOP')
  290  FORMAT('1AXISYMMETRIC ANALYSIS NOT FULLY IMPLEMENT IN THIS'
      +       ' VERSION OF SAMCR',///,' PROGRAM STOP')
C
       END
```

PROGRAM LISTING -- SAMCR (VERSION 3.0) -- RELEASED JANUARY 1 1984

```
      FUNCTION CRKFOR(E0,DA,B)
C
C  COMPUTES CRACK TIP NODAL FORCE AT EACH STEP IN THE ANALYSIS,
C  USING ALGORITHM FROM SECTION 2.8.1 IN SCHWARTZ ET AL., 1984.
C
      IMPLICIT REAL*8 (A-H,O-Z)
C
      CRKFOR = E0 * (1 - DA/B)
C
      RETURN
      END
```

PROGRAM LISTING -- SAMCR (VERSION 3.0) -- RELEASED JANUARY 1 1984

```
      SUBROUTINE DATAIN (R,Z,CODE,IX,MTYPE,RO,EE,INI,JNJ,PI,PJ,T,P,U,V,
     +                   ELOAD,TEMP,IERROR)
C
C  READS INPUT DATA (NON-RESTART) FROM CARD IMAGE FILE ON UNIT 'NTAPE';
C  PRINTS SUMMARY OF INPUT DATA
C
C  (SEE APPENDIX I IN SCHWARTZ ET AL. 1984 FOR DESCRIPTIONS OF
C   SUBROUTINE ARGUMENTS AND LABELED COMMON BLOCKS)
C
      IMPLICIT REAL*8 (A-H,O-Z)
C
      COMMON/BK1/NUMMAT,NUMNP,NUMEL,NUMPC,NUMLP,HED(16),RA,NTAPE,NEQ,
     +           MESH,IRSTRT,ITEMP
      COMMON/BK3/NDSOUT(160),NSTOUT(160),NUMDS,NUMST,
     +           TIO1(5),TIO2(5),TIOD(5)
      COMMON/BK6/NNN,NODENO,NN,CJINT,HK,CDOT,ADOTK(10,17,2),KK,KT,
     +           SIFRST,DXX,DX,X,NS,NSTEP,NT,NL,DYNMOD,NSRPTS,
     +           STRNRT(8),EDMULT(8),NAVG
      COMMON/BK11/ISTAT,NITER,TOL,VISC1,VISC2,VISC3
C
      DIMENSION  R(1),Z(1),CODE(1),IX(5,1),MTYPE(1),RO(1),EE(5,6,1),
     +           INI(1),JNJ(1),PI(1),PJ(1),T(1),P(2,1),U(1),V(1),
     +           ELOAD(1),TEMP(1)
C
C  READ AND WRITE STATIC ANALYSIS PARAMETERS (IF APPLICABLE)
C
      IF (ISTAT.EQ.0) GO TO 5
         READ(NTAPE,940) NITER,TOL,VISC1,VISC2,VISC3
         IF (NITER.EQ.0) NITER=100
         IF (TOL.LE.0.0) TOL=1.0D-4
         IF (VISC1.LE.0.0) VISC1=1.2E2
         IF (VISC2.LE.0.0) VISC2=0.06E2
         IF (VISC3.LE.0.0) VISC3=0.01E2
         WRITE(6,700)
         WRITE(6,950) NITER,TOL,VISC1,VISC2,VISC3
    5 CONTINUE
C
C  READ AND WRITE OF MATERIAL PROPERTIES
C
      WRITE (6,700)
      DO 10 M=1,NUMMAT
         IF (M.EQ.4) WRITE (6,700)
         READ (NTAPE,610) N,MTYPE(N),RO(N)
         WRITE (6,710) N,MTYPE(N),RO(N)
         IF (N.GT.NUMMAT) GO TO 560
         READ (NTAPE,620)
         WRITE (6,620)
         READ (NTAPE,630) ((EE(I,J,N),I=1,5),J=1,6)
         WRITE (6,720) ((EE(I,J,N),I=1,5),J=1,6)
   10 CONTINUE
```

```
C
C  READ AND WRITE OF NODAL POINT COORDINATE, BOUNDARY CONDITION,
C  AND TEMPERATURE DATA
C
      I=0
      ID=1
      ND=0
   20 IF (MESH) 40,30,40
   30 READ(7,640) N,CODE(N),R(N),Z(N),U1,U2,TNODE
      ND=0
      GO TO 50
   40 READ(NTAPE,640) N,CODE(N),R(N),Z(N),U1,U2,TNODE
   50 CONTINUE
      IF (ITEMP.EQ.1) TEMP(N)=TNODE
      JZ=N+N
      JR=JZ-1
      IF (CODE(N).EQ.-1.OR.CODE(N).EQ.-3) ELOAD(JZ)=U2
      IF (CODE(N).EQ.-2.OR.CODE(N).EQ.-3) ELOAD(JR)=U1
      IF(RA.NE.0.0) GO TO 55
         IF (R(N).EQ.0..AND.CODE(N).EQ.0.) CODE(N)=1.
         IF (R(N).EQ.0..AND.CODE(N).EQ.2.) CODE(N)=3.
   55 CONTINUE
      IF (ND) 60,70,60
   60 ID=ND
   70 IF (I) 80,140,80
   80 NL=N-I
      IF (NL-1) 140,130,90
   90 NL=NL/ID
      IF (I+NL*ID-N) 520,100,520
  100 IF (NL-1) 130,130,110
  110 ANL=NL
      DR=(R(N)-R(I))/ANL
      DZ=(Z(N)-Z(I))/ANL
      NL=N-2*ID
      DO 120 J=I,NL,ID
         I1=J+ID
         R(I1)=R(J)+DR
         IF (RA.NE.0.0) GO TO 115
            IF (R(I1).EQ.0..AND.CODE(N).EQ.0.) CODE(N)=1.
            IF (R(I1).EQ.0..AND.CODE(N).EQ.2.) CODE(N)=3.
  115    Z(I1)=Z(J)+DZ
         CODE(I1)=CODE(J)
         JZ=J+J
         JR=JZ-1
         IF (CODE(J).EQ.-1.OR.CODE(J).EQ.-3) ELOAD(JZ)=U2
         IF (CODE(J).EQ.-2.OR.CODE(J).EQ.-3) ELOAD(JR)=U1
  120 CONTINUE
  130 IF (NUMNP-N) 530,150,140
  140 I=N
      GO TO 20
```

```
  150 MPRINT=0
      J=0
      DO 170 N=1,NUMNP
         J=J+1
         IF (MPRINT.NE.0) GO TO 160
            IF (NUMNP.LT.J+50.AND.J.GT.1) GO TO 180
            IF (NUMNP.GT.J+49.AND.J.GT.1) J=J+50
            WRITE (6,730)
            MPRINT=50
  160    MPRINT=MPRINT-1
         NN=J+50
         IF (NUMNP.LT.NN) NN=NUMNP
         IF (J.GT.NUMNP) GO TO 180
         WRITE(6,740) (I,CODE(I),R(I),ELOAD(I+I-1),Z(I),ELOAD(I+I),
     +                 I=J,NN,50)
  170 CONTINUE
  180 CONTINUE
C
C  READ AND WRITE OF ELEMENT DATA
C
      I=0
  190 IF(MESH.NE.0) READ(NTAPE,650) M,(IX(J,M),J=1,5),HM1
      IF(MESH.EQ.0) READ(7,650) M,(IX(J,M),J=1,5),HM1
      I=I+1
      IF (M-I) 540,220,200
  200 NX=IABS(IX(1,I-1)-IX(2,I-1))
  210 IX(1,I)=IX(1,I-1)+NX
      IX(2,I)=IX(2,I-1)+NX
      IX(3,I)=IX(3,I-1)+NX
      IX(4,I)=IX(4,I-1)+NX
      IX(5,I)=IX(5,I-1)
      I=I+1
      IF (M-I) 220,220,210
  220 IF (NUMEL-M) 550,230,190
  230 CONTINUE
      MPRINT=0
      J=0
      DO 250 N=1,NUMEL
         J=J+1
         IF (MPRINT.NE.0) GO TO 240
            IF (NUMEL.LT.J+50.AND.J.GT.1) GO TO 260
            IF (NUMEL.GT.J+49.AND.J.GT.1) J=J+50
            WRITE (6,750)
            MPRINT=50
  240    MPRINT=MPRINT-1
         NN=J+50
         IF (NUMEL.LT.NN) NN=NUMEL
         IF (J.GT.NUMEL) GO TO 260
         WRITE (6,760) (I,(IX(K,I),K=1,5),I=J,NN,50)
  250 CONTINUE
```

```
  260 CONTINUE
C
C  READ AND WRITE OF PRESSURE BOUNDARY CONDITION DATA
C
      IF (NUMPC.EQ.0) GO TO 330
         WRITE (6,770)
         DO 295 K=1,NUMPC
            IF (MESH) 280,270,280
  270       READ (7,660) INI(K),JNJ(K),PI(K),PJ(K),T(K)
            GO TO 290
  280       READ (NTAPE,660) INI(K),JNJ(K),PI(K),PJ(K),T(K)
  290       N=INI(K)
            IF (CODE(N).LT.0.0) GO TO 515
            N=JNJ(K)
            IF (CODE(N).LT.0.0) GO TO 515
  295    CONTINUE
C
C  READ AND WRITE OF PRESSURE LOAD HISTORY
C
         READ (NTAPE,670) ((P(K,M),K=1,2),M=1,NUMLP)
         NN=NUMPC
         IF (NUMLP.GT.NN) NN=NUMLP
         K=1
  300    WRITE (6,600)
         IF (K.GT.NUMPC) GO TO 310
            WRITE (6,780) INI(K),JNJ(K),PI(K),PJ(K),T(K)
  310    IF (K.GT.NUMLP) GO TO 320
            WRITE (6,790) P(1,K),P(2,K)
  320    K=K+1
         IF (K.LE.NN) GO TO 300
  330 CONTINUE
C
C  READ AND WRITE OF INITIAL NODAL DISPLACEMENT AND VELOCITY CONDITIONS
C
      VEL=0.0
      READ (NTAPE,1001) RATIO
      DO 340 I=1,NUMNP
         J1=2*I-1
         J2=2*I
         IF(MESH) 344,342,344
  342    READ(7,1000) NODE,U(J1),U(J2)
         U(J1) = RATIO*U(J1)
         U(J2) = RATIO*U(J2)
         GO TO 340
  344    READ(NTAPE,1000) NODE,U(J1),U(J2)
         U(J1) = RATIO*U(J1)
         U(J2) = RATIO*U(J2)
  340 CONTINUE
      MPRINT=0
      J=0
```

```
    DO 351 N=1,NUMNP
       J=J+1
       IF (MPRINT.NE.0) GO TO 352
          IF (NUMNP.LT.J+100.AND.J.GT.1) GO TO 353
          IF (NUMNP.GT.J+99.AND.J.GT.1) J=J+100
          WRITE(6,1040)
          MPRINT=50
352    MPRINT=MPRINT-1
       NN=J+100
       IF (NUMNP.LT.NN) NN=NUMNP
       IF (J.GT.NUMNP) GO TO 353
       WRITE(6,820) (I,U(2*I-1),U(2*I),I=J,NN,50)
351 CONTINUE
353 CONTINUE
    I=0
    ID=1
350 READ (NTAPE,680) N,V(2*N-1),V(2*N),ND
    VEL=VEL+ABS(V(2*N-1))+ABS(V(2*N))
    IF (ND) 360,370,360
360 ID=ND
370 IF (I) 380,440,380
380 NL=N-I
    IF (NL-1) 440,430,390
390 NL=NL/ID
    IF (I+NL*ID-N) 570,400,570
400 IF (NL-1) 430,430,410
410 ANL=NL
    DR=(V(2*N-1)-V(2*I-1))/ANL
    DZ=(V(2*N)-V(2*I))/ANL
    NL=N-2*ID
    DO 420 J=I,NL,ID
      I1=J+ID
      V(2*I1-1)=V(2*J-1)+DR
      V(2*I1)=V(2*J)+DZ
420 CONTINUE
430 IF (NUMNP-N) 580,450,440
440 I=N
    GO TO 350
450 IF (VEL.NE.0.0) GO TO 460
       WRITE (6,800)
       WRITE (6,810)
       GO TO 490
460 CONTINUE
    MPRINT=0
    J=0
    DO 480 N=1,NUMNP
       J=J+1
       IF (MPRINT.NE.0) GO TO 470
          IF (NUMNP.LT.J+100.AND.J.GT.1) GO TO 490
          IF (NUMNP.GT.J+99.AND.J.GT.1) J=J+100
```

```
            WRITE (6,800)
            MPRINT=50
  470    MPRINT=MPRINT-1
         NN=J+100
         IF (NUMNP.LT.NN) NN=NUMNP
         IF (J.GT.NUMNP) GO TO 490
         WRITE (6,820) (I,V(2*I-1),V(2*I),I=J,NN,50)
  480 CONTINUE
  490 CONTINUE
C
C  WRITE NODAL TEMPERATURE DATA
C
      IF (ITEMP.EQ.0) GO TO 494
      MPRINT=0
      J=0
      DO 491 N=1,NUMNP
         J=J+1
         IF (MPRINT.NE.0) GO TO 492
            IF (NUMNP.LT.J+150.AND.J.GT.1) GO TO 493
            IF (NUMNP.GT.J+149.AND.J.GT.1) J=J+149
            WRITE(6,1020)
            MPRINT=50
  492    MPRINT=MPRINT-1
         NN=J+150
         IF (NUMNP.LT.NN) NN=NUMNP
         IF (J.GT.NUMNP) GO TO 493
         WRITE(6,1030) (I,TEMP(I),I=J,NN,50)
  491 CONTINUE
  493 CONTINUE
C
C  READ AND WRITE OF OUTPUT CONTROL PARAMETERS
C
  494 WRITE (6,830)
      READ(NTAPE,690) (TIO1(I),TIO2(I),TIOD(I),I=1,4)
      IF (IRSTRT.EQ.1) READ(NTAPE,690) TIO1(5),TIO2(5),TIOD(5)
      READ (NTAPE,692) NUMDS,NUMST
      IF (NUMDS.NE.0) READ (NTAPE,694) (NDSOUT(I),I=1,NUMDS)
      IF (NUMST.NE.0) READ (NTAPE,694) (NSTOUT(I),I=1,NUMST)
      IF (NUMDS.EQ.0) NUMDS=NUMNP
      IF (NUMST.EQ.0) NUMST=NUMEL
      WRITE(6,840) TIO1(1),TIO2(1),TIOD(1)
      WRITE (6,850) NUMDS,NUMST
      WRITE (6,860)
      WRITE(6,840) TIO1(2),TIO2(2),TIOD(2)
      WRITE(6,862)
      WRITE(6,840) TIO1(3),TIO2(3),TIOD(3)
      WRITE(6,864)
      WRITE(6,840) TIO1(4),TIO2(4),TIOD(4)
      IF (IRSTRT.EQ.0) GO TO 495
         WRITE(6,866)
```

