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USER'S GUIDE TO COMPUTER PROGRAM CIVM-JET 4B TO CALCULATE THE TRANSIENT STRUCTURAL RESPONSES OF PARTIAL AND/OR COMPLETE STRUCTURAL RINGS TO ENGINE-ROTOR-FRAGMENT IMPACT

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16 Abstract

Described in this report is a user-oriented computer program CIVM-JET 4B to predict the large-deflection elastic-plastic structural responses of fragment impacted single-layer: (a) partial-ring fragment containment or deflector structure or (b) complete-ring fragment containment structure. These two types of structures may be either free or supported in various ways. Supports accommodated include: (1) point supports such as pinned-fixed, ideally-clamped, or supported by a structural branch simulating mounting-bracket structure and (2) elastic foundation support distributed over selected regions of the structure. The initial geometry of each partial or complete ring may be circular or arbitrarily curved; uniform or variable thicknesses of the structure are accommodated. The structural material is assumed to be initially isotropic; strain hardening and strain rate effects are taken into account.

An approximate analysis utilizing kinetic energy and momentum conservation relations is used to predict the after-impact velocities of each fragment and of the impact-affected region of the ring; this procedure is termed the collision-imparted velocity method (CIVM). This imparted-velocity information is used in conjunction with a finite-element structural response computation code to predict the transient, large-deflection, elastic-plastic responses of the impacted structure whose deflections are assumed to be in essentially one plane and, hence, these structures are called two-dimensional (2-d). In this process the equations of motion of both the impacted structure and the fragment are solved in small steps in time.

Provisions are made in the CIVM-JET 4B code to analyze the responses of 2-d structures which are subjected to impact by from 1 to 6 fragments each with its own size, mass, mass moment of inertia, translational velocity, and rotational velocity. The effects of friction between each fragment and the impacted structure are included.

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FOREWORD

This report has been prepared by the Aeroelastic and Structures Research Laboratory (ASRL), Department of Aeronautics and Astronautics, Massachusetts Institute of Technology, Cambridge, Massachusetts under Grant No. NGR 22-009-339 from the Lewis Research Center, National Aeronautics and Space Administration, Cleveland, Ohio 44135. Mr. Solomon Weiss, Mr. Robert D. Siewert, and Mr. Ray Maga of the Lewis Research Center served as technical monitors.

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The authors wish to acknowledge appreciatively the help and advice of a former colleague Dr. Richard W-H Wu now with the Nuclear Energy Division of the General Electric Co. Dr. Wu developed the JET 3 series of computer codes and the preliminary version of the present program.

The use of SI units (NASA Policy Directive NPD 2220.4, September 14, 1970) was waived for the present document in accordance with provisions of paragraph 5d of that Directive by the authority of the Director of the Lewis Research Center.

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SUMMARY

Described in this report is a user-oriented computer program CIVM-JET 4B to predict the large-deflection elastic-plastic structural responses of fragment-impacted single-layer: (a) partial-ring fragment containment or deflector structure or (b) complete-ring fragment containment structure. These two types of structures may be either free or supported in various ways. Supports accommodated include: (1) point supports such as pinned-fixed, ideally-clamped, or supported by a structural branch simulating mounting-bracket structure and (2) elastic foundation support distributed over selected regions of the structure. The initial geometry of each partial or complete ring may be circular or arbitrarily curved; uniform or variable thicknesses of the structure are accommodated. The structural material is assumed to be initially isotropic; strain hardening and strain rate effects are taken into account.

An approximate analysis utilizing kinetic energy and momentum conservation relations is used to predict the after-impact velocities of each fragment and of the impact-affected region of the ring; this procedure is termed the collision-imparted velocity method (CIVM). This imparted-velocity information is used in conjunction with a finite-element structural response computation code to predict the transient, large-deflection, elastic-plastic responses of the impacted structure whose deflections are assumed to be in essentially one plane and, hence, these structures are called two-dimensional (2-d). In this process the equations of motion of both the impacted structure and the fragment are solved in small steps in time.

Provisions are made in the CIVM-JET 4B code to analyze the responses of 2-d structures which are subjected to impact by from 1 to 6 fragments each with its own size, mass, mass moment of inertia, translational velocity, and rotational velocity. The effects of friction between each fragment and the impacted structure are included.

SECTION 1

INTRODUCTION

The CIVM-JET 4B computer program is an addition to the series of computer programs which are intended to be made available to the aircraft industry for possible use in analyzing structural response problems such as containment/deflection rings intended to cope with engine rotor-burst fragments. This computer program may also be applicable to crashworthiness problems which are of interest to the automobile and nuclear power plant industries.

The computer program written in FORTRAN IV, permits one to predict the large, two-dimensional, elastic-plastic transient Kirchhoff-type response of a single-layer structural ring, which may be a complete ring or just a partial ring. The ring may be subjected to various restraints and supports* and to rigid-fragment impact. The geometrical shape of the structural ring can be simple circular or arbitrarily curved, and the ring may have independently-varying thickness along the circumferential direction. The material behavior may be elastic strain-hardening, and/or strain-rate sensitive.

The program employs the spatial finite-element representation of the ring and the temporal finite-difference solution procedure. For predicting the transient responses of the structural ring to rigid-fragment impact, energy and momentum considerations are employed in an approximate analysis to predict the collision-induced velocities which are imparted to the fragment and to the affected ring segments. The presence of fragment/ring surface friction is taken into account. The pertinent analytical development and the solution method upon which the program is based are presented concisely in Appendix A. The reader is invited to consult Refs. 1, 2, and 3 for background information and a detailed description of this solution procedure.

Section 2 of this report is devoted to describing the general organization and capabilities of CIVM-JET 4B, including (1) the ring structural geometry, supports, elastic restraints, and material properties accommodated, (2) circular

*This includes "ring support brackets" which are treated as "branches".

rigid-fragment collision interaction, and (3) the solution procedure. Next, in Section 3, the main program and subprograms of CIVM-JET 4B are described, including a partial list and explanation of the variable names used in the program. The input data and output information are presented in Section 4. A complete FORTRAN IV listing of the program is given in Section 5. Example problems, including input data and the resulting solution data are given in Section 6. Finally, Appendix A summarizes the equations on which the program is based.

SECTION 2

GENERAL DESCRIPTION OF THE CIVM-JET 4B PROGRAM

2.1 Ring Geometry, Supports, Elastic Restraints, and Material Properties

In the present analysis, the transient structural responses of the ring are assumed to consist of planar (two-dimensional) deformations. Also, the Bernoulli-Euler (or Kirchhoff) hypothesis is employed; that is, transverse shear deformation is excluded.

The computer program can treat single layer structural rings. The layer may be of independently-varying thickness; however, the total thickness remains small compared with the circumferential dimension of the ring. The cross section of the layer is assumed to be rectangular in shape, and the centroidal axis is employed as the circumferential reference axis of the ring (Fig. 1).

The structure can be either a complete ring or a partial ring with or without slope discontinuities. The geometric shape of the circumferential axis of the ring can be circular or arbitrarily curved. The outward-normal direction is defined in such a manner that as one moves along the circumferential axis in the positive η direction from an arbitrary reference point, the outward-normal direction is always toward one's left as shown in Fig. 2, where XYZ is the global reference Cartesian coordinate system with the X-axis pointing out of the paper. At any point on the circumferential axis, $\bar{i}$ is a local unit vector defined in the same direction as the +X axis, $\bar{a}$ is a unit tangent vector along the positive circumferential axis direction, and $\bar{n}$ is a unit outward-normal vector which is defined by the right-hand rule as $\bar{n} = \bar{i} \times \bar{a}$. Once the positive circumferential direction is defined, the outward-normal direction is then determined accordingly (see Fig. 2). For any given C/D structure, the positive circumferential direction must be chosen so that the positive outward-normal is directed toward the "outside" of the C/D structure such that fragment impact can occur <u>only</u> on the "inside" of the C/D structure.

In the spatial finite-element analysis, the ring is represented by an assemblage of discrete (or finite) elements compatibly joined at the nodal stations. The geometry and nomenclature of a typical arbitrarily curved ring element are shown in Fig. 3, where the deformation plane is η,ζ and the coordinates η along and ζ normal to the centroidal axis of the beam are employed as the reference coordinates of the beam element. The nodal number is increased along the positive circumferential direction.

The behavior of each finite-element is characterized by a knowledge of the four generalized displacements: v, w, $\psi = (\partial w/\partial \eta) - (v/R)$, and $\chi = (\partial v/\partial \eta) + (w/R)$ at each of its nodal stations where v and w are the reference plane displacements in the tangential and normal direction, respectively; R is the radius of curvature. The displacement behavior within each finite-element is represented by a cubic polynomial in η for the circumferential displacement v and a cubic polynomial in η for the normal displacement w, anchored to the four generalized nodal displacements at each node (see Appendix A and/or Ref. 1 for further details). For application to arbitrarily curved, variable thickness, ring structures, the finite elements are described by reading in at each nodal station (and each element end, for slope discontinuity) the global Y and Z coordinates, the slope (the angle between the tangent vector and the +Y axis), and the thickness. Within each finite element, the slope is approximated by a quadratic function in η and the thickness of each element is approximated as being piecewise linear between nodes.

As for the support conditions of the structure, the program includes two types of prescribed nodal displacement conditions (see Fig. 4a):

(1) Ideally-Clamped $(v = w = \psi = 0)$

(2) Smoothly-Hinged $(v = w = 0)$

and two types of elastic restraints (see Fig. 4b):

(a) Point elastically restrained (elastic restoring spring) at given locations (3 directions: normal, tangential, and torsional)

(b) Distributed elastically restrained (elastic foundation) over a given number of elements (3 directions: normal, tangential, and torsional).

A global effective stiffness matrix supplied by the elastic foundation and/or the restoring springs will be evaluated in the program from the virtual-work statement, for the case in which the structure is subjected to one or both of these two types of elastic restraints.

The 2-d containment/deflector (C/D) structure may also be regarded as being supported by attachment brackets as depicted, for example, in Fig. 4c. These attachment brackets (or branches) are idealized to behave in the 2-d fashion shown in Fig. 4d. These brackets are modeled as consisting of a single-layer, variable-thickness, 2-d structure of arbitrary initial shape in the plane of the C/D structure, and are connected compatibly with the C/D structure; the other end of each bracket may be supported in any of the common fashions (clamped, pinned, elastic support, etc.). The program provides for a maximum of five support brackets. In the fragment attack, usually only the C/D structure suffers physical impact; however, if the analyst has a physically plausible situation wherein the idealized support bracket could be impacted by a fragment (such a case is depicted in Fig. 4d), the impacted portion must be defined as the main C/D structure since impacts on a branch are not accommodated in this program. It should be noted, however, that the actual brackets in the bracket-supported C/D structure (see Fig. 4c) must undergo 3-d deformation -- this aspect is not accommodated in the present 2-d model. Finally, a support bracket (or branch) may be attached to any nodal station of the main 2-d C/D structure.

The main structure and branches can be of different elastic, or elastic, perfectly-plastic or elastic-strain-hardening behavior. The strain-rate effects of the material can also be taken into account. In the present analysis, the strain-hardening material is accounted for by using the "mechanical sub-layer model" (Ref. 1). A useful feature of this model is the inclusion of kinematic hardening and the Bauschinger effect. The strain-rate effect is approximated by assuming that the uniaxial stress-strain curve is affected by strain-rate only by a quasi-steady increase in the yield stress above the "static" value (Ref. 1)

2.2 Fragment/Ring Collision-Interaction Analysis

For analyzing the collision induced transient responses of two-dimensional containment and/or deflector rings and fragment motions, the fragment is idealized as a non-deformable fragment of circular configuration (Fig. 5). The modeled-fragment diameter, mass, mass moment of inertia, and velocity components are specified by the user to correspond with those of the actual fragment.

The process called the collision-imparted velocity method (CIVM) is used for the collision-interaction analysis (see Refs. 1-3). In this process, energy and momentum considerations are employed to predict the collision-induced velocities which are imparted to the fragment and to the impact affected zone of the ring. Also, the following simplifying assumptions are invoked:

(1) The collision process is instantaneous and involves only the fragment and the impact-affected zone of the target ring. The impact affected zone is defined as the fraction of the ring that responds to fragment impact instantaneously with momentum changes. The size of the impact-affected zone of the ring can be estimated from the speed of a longitudinal wave or from semi-empirical data.

(2) In an overall sense, the fragment is treated as being rigid but at the "immediate contact region" between the fragment and the struck ring the collision process is regarded as acting in a perfectly elastic ($e = 1$), perfectly inelastic ($e = 0$), or an intermediate fashion ($0<e<1$), where e represents the coefficient of restitution.

(3) The colliding surfaces of both the fragment and the target ring may be either perfectly smooth ($\mu = 0$) or may be "rough" ($\mu \neq 0$), where μ denotes the coefficient of sliding friction. Hence, respectively, force and/or momentum (or velocities) are transmitted only in the normal-to-surface direction or in both the normal and the tangential direction.

(4) During the collision, the contact forces are the only ones considered to act on the impact-affected region of the ring and in an anti-parallel fashion on the fragment. Any forces which the ring segment on either side of the impact-affected region may exert* on that segment as a result of this instantaneous collision are considered to be negligible because this impact duration is so short as to preclude their "effective development".

(5) To avoid unduly complicating the analysis and because of the smallness of the arc length of the ring finite elements, each affected

*Such forces are termed "internal forces" as distinguished from the "external impact forces".

ring element is treated as a straight beam segment (see Fig. 6) in the derivation of the impact inspections and equations. However, for modeling of the ring itself for transient response predictions, the ring is treated as being arbitrarily curved and of variable thickness.

An information flow schematic of the CIVM procedure is shown in Fig. 7. Briefly, the analysis procedure indicated in Fig. 7 consists of the following principal steps:

1. Motions and Positions of Bodies

The motions of the fragment and of the containment and/or deflector ring are predicted and the (tentative) region of space occupied by each body at a given instant in time is determined.

2. Collision Inspection

Next, an inspection is performed to determine whether a collision has occurred during the small increment (Δt) in time from the last instant at which the body locations were known to the present instant in time at which the body-location data are sought. If a collision has not occurred during this Δt, one follows the motion of each body for another Δt, etc. However, if a collision has occurred, one proceeds to carry out an (approximate) calculation of the time of fragment-ring contact.

3. Contact-Time Calculation

The fragment and ring-node positions, velocities, and accelerations are known at an instant in time prior to ring-fragment collision. Using this information, the (approximate) time of ring-fragment contact (within the small increment, Δt, in time), and the point of contact on the ring are calculated. When this information has been obtained, one then proceeds to carry out a collision-interaction calculation.

4. Collision-Interaction Calculation

In this calculation energy and momentum conservation relations are employed in an approximate analysis to compute the collision-induced changes in (a) the velocities V_f (translation) and ω_f (rotational) of the fragment and (b) nodal velocities of the ring impact-affected segments. The coordinates which locate the positions of the fragment and of the affected segments are thereby corrected from their tentative uncorrected-for-impact locations.

One then returns to step 1, and the process is repeated for as many time increments as desired.

The details of this analysis procedure as well as various considerations and simplifying assumptions employed are discussed further in Appendix A.

2.3 Solution Procedure

The spatial finite-element approach is utilized in conjunction with the Principle of Virtual Work and D'Alembert's Principle to obtain the equations of motion of the structural ring which is permitted to undergo large-deflection elastic-plastic transient deformations. In the interest of conciseness and convenience in this report, the user is invited to consult Ref. 1 and/or Appendix A for a detailed derivation and discussion of the equations of motion. For present purposes, it suffices to note that the governing equations of motion for the complete assembled discretized structural ring correspond to the unconventional (improved) formulation of Ref. 1 and may be written in the following form[+]:

$$[M^*]\{\ddot{q}^*\} + \{P^*\} + [H^*]\{q^*\} + [K_s^*]\{q^*\} = \{0\} \qquad (2.1)$$

where

$\{q^*\}$ and $\{\ddot{q}^*\}$	are the global generalized displacement vector and acceleration vector.
$[M^*]$	is the mass matrix of the complete structure.
$\{P^*\}$	is a "generalized loads" vector representing both elastic and some plastic behavior contributions.
$[H^*]\ \{q^*\}$	represents "generalized loads" arising from both large deflections and plastic strains.
$[K_s^*]$	represents the effective stiffness matrix supplied by the elastic foundation and/or the restraining spring.

In the present procedure, a diagonal "lumped" mass matrix is employed. The justification for the use of lumped mass instead of consistent mass is outlined next. A comparison of numerical results obtained using lumped mass

[+]The right-hand side of Eq. 2.1 is zero since it is assumed that there are no prescribed externally-applied forces acting.

vs. consistent mass, given in Ref. 1, for ring-type structures shows similar results for both mass systems. The use of a lumped mass matrix also results in a decrease of the highest natural frequency, compared with the use of a consistent mass matrix, for the assembled structure, and thus permits one to use a larger time step, Δt, for the structural response calculations (as will be described shortly). This fact, coupled with reduced storage requirements and additional savings of computation time in each time step because of the simple form of the mass matrix, makes the use of a lumped mass matrix computationally efficient. Finally, in the collision interaction analysis the element (and structure) mass properties are assumed to be lumped at the nodal points. Thus, for consistency, the mass properties of the ring structure used in the global timewise solution procedure should also be nodal lumped masses.

The resulting equations of motion are solved through the use of the 3-point central difference time operator whereby one obtains a recurrence equation which provides a solution step-by-step in finite-time increments. Based on computing experience, this operator is much more simple and requires a minimum of storage and operations (compared, for example, with the Houbolt operator) within each time step of calculation for advancing the solution ahead in time. However, it should be noted that in order for the 3-point central-difference operator to provide a reliable prediction, the time step size, Δt, employed must be small enough. To insure a suitably small Δt, the following procedures are built into the computer program utilizing this central-difference operator so that the time-step size, Δt, can be either specified by the user or the program will compute the largest natural frequency, ω_{max} of the system and will then choose a value of $\Delta t_{max} = 0.8\ (2/\omega_{max})$, where $\Delta t \leq 2/\omega_{max}$ is the stability criterion of a corresponding linear dynamic system; the factor 0.8 is introduced in order to take large-deflection effects into account. The ω_{max}, which represents the largest natural frequency contained in the (linear) mathematical model of the structure, is obtained by an iteration process applied to

$$\omega^2 [M^*]\{q^*\} = [K^*]\{q^*\} \tag{2.2}$$

where [K*] is the usual elastic stiffness matrix of the structure which is used only for the calculation of allowable Δt, and is not employed in the global timewise solution because of the use of Eq. 2.1 in place of the "conventional" equations of motion.

Following the calculation of the allowable Δt, the equation of motion is solved by using the central difference operator. Also, a collision inspection and correction procedure is carried out for each time-step of the advancing calculation. In the following, the general solution process is described briefly.

First, information is provided to define the geometry of the ring including its prescribed displacement conditions and elastic restraints. In addition, the ring material property constants and the attacking-fragment parameters are defined. Also defined is the structural discretization information and numerical integration data. It should be mentioned that Gaussian quadrature is employed in the present analysis to evaluate the element-property matrices -- this requires that the stresses and strains be evaluated at a selected finite number of Gaussian stations over the "spanwise" and depthwise region of each finite element. Next, the mass matrix and the stiffness matrix for the entire structure are evaluated by assembling the element mass and stiffness matrices. Then the proper prescribed displacement conditions are imposed and a reduced mass matrix and stiffness matrix are obtained by deleting the corresponding rows and columns associated with those generalized displacements which are prescribed to be zero. Also constructed are the discrete element property matrices that do not change with time (and remain constant throughout the program), such as the matrices relating strain to the nodal generalized displacements, etc. The maximum natural frequency, ω_{max}, of the structure is then calculated from Eq. 2.2, and the maximum allowable step size, Δt_{max}, is found. This value is compared with the user specified value of Δt, and the smaller of the two values is chosen for the timewise solution procedure. If the user has chosen the time-step "over-ride" option, the user specified Δt will be used.

The ring structure is assumed to be at rest at time t_o, and the position and velocity of the attacking fragments are known at time t_o. From this information the generalized nodal and fragment displacements and displacement increments are computed for the first time increment Δt. Then, the fragment-ring collision inspection and correction procedure is carried out. If one, or more, ring-fragment collisions have occurred during this Δt, the coordinates which locate the position of the fragment and impact-affected nodes of the ring are thereby corrected from their tentative uncorrected-impact locations. Next, the strain increment developed from t_o to t_1 at every Gaussian station (or point) required over and depthwise through each finite element are calculated. From a knowledge of the prescribed initial stresses (if any) and the strain increments, one can determine the stress increments, the stresses, and/or the plastic strains and the plastic strain increments through the use of the pertinent elastic-plastic stress-strain relations including the plastic yield condition and flow rule. Next, one can calculate the equivalent generalized load vectors arising from large deflections and plastic strains. Then, the proper recurrence equations, which is the finite-difference representation of the equations of motion, are solved to obtain the ring-nodal generalized displacements and displacement increments of the next time increment. The pertinent equations of motion for the fragment are also solved to obtain the displacements and displacement increments of the next time increment for each attacking fragment. The process then proceeds cyclically for as many time steps as desired. It should be noted that the ring structure remains at rest until the first ring-fragment collision occurs.

For the present purposes, the above general description is considered to be adequate; one may consult Appendix A and Refs. 1-3 for a more detailed discussion of the solution and evaluation process.

SECTION 3

DESCRIPTION OF PROGRAM AND SUBPROGRAMS

3.1 Program Contents

The CIVM-JET 4B program is composed of a main program and 23 subroutines which appear in the program in the order listed. The names and functions of these programs are as follows.

MAIN — Reads the ring geometry, material property data, the structural discretization information, and/or the prescribed displacement conditions and elastic restraints. Also, read in are the fragment geometry parameters and the fragment velocity components. It computes the quantities that are constant throughout the program and initializes most of the variables used in the subroutines. It controls the logical flow of information supplied by the various subroutines and the overall time cycle. Also, the lumped mass matrix ⌈M*⌋ is generated by this routine and stored in row form.

ASSEF — This subroutine assembles the generalized nodal load vectors (due to large-deflection elastic-plastic effects) of each individual element into a generalized nodal load vector for the structure as a whole.

ASSEM — This subroutine updates the structural stiffness matrix as the element stiffness matrix is generated. The components of the assembled stiffness matrix [K*], which is a symmetric matrix, are stored in a linear-array form; only the lower triangular part of [K*] need be and is stored (row-wise) starting with the first nonzero element in the row and ending with the diagonal term.

BRAN — This subroutine reads the geometry, boundary constraints, and elastic restraints for a branch. The global numbering system of the main structure is then modified to include the branches. BRAN establishes arrays which contain information facilitating the rotations required in other subroutines. It also establishes identifier arrays which distinguish between elements of the main structure and elements of the various branches.

CUBIC — A slave subroutine of ROOT4. Used to calculate one real root of a cubic equation.

DINIT — This subroutine initializes all ring response calculation vectors and advances each of N fragments to its location at a time (which is user specified) prior to initial impact.

ELMPP — This subroutine evaluates the element stiffness matrix [k], for each discrete element, and then performs discrete element assembly to form [K*] for the complete structure with respect to global coordinates. Next, the prescribed displacement conditions (if any) are imposed on [K*] to form a restrained matrix. Also evaluated are the transformation matrices between the strain at each spanwise checking (Gaussian, or other) station and the generalized nodal displacement conditions of the element.

ENERGY — Computes the energies of the fragment and the ring at each printout cycle. The ring energies are subdivided into the plastic energy, elastic energy, kinetic energy, and energy absorbed in the elastic foundations.

ERC — Imposes the proper prescribed displacement conditions to the [K*] matrix by restraining the corresponding rows and columns of the matrix.

FICOL — Finds the corresponding location of an element in the linear array expression to a location in a two dimensional array expression of the [K*] matrix.

IDENT — The IDENT subroutine is used to print out the values of certain input parameters at the beginning of the run, and is used to identify the type of run that is being made.

IMPACT — This subroutine is the controlling routine for carrying out the search for impact occurrence involving one of N fragments on each element of the ring for all fragments considered. When it is determined that a fragment-ring collision has taken place, IMPACT controls the application of appropriate correction factors to the velocities of the fragment and the nodal points of the affected elements.

IMPCTE — A slave subroutine of IMPACT. This subroutine calculates and applies the appropriate correction factors to the velocities of the fragment and the nodal points of the elements affected when a fragment-ring collision has occurred.

MINV — Performs the matrix inversion; a standard Gauss-Jordan inversion method is used.

OMULT — Performs the multiplication of a square matrix (stored as a vector) and a vector. A vector results.

PENTRN — A slave subroutine of IMPACT. Given the position of the fragment and ring nodes and the geometry of the fragment and idealized ring structure, this subroutine determines whether any "overlapping" (penetration) exists between the fragment geometry and the ring geometry.

PRINT — PRINT controls the program output and format.

QREM — Evaluates the effective stiffness matrix $[K_s^*]$, supplied by the elastic foundations and/or the restoring springs, and then imposes the prescribed displacement conditions on $[K_s^*]$ accordingly.

ROOT4 — A slave subroutine of TCONT. ROOT4 solves the quartic equation which is encountered in the calculation of the time of fragment-ring contact. Only real roots are calculated (imaginary roots have no meaning here).

ROTAT — This subroutine generates the transformation matrix necessary to rotate from the global displacement system to the element displacement system. This matrix is then applied to the element [k] matrix, the displacement vector and the equivalent load vector (as required) to perform the rotation for the connecting branch elements and any elements containing discontinuities.

STRESS — This subroutine evaluates the generalized load vectors, (R.H.S. of Eq. A.30a) arising from the presence of large-deflections and plastic strains. First, the stresses and plastic strains are determined at each quadrature station, which involves the use of the strain-displacement relation and the stress-strain relation. The strain-hardening and strain-rate sensitivity effects are taken in consideration. Next, the appropriate Gaussian integration scheme is used to form the element generalized nodal load for each discrete element, and finally, an assembled generalized nodal load vector is calculated.

TCONT A slave subroutine of IMPACT. This subroutine determines the (approximate) real time at which contact of the fragment onto the ring occurs (within a given increment in time). TCONT calculates the time of contact, element contacted, point(in space) of contact, and the fragment involved in this fragment-ring contact.

TSTEP This subroutine is called during each problem run to compute Δt_{max} and to constrain the user-specified Δt to be $\leq \Delta t_{max}$. It finds the highest natural frequency, ω_{max}, in the mathematical model of a corresponding linear dynamic system $[M^*] \{\ddot{q}^*\} + [K^*] \{q^*\} = 0$ by using an iteration process, and then calculates a value of $\Delta t_{max} = 0.8\ (2/\omega_{max})$.

UPDATE A slave subroutine of IMPACT. This subroutine calculates the position of the ring nodes and fragment c.g. at time t_1 given the position, velocity, and acceleration of the ring nodes and fragment c.g. at time t_o (where t_1 may be greater than or less than t_o).

3.2 Partial List of Variable Names

A(I,J) [A], an 8x8 matrix defines the transformation between the element generalized nodal displacements $\{q\}$ and the parameters $\{\beta\}$ in the assumed displacement field of each element. It is destroyed in computation and is replaced by its inverse $[A^{-1}]$.

AA(JR,I,J) A matrix that stores all of the $[A^{-1}]$ matrices.

ADOT(I) The angular velocity of the Ith fragment (rad/sec). Positive sign denotes counter-clockwise rotation.

AEP(I,J,K) Transformation matrix which relates strain at Ith additional strain point to the generalized nodal displacements of the element on which it is located.

AINT Pre-impact approach velocity of the fragment-impacted ring element system normal to the ring element relative to the fragment.

AL(I) Element arc length of the Ith element.

ALFA(I) Angular rotation of fragment I (rad.).

ANB(I) Same as ANG(I), applies to initial input for branch nodes.

ANG(I) The slope, which is the angle between the tangent vector and the +Y axis, at the Ith node.

ANGDB, ANGDI(I) The slope, which is the angle between the tangent vector and the +Y axis, at the Ith slope discontinuity. ANGDB refers to initial input for branches.

APHA The angle between the chord connecting the first node of the element to the second node, and the +Y axis.

APN Fragment-induced impulse normal to the impacted ring element surface.

APT Fragment-induced impulse tangential to the impacted ring element surface.

ASFL (I,J,K,L) Stress and/or plastic strain weighting factor on the Lth sublayer in the Kth depthwise Gaussian point at the Jth spanwise Gaussian station of the Ith element.

AXG(I), AWG(I) Input vectors with dimension NOGA: contain Gaussian quadrature constants, x_i, and weights, W_i of

$$\int_0^1 f(x)\,dx = \sum_i f(x_i) W_i$$

employed in the spanwise integration over each element.

B(L) Width of the ring (inches); L=1 for main structure; $L\geq 2$ for branches.

BEP(IR,J,I,K) Transformation matrix which relates the strain at the Jth spanwise Gaussian station to the generalized nodal displacements of the IRth element ($[D_I]$, I = 1,2,3, see Eq. A.14).

BI(L) Same as BIG(L), for largest average nodal strain.

BIG(L) The largest computed strain at the Gaussian stations for the Lth substructure , up to the present cycle. It should be noted that strains are computed at every cycle. L=1 for main structure, $L\geq 2$ for branches.

BIGA(L)	The largest computed strain at the additional strain points, up to the present cycle.
BINP(I,J) BIMP(I,J)	The longitudinal force and the bending moment, respectively, over the cross section at the Jth spanwise Gaussian station of the Ith element (see Eq. A.26).
BØNE	The highest natural frequency squared of a corresponding linear dynamic system.
BTIM(L)	Same as BTIME(L), applies to nodes.
BTIMA(L)	The time at which the largest computed strain occurs at the additional strain points. L=1 for main structure, L≥2 for branches.
BTIME(L)	The time at which the largest computed strain occurs at the Gaussian stations.
CELAS	Elastic energy stored in ring up to the present time.
CINETF	Kinetic energy stored in fragment up to the present time.
CINETO	Kinetic energy imparted to ring up to the present time.
CØPY(I) CØPZ(I)	Current global Y coordinate and Z coordinate, respectively, of the Ith node.
CR(J)	Coefficient of restitution between the Jth fragment and the impacted ring surface.
DALFA(I)	Impact-corrected angular displacement increment of the Ith fragment at the current time step.
DCRTE	Critical distance used in calculating where a positive penetration has occurred between a fragment and a ring element. It is equal to the fragment radius plus one half the mean element thickness.
DELD(I)	Vector contains the generalized nodal displacement increment during the current time step.
DELTAT	Time-step size used in the program, Δt.
DELTR	Time remaining during a time step Δt. Used in impact inspection and correction calculations.
DENS(L)	Density of the Lth structural segment. L=1 for main structure, L≥2 for branches ($lbs\text{-}sec^2/in^4$).

DFCGU(I)	Impact-corrected Y direction displacement increment applied to the position of fragment I.
DFCGW(I)	Impact-corrected Z direction displacement increment applied to the position of fragment I.
DISP(I)	Vector which contains the generalized nodal displacements at the current time instant.
DROT(L)	Stores information used in rotating a displacement vector into the global system at a point of slope discontinuity.
DS(L)	Material constant used in the strain-rate sensitivity formula. L=1 for main structure, L$\geq$2 for branches.
DUMMY	A dummy argument in the calling statement of Subroutine ROTAT.
EFLN(L)	The effective impact length of the ring (inches). L=1 for main structure. L$\geq$2 for branches.
ELK(I,J)	Element stiffness matrix of dimension 8x8 (Eq. A.18d).
ELMAS(I,J)	Element mass matrix of dimension 8x8 (Eq. A.16).
ELRP(I,J)	Element effective stiffness matrix of dimension 8x8 supplied by elastic restraints.
EPS(L,J)	Input quantities of abscissa of the uniaxial stress-strain curve for the Jth mechanical sublayer material model. L=1 for main structure, L$\geq$2 for branches.
EPSI(I) EPSØ(I)	Average axial strain on the inner surface and on the outer surface, respectively, at node I.
EXANG	If EXANG=360.0, the structure is considered to be a complete ring. If EXANG $\neq$ 360.0, the structure is considered to be a partial ring.
FACTFN	Impact-induced correction factor applied to the normal-to-impact displacement increment of the attacking fragment at the time of contact.

FACTFT Impact-induced correction factor applied to the tangential-to-impact displacement increment of the attacking fragment at the time of contact.

FACTFO Impact-induced correction factor applied to the rotational displacement increment of the attacking fragment at the time of contact.

FACTN Impact-induced correction factor applied to the normal-to-impact displacement increment of each affected node.

FACTT Impact-induced correction factor applied to the tangential-to-impact displacement increment of each affected node.

FARE, FCUR Midplane axial strain and curvature increment, respectively, at the selected spanwise Gaussian station of each element.

FCGU(I) The global Y coordinate of the centroid of the Ith fragment.

FCGW(I) The global Z coordinate of the centroid of the Ith fragment.

FLVA(I) Assembled generalized load vector corresponding to large deflections and plastic strain presence; it equals {P*} + [H*] {q*}.

FMASS(I) The mass of the Ith fragment ($lb\text{-}sec^2/in^4$).

FMØI(I) The mass moment of inertia of the Ith fragment ($lb\text{-}sec^2\text{-}in$).

FREQ The highest natural frequency of a corresponding linear dynamic system of the ring.

GFL(IR,I,J) Stress and/or plastic strain weighting factor on the Jth depthwise Gaussian point at the Ith spanwise Gaussian station of the IRth element.

GZETA(IR,I,J) Distance from the centroidal axis to the Jth depthwise Gaussian point at the Ith spanwise Gaussian station of the IRth element.

H(I) Thickness of the ring at the Ith node.

HB(I) Same as H(I), applies only to initial input for branches.

HTH(L) The branch thickness for the Lth branch at its connecting node.

IBI(L)	Same as IBIG(L), applies to nodes.
IBIG(L)	The element number whose strain, computed at one of its Gaussian stations, exhibits the largest value during the present computer run. L=1 for main structure, L≥2 for branches.
IBIGA(L)	Same as IBIG(L), applies to additional strain points.
ICØL(I)	Vector, of length NI, contains the column number of the first non-zero entry in the Ith row of the structural mass and/or stiffness matrix.
ICON	INDICATOR = 0 if last data input 1 if more runs are desired
ICONT	INDICATOR, if >0 then the program expects data for a continuation run.
IFLAG(I,J)	A flagging matrix which indicates whether element I has been impacted by fragment J during a given time step, Δt.
IK	Number of discrete elements into which the whole structure is discretized for analysis.
IMCO	Indicates the occurrence of an impact in the previous time cycle.
IMCOU	Indicates the number of impacts up to the present time instant.
INUM(I)	Vector of dimension NI contains the corresponding position in the linear-array of the first nonzero entry in the Ith row of the structural mass or stiffness matrix.
IRRUN	A counter: is equal to the number of runs of CIVM-JET 4B in a single computer submittal.
ISTA(I)	The number of the Gaussian station at which the strain is a maximum.
ISTAA(I)	The number of the additional strain point at which the strain is a maximum.
ISIZE	Number of locations required for the storage of the structural mass or stiffness matrix in linear-array form.
ISUR(L)	Same as ISURF(L), applies to nodes.
ISURA(L)	Same as ISURF(L), applies to additional strain points. L=1 for main structure, L≥2 for branches.
ISURF(L)	INDICATOR = 1 if largest computed strain occurs on inner surface = 2 if largest computed strain occurs on outer surface Refers only to strains calculated at Gaussian stations.

IT	Current time-step (cycle) number.
JF	The fragment number which is involved in the ring segment impact.
KII	Number of nodes included in impact-affected region.
KRØW(I)	The row number of the Ith irregular row in the structural mass or stiffness matrix.
LATT	Indicates how the branch is attached to the main structure: = -1 inner surface = 0 midsurface = 1 outer surface
LBR(I)	The number of a branch upon which a boundary condition is to be applied.
LHIT(I)	Indicator array. I = branch number. If LHIT(I)=0, branch is to be impacted; in the present program LHIT(I) must be set equal to zero.
LMT(I)	Array which stores the element numbers of those branch elements where impact cannot occur.
LNTMIN	Element upon which the first impact has occurred during a given time step.
MATT(L)	Indicates the node at which the Lth branch is attached.
MIRP	Indicates the first fragment that is released at a time after the initial impact.
MK(I)	Vector which contains new nodal numbers for the main structure, given I as the old nodal number.
MKE(I)	Indicates the substructure to which the Ith element belongs.
MM	Time step (cycle) at which run is to stop.
MNEL(I)	Number of elements in the Ith substructure.
M1	Cycle at which regular printing starts.
M2	Printout will occur every M2 cycles.
MPU	Indicator for punched output: IF MPU = 0, no punched output. IF MPU ≠ 0, data is punched from last time cycle.

MREAD, MWRITE, MPUNCH — Number for the data input tape unit, printed output tape unit, and the punched output tape unit, respectively. These names must be assigned a number in MAIN corresponding to the user's computing facility requirements.

NBS(I) — The prescribed-displacement condition identification number.

NBCB(I) — Same as NBC(I), applies to initial input for branches.

NBCØNB — The number of nodes at which the prescribed displacement condition is to be specified: refers only to branches.

NBCØND — The number of nodes at which the prescribed displacement conditions are to be specified.

NBR — Indicates the number of branches that are to be added to main structure (not to exceed 5).

NDEX(I) — The corresponding position in the linear-array of the first non-zero entry in the Ith irregular row.

NDIS — The number of elements containing a slope discontinuity.

NEDI(I) — The main structure element number of the Ith element containing a slope discontinuity.

NEDIB(I) — The branch element number of the Ith branch element containing a slope discontinuity.

NELT(I) — Number of elements in the Ith branch.

NF — The number of fragments considered to be impacting the ring.

NFL — The number of depthwise Gaussian points through the thickness of each layer for the numerical evaluation of stress resultants (axial forces and bending moment) at each spanwise Gaussian station.

NI — Total number of degrees of freedom (unrestrained); it equals the number of nodes times 4. Also, it is the number of rows in the assembled structural mass or stiffness matrix.

NIRREG — Number of irregular rows in the assembled structural mass or stiffness matrix.

NØDBB(I) — The node number along branch (I) at which a boundary condition is to be applied.

NØDEB(I) — The node number at which the prescribed displacement condition NBC(I) is to be specified.

NODP(I) — Nodal number (from main structure numbering system) at which the Ith branch starts.

NØGA — The number of Gaussian stations to be employed for the spanwise numerical integration of the element properties over each element.

NØRP, NØRU — The number of point elastic restraints (elastic restoring springs) and the number of locally distributed elastic restraints, respectively, which are to be specified over the structure.

NPP — Number of positive penetrations during time DELTR.

NQR — Indicator, which if > 0 indicates that this structure is subjected to elastic restraints (point and/or distributed).

NREL(I) — The element number at which the Ith point elastic restraint is to be specified.

NRST(I), NREU(I) — The first element and the number of elements, respectively, over which the Ith distributed elastic restraint is to be specified.

NS — The total number of nodes. For a partial ring NS=IK+1. For a complete ring NS=IK.

NSFL(L) — Equals the number of mechanical sublayers in the strain-hardening material model; also is the number of coordinate pairs defining the piecewise linear stress-strain curve of the substructure's material.

L = 1 for main structure, L $\geq$ 2 for branches.

NTOVR — Allows the user to override the automatic time check.

= 0 (or blank) time check used

= 1 User's DELTAT used regardless of value calculated by subroutine TSTEP

NVEC(I,J) — Array containing nodal numbers which form the end points of the Ith element. J = 1 or 2 [First or second node, number clockwise for main structure, outwards for branches, and inwards for a branch attached to node 1 of a partial ring.]

P(L) — Constant used in the strain-rate sensitivity formula.

L = 1 for main structure, L $\geq$ 2 for branches.

PAL	Fractional distance from point of impact to first node of the impacted element.
PAX	Fractional distance from point of impact to second node of the impacted element.
PIE	Represents π = 3.141592653589793.
PLAST	Total plastic work done on the structure up to the current time step (mechanical work dissipated during plastic flow).
QACL(I)	Vector which contains the generalized nodal accelerations at the current time instant.
QVEL(I)	Vector which contains the generalized nodal velocities at the current time instant.
RCOS(I) RSIN(I)	Cosine and sine, respectively of the angle that element I makes with the global Y axis. Used in transformation from impact to local and local to global coordinate systems.
REX(I)	The length coordinate along the centroidal axis from the node NREL(I) at which the Ith point elastic restraint is to be specified.
RFACTR	Strain rate factor used in the stress calculation.
RL(I)	Straight line length of ring element I used in the collision inspection and correction analysis.
RMASS(I) RMX(I)	Lumped mass and moment of inertia values, respectively, at ring structure node I.
ROT(I,J)	Array which contains information needed to rotate a stiffness matrix. I = Number of branch J = 1 or 2 ROT(I,1) = 0.0 if Ith branch connects to first node of main structure. Equals 1.0 for all other connecting points. ROT(I,2) = Angle of rotation.
RWORK	Total energy stored in ring, up to the current time.
SCTP SCTY	The tangential and normal translational restoring spring elastic constants, respectively.
SCRP	The rotational restoring spring elastic constant.

SCTU, SCTW	Tangential and normal translational elastic foundation stiffness constants, respectively.
SCRU	Elastic foundation modulus in torsion.
SIG(L,J)	Input quantities for the ordinate of the uniaxial static stress-strain curve for the Jth mechanical sublayer material model. L = 1 for main structure; L $\geq$ 2 for branches.
SINT	Relative tangential velocity between the ring impact-affected nodes and an impacting fragment.
SNØ(N,L)	Uniaxial static yield stress of the Nth mechanical sublayer material model. L = 1 for main structure; L $\geq$ 2 for branches.
SNS(I,J,K,L)	Axial stress of the Lth mechanical sublayer at the Kth depthwise Gaussian point at the Jth spanwise Gaussian station of the Ith element.
SNY	Uniaxial yield stress of the mechanical sublayer, taking strain-rate sensitivity into account.
SOL(I)	Contains the solution vector of a series of matrix equations.
SPDEN	Total energy stored in the elastically-restoring springs and/or the elastic foundations at the current time instant.
SPRIN(I)	The assembled effective stiffness matrix supplied by elastic restraints (stored in a linear array form).
STIFK(I)	Assembled structural elastic stiffness matrix, stored in a linear-array form.
TAII	Time of initial impact.
TANX	Boundary between rolling and sliding friction.
TIME	Current time (IT*DELTAT).
TIMF	Time at which all calculations are to stop.
TMIN	Time of first contact $t_{c_{min}}$ measured from start t_m^* of the sub-time step interval (see Eq. A.107).

TNJ(J) Indicates whether or not fragment J has been released before the start of calculations.

TPRIM(J) Length of time that fragment J has been traveling prior to initial impact of the <u>first</u> fragment.

TRAN(I,J) Transformation matrix, used to rotate displacement vector and element stiffness matrices into global coordinates. Used for branch connection and slope discontinuities.

TU(I), TW(I) Trial Y and Z coordinates, respectively, of the Ith node during impact calculations.

TWG(I), TXG(I) Input vectors with dimension NFL; contain Gaussian quadrature constants x_i and weights, W_i of

$$\int_{-1}^{+1} f(x)\,dx = \sum_i f(x_i) W_i$$

used in the numerical integration of stresses and/or plastic strains through the thickness.

UDOT(J) The velocity component of the Jth fragment parallel to the global Y axis.

UNK(J) Coefficient of friction for the Jth fragment.

VEL(I) Vector contains post impact nodal velocities.

VELFA(J), VELFU(J), VELFW(J) Same as: ADOT(J), UDOT(J), WDOT(J) used in impact calculations

WDOT(J) The velocity component of the Jth fragment parallel to the global Z axis.

XDIST(I) Distance from reference axis to attachment point of Ith branch.

YK(I) A general work vector. It is finally used to store either the number 1 or 0 for each element (I) to indicate whether a transformation is necessary. YK(I) is used together with ROT(I,J) to identify and aid in rotating an element's stiffness matrix.

YØUNG(L)	Elastic (Young's) modulus (the slope of the 1st segment in the piecewise linear approximation of the uniaxial stress-strain curve). L = 1, main structure; L $\geq$ 2 for branches.
Y(I) Z(I)	Initial Y coordinate and Z coordinate, respectively, of the Ith node.
YB(I) ZB(I)	Same as Y(I) and Z(I); applies only to branch nodal input.

SECTION 4

USE OF THE CIVM-JET 4B PROGRAM

4.1 Input Information and Procedure

The information required to punch a set of data cards for a run of the program is presented in a step-by-step manner in this section. The variables to be punched on the nth data card are shown, and to the right is the format to be used for that card; the definition of and some restrictions for each variable are given directly below. This is done for each card, in turn, until all are described.

Card 1	Format
B(1), DENS(1), EXANG	3D15.6

where

B(1)	The width of the main structure (inches) (other structural portions are called "branches")
DENS(1)	The material density of the main structure $(lb\text{-}sec^2)/in^4$
EXANG	The angle (in degrees) that the ring subtends: for a complete ring, EXANG = 360.0; for a partial ring, EXANG ≠ 360.0.

Card 2	
IK, NOGA, NFL, NSFL(1), MM, M1, M2, NF, TIMF	8I5,D15.6

where

IK	The number of finite elements used to model the main structure. The total number of elements, including branch elements cannot exceed 50 (however, this limitation may be relaxed by changing the appropriate dimension statements of the program).
NOGA	The number of spanwise Gaussian stations to be used for the spanwise numerical integration over each element in evaluating the element property matrices. NOGA=3 is used in CIVM-JET 4B.
NFL	The number of depthwise Gaussian points to be used for the numerical integration through the thickness at each spanwise Gaussian station. This number cannot exceed 6.
NSFL(1)	See Card 5A for description.

MM	The cycle number at which the run is to stop.
M1	The cycle number at which the regular printout is to begin. M1 must not equal 0.
M2	The number of cycles between regular printout (i.e., print every M2 cycles).
NF	The number of fragments considered to be impacting the ring. This number cannot exceed 6.
TIMF	The time at which the program will stop all calculations.

Card 3A

Y(1), Z(1), ANG(1), H(1) 4D15.6

where

Y(1) Z(1)	Initial Y coordinate and Z coordinate, respectively, of the first node (inches).
ANG(1)	The slope (degrees) which is the angle between the tangent vector and +Y axis at the first node. An angle from the +Y axis to the tangent vector in a counter-clockwise direction is defined as the positive direction.
H(1)	The thickness of the ring (inches) at the first node.

Additional Cards 3B, 3C,... are punched in exactly the same format as Card 3A until the total number of No. 3 cards equals the total number of nodes of the main structure (IK+1) for a partial ring and equals IK for a complete ring, where IK is the value appearing on Card 2.

Also the following two conditions must be satisfied by ANG(I) (where I is the node number):

(1) $-180^{\circ} < \text{ANG(I)} \leq +180^{\circ}$

(2) An element cannot have a change in slope between its first node and its second node that is greater than 15°. This refers only to the shape of one element (see Fig. 3); slope discontinuities between two elements are handled on Card 4.

Note that for bookkeeping purposes, the nodal slope is defined to be identified with the first end (left-hand end) of the element at that node for structures with continuous slopes. However, where a slope discontinuity occurs on the main structure, a node must be used and two slopes must be given: (1) one (given on Card 3) associated with the second end (right-hand end) of the pertinent element and (2) one associated with end one (L-H end) of the next element; the item (2) situation is dealt with by Cards 4A, 4BA, 4BB, 4BC, etc.

Card 4A

NDIS I5

where

NDIS The total number of elements in the main structure having a slope discontinuity at the first node of the element.

If there are no slope discontinuities on the main structure, set NDIS = 0 and go to Card 5.

Card 4BA

NEDI(I), ANGDI(I) 4(I5,D15.6)

where

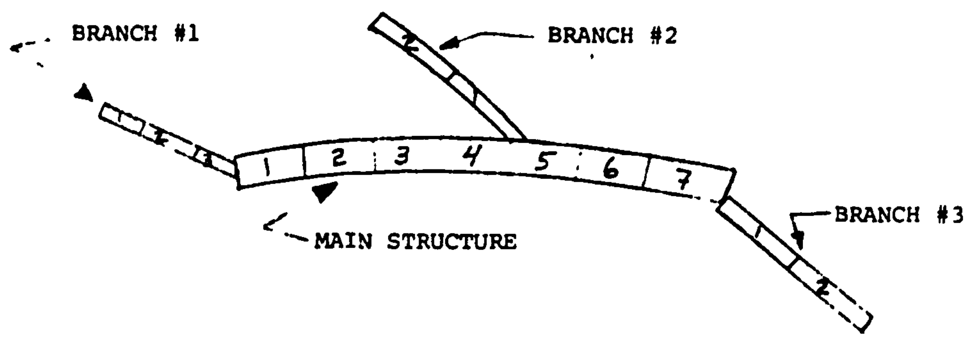
I = 1, NDIS

NEDI(I) The element (on the main structure) at which the Ith slope discontinuity appears on the element's first node.

ANGDI(I) The appropriate slope (degrees) for the Ith slope discontinuity; the slope is measured between the tangent vector to the element at the station in question and the +Y axis (see Card 3A, ANG(1) for a description of the measurement system).

Additional Cards 4BB, 4BC, etc. are used until all of the "slope discontinuities" are described. (See Fig. 8 for a further description of the discontinuity option.)

The sequence of cards starting with Card 5 and going through Card 5DB contains all of the data for branches to be applied to the main structure, except that elastic restraints must be handled as one unit on Card 15. If no branches are to be applied, Card 5 has NBR=0; then proceed to Card 6. Only 5 branches are allowed, with a maximum of 10 elements in any one branch. A branch may not be connected to another branch. Branches may be attached to any node on the main structure, or to the inner or outer surface of the main structure at any node but only one branch may be connected to a given main-structure node. Note that if a complete-ring primary structure is specified, no branch may connect to node 1 of the primary structure. The following sketch shows typical permissible arrangements of the branches:



Note the difference in the numbering schemes for branch 1 compared with branches 2 and 3; the last geometry input card for a branch pertains to its junction with the main structure. Numbering of the primary structure is done independent of any branches. Typical branch numbering is given in the above sketch. Note that all numbering in the above sketch is done in each substructure's system. The program will renumber (in a clockwise manner) the entire finite element system.

The following describes the sequence of Cards (5A through 5DB) needed to accommodate branches (these cards are nested in such a way that each branch's material and geometric properties are specified, branch by branch, followed by slope-discontinuity information for all branches, followed by boundary condition information for all branches):

Card 5	FORMAT
NBR	I5

where

NBR The number of individual branches being added to the main structure (NBR≤5).
If NBR=0 GO TO CARD 6

Card 5A

NSFL(L), B(L), DENS(L), DS(L), P(L) I5,4D15.6

where

L=2, NBR+1, (L-1) is the branch number, and the values of these variables when L=1 are equal to the main structure's material.

NSFL(L) The number of mechanical sublayers in the strain-hardening model of the material of the (L-1) branch, and is equal to the number of coordinate pairs defining the polygonal approximation of the stress-strain curve of the material (NSFL(L)≤5).

B(L) Width of the (L-1) branch (inches).

DENS(I) Mass density of the (L-1) branch $(\text{lb-sec}^2)/\text{in}^4$

DS(L) } See Card 6
P(L) } (L-1) Branch

Card 5AA

EPS(J,L), SIG(J,L) 4D15.6

where

J = coordinate pair number ≤ 5

(L-1) = branch number ≤ 5

EPS(J,L) } See Card 7 for definition of quantities
SIG(J,L) }

Additional Cards 5AB and 5AC are punched in exactly the same manner as Card 5AA until the number of coordinate pairs equals NSFL(L) punched on Card 5A. Do not include any unneeded (blank) cards.

Card 5B

NELT(I), NODP(I), LHIT(I), LATT(I) 4(I5)

where

I = 1,5 is the branch number

NELT(I) Number of elements in Ith branch (NELT(I)≤10)

NODP(I)   Node of main structure (in original numbering system) at which Ith branch is attached. See figure on page 31.

LHIT(I)   Determines whether or not branch can be impacted:

LHIT(I)=0   No impact

LHIT(I)=1   Impact

Note: In the present CIVM-JET 4B program, a branch cannot be impacted; set LHIT(I)=0 for all branches.

LATT(I)   Determines where branch is to be attached.

LATT(I)= -1   inner surface

0   midsurface of the main structure

1   outer surface

Card 5BA

YB(I,J), ZB(I,J), ANB(I,J), HB(I,J)   4D15.6

where   (I = branch number, J = node number). Nodes are to be numbered 1 to 10 where node 1 is the first node of a branch (not attachment point). Node is on circumferential axis of branch.

YB(I,J)   Y coordinate of node (inches)

ZB(I,J)   Z coordinate of node (inches)

ANB(I,J)   Tangent angle measured to Y axis (degrees); see angle θ of Fig. 3.

HB(I,J)   Thickness at node J

Note: See Card 3A [ANG(1)] for sign convention used for ANB(I,J).

Note: If a branch attaches to node 1 of a partial ring (it can not be attached to node 1 of a complete ring), the numbering starts with the branch node farthest away from the attachment point. Therefore, the (NELT+1) node is the attachment point. If the branch attaches to any other node of the primary structure, start numbering with the node immediately after the attachment point. Thus, node NELT will be the node farthest away from the attachment point. However, node (NELT+1) will always be the attachment-point node. Thus nodes 1 to NELT are always particular only to the branch, and node (NELT+1) is the common node with the primary structure. The subroutine BRAN automatically updates IK (the total number of elements), NS (number of nodes), and NI (D.O.F.). Therefore, the initial input (Cards 1-4 and 6-14) is punched as though the branches did not exist.

Cards 5BB, 5BC, etc., are punched until (NELT+1) nodes have been described.

Card 5C

NDISB I5

where

NDISB The number of elements in the branches having a discontinuity at their first node. (Do not count the discontinuities due to the attachment of the branch to the main structure.)

If there are no discontinuities on the branches, set NDISB = 0 and go to Card 5D.

Card 5CA

NEDIB, NBDI, ANGB 2I5,D15.6

where

NEDIB The element number (along a branch) at which the discontinuity occurs.

NBDI The branch in which the element NEDIB is contained.

ANGB The slope (degrees); See Card 3A [ANG(1)] for sign convention used for ANGB.

Cards 5CB, 5CC, etc. follow until the information for all NDISB branch slope-discontinuities has been given.

Card 5D

NBCONB I5

where

NBCONB The number of boundary conditions applied only to the branches. (Total B.C.'s on structure $\leq$ 7)
If Card 5D=0 go to Card 6.

Card 5DA

NBCB(I), NODBB(I), LBR(I) 4(3I5)

where

I =	1, NBCONB
NBCB(I)	Type of boundary condition. See Card 14 for description.
NODBB(I)	The node number of the particular branch on which the B.C. is being applied (see sketch prior to Card 5 description).
LBR(I)	The branch number on which the B.C. is being applied (see sketch).

A total of seven boundary conditions is allowed, including the primary structure and all branches. Therefore, Card 5DB is punched if more than 4 B.C.'s are to be applied to the branches.

The cards grouped under the number 5 contain the complete description of all the branches (except for elastic restraints). These cards are nested branch by branch, such that a branch's material and geometric layout are completely described before starting the next branch. After all branches have been described, and the branch slope-discontinuity information has been given, then the boundary conditions are applied to all the branches.

An example is given below for a main structure containing two branches, each of a different material, and five boundary conditions on the branches. For each material a three sublayer model is used. The first branch contains two elements, while the second branch has three elements. The first has one slope-discontinuity, the second branch has none. The following list gives the card number (described in this section) in the order they would appear in the input deck:

Branch 1:

Card 5
Card 5A
Card 5AA
Card 5AB
Card 5B
Card 5BA
Card 5BB
Card 5BC

go to top of next column

Branch 2:

Card 5A
Card 5AA
Card 5AB
Card 5B
Card 5BA
Card 5BB
Card 5BC
Card 5BD

Slope Discontinuities:

Card 5C
Card 5CA

Boundary Conditions:

Card 5D
Card 5DA
Card 5DB

Card 6

DELTAT, DS(1), P(1), NTOVR 3D15.6,I5

where

DELTAT The time step size, Δt (seconds) to be employed for the central difference time-wise integration operator. If the value of Δt is set equal to zero on this card, the program will compute the largest natural frequency, ω_{max}, of the corresponding linear system and will then choose a value of $\Delta t_{max} = 0.8(2/\omega_{max})$. If the user specifies a $\Delta t > \Delta t_{max}$, the DELTAT is reset to Δt_{max}:

NOTE: If the user specifies DELTAT = 0 then the user should establish MM, M1, and M2 on Card 2 based on a Δt = 1 microsecond. The program will then adjust these cycle numbers to correspond to the internally generated DELTAT.

DS(1), P(1) The values of the constants D and p, respectively, used in the strain-rate sensitivity formula for the main structure's material.

NTOVR Override for automatic check of DELTAT.

= BLANK DELTAT is checked.

= 1 DELTAT is not checked.

Card 7AA

EPS(1,1), SIG(1,1), EPS(2,1), SIG(2,1) 4D15.6

where

EPS(1,1), SIG(1,1) — The first coordinate pair of strain, ϵ, and stress, σ, curve of the main structure which is used to define the polygonal approximation of the stress-strain diagram. The stress-strain diagram from which these values (and those following) are obtained must be upwardly-convex with non-negative slopes; $\epsilon(J,1)$=in/in and $\sigma(J,1)$=lb/in^2.

EPS(2,1), SIG(2,1) — The second coordinate pair of strain and stress in the main structure.

Additional Cards 7AB and 7AC are punched in exactly the same manner as Card 7AA until the number of coordinate pairs equals NSFL(1) punched on Card 2. The total number of coordinate pairs must not exceed 5. Do not include any unneeded (blank) cards.

Card 8

NOP, NASP 2I5

where

NOP — Indicates the type of strain output desired (given at inner and outer surface)

- = 0 Average strain at each node
- = 1 Average strain at each node plus strain at each Gaussian station
- = 2 Average strain at each node plus strain at designated additional points
- = 3 Strain for all three of the above options

NASP — Number of additional strain points requested; NASP $\leq$ 50

If NOP $\neq$ 2 or 3, go to Card 9.

Note: It is suggested that the user use NOP=1 or NOP=3 in order to obtain a complete set of strain output for a first run of a problem. NOP=0 or 2 can be used for additional runs of the same problem in order to reduce output costs.

Card 8A 2I5,D15.6

NSBS(I), NSEL(I), AZET(I)

where

I = 1, NASP

NSBS(I) Number of the substructure on which the additional strain point is requested: NSBS = 1 main structure; if NSBS > 1 the substructure is a branch whose number is (NSBS - 1)

NSEL(I) The element along the NSBS substructure on which additional strain point is requested. No more than 10 additional strain points are allowed on any one element.

AZET(I) The $\bar{s}$ coordinate of the additional strain point measured from the first node of the element ($\bar{s}$ is a fractional length (in/in) of the element itself).

Cards 8B, 8C, etc. are used until all the additional strain points have been described.

Card 9AA

FH(I), FCG(I), FCGX(I), FMASS(I), FMOI(I) 5D15.6

Card 9AB

UNK(I) D15.6

Card 9AC

UDOT(I), WDOT(I), ADOT(I), TPRIM(I), CR(I)

where I = number of fragment. $I \leq 6$

FH(I) The diameter of the circular disk model of the Ith fragment (inches).

FCG(I) The Z coordinate of the centroid of the Ith fragment before and at the time of its release. The positive direction represents a location above the global Y axis (inches).

FCGX(I) The Y coordinate of the centroid of the Ith fragment before and at the time of its release. The positive direction represents a location to the right of the global Z axis (inches).

FMASS(I) The mass of the Ith fragment (lb-sec^2/in).

FMOI(I) The mass moment of inertia of the Ith fragment (lb-sec^2-in).

UNK(I) Coefficient of friction between the Ith fragment and the ring inner surface.

UDOT(I) The velocity component of the Ith fragment parallel to the global Y axis before initial impact (in/sec). Positive UDOT(I) represents a fragment traveling to the right.

WDOT(I) The velocity component of the Ith fragment parallel to the global Z axis before initial impact. The positive direction denotes a fragment traveling in an upward (+Z) direction (in/sec).

ADOT(I) The initial angular velocity of the Ith fragment (rad/sec). Positive sign denotes counterclockwise rotation.

TPRIM(I) Time (seconds) that the fragment is allowed to travel before program starts to track its location. One usage of TPRIM(I) allows fragments to be released after the first fragment has impacted and calculations have begun.

The fragments should be ordered as follows to allow proper use of the TPRIM capability: Fragment 1 should be the fragment that will make first contact with the ring. Time zero is the time of release of this fragment. The second group of fragments includes all of the fragments that will be released before the first fragment impacts. The fragments can be placed in any order within their group. The third group contains those fragments released after the first fragment impacts; these must be ordered such that the first fragment to be released is first and so on within this group. TPRIM(1) = Time of impact of first fragment minus time of release. Since time of release of fragment one is equal to 0, TPRIM(1) equals time of first impact. Actually, TPRIM(1) must be less than the time of first impact to guarantee a proper impact solution.

TPRIM(I) where I = 2, NF equals TPRIM(1) - Time of release of the Ith fragment. Thus, TPRIM, for those fragments released after the first fragment impacts, will be negative.

CR(I) Coefficient of restitution between the Ith fragment and the impacted ring inner surface; $0\leq CR\leq 1$, 1 for perfectly elastic, 0 for perfectly inelastic, $0<CR<1$ for intermediate, CR=1 is usually recommended.

Cards 9BA, 9BB, 9BC, 9CA, 9CB, 9CC,... should follow (in blocks of three cards) until the information for all NF fragments has been completely specified.

Card 10

AXG(1), AXG(2), AXG(3) 3D25.16

Card 11

AWG(1), AWG(2), AWG(3) 3D25.16

where

AXG(I), AWG(I) Vectors, of dimension NOGA, contain Gaussian quadrature constants, x_i and weights, W_i, respectively, for the numerical evaluation of

$$\int_0^1 f(x)\,dx = \sum_i f(x_i)\,W_i$$

The following data appear on Card 10, since NOGA=3:

0.1127016653792585D+00 0.5000000000000000D+00 0.8872983346207415D+00

and the data

0.2777777777777778D+00 0.4444444444444444D+00 0.2777777777777778D+00

on Card 11.

Card 12A

TXG(1), TXG(2), TXG(3) 3D25.16

Card 12B

TXG(4) 3D25.16

Card 13A

TWG(1), TWG(2), TWG(3) 3D25.16

Card 13B

TWG(4) D25.16

Note: If NFL $\leq$ 3, Cards 12B and 13B are eliminated.

If NFL > 4 the extra terms are added to Cards 12B and 13B.

where

TXG(I), TWG(I) — Vectors, of dimension NFL, contain Gaussian quadrature constants, x_i, and weights, W_i, respectively, for the numerical integration of

$$\int_{-1}^{+1} f(x)\,dx = \sum_i f(x_i)\,W_i$$

If NFL=4, for example, then the following data appear on Cards 12A, and 12B.

-0.8611363115940530D+00 -0.3399810435848560D+00 0.3399810435848560D+00
0.8611363115940530D+00

and the data

0.3478548451374540D+00 0.6521451548625460D+00 0.6521451548625460D+00
0.3478548451374540D+00

appear on CArds 13A and 13B.

Card 14A

NBCOND — I5

Card 14B

NBC(1), NODEB(1), NBC(2), NODEB(2)...NBC(4), NODEB(4) — 14I5

where

NBCOND — The number of prescribed displacement conditions to be specified on the main structure. The quantity NBCOND + NBCONB must not exceed 7. Note that the information on Card 14B corresponds to the original nodal numbering scheme for the main structure.

NBC(1), NODEB(1) — The identification number and the node number, respectively, for which the first prescribed displacement condition is to be imposed.

NBC(2), NODEB(2) — The second data group of the identification number and node number, respectively, for which the second prescribed displacement condition is to be imposed.

The appropriate form of the data group NBC(I) and NODEB(I) should be repeated NBCOND times. If NBCOND=0, that means there is no prescribed displacement condition to be imposed on the main structure; then, skip to Card 15.

The prescribed displacement condition identification number can be equal to 2 or 3, depending upon the type of the prescribed displacement condition. Its description follows:

NBC(I)=2	Ideally clamped condition. Setting v, w, and ψ at node NODEB(I) to zero.
NBC(I)=3	Smoothly-hinged condition. Setting v and w at node NODEB(I) to zero.

Card 15

NQR, NORP, NORU 3I5

where

NOR	Indicator, which if > 0 indicates that the structure is subjected to elastic restraints (point and/or distributed).
NORP	The number of point elastic restraints (elastic restoring springs) which are to be prescribed over the structure. This number must not exceed 4.
NORU	The number of local distributed elastic restraints (elastic foundations) which are to be prescribed over the structure. This number must not exceed 4.

If there are no prescribed restraints on the structure, set NQR=0 and let NORP and NORU be blank.

Card 15A and Card 15B are included only if NQR > 0 in Card 15. If NORP=0, skip to Card 15B.

Card 15A

SCTP, SCTY, SCRP 3D15.6

Card 15AA

NREL(1), REX(1), NREL(2), REX(2) ... NREL(4), REX(4) 4(I5,D15.6)

where

SCTP The translational-tangential restoring spring elastic constant (lb/in).

SCTY The translational-normal restoring spring elastic constant (lb/in).

SCRP The torsional restoring spring elastic constant (in-lb/radian).

NREL(I), REX(I) The element number and the length coordinate along the reference axis from node NREL(I) of the element, respectively, at which the Ith point elastic restraint is to be specified.

(Note that the element numbers used here must be in the numbering system which the program generates internally for the entire system after branches have been added.)

The data group NREL(I), REX(I) should be repeated NORP times. If NORU=0 in Card 15, omit Card 15B, and Card 16 follows directly.

Card 15B

SCTU, SCRU, SCTW 3D15.6

where

SCTU Elastic foundation modulus in translation along the tangential direction (lb/in^2).

SCRU Elastic foundation modulus in torsion (in-lb)/rad-in).

SCTW Elastic foundation modulus in translation along the normal direction (lb/in^2).

Card 15C

NRST(I), NREU(I),... NRST(4), NREU(4) 8I5

where

NRST(1), NREU(1) The first element and the number of elements, respectively, over which the first elastic foundation is to be specified (the first elastic foundation is distributed to element NRST(1), through and including element (NRST(1)+NREU(1)-1). (Note that the element numbers used here must be in the numbering system which the program generates internally for the entire system after branches have been added.)

NRST(2), NREU(2) The first element and the number of elements over which the second elastic foundation is to be specified.

Data group NRST(I) and NREU(I) are repeated NORU times.

Card 16

ICONT I5

where

ICONT Integer which if greater than 0 indicates that this is a continuation run. In order to use this option, it is necessary to obtain the following continuation cards from a previously run job. To do this, set the variable MPU=1 at the beginning of the MAIN routine. This will cause the following set of data cards (16A through 16IA) to be punched. When using this deck, set ICONT=1 and use the same data cards as used before, except to change the values of MM and M1 on Card 2.

If ICONT=0, skip Card 16A - 16I and go to Card 17.

If the indicator ICONT is greater than zero, the continuation deck produced from the output of the previous run follows immediately. The continuation deck contains the following information:

Card 16A

IT, TIME, IMCOU, TAII 2(I5,D20.13)

where (L=1 for main structure; L=2, NBR+1 for branches):

IT The number of the time cycle at which the previous run had stopped, and is the beginning time cycle of the present continuation run.

TIME The absolute time at which the previous run stopped, and is the beginning time of the present continuation run.

IMCOU The number of impacts up to the end of the last run.

TAII Time of initial impact.

Card 16B

IBIGA(L), ISTAA(L), BIGA(L), BTIMA(L), ISURA(L) 2I5,2D20.13,I5

where (L=1 for main structure; L=2, NBR+1 for branches):

IBIGA
ISTAA
BIGA
BTIMA
ISURA

Information for maximum "additional-point strain". Same as their counterparts on Card 16C.

Card 16C

IBIG(L), ISURF(L), ISTA(L), BIG(L), BTIME(L) (3I5,2D20.13)

where (L=1 for main structure; L=2, NBR+1 for branches):

IBIG(L)	The element number whose computed tensile strain exhibits the largest value during the previous run.
ISURF(L)	Equals 1 means largest computed tensile strain occurs on the inner surface; equals 2 means on the outer surface.
ISTA(L)	The Gaussian station at which the maximum strain occurred.
BIG(L)	The largest computed tensile strain during the previous run.
BTIME(L)	The time at which the largest computed tensile strain occurred during the previous run.

Card 16D

IBI(L), ISUR(L), BI(L), BTIM(L) 2I5,2D20.13

where (L=1 for main structure; L=2, NBR+1 for branches):

IBI(L)

ISUR(L) Information for maximum average nodal point strain. Same

BI(L) as their counterparts on Card 16C.

BTIM(L)

Card 16E

MIRP, TNJ(I),..., TNJ(NF) I5,6D12.5

where

NF	Number of fragments impacting structure.
MIRP	Number of next fragment waiting to be released.
TNJ(I)	Indicates whether or not the Ith fragment has been released.

TNJ(I)=0.0 not released

TNJ(I)=1.0 released

Card 16FA

DISP(I) 4D20.13

DISP(I) The displacement of the Ith degree of freedom at time cycle IT. Repeat cards until all degree-of-freedom displacements are specified with 4 different values/card.

Card 16GA

DELD(I) 4D20.13

DELD(I) The displacement increment change of the Ith degree-of-freedom of the structure at time cycle IT. Repeat cards until all degrees-of-freedom are included, with 4 different values/card.

Card 16HA

SNS(IR,J,K,L) 4D20.13

SNS(IR,J,K,L) The axial stress on the Lth mechanical sublayer at the Kth depthwise Gaussian point at the Jth spanwise Gaussian station of the IRth element at time cycle IT. Repeat cards until all values for the entire structure are included, with 4 different values/card.

Card 16IA

FCGU(J), FCGW(J), ALFA(J), UDOT(J), WDOT(J), ADOT(J) 4D20.13

FCGU(J)	The centroidal position of the Jth fragment in the Y direction at time cycle IT (inches).
FCGW(J)	The centroidal position of the Jth fragment in the Z direction at time cycle IT (inches).
ALFA(J)	The total angular displacement of the Jth fragment at time cycle IT (radians).
UDOT(J) WDOT(J) ADOT(J)	Fragment velocities at time cycle IT (in/sec); see Card 9AC for more details.

J = 1,NF

Card 17

ICON I5

where

ICON Integer that controls the stopping of the entire program.

= 0 The program will stop after all of the required print-outs are made for a particular run.

= 1 The program will expect a new set of Cards 1-17 for another ring problem.

4.2 Input for Special Cases of the General Stress-Strain Relations

In the following, the specific input data for three special cases of the general elastic, strain-hardening constitutive relation handled by the computer program are given. Only the relevant data are noted. (L=1 for main structure; L=2 to NBR+1 for the NBR branches):

1. Purely Elastic Case

   Set NSFL(L)=1 on Card 2 (Card 5A) and make EPS(1,L) and SIG(1,L) on Card 7 (Card 5AA) sufficiently high so that no plastic deformation occurs; for example, EPS(1,L)=1.0, SIG(1,L)=ES(1,L), where ES(1,L) equals the elastic (Young's) modulus.

2. Elastic, Perfectly-Plastic Case

   Set NSFL(L)=1 on Card 2 (Card 5A) and make EPS(1,L)=SIG(1,L)/ES(1,L) on Card 7 (Card 5AA).

3. Elastic, Linear Strain-Hardening Case

   Set NSFL(L)=2 on Card 2 (Card 5A) and set EPS(1,L)=SIG(1,L)/ES(1,L). Also EPS(2,L) and SIG(2,L) on Card 7 (Card 5AA) are taken sufficiently high in order to avoid plastic deformation in the second subflange. For example, EPS(2,L)=1.0, and SIG(2,L)=(1.0-EPS(1,L))*ES(2,L)+SIG(1,L), where ES(2,L) is the slope of the segment in the plastic range.

4.3 Description of the Output

The printed output begins with a partial reiteration of the program input which identifies the problem solved. This output includes information on initial geometry, the nodal and element numbering system originally assigned by the user, the new updated nodal and element system generated internally in the program if branches are present, the branch attachment points, the ring material properties for the main structure and each branch, the fragment properties, the boundary conditions and elastic restraints that are input, the Gaussian stations and weights used in the program, the lumped mass matrix and the element arc lengths, the time step used in the program and the maximum permitted time step, and the effective lengths associated with the main structure and the branches. (NOTE: If override option is used, the program will calculate a maximum Δt value and print this out. However, the Δt used in the program calculation will be the user-specified Δt regardless of its value.) Example outputs are presented in Section 6. After initial printout has been completed, the following information is printed out (assume NOP=3 here) after cycle M1 has been completed, and at every M2 cycles thereafter (see Subsection 4.1, Card 2):

WORK AND ENERGY TO END OF TIME CYCLE IT = TIME =

FRAGMENT   KINETIC ENERGY
[IT]   [CINETF(II)]

WORK INPUT INTO RING	=	[RWORK]
RING KINETIC ENERGY	=	[CINETO]
RING ELASTIC ENERGY	=	[CELAS]
RING PLASTIC WORK	=	[PLAST]
ENERGY STORED IN ELASTIC RESTRAINTS	=	[SPDEN]

CYCLE = [IT]

ELEMENT	SI	STA1	SO	SI	STA2	SO	SI	STA3	SO
1									
2									
3									
.									
.									
.									

CYCLE = [IT]

STRAIN AT ADDITIONAL POINTS	SI	SO	EI	EO
1				
2				
.				
.				
.				

J = [IT]   TIME = [TIME]

I	V	W	PSI	CHI	COPY	COPZ	L	M	STRAIN(IN)	STRAIN(OUT)
1										
2										
3										
.										
.										
.										

FRAG NO.	FCGU	FCGW	ALFA	FRUV	FRWV	FRAV
1						
2						
.						
.						
.						

SUBSTRUCTURE	MSTR	ELE	TIME	STA
1				
2				
.				
.				

SUBSTRUCTURE	LARGEST ADD. PT. STRAIN	ELEM	ADD. PT.	TIME
1				
2				
.				
.				

SUBSTRUCTURE	LARGEST NODAL STRAIN	NODE	SURF	TIME
1				
2				
.				

where

IT = Cycle number

TIME = Elapsed time corresponding to the <u>end</u> of cycle IT (sec.)

II = Fragment number II = 1,NF

CINETF(II) = The current value of the kinetic energy remaining in fragment II (in-lb).

RWORK = Total work imparted to the structural ring up to the present time by fragment impact (in-lb).

CINETO = The current value of kinetic energy present in the structural ring* (includes both the rigid body and the relative kinetic energies) (in-lb).

ELAST = Total elastic strain energy stored in the entire structural ring at the present time instant (in-lb).

PLAST = Total plastic work * done on the structural ring (mechanical work dissipated during plastic flow) (in-lb).

SPDEN = Total energy stored in the elastically-restoring springs and/or the elastic foundations at the current time instant (in-lb), if the presence of elastic restraints is specified.

SI = Strain at the inner surface of the ring

SO = Strain at the outer surface of the ring

STA1, STA2, STA3 = Spanwise Gaussian Station at which strain was calculated

EI, EO = Relative elongation at inner or outer surface, respectively, at the additional strain points; obtained from $E_1=\sqrt{1+2\gamma_{11}} - 1$.

It should be noted that the rigid body part of the kinetic energy, which is used to accelerate the "rigid body" mass of the structure, can be extracted and identified separately. However, for the present program dealing with rather general structural geometries and with various support/restraint conditions, it would be very unwieldy (but not impossible) to identify these separate kinetic energies; hence, the total kinetic energy is calculated and printed out.

**The plastic work done on the ring is estimated by subtracting the sum of the elastic and kinetic energies present in the ring from the total input energy (due to the fragment impact; i.e., RWORK=CINETO+ELAST+PLAST+SPDEN. It should be mentioned that the approximate nature of this numerical calculation will sometimes yield impossible results such as negative values of plastic work or values greater than zero when the ring has not yet reached a plastic condition; thus, the value of plastic work should be considered only approximate, and spurious results as noted above should be ignored. This form may also be considered to contain, in addition, the energy dissipated by friction.

I	=	Node number. For a partial ring, the value of the total number of nodes equals the value of the total number of elements plus one. For a complete ring, the value of the total number of nodes equals the value of the total number of elements.
V	=	The middle plane axial displacement at node I (in).
W	=	The middle plane transverse displacement at node I (in).
PSI	=	The generalized nodal displacement $\psi = (\partial v/\partial \eta) - v/R$ at node I (rad).
CHI	=	The generalized nodal displacement $\chi = (\partial v/\partial \eta) + w/R$ at node I (rad).
COPY	=	The Y-location of node I in the global (inertial) coordinate system (in).
COPZ	=	The Z-location of node I in the global coordinate system (in).
L	=	Axial internal force resultant over the cross section at the midspan point of <u>element</u> I (lb).
M	=	Internal bending moment of the cross section at the midspan point of <u>element</u> I (in-lb).
STRAIN(IN)	=	Average strain on the inner surface at node I.*
STRAIN(OUT)	=	Average strain on the outer surface at node I.*
FCGU	=	Global Y coordinate of the centroid of the fragment at the current time instant (in).
FCGW	=	Global Z coordinate of the centroid of the fragment at the current time instant (in).
ALFA	=	Angular rotation of the fragment to the current time instant (rad).
FRUV	=	The current velocity component of the fragment in the Y direction (in/sec).
FRWV	=	The current velocity component of the fragment in the Z direction (in/sec).
FRAV	=	The current angular velocity of the fragment (rad/sec). Positive sign denotes counter-clockwise rotation.

*At nodes on the main structure where a branch connection occurs, the contribution of strain from the branch is not included in the nodal averaging process.

SUBSTRUCTURE = The portion of the ring being considered.

1 = main structure

2 = 1st branch

3 = 2nd branch

.

.

.

MSTR = Maximum strain on the substructure at a Gaussian station.

ELE = Element on which max. tension strain occurred.

TIME = Time at which max. tension strain occurred.

STA = Gaussian station at which max. tension strain occurred on element ELE.

NODE = Node at which largest average value of tension strain occurred.

ELEM = Element on which largest value of tension strain occurred at an additional strain point.

ADD. PT. = Additional Point Number

TIME = Time at which the max. tension strain occurred

Note: Checks for largest average nodal strain and largest additional-point strain are made <u>only</u> at print out cycles. Check for largest Gaussian-station strain is made at <u>each</u> cycle.

In addition to the above information which is printed out at each desired time cycle, whenever there is an impact the following information is printed out:

```
THIS IS IMPACT NUMBER [M]    TIME =     IT =     FRAGMENT NO. = [JF]
ELEMENT NO. = [LNTMIN]       LOCATION ON ELEM = [RPC]
```

where

M = The number of the impact (total number of impacts up until that time]

TIME = The time of contact between fragment and ring

IT = Cycle during which impact takes place

JF = Fragment involved in this collision

LNTMIN = Element (on main structure) involved in the collision

RPC = Fraction of the element length from the point of ring-fragment contact to the first node of the impacted element.

At the conclusion of the run, a final update of the maximum strain occurring on each substructure (main structure and each branch) and for the additional strain points on the main structure and each branch is printed out. Also, a note as to whether or not continuation cards were punched is made.

4.4 Guides and Restrictions for Code Usage

4.4.1 General Instructions

The CIVM-JET 4B computer code is capable of handling a wide variety of transient, large-deflection structural response problems involving impact-induced loading. This capability is beneficial to the user since it is contained in one computer program; however, it can be unnecessarily costly to run the program if all of the options included are carried along but are not being used.

In order to save storage locations and therefore save computer costs on each run, several subroutines can be removed when they are not used during that particular job submittal.

The following is a list of subroutines which <u>must be included in every run</u> of the CIVM-JET 4B program:

1. MAIN
2. ASSEF
3. ASSEM
4. CUBIC
5. ELMPP
6. ENERGY
7. ERC
8. FICOL
9. IDENT
10. IMPACT
11. IMPCTE
12. MINV
13. PENTRN
14. PRINT
15. ROOT4
16. STRESS
17. TCONT
18. UPDATE

The remaining subroutines: BRAN, DINIT, OMULT, QREM, ROTAT, and TSTEP may be left out depending upon the type of problem being solved.

Subroutine TSTEP may be optional when the user desires. If the user inputs a time-step and does not wish this time step to be checked by the CIVM-JET 4B program, the user merely omits including the TSTEP subroutine, and only inputs the following three cards instead of TSTEP.*

```
SUBROUTINE TSTEP (KLOW, NDEX, NIRREG, DELTAT)
RETURN
END
```

In like manner, if the user does not wish to apply any branches to the main structure, the BRAN subroutine becomes optional. If no branches are used, BRAN is input as follows:

```
SUBROUTINE BRAN (NBR)
RETURN
END
```

Thus, for any subroutine that is not being used for a particular run, just submit the first card of the subroutine (the name card) and the RETURN and END cards. This will save the user input costs, compilation costs, and storage costs. The same procedure is used for QREM if no elastic restraints are defined, for ROTAT if no branches or slope discontinuities are used, for DINIT if continuation cards are being used for input, or for OMULT only if TSTEP and QREM are also left out.

4.4.2 Use of Branches vs. Use of Discontinuities

In the present CIVM-JET 4B program, both branches attached to and slope-discontinuities in the main structure can be accommodated. Because of the way in which these two features are handled in the program logic and, in particular, for determining ring-fragment collision, certain general guidelines should be followed by the user for more efficient us of the computer code.

The dominant consideration involves the determination of ring-fragment collision. In the present code, impact on a branch is not accommodated, so that if branch impact is an important consideration for a particular problem, then the slope-discontinuity option must be used in place of the branch option, thus identifying this region not as a branch but as a part of the main structure. Note, however, that in all cases where three elements are to be connected at a single nodal point (such as in the case of a branch at the midspan of a beam), one of the elements must be defined as a branch. In general,

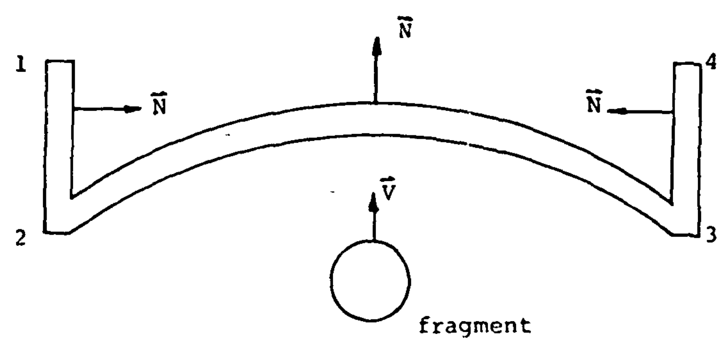
---

*Because the Central Difference Operator is conditionally stable, the use of subroutine TSTEP is recommended for the first run of a given structural geometry and finite-element mesh arrangement to insure that a stable Δt will be used in the timewise solution.

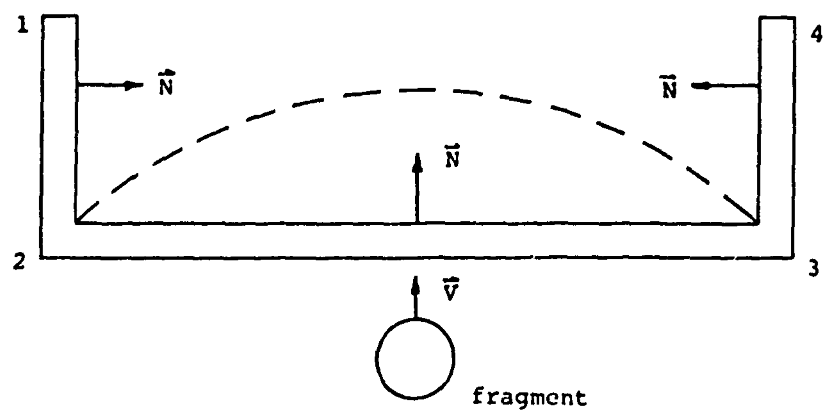
at any node where three elements are joined, one of these elements (and all subsequent elements in that portion of the structure) must be defined as branch elements. However, two branches may not start at the same node of the main structure.

During each increment in time, Δt, a collision inspection is carried out for each element on the main structure for each of the N fragments considered, but no collision inspection is carried out for elements defined as branch elements. This fact can be used to reduce the total computation time; if the user knows a priori that no collisions will occur in certain regions of the structure, then those regions should be defined as branches wherever possible (note that branches cannot be specified to be attached to another branch).

As noted in Section 2, the positive η direction must be chosen in such a way that the outward normal for each element is directed toward the outside of the structure, where the fragments are considered to be in the inside of the structure. In some special (but plausible) cases, the outside region of a portion of the structure may overlap with the inside region of another portion of the structure either in the initial structural configuration or after some deformation of the structure has occurred. Within the current collision inspection program logic, such overlapping regions cannot be accommodated. Consider the following initial structural configuration:



With the positive normal directions $\vec{N}$ as shown (and considering the entire structure as a main structure, using the slope-discontinuity option), the outside regions of segments 1-2 and 3-4 would overlap with the inside region of segment 2-3. To accommodate such a configuration, segments 1-2 and 3-4 must be defined as branches so that no collision inspection is performed for those segments. Consider now the following initial structural configuration:



For the initial configuration (solid lines), no inside-outside overlapping occurs. However, after deformation of segment 2-3 (dashed line, assuming fragment impact is as depicted above), the outside regions of segments 1-2 and 3-4 will overlap with the inside region of segment 2-3. Again, in this case, segments 1-2 and 3-4 must be defined as branches.

4.4.3 Impact at or Near a Constrained Node

In the present CIVM-JET 4B program, the case of fragment impact on or near a constrained node is handled in an approximate fashion. The nature of this approximation is discussed briefly here as a guide to the user in interpreting results when impact occurs on or near a constrained node.

The assumption used is as follows: when impact occurs near a constrained node, the only nodes which can respond with impact-induced velocity changes are those nodes which lie within the impact-affected region and which are located on the impacted side of the constrained node. In essence, no impact-induced information is allowed to propagate past the constrained node (for the purpose of impact corrections), and a portion of the impact-induced impulse is "absorbed" by the constraint. Although no impact-induced information is allowed to propagate past the constrained node for the purpose of impact-induced velocity, the impact-induced information will filter through the constrained node in the global timewise solution, if the constrained node is smoothly hinged. If the node is ideally clamped, no impact-induced information will filter past the constrained node in the global timewise solution. It should also be noted that as the point of ring-fragment impact approaches the constrained node, the impact-induced ring response approaches zero; when impact occurs directly on a constrained node, the fragment simply rebounds and no impact-induced structural response occurs.