```
           WRITE(6,840) TIO1(5),TIO2(5),TIOD(5)
  495 CONTINUE
C
C  PLOTTING TAPE 10, WRITE 1 OF 2
C
      IF (TIO2(2).LE.0.0) GO TO 496
         WRITE (10) HED,NUMEL,NUMNP
         WRITE (10) (R(I),I=1,NUMNP),(Z(I),I=1,NUMNP),((IX(I,J),
     +                J=1,NUMEL),I=1,5)
  496 CONTINUE
C
  510 RETURN
C
C  INPUT DATA ERROR EXITS
C
  515 WRITE(6,960) N
      GO TO 590
  520 WRITE (6,870) I,ND,N
      GO TO 590
  530 WRITE (6,880) N,NUMNP
      GO TO 590
  540 WRITE (6,890) I,M
      GO TO 590
  550 WRITE (6,900) M,NUMEL
      GO TO 590
  560 WRITE (6,910) N,NUMMAT
      GO TO 590
  570 WRITE (6,920) I,ND,N
      GO TO 590
  580 WRITE (6,930) N,NUMNP
  590 IERROR=0
      RETURN
C
  600 FORMAT (1H )
  610 FORMAT (2I5,2E10.0)
  620 FORMAT (80HTHIS IS A VARIABLE HEADING FILLED AT INPUT TIME--------
     1-------------------------)
  630 FORMAT (5E10.0)
  640 FORMAT(I5,6F10.0)
  650 FORMAT(6I5,F10.0)
  660 FORMAT (2I5,3E10.0)
  670 FORMAT (2E10.0)
  680 FORMAT (I5,2E10.0,I5)
  690 FORMAT(6E10.0,/,6E10.0)
  692 FORMAT (2I5)
  694 FORMAT(16I5)
  700 FORMAT (1H1)
  710 FORMAT (///16H0MATERIAL NUMBER,I3/1H05X,9HTYPE NO.=,I4/1H0,5X,9HDE
     1NSITY =,E15.6/)
  720 FORMAT (1H /(5E15.3))
```

```
  730 FORMAT(1H1,//,41X,'NODAL POINT COORDINATES AND CONCENTRATED'
     +' FORCES',///,3X,'NP',4X,'CODE',4X,'R-COOD',6X,'R-FORCE',5X,
     +'Z-COOD',6X,'Z-FORCE',11X,'NP',4X,'CODE',4X,'R-COOD',6X,
     +'R-FORCE',5X,'Z-COOD',6X,'Z-FORCE',/)
  740 FORMAT(1X,I4,F8.1,4E12.4,8X,I4,F8.1,4E12.4)
  750 FORMAT (1H1//46X,19HELEMENT DEFINITIONS///6X7HELEMENT,5X,1HI,5X,1H
     1J,5X,1HK,5X,1HL,5X,8HMATERIAL,8X7HELEMENT,5X,1HI,5X,1HJ,5X,1HK,5X,
     21HL,5X,8HMATERIAL/)
  760 FORMAT (1X,2(2X,2I8,3I6,I10,6X))
  770 FORMAT (1H1//11X,28HPRESSURE BOUNDARY CONDITIONS,30X,28HPRESSURE H
     1ISTORY DESCRIPTION///5X,1HI,5X,1HJ,7X,4HPI/P,8X,4HPJ/P,6X,10HSTART
     2 TIME,23X,4HTIME,9X,10HPRESSURE P/)
  780 FORMAT (1H+,I5,I6,7F12.3)
  790 FORMAT (1H+,65X,2F15.7)
  800 FORMAT(1H1//49X,24HINITIAL NODAL VELOCITIES///6X,2HNP,8X,
     +       5HR-VEL,11X,5HZ-VEL,10X,2HNP,8X,5HR-VEL,11X,5HZ-VEL,
     +       10X,2HNP,8X,5HR-VEL,11X,5HZ-VEL/)
  810 FORMAT (35X,47H**ALL NODAL POINT INITIAL VELOCITIES ARE ZERO**)
  820 FORMAT (1X,3(2X,I5,2E16.4,2X))
  830 FORMAT (26H1PRINTED OUTPUT PARAMETERS)
  840 FORMAT (1H0,5X,20HSTART OUTPUT AT-----,1PE10.2/1H0,5X,20HSTOP OUTP
     1UT AT------,1PE10.2/1H0,5X,20HSTEP OUTPUT AT------,1PE10.2)
  850 FORMAT (1H0,5X,30HNODAL POINTS TO BE PRINTED    ,I5/1H0,5X,30HELEM
     1ENT STRESSES TO BE PRINTED,I5)
  860 FORMAT (38H0PLOT TAPE (UNIT 10) OUTPUT PARAMETERS)
  862 FORMAT (26H0UNIT 11 OUTPUT PARAMETERS)
  864 FORMAT (26H0UNIT 12 OUTPUT PARAMETERS)
  866 FORMAT(41H0RESTART DATA (UNIT 13) OUTPUT PARAMETERS)
  870 FORMAT (23H1INCREMENTING FROM N.P.,I4,3H BY,I3,22H,S WILL NOT REAC
     1HN.P.,I4)
  880 FORMAT (5H1N.P.,I4,23H IS GREATER THAN NUMNP=,I4)
  890 FORMAT (25H1ELEMENT DEFINITION CARDS,2I4,13H OUT OF ORDER)
  900 FORMAT (19H1ELEMENT DEFINITION,I4,23H IS GREATER THAN NUMEL=,I4)
  910 FORMAT (17H1ELEMENT MATERIAL,I4,24H IS GREATER THAN NUMMAT=,I4)
  920 FORMAT (23H0INCREMENTING FROM N.P.,I4,3H BY,I3,22HS WILL NOT REACH
     1  N.P.,I4)
  930 FORMAT (5H1N.P.,I4,23H IS GREATER THAN NUMNP=,I4)
  940 FORMAT(I5,5X,4F10.0)
  950 FORMAT(' STATIC ANALYSIS BY DYNAMIC ITERATION:',//,T10,
     +        'NITER=',I10,//,T10,'TOL   =',1PE10.4,//,T10,
     +        'VISC1=',E10.4,//,T10,'VISC2=',E10.4,//,T10,
     +        'VISC3=',E10.4)
  960 FORMAT('1CONCENTRATED AND PRESSURE LOADS ARE BOTH PRESCRIBED',
     +' FOR NODE',I4)
 1000 FORMAT(I5,15X,E16.7,5X,E16.7)
 1001 FORMAT(F12.6)
 1020 FORMAT(1H1//52X,18HNODAL TEMPERATURES///,
     +      4(8X,2HNP,6X,11HTEMPERATURE,3X),/)
 1030 FORMAT(4(I10,E16.4,4X))
 1040 FORMAT(1H1//47X,27HINITIAL NODAL DISPLACEMENTS///6X,2HNP,
     +        8X,6HR-DISP,10X,6HZ-DISP,10X,2HNP,8X,6HR-DISP,10X,
     +        6HZ-DISP,10X,2HNP,8X,6HR-DISP,10X,6HZ-DISP/)
C
      END
```

PROGRAM LISTING -- SAMCR (VERSION 3.0) -- RELEASED JANUARY 1 1984

```
      SUBROUTINE DATE (MMDDYY)
C
C  UNIVAC'S FORTRAN-V LIBRARY ROUTINE 'ERTRAN' WILL RETURN THE
C  DATE AND TIME.  SEE 'SAMCR.SECOND' FOR MORE DETAILS.
C
      CALL ERTRAN (9, MMDDYY, HHMMSS)
      RETURN
      END
```

PROGRAM LISTING -- SAMCR (VERSION 3.0) -- RELEASED JANUARY 1 1984

```
      SUBROUTINE DATOUT (U,V,A,SIG,EPS,IWRT)
C
C  PRINTS EDITED NODAL POINT AND ELEMENT STRESS DATA DURING
C  ANALYSIS (IWRT.EQ.0); WRITES EDITED NODAL POINT DATA
C  UNIT 12 (IWRT.EQ.1)
C
C  (SEE APPENDIX I OF SCHWARTZ ET AL. 1984 FOR DESCRIPTIONS
C   OF SUBROUTINE ARGUMENTS AND LABELED COMMON BLOCKS)
C
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON/BK1/NUMMAT,NUMNP,NUMEL,NUMPC,NUMLP,HED(16),RA,NTAPE,NEQ,
     +           MESH,IRSTRT,ITEMP
      COMMON/BK3/NDSOUT(160),NSTOUT(160),NUMDS,NUMST,
     1           TI01(5),TI02(5),TIOD(5)
      COMMON/BK10/TT,EFRAC,STRENG,HKNENG,VISENG
      DIMENSION  U(1),V(1),A(1),SIG(4,1),EPS(5,1)
      DATA NCOUNT/0/
C
C  NODAL POINT DATA
C
      IF (IWRT.EQ.0) WRITE (6,110) TT
      IF (NUMDS.EQ.NUMNP) GO TO 20
C
C  ***OUTPUT EDITED NODAL POINT DATA (NUMDS.LT.NUMNP)
      DO 10 M=1,NUMDS
      N=NDSOUT(M)
      I=2*N-1
      J=2*N
      IF (IWRT.EQ.1) GO TO 5
      WRITE (6,120) N,U(I),U(J),V(I),V(J),A(I),A(J),N
      GO TO 10
    5 NCOUNT=NCOUNT+1
      WRITE(12,150) NCOUNT,TT,N,U(I),U(J),V(I),V(J),
     +                                A(I),A(J)
  150 FORMAT(I6,E10.4,I4,6E10.4)
   10 CONTINUE
C<<<<<  PATCH FOR STRAIN OUTPUT TO UNIT 14  >>>>>
         DO 510 MM=1,NUMST
            N=NSTOUT(MM)
            WRITE(14,520) TT,N,(EPS(I,N),I=1,4)
  520       FORMAT(E12.6,I5,4E12.6)
  510    CONTINUE
C<<<<<  END PATCH  >>>>>
      GO TO 40
C
C  ***OUTPUT NODAL POINT DATA FOR ALL NODES (NUMDS.EQ.NUMNP)
   20 DO 30 N=1,NUMNP
      I=2*N-1
      J=2*N
      IF (IWRT.EQ.1) GO TO 25
```

```
      WRITE (6,120) N,U(I),U(J),V(I),V(J),A(I),A(J),N
      GO TO 30
 25   NCOUNT=NCOUNT+1
      WRITE(12,150) NCOUNT,TT,N,U(I),U(J),V(I),V(J),
     +                              A(I),A(J)
 30   CONTINUE
C
 40   IF (IWRT.EQ.1) RETURN
C
C  ELEMENT STRESS DATA
C
      WRITE (6,90)
      IF (NUMST.EQ.NUMEL) GO TO 60
C
C  ***OUTPUT EDITED ELEMENT STRESS DATA (NUMST.LT.NUMEL)
      DO 50 M=1,NUMST
      N=NSTOUT(M)
      Q1=0.5*(SIG(1,N)+SIG(2,N))
      Q2=Q1-SIG(2,N)
      Q3=SQRT(Q2*Q2+SIG(4,N)*SIG(4,N))
      SIGMAX=Q1+Q3
      SIGMIN=Q1-Q3
      TAUMAX=Q3
      ANGLE=90.0
      IF (SIGMAX.EQ.SIG(2,N)) GO TO 50
      ANGLE=57.29578*ATAN(SIG(4,N)/(SIGMAX-SIG(2,N)))
 50   WRITE (6,100) N,(SIG(I,N),I=1,4),SIGMAX,SIGMIN,ANGLE,N
      GO TO 80
C
C  ***OUTPUT ELEMENT STRESS DATA FOR ALL ELEMENTS (NUMST.EQ.NUMEL)
 60   DO 70 N=1,NUMEL
      Q1=0.5*(SIG(1,N)+SIG(2,N))
      Q2=Q1-SIG(2,N)
      Q3=SQRT(Q2*Q2+SIG(4,N)*SIG(4,N))
      SIGMAX=Q1+Q3
      SIGMIN=Q1-Q3
      TAUMAX=Q3
      ANGLE=90.0
      IF (SIGMAX.EQ.SIG(2,N)) GO TO 70
      ANGLE=57.29578*ATAN(SIG(4,N)/(SIGMAX-SIG(2,N)))
 70   WRITE (6,100) N,(SIG(I,N),I=1,4),SIGMAX,SIGMIN,ANGLE,N
 80   RETURN
C
 90   FORMAT (//10X,5HEL.NO,7X,5HSIG-R,7X,5HSIG-Z,7X,5HSIG-T,6X,6HTAU-RZ
     1,5X,7HSIG-MAX,5X,7HSIG-MIN,3X,5HANGLE,4X,5HEL.NO)
 100  FORMAT (I15,1X,6E12.4,F8.2,I8)
 110  FORMAT (//
     *        8H TIME T=E10.3/118H NODAL POINT R-DISPLACEMENT  Z-DISPLAC
     1EMENT    R-VELOCITY      Z-VELOCITY  R-ACCELERATION  Z-ACCELERATIO
     2N  NODAL POINT)
 120  FORMAT (I9,6E16.4,I9)
      END
```

PROGRAM LISTING -- SAMCR (VERSION 3.0) -- RELEASED JANUARY 1 1984

```
      SUBROUTINE ENERGY(V,MS)
C
C  CALCULATE FRACTURE AND KINETIC ENRGIES AT EACH TIME STEP
C     XJ= ENERGY RELEASE RATE (CJINT)
C     A = CRACK TIP POSITION
C     V = NODAL VELOCITIES
C     MS= INVERSE OF NODAL MASSES
C
C  (SEE APPENDIX I OF SCHWARTZ ET AL. 1984 FOR DESCRIPTIONS
C   OF LABELED COMMON BLOCKS)
C
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON/BK1/NUMMAT,NUMNP,NUMEL,NUMPC,NUMLP,HED(16),RA,NTAPE,
     +          NEQ,MESH,IRSTRT,ITEMP
      COMMON/BK6/NNN,NODENO,NN,CJINT,HK,CDOT,ADOTK(10,17,2),KK,KT,
     +          SIFRST,DXX,DX,X,NS,NSTEP,NT,NL,DYNMOD,NSRPTS,
     +          STRNRT(8),EDMULT(8),NAVG
      COMMON/BK10/TT,EFRAC,STRENG,HKNENG,VISENG
      DIMENSION XJ(2),A(2),V(1)
      REAL*8 MS(1)
C
C  **NOTE** INDEX=1 ONLY FOR FIRST CALL TO SUBROUTINE; FOR SUBSEQUENT
C            CALLS, INDEX=2
      DATA INDEX/1/
C
C  FRACTURE ENERGY
C
      XJ(INDEX)=CJINT
      A(INDEX)=X
      IF (INDEX.NE.1) GO TO 10
      INDEX=2
      RETURN
10    EFRAC=EFRAC+0.5*(XJ(2)+XJ(1))*(A(2)-A(1))
      XJ(1)=XJ(2)
      A(1)=A(2)
C
C  KINETIC ENERGY
C  (DOUBLED TO REFLECT SYMMETRY ABOUT CRACK LINE)
C
      HKNENG=0.0
      DO 1011 N=1,NUMNP
      J1 = 2*N
      J2 = 2*N-1
      HKNENG = HKNENG + (V(J1)**2+V(J2)**2)/MS(N)
 1011 CONTINUE
      RETURN
      END
```

PROGRAM LISTING -- SAMCR (VERSION 3.0) -- RELEASED JANUARY 1 1984

```
      SUBROUTINE FORCE (R,Z,IX,RO,EE,U,V,VLAST,SIG,EPS,E)
C
C  SUBPROGRAM TO CALCULATE:
C        1)  INTERNAL NODAL FORCES DUE TO ELEMENT STIFFNESS AND
C            VISCOSITY (BULK AND KEYSTONE MODE)
C        2)  NEW TIME STEP 'DT2'
C        3)  STRAIN AND DISSIPATED (VISCOUS) ENERGIES
C            ** NOTE ** ENERGIES ARE NOT DOUBLED HERE TO REFLECT
C            SYMMETRY ABOUT THE CRACK LINE; THIS IS DONE IN
C            SUBROUTINE 'ROLOUT'
C  SUBROUTINE ALGORITHMS FOR NODAL FORCES ARE DESCRIBED IN SECTIONS 2.4
C  AND 2.6 OF SCHWARTZ ET AL., 1984.  SEE APPENDIX I IN SAME REPORT FOR
C  DESCRIPTIONS OF SUBROUTINE ARGUMENTS AND LABELED COMMON BLOCKS.
C
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON/BK1/NUMMAT,NUMNP,NUMEL,NUMPC,NUMLP,HED(16),RA,NTAPE,NEQ,
     +           MESH,IRSTRT,ITEMP
      COMMON/BK2/EPZ(5),D(4),C(4,4),DF,KLIN,DT1,DT2,WRZ
      COMMON/BK5/I1,I2,I3,I4,I5,I6,I7,I8
      COMMON/BK9/RDT,B1,B2,B3
      COMMON/BK10/TT,EFRAC,STRENG,HKNENG,VISENG
      COMMON/BK11/ISTAT,NITER,TOL,VISC1,VISC2,VISC3
      COMMON/BK12/FBFB,QBQB,FKFK,QKQK
      DIMENSION  R(1),Z(1),IX(1),E(1),SIG(1),EPS(1)
      DIMENSION U(1),V(1),VLAST(1),EE(5,6)
      DIMENSION F(8),NUMEQ(8),A(4),UHG(8)
C
C  VISCOSITY COEFFICIENTS FOR STATIC ANALYSIS BY DYNAMIC ITERATION
C
      IF (ISTAT.EQ.0) GO TO 5
      B1=VISC1
      B2=VISC2
      B3=VISC3
5     CONTINUE
C
C  INITIALIZE ELEMENT GEOMETRY TERMS
C
      I=IX(1)
      J=IX(2)
      K=IX(3)
      L=IX(4)
      NUMEQ(1)=I1
      NUMEQ(2)=I2
      NUMEQ(3)=I3
      NUMEQ(4)=I4
      NUMEQ(5)=I5
      NUMEQ(6)=I6
      NUMEQ(7)=I7
      NUMEQ(8)=I8
      X12=R(I)-R(J)
      X13=R(I)-R(K)
      X14=R(I)-R(L)
      X23=R(J)-R(K)
      X24=R(J)-R(L)
      X34=R(K)-R(L)
      Y12=Z(I)-Z(J)
```

```
      Y13=Z(I)-Z(K)
      Y14=Z(I)-Z(L)
      Y23=Z(J)-Z(K)
      Y24=Z(J)-Z(L)
      Y34=Z(K)-Z(L)
      DETJ=0.125*(X13*Y24-X24*Y13)
C
C  FIND MINIMUM MESH DIMENSION
C
      Q1=X12*X12+Y12*Y12
      Q2=X23*X23+Y23*Y23
      Q3=X34*X34+Y34*Y34
      Q4=X14*X14+Y14*Y14
      Q5=X13*X13+Y13*Y13
      Q6=X24*X24+Y24*Y24
      DX=SQRT(AMIN1(Q1,Q2,Q3,Q4,Q5,Q6))
C
C  FIND SOUND SPEED
C
      Q1=C(1,1)/RO
      Q2=C(2,2)/RO
      CX=AMAX1(Q1,Q2)
      IF (CX) 10,10,20
 10   WRITE (6,60)
      CX=DT2*1.E-6
      GO TO 30
 20   CX=SQRT(CX)
 30   CONTINUE
C
C
C  EVALUATE INTERNAL NODAL FORCES USING CONVENTIONAL
C  ONE-POINT GAUSS INTEGRATION
C
C
      IF (RA.NE.0.0) GO TO 40
      WRITE(6,2000)
2000  FORMAT('0***PROGRAM STOP***  AXISYMMETRIC ANALYSIS NOT YET',
     +    ' IMPLEMENTED IN THIS VERSION OF SUBROUTINE FORCE')
      STOP
C
40    CONTINUE
      F(1)=0.5*(Y24*SIG(1)-X24*SIG(4))
      F(2)=0.5*(-X24*SIG(2)+Y24*SIG(4))
      F(3)=0.5*(-Y13*SIG(1)+X13*SIG(4))
      F(4)=0.5*(X13*SIG(2)-Y13*SIG(4))
      F(5)=0.5*(-Y24*SIG(1)+X24*SIG(4))
      F(6)=0.5*(X24*SIG(2)-Y24*SIG(4))
      F(7)=0.5*(Y13*SIG(1)-X13*SIG(4))
      F(8)=0.5*(-X13*SIG(2)+Y13*SIG(4))
C
C  ***ADD CONTRIBUTION TO NET NODAL FORCE VECTOR AND
C  ***TOTAL STRAIN ENERGY (ASSUMING ELASTIC BEHAVIOR)
      DO 44 I=1,8
         II=NUMEQ(I)
         E(II)=E(II)-F(I)
         FBFB=FBFB+F(I)*F(I)
```

```
 44     CONTINUE
        STRENG=STRENG+2.0*DETJ*(SIG(1)*EPS(1)+SIG(2)*EPS(2)+
     +         SIG(4)*EPS(4))
C
C  ARTIFICIAL BULK VISCOSITY
C
        QX=0.0
        DD=D(1)+D(2)+D(3)
        IF (DD.GT.0.0) GO TO 50
        AR=SQRT(4.0*ABS(DETJ))
        QP= (RO/DF)*AR*DD*(B1*B1*AR*ABS(DD)+B2*CX)
        FACTOR=0.5*QP
        F(1)=+Y24*FACTOR
        F(2)=-X24*FACTOR
        F(3)=-Y13*FACTOR
        F(4)=+X13*FACTOR
        F(5)=-Y24*FACTOR
        F(6)=+X24*FACTOR
        F(7)=+Y13*FACTOR
        F(8)=-X13*FACTOR
        QX=B1*B1*AR*ABS(DD)+B2*CX
C
C  ***ADD CONTRIBUTION TO NET NODAL FORCE VECTOR AND DISSIPATED ENERGY
        DO 49 I=1,8
           II=NUMEQ(I)
           E(II)=E(II)-F(I)
           QBQB=QBQB+F(I)*F(I)
           VISENG=VISENG+F(I)*0.5*(VLAST(II)+V(II))*DT1
 49     CONTINUE
 50     CONTINUE
C
C
C  CORRECTION FOR KEYSTONE DEFORMATION MODES
C  (REFERENCE:  KOSLOFF AND FRAZIER, 1978)
C
C
C  ***CALCULATE A-COEFFICIENT TERMS
        A(4)=1.0
        FACTOR=Y12/X12
        A(3)=(Y14-FACTOR*X14)/(-Y13+FACTOR*X13)
        A(2)=-X14/X12-X13/X12*A(3)
        A(1)=-1.0-A(2)-A(3)
        ALNGTH=0.0
        DO 42 II=1,4
 42     ALNGTH=ALNGTH+A(II)*A(II)
        FACTOR=2.0/SQRT(ALNGTH)
        DO 43 II=1,4
 43     A(II)=FACTOR*A(II)
C
C  ***CALCULATE C-COEFFICIENTS (CO-ORDINATE DERIVATIVES)
        C1= (Y14+Y23)**2 + (Y34-Y12)**2
        C2= (X14+X23)**2 + (X34-X12)**2
        C3= -((Y14+Y23)*(X14+X23) + (Y34-Y12)*(X34-X12))
C
C  ***COMPUTE KEYSTONE MODE DEFORMATIONS AND NODAL FORCES
        EMOD=EE(1,1)
```

```
      IF (RA.LT.0.0) EMOD=EMOD/(1.0-EE(1,2)**2)
      FACTOR= EMOD/(192.0*DETJ)
      DO 46 I=1,8
      UHG(I)=0.0
46    F(I)=0.0
      DO 45 KROW=1,4
         L1=KROW*2-1
         L2=KROW*2
         DO 45 KCOL=1,4
            J1=NUMEQ(KCOL*2-1)
            J2=NUMEQ(KCOL*2)
            AA=A(KROW)*A(KCOL)
            UHG(L1)=UHG(L1)+0.25*AA*U(J1)
            UHG(L2)=UHG(L2)+0.25*AA*U(J2)
            F(L1)=F(L1)+FACTOR*AA*(C1*U(J1)+C3*U(J2))
            F(L2)=F(L2)+FACTOR*AA*(C3*U(J1)+C2*U(J2))
45    CONTINUE
C
C  ***ADD CONTRIBUTION TO NET NODAL FORCE VECTOR AND TO
C  ***TOTAL STRAIN ENERGY (ASSUMING LINEARLY ELASTIC BEHAVIOR)
      DO 47 I=1,8
         II=NUMEQ(I)
         E(II)=E(II)-F(I)
         FKFK=FKFK+F(I)*F(I)
         STRENG=STRENG+0.5*F(I)*UHG(I)
47    CONTINUE
C
C  ARTIFICIAL KEYSTONE MODE VISCOSITY
C
      FACTOR=RO*DX*B3*CX
      DO 70 I=1,8
70    F(I)=0.0
      DO 71 KROW=1,4
         L1=KROW*2-1
         L2=KROW*2
         DO 72 KCOL=1,4
            J1=NUMEQ(KCOL*2-1)
            J2=NUMEQ(KCOL*2)
            AA=A(KROW)*A(KCOL)
            F(L1)=F(L1)+FACTOR*AA*(C1*V(J1)+C3*V(J2))
            F(L2)=F(L2)+FACTOR*AA*(C3*V(J1)+C2*V(J2))
72       CONTINUE
71    CONTINUE
C
C  ***ADD CONTRIBUTION TO NET NODAL FORCE VECTOR AND DISSIPATED ENERGY
      DO 73 I=1,8
         II=NUMEQ(I)
         E(II)=E(II)-F(I)
         QKQK=QKQK+F(I)*F(I)
         VISENG=VISENG+F(I)*0.5*(VLAST(II)+V(II))*DT1
73    CONTINUE
C
C  FIND CRITICAL TIME STEP
C
      DTX=RDT*0.9*DX/(QX+SQRT(QX*QX+CX*CX))
      DT2=AMIN1(DT2,DTX)
```

```
C
      RETURN
C
   60 FORMAT (30X,37HSOUND SPEED IMAGINARY,  C**2 NEGATIVE)
      END
```

```
      SUBROUTINE INTPL(NPTS,XARRAY,YARRAY,X,Y)
C
C  GENERAL INTERPOLATION SUBROUTINE FOR DATA STORED IN
C  'YARRAY' VS. 'XARRAY'.  DATA MUST BE STORED IN ASCENDING ORDER
C  IN 'XARRAY'
C
      IMPLICIT REAL*8 (A-H,O-Z)
C
      DIMENSION XARRAY(1),YARRAY(1)
C
      IF (X.GT.XARRAY(1)) GO TO 10
        Y=YARRAY(1)
        RETURN
   10 IF (X.LT.XARRAY(NPTS)) GO TO 20
        Y=YARRAY(NPTS)
        RETURN
   20 I=2
   25 IF (X.LE.XARRAY(I)) GO TO 30
        I=I+1
        GO TO 25
   30 Y=YARRAY(I-1)+(YARRAY(I)-YARRAY(I-1))*(X-XARRAY(I-1))/
     +                                       (XARRAY(I)-XARRAY(I-1))
      RETURN
C
      END
```

```
      SUBROUTINE INTSTR(U,TEMP,R,Z,IX,EPS,EE)
C
C  COMPUTES INITIAL ELASTIC STRAINS FOR EACH ELEMENT AT FIRST
C  TIME STEP IN ANALYSIS
C
C  (SEE APPENDIX I OF SCHWARTZ ET AL. 1984 FOR DESCRIPTIONS
C   OF SUBROUTINE ARGUMENTS AND LABELED COMMON BLOCKS)
C
C  ELEMENT STRAINS ARE STORED IN 'EPS' IN THE FOLLOWING SEQUENCE:
C        EPS(1) = EPSRR = DU/DR
C        EPS(2) = EPSZZ = DW/DZ
C        EPS(3) = EPSTHETA = U/R
C        EPS(4) = GAMMARZ = DU/DZ + DW/DR
C        EPS(5) = DW/DR (REQUIRED FOR J-INTEGRAL CALCULATION
C
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON/BK1/NUMMAT,NUMNP,NUMEL,NUMPC,NUMLP,HED(16),RA,NTAPE,NEQ,
     +           MESH,IRSTRT,ITEMP
      COMMON/BK5/I1,I2,I3,I4,I5,I6,I7,I8
      DIMENSION U(1),TEMP(1),R(1),Z(1),IX(1),EPS(1),EE(5,6)
      I=IX(1)
      J=IX(2)
      K=IX(3)
      L=IX(4)
      R13=R(I)-R(K)
      R24=R(J)-R(L)
      Z13=Z(I)-Z(K)
      Z24=Z(J)-Z(L)
      VOL=1.0/(R13*Z24-Z13*R24)
      RM=1.0/(R(I)+R(J)+R(K)+R(L))
      Y1=Z24*VOL
      Y2=-Z13*VOL
      Y3=-Y1
      Y4=-Y2
      X1=-R24*VOL
      X2=R13*VOL
      X3=-X1
      X4=-X2
      VX1=U(I1)
      VX2=U(I2)
      VX3=U(I3)
      VX4=U(I4)
      VX5=U(I5)
      VX6=U(I6)
      VX7=U(I7)
      VX8=U(I8)
      ALPHA=EE(1,3)
      REFTMP=EE(1,4)
      TC=0.0
      IF (ITEMP.NE.0) TC=0.25*(TEMP(I)+TEMP(J)+TEMP(K)+TEMP(L))
```