For a more thorough discussion of this topic, the reader is referred to Appendix A.

4.4.4 Comments on Strain Calculation and Mesh Sizing

In the present CIVM-JET4B program, options are available which allow the user to obtain strain printout at the spanwise Gaussian stations (which includes the element midspan location), and/or at additional points on the structure specified by the user. Nodal average strains are given automatically at each regular printout cycle. This flexibility can be of great value to the user, but certain precautions should be taken by the user in interpreting the strain results.

The strain-displacement relation employed in the present curved beam elements is given by Eq. A.12. An examination of this equation shows that nonlinear terms are included only in the membrane behavior, and only linear terms are included in the bending behavior. Thus, the membrane nonlinearities have been assumed to be more significant than the bending nonlinearities. The calculated distribution of strain may be quite different from element to element, and the strain distribution within each element will, in general, not be the same as the "exact" distribution. This behavior corresponds to the fact that in the present finite-element model the predicted strain distribution approximates the actual strain distribution in an average (integral) sense, and not in a pointwise sense. Although the calculated distribution may be the same as the "exact" distribution at some points within the element, the choice of a "best" point (or points) for strain evaluation within an element is not obvious. The choice of v, w, ψ, and χ as generalized nodal parameters assures membrane strain continuity at the nodes, but in general the bending strain will not be continuous at the nodes; thus, the predicted strains at the inner and outer surface of an element will not, in general, be continuous at the nodes.

Because of these facts, certain precautions should be taken by the user when assessing strain distributions in space and/or time. If detailed strain distributions are required over a portion of the structure at a particular time instant, it is suggested that several printout points be chosen in each element (e.g. Gaussian stations and nodal averaged points) in the region of interest. When these calculated values are plotted, the analyst can then make a reasonable "faired" estimate of the "proper" distribution. It should be noted that severe strain gradients within an element do not necessarily indicate poor behavior of the solution; however, it is in these regions where the analyst must exercise the greatest caution in making a reasonable faired estimate of the proper distribution. Although not conclusive, experience to date with the present CIVM-JET4B computer code suggests that these regions of predicted severe strain gradients are most often observed near clamped boundaries and may be found near the region of ring-fragment impact.

If strain time-history information is required at various points on the structure, these points can be specified as additional strain points and the time histories may be obtained directly. In addition, it is recommended that spatial distributions near these points of interest be obtained at several time instants to assess whether or not the strain at the point of interest is in reasonable agreement with the curve-fitted (or faired) distribution in that region of the structure. If these steps are followed, a reasonable engineering assessment of strain information should be obtained.

The equations in Appendix A have been developed within the assumption of large deflections but small strains. Thus, reliable results may not be obtained in localized regions where large strains are predicted. However, the actual strain level at which the "small strain" assumption becomes invalid is not known. Thus, the limitations of the present analysis, for practical engineering problems, cannot be clearly stated; further study of the limitations of the present analysis versus appropriate well-defined experimental data is required. In the future it is recommended that models which can accommodate arbitrarily large strain be developed for both two-dimensional (planar) and three-dimensional (non-planar) deformations. In the meantime, however, it is believed that the capabilities of the present CIVM-JET 4B analysis and program can provide useful engineering estimates.

In the present CIVM-JET 4B program, considerable flexibility is given to the user in terms of defining the size and number of elements to be used for a particular structural geometry. However, certain guidelines should be followed in the selection of a finite-element mesh for the present impact analysis. It is recommended that a uniform mesh be employed for all analyses, the only exception being in regions where structural detail dictates the use of nonuniform elements. Clearly this recommendation is justified for the general case where the point of initial (and subsequent) impact is not known *a priori*. Now consider the special (limiting) case where it is known *a priori* that all ring-fragment impacts will occur at (approximately) the same point on the structure (e.g. initially straight, uniform thickness, doubly clamped beam with the only nonzero component of the fragment velocity being normal to the beam midsurface, and initial impact occurring at the midspan of the beam). A uniform mesh is again recommended for this special case, based on the following considerations. The impact effected length, L_{eff}, is directly related to the size of the time step (i.e. $L_{eff} = \sqrt{\frac{E}{\rho}}\,\Delta t$) and when using the central difference operator the allowable time step, Δt, is inversely related to the highest natural frequency, ω_{max}, of the assembled structure. If the element size in the region of impact is decreased, then ω_{max} is increased and Δt and, thus, L_{eff} are decreased. In the limit, as the element size is decreased, the impact-induced "loading" will become concentrated at the point of impact and unreasonably high strain predictions may be found near this region of concentrated loading. It is believed (based on experience to date with the present CIVM-JET 4B program) that the choice of a uniform mesh for this case will yield the most reliable predictions.

SECTION 5

COMPLETE FORTRAN IV LISTING OF THE CIVM-JET 4B PROGRAM

The CIVM-JET 4B program consists of the following main program and 23 subroutines:

1. MAIN
2. ASSEF
3. ASSEM
4. BRAN
5. CUBIC
6. DINIT
7. ELMPP
8. ENERGY
9. ERC
10. FICOL
11. IDENT
12. IMPACT
13. IMPCTE
14. MINV
15. OMULT
16. PENTRN
17. PRINT
18. QREM
19. ROOT4
20. ROTAT
21. STRESS
22. TCONT
23. TSTEP
24. UPDATE

The program is written in double precision arithmetic. A complete FORTRAN IV listing of the program is given below in the above order. The number of memory locations required on the IBM 370/168 computer at MIT is approximately 415,000 bytes; this includes locations for the MIT computer library subroutines.

```
C CIVM-JET 4B COPYRIGHT (C) 1976 MASSACHUSETTS INSTITUTE OF TECHNOLOGY   MAIN0010
C    ***** CIVM-JET 4B********      MAIN PROGRAM                          MAIN0020
      IMPLICIT REAL*8(A-H,O-Z)                                            MAIN0030
      DIMENSION          LEPS(3,3),EPI(3),EPU(3),HNIN(51)                 MAIN0040
      DIMENSION HMOI(51),CL(51),CLP(51),CLA(51),CLPA(51)                  MAIN0050
      DIMENSION AA(50,8,8),TXG(6),TWG(6),        GFL(50,3,6),ES(6,6)      MAIN0060
     *,SOL(205),INUM(205),              KROW(8),NDEX(8)                   MAIN0070
      DIMENSION NSBS(50),NSEL(50),AEPS(3)                                 MAIN0080
      DIMENSION BIGA(6),BTIMA(6),IBIGA(6),ISTAA(6) ,ISURA(6)              MAIN0090
      DIMENSION BI(6),BTIM(6),IBI(6),ISUR(6) , ITHR(51)                   MAIN0100
      DIMENSION DELM(8),DISM(8), DUMMY(8,8)                               MAIN0110
      DIMENSION  QACL(205)   , QVEL(205)                                  MAIN0120
      COMMON/IMPT/ VEL(102),IMCC,JVEL(51)                                 MAIN0130
      COMMON /HIT/ TNJ(6),MIRP                                            MAIN0140
       COMMON /BA/ EEI(50,3,3,8),AL(50),AXG(3),AWG(3)                     MAIN0150
      COMMON/ABC/RMX(51),RWORK,CINEY(205)                                 MAIN0160
      COMMON /ST/ STIFK(2060)                                             MAIN0170
      COMMON/SC/ BIG(6),BTIME(6),IBIG(6),ISURF(6),ISTA(6)                 MAIN0180
       COMMON /VQ/ PLVA(205),DISP(205),DELD(205),SNS(50,3,6,5),           MAIN0190
     *BINP(50,3),BIMP(50,3),TDISP(205),TU(205),TW(205),                   MAIN0200
     *COTY(205),COIZ(205),DELTAT                                          MAIN0210
      COMMON/FG/Y(51),Z(51),ANG(51),H(51),EXANG,NS,IK,NUGA,NPL,NI,        MAIN0220
     * ICOL(205),NBCOND,NBC(7),NODEB(7)                                   MAIN0230
      COMMON /GNU/                PEP(3,3,8)      ,NNN,NGUM               MAIN0240
       COMMON /TAPE/ MREAD,MWRITE,MPUNCH                                  MAIN0250
      COMMON /TIME/  IT                                                   MAIN0260
      COMMON/ IIAT/ TAII                                                  MAIN0270
      COMMON /TAM/ MKE(51)                                                MAIN0280
      COMMON/FRAG/FH(6),PCG(6),PMASS(6),PMOI(6),PCGU(6),PCGW(6),ALPA(6),MAIN0290
     *UDOT(6),WDOT(6),ADOT(6),TERIM(6),CR(6),PCGX(6),UNK(6),NP            MAIN0300
      COMMON /DFRAG/DPCGU(6),DPCGW(6),DALFA(6)                            MAIN0310
      COMMON/ENERG/PK(6),CINETC,CUMW,DELKE,CELAS,ELAS,PLASTC              MAIN0320
      COMMON /HM/ C5,C6,ASPL(50,3,6,5),GZFTA(50,3,6)                      MAIN0330
      COMMON /ADSP/ AZET(50),AEP(50,3,8) ,LKK(50,11)                      MAIN0340
      COMMON /LEFT/ RMASS(51)                                             MAIN0350
      COMMON/MAT/ DENS(6),B(6),YOUNG(6),DS(6),SNO(6,5),NSPL(6),P(6),      MAIN0360
```

```
*  PPS(6,5),SIG(6,5), FFIN(6)
  COMMON/ELPU/SPRIN(2060),FQPFF(205),REX(4),NQR,NORP,NORU,NREL(4),
 *NRST(4),NREU(4)
  COMMON /NODE/ DEP(50,2,3,8)
  COMMON /EP/ EPSI(51),EPSO(51)
  COMMON/DIS/ ANGDI(50),NEDI(50),NDIS
  COMMON/COU/ IMCOU
  COMMON /BN/ LMT(51)
  COMMON /THI/ HTH(5)
  COMMON /ML/ MNEL(6),MATT(6)
  COMMON /BOUN/ YK(51),NECONB,NBCB(7),NODBB(7),MK(51),BOT(5,2)
 a,DROT(50), NODP(6)
  COMMON /XD/ XDIST(6)
  COMMON /BR/ NVEC(51,2)
  SIN(Q)=DSIN(Q)
  COS(Q)=DCOS(Q)
  ATAN(Q)=DATAN(Q)
  ABS(Q)=DABS(Q)
  SQRT(Q)=DSQRT(Q)
   MREAD=5
   MWRITE=6
   MPUNCH=7
  IRRUN = 1
5555 READ(MREAD,1)B(1),DENS(1),EXANG,IK,NOGA,NPL,NSPL(1),MM,M1,M2,NP
    a,TIMP
   1 FORMAT(3D15.6,/,8I5,D15.6)
  IMCOU = 0
  TAII = 0.0
  MPU = 1
C    REMOVE MPU=0 IF CONTINUATION CARDS ARE DESIRED
  MPU=0
  NPZ1 = M1
  PIE= 3.141592653589793D+00
  PIE2= 2.0* PIE
  IKP1=IK+1
  NS=IK
```

```
      IF(EXANG.NE.360.)NS=IKP1
      MNEL(1) = IK
      NELF = 0
      NROUT = 0
      NNGG = 0
      LELF=0
      LELR=0
      IMCO = 0
C    GEOMETRY INPUT -- USER COULD SUBSTITUTE AN INTERNAL GENERATING
C     ROUTINE AT THIS POINT
 7901 READ(MREAD,7902)  (Y(I),Z(I),ANG(I),H(I),I=1,NS)
 7902 FORMAT(4D15.6)
      DO 7903 I=1,NS
 7903 ANG(I) = ANG(I) * PIE/180.0D+00
 7999 CONTINUE
C    DISCONTINUITY INPUT
      READ(MREAD,5300) NDIS
      NDI = NDIS
      IF(NDIS.EQ.0) GO TO 8100
      READ(MREAD,8101)  (NEDI(I),ANGDI(I),I=1,NDIS)
 8101 FORMAT (4(I5,D15.6))
      DO 8102 I=1,NDIS
 8102 ANGDI(I) = (ANGDI(I)*PIE)/180.0
 8100 CONTINUE
  201 READ(MREAD,5300) NBR
 5300 FORMAT(2I5)
      MNSPL= NSPL(1)
      DO 5305 I = 1, IK
      MKE(I) = 1
      LMT(I) = 0
      YK(I) = 0.0
      MK(I) = I
      NVEC(I,1) = I
 5305 NVEC(I,2) = I+1
      IF (EXANG.EQ.360.0)  NVEC(IK,2) = 1
      IF(EXANG.NE.360.0) MK(IK+1) = IK+1
```

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```
      IF (NBR.NE.0) GOTO 100                                            MAIN1090
      WRITE(MWRITE,105)                                                 MAIN1100
  105 FORMAT(//,' THERE ARE NO BRANCHES CONNECTED TO THE MAIN STRUCTURE MAIN1110
     @,THEREFORE',/,' THE NUMBERING SYSTEM FOR NODES AND ELEMENTS REMAINMAIN1120
     @S UNCHANGED')                                                     MAIN1130
  100 CONTINUE                                                          MAIN1140
      IF(NBR.EQ.0) GOTO 204                                             MAIN1150
                 CALL BRAN(NBR)                                         MAIN1160
      DO 8888 I=1,NBR                                                   MAIN1170
      IF (NSPL(I+1) .GT.MNSPL)   MNSPL= NSPL(I+1)                       MAIN1180
 8888 CONTINUE                                                          MAIN1190
  204  M=NSPL(1)                                                        MAIN1200
      READ(MREAD,2) DELTAT,DS(1),P(1),NTOVR,(EPS(1,L),SIG(1,L),L=1,M)   MAIN1210
    2 FORMAT(3D15.6,I5/(4D15.6))                                        MAIN1220
      DELTA= DELTAT                                                     MAIN1230
      IF(DELTAT.EQ.0.0) DELTA=1.0D-06                                   MAIN1240
      LGSP= 0                                                           MAIN1250
       LSPP =0                                                          MAIN1260
C   ADDITIONAL STRAIN POINT DATA                                        MAIN1270
      READ(MREAD,8200) NOP,NASP                                         MAIN1280
 8200 FORMAT(2I5)                                                       MAIN1290
      DO 8215 I=1,IK                                                    MAIN1300
      DO 8215 J=1,2                                                     MAIN1310
 8215 LKK(I,J) = 0                                                      MAIN1320
      IF(NOP.EQ.0) GO TO 8220                                           MAIN1330
      IF(NOP.NE.2)  LGSP=1                                              MAIN1340
      IF(NOP.NE.1) LSPP=1                                               MAIN1350
      IF(LSPP.NE.1) GO TO 8220                                          MAIN1360
      READ(MREAD,8210) (NSBS(I),NSEL(I),AZET(I),I=1,NASP)               MAIN1370
 8210 FORMAT(2I5, D15.6)                                                MAIN1380
      WRITE(MWRITE,156)                                                 MAIN1390
  156 FORMAT('0ADDITIONAL STRAIN POINT',5X,'ELEMENT',5X,'S  COORDINATE')MAIN1400
      DO 8216 J= 1,NASP                                                 MAIN1410
      IF(NSBS(J).NE.1) GO TO 8217                                       MAIN1420
      M= NSEL(J) +1                                                     MAIN1430
      IF(EXANG.EQ.360.0.AND.NSEL(J).EQ.IK)  MK(M) = IK+1                MAIN1440
```

```
      N= MK(M) -1
      LKK(N,1) = 1 + LKK(N,1)
      NO = LKK(N,1) + 1
      LKK(N,NO) = J
      GO TO 140
 8217 IF(NODP(NSBS(J)-1).EQ.1) GO TO 8218
      N= MK(NODP(NSBS(J)-1)) + NSEL(J) - 1
      GO TO 8219
 8218 N= NSEL(J)
 8219 LKK(N,1) = 1 + LKK(N,1)
      NO = LKK(N,1) +1
      LKK(N,NO) = J
  140 WRITE(MWRITE,145) J, N, AZET(J)
  145 FORMAT(' ',9X,I5,13X,I5,7X,D15.6)
 8216 CONTINUE
 8220 CONTINUE
      IF(NDIS.EQ.0) GO TO 8140
      IF (NBR.EQ.0) GOTO  8145
      IF(NDI.EQ.0) GOTO 8145
      DO 8146 J= 1,NDI
      M= NEDI(J) +1
      N = MK(M) -1
      NEDI(J) = N
 8146 CONTINUE
 8145 WRITE(MWRITE,8111)
       WRITE(MWRITE,8120) (NEDI(I),I=1,NDIS)
 8111 FORMAT('0EACH OF THE FOLLOWING ELEMENTS HAS A SLOPE DISCONTINUITY
     @AT ITS FIRST NODE')
 8120 FORMAT(' ', 25I5)
      WRITE(MWRITE,8112) (ANGDI(L) ,L=1,NDIS)
 8112 FORMAT('0THE GLOBAL SLOPE (RAD.) AT EACH DISCONTINUITY EQUALS:',/,
     @(8D15.6))
      DO 8130 I= 1,NDIS
      M=NEDI(I)
      YK(M) = YK(M) + 2.0
      L1= NVEC(M,1)
```

```
      DROT(M) = ANGDI(I) - ANG(I1)
 8130 CONTINUE
 8140 CONTINUE
      IKM1 = IK-1
      IKP1 = IK+1
      MGOOD = IK-NELE
C     FRAGMENT PROPERTIES
      DO 202 I=1,NP
      READ(MREAD,601) FH(I),FCG(I),FCGX(I),FMASS(I),FMOI(I)
      READ(MREAD,601) UNK(I)
202   READ(MREAD,602) UDOT(I),WDOT(I),ADOT(I),TPRIM(I),CR(I)
601   FORMAT(6D15.6)
602   FORMAT(5D15.6)
C     GAUSSIAN STATIONS AND WEIGHTS
       READ(MREAD,3) (AXG(K),K=1,NOGA)
       READ(MREAD,3) (AWG(K),K=1,NOGA)
       READ(MREAD,3) (TXG(K),K=1,NPL)
       READ(MREAD,3) (TWG(K),K=1,NPL)
    3 FORMAT(3D25.16)
      NI=NS*4
      READ(MREAD,4) NBCOND
      IF(NBCOND.EQ.0)GO TO 747
      READ(MREAD,4) (NBC(I),NODEB(I),I=1,NBCOND)
    4  FORMAT(9I5)
  747 IF (NBR.EQ.0) GO TO 748
      NIT = NBCOND+1
      NIT1 = NIT -1
      NBCOND= NBCOND+ NBCONB
      IF (NBCONB.EQ.0) GO TO 751
      DO 750 LOP= 1, NBCONB
      NBC(NIT1  +LOP) = NBCB(LOP)
  750 NODEB(NIT1  +LOP) = NODEBB(LOP)
  751 IF (NIT1.EQ.0) GO TO 748
      DO 753 LOP = 1,NIT1
      NTI = NODEB(LOP)
  753 NODEB(LOP) = MK(NTI)
```

```
748     READ(MREAD,9) NQR,NORP,NORU                                         MAIN2170
 9       FORMAT(3I5)                                                        MAIN2180
      MY=M1                                                                 MAIN2190
      MY=M2                                                                 MAIN2200
      CUMW=0.0                                                              MAIN2210
      DELKE=0.0                                                             MAIN2220
      DO 203 I=1,NP                                                         MAIN2230
203   FK(I)=(FMASS(I)/2.0)*(UDOT(I)**2+WDOT(I)**2)+(PMOI(I)/2.0)*(ADOT(IMAIN2240
     *)**2)                                                                 MAIN2250
          CALL IDENT(NQR,NBR)                                               MAIN2260
      WRITE(MWRITE,941) NP                                                  MAIN2270
      WRITE (MWRITE,940)  (TPRIM(I),I=1,NP)                                 MAIN2280
  941 FORMAT(///,' THE TPRIM FOR EACH OF ',I5,'  FRAGMENTS IS AS FOLLOWSMAIN2290
     @')                                                                    MAIN2300
  940 FORMAT  (8D15.6)                                                      MAIN2310
      WRITE(MWRITE,402)                                                     MAIN2320
  402 FORMAT(///,' GAUSSIAN STATIONS AND WEIGHTS:')                         MAIN2330
      WRITE(MWRITE,400)  (L,AXG(L),L, AWG(L),L=1,NOGA)                      MAIN2340
      WRITE(MWRITE,401)  (L,TXG(L),L,TWG(L),L=1,NPL)                        MAIN2350
  400 FORMAT(' ',12X,'AXG',I3,2X,'=',F20.15,8X,'AWG',I3,2X,'=',F20.15)      MAIN2360
  401 FORMAT(' ',12X,'TXG',I3,2X,'=',F20.15,8X,'TWG',I3,2X,'=',F20.15)      MAIN2370
      IC=0                                                                  MAIN2380
C    ESTABLISH VECTORS AND MATRICES FOR SUBLAYER CALCULATIONS               MAIN2390
       DO 70 IR=1,IK                                                        MAIN2400
      L1= NVEC(IR,1)                                                        MAIN2410
      L2= NVEC(IR,2)                                                        MAIN2420
      IF(YK(IR).EQ.1.0.OR.YK(IR).EQ.3.0)   IC=IC+1                          MAIN2430
       DO 70 J=1,NOGA                                                       MAIN2440
      IF(YK(IR).NE.1.0.AND.YK(IR).NE.3.0) GOTO 600                          MAIN2450
      IF(ROT(IC,1) .EQ.0.0) GO TO 610                                       MAIN2460
      RH= HTH(IC)*(1.0-AXG(J)) +H(L2)   *AXG(J)                             MAIN2470
      GO TO 611                                                             MAIN2480
  610 RH= H(L1)*(1.0-AXG(J))+HTH(IC)*AXG(J)                                 MAIN2490
      GO TO 611                                                             MAIN2500
  600 RH= H(L1)*(1.0-AXG(J)) + H(L2)*AXG(J)                                 MAIN2510
  611 CONTINUE                                                              MAIN2520
```

```
      DO 70 K=1,NPL
      GPL(IR,J,K) = RH*TWG(K)*B(MKE(IR))/2.0
70    GBETA(IR,J,K) =RH*TXG(K)/2.
      J=1+NBR
      DO 5400 I=1,J
      ES(I,1) = SIG(I,1)/EPS(I,1)
      M= NSPL(I)
      IF(M-1) 77,77,76
   76 DO 78 L=2,M
      K=L-1
   78 ES(I,L)= (SIG(I,L)-SIG(I,K))/(EPS(I,L)-EPS(I,K))
   77 N= NSPL(I) +1
      ES(I,N) = 0.0
      DO 79 L=1,M
   79 SNO(I,L)= ES(I,1)* EPS(I,L)
      YOUNG(I) = ES(I,1)
 5400 CONTINUE
       DO 71 IR=1,IK
      N=MKE(IR)
      M= NSPL(N)
       DO 71 J=1,NOGA
       DO 71 K=1,NPL
      DO 71 L=1,M
      LL=L+1
   71 ASPL(IR,J,K,L)=GPL(IR,J,K)* (ES(N,L)-ES(N,LL))/ES(N,1)
      IF(NBR.NE.0)  GO TO 218
       DO 15 I=1,8
15     ICOL(I)=1
       IKM1=IK-1
      IF(EXANG.NE.360.)GO TO 210
       DO 16 I=3,IKM1
       IK4=I*4
       IK3=IK4-1
       IK2=IK4-2
       IK1=IK4-3
       JJ= (I-1)*4-3
```

```
      ICOL(IK1)=JJ
      ICOL(IK2)=JJ
      ICOL(IK3)=JJ
      ICOL(IK4)=JJ
 16   CONTINUE
      ICOL(IK*4)=1
      ICOL(IK*4-1)=1
      ICOL(IK*4-2)=1
      ICOL(IK*4-3)=1
      GO TO 218
210   DO 211 I=3,IKP1
      IK4=I*4
      IK3=IK4-1
      IK2=IK4-2
      IK1=IK4-3
      JJ=(I-1)*4-3
      ICOL(IK1)=JJ
      ICOL(IK2)=JJ
      ICOL(IK3)=JJ
      ICOL(IK4)=JJ
211   CONTINUE
218   INUM(1)=1
      DO 99 I=2,NI
 99   INUM(I)=1-ICOL(I-1)+INUM(I-1)
      DO 990 I=1,NI
990   INUM(I)=INUM(I)-ICOL(I)
      NIRREG=0
      INDEX=0
      ISET=1
      DO 116 I=1,NI
      L=ICOL(I)
      IF(ICOL(I)-ISET)117,116,119
119   ISET=ICOL(I)
      GO TO 116
117   NIRREG=NIRREG+1
      IF(NIRREG-NI/2)711,711,90
```

```
 711   KROW(NIRREG)=I
       NDEX(NIRREG)=INDEX
 116   INDEX=INDEX+I-L
 90    CALL PICOL(NI,NI,L,ICCL)
       ISIZE=L
       WRITE(MWRITE,17) L
    17 FORMAT(/,'   SIZE OF ASSEMBLED STIFFNESS MATRIX =',I5)
      IF(L.LE.2060) GOTO 6012
      WRITE(MWRITE,6011)
 6011 FORMAT('OTHE SIZE OF THE STIFFNESS MATRIX HAS EXCEEDED 2060.  THIS
     ƏRUN HAS BEEN TERMINATED.  CHANGE DIMENSION OF STIFK IN',/   ,
     Ə' MAIN,ELMPP, AND TSTEP')
      GO TO 160
 6012 CONTINUE
      CALL ELMPP(DELTAT,AA,ISIZE,KROW,NDEX,NIRREG,INUM)
 61   DO 981 IR=1,IKP1
      RMASS(IR)=0.0
 981  RMX(IR)=0.0
      IC=0
C   CALCULATION OF LUMPED MASS MATRIX -- SOL
      DO 980 IR=1,IK
      K1= NVEC(IR,1)
      K2 = NVEC(IR,2)
      H1= H(K1)
      H2= H(K2)
      IF(YK(IR).NE.1.0.AND.YK(IR).NE.3.0) GOTO 641
      IC = IC+1
      IF(ROT(IC,1).EQ.0.0) GO TO 640
      H(K1) =      HTH(IC)
       GO TO 641
  640 H(K2) = HTH(IC)
  641 CONTINUE
      CL(IR)=(2.*H(K2  )+H(K1))/(3.*H(K2  )+3.*H(K1))
      CLP(IR)=1.0-CL(IR)
      CLA(IR)=AL(IR)*CL(IR)
      CLPA(IR)=AL(IR)*CLP(IR)
```

```
      RMOI(IR)=(H(K1)**2+4.*H(K1)*H(K2  )+H(K2  )**2)*AL(IR)**3/
     *(36.*(H(K1)+H(K2)))*B(MKE(IR))*DENS(MKE(IR))
      H(K1)  = H1
      H(K2)  = H2
  980 CONTINUP
      IC=0
      DO 982 I=1,IKM1
      L= NVEC(I  ,1)
      L2 = NVEC(I  ,2)
      H1 = H(L)
      H2 = H(L2)
      IP(YK(I ).NE.1.0.AND.YK(I ).NE.3.0)  GOTC 661
      IC = IC+1
      IP(ROT(IC,1).EQ.0.0)  GC TO 660
      H(L) = HTH  (IC)
       GO TO 661
  660 H(L2)  = HTH(IC)
  661 CONTINUE
      N= MKE(I)
      RMASS(L)=RMASS(L)+(H(L)+H(L2))*B(N)*DENS(N)*CLPA(I)/2.0
      RMASS(L2)=RMASS(L2)+(H(L)+H(L2))*B(N)*DENS(N)*CLA(I)/2.0
      RMX(L)=RMX(L)+RMOI(I)*CLP(I)
      RMX(L2 )=RMX(L2 )+RMOI(I)*CL(I)
      H(L)  = H1
      H(L2)  = H2
  982 CONTINUE
      K1 = NVEC(IK,1)
      H1= H(K1)
      H2 = H(IK+1)
      N= MKE(IK)
      IP(YK(IK).NE.1.0.AND.YK(IK).NE.3.0)  GOTO 681
       IC= IC+1
      IP(ROT(IC,1).EQ.0.0)  GO TO 680
      H(K1)  = HTH(IC)
       GO TO 681
  680 H(IK+1)  = HTH(IC)
```

```
  681 CONTINUE                                                                   MAIN3970
      IF(EXANG.EQ.360.)GO TO 983                                                 MAIN3980
      RMASS(K1)=RMASS(K1)+(H(K1)+H(IK+1))*B(N)*DENS(N)*CLPA(IK)/2.0              MAIN3990
      RMASS(IK+1)=RMASS(IK+1)+(H(K1)+H(IK+1))*B(N)*DENS(N)*CLA(IK)/2.0           MAIN4000
      RMX(K1)=RMX(K1)+RMOI(IK)*CLP(IK)                                           MAIN4010
      RMX(IK+1)=RMX(IK+1)+RMOI(IK)*CL(IK)                                        MAIN4020
      GO TO 984                                                                  MAIN4030
  983 RMASS(K1)=RMASS(K1)+(H(K1)+H(    1))*B(N)*DENS(N)*CLPA(IK)/2.0             MAIN4040
      RMASS(1)=RMASS(1)+(H(K1)+H(    1))*B(N)*DENS(N)*CLA(IK)/2.0                MAIN4050
      RMX(K1)=RMX(K1)+RMOI(IK)*CLP(IK)                                           MAIN4060
      RMX(1)=RMX(1)+RMOI(IK)*CL(IK)                                              MAIN4070
 984  CONTINUE                                                                   MAIN4080
      H(K1) = H1                                                                 MAIN4090
      H(IK+1) = H2                                                               MAIN4100
      WRITE(MWRITE,7836)                                                         MAIN4110
      WRITE(MWRITE,7837)   (RMASS(L),L=1,NS)                                     MAIN4120
      WRITE(MWRITE,7838)                                                         MAIN4130
      WRITE(MWRITE,7837)     (RMX(L),L=1,NS)                                     MAIN4140
 7836 FORMAT(//,' THE TRANSLATIONAL MASSES FOR EACH NODE ARE:')                  MAIN4150
 7838 FORMAT(//,' THE ROTATIONAL MASSES FOR EACH NODE ARE:')                     MAIN4160
 7837 FORMAT(' ',4D25.15)                                                        MAIN4170
      CALL TSTEP(                            KROW,NDEX,NIRREG,DELTAT)            MAIN4180
C     OVER RIDE ANY CHANGE IN DELTAT BY TSTEP                                    MAIN4190
      IF(NTOVR.EQ.1)  DELTAT=DELTA                                               MAIN4200
      DO 5 IR=1,NS                                                               MAIN4210
      SOL(IR*4-3)=RMASS(IR)                                                      MAIN4220
      SOL(IR*4-2)=RMASS(IR)                                                      MAIN4230
      SOL(IR*4-1)=RMX(IR)                                                        MAIN4240
5     SOL(IR*4)=RMX(IR)                                                          MAIN4250
      DO 6 I=1,NI                                                                MAIN4260
6     SOL(I)=DELTAT**2/SOL(I)                                                    MAIN4270
      DO 530 I= 1,NS                                                             MAIN4280
  530 JVEL(I) = 0                                                                MAIN4290
      IF (NOR .EQ.0) GO TO 21                                                    MAIN4300
       DO 23 L=1,ISIZE                                                           MAIN4310
 23    SPRIN(L)=0.0                                                              MAIN4320
```

```
            CALL QRFM(AA,AL,AXG,AWG)                                    MAIN4330
   21  MCRIT=0                                                          MAIN4340
      M= NBR+1                                                          MAIN4350
      DO 10005 J= 1,M                                                   MAIN4360
      BIG(J) = 0.0                                                      MAIN4370
      BIGA(J) = 0.0                                                     MAIN4380
      BI(J) = 0.0                                                       MAIN4390
      IBIGA(J) = 0                                                      MAIN4400
      IBIG(J) = 0                                                       MAIN4410
      IBI(J) = 0                                                        MAIN4420
      ISTA(J) = 0                                                       MAIN4430
      ISTAA(J) = 0                                                      MAIN4440
      BTIME(J) = 0.0                                                    MAIN4450
      BTIMA(J) = 0.0                                                    MAIN4460
      BTIM(J) = 0.0                                                     MAIN4470
10005 CONTINUE                                                          MAIN4480
      DO 75 I=1,NS                                                      MAIN4490
      COIY(I)=Y(I)                                                      MAIN4500
75    COIZ(I)=Z(I)                                                      MAIN4510
      READ(MREAD,82)ICONT                                               MAIN4520
82    FORMAT(I5)                                                        MAIN4530
   83 FORMAT(2(I5,D20.13))                                              MAIN4540
  387 FORMAT(2I5,2D20.13)                                               MAIN4550
  386 FORMAT(3I5,2D20.13)                                               MAIN4560
   84 FORMAT(4D20.13)                                                   MAIN4570
   86 FORMAT(2I5,2D20.13,I5)                                            MAIN4580
   89 FORMAT(I5,6D12.5)                                                 MAIN4590
385   FORMAT(6D13.6)                                                    MAIN4600
      DO 8400 K=1,NS                                                    MAIN4610
 8400 HNIN(K)= H(K)/2.0                                                 MAIN4620
      IKK= NS                                                           MAIN4630
      ICP=0                                                             MAIN4640
      IF(EXANG.EQ.360.0) ICP=1                                          MAIN4650
      N=NBR+1                                                           MAIN4660
C    DETERMINE EFFECTIVE LENGTH FOR EACH SUBSTRUCTURE                   MAIN4670
      DO 5551 I=1,N                                                     MAIN4680
```

```
5551 EPLN(I)=  (YOUNG(I)/DENS(I))**0.5*DELTAT                          MAIN4690
     WRITE (MWRITE,5552)                                                MAIN4700
     WRITE(MWRITE,5553)   (EPLN(J),J=1,N)                               MAIN4710
5552 FORMAT('0 THE FOLLOWING NUMBERS ARE THE VALUES FOR THE EFFECTIVE   MAIN4720
    * LENGTHS FOR THE NBR PLUS 1 SECTIONS OF THE STRUCTURE')            MAIN4730
5553 FORMAT(' ', 6D15.6)                                                MAIN4740
     WRITE(MWRITE,7839)                                                 MAIN4750
7839 FORMAT(/////,' THE FOLLOWING IS THE TIME SOLUTION OF THE FRAGMENT-MAIN4760
    D RING IMPACT')                                                     MAIN4770
     IF(ICONT-1) 80,81,81                                               MAIN4780
80   CALL DINIT(IT,TIME)                                                MAIN4790
     DO 6111 I=1,NI                                                     MAIN4800
     QACL(I) = 0.0                                                      MAIN4810
6111 QVEL(I) = 0.0                                                      MAIN4820
     NQ = MIRP                                                          MAIN4830
C    CHANGE CYCLE PARAMETERS IF TSTEP HAS BEEN ALLOWED TO OVER RIDE     MAIN4840
C         USER'S  DELTAT                                                MAIN4850
     IF(DELTAT.EQ.DELTA) GO TO 9102                                     MAIN4860
     M1= IDINT(M1*DELTA/DELTAT)                                         MAIN4870
     MM= IDINT(MM*DELTA/DELTAT)                                         MAIN4880
     M2= IDINT(M2*DELTA/DELTAT)                                         MAIN4890
     IF(M2.LT.1) M2 = 1                                                 MAIN4900
     NPZ1 = M1                                                          MAIN4910
     MX=M1                                                              MAIN4920
     MY= M2                                                             MAIN4930
9102 CONTINUE                                                           MAIN4940
     GO TO 992                                                          MAIN4950
  81 READ(MREAD,83) IT,TIME,IMCOU,TAII                                  MAIN4960
     M= NBR+1                                                           MAIN4970
     READ(MREAD,86) (IBIGA(L),ISTAA(L),BIGA(L),BTIMA(L),ISURA(L)  ,L=1,M) MAIN4980
     READ (MREAD ,386)  (IBIG(L),ISURF(L),ISTA(L),BIG(L),BTIME(L),L=1,M) MAIN4990
     READ (MREAD ,387)  (IDI(L),ISUR(L),BI(L),BTIM(L),L=1,M)            MAIN5000
     READ (MREAD ,89) MIRP,  (INJ(I),I=1,NP)                            MAIN5010
     READ(MREAD,84)(DISP(I),I=1,NI)                                     MAIN5020
     READ(MREAD,84)(DELD(I),I=1,NI)                                     MAIN5030
     READ (MREAD ,84)  (QVEL(I),I=1,NI)                                 MAIN5040
```

```
      READ (MREAD ,84) (QACL(I),I=1,NI)
      READ (MREAD ,84) ((((SNS(IR,J,K,L),L=1,MNSPL),K=1,NPL),J=1,NOGA),
     *IR=1,IK)
      READ (MREAD , 84) (FCGU(J),PCGW(J),ALFA(J),UDOT(J),WDOT(J)
     *,ADOT(J),J=1,NP)
      NQ= MIRP
C    ***** START OF THE TIME SOLUTION *****
992   IT=IT+1
      IF(TIME.GT.TIMP) GO TO 965
          CALL IMPACT(EPLN,IT,NBR,QACL,QVEL)
      DO 994 I=1,NI
994   DISP(I)=DISP(I)+DELD(I)
C   STAGGERED FRAGMENT RELEASE
 6010 IF(NQ.GT.NF.OR.NQ.EQ.0) GO TO 6020
      TI= (IT*DELTAT)-(TPRIM(1)-TPRIM(NQ))
      IF(DABS(TI).GT.DELTAT)   GOTO 6020
      TNJ(NQ)= 1.0
      NQ=NQ+1
      GO TO 6010
 6020 DO 822 I=1,NP
      FCGU(I)= PCGU(I)+DPCGU(I) * TNJ(I)
      PCGW(I) = PCGW(I)+DPCGW(I) * TNJ(I)
  822 ALFA(I) = ALFA(I) + DALFA(I) * TNJ(I)
      DO 522 I=1,NI
      PQREF(I)=0.0
522   PLVA(I)=0.0
      CALL STRESS
      IF(NQR.EQ.0)GO TO 735
      CALL OMULT(SPRIN,DISP,ICOL,NI,PQREF,KROW,NDEX,NIRREG)
      DO 736 I=1,NI
736   FLVA(I)=FLVA(I)+PQREF(I)
735   CONTINUE
11100 FORMAT('0***************************************************************
     @*********************************************************************
     @********',/)
696   IF(NBCOND.EQ.0)GO TO 889
```

```
      DO 888 I=1,NBCOND
      NXY=NODEB(I)
      IF(NBC(I).EQ.1)GO TO 886
      IF(NBC(I).EQ.2)GO TO 887
      IF(NBC(I).EQ.3)GO TO 885
886   PLVA(NXY*4-3)=0.0
      PLVA(NXY*4-1)=0.0
      GO TO 888
887   PLVA(NXY*4-3)=0.0
      PLVA(NXY*4-2)=0.0
      PLVA(NXY*4-1)=0.0
      GO TO 888
885   PLVA(NXY*4-3)=0.0
      PLVA(NXY*4-2)=0.0
888   CONTINUE
889   NIPE=NI
C   FIND NEW DISPLACEMENT INCREMENT
      DO 525 I=1,NI
      QACL(I) =  -PLVA(I)*SOL(I)
      QVEL(I)= QACL(I)/(2.0*DELTAT) + DELD(I)/DELTAT
  525 CONTINUE
      IF (IMCO.EQ.0) GOTO 527
      IMCO= 0
      DO 526 J=1,NS
      IF(JVEL(J).EQ.0) GOTO 526
      JVEL(J) = 0
      QVEL(J*4-3)= VEL(J*2-1)
      QVEL(J*4-2)= VEL(J*2)
  526 CONTINUE
  527 CONTINUE
      IF(IT-MX)815,816,815
816   MX=MX+MY
      WRITE(MWRITE,11100)
          CALL ENERGY(IT,KROW,NDEX,NIRREG,SOL,ES,GFL,QVEL)
815   CONTINUE
      DO 528 I=1,NI
```

```
  528 DELD(I)= QACL(I)/2.0 + QVEL(I)*DELTAT                              MAIN5770
      TIME=IT*DELTAT                                                     MAIN5780
      IF(IMCOU.EQ.0) TAII=TIME                                           MAIN5790
      MIZ=0                                                              MAIN5800
      NPZ= IT-NPZ1                                                       MAIN5810
      IF(NPZ.NE.0) GOTO 6700                                             MAIN5820
      IF(LGSP.EQ.0) GOTO 6700                                            MAIN5830
      WRITE (MWRITE,6705) IT                                             MAIN5840
 6705 FORMAT('0 CYCLE=' , I8)                                            MAIN5850
      WRITE (MWRITE,6707)                                                MAIN5860
 6707 FORMAT(' ELEM',7X,'SI',3X,'STA1',3X,'SO',11X,'SI',3X,'STA2',3X,    MAIN5870
     @'SO',11X,'SI',3X,'STA3',3X,'SO')                                   MAIN5880
      MIZ= 1                                                             MAIN5890
      NPZ1 = NPZ1+M2                                                     MAIN5900
      DO 6701 I= 1,NS                                                    MAIN5910
      ITHR(I) = C                                                        MAIN5920
      EPSI(I) = 0.0                                                      MAIN5930
 6701 EPSO(I) = C.0                                                      MAIN5940
C   GAUSSIAN STATION STRAIN CALCULATION                                  MAIN5950
 6700 DO 7161 IR=1,IK                                                    MAIN5960
      K1= NVEC(IR,1)                                                     MAIN5970
      K2= NVEC(IR,2)                                                     MAIN5980
      LSS = MKE(IR)                                                      MAIN5990
      DO 8018 K=1,8                                                      MAIN6000
      INDEX= (K1-1)*4+K                                                  MAIN6010
      IF(K.GT.4) INDEX= (K2-1)*4+K-4                                     MAIN6020
      DISM(K) = DISP(INDEX)                                              MAIN6030
 8018 CONTINUE                                                           MAIN6040
      IF(YK(IR).EQ.0.0) GOTO 901                                         MAIN6050
           CALL ROTAT(1,DUMMY,DISM,IR)                                   MAIN6060
  901 CONTINUE                                                           MAIN6070
      DO 604 I=1,NOGA                                                    MAIN6080
      DO 604 J=1,3                                                       MAIN6090
      BEPS (I,J)= 0.0                                                    MAIN6100
      DO 604 K=1,8                                                       MAIN6110
  604 BEPS(I,J)=BEPS(I,J)+BEP(IR,I,J,K)* DISM(K)                         MAIN6120
```

```
      H1 = H(K1)                                                        MAIN6130
      H2 = H(K2)                                                        MAIN6140
      N= MKL(IR)-1                                                      MAIN6150
      IF(YK(IR).EQ.1.0.AND.ROT(N,1).EQ.1.0)   H(K1)  = HTH(N)           MAIN6160
      IF(YK(IR).EQ.1.0.AND.ROT(N,1).EQ.0.0)   H(K2)  = HTH(N)           MAIN6170
      HDIF=H(K2)-H(K1)                                                  MAIN6180
      DO 60 M =1,3                                                      MAIN6190
      HHAG=(H(K1)+ AXG(M)* HDIF) /2.0                                   MAIN6200
      FARE= BEPS(M,1)+BEPS(M,2)**2/2.0                                  MAIN6210
     *+BEPS(M,1)**2/2.                                                  MAIN6220
      EPI(M)=FARE - HHAG*BEPS(M,3)                                      MAIN6230
      EPO(M) = FARE+HHAG*BEPS(M,3)                                      MAIN6240
C   FIND LARGEST GAUSSIAN STATION STRAIN                                MAIN6250
      IF(EPI(M).LE.BIG(LSS)) GO TO 591                                  MAIN6260
      BIG(LSS) = EPI(M)                                                 MAIN6270
      IBIG(LSS)= IR                                                     MAIN6280
      ISTA(LSS) = M                                                     MAIN6290
      ISURF(LSS) = 1                                                    MAIN6300
      BTIME(LSS) = TIME                                                 MAIN6310
  591 IF(EPO(M).LE.BIG(LSS)) GO TO 1200                                 MAIN6320
      BIG(LSS) = EPO(M)                                                 MAIN6330
      IBIG(LSS)= IR                                                     MAIN6340
      ISTA(LSS) = M                                                     MAIN6350
      ISURF(LSS) = 2                                                    MAIN6360
      BTIME(LSS) = TIME                                                 MAIN6370
 1200 CONTINUE                                                          MAIN6380
   60 CONTINUE                                                          MAIN6390
      IF (NPZ.NE.0) GOTO 6607                                           MAIN6400
C   AVERAGE NODAL STRAIN CALCULATION                                    MAIN6410
C   AT A  NODE WHERE A BRANCH ATTACHES TO THE MAIN STRUCTURE,           MAIN6420
C     THE BRANCH'S NODAL STRAIN IS NOT AVERAGED IN                      MAIN6430
      DO 6604 I=1,2                                                     MAIN6440
      DO 6604 J=1,3                                                     MAIN6450
      BEPS( I,J) = 0.0                                                  MAIN6460
      DO 6604 K=1,8                                                     MAIN6470
 6604 BEPS(I,J) = BEPS(I,J) +DEP(IR,I,J,K)* DISM(K)                     MAIN6480
```

```
      FAR1 =BEPS(1,1)+BEPS(1,2)**2/2.0 +BEPS(1,1)**2/2.0
      FAR2 =BEPS(2,1)+BEPS(2,2)**2/2.0 +BEPS(2,1)**2/2.0
      NKE = MKE(IR)
      IF(NKE.EQ.1) GOTO 6605
      IF(MATT(NKE-1).EQ.K1) GOTO 6606
 6605 ADEN = 1.0
      IF(ITHR(K1).GT.0)  ADEN=2.0
      ITHR(K1) = 1
      EPSI(K1)=(EPSI(K1) + FAR1-H(K1)*BEPS(1,3)/2.0)  /ADEN
      EPSO(K1) =(EPSO(K1) + FAR1+H(K1)*BEPS(1,3)/2.0)  /ADEN
      IF(NKE.EQ.1) GOTO 6606
      IF(MATT(NKE-1).EQ.K2)  GOTO 6607
 6606 ADEN = 1.0
      IF(ITHR(K2).GT.0)  ADEN=2.0
      ITHR(K2) = 1
      EPSI(K2) =(EPSI(K2) + FAR2- H(K2)*BEPS(2,3)/2.0) /ADEN
      EPSO(K2)=(EPSO(K2) + FAR2+H(K2) * BEPS(2,3)/2.0 ) /ADEN
 6607 CONTINUE
      H(K1) = H1
      H(K2) = H2
      IF (MIZ.NE.1) GO TO 7161
      IF(LGSP.EQ.0) GO TO 7161
 7940 WRITE(MWRITE,6710) IR,(EPI(L),EPO(L),L=1,3)
 6710 FORMAT(' ',I2,2X,3(2X,D11.4,1X,D11.4))
 7161  CONTINUE
      IF(NPZ.NE.0) GOTO 7180
C    FIND LARGEST AVERAGE NODAL STRAIN
      DO 7170 I= 1,NS
      N= 0
      DO 7171 IR=1,IK
      IF(NVEC(IR,1).NE.I) GOTO 7172
      IF(MKE(IR).EQ.1) N= N+1
      IF(MKE(IR).GT.1)  N= N+3
      IF(MKE(IR).GT.1) NKE=MKE(IR)
 7172 CONTINUE
      IF(NVEC(IR,2).NE.I) GOTO 7171
```

```
      IF(MKE(IR).EQ.1) N=N+1                                            MAIN6850
      IF(MKE(IP).GT.1)  N= N+3                                          MAIN6860
      IF(MKE(IF).GT.1)  NKE= MKE(IR)                                    MAIN6870
 7171 CONTINUE                                                          MAIN6880
      NK=1                                                              MAIN6890
      IF(N.EQ.3.OR.N.EQ.6) NK=NKE                                       MAIN6900
      IF(EPSI(I).LE.BI(NK)) GOTC 7174                                   MAIN6910
      BI(NK) = EPSI(I)                                                  MAIN6920
      IBI(NK) = I                                                       MAIN6930
      ISUR(NK) = 1                                                      MAIN6940
      BTIM(NK) = TIME                                                   MAIN6950
 7174 IF(EPSO(I).LE.BI(NK)) GOTO 7170                                   MAIN6960
      BI(NK) = EPSO(I)                                                  MAIN6970
      IBI(NK) = I                                                       MAIN6980
      ISUR(NK) = 2                                                      MAIN6990
      BTIM(NK) = TIME                                                   MAIN7000
 7170 CONTINUE                                                          MAIN7010
 7180 CONTINUF                                                          MAIN7020
      IF(LSPP.EQ.0) GOTO 8562                                           MAIN7030
      IF(NPZ.NE.0) GOTO 8562                                            MAIN7040
      KTI = KTI+1                                                       MAIN7050
      WRITE(MWRITE,6705) IT                                             MAIN7060
      WRITE(MWRITE,8707)                                                MAIN7070
 8707 FORMAT(' STRAIN AT ADDITIONAL POINTS',10X,'SI',18X,'SO',23X,'EI', MAIN7080
     @18X,'EO')                                                         MAIN7090
 8700 DO 8761 IR= 1,IK                                                  MAIN7100
      IF(LKK(IR,1).EQ.0)  GOTO 8761                                     MAIN7110
      K1 = NVEC(IR,1)                                                   MAIN7120
      K2= NVEC(IP,2)                                                    MAIN7130
      L= MKE(IR)                                                        MAIN7140
      DO 8019 K=1,8                                                     MAIN7150
      INDEX= (K1-1)*4+K                                                 MAIN7160
      IF(K.GT.4) INDEX= (K2-1)*4+K-4                                    MAIN7170
      DISM(K) = DISP(INDEX)                                             MAIN7180
 8019 CONTINUE                                                          MAIN7190
      IF(YK(IR).EQ.0.0) GOTO 902                                        MAIN7200
```

```
      CALL ROTAT(1,DUMMY,DISM,IR)
  902 CONTINUE
      H1 = H(K1)
      H2 = H(K2)
      N= MKE(IR)-1
      IF(YK(IR).EQ.1.C.AND.ROT(N,1).EQ.1.0)   H(K1) = HTH(N)
      IF(YK(IR).EQ.1.0.AND.ROT(N,1).EQ.0.0)   H(K2) = HTH(N)
      NO= LKK(IR,1)
      DO 8763 I= 1,NO
      IS = LKK(IR,I+1)
      DO 8604 J=1,3
      AEPS(J) = 0.0
      DO 8604 K= 1,8
 8604 AEPS(J)=AEPS(J) + AEP(IS,J,K)*DISM(K)
      HDIF= H(K2)-H(K1)
      HHAG= (H(K1) + AZET(IS)*HDIF)/2.0
      FARE= AEPS(1)+AEPS(2)**2/2.0+AEPS(1)**2/2.0
      EPASI= FARE-HHAG*AEPS(3)
      EPASO=FARE+HHAG*AEPS(3)
C   FIND LARGEST ADDITIONAL POINT STRAIN
      IF(EPASI.LE.BIGA(L))   GO TO 8591
      BIGA(L) = EPASI
      IBIGA(L) = IR
      ISTAA(L) = IS
      BTIMA(L) = TIME
      ISURA(L) = 1
 8591 IF(EPASO.LE.BIGA(L)) GO TO 8780
      BIGA(L) = EPASO
      IBIGA(L) = IR
      ISTAA(L) = IS
      BTIMA(L) = TIME
      ISURA(L) = 2
 8780 IF(MIZ.NE.1) GO TO 8763
      EI= DSQRT(1.0+2.0* EPASI) -1.0
      EO= DSQRT(1.0+2.0* EPASO) -1.0
      WRITE(MWRITE,8781) IS,EPASI,EPASO,EI,EC
```

```
 8781 FORMAT(' ',10X,I3,16X,D15.8,4X,D15.8,11X,D15.8,4X,D15.8)          MAIN7570
 8763 CONTINUE                                                          MAIN7580
      H(K1) = H1                                                        MAIN7590
      H(K2) = H2                                                        MAIN7600
 8761 CONTINUE                                                          MAIN7610
 8562 CONTINUE                                                          MAIN7620
 1250 IF(IT-M1)987,988,150                                              MAIN7630
988   M1=M1+M2                                                          MAIN7640
      CALL PRINT(IT,TIME)                                               MAIN7650
      M=NBR+1                                                           MAIN7660
      WRITE(MWRITE,66)                                                  MAIN7670
      WRITE(MWRITE,67) (L,BIG(L),IBIG(L),ISURP(L),ISTA(L),BTIME(L),L=1,M) MAIN7680
      IF(LSPP.NE.1) GO TO 8782                                          MAIN7690
      WRITE(MWRITE,6030)                                                MAIN7700
      WRITE(MWRITE,6035)  (L,BIGA(L),IBIGA(L),ISTAA(L),BTIMA(L),ISURA(L),MAIN7710
     @L=1,M)                                                            MAIN7720
 8782 CONTINUE                                                          MAIN7730
      WRITE(MWRITE,7181)                                                MAIN7740
      WRITE(MWRITE,7182) (L,BI(L),IGI(L),ISUR(L),BTIM(L),L=1,M)         MAIN7750
 7181 FORMAT('CSUBSTRUCTURE',5X,'LARGEST  NODAL  STRAIN ',5X,'NODE',7X, MAIN7760
     @'SURF',11X,'TIME')                                                MAIN7770
 7182 FORMAT(' ',4X,I3,16X,D15.6,7X,I3,6X,I5,5X,D15.6)                  MAIN7780
      WRITE(MWRITE,11100)                                               MAIN7790
987   IF(IT-MM)992,965,150                                              MAIN7800
  965 CONTINUE                                                          MAIN7810
      WRITE(MWRITE,6002)                                                MAIN7820
 6002 FORMAT('OTHE LARGEST COMPUTED STRAINS FOR EACH SUBSTRUCTURE--     MAIN7830
     @MAIN AND BRANCHES -- ARE PRINTED BELOW,  1= INNER  2= OUTER SURF')MAIN7840
      M= NBP+1                                                          MAIN7850
      WRITE(MWRITE,66)                                                  MAIN7860
      WRITE(MWRITE,67) (L,BIG(L),IBIG(L),ISURP(L),ISTA(L),BTIME(L),L=1,M) MAIN7870
   66 FORMAT('OSUBSTRUCTURE',8X,'MSTR',7X,'ELE',5X,'SURP',5X,'STA',     MAIN7880
     @9X,'TIME')                                                        MAIN7890
   67 FORMAT(' ',3X,I4,6X,D15.6,1X,I4,4X,I4,4X,I4,4X,D15.6)             MAIN7900
      IF(LSPP.NE.1) GOTO 149                                            MAIN7910
      WRITE(MWRITE,6030)                                                MAIN7920
```

```
      WRITE(MWRITE,6035)  (L,BIGA(L),IBIGA(L),ISTAA(L),BTIMA(L),ISURA(L),MAIN7930
     @L=1,M)                                                            MAIN7940
 6030 FORMAT('OSUBSTRUCTURE',5X,'LARGEST ADD. PT. STRAIN',5X,'ELEM',5X, MAIN7950
     @'ADD. PT.',9X,'TIME',10X,'SURFACE')                               MAIN7960
 6035 FORMAT(' ',4X,I3,16X,D15.6,7X,I3,6X,I5,5X,D15.6,6X,I4)            MAIN7970
  149 CONTINUE                                                          MAIN7980
      WRITE(MWRITE,7181)                                                MAIN7990
      WRITE(MWRITE,7182) (L,BI(L),IBI(L),ISUR(L),BTIM(L),L=1,M)         MAIN8000
  150 IF (MPU.EQ.0) GO TO 160                                           MAIN8010
C    PUNCHING OF CONTINUATION CARDS  IF MPU GT 0                        MAIN8020
      M= NBR+1                                                          MAIN8030
      WRITE( MPUNCH,83) IT,TIME,INCOU,TAII                              MAIN8040
      WRITE(MPUNCH,86)  (IBIGA(L),ISTAA(L),BIGA(L),BTIMA(L),ISURA(L),   MAIN8050
     @L=1,M)                                                            MAIN8060
      WRITE(MPUNCH,386)  (IBIG(L),ISURF(L),ISTA(L),BIG(L),BTIME(L),L=1,M) MAIN8070
      WRITE(MPUNCH,387)  (IBI(L),ISUR(L),BI(L),BTIM(L),L=1,M)           MAIN8080
      WRITE(MPUNCH,89) MIRP,  (TNJ(I),I=1,NF)                           MAIN8090
      WRITE(MPUNCH,84)  (DISP(I),I=1,NI)                                MAIN8100
      WRITE(MPUNCH,84)  (DELD(I),I=1,NI)                                MAIN8110
      WRITE(MPUNCH,84)  (QVEL(I),I=1,NI)                                MAIN8120
      WRITE(MPUNCH,84)  (QACL(I),I=1,NI)                                MAIN8130
      WRITE(MPUNCH,84) ((((SNS(IR,J,K,L),L=1,MNSFL),K=1,NPL),J=1,NOGA), MAIN8140
     *IR=1,IK)                                                          MAIN8150
      WRITE(MPUNCH, 84)  (PCGU(J),PCGW(J),ALPA(J),UDOT(J),WDOT(J)       MAIN8160
     *,ADOT(J),J=1,NF)                                                  MAIN8170
      WRITE(MWRITE,6005)                                                MAIN8180
 6005 FORMAT('OCONTINUATION CARDS HAVE BEEN PUNCHED FOR THIS RUN')      MAIN8190
      GO TO 161                                                         MAIN8200
  160 WRITE(MWRITE,151)                                                 MAIN8210
  151 FORMAT('ONO CARDS PUNCHED DURING THIS RUN FOR CONTINUATION.')     MAIN8220
  161 READ (MREAD,1100) ICON                                            MAIN8230
C    CHECK FOR ADDITIONAL DATA SETS,  IF NONE FOUND TERMINATE RUN       MAIN8240
      IF (ICON) 1120,1110,1120                                          MAIN8250
 1120 IRRUN = IRRUN + 1                                                 MAIN8260
      WRITE (MWRITE,1130) IRRUN                                         MAIN8270
 1130 FORMAT ('1     THIS IS DATA SET NUMBER',I5,'   FOR THIS RUN')     MAIN8280
```

```
      GO TO 5555                                        MAIN8290
 1100 FORMAT(I5)                                        MAIN8300
 1110 CALL EXIT                                         MAIN8310
      END                                               MAIN8320
```

```
      SUBROUTINE ASSEP(IR,IK,ELPP,PLVA,EXANG)
      IMPLICIT REAL*8(A-H,O-Z)
       DIMENSION NN(8),PLVA(1),ELPP(1)
      COMMON /BR/ NVEC(51,2)
      SIN(Q)=DSIN(Q)
      COS(Q)=DCOS(Q)
      ATAN(Q)=DATAN(Q)
      ABS(Q)=DABS(Q)
      SQRT(Q)=DSQRT(Q)
      J1 = NVEC(IR,1) * 4
       NN(1)=J1-3
       NN(2)=J1-2
       NN(3)=J1-1
       NN(4)=J1
      IF(EXANG.NE.360.)GO TO 121
       IF(IR-IK) 121,122,122
  121 J2 = NVEC(IK,2) * 4
       NN(5)=J2-3
       NN(6)=J2-2
       NN(7)=J2-1
       NN(8)=J2
       GO TO 123
  122  NN(5)=1
       NN(6)=2
       NN(7)=3
       NN(8)=4
  123  DO 101 I=1,8
       M=NN(I)
       PLVA(M)=PLVA(M)+ELPP(I)
  101  CONTINUE
       RETURN
      END
```

```
      SUBROUTINE ASSEM(IR,ELMAS,STIFM)                                  ASSM0010
      IMPLICIT REAL*8(A-H,O-Z)                                          ASSM0020
       DIMENSION ELMAS(8,8),NN(8),STIFM(1)                              ASSM0030
       COMMON /TAPE/ MREAD,MWRITE,MPUNCH                                ASSM0040
      COMMON/BG/Y(51),Z(51),ANG(51),H(51),EXANG,NS,IK,NCJA,NFL,NT,      ASSM0050
     * ICOL(255),NLCOND,NBC(7),NODEB(7)                                 ASSM0060
      COMMON/MAT/ DENS(6),B(6),YOUNG(6),DS(6),SNC(6,5),NSPL(6),P(6),    ASSM0070
     * EPS(6,5),SIG(6,5), EFLN(6)                                       ASSM0080
      COMMON /BR/ NVEC(51,2)                                            ASSM0090
      SIN(Q)=DSIN(Q)                                                    ASSM0100
      COS(Q)=DCOS(Q)                                                    ASSM0110
      ATAN(Q)=DATAN(Q)                                                  ASSM0120
      ABS(Q)=DABS(Q)                                                    ASSM0130
      SQRT(Q)=DSQRT(Q)                                                  ASSM0140
      J1 = NVEC(IR,1) * 4                                               ASSM0150
       NN(1)=J1-3                                                       ASSM0160
       NN(2)=J1-2                                                       ASSM0170
       NN(3)=J1-1                                                       ASSM0180
       NN(4)=J1                                                         ASSM0190
      IF(EXANG.NE.360.)GO TO 203                                        ASSM0200
       IF(IR-IK) 203,204,204                                            ASSM0210
  203 J2 = NVEC(IR,2) * 4                                               ASSM0220
       NN(5)=J2-3                                                       ASSM0230
       NN(6)=J2-2                                                       ASSM0240
       NN(7)=J2-1                                                       ASSM0250
       NN(8)=J2                                                         ASSM0260
       GO TO 202                                                        ASSM0270
  204  NN(5)=1                                                          ASSM0280
       NN(6)=2                                                          ASSM0290
       NN(7)=3                                                          ASSM0300
       NN(8)=4                                                          ASSM0310
  202  DO 402 I=1,8                                                     ASSM0320
       M=NN(I)                                                          ASSM0330
       DO 402 J=1,8                                                     ASSM0340
       N=NN(J)                                                          ASSM0350
       IF(M-N)402,403,403                                               ASSM0360
```

```
  403   CALL FICOL(M,N,L,ICOL)                                    ASSM0370
        STIFM(L)=STIFM(L)+ELMAS(I,J)                              ASSM0380
  402   CONTINUE                                                  ASSM0390
        RETURN                                                    ASSM0400
       END                                                        ASSM0410
```

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```
      SUBROUTINE BRAN(NBR)                                              BRAN0010
      IMPLICIT REAL*8(A-H,O-Z)                                          BRAN0020
      DIMENSION YB(5,11),ZB(5,11),ANB(5,11),HB(5,11),NELT(6)            BRAN0030
      DIMENSION           LPR(7), ZK(51),HK(51),ANGK(51)                BRAN0040
      DIMENSION LATT(6)                                                 BRAN0050
      DIMENSION  SLB(5)                                                 BRAN0060
      DIMENSION  LHIT(6)                                                BRAN0070
      COMMON/PG/Y(51),Z(51),ANG(51),H(51),EXANG,NS,IK,NOGA,NPL,NI,      BRAN0080
     * ICOL(205),NBCOND,NBC(7),NODEB(7)                                 BRAN0090
      COMMON /HM/ C5,C6,ASFL(50,3,6,5),GZETA(50,3,6)                    BRAN0100
      COMMON/MAT/ DENS(6),B(6),YOUNG(6),DS(6),SNO(6,5),NSPL(6),P(6),    BRAN0110
     * EPS(6,5),SIG(6,5), FFLN(6)                                       BRAN0120
       COMMON /TAPE/ MREAD,MWRITE,MPUNCH                                BRAN0130
      COMMON /BOUN/ YK(51),NBCONB,NBCB(7),NODEB(7),MK(51),ROT(5,2)      BRAN0140
     B,DROT(50), NODP(6)                                                BRAN0150
      COMMON /TAM/ MKE(51)                                              BRAN0160
      COMMON/DIS/ ANGDI(50),NRDI(50),NDIS                               BRAN0170
      COMMON /BN/ LMT(51)                                               BRAN0180
      COMMON /XD/ XDIST(6)                                              BRAN0190
      COMMON /THI/ HTH(5)                                               BRAN0200
      COMMON /ML/ MNEL(6),MATT(6)                                       BRAN0210
      COMMON /BR/ NVEC(51,2)                                            BRAN0220
C     RENUMBER NODES AND ELEMENTS                                       BRAN0230
      NNS = NS                                                          BRAN0240
      NIK = IK                                                          BRAN0250
      PIF= 3.141592653589793D+00                                        BRAN0260
      DO 5301 J= 1,6                                                    BRAN0270
      NELT(J) = 0                                                       BRAN0280
 5301 NODP(J) = 0                                                       BRAN0290
      DO 5302 K = 1,NS                                                  BRAN0300
      YK(K)= Y(K)                                                       BRAN0310
      ZK(K) = Z(K)                                                      BRAN0320
      HK(K)= H(K)                                                       BRAN0330
      MK(K) = 0                                                         BRAN0340
 5302 ANGK(K)= ANG(K)                                                   BRAN0350
      DO 5313 I = 1,NBR                                                 BRAN0360
```

```
      IB = I+1                                                          BRAN0370
      READ(MREAD,5500) NSPL(IB),B(IB),DENS(IB),DS(IB),P(IB)             BRAN0380
 5500 FORMAT(I5,4D15.6)                                                 BRAN0390
      L= NSPL(IB)                                                       BRAN0400
      READ(MREAD,5510) (EPS(IB,J),SIG(IB,J),J=1,L)                      BRAN0410
 5510 FORMAT(4D15.6)                                                    BRAN0420
      READ (MREAD,5300) NELT(I),NODP(I),LHIT(I),LATT(I)                 BRAN0430
 5300 FORMAT(14I5)                                                      BRAN0440
      MNEL(I+1) = NELT(I)                                               BRAN0450
      NODPH= NODP(I)                                                    BRAN0460
      IF (LATT(I)) 5210,5230,5220                                       BRAN0470
 5210 XDIST(I) =  H(NODPH)/2.0                                          BRAN0480
      GO TO 5240                                                        BRAN0490
 5220 XDIST(I) =-H(NODPH)/2.0                                           BRAN0500
      GO TO 5240                                                        BRAN0510
 5230 XDIST(I) = 0.0                                                    BRAN0520
 5240 CONTINUE                                                          BRAN0530
      NO1 = NELT(I) + 1                                                 BRAN0540
      DO 5310 J = 1,NO1                                                 BRAN0550
      READ(MREAD,5305) YB(I,J),ZB(I,J),ANB(I,J),HB(I,J)                 BRAN0560
 5305 FORMAT(4D15.6)                                                    BRAN0570
      ANB(I,J)= ANB(I,J)*PIE/180.0                                      BRAN0580
 5310 CONTINUE                                                          BRAN0590
      HTH(I) = HB(I,NO1)                                                BRAN0600
      SLB(I) = ANB(I,NO1)                                               BRAN0610
      NS=NS+NPLT(I)                                                     BRAN0620
      IK= IK+NELT(I)                                                    BRAN0630
 5111 CONTINUE                                                          BRAN0640
      DO 5200 K=1,NS                                                    BRAN0650
      MK(K) = 0                                                         BRAN0660
 5200 LMT(K)= 0                                                         BRAN0670
       DO 5270 I=NIK,IK                                                 BRAN0680
 5270 MKE(I) = 1                                                        BRAN0690
      WRITE(MWRITE,5311) IK,NS                                          BRAN0700
 5311 FORMAT('OTHERE ARE ',I3,' ELEMENTS AND ',I3,' NODES')             BRAN0710
      WRITE(MWRITE,5312)  NBR,(NODP(M),M=1,NBP)                         BRAN0720
```