```
     +                     - REFTMP
      EPS(1)=Y1*VX1+Y2*VX3+Y3*VX5+Y4*VX7 - ALPHA*TC
      EPS(2)=X1*VX2+X2*VX4+X3*VX6+X4*VX8 - ALPHA*TC
      IF(RA.EQ.0.0)GO TO 10
      IF(RA.GT.0.0)GO TO 30
      EPS(3)= -ALPHA*TC
      GO TO 20
   30 EPS(3)=(-EE(1,2)*EPS(1)-EE(1,2)*EPS(2))/(1.-EE(1,2))
      GO TO 20
   10 EPS(3)=RM*(VX1+VX3+VX5+VX7) - ALPHA*TC
   20 EPS(4)=X1*VX1+Y1*VX2+X2*VX3+Y2*VX4
     1+X3*VX5+Y3*VX6+X4*VX7+Y4*VX8
      EPS(5)=Y1*VX2+Y2*VX4+Y3*VX6+Y4*VX8
      RETURN
      END
```

```
      SUBROUTINE INVEL(TEMP,R,CODE,IX)
C
C  COMPUTES INITIAL CRACK TIP VELOCITY AT FIRST TIME STEP IN ANALYSIS
C
C  (SEE APPENDIX I OF SCHWARTZ ET AL. 1984 FOR DESCRIPTIONS
C   OF SUBROUTINE ARGUMENTS AND LABELED COMMON BLOCKS)
C
C  FRACTURE CONSTITUTIVE DATA ARE STORED IN 'ADOTK(L,M,N)' USING
C  THE FOLLOWING SCHEME:
C       ADOTK(L,1,1) = TEMPERATURE FOR CURVE L
C       ADOTK(L,I,1) = STRESS INTENSITY VALUE FOR POINT I ON CURVE L
C       ADOTK(L,I,2) = CRACK TIP VELOCITY FOR POINT I ON CURVE L
C  DATA ARE STORED IN ASCENDING ORDER IN 'ADOTK'
C
      IMPLICIT REAL*8 (A-H,O-Z)
C
      COMMON/BK1/NUMMAT,NUMNP,NUMEL,NUMPC,NUMLP,HED(16),RA,NTAPE,NEQ,
     +           MESH,IRSTRT,ITEMP
      COMMON/BK6/NNN,NODENO,NN,CJINT,HK,CDOT,ADOTK(10,17,2),KK,KT,
     +           SIFRST,DXX,DX,X,NS,NSTEP,NT,NL,DYNMOD,NSRPTS,
     +           STRNRT(8),EDMULT(8),NAVG
      COMMON/BK10/TT,EFRAC,STRENG,HKNENG,VISENG
      DIMENSION TEMP(1),R(1),CODE(1),IX(1)
      DIMENSION ADOT(16),SIF(16)
C
      IF(CJINT)100,10,10
C
C  ADJUST REFERENCE DYNAMIC MODULUS FOR STRAIN RATE EFFECTS
C
   10 EPSDOT=0.0
      FACTOR=1.0
      IF (NSRPTS.GT.0) CALL INTPL(NSRPTS,STRNRT,EDMULT,EPSDOT,FACTOR)
      EDYN=DYNMOD*FACTOR
C
C  COMPUTE STRESS INTENSITY FACTOR
C
      HK=SQRT(EDYN*CJINT)
      GO TO 20
  100 WRITE(6,1000) TT,CJINT
1000  FORMAT(////,' *** AT TIME=',1PE11.5,' THE J-INTEGRAL IS',
     +       ' NEGATIVE AND EQUAL TO',1PE12.5,/,' THE STRESS INTENSITY'
     +       ' FACTOR K HAS BEEN ARBITRARILY SET TO ZERO',/)
      HK=0.0
C
C  COMPUTE CRACK TIP VELOCITY
C
   20 IF (ITEMP.NE.0) GO TO 30
C
C  ***NONTHERMAL CASE
      DO 25 I=2,KK
```

```
         SIF(I-1)=ADOTK(1,I,1)
         ADOT(I-1)=ADOTK(1,I,2)
   25 CONTINUE
      CALL INTPL(KK-1,SIF,ADOT,HK,CDOT)
      IF (CDOT.GT.0.0) GO TO 500
      RETURN
C
C  ***THERMAL CASE
   30 I=IX(1)
      J=IX(2)
      DELTA=R(J)-R(I)
      TC=TEMP(I)+(DXX/DELTA)*(TEMP(J)-TEMP(I))
      IF (TC.GT.ADOTK(1,1,1)) GO TO 32
         IT=1
         JT=1
         GO TO 50
   32 IF (TC.LT.ADOTK(KT,1,1)) GO TO 35
         IT=KT
         JT=KT
         GO TO 50
   35 DO 40 JT=2,KT
         IT=JT-1
         IF (TC.GT.ADOTK(IT,1,1).AND.TC.LT.ADOTK(JT,1,1)) GO TO 50
   40 CONTINUE
C
   50 DO 55 I=2,KK
         SIF(I-1)=ADOTK(IT,I,1)
         ADOT(I-1)=ADOTK(IT,I,2)
   55 CONTINUE
      CALL INTPL(KK-1,SIF,ADOT,HK,CDOTI)
      DO 60 I=2,KK
         SIF(I-1)=ADOTK(JT,I,1)
         ADOT(I-1)=ADOTK(JT,I,2)
   60 CONTINUE
      CALL INTPL(KK-1,SIF,ADOT,HK,CDOTJ)
      CDOT=CDOTI+(CDOTJ-CDOTI)*(TC-ADOTK(IT,1,1))/
     +     (ADOTK(JT,1,1)-ADOTK(IT,1,1))
      IF (CDOT.GT.0.0) GO TO 500
      RETURN
C
C  MODIFY BOUNDARY CONDITION CODE FOR RELEASED NODE
C
  500 J=IX(1)
      CODE(J)=0.0
      RETURN
      END
```

```
      SUBROUTINE JINTGL(IX,R,Z,EE,RO,V,SIG,EPS)
C
C  EVALUATES J-INTEGRAL, INCLUDING EFFECTS OF KINETIC ENERGY TERMS, AT
C  EACH TIME STEP OF THE ANALYSIS, USING ALGORITHM FROM SECTION 2.8.2
C  IN SCHWARTZ ET AL., 1984.  (SEE APPENDIX I IN SAME REPORT FOR
C  DESCRIPTIONS OF SUBROUTINE ARGUMENTS AND LABELED COMMON BLOCKS.)
C
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON/BK6/NNN,NODENO,NN,CJINT,HK,CDOT,ADOTK(10,17,2),KK,KT,
     +          SIFRST,DXX,DX,X,NS,NSTEP,NT,NL,DYNMOD,NSRPTS,
     +          STRNRT(8),EDMULT(8),NAVG
      DIMENSION IX(5,1),R(1),Z(1),EE(5,6,1),RO(1),SIG(4,1),EPS(5,1)
                  DIMENSION V(1)
C
C  CONTOUR INTEGRAL OF STRAIN, KINETIC ENERGY DENSITIES AND TRACTIONS
C
      DO 410 JCNTUR=1,2
C
C  ***VERTICAL LEG AHEAD OF CRACK TIP
      N=(NODENO+JCNTUR-1)+NNN
      IF (N.GT.NN) GO TO 450
      II=1
      CJ1=0.0
  205 I2=IX(1,N)+IX(1,N)
      I1=I2-1
      I4=IX(2,N)+IX(2,N)
      I3=I4-1
      I6=IX(3,N)+IX(3,N)
      I5=I6-1
      I8=IX(4,N)+IX(4,N)
      I7=I8-1
      MX=IX(5,N)
      J=IX(2,N)
      K=IX(3,N)
      HY=ABS(Z(J)-Z(K))
      UDOT=(V(I1)+V(I3)+V(I5)+V(I7))/4.0
      VDOT=(V(I2)+V(I4)+V(I6)+V(I8))/4.0
      C1=SIG(1,N)+SIG(2,N)
      C2=(C1*C1)/EE(1,1,MX)
      C3=2.*(1.+EE(1,2,MX))*(SIG(4,N)*SIG(4,N)-SIG(1,N)*SIG(2,N))/
     1EE(1,1,MX)
      C4=-2.*SIG(1,N)*EPS(1,N)-2.*SIG(4,N)*EPS(5,N)
      C5=RO(MX)*(UDOT*UDOT+VDOT*VDOT)
      DCJ1=(C2+C3+C4+C5)*HY
      IF(II.EQ.NT)GO TO 210
      CJ1=CJ1+DCJ1
      II=II+1
      N=N+NN
      GO TO 205
C
```

```
C  ***HORIZONTAL LEG ABOVE CRACK
  210 CJ1=CJ1+DCJ1/2.
      CJ2=0.0
      NN1=NL+NNN
      DO 220 II=1,NN1
      I=IX(1,N)
      J=IX(2,N)
      HX=ABS(R(I)-R(J))
      DCJ2=2.*(SIG(2,N)*EPS(5,N)+SIG(4,N)*EPS(1,N))*HX
      DCJ2=-DCJ2
      IF(II.EQ.1) DCJ2=DCJ2/2.
      IF(II.EQ.NN1) GO TO 230
      CJ2=CJ2+DCJ2
      N=N-1
  220 CONTINUE
C
C  ***VERTICAL LEG BEHIND CRACK TIP
  230 CJ2=CJ2+DCJ2/2.
      CJ3=0.0
      II=1
  260 I2=IX(1,N)+IX(1,N)
      I1=I2-1
      I4=IX(2,N)+IX(2,N)
      I3=I4-1
      I6=IX(3,N)+IX(3,N)
      I5=I6-1
      I8=IX(4,N)+IX(4,N)
      I7=I8-1
      MX=IX(5,N)
      J=IX(2,N)
      K=IX(3,N)
      HY=ABS(Z(J)-Z(K))
      VDOT=(V(I1)+V(I3)+V(I5)+V(I7))/4.0
      UDOT=(V(I2)+V(I4)+V(I6)+V(I8))/4.0
      C1=SIG(1,N)+SIG(2,N)
      C2=(C1*C1)/EE(1,1,MX)
      C3=2.*(1.+EE(1,2,MX))*(SIG(4,N)*SIG(4,N)-SIG(1,N)*SIG(2,N))/
     1EE(1,1,MX)
      C4=-2.*SIG(1,N)*EPS(1,N)-2.*SIG(4,N)*EPS(5,N)
      C5=RO(MX)*(UDOT*UDOT+VDOT*VDOT)
      DCJ3=(C2+C3+C4+C5)*HY
      DCJ3=-DCJ3
      IF(II.EQ.NT)GO TO 250
      IF(II.EQ.1) DCJ3=DCJ3/2.
      CJ3=CJ3+DCJ3
      II=II+1
      N=N-NN
      GO TO 260
  250 CJ3=CJ3+DCJ3
C
```

```
C
      CJINT2=CJ1+CJ2+CJ3
      IF (JCNTUR.EQ.1) CJINT1=CJINT2
C
  410 CONTINUE
C
C  INTERPOLATE BETWEEN TWO J-INTEGRAL CONTOURS BASED
C  ON CURRENT CRACK TIP POSITION
C
      N=NODENO+1
      I=IX(1,N)
      J=IX(2,N)
      DELTA=R(J)-R(I)
      CJINT=CJINT1 + (DXX/DELTA)*(CJINT2-CJINT1)
      RETURN
C
C  ERROR CONDITION--CONTOUR REACHES END OF SPECIMEN
C
  450 WRITE(6,1000)
 1000 FORMAT(///,'*** PROGRAM STOP ***   J-INTEGRAL CONTOUR HAS',
     +        ' REACHED END OF SPECIMEN')
      STOP
      END
```

```
      SUBROUTINE LOAD (R,Z,INI,JNJ,PI,PJ,T,P,TT,B,ELOAD)
C
C  ASSEMBLES SYSTEM APPLIED LOAD VECTOR AT EACH TIME STEP USING
C  ALGORITHM FROM SECTION 2.7 OF SCHWARTZ ET AL., 1984
C
C  (SEE APPENDIX I OF SAME REPORT FOR DESCRIPTIONS OF
C   SUBROUTINE ARGUMENTS AND LABELED COMMON BLOCKS)
C
      IMPLICIT REAL*8 (A-H,O-Z)
C
      COMMON/BK1/NUMMAT,NUMNP,NUMEL,NUMPC,NUMLP,HED(16),RA,NTAPE,NEQ,
     +           MESH,IRSTRT,ITEMP
      DIMENSION  R(1),Z(1),INI(1),JNJ(1),PI(1),PJ(1),T(1),P(2,1),B(1)
      DIMENSION  ELOAD(1)
C
C  APPLY CONCENTRATED NODAL LOADS
C
      DO 10 I=1,NEQ
   10 B(I)=ELOAD(I)
C
C  APPLY PRESSURE LOAD
C
      IF (NUMPC.EQ.0) RETURN
      DO 40 N=1,NUMPC
      TAU=TT-T(N)
      IF (TAU.LT.0.0) GO TO 40
      IF (TAU-P(1,NUMLP).GT.0.0) GO TO 40
      DO 20 M=2,NUMLP
      IF (TAU-P(1,M).LE.0.0) GO TO 30
   20 CONTINUE
      RETURN
C
   30 DT=TAU-P(1,M-1)
      D1=P(1,M)-P(1,M-1)
      D2=P(2,M)-P(2,M-1)
      F=P(2,M-1)+DT*D2/D1
      I=INI(N)
      J=JNJ(N)
      DR=(R(J)-R(I))/12.0
      DZ=(Z(I)-Z(J))/12.0
      Q1=PI(N)
      Q2=PJ(N)
      IF(RA.EQ.0.0) GO TO 50
C  ***PLANE STRESS/STRAIN
      RX=4.0*Q1+2.0*Q2
      ZX=2.0*Q1+4.0*Q2
      GO TO 60
C  ***AXISYMMETRIC (OPTION NOT FULLY IMPLEMENTED IN CURRENT
C  ***VERSION OF SAMCR)
   50 RX=Q1*(3.0*R(I)+R(J))+Q2*(R(I)+R(J))
```

```
      ZX=Q1*(R(I)+R(J))+Q2*(R(I)+3.0*R(J))
C
   60 I=I+I
      II=I-1
      J=J+J
      JJ=J-1
      B(II)=B(II)+F*RX*DZ
      B(JJ)=B(JJ)+F*ZX*DZ
      B(I)=B(I)+F*RX*DR
      B(J)=B(J)+F*ZX*DR
   40 CONTINUE
      RETURN
C
      END
```