C.2

```
5312 FORMAT('OTHERE ARE ',I3,'  BRANCHES AND THEY ARE AT NODES',5I6)    BRAN0730
     WRITE(MWRITE, 8500)   (SLB(K),K=1,NBR)                               BRAN0740
8500 FORMAT('OTHE GLOBAL SLOPE(RAD) AT EACH BRANCH CONNECTION:',5D15.6) BRAN0750
     WRITE  (MWRITE,5250) NBR                                             BRAN0760
5250  FORMAT('OTHE ATTACHMENT POINT CODE FOR THE ',I4,'  BRANCHES IS ASBRAN0770
    @ FOLLOWS:')                                                          BRAN0780
     WRITE(MWRITE,5260)   (LATT(L),L=1,NBR)                               BRAN0790
5260 FORMAT(' ',5I8,'    WHERE -1= INNER, 0= MID, AND 1= OUTER SURFACESBRAN0800
    @ OF THE MAIN STRUCTURE')                                             BRAN0810
     NODP(NBR+1) = NNS                                                    BRAN0820
     NELTT= 0                                                             BRAN0830
     DO 5316 I= 1,NBR                                                     BRAN0840
     NELTT=NELTT+ NELT(I)                                                 BRAN0850
     NO1 = NODP(I) + 1                                                    BRAN0860
     NOD=NODP(I+1)                                                        BRAN0870
     DO 5315 J = NO1,NOD                                                  BRAN0880
     KN= J+NELTT                                                          BRAN0890
     Y(KN) = YK(J)                                                        BRAN0900
     Z(KN)= ZK(J)                                                         BRAN0910
     H(KN) = HK(J)                                                        BRAN0920
     ANG(KN) = ANGK(J)                                                    BRAN0930
     MK(J) = KN                                                           BRAN0940
5315 CONTINUE                                                             BRAN0950
5316 CONTINUE                                                             BRAN0960
     IF(NODP(1).NE.1) GOTO 5320                                           BRAN0970
     KN= 1+NELT(1)                                                        BRAN0980
     Y(KN) = YK(1)                                                        BRAN0990
     Z(KN) = ZK(1)                                                        BRAN1000
     H(KN) = HK(1)                                                        BRAN1010
     ANG(KN) = ANGK(1)                                                    BRAN1020
     MK(1) = KN                                                           BRAN1030
      NEL = NELT(1)                                                       BRAN1040
     DO 5325 I= 1,NEL                                                     BRAN1050
     Y(I)= YB(1,I)                                                        BRAN1060
     Z(I) = ZB(1,I)                                                       BRAN1070
     ANG(I) = ANB(1,I)                                                    BRAN1080
```

```
5325 H(I) = HB(1,I)
     GOTO 5322
5320 NO1= NODP(1)
      DO 5321 J = 1,NO1
5321 MK(J) = J
5322 NELTT=0
     DO 5330 I= 1,NBR
     IF(NODP(I).EQ.1) GOTO 5334
     NEL = NELT(I)
     DO 5335 J= 1,NEL
     KN= J+ NODP(I) + NELTT
     Y(KN) = YB(I,J)
     Z(KN) = ZB(I,J)
     ANG(KN) = ANB(I,J)
5335 H(KN) = HB(I,J)
5334 NELTT= NELTT + NELT(I)
5330 CONTINUE
     NZB = 0
     NYB = 0
     LTIME= 0
     LELT = 1
     DO 5100 J = 1,NS
     NXB = J + NYB
     IF( NXB.EQ.MK(J)) GO TO 5100
     MKL = 0
     LTIME= LTIME+1
     MXX  = NXB-2
     NYB= NYB+ NELT(LTIME)
     IF(LHIT(LTIME).NE.0) GO TC 5140
     NZB = NZB+NELT(LTIME)
     IF(J.EQ.1) MXX=0
     MKL=MKL+MXX
     DO 5130 I= LELT,NZB
     MKL=MKL+1
5130 LMT(I) = MKL
     LELT = NZB+1
```

```
5140 IF (LTIME.EQ.NBR)   GOTO 5145                                        BRAN1450
5100 CONTINUE                                                             BRAN1460
5145 CONTINUE                                                             BRAN1470
     LELT=0                                                               BRAN1480
     NYB=0                                                                BRAN1490
     LTIME = 0                                                            BRAN1500
     DO 5275 J=1,NS                                                       BRAN1510
     NXB=J+NTB                                                            BRAN1520
     IF(NXB.EQ.MK(J)) GO TO 5275                                          BRAN1530
     LTIME=LTIME+1                                                        BRAN1540
     MXX  = NXB-2                                                         BRAN1550
     NYB=NYB+NELT(LTIME)                                                  BRAN1560
     IF(J.EQ.1) MXX=0                                                     BRAN1570
     LELT=MXX+1                                                           BRAN1580
     NZB= MXX+NELT(LTIME)                                                 BRAN1590
     DO 5280 I=LELT,NZB                                                   BRAN1600
5280 MKE(I) = LTIME+1                                                     BRAN1610
     IF(LTIME.EQ.NBR) GO TO 5285                                          BRAN1620
5275 CONTINUE                                                             BRAN1630
5285 CONTINUE                                                             BRAN1640
     NODP(NBR+1) = IK                                                     BRAN1650
     NT= NELT(1) + NODP(2)+ NELT(2) -1                                    BRAN1660
     NTT= NELT(1) + NELT(2)                                               BRAN1670
     IF(NBR.EQ.1) NT = IK                                                 BRAN1680
     IF (NODP(1).EQ.1) GO TO 5340                                         BRAN1690
     NT= NODP(1)+ NELT(1) - 1                                             BRAN1700
     NTT= NELT(1)                                                         BRAN1710
5340 DO 5345 I= 1,NT                                                      BRAN1720
     NVEC(1,1) = I                                                        BRAN1730
5345 NVEC(I,2) = I+1                                                      BRAN1740
     NO = 2                                                               BRAN1750
     IF(NODP(1) - 1) 5350,5355,5350                                       BRAN1760
5355 IF(NBR.EQ.1)  GO TO  5350                                            BRAN1770
     NO= 3                                                                BRAN1780
5350 NB1 = NBR+1                                                          BRAN1790
     DO 5360 I = NO,NB1                                                   BRAN1800
```

```
      IF (NT.EQ.IK) GO TO  5400                                         BRAN1810
      NT= NT+1                                                          BRAN1820
      NVEC(NT,1)  = NT-NELT(I-1)                                        BRAN1830
      NVEC(NT,2)= NT+1                                                  BRAN1840
      NT = NT+1                                                         BRAN1850
      NTT= NTT+ NELT(I)                                                 BRAN1860
      NOO   = NTT+ NODP(I)  -1                                          BRAN1870
      IF(NODP(I).EQ.IK)   NOO=IK                                        BRAN1880
      DO 5365 J=NT,NOO                                                  BRAN1890
      NVEC(J,1)  = J                                                    BRAN1900
 5365 NVEC(J,2)  = J+1                                                  BRAN1910
      NT = NOO                                                          BRAN1920
 5360 CONTINUE                                                          BRAN1930
      IF(EXANG.EQ.360.0) NVEC(IK,2)  = 1                                BRAN1940
 5400 CONTINUF                                                          BRAN1950
      WRITE(MWRITE,110)                                                 BRAN1960
  110 FORMAT(//,' PRESENT ELEM. NO.',5X,'NODE1',5X,'NODE2',5X,'SUBSTRUCTBRAN1970
     @URE',5X,'SUBST. ELEM. NC.')                                       BRAN1980
      JEL = 0                                                           BRAN1990
      JL=0                                                              BRAN2000
      DO 115 IR=1,IK                                                    BRAN2010
      IF(MKE(IR).NE.1) GO TO 120                                        BRAN2020
      JL=0                                                              BRAN2030
      JEL=JEL+1                                                         BRAN2040
      JELE=JEL                                                          BRAN2050
      GO TO 125                                                         BRAN2060
  120 JL=JL+1                                                           BRAN2070
      JELE=JL                                                           BRAN2080
  125 WRITE(MWRITE,126) IR,NVEC(IR,1),NVEC(IR,2),MKE(IR),JELE           BRAN2090
  126 FORMAT(' ',4X,I5,11X,I5,5X,I5,7X,I5,13X,I5)                       BRAN2100
  115 CONTINUE                                                          BRAN2110
      WRITE(MWRITE,130)                                                 BRAN2120
  130 FORMAT('OTHE UPDATED NODE NUMBERS FOR THE MAIN STRUCTURE, GIVEN INBRAN2130
     @ THEIR ORIGINAL NUMBERING ORDER:')                                BRAN2140
      WRITE (MWRITE,5323) (MK(L),L=1,NNS)                               BRAN2150
 5323 FORMAT('0',25I5)                                                  BRAN2160
```

```
      WRITE(MWRITE,1010)
 1010 FORMAT(//,' NOTE:  THE ELEMENT NUMBERS REFERRED TO BELOW ARE PRESE
     &NT ELEMENT NUMBERS',//)
      WRITE (MWRITE,2110)
      WRITE (MWRITE,2100)   (LMT(N),N=1,NS)
 2100 FORMAT(' ',10I5)
 2110 FORMAT('0ELEMENTS THAT CAN NOT BE IMPACTED:')
C     ESTABLISH BOUNDARY CONDITIONS
C     VECTOR YK(51) NOW CONTAINS ACTUAL NODE NUMBER OF ORIGINAL DEFLECTO
      READ(MREAD,5300) NDISB
      IF(NDISB.EQ.0) GO TO 8100
      DO 8101 I=1,NDISB
      READ(MREAD,8102) NEDIB,NBDI,ANGDB
 8102 FORMAT(2I5,E15.6)
      ANGDB= ANGDB*PIE/180.0
      NDIS= NDIS+1
      ANGDI(NDIS) = ANGDB
      L= NODP(NBDI)
      K=NK(L)
      IF(L.EQ.1) K=1
 8103 NEDI(NDIS)  = NEDIB +K -1
 8101 CONTINUE
 8100 CONTINUE
      READ(MREAD,5300) NBCONB
      IF(NBCONB.EQ.0) GOTO 5376
      READ(MREAD,5300) (NBCB(L),NODBB(L),LBR(L),L=1,NBCONB)
      DO 5370 L = 1,NBCONB
      NO1 = NODP(LBR(L))
      NELTT= 0
      LB= LBR(L)-1
      DO 5375 J= 1,LB
 5375 NELTT= NELTT + NELT(J)
      IF (LB.NE.0) GOTO 5371
      NELTT = 0
      IF(NODP(1).EQ.1) GO TO 5370
 5371 NODBB(L) = NODBB(L) + NO1 + NELTT
```

```
 5370 CONTINUE                                                          BRAN2530
 5376 CONTINUE                                                          BRAN2540
      DO 5410 I=1,NBR                                                   BRAN2550
      L= NODP(I)                                                        BRAN2560
 5410 MATT(I) = MK(L)                                                   BRAN2570
C         DETERMINE LEADING NCN ZERO TERM IN EACH ROW                   BRAN2580
      DO 15 I= 1,8                                                      BRAN2590
   15 ICOL(I) = 1                                                       BRAN2600
      IKM1 = IK-1                                                       BRAN2610
      NI = NS*4                                                         BRAN2620
      IF(EXANG.NE.360.0) GO TO 210                                      BRAN2630
      DO 16 I = 2,IKM1                                                  BRAN2640
      J= (I+1)*4                                                        BRAN2650
      ICOL(J)   = NVEC(I,1) * 4 - 3                                     BRAN2660
      ICOL(J-1) = NVEC(I,1) * 4 - 3                                     BRAN2670
      ICOL(J-2) = NVEC(I,1) * 4 - 3                                     BRAN2680
      ICOL(J-3) = NVEC(I,1) * 4 - 3                                     BRAN2690
   16 CONTINUE                                                          BRAN2700
      I= NVEC(IK,1)                                                     BRAN2710
      ICOL(I*4)     = 1                                                 BRAN2720
      ICOL(I*4-1)   = 1                                                 BRAN2730
      ICOL(I*4-2)   = 1                                                 BRAN2740
      ICOL(I*4-3)   = 1                                                 BRAN2750
      GO TO 218                                                         BRAN2760
  210 DO 211 I= 2,IK                                                    BRAN2770
      J= (I+1)*4                                                        BRAN2780
      ICOL(J)   = NVEC(I,1) * 4 - 3                                     BRAN2790
      ICOL(J-1) = NVEC(I,1) * 4 - 3                                     BRAN2800
      ICOL(J-2) = NVEC(I,1) * 4 - 3                                     BRAN2810
      ICOL(J-3) = NVEC(I,1) * 4 - 3                                     BRAN2820
  211 CONTINUE                                                          BRAN2830
  218 CONTINUE                                                          BRAN2840
      DO 5341 M= 1,IK                                                   BRAN2850
 5341 YK(M) = 0.0                                                       BRAN2860
      DO 5342 M = 1,NBR                                                 BRAN2870
      IF (NODP(M).NE.1) GO TO 5343                                      BRAN2880
```

```
      YK(NELT(M)) = 1.0
      ROT(M,1) = 0.0
       MKS = NELT(M) + 1
      ROT(M,2) = ANB(M,MKS) - ANGK(1)
      GO TO 5342
 5343 N= NODP(M)
      NM= MK(N)
      YK(NM) = 1.0
      ROT(M,1) = 1.0
       MKS = NELT(M) + 1
      ROT(M,2) = ANB(M,MKS) - ANG(NM)
 5342 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE CUBIC(P,Q,R,Y,IER)                                     CUBE0010
      IMPLICIT REAL*8(A-H,O-Z)                                          CUBE0020
C   FIND A SINGLE REAL ROOT OF THE CUBIC EQN. Y**3+P*Y**2+Q*Y+R=0       CUBE0030
C   REDUCE EQN., DEFINE NEW COEFS.                                      CUBE0040
      TEN = 10.0D+00                                                    CUBE0050
      D22 = 1.0D+22                                                     CUBE0060
      D33 = 1.0D+33                                                     CUBE0070
      NEXP= 0                                                           CUBE0080
      A=(3.0*Q-P*P)/3.0                                                 CUBE0090
      B=(2.0*P**3-9.0*P*Q+27.0*R)/27.0                                  CUBE0100
  205 IF(A.GE.D22.OR.A.LE.-D22) GOTO 200                                CUBE0110
      IF(B.GE.D33.OR.B.LE.-D33) GOTO 200                                CUBE0120
      GOTO 210                                                          CUBE0130
  200 A=A/1.0D+08                                                       CUBE0140
      B=B/1.0D+12                                                       CUBE0150
      NEXP= NEXP+1                                                      CUBE0160
      GOTO 205                                                          CUBE0170
  210 CONTINUE                                                          CUBE0180
C   FORM INNER SQUARE-ROOT FACTOR                                       CUBE0190
      D=B*B/4.0+A**3/27.0                                               CUBE0200
      IF(D) 100,10,10                                                   CUBE0210
C   SQUARE ROOT WILL NOT YIELD IMAGINARY NUMBER                         CUBE0220
 10   D=DSQRT(D)                                                        CUBE0230
C   FORM COEFS, CAPITAL A AND B                                         CUBE0240
      D= D*TEN**(NEXP*12)                                               CUBE0250
      B=B*TEN**(NEXP*12)                                                CUBE0260
      CA=-B/2.0+D                                                       CUBE0270
      CB=-B/2.0-D                                                       CUBE0280
C   SIGN OF THESE COEFS                                                 CUBE0290
      SCA=1.0                                                           CUBE0300
      SCB=1.0                                                           CUBE0310
      IF(CA.LT.0.0)SCA=-1.0                                             CUBE0320
      IF(CB.LT.0.0)SCB=-1.0                                             CUBE0330
C   TAKE CUBE ROOT OF ABS. VALUE OF CA AND CB                           CUBE0340
      CA=CA*SCA                                                         CUBE0350
      CB=SCB*CB                                                         CUBE0360
```

```
      CA=CA**(1.C/3.0)                                                  CUBE0370
      CB=CB**(1.C/3.0)                                                  CUBE0380
C    ROOTS OF REDUCED EQN.                                              CUBE0390
      X=CA*SCA+CE*SCB                                                   CUBE0400
C    ROOT OF ORIGINAL EQN.                                              CUBE0410
      Y=X-P/3.0                                                         CUBE0420
      RETURN                                                            CUBE0430
C    THREE UNEQUAL REAL POOTS.  CHOOSE ROOT=CA+CB.                      CUBE0440
C    CALC. REAL PORTION OF CA BY USING POLAR FORM OF COMPLEX NO..      CUBE0450
 100  U=-B/2.0                                                          CUBE0460
      D=-D                                                              CUBE0470
      V=DSQRT(D)                                                        CUBE0480
      DIST=DSQRT(U*U+V*V)                                               CUBE0490
      COEF=DIST**(1.0/3.0)                                              CUBE0500
      COST=U/DIST                                                       CUBE0510
      THETA=DARCOS(COST)                                                CUBE0520
      THETA=THETA/3.0                                                   CUBE0530
      COST=DCOS(THFTA)                                                  CUBE0540
      X=COEF*COST*2.0                                                   CUBE0550
      Y=X-P/3.0                                                         CUBE0560
      RETURN                                                            CUBE0570
      END                                                               CUBE0580
```

```
      SUBROUTINE DINIT(IT,TIME)
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON /TAM/ MKE(51)
      COMMON /HIT/ TNJ(6),MIRP
       COMMON /VQ/ PLVA(205),DISP(205),DELD(205),SNS(50,3,6,5),
     *BIMP(50,3),BIMP(50,3),TDISP(205),TU(205),TW(205),
     *COIY(205),COIZ(205),DELTAT
      COMMON/FG/Y(51),Z(51),ANG(51),H(51),EXANG,NS,IK,NOGA,NFL,NI,
     * ICOL(205),NBCCND,NBC(7),NODEB(7)
      COMMON/MAT/ DENS(6),B(6),YOUNG(6),DS(6),SNO(6,5),NSFL(6),P(6),
     * EPS(6,5),SIG(6,5), EFLN(6)
      COMMON /HM/ C5,C6,ASPL(50,3,6,5),GZETA(50,3,6)
      COMMON/PRAG/PH(6),PCG(6),PMASS(6),PMCI(6),PCGU(6),PCGW(6),ALFA(6),
     *UDOT(6),WDOT(6),ADOT(6),TPRIM(6),CR(6),PCGX(6),UNK(6),NF
      COMMON /DPRAG/DPCGU(6),DPCGW(6),DALFA(6)
      MIRP=0
      XY =  TPRIM(1)/ DELTAT
      IT= XY+ 0.02
      TIME=  IT*DELTAT
      DO 1 I=1,205
      DELD(I)=0.0
    1 DISP(I)=0.0
      DO 2 IR=1,IK
      N= MKE(IR)
      M= NSFL(N)
      DO 2 J=1,NOGA
      DO 2 K=1,NFL
      DO 2 L= 1,M
    2 SNS(IR,J,K,L)=0.0
      DO 16 NPO=1,NF
   16 TNJ(NPO) = 1.0
      IF(NF.EQ.1) GO TO 40
      DO 10 NTS=2,NF
      IF(TPRIM(NTS).GE.0.0) GO TO 10
      MIRP = NTS
      GO TO 40
```

```
10 CONTINUE                                                    DINT0370
40 IF(MIRP.EQ.0) GO TO 50                                      DINT0380
   DO 17 NPN = MIRP,NF                                         DINT0390
17 TNJ(NPN) = 0.0                                              DINT0400
50 DO 5 I=1,NF                                                 DINT0410
   DPCGU(I)=UDOT(I)*DELTAT                                     DINT0420
   DPCGW(I)=WDOT(I)*DELTAT                                     DINT0430
   DALFA(I)=      ADOT(I)*DELTAT                               DINT0440
   PCGU(I)  = PCGX(I)+UDOT(I)*TPRIM(I)*TNJ(I)                  DINT0450
   PCGW(I)= PCG(I)+WDOT(I)*TPRIM(I)*TNJ(I)                     DINT0460
 5 ALPA(I)  = ADOT(I)*TPRIM(I)*TNJ(I)                          DINT0470
   RETURN                                                      DINT0480
   END                                                         DINT0490
```

```
      SUBROUTINE ELMPP(DELTAT,AA,ISIZE,KROW,NDEX,NIRREG,INUM)            ELMP0010
      IMPLICIT REAL*8(A-H,O-Z)                                           ELMP0020
      DIMENSION A(8,8),AA(50,8,8),LMI(8),MMI(8),        E(8,8),EK1(8,8)ELMP0030
     *,BE1(3,3,8),KROW(1),NDEX(1),INUM(1),BNG(51),ELK(8,8)              ELMP0040
      DIMENSION  AE1(3,8) ,BX(2)                                         ELMP0050
      DIMENSION DELM(8),DISM(8), DUMMY(8)                                ELMP0060
      COMMON/FG/Y(51),Z(51),ANG(51),H(51),EXANG,NS,IK,NOGA,NFL,NI,       ELMP0070
     * ICCL(205),NBCOND,NBC(7),NODEB(7)                                  ELMP0080
      COMMON/MAT/ DENS(6),B(6),YOUNG(6),DS(6),SNO(6,5),NSFL(6),P(6),     ELMP0090
     * EPS(6,5),SIG(6,5), EFLN(6)                                        ELMP0100
      COMMON /TAM/ MKE(51)                                               ELMP0110
      COMMON /BOUN/ YK(51),NBCONB,NBCB(7),NODBB(7),MK(51),ROT(5,2)       ELMP0120
     @,DROT(50), NODP(6)                                                 ELMP0130
      COMMON /ADSP/ AZET(50),AEP(50,3,8) ,LKK(50,11)                     ELMP0140
       COMMON /BA/ BEP(50,3,3,8),AL(50),AXG(3),AWG(3)                    ELMP0150
      COMMON /ST/ STIFK(2560)                                            ELMP0160
       COMMON /TAPE/ MREAD,MWRITE,MPUNCH                                 ELMP0170
      COMMON /XD/ XDIST(6)                                               ELMP0180
      COMMON /THI/ HTH(5)                                                ELMP0190
      COMMON /NODE/ DEP(50,2,3,8)                                        ELMP0200
      COMMON /BR/ NVEC(51,2)                                             ELMP0210
      SIN(Q)=DSIN(Q)                                                     ELMP0220
      COS(Q)=DCOS(Q)                                                     ELMP0230
      ATAN(Q)=DATAN(Q)                                                   ELMP0240
      ABS(Q)=DABS(Q)                                                     ELMP0250
      SQRT(Q)=DSQRT(Q)                                                   ELMP0260
      MOP=0                                                              ELMP0270
       DO 51 L=1,ISIZE                                                   ELMP0280
   51 STIFK(L)= 0.0                                                      ELMP0290
   50 DO 101 IR = 1,IK                                                   ELMP0300
      K1= NVEC(IR,1)                                                     ELMP0310
      K2= NVEC(IR,2)                                                     ELMP0320
      L= MKE(IR)-1                                                       ELMP0330
       P5=Z(K2  )-Z(K1)                                                  ELMP0340
       P6=Y(K2  )-Y(K1)                                                  ELMP0350
       P7=ANG(K2  )-ANG(K1)                                              ELMP0360
```

```
      IF(YK(IR).EQ.1.0) P7=ANG(K2) - ROT(L,2)-ANG(K1)                    ELMP0370
      IF(YK(IR).EQ.1.0.AND.ROT(L,1).EQ. .0) P7=ROT(L,2)+ANG(K2)-ANG(K1)  ELMP0380
      IF(YK(IR).EQ.2.0)  P7= ANG(K2)- DROT(IR) - ANG(K1)                 ELMP0390
      IF(YK(IR).EQ.3.0) P7=ROT(L   ,2)+ANG(K2)-DROT(IR) -ANG(K1)         ELMP0400
      PIE= 3.14159265358979300+0                                         ELMP0410
      PIE2= 2.0*PIE                                                      ELMP0420
      PIE32= 1.5 *PIE                                                    ELMP0430
      ANG2=ANG(K2)                                                       ELMP0440
      ANG1=ANG(K1)                                                       ELMP0450
      IF(YK(IR).EQ.1.0.AND.ROT(L,1).EQ. .0)ANG(K2)=ROT(L,2)+ANG(K2)      ELMP0460
      IF(YK(IR).EQ.1.0.AND.ROT(L   ,1).EQ.1.0)ANG(K1)=ROT(L   ,2)+ANG(K1) ELMP0470
      IF(YK(IR).EQ.2.0) ANG(K1)= DROT(IR) + ANG(K1)                      ELMP0480
      IF(YK(IR).EQ.3.0)  ANG(K2) = ROT(L,2) + ANG (K2)                   ELMP0490
      IF(YK(IR).EQ.3.0)  ANG(K1)= DROT(IR) + ANG (K1)                    ELMP0500
      APHA = PIE / 2.0                                                   ELMP0510
      IF(P5.LT.0.0) APHA= -APHA                                          ELMP0520
      IF(P6.NE.0.0) APHA= ATAN(P5/P6)                                    ELMP0530
      IF(P6.LT.0.0.AND.P5.LT.0..)APHA=APHA-PIE                           ELMP0540
       IF(P6.LT.0.0 .AND. P5.GE.0..) APHA=APHA+PIE                       ELMP0550
       IF(P7 .EQ. 0.0) GO TO 60                                          ELMP0560
       AL(IR)=P7*SQRT(P5**2+P6**2)/SIN(P7/2.)/2.                         ELMP0570
      IF(P7.GT.PIE32)AL(IR)=(P7-PIE2)*SQRT(P5**2+P6**2)/SIN(P7/2.-PIE)   ELMP0580
     */2.0                                                               ELMP0590
      IF(P7.LT.(-PIE32     ))AL(IR)=(P7+PIE2     )*SQRT(P5**2+P6**2)     ELMP0600
     */SIN(P7/2.+PIE       )/2.                                          ELMP0610
       GO TO 61                                                          ELMP0620
60     AL(IR)=SQRT(P5**2+P6**2)                                          ELMP0630
61     BNG(IR+1)=ANG(K2   )                                              ELMP0640
       BNG(IR)=ANG(K1)                                                   ELMP0650
      IF(P7.GT.(PIE32 ).AND.APHA.LT.0.0) BNG(IR+1)=ANG(K2)   -PIE2       ELMP0660
      IF(P7.GT.(PIE32 ).AND.APHA.GT.0..) BNG(IR)=ANG(K1)+PIE2            ELMP0670
      IF(P7.LT.(-PIE32 ).AND.APHA.GT.0.0) BNG(IR+1)=ANG(K2)   +PIE2      ELMP0680
      IF(P7.LT.(-PIE32 ).AND.APHA.LT.0..) BNG(IR)=ANG(K1)-PIE2           ELMP0690
       BZER=BNG(IR)-APHA                                                 ELMP0700
       B1=(-2.*BNG(IR+1)-4.*BNG(IR)+6.*APHA)/AL(IR)                      ELMP0710
       B2=(3.*BNG(IR+1)+3.*BNG(IR)-6.*APHA)/AL(IR)**2                    ELMP0720
```

```
      ANG(K2)= ANG2                                                     ELMP0730
      ANG(K1)= ANG1                                                     ELMP0740
      DO 102 I=1,8                                                      ELMP0750
      DO 102 J=1,8                                                      ELMP0760
      E(I,J) = 0.0                                                      ELMP0770
  102 A(I,J)=0.0                                                        ELMP0780
      A(1,1)= COS(BNG(IR)-APHA)                                         ELMP0790
      A(1,2)= SIN(BNG(IR)-APHA)                                         ELMP0800
      A(2,1)=-SIN(BNG(IR)-APHA)                                         ELMP0810
      A(2,2)= COS(BNG(IR)-APHA)                                         ELMP0820
      A(3,3)=1.                                                         ELMP0830
      A(5,1)=COS(BNG(IR+1)-APHA)                                        ELMP0840
      A(5,2)=SIN(BNG(IR+1)-APHA)                                        ELMP0850
      A(5,3)=P6*SIN(BNG(IR+1))-P5*COS(BNG(IR+1))                        ELMP0860
      A(6,1)=-SIN(BNG(IR+1)-APHA)                                       ELMP0870
      A(6,2)=COS(BNG(IR+1)-APHA)                                        ELMP0880
      A(6,3)=P6*COS(BNG(IR+1))+P5*SIN(BNG(IR+1))                        ELMP0890
      A(7,3)=1.                                                         ELMP0900
      A(4,4)=1.                                                         ELMP0910
      A(5,4)=AL(IR)                                                     ELMP0920
      A(5,7)=AL(IR)**2                                                  ELMP0930
      A(5,8)=AL(IR)**3                                                  ELMP0940
      A(6,5)=AL(IR)**2                                                  ELMP0950
      A(6,6)=AL(IR)**3                                                  ELMP0960
      P8=B1+2.*B2*AL(IR)                                                ELMP0970
      A(7,4)=AL(IR)*P8                                                  ELMP0980
      A(7,5)=2.*AL(IR)                                                  ELMP0990
      A(7,6)=3.*AL(IR)**2                                               ELMP1000
      A(7,7)=AL(IR)**2*P8                                               ELMP1010
      A(7,8)=AL(IR)**3*P8                                               ELMP1020
      A(8,4)=1.0                                                        ELMP1030
      A(8,5)=-AL(IR)**2*P8                                              ELMP1040
      A(8,7)=2.*AL(IR)                                                  ELMP1050
      A(8,6)=-AL(IR)**3*P8                                              ELMP1060
      A(8,8)=3.*AL(IR)**2                                               ELMP1070
      CALL MINV(A,8,DET,LMI,MMI)                                        ELMP1080
```

```
      DO 52 I=1,8                                                       ELMP1090
      DO 52 J=1,8                                                       ELMP1100
52    AA(IR,I,J)=A(I,J)                                                 ELMP1110
      DO 103 J=1,NCGA                                                   ELMP1120
      ZET=AL(IR)*AXG(J)                                                 ELMP1130
      PHIP=B1+2.*B2*ZET                                                 ELMP1140
      PHI=BZER+B1*ZET+B2*ZET**2                                         ELMP1150
      WET=AL(IR)*AWG(J)                                                 ELMP1160
      YZET=0.0                                                          ELMP1170
      ZZET=0.0                                                          ELMP1180
      DO 104 JJ=1,NCGA                                                  ELMP1190
      P2=BZER+B1*ZET*AXG(JJ)+B2*(ZET*AXG(JJ))**2+APHA                   ELMP1200
      YZET=YZET+COS(P2)*ZET*AWG(JJ)                                     ELMP1210
104   ZZET=ZZET+SIN(P2)*ZET*AWG(JJ)                                     ELMP1220
      P3=YZET*SIN(PHI+APHA)-ZZET*COS(PHI+APHA)                          ELMP1230
      P4=YZET*COS(PHI+APHA)+ZZET*SIN(PHI+APHA)                          ELMP1240
      DO 201 M=1,3                                                      ELMP1250
      DO 201 N=1,8                                                      ELMP1260
201   BE1(J,M,N)=0.0                                                    ELMP1270
      BE1(J,1,4)=1.                                                     ELMP1280
      BE1(J,1,5)=-ZET**2*PHIP                                           ELMP1290
      BE1(J,1,6)=-ZET**3*PHIP                                           ELMP1300
      BE1(J,1,7)=2.*ZET                                                 ELMP1310
      BE1(J,1,8)=3.*ZET**2                                              ELMP1320
      BE1(J,2,3)=1.                                                     ELMP1330
      BE1(J,2,4)=ZET*PHIP                                               ELMP1340
      BE1(J,2,5)=2.*ZET                                                 ELMP1350
      BE1(J,2,6)=3.*ZET**2                                              ELMP1360
      BE1(J,2,7)=ZET**2*PHIP                                            ELMP1370
      BE1(J,2,8)=ZET**3*PHIP                                            ELMP1380
      BE1(J,3,4)=-PHIP-ZET*2.*B2                                        ELMP1390
      BE1(J,3,5)=-2.                                                    ELMP1400
      BE1(J,3,6)=-6.*ZET                                                ELMP1410
      BE1(J,3,7)=-2.*ZET*PHIP-ZET**2*2.*B2                              ELMP1420
      BE1(J,3,8)=-3.*ZET**2*PHIP-ZET**3*2.*B2                           ELMP1430
      DO 202 M=1,3                                                      ELMP1440
```

```
      DO 202 N=1,8                                                      ELMP1450
      BEP(IR,J,M,N)=0.0                                                 ELMP1460
      DO 202 K=1,8                                                      ELMP1470
  202 BEP(IR,J,M,N)=BEP(IR,J,M,N)+BE1(J,M,K)*A(K,N)                     ELMP1480
      H1 = H(K1)                                                        ELMP1490
      H2 = H(K2)                                                        ELMP1500
      M = MKE(IR) -1                                                    ELMP1510
      IF(YK(IR).NE.1.0.AND.YK(IR).NE.3.0) GOTO 600                      ELMP1520
      IF (ROT(M,1).NE.0.)) GO TO 610                                    ELMP1530
      H(K2) = HTH(M)                                                    ELMP1540
      GO TO 600                                                         ELMP1550
  610 H(K1) = HTH(M)                                                    ELMP1560
  600 RH=H(K2)*AXG(J)+H(K1)*(1.-AXG(J))                                 ELMP1570
      H(K1) = H1                                                        ELMP1580
      H(K2) = H2                                                        ELMP1590
      RI=RH**3/12.                                                      ELMP1600
      T1=PHIP+ZET*2.*B2                                                 ELMP1610
      T2=2.*ZET*PHIP+ZET**2*2.*B2                                       ELMP1620
      T3=3.*ZET**2*PHIP+ZET**3*2.*B2                                    ELMP1630
      E(4,4)=E(4,4)+(RH+T1**2*RI)*WET                                   ELMP1640
      E(5,4)=E(5,4)+(-ZET**2*PHIP*RH+2.*T1*RI)*WET                      ELMP1650
      E(6,4)=E(6,4)+(-ZET**3*PHIP*RH+6.*ZET*T1*RI)*WET                  ELMP1660
      E(7,4)=E(7,4)+(2.*ZET*RH+T2*T1*RI)*WET                            ELMP1670
      E(8,4)=E(8,4)+(3.*ZET**2*RH+T3*T1*RI)*WET                         ELMP1680
      E(5,5)=E(5,5)+(ZET**4*PHIP**2*RH+4.*RI)*WET                       ELMP1690
      E(6,5)=E(6,5)+(ZET**5*PHIP**2*RH+12.*ZET*RI)*WET                  ELMP1700
      E(7,5)=E(7,5)+(-2.*ZET**3*PHIP*RH+2.*T2*RI)*WET                   ELMP1710
      E(8,5)=E(8,5)+(-3.*ZET**4*PHIP*RH+2.*T3*RI)*WET                   ELMP1720
      E(6,6)=E(6,6)+(ZET**6*PHIP**2*RH+36.*ZET**2*RI)*WET               ELMP1730
      E(7,6)=E(7,6)+(-2.*ZET**4*PHIP*RH+6.*ZET*T2*RI)*WET               ELMP1740
      E(8,6)=E(8,6)+(-3.*ZET**5*PHIP*RH+6.*ZET*T3*RI)*WET               ELMP1750
      E(7,7)=E(7,7)+(4.*ZET**2*RH+T2**2*RI)*WET                         ELMP1760
      E(8,7)=E(8,7)+(6.*ZET**3*RH+T2*T3*RI)*WET                         ELMP1770
      E(8,8)=E(8,8)+(9.*ZET**4*RH+T3**2*RI)*WET                         ELMP1780
  103 CONTINUE                                                          ELMP1790
      IF(LKK(IR,1) .EQ.0)  GOTO 8200                                    ELMP1800
```

```
      NPE= LKK(IR,1)                                                    ELMP1810
      DO 8210 NO=1,NPE                                                  ELMP1820
      MO = NO+1                                                         ELMP1830
      M= LKK(IR,MO)                                                     ELMP1840
      ZET = AZET(M) * AL(IR)                                            ELMP1850
      PHIP= B1+2.0*B2*ZET                                               ELMP1860
      DO8240 I=1,3                                                      ELMP1870
      DO 8240 N=1,8                                                     ELMP1880
 8240 AE1(I,N) = 0.0                                                    ELMP1890
      AE1(1,4) =1.0                                                     ELMP1900
      AE1(1,5) = -ZET**2*PHIP                                           ELMP1910
      AE1(1,6) = -ZET**3*PHIP                                           ELMP1920
      AE1(1,7)= 2.*ZET                                                  ELMP1930
      AE1(1,8) = 3.*ZET**2                                              ELMP1940
      AE1(2,3) = 1.0                                                    ELMP1950
      AE1(2,4) = ZET*PHIP                                               ELMP1960
      AE1(2,5) = AE1 (1,7)                                              ELMP1970
      AE1(2,6) = AE1(1,8)                                               ELMP1980
      AE1(2,7) =-AE1(1,5)                                               ELMP1990
      AE1(2,8) =-AE1(1,6)                                               ELMP2000
      AE1(3,4) = -PHIP-ZET*2.*B2                                        ELMP2010
      AE1(3,5) = -2.0                                                   ELMP2020
      AE1(3,6)= -6.*ZET                                                 ELMP2030
      AE1(3,7)=-2.0*ZET*PHIP-ZET**2*2.0*B2                              ELMP2040
      AE1(3,8)=-3.*ZET**2*PHIP-ZET**3*2.0*B2                            ELMP2050
      DO 8245 I=1,3                                                     ELMP2060
      DO 8245 N= 1,8                                                    ELMP2070
      AEP(M,I,N) = 0.0                                                  ELMP2080
      DO 8245 K= 1,8                                                    ELMP2090
 8245 AEP(M,I,N) = AEP(M,I,N) +AE1(I,K)*A(K,N)                          ELMP2100
 8210 CONTINUE                                                          ELMP2110
 8200 CONTINUE                                                          ELMP2120
      BX(1) = 0.0                                                       ELMP2130
      BX(2)  =1.0                                                       ELMP2140
      DO 303 J=1,2                                                      ELMP2150
      ZET = AL(IR) * BX(J)                                              ELMP2160
```

```
      PHIP = B1+2.0*B2*ZET                                              ELMP2170
      DO 301 M=1,3                                                      ELMP2180
      DO 301 N= 1,8                                                     ELMP2190
  301 BE1(J,M,N) = 0.0                                                  ELMP2200
       BE1(J,1,4)=1.                                                    ELMP2210
       BE1(J,1,5)=-ZET**2*PHIP                                          ELMP2220
       BE1(J,1,6)=-ZET**3*PHIP                                          ELMP2230
       BE1(J,1,7)=2.*ZET                                                ELMP2240
       BE1(J,1,8)=3.*ZET**2                                             ELMP2250
       BE1(J,2,3)=1.                                                    ELMP2260
       BE1(J,2,4)=ZET*PHIP                                              ELMP2270
       BE1(J,2,5)=2.*ZET                                                ELMP2280
       BE1(J,2,6)=3.*ZET**2                                             ELMP2290
       BE1(J,2,7)=ZET**2*PHIP                                           ELMP2300
       BE1(J,2,8)=ZET**3*PHIP                                           ELMP2310
       BE1(J,3,4)=-PHIP-ZET*2.*B2                                       ELMP2320
       BE1(J,3,5)=-2.                                                   ELMP2330
      BE1(J,3,6)=-6.*ZET                                                ELMP2340
       BE1(J,3,7)=-2.*ZET*PHIP-ZET**2*2.*B2                             ELMP2350
       BE1(J,3,8)=-3.*ZET**2*PHIP-ZET**3*2.*B2                          ELMP2360
      DO 302 M=1,3                                                      ELMP2370
      DO 302 N= 1,8                                                     ELMP2380
      DEP(IR,J,M,N) =0.0                                                ELMP2390
      DO 302 K=1,8                                                      ELMP2400
  302 DEP(IR,J,M,N) = DEP(IR,J,M,N)+BE1(J,M,K)* A(K,N)                  ELMP2410
  303 CONTINUE                                                          ELMP2420
       DO 20 I=1,7                                                      ELMP2430
       IP1=I+1                                                          ELMP2440
       DO 20 J=IP1,8                                                    ELMP2450
 20    E(I,J)=E(J,I)                                                    ELMP2460
       DO 21 I=1,8                                                      ELMP2470
       DO 21 J=1,8                                                      ELMP2480
      EK1(I,J)=0.0                                                      ELMP2490
       DO 21 K=1,8                                                      ELMP2500
 21    EK1(I,J)=EK1(I,J)+A(K,I)*E(K,J)                                  ELMP2510
       DO 22 I=1,8                                                      ELMP2520
```

```
      DO 22 J=1,8                                                      ELMP2530
      ELK(I,J)=0.0                                                     ELMP2540
      DO 22 K=1,8                                                      ELMP2550
22    ELK(I,J)=ELK(I,J)+EK1(I,K)*A(K,J)                                ELMP2560
      DO 23 I=1,8                                                      ELMP2570
      DO 23 J=1,8                                                      ELMP2580
   23 ELK(I,J)= ELK(I,J)*YOUNG(MKE(IR))*B(MKE(IR))                     ELMP2590
      IF( YK(IR).EQ.0.0) GO TO 502                                     ELMP2600
           CALL ROTAT(3,ELK ,DUMMY,IR)                                 ELMP2610
  502 CALL ASSEM(IR,ELK,STIFK)                                         ELMP2620
  101 CONTINUE                                                         ELMP2630
      RETURN                                                           ELMP2640
      END                                                              ELMP2650
```

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```
      SUBROUTINE ENERGY(IT,KROW,NDFX,NIRREG,SCL,ES,GFL,QVEL)              ENER0010
C     THIS IS THE ENERGY CALCULATION SUBROUTINE                            ENER0020
      IMPLICIT REAL*8(A-H,O-Z)                                             ENER0030
      DIMENSION QVEL(205)                                                  ENER0040
      DIMENSION CINETF(6),SOL(1),ES(6,6), GFL(50,3,6)                      ENER0050
       COMMON /BA/ BFP(50,3,3,8),AL(50),AXG(3),AWG(3)                      ENER0060
       COMMON /TAPE/ MREAD,MWRITE,MPUNCH                                   ENER0070
       COMMON /VQ/ FLVA(205),DISP(205),DELD(205),SNS(50,3,6,5),            ENER0080
     *BINP(50,3),BIMP(50,3),TDISP(205),TU(205),TW(205),                    ENER0090
     *COIY(205),COIZ(205),DELTAT                                           ENER0100
      COMMON /TAM/ MKE(51)                                                 ENER0110
      COMMON/FRAG/FH(6),FCG(6),FMASS(6),FMOI(6),FCGU(6),FCGW(6),ALFA(6),   ENER0120
     *UDOT(6),WDOT(6),ADOT(6),TPRIM(6),CR(6),FCGX(6),UNK(6),NP             ENER0130
      COMMON /DFRAG/DFCGU(6),DFCGW(6),DALFA(6)                             ENER0140
      COMMON/ENERG/FK(6),CINETO,CUMW,DELKE,CELAS,ELAS,PLASTC               ENER0150
      COMMON/ABC/RMX(51),RWORK,CINEY(205)                                  ENER0160
      COMMON/FG/Y(51),Z(51),ANG(51),H(51),EXANG,NS,IK,NOGA,NFL,NI,         ENER0170
     * ICOL(205),NBCOND,NBC(7),NODEB(7)                                    ENER0180
      COMMON/MAT/ DENS(6),B(6),YOUNG(6),DS(6),SNO(6,5),NSPL(6),P(6),       ENER0190
     * EPS(6,5),SIG(6,5), EFLN(6)                                          ENER0200
      COMMON /HM/ C5,C6,ASPL(50,3,6,5),CZETA(50,3,6)                       ENER0210
      COMMON/ELPU/SPRIN(2060),FORZP(205),REX(4),NQR,NORP,NORU,NREL(4),     ENER0220
     *NRST(4),NREU(4)                                                      ENER0230
      SIN(Q)=DSIN(Q)                                                       ENER0240
      COS(Q)=DCOS(Q)                                                       ENER0250
      ATAN(Q)=DATAN(Q)                                                     ENER0260
      ABS(Q)=DABS(Q)                                                       ENER0270
      SQRT(Q)=DSQRT(Q)                                                     ENER0280
      WRITE(MWRITE,7) IT                                                   ENER0290
    7 FORMAT( ///,'   ENERGY AND WORK AT THE END OF TIME CYCLE',I5)        ENER0300
      WRITE(MWRITE,80)                                                     ENER0310
   80 FORMAT('0          FRAGMENT',10X,'KINETIC ENERGY',/)                 ENER0320
      IMX=IK+1                                                             ENER0330
    3 RWORK=0.0                                                            ENER0340
      DO 5 I=1,NP                                                          ENER0350
      FUV= UDOT(I)                                                         ENER0360
```

```
      PWV= WDOT(I)                                                      ENER0370
      PAV= ADOT(I)                                                      ENER0380
      CINETF(I)=PMASS(I)/2.0*(PUV**2+PWV**2)+PMOI(I)/2.0*(PAV**2)       ENER0390
      RWORK=RWORK+(FK(I)-CINETF(I))                                     ENER0400
      WRITE(MWRITE,6) I,CINETF(I)                                       ENER0410
    6 FORMAT(' ',10X,I5,13X,D15.6)                                      ENER0420
5     CONTINUE                                                          ENER0430
      WRITE(MWRITE,8) RWORK                                             ENER0440
    8 FORMAT(/,'      WORK INPUT INTO RING',2X,' =', D15.6)             ENER0450
      CINETO= 0.0                                                       ENER0460
      NI= NS*4                                                          ENER0470
      DO 10 I= 1,NI                                                     ENER0480
   10 CINETO = CINETO+ (QVEL(I)**2*DELTAT**2/SOL(I)) /2.0D+00           ENER0490
      WRITE(MWRITE,11) CINETO                                           ENER0500
   11 FORMAT('      RING KINETIC ENERGY     =',D15.6)                   ENER0510
      IF(EXANG.NE.360.)GO TO 13                                         ENER0520
      DO 12 K=1,4                                                       ENER0530
      DISP(IK*4+K)=DISP(K)                                              ENER0540
12    DELD(IK*4+K)=DELD(K)                                              ENER0550
   13 CELAS=0.0                                                         ENER0560
      DO 15 IR=1,IK                                                     ENER0570
      N= MKE(IR)                                                        ENER0580
      M= NSPL(N)                                                        ENER0590
      DO 16 J=1,NOGA                                                    ENER0600
      SUM=0.0                                                           ENER0610
      DO 17 K=1,NFL                                                     ENER0620
      STRS= 0.0                                                         ENER0630
      DO 30 L=1,M                                                       ENER0640
      LL = L+1                                                          ENER0650
      AB = (ES(N,L)-ES(N,LL))/ES(N,1)                                   ENER0660
   30 STRS= STRS + SNS(IR,J,K,L) * AB                                   ENER0670
      STRS = STRS**2                                                    ENER0680
   17 SUM= SUM+STRS*GFL(IR,J,K)                                         ENER0690
   16 CELAS=CELAS+ (SUM*AWG(J)*AL(IR)) / YOUNG(N) /2.0                  ENER0700
15    CONTINUE                                                          ENER0710
      SPDEN=0.0                                                         ENER0720
```

```
      IF(NQR.EQ.0)GO TO 18
      DO 20 I=1,NI
20    SPDEN=SPDEN+DISP(I)*FQREF(I)
      SPDEN=SPDEN/2.0
   18 WRITE(MWRITE,21) CELAS
   21 FORMAT('      RING ELASTIC ENERGY     =',D15.6 )
      PLAST=RWORK-CINETO-CELAS-SPDEN
      WRITE(MWRITE,22) PLAST
   22 FORMAT('      RING PLASTIC WORK       =',D15.6)
      WRITE(MWRITE,23) SPDEN
23    FORMAT('      ENERGY STORED IN ELASTIC RESTRAINTS      = ',D15.6)
      RETURN
      END
```

```
      SUBROUTINE ERC(II,STIFM,NI,ICOL)                                  ERC 0010
      IMPLICIT REAL*8(A-H,O-Z)                                          ERC 0020
C      FOR ELIMINATING ROWS AND COLUMNS IN STIFM                        ERC 0030
       DIMENSION STIFM(1),ICOL(1)                                       ERC 0040
      IC=ICOL(II)                                                       ERC 0050
      DO 101 J=IC,II                                                    ERC 0060
      CALL FICOL(II,J,L,ICOL)                                           ERC 0070
  101  STIFM(L)= 0.0                                                    ERC 0080
      DO 102 I=II,NI                                                    ERC 0090
      IC1=ICOL(I)                                                       ERC 0100
      IF(II-IC1)102,103,103                                             ERC 0110
103   CALL FICOL(I,II,L,ICOL)                                           ERC 0120
      STIFM(L)=0.                                                       ERC 0130
102   CONTINUE                                                          ERC 0140
      CALL FICOL(II,II,L,ICOL)                                          ERC 0150
      STIFM(L)=1.                                                       ERC 0160
      RETURN                                                            ERC 0170
      END                                                               ERC 0180
```

```
      SUBROUTINE PICOL(I,J,L,ICOL)
      IMPLICIT REAL*8(A-H,O-Z)
C     USING FORMULA L=J+SUM(K-ICOL(K)),K=1,I TO RELATE I,J,TO L
       DIMENSION ICOL(1)
      IF(J-ICOL(I)) 200,300,300
  300 ISUM=0
      DO 305 K=1,I
      ISUM=K-ICOL(K)+ISUM
  305 CONTINUE
      L=J+ISUM
      RETURN
  200  WRITE(6,4)I,J
    4 FORMAT(31H ELEMENT IS NOT IN BAND REGION,3H I=,I5,3H J=,I5)
      RETURN
      END
```

```
      SUBROUTINE IDENT(NQP,NBR)
      IMPLICIT REAL*8(A-H,O-Z)
       COMMON /TAPE/ MREAD,MWRITE,MPUNCH
      COMMON/SC/CRITS,BIG,BTIME,MCRIT,IBIG,ISURF
       COMMON /VO/ FLVA(205),DISP(205),DELD(205),SNS(50,3,6,5),
     *BINP(50,3),BIMP(50,3),TDISP(205),TU(205),FW(205),
     *CCIY(205),COIZ(205),DELTAT
      COMMON/FRAG/FM(6),FCG(6),FMASS(6),FMOI(6),FCGU(6),FCGW(6),ALFA(6),
     *UDOT(6),WDOT(6),ADOT(6),TPRIM(6),CR(6),FCGX(6),UNK(6),NF
      COMMON/ENERG/FK(6),CINFTO,CUMW,DELKE,CELAS,ELAS,PLASTC
      COMMON /HM/ C5,C6,ASPL(50,3,6,5),GZETA(50,3,6)
      COMMON/PG/Y(51),Z(51),ANG(51),H(51),EXANG,NS,IK,NOGA,NPL,NI,
     * ICOL(205),NBCCND,NBC(7),NODEB(7)
      COMMON /LEFT/ RMASS(51)
      COMMON/MAT/ DENS(6),B(6),YOUNG(6),DS(6),SNO(6,5),NSPL(6),P(6),
     * EPS(6,5),SIG(6,5), EPLN(6)
      COMMON/THI/ HTH(5)
      COMMON /ML/ MNFL(6),MATT(6)
      SIN(Q)=DSIN(Q)
      COS(Q)=DCOS(Q)
      ATAN(Q)=DATAN(Q)
      ABS(Q)=DABS(Q)
      SQRT(Q)=DSQRT(Q)
      WRITE(MWRITE,1000)
 1000 FORMAT(/////,'     ')
      IF(EXANG.EQ.360.)GO TO 81
      WRITE(MWRITE,2)
      GO TO 80
   81 WRITE(MWRITE,1)
    1 FORMAT('     COMPLETE RING **CIVM-JET 4B** CONTAINMENT ANALYSIS',
     @//,' RING PROPERTIES',//)
    2 FORMAT('     PARTIAL  RING **CIVM-JET 4B** CONTAINMENT ANALYSIS',
     @//,' RING PROPERTIES',//)
   80 CONTINUE
      NBR1 = NBR+1
      DO 600 JT= 1,NBR1
```

```
      IF (JT.NE.1)   GO TO 610                                          IDNT0370
      WRITE(MWRITE,500)                                                 IDNT0380
  500 FORMAT('0MATERIAL PROPERTIES OF MAIN STRUCTURE ARE:')             IDNT0390
      GO TO 611                                                         IDNT0400
  610 JT1 = JT-1                                                        IDNT0410
      WRITE (MWRITE,510)  JT1                                           IDNT0420
  510 FORMAT('0MATERIAL PROPERTIES OF BRANCH NUMBER',I3,3X,'ARE AS      IDNT0430
     *FOLLOWS:')                                                        IDNT0440
  611 WRITE(MWRITE,3) E(JT),DENS(JT),MNEL(JT),NOGA,NPL,NSPL(JT)         IDNT0450
      MNO = NSPL(JT)                                                    IDNT0460
      WRITE(MWRITE,1015) DS(JT)                                         IDNT0470
      WRITE(MWRITE,1020) P(JT)                                          IDNT0480
 1015 FORMAT(12X,'DS FOR STRAIN RATE',30X,'=',D15.6)                    IDNT0490
 1020 FORMAT(12X,'P  FOR STRAIN RATE',30X,'=',D15.6)                    IDNT0500
      IF (JT.GT.1) WRITE(MWRITE,100)  HTH(JT1)                          IDNT0510
      WRITE(MWRITE,4)  (L,EPS(JT,L),L,SIG(JT,L),L=1,MNO)                IDNT0520
 3    FORMAT(12X,'WIDTH OF RING(IN)',31X,'=',D15.6,/,12X,'DENSITY OF RINIDNT0530
     *G',33X,'=',D15.6,/,12X,'NUMBER OF ELEMENTS',30X,'=',I5,/,12X,'NUMBIDNT0540
     *ER OF SPANWISE GAUSSIAN PTS.',16X,'=',I5,/,12X,'NUMBER OF DEPTHWISIDNT0550
     *E GAUSSIAN PTS.',15X,'=',I5,/,12X,'NUMBER OF MECHANICAL SUBLAYERS'IDNT0560
     *,18X,'=',I5,/)                                                    IDNT0570
 4    FORMAT(15X,'STRAIN (',I1,') =',D15.6,5X,'STRESS(',I1,') =',D15.6, IDNT0580
     @/)                                                                IDNT0590
  100 FORMAT(12X,'THICKNESS AT THE CONNECTING NODE',16X,'=', D15.6,/)   IDNT0600
  600 CONTINUE                                                          IDNT0610
      WRITE(MWRITE,1005)                                                IDNT0620
 1005 FORMAT(//' INITIAL GEOMETRY AT EACH NODE IS AS FOLLOWS:',/)       IDNT0630
      WRITE(MWRITE,5)                                                   IDNT0640
 5    FORMAT(12X,'NODE NO.',10X,'Y COORD',10X,'Z COORD',7X,'SLOPE(RAD.)'IDNT0650
     @,8X,'RING THICKNESS AT NODE I',/)                                 IDNT0660
      WRITE(MWRITE,6) (I,Y(I),Z(I),ANG(I),H(I),I=1,NS)                  IDNT0670
    6 FORMAT (12X,I5,7X,4D16.6,//)                                      IDNT0680
      WRITE(MWRITE,7)                                                   IDNT0690
 7    FORMAT( 1X,'FRAGMENT PROPERTIES',/)                               IDNT0700
      WRITE(MWRITE,8)                                                   IDNT0710
 8    FORMAT(12X,'FRAG.NO.',5X,' DIA. OF FRAG.',5X,'MASS OF FRAG.',5X,'MIDNT0720
```

```
     *OMENT OF INERTIA OF FRAG.',6X,'FCGY',13X,'FCGZ',/)                 IDNT0730
      WRITE(MWRITE,9)(I,FH(I),FMASS(I),FMOI(I),FCGX(I),FCG(I),I=1,NF)    IDNT0740
    9 FORMAT (11X,I5,6X,D15.6,4X,D15.6,8X,D15.6,11X,D15.6,2X,D15.6,//)   IDNT0750
      WRITE(MWRITE,10)                                                   IDNT0760
      WRITE(MWRITE,11)                                                   IDNT0770
      WRITE(MWRITE,12) (I,UDOT(I),WDOT(I),ADOT(I),CR(I),FK(I),UNK(I),    IDNT0780
     *I=1,NF)                                                            IDNT0790
   10 FORMAT( 1X,'COLLISION PARAMETERS',/)                               IDNT0800
   11 FORMAT(12X,'FRAG.NO.',3X,'VEL IN Y DIR.',3X,'VEL IN Z DIR.',3X,'ANIDNT0810
     *G. VEL.',3X,'COEFF.OF RESTIT.',3X,'INITIAL KINETIC ENERGY',3X,     IDNT0820
     *'COEFF. OF FRICT',/)                                               IDNT0830
   12 FORMAT (11X,I5,4X,4D16.6,6X,D15.6,6X,D15.6,//)                     IDNT0840
      IF(NBCOND .EQ. 0) GO TO 28                                         IDNT0850
      WRITE(MWRITE,1010)                                                 IDNT0860
 1010 FORMAT(//,' BOUNDARY CONDITIONS ARE:',/)                           IDNT0870
      DO 14 I=1,NBCOND                                                   IDNT0880
      IF(NBC(I) .EQ. 1) WRITE(MWRITE,15) NODEB(I)                        IDNT0890
      IF(NBC(I) .EQ. 2) WRITE(MWRITE,16) NODEB(I)                        IDNT0900
      IF(NBC(I) .EQ. 3) WRITE(MWRITE,17) NODEB(I)                        IDNT0910
   14 CONTINUE                                                           IDNT0920
   15 FORMAT('   SYMMETRY DISPLACEMENT CONDITION AT NODE =',I5)          IDNT0930
   16 FORMAT('    CLAMPED DISPLACEMENT CONDITION AT NODE =',I5)          IDNT0940
   17 FORMAT('    HINGED  DISPLACEMENT CONDITION AT NODE =',I5)          IDNT0950
      GO TO 18                                                           IDNT0960
   28 WRITE(MWRITE,13)                                                   IDNT0970
   13 FORMAT(/,'   THERE IS NO PRESCRIBED DISPLACEMENT CONDITION')       IDNT0980
   18 IF(NOP .EQ. 0) GO TO 19                                            IDNT0990
      WRITE(MWRITE,20)                                                   IDNT1000
   20 FORMAT(/,'   CONSTRAINTS (ELASTIC FOUNDATION/SPRING) AS DESCRIBEDIDNT1010
     * LATER')                                                           IDNT1020
      GO TO 23                                                           IDNT1030
   19 WRITE(MWRITE,21)                                                   IDNT1040
   21 FORMAT(/,'     THERE ARE NO ELASTIC SPRING CONSTANTS')             IDNT1050
   23 RETURN                                                             IDNT1060
      END                                                                IDNT1070
```

```
      SUBROUTINE IMPACT(EFLN,IT,NBR,QACL,QVEL)                          IMPA0010
      IMPLICIT REAL*8(A-H,O-Z)                                          IMPA0020
      DIMENSION  QACL(205)   , QVEL(205)                                IMPA0030
      DIMENSION AY(51),AZ(51)                                           IMPA0040
      DIMENSION VY(51),VZ(51),TFCGU(6),TFCGW(6),TALFA(6),IFLAG(51,6),   IMPA0050
     2NTSD(6),NEF(6),RL(50),EFLN(6)                                     IMPA0060
      COMMON/IMPT/ VEL(102),IMCO,JVEL(51)                               IMPA0070
      COMMON/TAPE/MREAD,MWRITE,MPUNCH                                   IMPA0080
      COMMON/VQ/FLVA(205),DISP(205),DELD(205),SNS(50,3,6,5),BINP(50,3), IMPA0090
     2BIMP(50,3),TDISP(205),TU(205),TW(205),COIY(205),COIZ(205),DELTAT  IMPA0100
      COMMON/FRAG/FH(6),FCG(6),FMASS(6),FMOI(6),FCGU(6),FCGW(6),ALFA(6),IMPA0110
     2VELFU(6),VELFW(6),VELFA(6),TPRIM(6),CR(6),FCGX(6),UNK(6),NF       IMPA0120
      COMMON/DFRAG/DFCGU(6),DFCGW(6),DALFA(6)                           IMPA0130
      COMMON/FG/Y(51),Z(51),ANG(51),H(51),EXANG,IKK,IK,NOGA,NFL,NDT,    IMPA0140
     2ICOL(205),NBCOND,NBC(7),NCDBB(7)                                  IMPA0150
      COMMON/ IIAT/ TAII                                                IMPA0160
      COMMON/BN/LMT(51)                                                 IMPA0170
      COMMON/BR/NVEC(51,2)                                              IMPA0180
      COMMON/LEFT/BMASS(51)                                             IMPA0190
      COMMON/COU/ IMCOU                                                 IMPA0200
      COS(ZZZ)=DCOS(ZZZ)                                                IMPA0210
      SIN(ZZZ)=DSIN(ZZZ)                                                IMPA0220
C    ********************************************                       IMPA0230
C                                                                       IMPA0240
C **** MODIFIED IMPACT CONTROLLING ROUTINE  *********                   IMPA0250
C                                                                       IMPA0260
C   CURRENT TIME REMAINING IN THIS TIME STEP=EXTERNAL TIME STEP         IMPA0270
C   AND CURRENT TIME = TB.                                              IMPA0280
      TIMEI=(IT-1)*DELTAT                                               IMPA0290
      TIMEF = IT*DELTAT                                                 IMPA0300
      DELTR=DELTAT                                                      IMPA0310
      TB=TIMEI                                                          IMPA0320
      JF=1                                                              IMPA0330
      ICP=0                                                             IMPA0340
      IF(EXANG.EQ.360.0) ICP=1                                          IMPA0350
C                                                                       IMPA0360
```

```
C     INITIALIZE CORRECTION 'FLAGS' TO NO-PREV.-CORR. POSITION  (=0),      IMPA0370
C     AND NO. OF SUBDIVISIONS FOR EACH FRAG. TO ZERO                       IMPA0380
         DO 5 I=1,IK                                                       IMPA0390
         DO 5 J=1,NF                                                       IMPA0400
         NTSD(J)=0                                                         IMPA0410
 5       IFLAG(I,J)=0                                                      IMPA0420
C                                                                          IMPA0430
C     TRANSFORM NODAL VELOCITIES INTO Y AND Z COMPONENTS                   IMPA0440
      6 DO 10 I=1,IKK                                                      IMPA0450
         VY(I)= QVEL(I*4-3)*COS(ANG(I))-QVEL(I*4-2)*SIN(ANG(I))            IMPA0460
   10 VZ(I)=   QVEL(I*4-3)*SIN(ANG(I))+QVEL(I*4-2)*COS(ANG(I))             IMPA0470
C                                                                          IMPA0480
C     CALC. TRIAL POSITION OF RING NODES AND FRAGMENT TO THE END OF THIS   IMPA0490
C     INTERNAL TIME STEP                                                   IMPA0500
         DO 25 I=1,IKK                                                     IMPA0510
         AY(I)= 0.5D+00       *(QACL(I*4-3)*COS(ANG(I))-QACL(I*4-2)*      IMPA0520
        @SIN(ANG(I)))/DELTAT**2                                            IMPA0530
         AZ(I)= 0.5D+00       *(QACL(I*4-3)*SIN(ANG(I))+QACL(I*4-2)*      IMPA0540
        @COS(ANG(I)))/DELTAT**2                                            IMPA0550
         TU(I)=Y(I)+DISP(I*4-3)*COS(ANG(I))-DISP(I*4-2)*SIN(ANG(I))        IMPA0560
         TW(I)=Z(I)+DISP(I*4-3)*SIN(ANG(I))+DISP(I*4-2)*COS(ANG(I))        IMPA0570
   25 CONTINUE                                                             IMPA0580
C                                                                          IMPA0590
C     TRIAL POSITION OF FRAGMENT                                           IMPA0600
         DO 35 I=1,NF                                                      IMPA0610
         TPCGU(I)=FCGU(I)                                                  IMPA0620
         TPCGW(I)=FCGW(I)                                                  IMPA0630
 35      TALPA(I)=ALFA(I)                                                  IMPA0640
C                                                                          IMPA0650
C     RETURN POSITION FOR SUBSEQUENT INSPECTION AFTER INITIAL PENETRATION  IMPA0660
C     CORRECTION.                                                          IMPA0670
 20      CONTINUE                                                          IMPA0680
C                                                                          IMPA0690
         CALL UPDATE(1.0D0,TU,TW,VY,VZ,TPCGU,TPCGW,TALPA,VELPU,VELPW,      IMPA0700
        2VELPA,DELTR,IKK,NF,ICP,AY,AZ)                                     IMPA0710
         IF(NTSD(JP).GT.50) CALL EXIT                                      IMPA0720
```

```
C
C     CALC. PENETRATION DISTANCES FOR THIS TRIAL POSITION.
        CALL PENTRN(TU,TW,TFCGU,TFCGW,NPP,PMAX,NEF,NEQ,JP,PAL,RL,IBIG,
       2H,FH,IK,NP,ICP)
C
C     CHECK PENETRATIONS.
C     IF THE NUMBER OF POSITIVE PENETRATIONS, NPP, IS ZERO, AND THE
C     MAX.PENETRATION IS LESS THAN ZERO, NO (MORE) PENETRATIONS OCCUR FOR
C     THIS TIME STEP.
        IF(NPP.EQ.0.AND.PMAX.LT.0.0)GO TO 150
C
C     IF MAX. PENETRATION IS ZERO, SKIP SUBDIVISION PROCESS.
        TT=TB+DELTR
        TMIN=DELTR
C
C     RETURN FRAGMENT AND NODAL POSITIONS TO BEGINNING OF THIS INTERNAL
C     TIME STEP.
        CALL UPDATE(-1.0D0,TU,TW,VY,VZ,TFCGU,TFCGW,TALFA,VELFU,VELFW,
       2VELFA,DELTR,IKK,NP,ICP,AY,AZ)
C
C     CALC. TIME OF CONTACT, ELEM. AFFECTED, AND POINT OF CONTACT.
        CALL TCONT(TU,TW,VY,VZ,TFCGU,TFCGW,VELFU,VELFW,DELTR,IK ,
       2TMIN,LNTMIN,RPC,JP,IFLAG,H,FH,NP,AY,AZ)
C
C     UPDATE NODAL AND FRAG. POSITIONS TO THIS TIME
        IBIG = LNTMIN
        PAL=RPC
        CALL UPDATE(1.0D0,TU,TW,VY,VZ,TFCGU,TFCGW,TALFA,VELFU,VELFW,
       2VELFA,TMIN,IKK,NP,ICP,AY,AZ)
        TT=TB+TMIN
C
C     IF NO ACCEPTABLE CONTACT TIMES HAVE BEEN FOUND, GO TO END OF ROUTINE
        IF(LNTMIN.EQ.0)GO TO 150
  100   CONTINUE
        NTSD(JP)=NTSD(JP)+1
        IMCOU = IMCOU+1
```

```
C
C   UPDATE NODAL VELOCITIES (VY,VZ), AND FRAGMENT VELOCITIES (VELFU,
C   VELFW, VELFA) TO POST-IMPACT VALUES.
      WRITE(MWRITE,8000) IMCOU,TT,IT,IBIG,JP,PAL
 8000 FORMAT('OIMPACT NO.',I5,5X,'TIME',D15.6,5X,'DURING CYCLE',I5,5X,
     @'ELEM',I5,5X,'FRAG',I5,5X,'DISTANCE',D15.6)
C
C   TIME REMAINING IN THIS EXTERNAL TIME STEP
      DELTR=TIMEF-TT
      IF(IMCOU.EQ.1)      TAII = TT
      TB=TT
      DO 110 I= 1,IKK
      VY(I)  = VY(I)+AY(I)*TMIN*2.0D+00
      VZ(I)  = VZ(I)  +AZ(I)*  TMIN* 2.0D+00
  110 CONTINUE
             CALL IMPCTE(TU,TW,VY,VZ,VELFU,VELFW,VELFA,JP,IBIG,RMASS,
     2FMASS,FMOI,CR,UNK,PAL,EFLN,H,FH,IK,NP,ICP,RL,NBR,NBCOND,NODEB
     3,DELTP,AY,AZ,ANG)
      IMCO = 1
C
C   CHECK FOR ADDITIONAL IMPACTS IN THIS EXTERNAL TIME STEP.
      GO TO 20
C
C   NO ADDITIONAL IMPACTS OCCUR IN THIS TIME STEP.
  150 CONTINUE
C
C   RETURN TO CONTROLLING ROUTINE WITH FINAL DISPLACEMENT INCREMENTS.
C   FRAGMENT LOCATION.
      DO 160 I=1,NP
      DPCGU(I)= TPCGU(I)-PCGU(I)
      DPCGW(I)  = TPCGW(I)- FCGW(I)
  160 DALFA(I)= TALFA(I)  - ALFA(I)
C
C   IF NO IMPACTS HAVE OCCURED, NO FURTHER UPDATE IS REQUIRED.
      NSUM=0
      DO 165 I=1,NP
```

```
 165  NSUM=NSUM+NTSD(I)                                                IMPA1450
      IF(NSUM.EQ.0) RETURN                                             IMPA1460
C                                                                      IMPA1470
C    IF IMPACT HAS OCCURED, UPDATE VELOCITIES                          IMPA1480
      DO 170 I=1,IKK                                                   IMPA1490
      TU(I)= TU(I)-Y(I)                                                IMPA1500
  170 TW(I)= TW(I)-Z(I)                                                IMPA1510
C                                                                      IMPA1520
C    TRANSFORM BACK TO RING COORDS.--- RETURN UPDATED DELD.            IMPA1530
      DO 180 I=1,IKK                                                   IMPA1540
      DELD(I*4-3)= TU(I)*COS(ANG(I))+TW(I)*SIN(ANG(I))-DISP(I*4-3)     IMPA1550
  180 DELD(I*4-2)=-TU(I)*SIN(ANG(I))+TW(I)*COS(ANG(I))-DISP(I*4-2)     IMPA1560
      RETURN                                                           IMPA1570
      END                                                              IMPA1580
```

```
      SUBROUTINE IMPCPF(TU,TW,VU,VW,VELPU,VELPW,VELPA,JBIG,IBIG,RMASS,
     2PMASS,FMOI,CR,UNK,FAL,EPLN,H,PH,IK,NP,ICP,RL,NBR,NBCOND,NODEB
     3,DELTR,AY,AZ,ANG)
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION NODEB(1)
      DIMENSION AY(1),AZ(1),ANG(1)
      DIMENSION TU(1),TW(1),VU(1),VW(1),VELPU(1),VELPW(1),VELPA(1),
     * PMASS(1),RMASS(1),FMOI(1),CR(1),UNK(1),EPLN(1),RL(1),H(1),PH(1)
      DIMENSION         SSL(25),GAM(25),BET(25),SSR(25)
      DIMENSION MNO(51) , MNCD(51),  LP(11),PK(11)
      DIMENSION MBC(8)     , EP(6)
      COMMON /BOUN/ YK(51),NECCNB,NBC3(7),NCDEB(7),MK(51),ROT(5,2)
     3,DROT(50), NODP(6)
      COMMON/IMPT/ VEL(102),IMCO,JVEL(51)
       COMMON /TAPE/ MREAD,MWRITE,MPUNCH
      COMMON/BR/NVEC(51,2)
      COMMON /TAM/ MKE(51)
      COMMON /ML/ MNEL(6),MATT(6)
      SIN(Q)= DSIN(Q)
      COS(Q)  = DCOS(Q)
      MEP=1
      IF(NBCOND.EQ.0) NODEB(1)  = 0
      DO 1000 I=1,IK
      L1= NVEC(I,1)
      L2= NVEC(I,2)
C   ESTABLISH ELEMENT LENGTH, ANGLES AND DISTANCES TO NODES
      RL(I)  = DSQRT((TW(L2)-TW(L1))**2+(TU(L2)-TU(L1))**2)
 1000 CONTINUE
      JNBR=NBR+1
      DO 100 I=1,JNBR
  100 EP(I)= EPLN(I)
      L1 = NVEC(IBIG,1)
      L2 = NVEC(IBIG,2)
      RSIN=  (TW(L2)-TW(L1))/RL(IBIG)
      RCOS=  (TU(L2)-TU(L1)) / RL(IBIG)
      IBI= NVEC(IBIG,1)
```

```
C     PAL = DISTANCE TO NODE1   PAX = DISTANCE TC NODE2                 IMPT0370
      IF(PAL.EQ.0.0.OR.PAL.EQ.1.0)   GOTO 937                           IMPT0380
      GOTO 934                                                          IMPT0390
  937 LZ=L1                                                             IMPT0400
      IF(PAL.EQ.1.0) LZ=L2                                              IMPT0410
      DO 1007 I=1,NBCOND                                                IMPT0420
      IF(LZ.EQ.NCDEB(I))   GOTO 1006                                    IMPT0430
 1007 CONTINUE                                                          IMPT0440
      GOTO 934                                                          IMPT0450
 1006 CONTINUE                                                          IMPT0460
      KII=1                                                             IMPT0470
      BET(1) = 0.0                                                      IMPT0480
      MNOD(1) = NVEC(IBIG,1)                                            IMPT0490
      IF(PAL .EQ.1.0) MNOD(1) = NVEC(IBIG,2)                            IMPT0500
      GOTO 936                                                          IMPT0510
  934 CONTINUE                                                          IMPT0520
      PAL= PAL *RL(IBIG)                                                IMPT0530
      PAX= RL(IBIG)-PAL                                                 IMPT0540
 5555 CONTINUE                                                          IMPT0550
      MBC(1) =0                                                         IMPT0560
      ZK=1.0                                                            IMPT0570
       MIML=0                                                           IMPT0580
      MIMR = 0                                                          IMPT0590
      DO 998 I= 2,JNBR                                                  IMPT0600
  998 EFLN(I) = EF(I)                                                   IMPT0610
      MMPL = 0                                                          IMPT0620
       KIL=1                                                            IMPT0630
C     ESTABLISH THE NUMBER OF NODES  COUNTERCLOCKWISE FROM IMPACT WITHINIMPT0640
       SSL(KIL)=PAL                                                     IMPT0650
      MEP=MKE(IBIG)                                                     IMPT0660
      IF(MEP.EQ.1)    GO TO 1010                                        IMPT0670
      WRITE  (MWRITE,1009)                                              IMPT0680
 1009 FORMAT(' IMPACT ON A BRANCH IS NOT PRESENTLY ALLOWED-- NO IMPACT')IMPT0690
      GO TO 350                                                         IMPT0700
 1010 CONTINUE                                                          IMPT0710
      IF(PAL.GE.EFLN(MEP)) GO TC 30C                                    IMPT0720
```

```
      MNO(KIL) = NVEC(IBIG, 1)
      IFF = 0
      IF2=0
      IF3 =0
       MIML=1
      DO 301 J=1,25
      GAM(KIL)= ZK-SSL(KIL-IF3)/EPLN(MEF)
      IF(MMPL.NE.1) GO TO 931
      EPLN(MFF) = 0.99*SSL(KIL-IF3)
      GO TO  5555
  931 DO 940 NC=1,NBCOND
      IF(MNO(KIL).NE.NODEB(NC)) GOTO 940
      MBC(1) = MBC(1) +1
      MBC(MBC(1)+1) = NODEB(NC)
      MMPL=1
      IF(MNO(KIL).NE.1.AND.MKE(JEL-1).EQ.1) GOTO 932
      EPLN(MEF) = SSL(KIL-IF3)
      GOTO 5555
  932 CONTINUE
      GOTO 950
  940 CONTINUE
  950 CONTINUE
      JEL = IBIG - KIL -IFF
      IF2 =0
       IF(ICP.LE.0.AND.JEL.LE.0) GO TO 302
       IF(ICP.GT.0.AND.JEL.LE.0) JEL=JEL+IK
C   CHECK FOR A BRANCH ATTACHMENT POINT
      IF(NBR.EQ.0) GO TO 1038
      DO 1020 I = 1,NBR
      IF(MNO(KIL).NE.MATT(I)) GO TO 1020
      NB = I+1
      MTI = MATT(I)
      EST = GAM(KIL)
      GO TO 1030
 1020 CONTINUE
      GO TO  1038
```

```
C     COMPUTE ERANCH NODES INVCLVED IN MOMENTUM TRANSPER,                 IMPT1090
 1030 RX = 0.0                                                            IMPT1100
      IF(MMPL.EQ.1) GOTO 1038                                             IMPT1110
      NUMB = 0                                                            IMPT1120
      MBFL=0                                                              IMPT1130
      KL = 0                                                              IMPT1140
      DO 1035 I= 1,10                                                     IMPT1150
      IF(MBFL.NE.1) GO TO 910                                             IMPT1160
      NUMB = NUMB+1                                                       IMPT1170
      IF(NUMB.NE.2) GOTO 910                                              IMPT1180
      EFLN(NB) = 0.99* RX/EST                                             IMPT1190
      GOTO 1030                                                           IMPT1200
  910 CONTINUE                                                            IMPT1210
      IF(NODP(NB-1).NE.1) GOTO 2050                                       IMPT1220
      IF((MTI-1).EQ.0) GOTO 1037                                          IMPT1230
      RX= RX+RL(MTI-I)                                                    IMPT1240
      P = EST-RX/EFLN(NB)                                                 IMPT1250
      IF (P.LF.0.0) GO TO 1037                                            IMPT1260
      LT(KL+1) = MTI-I                                                    IMPT1270
      GOTO 2060                                                           IMPT1280
 2050 CONTINUE                                                            IMPT1290
      IF (MKF(MTI+I-1).NE.NB)  GO TO 1037                                 IMPT1300
      RX= RX+RL(MTI+I-1)                                                  IMPT1310
      P = EST-RX/EFLN(NB)                                                 IMPT1320
      IF (P.LE.0.0) GO TO 1037                                            IMPT1330
      LT(KL+1) = MTI+I                                                    IMPT1340
 2060 CONTINUE                                                            IMPT1350
      PK(KL+1) = P                                                        IMPT1360
      DO 900 NC= 1,NBCOND                                                 IMPT1370
      IF(LT(KL+1).NE.NODEB(NC)) GOTO 900                                  IMPT1380
      MBC(1) = MBC(1)+1                                                   IMPT1390
      MBC(MBC(1)+1) = NODEB(NC)                                           IMPT1400
      MBFL=1                                                              IMPT1410
      GOTO 920                                                            IMPT1420
  900 CONTINUP                                                            IMPT1430
  920 CONTINUF                                                            IMPT1440
```

```
      KL = KL+1                                                         IMPT1450
 1035 CONTINUF                                                          IMPT1460
 1037 L = KIL+1                                                         IMPT1470
      IF3 = IF3 +KL                                                     IMPT1480
      IFF=MNFL(NB-1) -KL +IFF                                           IMPT1490
      IF2 = MNEL(NB-1)                                                  IMPT1500
      IF (KL.EQ.0) GO TO 1038                                           IMPT1510
      KIL = KIL +KL                                                     IMPT1520
      DO 1036 I = L,KIL                                                 IMPT1530
      LZ= KL -I+L                                                       IMPT1540
      GAM(I) = PK(LZ)                                                   IMPT1550
 1036 MNO (I) = LT(LZ)                                                  IMPT1560
 1038 CONTINUE                                                          IMPT1570
      JEL = JEL -IF2                                                    IMPT1580
      IF (JEL.EQ.0) GO TO 302                                           IMPT1590
      SSL(KIL+1-IF3) = SSL(KIL-IF3) + RL(JEL)                           IMPT1600
      IF(EPLN(MEF).LE.SSL(KIL+1-IF3)) GOTO 302                          IMPT1610
      KIL = KIL +1                                                      IMPT1620
      MNO(KIL) = NVEC(JEL,1)                                            IMPT1630
  301 CONTINUE                                                          IMPT1640
  302 DO 303 JJ= 1,KIL                                                  IMPT1650
      MNOD(JJ) = MNO(KIL-JJ+1)                                          IMPT1660
  303 BET(JJ) = GAM(KIL-JJ+1)                                           IMPT1670
  300 CONTINUE                                                          IMPT1680
      IF2=0                                                             IMPT1690
      IF3 =0                                                            IMPT1700
      IFF = 0                                                           IMPT1710
      MMPL = 0                                                          IMPT1720
      KIR=1                                                             IMPT1730
C     ESTABLISH THE NUMBER OF NODES          CLOCKWISE FROM IMPACT WITHINIMPT1740
       SSR(KIR)=PAX                                                     IMPT1750
      IF(PAX          .GE.EPLN(MEF)) GO TO 304                          IMPT1760
      MNOD(KIR+KIL) = NVEC(IBIG,2)                                      IMPT1770
       MIMR=1                                                           IMPT1780
      DO 305 J = 1,25                                                   IMPT1790
      BET(KIL+KIR) = ZK-SSR(KIR-IF3) /EPLN(MEF)                         IMPT1800
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```
      IF(MMPL.NE.1) GO TO 941                                           IMPT1810
      EPLN(MEP) = 0.99*SSF(KIR-IP3)                                     IMPT1820
      GO TO  5555                                                       IMPT1830
  941 DO 945 NC= 1,NBCOND                                               IMPT1840
      IF(MNOD(KIL+KIR).NE.NODEB(NC)) GO TO 945                          IMPT1850
      MBC(1) = MBC(1) +1                                                IMPT1860
      MBC(MBC(1)+1) = NODEB(NC)                                         IMPT1870
      MMPL=1                                                            IMPT1880
      IF(MNOD(KIL+KIR).NE.NS.AND.MKE(JEL+1).EQ.1)GOTO 933               IMPT1890
      EPLN(MEP) = SSR(KIR-IP3)                                          IMPT1900
      GOTO 5555                                                         IMPT1910
  933 CONTINUE                                                          IMPT1920
      GOTO 955                                                          IMPT1930
  945 CONTINUE                                                          IMPT1940
  955 CONTINUE                                                          IMPT1950
      JER= LBIG+KIR+IPP                                                 IMPT1960
      IP2=0                                                             IMPT1970
       IF(ICP.LE.0.AND.JER.GT.IK) GO TO 306                             IMPT1980
       IF(ICP.GT.0.AND.JER.GT.IK) JER=JER-IK                            IMPT1990
C     CHECK FOR A BRANCH ATTACHMENT POINT                               IMPT2000
      IF(NBR.EQ.0) GO TO 1080                                           IMPT2010
      DO 1050 I = 1,NBR                                                 IMPT2020
      IF (MNOD(KIL+KIR) .NE.MAT1(I)) GO TO 1050                         IMPT2030
      NB= I+1                                                           IMPT2040
      MTI = MATT(I)                                                     IMPT2050
      FST = BET(KIL+KIR)                                                IMPT2060
      GO TO 1060                                                        IMPT2070
 1050 CONTINUE                                                          IMPT2080
      GO TO 1080                                                        IMPT2090
C     COMPUTE BRANCH NODES INVOLVED IN MOMENTUM TRANSFER,               IMPT2100
 1060 RX =0                                                             IMPT2110
      MBFL=0                                                            IMPT2120
      NUMB = 0                                                          IMPT2130
      KL =0                                                             IMPT2140
      DO 1055 I = 1,10                                                  IMPT2150
      IF(MMPL.EQ.1) GOTO 1080                                           IMPT2160
```

```
      IF(MBPL.NE.1) GO TO 915
      NUMB = NUMB+1
      IF(NUMB.NE.2) GOTO 915
      EFLN(NB) = 0.99* RX/EST
      GOTO 1060
  915 CONTINUE
      IF (MKE(MTI+I-1).NE.NB) GO TO 1057
      RX=RX+RL(MTI+I-1)
      P=EST-RX/EFLN(NB)
      IF(P.LE.0.0) GO TO 1057
      LT(KL+1) = MTI+I
      PK(KL+1) = P
      DO 905 NC= 1,NBCOND
      IF(LT(KL+1).NE.NODEB(NC)) GOTO 905
      MBC(1) = MBC(1)+1
      MBC(MBC(1)+1) = NODEB(NC)
      MBPL=1
      GOTO 925
  905 CONTINUE
  925 CONTINUE
      KL= KL +1
 1055 CONTINUE
 1057 L=KIR+1
      M = KIR
      IP3 = IP3 +KL
      IP2 = MNEL(NB-1)
      IPP=MNEL(NB-1) -KL +IPP
      IF (KL.EQ.0) GO TO 1080
       KIR = KIR +KL
      DO 1056 I = L,KIR
      BET(KIL+I) = PK(I-M)
 1056 MNOD(KIL+I) = LT(I-M)
 1080 CONTINUE
      JER= JER+IP2
      IF (JER.GT.IK) GO TO  306
      SSR(KIR+1-IP3) = SSR(KIR-IP3) +RL(JER)
```

```
      IF(EPLN(MIF).LE.SSB(KIR+1-IF3)) GOTO 306                          IMPT2530
      KIR = KIR +1                                                      IMPT2540
      MNOD(KIL+KIR) = NVEC(JER,2)                                       IMPT2550
  305  CONTINUE                                                         IMPT2560
  306 CONTINUE                                                          IMPT2570
      IF(KIL.LE.1.AND.KIR.LE.1) GOTO 308                                IMPT2580
      IF(MIML.NE.0) GOTO 307                                            IMPT2590
       BET(1)=PAX              *BET(2)/PAL                              IMPT2600
      MNOD(1) = NVEC(IBIG,1)                                            IMPT2610
      DO 971 J=1,NBCOND                                                 IMPT2620
      IF(MNOD(1).NE.NODEB(J)) GOTO 971                                  IMPT2630
      MBC(1) = MBC(1) +1                                                IMPT2640
      MBC(MBC(1)+1) = NODEB(J)                                          IMPT2650
  971 CONTINUE                                                          IMPT2660
       GO TO 307                                                        IMPT2670
 304   IF(MIML.EQ.0) GO TO 308                                          IMPT2680
      IF(KIL.LE.1.AND.KIR.LE.1) GOTO 308                                IMPT2690
       BET(KIL+1)=PAL*BET(KIL)/PAX                                      IMPT2700
      MNOD(KIL+1) = NVEC(IBIG,2)                                        IMPT2710
      DO 972 J=1,NBCOND                                                 IMPT2720
      IF(MNOD(KIL+1).NE.NODEB(J)) GOTO 972                              IMPT2730
      MBC(1) = MBC(1) +1                                                IMPT2740
      MBC(MBC(1)+1) = NODEB(J)                                          IMPT2750
  972 CONTINUE                                                          IMPT2760
       GO TO 307                                                        IMPT2770
 308   BET(1)=PAX                                                       IMPT2780
       BET(2)=PAL                                                       IMPT2790
      MNOD(1) = NVEC(IBIG,1)                                            IMPT2800
      MNOD(2) = NVEC(IBIG,2)                                            IMPT2810
      DO 973 J= 1,NBCOND                                                IMPT2820
      IF(MNOD(1).NE.NODEB(J)) GOTO 974                                  IMPT2830
      MBC(1) = MBC(1) +1                                                IMPT2840
      MBC(MBC(1)+1) = NODEB(J)                                          IMPT2850
  974 IF(MNOD(2) .NE.NODEB(J)) GOTO 973                                 IMPT2860
      MBC(1) = MBC(1) +1                                                IMPT2870
      MBC(MBC(1)+1) = NODEB(J)                                          IMPT2880
```

```
  973 CONTINUE                                                            IMPT2890
  307   KII=KIL+KIR                                                       IMPT2900
        SUM=0.                                                            IMPT2910
        DO 311 J=1,KII                                                    IMPT2920
  311   SUM=SUM+BET(J)                                                    IMPT2930
C    BET = WEIGHTING FACTOR FOR THE EFFECTED NODES                        IMPT2940
        DO 312 J=1,KII                                                    IMPT2950
      BET(J) = BET(J)/SUM                                                 IMPT2960
      IF(MBC(1).EQ.0) GO TO 312                                           IMPT2970
      L= MBC(1)+1                                                         IMPT2980
      DO 989 I= 2,L                                                       IMPT2990
      IF(MNOD(J).EQ.MBC(I)) BET(J)=0.0                                    IMPT3000
  989 CONTINUE                                                            IMPT3010
  312 CONTINUE                                                            IMPT3020
  936 CONTINUE                                                            IMPT3030
      DO 101 I=1,JNBR                                                     IMPT3040
  101 EPLN(I) = ZP(I)                                                     IMPT3050
        SUMB=0.                                                           IMPT3060
        DO 313 J=1,KII                                                    IMPT3070
      JEE= MNOD(J)                                                        IMPT3080
        IF(ICP.GT.0.AND.JEE.GT.IK) JEE=JEE-IK                             IMPT3090
        SUMB=SUMB+BET(J)**2/RMASS(JEE)                                    IMPT3100
  313   CONTINUE                                                          IMPT3110
        B1=1./PMASS(JBIG)+(PH(JBIG)/2.)**2/PMOI(JBIG)+SUMB                IMPT3120
        B2=1./PMASS(JBIG)+SUMB                                            IMPT3130
        SUMN=0.                                                           IMPT3140
        SUMT=0.                                                           IMPT3150
      DO 340 J=1,KII                                                      IMPT3160
      JEE= MNOD(J)                                                        IMPT3170
        IF(ICP.GT.0.AND.JEE.GT.IK) JEE=JEE-IK                             IMPT3180
C     ESTABLISH THE TANGENTIAL AND NORMAL VELOCITIES OF RING AND FRAGMENTIMPT3190
      SUMN=SUMN +BET(J)*(VW(JEE)*RCOS-VU(JEE)*RSIN)                       IMPT3200
  340 SUMT=SUMT + BET(J)*(VW(JEE)*RSIN+VU(JEE)*RCOS)                      IMPT3210
      VPN= VELPW(JBIG)*RCOS - VELPU(JBIG)*RSIN                            IMPT3220
      VPT= VELPW(JBIG) * RSIN  + VELPU(JBIG)*RCOS                         IMPT3230
C    SINT= RELATIVE TANGENTIAL VEL BETWEEN RING AND FRAG., AINT IS REL. NIMPT3240
```

```
      SINT= VFT-VELPA(JBIG)*FH(JBIG) /2.0 -SUMT                         IMPT3250
      AINT=VFN-SUMN                                                     IMPT3260
C   IF AINT LE 0 THE FRAG IS NOT APPROACHING THE RING SO SKIP OUT OF THEIMPT3270
      IF(AINT.GT.0.0) GOTO 3005                                         IMPT3280
      WRITE(MWRITE,3006) AINT                                           IMPT3290
 3006 FORMAT('0AINT=',D15.6,'   NO IMPACT--LEAVING IMPCT2')             IMPT3300
      GOTO 350                                                          IMPT3310
 3005 CONTINUE                                                          IMPT3320
      IF(UNK(JBIG).EQ.0.0)GC TC 702                                     IMPT3330
C   CALCULATE THE EFFECT OF FRICTION ON THE RELATIVE VELOCITIES AND THE IMPT3340
       TANX=SINT*B2/(AINT*B1)                                           IMPT3350
705   IF(UNK(JBIG).LE.TANX)GC TC 706                                    IMPT3360
      APN=(1.0+CR(JBIG))*AINT/B2                                        IMPT3370
       APT=SINT/B1                                                      IMPT3380
      GO TO 760                                                         IMPT3390
 706   APN=(1.+CR(JBIG))*AINT/B2                                        IMPT3400
      APT=UNK(JBIG)*APN                                                 IMPT3410
      GO TO 760                                                         IMPT3420
702   APN=(1.0+CR(JBIG))*AINT/B2                                        IMPT3430
      APT=0.0                                                           IMPT3440
760   CONTINUE                                                          IMPT3450
      PACTPN=-1.0*APN/PMASS(JBIG)                                       IMPT3460
      PACTPT=-1.0*APT/PMASS(JBIG)                                       IMPT3470
      PACTPO=APT*FH(JBIG)/FMOI(JBIG)/2.0                                IMPT3480
C   UPDATE THE RING AND FRAGMENT VELOCITIES                             IMPT3490
      VELPU(JBIG) = (-PACTPN*RSIN+PACTPT*RCOS) +VELPU(JBIG)             IMPT3500
      VELPW(JBIG) =(PACTPN*RCOS+PACTPT*RSIN) +VELPW(JBIG)               IMPT3510
      VELPA(JBIG) = PACTPO +VELPA(JBIG)                                 IMPT3520
       DO 350 J=1,KII                                                   IMPT3530
      JEE= MNOD(J)                                                      IMPT3540
       IF(ICP.GT.0.AND.JEE.GT.IK) JEF=JEE-IK                            IMPT3550
       PACTN=BET(J)*APN/RMASS(JEE)                                      IMPT3560
       FACTT=BET(J)*APT/RMASS(JEE)                                      IMPT3570
      VU(JEE)= (-PACTN*RSIN+FACTT*RCOS) +VU(JEE)                        IMPT3580
      VW(JEF) = (PACTN*RCOS+PACTT*RSIN) +VW(JEE)                        IMPT3590
      A= VU(JEE)+AY(JEE)*DELTR*2.0D+00                                  IMPT3600
```

```
      B=  VW(JEE) +AZ(JEE) *DELTR*2.0D+00                          IMPT3610
      VEL(JEE*2-1) =  A*COS(ANG(JEE)) +B*SIN(ANG(JEE))             IMPT3620
      VEL(JEE*2) =-A*SIN(ANG(JEE))+B*COS(ANG(JEE))                 IMPT3630
      JVEL(JEE)=  1                                                IMPT3640
  350  CONTINUE                                                    IMPT3650
      RETURN                                                       IMPT3660
      END                                                          IMPT3670
```

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```
      SUBROUTINE MINV(A,N,DET,L,M)                                      MINV0010
      IMPLICIT REAL*8(A-H,O-Z)                                          MINV0020
C                                                                       MINV0030
C        SEARCH FOR THE LARGEST ELEMENT                                 MINV0040
C                                                                       MINV0050
      DIMENSION A(1),L(1),M(1)                                          MINV0060
      DET=1.0                                                           MINV0070
      NK=-N                                                             MINV0080
      DO 80 K=1,N                                                       MINV0090
      NK=NK+N                                                           MINV0100
      L(K)=K                                                            MINV0110
      M(K)=K                                                            MINV0120
      KK=NK+K                                                           MINV0130
      BIGA=A(KK)                                                        MINV0140
      DO 20 J=K,N                                                       MINV0150
      IZ=N*(J-1)                                                        MINV0160
      DO 20 I=K,N                                                       MINV0170
      IJ=IZ+I                                                           MINV0180
   10 IF(DABS(BIGA)-DABS(A(IJ)))15,20,20                                MINV0190
   15 BIGA=A(IJ)                                                        MINV0200
      L(K)=I                                                            MINV0210
      M(K)=J                                                            MINV0220
   20 CONTINUE                                                          MINV0230
C                                                                       MINV0240
C        INTERCHANGE ROWS                                               MINV0250
C                                                                       MINV0260
      J=L(K)                                                            MINV0270
      IF(J-K) 35,35,25                                                  MINV0280
   25 KI=K-N                                                            MINV0290
      DO 30 I=1,N                                                       MINV0300
      KI=KI+N                                                           MINV0310
      HOLD=-A(KI)                                                       MINV0320
      JI=KI-K+J                                                         MINV0330
      A(KI)=A(JI)                                                       MINV0340
   30 A(JI) =HOLD                                                       MINV0350
C        INTERCHANGE COLUMNS                                            MINV0360
```

```
C                                                                       MINV0370
   35 I=M(K)                                                            MINV0380
      IF(I-K) 45,45,38                                                  MINV0390
   38 JP=N*(I-1)                                                        MINV0400
      DO 40 J=1,N                                                       MINV0410
      JK=NK+J                                                           MINV0420
      JI=JP+J                                                           MINV0430
      HOLD=-A(JK)                                                       MINV0440
      A(JK)=A(JI)                                                       MINV0450
   40 A(JI) =HOLD                                                       MINV0460
C                                                                       MINV0470
C        DIVIDE COLUMN BY MINUS PIVOT (VALUE OF PIVOT ELEMENT IS        MINV0480
C        CONTAINED IN BIGA)                                             MINV0490
C                                                                       MINV0500
   45 IF(BIGA) 48,46,48                                                 MINV0510
   46 DET=0.0                                                           MINV0520
      RETURN                                                            MINV0530
   48 DO 55 I=1,N                                                       MINV0540
      IF(I-K) 50,55,50                                                  MINV0550
   50 IK=NK+I                                                           MINV0560
      A(IK)=A(IK)/(-BIGA)                                               MINV0570
   55 CONTINUE                                                          MINV0580
C                                                                       MINV0590
C        REDUCE MATRIX                                                  MINV0600
C                                                                       MINV0610
      DO 65 I=1,N                                                       MINV0620
      IK=NK+I                                                           MINV0630
      HOLD=A(IK)                                                        MINV0640
      IJ=I-N                                                            MINV0650
      DO 65 J=1,N                                                       MINV0660
      IJ=IJ+N                                                           MINV0670
      IF(I-K) 60,65,60                                                  MINV0680
   60 IF(J-K) 62,65,62                                                  MINV0690
   62 KJ=IJ-I+K                                                         MINV0700
      A(IJ)=HOLD*A(KJ) +A(IJ)                                           MINV0710
   65 CONTINUE                                                          MINV0720
```

```
C                                                                       MINV0730
C        DIVIDE ROW BY PIVOT                                            MINV0740
C                                                                       MINV0750
      KJ=K-N                                                            MINV0760
      DO 75 J=1,N                                                       MINV0770
      KJ=KJ+N                                                           MINV0780
      IF(J-K) 70,75,70                                                  MINV0790
   70 A(KJ)=A(KJ)/BIGA                                                  MINV0800
   75 CONTINUE                                                          MINV0810
C                                                                       MINV0820
C        PRODUCT OF PIVOTS                                              MINV0830
C                                                                       MINV0840
      DET=DET*BIGA                                                      MINV0850
C                                                                       MINV0860
C        REPLACE PIVOT BY RECIPROCAL                                    MINV0870
C                                                                       MINV0880
      A(KK)=1.0/BIGA                                                    MINV0890
   80 CONTINUE                                                          MINV0900
C                                                                       MINV0910
C        FINAL ROW AND COLUMN INTERCHANGE                               MINV0920
C                                                                       MINV0930
      K=N                                                               MINV0940
  100 K=(K-1)                                                           MINV0950
      IF(K) 150,150,105                                                 MINV0960
  105 I=L(K)                                                            MINV0970
      IF(I-K) 120,120,108                                               MINV0980
  108 JQ=N*(K-1)                                                        MINV0990
      JR=N*(I-1)                                                        MINV1000
      DO 110 J=1,N                                                      MINV1010
      JK=JQ+J                                                           MINV1020
      HOLD=A(JK)                                                        MINV1030
      JI=JR+J                                                           MINV1040
      A(JK)=-A(JI)                                                      MINV1050
  110 A(JI) =HOLD                                                       MINV1060
  120 J=M(K)                                                            MINV1070
      IF(J-K) 100,100,125                                               MINV1080
```

```
125 KI=K-N                                                  MINV1090
    DO 130 I=1,N                                            MINV1100
    KI=KI+N                                                 MINV1110
    HOLD=A(KI)                                              MINV1120
    JI=KI-K+J                                               MINV1130
    A(KI)=-A(JI)                                            MINV1140
130 A(JI) =HOLD                                             MINV1150
    GO TO 100                                               MINV1160
150 RETURN                                                  MINV1170
    END                                                     MINV1180
```

```
      SUBROUTINE OMULT(SQVCT,RWVCT,NCOL,NROWS,ACC,KROW,NDEX,NIRREG)      OMLT0010
     IMPLICIT REAL*8(A-H,O-Z)                                            OMLT0020
C     TO FIND ACC OF  (SQVCT)*(RWVCT)=(ACC)                              OMLT0030
      DIMENSION SQVCT(1),RWVCT(1),NCOL(1),ACC(1),KROW(1),NDEX(1)         OMLT0040
      INDEX=0                                                            OMLT0050
      NROWM=NROWS-1                                                      OMLT0060
      IF (NIRREG .GT. 0) GO TO 200                                       OMLT0070
C     HIGH SPEED PRODUCT FOR REGULAR MATRICES                            OMLT0080
      DO 100 NN=1,NROWM                                                  OMLT0090
      SUM=0.0                                                            OMLT0100
      IP1=NN+1                                                           OMLT0110
      KST=NCOL(NN)                                                       OMLT0120
      INDEX=INDEX+NN-KST                                                 OMLT0130
      DO 101 KPL=KST,NN                                                  OMLT0140
      IJ=INDEX+KPL                                                       OMLT0150
  101 SUM=SUM+SQVCT(IJ)*RWVCT(KPL)                                       OMLT0160
C     NOW FOR THE COLUMN ELEMENTS                                        OMLT0170
      JNDEX=IJ                                                           OMLT0180
      DO 102 KPL=IP1,NROWS                                               OMLT0190
      IF(NN.LT.NCOL(KPL))GO TO 100                                       OMLT0200
      JNDEX=JNDEX+KPL-NCOL(KPL)                                          OMLT0210
  102 SUM=SUM+SQVCT(JNDEX)*RWVCT(KPL)                                    OMLT0220
  100 ACC(NN)=ACC(NN)+SUM                                                OMLT0230
C     NOW FOR THE LAST ROW                                               OMLT0240
  104 KADD=NCOL(NROWS)                                                   OMLT0250
      SUM=0.0                                                            OMLT0260
      INDEX=INDEX+NROWS-KADD                                             OMLT0270
      DO 103 KPL=KADD,NROWS                                              OMLT0280
      IJ=INDEX+KPL                                                       OMLT0290
  103 SUM=SUM+SQVCT(IJ)*RWVCT(KPL)                                       OMLT0300
      ACC(NROWS)=ACC(NROWS)+SUM                                          OMLT0310
      RETURN                                                             OMLT0320
C     MEDIUM SPEED PRODUCT FOR NIRREG .LE. NROWS/2                       OMLT0330
  200 IF (NIRREG .GT. NROWS/2) GO TO 201                                 OMLT0340
      DO 105 NN=1,NROWM                                                  OMLT0350
      IP1=NN+1                                                           OMLT0360
```

```
      KST=NCOL(NN)                                          OMLT0370
      INDEX=INDEX+NN-KST                                    OMLT0380
      SUM=0.0                                               OMLT0390
      DO 106 KPL=KST,NN                                     OMLT0400
      IJ=INDEX+KPL                                          OMLT0410
106   SUM=SUM+SQVCT(IJ)*RWVCT(KPL)                          OMLT0420
      NCK=0                                                 OMLT0430
      JNDEX=IJ                                              OMLT0440
107   DO 108 KPL=IP1,NROWS                                  OMLT0450
      IF(NN .LT. NCOL(KPL)) GO TO 109                       OMLT0460
      JNDEX=JNDEX+KPL-NCOL(KPL)                             OMLT0470
108   SUM=SUM+SQVCT(JNDEX)*RWVCT(KPL)                       OMLT0480
      GO TO 105                                             OMLT0490
109   NCK=NCK+1                                             OMLT0500
      IF (NCK .GT.NIRREG) GO TO 105                         OMLT0510
      IF (KPL .GE. KROW(NCK)) GO TO 109                     OMLT0520
      IP1=KROW(NCK)                                         OMLT0530
      JNDEX=NDEX(NCK)+NN                                    OMLT0540
      GO TO 107                                             OMLT0550
105   ACC(NN)=ACC(NN)+SUM                                   OMLT0560
      GO TO 104                                             OMLT0570
201   DO 503 NN=1,NROWM                                     OMLT0580
      IP1=NN+1                                              OMLT0590
      K=NCOL(NN)                                            OMLT0600
      INDEX=INDEX+NN-K                                      OMLT0610
      SUM=0.0                                               OMLT0620
      DO 502 KRX=K,NN                                       OMLT0630
      IJ=INDEX+KRX                                          OMLT0640
502   SUM=SUM+SQVCT(IJ)*RWVCT(KPX)                          OMLT0650
      JNDEX=IJ                                              OMLT0660
      DO 504 KRX=IP1,NROWS                                  OMLT0670
      K=NCOL(KRX)                                           OMLT0680
      JNDEX=JNDEX+KRX-K                                     OMLT0690
      IF (NN .LT. K) GO TO 504                              OMLT0700
      SUM=SUM+SQVCT(JNDEX)*RWVCT(KRX)                       OMLT0710
504   CONTINUE                                              OMLT0720
```

```
503   ACC(NN)=ACC(NN)+SUM                                              OMLT0730
      GO TO 104                                                        OMLT0740
      END                                                              OMLT0750
```

```
      SUBROUTINE PENTRN(TU,TW,TFCGU,TFCGW,NPP,PMAX,NEF,NEQ,JF,PAL,RL
     2,IBIG,H,FH,IK,NP,ICP)
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION PND(51,6),PD(50,6),PALE(50,6)
      DIMENSION TU(1),TW(1),TFCGU(1),TFCGW(1), NEF(1) ,RL(1),H(1),FH(1)
      COMMON /TAPE/ MWRITE,MREAD,MPUNCH
      COMMON/BR/NVEC(51,2)
      COMMON/BN/ LMT(51)
C     CHECK FOR NODAL IMPACT AND ELEMENT IMPACT
      DO 110 IP = 1,NP
      L=1
      DO 100 IR=1,IK
      PD(IR,IP) = -10.0
      PND(IR,IF)  = -10.0
      L1= NVEC(IR,1)
      L2=NVEC(IR,2)
      IF(IR.NE.LMT(L)) GO TO 90
      L=L+1
      GO TO 100
   90 CONTINUE
C CALCULATE DIST FROM FRAG TO NODE1 -- DFN AND LENGTH OF ELEMENT  DEL
      DFN=DSQRT((TFCGU(IP)-TU(L1))**2+(TFCGW(IP)-TW(L1))**2)
      DEL=DSQRT((TU(L2)-TU(L1))**2+(   TW(L2)-TW(L1))**2)
      RL(IR) = DEL
C    DCRTN IS THE CRITICAL DISTANCE = HALF ( FRAG DIA. + AVG ELEMENT THIC
      DCRTN=  (FH(IP)+  (H(L1)+H(L2))/2.0)/2.0
      DCRTE=DCRTN
      DU= TU(L1)-TFCGU(IP)
      DW = TW(L1) - TFCGW(IP)
      DEU= TU(L2) -TU(L1)
      DEW= TW(L2) - TW(L1)
      TCOS = DEU / DEL
      TSIN = DEW/ DEL
      PAL = -(DU*TCOS+DW*TSIN)
      PALE(IR,IP) = PAL
       IF (PAL.LT.0.0) GO TO 100
```

```
      IF (PAL.GT.DEL) GO TO 100                                         PENT0370
      DFE= -(-DW*TCOS+ DU*TSIN)                                         PENT0380
       PD(IR,IP) = DCRTE-DPF                                            PENT0390
  100 CONTINUE                                                          PENT0400
  110 CONTINUE                                                          PENT0410
C    CALCULATE THE LARGEST PENETRATION DIST, AND NUMBER OF + PENETRATIONSPENT0420
      K = 0                                                             PENT0430
      IF (ICP.GT.0)  K=1                                                PENT0440
      DO 290 J=1,NP                                                     PENT0450
  290 NEF(J) = 0                                                        PENT0460
      NEQ=0                                                             PENT0470
      PMAX= -5.0                                                        PENT0480
      NPP = 0                                                           PENT0490
      PAL = -1.5                                                        PENT0500
      DO 300 IR=1,IK                                                    PENT0510
      L1= NVEC(IR,1)                                                    PENT0520
      L2= NVEC(IR,2)                                                    PENT0530
      DO 300 IP= 1,NP                                                   PENT0540
  335 IF(PD(IR,IP).GT.0.0)  NPP=NPP+1                                   PENT0550
      IF(PD(IR,IP)-PMAX)  360 ,350,340                                  PENT0560
  340 PMAX= PD(IR,IP)                                                   PENT0570
      PAL = PALE(IR,IP)/ RL(IR)                                         PENT0580
      IBIG = IR                                                         PENT0590
      NEQ=0                                                             PENT0600
      JP=IP                                                             PENT0610
      DO 345 J=1,NP                                                     PENT0620
  345 NPP(J) =0                                                         PENT0630
      GO TO 360                                                         PENT0640
  350 NEP(IP) =1                                                        PENT0650
      NEQ= NEQ+1                                                        PENT0660
  360 CONTINUE                                                          PENT0670
  300 CONTINUE                                                          PENT0680
      RETURN                                                            PENT0690
      END                                                               PENT0700
```

```
      SUBROUTINE PRINT(IT,TIME)
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION COPY(51),COPZ(51),FAILI(51),FAILO(51)
       COMMON /VQ/ PLVA(205),DISP(205),DELD(205),SNS(50,3,6,5),
     *BINP(50,3),BIMP(50,3),TDISP(205),TU(205),TW(205),
     *COIY(205),COIZ(205),DELTAT
      COMMON/FG/Y(51),Z(51),ANG(51),H(51),EXANG,NS,IK,NOGA,NFL,NI,
     * ICOL(205),NBCOND,NBC(7),NODEB(7)
      COMMON/ IIAT/ TAII
      COMMON/MAT/ DENS(6),B(6),YOUNG(6),DS(6),SNO(6,5),NSPL(6),P(6),
     * EPS(6,5),SIG(6,5), EFLN(6)
      COMMON /HM/ C5,C6,ASFL(5C,3,6,5),GZETA(50,3,6)
       COMMON /BA/ BEP(50,3,3,8),AL(50),AXG(3),ANG(3)
      COMMON/FRAG/FH(6),FCG(6),FMASS(6),FMOI(6),FCGU(6),FCGW(6),ALPA(6),
     *UDOT(6),WDOT(6),ADOT(6),TPRIM(6),CR(6),FCGX(6),UNK(6),NP
      COMMON /DFRAG/DFCGU(6),DFCGW(6),DALPA(6)
       COMMON /TAPE/ MREAD,MWRITE,MPUNCH
      COMMON /EP/ EPSI(51),EPSO(51)
      SIN(Q)=DSIN(Q)
      COS(Q)=DCOS(Q)
      ATAN(Q)=DATAN(Q)
      ABS(Q)=DABS(Q)
      SQRT(Q)=DSQRT(Q)
C   CALCULATING PRESENT POSITION OF EACH NODE
      DO 11 I=1,NS
       COPY(I)=Y(I)+DISP(I*4-3)*COS(ANG(I))-DISP(I*4-2)*SIN(ANG(I))
 11    COPZ(I)=Z(I)+DISP(I*4-3)*SIN(ANG(I))+DISP(I*4-2)*COS(ANG(I))
      TAIIT= TIME - TAII
      WRITE(MWRITE,1)IT,TIME, TAIIT
 1    FORMAT(///,'    J=',I5,'    TIME=',D12.5,'    TIME AFTER INITIAL I
     &MPACT =', D15.6)
       WRITE(MWRITE,2)
 2     FORMAT(/,'   I ',5X,'V',11X,'W',9X,'PSI',9X,'CHI',10X,'COPY',
     *8X,'COPZ',9X,'L',11X,'M',7X,'STRAIN(IN)',4X,'STRAIN(OUT)')
 50    DO 21 I=1,IK
 21    WRITE(MWRITE,22)I,DISP(I*4-3),DISP(I*4-2),DISP(I*4-1),DISP(I*4),
```

```
     *COPY(I),COPZ(I),BINP(I,2),BINP(I,2),EPSI(I),EPSO(I)
      IF(EXANG.EQ.360.)GO TO 189
22     FORMAT(I5,9D12.4,2X,D12.4)
      IKP1=IK+1
      WRITE(MWRITE,23)IKP1,DISP(IKP1*4-3),DISP(IKP1*4-2),DISP(IKP1*4-1)
     &,DISP(IKP1*4),COPY(IKP1),COPZ(IKP1),EPSI(IKP1),EPSO(IKP1)
   23 FORMAT(I5,6D12.4,24X,D12.4,2X,D12.4)
189   WRITE(MWRITE,35)
   35 FORMAT(10X,'FRAG NO.=',5X,'PCGU =',9X,'PCGW =',9X,'ALFA =',9X,
     *'FRUV =',9X,'FRWV =',9X,'FRAV =',/)
      DO 36 I=1,NF
   36 WRITE(MWRITE,37) I,PCGU(I),PCGW(I),ALPA(I),UDOT(I),WDOT(I),ADOT(I)
   37 FORMAT(10X,I5,3X,6D15.6,/)
      RETURN
      END
```

```
      SUBROUTINE QREM(AA,AL,AXG,AWG)                                    QREM0010
      IMPLICIT REAL*8(A-H,O-Z)                                          QREM0020
C      TO FIND EFFECTIVE STIFFNESS MATRIX DUE TO ELASTIC RESTRAINTS    QREM0030
       DIMENSION AA(50,8,8),AL(1),AXG(1),AWG(1),BNG(51)                QREM0040
     *,ELF(8,8),ELRR(8,8),ELRP(8,8)                                    QREM0050
      DIMENSION DELM(8),EISM(8), DUMMY(8)                              QREM0060
      COMMON/FG/Y(51),Z(51),ANG(51),H(51),EXANG,NS,IK,NOGA,NPL,NI,      QREM0070
     * ICOL(205),NPCOND,NBC(7),NODEB(7)                                QREM0080
      COMMON/MAT/ DENS(6),B(6),YOUNG(6),DS(6),SNO(6,5),NSPL(6),P(6),   QREM0090
     * EPS(6,5),SIG(6,5), EFLN(6)                                      QREM0100
      COMMON/ELPU/SPRIN(2060),ECREP(205),REX(4),NQR,NORP,NORU,NREL(4), QREM0110
     *NRST(4),NREU(4)                                                  QREM0120
       COMMON /TAPE/ MREAD,MWRITE,MPUNCH                               QREM0130
      COMMON /BR/ NVEC(51,2)                                           QREM0140
      COMMON /BOUN/ YK(51),NBCCNB,NBCB(7),NODPB(7),MK(51),ROT(5,2)     QREM0150
     ∂,DROT(50), NODP(6)                                               QREM0160
      COMMON /XD/ XDIST(6)                                             QREM0170
      COMMON/TAM/ MKE(51)                                              QREM0180
      SIN(Q)=DSIN(Q)                                                   QREM0190
      COS(Q)=DCOS(Q)                                                   QREM0200
      ATAN(Q)=DATAN(Q)                                                 QREM0210
      ABS(Q)=DABS(Q)                                                   QREM0220
      SQRT(Q)=DSQRT(Q)                                                 QREM0230
      PIE= 3.14159265358979ЗD+00                                       QREM0240
      PIE2= 2.0*PIE                                                    QREM0250
      PIE32= 1.5 *PIE                                                  QREM0260
       IF (NORP .EQ. 0) GO TO 1                                        QREM0270
      READ(MREAD,2)SCTP,SCTY,SCRP,(NREL(I),REX(I),I=1,NORP)            QREM0280
2     FORMAT(3D15.6/(4(I5,D15.6)))                                     QREM0290
      WRITE(MWRITE,1100) NORP                                          QREM0300
 1100 FORMAT(//,' THE CONSTANTS FOR',I3,'  ELASTIC POINT CONSTRAINTS AREQREM0310
     ∂:')                                                              QREM0320
      WRITE(MWRITE,777)SCTP,SCTY,SCRP                                  QREM0330
      WRITE(MWRITE,1140)                                               QREM0340
 1140 FORMAT(/,10X,'ELEMENT',10X,'S  COORDINATE')                      QREM0350
      WRITE(MWRITE,1145)  (NREL(I),REX(I),I=1,NORP)                    QREM0360
```

```
1145 FORMAT(' ',10X,I3,13X,D13.6)                                       QREM0370
      DO 10 IQ=1,NORP                                                   QREM0380
      SL=REX(IQ)                                                        QREM0390
      NE=NREL(IQ)                                                       QREM0400
     K1 = NVEC(NE,1)                                                    QREM0410
     K2= NVEC(NE,2)                                                     QREM0420
     MOP = MKE(NE) -1                                                   QREM0430
     L=MOP                                                              QREM0440
      P5=Z(K2)   -Z(K1)                                                 QREM0450
      P6=Y(K2)   -Y(K1)                                                 QREM0460
      P7=ANG(K2  )-ANG(K1)                                              QREM0470
     IF(YK(NE).EQ.1.0)  P7=ANG(K2)  - ROT(L,2)-ANG(K1)                  QREM0480
     IF(YK(NE).EQ.1.0.AND.ROT(L,1).EQ.0.0)  P7=ROT(L,2)+ANG(K2)-ANG(K1) QREM0490
     IF(YK(NE).EQ.2.0)   P7= ANG(K2)- DROT(NE)  - ANG(K1)               QREM0500
     IF(YK(NE).EQ.3.0)  P7=ROT(MOP,2)+ANG(K2)-DROT(NE)  -ANG(K1)        QREM0510
     ANG2=ANG(K2)                                                       QREM0520
     ANG1=ANG(K1)                                                       QREM0530
     IF(YK(NE).EQ.1.0.AND.ROT(L,1).EQ.0.0)ANG(K2)=ROT(L,2)+ANG(K2)      QREM0540
     IF(YK(NE).EQ.1.0.AND.ROT(L   ,1).EQ.1.0)ANG(K1)=ROT(L   ,2)+ANG(K1) QREM0550
     IF(YK(NE).EQ.2.0)  ANG(K1)= DROT(NE)  + ANG(K1)                    QREM0560
     IF(YK(NE).EQ.3.0)   ANG(K2)  = ROT(MOP,2)  + ANG(K2)               QREM0570
     IF(YK(NE).EQ.3.0)   ANG(K1)= DROT(NE)  +  ANG  (K1)                QREM0580
     APHA  = PIE / 2.0                                                  QREM0590
     IF(P5.LT.0.0) APHA= -APHA                                          QREM0600
     IF(P6.NE.0.0)  APHA= ATAN(P5/P6)                                   QREM0610
     IF(P6.LT.0.C.AND.P5.LT.0.C)APHA=APHA-PIE                           QREM0620
      IF(P6.LT.0.0 .AND. P5.GE.0.0)  APHA=APHA+PIE                      QREM0630
      BNG(NE+1)=ANG(K2  )                                               QREM0640
      BNG(NE)=ANG(K1)                                                   QREM0650
     IF(P7.GT.(PIE32 ).AND.APHA.LT.0.0)  BNG(NE+1)=ANG(K2)   -PIE2      QREM0660
     IF(P7.GT.(PIE32 ).AND.APHA.GT.0.0)  BNG(NE)=ANG(K1)+PIE2           QREM0670
     IF(P7.LT.(-PIE32 ).AND.APHA.GT.0.0)  BNG(NE+1)=ANG(K2)   +PIE2     QREM0680
     IF(P7.LT.(-PIE32 ).AND.APHA.LT.0.0)  BNG(NE)=ANG(K1)-PIE2          QREM0690
      BZER=BNG(NE)-APHA                                                 QREM0700
      B1=(-2.*BNG(NE+1)-4.*BNG(NE)+6.*APHA)/AL(NE)                      QREM0710
      B2=(3.*BNG(NE+1)+3.*BNG(NE)-6.*APHA)/AL(NE)**2                    QREM0720
```

```
      ANG(K2)=  ANG2                                                    QREM0730
      ANG(K1)=  ANG1                                                    QREM0740
       PHI=BZER+B1*SL+B2*SL**2                                          QREM0750
       PHIP=B1+2.*B2*SL                                                 QREM0760
       YZET=0.0                                                         QREM0770
       ZZET=0.0                                                         QREM0780
       DO  104  JJ=1,NOGA                                               QREM0790
       P2=BZER+B1*SL*AXG(JJ)+B2*(SL*AXG(JJ))**2+APHA                    QREM0800
       YZET=YZET+COS(P2)*SL*AWG(JJ)                                     QREM0810
  104  ZZET=ZZET+SIN(P2)*SL*AWG(JJ)                                     QREM0820
       P3=YZET*SIN(PHI+APHA)-ZZET*COS(PHI+APHA)                         QREM0830
       P4=YZET*COS(PHI+APHA)+ZZET*SIN(PHI+APHA)                         QREM0840
      ELR(1,1)=SCTP*COS(PHI)**2+SCTY*SIN(PHI)**2                        QREM0850
       ELR(2,1)=  (SCTP-SCTY)*COS(PHI)*SIN(PHI)                         QREM0860
      ELR(3,1)=P3*COS(PHI)*SCTP-P4*SIN(PHI)*SCTY                        QREM0870
       ELR(4,1)=SL*COS(PHI)*SCTP                                        QREM0880
       ELR(5,1)=-SL**2*SIN(PHI)*SCTY                                    QREM0890
      ELR(6,1)=-SL**3*SIN(PHI)*SCTY                                     QREM0900
       ELR(7,1)=SL**2*COS(PHI)*SCTP                                     QREM0910
       ELR(8,1)=SL**3*COS(PHI)*SCTP                                     QREM0920
      ELR(2,2)=SCTP*SIN(PHI)**2+SCTY*COS(PHI)**2                        QREM0930
       ELR(3,2)=P3*SIN(PHI)*SCTP+P4*COS(PHI)*SCTY                       QREM0940
       ELR(4,2)=SL*SIN(PHI)*SCTP                                        QREM0950
      ELR(5,2)=SL**2*COS(PHI)*SCTY                                      QREM0960
       ELR(6,2)=SL**3*COS(PHI)*SCTY                                     QREM0970
       ELR(7,2)=SL**2*SIN(PHI)*SCTP                                     QREM0980
       ELR(8,2)=SL**3*SIN(PHI)*SCTP                                     QREM0990
      ELR(3,3)=P3**2*SCTP+P4**2*SCTY+SCRP                               QREM1000
       ELR(4,3)=P3*SL*SCTP+SL*PHIP*SCRP                                 QREM1010
       ELR(5,3)=P4*SL**2*SCTY+2.*SL*SCRP                                QREM1020
      ELR(6,3)=P4*SL**3*SCTY+3.*SL**2*SCRP                              QREM1030
       ELR(7,3)=(P3*SCTP+PHIP*SCRP)*SL**2                               QREM1040
       ELR(8,3)=(P3*SCTP+PHIP*SCRP)*SL**3                               QREM1050
       ELR(4,4)=(SCTP+PHIP**2*SCRP)*SL**2                               QREM1060
       ELR(5,4)=2.*SL**2*PHIP*SCRP                                      QREM1070
       ELR(6,4)=3.*SL**3*PHIP*SCRP                                      QREM1080
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      ELR(7,4)=(SCTP+PHIP**2*SCRP)*SL**3                              QREM1090
      ELR(8,4)=(SCTP+PHIP**2*SCRP)*SL**4                              QREM1100
     ELR(5,5)=SL**4*SCTY+4.*SL**2*SCRP                                QREM1110
      ELR(6,5)=SL**5*SCTY+6.*SL**3*SCRP                               QREM1120
      ELR(7,5)=2.*SL**3*PHIP*SCRP                                     QREM1130
      ELR(8,5)=2.*SL**4*PHIP*SCRP                                     QREM1140
     ELR(6,6)=SL**6*SCTY+9.*SL**4*SCRP                                QREM1150
      ELR(7,6)=3.*SL**4*PHIP*SCRP                                     QREM1160
      ELR(8,6)=3.*SL**5*PHIP*SCRP                                     QREM1170
      ELR(7,7)=(SCTP+PHIP**2*SCRP)*SL**4                              QREM1180
      ELR(8,7)=(SCTP+PHIP**2*SCRP)*SL**5                              QREM1190
      ELR(8,8)=(SCTP+PHIP**2*SCRP)*SL**6                              QREM1200
      DO 12 I=1,7                                                     QREM1210
      IP1=I+1                                                         QREM1220
      DO 12 J=IP1,8                                                   QREM1230
12    ELR(I,J)=ELR(J,I)                                               QREM1240
      DO 13 I=1,8                                                     QREM1250
      DO 13 J=1,8                                                     QREM1260
      ELRR(I,J)=0.0                                                   QREM1270
      DO 13 K=1,8                                                     QREM1280
13    ELRR(I,J)=ELRR(I,J)+ELR(I,K)*AA(NE,K,J)                         QREM1290
      DO 14 I=1,8                                                     QREM1300
      DO 14 J=1,8                                                     QREM1310
      ELRP(I,J)=0.0                                                   QREM1320
      DO 14 K=1,8                                                     QREM1330
14    ELRP(I,J)=ELRP(I,J)+AA(NE,K,I)*ELRR(K,J)                        QREM1340
      IF (YK(NE).EQ.0.0)  GO TO 502                                   QREM1350
          CALL ROTAT(3,ELRP,DUMMY,NE)                                 QREM1360
 502 CONTINUE                                                         QREM1370
      CALL ASSEM(NE,ELRP,SPRIN)                                       QREM1380
10    CONTINUE                                                        QREM1390
1     IF(NORU .EQ.0) GO TO 4                                          QREM1400
     READ(MRFAD,3) SCTU,SCRU,SCTW,(NRST(I),NREU(I),I=1,NORU)          QREM1410
   3 FORMAT(3D15.6/(8I5))                                             QREM1420
     WRITE(MWRITE,1120) NORU                                          QREM1430
1120 FORMAT(//,' THE CONSTANTS FOR',I3,'  ELASTIC FOUNDATIONS ARE:')  QREM1440
```

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      WRITE(MWRITE,777)SCTU,SCTW,SCRU                                   QREM1450
  777 FORMAT(/,10X,'THE VALUE OF THE TANGENTIAL SPRING CONSTANT IS =',D1QREM1460
     *5.6,/,10X,'THE VALUE OF THE NORMAL SPRING CONSTANT IS =',D15.6,/, QREM1470
     *10X,'THE VALUE OF THE TORSIONAL SPRING CONSTANT IS =',D15.6,/)    QREM1480
      WRITE(MWRITE,1150)                                                QREM1490
 1150 FORMAT(/,10X,'FIRST ELEMENT',10X,'NUMBER OF ELEMENTS')            QREM1500
      WRITE(MWRITE,1155)  (NRST(I),NRFU(I),I=1,NORU)                    QREM1510
 1155 FORMAT(' ',13X,I3,24X,I3)                                         QREM1520
       DO 15 IQ=1,NORU                                                  QREM1530
       NSTAT=NRST(IQ)                                                   QREM1540
       NEND=NRFU(IQ)                                                    QREM1550
       DO 16 IR=1,NEND                                                  QREM1560
       NE=(NSTAT-1)+IR                                                  QREM1570
       IF(NE .GT. IK)  NE=NE-IK                                         QREM1580
      K1 = NVEC(NE,1)                                                   QREM1590
      K2= NVEC(NE,2)                                                    QREM1600
      MOP = NKE(NE)  -1                                                 QREM1610
      L=MOP                                                             QREM1620
       P5=Z(K2)   -Z(K1)                                                QREM1630
       P6=Y(K2)   -Y(K1)                                                QREM1640
       P7=ANG(K2   )-ANG(K1)                                            QREM1650
      IF(YK(NE).EQ.1.0)  P7=ANG(K2)  - ROT(L,2)-ANG(K1)                 QREM1660
      IF(YK(NE).EQ.1.0.AND.ROT(L,1).EQ.0.0)  P7=ROT(L,2)+ANG(K2)-ANG(K1) QREM1670
      IF(YK(NE).EQ.2.0)   P7= ANG(K2)- DROT(NE)  - ANG(K1)              QREM1680
      IF(YK(NE).EQ.3.0)  P7=ROT(MOP,2)+ANG(K2)-DROT(NE)  -ANG(K1)       QREM1690
      ANG2=ANG(K2)                                                      QREM1700
      ANG1=ANG(K1)                                                      QREM1710
      IF(YK(NE).EQ.1.0.AND.ROT(L,1).EQ.0.0)ANG(K2)=ROT(L,2)+ANG(K2)     QREM1720
      IF(YK(NE).EQ.1.0.AND.ROT(L   ,1).EQ.1.0)ANG(K1)=ROT(L   ,2)+ANG(K1) QREM1730
      IF(YK(NE).EQ.2.0)  ANG(K1)= DROT(NE)  + ANG(K1)                   QREM1740
      IF(YK(NE).EQ.3.0)   ANG(K2)  =  ROT(MOP,2)  + ANG(K2)             QREM1750
      IF(YK(NE).EQ.3.0)   ANG(K1)= DROT(NE)  +  ANG  (K1)               QREM1760
      APHA = PIE / 2.0                                                  QREM1770
      IF(P5.LT.0.0)  APHA= -APHA                                        QREM1780
      IF(P6.NE.0.0)  APHA= ATAN(P5/P6)                                  QREM1790
      IF(P6.LT.0.0.AND.P5.LT.0.0)APHA=APHA-PIF                          QREM1800
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      IF(P6.LT.0.0 .AND. P5.GE.0.0) APHA=APHA+PIE                       QREM1810
      BNG(NE+1)=ANG(K2  )                                               QREM1820
      BNG(NE)=ANG(K1)                                                   QREM1830
     IF(P7.GT.(PIE32 ).AND.APHA.LT.0.0) BNG(NE+1)=ANG(K2)   -PIE2       QREM1840
     IF(P7.GT.(PIE32 ).AND.APHA.GT.0.0) BNG(NE)=ANG(K1)+PIE2            QREM1850
     IF(P7.LT.(-PIE32 ).AND.APHA.GT.0.0) BNG(NE+1)=ANG(K2)   +PIE2      QREM1860
     IF(P7.LT.(-PIE32 ).AND.APHA.LT.0.0) BNG(NE)=ANG(K1)-PIE2           QREM1870
      BZER=BNG(NE)-APHA                                                 QREM1880
      B1=(-2.*BNG(NE+1)-4.*BNG(NE)+6.*APHA)/AL(NE)                      QREM1890
      B2=(3.*BNG(NF+1)+3.*BNG(NE)-6.*APHA)/AL(NE)**2                    QREM1900
     ANG(K2)= ANG2                                                      QREM1910
     ANG(K1)= ANG1                                                      QREM1920
      DO 102 I=1,8                                                      QREM1930
      DO 102 J=1,8                                                      QREM1940
102    FLR(I,J)=0.0                                                     QREM1950
      DO 103 J=1,NOGA                                                   QREM1960
      ZET=AL(NE)*AXG(J)                                                 QREM1970
      PHIP=B1+2.*B2*ZET                                                 QREM1980
      PHI=BZER+B1*ZET+B2*ZET**2                                         QREM1990
      WET=AL(NE)*AWG(J)                                                 QREM2000
      YZET=0.0                                                          QREM2010
      ZZET=0.0                                                          QREM2020
      DO 105 JJ=1,NOGA                                                  QREM2030
      P2=BZER+B1*ZET*AXG(JJ)+B2*(ZET*AXG(JJ))**2+APHA                   QREM2040
      YZET=YZET+COS(P2)*ZET*AWG(JJ)                                     QREM2050
105   ZZET=ZZET+SIN(P2)*ZET*AWG(JJ)                                     QREM2060
      P3=YZET*SIN(PHI+APHA)-ZZET*COS(PHI+APHA)                          QREM2070
      P4=YZET*COS(PHI+APHA)+ZZET*SIN(PHI+APHA)                          QREM2080
     ELR(1,1)=ELR(1,1)+(SCTU*COS(PHI)**2+SCTW*SIN(PHI)**2)*WET          QREM2090
     ELR(2,1)=ELR(2,1)+((SCTU-SCTW)*SIN(PHI)*COS(PHI))*WET              QREM2100
     ELR(3,1)=ELR(3,1)+(P3*SCTU*COS(PHI)-P4*SCTW*SIN(PHI))*WET          QREM2110
     ELR(5,1)=ELR(5,1)-(ZET**2*SCTW*SIN(PHI))*WET                       QREM2120
     ELR(6,1)=ELR(6,1)-(ZET**3*SCTW*SIN(PHI))*WET                       QREM2130
     ELR(2,2)=ELR(2,2)+(SCTU*SIN(PHI)**2+SCTW*COS(PHI)**2)*WET          QREM2140
     ELR(3,2)=ELR(3,2)+(P3*SCTU*SIN(PHI)+P4*SCTW*COS(PHI))*WET          QREM2150
     ELR(5,2)=ELR(5,2)+(ZET**2*SCTW*COS(PHI))*WET                       QREM2160
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```
      ELR(6,2)=ELR(6,2)+(ZET**3*SCTW*COS(PHI))*WET
      ELR(3,3)=ELR(3,3)+(P3**2*SCTU+P4**2*SCTW+SCRU)*WET
      ELR(5,3)=ELR(5,3)+(P4*SCTW*ZET**2+2.0*SCRU*ZET)*WET
      ELR(6,3)=ELR(6,3)+(P4*SCTW*ZET**3+3.0*SCRU*ZET**2)*WET
      ELR(5,5)=ELR(5,5)+(ZET**4*SCTW+4.0*ZET**2*SCRU)*WET
      ELR(6,5)=ELR(6,5)+(ZET**5*SCTW+6.0*ZET**3*SCRU)*WET
      ELR(6,6)=ELR(6,6)+(ZET**6*SCTW+9.0*ZET**4*SCRU)*WET
       ELR(4,1)=ELR(4,1)+ZET*COS(PHI)*SCTU*WET
       ELR(7,1)=ELR(7,1)+ZET**2*COS(PHI)*SCTU*WET
       ELR(8,1)=ELR(8,1)+ZET**3*COS(PHI)*SCTU*WET
       ELR(4,2)=ELR(4,2)+ZET*SIN(PHI)*SCTU*WET
       ELR(7,2)=ELR(7,2)+ZET**2*SIN(PHI)*SCTU*WET
       ELR(8,2)=ELR(8,2)+ZET**3*SIN(PHI)*SCTU*WET
       ELR(4,3)=ELR(4,3)+(P3*SCTU+PHIP*SCRU)*ZET*WET
       ELR(7,3)=ELR(7,3)+(P3*SCTU+PHIP*SCRU)*ZET**2*WET
       ELR(8,3)=ELR(8,3)+(P3*SCTU+PHIP*SCRU)*ZET**3*WET
       ELR(4,4)=ELR(4,4)+(SCTU+PHIP**2*SCRU)*ZET**2*WET
       ELR(5,4)=ELR(5,4)+2.*ZET**2*PHIP*SCRU*WET
       ELR(6,4)=ELR(6,4)+3.*ZET**3*PHIP*SCRU*WET
       ELR(7,4)=ELR(7,4)+(SCTU+PHIP**2*SCRU)*ZET**3*WET
       ELR(8,4)=ELR(8,4)+(SCTU+PHIP**2*SCRU)*ZET**4*WET
       ELR(7,5)=ELR(7,5)+2.*ZET**3*PHIP*SCRU*WET
       ELR(8,5)=ELR(8,5)+2.*ZET**4*PHIP*SCRU*WET
       ELR(7,6)=ELR(7,6)+3.*ZET**4*PHIP*SCRU*WET
       ELR(8,6)=ELR(8,6)+3.*ZET**5*PHIP*SCRU*WET
       ELR(7,7)=ELR(7,7)+(SCTU+PHIP**2*SCRU)*ZET**4*WET
       ELR(8,7)=ELR(8,7)+(SCTU+PHIP**2*SCRU)*ZET**5*WET
       ELR(8,8)=ELR(8,8)+(SCTU+PHIP**2*SCRU)*ZET**6*WET
  103  CONTINUE
       DO 5 I=1,7
       IP1=I+1
       DO 5 J=IP1,8
  5    ELR(I,J)=ELR(J,I)
       DO 6 I=1,8
       DO 6 J=1,8
       ELRR(I,J)=0.0
```

```
      DO 6 K=1,8                                                        QREM2530
6     ELRR(I,J)=ELRR(I,J)+ELR(I,K)*AA(NE,K,J)                           QREM2540
      DO 7 I=1,8                                                        QREM2550
      DO 7 J=1,8                                                        QREM2560
      ELRP(I,J)=0.0                                                     QREM2570
      DO 7 K=1,8                                                        QREM2580
7     ELRP(I,J)=ELRP(I,J)+AA(NE,K,I)*ELRR(K,J)                          QREM2590
      IF (YK(NE).EQ.0.0)  GO TO 503                                     QREM2600
          CALL ROTAT(3,ELRP,DUMMY,NE)                                   QREM2610
 503 CONTINUE                                                           QREM2620
16   CALL ASSEM(NE,ELRP,SPRIN)                                          QREM2630
 15   CONTINUE                                                          QREM2640
 4    IF(NBCOND .EQ. 0) RETURN                                          QREM2650
      DO 91 I=1,NBCOND                                                  QREM2660
      JT4=NOD2B(I)*4                                                    QREM2670
      JT4M3=JT4-3                                                       QREM2680
      JT4M2=JT4-2                                                       QREM2690
      JT4M1=JT4-1                                                       QREM2700
      CALL ERC(JT4M3,SPRIN,NI,ICOL)                                     QREM2710
      IF(NBC(I).EQ.1 .OR. NBC(I).EQ.2) CALL ERC(JT4M1,SPRIN,NI,ICOL)    QREM2720
      IF(NBC(I).EQ.2 .OR. NBC(I).EQ.3) CALL ERC(JT4M2,SPRIN,NI,ICOL)    QREM2730
 91   CONTINUE                                                          QREM2740
      RETURN                                                            QREM2750
     END                                                                QREM2760
```

```
      SUBROUTINE ROOT4(A,B,C,D,X,IER,IMAGN)                             ROOT0010
      IMPLICIT REAL*8(A-H,O-Z)                                          ROOT0020
      DIMENSION X(4),IMAGN(4)                                           ROOT0030
C                                                                       ROOT0040
C    FIND REAL ROOTS OF QUARTIC EQN. X**4+A*X**3+B*X**2+C*X+D=0         ROOT0050
C    IF IMAGN(I).EQ.0, THEN I-TH ROOT IS REAL.                          ROOT0060
C    IF IMAGN(I).EQ.1, THEN I-TH ROOT IS IMAGINARY AND IS SET EQUAL     ROOT0070
C    TO A REAL NUMBER OF ORDER 10**25.                                  ROOT0080
C                                                                       ROOT0090
      DO 5 I=1,4                                                        ROOT0100
    5 IMAGN(I)=0                                                        ROOT0110
C    DEFINE COEFS. OF RESOLVENT CUBIC                                   ROOT0120
      IER=0                                                             ROOT0130
      P=-B                                                              ROOT0140
      Q=A*C-4.0*D                                                       ROOT0150
      R=-A*A*D+4.0*B*D-C*C                                              ROOT0160
C    FIND ROOT, Y, OF RESOLVENT CUBIC                                   ROOT0170
      CALL CUBIC(P,Q,R,Y,IER)                                           ROOT0180
C    DEFINE R*R                                                         ROOT0190
      R=A*A/4.0-B+Y                                                     ROOT0200
C    IF R*R IS LESS THAN ZERO, CANNOT CONTINUE                          ROOT0210
      IF(R.GE.0.0)GO TO 10                                              ROOT0220
      IER=-1                                                            ROOT0230
      WRITE(6,200)                                                      ROOT0240
  200 FORMAT('0','R*R LESS THAN 0.0-- NO ROOTS FOUND FOR QUARTIC')      ROOT0250
      RETURN                                                            ROOT0260
C    DEFINE R                                                           ROOT0270
   10 R=DSQRT(R)                                                        ROOT0280
      IF(R.LT.1.0D-30) R=0.0                                            ROOT0290
C    DEFINE COEFS. E AND F (SQUARED)                                    ROOT0300
      IF(R.EQ.0.0)GO TO 20                                              ROOT0310
      C1=(4.0*A*B-8.0*C-A*A*A)/(4.0*R)                                  ROOT0320
      E=3.0*A*A/4.0-R*R-2.0*B                                           ROOT0330
      F=E-C1                                                            ROOT0340
      E=E+C1                                                            ROOT0350
      GO TO 30                                                          ROOT0360
```

```
C     FOR R=0.0
 20      C2=Y*Y-4.0*D
         IF(C2.GE.0.0)GO TO 25
         IER=-1
         WRITE(6,300)
300      FORMAT('0','Y*Y-4*D.LT.0.0--- NO ROOTS FOUND FOR QUARTIC')
 25      C2=DSQRT(C2)
         C2=2.0*C2
         E=3.0*A*A/4.0-2.0*B
         F=E-C2
         E=E+C2
C     IF EITHER E OR F (SQUARED) ARE NEGATIVE, IMAGINARY ROOTS WILL
C     RESULT.  SET THEM TO LARGE VALUES.
 30      CONTINUE
         IF(E.GE.0.0)GO TO 35
         E=1.0D50
         IMAGN(1)=1
         IMAGN(2)=1
 35      CONTINUE
         IF(F.GE.0.0)GO TO 40
         F=1.0D50
         IMAGN(3)=1
         IMAGN(4)=1
 40      CONTINUE
C     CALC. E AND F
         E=DSQRT(E)
         F=DSQRT(F)
C     CALC. THE FOUR ROOTS.
         X(1)=-A/4.0+R/2.0+E/2.0
         X(2)=-A/4.0+R/2.0-E/2.0
         X(3)=-A/4.0-R/2.0+F/2.0
         X(4)=-A/4.0-R/2.0-F/2.0
         RETURN
         END
```

```
      SUBROUTINE ROTAT(IND,ELM,ELV,IR)
C     THIS SUBROUTINE TRANSFORMS MATRICES FROM ELEMENT  SYSTEMS TO THE
C     GLOBAL SYSTEM AND VICE-VERSA.   IND = 1 FOR  GLOBAL VECTOR INTO
C     ELEMENT VECTOR, IND=2 FOR ELEMENT VECTOR INTO GLOBAL VECTOR, IND = 3
C     FOR ELEMENT MATRIX INTO GLOBAL SYSTEM
C     ELM IS THE MATRIX TO BE TRANSFORMED, ELV IS THE VECTOR TO BE
C     TRANSFORMED, WHILE IR IS THE ELEMENT NUMBER   YK,ROT,AND DROT USED
C     BELOW, INDICATE WHETHER A BRANCH OR A DISCONTINUITY IS BEING CON-
C     SIDERED AND WHAT THE ANGLE OF ROTATION IS.
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION ELM(8,8),ELV(8),TR(4,4),TRAN(8,8),WORK(8),ELRS(8,8)
      COMMON /BOUN/ YK(51),NBCONB,NBCB(7),NODBB(7),MK(51),ROT(5,2)
     @,DROT(50), NODP(6)
      COMMON /TAM/ MKF(51)
      COMMON /XD/ XDIST(6)
      COMMON /BR/ NVEC(51,2)
       COMMON /TAPE/ MREAD,MWRITE,MPUNCH
      COMMON /TIME/  IT
      SIN(Q)=DSIN(Q)
      COS(Q)=DCOS(Q)
      ATAN(Q)=DATAN(Q)
      ABS(Q)=DABS(Q)
      SQRT(Q)=DSQRT(Q)
      DO 1100 I=1,4
      DO 1100 J = 1,4
 1100 TR(I,J)  = 0.0
      TR(3,3)  = 1.0
      TR(4,4)  = 1.0
      MOP = MKF(IR)  -1
      DO 1110 J = 1,8
      DO 1110 K = 1,8
 1110 TRAN(J,K)  = 0.0
      DO 1115 J= 1,8
 1115 TRAN(J,J)  = 1.0
      ANGK= DROT(IR)
      IF(YK(IR).EQ.1.0.OR.YK(IR).EQ.3.0) ANGK=ROT(MOP,2)
```

```
      TR(1,1)  = DCOS(ANGK)                                          ROTA0370
      TR(1,2)  = DSIN(ANGK)                                          ROTA0380
      TR(2,1)  = -DSIN(ANGK)                                         ROTA0390
      TR(2,2)  = DCOS(ANGK)                                          ROTA0400
      IF(YK(IR).EQ.2.0)  GO TO  1120                                 ROTA0410
      IF  (ROT(MOP,1).NE.0.0)  GO TO  1120                           ROTA0420
      DO  1130  J  = 5,8                                             ROTA0430
      DO  1130  K  = 5,8                                             ROTA0440
 1130 TRAN(J,K)  = TR(J-4,K-4)                                       ROTA0450
      TRAN(5,7)  = XDIST(MOP)* TR(1,1)                               ROTA0460
      TRAN(6,7)  = XDIST(MOP)  * TR(2,1)                             ROTA0470
      GOTO  1150                                                     ROTA0480
 1120 DO  1140  J  = 1,4                                             ROTA0490
      DO  1140  K  = 1,4                                             ROTA0500
 1140 TRAN(J,K)  = TR(J,K)                                           ROTA0510
      IF(YK(IR).EQ.2.0)  GO TO  1150                                 ROTA0520
      TRAN(1,3)  = XDIST(MOP)* TR(1,1)                               ROTA0530
      TRAN(2,3)  = XDIST(MOP)  * TR(2,1)                             ROTA0540
 1150 CONTINUE                                                       ROTA0550
      IF(YK(IR).NE.3.0)  GO TO 3000                                  ROTA0560
      ANGZ= DROT(IR)                                                 ROTA0570
      TRAN(1,1)  =   DCOS(ANGZ)                                      ROTA0580
      TRAN(1,2)  = DSIN(ANGZ)                                        ROTA0590
      TRAN(2,1)= -DSIN(ANGZ)                                         ROTA0600
      TRAN(2,2)  = DCOS(ANGZ)                                        ROTA0610
 3000 CONTINUE                                                       ROTA0620
      IF(IND.EQ.3)  GOTO 800                                         ROTA0630
      IF(IND.EQ.1)   GOTO 100                                        ROTA0640
      DO 210 I=1,8                                                   ROTA0650
      DO 210 J=1,8                                                   ROTA0660
  210 ELRR(I,J)  = TRAN(J,I)                                         ROTA0670
      DO 215 I=1,8                                                   ROTA0680
      DO 215 J= 1,8                                                  ROTA0690
  215 TRAN(I,J)  = ELRR(I,J)                                         ROTA0700
  100 CONTINUE                                                       ROTA0710
  110 CONTINUE                                                       ROTA0720
```

```
      DO 1160 I = 1,8                                            ROTA0730
      WORK(I) = 0.0                                              ROTA0740
      DO 1160 J = 1,8                                            ROTA0750
 1160 WORK(I) = WORK(I) + TRAN(I,J) * ELV(J)                     ROTA0760
      DO 1170 I= 1,8                                             ROTA0770
 1170 ELV(I) = WORK(I)                                           ROTA0780
      RETURN                                                     ROTA0790
  800 CONTINUE                                                   ROTA0800
      DO 2160 I = 1,8                                            ROTA0810
      DO 2160 J = 1,8                                            ROTA0820
      ELRR(I,J) = 0.0                                            ROTA0830
      DO 2160 K = 1,8                                            ROTA0840
 2160 ELRR(I,J) = ELRR(I,J) + ELM(I,K)*TRAN(K,J)                 ROTA0850
      DO 2170 I= 1,8                                             ROTA0860
      DO 2170 J= 1,8                                             ROTA0870
      ELM(I,J) = 0.0                                             ROTA0880
      DO 2170 K = 1,8                                            ROTA0890
 2170 ELM(I,J) = ELM(I,J) + TRAN(K,I) * ELRR(K,J)                ROTA0900
      RETURN                                                     ROTA0910
      END                                                        ROTA0920
```

```
      SUBROUTINE STRESS
      IMPLICIT REAL*8(A-H,O-Z)
C      TO EVALUATE GENERALIZED NODAL LOAD VECTOR DUE TO LARGE DEFLECTION
C      AND PLASTIC-PLASTIC STRAIN
       DIMENSION ELPP(8),EEPS(3),CEPS(3,3),BINPW(3),BIMPW(3),HWB(3,3),
     *PN(8),PM(8),INL(8)
      DIMENSION DELM(8),DISM(8), DUMMY(8,8)
      COMMON /BCUN/ YK(51),NBCONB,NBCB(7),NODBB(7),MK(51),ROT(5,2)
     @,DROT(50), NODE(6)
       COMMON /VQ/ PLVA(205),DISP(205),DELD(205),SNS(50,3,6,5),
     *EINP(50,3),EIMP(50,3),TDISP(205),TU(205),TW(205),
     *CCIY(205),CCIZ(205),DELTAT
      COMMON /TAM/ MKE(51)
      COMMON/PG/Y(51),Z(51),ANG(51),H(51),EXANG,NS,IK,NOGA,NFL,NI,
     * ICOL(205),NBCOND,NPC(7),NODEB(7)
      COMMON/MAT/ DENS(6),B(6),YOUNG(6),DS(6),SNO(6,5),NSPL(6),P(6),
     * EPS(6,5),SIG(6,5), EPLN(6)
      COMMON /HM/ C5,C6,ASPL(50,3,6,5),GZETA(50,3,6)
       COMMON /FA/ BFP(50,3,3,8),AL(50),AXG(3),AWG(3)
      COMMON /XD/ XDIST(6)
      COMMON /BR/ NVFC(51,2)
       COMMON /TAPE/ MREAD,MWRITE,MPUNCH
      SIN(Q)=DSIN(Q)
      COS(Q)=DCOS(Q)
      ATAN(Q)=DATAN(Q)
      ABS(Q)=DABS(Q)
      SQRT(Q)=DSQRT(Q)
      MOP=0
       DO 502 IR=1,IK
      K1= NVFC(IR,1)
      K2= NVFC(IR,2)
      DO 8000 K=1,8
      INDEX= (K1-1)*4+K
      IF(K.GT.4)  INDEX=(K2-1)*4+K-4
      DELM(K)=DELD(INDEX)
      DISM(K) = DISP(INDEX)
```

```
9000 CONTINUE
     IF(YK(IR).EQ.0.0) GOTO 901
          CALL ROTAT(1,DUMMY,DELM,IR)
          CALL ROTAT(1,DUMMY,DISM,IR)
 901 CONTINUE
     M= MKF(IR)
      DO 503 J=1,NOGA
      BINP(IR,J)=0.
      BIMP(IR,J)=0.
202   DO 402 I=1,3
      BEPS(I)=0.
      DO 402 K=1,8
 402 BEPS(I)=BEPS(I)+BEP(IR,J,I,K)*DELM(K)
      CEPS(J,1)=0.0
      CEPS(J,2)=0.0
      DO 403 K=1,8
     CEPS(J,1)=CEPS(J,1)+BEP(IR,J,1,K)*DISM(K)
 403 CEPS(J,2)=CEPS(J,2)+BEP(IR,J,2,K)*DISM(K)
205   FARE=BEPS(1)+CEPS(J,2)*BEPS(2)-BEPS(2)**2/2.
    *+CEPS(J,1)*BEPS(1)-BEPS(1)**2/2.
      PCUR=BEPS(3)
      DO 151 K=1,NPL
      BFNP=0.
      BEPX=FARE+GZETA(IR,J,K)*PCUR
     IF(DS(M).EQ.0.0) GO TO 5100
     C5= 1.0/P(M)
     C6 = 1.0/ DS(M)/DELTAT
     RFACTR= 1.0 + (C6*ABS(BEPX))**C5
5100 N= NSFL(M)
     DO 35 L=1,N
     SNS(IR,J,K,L) = SNS(IR,J,K,L)+YOUNG(M)*BEPX
     IF(DS(M).EQ.0.0) GO TO 255
     IF (SNS(IR,J,K,L)-SNO(M,L)) 30,301,31
  31 SNY=SNO(M,L)*RFACTR
      IF(SNS(IR,J,K,L)-SNY) 301,301,20
20    SNS(IR,J,K,L)=SNY
```

```
      GO TO 301                                                         STRS0730
   30 IF (SNS(IR,J,K,L)+SNO(M,L)) 92,301,301                            STRS0740
   92 SNY= SNO(M,L)*RFACTR                                              STRS0750
      IF(SNS(IR,J,K,L)+SNY) 40, 301,301                                 STRS0760
   40 SNS(IR,J,K,L)=-SNY                                                STRS0770
      GO TO 301                                                         STRS0780
  255 IF(SNS(IR,J,K,L)-SNO(M,L)) 18,301,17                              STRS0790
   17 SNS(IR,J,K,L) = SNO(M,L)                                          STRS0800
      GO TO 301                                                         STRS0810
   18 IF(SNS(IR,J,K,L)+SNO(M,L)) 19,301,301                             STRS0820
   19 SNS(IR,J,K,L) = -SNO(M,L)                                         STRS0830
  301 BFNP=BFNP+SNS(IR,J,K,L)*ASPL(IR,J,K,L)                            STRS0840
   35 CONTINUE                                                          STRS0850
      BINP(IR,J)=BINP(IR,J)+BFNP                                        STRS0860
      BIMP(IR,J)=BIMP(IR,J)+BFNP*GZETA(IR,J,K)                          STRS0870
  151 CONTINUE                                                          STRS0880
  503 CONTINUE                                                          STRS0890
  107 DO 101 J=1,NOGA                                                   STRS0900
      HWB(J,1)=CEPS(J,1)*AWG(J)*BINP(IR,J)*AL(IR)                       STRS0910
      HWB(J,2)=CEPS(J,2)*AWG(J)*BINP(IR,J)*AL(IR)                       STRS0920
      BINPW(J)=BINP(IR,J)*AWG(J)*AL(IR)                                 STRS0930
      BIMPW(J)=BIMP(IR,J)*AWG(J)*AL(IR)                                 STRS0940
  101  CONTINUE                                                         STRS0950
      DO 102 I=1,8                                                      STRS0960
      PN(I)=0.                                                          STRS0970
      PM(I)=0.                                                          STRS0980
      HNL(I)=0.0                                                        STRS0990
      DO 102 J=1,NOGA                                                   STRS1000
      PN(I)=PN(I)+BEP(IR,J,1,I)*BINPW(J)                                STRS1010
      PM(I)=PM(I)+BEP(IR,J,3,I)*BIMPW(J)                                STRS1020
  102 HNL(I)=HNL(I)+BEP(IR,J,2,I)*HWB(J,2)                              STRS1030
     *+BEP(IR,J,1,I)*HWB(J,1)                                           STRS1040
  200 DO 105 I=1,8                                                      STRS1050
  105 ELPP(I)=PN(I)+PM(I)+HNL(I)                                        STRS1060
      IF( YK(IR).EQ.0.0) GO TO 502                                      STRS1070
           CALL ROTAT(2,DUMMY,ELPP,IR)                                  STRS1080
```

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```
502   CALL ASSLP(IR,IK,RLFP,FLVA,EXANG)                                      STRS1090
       RETURN                                                                STRS1100
      END                                                                    STRS1110
```

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```
      SUBROUTINE TCON (TY,TZ,VY,VZ,FCGU,FCGW,VELPU,VELPW,DELTP,NET,TMIN,
     2LNTMIN,RPC,NPTS,IFLAG,H,FH,NP,AY,AZ)
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION    Y(4), IMAGN(4)
      DIMENSION AY(51),AZ(51)
      DIMENSION TY(1),TZ(1),VY(1),VZ(1),PCGU(1),PCGW(1),VELPU(1),
     2VELPW(1),IFLAG(51,6),H(1),FH(1)
       COMMON /TAPE/ MREAD,MWRITE,MPUNCH
      COMMON /HIT/ TNJ(6),MIRP
      COMMON/BN/LMT(51)
      COMMON/BR/NVEC(51,2)
C
C    ROUTINE TO CALCULATE THE TIME OF CONTACT OF FRAGMENT ON RING.
C    INITIALIZE MIN. TIME AND ELEM. NO..
      TMIN= DELTR  * 1.1
      LNTMIN=0
      EPS= DELTR* 1.0D-03
      EPSN =  - EPS
      TEN= 10.0D+00
      NUM= -6
C
C    LOOP OVER ALL ELEMS.(ASSUME CLOCKWISE NUMBERING OF NODES)
      DO 100 IP=1,NF
      VEPUT= VELFU(IP)*TNJ(IF)
      VFPWT= VELFW(IP)*TNJ(IF)
      L=1
      DO 100 LNUM=1,NET
C
C    IF THIS ELEMENT IS A BRANCH ELEM. FOR WHICH NO IMPACT
C    CAN OCCUR, SKIP TO NEXT ELEMENT.
      IF(LNUM.NE.LMT(L))GO TO 20
      L=L+1
      GO TO 100
C
C    DEFINE CA,CB,.....
 20   I1= NVEC(LNUM,1)
```

```
      I2= NVEC(LNUM,2)
      TTT=(H(I1)+H(I2))/2.0
      DC=(TTT+FH(IF))/2.0
      CA=AZ(I1)*(AY(I1)+AY(I2))-AY(I1)*(AZ(I2)+AZ(I1))
      CB=(VY(I1)-VEFUT)*(AZ(I1)-AZ(I2))+(VZ(I1)-VZ(I2))*AY(I1)+
     @(VEFWT-VZ(I1))*(AY(I1)-AY(I2))+(VY(I2)-VY(I1))*AZ(I1)
      CC= (FCGU(IF)-TY(I1))*(AZ(I2)-AZ(I1))+(VEFUT-VY(I1))*(VZ(I2)-
     @VZ(I1))+(TZ(I1)-TZ(I2))*AY(I1)+(TZ(I1)-FCGW(IF))*(AY(I2)-AY(I1))+
     @(VZ(I1)-VEFWT)*(VY(I2)-VY(I1))+(TY(I2)-TY(I1))*AZ(I1)
      CD= (FCGU(IF)-TY(I1))*(VZ(I2)-VZ(I1))+(VEFUT-VY(I1))*(TZ(I2)-
     @TZ(I1))+(TZ(I1)-FCGW(IF))*(VY(I2)-VY(I1))+(VZ(I1)-VEFWT)*
     @(TY(I2)-TY(I1))
      CE= (TZ(I1)-TZ(I2))*(TY(I1)-FCGU(IF))-(TY(I1)-TY(I2))*
     @(TZ(I1)-FCGW(IF))
      CF= (AY(I2)-AY(I1))**2+(AZ(I2)-AZ(I1))**2
      CG=    ((AY(I2)-AY(I1))*(VY(I2)-VY(I1))+(AZ(I2)-AZ(I1))*
     @(VZ(I2)-VZ(I1)))*2.0
      CH=(VY(I2)-VY(I1))**2+(VZ(I2)-VZ(I1))**2+    ((AY(I2)-AY(I1))*
     @(TY(I2)-TY(I1))+(AZ(I2)-AZ(I1))*(TZ(I2)-TZ(I1)))*2.0
      CI=2.0*((TY(I2)-TY(I1))*(VY(I2)-VY(I1))+(TZ(I2)-TZ(I1))*
     @(VZ(I2)-VZ(I1)))
      CJ= (TY(I2)-TY(I1))**2 + (TZ(I2)-TZ(I1))**2
      CJ= DSQRT(CJ)
      A=CA-DC*((3.0/16.0)*CI**2*CH/CJ**5-5.0*CI**4/(128.0*CJ**7)
     @-(CH**2+6.0*CI*CG)/(8.0*CJ**3)+CF/(2.0*CJ))
      B= CB-DC*(CI**3/(16.0*CJ**5)-CI*CH/(4.0*CJ**3)+CG/(2.0*CJ))
      C=CC-DC*(CH/(2.0*CJ)-CI**2/(8.0*CJ**3))
      D= CD-DC*CI/(2.0*CJ)
      E= CE-DC*CJ
      TM = 0.0
      IF(E.LT.0.0.AND.IFLAG(LNUM,IF).EQ.2) E= 0.0
      IF( E.EQ.0.0) GOTO 30
      AP= D/E
      BP= C/E
      CP= B/E
      DP= A/E
```

```
      RTLED= 1.0/(DELTR*1.1)                                            TCON0730
      RT2=RTLED*RTLED                                                   TCONC740
      RT3=RT2*RTLED                                                     TCON0750
      RT4= RT3*RTLED                                                    TCON0760
      DB=RT4+AP*RT3+BP*RT2+CP*RTLED+DP                                  TCON0770
      IF(DB.LT.0.0) GOTO 25                                             TCON0780
      CB= 4.0*RT3+3.0*RT2*AP+2.0*RTLED*BP+CP                            TCON0790
      IF(CB.LT.0.0) GOTO 25                                             TCON0800
      BB= 6.0*RT2+3.0*RTLED*AP+BP                                       TCON0810
      IF(BB.LT.0.0) GOTO 25                                             TCON0820
      AB= 4.0*RTLED+AP                                                  TCON0830
      IF(AB.LT.0.0) GOTO 25                                             TCON0840
      B1= BB-CB/AB                                                      TCON0850
      IF(B1.LE.0.0) GOTO 25                                             TCON0860
      C1= CB-AB*DB/B1                                                   TCON0870
      IF(C1.LE.0.0) GOTO 25                                             TCON0880
      GOTO 100                                                          TCON0890
   25 CONTINUE                                                          TCON0900
      AP=AP*TEN**NUM                                                    TCON0910
      BP= BP*TEN**(NUM*2)                                               TCON0920
      CP= CP*TEN**(NUM*3)                                               TCON0930
      DP= DP*TEN**(NUM*4)                                               TCON0940
          CALL ROOT4(AP,BP,CP,DP,X,IER,IMAGN)                           TCON0950
      TM= 1000.0                                                        TCON0960
      IF(IER.NE.0) GOTO 100                                             TCON0970
      DO 40 I= 1,4                                                      TCON0980
      IF(IMAGN(I).EQ.1) GOTO 40                                         TCON0990
       IF(X(I).EQ.0.0) GOTO 40                                          TCON1000
       T= TEN**NUM/X(I)                                                 TCON1010
      IF(T.GT.EPSN.AND.T.LT.0.0)  T=0.0                                 TCON1020
      IF(T.LT.0.0) T= 1.0D+25                                           TCON1030
      IF(T.LT.EPS.AND.IFLAG(LNUM,IF).EQ.1) GOTO 40                      TCON1040
      IF(T.LT.TM) TM=T                                                  TCON1050
   40 CONTINUE                                                          TCON1060
      XY=1.1* DELTR                                                     TCON1070
      IF(TM.LE.XY) IFLAG(LNUM,IF)= 2                                    TCON1080
```

```
      IF(TM.GT.TMIN) GOTO 100
   30 CONTINUE
      IF(TM.LT.EPS.AND.IFLAG(LNUM,IF).EQ.1) GOTO 100
      IFLAG(LNUM,IF) = 2
C
C    CHECK FOR CONTACT ON ELEMENT.
C    UPDATE POSITIONS (FOR THIS ELEM.) TO TM
      Y1= TY(I1)+TM*VY(I1)+ AY(I1)*TM**2
      Y2= TY(I2)+TM*VY(I2)+ AY(I2)*TM**2
      Z1=TZ(I1)+TM*VZ(I1)  +AZ(I1)*TM**2
      Z2=TZ(I2)+TM*VZ(I2)  +AZ(I2)*TM**2
      YP=PCGU(IF)+TM*VFPUT
      ZP=PCGW(IP)+TM*VEPWT
C
C    MAGNITUDE OF VECTORS P1 AND P2
      P1=DSQRT((Y2-Y1)**2+(Z2-Z1)**2)
      P2=DSQRT((YF-Y1)**2+(ZP-Z1)**2)
C
C    DEFINE P2*COS(THETA)
      P2CT=((Y2-Y1)*(YF-Y1)+(Z2-Z1)*(ZP-Z1))/P1
C
C    IF P2*COS(THETA) IS LESS THAN ZERO OR GREATER THAN P1, CONTACT
C    HAS OCCURED OUTSIDE OF ELEMENT LIMITS.  GO TO NEXT ELEM..
      IF(P2CT.LT.0.0.OR.P2CT.GT.P1)GO TO 100
C
C    OTHERWISE, CONTACT HAS OCCURED.  UPDATE TMIN, LNTMIN, AND
C    RPC (RELATIVE POSITION OF CONTACT---FRACTION OF ELEM LENGTH FROM
C    NODE 1)
      TMIN=TM
      LNTMIN=LNUM
      NPTMIN=IF
      IF(TMIN.GT.DELTR) TMIN= DELTR
      RPC=P2CT/P1
C
C    LOOP TO NEXT ELEMENT
  100 CONTINUE
```

```
      XY= 0.999D+00 * DELTR                                             TCON1450
      IF(TMIN.GT.XY) TMIN = DELTR                                       TCON1460
C                                                                       TCON1470
C   SET FLAG FOR THIS CONTACT TO 1                                      TCON1480
      IFLAG(LNTMIN,NPTMIN)=1                                            TCON1490
C                                                                       TCON1500
C   IF NODAL IMPACT, SET FLAG FOR ADJACENT ELEMENT                      TCON1510
      IF(RPC.GT.0.01.AND.RPC.LT.0.99)RETURN                             TCON1520
      IF(RPC.LE.0.01) NN=NVEC(LNTMIN,1)                                 TCON1530
      IF(RPC.GE.0.99) NN=NVEC(LNTMIN,2)                                 TCON1540
      DO 120 I=1,2                                                      TCON1550
      DO 120 J=1,NPT                                                    TCON1560
      IF(NVEC(J,I).EQ.NN)IFLAG(J, NPTMIN)=1                             TCON1570
  120 CONTINUE                                                          TCON1580
      RETURN                                                            TCON1590
      END                                                               TCON1600
```

```
      SUBROUTINE TSTEP(                             KROW,NDEX,NIRREG,DELTAT)
C      ***** JET 3C *****
C      TO FIND DELTAT IF IT IS NOT SPECIFIED
      IMPLICIT REAL*8(A-H,O-Z)
       DIMENSION   AMKE(205),       TRIAL(205),VMULT(205),VECTR(205),
     *KROW(1),NDEX(1)
      COMMON/ABC/RMX(51),RWORK,CINEY(205)
      COMMON/RG/Y(51),Z(51),ANG(51),H(51),EXANG,NS,IK,NOGA,NFL,NI,
     * ICOL(205),NBCOND,NBC(7),NODEB(7)
      COMMON/MAT/ DENS(6),B(6),YOUNG(6),DS(6),SYO(6,5),NSPL(6),P(6),
     * EPS(6,5),SIG(6,5), EPLN(6)
      COMMON /LEFT/ RMASS(51)
      COMMON /ST/ STIFK(2060)
       COMMON /TAPE/ MREAD,MWRITE,MPUNCH
      SIN(Q)=DSIN(Q)
      COS(Q)=DCOS(Q)
      ATAN(Q)=DATAN(Q)
      ABS(Q)=DABS(Q)
      SQRT(Q)=DSQRT(Q)
      INT(Q)  = IDINT(Q)
      MREAD=5
      MWRITE=6
      IMX=IK+1
      IF(EXANG.NE.360.)GO TO 1
      DO 5 I=1,IK
      AMKE(I*4-3)=RMASS(I)
      AMKE(I*4-2)=RMASS(I)
      AMKE(I*4-1)=RMX(I)
    5 AMKE(I*4)=RMX(I)
      AMKE(IMX*4-3)=RMASS(1)
      AMKE(IMX*4-2)=RMASS(1)
      AMKE(IMX*4-1)=RMX(1)
      AMKE(IMX*4)=RMX(1)
      GO TO 700
    1 DO 20 I=1,IMX
      AMKE(I*4-3)=RMASS(I)
```

```
      AMKE(I*4-2)=RMASS(I)                                              TSTP0370
      AMKE(I*4-1)=RMX(I)                                                TSTP0380
   20 AMKE(I*4)=RMX(I)                                                  TSTP0390
  700 DO 3 K=1,NI                                                       TSTP0400
    3 TRIAL(K)=1.0                                                      TSTP0410
      IF(NBCOND .EQ. 0) GO TO 90                                        TSTP0420
      DO 91 I=1,NBCOND                                                  TSTP0430
      JT4=NODEB(I)*4                                                    TSTP0440
      JT4M3=JT4-3                                                       TSTP0450
      JT4M2=JT4-2                                                       TSTP0460
      JT4M1=JT4-1                                                       TSTP0470
      CALL ERC(JT4M3,STIFK,NI,ICOL)                                     TSTP0480
      TRIAL(JT4M3)=0.0                                                  TSTP0490
      IF(NBC(I).EQ.1 .OR. NBC(I).EQ.2) CALL ERC(JT4M1,STIFK,NI,ICOL)    TSTP0500
      IF(NBC(I).EQ.2 .OR. NBC(I).EQ.3) CALL ERC(JT4M2,STIFK,NI,ICOL)    TSTP0510
      IF(NBC(I).EQ.1 .OR. NBC(I).EQ.2) TRIAL(JT4M1)=0.0                 TSTP0520
      IF(NBC(I).EQ.2 .OR. NBC(I).EQ.3) TRIAL(JT4M2)=0.0                 TSTP0530
   91 CONTINUE                                                          TSTP0540
   90 MRANK=NI                                                          TSTP0550
      BONE=0.                                                           TSTP0560
      EPSLN=1.0E-07                                                     TSTP0570
    2 BOLD=1.0                                                          TSTP0580
      DO 14 IKK=1,4                                                     TSTP0590
      DO 12 ILL=1,50                                                    TSTP0600
      DO 4 I=1,MRANK                                                    TSTP0610
    4 VMULT(I)=0.0                                                      TSTP0620
      CALL OMULT(STIFK,TRIAL,ICOL,NI,VMULT,KROW,NDEX,NIRREG)            TSTP0630
  310 DO 320 JT= 1,NI                                                   TSTP0640
  320 VECTR(JT) = VMULT(JT)/AMKE(JT)                                    TSTP0650
      BNEW=-1.                                                          TSTP0660
      DO 6 K=1,MRANK                                                    TSTP0670
      IF(BNEW- ABS(VECTR(K)))60,60,6                                    TSTP0680
   60 BNEW= ABS(VECTR(K))                                               TSTP0690
    6 CONTINUE                                                          TSTP0700
      DO 7 K=1,MRANK                                                    TSTP0710
      IF(BNEW- ABS(VECTR(K)))7,8,7                                      TSTP0720
```

```
    7 CONTINUE
    8 MROW=K
      BNEW=VECTR(K)
      DO 9 K=1,MRANK
    9 TRIAL(K)=VECTR(K)/BNEW
      IF( ABS(BNEW/BOLD-1.0)-EPSLN) 15,15,10
C     ITERATION
   10 BKTH=BOLD
      BOLD=BNEW
   12 CONTINUE
      EPSLN=EPSLN*10.
   14 CONTINUE
C     NOT CONVERGING AFTER IL*IK ITERATIONS
      EPSLN=1.0
      BONE=BNEW
      GO TO 32
C     EIGEN VALUE FOUND
   15 BONE=BNEW
   32 WRITE(MWRITE,24) (TRIAL(J),J=1,NI)
   24 FORMAT(/,'     EIGEN VECTOR OF HIGHEST MODE',/,18X,'V',14X,'W',13X
     *,'PSI',12X,'CHI',/,(11X,4E15.6))
      FREQ= SQRT(BONE)
      FACTCL=0.8
      DELTAN=FACTCL*2./FREQ
      WRITE(MWRITE,25)FREQ
   25 FORMAT(/,'     HIGHEST NATURAL FREQUENCY (RAD/SEC) =',D25.16)
      WRITE(MWRITE,31) DELTAN
   31 FORMAT('0THE COMPLETE VALUE OF THE MAX  DELTAT =', D25.16)
      MP= 0
   30 DELTAN= DELTAN*10.0
      MP = MP+1
      IF(DELTAN.LT.10.0) GO TO 30
      DELTAN= INT(DELTAN) *10.0**(-MP)
      IF(DELTAT.GT.DELTAN)   DELTAT = DELTAN
      IF(DELTAT.EQ.0.0)  DELTAT = DELTAN
      WRITE(MWRITE,28) DELTAN
```

```
28 FORMAT('0DELTAT SHOULD EQUAL:',5X,D13.6)                    TSTP1090
   WRITE(MWRITE,33) DELTAT                                      TSTP1100
33 FORMAT(' THE VALUE OF DELTAT USED IN THE PROGRAM IS:',D15.6) TSTP1110
   RETURN                                                       TSTP1120
   END                                                          TSTP1130
```

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```
      SUBROUTINE UPDATE(SIGN,TU,TW,VY,VZ,TPCGU,TPCGW,TALPA,VELPU,VELPW, UPDA0010
     2VELPA,DELTR,IKK,NF,ICP,AY,AZ)                                     UPDA0020
      IMPLICIT REAL*8(A-H,O-Z)                                          UPDA0030
      DIMENSION AY(51),AZ(51)                                           UPDA0040
      DIMENSION TU(1),TW(1),VY(1),VZ(1),TPCGU(1),TPCGW(1),TALPA(1),     UPDA0050
     2VELPU(1),VELPW(1),VELPA(1)                                        UPDA0060
      COMMON /HIT/ TNJ(6),MIMP                                          UPDA0070
C    UPDATE NODAL POSITIONS                                             UPDA0080
      DO 10 I=1,IKK                                                     UPDA0090
      TU(I)= TU(I)+SIGN*(VY(I)*DELTR+AY(I)*DELTR**2)                    UPDA0100
      TW(I)= TW(I)+ SIGN*(VZ(I)*DELTR+AZ(I)*DELTR**2)                   UPDA0110
   10 CONTINUE                                                          UPDA0120
      IF(ICP.LE.0)GO TO 20                                              UPDA0130
      TU(IKK+1)=TU(1)                                                   UPDA0140
      TW(IKK+1)=TW(1)                                                   UPDA0150
C    UPDATE FRAGMENT POSITION                                           UPDA0160
 20   DO 30 I=1,NF                                                      UPDA0170
      TPCGU(I)= TPCGU(I)+VELPU(I)*DELTR*SIGN*TNJ(I)                     UPDA0180
      TPCGW(I)= TPCGW(I)+VELPW(I)*DELTR*SIGN*TNJ(I)                     UPDA0190
   30 TALPA(I)=TALPA(I) +VELPA(I)*DELTR*SIGN*TNJ(I)                     UPDA0200
      RETURN                                                            UPDA0210
      END                                                               UPDA0220
```

SECTION 6

ILLUSTRATIVE EXAMPLES

The following two examples are presented to assist the user in checking the adaptation of CIVM-JET 4B to his computer facility.

6.1 A Variable-Thickness, Partial Ring -- Includes Branches, Slope Discontinuities, and an Elastic Foundation

6.1.1 Problem Description

The geometry of the main structure, as shown in Fig. 9, is a partial ring composed of an initially-straight portion and a circular portion. The straight section is 10.0 in long, 1.5 in wide, and varies linearly in thickness from 0.3 in at its pinned end to 0.1 in where it joins the circular portion. The circular section has a 5.0 in mean radius, a 1.5 in width, a 0.1 in uniform thickness, and consists of a 60° arc. The partial ring is supported by a pinned joint at its left-hand end, a branch connected at the straight-circular junction, and an elastic foundation located as depicted in Fig. 9a. This foundation consists of arbitrarily chosen normal k_N and tangential k_T stiffness equal to 1500 psi and 3000 psi, respectively.

The "main structure" of the partial ring is called substructure one (1) and is assumed to consist of aluminum material with a yield stress of 46,000 psi, an elastic modulus of 10^7 psi, and is represented by a two-mechanical-sublayer model defined by the following stress-strain (σ, ε) pairs: σ_1, ε_1 = 46,000 psi, .0046 and σ_2, ε_2 = 58,000 psi, 0.18000. The strain-rate constants were chosen to be D = 6500 sec^{-1} and P = 4. The mass density is 0.25×10^{-3} $(lb\text{-}sec^2)/in^4$.

The branch (termed substructure 2) is a steel structure 1.0 in wide, 2.23607 in long, and has a constant thickness of 0.4 in. The branch has a slope discontinuity between its two equal-length elements. The branch attaches to the outer surface of the main structure at the eleventh node of the ring and is clamped at its other end. The branch material is represented by a three-mechanical-sublayer model defined by σ_1, ε_1 = 80,950 psi, .00279; σ_2, ε_2 = 105,300 psi, .02250; and σ_3, ε_3 = 121,000 psi, .20000 (with an elastic modulus of 29 x 10^6 psi and a yield stress of 80,950 psi). The strain rate constants for the branch are D = 40.4 sec^{-1} and P = 5, with a mass density of 0.733085 x 10^{-3} $(lb\text{-}sec^2)/in^4$.

The variable-thickness straight portion of the structure is modeled by 10 equal-length finite elements; 6 equal-arc finite elements represent the constant thickness curved section; and 2 equal-length elements represent the constant thickness branch. This makes a total of 18 finite elements used for the entire structure.

The elements of the main structure are initially numbered consecutively from 1 to 16, and the branch elements are initially numbered from 1 to 2; this is depicted in Fig. 9b. The program will then renumber the elements from left to right to include the branch elements in the global system; the resulting renumbering is shown in Fig. 9c.

The attacking fragment has the following parameters (see Fig. 9a): radius r_f = 0.5 in, mass m_f = .385610 x 10^{-3} $(lb\text{-}sec^2/in)$; mass moment of inertial I_f = 0.482014 x 10^{-4} $(lb\text{-}sec^2\text{-}in)$; initial translational velocity components: $\dot{Y}_f$ = 2607.96 in/sec, $\dot{Z}_f$ = 1482.75 in/sec; initial rotational velocity $\dot{\theta}_f$ = 0.0; initial C.G. position Y_{CG} = 6.0 in, Z_{CG} = -2.0 in. The value of the coefficient of restitution, e, is set at 1.0 to represent a perfectly-elastic impact reaction, and the coefficient of friction is set to 0.0.

The strain is to be calculated at each of the three spanwise Gaussian stations and each node of the main structure and the branch. Also, 3 additional points at which strain predictions are desired are requested. Two of these are on main structural elements 9 and 11; the point on element 9 is located near the point of first impact and the point on element 11 is located near the branch connection ($\bar{s}$ coordinates 0.53 and 0.05, respectively). The additional strain point on the branch is located at $\bar{s}$ = 0.50 of the first element. This corresponds to the same location as the second Gaussian station on this element. The strains should be exactly the same at this point since both the Gaussian station and the additional point are at the same physical location.

The CIVM-JET 4B program will be used to calculate the structural response of the ring and the motion of the fragment, using a time step of 1 microsecond. Printout of structural responses and fragment position data are desired at intervals of every 40 cycles until 600 cycles have been completed.

6.1.2 Input Data

The values to be punched on the data cards are as follows:

FORMAT

Card 1 — 3D15.6

E(1) = 0.150000D+01
DENS(1) = 0.250000D-03
EXANG = 0.360000D+02 (partial ring)
(arbitrary value; EXANG ≠ 360.0 for partial ring)

Card 2 — 8I5,D15.6

IK = 16
NOGA = 3
NFL = 4
NSFL(1) = 2
MM = 1580
M1 = 780
M2 = 40
NF = 1
TIMF = 0.158000D-02

Card 3A — 4D15.6

Y(1) = 0.0
Z(1) = 0.0
ANG(1) = 0.0
H(1) = 0.3
.
.
.
.
.

Additional cards are provided until all 17 nodal stations of the main structure are described.

Y(17) = 0.143301D+02

Z(17) = -0.250000D+01

ANG(17) = -0.600000D+02

H(17) = 0.100000D+00

Card 4A — I5

ND15 = 0

There are no slope discontinuities on the main structure; skip to Card 5.

Card 5 — I5

NBR = 1

Card 5A — I5, 4D15.6

NSFL(2) = 3

B(2) = 0.100000D+01

DENS(2) = 0.733085D-03

DS(2) = 0.404000D+02

P(2) = 0.500000D+01

Card 5AA — 4D15.6

EPS(1,2) = 0.279000D-02

SIG(1,2) = 0.809500D+05

EPS(2,2) = 0.225000D-01

SIG(2,2) = 0.105300D+06

EPS(3,2) = 0.200000D+00

SIG(3,2) = 0.121000D+06

Card 5B — 4I5

NELT(1) = 2

NODP(1) = 11

LHIT(1) = 0

LATT(1) = 1

4D15.6

Card 5BA

YB(1,1) = 0.105000D+02

ZB(1,1) = 0.100000D+01

ANB(1,1) = 0.634349D+02

HB(1,1) = 0.400000D+00

Additional cards 5BB are provided until all branch nodes of this branch are described.

Card 5BC below contains information about the branch attachment point.

YBB(1,3) = 0.100000D+02

ZB(1,3) = 0.0

ANB(1,3) = 0.634349D+02

HB(1,3) = 0.400000D+00

I5

Card 5C

NDISB = 1

2I5, D15.6

Card 5CA

NEDIB = 2

NBDI = 1

ANGB = 0.265651D+02

I5

Card 5D

NBCOND = 1

4(3I5)

Card 5DA

NBCB(1) = 2

NODBB(1) = 2

LBR(1) = 1

3D15.6,I5

Card 6

DELTAT = 0.100000D-05

DS(1) = 0.650000D+04

P(1) = 0.400000D+01

NTOVR = BLANK

Card 7AA 4D15.6

EPS(1,1) = 0.460000D-02

SIG(1,1) = 0.460000D+05

EPS(2,1) = 0.180000D+00

SIG(2,1) = 0.580000D+05

Card 8 2I5

NOP = 3

NASP = 3

Card 8A 2I5, D15.6

NSBS(1) = 1

NSEL(1) = 9

AZET(1) = 0.530000D+00

⋮

Additional cards are punched until all 3 additional strain points are described.

NSBS(3) = 1

NSEL(3) = 11

AZET(3) = 0.500000D-01

Card 9AA 5D15.6

FH(1) = 0.100000D+01

FCG(1) = -0.200000D+01

FCGX(1) = 0.600000D+01

FMASS(1) = 0.385610D+01

FMOI(1) = 0.482014D-04

Card 9AB D15.6

UNK(1) = 0.0

Card 9AC 5D15.6

UDOT(1) = 0.260796D+04

WDOT(1) = 0.148275D+04

ADOT(1) = 0.0

```
    TPRIM(1) = 0.960000D-03
    CR(1)    = 0.100000D+01

Card 10                                                    3D25.16
    AXG(1)   = 0.1127016653792585D+00
    AXG(2)   = 0.5000000000000000D+00
    AXG(3)   = 0.8872983346207415D+00

Card 11                                                    3D25.16
    AWG(1)   = 2.7777777777777778D+00
    AWG(2)   = 0.4444444444444444D+00
    AWG(3)   = 0.2777777777777778D+00

Card 12A                                                   3D25.16
    TXG(1)   = -0.8611363115940539D+00
    TXG(2)   = -0.3399810435848560D+00
    TXG(3)   = 0.3399810435848560D+00

Card 12B                                                   D25.16
    TXG(4)   = 0.8611363115940530D+00

Card 13A                                                   3D25.16
    TWG(1)   = 0.3478548451374540D+00
    TWG(2)   = 0.6521451548625460D+00
    TWG(3)   = 0.6521451548625460D+00

Card 13B                                                   D25.16
    TWG(4)   = 0.3478548451374540D+00

Card 14A                                                   I5
    NBCOND   = 1

Card 14B                                                   14I5
    NBC(1)   = 3
    NODEB(1) = 1
```

Card 15 3I5

NQR = 2

NORP = 0

NORU = 2

Ship Card 15A and go to Card 15B

Card 15B 3D15.6

SCTU = 0.300000D+04

SCRU = 0.0

SCTW = 0.150000D+04

Card 15C 8I5

NRST(1) = 9

NREU(1) = 2

NRST(2) = 13

NREU(2) = 3

Card 16 I5

ICONT = 0

Skip to Card 17

Card 17 I5

ICON = 1

Note: Setting ICON = 1 causes the program to search for another complete set (Cards 1-17) of data cards. In this case the data cards for example number 2 (described in Section 6.2.1) followed immediately after the data cards for example number 1 and both problems were run during the same computer submittal. If ICON = 0 the job will terminate.

```
   THIS IS THE INPUT DECK FOR EXAMPLE  6.1
00.150000D 01  00.250000D-03  00.360000D 02
 16    3    4    2 1580  980   40    1  00.158000D-02
00.0           00.0           00.0           00.300000D+00
00.100000D+01  00.0           00.0           00.290000D+00
00.200000D+01  00.0           00.0           00.250000D+00
00.300000D+01  00.0           00.0           00.240000D+00
00.400000D+01  00.0           00.0           00.220000D+00
00.500000D+01  00.0           00.0           00.200000D+00
00.600000D+01  00.0           00.0           00.180000D+00
00.700000D+01  00.0           00.0           00.160000D+00
00.800000D+01  00.0           00.0           00.140000D+00
00.900000D+01  00.0           00.0           00.120000D+00
00.100000D+02  00.0           00.0           00.100000D+00
00.108662D+02  -0.759612D-01  -0.100000D+02  00.100000D+00
00.117101D+02  -0.391537D+00  -0.200000D+02  00.100000D+00
00.125000D+02  -0.669873D+00  -0.300000D+02  00.100000D+00
00.132139D+02  -0.116978D+01  -0.400000D+02  00.100000D+00
00.138302D+02  -0.178606D+01  -0.500000D+02  00.100000D+00
00.143301D+02  -0.250000D+01  -0.600000D+02  00.100000D+00
  0
  1
  3  00.100000D+01  00.733085D-03  00.404000D+02  00.500000D+01
00.279000D-02  00.809510D+05  00.225100D-01  00.115330D+06
00.200000D+00  00.121000D+06
  2   11    0    1
00.105000D+02  00.100000D+01  00.634349D+02  00.400000D+00
00.115000D+02  00.150000D+01  00.265651D+02  00.400000D+00
00.100000D+02  00.0           00.634349D+02  00.400000D+00
  1
  2    1  00.265651D+02
  1
  2    2    1
00.100000D-05  00.650000D+04  00.400000D+01
00.460000D-02  00.460000D+05  00.180000D+00  00.580000D+05
  3    3
```

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```
  1     9  00.530000D+00
  2     1  00.500000D+00
  1    11  00.500000D-01
00.100000D+01  -0.200000D+01  00.600000D+01  00.395610D-03  00.482014D-04
00.0
00.260796D+04  00.148275D+04  00.0            00.960000D-03  00.100000D+01
00.112701665379258 5D+00  00.500000000000000D+00  00.387298334620741 5D+00
00.277777777777777 8D+00  00.444444444444444 4D+00  00.277777777777777 8D+00
-0.861136311594053 0D+00  -0.339981043584856 0D+00  00.339981043584856 0D+00
00.861136311594053 0D+00
00.347854845137454 0D+00  00.652145154862546 0D+00  00.652145154862546 0D+00
00.347854845137454 0D+00
  1
  3     1
  2     0     2
00.300000D+04  00.1             00.150000D+04
  9     2    13     3
  0
  1
```

6.1.3 Solution Output Data

The following is the output obtained as a result of the CIVM-JET 4B analysis of this partial ring example.

The numbering system for the nodes and elements is listed as well as an identification of the branch attachment point and the slopes at the branch connection and at the slope discontinuity. The partial ring initial geometry, boundary conditions, and elastic foundations are defined as well as all the necessary data pertaining to the impacting fragment. A "maximum allowable" time step is computed and the user generated time step is checked against this.

Each impact is recorded (there are 7 impacts during this run) and the essential data concerning element number, fragment number, time, and location are output. For each printout cycle, an update of each nodal position, the fragment position, the strains at each Gaussian point, each node, and each additional strain point is given.

Initial impact occurs on element 9 at 967.796 microsecond after fragment release. During this computer run the maximum strain reaches 5.79% on the main structure and only 1.28% on the branch.

Note that for conciseness only a portion of the requested output is presented here. Included are: all initial problem data, printout at time cycles 980, 1020, 1060, 1100, 1140, 1180, ... skip to 1540, 1580 (last); a record of all impacts occurring up to time cycle 1580 is retained.