```
      SUBROUTINE MASS (R,Z,IX,RO,MS)
C
C  ASSEMBLES DIAGONAL (LUMPED MASS) SYSTEM MASS MATRIX AT BEGINNING
C  OF ANALYSIS, USING ALGORITHM FROM SECTION 2.5 OF SCHWARTZ ET AL., 198
C
C  (SEE APPENDIX I IN SAME REPORT FOR DESCRIPTIONS OF SUBROUTINE
C   ARGUMENTS AND LABELED COMMON BLOCKS)
C
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION  R(1),Z(1),IX(1),MS(1),ELMASS(4)
      COMMON/BK1/NUMMAT,NUMNP,NUMEL,NUMPC,NUMLP,HED(16),RA,NTAPE,NEQ,
     +           MESH,IRSTRT,ITEMP
      REAL*8     MS
C
      I=IX(1)
      J=IX(2)
      K=IX(3)
      L=IX(4)
      XC=0.25*(R(I)+R(J)+R(K)+R(L))
      RM=8.*XC
      R12=R(I)-R(J)
      R13=R(I)-R(K)
      R14=R(I)-R(L)
      R23=R(J)-R(K)
      R24=R(J)-R(L)
      R34=R(K)-R(L)
      Z12=Z(I)-Z(J)
      Z13=Z(I)-Z(K)
      Z14=Z(I)-Z(L)
      Z23=Z(J)-Z(K)
      Z24=Z(J)-Z(L)
      Z34=Z(K)-Z(L)
      ROM=RO/72.0
      AR=(R13*Z24-Z13*R24)*ROM
      BR=(R34*Z12-Z34*R12)*ROM
      CR=(R23*Z14-Z23*R14)*ROM
      IF(RA.EQ.0.0) GO TO 20
C  ***PLANE STRESS/STRAIN
      ELMASS(1)=9.0*AR-3.0*BR-3.0*CR
      ELMASS(2)=9.0*AR+3.0*BR-3.0*CR
      ELMASS(3)=9.0*AR+3.0*BR+3.0*CR
      ELMASS(4)=9.0*AR-3.0*BR+3.0*CR
      GO TO 30
C  ***AXISYMMETRIX (OPTION NOT FULLY IMPLEMENTED IN
C  ***CURRENT VERSION OF SAMCR)
   20 ELMASS(1)=AR*(RM+R13+R(I))-BR*(R(I)+R(I)+R(L))-CR*(R(I)+R(I)+R(J))
      ELMASS(2)=AR*(RM+R24+R(J))+BR*(R(J)+R(J)+R(K))-CR*(R(I)+R(J)+R(J))
      ELMASS(3)=AR*(RM+R(K)-R13)+BR*(R(J)+R(K)+R(K))+CR*(R(K)+R(K)+R(L))
      ELMASS(4)=AR*(RM+R(L)-R24)-BR*(R(I)+R(L)+R(L))+CR*(R(K)+R(L)+R(L))
C
   30 CONTINUE
      DO 10 M=1,4
      MX=IX(M)
 10   MS(MX)=MS(MX)+ABS(ELMASS(M))
C
      RETURN
      END
```

```
      SUBROUTINE NEWUV(A,ULAST,VLAST,U,V)
C
C  UPDATES DISPLACEMENTS, VELOCITIES USING EXPLICIT FORWARD AND BACKWARD
C  DIFFERENCE FORMULAE, BASED ON ALGORITHM FROM SECTION 2.9 OF
C  SCHWARTZ ET AL., 1984.  SEE APPENDIX I IN SAME REPORT FOR
C  DESCRIPTIONS OF SUBROUTINE ARGUMENTS AND LABELED COMMON BLOCKS.
C
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON/BK1/NUMMAT,NUMNP,NUMEL,NUMPC,NUMLP,HED(16),RA,NTAPE,
     +           NEQ,MESH,IRSTRT,ITEMP
      COMMON/BK2/EPZ(5),D(4),C(4,4),DF,KLIN,DT1,DT2,WRZ
      COMMON/BK6/NNN,NODENO,NN,CJINT,HK,CDOT,ADOTK(10,17,2),KK,KT,
     +           SIFRST,DXX,DX,X,NS,NSTEP,NT,NL,DYNMOD,NSRPTS,
     +           STRNRT(8),EDMULT(8),NAVG
      DIMENSION A(1),ULAST(1),VLAST(1),U(1),V(1)
C
      DO 10 I=1,NEQ
         VLAST(I)=V(I)
         V(I)=VLAST(I)+A(I)*DT2
         ULAST(I)=U(I)
         U(I)=ULAST(I)+0.5*(VLAST(I)+V(I))*DT2
   10    CONTINUE
      RETURN
      END
```

```
      SUBROUTINE ROLIN(IERROR)
C
C  READS CRACK INPUT DATA (NON-RESTART ANALYSIS) FROM CARD IMAGE FILE
C  ON UNIT 'NTAPE'; PRINTS SUMMARY OF CRACK INPUT DATA
C
C  (SEE APPENDIX I IN SCHWARTZ ET AL. 1984 FOR DESCRIPTIONS OF
C   SUBROUTINE ARGUMENTS AND LABELED COMMON BLOCKS)
C
      IMPLICIT REAL*8 (A-H,O-Z)
C
      COMMON/BK1/NUMMAT,NUMNP,NUMEL,NUMPC,NUMLP,HED(16),RA,NTAPE,
     +          NEQ,MESH,IRSTRT,ITEMP
      COMMON/BK6/NNN,NODENO,NN,CJINT,HK,CDOT,ADOTK(10,17,2),KK,KT,
     +          SIFRST,DXX,DX,X,NS,NSTEP,NT,NL,DYNMOD,NSRPTS,
     +          STRNRT(8),EDMULT(8),NAVG
      COMMON/BK8/BETA1
      COMMON/BK9/RDT,B1,B2,B3
C
C
C  READ CRACK DATA AND SET DEFAULT VALUES, IF REQUIRED
C
      READ(NTAPE,1000) NSTEP,RDT,B1,B2,B3
         IF (RDT.LE.0.0) RDT=1.0
         IF (NSTEP.LE.0) GO TO 900
         IF (B1.LE.0.0) B1=1.2E1
         IF (B2.LE.0.0) B2=0.06E1
         IF (B3.LE.0.0) B3=0.01E1
      READ(NTAPE,1010) X,NODENO,NNN,NT,NL,NN
         IF (NODENO.LE.0) GO TO 910
         IF (NNN.LE.0) NNN=3
         IF (NT.LE.0) NT=2
         IF (NL.LE.0) NL=6
         IF (NN.LE.0) GO TO 920
      READ(NTAPE,1020) DYNMOD,NSRPTS
         IF (NSRPTS.GT.8) GO TO 970
         IF (NSRPTS.EQ.0) GO TO 10
            READ(NTAPE,1025) (STRNRT(I),I=1,NSRPTS)
            READ(NTAPE,1025) (EDMULT(I),I=1,NSRPTS)
   10    CONTINUE
      READ(NTAPE,1030) KK,KT,NAVG,SIFRST
         IF (KK.LT.1) GO TO 930
         IF (KK.GT.16) GO TO 940
         IF (KT.LE.0) KT=1
         IF (KT.GT.10) GO TO 950
         IF (NAVG.LE.0) NAVG=1
         IF (NAVG.GT.50) GO TO 980
         IF (SIFRST.LE.0.0) SIFRST=1.0
      KK=KK+1
      DO 20 I=1,KT
         READ(NTAPE,1040) ADOTK(I,1,1)
```

```
         READ(NTAPE,1025) (ADOTK(I,J,1),J=2,KK)
         READ(NTAPE,1025) (ADOTK(I,J,2),J=2,KK)
   20 CONTINUE
C
C  INITIALIZE REMAINING CRACK DATA
C
      NS=0
      DXX=0.0
      DX=0.0
C
C  PRINT CRACK INPUT DATA SUMMARY
C
      WRITE(6,2000)
      WRITE(6,2010) NSTEP,RDT
      WRITE(6,2020) B1,B2,B3
      WRITE(6,2030) X,NODENO
      WRITE(6,2040) NNN,NT,NL,NN
      WRITE(6,2050) DYNMOD
      IF (NSRPTS.EQ.0) GO TO 30
         WRITE(6,2060) (STRNRT(I),I=1,NSRPTS)
         WRITE(6,2070) (EDMULT(I),I=1,NSRPTS)
   30 WRITE(6,2080) NAVG,SIFRST
      WRITE(6,2085)
      DO 40 I=1,KT
         WRITE(6,2090) ADOTK(I,1,1)
         WRITE(6,2100) (ADOTK(I,J,1),J=2,KK)
         WRITE(6,2110) (ADOTK(I,J,2),J=2,KK)
   40 CONTINUE
      RETURN
C
C  ERROR EXITS
C
  900 WRITE(6,3000)
      GO TO 999
  910 WRITE(6,3010)
      GO TO 999
  920 WRITE(6,3020)
      GO TO 999
  930 WRITE(6,3030)
      GO TO 999
  940 WRITE(6,3040)
      GO TO 999
  950 WRITE(6,3050)
      GO TO 999
  970 WRITE(6,3070)
      GO TO 999
  980 WRITE(6,3080)
  999 IERROR=0
      RETURN
C
```

```
C
 1000 FORMAT(I5,4F10.0)
 1010 FORMAT(F10.0,5I5)
 1020 FORMAT(F15.0,I5)
 1025 FORMAT(8F10.0)
 1030 FORMAT(3I5,F10.0)
 1040 FORMAT(F10.0)
 2000 FORMAT(1H1,//,T45,'DYNAMIC FRACTURE ANALYSIS DATA',////)
 2010 FORMAT(1H0,T10,'NUMBER OF TIME STEPS (NSTEP)',T60,I10,//,
     +       T10,'TIME STEP ADJUSTMENT FACTOR (RDT)',T60,F10.6)
 2020 FORMAT(//,T10,'DYNAMIC VISCOSITY COEFFICIENTS:',//,
     +       T24,'B1',1PE15.5,//,T24,'B2',E15.5,//,T24,'B3',E15.5)
 2030 FORMAT(//,T10,'INITIAL CRACK TIP LOCATION:',//,T25,'X',F10.4,
     +       //,T20,'NODENO',I10)
 2040 FORMAT(//,T10,'J-INTEGRAL CONTOUR GEOMETRY:',//,T23,'NNN',I5,
     +       //,T24,'NT',I5,//,T24,'NL',I5,//,T24,'NN',I5)
 2050 FORMAT(//,T10,'REFERENCE DYNAMIC MODULUS (DYNMOD)',T55,1PE15.5)
 2060 FORMAT(//,T10,'STRAIN RATE CORRECTION FOR DYNMOD:',//,T12,
     +       'STRNRT',8E12.5)
 2070 FORMAT(/,T12,'EDMULT',8E12.5)
 2080 FORMAT(//,T10,'NUMBER OF TIME STEPS FOR K-SMOOTHING (NAVG)',
     +       T60,I10,///,T10,
     +       'REINITIATION STRESS INTENSITY MULTIPLIER (SIFRST)',
     +       T60,F10.6)
 2085 FORMAT(1H1,T10,'TEMPERATURE VS. ADOT VS. K DATA:')
 2090 FORMAT(//,T12,'TEMP:',E12.5)
 2100 FORMAT(/,T12,'   K:',8E12.5,/,T17,8E12.5)
 2110 FORMAT(/,T12,'ADOT:',8E12.5,/,T17,8E12.5)
 3000 FORMAT('1INPUT ERROR--NSTEP.LE.0')
 3010 FORMAT('1INPUT ERROR--NODENO.LE.0')
 3020 FORMAT('1INPUT ERROR--NN.LE.0')
 3030 FORMAT('1INPUT ERROR--KK.LT.1')
 3040 FORMAT('1INPUT ERROR--KK.GT.16')
 3050 FORMAT('1INPUT ERROR--KT.GT.10')
 3070 FORMAT('1INPUT ERROR--NSRPTS.GT.8')
 3080 FORMAT('1INPUT ERROR--NAVG.GT.50')
C
      END
```

PROGRAM LISTING -- SAMCR (VERSION 3.0) -- RELEASED JANUARY 1 1984

```
      SUBROUTINE ROLOUT(IWRT)
C
C  PRINTS CRACK AND ENERGY DATA DURING ANALYSIS (IWRT.EQ.0);
C  WRITES SAME INFORMATION TO UNIT 11 (IWRT.EQ.1)
C
C  (SEE APPENDIX I OF SCHWARTZ ET AL. 1984 FOR DESCRIPTIONS
C   OF LABELED COMMON BLOCKS)
C
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON/BK6/NNN,NODENO,NN,CJINT,HK,CDOT,ADOTK(10,17,2),KK,KT,
     +           SIFRST,DXX,DX,X,NS,NSTEP,NT,NL,DYNMOD,NSRPTS,
     +           STRNRT(8),EDMULT(8),NAVG
      COMMON/BK7/E0,F0,DDX,NBETA
      COMMON/BK10/TT,EFRAC,STRENG,HKNENG,VISENG
C
      STREN2=2.0*STRENG
      VISEN2=2.0*VISENG
      TOTENG = EFRAC+STREN2+HKNENG+VISEN2
      IF (IWRT.EQ.0) WRITE(6,200) X,CDOT,CJINT,HK,E0,F0,DDX,NBETA,EFRAC,
     +             STREN2,HKNENG,VISEN2,TOTENG
C
      IF (IWRT.EQ.1)
     +   WRITE(11,300) TT,X,CDOT,CJINT,HK,E0,F0,DDX,EFRAC,STREN2,HKNENG,
     +                 VISEN2,TOTENG
C
      RETURN
C
200   FORMAT(//,' X=',E12.6,' CDOT=',E12.6,' CJINT=',E12.6,' HK=',E12.6,
     +       ' E0=',E12.6,' F0=',E12.6,' DDX=',E12.6,' NBETA=',I2,//,
     +       ' ENERGIES:  FRACTURE=',E12.6,' STRAIN=',E12.6,
     +       ' KINETIC=',E12.6,
     +       ' DISSIPATED=',E12.6,' TOTAL=',E12.6)
300   FORMAT(13E10.4)
C
      END
```

PROGRAM LISTING -- SAMCR (VERSION 3.0) -- RELEASED JANUARY 1 1984