```
THERE ARE   18  ELEMENTS AND   19  NODES

THERE ARE   1  BRANCHES AND THEY ARE AT NODES     11

THE GLOBAL SLOPE(RAD) AT EACH BRANCH CONNECTION:    0.110715D+01

THE ATTACHMENT POINT CODE FOR THE    1  BRANCHES IS AS FOLLOWS:
      1


PRESENT ELEM. NO.      NODE1      NODE2      SUBSTRUCTURE      SUBST. ELEM. NO.
       1                 1          2             1                  1
       2                 2          3             1                  2
       3                 3          4             1                  3
       4                 4          5             1                  4
       5                 5          6             1                  5
       6                 6          7             1                  6
       7                 7          8             1                  7
       8                 8          9             1                  8
       9                 9         10             1                  9
     -10                10         11             1                 10
      11                11         12             2                  1
      12                12         13             2                  2
      13                11         14             1                 11
      14                14         15             1                 12
      15                15         16             1                 13
      16                16         17             1                 14
      17                17         18             1                 15
      18                18         19             1                 16

THE UPDATED NODE NUMBERS FOR THE MAIN STRUCTURE, GIVEN IN THEIR ORIGINAL NUMBERING ORDER:

    1    2    3    4    5    6    7    8    9   10   11   14   15   16   17   18   19


NOTE:  THE ELEMENT NUMBERS REFERRED TO BELOW ARE PRESENT ELEMENT NUMBERS


ELEMENTS THAT CAN NOT BE IMPACTED:
   11   12    0    0    0    0    0    0    0    0
    0    0    0    0    0    0    0    0    0

ADDITIONAL STRAIN POINT      ELEMENT      S  COORDINATE
             1                   9           0.5000000D+00
             2                  11           0.5000000D+00
             3                  13           0.5000000D-01

EACH OF THE FOLLOWING ELEMENTS HAS A SLOPE DISCONTINUITY AT ITS FIRST NODE
   12

THE GLOBAL SLOPE (RAD.) AT EACH DISCONTINUITY EQUALS:
  0.463648D+00
```

PARTIAL RING **CIVM-JET 4B** CONTAINMENT ANALYSIS

RING PROPERTIES

MATERIAL PROPERTIES OF MAIN STRUCTURE ARE:

```
     WIDTH OF RING(IN)                          =  0.150000D+01
     DENSITY OF RING                            =  0.250000D-03
     NUMBER OF ELEMENTS                         =  16
     NUMBER OF SPANWISE GAUSSIAN PTS.           =   3
     NUMBER OF DEPTHWISE GAUSSIAN PTS.          =   4
     NUMBER OF MECHANICAL SUBLAYERS             =   2

     DS FOR STRAIN RATE                         =  0.650000D+04
     P  FOR STRAIN RATE                         =  0.400000D+01
        STRAIN (1) =  0.460000D-02    STRESS(1) =  0.460000D+05

        STRAIN (2) =  0.180000D+00    STRESS(2) =  0.580000D+05
```

MATERIAL PROPERTIES OF BRANCH NUMBER 1 ARE AS FOLLOWS:

```
     WIDTH OF RING(IN)                          =  0.100000D+01
     DENSITY OF RING                            =  0.733085D-03
     NUMBER OF ELEMENTS                         =   2
     NUMBER OF SPANWISE GAUSSIAN PTS.           =   3
     NUMBER OF DEPTHWISE GAUSSIAN PTS.          =   4
     NUMBER OF MECHANICAL SUBLAYERS             =   3

     DS FOR STRAIN RATE                         =  0.404000D+02
     P  FOR STRAIN RATE                         =  0.500000D+01
     THICKNESS AT THE CONNECTING NODE           =  0.400000D+00

        STRAIN (1) =  0.279000D-02    STRESS(1) =  0.809500D+05

        STRAIN (2) =  0.225000D-01    STRESS(2) =  0.105300D+06

        STRAIN (3) =  0.200000D+00    STRESS(3) =  0.121000D+06
```

INITIAL GEOMETRY AT EACH NODE IS AS FOLLOWS:

NODE NO.	Y COORD	Z COORD	SLOPE(RAD.)	RING THICKNESS AT NODE I
1	0.0	0.0	0.0	0.300000D+00
2	0.100000D+01	0.0	0.0	0.280000D+00
3	0.200000D+01	0.0	0.0	0.260000D+00
4	0.300000D+01	0.0	0.0	0.240000D+00
5	0.400000D+01	0.0	0.0	0.220000D+00
6	0.500000D+01	0.0	0.0	0.200000D+00
7	0.600000D+01	0.0	0.0	0.180000D+00
8	0.700000D+01	0.0	0.0	0.160000D+00

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9	0.800000D+01	0.0	0.0	0.140000D+00
10	0.900000D+01	0.0	0.0	0.120000D+00
11	0.100000D+02	0.0	0.0	0.100000D+00
12	0.105000D+02	0.100000D+01	0.110715D+01	0.400000D+00
13	0.115000D+02	0.350000D+01	0.463648D+00	0.400000D+00
14	0.108682D+02	-0.759612D-01	-0.174533D+00	0.100000D+00
15	0.117101D+02	-0.301537D+00	-0.349066D+00	0.100000D+00
16	0.125000D+02	-0.669873D+00	-0.523599D+00	0.100000D+00
17	0.132139D+02	-0.116970D+01	-0.698132D+00	0.100000D+00
18	0.138362D+02	-0.178606D+01	-0.872665D+00	0.100000D+00
19	0.143301D+02	-0.250000D+01	-0.104720D+01	0.100000D+00

FRAGMENT PROPERTIES

FRAG.NO.	DIA. OF FRAG.	MASS OF FRAG.	MOMENT OF INERTIA OF FRAG.	FCGY	FCGZ
1	0.100000D+01	0.385610D-01	0.482014D-04	0.600000D+01	-0.200000D+01

COLLISION PARAMETERS

FRAG.NO.	VEL IN Y DIR.	VEL IN Z DIR.	ANG. VEL.	COEFF.OF RESTIT.	INITIAL KINETIC ENERGY	COEFF. OF FRICT
1	0.260796D+04	0.146275D+04	0.0	0.100000D+01	0.173525D+04	0.0

BOUNDARY CONDITIONS ARE:

HINGED DISPLACEMENT CONDITION AT NODE = 1
CLAMPED DISPLACEMENT CONDITION AT NODE = 13

CONSTRAINTS (ELASTIC FOUNDATION/SPRING) AS DESCRIBED LATER

THE TRAIN FOR EACH OF 1 FRAGMENTS IS AS FOLLOWS
0.900000D-01

GAUSSIAN STATIONS AND WEIGHTS:

AE, 1 =	0.1127[illegible]59		AW; 1 =	0.27777777777777 8
AE, 2 =	0.5[illegible]		AW; 2 =	0.[illegible]44448
AE, 3 =	0.8[illegible]741		AW, 3 =	0.27777777777777 8
TE, 1 =	-0.[illegible]		TW; 1 =	0.[illegible]517454
TE, 2 =	-0.3[illegible]0410456		TW, 2 =	0.[illegible]4515485 2546
TE, 3 =	0.3[illegible]456		TW, 3 =	0.[illegible]54462546
TE, 4 =	0.[illegible]059		TW, 4 =	0.347[illegible]517454

SIZE OF ASSEMBLED STIFFNESS MATRIX = 510

THE TRANSLATIONAL MASSES FOR EACH NODE ARE:

0.5500[illegible]D-16	0.10[illegible]000000D-03	0.175000000000000D-04	0.900000000000000D-04
0.8250[illegible]0000D-16	0.750[illegible]000000D-04	0.675000000000000D-04	0.600000000000000D-04
0.525[illegible]0000D-16	0.450[illegible]0000D-04	0.[illegible]2 198 10D-03	0.3273455788570870-03
0.1619[illegible]410D-03	0.3272[illegible]0359D-04	0.3272[illegible]570-04	0.327263735219257D-04
0.3272451[illegible]6205D-04	0.3272505[illegible]15E-04	0.1636[illegible]268122D-04	

THE ROTATIONAL MASSES FOR EACH NODE ARE:

0.[illegible]1516712[illegible]D-05	0.[illegible]7[illegible]60[illegible]D-05	0.[illegible]120[illegible]151044D-0[illegible]	0.747[illegible]713295526D-05
0.[illegible]D-0[illegible]	0.[illegible]D-05	0.[illegible]111111D-05	0.[illegible]696[illegible]4258D-05
0.[illegible]D-0[illegible]	0.[illegible]D-05	0.1[illegible]D-04	0.[illegible]150111011320-04
0.173[illegible]D-04	0.2[illegible]D-05	0.2376[illegible]D-05	0.237698316531070D-05
0.2[illegible]D-05	0.[illegible]D-05	0.13[illegible]907330D-05	

EIGEN VECTOR OF HIGHEST MODE

V	W	PSI	CHI
0.0	0.0	-0.622[illegible]D-25	-0.234167D-08
0.16[illegible]D-2[illegible]	0.58[illegible]D-24	0.71[illegible]D-24	0.5[illegible]715D-08
-0.7[illegible]D-24	0.76[illegible]D-22	0.[illegible]D-21	-0.202[illegible]D-07
0.[illegible]D-2[illegible]	0.[illegible]D-20	0.241[illegible]D-1[illegible]	0.[illegible]1[illegible]D-07
-0.[illegible]D-1[illegible]	-0.4[illegible]D-14	-0.[illegible]D-14	-0.36[illegible]D-06
0.[illegible]D-1[illegible]	-0.1[illegible]D-1[illegible]	-0.[illegible]D-1[illegible]	0.15[illegible]D-05
-0.2[illegible]D-1[illegible]	-0.1434[illegible]D-1[illegible]	-0.[illegible]D-1[illegible]	-0.66[illegible]D-05
0.115111D-1[illegible]	0.2522[illegible]D-11	-0.[illegible]D-11	0.2[illegible]D-04
-0.51[illegible]D-0[illegible]	0.1[illegible]D-08	0.[illegible]D-0[illegible]	-0.1320[illegible]D-03
0.22[illegible]D-0[illegible]	0.[illegible]D-0[illegible]	0.71[illegible]D-0[illegible]	0.59[illegible]D-03
-0.1[illegible]D-0[illegible]	-0.114[illegible]D-0[illegible]	0.[illegible]D-01	-0.279[illegible]D-02
0.1[illegible]D-0[illegible]	-0.3123710D-04	0.1[illegible]100D-01	0.[illegible]D-04
0.0	0.0	0.0	0.[illegible]D-04
0.27[illegible]D-01	-0.12[illegible]D-02	-0.5[illegible]D-02	0.8[illegible]D-01
-0.[illegible]D-0[illegible]	0.177[illegible]D-02	0.[illegible]D-01	-0.12[illegible]D+00
0.12[illegible]D+0[illegible]	-0.2[illegible]D-02	-0.[illegible]D-01	0.1[illegible]D+00
-0.1[illegible]D+0[illegible]	0.15[illegible]D-02	0.[illegible]70-01	-0.14[illegible]D+00
0.2[illegible]D+0[illegible]	-0.[illegible]D-02	-0.[illegible]D-01	-0.[illegible]D-01
-0.3[illegible]D+0[illegible]	-0.277[illegible]D-01	0.5[illegible]D-01	0.1[illegible]D+01

HIGHEST NATURAL FREQUENCY (RAD/SEC) = 0.510[illegible]2751326053[illegible]D+06

THE COMPLETE VALUE OF THE MAX DELTAT = 0.313[illegible]7431706[illegible]D-05

DELTAT SHOULD EQUAL: 0.3130000D-05
THE VALUE OF DELTAT USED IN THE PROGRAM IS. 0.1000000D-05

THE CONSTANTS FOR 2 ELASTIC FOUNDATIONS ARE.

THE VALUE OF THE TANGENTIAL SPRING CONSTANT IS = 0.3000000D+04
THE VALUE OF THE NORMAL SPRING CONSTANT IS = 0.1500000D+04
THE VALUE OF THE TORSIONAL SPRING CONSTANT IS = 0.0

FIRST ELEMENT	NUMBER OF ELEMENTS
9	2
13	3

THE FOLLOWING NUMBERS ARE THE VALUES FOR THE EFFECTIVE LENGTHS FOR THE NBU PLUS 1 SECTIONS OF THE STRUCTURE
0.200000D+00 [illegible]1951410+00

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THE FOLLOWING IS THE TIME SOLUTION OF THE FRAGMENT- RING IMPACT

IMPACT NO. 1 TIME 0.9677960-03 DURING CYCLE 980 ELEM 9 FRAG 1 DISTANCE 0.5219740D+00

....

ENERGY AND WORK AT THE END OF TIME CYCLE 980

FRAGMENT	KINETIC ENERGY
1	0.1464650D+00

WORK INPUT INTO RING = 0.2706000D+01
RING KINETIC ENERGY = 0.2691720D+01
RING ELASTIC ENERGY = 0.2110470D+02
RING PLASTIC WORK = 0.1746070D+00
ENERGY STORED IN ELASTIC RESTRAINTS = 0.9040740D+00

CYCLE= 980

ELEM	SI STA1 SO		SI STA2 SO		SI STA3 SO	
1	0.79729D-12	0.79720D-12	0.29410D-11	[illegible]	0.4865D-11	0.44850D-11
2	0.4486D-10	0.4465D-10	[illegible]	[illegible]	0.2794D-09	0.2790D-09
3	0.1611D-08	0.1111D-08	[illegible]	[illegible]	0.1061D-07	0.1061D-07
4	0.4952D-07	0.4151D-07	[illegible]	0.1615D-06	0.2601D-06	0.2601D-06
5	0.8180D-06	0.8171D-06	[illegible]	[illegible]	0.1112D-05	0.1113D-05
6	0.7951D-05	[illegible]	[illegible]	[illegible]	[illegible]	0.1783D-04
7	-0.1311D-01	0.1035D-01	[illegible]	[illegible]	0.8C14D-01	-0.4927D-01
8	0.7771D-02	-0.7591D-02	[illegible]	[illegible]	[illegible]	0.4114D-02
9	0.1911D-02	[illegible]	[illegible]	[illegible]	[illegible]	0.1773D-02
10	-0.6114D-02	[illegible]	[illegible]	[illegible]	[illegible]	-0.7617D-02
11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
12	-0.1516D-06	[illegible]	[illegible]	[illegible]	[illegible]	-0.1157D-06
13	0.1177D-04	0.4553D-04	[illegible]	[illegible]	[illegible]	[illegible]
14	[illegible]	0.2154D-04	[illegible]	[illegible]	0.9111D-05	0.4524D-05
15	0.3964D-05	0.3182D-05	[illegible]	[illegible]	[illegible]	0.1697D-05
16	0.3622D-06	[illegible]	[illegible]	[illegible]	0.6657D-07	0.4010D-07
17	0.2121D-07	[illegible]	[illegible]	[illegible]	[illegible]	0.3444D-08
18	0.7196D-08	[illegible]	0.4014D-09	[illegible]	0.1666D-09	0.1299D-09

CYCLE= 980
STRAIN AT ADDITIONAL POINTS

	SI	SO	SI	SO
1	-0.2007194D-03	0.7471121D-03	-0.2007297D-03	0.7872611D-03
2	0.1819451D-04	-0.1615560D-04	0.1031411D-04	-0.9616024D-04
3	0.1041671D-03	0.1659449D-04	0.1041619D-03	0.1659491D-04

J= 980 TIME= 0.980000-03 TIME AFTER INITIAL IMPACT = 0.1220372D-04

I	U	V	PSI	CHI	COPT	COPZ	L	M	STRAIN(IN)	STRAIN(OUT)
1	0.0	0.0	-0.5451D-20	0.1265D-12	0.0	0.0	0.1281D-04	-0.7303D-13	0.1265D-12	0.1265D-12
2	0.2844D-11	[illegible]	[illegible]	[illegible]	0.1000D+01	0.1541D-18	[illegible]	[illegible]	0.5378D-11	0.5378D-11
3	0.1631D-09	[illegible]	[illegible]	[illegible]	0.2300D+01	0.2764D-15	[illegible]	0.1775D-07	0.3084D-09	0.3084D-09
4	0.6524D-08	[illegible]	[illegible]	0.1167D-07	0.1333D+01	[illegible]	[illegible]	[illegible]	0.1165D-07	0.1170D-07
5	0.1653D-06	[illegible]	[illegible]	[illegible]	0.4333D+01	0.6937D-10	0.330D+01	[illegible]	[illegible]	0.2787D-06
6	0.2660D-05	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.4314D-05	0.4211D-05
7	[illegible]	[illegible]	[illegible]	[illegible]	0.6130D+01	[illegible]	0.215D+01	-0.1446D+02	[illegible]	0.1767D-03
8	0.1159D-03	[illegible]	[illegible]	[illegible]	0.7303D+01	[illegible]	[illegible]	-0.3023D+01	[illegible]	-0.5196D-02
9	-0.7675D-04	[illegible]	[illegible]	[illegible]	0.8000D+01	[illegible]	[illegible]	[illegible]	[illegible]	0.3520D-02
10	0.1844D-03	[illegible]	[illegible]	[illegible]	0.9000D+01	0.3145D-01	[illegible]	-0.2106D+01	[illegible]	0.7139D-02
11	-0.7678D-04	[illegible]	[illegible]	[illegible]	0.1000D+02	[illegible]	[illegible]	[illegible]	[illegible]	-0.4631C-02
12	0.1065D-04	-0.2641D-05	[illegible]	[illegible]	0.1150D+02	[illegible]	-0.1197D+01	0.1065D+01	-0.2078D-04	0.1202C-04
13	0.0	0.0	0.0	[illegible]	[illegible]	0.1503D+01	0.125D+01	[illegible]	0.3337D-05	-0.9999D-05
14	-0.1419D-04	-0.2446D-05	[illegible]	[illegible]	[illegible]	-0.7510D-01	[illegible]	[illegible]	[illegible]	0.2891D-04
15	-0.2419D-05	[illegible]	[illegible]	[illegible]	0.1171D+02	-0.3015D+00	[illegible]	[illegible]	[illegible]	0.6556D-05
16	-0.2064D-06	[illegible]	[illegible]	[illegible]	0.1250D+02	[illegible]	[illegible]	0.5172D-06	0.3441D-06	0.4404D-06
17	-0.3041D-07	[illegible]	[illegible]	[illegible]	0.1121D+02	-0.1117D+01	0.1627D-01	[illegible]	0.1914D-07	0.2620C-07
18	-0.3630D-09	[illegible]	[illegible]	[illegible]	[illegible]	-0.1786D+01	[illegible]	0.8752D-07	0.6356D-09	0.1015D-08
19	-0.1763D-10	-0.1454D-11	0.1012D-11	[illegible]	0.1613C+02	-0.2503D+01			0.2394D-10	0.5238C-10

FRAG NO.=	FU =	FGV =	ALPHA =	FUV =	FRAT =	FRAT =
1	0.8555800D+01	-0.2541180D+00	0.0	0.2607963D+04	0.8916610D+03	0.0

SUBSTRUCTURE	RSTR	ELE	SURF	STA	TIME
1	0.8616410-02	10	2	1	0.980000D-03
2	0.1842770-03	11	1	1	0.980000D-03

SUBSTRUCTURE	LARGEST ADD. PT. STRAIN	ELEM	ADD. PT.	TIME	SURFACE
1	0.7875731D-03	9	1	0.9800000D-03	2
2	0.1804840D-04	11	2	0.9800000D-03	1

SUBSTRUCTURE	LARGEST NODAL STRAIN	NODE	SURF	TIME
1	0.7139130D-02	10	2	0.9800000D-03
2	0.1202410D-04	12	2	0.9800000D-03

....

ENERGY AND WORK AT THE END OF TIME CYCLE 1020

FRAGMENT	KINETIC ENERGY
1	0.1444650+04

WORK INPUT INTO RING = 0.2706060+03
RING KINETIC ENERGY = 0.1569510+03
RING ELASTIC ENERGY = 0.5745240+02
RING PLASTIC WORK = 0.4207550+02
ENERGY STORED IN ELASTIC RESTRAINTS = 0.1332070+02

CYCLE= 1020

ELEM	SI (STA1)	SO (STA1)	SI (STA2)	SO (STA2)	SI (STA3)	SO (STA3)
1	0.3087D-01	0.1097D-01	0.3233D-03	0.3233D-03	0.3377D-03	0.3377D-03
2	0.3513D-03	0.3512D-03	0.3839D-03	0.3839E-03	0.4168D-03	0.4169D-03
3	0.4340D-03	0.4199D-03	0.4913D-03	0.4431E-03	0.5265D-03	0.5295D-03
4	0.5587D-03	0.5531D-03	0.5914D-03	0.5707D-03	0.6263D-03	0.5965D-03
5	0.6489D-03	0.5659D-03	0.5455D-03	0.7722E-03	0.3798D-03	0.9298D-03
6	-0.3146D-03	0.1636D-02	0.5285D-03	0.6552E-03	0.1495D-04	0.1352D-03
7	0.4996D-02	-0.3134D-02	0.5687D-02	-0.4193D-02	0.6490D-02	-0.4308D-02
8	0.3444D-02	-0.1716D-02	0.3123D-02	-0.1784D-02	0.3319D-02	-0.1551D-02
9	-0.7153D-02	0.9343D-02	-0.8366D-02	0.1291D-01	-0.8830D-02	0.1256D-01
10	-0.1725D-01	0.2037D-01	0.4178D-02	-0.1551D-02	0.1918D-01	-0.2368D-01
11	0.7657E-03	-0.3923D-03	0.6417D-03	-0.7542E-03	0.8187E-03	-0.8151D-03
12	0.8262D-03	-0.7134E-03	0.3882E-03	-0.3414D-03	0.5466E-05	0.7691D-04
13	0.3983D-03	0.5397D-03	0.1134E-02	0.4113E-03	0.1533D-02	-0.1111D-03
14	0.8774D-03	0.4338D-03	0.6491D-03	0.6143D-03	0.4951D-03	0.7716D-03
15	0.5366D-03	0.5522E-03	0.5151E-03	0.5742E-03	0.4312D-03	0.6354D-03
16	0.5406D-03	0.4143D-03	0.4144E-03	0.4357D-03	0.2523D-03	0.4406E-03
17	0.3454D-03	0.2653D-03	0.2524D-03	0.2673D-03	0.1265E-03	0.2487D-03
18	0.1776D-03	0.1231D-03	0.6443E-04	0.7196E-04	0.5207D-04	0.1225D-03

CYCLE= 1020

STRAIN AT ADDITIONAL POINTS	SI	SO	EI	EO
1	-0.84525400D-02	0.10937225D-01	-0.84880630D-02	0.10848351D-01
2	0.64161547D-03	-0.75423955D-03	0.64148972D-03	-0.75452420E-03
3	0.23222140D-03	0.56534002D-03	0.23219444D-03	0.56577976D-03

J= 1020 TIME= 0.102000D-02 TIME AFTER INITIAL IMPACT = 0.522037D-04

I	Y	W	PSI	CHI	COPY	COPZ	L	M	STRAIN(IN)	STRAIN(OUT)
1	0.0	0.0	-0.2246D-09	0.3043D-03	0.0	0.0	0.1407D+04	-0.2670D-03	0.3043D-03	0.3043D-03
2	0.3232D-03	0.2379D-08	0.8534D-08	0.3418D-03	0.1003D+01	0.2379D-08	0.1555D+04	0.3793D-02	0.3418D-03	0.3418D-03
3	0.7071D-03	-0.6433D-08	-0.1456D-06	0.4264D-03	0.2001E+01	-0.6433D-08	0.1806D+04	0.3215D-01	0.4262D-03	0.4268D-03
4	0.1193E-02	-0.1351E-05	-0.1742E-05	0.5426D-03	0.3301E+01	-0.1351D-05	0.2003D+04	-0.1503D+01	0.5426D-03	0.5430D-03
5	0.1773D-02	0.2923D-04	0.9745E-04	0.6173D-03	0.4002E+01	0.2923D-04	0.2275D+04	0.1250D+02	0.6804D-03	0.5442D-03
6	0.2419D-02	-0.6060D-04	-0.9826E-03	0.6465D-03	0.5002E+01	-0.6063D-04	0.1976D+04	0.1488D+02	-0.1222D-03	0.1417D-02
7	0.3101D-02	-0.3653E-02	-0.2717E-02	0.7156D-03	-0.6003E+01	-0.3653D-02	0.1904D+04	-0.3569E+03	0.3359D-02	-0.1620D-02
8	0.3437D-02	0.2021E-01	0.5542D-01	-0.6034D-01	0.7001E+01	0.2021D-01	0.1723D+04	-0.1437D+03	0.5141D-02	-0.3278E-02
9	0.1618D-02	0.9234D-01	0.6945E-01	-0.3065E-02	0.8002E+01	0.9234D-01	0.1617D+04	0.3372E+03	-0.1727E-02	0.3607D-02
10	0.1841D-02	0.1140E+00	-0.5803D-01	0.7433D-03	0.9002E+01	0.1140D+00	0.2167D+04	-0.8665D+02	-0.1579D-01	0.2064D-01
11	-0.4752D-02	0.2572E-02	-0.5947E-02	0.2461D-03	0.9935E+01	0.2572D-02	-0.6531D+03	-0.5400D+03	0.1341D-01	-0.1279E-01
12	0.3284D-03	0.5057D-03	-0.2046D-04	0.7333D-04	0.1357E+02	0.1001D+01	0.2568D+03	-0.2831D+03	0.9442D-03	-0.7333D-03
13	0.0	0.0	0.0	0.5755E-04	0.1150E+02	0.1500D+01	0.1159D+04	-0.9223D+01	-0.9659E-04	0.2117E-03
14	-0.4127D-02	-0.2143D-02	0.3762D-03	0.6608D-01	0.1095E+02	-0.7736D-01	0.9443D+03	-0.1364D+01	0.1277D-02	0.4540D-04
15	-0.3227E-02	-0.1543D-02	0.1121D-02	0.6359D-03	0.1171E+02	-0.3019D+00	0.8354D+03	0.5465D+00	0.5467D-03	0.6747D-03
16	-0.2521D-02	-0.1017D-02	0.7381D-03	0.5022D-01	0.1253D+02	-0.6695D+00	0.6361D+03	0.2919D+00	0.4904E-03	0.5148D-03
17	-0.2003D-02	-0.6171D-03	0.5337E-03	0.3554D-01	0.1321E+02	-0.1169D+01	0.3594D+03	0.1359D+00	0.3498D-03	0.3690D-03
18	-0.1699D-02	-0.2912D-01	0.4024D-03	0.1944D-01	0.1383E+02	-0.1765D+01	0.1038D+03	0.6856D-01	0.1607D-03	0.2244D-03
19	-0.1577D-02	-0.1421D-03	0.3502D-03	0.1687D-03	0.1433E+02	-0.2491D+01			0.6394D-04	0.1536D-03

FRAG NO.=	FCGU =	FCGW =	ALFA =	FRUY =	FRAY =	FRAT =
1	0.8660120+01	-0.5104520+00	0.0	0.2607940+04	0.8916610+03	0.0

SUBSTRUCTURE	RSTN	ELE	SURF	STA	TIME
1	0.2396440D-01	10	2	1	0.102000D-02
2	0.8241570D-03	12	1	1	0.102000D-02

SUBSTRUCTURE	LARGEST ADD. PT. STRAIN	ELEM	ADD. PT.	TIME	SURFACE
1	0.1093740D-01	9	1	0.102000D-02	2
2	0.6416950D-03	11	2	0.102000D-02	1

SUBSTRUCTURE	LARGEST NODAL STRAIN	NODE	SURF	TIME
1	0.2364480D-01	10	2	0.102000D-02
2	0.9442140D-03	12	1	0.102000D-02

C.3

ENERGY AND WORK AT THE END OF TIME CYCLE 1060

FRAGMENT	KINETIC ENERGY
1	0.146465D+04

WORK INPUT INTO RING = 0.270600D+03
RING KINETIC ENERGY = 0.102041D+03
RING ELASTIC ENERGY = 0.446897D+02
RING PLASTIC WORK = 0.718117D+02
ENERGY STORED IN ELASTIC RESTRAINTS = 0.283577D+02

CYCLE= 1060

ELEM	SI STA1	SO STA1	SI STA2	SO STA2	SI STA3	SO STA3
1	0.7671D-03	0.7655D-03	0.7763D-03	0.7770D-03	0.7999D-03	0.8024D-03
2	0.8387D-03	0.8270D-03	0.8343D-03	0.8542E-03	0.8667D-03	0.8822D-03
3	0.9082D-03	0.9125D-03	0.1030D-02	0.8544D-03	0.1124D-02	0.7911D-03
4	0.1256D-02	0.6571D-03	0.7955D-03	0.1125E-02	0.3557D-03	0.1553D-02
5	-0.7968D-03	0.2041D-02	-0.2528E-03	0.2602E-02	0.3186D-03	0.1463D-02
6	0.3224D-02	-0.1475D-02	0.4356D-02	-0.3034D-02	0.5925D-02	-0.4309D-02
7	0.3831D-02	-0.2165D-02	0.5161D-02	-0.3883D-02	0.6531D-02	-0.5143D-02
8	0.7654D-02	-0.6549D-02	0.2113D-01	0.7043D-03	-0.6813D-02	0.7083D-02
9	-0.8440D-02	0.6544D-02	-0.1104D-01	0.1102D-01	-0.1763D-01	0.1940D-01
10	-0.1495D-01	0.1493D-01	0.5645D-02	-0.5383D-02	0.2101D-01	-0.2833D-01
11	0.6137D-03	-0.4464D-03	0.8461D-03	-0.8795D-03	0.1219D-02	-0.1170D-02
12	0.1421D-02	-0.1319D-02	0.1467D-02	-0.1331D-02	0.1533D-02	-0.1431D-02
13	-0.1154D-02	0.1237D-02	-0.1125E-03	-0.4473D-03	0.1283D-02	-0.1823D-02
14	0.1469D-02	-0.1829D-02	0.6741E-03	-0.1204D-02	-0.5996D-05	-0.4712D-03
15	-0.4089D-03	-0.1736D-03	-0.3142E-03	-0.1254E-03	-0.2467D-03	-0.1665D-03
16	-0.3163D-03	-0.1136D-03	-0.1413E-03	-0.1758D-03	-0.7195D-04	-0.2486E-03
17	-0.2435D-03	-0.2597E-04	-0.1541E-03	-0.5633E-04	-0.7271D-04	-0.9770D-04
18	-0.1681D-03	0.7506D-04	-0.7519D-04	0.2067E-04	0.4302E-05	-0.6748D-04

CYCLE= 1060

STRAIN AT ADDITIONAL POINTS	SI	SO	EI	EO
1	-0.124691410D-01	0.133493210D-01	-0.125478650D-01	0.133008650D-01
2	0.846088870D-03	-0.378491950D-03	0.845731240D-03	-0.860879160D-03
3	-0.132154170D-02	0.151661700D-02	-0.132241600D-02	0.151546870D-02

J= 1060 TIME= 0.106300D-02 TIME AFTER INITIAL IMPACT = 0.922037D-04

I	V	W	PSI	CHI	COPY	COPZ	L	M	STRAIN(IN)	STRAIN(OUT)
1	0.0	0.0	0.2222D-05	0.7657D-01	0.0	0.0	0.3378D+04	0.1129D+00	0.7671D-03	0.7648D-03
2	0.7801D-03	0.2293E-05	-0.1482D-05	0.6100D-03	0.1001E+01	0.2293D-05	0.3413D+04	0.1817D+01	0.8048D-03	0.8158D-03
3	0.1628D-02	-0.3431E-04	-0.7536D-04	0.6791D-03	0.2003E+01	-0.3436D-04	0.3555D+04	-0.1402D+02	0.8655D-03	0.8935D-03
4	0.2581D-02	0.1073D-03	0.6424D-03	0.9527D-01	0.3003D+01	0.3076D-03	0.3313D+04	0.2181E+02	0.1268D-02	0.6393D-03
5	0.3518D-02	0.8931D-03	-0.7916D-03	0.9560D-03	-0.4004E+01	-0.6831D-03	0.2753D+04	0.1243D+03	-0.3573D-03	0.2260D-02
6	0.4378E-02	-0.4363D-02	-0.1153D-01	0.3344D-03	0.5000E+01	-0.6161D-02	0.2171D+04	-0.3426D+03	0.1643D-02	0.1595D-03
7	0.5164E-02	-0.1370D-02	0.2843E-01	0.4942D-01	0.6005E+01	-0.1196D-02	0.1553D+04	-0.3245D+03	0.4905D-02	-0.3108E-02
8	0.4393E-02	0.4914D-01	0.8123D-01	-0.2455D-02	0.7004E+01	0.4934D-01	0.1053D+04	0.1330D+02	0.6705D-02	-0.7003D-02
9	-0.2358D-03	0.1474D+00	0.7812D-01	-0.2538D-02	0.8000D+01	0.1474D+00	0.1755D+03	0.3234D+03	-0.5818D-02	0.6254D-02
10	-0.1035D-02	0.1559E+00	-0.1131D+00	-0.1624D-02	0.8999E+01	0.1559D+00	0.2125D+03	-0.1669D+03	-0.1933D-01	0.2484D-01
11	-0.1345D-01	0.4452D-02	-0.1274E-01	0.5647D-04	0.9987E+01	0.4452D-02	-0.1883D+03	-0.6672D+03	0.1437D-01	-0.1610D-01
12	0.2683D-02	0.1645D-02	-0.7960E-02	-0.3112D-04	0.1050D+02	0.1034D+01	0.5032D+03	-0.1102D+04	0.1383D-02	-0.1257E-02
13	0.0	0.0	0.0	0.5771D-04	0.1150E+02	0.1303D+01	-0.4723D+03	-0.4561D+01	0.1557D-02	-0.1841D-02
14	-0.1390D-01	-0.7257D-02	-0.9620D-04	-0.1173D-03	0.1055E+02	-0.8067D-01	-0.3472D+03	-0.2346D+02	0.1635D-02	-0.1976D-02
15	-0.1253D-01	-0.4974E-02	0.6786D-04	-0.2899D-03	0.1170E+02	-0.3052D+00	-0.3514D+01	0.2724D+01	-0.3366E-03	-0.1971D-03
16	-0.1155D-01	-0.5627E-02	0.4886D-02	-0.2416D-03	0.1249E+02	-0.6693D+00	-0.2750E+03	0.1900D+00	-0.3210D-03	-0.1386D-03
17	-0.1190D-01	-0.3690D-02	0.4754D-02	-0.1595D-03	0.1320E+02	-0.1166D+01	-0.1592D+03	0.1201D+01	-0.1516E-03	-0.1634D-03
18	-0.1652D-01	-0.1973E-02	0.3915D-02	-0.6446D-04	0.1342E+02	-0.1779D+01	-0.4089D+02	0.1198D+01	-0.1396D-03	-0.1388E-04
19	-0.1031D-01	-0.1011E-02	0.3079D-02	-0.3837D-04	0.1432E+02	-0.2492D+01			0.2665D-04	-0.3392D-04

FRAG NO.=	FLUD =	FLUW =	ALFA =	FRUV =	FRWV =	FRAT =
1	0.876444D+01	-0.452786E+00	0.0	0.260796E+04	0.891661D+03	0.0

SUBSTRUCTURE	ASTR	ELM	SURF	STA	TIME
1	0.210051D-01	10	1	3	0.106000D-02
2	0.153349D-02	12	1	3	0.106000D-02

SUBSTRUCTURE	LARGEST ADD. PT. STRAIN	ELEM	ADD. PT.	TIME	SURFACE
1	0.133843D-01	9	1	0.106000D-02	2
2	0.846089D-03	11	2	0.106000D-02	1

SUBSTRUCTURE	LARGEST NODAL STRAIN	NODE	SURF	TIME
1	0.248450D-01	10	2	0.106000D-02
2	0.155674D-02	13	1	0.106000D-02

ENERGY AND WORK AT THE END OF TIME CYCLE 1100

FRAGMENT	KINETIC ENERGY
1	0.1464650D+04

WORK INPUT INTO RING = 0.2706000D+03
RING KINETIC ENERGY = 0.8454510D+02
RING ELASTIC ENERGY = 0.7024240D+02
RING PLASTIC WORK = 0.7693480E+02
ENERGY STORED IN ELASTIC RESTRAINTS = 0.3684710D+02

CYCLE= 1100

ELEM	SI (STA1)	SO (STA1)	SI (STA2)	SO (STA2)	SI (STA3)	SO (STA3)
1	-0.4213D-03	-0.3279D-03	-0.4198D-03	-0.3073D-03	-0.4585D-03	-0.3106D-03
2	-0.3324D-03	-0.4224D-03	-0.5101D-04	-0.6478D-03	0.1768D-03	-0.8119D-03
3	0.3266D-03	-0.1054D-02	-0.5300D-03	-0.1379D-02	-0.1265D-02	0.6395D-03
4	-0.2612D-02	0.2301D-02	-0.2083D-02	0.1501D-02	-0.1524D-02	0.1070D-02
5	0.8413D-03	-0.1103D-02	0.1903D-02	-0.2232D-02	0.3024D-02	-0.3305D-02
6	0.1788D-02	-0.2146D-02	0.4033D-02	-0.4246D-02	0.6446D-02	-0.5996D-02
7	0.4082D-02	-0.2314D-02	0.8124D-02	-0.4307D-02	0.8258D-02	-0.3732D-02
8	0.2080D-02	-0.1671D-02	-0.2724D-02	0.2759D-02	-0.6814D-02	0.6938D-02
9	-0.9370D-02	0.1056D-01	-0.1114D-01	0.1164D-01	-0.1112D-01	0.1386D-01
10	-0.1448D-01	0.1763D-01	0.5330D-02	-0.5124D-02	0.2023D-01	-0.2710D-01
11	0.5062D-03	-0.5676D-03	0.6421D-03	-0.9612D-03	0.1235D-02	-0.1303D-02
12	0.1073D-02	-0.1873D-02	0.2728D-02	-0.2641D-02	0.3548D-02	-0.3534D-02
13	-0.2942D-03	0.6316D-03	0.4351D-03	0.4151D-03	0.8395D-03	-0.1024D-03
14	0.1651D-02	-0.9170D-03	0.1754D-02	-0.1211D-02	0.2251D-02	-0.1514D-02
15	0.1179D-02	-0.5221D-03	0.4112D-03	0.1902D-03	-0.3471D-03	0.3292D-03
16	0.1986D-04	0.4611D-04	0.4623D-04	0.4124D-03	0.5642D-04	0.3608D-03
17	0.2476D-03	0.1137D-03	0.1117D-03	0.1912D-03	0.1491D-05	0.2893D-03
18	0.1273D-03	0.7877D-04	0.1153D-04	0.7898D-04	-0.2929D-05	0.1796D-03

CYCLE= 1100
STRAIN AT ADDITIONAL POINTS

	SI	SO	EI	EO
1	-0.11426487D-01	0.11782769D-01	-0.11492504D-01	0.11714158D-01
2	0.84256002D-03	-0.96315858D-03	0.84222535D-03	-0.96362286D-03
3	-0.45400605D-03	0.59063525D-03	-0.45410916D-03	0.59046093D-03

J= 1100 TIME= 0.11000D-02 TIME AFTER INITIAL IMPACT = 0.132204D-03

I	V	W	PSI	CHI	COPY	COPZ	L	M	STRAIN (IN)	STRAIN (OUT)
1	0.0	0.0	-0.9073D-05	-0.3796D-03	0.0	0.0	-0.1610D+04	0.1278D+02	-0.4220D-03	-0.3370D-03
2	-0.3754D-03	-0.1964D-03	-0.4289D-03	-0.3425D-01	0.9996E+00	-0.1964D-03	-0.1419D+04	-0.5423D+02	-0.4468D-03	-0.3380D-03
3	-0.7355D-03	0.7159D-04	0.1774E-02	-0.3461D-01	0.1999E+01	0.7153D-04	-0.1322D+04	0.2430D+02	0.4108D-03	-0.1140D-02
4	-0.1084D-02	0.2547D-02	0.5301D-03	-0.2750D-03	0.2999E+01	0.2547D-02	-0.1006D+04	0.2371D+03	-0.2113D-02	0.1523D-02
5	-0.1403D-02	-0.5439D-02	-0.1506D-01	-0.3644D-03	0.3999E+01	-0.5439D-02	-0.4710D+03	-0.2351D+03	-0.8427D-03	0.6091E-04
6	-0.1599D-02	-0.1272D-01	0.7246D-02	-0.1334D-03	0.4998E+01	-0.1272D-01	-0.3027D+03	-0.3730D+03	0.2333D-02	-0.2572D-02
7	-0.1994D-02	0.4477D-02	0.4782D-01	-0.1024D-02	0.5998E+01	0.9477D-02	-0.2329D+03	-0.3046D+03	0.8115D-02	-0.7788D-02
8	-0.5530D-02	0.4213D-01	[illegible]	-0.4570D-02	0.6994E+01	0.4218D-01	0.3989D+02	0.1542D+03	0.1718D-02	-0.1153D-02
9	-0.9452D-02	0.1852D+00	0.6106D-01	-0.1594D-02	0.7990E+01	0.1852D+00	-0.3534D+02	0.2617D+03	-0.8562D-02	0.9202D-02
10	-0.1385D-01	0.1647D+00	-0.1153D+00	-0.4477D-02	0.8999E+01	0.1647D+00	0.1743D+03	-0.1562D+03	-0.1565D-01	0.2000D-01
11	-0.2325D-01	0.1735D-01	-0.2914D-01	-0.2156D-01	0.9977E+01	0.1765D-01	-0.6997D+03	-0.6956D+03	0.1394D-01	-0.1397D-01
12	0.5781D-02	0.7641D-02	-0.1513D-01	-0.1249D-01	0.1350E+02	0.1009D+01	0.2159D+03	-0.2695D+04	0.1468D-02	-0.1518D-02
13	0.0	0.0	0.0	0.2564D-05	0.1153E+02	0.1550D+01	0.6376D+03	-0.2492D+00	0.3787D-02	-0.3781D-02
14	-0.2625D-01	-0.5147D-02	-0.1994D-01	0.1425D-03	0.1084E+02	-0.7707D-01	0.5597D+03	-0.3946D+02	0.1232D-02	-0.5863D-03
15	-0.2178D-01	-0.1577D-01	0.7765D-02	0.3617D-03	0.1164E+02	-0.3084D+00	0.4571D+03	-0.2682E+01	0.1911D-02	-0.1124D-02
16	-0.1938D-01	-0.1165D-02	0.9563D-02	0.1550D-03	0.1248E+02	-0.4683D+00	0.3399D+03	0.4654D+01	-0.3024D-03	0.7839D-03
17	-0.1784D-01	-0.5745D-02	0.6306D-02	0.1448D-03	0.1320E+02	-0.1163D+01	0.2272D+03	0.9931D+00	0.1806D-03	0.2289D-03
18	-0.1698D-01	-0.1249D-02	0.5411D-02	0.1261D-03	0.1382E+02	-0.1775D+01	0.6930D+02	0.8169D+00	0.7502D-04	0.2087E-03
19	-0.1653D-01	-0.1376D-02	0.5035D-02	0.1621D-03	0.1432E+02	-0.2480D+01			0.6848D-05	0.2227D-03

FRAG NO.=	PLGG =	FLGW =	ALFA =	PHOV =	PHWV =	PRAV =
1	0.8468760D+01	-0.4471198E+00	0.0	0.2607960D+04	0.8916610D+03	0.0

SUBSTRUCTURE	ASTR	ELE	SURF	STA	TIME
1	0.2105430D-01	10	1	3	0.1067000D-02
2	0.3548090D-02	12	1	3	0.1100000D-02

SUBSTRUCTURE	LARGEST ADD. PT. STRAIN	ELEM	ADD. PT.	TIME	SURFACE
1	0.1118430D-01	9	1	0.1060000D-02	2
2	0.8460490D-03	11	2	0.1060000D-02	1

SUBSTRUCTURE	LARGEST NODAL STRAIN	NODE	SURF	TIME
1	0.2484500D-01	10	2	0.1060000D-02
2	0.3786750D-02	13	1	0.1100000D-02

ENERGY AND WORK AT THE END OF TIME CYCLE 1140

FRAGMENT	KINETIC ENERGY
1	0.146465D+04

WORK INPUT INTO RING = 0.270600D+03
RING KINETIC ENERGY = 0.557450D+02
RING ELASTIC ENERGY = 0.902460D+02
RING PLASTIC WORK = 0.847750D+02
ENERGY STORED IN ELASTIC RESTRAINTS = 0.396298D+02

CYCLE= 1140

ELEM	SI STA1	SO	SI STA2	SO	SI STA3	SO
1	-0.22100-01	-0.10710-02	0.35500-03	-0.14660-02	0.82480-03	-0.19900-02
2	0.52170-03	-0.17560-02	-0.82240-03	-0.47520-03	-0.26520-02	0.77510-03
3	-0.32150-02	0.13150-02	-0.27350-02	0.32070-02	-0.22130-02	0.69940-03
4	-0.78110-03	-0.74110-03	-0.13710-03	-0.11760-02	-0.23650-04	-0.15160-02
5	-0.24350-03	-0.11170-02	0.21500-02	-0.37910-02	0.43720-02	-0.60570-02
6	0.57200-02	-0.76110-02	0.49410-02	-0.72410-02	0.45690-02	-0.65120-02
7	0.28600-02	-0.40410-02	0.49240-03	-0.22220-02	-0.15550-02	0.14770-03
8	-0.12900-02	0.21410-02	-0.64500-02	0.46650-02	-0.51610-02	0.70710-02
9	-0.81780-02	0.67650-02	-0.10140-01	0.84240-02	-0.11210-01	0.11630-01
10	-0.10760-01	0.11140-01	0.41640-02	-0.67610-02	0.16550-01	-0.23320-01
11	0.11470-01	-0.60920-01	0.11140-02	-0.13140-02	0.17570-02	-0.17350-02
12	0.24660-02	-0.24470-02	0.14820-02	-0.32070-02	0.43710-02	-0.42370-02
13	-0.35650-01	-0.79140-03	-0.78110-03	-0.12150-02	-0.63420-03	-0.12010-02
14	-0.17410-01	-0.11110-02	0.14560-03	-0.16110-02	0.51630-03	-0.21350-02
15	0.11890-02	-0.26370-02	0.61710-03	-0.20330-02	0.11640-03	-0.13600-02
16	-0.12450-02	0.17410-04	-0.15580-02	0.16090-04	-0.96030-03	-0.11430-04
17	-0.75670-03	-0.25540-04	-0.11360-03	-0.23340-03	-0.57060-04	-0.46790-03
18	-0.27090-03	-0.83370-04	-0.88020-04	-0.81160-04	-0.29820-04	-0.20620-03

CYCLE= 1140

STRAIN AT ADDITIONAL POINTS	SI	SO	EI	EO
1	-0.10527297D-01	0.84841672D-02	-0.10593307D-01	0.69141642D-02
2	0.11044586D-02	-0.10315595D-02	0.11036790D-02	-0.10340932D-02
3	0.24791246D-03	-0.66245429D-03	-0.24704296D-03	-0.66207346D-03

J= 1140 TIME= 0.114000D-02 TIME AFTER INITIAL IMPACT = 0.172204D-03

I	V	W	PSI	CHI	COPY	COPZ	L	M	STRAIN(INN)	STRAIN(OUT)
1	0.0	0.0	-0.27500-02	-0.64490-03	0.0	0.0	-0.24170+04	-0.19140+03	-0.40470-03	-0.97620-03
2	-0.57310-03	-0.39730-03	0.35530-02	-0.60350-01	0.49940+00	-0.39730-01	-0.26230+04	0.31660+02	0.94100-03	-0.21350-02
3	-0.12230-02	0.45120-02	0.22420-02	-0.62620-03	0.19990+01	0.45320-02	-0.27050+04	0.31090+03	-0.24620-02	0.16150-02
4	-0.19870-02	-0.29150-02	-0.13480-01	-0.65180-03	0.24980+01	-0.20150-02	-0.26740+04	-0.52140+02	-0.14700-02	-0.30070-04
5	-0.24520-02	-0.18730-01	-0.10250-01	-0.66400-03	0.39970+01	-0.14750-01	-0.25850+04	-0.32750+03	-0.46320-03	-0.31590-02
6	-0.37070-02	-0.15100-01	0.14300-01	-0.45700-03	0.47460+01	-0.15460-01	-0.26340+04	-0.49710+03	0.55440-02	-0.71310-02
7	-0.62170-02	0.18400-01	0.12170-01	-0.24240-02	0.59740+01	0.14310-01	-0.22050+04	-0.94050+02	0.44430-02	-0.58080-02
8	-0.11670-01	0.13380+00	0.70110-01	-0.54740-02	0.69480+01	0.13040+03	-0.23200+04	0.31250+03	-0.22720-02	0.97610-03
9	-0.15290-01	0.23050+00	0.24060-01	-0.11260-02	0.73850+01	0.20650+00	-0.18700+04	0.14100+03	-0.66330-02	0.69650-02
10	-0.17470-01	0.15910+00	-0.12370+00	-0.65670-02	0.89830+01	0.15910+03	-0.21600+04	-0.16310+03	-0.13140-01	0.15350-01
11	-0.24070-01	0.22220-01	-0.24860-01	-0.65350-01	0.99710+01	0.22220-01	0.41160+03	-0.32710+03	0.11520-01	-0.12310-01
12	0.70870-02	0.94410-02	-0.18900-01	-0.22510-01	0.10490+02	0.10110+01	0.11740+04	-0.26160+04	0.20130-02	-0.21120-02
13	0.0	0.0	0.0	0.41670-04	0.11500+02	0.15000+01	-0.15510+04	-0.62700+01	0.46130-02	-0.45320-02
14	-0.31690-01	-0.30650-02	-0.20510-01	-0.94500-01	0.10480+02	-0.73430-01	-0.12400+04	-0.24450+02	-0.37760-03	-0.11710-02
15	-0.30220-01	-0.27190-01	-0.34470-02	-0.60110-01	0.11670+02	-0.31000+00	-0.10400+04	-0.33060+02	0.10480-02	-0.24480-02
16	-0.27410-01	-0.16180-01	0.19680-01	-0.84510-03	0.12470+02	-0.67020+00	-0.78120+03	0.13420+02	-0.61590-03	-0.60620-03
17	-0.25970-01	-0.30460-02	0.10300-01	-0.48930-03	0.11190+02	-0.11140+01	-0.47070+03	0.20030+01	-0.86490-03	-0.33540-05
18	-0.25150-01	-0.59560-02	0.89030-02	-0.27340-03	0.11410+02	-0.17700+01	-0.12690+03	0.85600-01	-0.14940-03	-0.31810-03
19	-0.24670-01	-0.19510-02	0.94500-02	-0.10660-03	0.14321+02	-0.24600+01			-0.30260-04	-0.26050-03

FRAG NO.=	FCUU =	FCUW =	ALFA =	FRUV =	FRVV =	FRAT =
1	0.897107D+01	-0.411453D+00	0.0	0.260796D+04	0.891661D+03	0.0

SUBSTRUCTURE	MSTN	ELE	SURF	STA	TIME
1	0.210563D-01	10	1	3	0.106700D-02
2	0.437275D-02	12	1	3	0.114000D-02

SUBSTRUCTURE	LARGEST ADD. PT. STRAIN	ELEM	ADD. PT.	TIME	SURFACE
1	0.133849D-01	9	1	0.106000D-02	2
2	0.110449D-02	11	2	0.114000D-02	1

SUBSTRUCTURE	LARGEST NODAL STRAIN	NODE	SURF	TIME
1	0.244450D-01	10	2	0.106000D-02
2	0.441435D-02	13	1	0.114000D-02

IMPACT NO. 2 TIME 0.1140140-02 DURING CYCLE 1149 -ALES 10 FRAG 1 DISTANCE 0.4829626-01

ENERGY AND WORK AT THE END OF TIME CYCLE 1160

FRAGMENT	KINETIC ENERGY
1	0.1324640+04

WORK INPUT INTO RING	=	0.4112090+03
RING KINETIC ENERGY	=	0.1124570+03
RING ELASTIC ENERGY	=	0.1083060+03
RING PLASTIC WORK	=	0.1284660+03
ENERGY STORED IN ELASTIC RESTRAINTS	=	0.5748450+02

CYCLE= 1160

ELEM	SI STA1	SO	SI STA2	SO	SI STA3	SO
1	-0.97850-03	0.45200-03	-0.14870-02	0.13530-02	-0.26990-02	0.22470-02
2	-0.22910-02	0.16910-02	-0.11940-02	0.65200-03	-0.55750-03	0.65640-05
3	-0.76290-03	0.23550-03	-0.12200-02	0.94330-03	-0.17050-02	0.15600-02
4	-0.11410-02	0.13990-02	0.11900-02	-0.11540-02	0.37650-02	-0.32240-02
5	0.45570-02	-0.45940-02	0.57720-02	-0.53490-02	0.65460-02	-0.60680-02
6	0.61200-02	-0.55760-02	0.53160-02	-0.44770-02	0.44750-02	-0.35160-02
7	0.22690-02	-0.17460-02	-0.81500-03	0.23270-02	-0.37300-02	0.63510-02
8	-0.29520-02	0.53710-02	-0.24420-02	0.35080-02	-0.95590-03	0.27130-02
9	0.67930-02	-0.22340-02	-0.83000-02	0.99210-02	-0.16000-01	0.24510-01
10	-0.28990-01	0.36110-01	0.53030-02	-0.30040-02	0.28370-01	-0.43720-01
11	0.67670-03	-0.71320-03	0.14610-02	-0.14420-02	0.27660-02	-0.22190-02
12	0.24250-02	-0.24340-02	0.34300-02	-0.31470-02	0.43430-02	-0.39910-02
13	0.26080-02	-0.22550-02	0.15000-02	-0.74260-03	-0.14450-03	0.17150-02
14	0.17190-03	0.11650-02	0.11420-03	0.62220-03	0.17850-02	-0.29660-03
15	0.19450-02	-0.19350-03	0.19160-02	-0.52560-03	0.24800-02	-0.72640-03
16	0.13810-02	-0.74560-03	0.86350-03	0.41190-03	-0.57640-03	0.15460-02
17	-0.53170-03	0.11240-02	-0.17960-03	0.52680-03	0.16320-03	0.31190-03
18	0.44910-03	-0.84600-04	0.25900-03	-0.90000-04	0.17190-03	0.12150-04

CYCLE= 1160

STRAIN AT ADDITIONAL POINTS	SI	SO	SI	SO
1	-0.92480586D-02	0.10505199D-01	-0.92912220D-02	0.10767445D-01
2	0.14609247D-02	-0.14722013D-02	0.14599591D-02	-0.14933160D-02
3	0.27719090D-02	-0.24226733D-02	0.27680779D-02	-0.24256151D-02

J= 1160 TIME= 0.116000D-02 TIME AFTER INITIAL IMPACT = 0.212208D-03

I	V	W	PSI	CHI	COPY	COPZ	L	M	STRAIN(IN)	STRAIN(OUT)
1	0.0	0.0	0.1146D-01	-0.3048D-03	0.0	0.0	-0.1380D+04	0.3511D+03	-0.6707D-03	0.1845D-03
2	-0.3361D-03	0.7142D-02	-0.6244D-04	-0.3146D-03	0.9997E+00	0.7142D-02	-0.1398D+04	0.2047D+03	-0.2851D-02	0.2224D-02
3	-0.6403D-03	0.1625D-02	-0.6380D-02	-0.3502D-03	0.1999E+01	0.1623D-02	-0.5104D+01	0.1694D+03	-0.5119D-03	-0.1182E-03
4	-0.8657D-03	-0.1036D-01	-0.1760E-01	-0.2049D-03	0.2999E+01	-0.1066D-01	0.4068D+03	-0.1662E+03	-0.1878D-02	0.1751D-02
5	-0.8751D-03	-0.2594E-01	-0.5997D-02	0.3377D-01	0.3999E+01	-0.2599D-01	0.1076D+04	-0.5987D+03	0.4506D-02	-0.3795E-02
6	-0.8159D-03	-0.4822D-02	0.4572D-01	-0.8093D-03	0.4999E+01	-0.8424D-02	0.1842E+04	-0.3995D+03	0.6577D-02	-0.6105D-02
7	-0.3211E-02	0.6471D-01	0.4727D-01	-0.4499D-02	0.5997E+01	0.6471D-01	0.2539E+04	0.1323D+03	0.3709D-02	-0.2827D-02
8	-0.6808D-02	0.1599D+00	0.7573D-01	-0.1191D-02	0.6991E+01	0.1599D+00	0.1123D+04	0.1521D+03	-0.3661D-02	0.6616D-02
9	-0.7591D-02	0.2113E+00	0.3746E-01	0.4624D-01	0.7992E+01	0.2135E+00	0.1217D+04	0.1602E+03	0.4140D-02	-0.1775D-02
10	-0.6717D-02	0.2224E+00	-0.1023E+00	0.3660D-02	0.8991E+01	0.2223D+03	0.2137D+04	-0.1179D+03	-0.2520D-01	0.4217D-01
11	-0.2975D-01	0.2221E-01	-0.2667D-01	-0.5350D-03	0.9372E+01	0.2221D-01	-0.1815D+01	-0.1142D+04	0.2371D-01	-0.2350D-01
12	0.6843D-02	0.4213E-02	-0.1844D-01	-0.2494D-01	0.1049E+02	0.1013D+01	0.1754D+04	-0.2552D+04	0.2160D-02	-0.2339D-02
13	0.0	0.0	0.0	0.1648D-01	0.1150E+02	0.1503D+01	0.1351D+04	-0.1743D+02	0.4565D-02	-0.4255E-02
14	-0.3139D-01	0.4141D-02	-0.1449D-01	0.3512D-03	0.1348E+02	-0.6435D-01	0.1308D+04	-0.6752E+01	-0.5619D-03	0.1554D-02
15	-0.2997D-01	-0.1610E-01	-0.9757D-02	0.6550D-03	0.1164E+02	-0.33 D+00	0.1097E+04	-0.3142D+02	0.1875D-02	-0.8693D-03
16	-0.2610D-01	-0.1594E-01	0.1221E-01	0.5873D-03	0.1247E+02	-0.6721D+00	0.8058D+03	-0.3159D+01	0.2215D-02	-0.8902D-03
17	-0.2348D-01	-0.7174D-02	0.1642D-01	0.2895D-03	0.1319E+02	-0.1160D+01	0.4884D+03	0.1253D+02	-0.8374D-03	0.1624D-02
18	-0.2234D-01	-0.4711D-02	0.5649D-02	0.2182D-03	0.1341D+02	-0.1772D+01	0.1268D+03	-0.4363D+01	0.4072D-03	0.6134D-04
19	-0.2177D-01	-0.1275D-02	0.6703D-02	0.6914D-04	0.1483E+02	-0.2482D+01			0.1593D-03	0.5474D-04

FRAG NO.=	FCUO =	FCUW =	ALPA =	FRUF =	FRUY =	FRAT =
1	0.907592D+01	-0.386583E+00	0.0	0.256158D+04	0.552768D+03	0.0

SUBSTRUCTURE	ASTR	ELT	SURF	STA	TIME
1	0.361107D-01	10	2	1	0.118000D-02
2	0.451581D-02	12	1	3	0.117600D-02

SUBSTRUCTURE	LARGEST ADD. PT. STRAIN	ELEM	ADD. PT.	TIME	SURFACE
1	0.111691D-01	9	1	0.106000D-02	2
2	0.146092D-02	11	2	0.116000D-02	1

SUBSTRUCTURE	LARGEST NODAL STRAIN	NODE	SURF	TIME
1	0.421717D-01	10	2	0.114033D-02
2	0.461535D-02	13	1	0.116000D-02

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IMPACT NO.	3	TIME	0.121788D-02	DURING CYCLE	1218	ELEM	10	FRAG	1	DISTANCE	0.304644D+00
IMPACT NO.	4	TIME	0.126018D-02	DURING CYCLE	1261	ELEM	10	FRAG	1	DISTANCE	0.438616D+00
IMPACT NO.	5	TIME	0.129900D-02	DURING CYCLE	1300	ELEM	10	FRAG	1	DISTANCE	0.551844D+00
IMPACT NO.	6	TIME	0.133756D-02	DURING CYCLE	1338	ELEM	10	FRAG	1	DISTANCE	0.653507D+00
IMPACT NO.	7	TIME	0.137223D-02	DURING CYCLE	1373	ELEM	10	FRAG	1	DISTANCE	0.734153D+00

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ENERGY AND WORK AT THE END OF TIME CYCLE 1540

FRAGMENT	KINETIC ENERGY
1	0.105911D+04

WORK INPUT INTO RING = 0.676136D+03
RING KINETIC ENERGY = 0.115374D+03
RING ELASTIC ENERGY = 0.103445D+03
RING PLASTIC WORK = 0.407417D+03
ENERGY STORED IN ELASTIC RESTRAINTS = 0.493603D+02

CYCLE= 1540

ELEM	SI STA1	SO	SI STA2	SO	SI STA3	SO
1	0.1610D-01	0.4492D-03	0.7121D-01	0.1670D-01	0.5611D-03	-0.0136D-03
2	0.1374D-03	-0.9547D-03	0.4329D-01	-0.7739D-01	0.9717D-03	-0.2930D-03
3	0.1926D-02	-0.1091D-02	0.2852D-02	-0.2460D-02	0.4232D-02	-0.3037D-02
4	0.4996D-02	-0.1314D-02	0.4514D-02	-0.2365D-02	0.1935D-02	-0.2534D-02
5	0.3641D-02	-0.2514D-02	0.4450D-02	-0.3773D-02	0.5354D-02	-0.4767D-02
6	0.4359D-02	-0.3145D-02	0.7043D-01	0.5114D-03	-0.2145D-02	0.4276D-02
7	-0.4906D-02	0.7435D-02	-0.6021D-02	0.5307D-02	-0.9642D-02	0.1149D-01
8	-0.6334D-02	0.9227D-02	-0.4604D-02	0.6311D-02	-0.1674D-02	0.4606D-02
9	0.5146D-02	-0.1176D-02	0.1694D-02	0.6311D-02	0.2378D-02	0.1606D-01
10	-0.1668D-01	0.3311D-01	0.7012D-02	-0.2549D-02	0.2414D-01	-0.3703D-01
11	0.1347D-03	-0.1244D-02	0.7463D-03	-0.4154D-03	-0.1451D-03	-0.1074D-02
12	-0.9157D-03	-0.1214D-03	0.2353D-02	-0.2328D-02	0.4155D-02	-0.5814D-02
13	0.2079D-02	-0.2147D-02	0.2843D-02	0.1286D-02	0.7644D-03	0.1860D-02
14	0.1656D-02	0.3641D-03	0.1611D-02	0.1727D-02	0.1237D-03	0.1246D-02
15	-0.2493D-04	0.1411D-02	0.4731D-03	0.2466D-02	-0.1026D-02	0.1466D-02
16	0.1039D-02	-0.1312D-02	0.2403D-02	-0.6179D-03	0.1583D-02	-0.1725D-02
17	-0.4163D-03	0.7643D-03	0.1371D-02	0.1406D-03	0.1677D-02	-0.2049D-02
18	0.3352D-03	-0.1397D-02	-0.8204D-04	0.7013D-03	-0.2113D-02	0.1167D-02

CYCLE= 1540

STRAIN AT ADDITIONAL POINTS	SI	SO	EI	EO
1	0.158441450D-02	0.703378960D-02	0.158316130D-02	0.698538280D-02
2	0.746773430D-03	-0.416827440D-03	0.746436830D-03	-0.416910350D-03
3	0.177307480D-02	-0.291713640D-02	0.177150570D-02	-0.252140370D-02

J= 1540 TIME= 0.154000D-02 TIME AFTER INITIAL IMPACT = 0.572204D-03

I	V	W	PSI	CHI	COPY	COPZ	L	M	STRAIN(IN)	STRAIN(OUT)
1	0.0	0.0	-0.1403D-02	0.1397D-03	0.0	0.0	0.1570D+04	-0.5948D+02	-0.3323D-03	0.4133D-03
2	0.2803D-03	-0.1061D-02	0.5423D-03	-0.4155D-03	0.1000E+01	-0.1061D-02	0.1119D+04	0.1565E+03	0.2512D-03	-0.1082D-02
3	0.1323D-03	0.1575D-02	0.4923D-02	0.5364D-03	0.2002E+01	0.7575D-02	0.9125D+03	-0.4377D+03	0.1463E-02	-0.3614D-03
4	0.4136D-03	0.1497D-01	0.2571D-01	0.4843D-03	0.3300E+01	0.1497D-01	0.1604D+04	-0.3711E+03	0.4924D-02	-0.3302E-02
5	0.2595D-01	0.5744D-01	0.5741D-01	-0.1034D-02	0.4330E+01	0.5744D-01	0.2254D+03	-0.3774D+03	0.3570D-02	-0.2298D-02
6	-0.2242D-02	0.1126D+00	0.4704D-01	-0.4371D-02	0.4194E+01	0.1126D+00	0.2321D+04	0.3426D+02	0.5438D-02	-0.4719D-02
7	-0.7153D-02	0.2319D+00	0.5863E-01	-0.3561D-02	0.5193E+01	0.2374D+00	0.2236D+04	0.5155D+03	-0.3637D-02	0.6093D-02
8	-0.7719D-02	0.2946E+00	0.3110D-02	0.2126D-02	0.6492E+01	0.2942D+00	0.1474D+04	0.2806D+03	-0.7435D-02	0.1150D-01
9	-0.7564D-02	0.2556D+00	-0.4814E-01	-0.4144D-03	0.7492E+01	0.2556D+00	0.2395D+04	-0.2617D+03	0.3131D-02	0.6512D-03
10	-0.4993D-02	0.1175D+00	-0.1037D+00	0.6344D-02	0.4445E+01	0.1675D+00	0.1301D+04	-0.7004D+02	-0.9193D-02	0.3369E-01
11	-0.1961D-01	0.1754D-01	-0.1033D-01	-0.1174D-02	0.1134E+01	0.1754D-01	0.1415D+04	-0.4501D+03	0.1594D-01	-0.2997D-01
12	0.6927D-02	0.3134D-02	-0.1307E-01	-0.1167D-02	0.1053E+02	0.1312D+01	0.8744D+03	0.2332E+03	-0.1417D-02	-0.7634E-03
13	0.0	0.0	0.0	-0.1334D-02	0.1150E+02	0.1530D+01	0.3394D+04	-0.1442D+02	0.4420D-02	-0.7089D-02
14	-0.2076D-01	0.1012D-01	-0.2604D-02	0.4754D-03	0.1345E+02	-0.4234D-01	0.2713D+04	-0.2043E+01	0.4264E-03	0.5305D-03
15	-0.2106D-01	0.6604D-02	-0.1041E-02	0.1046D-03	0.1167E+02	-0.2491D+00	0.2204D+04	0.2441E+02	-0.5226D-03	0.7430E-03
16	-0.2372D-01	-0.4654D-02	-0.1463D-01	-0.7064E-03	0.1248E+02	-0.6536D+00	0.1216D+04	-0.3572D+02	-0.7348D-03	-0.3314D-03
17	-0.1991D-01	-0.1451D-01	0.6633D-02	-0.3364D-01	0.1111D+02	-0.1164D+01	0.9327D+03	-0.1193D+02	0.2334E-03	-0.8501D-03
18	-0.1568D-01	-0.1168D-01	0.1505D-01	-0.1113D-02	0.1151D+02	-0.1711E+01	0.4659D+03	0.9817D+01	0.5603D-03	-0.2557D-02
19	-0.1519D-01	-0.1436D-04	0.8265D-02	-0.1101D-02	0.1432D+02	-0.2467D+01			-0.3065D-02	0.9321D-03

FRAG NO.=	FCWD =	FCWN =	ALFA =	FROT =	FREV =	FRAT =
1	0.990431D+01	-0.346525E+00	0.0	0.220312D+04	-0.799633D+03	0.0

SUBSTRUCTURE	KSTP	ELE	SURF	STA	TIME
1	0.579012D-01	10	2	1	0.127400D-02
2	0.127452D-01	14	1	3	0.136400D-02

SUBSTRUCTURE	LARGEST ADD. PT. STRAIN	ELEM	ADD. PT.	TIME	SURFACE
1	0.176136E-01	9	1	0.130000D-02	2
2	0.182435D-02	11	2	0.126000D-02	1

SUBSTRUCTURE	LARGEST NODAL STRAIN	ELEM	SURF	TIME
1	0.640072D-01	10	2	0.130000D-02
2	0.115226D-01	13	1	0.134000D-02

ENERGY AND WORK AT THE END OF TIME CYCLE 1580

FRAGMENT	KINETIC ENERGY
1	0.105911D+04

WORK INPUT INTO RING = 0.676136D+03
RING KINETIC ENERGY = 0.967770D+02
RING ELASTIC ENERGY = 0.883312D+02
RING PLASTIC WORK = 0.458065D+03
ENERGY STORED IN ELASTIC RESTRAINTS = 0.321583D+02

CYCLE= 1580

ELEM	SI STA1	SO	SI STA2	SO	SI STA3	SO
1	-0.3441D-03	0.1539D-03	0.1416D-01	-0.6080E-01	0.5523D-01	-0.1376D-02
2	0.1881D-02	-0.2218D-02	0.2039D-02	-0.2812D-02	0.2512D-02	-0.2653D-02
3	0.2126D-02	-0.2312D-02	0.1146D-02	-0.6018E-03	-0.9317D-05	0.4452D-03
4	0.6393D-01	0.1244D-03	0.3113D-02	-0.1711E-02	0.5424D-02	-0.3230D-02
5	0.6122D-02	-0.3913D-02	0.6424D-02	-0.3776D-02	0.3024D-02	-0.1994E-02
6	0.2264D-02	-0.1443D-02	0.1240D-02	-0.4467E-03	0.9538D-03	0.1231D-02
7	-0.1494D-02	0.8676D-02	-0.8546D-02	0.1642E-01	-0.1444D-01	0.1634D-01
8	-0.8517D-02	0.1431D-01	-0.5028E-02	0.5533D-02	-0.1016D-02	0.1741D-02
9	0.3577D-02	-0.2769D-02	0.3633D-02	0.2658E-02	0.9354D-02	0.1163D-01
10	-0.1077D-01	0.2743D-01	0.3777D-02	-0.2512D-02	0.1694D-01	-0.2774E-01
11	0.5247D-01	-0.6448D-03	0.3400D-03	-0.5460D-03	-0.8937D-04	-0.8665D-03
12	-0.1336D-02	0.1637D-01	0.3507D-02	-0.2244E-02	0.3404D-02	-0.5144D-02
13	-0.6346D-03	0.9194D-04	0.9612D-04	-0.2359D-03	0.3756D-03	-0.1447D-02
14	-0.1262D-02	-0.7593D-04	-0.1226E-02	-0.1423E-02	0.2071D-03	-0.2345D-02
15	0.5460D-03	-0.1084D-02	-0.5040D-03	-0.2492E-02	-0.3565D-03	-0.6739D-03
16	-0.3497D-02	0.3277E-02	-0.3925D-02	0.9645E-03	-0.1735D-02	0.1531D-02
17	0.1736D-02	-0.1254D-02	0.6862D-03	-0.2340E-02	0.8742E-03	-0.2144D-02
18	0.2426D-02	-0.2446D-02	0.2466D-02	-0.3238D-02	0.3219D-02	-0.3637D-02

CYCLE= 1580

STRAIN AT ADDITIONAL POINTS	SI	SO	EI	EO
1	0.35C46598D-02	0.26140874D-02	0.35981861D-02	0.26336271D-02
2	0.38037724D-03	-0.59657211E-03	0.37995506D-03	-0.59675316D-03
3	-0.50103742D-03	0.24324392D-03	-0.50116206D-03	0.24321434D-03

J= 1580 TIME= 0.158300D-02 TIME AFTER INITIAL IMPACT = 0.612204D-03

I	V	W	PSI	CHI	COPT	CUPZ	L	M	STRAIN(IN)	STRAIN(OUT)
1	0.0	0.0	0.3973D-02	-0.6599D-04	0.0	0.0	-0.1014D+04	-0.7880D+02	-0.4948D-03	0.3697E-03
2	-0.2441D-01	0.2352D-02	0.4553E-02	-0.4412E-03	0.1998E+00	0.2352D-02	0.1146D+04	-0.1405D+03	0.9647D-03	-0.1491D-02
3	-0.5614D-03	0.1441D-01	0.2103E-01	-0.2763D-03	0.1749E+01	0.1444D-01	0.1036D+04	-0.1172D+03	0.2537D-02	-0.2622E-02
4	-0.6945E-03	0.4391D-01	0.2401E-01	-0.2059D-03	0.2997E+01	0.4091D-01	0.8592D+03	-0.1901D+03	-0.3543D-03	0.7322D-03
5	-0.6535E-03	0.7474D-01	0.4822E-01	0.1741D-03	0.1999E+01	0.7414D-01	0.1402D+04	-0.3320D+03	0.6444D-02	-0.3913D-02
6	-0.2254D-02	0.1411D+00	0.8344D-01	-0.2441D-02	0.4399E+01	0.1431D+00	0.1772E+04	-0.2790D+02	0.2642D-02	-0.1594D-02
7	-0.5731D-02	0.2131D+00	0.4217E-01	-0.2563D-02	0.5994E+01	0.2331D+00	0.2164D+04	0.4757E+03	0.6956E-03	0.2194D-02
8	-0.8569E-02	0.2167D+00	-0.1939D-01	0.1141D-02	0.6943E+01	0.2980D+00	0.5270D+03	0.2763D+03	-0.1225D-01	0.1530D-01
9	-0.9415E-02	0.2215D+00	-0.6461D-01	-0.1467E-02	0.7992E+01	0.2216D+00	0.1649D+03	-0.2839D+03	0.2357D-02	-0.1244E-02
10	-0.7243D-02	0.1445D+00	-0.7945D-01	0.9445D-02	0.3993E+01	0.1445D+00	-0.1462E+04	-0.3437D+02	-0.1237D-02	0.2733D-01
11	-0.1554D-01	0.1414E-01	-0.1297D-01	-0.1342D-03	0.3944E+01	0.1414D-01	-0.1257D+04	-0.3774D+03	0.1373D-01	-0.1478E-01
12	0.5406D-02	0.6874D-02	-0.1026E-01	-0.6945D-03	0.1350E+02	0.1036D+01	-0.2120D+04	0.6226D+03	-0.1124D-02	-0.1696E-03
13	0.0	0.0	0.0	-0.1154D-02	0.1153E+02	0.1520D+01	-0.5549E+03	-0.1165D+02	0.3745E-02	-0.6173D-02
14	-0.1713D-01	0.1303D-02	-0.4861D-02	-0.1494D-03	0.1065E+02	-0.7171D-01	-0.2362D+04	-0.8823D+01	0.4234E-04	-0.4555E-03
15	-0.1755E-01	-0.6373E-02	0.1236E-02	-0.5626D-03	0.1169E+02	-0.3317E+03	-0.2923D+04	-0.2647D+02	0.1212D-02	-0.2375D-02
16	-0.1843E-01	0.1714E-02	0.1624D-01	-0.1647D-03	0.1249E+02	-0.6572D+03	-0.2221D+04	0.6112D+02	-0.1522E-02	0.2464D-02
17	-0.1314D-01	-0.6347D-02	-0.2457E-01	0.6742D-03	0.1319E+02	-0.1153D+01	-0.1240D+04	-0.3742D+02	0.7457D-03	0.7647E-03
18	-0.1731D-01	-0.2094D-01	0.1792E-02	-0.3634D-03	0.1340E+02	-0.1734E+01	-0.2793D+03	-0.7631D+02	0.1629D-02	-0.2417D-02
19	-0.1527D-01	0.8761D-03	0.5516E-01	-0.1712D-02	0.1632E+02	-0.2460D+01			0.3352D-02	-0.3731E-02

FRAG NO.=	FCGX =	FCGY =	ALFA =	FAUT =	FRAT =	FRAT =
1	0.999243D+01	-0.578511E+00	0.0	0.220312D+04	-0.799533D+03	0.0

SUBSTRUCTURE	MSTN	ELE	SURF	STA	TIME
1	0.579012D-01	10	2	1	0.127400D-02
2	0.127942D-01	12	1	3	0.136903D-02

SUBSTRUCTURE	LARGEST ADD. PT. STRAIN	ELEM	ADD. PT.	TIME	SURFACE
1	0.170128D-01	9	1	0.130000D-02	2
2	0.182435D-02	11	2	0.126000D-02	1

SUBSTRUCTURE	LARGEST NODAL STRAIN	NODE	SURF	TIME
1	0.640032E-01	10	2	0.130000D-02
2	0.135229E-01	13	1	0.134000D-02

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THE LARGEST COMPUTED STRAINS FOR EACH SUBSTRUCTURE-- MAIN AND BRANCHES -- ARE PRINTED BELOW, 1= INNER 2= OUTER SURF

SUBSTRUCTURE	MSTN	ELE	SURF	STA	TIME
1	0.579012D-01	10	2	1	0.127400D-02
2	0.127942D-01	12	1	3	0.136903D-02

SUBSTRUCTURE	LARGEST ADD. PT. STRAIN	ELEM	ADD. PT.	TIME	SURFACE
1	0.170128E-01	9	1	0.130000D-02	2
2	0.182435D-02	11	2	0.126000D-02	1

SUBSTRUCTURE	LARGEST NODAL STRAIN	NODE	SURF	TIME
1	0.640032E-01	10	2	0.130000D-02
2	0.135226E-01	13	1	0.134000D-02

NO CARDS PUNCHED DURING THIS RUN FOR CONTINUATION.

ORIGINAL PAGE IS
OF POOR QUALITY

6.2 A Uniform-Thickness, Unsupported Complete Circular Ring Subjected to a T-58 Rotor Tri-Hub Burst

6.2.1 *Problem Description*

The geometry of the free-ring containment structure, as shown in Fig. 10, is a free circular ring, 0.4 in thick, 2.5 in wide, with a mean radius of 7.7 in. The ring is subjected to a tri-hub burst (consisting of three perfectly symmetric fragments which are idealized as being circular and non-deformable) with each fragment being released at different times. Forty uniform finite elements are used to model the complete ring.

The 4130 cast steel ring material is represented by a three-mechanical-sublayer model defined by σ_1, ϵ_1 = 80,950 psi, .00279; σ_2, ϵ_2 = 105,300 psi, .0225; and σ_3, ϵ_3 = 121,000 psi, .2000 with an elastic modulus of 29 x 10^6 psi and a yield stress of 80,950 psi. The strain rate constants are D = 40.4 sec^{-1} and P = 5, and the mass density is taken to be 0.733085 x 10^3 ($lb\text{-}sec^2/in^4$).

The attacking fragments (Fig. 10) have the following similar properties: radius r_f = 2.42 in; mass m_f = 0.932 x 10^{-2} ($lb\text{-}sec^2$); mass moment of inertia I_f = 0.666 x 10^{-1} ($lb\text{-}sec^2\text{-}in$); initial translational velocity of 5515 in/sec and an initial clockwise negative angular velocity of -1972.0 (rad/sec). The value of the coefficient of restitution, e, is set at 1.0 to represent a perfectly-elastic impact reaction, and the coefficient of friction μ is assumed for illustration to equal 0.5.

The fragments are located 120^o apart from each other, and their C.G.'s are at the same radial location 2.797 in. The TPRIM of the first fragment equals 0.760000 x 10^{-3} sec and determines the start of the computer calculations. The second fragment is assumed to be released 160 μseconds after the first fragment; hence, its TPRIM equals 0.600000 x 10^{-3} sec. The third and last fragment is assumed to be released 910 μseconds after the first fragment; thus, its TPRIM equals -0.150000 x 10^{-3} sec. (Note: the third fragment is released after calculations have begun.) An additional strain point is specified on element 40 near the point of first impact; the $\bar{s}$ coordinate equals 0.57.

The CIVM-JET 4B program will solve this collision interaction using a time step of 2 microseconds. Printout starts several microseconds after initial impact and will continue every 20 cycles until 300 cyles have been completed.

6.2.2 Input Data

The values to be punched on the data cards are as follows:

Card 1 3D15.6

B(1)	= 0.250000D+01	
DENS(1)	= 0.733085D-03	
EXANG	= 0.360000D+03	(Complete ring)

Card 2 8I5, D15.6

IK	= 40
NOGA	= 3
NFL	= 4
NSFL(1)	= 3
MM	= 690
M1	= 390
M2	= 20
NF	= 3
TIMF	= 0.138000D-02

Card 3A 4D15.6

Y(1)	= 0.0
Z(1)	= 0.770000D+01
ANG(1)	= 0.0
N(1)	= 0.400000D+00

⋮

Additional cards are punched until all 40 nodes of the main structure are described.

Y(40)	= -0.120454D+01
Z(40)	= 0.760520D+01
ANG(40)	= 0.900000D+01
H(40)	= 0.400000D+00

Card 4A I5

NDIS = 0

Skip to Card 5

Card 5 I5

NBR = 0

Skip to Card 6

Card 6 3D15.6,I5

DELTAT = 0.200000D-05

DS(1) = 0.404000D+02

$\bar{P}$(1) = 0.500000D+01

NTOVR = BLANK

Card 7AA 4D15.6

EPS(1,1) = 0.279000D-02

SIG(1,1) = 0.809500D+05

EPS(2,1) = 0.225000D-01

SIG(2,1) = 0.105300D+06

EPS(3,1) = 0.200000D+00

SIG(3,1) = 0.121000D+06

Card 8 2I5

NOP = 3

NASP = 1

Card 8A 2I5, D15.6

NSBS(1) = 1

NSEL(1) = 40

AZET(1) = 0.570000D+00

Card 9AA 5D15.6

FH(1) = 0.484000D+01

FCG(1) = 0.139850D+01

FCGX(1) = -0.242227D+01

FMASS(1) = 0.932000D-02

FMOI(1) = 0.666000D-01

Card 9AB D15.6

UNK = 0.500000D+00

Card 9AC 5D15.6

UDOT(1) = 0.275750D+04

WDOT(1) = 0.477613D+04

ADOT(1) = -0.197200D+04

TPRIM(1) = 0.760000D-03

CR(1) = 0.100000D+01

Repeat the above block of 3 cards until all 3 fragments are described.

Card 9CA 5D15.6

FH(3) = 0.484000D+01

FCG(3) = -0.279700D+01

FCGX(3) = 0.0

FMASS(3) = 0.932000D-02

FMOI(3) = 0.666000D-C1

Card 9CB D15.6

UNK(3) = 0.500000D+00

Card 9CC 5D15.6

UDOT(3) = -0.551500D+04

WDOT(3) = 0.0

ADOT(3) = -0.197200D+04

TPRIM(3) = -0.150000D-03

CR(3) = C.100000D+01

Card 10 3D25.16

AXG(1) = 0.1127016653792585D+00

AXG(3) = 0.5000000000000000D+00

AXG(3) = 0.8872983346207415D+00

Card 11 3D25.16

AWG(1) = 0.2777777777777778D+00

AWG(2) = 0.4444444444444444D+00

AWG(3) = 0.2777777777777778D+00

Card 12A 3D25.16

TXG(1) = -0.8611363115940530D+00

TXG(2) = -0.3399810435848560D+00

TXG(3) = 0.3399810435848560D+00

Card 12B 3D25.16

TXG(4) = 0.8611363115940530D+00

Card 13A 3D25.16

TWG(1) = 0.3478548451374540D+00

TWG(2) = 0.6521451548625460D+00

TWG(3) = 0.6521451548625460D+00

Card 13B 3D25.16

TWG(4) = 0.3478548451374540D+00

Card 14A I5

NBCOND = 0

Skip to Card 15

Card 15 3I5

NQR = 0

NORP = 0

NORU = 0

Skip to Card 16

Card 16 I5

ICONT = 0

Skip to Card 17

Card 17 I5

ICON = 0

The program will now terminate its run.

```
   THIS IS THE INPUT DECK FOR EXAMPLE 6.2
00.250000D+01  00.733085D-03  00.360000D+03
 40    3    4    3  690  390   20    3  00.139000D-02
 0.000000D000   0.770000D 01   0.000000D 00   0.400000D 00
 0.120455D 01  00.760520D 01  -0.900000D 01  00.400000D 00
00.237943D 01  00.732314D 01  -0.180000D 02  00.400000D 00
00.349573D 01  00.686075D 01  -0.270000D 02  00.400000D 00
00.452595D 01  00.622943D 01  -0.360000D 02  00.400000D 00
00.544472D 01  00.544472D 01  -0.450000D 02  00.400000D 00
00.622943D 01  00.452595D 01  -0.540000D 02  00.400000D 00
00.686075D 01  00.349573D 01  -0.630000D 02  00.400000D 00
00.732314D 01  00.237943D 01  -0.720000D 02  00.400000D 00
00.760520D 01  00.120455D 01  -0.810000D 02  00.400000D 00
00.770000D 01  00.0           -0.900000D 02  00.400000D 00
00.760520D 01  -0.120455D 01  -0.990000D 02  00.400000D 00
00.732314D 01  -0.237943D 01  -0.108000D 03  00.400000D 00
00.686075D 01  -0.349573D 01  -0.117000D 03  00.400000D 00
00.622943D 01  -0.452595D 01  -0.126000D 03  00.400000D 00
00.544472D 01  -0.544472D 01  -0.135000D 03  00.400000D 00
00.452595D 01  -0.622943D 01  -0.144000D 03  00.400000D 00
00.349573D 01  -0.686075D 01  -0.153000D 03  00.400000D 00
00.237943D 01  -0.732314D 01  -0.162000D 03  00.400000D 00
00.120455D 01  -0.760520D 01  -0.171000D 03  00.400000D 00
00.0           -0.770000D+01  00.180000D 03  00.400000D 00
-0.120455D 01  -0.760520D 01  00.171000D 03  00.400000D 00
-0.237943D 01  -0.732313D 01  00.162000D 03  00.400000D 00
-0.349573D 01  -0.696075D 01  00.153000D 03  00.400000D 00
-0.452595D 01  -0.622943D 01  00.144000D 03  00.400000D 00
-0.544472D 01  -0.544472D 01  00.135000D 03  00.400000D 00
-0.622943D 01  -0.452595D 01  00.126000D 03  00.400000D 00
-0.686075D 01  -0.349573D 01  00.117000D 03  00.400000D 00
-0.732314D 01  -0.237943D 01  00.108000D 03  00.400000D 00
-0.760520D 01  -0.120455D 01  00.990000D 02  00.400000D 00
-0.770000D 01  00.0           00.900000D 02  00.400000D 00
-0.760520D+01  00.120455D 01  00.810000D 02  00.400000D 00
-0.732313D 01  00.237943D 01  00.720000D 02  00.400000D 00
```