```
      SUBROUTINE RSTIN(NDUMP,IFLAG,IERROR)
C
C  READS ANALYSIS RESTART INFORMATION FROM UNIT 14 IN TWO PASSES:
C     IFLAG=0 ==> READ LABELED COMMON BLOCK ANALYSIS CONTROL DATA
C     IFLAG=1 ==> READ ARRAY DATA
C  'IERROR' IS SET TO 0 IF A READ ERROR IS ENCOUNTERED ON UNIT 14
C
C  SUPPLEMENTARY RESTART INFORMATION IS READ FROM UNIT 'NTAPE'
C
C  (SEE APPENDIX I IN SCHWARTZ ET AL. 1984 FOR DESCRIPTIONS
C   OF SUBROUTINE ARGUMENTS AND LABELED COMMON BLOCKS)
C
      IMPLICIT REAL*8 (A-H,O-Z)
C
      COMMON/BK1/NUMMAT,NUMNP,NUMEL,NUMPC,NUMLP,HED(16),RA,NTAPE,NEQ,
     +          MESH,IRSTRT,ITEMP
      COMMON/BK2/EPZ(5),D(4),C(4,4),DF,KLIN,DT1,DT2,WRZ
      COMMON/BK3/NDSOUT(160),NSTOUT(160),NUMDS,NUMST,
     +          TIO1(5),TIO2(5),TIOD(5)
      COMMON/BK6/NNN,NODENO,NN,CJINT,HK,CDOT,ADOTK(10,17,2),KK,KT,
     +          SIFRST,DXX,DX,X,NS,NSTEP,NT,NL,DYNMOD,NSRPTS,
     +          STRNRT(8),EDMULT(8),NAVG
      COMMON/BK7/EO,FO,DDX,NBETA
      COMMON/BK8/BETA1
      COMMON/BK9/RDT,B1,B2,B3
      COMMON/BK10/TT,EFRAC,STRENG,HKNENG,VISENG
      COMMON/BK13/ITWO,NDIMA,N1,N2,N3,N4,N5,N6,N7,N8,N9,N10,N11,N12,
     +           N13,N14,N15,N16,N17,N18,N19,N20,N21,N22,N23,N24
      COMMON A(1)
      REAL A
C
      DIMENSION TITLE(16),TIM1(5),TIM2(5),TIMD(5)
      DIMENSION V(1),XMS(1)
      DATA BLANK/12H            /
      DATA IDUMP/0/
C
      IF (IFLAG.EQ.1) GO TO 50
C
C  LOCATE DUMP NUMBER 'NDUMP'
C
    3 READ(14,END=98,ERR=99) IDUMP
      IF (IDUMP.EQ.NDUMP) GO TO 4
      READ(14,END=98,ERR=99) NUMMAT,NUMNP,NUMEL,NUMPC,NUMLP,HED,RA,
     +                       NTAPE,NEQ,MESH,IRSTRT,ITEMP
      READ(14,END=98,ERR=99) EPZ,D,C,DF,KLIN,DT1,DT2,WRZ
      READ(14,END=98,ERR=99) NDSOUT,NSTOUT,NUMDS,NUMST,
     +                       TIO1,TIO2,TIOD
      READ(14,END=98,ERR=99) NNN,NODENO,NN,CJINT,HK,CDOT,ADOTK,KK,
     +                       KT,SIFRST,DXX,DX,X,NS,NSTEP,NT,NL,DYNMOD,
     +                       NSRPTS,STRNRT,EDMULT,NAVG
```

```
      READ(14,END=98,ERR=99) E0,F0,DDX,NBETA
      READ(14,END=98,ERR=99) BETA1
      READ(14,END=98,ERR=99) RDT,B1,B2,B3
      READ(14,END=98,ERR=99) TT,EFRAC,STRENG,HKNENG,VISENG
      READ(14,END=98,ERR=99) ITWO,NDIMA,N1,N2,N3,N4,N5,N6,N7,N8,N9,N10,
     +                       N11,N12,N13,N14,N15,N16,N17,N18,N19,N20,
     +                       N21,N22,N23,N24
      NEND=N24+NUMNP*ITWO*ITEMP-1
      READ(14,END=98,ERR=99) (A(I),I=N1,NEND)
      GO TO 3
C
C  READ LABELED COMMON DATA
C
    4 READ(14,END=98,ERR=99) NUMMAT,NUMNP,NUMEL,NUMPC,NUMLP,HED,RA,
     +                       NTAPE,NEQ,MESH,IRSTRT,ITEMP
      BACKSPACE NTAPE
      BACKSPACE NTAPE
      READ(NTAPE,1000) (TITLE(I),I=1,16)
      READ(NTAPE,1010) IRSTRT,NDUMP
         ITITL=0
         DO 5 I=1,16
            IF (TITLE(I).NE.BLANK) ITITL=1
    5    CONTINUE
         IF (ITITL.EQ.0) GO TO 10
         DO 6 I=1,16
    6    HED(I)=TITLE(I)
   10 READ(14,END=98,ERR=99) EPZ,D,C,DF,KLIN,DT1,DT2,WRZ
      READ(14,END=98,ERR=99) NDSOUT,NSTOUT,NUMDS,NUMST,
     +                       TIO1,TIO2,TIOD
      READ(NTAPE,1030) (TIM1(I),TIM2(I),TIMD(I),I=1,5)
         DO 25 I=1,5
            IF (TIM2(I).LE.0.0) GO TO 25
               TIO1(I)=TIM1(I)
               TIO2(I)=TIM2(I)
               TIOD(I)=TIMD(I)
   25    CONTINUE
      READ(NTAPE,1010) NNUMDS,NNUMST
         IF (NNUMDS.EQ.0) GO TO 15
            NUMDS=NNUMDS
            READ(NTAPE,1020) (NDSOUT(I),I=1,NUMDS)
   15    IF (NNUMST.EQ.0) GO TO 20
            NUMST=NNUMST
            READ(NTAPE,1020) (NSTOUT(I),I=1,NUMST)
   20 READ(14,END=98,ERR=99) NNN,NODENO,NN,CJINT,HK,CDOT,ADOTK,KK,
     +                       KT,SIFRST,DXX,DX,X,NS,NSTEP,NT,NL,DYNMOD,
     +                       NSRPTS,STRNRT,EDMULT,NAVG
      READ(14,END=98,ERR=99) E0,F0,DDX,NBETA
      READ(14,END=98,ERR=99) BETA1
      READ(14,END=98,ERR=99) RDT,B1,B2,B3
      READ(NTAPE,1040) NNSTEP,RRDT,BB1,BB2,BB3
```

```
         IF (NNSTEP.NE.0) NSTEP=NNSTEP
         IF (RRDT.GT.0.0) RDT=RRDT
         IF (BB1.GT.0.0) B1=BB1
         IF (BB2.GT.0.0) B2=BB2
         IF (BB3.GT.0.0) B3=BB3
      READ(14,END=98,ERR=99) TT,EFRAC,STRENG,HKNENG,VISENG
         DO 30 I=1,5
            IF (TI01(I).LT.TT) TI01(I)=TT
   30    CONTINUE
      READ(14,END=98,ERR=99) ITWO,NDIMA,N1,N2,N3,N4,N5,N6,N7,N8,N9,N10,
     +                        N11,N12,N13,N14,N15,N16,N17,N18,N19,N20,
     +                        N21,N22,N23,N24
C
C  INITIALIZE FRACTURE ENERGY CALCULATIONS
C
      CALL ENERGY(V,XMS)
      RETURN
C
C  READ ARRAY DATA
C
   50 NEND-N24+NUMNP*ITWO*ITEMP-1
      READ(14,END=98,ERR=99) (A(I),I=N1,NEND)
      RETURN
C
C  ERROR EXIT
C
   98 WRITE(6,1070) IDUMP
      GO TO 100
   99 WRITE(6,1060)
  100 IERROR=0
      RETURN
C
 1000 FORMAT(16A5)
 1010 FORMAT(2I5)
 1020 FORMAT(16I5)
 1030 FORMAT(6E10.0)
 1040 FORMAT(I5,4F10.0)
 1060 FORMAT(43H1ERROR IN READING RESTART DATA FROM UNIT 14)
 1070 FORMAT('1END OF FILE REACHED WHILE READING RESTART DATA FROM',
     +' UNIT 14',/,' DUMP NO.',I4,' WAS THE LAST DUMP PROCESSED')
C
      END
```

PROGRAM LISTING -- SAMCR (VERSION 3.0) -- RELEASED JANUARY 1 1984

```
      SUBROUTINE RSTOUT
C
C  WRITES ANALYSIS RESTART INFORMATION TO UNIT 13
C
C  (SEE APPENDIX I IN SCHWARTZ ET AL. FOR DESCRIPTIONS
C   OF LABELED COMMON BLOCKS)
C
      IMPLICIT REAL*8 (A-H,O-Z)
C
      COMMON/BK1/NUMMAT,NUMNP,NUMEL,NUMPC,NUMLP,HED(16),RA,NTAPE,NEQ,
     +           MESH,IRSTRT,ITEMP
      COMMON/BK2/EPZ(5),D(4),C(4,4),DF,KLIN,DT1,DT2,WRZ
      COMMON/BK3/NDSOUT(160),NSTOUT(160),NUMDS,NUMST,
     +           TI01(5),TI02(5),TIOD(5)
      COMMON/BK6/NNN,NODENO,NN,CJINT,HK,CDOT,ADOTK(10,17,2),KK,KT,
     +           SIFRST,DXX,DX,X,NS,NSTEP,NT,NL,DYNMOD,NSRPTS,
     +           STRNRT(8),EDMULT(8),NAVG
      COMMON/BK7/E0,F0,DDX,NBETA
      COMMON/BK8/BETA1
      COMMON/BK9/RDT,B1,B2,B3
      COMMON/BK10/TT,EFRAC,STRENG,HKNENG,VISENG
      COMMON/BK13/ITWO,NDIMA,N1,N2,N3,N4,N5,N6,N7,N8,N9,N10,N11,N12,
     +            N13,N14,N15,N16,N17,N18,N19,N20,N21,N22,N23,N24
      COMMON A(1)
      REAL A
C
      DATA NDUMP/0/
C
C
C  PRINT LOG MESSAGE
C
      NDUMP=NDUMP+1
      WRITE(6,1000) NDUMP,TT
      WRITE(13,END=98,ERR=99) NDUMP
C
C  WRITE LABELED COMMON BLOCK DATA
C
      WRITE(13,END=98,ERR=99) NUMMAT,NUMNP,NUMEL,NUMPC,NUMLP,HED,RA,
     +                        NTAPE,NEQ,MESH,IRSTRT,ITEMP
      WRITE(13,END=98,ERR=99) EPZ,D,C,DF,KLIN,DT1,DT2,WRZ
      WRITE(13,END=98,ERR=99) NDSOUT,NSTOUT,NUMDS,NUMST,
     +                        TI01,TI02,TIOD
      WRITE(13,END=98,ERR=99) NNN,NODENO,NN,CJINT,HK,CDOT,ADOTK,KK,KT,
     +                         SIFRST,DXX,DX,X,NS,NSTEP,NT,NL,DYNMOD,
     +                         NSRPTS,STRNRT,EDMULT,NAVG
      WRITE(13,END=98,ERR=99) E0,F0,DDX,NBETA
      WRITE(13,END=98,ERR=99) BETA1
      WRITE(13,END=98,ERR=99) RDT,B1,B2,B3
      WRITE(13,END=98,ERR=99) TT,EFRAC,STRENG,HKNENG,VISENG
      WRITE(13,END=98,ERR=99) ITWO,NDIMA,N1,N2,N3,N4,N5,N6,N7,N8,N9,N10,
```

```
     +                        N11,N12,N13,N14,N15,N16,N17,N18,N19,N20,
     +                        N21,N22,N23,N24
C
C  WRITE ARRAY INFORMATION
C
      NEND=N24+NUMNP*ITWO*ITEMP-1
      WRITE(13,END=98,ERR=99) (A(I),I=N1,NEND)
C
      RETURN
C
C  ERROR EXITS
C
   98 WRITE(6,1010)
      GO TO 100
   99 WRITE(6,1020)
  100 STOP
C
 1000 FORMAT(///,' <<< RESTART DUMP NO.',I4,' WRITTEN AT TIME =',
     +1PE10.4,' >>>',//)
 1010 FORMAT('1END OF FILE REACHED WHILE WRITING RESTART DATA TO',
     +' UNIT 13')
 1020 FORMAT('1ERROR IN WRITING RESTART DATA TO UNIT 13')
C
      END
```

```
      SUBROUTINE SECOND (TIME)
C
C  THE PURPOSE OF THIS SUBROUTINE IS TO ASCERTAIN THE TIME OF DAY
C  IN SECONDS.  UNIVAC'S FORTRAN-V LIBRARY ROUTINE 'ERTRAN' PROVIDES
C  THE TIME OF DAY IN A CHARACTER STRING OF THE FORM HHMMSS.  UNIVAC'S
C  INTRINSIC FORTRAN-V ROUTINE 'FLD' CAN BE USED TO DECODE THE
C  CHARACTER STRING.
C
      CALL ERTRAN (9, MMDDYY, HHMMSS)
      IZERO = FLD(0,6,'0')
      ISECS =        1 * (FLD(30,6,HHMMSS) - IZERO)
     *            + 10 * (FLD(24,6,HHMMSS) - IZERO)
     *            + 60 * (FLD(18,6,HHMMSS) - IZERO)
     *           + 600 * (FLD(12,6,HHMMSS) - IZERO)
     *          + 3600 * (FLD( 6,6,HHMMSS) - IZERO)
     *         + 36000 * (FLD( 0,6,HHMMSS) - IZERO)
C
C  CALLING PROCEDURE EXPECTS A FLOATING-POINT NUMBER.  NOTE THAT
C  'ERTRAN' DOES NOT PROVIDE THE FRACTIONAL PART OF A SECOND.
C
      TIME = ISECS
      RETURN
      END
```

PROGRAM LISTING -- SAMCR (VERSION 3.0) -- RELEASED JANUARY 1 1984

```
      SUBROUTINE SOLVE (R,Z,CODE,IX,MTYPE,RO,EE,INI,JNJ,PI,PJ,T,P,U,V,A,
     1E,MS,SIG,EPS,ELOAD,ULAST,VLAST,TEMP)
C
C  SUBPROGRAM TO CONTROL STEP-BY-STEP ANALYSIS PHASE
C
C  (SEE APPENDIX I IN SCHWARTZ ET AL. 1984 FOR DESCRIPTIONS OF
C   SUBROUTINE ARGUMENTS AND LABELED COMMON BLOCKS)
C
      IMPLICIT REAL*8 (A-H,O-Z)
C
      COMMON/BK1/NUMMAT,NUMNP,NUMEL,NUMPC,NUMLP,HED(16),RA,NTAPE,NEQ,
     +           MESH,IRSTRT,ITEMP
      COMMON/BK2/EPZ(5),D(4),C(4,4),DF,KLIN,DT1,DT2,WRZ
      COMMON/BK3/NDSOUT(160),NSTOUT(160),NUMDS,NUMST,
     1           TIO1(5),TIO2(5),TIOD(5)
      COMMON/BK5/I1,I2,I3,I4,I5,I6,I7,I8
      COMMON/BK6/NNN,NODENO,NN,CJINT,HK,CDOT,ADOTK(10,17,2),KK,KT,
     +           SIFRST,DXX,DX,X,NS,NSTEP,NT,NL,DYNMOD,NSRPTS,
     +           STRNRT(8),EDMULT(8),NAVG
      COMMON/BK7/E0,F0,DDX,NBETA
      COMMON/BK8/BETA1
      COMMON/BK10/TT,EFRAC,STRENG,HKNENG,VISENG
      COMMON/BK11/ISTAT,NITER,TOL,VISC1,VISC2,VISC3
      COMMON/BK12/FBFB,QBQB,FKFK,QKQK
C
      DIMENSION  R(1),Z(1),CODE(1),IX(5,1),MTYPE(1),RO(1),
     1           EE(5,6,1),INI(1),JNJ(1),PI(1),PJ(1),T(1),P(2,1),U(1),
     2           V(1),A(1),E(1),MS(1),SIG(4,1),EPS(5,1),ELOAD(1)
      DIMENSION ULAST(1),VLAST(1),TIOT(5),TEMP(1)
      REAL*8     MS
C
C***********************************************************************
C                          ANALYSIS INITIALIZATION
C***********************************************************************
C
      NDFLAG=0
      DO 5 I=1,5
    5 TIOT(I)=TIO1(I)
C
      IF (IRSTRT.EQ.-1) GO TO 60
C
      DF=1.0
      WRZ=0.0
      TT=0.0
C
C  ELEMENT INITIALIZATION
C
C  CONVERT INITIAL SURFACE PRESSURES TO NODAL LOADS
C
      CALL LOAD (R,Z,INI,JNJ,PI,PJ,T,P,TT,E,ELOAD)
```

PROGRAM LISTING -- SAMCR (VERSION 3.0) -- RELEASED JANUARY 1 1984