```
-0.636075D 01   00.349573D 01   00.630000D 02   00.400000D 00
-0.622943D 01   00.452595D 01   00.540000D 02   00.400000D 00
-0.544472D 01   00.544473D 01   00.450000D 02   00.400000D 00
-0.452595D 01   00.622943D 01   00.360000D 02   00.400000D 00
-0.349573D 01   00.686075D 01   00.270000D 02   00.400000D 00
-0.237943D 01   00.732314D 01   00.180000D 02   00.400000D 00
-0.120455D 01   00.760520D 01   00.900000D 01   00.400000D 00
  0
  0
00.200000D-05   00.404000D+02   00.500000D+01
00.279000D-02   00.809500D 05   00.225000D-01   00.105300D 06
00.200000D 00   00.121000D 06
  3     1
  1    40   00.570000D+00
00.484000D+01   00.139850D+01   -0.242227D+01   00.932000D-02   00.666000D-01
00.500000D+00
00.275750D+04   00.477613D+04   -0.197200D+04   00.760000D-03   00.100000D+01
00.484000D+01   00.139850D+01   00.242227D+01   00.932000D-02   00.666000D-01
00.500000D+00
00.275750D+04   -0.477613D+04   -0.197200D+04   00.600000D-03   00.100000D+01
00.484000D+01   -0.279700D+01   00.0            00.932000D-02   00.666000D-01
00.500000D+00
-0.551500D+04   00.0            -0.197200D+04   +0.150000D-03   00.100000D+01
00.1127016653792585D+00   00.5000000000000000D+00   00.8872983346207415D+00
00.2777777777777778D+00   00.4444444444444444D+00   00.2777777777777778D+00
-0.8611363115940530D+00   -0.3399810435848560D+00   00.3399810435848560D+00
00.8611363115940530D+00
00.3478548451374540D+00   00.6521451548625460D+00   00.6521451548625460D+00
00.3478548451374540D+00
  0
  0
  0
  0
```

6.2.3 Solution Output Data

The following is the output for about 600 microseconds of response after initial impact of the complete ring tri-hub burst impact interaction. Each fragment was released at a different time, and the position of each fragment is tracked separately during the run.

The first segment of output gives a breakdown of the ring initial geometry and the defining quantities of the 3 fragments. A calculation of the maximum time step is made and is used to check the user-generated time step.

Initial impact occurs on element 40 by fragment one, at 763.913 microseconds after the release of the first fragment. The second fragment impacts on element 13 at 158.214 microseconds after the first impact. Fragment 3 was released at time 0.910×10^{-3} sec. and has not impacted during this run.

Strain information is printed at each Gaussian station, at each node, and at the designated additional strain point. The maximum strain is 14.58% and occurs on the outer surface of element 13 at 245.087 microseconds after initial impact.

In the interest of conciseness, only a portion of the called-for output is given. Included is all input verification information, scheduled output at the end of time cycles 390, 410, 430, 450, 470, 670, and 690 (last), and regular printout occurring at each ring-fragment impact (note that all impacts are listed). This output listing is intended for use in verification of the adaptation of the CIVM-JET 4B computer code to other computing facilities.

THERE ARE NO BRANCHES CONNECTED TO THE MAIN STRUCTURE ,THEREFORE
THE NUMBERING SYSTEM FOR NODES AND ELEMENTS REMAINS UNCHANGED

ADDITIONAL STRAIN POINT	ELEMENT	S COORDINATE
1	40	0.5700000+00

COMPLETE RING **CIVM-JET 4B** CONTAINMENT ANALYSIS

RING PROPERTIES

MATERIAL PROPERTIES OF MAIN STRUCTURE ARE:

WIDTH OF RING(IN)	=	0.2500000D+01
DENSITY OF RING	=	0.7330850-03
NUMBER OF ELEMENTS	=	40
NUMBER OF SPANWISE GAUSSIAN PTS.	=	3
NUMBER OF DEPTHWISE GAUSSIAN PTS.	=	4
NUMBER OF MECHANICAL SUBLAYERS	=	3
DS FOR STRAIN RATE	=	0.4040000D+02
P FOR STRAIN RATE	=	0.5000000D+01

STRAIN (1) = 0.2790000-02 STRESS(1) = 0.8095000+05

STRAIN (2) = 0.2250000-01 STRESS(2) = 0.1053000+06

STRAIN (3) = 0.2000000+00 STRESS(3) = 0.1210000+06

INITIAL GEOMETRY AT EACH NODE IS AS FOLLOWS:

NODE NO.	Y COORD	Z COORD	SLOPE(RAD.)	RING THICKNESS AT NODE I
1	0.0	0.7700000D+01	0.0	0.4000000D+00
2	0.1204550+01	0.7605200+01	-0.1570800+00	0.4000000+00
3	0.2379430+01	0.7323140+01	-0.3141590+00	0.4000000+00
4	0.3495730+01	0.6860750+01	-0.4712390+00	0.4000000+00
5	0.4525950+01	0.6229430+01	-0.6283190+00	0.4000000+00
6	0.5444720+01	0.5444720+01	-0.7853980+00	0.4000000+00
7	0.6229430+01	0.4525950+01	-0.9424780+00	0.4000000+00
8	0.6860750+01	0.3495730+01	-0.1099560+01	0.4000000+00
9	0.7323140+01	0.2379430+01	-0.1256640+01	0.4000000+00
10	0.7605200+01	0.1204550+01	-0.1413720+01	0.4000000+00
11	0.7700000D+01	0.0	-0.1570800+01	0.4000000+00
12	0.7605200+01	-0.1204550+01	-0.1727880+01	0.4000000+00
13	0.7323140+01	-0.2379430+01	-0.1884960+01	0.4000000+00

ORIGINAL PAGE IS
OF POOR QUALITY

14	0.686075D+01	-0.349573D+01	-0.204204D+01	0.400000D+00
15	0.622943D+01	-0.452595D+01	-0.219911D+01	0.400000D+00
16	0.544472D+01	-0.544472D+01	-0.235619D+01	0.400000D+00
17	0.452595D+01	-0.622943D+01	-0.251327D+01	0.400000D+00
18	0.349573D+01	-0.686075D+01	-0.267035D+01	0.400000D+00
19	0.237943D+01	-0.732314D+01	-0.282743D+01	0.400000D+00
20	0.120455D+01	-0.760520D+01	-0.298451D+01	0.400000D+00
21	0.0	-0.770000D+01	0.314159D+01	0.400000D+00
22	-0.120455D+01	-0.760520D+01	0.298451D+01	0.400000D+00
23	-0.237943D+01	-0.732313D+01	0.282743D+01	0.400000D+00
24	-0.349573D+01	-0.686075D+01	0.267035D+01	0.400000D+00
25	-0.452595D+01	-0.622943D+01	0.251327D+01	0.400000D+00
26	-0.544472D+01	-0.544472D+01	0.235619D+01	0.400000D+00
27	-0.622943D+01	-0.452595D+01	0.219911D+01	0.400000D+00
28	-0.686075D+01	-0.349573D+01	0.204204D+01	0.400000D+00
29	-0.732314D+01	-0.237943D+01	0.188496D+01	0.400000D+00
30	-0.760520D+01	-0.120455D+01	0.172788D+01	0.400000D+00
31	-0.770000D+01	0.0	0.157080D+01	0.400000D+00
32	-0.760520D+01	0.120455D+01	0.141372D+01	0.400000D+00
33	-0.732313D+01	0.237943D+01	0.125664D+01	0.400000D+00
34	-0.686075D+01	0.349573D+01	0.109956D+01	0.400000D+00
35	-0.622943D+01	0.452595D+01	0.942478D+00	0.400000D+00
36	-0.544472D+01	0.544473D+01	0.785398D+00	0.400000D+00
37	-0.452595D+01	0.622943D+01	0.628319D+00	0.400000D+00
38	-0.349573D+01	0.686075D+01	0.471239D+00	0.400000D+00
39	-0.237943D+01	0.732314D+01	0.314159D+00	0.400000D+00
40	-0.120455D+01	0.760520D+01	0.157080D+00	0.400000D+00

FRAGMENT PROPERTIES

FRAG.NO.	DIA. OF FRAG.	MASS OF FRAG.	MOMENT OF INERTIA OF FRAG.	FCGY	FCGZ
1	0.4840000+01	0.9320000-02	0.4460000-01	-0.2422270+01	0.1398500+01
2	0.4840000+01	0.9320000-02	0.4460000-01	0.2422270+01	0.1398500+01
3	0.4840000+01	0.9320000-02	0.4460000-01	0.0	-0.2797000+01

COLLISION PARAMETERS

FRAG.NO.	VEL IN Y DIR.	VEL IN Z DIR.	ANG. VEL.	COEFF.OF RESTIT.	INITIAL KINETIC ENERGY	COEFF. OF FRICT
1	0.2757500+04	0.4776130+04	-0.1972000+04	0.1000000+01	0.2712310+06	0.5000000+00
2	0.2757500+04	-0.4776130+04	-0.1972000+04	0.1000000+01	0.2712310+06	0.5000000+00
3	-0.5515000+04	0.0	-0.1972000+04	0.1000000+01	0.2712310+06	0.5000000+00

THERE IS NO PRESCRIBED DISPLACEMENT CONDITION

THERE ARE NO ELASTIC SPRING CONSTANTS

THE TPRIM FOR EACH OF 3 FRAGMENTS IS AS FOLLOWS
0.7600000-03 0.6000000-03 -0.1500000-03

GAUSSIAN STATIONS AND WEIGHTS:

AXG 1 =	0.112701665379259	AWG 1 =	0.277777777777778
AXG 2 =	0.500000000000000	AWG 2 =	0.444444444444444
AXG 3 =	0.887298334620741	AWG 3 =	0.277777777777778
TXG 1 =	-0.861136311594053	TWG 1 =	0.347854845137454
TXG 2 =	-0.339981043584856	TWG 2 =	0.652145154862546
TXG 3 =	0.339981043584856	TWG 3 =	0.652145154862546
TXG 4 =	0.861136311594053	TWG 4 =	0.347854845137454

SIZE OF ASSEMBLED STIFFNESS MATRIX = 1632

THE TRANSLATIONAL MASSES FOR EACH NODE ARE:

0.8866791555348720-03	0.8866752734765370-03	0.8866756469326270-03	0.8866782786950390-03
0.8866749223314100-03	0.8866733597198200-03	0.8866749223314130-03	0.8866782786451390-03
0.8866756469326270-03	0.8866752734765370-03	0.8866791555348790-03	0.8866752734765370-03
0.8866756469326270-03	0.8866782786950390-03	0.8866749223314290-03	0.8866733597198200-03
0.8866749223314190-03	0.8866782786950390-03	0.8866756469326270-03	0.8866752734765370-03
0.8866791555348720-03	0.8866761300364700-03	0.8866750993566770-03	0.8866768745596360-03
0.8866749223314070-03	0.8866733597198200-03	0.8866749223314070-03	0.8866782786950390-03
0.8866756469326270-03	0.8866752734765370-03	0.8866791555348790-03	0.8866761300364700-03
0.8866750993566770-03	0.8866768745596360-03	0.8866777124061690-03	0.8866737751404660-03
0.8866725371763150-03	0.8866782786950390-03	0.8866756469326270-03	0.8866752734765370-03

THE ROTATIONAL MASSES FOR EACH NODE ARE

0.1080960633847660-03	0.1080945704537170-03	0.1080947070391700-03	0.1080956675501800-03
0.1080944492235700-03	0.1080934481520311-03	0.1080944492235700-03	0.1080956675501800-03
0.1080947070391700-03	0.1080945704537170-03	0.1080960633847660-03	0.1080945704537170-03
0.1080947070391700-03	0.1080955675501800-03	0.1080944492235700-03	0.1080934481520330-03
0.1080944492235700-03	0.1080956675501800-03	0.1080947070391700-03	0.1080945704537170-03
0.1080960633847660-03	0.1080944812125700-03	0.1080934506767340-03	0.1080951554115640-03
0.1080944492235700-03	0.1080934481520310-03	0.1080944492235700-03	0.1080956675501800-03
0.1080947070391700-03	0.1080945704537170-03	0.1080960633847660-03	0.1080944881212570-03
0.1080945747671940-03	0.10809[illegible]5911664D-03	0.1080954462491760-03	0.1080940304697170-03
0.1080935755141080-03	0.1080956675503800-03	0.1080947070391700-03	0.1080945704537170-03

EIGEN VECTOR OF HIGHEST MODE

V	W	PSI	CHI
-0.2610610D+00	0.5586570D-02	0.3750160D-01	-0.4416760D+00
0.4309930D+00	-0.5174720D-02	-0.6207360D-01	0.4093050D+00
-0.5527640D+00	0.4633520D-02	0.8397220D-01	-0.3500880D+00
0.7082290D+00	-0.3506660D-02	-0.1020050D+00	0.2777240D+00
-0.8042270D+00	0.2558430D-02	0.1157050D+00	-0.2029010D+00
0.8723970D+00	-0.1734160D-02	-0.1253210D+00	0.1379740D+00
-0.9175330D+00	0.1127790D-02	0.1316930D+00	-0.9013350D-01
0.9475300D+00	-0.7575540D-03	-0.1358590D+00	0.6059630D-01
-0.9605370D+00	0.5646490D-03	0.1387900D+00	-0.4486780D-01
0.9844300D+00	-0.4616740D-03	-0.1410570D+00	0.3482340D-01
-0.9957350D+00	0.2784670D-03	0.1427290D+00	-0.2177510D-01
0.1000000D+01	0.4722420D-05	-0.1434270D+00	-0.6613620D-03
-0.9930150D+00	-0.4332760D-03	0.1425120D+00	0.3454600D-01
0.9707540D+00	0.9707160D-03	-0.1393710D+00	-0.7710130D-01
-0.9310590D+00	-0.1537470D-02	0.1336740D+00	0.1218610D+00
0.8746500D+00	0.2337690D-02	-0.1255190D+00	-0.1606870D+00
-0.8053790D+00	-0.2354180D-02	0.1154710D+00	0.1861450D+00
0.7295030D+00	0.2452380D-02	-0.1044620D+00	-0.1936740D+00
-0.6542930D+00	-0.2111590D-02	0.9356050D-01	0.1929370D+00
0.5862220D+00	0.1795540D-02	-0.8372750D-01	-0.1590020D+00
-0.5294380D+00	-0.1595240D-02	0.7557940D-01	0.1265220D+00
0.4846510D+00	0.1231810D-02	-0.6722710D-01	-0.9812890D-01
-0.4487450D+00	-0.1327490D-02	0.6421130D-01	0.8218490D-01
0.4153730D+00	0.1371290D-02	-0.5957710D-01	-0.8549170D-01
-0.3763610D+00	-0.1389720D-02	0.5417480D-01	0.1104680D+00
0.3236200D+00	0.1741210D-02	-0.4574220D-01	-0.1541740D+00
-0.2512610D+00	-0.2532750D-02	0.3642200D-01	0.2255560D+00
0.1573370D+00	0.3312270D-02	-0.2291510D-01	-0.2620360D+00
-0.4463470D-01	-0.3321190D-02	0.6630490D-02	0.3320570D+00
-0.7911910D-01	0.4023790D-02	0.1131240D-01	-0.3178470D+00
0.2030840D+00	-0.3933170D-02	-0.2431760D-01	0.3027450D+00
-0.3145730D+00	0.3234420D-02	0.4552690D-01	-0.2553190D+00
0.4013580D+00	-0.2267760D-02	-0.5815650D-01	0.1790520D+00
-0.4533440D+00	0.1327190D-02	0.6573820D-01	-0.8110890D-01
0.4637000D+00	0.1699290D-03	-0.6729410D-01	-0.2938860D-01
-0.4293540D+00	-0.1403430D-02	0.6235370D-01	0.1427420D+00
0.3510730D+00	0.3152600D-02	-0.5105780D-01	-0.2493440D+00
-0.2333970D+00	-0.4294800D-02	0.3404460D-01	0.3397340D+00
0.8441710D-01	0.5136990D-02	-0.1269910D-01	-0.4360870D+00
0.8476970D-01	-0.5580030D-02	-0.1198750D-01	0.4411150D+00

HIGHEST NATURAL FREQUENCY (RAD/SEC) = 0.35978804686908369D+06

THE COMPLETE VALUE OF THE MAX DELTAT = 0.44470627351527070-05

DELTAT SHOULD EQUAL: 0.4403000D-05
THE VALUE OF DELTAT USED IN THE PROGRAM IS: 0.2000000-05

THE FOLLOWING NUMBERS ARE THE VALUES FOR THE EFFECTIVE LENGTHS FOR THE NBR PLUS 1 SECTIONS OF THE STRUCTURE
0.3978863D+00

THE FOLLOWING IS THE TIME SOLUTION OF THE FRAGMENT- RING IMPACT

IMPACT NO. 1 TIME 0.7619130-03 DURING CYCLE 382 ELEM 40 FRAG 1 DISTANCE 0.5671880D+00

****

ORIGINAL PAGE IS OF POOR QUALITY

ENERGY AND WORK AT THE END OF TIME CYCLE 390

FRAGMENT	KINETIC ENERGY
1	0.171819D+06
2	0.271231D+06
3	0.271231D+06

WORK INPUT INTO RING = 0.994120D+05
RING KINETIC ENERGY = 0.452466D+05
RING ELASTIC ENERGY = 0.469132D+04
RING PLASTIC WORK = 0.494741D+05
ENERGY STORED IN ELASTIC RESTRAINTS = 0.0

CYCLE= 390

ELEM	SI (STA1)	SO (STA1)	SI (STA2)	SO (STA2)	SI (STA3)	SO (STA3)
1	-0.6520D-01	0.6705D-01	-0.1742D-02	0.3773D-02	0.5297D-01	-0.6779D-01
2	0.5969D-02	-0.1615D-01	0.4705D-02	-0.5581D-02	-0.3525D-02	-0.2406D-02
3	-0.5025D-02	-0.4344D-02	-0.3180D-02	-0.3039D-02	-0.1650D-02	-0.2064D-02
4	-0.1431D-02	-0.1400D-02	-0.8936D-03	-0.9529D-03	-0.2891D-03	-0.4349D-03
5	-0.1680D-03	-0.1666D-03	-0.1034D-03	-0.1067D-03	-0.2557D-04	-0.3962D-04
6	-0.9354D-05	-0.9290D-05	-0.5379D-05	-0.5711D-05	-0.1150D-05	-0.1874D-05
7	-0.2538D-06	-0.2522D-06	-0.1420D-06	-0.1507D-06	-0.2671D-07	-0.4558D-07
8	-0.3013D-08	-0.2997D-08	-0.1656D-08	-0.1756D-08	-0.2886D-09	-0.5033D-09
9	-0.9621D-11	-0.9571D-11	-0.5234D-11	-0.5546D-11	-0.8769D-12	-0.1553D-11
10	0.0	0.0	0.0	0.0	0.0	0.0
11	0.0	0.0	0.0	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0	0.0	0.0
13	0.0	0.0	0.0	0.0	0.0	0.0
14	0.0	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0	0.0	0.0
26	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0
28	0.0	0.0	0.0	0.0	0.0	0.0
29	0.0	0.0	0.0	0.0	0.0	0.0
30	0.0	0.0	0.0	0.0	0.0	0.0
31	0.1287D-11	0.2282D-11	0.7698D-11	0.8157D-11	0.1417D-10	0.1439D-10
32	0.4393D-09	0.7667D-09	0.2525D-08	0.2676D-08	0.4596D-08	0.4570D-08
33	0.4122D-07	0.6981D-07	0.2175D-06	0.2306D-06	0.3882D-06	0.3857D-06
34	0.1769D-05	0.2879D-05	0.3247D-05	0.8758D-05	0.1429D-04	0.1418D-04
35	0.3967D-04	0.6150D-04	0.1555D-03	0.1654D-03	0.2577D-03	0.2549D-03
36	0.4717D-03	0.6844D-03	0.1426D-02	0.1525D-02	0.2206D-02	0.2182D-02
37	0.2633D-02	0.3749D-02	0.5290D-02	0.5900D-02	0.7351D-02	0.7425D-02
38	0.5540D-02	0.9281D-02	0.1228D-01	0.5305D-02	0.2386D-01	0.6390D-02
39	0.6014D-01	-0.1351D-01	0.3622D-01	0.3063D-01	-0.9326D-02	0.5232D-01
40	0.1416D-01	0.6623D-02	-0.5609D-02	0.1099D-01	-0.1973D-01	0.2139D-01

CYCLE= 390

STRAIN AT ADDITIONAL POINTS	SI	SO	EI	EO
1	-0.857824230D-02	0.124242150D-01	-0.861535450D-02	0.123479790D-01

J= 390 TIME= 0.780000D-03 TIME AFTER INITIAL IMPACT = 0.160874D-04

I	V	W	PSI	CHI	CDPY	CDPZ	L	M	STRAIN(IN)	STRAIN(OUT)
1	0.2900D-01	0.1129D+00	-0.1415D-01	0.1378D-02	0.2900D-01	0.7833D+01	0.1567D+06	0.9152D+04	-0.5790D-01	0.5586D-01
2	0.8388D-02	0.8722D-02	-0.3124D-01	-0.8083D-02	0.1214D+01	0.7613D+01	-0.4512D+06	-0.9731D+04	0.3821D-01	-0.5331D-01
3	0.5144D-02	0.1020D-03	0.2179D-03	-0.5222D-02	0.2384D+01	0.7322D+01	-0.9021D+05	0.1369D+03	-0.6508D-02	0.3911D-02
4	0.1235D-02	0.1259D-03	-0.1967D-03	-0.1549D-02	0.3497D+01	0.6869D+01	-0.2679D+05	-0.5736D+02	-0.1417D-02	-0.167[illegible]D-02
5	0.1306D-03	0.1161D-04	-0.2016D-04	-0.1946D-03	0.4526D+01	0.6229D+01	-0.3709D+04	-0.6299D+01	-0.1429D-03	-0.2282D-03
6	0.6942D-05	0.5693D-06	-0.1017D-05	-0.1037D-04	0.5445D+01	0.5445D+01	-0.1609D+03	-0.3212D+00	-0.6362D-05	-0.1438D-04
7	0.1790D-06	0.1442D-07	-0.2622D-07	-0.2835D-06	0.6229D+01	0.4526D+01	-0.4246D+01	-0.8337D-02	-0.7576D-07	-0.6912D-06
8	0.2279D-08	0.1642D-09	-0.3509D-09	-0.3383D-08	0.6861D+01	0.3496D+01	-0.4950D-01	-0.9610D-04	0.1996D-08	-0.8742D-08
9	0.6568D-11	0.5142D-12	-0.9457D-12	-0.1083D-10	0.7323D+01	0.2379D+01	-0.1564D-03	-0.3020D-06	0.5118D-10	-0.7285D-10
10	0.0	0.0	0.0	0.0	0.7605D+01	0.1205D+01	0.0	0.0	0.1956D-12	-0.1956D-12
11	0.0	0.0	0.0	0.0	0.7700D+01	0.0	0.0	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0	0.7605D+01	-0.1205D+01	0.0	0.0	0.0	0.0
13	0.0	0.0	0.0	0.0	0.7323D+01	-0.2379D+01	0.0	0.0	0.0	0.0
14	0.0	0.0	0.0	0.0	0.6861D+01	-0.3496D+01	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	0.6229D+01	-0.4526D+01	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	0.5445D+01	-0.5445D+01	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0	0.4526D+01	-0.6229D+01	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0	0.3496D+01	-0.6861D+01	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0	0.2379D+01	-0.7323D+01	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.1205D+01	-0.7605D+01	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0	-0.7700D+01	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	-0.1205D+01	-0.7605D+01	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0	-0.2379D+01	-0.7323D+01	0.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0	-0.3496D+01	-0.6861D+01	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0	-0.4526D+01	-0.6229D+01	0.0	0.0	0.0	0.0
26	0.0	0.0	0.0	0.0	-0.5445D+01	-0.5445D+01	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	-0.6229D+01	-0.4526D+01	0.0	0.0	0.0	0.0
28	0.0	0.0	0.0	0.0	-0.6861D+01	-0.3496D+01	0.0	0.0	0.0	0.0
29	0.0	0.0	0.0	0.0	-0.7323D+01	-0.2379D+01	0.0	0.0	0.0	0.0
30	0.0	0.0	0.0	0.0	-0.7605D+01	-0.1205D+01	0.0	0.0	0.0	0.0
31	0.0	0.0	0.0	0.0	-0.7700D+01	0.0	0.2300D-03	0.4438D-06	-0.2980D-12	0.2880D-12
32	0.9666D-11	-0.7566D-12	-0.1390D-11	0.1596D-10	-0.7605D+01	0.1205D+01	0.7546D-01	0.1464D-03	-0.7862D-10	0.1115D-09
33	0.3169D-08	-0.2503D-09	-0.4546D-09	0.5160D-09	-0.7323D+01	0.2379D+01	0.6501D+01	0.1276D-01	-0.3974D-09	0.1339D-07
34	0.2739D-06	-0.2227D-07	-0.4211D-07	0.4335D-06	-0.6861D+01	0.3496D+01	0.2467D+03	0.4938D+00	0.1154D-06	0.7518D-06
35	0.1346D-04	-0.8742D-06	-0.1565D-05	0.1563D-04	-0.6229D+01	0.4526D+01	0.4655D+04	0.9544D+01	0.9611D-05	0.2259D-04
36	0.2312D-03	-0.1776D-04	-0.3070D-04	0.2818D-03	-0.5445D+01	0.5445D+01	0.4281D+05	0.9591D+02	0.2225D-03	0.3412D-03
37	0.1939D-02	-0.1249D-03	-0.3279D-03	0.2359D-02	-0.4526D+01	0.6230D+01	0.1623D+06	0.5901D+03	0.2072D-02	0.2671D-02
38	0.6556D-02	-0.1152D-02	-0.2142D-02	0.7766D-02	-0.3497D+01	0.6863D+01	0.1963D+06	-0.2291D+04	0.6098D-02	0.9524D-02
39	0.2105D-01	0.2529D-02	0.1876D-01	0.1775D-01	-0.2360D+01	0.7332D+01	0.2133D+06	-0.1652D+04	0.4661D-01	-0.1345D-01
40	0.4308D-01	0.9440D-01	0.3636D-01	0.1313D-01	-0.1177D+01	0.7705D+01	0.6565D+05	0.1416D+05	-0.2763D-02	0.3052D-01

FRAG NO.=	FCGU =	FCGW =	ALFA =	FRUV =	FRWV =	FRAV =
1	-0.281092D+03	0.510002D+01	-0.153426D+01	0.215631D+04	0.329298D+04	-0.172962D+04
2	0.413192D+01	-0.156273D+01	-0.122264D+01	0.275750D+04	-0.477613D+04	-0.197200D+04
3	0.0	-0.279700D+01	0.0	-0.551500D+04	0.0	-0.197200D+04

SUBSTRUCTURE	MSTR	ELE	SURF	STA	TIME
1	0.670466D-01	1	2	1	0.780000D-03

SUBSTRUCTURE	LARGEST ADD. PT. STRAIN	ELEM	ADD. PT.	TIME	SURFACE
1	0.124242D-01	40	1	0.780000D-03	2

SUBSTRUCTURE	LARGEST NODAL STRAIN	NODE	SURF	TIME
1	0.556617D-01	1	2	0.780000D-03

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ENERGY AND WORK AT THE END OF TIME CYCLE 410

FRAGMENT	KINETIC ENERGY
1	0.171819D+06
2	0.271231D+06
3	0.271231D+06

WORK INPUT INTO RING = 0.974129D+05
RING KINETIC ENERGY = 0.267862D+05
RING ELASTIC ENERGY = 0.706070D+04
RING PLASTIC WORK = 0.655651D+05
ENERGY STORED IN ELASTIC RESTRAINTS = 0.0

CYCLE= 410

		STA1		STA2		STA3
ELEM	SI	SO	SI	SO	SI	SO
1	-0.6082D-01	0.9149D-01	-0.6141D-02	0.1069D-01	0.6208D-01	-0.5393D-01
2	0.3519D-01	-0.1242D-01	0.1454D-01	-0.1013D-01	0.3284D-01	-0.9291D-02
3	0.1844D-01	-0.1122D-02	0.9714D-02	-0.1539D-02	0.6995D-02	0.4318D-02
4	0.3035D-02	0.8901D-02	0.9245D-03	0.5697D-02	0.8777D-03	0.4681D-02
5	0.2718D-02	0.3671D-02	0.3081D-02	0.3551D-02	0.2795D-02	0.2750D-02
6	0.3362D-02	0.2768D-02	0.3492D-02	0.3787D-02	0.3136D-02	0.4794D-02
7	0.3895D-02	0.3224D-02	0.2210D-02	0.2228D-02	0.4949D-03	0.1200D-02
8	0.2111D-03	0.5232D-04	-0.7884D-03	-0.1012D-02	-0.1772D-02	-0.2061D-02
9	-0.2478D-02	-0.2132D-02	-0.1889D-02	-0.2099D-02	-0.1624D-02	-0.2093D-02
10	-0.1715D-02	-0.1671D-02	-0.1220D-02	-0.1327D-02	-0.7469D-03	-0.1005D-02
11	-0.7047D-03	-0.6890D-03	-0.4602D-03	-0.4959D-03	-0.2246D-03	-0.3124D-03
12	-0.1905D-03	-0.1869D-03	-0.1183D-03	-0.1269D-03	-0.4859D-04	-0.6947D-04
13	-0.3703D-04	-0.3643D-04	-0.2224D-04	-0.2378D-04	-0.7947D-05	-0.1165D-04
14	-0.5429D-05	-0.5352D-05	-0.3184D-05	-0.3397D-05	-0.1014D-05	-0.1521D-05
15	-0.6186D-06	-0.6109D-06	-0.3565D-06	-0.3798D-06	-0.1032D-06	-0.1577D-06
16	-0.5588D-07	-0.5526D-07	-0.3176D-07	-0.3380D-07	-0.8445D-08	-0.1318D-07
17	-0.4053D-08	-0.4012D-08	-0.2279D-08	-0.2423D-09	-0.5643D-09	-0.8961D-09
18	-0.2380D-09	-0.2359D-09	-0.1326D-09	-0.1409D-07	-0.3064D-10	-0.4978D-10
19	-0.1135D-10	-0.1125D-10	-0.6273D-11	-0.6661D-11	-0.1362D-11	-0.2245D-11
20	-0.3625D-12	-0.3073D-12	0.1306D-12	0.1386D-12	0.6273D-12	0.5884D-12
21	0.2119D-11	0.3483D-11	0.9693D-11	0.1029D-10	0.1753D-10	0.1738D-10
22	0.4774D-10	0.7711D-10	0.2056D-09	0.2185D-09	0.3690D-09	0.3656D-09
23	0.8776D-09	0.1395D-08	0.3554D-09	0.1778D-09	0.6322D-08	0.6258D-08
24	0.1323D-07	0.2069D-07	0.4993D-07	0.5312D-07	0.9789D-07	0.8689D-07
25	0.1630D-06	0.2498D-06	0.5667D-06	0.6036D-06	0.9842D-06	0.9719D-06
26	0.1526D-05	0.2442D-05	0.5143D-05	0.5487D-05	0.8782D-05	0.8658D-05
27	0.1290D-04	0.1908D-04	0.3576D-04	0.3929D-04	0.6136D-04	0.6038D-04
28	0.8154D-04	0.1170D-03	0.2023D-03	0.2169D-03	0.3274D-03	0.3213D-03
29	0.3922D-03	0.5481D-03	0.8290D-03	0.9918D-03	0.1280D-02	0.1253D-02
30	0.1386D-02	0.1890D-02	0.2385D-02	0.2599D-02	0.3425D-02	0.3342D-02
31	0.3357D-02	0.4190D-02	0.4405D-02	0.4863D-02	0.5505D-02	0.5391D-02
32	0.4971D-02	0.6157D-02	0.4849D-02	0.5517D-02	0.4892D-02	0.5052D-02
33	0.4658D-02	0.5601D-02	0.5010D-02	0.5574D-02	0.4682D-02	0.4832D-02
34	0.4164D-02	0.5063D-02	0.4583D-02	0.5349D-02	0.4761D-02	0.5364D-02
35	0.4702D-02	0.5431D-02	0.5043D-02	0.5565D-02	0.5643D-02	0.5972D-02
36	0.4330D-02	0.6757D-02	0.3866D-02	0.6604D-02	0.5324D-02	0.8482D-02
37	0.5113D-02	0.9264D-02	0.9129D-02	0.5316D-02	0.1662D-01	0.5017D-02
38	0.2462D-01	0.1850D-03	0.3689D-01	-0.7834D-02	0.5733D-01	-0.7661D-02
39	0.7124D-01	-0.1103D-01	0.3709D-01	0.2497D-01	-0.7151D-02	0.5115D-01
40	-0.3754D-02	0.4032D-01	-0.2449D-01	0.6339D-01	-0.4318D-01	0.8802D-01

CYCLE= 410

STRAIN AT ADDITIONAL POINTS	SI	SO	EI	EO
1	-0.283921260D-01	0.673158430D-01	-0.288070490D-01	0.651909150D-01

J= 410 TIME= 0.82000D-03 TIME AFTER INITIAL IMPACT = 0.560874D-04

I	V	W	PSI	CHI	COPY	COPZ	L	M	STRAIN(IN)	STRAIN(OUT)
1	0.38390-01	0.35740+00	-0.10109+00	0.20500-01	0.38100-01	0.80570+01	0.10820+06	0.69990+04	-0.56190-01	0.10951+00
2	-0.20050-01	0.99750-01	-0.15410+00	-0.84590-03	0.12000+01	0.77060+01	0.11570+06	-0.81820+04	0.61700-01	-0.39643-01
3	-0.16060-01	-0.64360-02	-0.16730-01	0.11070-01	0.23620+01	0.73270+01	0.10020+06	-0.87180+04	0.27160-01	-0.45430-02
4	-0.77210-02	-0.42540-02	0.15170-01	0.69980-02	0.34970+01	0.69600+01	0.95550+05	0.45280+04	0.56170-02	0.56550-02
5	-0.32230-02	0.35330-02	0.51620-03	0.30260-02	0.45250+01	0.62340+01	0.96200+05	0.45450+03	0.13730-02	0.41830-02
6	0.43660-04	0.27560-02	-0.85700-03	0.24920-02	0.54470+01	0.54470+01	0.10560+06	0.28480+03	0.29210-02	0.20640-02
7	0.38460-02	0.25670-02	-0.17760-02	0.39630-02	0.62340+01	0.45260+01	0.64390+05	0.17400+02	0.36530-02	0.42470-02
8	0.61730-02	0.15290-02	-0.17790-02	0.43310-03	0.69650+01	0.34910+01	-0.26120+05	-0.21850+03	0.24160-03	0.62570-03
9	0.48770-02	0.96180-03	-0.11023-02	-0.22130-02	0.73460+01	0.23750+01	-0.57850+05	-0.20360+03	-0.21630-02	-0.22560-02
10	0.23570-02	0.35490-03	-0.46130-03	-0.19230-02	0.76060+01	0.12320+01	-0.36950+05	-0.19330+03	-0.17070-02	-0.19350-02
11	0.77420-03	0.97110-04	-0.14303-03	-0.76320-03	0.77000+01	-0.77420-03	-0.13870+05	-0.34590+02	-0.63480-03	-0.83110-03
12	0.18380-03	0.21350-04	-0.31420-04	-0.20860-03	0.76050+01	-0.12050+01	-0.35570+04	-0.82860+01	-0.15460-03	-0.23260-03
13	0.32830-04	0.34690-05	-0.53150-05	-0.40850-04	0.73230+01	-0.23790+01	-0.66760+03	-0.14960+01	-0.35930-04	-0.44670-04
14	0.45340-05	0.45160-06	-0.72161-06	-0.60220-05	0.68610+01	-0.34960+01	-0.75490+02	-0.20590+00	-0.49750-05	-0.72650-05
15	0.49540-06	0.47060-07	-0.77403-07	-0.68870-06	0.62290+01	-0.45260+01	-0.10680+02	-0.22500-01	-0.54460-06	-0.83290-06
16	0.43310-07	0.37700-08	-0.66553-08	-0.62390-07	0.54450+01	-0.54450+01	-0.75120+00	-0.19580-02	-0.46740-07	-0.75350-07
17	0.30620-09	0.27270-09	-0.45440-09	-0.45360-08	0.45260+01	-0.62290+01	-0.69220-01	-0.13920-03	-0.31770-08	-0.58960-08
18	0.17610-09	0.15320-10	-0.26440-10	-0.26690-09	0.34960+01	-0.64610+01	-0.39670-02	-0.83110-05	-0.17130-09	-0.36240-09
19	0.82670-11	0.73540-12	-0.12300-11	-0.12750-10	0.23790+01	-0.73230+01	-0.19760-03	-0.37530-06	-0.72300-11	-0.18220-10
20	0.33150-12	0.25310-13	-0.48160-13	-0.47160-12	0.12050+01	-0.76050+01	0.39060-05	0.77420-08	-0.23150-12	-0.71160-12
21	0.49670-12	-0.47460-13	-0.73330-13	0.74700-12	-0.49670-12	-0.77000+01	0.25990-03	0.57950-06	0.36290-12	0.14310-11
22	0.12760-10	-0.10490-11	-0.16370-11	0.19690-10	-0.12050+01	-0.76050+01	0.61520-02	0.12410-04	0.11220-10	0.28160-10
23	0.27300-09	-0.21740-10	-0.40340-10	0.41370-09	-0.23790+01	-0.73230+01	0.13640+00	0.21690-03	0.26480-09	0.56270-09
24	0.47720-08	-0.41420-09	-0.72130-09	0.70750-08	-0.34960+01	-0.68610+01	0.14950+01	0.30900-02	0.47390-08	0.92120-08
25	0.68230-07	-0.67300-08	-0.10440-07	0.99130-07	-0.45260+01	-0.62240+01	0.16980+02	0.35720-01	0.73280-07	0.12330-06
26	0.78560-06	-0.74620-07	-0.12270-06	0.10960-05	-0.54450+01	-0.54450+01	0.15420+03	0.33180+00	0.86350-06	0.13230-05
27	0.73160-05	-0.72570-06	-0.11560-05	0.97400-05	-0.62290+01	-0.45260+01	0.11030+04	0.24480+01	0.87190-05	0.11440-04
28	0.54070-04	-0.55110-05	-0.85580-05	0.67720-04	-0.68610+01	-0.34960+01	0.63810+04	0.14090+02	0.57830-04	0.77620-04
29	0.31210-03	-0.35410-04	-0.53100-04	0.35880-03	-0.73230+01	-0.23790+01	0.24950+05	0.61550+02	0.31610-03	0.40150-03
30	0.13730-02	-0.17310-03	-0.24570-03	0.13990-02	-0.76050+01	-0.12030+01	0.72160+05	0.19760+03	0.12580-02	0.15210-02
31	0.44520-02	-0.65280-03	-0.86570-03	0.36490-02	-0.76990+01	0.44520-02	0.13440+06	0.44260+03	0.33980-02	0.39150-02
32	0.10250-01	-0.13710-02	-0.22440-02	0.56830-02	-0.76020+01	0.12140+01	0.15040+06	0.64200+03	0.54370-02	0.59670-02
33	0.17090-01	-0.40800-02	-0.47410-02	0.47260-02	-0.73140+01	0.23940+01	0.14040+06	0.48250+03	0.46630-02	0.52130-02
34	0.24020-01	-0.73610-02	-0.53570-02	0.44460-02	-0.68430+01	0.35140+01	0.13330+06	-0.27660+03	0.42280-02	0.47130-02
35	0.31380-01	-0.11750-01	-0.92520-02	0.49990-02	-0.62010+01	0.45440+01	0.12180+06	-0.43950+03	0.47090-02	0.53820-02
36	0.40080-01	-0.17270-01	-0.94510-02	0.59410-02	-0.54040+01	0.54610+01	0.12650+06	0.17550+04	0.53480-02	0.66650-02
37	0.50130-01	-0.26710-01	-0.13220-01	0.75540-02	-0.44690+01	0.62370+01	0.12860+06	-0.43240+04	0.53080-02	0.10210-01
38	0.65400-01	-0.39280-01	-0.68430-02	0.12550-01	-0.34200+01	0.69550+01	0.13480+06	-0.12830+05	0.20740-01	0.45590-02
39	0.86170-01	0.30150-01	0.12130+00	0.21710-01	-0.23070+01	0.73780+01	0.11560+06	-0.43880+04	0.73540-01	-0.13190-01
40	0.74110-01	0.27610+00	0.16470+00	0.36270-02	-0.11750+01	0.78890+01	0.12370+06	0.16200+05	-0.10510-01	0.44920-01

FRAG NO.=	FCGU =	FCGW =	ALFA =	FRUV =	FRWV =	FRAV =
1	-0.1948390+03	0.5231740+01	-0.1603450+01	0.2156310+04	0.3292980+04	-0.1729620+04
2	0.4242220+01	-0.1753750+01	-0.1301520+01	0.2757500+04	-0.4776130+04	-0.1972000+04
3	0.0	-0.2797000+01	0.0	-0.5515000+04	0.0	-0.1972000+04

SUBSTRUCTURE	MSTR	ELE	SURF	STA	TIME
1	0.9149650-01	1	2	1	0.8200000-03

SUBSTRUCTURE	LARGEST ADD. PT. STRAIN	ELEM	ADD. PT.	TIME	SURFACE
1	0.6731580-01	40	1	0.8200000-03	2

SUBSTRUCTURE	LARGEST NODAL STRAIN	NODE	SURF	TIME
1	0.1099280+00	1	2	0.8200000-03

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ORIGINAL PAGE IS
OF POOR QUALITY

ENERGY AND WORK AT THE END OF TIME CYCLE 430

FRAGMENT	KINETIC ENERGY
1	0.171819L+06
2	0.271231D+06
3	0.271231D+06

WORK INPUT INTO RING = 0.994120D+05
RING KINETIC ENERGY = 0.239915D+05
RING ELASTIC ENERGY = 0.565202D+04
RING PLASTIC WORK = 0.697685D+05
ENERGY STORED IN ELASTIC RESTRAINTS = 0.0

CYCLE= 430

ELEM	SI STA1	SO	SI STA2	SO	SI STA3	SO
1	-0.6719D-01	0.9483D-01	-0.1493D-01	0.1731D-01	0.5031D-01	-0.4451D-01
2	0.2444D-01	-0.6621D-02	0.2904D-01	-0.8613D-02	0.3308D-01	-0.1139D-01
3	0.2987D-01	-0.1055D-01	0.2225D-01	-0.9518D-02	0.1599D-01	-0.7264D-02
4	0.9269D-02	-0.2731D-02	0.5106D-02	-0.2145D-03	0.1862D-02	0.3256D-02
5	-0.1748D-03	0.5927D-02	-0.7162D-04	0.5949D-02	-0.8629D-03	0.5049D-02
6	0.2553D-03	0.4012D-02	0.2496D-02	0.3784D-02	0.4002D-02	0.2786D-02
7	0.4286D-02	0.1983D-02	0.2868D-02	0.2453D-02	0.2084D-02	0.3688D-02
8	0.3054D-02	0.2713D-02	0.3021D-02	0.3364D-02	0.3641D-02	0.4503D-02
9	0.3886D-02	0.4798D-02	0.3923D-02	0.4081D-02	0.4042D-02	0.3449D-02
10	0.2755D-02	0.4324D-02	0.2742D-02	0.3151D-02	0.2683D-02	0.1937D-02
11	0.2027D-02	0.2593D-02	0.2680D-02	0.3268D-02	0.3415D-02	0.4030D-02
12	0.4183D-02	0.3717D-02	0.3819D-02	0.4286D-02	0.3594D-02	0.5002D-02
13	0.4353D-02	0.3757D-02	0.2881D-02	0.3052D-02	0.1445D-02	0.2384D-02
14	0.1466D-02	0.1165D-02	0.3714D-03	0.2747D-03	-0.7206D-03	-0.6138D-03
15	-0.9332D-03	-0.1044D-02	-0.1158D-02	-0.1310D-02	-0.1313D-02	-0.1597D-02
16	-0.1466D-02	-0.1449D-02	-0.1183D-02	-0.1308D-02	-0.9205D-03	-0.1190D-02
17	-0.9440D-03	-0.9246D-03	-0.6802D-03	-0.7421D-03	-0.4289D-03	-0.5728D-03
18	-0.4100D-03	-0.4010D-03	-0.2764D-03	-0.2934D-03	-0.1491D-03	-0.2033D-03
19	-0.1317D-03	-0.1276D-03	-0.7955D-04	-0.3579D-04	-0.2900D-04	-0.4567D-04
20	-0.1876D-04	-0.1119D-04	0.1649D-04	0.1770D-04	0.5207D-04	0.4696D-04
21	0.6666D-04	0.9634D-04	0.1538D-03	0.1657D-03	0.2440D-03	0.2383D-03
22	0.2772D-03	0.3812D-03	0.5301D-03	0.5734D-03	0.7934D-03	0.7766D-03
23	0.9460D-03	0.1138D-02	0.1409D-02	0.1534D-02	0.1999D-02	0.1958D-02
24	0.2006D-02	0.2629D-02	0.2829D-02	0.3112D-02	0.3703D-02	0.3647D-02
25	0.3508D-02	0.4427D-02	0.4019D-02	0.4492D-02	0.4602D-02	0.4636D-02
26	0.4166D-02	0.4968D-02	0.3789D-02	0.4434D-02	0.3644D-02	0.4149D-02
27	0.3836D-02	0.3570D-02	0.2889D-02	0.3527D-02	0.2063D-02	0.3614D-02
28	0.3165D-02	0.2307D-02	0.2550D-02	0.2813D-02	0.1844D-02	0.3223D-02
29	0.2125D-02	0.2644D-02	0.2345D-02	0.2344D-02	0.2935D-02	0.2433D-02
30	0.1852D-02	0.3074D-02	0.1389D-02	0.2042D-02	0.1879D-02	0.2016D-02
31	0.1212D-02	0.2800D-02	0.1399D-02	0.2175D-02	0.2323D-02	0.2331D-02
32	0.2127D-02	0.2509D-02	0.1456D-02	0.2021D-02	0.1537D-02	0.2330D-02
33	0.1790D-02	0.2466D-02	0.1946D-02	0.2290D-02	0.2140D-02	0.2155D-02
34	0.2040D-02	0.1986D-02	0.1394D-02	0.2268D-02	0.1224D-02	0.3053D-02
35	-0.4485D-03	0.4976D-02	-0.5973D-05	0.4995D-02	0.1042D-02	0.5669D-02
36	0.8054D-03	0.5609D-02	0.3190D-02	0.2057D-02	0.7665D-02	0.7364D-03
37	0.1017D-01	-0.2050D-05	0.1868D-01	-0.5724D-02	0.3130D-01	-0.7250D-02
38	0.3700D-01	-0.1069D-01	0.3794D-01	-0.1137D-01	0.4815D-01	-0.2693D-02
39	0.5972D-01	-0.4460D-02	0.2704D-01	0.2909D-01	-0.1500D-01	0.5376D-01
40	-0.1296D-01	0.4576D-01	-0.3029D-01	0.5480D-01	-0.4438D-01	0.8708D-01

CYCLE= 430

STRAIN AT ADDITIONAL POINTS	SI	SO	EI	EO
1	-0.3144539 7D-01	0.682415330-01	-0.339931650-01	0.660595980-01

J= 430 TIME= 0.860000-03 TIME AFTER INITIAL IMPACT = 0.960874D-04

I	V	W	PSI	CHI	COPY	COPZ	L	M	STRAIN(IN)	STRAIN(OUT)
1	0.42180D-01	0.47220D+00	-0.10070D+00	0.17790D-01	0.42180D-01	0.81720D+01	0.29370D+05	0.13670D+05	-0.60540D-01	0.11060D+00
2	-0.40210D-01	0.18910D+00	-0.20760D+00	-0.11950D-01	0.11940D+01	0.77980D+01	0.54420D+05	0.45470D+03	0.48320D-01	-0.31910D-01
3	-0.55210D-01	0.21710D-02	-0.86400D-01	0.73660D-02	0.23280D+01	0.73420D+01	0.59410D+05	-0.14200D+05	0.33490D-01	-0.11240D-01
4	-0.41290D-01	-0.45190D-01	0.37810D-02	0.37300D-02	0.34370D+01	0.69400D+01	0.66520D+05	-0.57030D+04	0.12470D-01	-0.49000D-02
5	-0.34600D-01	-0.24420D-01	0.25640D-01	0.23490D-02	0.44940D+01	0.62300D+01	0.77000D+05	0.47450D+04	0.31740D-03	0.50550D-02
6	-0.29170D-01	-0.92070D-02	0.76580D-02	0.16470D-02	0.54180D+01	0.54590D+01	0.91100D+05	0.12460D+04	-0.90860D-03	0.42630D-02
7	-0.24310D-01	-0.84650D-02	0.37930D-02	0.33390D-02	0.62090D+01	0.45410D+01	0.77200D+05	-0.40190D+03	0.45940D-02	0.21210D-02
8	-0.17310D-01	-0.50110D-02	0.50220D-02	0.30160D-02	0.68470D+01	0.35110D+01	0.92630D+05	0.33140D+03	0.25730D-02	0.35340D-02
9	-0.15200D-01	-0.19510D-02	0.37560D-02	0.44370D-02	0.73170D+01	0.23910D+01	0.11610D+06	0.15250D+03	0.39120D-02	0.49880D-02
10	-0.10190D-01	-0.30060D-04	0.34760D-02	0.36810D-02	0.76040D+01	0.12150D+01	0.85480D+05	0.39580D+03	0.34200D-02	0.39680D-02
11	-0.67570D-02	0.12090D-02	0.22190D-02	0.21280D-02	0.77010D+01	0.67570D-02	0.86270D+05	0.55730D+03	0.22650D-02	0.20030D-02
12	-0.34140D-02	0.20320D-02	0.45650D-03	0.39490D-02	0.76080D+01	-0.12010D+01	0.11760D+06	-0.45150D+03	0.39840D-02	0.39290D-02
13	0.11740D-02	0.22910D-02	-0.96210D-03	0.43770D-02	0.73250D+01	-0.23810D+01	0.86040D+05	0.16520D+03	0.41710D-02	0.46010D-02
14	0.44390D-02	0.19920D-02	-0.14900D-02	0.16050D-02	0.69600D+01	-0.35010D+01	0.93710D+04	-0.93560D+02	0.14060D-02	0.18040D-02
15	0.45720D-02	0.11480D-02	-0.11870D-02	-0.95970D-03	0.62280D+01	-0.45100D+01	-0.35510D+05	-0.16650D+03	-0.99170D-03	-0.72340D-03
16	0.29690D-02	0.59090D-03	-0.66550D-03	-0.15260D-02	0.54430D+01	-0.54470D+01	-0.36140D+05	-0.12150D+03	-0.14600D-02	-0.15900D-02
17	0.13940D-02	0.22720D-03	-0.29440D-03	-0.10030D-02	0.45250D+01	-0.62300D+01	-0.27630D+05	-0.52840D+02	-0.93540D-03	-0.10700D-02
18	0.50640D-03	0.72390D-04	-0.96720D-04	-0.44120D-03	0.34950D+01	-0.64610D+01	-0.83530D+04	-0.22170D+02	-0.40370D-03	-0.47850D-03
19	0.14940D-03	0.18720D-04	-0.27140D-04	-0.14370D-03	0.23790D+01	-0.73230D+01	-0.23940D+04	-0.65220D+01	-0.17930D-03	-0.15810D-03
20	0.47350D-04	0.27000D-05	-0.92160D-05	-0.24320D-04	0.12050D+01	-0.76050D+01	0.49610D+03	0.11670D+01	-0.21740D-04	-0.26890D-04
21	0.65410D-04	-0.83010D-05	-0.11880D-04	0.59110D-04	-0.68410D-04	-0.77000D+01	0.46350D+04	0.11480D+02	0.52130D-04	0.66070D-04
22	0.26570D-03	-0.33700D-04	-0.47930D-04	0.26560D-03	-0.12050D+01	-0.76050D+01	0.16010D+05	0.41880D+02	0.23790D-03	0.29340D-03
23	0.94880D-03	-0.13290D-03	-0.17340D-03	0.85520D-03	-0.23800D+01	-0.73230D+01	0.42710D+05	0.12090D+03	0.77980D-03	0.93230D-03
24	0.27770D-02	-0.43910D-03	-0.55840D-03	0.21300D-02	-0.34980D+01	-0.68590D+01	0.96200D+05	0.27340D+03	0.19740D-02	0.22920D-02
25	0.65060D-02	-0.11990D-02	-0.14160D-02	0.39450D-02	-0.45310D+01	-0.62250D+01	0.12350D+06	0.45860D+03	0.36690D-02	0.41170D-02
26	0.11960D-01	-0.26960D-02	-0.28460D-02	0.47280D-02	-0.54510D+01	-0.54340D+01	0.11930D+06	0.62530D+03	0.45540D-02	0.49330D-02
27	0.17590D-01	-0.51250D-02	-0.44200D-02	0.38610D-02	-0.62360D+01	-0.45090D+01	0.93070D+05	0.61750D+03	0.38960D-02	0.38650D-02
28	0.22510D-01	-0.82500D-02	-0.67580D-02	0.27190D-02	-0.68640D+01	-0.34720D+01	0.73920D+05	0.50390D+03	0.25870D-02	0.29040D-02
29	0.27290D-01	-0.12110D-01	-0.75480D-02	0.24310D-02	-0.73200D+01	-0.23500D+01	0.65910D+05	-0.32300D+03	0.19680D-02	0.30560D-02
30	0.32510D-01	-0.16770D-01	-0.75600D-02	0.28270D-02	-0.75940D+01	-0.11700D+01	0.49770D+05	0.63150D+03	0.26710D-02	0.30480D-02
31	0.37920D-01	-0.22230D-01	-0.95790D-02	0.21560D-02	-0.76780D+01	0.37920D-01	0.51180D+05	0.63540D+03	0.17470D-02	0.26610D-02
32	0.44290D-01	-0.29440D-01	-0.11960D-01	0.25630D-02	-0.75690D+01	0.12440D+01	0.50610D+05	0.54320D+03	0.26020D-02	0.26660D-02
33	0.51790D-01	-0.37270D-01	-0.13710D-01	0.20190D-02	-0.72720D+01	0.24170D+01	0.44300D+05	0.27000D+03	0.17260D-02	0.25450D-02
34	0.60760D-01	-0.45910D-01	-0.14750D-01	0.20560D-02	-0.67920D+01	0.35290D+01	0.42370D+05	-0.17160D+03	0.22660D-02	0.20670D-02
35	0.70850D-01	-0.54310D-01	-0.17420D-01	0.21570D-02	-0.61440D+01	0.45510D+01	0.40300D+05	0.35930D+04	0.39400D-03	0.42280D-02
36	0.83440D-01	-0.72790D-01	-0.32580D-01	0.31930D-02	-0.53340D+01	0.54520D+01	0.50590D+05	-0.19790D+04	0.95880D-03	0.64940D-02
37	0.10030D+00	-0.10050D+00	-0.29280D-01	0.47020D-02	-0.43860D+01	0.62070D+01	0.47510D+05	-0.15470D+05	0.87950D-02	0.14890D-02
38	0.12500D+00	-0.84890D-01	0.44440D-01	0.11740D-01	-0.33460D+01	0.68420D+01	0.41690D+05	-0.67290D+04	0.37280D-01	-0.76420D-02
39	0.13750D+00	0.78780D-01	0.19350D+00	0.85260D-02	-0.22730D+01	0.74410D+01	0.32700D+05	0.92980D+04	0.60930D-01	-0.63770D-02
40	0.98910D-01	0.38650D+00	0.18690D+00	-0.21030D-02	-0.11660D+01	0.79960D+01	0.39420D+05	0.12460D+05	-0.18740D-01	0.49460D-01

FRAG NO.=	FCGU =	FCGW =	ALFA =	FRUV =	FRWV =	FRAV =
1	-0.1085570+00	0.5363460+01	-0.1672630+01	0.2156310+04	0.3292980+04	-0.1729620+04
2	0.4352520+01	-0.1944790+01	-0.1380400+01	0.2757500+04	-0.4776130+04	-0.1972000+04
3	0.0	-0.2797000+01	0.0	-0.5515000+04	0.0	-0.1972000+04

SUBSTRUCTURE	MSTR	ELE	SURF	STA	TIME
1	0.9482870-01	1	2	1	0.8600000-03

SUBSTRUCTURE	LARGEST ADD. PT. STRAIN	ELEM	ADD. PT.	TIME	SURFACE
1	0.6824150-01	40	1	0.8600000-03	2

SUBSTRUCTURE	LARGEST NODAL STRAIN	NODE	SURF	TIME
1	0.1126420+00	1	2	0.8600000-03

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ENERGY AND WORK AT THE END OF TIME CYCLE 450

FRAGMENT	KINETIC ENERGY
1	0.171819D+06
2	0.271231D+06
3	0.271231D+06

WORK INPUT INTO RING = 0.994120D+05
RING KINETIC ENERGY = 0.222038D+05
RING ELASTIC ENERGY = 0.533954D+04
RING PLASTIC WORK = 0.718686D+05
ENERGY STORED IN ELASTIC RESTRAINTS = 0.0

CYCLE= 450

ELEM	SI STA1	SO	SI STA2	SO	SI STA3	SO
1	-0.7131D-01	0.9370D-01	-0.2035D-01	0.1786D-01	0.4322D-01	-0.4262D-01
2	0.2032D-01	-0.8677D-02	0.2426D-01	-0.8828D-02	0.2682D-01	-0.1058D-01
3	0.2240D-01	-0.9020D-02	0.1881D-01	-0.1251D-01	0.1713D-01	-0.1416D-01
4	0.1348D-01	-0.1228D-01	0.4603D-02	-0.9423D-02	0.5218D-02	-0.5087D-02
5	0.3388D-02	-0.3144D-02	0.9423D-03	-0.1661D-02	-0.1399D-02	-0.7140D-04
6	-0.4342D-02	0.2724D-02	-0.4178D-02	0.3170D-02	-0.3883D-02	0.3778D-02
7	-0.3156D-02	0.2579D-02	-0.2116D-02	0.2504D-03	0.1322D-03	-0.7977D-03
8	0.2079D-02	-0.2516D-02	0.3583D-03	-0.1876D-02	-0.3067D-03	-0.3164D-04
9	-0.2259D-04	0.4965D-03	-0.7924D-03	0.5721D-03	-0.1002D-02	0.1975D-03
10	-0.8396D-03	0.1150D-03	0.1223D-03	0.1165D-03	0.3906D-03	-0.6235D-03
11	-0.7012D-03	0.5274D-03	0.4187D-03	0.8436D-03	0.1472D-02	0.1091D-02
12	0.9195D-03	0.1653D-02	0.5521D-03	0.1068D-02	0.4081D-03	0.7205D-03
13	0.9350D-03	0.2577D-03	0.9260D-03	0.1113D-02	0.7099D-03	0.2026D-02
14	0.2021D-02	0.1381D-02	0.2419D-02	0.2565D-02	0.2832D-02	0.3764D-02
15	0.3149D-02	0.3730D-02	0.3100D-02	0.3205D-02	0.3100D-02	0.2731D-02
16	0.2097D-02	0.3545D-02	0.2740D-02	0.3043D-02	0.3427D-02	0.2487D-02
17	0.2674D-02	0.3925D-02	0.4116D-02	0.4814D-02	0.5783D-02	0.5941D-02
18	0.6164D-02	0.6711D-02	0.6607D-02	0.7450D-02	0.7311D-02	0.8466D-02
19	0.7796D-02	0.9055D-02	0.6757D-02	0.7512D-02	0.5995D-02	0.7146D-02
20	0.5994D-02	0.5911D-02	0.4116D-02	0.4637D-02	0.2421D-02	0.3452D-02
21	0.2438D-02	0.2023D-02	0.1106D-02	0.1354D-02	-0.2294D-03	0.6805D-03
22	0.1830D-03	-0.4240D-03	-0.2140D-03	-0.2501D-03	-0.5720D-03	-0.3537D-04
23	-0.4735D-03	-0.1537D-03	-0.3220D-03	-0.2679D-03	-0.1768D-03	-0.3884D-03
24	-0.5686D-03	0.1536D-04	-0.3695D-03	-0.2782D-03	-0.2206D-03	-0.6239D-03
25	-0.9332D-03	0.6134D-04	-0.6200D-03	-0.7666D-04	-0.2601D-03	-0.1650D-03
26	-0.3290D-03	-0.9013D-04	-0.4410D-03	0.1601D-04	-0.3406D-03	0.3374D-03
27	0.3679D-03	-0.3927D-03	-0.5721D-03	-0.1606D-04	-0.1464D-02	0.4029D-03
28	-0.2075D-03	-0.9585D-03	-0.7084D-03	-0.5813D-03	-0.1469D-02	-0.4732D-03
29	-0.1380D-02	-0.6060D-03	-0.7509D-03	-0.5619D-03	-0.2620D-03	-0.6644D-03
30	-0.1419D-02	0.2556D-03	-0.1500D-02	-0.3559D-03	-0.1320D-02	-0.6957D-03
31	-0.1971D-02	-0.1395D-03	-0.1804D-02	-0.4628D-03	-0.1317D-02	-0.4436D-03
32	-0.7926D-03	-0.9342D-03	-0.9460D-03	-0.1150D-02	-0.7929D-03	-0.1344D-02
33	0.2272D-04	-0.2329D-02	-0.1028D-02	-0.1029D-02	-0.1520D-02	0.8564D-03
34	-0.3971D-02	0.2333D-02	-0.5184D-02	0.2879D-02	-0.5600D-02	0.4315D-02
35	-0.5097D-02	0.4397D-02	-0.9393D-03	0.4983D-03	0.4693D-02	-0.2037D-02
36	0.4391D-02	-0.2196D-02	0.6466D-02	-0.7472D-02	0.1197D-01	-0.9183D-02
37	0.1563D-01	-0.1132D-01	0.1898D-01	-0.1293D-01	0.2729D-01	-0.9329D-02
38	0.3332D-01	-0.9453D-02	0.3264D-01	-0.1109D-01	0.4361D-01	-0.3933D-02
39	0.5548D-01	-0.5886D-02	0.2233D-01	0.2823D-01	-0.2063D-01	0.5313D-01
40	-0.1956D-01	0.4649D-01	-0.3707D-01	0.6533D-01	-0.5061D-01	0.8782D-01

CYCLE= 450

STRAIN AT ADDITIONAL POINTS	SI	SO	EI	EO
1	-0.40162513D-01	0.68751342D-01	-0.41003142D-01	0.66537709D-01

J= 450 TIME= 0.900000-03 TIME AFTER INITIAL IMPACT = 0.1360870-03

I	V	W	PSI	CHI	COPY	COPZ	L	M	STRAIN(IN)	STRAIN(OUT)
1	0.52850-01	0.54320+00	-0.19610+00	0.16660-01	0.57850-01	0.82490+01	-0.27080+05	0.11370+05	-0.65200-01	0.11050+00
2	-0.47870-01	0.25120+00	-0.22400+00	-0.20400-01	0.11370+01	0.78610+01	-0.18050+05	0.48730+04	0.47210-01	-0.32410-01
3	-0.73790-01	0.26[illegible]0-01	0.12170+00	0.42550-03	0.23130+01	0.73730+01	-0.21770+05	-0.84110+04	0.25630-01	-0.94690-0[illegible]
4	-0.72830-01	-0.77540-01	-0.19170-01	0.92350-03	0.33160+01	0.64250+01	-0.15460+05	-0.14460+05	0.16170-01	-0.13440-01
5	-0.53420-01	-0.41120-01	0.15640-01	0.51120-05	0.64290+01	0.61960+01	-0.16640+05	-0.35460+04	0.42650-02	-0.16020-02
6	-0.49530-01	-0.51440-01	0.14410-01	-0.14230-02	0.54720+01	0.54420+01	-0.14440+05	0.71070+04	-0.32140-02	0.14970-02
7	-0.41860-01	-0.33750-01	0.11170-01	0.41030-04	0.61760+01	0.45420+01	-0.27060+05	0.22890+04	-0.35160-02	0.37270-02
8	-0.37450-01	-0.33790-01	0.33520-02	0.94580-04	0.68130+01	0.35150+01	-0.22020+05	-0.21610+04	0.13[illegible]70-02	-0.17120-02
9	-0.34970-01	-0.29510-01	0.10670-01	0.12030-04	0.72950+01	0.24040+01	0.47570+04	0.53610+03	-0.17650-03	0.53170-03
10	-0.31020-01	-0.27340-01	0.93710-02	-0.64990-03	0.75780+01	0.12320+01	0.30750+04	-0.81110+02	-0.12780-02	-0.17740-04
11	-0.27960-01	-0.17370-01	0.81600-02	-0.34990-03	0.76820+01	0.27490-01	0.19250+05	0.39960+03	-0.35700-01	-0.27490-03
12	-0.24710-01	-0.13720-01	0.69380-02	0.14470-02	0.75960+01	-0.11780+01	0.23510+05	0.49940+03	0.14710-02	0.15120-02
13	-0.21900-01	-0.10210-01	0.5[illegible]650-02	0.52370-03	0.73200+01	-0.23550+01	0.24210+05	0.29290+03	0.72140-03	0.34570-03
14	-0.13460-01	-0.64110-02	0.43790-02	0.14710-02	0.[illegible]8630+01	-0.34750+01	0.72300+05	0.14120+03	0.17450-02	0.16680-02
15	-0.15550-01	-0.23750-02	0.39160-02	0.35140-02	0.62150+01	-0.45110+01	0.71210+05	0.57640+02	0.31570-02	0.39930-02
16	-0.11270-01	-0.15560-02	0.35160-02	0.29510-02	0.5451[illegible]	-0.56350+01	0.83700+05	0.27240+03	0.25100-02	0.32120-02
17	-0.75860-02	-0.49430-03	0.25190-02	0.29870-02	0.45320+01	-0.62250+01	0.12750+06	0.67470+03	0.27630-02	0.30250-02
18	-0.21270-02	0.24420-03	0.57550-03	0.62490-02	0.34380+01	-0.65600+01	0.17710+06	0.31140+03	0.62020-02	0.64350-02
19	0.61970-02	[illegible]	-0.13310-02	0.81510-02	0.23730+01	-0.73250+01	0.20040+06	0.11940+03	0.79420-02	0.85310-02
20	0.15170-01	-0.17470-02	-0.42750-02	0.63400-02	0.11490+01	-0.76360+01	0.12790+06	0.90490+03	0.60570-02	0.66840-02
21	0.23950-01	-0.45760-02	-0.54560-02	0.25040-02	-0.20950-01	-0.76950+01	0.35630+05	0.21940+03	0.23550-02	0.26720-02
22	0.23630-01	-0.51710-02	-0.65640-02	-0.96340-04	-0.12260+01	-0.75940+01	-0.67330+04	-0.34850+02	-0.15700-03	0.79030-05
23	0.24670-01	-0.11770-01	-0.64470-02	-0.34410-03	-0.23990+01	-0.73040+01	-0.85590+04	0.52330+02	-0.59410-03	-0.47710-04
24	0.25460-01	-0.15730-01	-0.65610-02	-0.29760-03	-0.35120+01	-0.68350+01	-0.93970+04	0.84360+02	-0.32690-03	-0.16170-03
25	0.28860-01	-0.20270-01	-0.69150-02	-0.47960-03	-0.45370+01	-0.61760+01	-0.10110+05	0.92560+03	-0.67070-03	-0.31000-03
26	0.31960-01	-0.25440-01	-0.85770-02	-0.19600-03	-0.54500+01	-0.54040+01	-0.61650+04	0.44200+03	-0.19620-01	-0.12030-03
27	0.36120-01	-0.30390-01	-0.93750-02	0.49160-04	-0.62260+01	-0.44770+01	-0.85310+04	0.51780+03	0.19530-03	0.25500-05
28	0.41030-01	[illegible]	-0.11560-01	-0.67070-03	-0.63470+01	-0.34420+01	-0.22600+05	0.37290+03	-0.91120-03	-0.24390-03
29	0.46470-01	-0.43670-01	-0.12030-01	-0.11370-02	-0.72960+01	-0.23220+01	-0.21160+05	-0.13490+03	-0.16710-02	-0.57670-03
30	0.51940-01	-0.51260-01	-0.12650-01	-0.50730-03	-0.75630+01	-0.11440+01	-0.26930+05	0.11070+04	-0.74500-03	-0.11060-03
31	0.60430-01	-0.60110-01	-0.14580-01	-0.11050-02	-0.76400+01	0.63480-01	-0.33550+05	0.11810+04	-0.15490-02	-0.36100-03
32	0.69360-01	-0.72230-01	-0.20150-01	-0.94330-03	-0.75230+01	0.12620+01	-0.29980+05	-0.23770+03	-0.91430-03	-0.54550-03
33	0.82320-01	-0.84510-01	-0.13130-01	-0.12430-02	-0.72180+01	0.24300+01	-0.42940+05	-0.64070+02	-0.14010-03	-0.19740-02
34	0.92950-01	-0.92350-01	-0.17150-01	-0.23900-03	-0.67360+01	0.35370+01	-0.47070+05	0.61740+04	-0.23600-02	0.22910-02
35	0.13710+00	-0.11340+00	-0.44320-01	-0.12030-02	-0.60700+01	0.45460+01	-0.37020+05	0.34990+03	-0.57950-02	0.53540-02
36	0.12710+00	-0.15410+00	-0.43440-01	0.72250-03	-0.52430+01	0.54230+01	-0.35900+05	-0.13070+05	0.54640-02	-0.12710-02
37	0.15380+00	-0.17500+00	-0.64120-02	0.27280-02	-0.42990+01	0.61720+01	-0.30830+05	-0.13260+05	0.14940-01	-0.94360-02
38	0.18110+00	-0.13250+00	0.29740-01	0.77940-02	-0.32950+01	0.68520+01	-0.31060+05	-0.13110+04	0.31000-01	-0.73010-02
39	0.18320+00	0.11260+00	0.22180+00	-0.36320-03	-0.22400+01	0.74870+01	-0.29310+05	0.97330+04	0.56610-01	-0.81210-02
40	0.12600+00	0.44810+00	0.20350+00	-0.85030-02	-0.11500+01	0.80670+01	-0.23820+05	0.14380+05	-0.25130-01	0.49610-01

FRAG NO.=	FCGU =	FCGW =	ALFA =	FRUV =	FRWV =	FRAV =
1	-0.2233440-01	0.5495180+01	-0.1741820+01	0.2156310+04	0.3292980+04	-0.1729420+04
2	0.4462820+01	-0.2135840+01	-0.1459280+01	0.2757500+04	-0.4776130+04	-0.1972000+04
3	0.0	-0.2797000+01	0.0	-0.5515000+04	0.0	-0.1972000+04

SUBSTRUCTURE	MSTR	ELE	SURF	STA	TIME
1	0.9493870-01	1	2	1	0.8640000-03

SUBSTRUCTURE	LARGEST ADD. PT. STRAIN	ELEM	ADD. PT.	TIME	SURFACE
1	0.6875130-01	40	1	0.9000000-03	2

SUBSTRUCTURE	LARGEST NODAL STRAIN	NODE	SURF	TIME
1	0.1106420+00	1	2	0.8600000-03

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ORIGINAL PAGE IS
OF POOR QUALITY

IMPACT NO. 2 TIME 0.905193D-03 DURING CYCLE 455 ELEM 1 FRAG 1 DISTANCE 0.686058D+00

IMPACT NO. 3 TIME 0.922127D-03 DURING CYCLE 462 ELEM 13 FRAG 2 DISTANCE 0.787282D+00

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ENERGY AND WORK AT THE END OF TIME CYCLE 470

FRAGMENT	KINETIC ENERGY
1	0.135563D+06
2	0.183985D+06
3	0.271231D+06

WORK INPUT INTO RING = 0.222915D+06
RING KINETIC ENERGY = 0.732661D+05
RING ELASTIC ENERGY = 0.918864D+04
RING PLASTIC WORK = 0.140460D+06
ENERGY STORED IN ELASTIC RESTRAINTS = 0.0

CYCLE= 470

ELEM	SI (STA1)	SO (STA1)	SI (STA2)	SO (STA2)	SI (STA3)	SO (STA3)
1	-0.6506D-01	0.9481D-01	-0.1489D-01	0.3655D-01	0.1092D-01	-0.4182D-02
2	-0.2111D-01	0.3287D-01	0.1242D-01	-0.2204D-02	0.4565D-01	-0.3641D-01
3	0.3926D-01	-0.2750D-01	0.3137D-01	-0.2253D-01	0.2340D-01	-0.1816D-01
4	0.1394D-01	-0.1315D-01	0.8890D-02	-0.1101D-01	0.6636D-02	-0.6072D-02
5	0.7372D-02	-0.6245D-02	0.4677D-02	-0.5914D-02	0.2356D-02	-0.5732D-02
6	-0.1946D-03	-0.3457D-02	-0.2910D-02	-0.1953D-02	-0.5669D-02	-0.6797D-03
7	-0.8347D-02	0.1565D-02	-0.7757D-02	0.1547D-02	-0.7136D-02	0.1639D-02
8	-0.5222D-02	0.1350D-03	-0.3177D-02	-0.1145D-02	-0.1129D-02	-0.2417D-02
9	0.1752D-02	-0.1637D-02	0.2467D-02	-0.1317D-02	0.1854D-02	-0.2227D-03
10	0.1013D-02	0.2471D-02	0.3655D-02	0.5651D-02	0.5033D-02	0.7692D-02
11	0.3041D-02	0.5555D-02	0.4071D-02	0.3951D-02	0.1860D-01	0.5115D-02
12	0.2338D-01	0.2199D-02	0.1799D-01	0.6674D-07	0.2094D-01	0.2013D-01
13	0.7368D-01	-0.2577D-01	0.1630D-01	0.3324D-01	-0.5071D-01	0.8324D-01
14	-0.8407D-01	0.1317D+00	-0.2881D-02	0.1055D-01	0.7189D-01	-0.8588D-01
15	0.1263D-01	-0.1512D-01	0.4090D-02	-0.5948D-02	-0.5649D-02	-0.3575D-02
16	-0.8061D-02	-0.6841D-02	-0.5649D-02	-0.5170D-02	-0.4567D-02	-0.4901D-02
17	-0.5227D-02	-0.3792D-07	-0.3028D-02	[illegible]	-0.4647D-04	-0.1699D-02
18	0.1064D-04	-0.1351D-03	0.2807D-03	0.2630D-03	0.1072D-02	0.1210D-02
19	0.4326D-03	0.1779D-02	[illegible]	0.2973D-03	-0.8464D-03	0.9316D-03
20	0.6638D-03	-0.4975D-03	0.3416D-04	-0.5439D-05	-0.5897D-03	0.4924D-03
21	0.4109D-03	-0.3451D-03	0.1171D-03	0.3487D-03	-0.5035D-03	0.7063D-03
22	-0.3655D-03	0.1386D-03	-0.4755D-03	-0.3976D-03	-0.4981D-03	-0.8392D-03
23	-0.1454D-02	0.5799D-04	-0.8664D-03	-0.4239D-03	-0.2327D-03	-0.8497D-03
24	-0.9484D-03	0.3373D-03	-0.1023D-03	0.6628D-03	0.6711D-03	0.9291D-03
25	0.6973D-03	0.1056D-02	0.7440D-03	0.1190D-02	-0.1060D-03	0.1428D-02
26	0.3876D-03	0.4553D-03	-0.4983D-03	0.2415D-03	-0.1124D-02	0.7708D-03
27	-0.2700D-03	-0.1171D-07	-0.1767D-02	-0.1507D-02	-0.2755D-02	-0.1117D-02
28	-0.2145D-02	-0.2190D-02	-0.2712D-02	-0.2593D-0?	-0.2835D-02	-0.2521D-02
29	-0.3429D-02	-0.1430D-02	[illegible]	-0.2063D-0?	-0.1723D-02	-0.1809D-02
30	-0.3535D-02	-0.1670D-03	-0.3709D-02	-0.1369D-02	-0.2913D-02	-0.1498D-02
31	-0.2841D-02	0.9951D-03	-0.1649D-02	-0.2344D-02	-0.4111D-03	-0.3644D-02
32	0.4219D-03	-0.4313D-02	-0.1252D-02	-0.1761D-02	-0.3144D-02	-0.1555D-03
33	-0.4791D-02	0.1196D-02	-0.3639D-02	0.3129D-02	-0.6516D-02	0.4569D-02
34	-0.7086D-02	0.5148D-02	-0.3751D-02	0.3059D-02	-0.4521D-03	0.1023D-02
35	0.7646D-03	0.1101D-02	0.6302D-0?	-0.1123D-02	0.1223D-01	-0.3137D-02
36	0.1169D-01	-0.2342D-02	0.1414D-01	-0.6726D-0?	0.1942D-01	-0.8321D-02
37	0.1923D-01	-0.7579D-02	0.2105D-01	-0.9865D-02	0.2810D-01	-0.6861D-02
38	0.3070D-01	-0.4902D-02	0.1242D-01	-0.7688D-02	0.4199D-01	-0.5013D-03
39	0.5621D-01	-0.4352D-02	0.2683D-01	0.2746D-01	-0.1274D-01	0.5026D-01
40	-0.8581D-02	0.3480D-01	-0.2838D-01	0.6199D-01	-0.4439D-01	0.8853D-01

CYCLE= 470

STRAIN AT ADDITIONAL POINTS	SI	SO	EI	EO
1	-0.31899111D-01	0.66080061D-01	-0.32424794D-01	0.64030132D-01

J= 470 TIME= 0.940000-03 TIME AFTER INITIAL IMPACT = 0.1760870-03

I	V	W	PSI	CHI	COPY	COPZ	L	M	STRAIN(IN)	STRAIN(OUT)
1	0.97360D-01	0.67500D+00	-0.42310D-01	0.25520D-01	0.79360D-01	0.81750D+01	0.53040D+04	0.22320D+05	-0.55990D-01	0.10950D+00
2	-0.11910D-01	0.41750D+00	-0.25490D+00	-0.28410D-01	0.12580D+01	0.80130D+01	0.15410D+05	0.12690D+05	-0.27960D-02	0.14330D-01
3	-0.96560D-01	0.79150D-01	-0.21670D+00	-0.16700D-01	0.23120D+01	0.74280D+01	0.22640D+05	-0.17170D+05	0.49850D-01	-0.36170D-01
4	-0.98980D-01	-0.90170D-01	-0.51260D-01	0.94610D-04	0.31670D+01	0.68250D+01	0.14390D+05	-0.84540D+04	0.18330D-01	-0.15320D-01
5	-0.81700D-01	-0.12680D+00	0.60950D-02	0.10950D-02	0.41950D+01	0.61750D+01	-0.11750D+05	-0.91760D+04	0.72970D-02	-0.52390D-02
6	-0.61760D-01	-0.10950D+00	0.38960D-01	-0.24190D-02	0.53230D+01	0.54130D+01	-0.69100D+05	0.82900D+03	0.11410D-02	-0.44560D-02
7	-0.53880D-01	-0.68370D-01	0.36350D-01	-0.41550D-02	0.61420D+01	0.45290D+01	-0.83910D+05	0.81050D+04	-0.75530D-02	0.58230D-03
8	-0.49080D-01	-0.50040D-01	0.80390D-02	-0.27180D-02	0.67940D+01	0.35170D+01	-0.62720D+05	0.19640D+04	-0.64320D-02	0.10590D-02
9	-0.41620D-01	-0.51760D-01	0.18720D-02	-0.16290D-02	0.72580D+01	0.24040D+01	0.15810D+05	-0.36610D+04	0.47460D-03	-0.36910D-02
10	-0.35090D-01	-0.43720D-01	0.13220D-01	0.55240D-03	0.75510D+01	0.12310D+01	0.13750D+06	0.20470D+04	0.74150D-03	0.53820D-03
11	-0.22760D-01	-0.41750D-01	0.66790D-02	0.66410D-02	0.76580D+01	0.22760D-01	0.15430D+06	-0.17910D+04	0.39240D-02	0.95500D-02
12	-0.73160D-02	-0.36790D-01	0.12960D-01	0.14490D-01	0.75710D+01	-0.11920D+01	0.16120D+06	-0.62270D+04	0.74510D-01	0.47240D-02
13	0.11450D-01	0.15140D-01	0.52410D-01	0.27920D-01	0.73140D+01	-0.23950D+01	0.12480D+06	0.92650D+04	0.51270D-01	-0.83630D-02
14	0.17750D-01	0.14190D+00	0.77150D-01	0.14460D-01	0.69790D+01	-0.35760D+01	0.16890D+06	0.27390D+04	-0.86500D-01	0.11550D+00
15	-0.23210D-02	-0.16240D-01	-0.45790D-01	-0.61230D-02	0.62180D+01	-0.45150D+01	0.36070D+05	-0.12720D+05	0.55500D-01	-0.66050D-01
16	-0.30820D-03	-0.26970D-01	0.21330D-02	-0.81470D-02	0.54260D+01	-0.54250D+01	-0.15700D+06	0.46240D+03	-0.10340D-01	-0.62830D-02
17	-0.32000D-02	-0.26090D-01	0.74560D-03	-0.47490D-02	0.45130D+01	-0.62060D+01	-0.91710D+05	-0.25940D+03	-0.51170D-02	-0.44540D-02
18	-0.25230D-02	-0.25710D-01	0.11310D-02	-0.58470D-04	0.34960D+01	-0.69360D+01	-0.60480D+05	-0.29750D+03	0.50830D-03	-0.62400D-03
19	0.20800D-02	-0.25400D-01	0.11310D-02	0.14920D-02	0.23700D+01	-0.71000D+01	-0.[illegible]5400D+05	-0.16780D+03	0.11230D-02	0.18590D-02
20	0.65410D-02	-0.25710D-01	-0.35660D-02	0.10970D-03	0.11940D+01	-0.75810D+01	-0.67660D+04	-0.13690D+04	0.23640D-04	0.20840D-03
21	0.13790D-01	-0.27910D-01	-0.34460D-02	-0.83160D-04	-0.10790D-01	-0.76720D+01	0.67140D+04	0.22670D+03	-0.16720D-03	0.12710D-04
22	0.15480D-01	-0.29660D-01	-0.41420D-02	-0.16530D-04	-0.12150D+01	-0.75730D+01	-0.12670D+05	0.79440D+02	-0.51720D-03	0.52130D-03
23	0.19640D-01	-0.32370D-01	-0.41820D-02	-0.72520D-03	-0.23880D+01	-0.72860D+01	-0.18680D+05	0.43090D+03	-0.10560D-02	-0.37490D-03
24	0.24410D-01	-0.35960D-01	-0.57330D-02	-0.53760D-03	-0.35910D+01	-0.69190D+01	0.80300D+04	0.74690D+03	-0.61980D-03	-0.36330D-03
25	0.30650D-01	-0.40370D-01	-0.70680D-02	0.91380D-03	-0.45270D+01	-0.61790D+01	0.27660D+05	0.91120D+03	0.87220D-03	0.10210D-02
26	0.38250D-01	-0.45760D-01	-0.10720D-01	0.57710D-03	-0.54370D+01	-0.53850D+01	-0.37220D+04	0.71580D+03	0.25180D-03	0.10630D-02
27	0.45850D-01	-0.53390D-01	0.13180D-01	-0.55960D-03	-0.62130D+01	-0.44570D+01	-0.47430D+05	0.24670D+03	-0.49830D-03	-0.44700D-03
28	0.52960D-01	-0.60360D-01	-0.13970D-01	-0.20400D-02	-0.68300D+01	-0.34210D+01	-0.80770D+05	0.36960D+03	-0.24290D-02	-0.14510D-02
29	0.60000D-01	-0.69380D-01	-0.14360D-01	-0.27120D-02	-0.72760D+01	-0.23010D+01	-0.72740D+05	0.39620D+03	-0.31630D-02	-0.20470D-02
30	0.69620D-01	-0.78620D-01	-0.16610D-01	-0.16140D-02	-0.75380D+01	-0.11250D+01	-0.73160D+05	0.22820D+04	-0.23120D-02	-0.63600D-03
31	0.78930D-01	-0.92290D-01	-0.23420D-01	-0.21990D-02	-0.76090D+01	0.75730D-01	-0.55580D+05	-0.75810D+03	-0.28460D-02	-0.97850D-03
32	0.91960D-01	-0.10420D+00	-0.21720D-01	-0.22380D-02	-0.74840D+01	0.12740D+01	-0.45360D+05	-0.63150D+03	0.38090D-03	-0.43700D-02
33	0.10740D+00	-0.11460D+00	-0.19530D-01	-0.20740D-02	-0.71810D+01	0.24460D+01	-0.44720D+05	0.76230D+04	-0.42520D-02	0.49100D-03
34	0.12430D+00	-0.13410D+00	-0.16050D-01	-0.22340D-02	-0.66850D+01	0.35460D+01	-0.13360D+05	0.42890D+04	-0.76570D-02	0.53140D-02
35	0.14650D+00	-0.18530D+00	-0.66670D-01	-0.16760D-02	-0.59930D+01	0.45360D+01	0.43060D+05	-0.81240D+04	-0.13230D-03	0.12290D-02
36	0.18090D+00	-0.23320D+00	-0.44440D-01	0.43310D-02	-0.51920D+01	0.54080D+01	0.96400D+05	-0.13820D+05	0.12740D-01	-0.21030D-02
37	0.22270D+00	-0.22220D+00	0.11740D-01	0.65670D-02	-0.42150D+01	0.61810D+01	0.44090D+05	-0.91530D+04	0.20600D-01	-0.70620D-02
38	0.25590D+00	-0.10420D+00	0.11240D+00	0.69490D-02	-0.32190D+01	0.68810D+01	0.15090D+05	0.22230D+04	0.31430D-01	-0.90570D-02
39	0.25440D+00	0.13980D+00	0.23350D+00	-0.25340D-02	-0.21810D+01	0.75350D+01	0.17810D+05	0.26460D+04	0.55300D-01	-0.98200D-02
40	0.18780D+00	0.53540D+00	0.23120D+00	-0.12220D-01	-0.10980D+01	0.81340D+01	-0.21180D+05	-0.70460D+04	-0.14790D-01	0.43940D-01

FRAG NO.=	FCGU =	FCGW =	ALFA =	FRUV =	FRWV =	FRAV =
1	0.4566770D-01	0.5608950D+01	-0.1807120D+01	0.1631980D+04	0.2777400D+04	-0.1618250D+04
2	0.4556730D+01	-0.2308210D+01	-0.1534400D+01	0.1840390D+04	-0.3731360D+04	-0.1761450D+04
3	-0.1764800D+00	-0.2797000D+01	-0.6310400D-01	-0.5515000D+04	0.0	-0.1972000D+04

SUBSTRUCTURE	MSTR	ELE	SURF	STA	TIME
1	0.1017300D+00	14	2	1	0.9400000D-03

SUBSTRUCTURE	LARGEST ADD. PT. STRAIN	ELEM	ADD. PT.	TIME	SURFACE
1	0.6875130D-01	40	1	0.9000000D-03	2

SUBSTRUCTURE	LARGEST NODAL STRAIN	NODE	SURF	TIME
1	0.1156150D+00	14	2	0.9400000D-03

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IMPACT NO. 4 TIME 0.1000280D-02 DURING CYCLE 501 ELEM 14 FRAG 2 DISTANCE 0.8186180D+00

IMPACT NO. 5 TIME 0.1039070D-02 DURING CYCLE 520 ELEM 1 FRAG 1 DISTANCE 0.6270680D+00

IMPACT NO. 6 TIME 0.1063140D-02 DURING CYCLE 532 ELEM 40 FRAG 1 DISTANCE 0.4031310D+00

IMPACT NO. 7 TIME 0.1067380D-02 DURING CYCLE 534 ELEM 15 FRAG 2 DISTANCE 0.2861770D+00

IMPACT NO. 8 TIME 0.1115900D-02 DURING CYCLE 558 ELEM 39 FRAG 1 DISTANCE 0.6117520D+00

IMPACT NO. 9 TIME 0.1141990D-02 DURING CYCLE 571 ELEM 15 FRAG 2 DISTANCE 0.4313310D+00

IMPACT NO. 10 TIME 0.1154770D-02 DURING CYCLE 578 ELEM 13 FRAG 2 DISTANCE 0.3657160D+00

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IMPACT NO. 11 TIME 0.1220700-02 DURING CYCLE 611 ELEM 19 FRAG 2 DISTANCE 0.4838620+00
IMPACT NO. 12 TIME 0.1248920-02 DURING CYCLE 625 ELEM 2 FRAG 1 DISTANCE 0.5263690+00
IMPACT NO. 13 TIME 0.1257980-02 DURING CYCLE 629 ELEM 13 FRAG 2 DISTANCE 0.3144360+00
IMPACT NO. 14 TIME 0.1300980-02 DURING CYCLE 651 ELEM 39 FRAG 1 DISTANCE 0.4593990+00
IMPACT NO. 15 TIME 0.1334060-02 DURING CYCLE 668 ELEM 13 FRAG 2 DISTANCE 0.2480630+00

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ENERGY AND WORK AT THE END OF TIME CYCLE 670

FRAGMENT	KINETIC ENERGY
1	0.7630810+05
2	0.8909790+05
3	0.2712310+06

WORK INPUT INTO RING = 0.3770570+06
RING KINETIC ENERGY = 0.7080490+05
RING ELASTIC ENERGY = 0.7327500+04
RING PLASTIC WORK = 0.2789190+06
ENERGY STORED IN ELASTIC RESTRAINTS = 0.0

CYCLE= 670

ELEM	SI (STA1)	SO (STA1)	SI (STA2)	SO (STA2)	SI (STA3)	SO (STA3)
1	-0.71210D-01	0.10460D+00	-0.47040D-01	0.60870D-01	-0.83440D-02	0.33110D-01
2	-0.40550D-01	0.63970D-01	-0.10280D-01	0.32570D-01	0.18560D-01	0.19040D-02
3	0.11800D-01	0.59710D-02	0.16340D-01	-0.26740D-02	0.22340D-01	-0.93830D-02
4	0.20570D-01	-0.63930D-02	0.26000D-01	-0.13000D-01	0.32950D-01	-0.17990D-01
5	0.26650D-01	-0.11970D-01	0.20930D-01	-0.11580D-01	0.16490D-01	-0.10150D-01
6	0.14580D-01	-0.99750D-02	0.15000D-01	-0.10980D-01	0.17420D-01	-0.99150D-02
7	0.17170D-01	-0.69890D-02	0.22560D-01	-0.78170D-02	0.30120D-01	-0.64880D-02
8	0.34510D-01	-0.98260D-02	0.32200D-01	-0.14300D-01	0.32410D-01	-0.16440D-01
9	0.34130D-01	-0.19860D-01	0.27400D-01	-0.16550D-01	0.21970D-01	-0.12100D-01
10	0.16450D-01	-0.96930D-02	0.15640D-01	-0.10330D-01	0.20390D-01	-0.51820D-02
11	0.27460D-01	-0.91150D-02	0.30240D-01	-0.89850D-02	0.37290D-01	-0.56960D-02
12	0.42030D-01	-0.10100D-01	0.29890D-01	0.54980D-02	0.14670D-01	0.28380D-01
13	0.44750D-01	0.10100D-01	-0.11640D-01	0.72400D-01	-0.71930D-01	0.13390D+00
14	-0.85930D-01	0.13510D+00	-0.51610D-01	0.78010D-01	0.28140D-03	0.39000D-01
15	-0.38330D-01	0.69740D-01	-0.23300D-01	0.39950D-01	-0.62000D-02	0.14440D-01
16	0.26560D-02	0.47040D-02	0.12690D-01	-0.12040D-02	0.21400D-01	-0.83780D-02
17	0.17540D-01	-0.74640D-02	0.20620D-01	-0.18790D-01	0.29660D-01	-0.23820D-01
18	0.29910D-01	-0.18410D-01	0.29020D-01	-0.16860D-01	0.29770D-01	-0.14890D-01
19	0.27510D-01	-0.14230D-01	0.21810D-01	-0.14170D-01	0.17450D-01	-0.12950D-01
20	0.16010D-01	-0.13250D-01	0.10950D-01	-0.95360D-02	0.62770D-02	-0.34780D-02
21	0.48690D-03	0.44620D-03	-0.19260D-03	0.22550D-02	-0.15430D-02	0.33780D-02
22	-0.18320D-02	0.34760D-02	-0.42650D-02	0.63690D-02	-0.69500D-02	0.90470D-02
23	-0.71330D-02	0.97070D-02	-0.36630D-02	0.76090D-02	-0.64180D-03	0.50620D-02
24	-0.32370D-02	0.91960D-02	-0.15890D-02	0.99300D-02	-0.20710D-02	0.84530D-02
25	-0.40640D-02	0.79660D-02	-0.24730D-02	0.42170D-02	0.38140D-03	0.18560D-02
26	0.16980D-02	0.49720D-03	0.62450D-03	0.11690D-03	0.20910D-03	0.34320D-03
27	0.13560D-02	-0.46490D-03	-0.97530D-03	0.19970D-02	-0.38530D-02	0.38640D-02
28	-0.46620D-02	0.41320D-02	-0.60190D-02	0.54190D-02	-0.77560D-02	0.62610D-02
29	-0.94440D-02	0.75030D-02	-0.74440D-02	0.58320D-02	-0.54490D-02	0.41210D-02
30	-0.70140D-02	0.59900D-02	-0.50230D-02	0.50120D-02	-0.23810D-02	0.46790D-02
31	-0.83450D-03	0.35870D-02	-0.24190D-02	0.41660D-02	-0.28400D-02	0.59710D-02
32	-0.11550D-02	0.46700D-02	0.27720D-03	0.30230D-02	0.29180D-02	0.25940D-02
33	0.19960D-02	0.33610D-02	0.35040D-02	-0.82870D-03	0.61490D-02	-0.35560D-02
34	0.86630D-02	-0.46110D-02	0.14900D-01	-0.10530D-01	0.21450D-01	-0.16140D-01
35	0.21670D-01	-0.12960D-01	0.28060D-01	-0.14100D-01	0.33440D-01	-0.16680D-01
36	0.35470D-01	-0.15660D-01	0.34930D-01	-0.19400D-01	0.36050D-01	-0.18810D-01
37	0.34640D-01	-0.19840D-01	0.29970D-01	-0.15610D-01	0.32150D-01	-0.43230D-02
38	0.35980D-01	-0.55840D-02	0.32490D-01	-0.10360D-02	0.36350D-01	0.11270D-01
39	0.32900D-01	0.24120D-01	0.61590D-02	0.47320D-01	-0.28900D-01	0.63110D-01
40	-0.27330D-01	0.63720D-01	-0.39150D-01	0.82770D-01	-0.50320D-01	0.10000D+00

CYCLE= 670

STRAIN AT ADDITIONAL POINTS	SI	SO	EI	EO
1	-0.414009290D-01	0.856841960D-01	-0.422953790D-01	0.822977380D-01

J= 670 TIME= 0.134000D-02 TIME AFTER INITIAL IMPACT = 0.576087D-03

I	V	W	PSI	CHI	COPY	COPZ	L	M	STRAIN(IN)	STRAIN(OUT)
1	0.73880D+00	0.14900D+01	-0.63740D-01	0.24880D-01	0.73880D+00	0.91900D+01	0.14100D+05	0.78100D+04	-0.61370D-01	0.11580D+00
2	0.47950D+00	0.12590D+01	-0.37130D+00	-0.64760D-01	0.18750D+01	0.87740D+01	0.30960D+05	0.14070D+05	-0.22390D-01	0.50170D-01
3	0.17640D+00	0.71000D+00	-0.57260D+00	-0.13630D+00	0.27670D+01	0.79440D+01	0.23560D+05	0.10940D+05	0.19370D-01	0.62150D-03
4	-0.41510D-01	0.11120D+00	-0.46550D+00	-0.10700D+00	0.35090D+01	0.69790D+01	0.23970D+05	0.10350D+04	0.21770D-01	-0.75870D-02
5	-0.11730D+00	-0.49440D+00	-0.34710D+00	-0.53330D-01	0.41930D+01	0.53710D+01	0.12290D+05	-0.49140D+04	0.32750D-01	-0.15170D-01
6	-0.70750D-01	-0.77460D+00	-0.24720D+00	-0.28690D-01	0.48460D+01	0.49460D+01	0.57940D+04	-0.90390D+04	0.15020D-01	-0.94860D-02
7	0.45640D-01	-0.17340D+01	-0.17390D+00	-0.99970D-02	0.54210D+01	0.38790D+01	0.20290D+05	-0.11310D+05	0.17190D-01	-0.78690D-02
8	0.22270D+00	-0.11700D+01	-0.79050D-01	0.10530D-01	0.59200D+01	0.27660D+01	0.16060D+05	-0.16600D+05	0.34750D-01	-0.68340D-02
9	0.41660D+00	-0.11120D+01	0.61710D-01	0.63210D-02	0.63760D+01	0.16340D+01	0.10870D+05	-0.15720D+05	0.34800D-01	-0.18390D-01
10	0.57290D+00	-0.49320D+00	0.19470D+00	-0.14390D-01	0.69160D+01	0.49950D+00	0.17870D+05	-0.93190D+04	0.19030D-01	-0.96700D-02
11	0.65550D+00	-0.59960D+00	0.27300D+00	-0.27590D-01	0.71900D+01	-0.65550D+00	0.76700D+05	0.35820D+03	0.25070D-01	-0.49180D-02
12	0.64440D+00	-0.67110D-02	0.37180D+00	-0.60340D-01	0.74980D+01	-0.18400D+01	0.12170D+05	0.63900D+04	0.44560D-01	-0.81380D-02
13	0.49500D+00	0.61770D+00	0.45060D+00	-0.81190D-01	0.77600D+01	-0.30420D+01	0.39810D+05	0.14250D+05	0.34900D-01	0.12410D-01
14	0.28270D+00	0.11650D+01	0.17430D+00	0.19540D-01	0.77700D+01	-0.42760D+01	-0.11550D+05	0.16940D+05	-0.83350D-01	0.16120D+00
15	0.10800D+00	0.11220D+01	-0.19410D+00	0.78370D-03	0.70730D+01	-0.52710D+01	0.72340D+04	0.14610D+05	-0.12950D-01	0.53770D-01
16	-0.96770D-01	0.73150D+00	-0.39710D+00	-0.77110D-01	0.60310D+01	-0.59930D+01	0.60400D+04	0.12350D+05	-0.11010D-02	0.65290D-02
17	-0.25760D+00	0.24387D+00	-0.35320D+00	-0.54020D-01	0.48760D+01	-0.62730D+01	-0.62797D+04	0.31210D+04	0.20660 01	-0.66810D-02
18	-0.31480D+00	-0.16490D+00	-0.21140D+00	-0.21790D-01	0.37700D+01	-0.65680D+01	0.82450D+04	-0.84097D+04	0.31640D-01	-0.21100D-01
19	-0.27670D+00	-0.41750D+00	-0.96370D-01	0.36110D-02	0.25150D+01	-0.68470D+01	0.15170D+05	-0.16260D+05	0.29830D-01	-0.14060D-01
20	-0.19990D+00	-0.64340D+00	0.16580D-01	0.17160D-02	0.13250D+01	-0.70910D+01	0.19690D+05	-0.11760D+05	0.17020D-01	-0.13310D-01
21	-0.12590D+00	-0.45040D+00	0.78560D-01	-0.28730D-02	0.12590D+00	-0.72500D+01	0.33870D+05	-0.96760D+03	0.26760D-02	-0.23010D-02
22	-0.63760D-01	-0.37260D+00	0.71170D-01	-0.17970D-02	-0.10830D+01	-0.72470D+01	0.32180D+05	0.48560D+04	-0.16140D-02	0.30810D-02
23	-0.11670D-01	-0.30760D+00	0.38780D-01	0.22910D-03	-0.22730D+01	-0.70340D+01	0.53070D+05	0.72190D+04	-0.80180D-02	0.99960D-02
24	0.36290D-01	-0.29150D+00	0.49020D-02	0.22040D-02	-0.33790D+01	-0.65727D+01	0.47930D+05	0.74050D+04	-0.19700D-02	0.64140D-02
25	0.85010D-01	-0.29490D+00	-0.27360D-01	0.20540D-02	-0.44240D+01	-0.59450D+01	0.24120D+05	0.62680D+04	-0.14490D-02	0.84520D-02
26	0.13340D+00	-0.37530D+00	-0.53180D-01	0.22140D-03	-0.53090D+01	-0.51200D+01	0.10750D+05	-0.49100D+03	0.18090D-02	0.11520D-02
27	0.18560D+00	-0.35950D+00	-0.40670D-01	-0.81800D-03	-0.60480D+01	-0.41640D+01	0.80070D+04	0.10310D+04	0.10900D-02	-0.35640D-03
28	0.24400D+00	-0.38620D+00	-0.57610D-01	-0.19440D-02	-0.66270D+01	-0.31030D+01	-0.29290D+05	0.94960D+04	-0.45780D-02	0.40140D-02
29	0.30400D+00	-0.43180D+00	-0.92170D-01	-0.52160D-02	-0.70060D+01	-0.17577D+01	-0.26440D+05	0.88410D+04	-0.91870D-02	0.72770D-02
30	0.36710D+00	-0.51770D+00	-0.13240D+00	-0.94090D-02	-0.71520D+01	-0.75900D+00	-0.12280D+05	0.76180D+04	-0.61700D-02	0.49630D-02
31	0.44570D+00	-0.63470D+00	-0.16780D+00	-0.11560D-01	-0.70650D+01	0.44590D+00	-0.67780D+04	0.17280D+04	-0.80790D-03	0.43300D-02
32	0.53720D+00	-0.76470D+00	-0.18280D+00	-0.14430D-01	-0.67660D+01	0.16170D+01	0.22420D+05	-0.24290D+04	-0.20730D-02	0.60330D-02
33	0.65070D+00	-0.90010D+00	-0.19110D+00	-0.15120D-01	-0.62660D+01	0.27200D+01	0.14580D+05	-0.46480D+04	0.27690D-02	0.37570D-02
34	0.78210D+00	-0.12160D+01	-0.17410D+00	-0.14210D-01	-0.56310D+01	0.37320D+01	0.25150D+05	-0.13330D+05	0.70690D-02	-0.35530D-02
35	0.93580D+00	-0.10570D+01	-0.10130D+00	-0.19170D-02	-0.48220D+01	0.46630D+01	0.34710D+05	-0.12620D+05	0.21570D-01	-0.15190D-01
36	0.11020D+01	-0.95070D+00	0.26500D-01	0.84670D-02	-0.39910D+01	0.55520D+01	0.51960D+05	-0.10800D+05	0.35510D-01	-0.17890D-01
37	0.12310D+01	-0.63520D+00	0.17110D+00	-0.91190D-02	-0.31570D+01	0.64390D+01	0.67060D+04	-0.74690D+04	0.37210D-01	-0.18850D-01
38	0.12590D+01	-0.11670D+00	0.32870D+00	-0.37930D-01	-0.23210D+01	0.73280D+01	0.28400D+05	0.10610D+05	0.36220D-01	-0.25960D-02
39	0.11570D+01	0.56200D+00	0.42970D+00	-0.67320D-01	-0.14460D+01	0.81940D+01	0.50140D+05	0.12780D+05	0.38700D-01	0.15860D-01
40	0.94840D+00	0.11900D+01	0.30450D+00	-0.32800D-01	-0.45390D+00	0.89290D+01	0.36970D+05	0.10430D+05	-0.33770D-01	0.61990D-01

FRAG NO.=	FCGU =	FCGW =	ALFA =	FRUV =	FRWV =	FRAV =
1	0.562321D+00	0.640976D+01	-0.239891D+01	0.112949D+04	0.135186D+04	-0.136281D+04
2	0.514099D+01	-0.336865D+01	-0.216576D+01	0.102309D+04	-0.187362D+04	-0.142754D+04
3	-0.238248D+01	-0.279700D+01	-0.851904D+00	-0.551500D+04	0.0	-0.197200D+04

SUBSTRUCTURE	MSTR	ELE	SURF	STA	TIME
1	0.145544D+00	13	2	3	0.100800D-02

SUBSTRUCTURE	LARGEST ADD. PT. STRAIN	ELEM	ADD. PT.	TIME	SURFACE
1	0.687473D-01	40	1	0.126000D-02	2

SUBSTRUCTURE	LARGEST NODAL STRAIN	NODE	SURF	TIME
1	0.180405D+00	14	2	0.980000D-03

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ORIGINAL PAGE IS OF POOR QUALITY

IMPACT NO. 16 TIME 0.134942D-02 DURING CYCLE 675 ELEM 2 FRAG 1 DISTANCE 0.532596D+00
IMPACT NO. 17 TIME 0.135945D-02 DURING CYCLE 678 ELEM 15 FRAG 2 DISTANCE 0.579123D+00
IMPACT NO. 18 TIME 0.136419D-02 DURING CYCLE 683 ELEM 39 FRAG 1 DISTANCE 0.436379D+00
IMPACT NO. 19 TIME 0.136780D-02 DURING CYCLE 684 ELEM 12 FRAG 2 DISTANCE 0.762991D+00

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ENERGY AND WORK AT THE END OF TIME CYCLE 690

FRAGMENT	KINETIC ENERGY
1	0.672946D+05
2	0.817813D+05
3	0.271231D+06

WORK INPUT INTO RING = 0.193387D+06
RING KINETIC ENERGY = 0.961957D+05
RING ELASTIC ENERGY = 0.853949D+04
RING PLASTIC WORK = 0.268692D+06
ENERGY STORED IN ELASTIC RESTRAINTS = 0.0

CYCLE= 690

ELEM	SI STA1	SO STA1	SI STA2	SO STA2	SI STA3	SO STA3
1	-0.6979D-01	0.1002D+00	-0.4672D-01	0.5838D-01	-0.8478D-02	0.3320D-01
2	-0.4440D-01	0.6722D-01	-0.1395D-01	0.3348D-01	0.1580D-01	0.1076D-02
3	0.6261D-02	0.7911D-02	0.1231D-01	-0.1126D-02	0.1925D-01	-0.8641D-02
4	0.2191D-01	-0.9361D-02	0.2993D-01	-0.1249D-01	0.3175D-01	-0.1410D-01
5	0.2550D-01	-0.7874D-02	0.2154D-01	-0.1004D-01	0.1886D-01	-0.1107D-01
6	0.1800D-01	-0.1170D-01	0.1797D-01	-0.1285D-01	0.1922D-01	-0.1254D-01
7	0.2001D-01	-0.1164D-01	0.2506D-01	-0.1149D-01	0.3209D-01	-0.9457D-02
8	0.1620D-01	-0.1211D-01	0.3527D-01	-0.1452D-01	0.3710D-01	-0.1847D-01
9	0.3977D-01	-0.2236D-01	0.3123D-01	-0.1854D-01	0.2308D-01	-0.1466D-01
10	0.1648D-01	-0.1066D-01	0.1835D-01	-0.9637D-02	0.2381D-01	-0.5116D-02
11	0.3041D-01	-0.1091D-01	0.3022D-01	-0.1233D-01	0.3811D-01	-0.4937D-02
12	0.4388D-01	-0.9726D-02	0.2375D-01	0.9457D-02	0.8679D-02	0.3425D-01
13	0.3430D-01	0.2072D-01	-0.1531D-01	0.7503D-01	-0.6810D-01	0.1284D+00
14	-0.2431D-01	0.1129D+00	-0.4977D-01	0.7878D-01	-0.9404D-01	0.3930D-01
15	-0.4045D-01	0.7033D-01	-0.2741D-01	0.4560D-01	-0.1112D-01	0.2491D-01
16	0.7207D-03	0.1203D-01	0.1325D-01	0.6557D-03	0.2552D-01	-0.1039D-01
17	0.2269D-01	-0.9558D-02	0.2360D-01	-0.1836D-01	0.3006D-01	-0.2147D-01
18	0.2885D-01	-0.1677D-01	0.2780D-01	-0.1537D-01	0.2776D-01	-0.1325D-01
19	0.2592D-01	-0.1131D-01	0.2192D-01	-0.1509D-01	0.2016D-01	-0.1474D-01
20	0.1735D-01	-0.1404D-01	0.1002D-01	-0.1049D-01	0.4614D-02	-0.4977D-02
21	0.6798D-03	-0.1246D-02	0.7014D-03	-0.2327D-02	0.1900D-02	-0.2613D-02
22	0.1763D-02	-0.2622D-02	-0.2233D-02	0.2737D-03	-0.5686D-02	0.3782D-02
23	-0.6602D-02	0.6435D-02	-0.5810D-02	0.4301D-02	-0.4525D-02	0.3997D-02
24	-0.8659D-02	0.9152D-02	-0.7617D-02	0.1017D-01	-0.7726D-02	0.1031D-01
25	-0.6213D-02	0.7135D-02	-0.4373D-02	0.3987D-02	-0.1223D-02	0.2299D-02
26	-0.1163D-02	0.3429D-02	-0.9550D-03	0.3703D-02	-0.8240D-03	0.3913D-02
27	-0.1173D-02	0.4761D-02	-0.1848D-02	0.4317D-02	-0.2397D-02	0.5722D-02
28	-0.2823D-03	0.3526D-02	-0.1064D-02	0.4115D-02	-0.1550D-02	0.5032D-02
29	-0.3873D-02	0.7408D-02	-0.4175D-02	0.7711D-02	-0.4062D-02	0.9483D-02
30	-0.7041D-02	0.1161D-01	-0.5259D-02	0.9961D-02	-0.2679D-02	0.9232D-02
31	-0.1972D-02	0.4469D-02	-0.2472D-02	0.6853D-02	-0.2143D-02	0.6169D-02
32	-0.6298D-03	0.4460D-02	0.2254D-02	0.8933D-04	0.6036D-02	-0.1661D-02
33	0.5084D-02	-0.3252D-03	0.7270D-02	-0.4485D-02	0.9797D-02	-0.8260D-02
34	0.8473D-02	-0.6398D-02	0.1308D-01	-0.1067D-01	0.1762D-01	-0.1506D-01
35	0.2079D-01	-0.1474D-01	0.2902D-01	-0.1731D-01	0.3579D-01	-0.2177D-01
36	0.3892D-01	-0.2531D-01	0.3589D-01	-0.2210D-01	0.3519D-01	-0.1691D-01
37	0.3119D-01	-0.1417D-01	0.2890D-01	-0.1046D-01	0.3361D-01	-0.4739D-03
38	0.3870D-01	-0.5656D-02	0.3031D-01	-0.1397D-02	0.3319D-01	0.1492D-01
39	0.2825D-01	0.2985D-01	-0.7974D-03	0.5078D-01	-0.3590D-01	0.6659D-01
40	-0.3156D-01	0.6355D-01	-0.3787D-01	0.7966D-01	-0.4601D-01	0.9341D-01

CYCLE= 690

STRAIN AT ADDITIONAL POINTS	SI	SO	EI	EO
1	-0.394497410-01	0.820755170-01	-0.402601820-01	0.789583100-01

J= 690   TIME= 0.13800D-02   TIME AFTER INITIAL IMPACT = 0.6160870-03

I	V	W	PSI	CHI	COPY	COPZ	L	M	STRAIN(IN)	STRAIN(OUT)
1	0.83100+00	0.15770+01	-0.78990-01	0.22080-01	0.83100+00	0.92270+01	-0.17360+05	0.50820+04	-0.59500-01	0.10920+00
2	0.56200+00	0.12990+01	-0.34770+00	-0.66720-01	0.19630+01	0.85000+01	-0.26270+04	0.16210+05	-0.24070-01	0.53050-01
3	0.24030+00	0.74120+00	-0.54240+00	-0.15140+00	0.28350+01	0.77560+01	0.20510+04	0.11260+05	0.14010-01	0.91970-03
4	-0.44580-02	0.11600+00	-0.50[illegible]90+00	-0.12880+00	0.35440+01	0.84660+01	0.30920+05	0.16380+04	0.21050-01	-0.92990-02
5	-0.99090-01	-0.44430+00	-0.39690+00	-0.67060-01	0.41890+01	0.59330+01	0.41590+05	-0.40140+04	0.30480-01	-0.10970-01
6	-0.56380-01	-0.85030+00	-0.[illegible]9120+00	-0.39860-01	0.47950+01	0.48780+01	0.20140+05	-0.13820+05	0.19240-01	-0.11190-01
7	0.67990-01	-0.11570+01	-0.14790+00	-0.16070-01	0.55330+01	0.37910+01	-0.15100+04	-0.15650+05	0.14310-01	-0.12030-01
8	0.25910+00	-0.13240+01	-0.87[illegible]70-01	0.95160-02	0.59120+01	0.26710+01	0.86770+04	-0.15200+05	0.35760-01	-0.14210-02
9	0.47500+00	-0.12640+01	[illegible].63600-01	0.74450-02	0.67670+01	0.15370+01	0.14790+05	-0.15370+05	0.42550-01	-0.20680-01
10	0.64720+00	-0.94920+00	0.22740+00	-0.21360-01	0.67280+01	0.41340+00	0.64650+05	-0.11120+05	0.19450-01	-0.12120-01
11	0.73470+00	-0.75130+00	0.30520+00	-0.35720-01	0.71370+01	-0.73470+00	0.32030+05	-0.25660+04	0.29050-01	-0.60510-02
12	0.70970+00	-0.24010-02	0.45270+00	-0.76330-01	0.74920+01	-0.19050+01	0.25970+05	0.10540+05	0.46950-01	-0.64040-02
13	0.53160+00	0.67560+00	0.47480+00	-0.33610-01	0.78020+01	-0.30960+01	0.27670+05	0.16060+05	0.24980-01	0.22010-01
14	0.30770+00	0.12330+01	0.13790+00	0.17040-01	0.78190+01	-0.43290+01	0.14260+05	0.13950+05	-0.40630-01	0.15490+00
15	0.12240+00	0.12230+01	-0.16750+00	0.10140-02	0.71110+01	-0.53320+01	0.11650+05	0.15770+05	-0.15170-01	0.53030-01
16	-0.95490-0.	0.81320+00	-0.41030+00	-0.81910-01	0.60570+01	-0.59520+01	0.32310+05	0.12750+05	-0.50580-02	0.16410-01
17	-0.27780+00	0.24970+00	-0.37330+00	-0.63330-01	0.49210+01	-0.63010+01	0.39940+05	0.10350+03	0.24370-01	-0.96170-02
18	-0.34510+00	-0.14320+00	-0.24660+00	-0.24450-01	0.37360+01	-0.65760+01	0.12210+05	-0.57940+04	0.31420-01	-0.18910-01
19	-0.31290+00	-0.41120+00	-0.11590+00	0.92440-03	0.25480+01	-0.69340+01	0.16420+04	-0.14020+05	0.27710-01	-0.12450-01
20	-0.23490+00	-0.52690+00	-0.38110-02	0.28270-02	0.13530+01	-0.70450+01	-0.59000+04	-0.11490+05	0.22060-01	-0.14390-01
21	-0.15150+00	-0.51970+00	0.53150-01	-0.17160-02	0.15150+00	-0.7[illegible]940+01	-0.16710+05	-0.64560+04	0.19530-02	-0.20140-02
22	-0.77680-01	-0.45370+00	0.67170-01	-0.23790-02	-0.10560+01	-0.71650+01	-0.26770+05	-0.33040+04	0.27240-02	-0.29050-02
23	-0.15480-01	-0.38750+00	0.60570-01	-0.27060-02	-0.22470+01	-0.67660+01	-0.21060+05	0.60950+04	-0.67210-02	0.49490-02
24	0.37530-01	-0.32730+00	0.27660-01	-0.70530-03	-0.33810+01	-0.63520+01	-0.20760+05	0.11430+05	-0.64540-02	0.62710-02
25	0.89470-01	-0.31410+00	-0.24110-0.	0.60590-03	-0.44130+01	-0.59230+01	-0.70610+04	0.79020+04	-0.72420-02	0.90150-02
26	0.13710+00	-0.34470+00	-0.44550-01	-0.17800-03	-0.52990+01	-0.51030+01	0.39970+05	0.45050+04	-0.6[illegible]670-03	0.27250-02
27	0.19620+00	-0.39590+00	-0.63640-01	-0.44470-03	-0.60320+01	-0.41400+01	0.37810+05	0.47060+04	-0.87270-03	0.40340-02
28	0.25950+00	-0.43740+00	-0.84170-01	-0.18220-02	-0.65470+01	-0.30650+01	0.32660+05	0.34550+04	-0.12650-02	0.47030-02
29	0.33040+00	-0.50330+00	-0.99810-01	-0.31340-02	-0.69470+01	-0.19130+01	0.47810+05	0.74970+04	-0.26750-02	0.63590-02
30	0.40950+00	-0.59730+00	-0.13590+00	-0.65220-02	-0.70590+01	-0.70320+00	0.44900+05	0.10970+05	-0.56820-02	0.10530-01
31	0.49820+00	-0.71100+00	-0.13190+00	-0.12720-01	-0.67890+01	0.44920+00	0.31520+05	0.43850+04	-0.17230-02	0.91520-02
32	0.60090+00	-0.86[illegible]40+00	-0.21020+00	-0.20170-01	-0.66590+01	0.16630+01	0.20070+05	-0.64110+04	-0.16260-02	0.58490-02
33	0.72340+00	-0.1[illegible]60+01	-0.2[illegible]520+00	-0.18800-01	-0.61330+01	0.27530+01	0.16530+05	-0.10910+05	0.54770-02	-0.63440-03
34	0.87150+00	-0.11240+01	-0.17[illegible]70+00	-0.13490-01	-0.56640+01	0.37620+01	-0.31610+04	-0.11680+05	0.88190-02	-0.72720-02
35	0.10490+01	-0.11440+01	-0.74820-01	-0.33670-02	-0.46920+01	0.46450+01	0.11140+05	-0.14710+05	0.19660-01	-0.15410-01
36	0.12170+01	-0.10[illegible]90+01	0.41670-01	0.65650-02	-0.39700+01	0.55910+01	0.31660+05	-0.13410+05	0.39220-01	-0.24270-01
37	0.13470+01	-0.64600+00	0.21730+00	-0.13760-01	-0.30570+01	0.64980+01	0.58960+05	-0.19190+06	0.34290-01	-0.14390-01
38	0.13710+01	-0.71[illegible]10-01	0.33760+00	-0.37810-01	-0.22330+01	0.74020+01	0.84520+04	0.94760+04	0.39960-01	-0.17190-03
39	0.12570+01	0.53340+00	0.43280+00	-0.67350-01	-0.13670+01	0.82760+01	0.19640+05	0.17370+05	0.35340-01	0.21650-01
40	0.10440+01	0.12430+01	0.27610+00	-0.25330-01	-0.36750+00	0.89970+01	0.10420+05	0.61890+04	-0.38380-01	0.64600-01

FRAG NO.=	FCGU =	FCGW =	ALFA =	FRUV =	FRWV =	FRAV =
1	0.6025640D+00	0.6459150D+01	-0.2452140D+01	0.9821420D+03	0.1116630D+04	-0.1308200D+04
2	0.5180070D+01	-0.3440380D+01	-0.2222180D+01	0.8808540D+03	-0.1727410D+04	-0.1389150D+04
3	-0.2603080D+01	-0.2797000D+01	-0.9307840D+00	-0.5515000D+04	0.0	-0.1972000D+04

SUBSTRUCTURE	MSTR	ELE	SURF	STA	TIME
1	0.1458440D+00	13	2	3	0.1008000D-02

SUBSTRUCTURE	LARGEST ADD. PT. STRAIN	ELEM	ADD. PT.	TIME	SURFACE
1	0.8874730D-01	40	1	0.1260000D-02	2

SUBSTRUCTURE	LARGEST NODAL STRAIN	NODE	SURF	TIME
1	0.1804050D+00	14	2	0.9800000D-03

****

THE LARGEST COMPUTED STRAINS FOR EACH SUBSTRUCTURE-- MAIN AND BRANCHES -- ARE PRINTED BELOW. 1= INNER 2= OUTER SURF

SUBSTRUCTURE	MSTR	ELE	SURF	STA	TIME
1	0.1458440D+00	13	2	3	0.1008000D-02

SUBSTRUCTURE	LARGEST ADD. PT. STRAIN	ELEM	ADD. PT.	TIME	SURFACE
1	0.8874730D-01	40	1	0.1260000D-02	2

SUBSTRUCTURE	LARGEST NODAL STRAIN	NODE	SURF	TIME
1	0.1804050D+00	14	2	0.9800000D-03

NO CARDS PUNCHED DURING THIS RUN FOR CONTINUATION.

ORIGINAL PAGE IS
OF POOR QUALITY

REFERENCES

1. Wu, R.W.H., and Witmer, E.A., "Finite-Element Analysis of Large Transient Elastic-Plastic Deformation of Simple Structures, with Application to the Engine Rotor Fragment Containment/Deflection Problem", ASRL TR 154-4, MIT, January 1972 (available as NASA CR-120886).

2. Wu, R.W.H., and Witmer, E.A., "Computer Program-JET 3 - to Calculate the Large Elastic-Plastic Dynamically-Induced Deformations of Free and Restrained, Partial and/or Complete Structural Rings", ASRL TR 154-7, MIT, August 1972 (Available as NASA CR-120993).

3. Collins, T.P., and Witmer, E.A., "Application of the Collision-Imparted Velocity Method for Analyzing the Responses of Containment and Deflector Structures to Engine Rotor Fragment Impact", ASRL TR 154-8, MIT, August 1973 (Available as NASA CR-134494).

4. Goldsmith, W., Impact: The Theory and Physical Behavior of Colliding Solids, Edward Arnold (Publishers) Ltd., London, 1960.

5. Selby, S.M. (Editor-in-Chief of Mathematics), CRC Standard Mathematical Tables, 20th Edition, CRC Press, Cleveland, Ohio, p. 106.

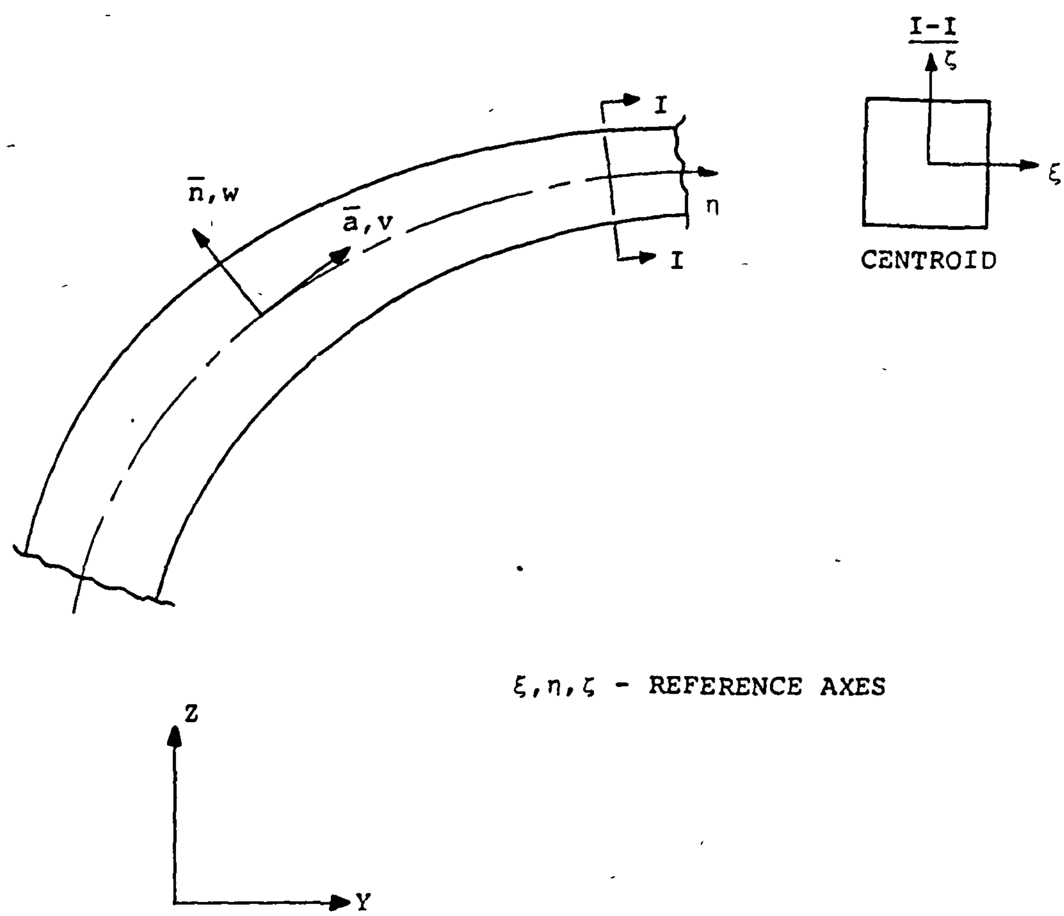
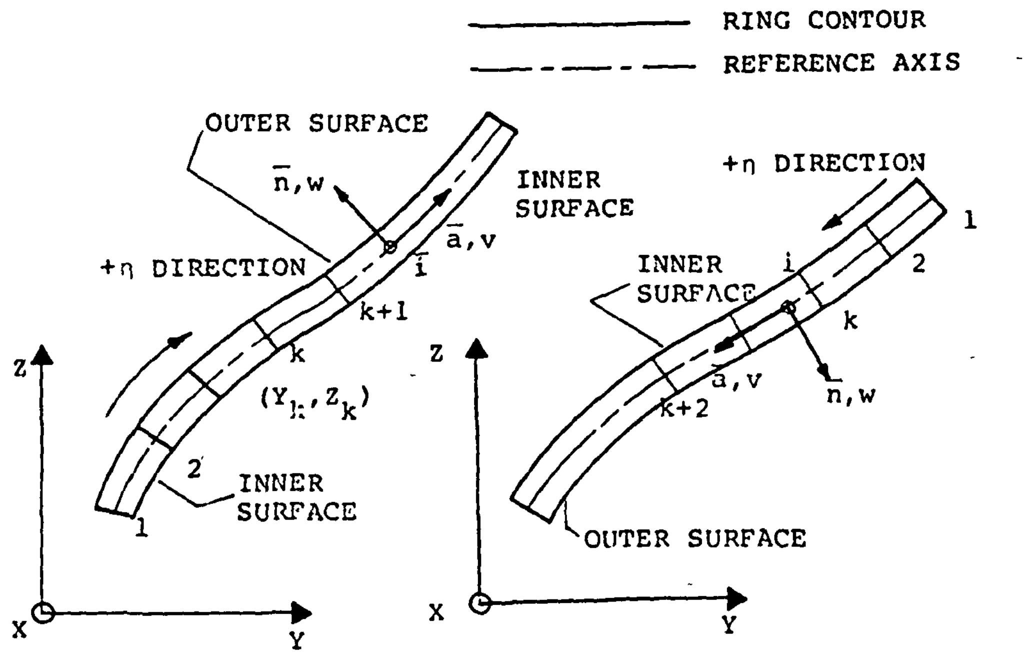
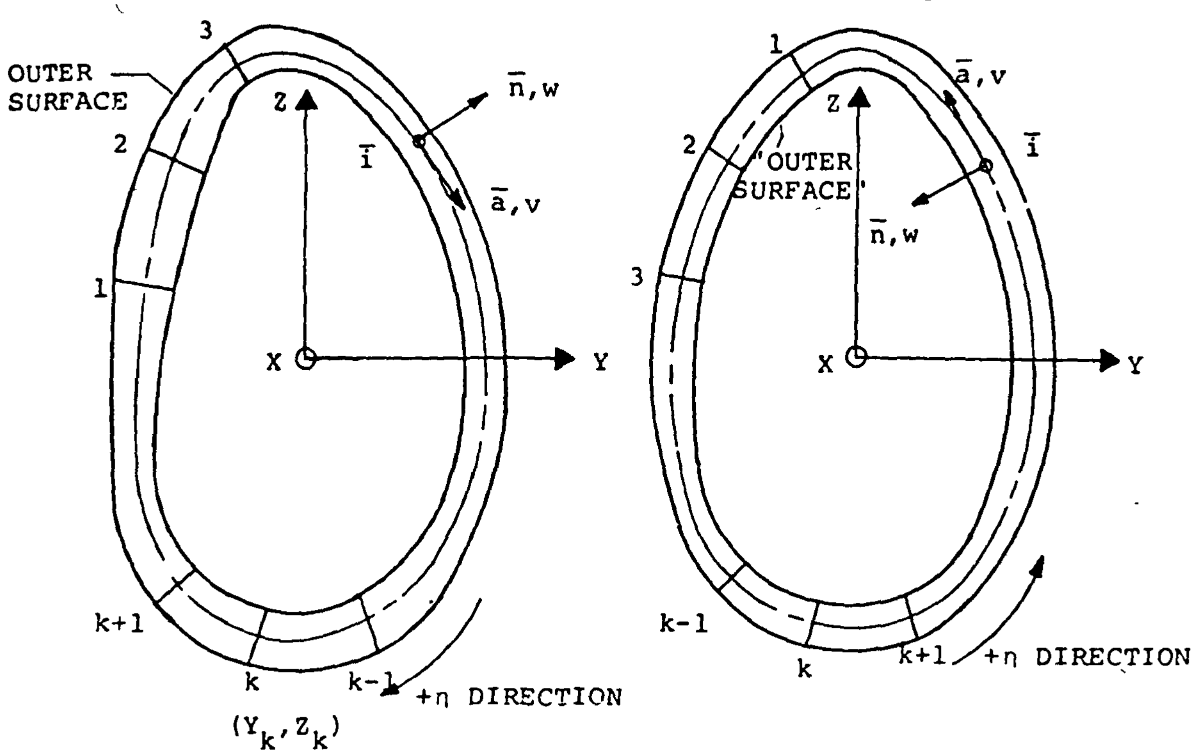


FIG. 1 ILLUSTRATION OF A VARIABLE-THICKNESS, ARBITRARILY-CURVED BEAM

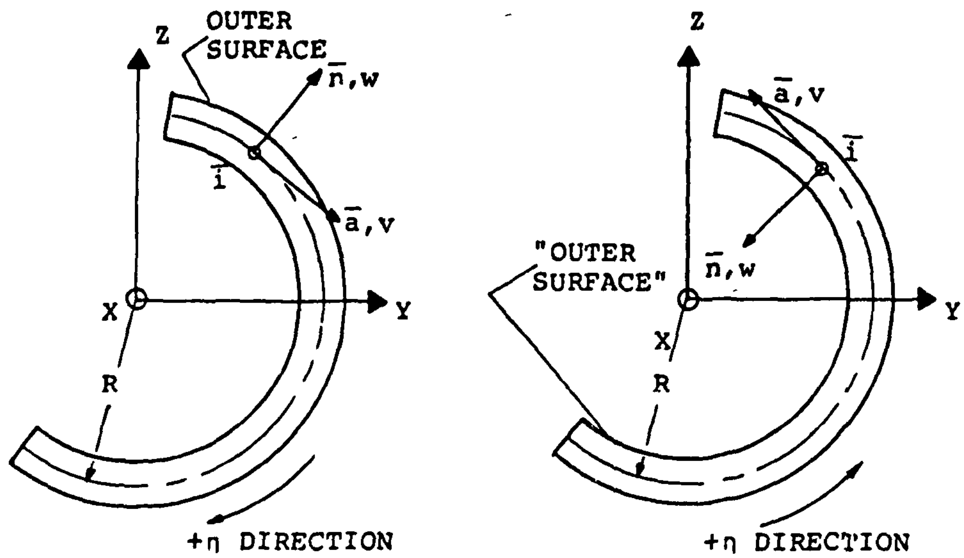


(a) Variable-Thickness Arbitrarily-Curved Partial Ring

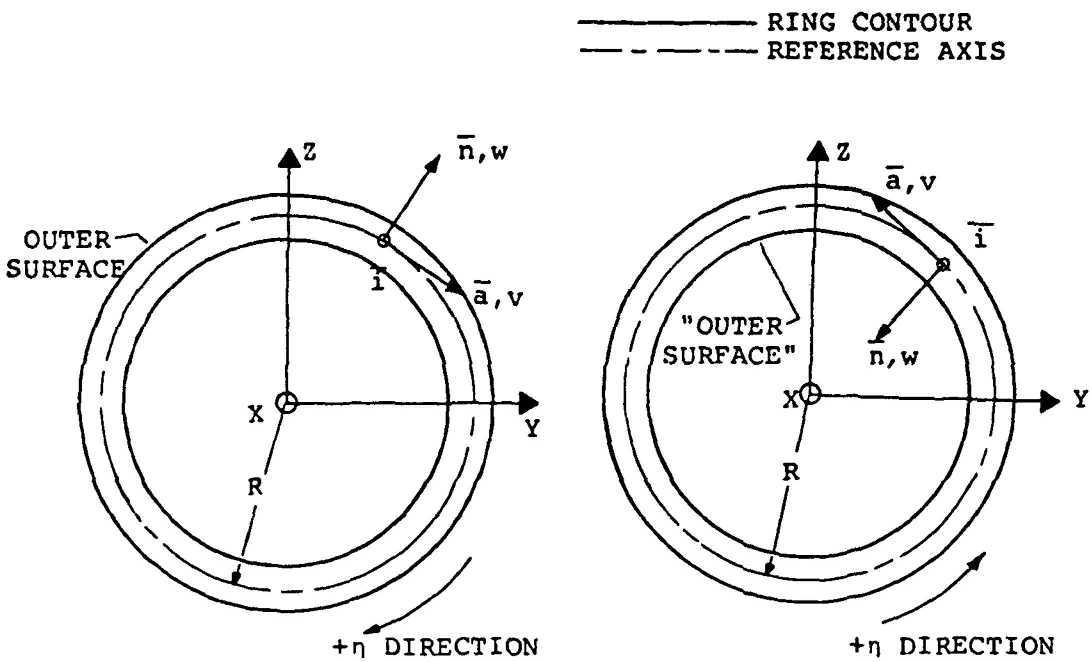


(b) Variable-Thickness Arbitrarily-Curved Complete Ring

FIG. 2 EXAMPLE GEOMETRICAL SHAPES OF STRUCTURAL RINGS ANALYZED BY THE CIVM-JET 4B PROGRAM

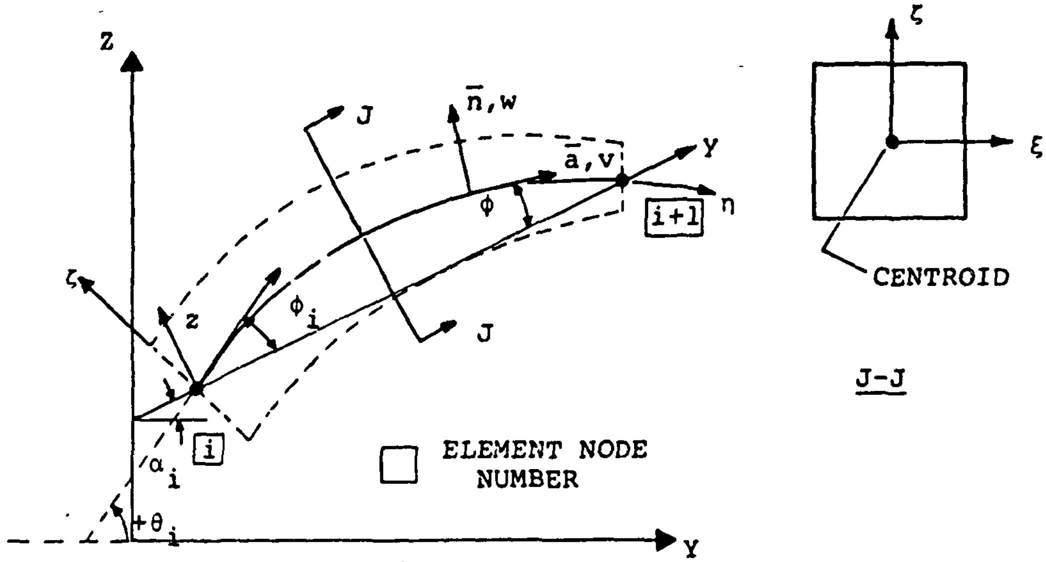


(c) Variable-Thickness Partial Circular Ring



(d) Variable-Thickness Complete Circular Ring

FIG. 2 CONCLUDED



$$-15^{\circ} \leq \phi_{i+1} - \phi_i \leq 0$$

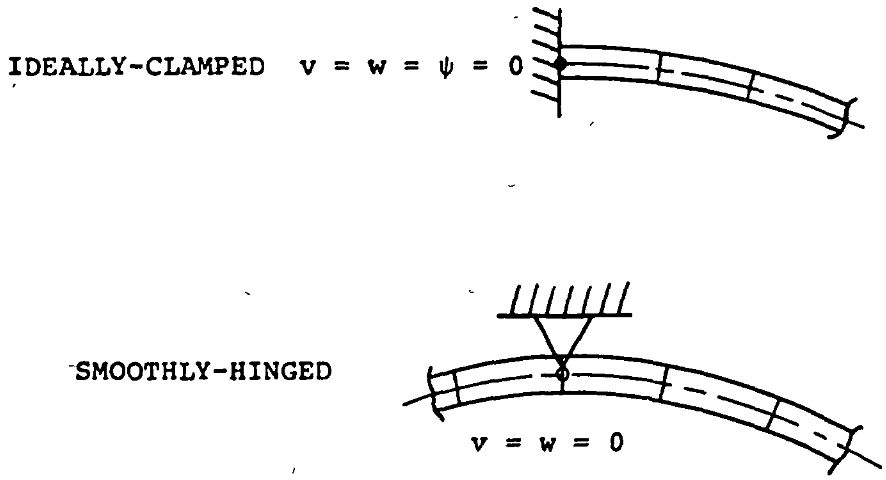
$$-180^{\circ} < \phi_i \leq 180^{\circ}$$

$$\phi(\eta) = b_o + b_1 \eta + b_2 \eta^2$$

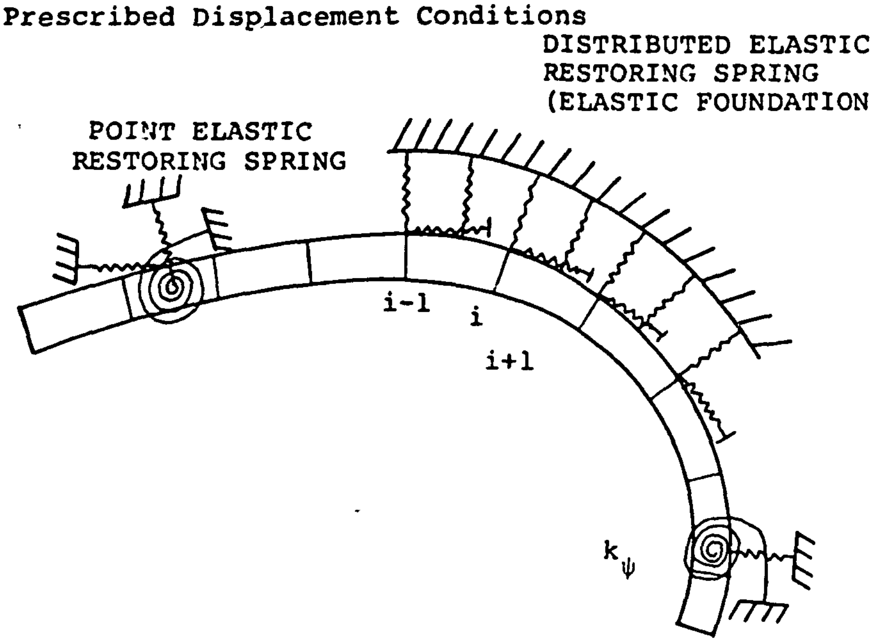
$$h = h_i \left(1 - \frac{\eta}{\eta_i}\right) + h_{i+1} \frac{\eta}{\eta_i}$$

LOCAL SYSTEM		CARTESIAN REFERENCE
ξ, η, ζ	- COORDINATES	Y,Z - COORDINATES
v, w, ψ, χ	- DISPLACEMENTS	y,z - COORDINATES
$q_1, q_2, \ldots q_8$	- ELEMENT GENERALIZED DISPLACEMENTS	

FIG. 3 NOMENCLATURE FOR GEOMETRY, COORDINATES, AND DISPLACEMENTS OF A CURVED-BEAM FINITE ELEMENT

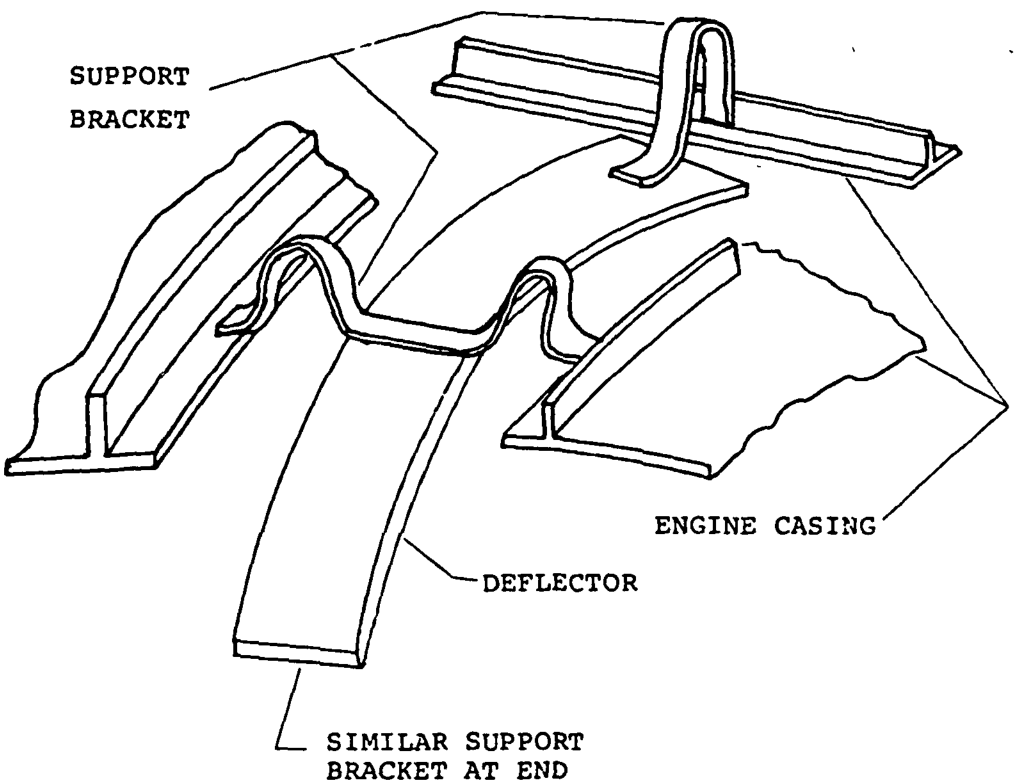


(a) Prescribed Displacement Conditions



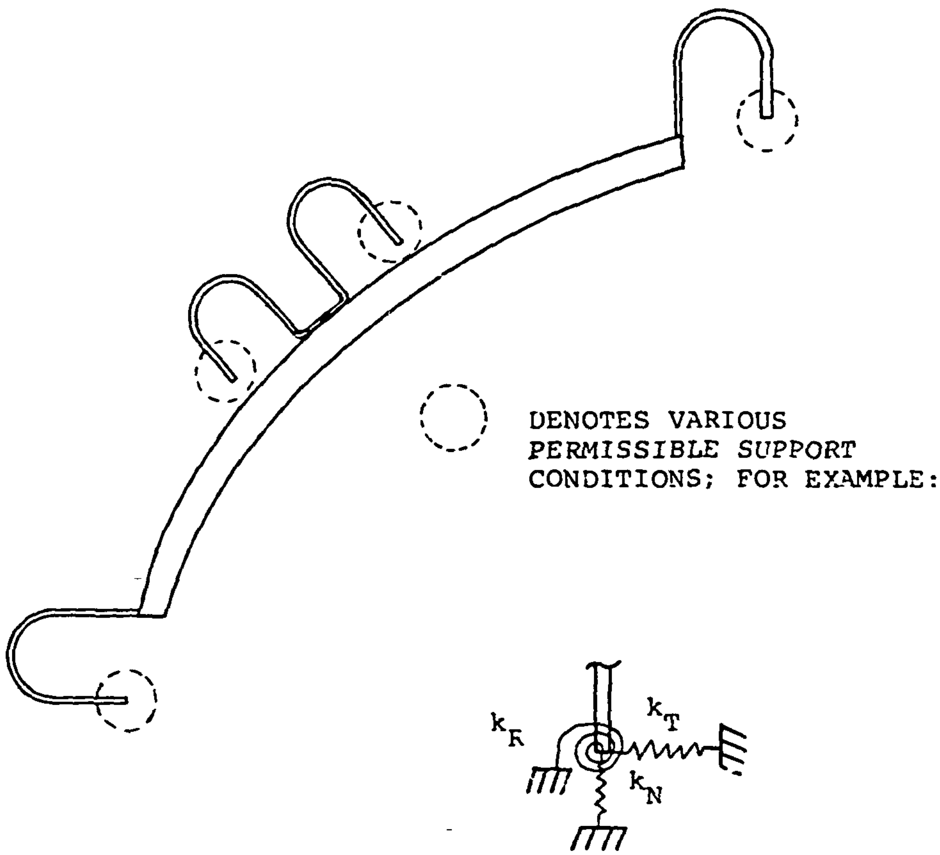
(b) Elastic Restraints

FIG. 4 SCHEMATICS FOR THE SUPPORT CONDITIONS OF THE STRUCTURE



(c) Schematic of a Bracket-Supported Fragment Containment/ Deflector Structure

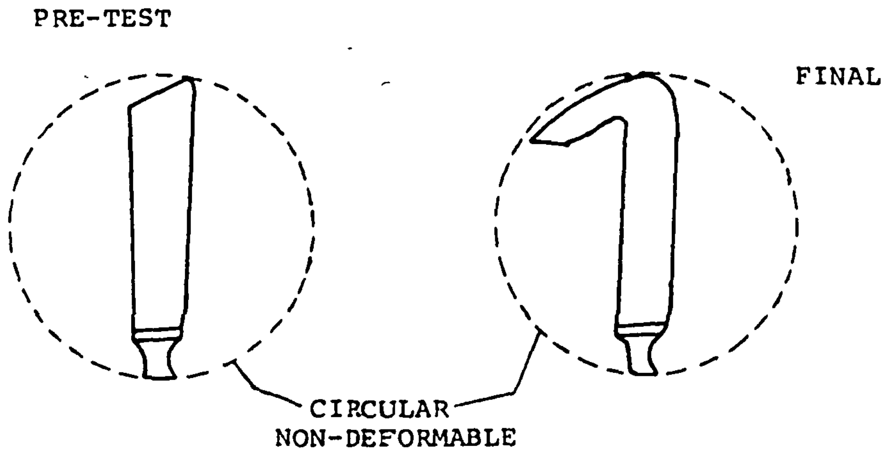
FIG. 4 CONTINUED



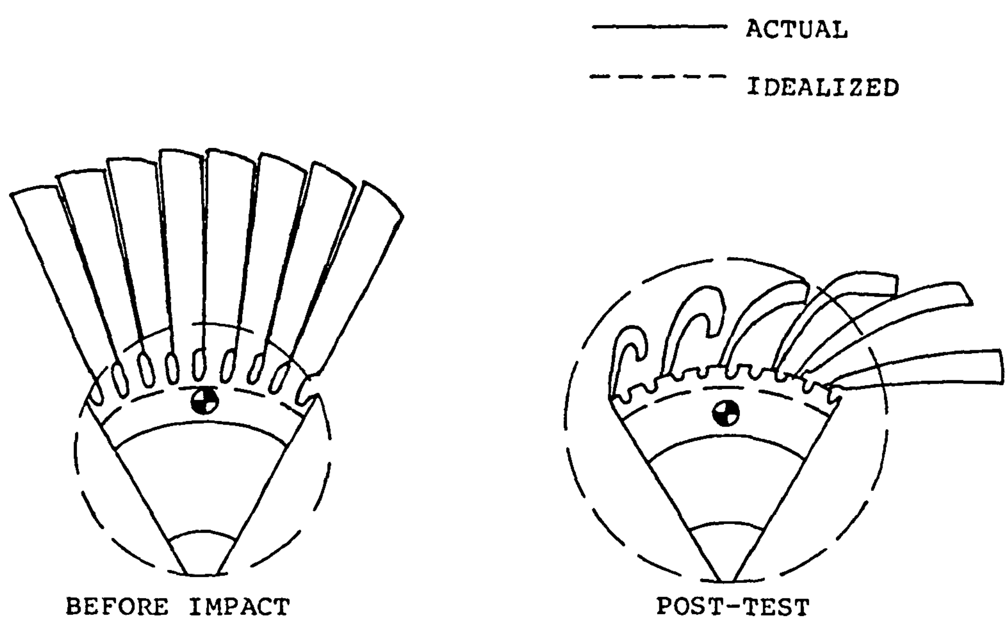
MAIN FRAGMENT C/D STRUCTURE

(d) Idealized Two-Dimensional Model of the Configuration Depicted in (c)

FIG. 4 CONCLUDED

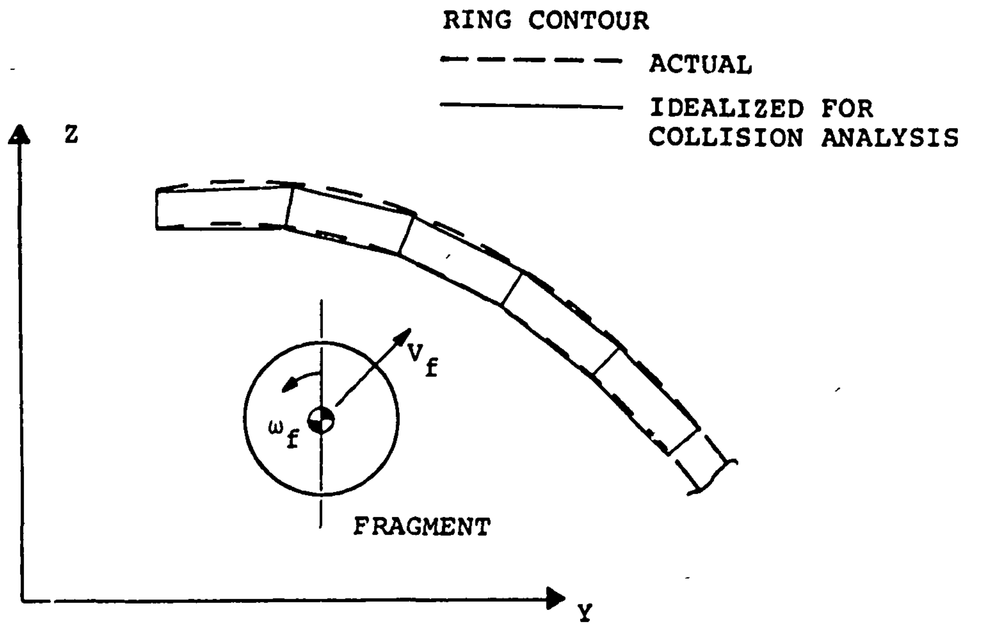


(a) Single Blade Fragment

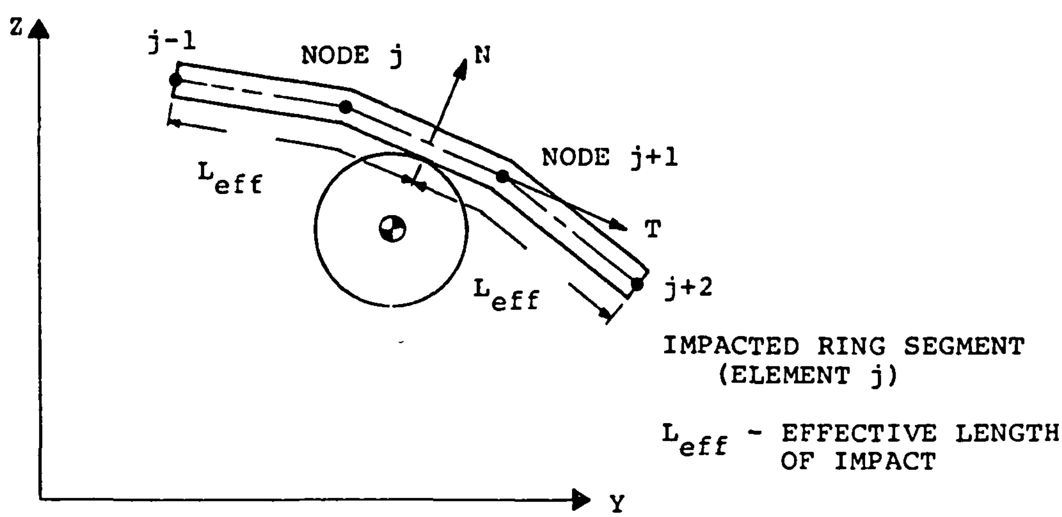


(b) Bladed-Disk Type Fragment

FIG. 5 SCHEMATICS OF ACTUAL AND IDEALIZED FRAGMENTS



(a) Pre-Impact Location



(b) Fragment and Impact-Affected Ring Segment

FIG. 6 IDEALIZATION OF RING CONTOUR FOR COLLISION ANALYSIS

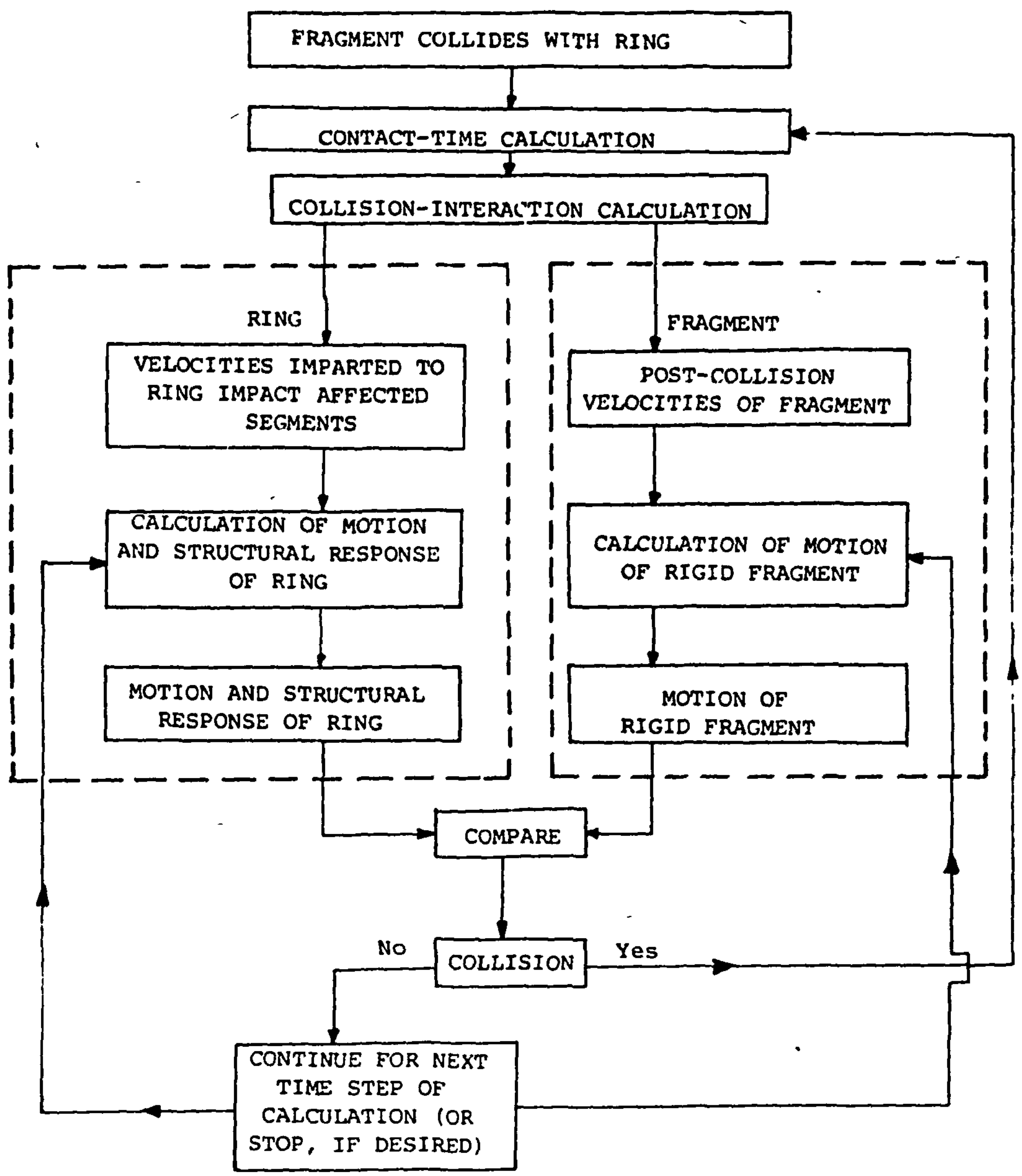
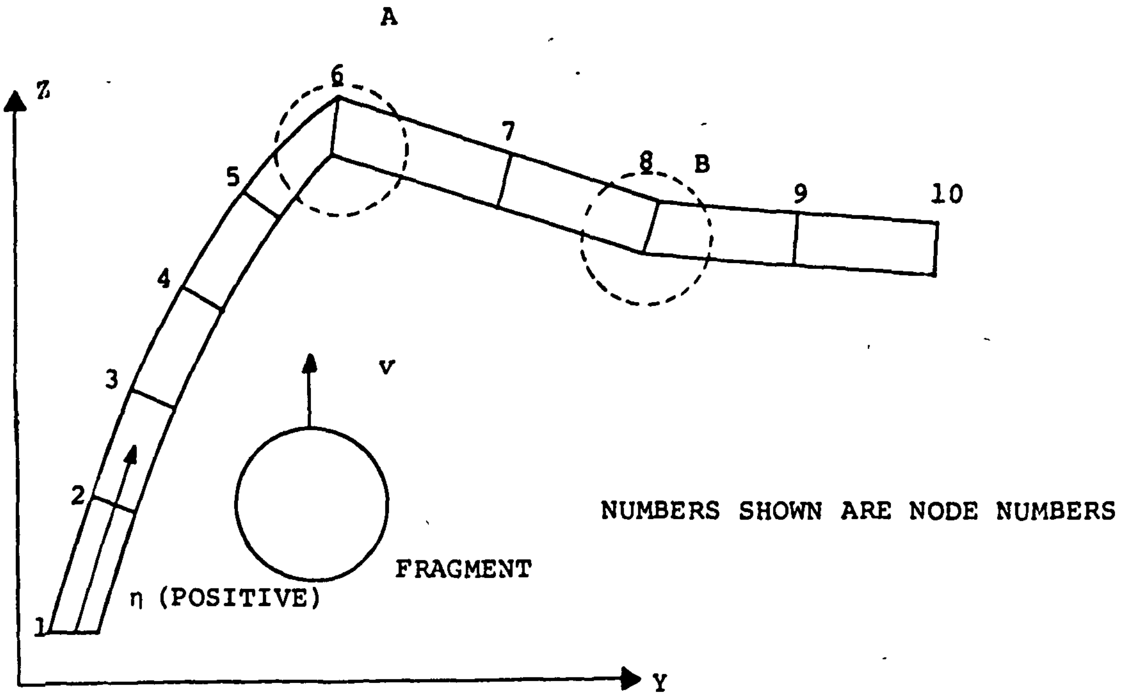
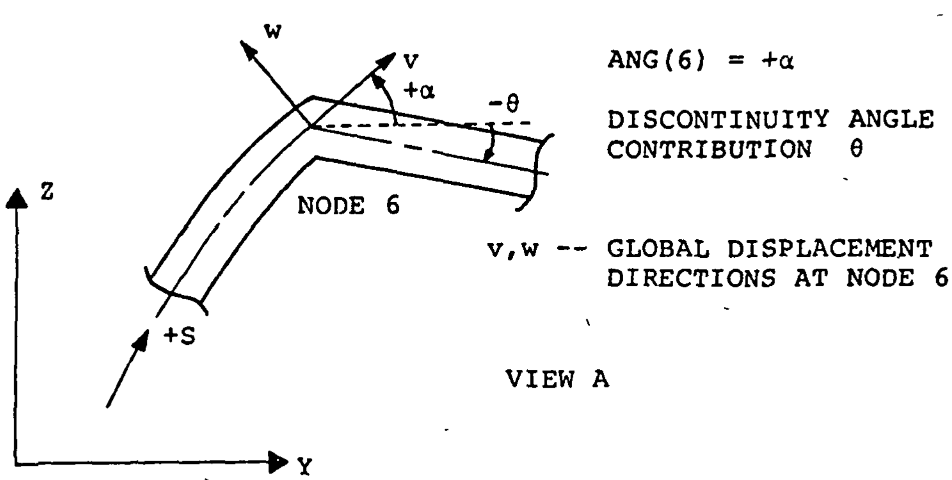


FIG. 7 INFORMATION FLOW SCHEMATIC FOR PREDICTING RING AND FRAGMENT MOTIONS IN THE COLLISION-IMPARTED VELOCITY METHOD

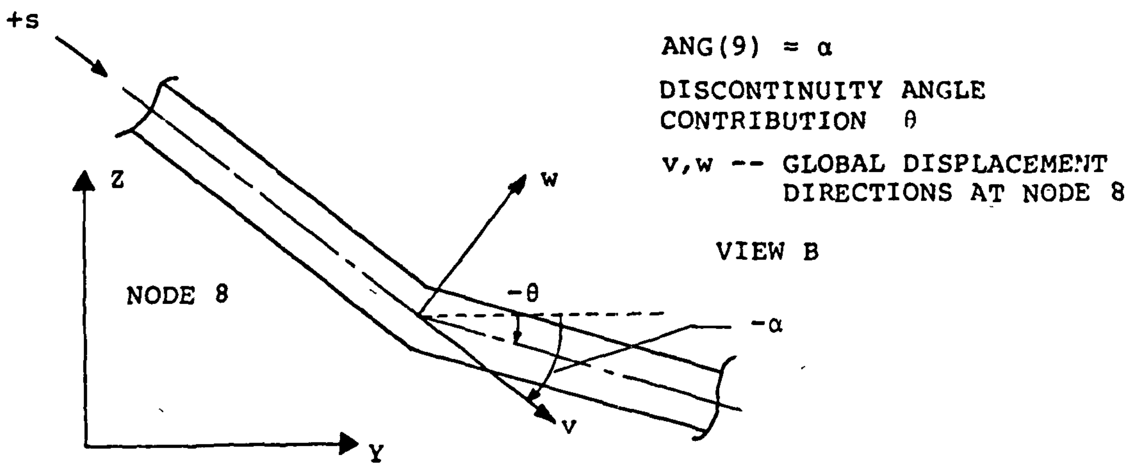


(a) Illustrative Fragment C/D Structure with Slope Discontinuities



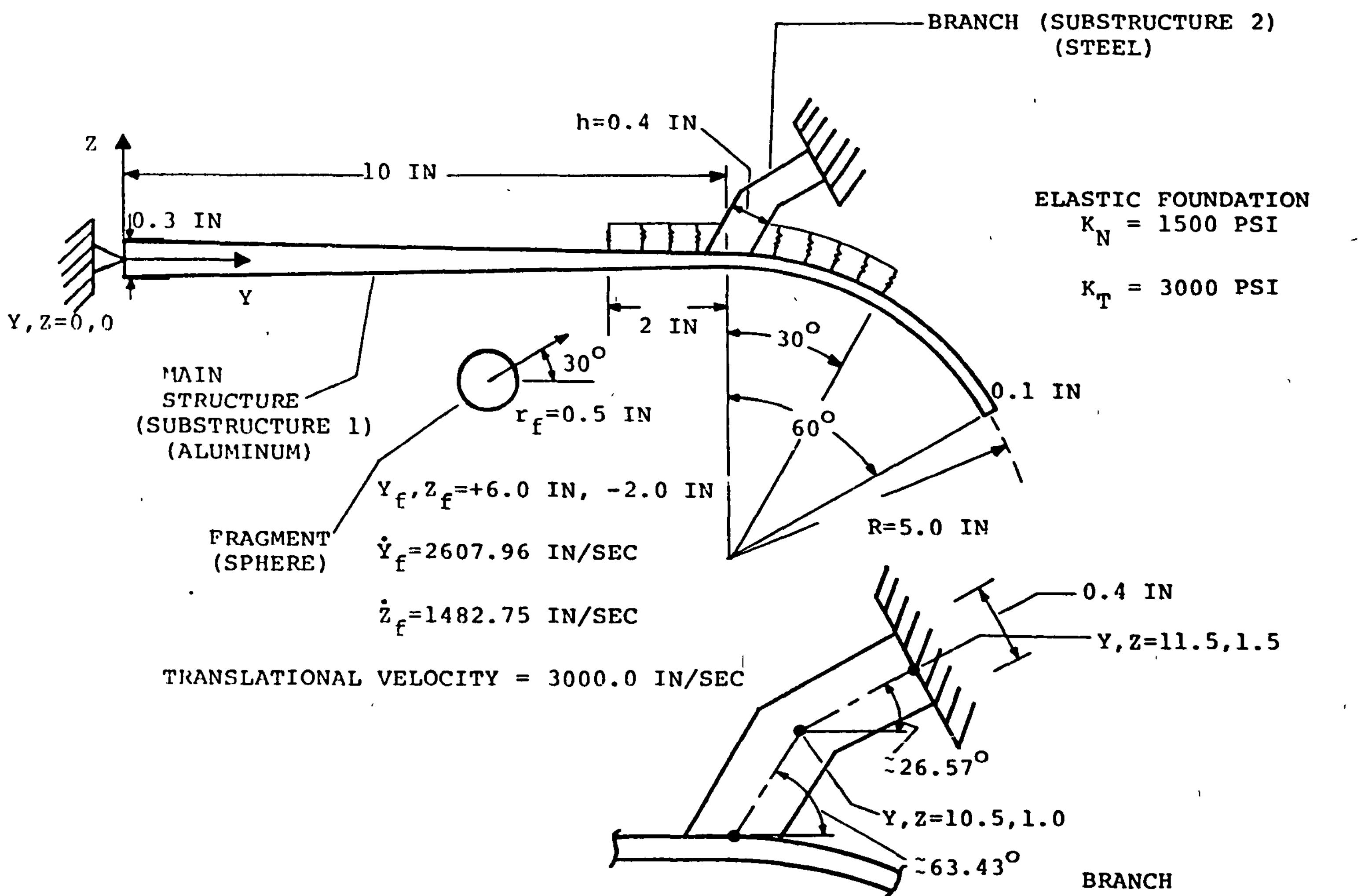
(b) Exploded View of Node 6 -- Angle Definitions

FIG. 8 DEFINITION OF SLOPE-DISCONTINUITY ANGLES FOR AN ILLUSTRATIVE FRAGMENT AND C/D STRUCTURE



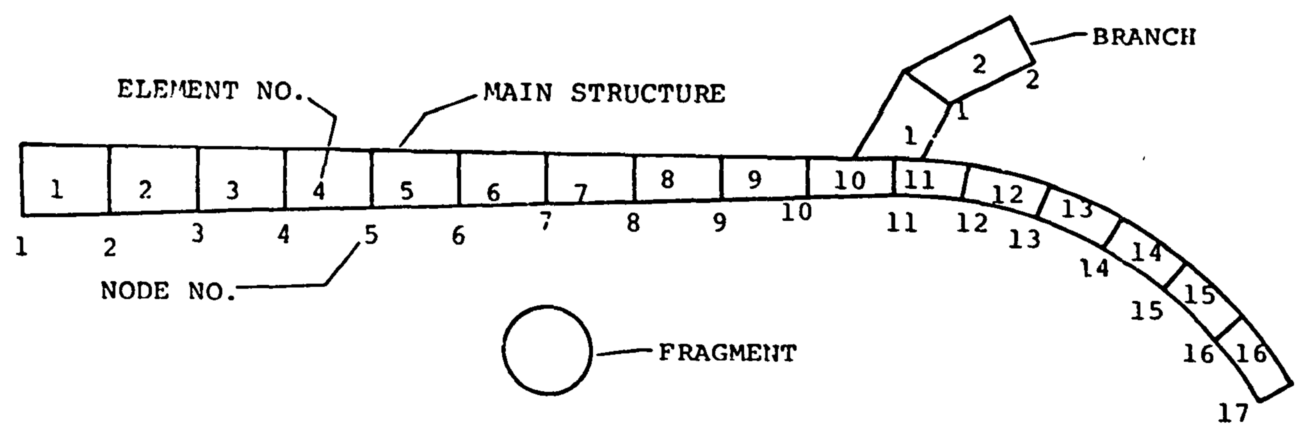
(c) Exploded View of Node 8 -- Angle Definitions

FIG. 8 CONCLUDED



(a) Geometry and Nomenclature

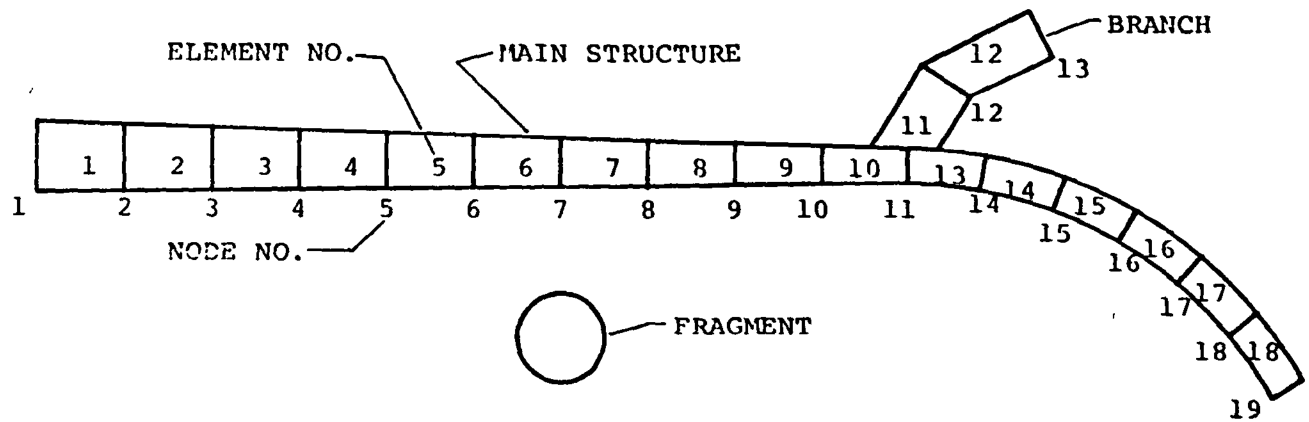
FIG. 9 PROBLEM DATA, GEOMETRY, NOMENCLATURE, AND FINITE-ELEMENT MODELING FOR EXAMPLE 6.1



NOTE: NODAL NUMBERS USED FOR B.C.'S ARE FOUND ON THIS FIGURE.

(b) User-Generated Numbering System

FIG. 9 CONTINUED



NOTE: USER MUST GENERATE ELASTIC FOUNDATION NUMBERS FROM THIS NUMBERING SCHEME. ELASTIC FOUNDATION #1 COVERS ELEMENTS 9 and 10. ELASTIC FOUNDATION #2 COVERS ELEMENTS 13, 14, and 15.

(c) Computer Generated Global Numbering System

FIG. 9 CONCLUDED

NOTE: FRAGMENTS ARE MATERIALLY SYMMETRIC, THEIR C.G.'S ARE RADIALLY SYMMETRIC, AND THEIR TRANSLATIONAL AND ROTATIONAL VELOCITY MAGNITUDES ARE EQUAL

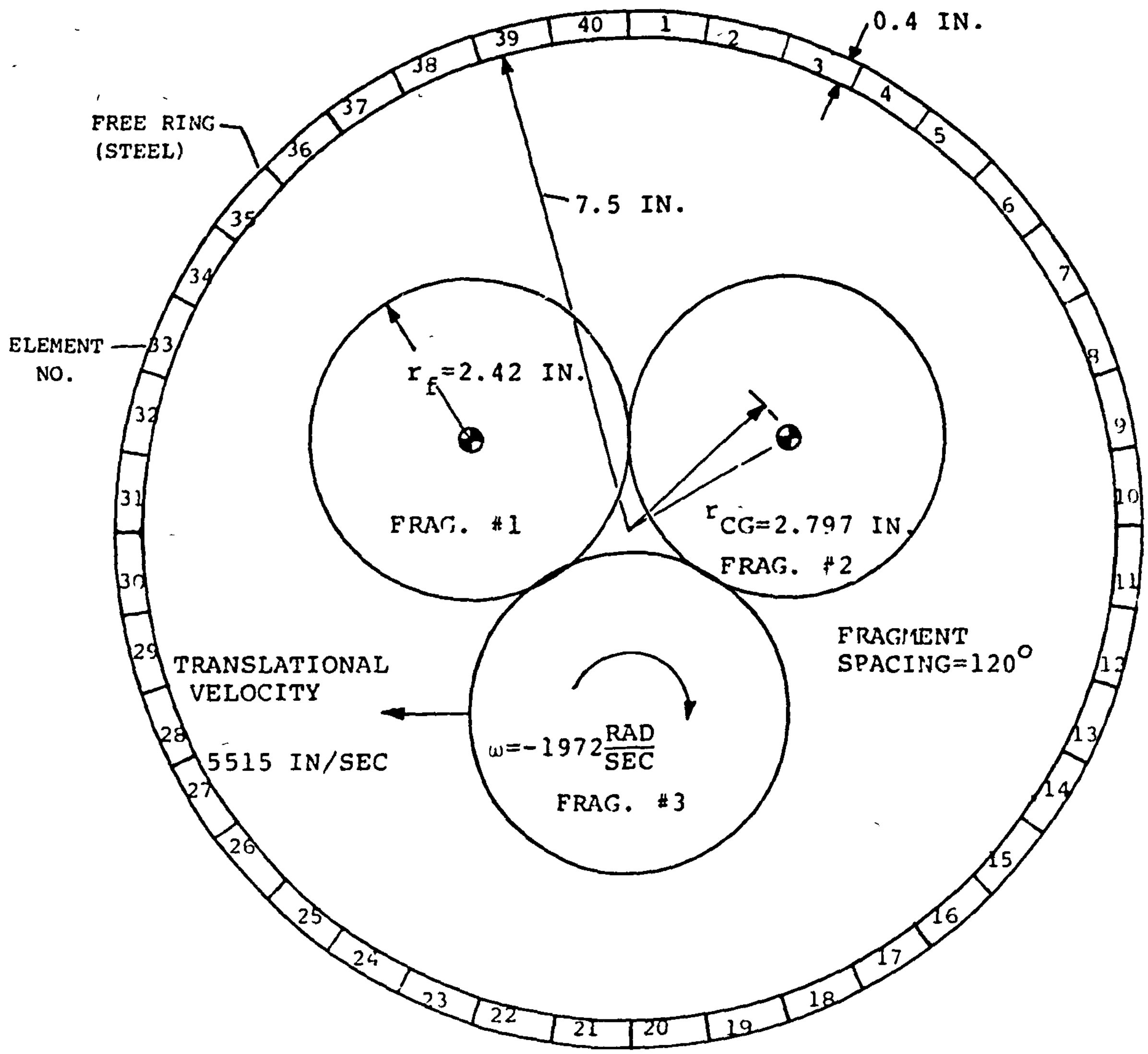


FIG. 10 PROBLEM DATA, GEOMETRY, NOMENCLATURE, AND FINITE-ELEMENT MODELING FOR EXAMPLE 6.2

APPENDIX A

GOVERNING EQUATIONS ON WHICH THE PROGRAM IS BASED

A.1 Formulation for Variable-Thickness Arbitrarily-Curved Beam Elements and Structures