```
C
      DT1=0.0
      DT2=1.0E+6
      FBFB=0.
      QBQB=0.
      FKFK=0.
      QKQK=0.
      VISENG=0.0
      STRENG=0.0
      DO 40 N=1,NUMEL
         I2=IX(1,N)+IX(1,N)
         I1=I2-1
         I4=IX(2,N)+IX(2,N)
         I3=I4-1
         I6=IX(3,N)+IX(3,N)
         I5=I6-1
         I8=IX(4,N)+IX(4,N)
         I7=I8-1
         MX=IX(5,N)
C
C     COMPUTE MASS MATRIX, MS
C
         CALL MASS (R,Z,IX(1,N),RO(MX),MS)
C
C     COMPUTE INITIAL STRAINS FOR ELEMENTS
C
         CALL INTSTR(U,TEMP,R,Z,IX(1,N),EPS(1,N),EE(1,1,MX))
C
C     FIND INITIAL ELASTIC MODULI AND STRESS
C
         CALL STRESS(SIG(1,N),EPS(1,N),EE(1,1,MX))
C
C     COMPUTE INITIAL STIFFNESS AND VISCOSITY FORCES, INITIAL STRAIN
C     ENERGY, AND TIME STEP
C
         CALL FORCE(R,Z,IX(1,N),RO(MX),EE(1,1,MX),U,V,VLAST,SIG(1,N),
     +              EPS(1,N),E)
C
   40 CONTINUE
C
C  J-INTEGRAL CALCULATION
C
      IF (ISTAT.NE.0) GO TO 200
C
      CALL JINTGL(IX,R,Z,EE,RO,V,SIG,EPS)
C
C
      N=NODENO+1
      I2=IX(1,N)+IX(1,N)
      E0=E(I2)
```

```
      MX=IX(5,N)
      CALL INVEL(TEMP,R,CODE,IX(1,N))
      I=IX(1,N)
      J=IX(2,N)
      DELTA=R(J)-R(I)
      DDX=CDOT*DT2
      FO=CRKFOR(EO,DDX,DELTA)
      NBETA=0
      DX=CDOT*DT2
200   CONTINUE
      DT1=DT2
C
C  COMPUTE INITIAL KINETIC, FRACTURE ENERGIES
C
      EFRAC=0.0
      CALL ENERGY(V,MS)
C
C  INVERT MASS MATRIX
C
      DO 50 N=1,NUMNP
 50   MS(N)=1.0/MS(N)
C
C*************************************************************
C           BEGINNING OF TIME INTEGRATION LOOP
C*************************************************************
C
C  COMPUTE ACCELERATIONS
C
   60 N=NODENO+1
      I2=IX(1,N)+IX(1,N)
      DO 70 N=1,NEQ
         IF (ISTAT.EQ.0.AND.I2.EQ.N) GO TO 65
            NX=(N+1)/2
            A(N)=MS(NX)*E(N)
            GO TO 70
   65    CONTINUE
            A(N)=MS(NX)*(E(I2)-FO)
   70 CONTINUE
C
C  APPLY DISPLACEMENT BOUNDARY CONDITIONS
C
      DO 80 N=1,NUMNP
         PHI=CODE(N)
         IF (PHI.LE.0.0) GO TO 80
            I2=N+N
            I1=I2-1
            Q1=A(I1)
            A(I1)=0.0
            Q2=A(I2)
            A(I2)=0.0
```

```
            IF (PHI.EQ.1.0) PHI=90.0
            IF (PHI.EQ.2.0) PHI=0.0
            IF (PHI.EQ.3.0) GO TO 80
               CSP=COS(PHI/57.2957795)
               SNP=SIN(PHI/57.2957795)
               Q3=Q1*CSP+Q2*SNP
               A(I1)=CSP*Q3
               A(I2)=SNP*Q3
 80   CONTINUE
C
C  IF STATIC ANALYSIS, CHECK FOR CONVERGENCE OF DYNAMIC ITERATION
C
      IF (ISTAT.NE.0) CALL CONVRG(A,U,NS)
C
C  OUTPUT RESULTS
C
C  ***PRINT FILE
      IF (ISTAT.NE.0) GO TO 95
      IF (TT.LT.TIOT(1)) GO TO 90
      TIOT(1)=TIOT(1)+TIOD(1)
      WRITE(6,160) NS,TT,DT1,DT2
      CALL DATOUT(U,V,A,SIG,EPS,0)
      CALL ROLOUT(0)
      RMSFB=SQRT(FBFB/(NUMEL*8.))
      RMSQB=SQRT(QBQB/(NUMEL*8.))
      RMSFK=SQRT(FKFK/(NUMEL*8.))
      RMSQK=SQRT(QKQK/(NUMEL*8.))
      WRITE(6,180) RMSFB,RMSQB,RMSFK,RMSQK
   90 IF (TT.GT.TIO2(1)) NDFLAG=1
C
C  ***UNIT 10 (PLOT TAPE), WRITE 2 OF 2
      IF ((TT.LT.TIOT(2)).OR.(TT.GT.TIO2(2))) GO TO 92
      TIOT(2)=TIOT(2)+TIOD(2)
      WRITE(10) TT
      WRITE(10) (U(I),I=1,NEQ),(V(I),I=1,NEQ),(A(I),I=1,NEQ)
      WRITE(10) ((SIG(I,J),J=1,NUMEL),I=1,4)
      WRITE(10) ((EPS(I,J),J=1,NUMEL),I=1,4)
C
C  ***UNIT 11 (CRACK DATA)
   92 IF ((TT.LT.TIOT(3)).OR.(TT.GT.TIO2(3))) GO TO 94
      TIOT(3)=TIOT(3)+TIOD(3)
      CALL ROLOUT(1)
C
C  ***UNIT 12 (EDITED NODAL DISP, VEL, ACC)
   94 IF ((TT.LT.TIOT(4)).OR.(TT.GT.TIO2(4))) GO TO 96
      TIOT(4)=TIOT(4)+TIOD(4)
      CALL DATOUT(U,V,A,SIG,EPS,1)
   96 CONTINUE
C
C  UPDATE VELOCITIES AND DISPLACEMENTS
```

```
C
      TT=TT+DT2
   95 CALL NEWUV(A,ULAST,VLAST,U,V)
C
C  UPDATE SURFACE PRESSURES
C
      CALL LOAD (R,Z,INI,JNJ,PI,PJ,T,P,TT,E,ELOAD)
C
      DT1=DT2
      DT2=1.0E+6
      FBFB=0.
      QBQB=0.
      FKFK=0.
      QKQK=0.
      STRENG=0.0
      IERROR=1
      DO 150 N=1,NUMEL
         I2=IX(1,N)+IX(1,N)
         I1=I2-1
         I4=IX(2,N)+IX(2,N)
         I3=I4-1
         I6=IX(3,N)+IX(3,N)
         I5=I6-1
         I8=IX(4,N)+IX(4,N)
         I7=I8-1
         MX=IX(5,N)
C
C     UPDATE STRAINS
C
         CALL STRAIN(V,R,Z,IX(1,N),EPS(1,N),EE(1,1,MX),1)
C
C     UNPDATE STRESSES
C
         CALL STRESS(SIG(1,N),EPS(1,N),EE(1,1,MX))
C
C     UPDATE STIFFNESS FORCES, VISCOSITY FORCES,
C     STRAIN ENERGY, AND TIME STEP
C
         IF (SIG(1,N).NE.0.0) GO TO 140
         IF (SIG(2,N).NE.0.0) GO TO 140
         IF (SIG(3,N).NE.0.0) GO TO 140
         IF (SIG(4,N).NE.0.0) GO TO 140
         GO TO 150
C
140      CALL FORCE(R,Z,IX(1,N),RO(MX),EE(1,1,MX),U,V,VLAST,SIG(1,N),
     +                EPS(1,N),E)
         IERROR=0
C
 150  CONTINUE
C
```

```
C  J-INTEGRAL CALCULATION
C
      IF (ISTAT.NE.0) GO TO 210
      DXX=DXX+DX
      CALL JINTGL(IX,R,Z,EE,RO,V,SIG,EPS)
C
C  DETERMINE CRACK TIP STRAIN RATE, VELOCITY, AND ADVANCE;
C  UPDATE KINETIC AND FRACTURE ENERGIES
C
      N=NODENO+1
      MX=IX(5,N)
      EPSDOT=0.C
      IF (NSRPTS.EQ.0) GO TO 157
         MNSTRT=N-1
         MNEND=N+1
         DO 155 MN=MNSTRT,MNEND
            I2=IX(1,MN)+IX(1,MN)
            I1=I2-1
            I4=IX(2,MN)+IX(2,MN)
            I3=I4-1
            I6=IX(3,MN)+IX(3,MN)
            I5=I6-1
            I8=IX(4,MN)+IX(4,MN)
            I7=I8-1
            MMX=IX(5,MN)
            CALL STRAIN(V,R,Z,IX(1,MN),EPS(1,MN),EE(1,1,MMX),0)
            DO 156 I=1,3
               IF (ABS(D(I)).GT.ABS(EPSDOT)) EPSDOT=D(I)
  156       CONTINUE
  155    CONTINUE
  157 CONTINUE
      CALL VEL(TEMP,R,EPSDOT,IX(1,N))
      CALL ENERGY(V,MS)
      IF(NBETA.EQ.0) GO TO 700
C
C  ***CRACK ADVANCES TO NEXT NODE
      DXX=0.0
      DDX=CDOT*DT2
      NODENO=NODENO+1
      N=NODENO+1
      CODE(N)=0.0
      NBETA=0
C  ** CALCULATE NODAL FORCE BEHIND CRACK TIP
      I=IX(1,N)
      J=IX(2,N)
      DELTA=R(J)-R(I)
      I2=IX(1,N)+IX(1,N)
      E0=E(I2)
      F0=CRKFOR(E0,DDX,DELTA)
      GO TO 660
```

```
C
C  ***CRACK DOES NOT ADVANCE TO NEXT NODE
C  ***CALCULATE NEW FORCE BEHIND CRACK TIP
   700 I=IX(1,N)
        J=IX(2,N)
        I2=IX(1,N)+IX(1,N)
        DELTA=R(J)-R(I)
        DDX=DDX+CDOT*DT2
        IF(DDX.GE.DELTA)GO TO 600
            F0=CRKFOR(E0,DDX,DELTA)
            GO TO 660
   600 F0=0.0
   660 CONTINUE
        N=NODENO+1
C
C  CHECK WHETHER CRACK WILL OVERSHOOT NODE DURING NEXT TIME STEP
C
        CALL TERM(IX(1,N),R)
C
C  CHECK WHETHER TIME STEP OR PRINT OUTPUT TIME LIMIT HAS BEEN REACHED
C
   210 NS=NS+1
        IF (ISTAT.EQ.0.AND.NS.GT.NSTEP) RETURN
        IF (NDFLAG.EQ.1) RETURN
C
C  UNIT 13 (RESTART DATA) OUTPUT
C
        IF (IRSTRT.EQ.0) GO TO 98
        IF ((TT.LT.TIOT(5)).OR.(TT.GT.TIO2(5))) GO TO 98
        TIOT(5)=TIOT(5)+TIOD(5)
        CALL RSTOUT
    98 CONTINUE
C
        IF (IERROR.EQ.0) GO TO 60
C
C*****************************************************************
C                 END OF TIME INTEGRATION LOOP
C*****************************************************************
C
C
C  ERROR EXIT
C
        WRITE (6,170) TT
        RETURN
C
   160 FORMAT(/////,7H CYCLE=,I5,6X,13HCURRENT TIME=,1PE13.6,6X,
     +        15HLAST TIME STEP=,E13.6,6X,15HNEXT TIME STEP=,E13.6)
   170 FORMAT (1H0,15X,76H***FATAL ERROR*** ACTIVITY TEST SHOWS ZERO STRE
     1SSES IN ALL ELEMENTS.  TIME =,E15.6)
   180 FORMAT('ORMSFB='1PE12.5,'  RMSQB='E12.5,'  RMSFK=',E12.5,
     +          ' RMSQK=',E12.5)
C
        END
```

```
      SUBROUTINE STRAIN(V,R,Z,IX,EPS,EE,IFLAG)
C
C  COMPUTES ELEMENT STRAIN RATES AND STRAINS AT SECOND AND
C  SUBSEQUENT TIME STEPS DURING THE ANALYSIS.
C
C  (SEE APPENDIX I OF SCHWARTZ ET AL. 1984 FOR DESCRIPTIONS
C   OF SUBROUTINE ARGUMENTS AND LABELED COMMON BLOCKS)
C
C  'IFLAG' CONTROLS LOGIC IN SUBROUTINE:
C     IFLAG=0 ==> COMPUTE STRAIN RATES ONLY
C     IFLAG=1 ==> COMPUTE STRAIN RATES AND STRAINS
C
C  ELEMENT STRAINS ARE STORED IN 'EPS' IN THE FOLLOWING SEQUENCE:
C     EPS(1) = EPSRR = DU/DR
C     EPS(2) = EPSZZ = DW/DZ
C     EPS(3) = EPSTHETA = U/R
C     EPS(4) = GAMMARZ = DU/DZ + DW/DR
C     EPS(5) = DW/DR (REQUIRED FOR J-INTEGRAL CALCULATION)
C  STRAIN RATES D(1) THROUGH D(4) APE STORED IN THE SAME SEQUENCE
C  AS THE STRAINS EPS(1) THROUGH EPS(4)
C
      IMPLICIT REAL*8 (A-H,O-Z)
C
      COMMON/BK1/NUMMAT,NUMNP,NUMEL,NUMPC,NUMLP,HED(16),RA,NTAPE,NEQ,
     +          MESH,IRSTRT,ITEMP
      COMMON/BK2/EPZ(5),D(4),C(4,4),DF,KLIN,DT1,DT2,WRZ
      COMMON/BK5/I1,I2,I3,I4,I5,I6,I7,I8
      DIMENSION V(1),R(1),Z(1),IX(1),EPS(1),EE(5,6)
C
C  INITIALIZATION
C
      I=IX(1)
      J=IX(2)
      K=IX(3)
      L=IX(4)
      R13=R(I)-R(K)
      R24=R(J)-R(L)
      Z13=Z(I)-Z(K)
      Z24=Z(J)-Z(L)
      VOL=1.0/(R13*Z24-Z13*R24)
      RM=1.0/(R(I)+R(J)+R(K)+R(L))
      Y1=Z24*VOL
      Y2=-Z13*VOL
      Y3=-Y1
      Y4=-Y2
      X1=-R24*VOL
      X2=R13*VOL
      X3=-X1
      X4=-X2
      VX1=V(I1)
```

```
      VX2=V(I2)
      VX3=V(I3)
      VX4=V(I4)
      VX5=V(I5)
      VX6=V(I6)
      VX7=V(I7)
      VX8=V(I8)
C
C  EVALUATION OF STRAIN RATE AND STRAIN
C
      D(1)=Y1*VX1+Y2*VX3+Y3*VX5+Y4*VX7
      D(2)=X1*VX2+X2*VX4+X3*VX6+X4*VX8
      IF(RA.EQ.0.0)GO TO 10
      IF(RA.GT.0.0)GO TO 30
      D(3)=0.0
      GO TO 20
   30 D(3)=(-EE(1,2)*D(1)-EE(1,2)*D(2))/(1.-EE(1,2))
      GO TO 20
   10 D(3)=RM*(VX1+VX3+VX5+VX7)
   20 D(4)=X1*VX1+Y1*VX2+X2*VX3+Y2*VX4+X3*VX5+Y3*VX6+X4*VX7+Y4*VX8
      IF (IFLAG.EQ.0) RETURN
C
      EPS(1)=EPS(1)+DT1*D(1)
      EPS(2)=EPS(2)+DT1*D(2)
      EPS(3)=EPS(3)+DT1*D(3)
      EPS(4)=EPS(4)+DT1*D(4)
      EPS(5)=EPS(5)+DT1*(Y1*VX2+Y2*VX4+Y3*VX6+Y4*VX8)
C
      RETURN
      END
```

PROGRAM LISTING -- SAMCR (VERSION 3.0) -- RELEASED JANUARY 1 1984

```
      SUBROUTINE STRESS(SIG,EPS,EE)
C
C  SUBPROGRAM TO EVALUATE ELEMENT STRESS-STRAAIN MATRIX AT BEGINNING
C  OF ANALYSIS AND ELEMENT STRESSES AT EACH TIME STEP DURING ANALYSIS
C
C  (SEE APPENDIX I OF SCHWARTZ ET AL. 1984 FOR DESCRIPTIONS
C   OF SUBROUTINE ARGUMENTS AND LABELED COMMON BLOCKS)
C
C  ELEMENT STRESSES ARE STORED IN 'SIG' IN THE FOLLOWING SEQUENCE:
C        SIG(1) = SIGRR
C        SIG(2) = SIGZZ
C        SIG(3) = SIGTHETA
C        SIG(4) = TAURZ
C  ELEMENT STRAINS EPS(1) THROUGH EPS(4) ARE STORED IN THE SAME
C  SEQUENCE AS THE STRESSES SIG(1) THROUGH SIG(4)
C
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON/BK1/NUMMAT,NUMNP,NUMEL,NUMPC,NUMLP,HED(16),RA,NTAPE,NEQ,
     +           MESH,IRSTRT,ITEM
      COMMON/BK2/EPZ(5),D(4),C(4,4),DF,KLIN,DT1,DT2,WRZ
      DIMENSION SIG(1),EPS(1),EE(5,6),T(4)
      DATA KK1/0/, M1/1/
C
C  INITIALIZE EE(I,J) STORAGE
C
      IF (EE(2,1).NE.0.0) GO TO 20
      DO 10 I=2,5
      DO 10 J=1,5
   10 EE(I,J)=0.0
      Q1=EE(1,1)*EE(1,2)/((1.0+EE(1,2))*(1.0-2.0*EE(1,2)))
      Q2=EE(1,1)*0.5/(1.0+EE(1,2))
      Q3=Q1+2.0*Q2
      EE(2,1)=Q3
      EE(3,2)=Q3
      EE(4,3)=Q3
      EE(5,4)=Q2
      EE(2,2)=Q1
      EE(2,3)=Q1
      EE(3,1)=Q1
      EE(3,3)=Q1
      EE(4,1)=Q1
      EE(4,2)=Q1
   20 CONTINUE
C
C  ELASTIC MODULI
C
      DO 30 I=1,4
      DO 30 J=1,4
   30 C(I,J)=EE(I+1,J)
C
```

```
C  COMPUTE TRIAL STRESS
C
      IF (IRSTRT.EQ.-1) GO TO 200
      IF(KK1.NE.0)GO TO 200
C
C  ***INITIAL STRESSES
      DO 100 I=1,4
      T(I)=SIG(I)
      DO 100 J=1,4
  100 T(I)=T(I)+C(I,J)*EPS(J)
      IF(M1.EQ.NUMEL)KK1=1
      M1=M1+1
      GO TO 270
C
C ***STRESSES FOR TIME.GT.0
  200 DO 40 I=1,4
      T(I)=SIG(I)
      DO 40 J=1,4
 40   T(I)=T(I)+C(I,J)*D(J)*DT1
 270  DO 280 I=1,4
 280  SIG(I)=T(I)
C
      RETURN
      END
```

```
      SUBROUTINE TERM(IX,R)
C
C  CHECK FOR CRACK TIP OVERSHOOT OF NEXT NODE DURING NEXT TIME STEP
C
C  (SEE APPENDIX I OF SCHWARTZ ET AL. 1984 FOR DESCRIPTIONS
C   OF SUBROUTINE ARGUMENTS AND LABELED COMMON BLOCKS)
C
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON/BK2/EPZ(5),D(4),C(4,4),DF,KLIN,DT1,DT2,WRZ
      COMMON/BK6/NNN,NODENO,NN,CJINT,HK,CDOT,ADOTK(10,17,2),KK,KT,
     +           SIFRST,DXX,DX,X,NS,NSTEP,NT,NL,DYNMOD,NSRPTS,
     +           STRNRT(8),EDMULT(8),NAVG
      COMMON/BK7/E0,F0,DDX,NBETA
      COMMON/BK10/TT,EFRAC,STRENG,HKNENG,VISENG
      DIMENSION IX(1),R(1)
      I=IX(1)
      J=IX(2)
      HX=ABS(R(I)-R(J))
      HHX=HX-0.001
      IF(DDX.LT.HHX)GO TO 50
      DT2=(HX-DXX)/CDOT
      NBETA=1
      DX=CDOT*DT2
      PRINT 10,TT,HX,DXX,CDOT,DT2,NBETA
   10 FORMAT(///,' <<< CORRECTION FOR PREDICTED OVERSHOOT OF CRACK TIP',
     +      ' AT TIME =',1PE10.4,' >>>',
     +      /,' <<< HX=',E12.5,' DXX=',E12.5,' CDOT=',E12.5,' DT2=',
     +      E12.5,' NBETA=',I2,' >>>',//)
C
   50 RETURN
      END
```

```
      SUBROUTINE VEL(TEMP,R,EPSDOT,IX)
C
C  CALCULATES THE CURRENT STRESS INTENSITY FACTOR AND INSTANTANEOUS
C  CRACK TIP VELOCITY AT SECOND AND SUBSEQUENT TIME STEPS DURING
C  THE ANALYSIS.
C
C  (SEE APPENDIX I OF SCHWARTZ ET AL. 1984 FOR DESCRIPTIONS
C   OF SUBROUTINE ARGUMENTS AND LABELED COMMON BLOCKS)
C
C  FRACTURE CONSTITUTIVE DATA ARE STORED IN 'ADOTK(L,M,N)' USING THE
C  FOLLOWING SCHEME:
C     ADOTK(L,1,1) = TEMPERATURE FOR CURVE L
C     ADOTK(L,I,1) = STRESS INTENSITY VALUE FOR POINT I ON CURVE L
C     ADOTK(L,I,2) = CRACK TIP VELOCITY FOR POINT I ON CURVE L
C  DATA ARE STORED IN ASCENDING ORDER IN 'ADOTK'
C
C  THE DYNAMIC MODULUS VALUE USED TO COMPUTE THE CURRENT STRESS
C  INTENSITY FACTOR MAY BE STRAIN RATE DEPENDENT
C
C  THE CRACK TIP VELOCITY CALCULATION IS BASED ON A SMOOTHED VALUE
C  FOR THE STRESS INTENSITY FACTOR; 'HK' IS COMPUTED AS THE MOVING
C  AVERAGE OF THE STRESS INTENSITY FACTORS FOR THE PRECEDING 'NAVG'
C  TIME STEPS.
C
C  IF THE CRACK HAS ARRESTED FOR A DURATION ('DURAST') GREATER THAN
C  A THRESHOLD VALUE ('THRESH'--SPECIFIED IN DATA STATEMENT), THE
C  CURRENT SMOOTHED STRESS INTENSITY FACTOR MUST BE GREATER THAN
C  SIFRST*ARESTK FOR REINITIATION, WHERE 'ARESTK' IS THE ARREST
C  FRACTURE TOUGHNESS
C
      IMPLICIT REAL*8 (A-H,O-Z)
C
      COMMON/BK1/NUMMAT,NUMNP,NUMEL,NUMPC,NUMLP,HED(16),RA,NTAPE,NEQ,
     +           MESH,IRSTRT,ITEMP
      COMMON/BK2/EPZ(5),D(4),C(4,4),DF,KLIN,DT1,DT2,WRZ
      COMMON/BK6/NNN,NODENO,NN,CJINT,HK,CDOT,ADOTK(10,17,2),KK,KT,
     +           SIFRST,DXX,DX,X,NS,NSTEP,NT,NL,DYNMOD,NSRPTS,
     +           STRNRT(8),EDMULT(8),NAVG
      COMMON/BK10/TT,EFRAC,STRENG,HKNENG,VISENG
      DIMENSION TEMP(1),R(1),IX(1),PREHK(50)
      DIMENSION ADOT(16),SIF(16)
C
      DATA DURAST/0.0D0/
      DATA THRESH/100.0D-6/
      DATA N/0/
C
      X=X+DX
      IF(CJINT)100,10,10
C
C  ADJUST REFERENCE DYNAMIC MODULUS FOR STRAIN RATE EFFECTS
```

```
C
   10 FACTOR=1.0
      IF (NSRPTS.GT.0) CALL INTPL(NSRPTS,STRNRT,EDMULT,EPSDOT,FACTOR)
      EDYN=DYNMOD*FACTOR
C
C  COMPUTE CURRENT (UNSMOOTHED) STRESS INTENSITY FACTOR
C
      HK=SQRT(EDYN*CJINT)
      GO TO 20
  100 WRITE(6,1000) TT,CJINT
 1000 FORMAT(////,' *** AT TIME=',1PE11.5,' THE J-INTEGRAL IS',
     +      ' NEGATIVE AND EQUAL TO',1PE12.5,/,' THE STRESS INTENSITY',
     +       ' FACTOR K HAS BEEN ARBITRARILY SET TO ZERO',/)
      HK=0.0
C
C  SMOOTH STRESS INTENSITY FACTOR AND COMPUTE NEW CRACK TIP VELOCITY
C
   20 N=N+1
      IF (N.LE.NAVG) GO TO 24
      N=NAVG
      NM=N-1
      DO 22 I=1,NM
   22 PREHK(I)=PREHK(I+1)
   24 PREHK(N)=HK
      SUM=0.0
      DO 26 I=1,N
   26 SUM=SUM+PREHK(I)
      HK=SUM/N
      PREHK(N)=HK
C
C  COMPUTE CRACK TIP VELOCITY (AND CURRENT ARREST TOUGHNESS, FOR
C  TEMPFRATURE-DEPENDENT ANALYSIS)
C
      IF (ITEMP.NE.0) GO TO 130
C
C  ***NONTHERMAL CASE
      DO 125 I=2,KK
         SIF(I-1)=ADOTK(1,I,1)
         ADOT(I-1)=ADOTK(1,I,2)
  125 CONTINUE
      CALL INTPL(KK-1,SIF,ADOT,HK,CDOT)
      ARESTK=ADOTK(1,2,1)
      GO TO 170
C
C  ***THERMAL CASE
  130 I=IX(1)
      J=IX(2)
      DELTA=R(J)-R(I)
      TC=TEMP(I)+(DXX/DELTA)*(TEMP(J)-TEMP(I))
      IF (TC.GT.ADOTK(1,1,1)) GO TO 132
```

```
         IT=1
         JT=1
         GO TO 150
  132 IF (TC.LT.ADOTK(KT,1,1)) GO TO 135
         IT=KT
         JT=KT
         GO TO 150
  135 DO 140 JT=2,KT
         IT=JT-1
         IF (TC.GT.ADOTK(IT,1,1).AND.TC.LT.ADOTK(JT,1,1)) GO TO 150
  140 CONTINUE
C
  150 DO 155 I=2,KK
         SIF(I-1)=ADOTK(IT,I,1)
         ADOT(I-1)=ADOTK(IT,I,2)
  155 CONTINUE
      CALL INTPL(KK-1,SIF,ADOT,HK,CDOTI)
      DO 160 I=2,KK
         SIF(I-1)=ADOTK(JT,I,1)
         ADOT(I-1)=ADOTK(JT,I,2)
  160 CONTINUE
      CALL INTPL(KK-1,SIF,ADOT,HK,CDOTJ)
      FACTOR=(TC-ADOTK(IT,1,1))/(ADOTK(JT,1,1)-ADOTK(IT,1,1))
      CDOT=CDOTI+(CDOTJ-CDOTI)*FACTOR
      ARESTK=ADOTK(IT,2,1)+(ADOTK(JT,2,1)-ADOTK(IT,2,1))*FACTOR
C
C  CHECK IF CRACK IS RUNNING, ARRESTED, OR REINITIATING
C
  170 IF (CDOT.GT.0.0) GO TO 30
C     ***CRACK HAS ARRESTED
         DURAST=DURAST+DT2
         DX=0.0
         RETURN
   30 IF (DURAST.GT.0.0) GO TO 40
C     ***CRACK IS RUNNING
         DX=CDOT*DT2
         RETURN
   40 IF (DURAST.GE.THRESH) GO TO 50
C     ***CRACK REINITIATES BEFORE REACHING ARREST THRESHOLD
         DURAST=0.0
         DX=CDOT*DT2
         RETURN
   50 IF (HK.GT.SIFRST*ARESTK) GO TO 60
C     ***CRACK ARRESTED, NO REINITIATION
         DURAST=DURAST+DT2
         CDOT=0.0
         DX=0.0
         RETURN
C     ***CRACK REINITIATES AFTER ARREST
   60    DURAST=0.0
         DX=CDOT*DT2
         RETURN
C
      END
```

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13 ABSTRACT (200 words or less)

The mathematical formulation, program structure, and details of required input data are described for SAMCR, a two-dimensional dynamic finite element code for the Stress Analysis of Moving CRacks, which has been developed at the University of Maryland. The code has been shown, through an extensive series of verification analyses, to perform well in modeling dynamic behavior of both uncracked and cracked structures. In particular, the code has been demonstrated to provide useful information regarding run-arrest events in polymeric laboratory samples and large thermally shocked steel cylinders. Complete documentation of the code has been included so that this document can serve as both a technical manual and a user's manual for the code.

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