The geometry and nomenclature of a typical curved beam discrete element are shown in Fig. 3, where the deformation plane is η, ζ and the coordinates η along and ζ normal to the centroidal axis of the beam are employed as the reference coordinates of the beam element. The slope, ϕ, of the reference circumferential axis, which is the angle between the tangent vector and the y-axis of the local-reference Cartesian coordinates may be approximated by a second degree polynomial in η as follows:

$$\phi(\eta) = b_o + b_1 \eta + b_2 \eta^2 \tag{A.1}$$

where the constants b_o, b_1, and b_2 can be determined from the known initial geometry of the curved beam element. Assume that the change in element slope between nodes i and i+1 is small so that

$$\cos(\phi_{i+1} - \phi_i) \doteq 1 \tag{A.2a}$$

and

$$\sin(\phi_{i+1} - \phi_i) = \phi_{i+1} - \phi_i \tag{A.2b}$$

This restricts the slope change within an element to $\lesssim$ 15 degrees. The arc length, η_i, of the element is approximated to be the same as the length of a circular arc passing through the nodal points at the slopes ϕ_i and ϕ_{i+1}; η_i is given by

$$\eta_i = \frac{L_i (\phi_{i+1} - \phi_i)}{2 \sin\left(\frac{\phi_{i+1} - \phi_i}{2}\right)} \tag{A.3}$$

where L_i is the length of the chord joining nodes i and i+1 and is given by

$$L_i = \left[(Z_{i+1} - Z_i)^2 + (Y_{i+1} - Y_i)^2 \right]^{1/2} \tag{A.3a}$$

and Y_i and Z_i are the initial Y and Z coordinates, respectively, of the ith node. The three constants in Eq. A.1 are then determined from the relations

$$\begin{aligned} &\phi(\eta = 0) = \phi_i \\ &\phi(\eta = \eta_i) = \phi_{i+1} \\ &\int_0^{\eta_i} \sin\phi \, d\eta \doteq \int_0^{\eta_i} \phi \, d\eta = 0 \end{aligned} \tag{A.4}$$

From Eq. A.4, the constants in Eq. A.1 are found to be

$$\begin{aligned} b_0 &= \phi_i \\ b_1 &= -2(\phi_{i+1} + 2\phi_i)/\eta_i \\ b_2 &= 3(\phi_{i+1} + \phi_i)/(\eta_i)^2 \end{aligned} \tag{A.5}$$

Accordingly, the radius of curvature, R, of the centroidal axis may be expressed as $R = -(\partial\phi/\partial\eta)^{-1} = -(b_1 + 2b_2\eta)^{-1}$, and the coordinates $Y(\eta)$ and $Z(\eta)$ of the centroidal axis are given by

$$Y(\eta) = Y_i + \int_0^{\eta} \cos\left[\phi(\eta) + \alpha\right] d\eta \tag{A.6a}$$

and

$$Z(\eta) = Z_i + \int_0^{\eta} \sin\left[\phi(\eta) + \alpha\right] d\eta \tag{A.6b}$$

where

$$\alpha = \tan^{-1}\left(\frac{Z_{i+1} - Z_i}{Y_{i+1} - Y_i} \right) \tag{A.6c}$$

The thickness variation of the element is approximated as being linear between nodes; thus

$$h = h_i\left(1-\frac{\eta}{\eta_i}\right) + h_{i+1}\frac{\eta}{\eta_i} \tag{A.7}$$

Employing the Bernoulli-Euler hypothesis, the displacement field $\tilde{v}$, $\tilde{w}$ of the beam may be specified by the reference plane displacements v and w, and the rotation, ψ, as follows:

$$\begin{aligned} \tilde{v}(\eta,\zeta) &= v(\eta) - \zeta\,\psi(\eta) \\ \tilde{w}(\eta,\zeta) &= w(\eta) \end{aligned} \tag{A.8}$$

where

$$\psi(\eta) = \frac{\partial w}{\partial \eta} - \frac{v}{R} \tag{A.8a}$$

To account for the strain-inducing modes and the rigid-body modes, the assumed displacement field takes the form:

$$\begin{Bmatrix} v \\ w \end{Bmatrix} = \begin{bmatrix} \cos\phi & \sin\phi & -(Z-Z_i)\cos(\phi+\alpha)+(Y-Y_i)\sin(\phi+\alpha) & \eta & 0 & 0 & \eta^2 & \eta^3 \\ -\sin\phi & \cos\phi & (Z-Z_i)\sin(\phi+\alpha)+(Y-Y_i)\cos(\phi+\alpha) & 0 & \eta^2 & \eta^3 & 0 & 0 \end{bmatrix} \begin{Bmatrix} \beta_1 \\ \vdots \\ \beta_8 \end{Bmatrix} \tag{A.9}$$

or in more compact matrix form, Eq. A.9 becomes

$$\{u\} \equiv \begin{Bmatrix} v \\ w \end{Bmatrix} = \begin{bmatrix} G_v(\eta) \\ G_w(\eta) \end{bmatrix} \{\beta\} \equiv \left[U(\eta) \right] \{\beta\} \tag{A.9a}$$

The generalized displacements $\{q\}$ are selected so that there are four degrees of freedom v, w, ψ, $\chi=(\partial v/\partial\eta) + w/R$ at each node of the element:

$$\{q\} = \lfloor v_i \;\; w_i \;\; \psi_i \;\; \chi_i \;\; v_{i+1} \;\; w_{i+1} \;\; \psi_{i+1} \;\; \chi_{i+1} \rfloor^T = [\;\cdot\;]\{\beta\} \tag{A.10}$$

where

$$[A] = \begin{bmatrix} \cos\phi_i & \sin\phi_i & 0 & 0 & 0 & 0 & 0 & 0 \\ -\sin\phi_i & \cos\phi_i & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ \cos\phi_{i+1} & \sin\phi_{i+1} & A_{53} & \eta_i & 0 & 0 & \eta_i^2 & \eta_i^3 \\ -\sin\phi_{i+1} & \cos\phi_{i+1} & A_{63} & 0 & \eta_i^2 & \eta_i^3 & 0 & 0 \\ 0 & 0 & 1 & \eta_i(\phi')_{\eta_i} & 2\eta_i & 3\eta_i^2 & \eta_i^2(\phi')_{\eta_i} & \eta_i^3(\phi')_{\eta_i} \\ 0 & 0 & 0 & 1 & -\eta_i^2(\phi')_{\eta_i} & -\eta_i^3(\phi')_{\eta_i} & 2\eta_i & 3\eta_i^2 \end{bmatrix}$$

(A.10a)

and

$$A_{53} = (Y_{i+1} - Y_i)\sin(\phi_{i+1}+\alpha) - (Z_{i+1} - Z_i)\cos(\phi_{i+1}+\alpha)$$

(A.10b)

$$A_{63} = (Y_{i+1} - Y_i)\cos(\phi_{i+1}+\alpha) + (Z_{i+1} - Z_i)\sin(\phi_{i+1}+\alpha)$$

Corresponding to the assumed displacement field Eq. A.9, one finds

$$\psi = \lfloor 0 \quad 0 \quad 1 \quad -\frac{\eta}{R} \quad 2\eta \quad 3\eta^2 \quad -\frac{\eta^2}{R} \quad -\frac{\eta^3}{R} \rfloor \{\beta\} \equiv \lfloor G_\psi \rfloor \{\beta\} \qquad \text{(A.11a)}$$

and

$$\chi = \lfloor 0 \quad 0 \quad 0 \quad 1 \quad \frac{\eta^2}{R} \quad \frac{\eta^3}{R} \quad 2\eta \quad 3\eta^2 \rfloor \{\beta\} \equiv \lfloor G_\chi \rfloor \{\beta\} \qquad \text{(A.11b)}$$

Under the Bernoulli-Euler hypothesis, the only nonvanishing strain component and corresponding stress component are the axial strain, $\tilde{\varepsilon}$, and the axial stress, σ. For this case, the nonlinear strain-displacement relation may be expressed as:

$$\tilde{\varepsilon}(\eta, \zeta) = \varepsilon(\eta) + \zeta\, \mathcal{K}(\eta) \tag{A.12}$$

where

$$\varepsilon(\eta) = \left(\frac{\partial v}{\partial \eta} + \frac{w}{R}\right) + \frac{1}{2}\left(\frac{\partial v}{\partial \eta} + \frac{w}{R}\right)^2 + \frac{1}{2}\left(\frac{\partial w}{\partial \eta} - \frac{v}{R}\right)^2$$

$$\equiv \lfloor B_1 \rfloor \{u\} + \frac{1}{2} \lfloor u \rfloor \{B_1\} \lfloor B_1 \rfloor \{u\} + \frac{1}{2} \lfloor u \rfloor \{B_2\} \lfloor B_2 \rfloor \{u\} \tag{A.12a}$$

$$\mathcal{K}(\eta) = -\frac{\partial}{\partial \eta}\left(\frac{\partial w}{\partial \eta} - \frac{v}{R}\right) \equiv \lfloor B_3 \rfloor \{u\}$$

Combining Eqs. A.9 through A 12, one obtains

$$\{u\} = \left[U(\eta)\right]\left[A^{-1}\right]\{q\} \tag{A.13}$$

and

$$\varepsilon = \lfloor D_1 \rfloor \{q\} + \frac{1}{2} \lfloor q \rfloor \{D_1\} \lfloor D_1 \rfloor \{q\} + \frac{1}{2} \lfloor q \rfloor \{D_2\} \lfloor D_2 \rfloor \{q\}$$

$$\mathcal{K} = \lfloor D_3 \rfloor \{q\} \tag{A.14}$$

where

$$\lfloor D_i \rfloor = \lfloor B_i \rfloor [U] [A^{-1}] \qquad \text{for } i = 1, 2, 3 \tag{A.14a}$$

and

$$\lfloor B_1 \rfloor [U] = \lfloor 0 \quad 0 \quad 0 \quad 1 \quad -\eta^2\phi' \quad -\eta^3\phi' \quad 2\eta \quad 3\eta^2 \rfloor$$

$$\lfloor B_2 \rfloor [U] = \lfloor 0 \quad 0 \quad 1 \quad \eta\phi' \quad 2\eta \quad 3\eta^2 \quad \eta^2\phi' \quad \eta^3\phi' \rfloor \tag{A.14b}$$

$$\lfloor B_3 \rfloor [U] = \lfloor 0 \quad 0 \quad 0 \quad -\phi'-\eta\phi'' \quad -2 \quad -6\eta \quad -2\eta\phi'-\eta^2\phi'' \quad -3\eta^2\phi'-\eta^3\phi'' \rfloor$$

In the process of solution, it is necessary to evaluate the strain increment $\Delta\tilde{\varepsilon}_m$ from time t_{m-1} to time t_m. Using Eqs. A.12 and A.14, one has

$$\Delta\tilde{\varepsilon}_m = \Delta\varepsilon_m + \zeta\,\Delta\kappa_m \tag{A.15}$$

where

$$\Delta\varepsilon_m = \lfloor D_1 \rfloor \{\Delta q_m\} + \lfloor q_m \rfloor \{D_1\} \lfloor D_1 \rfloor \{\Delta q_m\} + \lfloor q_m \rfloor \{D_2\} \lfloor D_2 \rfloor \{\Delta q_m\}$$
$$-\frac{1}{2} \lfloor \Delta q_m \rfloor \{D_1\} \lfloor D_1 \rfloor \{q_m\} - \frac{1}{2} \lfloor \Delta q_m \rfloor \{D_2\} \lfloor D_2 \rfloor \{q_m\} \tag{A.15a}$$

$$\Delta\kappa_m = \lfloor D_3 \rfloor \{\Delta q_m\}$$

In the formulation of the impact analysis scheme, a lumped mass model has been assumed. For consistency a lumped (diagonal) mass matrix must be employed in the global timewise solution (note that the use of lumped mass also results in additional storage and computational efficiencies when compared with the use of a consistent mass matrix which is, in general, fully populated). The lumped mass matrix of the ith discrete element is given by the following expression:

$$[m] = \begin{bmatrix} m_{R_i} & & & & & & & \\ & m_{r_i} & & & & & 0 & \\ & & I_{R_i} & & & & & \\ & & & I_{R_i} & & & & \\ & & & & m_{R_{i+1}} & & & \\ & 0 & & & & m_{R_{i+1}} & & \\ & & & & & & I_{R_{i+1}} & \\ & & & & & & & I_{R_{i+1}} \end{bmatrix} \qquad \text{(A.16)}$$

where

$$m_{R_i} = \frac{1}{2}\left(h_i + h_{i+1}\right) b \rho \eta_i \left(1 - c_1\right) \qquad \text{(A.16a)}$$

$$m_{R_{i+1}} = \frac{1}{2}\left(h_i + h_{i+1}\right) b \rho \eta_i c_1 \qquad \text{(A.16b)}$$

$$I_{R_i} = c_2 \eta_i^3 b \rho \left(1 - c_1\right) \qquad \text{(A.16c)}$$

$$I_{R_{i+1}} = c_2 \eta_i^3 b \rho c_1 \qquad \text{(A.16d)}$$

and where the thickness-dependent constants, c_1 and c_2, are given by

$$c_1 = \frac{\left(2h_{i+1} + h_i\right)}{3\left(h_i + h_{i+1}\right)} \qquad \text{(A.16e)}$$

$$c_2 = \frac{h_i^2 + 4h_i h_{i+1} + h_{i+1}^2}{36\left(h_i + h_{i+1}\right)} \qquad \text{(A.16f)}$$

In these expressions, ρ is the mass per unit volume of the beam element, b is the width of the ring, η_1 is the arc length calculated from Eq. A.3, and Eq. A.7 has been employed to accommodate the variable-thickness properties of the beam element.

The effective stiffness matrix supplied by the elastic restraints may be obtained from the variation of the work done by the elastic restoring spring forces, δW_s:

$$- \delta W_s = \int_0^{\eta_1} (k_v \, v \, \delta v + k_w \, w \, \delta w + k_\psi \, \psi \, \delta \psi) \, d\eta \tag{A.17}$$

or

$$- \delta W_s = \int_0^{\eta_1} \lfloor \delta v \quad \delta w \quad \delta \psi \rfloor \, [C] \begin{Bmatrix} v \\ w \\ \psi \end{Bmatrix} d\eta \tag{A.17a}$$

where

$$[C] = \begin{bmatrix} k_v & 0 & 0 \\ 0 & k_w & 0 \\ 0 & 0 & k_\psi \end{bmatrix} \tag{A.17b}$$

and k_v and k_w, respectively, are the linear elastic spring constants and k_ψ is the torsional elastic spring constant.

Substituting the assumed displacement function into Eq. A.17, one has

$$- \delta W_s = \lfloor \delta q \rfloor [A^{-1}]^T \int_0^{\eta_1} [N]^T [C] [N] \, d\eta \; [A^{-1}] \{q\} \tag{A.18}$$

$$\equiv \lfloor \delta q \rfloor \, [k_s] \, \{q\}$$

where

$$[k_s] = [A^{-1}]^T \int_0^{\eta_1} [N]^T [C] [N] \, d\eta \, [A^{-1}] \tag{A.18a}$$

= effective element stiffness matrix
supplied by the elastic restraint

In the present analysis, the equations of motion for the complete discretized structure are based on an "unconventional" formulation in which the conventional elastic stiffness matrix, [K], does not appear explicitly. However, in order to calculate an allowable time step size, Δt, for the conditionally-stable central-difference timewise operator, the largest natural frequency contained in the (linear) mathematical model of the structure must be determined. To perform this calculation, the elastic stiffness matrix for the assembled structure must be computed. The elastic stiffness matrix for an element is obtained by considering the variation of the work of the axial stress, δU_i, expressed in terms of displacements and plastic strains, $\tilde{\varepsilon}^P$ in the form:

$$\delta U_i = \int_{V_i} \sigma \, \delta \tilde{\varepsilon} \, dV = \int_{V_i} E(\varepsilon + \zeta \kappa - \tilde{\varepsilon}^P)(\delta \varepsilon + \zeta \, \delta \kappa) \, dV \qquad \text{(A.18b)}$$

Employing the strain-displacement relations given by Eqs. A.12 and A.14, Eq. A.18b becomes

$$\delta U_i = \lfloor \delta q \rfloor \left([k] \{q\} - \{f_q^{NL}\} - \{f_P^L\} - \{f_P^{NL}\} \right) \qquad \text{(A.18c)}$$

where [k] is the element elastic stiffness matrix and is given by

$$[k] = \int_0^{\eta_i} [D_1 \vdots D_3] \begin{bmatrix} Ebh(\eta) & 0 \\ 0 & \dfrac{Ebh^3(\eta)}{12} \end{bmatrix} \begin{bmatrix} D_1 \\ --- \\ D_3 \end{bmatrix} d\eta \qquad \text{(A.18d)}$$

The additional terms in Eq. A.18c are equivalent loading vectors corresponding to geometric and material nonlinearities. These terms are employed in the conventional formulation of the equations of motion for the assembled structure, but are not employed in the unconventional formulation used in the CIVM-JET 4B analysis. Again it should be emphasized that the elastic stiffness matrix is used only in the calculation of the largest natural frequency of the structure, and is not used in any subsequent calculations.

The equivalent nodal force which corresponds to the internal axial stress, σ, can be obtained from the expression of the variation of the work of the axial stress:

$$\delta U_i = \int_{V_i} \sigma \delta \tilde{\varepsilon}\, dV = \int_{V_i} \sigma (\delta \varepsilon + \zeta \delta \kappa)\, dV \tag{A.19}$$

Substituting Eq. A.14 into Eq. A.19 and introducing the stress resultants for the beam cross section

$$L = \int_{A_i} \sigma\, dA \quad , \quad M = \int_{A_i} \sigma \zeta\, dA \tag{A.20}$$

where the integrations are taken over the cross section, A_i of the ith beam element, L, is the internal force, and M is the internal bending moment of the cross section, results in

$$\begin{aligned} \delta U_i = \lfloor \delta q \rfloor \Big[& \int_0^{\eta_i} (\{D_1\} L + \{D_3\} M)\, d\eta \\ & + \int_0^{\eta_i} (\{D_1\} \lfloor D_1 \rfloor + \{D_2\} \lfloor D_2 \rfloor) L\, d\eta \; \{q\} \Big] \\ \equiv \; & \lfloor \delta q \rfloor (\{p\} + [h] \{q\}) \end{aligned} \tag{A.21}$$

where

$$\{p\} = \int_0^{\eta_i} (\{D_1\} L + \{D_3\} M)\, d\eta$$

$$[h] = \int_0^{\eta_i} (\{D_1\} \lfloor D_1 \rfloor + \{D_2\} \lfloor D_2 \rfloor) L\, d\eta \tag{A.22}$$

Note that {p} and [h] are quantities pertinent to the unconventional formulation of the equations of motion, Eq. 2.1. The integrations along the centroidal axis length of the beam element which appear in {p} and [h] of Eq. A.22 are performed numerically by using the Gaussian quadrature scheme. The axial force L and moment M at those spanwise stations will be described and evaluated next.

Because of nonlinear material behavior, although the strain variation through the beam thickness, by the Bernoulli-Euler hypothesis, is linear, the variation of stress across the thickness may be nonlinear. For computational convenience, the stresses are evaluated at selected Gaussian points across the thickness, and the corresponding weighting factors are used in evaluating the pertinent integrals by Gaussian quadrature. The strain-hardening behavior of the material may be accounted for by using the mechanical sublayer model in which the material at each Gaussian station is treated as consisting of equally-strained sublayers of elastic, perfectly-plastic material, with each sublayer having the same elastic modulus but an appropriately different yield stress. For example, if the yield strain of the kth sublayer is ε_{ok}, the yield stress of that sublayer is

$$\sigma_{ok} = E\,\varepsilon_{ok} \qquad (k = 1, 2, \ldots, n) \qquad (A.23)$$

where E is the elastic (Young's) modulus.

An illustration of the method of computing the axial stress and/or plastic strain increment is presented as follows. One begins by knowing the sublayer stress $\sigma_{jk,m-1}$ at time t_{m-1} for the kth sublayer of the jth depthwise Gaussian station, and the strain increment $\Delta\varepsilon_{j,m}$ at station j at time t_m (that is the strain increment from time t_{m-1} to time t_m). One then takes a trial value (superscript T) of $\sigma_{jk,m}$ which is computed by assuming an elastic path:

$$\sigma^{T}_{jk,m} = \sigma_{jk,m-1} + E\,\Delta\varepsilon_{j,m} \qquad (A.24)$$

A check is then performed to see what the correct value of $\sigma_{jk,m}$ must be.

If $-\sigma_{ok} \leq \sigma^{T}_{jk,m} \leq \sigma_{ok}$ then $\sigma_{jk,m} = \sigma^{T}_{jk,m}$ and $\Delta\varepsilon^{p}_{jk,m} = 0$

If $\sigma^{T}_{jk,m} > \sigma_{ok}$ then $\sigma_{jk,m} = \sigma_{ok}$ and $\Delta\varepsilon^{p}_{jk,m} = \dfrac{\sigma^{T}_{jk,m} - \sigma_{ok}}{E}$

If $\sigma^{T}_{jk,m} < -\sigma_{ok}$ then $\sigma_{jk,m} = -\sigma_{ok}$ and $\Delta\varepsilon^{p}_{jk,m} = \dfrac{\sigma^{T}_{jk,m} + \sigma_{ok}}{E}$

(A.25)

This procedure is applied to all sublayers of each Gaussian station j; having done this, the axial force and moment of the beam cross section can be determined by

$$L = \int_{A_L} \sigma \, dA \doteq b\frac{h}{2} \sum_{j} \left(\sum_{k} \sigma_{jk} A_{jk} \right)$$

$$M = \int_{A_L} \sigma \zeta \, dA \doteq b\frac{h}{2} \sum_{j} \zeta_j \left(\sum_{k} \sigma_{jk} A_{jk} \right) \tag{A.26}$$

where A_{jk} is a combination of the mechanical sublayer weighting factor and the Gaussian weighting factor W_j, which is defined by

$$A_{jk} = \frac{W_j}{E} \left(E_k - E_{k+1} \right) \tag{A.27}$$

In Eq. A.27, W_j is the Gaussian weighting factor and

$$E_k = \frac{\sigma_k - \sigma_{k-1}}{\varepsilon_k - \varepsilon_{k-1}} \tag{A.28}$$

is the kth slope of the polygonal approximate stress-strain diagram.

If desired, the sublayer yield stresses may be treated as strain-rate dependent. Since the strain increment at the jth Gaussian station and hence the strain rate is known at this stage of computation, the rate-dependent yield stress σ_{yk} of this kth sublayer at station j is

$$\sigma_{yk} = \sigma_{ok} \left(1 + \left| \frac{\Delta\bar{\epsilon}/\Delta t}{D} \right|^{\frac{1}{p}} \right) \tag{A.29}$$

where D and p are empirically-determined constants for the material and may, in general, be different for each sublayer, σ_{ok} is the static uniaxial yield stress of the kth sublayer at any jth Gaussian station.

Finally, by employing the standard finite-element assembling procedure, the resulting equations of motion for the "complete discretized structure" are (for impact-induced loading only)

$$[M^*]\{\ddot{q}^*\} + \{P^*\} + [H^*]\{q^*\} + [K_s]\{q^*\} = 0 \tag{A.30}$$

where the nomenclature of each term is explained in Subsection 2.4. In the computer program it is convenient to employ Eq. A,30 in the following form:

$$[M^*]\{\ddot{q}^*\} = -\{P^*\} - [H^*]\{q^*\} - [K_s]\{q^*\} \tag{A.30a}$$

where the terms on the right hand side are treated conveniently as one vector.

A.2 Collision-Interaction Analysis, Including Friction

In the present collision-interaction analysis, the curved variable-thickness containment/deflection ring is represented by straight-line segments (Fig. A.1): (a) to identify in a simple and approximate way the space occupancy of the beam segment under imminent impact attack and (b) to derive the impact equations. The inertia effects of the impacted beam segments are taken into account by means of a lumped-mass collision model; that is, the ring is treated as having only point masses lumped at each nodal station as indicated in Fig. A.2. Other simplifying assumptions which are invoked in the present analysis are described in Subsection 2.2.

For the lumped-mass collision model, the impact-affected beam segments are represented, as depicted in the exploded-line schematic of Fig. A.2, by concentrated masses m_1, ..., m_{j+1}, ..., m_k (or i+k-1), respectively, where the ring-fragment collision point is encompassed by the jth segment which is bounded by nodal station j and j+1 ---- a clockwise numbering sequence is used. In the collision analysis, it is convenient to resolve and discuss impulses, velocities, etc., for both the fragment and the ring impact-affected nodes in directions normal (N) and tangential (T) to the straight line segment j; the positive normal direction is always taken from the inside toward the outside of the ring, while the positive-tangential direction is along the straight line from node j toward node j+1 (see Fig. A.2a). Consequently, the *lumped-mass velocities for each of the impact-affected nodes and the idealized-fragment velocities are expressed with respect to this local N,T inertial* coordinate system as (V_{1N}, V_{1T}), (V_{2N}, V_{2T}) ---- (V_{kN}, V_{kT}), and (V_{fN}, V_{fT}) in the exploded schematic shown in Fig. A.2a.

It is assumed that the instantaneous collision process results in a normal-direction impulse $\tilde{P}_N$ and a tangentially-directed impulse $\tilde{P}_T$ applied to the ring, and in equal but anti-parallel impulses to the fragment. The impulses applied to the ring are assumed to be distributed over the impact-affected nodes (see Fig. A.2b) as

$$\left.\begin{aligned} P_{iN} &= C\left(1-\frac{|s_i|}{L_{eff}}\right)\tilde{P}_N \equiv C\alpha_i'\tilde{P}_N \\ P_{iT} &= C\left(1-\frac{|s_i|}{L_{eff}}\right)\tilde{P}_T \equiv C\alpha_i'\tilde{P}_T \end{aligned}\right\} i=1,2,\cdots k \qquad \text{(A.31)}$$

where (see Fig. A.2b) the effective length*, L_{eff}, bounds the impact-affected zone of the ring, which is the fraction of the ring that responds with momentum changes due to the collision of a fragment, s_i is the distance measured from the

---

*For present purposes, L_{eff} is taken to be equal to the finite-difference-calculation time interval Δt times the longitudinal wave speed $(E/\rho)^{1/2}$ of the structural material; one may employ other estimates of L_{eff}, if desired. In the preceding, E is the elastic modulus and ρ is the mass per unit volume.

impacted point to the ith impact-affected node, and the constant, C, is determined by assuming that the sum of the impulse applied to each impact-affected node equals the total impulse imparted; thus,

$$\sum_{i=1}^{k} P_{iN} = \tilde{P}_N \qquad \left(\text{or} \quad \sum_{i=1}^{k} P_{iT} = \tilde{P}_T \right) \tag{A.31a}$$

therefore, one has

$$C = 1 \Big/ \sum_{i=1}^{k} \left(1 - \frac{|s_i|}{L_{eff}} \right) \equiv 1 \Big/ \sum_{i=1}^{k} \alpha_i' \tag{A.31b}$$

The impacted-affected nodes are those nodes located within the impact affected zone; that is $|s_i|<L_{eff}$. However, it is assumed that the two-mass nodes j and j+1 of the segment j which encompasses the impact point always respond to impact with momentum changes, even if the distance from the impact point to one or both of the two nodes (j and j+1) is greater than L_{eff}. Let β and γ be the distances measured from the "point of fragment impact" to masses m_j and m_{j+1}, respectively, as indicated in Fig. A.2. The distribution of the impulses is estimated in the following manner:

(1) If $\beta \geq L_{eff}$ and $\gamma < L_{eff}$, then (Fig. A.2c):

$$P_{1N} = P_{jN} = C \alpha_1' \tilde{P}_N$$
$$P_{1T} = P_{jT} = C \alpha_1' \tilde{P}_T \tag{A.32}$$

where

$$\alpha_1' = \frac{\gamma}{\beta} \alpha_2' \qquad \text{and} \qquad C = 1 \Big/ \sum_{i=1}^{k} \alpha_i' \tag{A.32a}$$

(2) If $\beta < L_{eff}$ and $\gamma \geq L_{eff}$, then (Fig. A.2d):

$$P_{kN} = P_{(j+1)N} = C \alpha_k' \tilde{P}_N$$
$$P_{kT} = P_{(j+1)T} = C \alpha_k' \tilde{P}_T \tag{A.33}$$

where

$$\alpha_k' = \frac{\beta}{\gamma} \alpha_{k-1}' \qquad \text{and} \qquad C = 1 \Big/ \sum_{i=1}^{k} \alpha_i' \tag{A.33a}$$

(3) If $\beta \geq L_{eff}$ and $\gamma \geq L_{eff}$, then (Fig. A.2e)

$$P_{1N} = P_{jN} = C\gamma \tilde{P}_N \equiv C\alpha_1' \tilde{P}_N \tag{A.34a}$$

$$P_{2N} = P_{(j+1)N} = C\beta \tilde{P}_N \equiv C\alpha_2' \tilde{P}_N$$

$$P_{1T} = P_{jT} = C\gamma \tilde{P}_T \equiv C\alpha_1' \tilde{P}_T \tag{A.34b}$$

$$P_{2T} = P_{(j+1)T} = C\beta \tilde{P}_T \equiv C\alpha_2' \tilde{P}_T$$

where

$$C = 1 / (\beta + \gamma) \tag{A.34c}$$

It should be emphasized here that the determination of which mass nodes fall within the impact-affected region is a discrete process in the sense that only mass node locations are considered instead of considering the true volume of mass included in the impact-affected region of the structure. Such an approximation is made necessary by the use of a lumped-mass model in the collision-interaction analysis. In essence, the use of a lumped-mass model implies that the nodal mass represents the mass distribution in a region of the structure surrounding the node, and, thus, by including a mass node in the impact-affected region, one is automatically including, in the impact-affected region, that portion of mass in the region of the node. It is clear that, in general, this approximate technique will result in having more or less structural mass included in the impact-affected region compared with the true structural mass within L_{eff}. However, in an average sense, this discrepancy is within the overall approximate nature of the impact-interaction analysis. In addition, the calculation of L_{eff}, which defines the distance the collision-imparted impulse "signal" travels in the structure during a finite time interval, is based on the global increment in time, Δt. This implies that the collision occurs at the beginning of a time step, and that the "signal" travels for a length of time equal to Δt. As will be shown in detail in Subsection A.5, the scheme employed in the present program can determine ring-fragment collision at any time within a given Δt. In general, a collision will not occur at the beginning of a time step, so that the signal propogates for a time, Δt^*, which is less than Δt, and the true L_{eff} is then less than the L_{eff} based on Δt; however, L_{eff} is assumed to remain constant and is based on Δt. This approximation of L_{eff} counterbalances the discrete process of determining which mass nodes fall within the impact-affected region. It is believed that these calculations, although approximate, will yield reasonable results for the fragment-impact-induced structural response.

Denoting by primes the "after-impact" translational and/or rotational velocities, the impulse-momentum law may be written to characterize the "instantaneous impact behavior" of the system, as follows:

Normal-Direction Translation Impulse-Momentum Law

$$m_f \left[V'_{fN} - V_{fN} \right] = -\tilde{P}_N \qquad \text{(fragment)} \tag{A.35}$$

$$\left.\begin{aligned} m_1 \left[V'_{1N} - V_{1N} \right] &= \alpha_1 \tilde{P}_N \\ m_2 \left[V'_{2N} - V_{2N} \right] &= \alpha_2 \tilde{P}_N \\ &\vdots \\ m_K \left[V'_{KN} - V_{KN} \right] &= \alpha_K \tilde{P}_N \end{aligned}\right\} \qquad \text{(ring impact-affected nodes)} \tag{A.36}$$

Tangential-Direction Translational Impulse-Momentum Law

$$m_f \left[V'_{fT} - V_{fT} \right] = -\tilde{P}_T \qquad \text{(fragment)} \tag{A.37}$$

$$\left.\begin{aligned} m_1\left[V_{1T}'-V_{1T}\right] &= \alpha_1\tilde{P}_T \\ m_2\left[V_{2T}'-V_{2T}\right] &= \alpha_2\tilde{P}_T \\ &\vdots \\ m_k\left[V_{kT}'-V_{kT}\right] &= \alpha_k\tilde{P}_T \end{aligned}\right\}$$ (ring impact-affected nodes) (A.38)

Rotational Impulse-Momentum Law

$$I_f\left[\omega_f'-\omega_f\right] = r_f\tilde{P}_T$$ (fragment) (A.39)

where

m_f = mass of the fragment

I_f = mass moment of inertia of the fragment about its CG

r_f = the radius of the circular disk model of the fragment

$\tilde{P}_N$ = normal-direction impulse

$\tilde{P}_T$ = tangential-direction impulse

α_i = proportional constant which is equal to $(C\alpha_i')$ as defined by Eqs. A.31 through A.34.

The relative velocity of sliding S' and the relative velocity of approach A' at the immediate "contact points" between the fragment (at C_f) and the ring segment j (at C_r) are defined by

$$S' = \left[V_{fT}'-\omega_f' r_f\right]-\left[\alpha_1 V_{1T}'+\alpha_2 V_{2T}'+\cdots+\alpha_k V_{kT}'\right] \tag{A.40}$$

$$A' = V_{fN}'-\left[\alpha_1 V_{1N}'+\alpha_2 V_{2N}'+\cdots+\alpha_k V_{kN}'\right] \tag{A.41}$$

Substituting Eqs. A.35 through A.39 into Eqs. A.40 and A.41, one obtains

$$S' = S_o - B_1\tilde{P}_T \tag{A.42}$$

$$A' = A_o - B_2 \tilde{P}_N \tag{A.43}$$

where the initial (pre-impact) relative velocity of sliding S_o, the initial relative velocity of approach A_o, and the geometrical constants B_1 and B_2 are given by

$$S_o = [V_{fT} - \omega_f r_f] - [\alpha_1 V_{1T} + \alpha_2 V_{2T} + \cdot \cdot \cdot + \alpha_k V_{kT}] \tag{A.44}$$

$$A_o = V_{fN} - [\alpha_1 V_{1N} + \alpha_2 V_{2N} + \cdot \cdot \cdot + \alpha_k V_{kN}] \tag{A.45}$$

$$B_1 = \frac{1}{m_f} + \frac{r_f^2}{I_f} + \frac{\alpha_1^2}{m_1} + \frac{\alpha_2^2}{m_2} + \cdot \cdot \cdot + \frac{\alpha_k^2}{m_k} \tag{A 46}$$

$$B_2 = \frac{1}{m_f} + \frac{\alpha_1^2}{m_1} + \frac{\alpha_2^2}{m_2} + \cdot \cdot \cdot + \frac{\alpha_k^2}{m_k} \tag{A.47}$$

where in Eqs. A.44 and A.45 by defintion $A_o \geq 0$; otherwise, the two bodies will not collide with each other. Also, if $S_o \geq 0$, the fragment slides initially along the ring segment. It perhaps should be noted that sliding of the bodies on each other is assumed to occur at the value of "limiting friction" which requires that $P_T = |\mu p_N|$, and when $P_T < |\mu p_N|$, only rolling (i.e., no sliding) exists. For a given value of e and a given value of μ which, respectively, describes the degree of "plasticity" of the collision process, and accounts for the frictional properties (roughness) of the contact surfaces, 2(k+1)+3 equations (Eqs. A.35 - A.39 and Eqs. A.42 - A.43) can be solved to obtain the post-impact quantitites (V'_{1N}, V'_{1T}), (V'_{2N}, V'_{2T}), ... , (V'_{kN}, V'_{kT}), (V'_{fN}, V'_{fT}) and ω'_f as well as $\tilde{P}_N$ and $\tilde{P}_T$; these are the 2 (k+1)+3 "unknowns".

The graphic technique which provides a convenient way to obtain the values of $\tilde{P}_N$ and $\tilde{P}_T$ at the instant of the termination of impact as described in Ref. 4 is employed in the present collision-interaction analysis. In this technique, the trajectory of an "image" point $\bar{P}$ in the plane formed by the impulse coc dinates $\tilde{P}_N$ and $\tilde{P}_T$ (Fig. A.3) represents the state of the colliding bodies at each instant of the contact interval. The image point $\bar{P}$ which is initially located at the origin and is denoted by $\tilde{P}_o$ ($\tilde{P}_N = 0$, $\tilde{P}_T = 0$) will always proceed in the upper half-plane with increasing $\tilde{P}_N$. The locations of the line of no sliding S' = 0 and the line of maximum approach A' = 0 are determined by the system constants B_1 and B_2. From Eqs. A.42 through A.47, it is noted that B_1 and B_2 are positive always; also the lines S' = 0 and A' = 0 are parallel to the $\tilde{P}_N$ axis and the $\tilde{P}_T$ axis, respectively, and intersect with each other at point P_3 in the first quadrant of the $\tilde{P}_N$, $\tilde{P}_T$ plane as shown in Fig. A.3. Depending on the values of the coefficient of sliding friction μ, the coefficient of restitution e, the system constants B_1 and B_2, and the initial conditions S_o and A_o, several variations of the impact process may occur and will be discussed in the following.

First, the cases in which the coefficient of sliding friction μ ranges from $0<\mu<\infty$ will be considered; the two special cases with $\mu = 0$ (perfectly-smooth contact surfaces) and $\mu = \infty$ (completely rough surfaces) will be discussed shortly thereafter.

Case I: If $0<\mu<\infty$, the friction angle ν and the angle Λ formed with the $\tilde{P}_N$ axis by the line connecting P_o and P_3 are defined by

$$\nu = \tan^{-1}\mu$$

and

$$\Lambda = \tan^{-1}\left(\frac{B_2 S_o}{B_1 A_o}\right) \tag{A.49}$$

Initially, the image point $\bar{P}$ travels from point P_o along the path P_oL which subtends an angle ν with the $\tilde{P}_N$ axis because the limiting friction impulse $P_T = \mu P_N$ is developed during the initial stage of impact. Subsequently:

(a) if $\mu = \tan\nu < \tan\Lambda$ (Fig. A.3a), line P_oL will intersect the line of maximum approach $A' = 0$ at point P_1, before reaching the line of no sliding $S' = 0$. The intersection point P_1 represents the state at the instant of the termination of the approach period. This is followed by the restitution period; the impact process ceases at point P' (path $P_o - P_1 - P'$). The coordinates of P' are

$$\tilde{P}_N = (1 + e)\, p_{N1} \tag{A.50}$$

$$\tilde{P}_T = \mu \tilde{P}_N = \mu (1 + e)\, p_{N1} \tag{A.51}$$

where p_{N1}, the ordinate of point P_1 is determined from the simultaneous solution of equations $P_T = \mu p_N$ and $A' = 0$, and is given by

$$p_{N1} = \frac{A_o}{B_2} \tag{A.52}$$

(b) However, if $\mu = \tan \nu \geq \tan \Lambda$ (Fig. A.3b), line P_oL will intersect the line of no sliding $S' = 0$ first at the intersection point P_2 which marks the end of the initial sliding phase. The image point $\tilde{P}$ then will continue to proceed along the line of no sliding $S' = 0$ through the intersection point P_3 with line $A' = 0$ to the end of impact at point P' (path $P_o - P_2 - P_3 - P'$). The final values of $\tilde{P}_N$ and $\tilde{P}_T$ are:

$$\tilde{P}_N = (1 + e)\, p_{N3} \tag{A.53}$$

$$\tilde{P}_T = \frac{S_o}{B_1} \tag{A.54}$$

where P_{N3} is the ordinate of point P_3 which represents the end of the approach period and is given by

$$P_{N3} = \frac{A_o}{B_2} \tag{A.55}$$

The above solution process can be specialized to represent the cases with $\mu = 0$ and $\mu = \infty$.

Case II: If $\mu = 0$ (perfectly smooth contact surfaces), line P_oL coalesces with the $\tilde{p}_N$ axis. The image point $\bar{P}$ will move along the $\tilde{p}_N$ axis to the end of impact. Thus

$$\tilde{P}_N = (1 + e) \frac{A_o}{B_2} \tag{A.56}$$

$$\tilde{P}_T = 0 \tag{A.57}$$

Case III: If $\mu = \infty$ (completely rough contact surface), point $\bar{P}$ moves initially along the $\tilde{p}_T$ axis to the intersection with $S' = 0$, then will follow the line $S' = 0$ to the end of impact. The post-impact value of $\tilde{p}_N$ and $\tilde{p}_T$ are

$$\tilde{P}_N = (1 + e) \frac{A_o}{B_2} \tag{A.58}$$

$$\tilde{P}_T = \frac{S_o}{B_1} \tag{A.59}$$

Knowing the values of $\tilde{p}_N$ and $\tilde{p}_T$ at the end of impact for the above discussed various impact processes, the corresponding post-impact velocities then can be determined from Eqs. A.35 through A.39 as follows:

$$\left.\begin{aligned} V_{1N}' &= V_{1N} + \frac{\alpha_1 \tilde{P}_N}{m_1} \\ V_{1T}' &= V_{1T} + \frac{\alpha_1 \tilde{P}_T}{m_1} \end{aligned}\right\} \text{Node 1} \tag{A.60}$$

$$V'_{2N} = V_{2N} + \frac{\alpha_2 \tilde{P}_N}{m_2}$$

$$V'_{2T} = V_{2T} + \frac{\alpha_2 \tilde{P}_T}{m_2}$$

Node 2 (A.61)

$$\vdots$$

$$V'_{KN} = V_{KN} + \frac{\alpha_K \tilde{P}_N}{m_K}$$

$$V'_{KT} = V_{KT} + \frac{\alpha_K \tilde{P}_T}{m_K}$$

Node K (A.62)

$$V'_{fN} = V_{fN} - \frac{\tilde{P}_N}{m_f}$$

$$V'_{fT} = V_{fT} - \frac{\tilde{P}_T}{m_f}$$

$$\omega'_f = \omega_f + \frac{r_f \tilde{P}_T}{I_f}$$

Fragment (A.63)

Thus, this approximate analysis provides the post-impact velocity information for the impact-affected nodes of the ring and for the fragment so that the timewise step-by-step solution of this ring/fragment response problem may proceed. Note that these post-impact velocity components are given in directions N and T at each node of the idealized impact-affected ring segments; as explained later, these velocity components are then transformed to (different) global directions appropriate for the curved-ring dynamic response analysis.

A.3 Prediction of Containment/Deflector Ring Motion and Position

The timewise solution of the resulting equations of motion for the "complete assembled discretized structure", Eq. A.30, may be accomplished by employing an appropriate timewise finite-difference scheme. The 3-point central-difference operator is chosen for use in the present analysis. In this solution scheme, the relations between displacements and displacement increments at any instant of time are

$$\{\Delta q^*\}_m = \{q^*\}_m - \{q^*\}_{m-1} \tag{A.64}$$

and

$$\{q^*\}_m = \{q^*\}_o + \{\Delta q^*\}_1 + \cdots + \{\Delta q^*\}_m \tag{A.65}$$

At time t_m, the acceleration and velocity may be expressed in terms of displacement increments by the following central-difference finite-difference expression:

$$\{\ddot{q}^*\}_m = \frac{\{q^*\}_{m+1} - 2\{q^*\}_m + \{q^*\}_{m-1}}{(\Delta t)^2} = \frac{\{\Delta q^*\}_{m+1} - \{\Delta q^*\}_m}{(\Delta t)^2} + O(\Delta t)^2 \tag{A.66a}$$

$$\{\dot{q}^*\}_m = \frac{\{q^*\}_{m+1} - \{q^*\}_{m-1}}{2(\Delta t)} = \frac{\{\Delta q^*\}_{m+1} + \{\Delta q^*\}_m}{2(\Delta t)} + O(\Delta t)^2 \tag{A.66b}$$

Employing Eq. A.30, the unconventional form of the dynamic equations of motion at any time instant t_m becomes

$$[M^*]\{\ddot{q}^*\}_m = -[K_s^*]\{q^*\}_m - \{P^*\}_m - [H^*]_m\{q^*\}_m \tag{A.67}$$

Since the right-hand side of Eq. A.67 is known, one can solve for $\{\ddot{q}^*\}_m$. Because the assembled mass matrix, $[M^*]$, is a diagonal matrix, the "inversion" of $[M^*]$ required for the solution of Eq. A.67 is accomplished simply by taking the inverse of each diagonal term in $[M^*]$. In practice, only the diagonal entries in $[M^*]$ are retained in the computer storage. With $\{\ddot{q}^*\}_m$ now known, one can calculate $\{\Delta q^*\}_{m+1}$ from Eq. A.66a as

$$\{\Delta q^*\}_{m+1} = \{\Delta q^*\}_m + (\Delta t)^2 \{\ddot{q}^*\}_m \tag{A.68}$$

Thus, from Eq. A.64 one has

$$\{q^*\}_{m+1} = \{q^*\}_m + \{\Delta q^*\}_{m+1} \tag{A.69}$$

The calculations of $\{\Delta q^*\}_{m+1}$ and $\{q^*\}_{m+1}$ have been made assuming that no ring-fragment collisions have occurred between time instants t_m and t_{m+1}. However, a ring-fragment collision may occur between time instants t_m and t_{m+1}; this would require a "correction" to the $\{\Delta q^*\}_{m+1}$ found from Eq. A.68. Thus, one first uses Eq. A.68 to form a trial value (overscript T) for $\{\Delta q^*\}_{m+1}$, and, hence, a trial value for $\{q^*\}_{m+1}$:

$$\{\overset{T}{q}{}^*\}_{m+1} = \{q^*\}_m + \{\Delta \overset{T}{q}{}^*\}_{m+1} \tag{A.70}$$

Next, the collision inspection and correction procedures, which will be described in Subsection A.6, are performed to determine the <u>actual</u> displacement increments $\{\Delta q^*\}_{m+1}$. Then the actual displacement at time t_{m+1} is given by Eq. A.69.

After the calculation of $\{\Delta q^*\}_{m+1}$ and $\{q^*\}_{m+1}$, the strain increment at any point in the element can be obtained. With the strain increment available, the stress increment and stress is computed from the stress-strain relation. Then the stress resultants are obtained. Equations A.67, A.68, and A.69 furnish the displacement increment and displacement for the next time step. The process is cyclic thereafter.

It should be noted that no "commencing sequence" is required in the present analysis for the central-difference timewise operator. This is because there are no prescribed initial velocity distributions or prescribed externally-applied forces in the present analysis; only impact-induced structural motion is taken into account. Thus, the ring structure is assumed to be at rest (thus $\{\Delta q^*\}_m = \{q^*\}_m = 0$) at all time instants prior to <u>initial</u> fragment-ring collision. When initial (and subsequent) fragment-ring collision occurs, a nonzero value for $\{\Delta q^*\}_{m+1}$ results, which is determined from the impact-interaction scheme, and no additional starting sequence is required.

A.4 Prediction of Fragment Motion and Position

In the present analysis, the fragment is assumed (see Ref. 3) to be nondeformable and, for analysis convenience to be circular; hence, its equations of motion for the case of no externally-applied forces are:

$$m_f \ddot{Y}_f = 0 \tag{A.71}$$

$$m_f \ddot{Z}_f = 0 \tag{A.72}$$

$$I_f \ddot{\theta} = 0 \tag{A.73}$$

where (Y_f, Z_f) and $(\ddot{Y}_f, \ddot{Z}_f)$ denote, respectively, the global coordinates and acceleration components of the center of gravity of the fragment (see Fig. A.2).

θ represents the angular displacement of the fragment in the $+\omega_f$ direction (Fig. A.2).

In timewise finite-difference form, Eqs. A.71 through A.73 become

$$(\Delta \overset{T}{Y}_f)_{m+1} = (\Delta Y_f)_m \tag{A.74}$$

$$(\Delta \overset{T}{Z}_f)_{m+1} = (\Delta Z_f)_m \tag{A.75}$$

$$(\Delta \overset{T}{\theta})_{m+1} = (\Delta \theta)_m \tag{A.76}$$

where overscript "T" signifies a trial value which requires modification, as explained later, if ring-fragment collision occurs between t_m and t_{m+1}.

A.5 Calculation of Ring-Fragment Time of Contact

In this subsection, an improved method* for determining the time of ring-fragment contact will be developed. It is assumed, based on the ring node and fragment c.g. locations at time t_m, that no overlapping of ring-fragment geometries occurs at time instant t_m, , based on the (trial) ring node and fragment c.g locations at time instant t_{m+1}, that overlapping of ring-fragment geometries does occur at time t_{m+1}. Thus during the finite increment in time, $\Delta t (= t_{m+1} - t_m)$, ring-fragment contact must have occurred. The problem, then, is to determine at what time, between t_m and t_{m+1}, ring-fragment contact occurs, and where on the C/D structure it occurs.

In the present development, only a single fragment and single element need be considered; a similar calculation can be carried out for each element separately and for each fragment being considered. Consider the uniform-thickness straight beam element shown in Fig. A.4. As noted in Subsection A.2, the (generally) curved element is approximated, for the impact analysis, as a straight beam, and, in addition, the variable-thickness element will be assumed to be of uniform thickness (equal to the average thickness, $\bar{h}$, of the element) for the impact analysis. The global Y,Z coordinate system is taken as the reference system for this analysis. Define vectors $\vec{P}_1$ and $\vec{P}_2$ (see Fig. A.4) such that $\vec{P}_1$ is the vector from node 1 to node 2 and $\vec{P}_2$ is the vector from node 1 to the fragment c.g. The vectors $\vec{P}_1$ and $\vec{P}_2$ define the relative position of node 2 and the fragment c.g., respectively, with respect to node 1 at time instant t_m, where it has been assumed that no ring-fragment overlapping occurs at time t_m.

The perpendicular distance, d, from the fragment c.g. to the vector $\vec{P}_1$ (midsurface of the element) at time t_m can be obtained by using the vector cross-product:

$$\vec{P}_1 \times \vec{P}_2 = (p_1 p_2 \sin\theta)\,\hat{i}_{\sim} \tag{A.77}$$

where p_i is the magnitude of the vector $\vec{P}_i$ and θ is the angle from $\vec{P}_1$ to $\vec{P}_2$. Denoting the nodal coordinates by Y_i and Z_i $(i = 1,2)$ and the fragment c.g. coordinates by Y_f and Z_f, the vectors $\vec{P}_1$ and $\vec{P}_2$ can be expressed as

*Improved compared with that used in Refs. 1 and 3.

$$\vec{P}_1 = (Y_2 - Y_1)\,\hat{\imath}_Y + (Z_2 - Z_1)\,\hat{\imath}_Z$$

$$\vec{P}_2 = (Y_f - Y_1)\,\hat{\imath}_Y + (Z_f - Z_1)\,\hat{\imath}_Z \tag{A.78}$$

and the distance, d, at time t_m is calculated by

$$d = \rho_2 \sin\theta = \frac{|\vec{P}_1 \times \vec{P}_2|}{P_1} = \frac{[(Y_f - Y_1)(Z_2 - Z_1) - (Y_2 - Y_1)(Z_f - Z_1)]}{[(Y_2 - Y_1)^2 + (Z_2 - Z_1)^2]^{1/2}} \tag{A.79}$$

In order to calculate the time of contact, the perpendicular distance, d, from the fragment c.g. to the element midsurface must be known as a function of time. The element nodal and fragment c.g. velocities and nodal accelerations are known at time t_m, and the accelerations are assumed to be constant over the finite increment in time, $\Delta t (= t_{m+1} - t_m)$. Denote the velocities and accelerations in the Y and Z directions at node i by v_{yi}, v_{zi}, a_{yi} and a_{zi}, respectively, and the fragment c.g. velocities in the Y and Z directions by v_{yf} and v_{zf}, respectively. The position of node 1 (for example) as a function time, $y_1(t)$, can then be expressed by the following Taylor series expression:

$$Y_1(t) = Y_1 + V_{Y_1} t + \frac{1}{2} a_{Y_1} t^2 \tag{A.80}$$

where the time reference has been shifted in such a way that t=0 corresponds to time t_m. Expressions similar to Eq. A.80 can be obtained for the quantities $y_2(t)$, $z_1(t)$, $z_2(t)$, $y_f(t)$, and $z_f(t)$ where it is noted that the acceleration of the fragment is zero. When these expressions are substituted into Eq. A.79, an expression for the distance, d(t), from the fragment c.g. to the element reference surface, as a function of time is obtained in the form

$$d(t) = \frac{At^4 + Bt^3 + Ct^2 + Dt + E}{[Ft^4 + Gt^3 + Ht^2 + It + J]^{1/2}} \tag{A.81}$$

where

$$A = \frac{1}{4}\left[(a_{Y_1} + a_{Y_2})\, a_{z_1} - (a_{z_2} + a_{z_1})\, a_{Y_1}\right] \tag{A.82a}$$

$$B = \frac{1}{2}\left[(V_{Y_1} - V_{Y_f})(a_{z_1} - a_{z_2}) + (V_{z_1} - V_{z_2})\, a_{Y_1} + (V_{z_f} - V_{z_1})(a_{Y_1} - a_{Y_2}) + (V_{Y_2} - V_{Y_1})\, a_{z_1}\right] \tag{A.82b}$$

$$C = \frac{1}{2}\left[(Y_f - Y_1)(a_{z_2} - a_{z_1}) + 2(V_{Y_f} - V_{Y_1})(V_{z_2} - V_{z_1}) + (z_2 - z_1)\, a_{Y_1} + (z_1 - z_f)(a_{Y_2} - a_{Y_1}) + 2(V_{z_1} - V_{z_f})(V_{Y_2} - V_{Y_1}) + (Y_2 - Y_1)\, a_{z_1}\right] \tag{A.82c}$$

$$D = (Y_f - Y_1)(V_{z_2} - V_{z_1}) + (V_{Y_f} - V_{Y_1})(z_2 - z_1) + (z_1 - z_f)(V_{Y_2} - V_{Y_1}) + (V_{z_1} - V_{z_f})(Y_2 - Y_1) \tag{A.82d}$$

$$E = (z_1 - z_2)(Y_1 - Y_f) - (Y_1 - Y_2)(z_1 - z_f) \tag{A.82e}$$

$$F = \frac{1}{4}\left[(a_{Y_2} - a_{Y_1})^2 + (a_{z_2} - a_{z_1})^2\right] \tag{A.82f}$$

$$G = (a_{Y_2} - a_{Y_1})(V_{Y_2} - V_{Y_1}) + (a_{z_2} - a_{z_1})(V_{z_2} - V_{z_1}) \tag{A.82g}$$

$$H = (V_{Y_2} - V_{Y_1})^2 + (V_{z_2} - V_{z_1})^2 + (a_{Y_2} - a_{Y_1})(Y_2 - Y_1) + (a_{z_2} - a_{z_1})(z_2 - z_1) \tag{A.82h}$$

$$I = 2\left[(Y_2 - Y_1)(V_{Y_2} - V_{Y_1}) + (z_2 - z_1)(V_{z_2} - V_{z_1})\right] \tag{A.82i}$$

$$J = (Y_2 - Y_1)^2 + (Z_2 - Z_1)^2 \tag{A.82j}$$

It should be noted here that the coefficients in Eq. A.81 are dependent only on the element nodal and fragment c.g. locations, velocities, and accelerations at time instant t_m. The time of contact is defined as that time at which $d(t)$ is equal to the critical distance, d_c, where the critical distance is the sum of the radius of the fragment, r_f, and half the average element thickness, $\bar{h}$:

$$d_c = r_f + \frac{1}{2}\bar{h} \tag{A.83}$$

Thus, the calculation of the time of contact, t_c, reduces to the solution of the following equation:

$$d_c = \frac{At^4 + Bt^3 + Ct^2 + Dt + E}{[Ft^4 + Gt^3 + Ht^2 + It + J]^{1/2}} \tag{A.84}$$

or

$$At^4 + Bt^3 + Ct^2 + Dt + E = d_c\,[Ft^4 + Gt^3 + Ht^2 + It + J]^{1/2} \tag{A.85}$$

Several approaches for the solution of Eq. A.85 may be envisioned. However, before discussing the alternate approaches, it is important to note that the only solution of Eq. A.85 which is of interest in the calculation of time of contact must be non-negative and less than or equal to Δt since contact must occur between time t_m and time t_{m+1} (recall that $\Delta t = t_{m+1} - t_m$). Since Δt is, typically, of order 10^{-5} or 10^{-6}, the solution method chosen must be able to solve Eq. A.85 accurately for small values of t.

Because no closed-form solution of Eq. A.85 is available, the use of a numerical iterative (approximate) solution scheme such as the Newton Raphson procedure would be necessary. However, such schemes often suffer from poor convergence behavior unless an accurate "initial guess" is made. For the general impact problem, the use of such numerical iterative schemes has thus been judged to be too unreliable and more direct methods have been sought for the solution of Eq. A.85, as discussed next.

The right-hand-side of Eq. A.85 (term in brackets) is expanded in a Taylor series about t=0 as

$$\begin{aligned}[Ft^4 + Gt^3 + Ht^2 + It + J]^{1/2} = {} & J^{1/2} + \left(\frac{I}{2J^{1/2}}\right)t + \left(\frac{H}{2J^{1/2}} - \frac{I^2}{8J^{3/2}}\right)t^2 \\ & + \left(\frac{1}{16}\frac{I^3}{J^{5/2}} - \frac{1}{4}\frac{IH}{J^{3/2}} + \frac{G}{2J^{1/2}}\right)t^3 + \left(\frac{3}{16}\frac{I^2H}{J^{5/2}} - \frac{5}{128}\frac{I^4}{J^{7/2}} - \frac{H^2+6IG}{8J^{3/2}}\right. \\ & \left. + \frac{F}{2J^{1/2}}\right)t^4 + O(t^5)\end{aligned} \tag{A.86}$$

If the terms of order t^5 are neglected and Eq. A.86 is substituted into Eq. A.85, the following quartic equation results:

$$\begin{aligned} &\left[A - d_c\left(\frac{3}{16}\frac{I^2 H}{J^{5/2}} - \frac{5}{128}\frac{I^4}{J^{7/2}} - \frac{H^2+6IG}{8J^{3/2}} + \frac{F}{2J^{1/2}}\right)\right]t^4 \\ &+\left[B - d_c\left(\frac{1}{16}\frac{I^3}{J^{5/2}} - \frac{1}{4}\frac{IH}{J^{3/2}} + \frac{G}{2J^{1/2}}\right)\right]t^3 + \left[C - d_c\left(\frac{H}{2J^{1/2}} - \right.\right. \\ &\left.\left.\frac{I^2}{8J^{3/2}}\right)\right]t^2 + \left[D - d_c\left(\frac{I}{2J^{1/2}}\right)\right]t + \left[E - d_c J^{1/2}\right] = 0 \end{aligned} \tag{A.87}$$

The advantage of using Eq. A.87 in place of Eq. A.85 is that closed-form solutions to quartic equations are available (see, for example, Ref. 5); thus, a computer subroutine which obtains the real roots (imaginary roots are of no interest in the present time-of-contact solution) of a general quartic equation has been included in the present CIVM-JET 4B program. The coefficients in Eq. A.87 are determined from known displacement, velocity, and acceleration information using Eqs. A.82, and the calculation of the time of contact is thus reduced to the solution of Eq. A.87.

Numerical experimentation with the solution of general quartic equations suggests that the roots of larger magnitude are predicted more accurately. In particular if, for example, the exact solution of a given quartic equation has one real root of order 10^{-6} and another real root of order 1, then the order 1 root will be predicted accurately, but large errors will be found in the prediction of the order 10^{-6} root. In the present impact analysis, the roots of interest are of the order of Δt (typically 10^{-6}). To avoid errors in the prediction of these small roots, a change of variables, namely $t=1/x$ is made in Eq. A.87, and the resulting quartic equation in x is solved. In this way, the x roots of interest are large (corresponding to small t roots) and accuracy of these roots is assured. It should be noted that if the constant term in Eq. A.87 is zero, then $t=0$ is a valid root and the solution of the full quartic is not required.

Finally, it is important to clarify under what conditions the use of Eq. A.87 instead of Eq. A.85 is valid. The only approximation employed in the development of Eq. A.87 is that the right-hand-side of Eq. A.85 can be approximated by a Taylor Series expansion, retaining only those terms up to order t^4.

The coefficients in Eq. A.86 are related only to information at the nodes of the element and, in fact, Eq. A.86 is an expression for the change in the length of the element as a function of time. The use of Eq. A.87 in place of Eq. A.85 is deemed valid if for the values of t of interest (i.e. $0 \leq t \leq \Delta t$), the Taylor series of Eq. A.86 can be shown to behave as

$$\left[Ft^4+Gt^3+Ht^2+It+J\right]^{1/2} = J^{1/2}\left[1+O(10^{-1})+O(10^{-2})+O(10^{-3})+\ldots\right] \tag{A.88}$$

where $J^{1/2}$ is the element length at time zero. It can be shown, after some manipulation, that the behavior of the Taylor series is (at worst) that given by Eq. A.88 if the relative displacement in the time increment, Δt, of node 2 with respect to node 1 in a direction parallel or perpendicular to the element midsurface does not exceed 10% of the element length at the beginning of the time increment (i.e. at time t_m). This condition should be satisfied for all conceivable engineering applications of the current ring-fragment impact analysis and, thus, the use of Eq. A.87 to calculate the time of ring-fragment contact (impact) is justified.

In summary, when ring-fragment impact is determined to occur between times t_m and t_{m+1}, Eq. A.87 (along with Eqs. A.82) is employed to calculate the time of ring-fragment contact, t_c, within that time interval. In practice (as will be explained in detail in the next subsection), this calculation is performed for each element in order, considering each of the n attacking fragments one by one. The only roots of Eq. A.87 which are considered valid are those real roots which satisfy

$$0 \leq t \leq \Delta t = t_{m+1} - t_m \tag{A.89}$$

When a valid value is found for t_c, the point of ring-fragment contact, p_c, can be calculated by the following vector dot product:

$$p_c = \frac{\vec{P}_1 \cdot \vec{P}_2}{|\vec{P}_1|} \tag{A.90}$$

where the vectors $\vec{P}_1$ and $\vec{P}_2$ are evaluated at time $t = t_c$. The quantity p_c is the distance from node 1 to the point of contact divided by the element length (at time t_c). The point of contact, as defined by Eq. A.90 must be between 0 and 1 for contact to have occurred on the element length, i.e.

$$0 \le P_c \le 1 \tag{A.91}$$

If Eq. A.91 is not satisfied, contact has not occurred on the element length. Thus, both Eqs. A.89 and A.91 must be satisfied for element-fragment contact to be valid. Note that the method developed in this subsection will, in general, determine contact between a fragment (assumed to be circular) and an infinitely-long straight "element" passing through nodes 1 and 2 of the actual structural element under consideration, and thus, the condition given in Eq. A.91 must be imposed.

A.6 Collision Inspection and Solution Procedure

A.6.1 One-Fragment Attack

The collision inspection and solution procedure will be described first for the case in which only one idealized fragment is present. With minor modification this procedure can also be applied for an n-fragment attack as discussed in Subsection A.6.2.

At various stages in the impact inspection and solution procedure, the updating of ring node (or fragment) positions and/or velocities is required. In the interest of conciseness, the form of these updating equations is presented now, and reference to these equations will be made. The location (denoted by an over-bar) of the ring nodes $\{\bar{q}^*\}_{t'}$, at some time t' is given by

$$\{\bar{q}^*\}_{t'} = \{\bar{q}^*\}_o + \{q^*\}_{t'} \tag{A.92}$$

where $\{\bar{q}^*\}_o$ is the initial (i.e. t=0) location of the ring nodes and $\{q^*\}_{t'}$ is the total displacement of the ring nodes up to time, t=t'. The location of the ring nodes, $\{\bar{q}^*\}_{t'+\Delta t'}$, at a time, $t=t'+\Delta t'$ (within a time increment Δt), in terms of the location $\{\bar{q}^*\}_{t'}$, velocity $\{\dot{q}^*\}_{t'}$, and acceleration $\{\ddot{q}^*\}_{t'}$, of the ring nodes at time, t=t', is given by the following Taylor Series expansion:

$$\{\bar{q}^*\}_{t'+\Delta t'} = \{\bar{q}^*\}_{t'} + (\Delta t')\{\dot{q}^*\}_{t'} + \frac{1}{2}(\Delta t')^2\{\ddot{q}^*\}_{t'} \tag{A.93}$$

It should be noted that Eq. A.93 can be derived from the central difference expressions, and is thus consistent with the central difference timewise operator employed in the present CIVM-JET 4B program. Finally, the velocity at some time, $t=t'+\Delta t'$, is given by the expression

$$\{\dot{q}^*\}_{t'+\Delta t'} = \{\dot{q}^*\}_{t'} + (\Delta t')\{\ddot{q}^*\}_{t'} \quad (A.94)$$

Equations A.92 through A.94 have been written for the ring nodes; the updating equations for the fragment are of the same form with the acceleration of the fragment taken to be zero. It should be noted that the acceleration of the ring nodes is assumed to be constant within a time increment and is equal to the ring-node acceleration at the beginning of the time step being considered.

The following procedure indicated in the flow diagram of Fig. 7 may be employed to predict the motions of the ring and rigid fragment, their possible collision, the resulting collision-imparted velocities experienced by each, and the subsequent motion of each body:

Step 1: Let it be assumed at time t_m that the displacements $\{q^*\}_m$, $(Y_f)_m$, and $(Z_f)_m$ and displacement increments $\{\Delta q^*\}_m$, $(\Delta Y_f)_m$, and $(\Delta Z_f)_m$ are known. One can then calculate the strain increments $(\Delta\varepsilon)_m$ at all Gaussian stations along and through the thickness of the ring.

Step 2: Using a suitable constitutive relation for the ring material, the stress increments $(\Delta\sigma)_m$ and the plastic strain increments $(\Delta\varepsilon^p_m)$ at corresponding Gaussian stations within each finite element can be determined from the known strain increments $(\Delta\varepsilon)_m$. This information permits determining all quantities on the right-hand side of Eq. A.67.

Step 3: Solve Eq. A.67 for the nodal accelerations, $\{\ddot{q}^*\}_m$, then solve for the trial displacement increments, $\{\Delta\overset{T}{q}{}^*\}_{m+1}$, by using Eq. A.68, the trial ring displacements, $\{\overset{T}{q}{}^*\}_{m+1}$, by using Eq. A.70, and use Eqs. A.74 through A.76 for the trial fragment displacement increments $(\Delta\overset{T}{Y}_f)_{m+1}$, $(\Delta\overset{T}{Z}_f)_{m+1}$, and $(\Delta\overset{T}{\theta})_{m+1}$. In addition, the ring node velocities $\{\dot{q}^*\}_m$ at time t_m are calculated by using Eq. A.68

for those nodes not impact-corrected during the previous time cycle, and using the impact-corrected velocity updated to the end of the previous time cycle for those nodes subject to impact corrections during the previous time cycle. It is assumed that the fragment velocities, $(\dot{Y}_f)_m$, $(\dot{Z}_f)_m$, and $(\dot{\theta}_f)_m$ at time t_m are known.

Since one or more ring-fragment collisions may have occurred between t_m and t_{m+1}, the following sequence of steps may be employed to determine whether or not a collision occurred and, if so, to effect a correction of the displacement increments of the impact affected ring segments and of the fragment.

Step 4: In the present scheme, several collisions may occur during a given global time step $\Delta t = (t_{m+1} - t_m)$. Thus, the global Δt will be subdivided into subincrements in time which will be denoted by Δt^*, where Δt^* is the time remaining in the global Δt and is given by

$$\Delta t^* = t_{m+1} - t_m^* \tag{A.95}$$

where t_m^* is the reference "beginning" time for the current collision inspection cycle. Thus, for the first inspection for a given Δt, t_m^* must be initialized to t_m, and Δt^* must be initialized to Δt. In subsequent inspections (if any) within this Δt, the value of t_m^* will be updated to the time of ring-fragment contact, and Eq. A.95 will be used to calculate Δt^*. Because the impact inspection is most conveniently carried out in the global Y,Z coordinate system, one first transforms the nodal displacement, velocity, and acceleration vectors at time t_m, $\{q^*\}_m$, $\{\dot{q}^*\}_m$, $\{\ddot{q}^*\}_m$, into the global Y,Z coordinate system (note that the fragment information is already in the global Y,Z system). Then the ring node and fragment locations, $\{\bar{q}^*\}_m$, $(\bar{Y}_f)_m$, etc. at time t_m are calculated by using Eq. A.92 and the trial ring node and fragment locations at time t_{m+1}, $\overset{T}{\{q^*\}}_{m+1}$, $\overset{T}{(Y_f)}_{m+1}$, etc. are calculated by using Eq. A.93 (where $t'=t_m$, and $\Delta t'=\Delta t^*$). Having completed these initializations, the following sequence of substeps may be employed to determine whether or not a collision occurs within the subincrement Δt^* ($=\Delta t$ on this first inspection).

Step 4a: To check for the possibility of a collision between the fragment and ring element j (approximated as a straight beam) as depicted in Fig. A.5, compute the trial projection $(\overset{T}{p}_j)_{m+1}$ of the line from ring node j to point C_f at the center of the fragment, upon the straight line connecting ring nodes j and j+1, as follows, at time instant t_{m+1}:

$$\begin{aligned}(\overset{T}{p}_j)_{m+1} &= [\overset{T}{Y}_j - \overset{T}{Y}_f]_{m+1} \cos(\overset{T}{\delta}_j)_{m+1} \\ &+ [\overset{T}{Z}_j - \overset{T}{Z}_f]_{m+1} \sin(\overset{T}{\delta}_j)_{m+1}\end{aligned} \tag{A.96}$$

where the Y,Z are inertial Cartesian coordinates obtained from $\overset{T}{\{q^*\}}_{m+1}$, $\overset{T}{(Y)}_{m+1}$ etc. Now, examine $(\overset{T}{p}_j)_{m+1}$; three cases are illustrated in Fig. A.5a.

Step 4b: If $(\overset{T}{p}_j)_{m+1} < 0$ or if $(\overset{T}{p}_j)_{m+1} > \ell_j$ where $\ell_j > 0$, a collision between the fragment and ring element j is impossible. Proceed to check ring element j+1, etc., for the possibility of a collision of the fragment with other ring elements. Note that ℓ_j is the length of the jth element at time t_{m+1}.

Step 4c: If $0 \leq (\overset{T}{p}_j)_{m+1} \leq \ell_j$, a collision with ring element j is possible, and further checking is pursued. Next, calculate the fictitious "penetration distance" $(\overset{T}{a}_j)_{m+1}$ of the fragment into ring element j at point C_r by (see Fig. A.5b):

$$(\overset{T}{a}_j)_{m+1} = \left[\tfrac{1}{4}(h_{1j} + h_{2j}) + r_f\right]_{m+1} - [\overset{T}{d}_j]_{m+1} \tag{A.97}$$

where

$[\frac{1}{4}(h_{1j} + h_{2j})]$ = average distance from the reference surface to the inner surface of the ring element which is approximated as a straight beam in this "collision calculation".

r_f = radius of the fragment.

$$(\overset{T}{d}_j)_{m+1} = -[\overset{T}{Y}_j - \overset{T}{Y}_f]_{m+1} \sin(\overset{T}{\delta}_j)_{m+1} + [\overset{T}{Z}_j - \overset{T}{Z}_f]_{m+1} \cos(\overset{T}{\delta}_j)_{m+1} \qquad \text{(A.98)}$$

= the projection of the line connecting node j with the center of the fragment upon a line perpendicular to the line joining nodes j and j+1.

Next, examine $(\overset{T}{a}_j)_{m+1}$ which is indicated schematically in Fig. A.5b and is given by Eq. A.97.

Step 4d: If $(\overset{T}{a}_j)_{m+1} \leq 0$, no collision of the fragment upon element j has occurred during the time interval from t^*_m to t_{m+1}. Hence, one can proceed to check element j+1, etc. for the possibility of a collision of the fragment with other ring elements.

Step 4e: If $(\overset{T}{a}_j)_{m+1} > 0$, a collision has occurred. Steps 4a through 4d are repeated for each element; if no positive values of $(\overset{T}{a}_j)_{m+1}$ have been found, no ring-fragment collisions have occurred; then proceed to Step 9. If any positive values of $(\overset{T}{a}_j)_{m+1}$ have been found, ring-fragment collision has occurred; proceed to the next step.

Step 5: Since ring-fragment collision has been determined to have occurred between times t^*_m and t_{m+1}, the following sequence of substeps may be employed to determine the time and location of ring-fragment contact:

Step 5a: Given the locations and velocities of the fragment and the nodes of element j at time t_m^*, form the coefficients A-G given by Eqs. A.82 and solve for the roots of Eq. A.87. Choose the smallest, positive, real root. If this root satisfies Eq. A.89 (where Δt in Eq. A.89 has been replaced by Δt^* here)

$$0 \leq t \leq \Delta t^* \qquad (A.99)$$

then this root is the time of contact $(t_c)_j$ for element j, and proceed to the next step. If this root does not satisfy Eq. A.99, set $(t_c)_j$ equal to a large negative number and proceed to the next element.

Step 5b: Special consideration must be given to the case where $(t_c)_j=0$. Because the present scheme allows for several subincrements, Δt^*, in time within the "global" increment in time, Δt, for the purpose of collision inspection and correction, the value of $(t_c)_j=0$ is allowable only if this element has not been impacted at some prior time during the current global increment in time, Δt. Thus, a "flagging" array is set up at the start of each Δt to determine whether or not a particular $(t_c)_j=0$ is allowable. If $(t_c)_j=0$ is not allowable, set $(t_c)_j$ equal to a large negative number and proceed to the next element. Otherwise, proceed to the next step.

Step 5c: The point of contact, $(p_c)_j$, on element j is now calculated by using Eq. A.90. This value is then inspected to determine whether or not contact occurs within the actual boundaries of element j. If $(p_c)_j$ satisfies Eq. A.91 (repeated here for convenience)

$$0 \leq (p_c)_j \leq 1 \qquad (A.100)$$

then contact has occurred on element j, and one proceeds to the next element. If Eq. A.100 is not satisfied, contact has not occurred on element j: set $(t_c)_j$ (for the jth element) equal to a large negative number and proceed to the next element.

Step 5d: Steps 5a through 5c are repeated for each element until all elements on the main structure have been considered. In practice, several allowable values of t_c can be found, corresponding to different elements, in one subincrement in time, Δt^*, the desired value being the minimum $(t_c)_j$ value of all allowable values. Thus, a quantity, $(t_c)_{min}$, which is the minimum of all calculated (allowable) values of $(t_c)_j$, is initialized to Δt^* just prior to Step 5a. Following Step 5c, the calculated value of $(t_c)_j$ is compared with the current value of $(t_c)_{min}$. If the following condition is satisfied

$$0 \leq (t_c)_j \leq (t_c)_{min} \tag{A.101}$$

then the value of $(t_c)_{min}$ is redefined to be the value of $(t_c)_j$. When all elements have been processed, the quantity $(t_c)_{min}$ will contain the actual minimum value of all values of $(t_c)_j$. The element number and point of contact associated with this value of $(t_c)_{min}$ are also identified. Because of the form of Eq. A.101, if equal values of $(t_c)_j$ are calculated for two or more elements, the higher element number will be associated with $(t_c)_{min}$ (elements are processed in ascending numerical order). Following the determination of $(t_c)_{min}$, a "flag" is set for the element corresponding to $(t_c)_{min}$ indicating that a value of $(t_c)_j=0$, for this element, is not allowed during the remainder of the current global increment in time, Δt.

Step 6: Having determined the time of ring-fragment contact, the ring-node positions, $\{\bar{q}^*\}_m$, and the fragment position, $(\bar{Y}_f)_m$, etc., are updated to the time of contact by using Eq. A.93, and the ring-node velocities, $\{\dot{q}^*\}_m$, are updated to the time of contact by using Eq. A.94. For both calculations, $t'=t^*_m$, and $\Delta t' = (t_c)_{min}$. Again, it should be recalled that $(t_c)_{min}$ is the time of contact, referenced to time t^*_m. The reference beginning time, t^*_m, is now updated to the time of contact by

$$t_m^{**} = t_m^* + (t_c)_{min} \tag{A.102}$$

and the time subincrement, Δt^*, remaining in the global increment in time, Δt, is updated by using Eq. A.95. The quantities $\{\bar{q}^*\}_m$, $\{\dot{q}^*\}_m$, $(\bar{Y}_f)_m$, etc. are no longer needed, so their values are replaced by the appropriate updated values. Thus, the quantities $\{\bar{q}^*\}_m$, $\{\dot{q}^*\}_m$, $(\bar{Y}_f)_m$, $(\bar{Z}_f)_m$, and $(\bar{\theta}_f)_m$ now refer to the ring node locations and velocities and fragment locations in the global Y,Z coordinate system, at time t_m^* which is the time of ring-fragment contact (see Eq. A.102).

Step 7: Based on the collision-interaction analysis developed in Subsection A.2, the post-impact velocities of the impact-affected ring nodes and the fragment are now calculated. That is, the pre-impact nodal velocities ($\{\dot{q}^*\}$ at time $t = t_m^*$) and fragment velocities ($\dot{Y}_f$, $\dot{Z}_f$, $\dot{\theta}_f$ at time $t = t_m^*$) are updated to their post-impact values using Eqs. A.60 through A.63.

(Note that Eqs. A.60-A.63 are written in terms of an N,T coordinate system, as defined in Subsection A.2. Thus, the nodal and fragment velocities, assumed to be in the global Y,Z coordinate system prior to the collision-interaction analysis, must be transformed into the N,T system at the start of the collision-interaction analysis, and the resulting post-impact velocities, calculated in the N,T system via. Eqs. A.60-A.63, must then be transformed back to the global Y,Z system after completion of the collision-interaction analysis).

For convenience, the post-impact velocity information, in the global Y,Z coordinate system, is assumed to "replace" the pre-impact velocity information. Thus, the quantities $\{\dot{q}^*\}_m$, $(\dot{Y}_f)_m$, $(\dot{Z}_f)_m$, and $(\dot{\theta}_f)_m$ now refer to the post-impact velocity of the ring-nodes and fragment at the time of contact, t_m^*.

Step 8: A decision must now be made concerning whether or not to continue on to another collision inspection. The collision inspection/correction process is repeated: (1) if the value of Δt^* is positive and (2) if the number of collision inspection/corrections within the current Δt has not exceeded a specified maximum[+] (equal to 50 per fragment in the present analysis). If either of these conditions is violated, no further inspection is performed, but if both conditions are satisfied, further collision-inspection is carried out. In either case, the next step is followed.

Step 8a: Before proceeding to the next collision inspection (or proceeding to Step 9, if no further inspections are to be made), the ring-node and fragment (trial) positions at time t_{m+1}, must be updated using their positions, post-impact velocities, and accelerations (ring nodes only) at time t_m^*, but using Eq. A.93 with $t'=t_m^*$, and $\Delta t'=\Delta t^*$. If further collision inspection is to be done, Steps 4a through 8a are then repeated to determine whether or not a ring-fragment collision occurs during the subincrement of time, Δt^*, from time t_m^* to time t_{m+1}, and, if so, to effect a <u>correction</u> of the impact-affected ring nodes and fragment velocities. If no further collision inspections are to be carried out (because of the conditions stated in Step 8) the next step (Step 9) should be followed. At this point, the reason for the special consideration given to the case $(t_c)_j=0$ in Step 5b can be clearly seen. The ring node and fragment positions have already been updated to the <u>time of</u> contact, t_m^*, via Step 6. On the next pass through Steps 5a-5d (calculation of the time of contact during the sub-interval in time Δt^*), the ring and fragment are, in fact, in contact (recall that a contact time of zero corresponds to time t_m^*) and a value of $(t_c)_{j=0}$ will be obtained from Eq. A.87 for

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[+]In the present impact inspection scheme, corrections must be made for <u>all</u> ring-fragment collisions to avoid spurious results in subsequent inspections. The specified maximum of 50 has been included only to guard against user input errors. In practice (assuming correct user input information) this limit should never be exceeded.

that element impacted during the previous Δt^*. Thus, the special consideration and flagging procedure described in Step 5b must be employed so that multiple corrections for the same ring-fragment collision can be avoided.

Step 9: This step will be executed when no (further) ring-fragment collisions are found up to time t_{m+1}. The corrected ring-node and fragment displacements in the global Y,Z coordinate system at time t_{m+1} are now calculated by solving Eq. A.92 for $\{q^*\}_{t'}$, where $t'=t_{m+1}$. The velocity at those nodes affected by one or more impacts is then updated to time t_{m+1} using Eq. A.94 where $t'=t_m^*$, $\Delta t'=\Delta t^*$ and assuming that $\{\ddot{q}^*\}_{t_m^*} = \{\ddot{q}^*\}_{t_m}$. It should be noted that the velocity at time t_{m+1} for those nodes not affected by impact is calculated using the central-difference expression as discussed in Step 3. The corrected nodal displacement and velocity vectors, currently in the global Y,Z coordinate system, are now transformed back into the appropriate ring coordinate system. Following this transformation, the corrected ring node and fragement displacement increments ($\{\Delta q^*\}_{m+1}$, $(\Delta Y_f)_{m+1}$, etc.) are calculated by subtracting the displacements at time t_m (i.e. $\{q^*\}_m$, $(Y_f)_m$, etc.) from the corrected displacements at time t_{m+1}.

Step 10: Having determined the corrected+ displacement increments and displacements for the ring elements and fragment, this time cycle of calculation is now complete. One then proceeds to calculate the ring nodal coordinate increments and the fragment coordinates for the time step from t_{m+1} to t_{m+2}, starting with Step 1. The process proceeds cyclically thereafter for as many time increments as desired.

+It should be noted that in this approximate calculation, only the coordinate increments of the fragment and of the impact affected ring segments are corrected. Those for all other ring segments are regarded as already being correct. The time increment Δt is regarded as being sufficiently small to make these approximations acceptable.

This solution procedure may be carried out for as many time steps as desired or may be terminated by invoking the use of a termination criterion such as, for example, the reaching of a critical value of the strain at the inner surface or the outer surface of the ring. Appropriate modifications of this approximate analysis could be made, if desired, to follow the behavior of the ring and the fragment after the initiation and/or completion of local fracturing of the ring has occurred; however, this has not been done in the present program.

Finally, note that it is possible for the fragment to come in contact with two ring elements simultaneously. In this situation, a correction would be made for the higher-numbered element first as noted in Step 5d. The higher-numbered element will then be "flagged" as being impacted and on the next subincrement in time, Δt^*, a value of $(t_c)_j=0$ will be found for the lower-numbered element and a correction will be made. A similar situation arises when multiple fragments impact the ring simultaneously, as will be discussed in the next subsection.

A.6.2 N-Fragment Attack

In the case of "attack" by n idealized fragments, each with its individual m_f, I_f, r_f, ω_f, V_{fN}, and V_{fT}, a similar procedure is used. During each Δt^*, the collision-inspection procedure is carried out for every fragment; none, some, or all of these n fragments may have collided with one or more of the ring segments. If any positive penetration distances are computed, the calculation of ring-fragment contact time will follow for each element and each of the n fragments in turn. This calculation sequence will identify the first ring-fragment contact within Δt^*, and the fragment number and element number involved in the collision. The appropriate corrections, as a result of this collision, will be made, and the process will be repeated for the next Δt^*. During the next Δt^*, the same fragment or a different fragment may collide with the ring structure; the appropriate corrections will then be made for this collision. This process is repeated until either (1) more than 50 ring-fragment collisions occur for a given fragment, or (2) the value of Δt^* is zero, which occurs at $t=t_{m+1}$, or (3) no (more) ring-fragment collisions are found within the global time step, Δt. After all of the corrections have been carried out for the present Δt time interval, the calculation process of Fig. 7 proceeds similarly for the next Δt.

Note that it is possible for two or more fragments to impact the ring structure simultaneously. This plausible situation is accommodated in the present scheme. Because of the "flagging" scheme discussed in Step 5b of the previous subsection, the collision involving the higher fragment number will be corrected for first (and will be flagged). On the next Δt^* (sub) step, the next highest fragment number involved in the simultaneous impact will yield a value of $(t_c)_{min}=0$ and a correction will be made corresponding to this ring-fragment collision, and so on, until corrections have been made for all fragments involved in the simultaneous impact. In essence, the ring structure and fragment positions remain unaltered while a series of corrections is made (with $(t_c)_{min}=0$), corresponding to all of the fragments which impact simultaneously.

Finally, it should be noted that no provisions have been made for collisions (or interactions) between the fragments themselves. Thus, all collisions (and subsequent interactions) are assumed to be between a fragment and the ring structure.

A.7 Ring-Fragment Collision on or Near a Constrained Node

The impact-interaction analysis presented in Subsection A.2 is based on the assumption that all nodes within the impact-affected region are free to respond with velocity changes as a result of ring-fragment collision. If any of the nodes within the impact-affected region are constrained, then the analysis of Subsection A.2 must be modified slightly. These modifications, and their subsequent application to the present analysis, are described in the present subsection.

For the present analysis, assume that one of the nodes within the impact-affected region is constrained such that no normal or tangential motion is permitted. Denote this node number by the subscript "c". At node c, the constraint will contribute a reaction force (or reaction impulse) so that the translational impulse-momentum relations (Eqs. A.36 and A.38) at node c must now be written as

$$m_c [V'_{cN} - V_{cN}] = \alpha_c \tilde{P}_N - P_N^R \qquad \text{(A.103a)}$$

$$m_c [V'_{cT} - V_{cT}] = \alpha_c \tilde{P}_T - P_T^R \qquad \text{(A.103b)}$$

where the additional terms p_N^R and p_T^R are the reaction impulses at node c in the normal and tangential directions, respectively. The pre-impact velocities, V_{CN} and V_{CT}, must be zero and because of the constraint, the post-impact velocities must also be zero, thus Eqs. A.103 state that the restraint "absorbs" all of the impulse associated with the constrained node.

The analysis developed in Subsection A.2 can be followed exactly if the value of α for the constrained node is set equal to zero, i.e.

$$\alpha_c = 0 \qquad \text{(A.104)}$$

This is equivalent to introducing equations of the form of Eq. A.103 and immediately solving for the reaction impulse, which yields a total value of zero on the right-hand side of Eq. A.103 In practice, the use of Eq. A.104 allows one to treat the special case of impact on or near a constrained node within the framework and equations developed in Subsection A.2.

It should be noted that the quantity α' for the constrained node is not set equal to zero. This quantity defines the relative portion of the total imparted impulse which is associated with a given node which lies within the impact-affected region, and is calculated by using Eq. A.31 whether or not the node is constrained. In general, the constrained node may fall anywhere within the impact-affected region. Because of the character of the present impact interaction analysis in which only translational (not rotational) motion of the ring is considered (both translational and rotational motion are included in the global timewise solution), it is difficult to include the effects of impulse propogated past the constrained node. For the case where the node is ideally clamped, no information can propogate through the constraint. But if the node is pinned-fixed, rotational information could propogate past the constraint; to accommodate this situation, rotational effects would have to be included in the analysis of Subsection A.2. An alternate, interim measure is taken in the present analysis, and is described next.

Assume that the point of contact and the effective length, L_{eff}, are such that the constrained node and nodes beyond the constrained node fall within the impact-affected region. Because the analysis of Subsection A.2 cannot predict the propagation of impact information past the constrained node, the effective length, L_{eff}, is, in the present scheme, artificially reduced (for the current Δt only) in such a way that the constrained node falls within the impact-affected region but no nodes past the constrained node fall in the impact-affected region. Having redefined L_{eff} in this fashion, the equations of Subsection A.2 are then followed exactly with Eq. A.104 being employed at the constrained node. This approach has the effect of concentrating the impact-induced impulse at those ring nodes on the impacted side of the constraint, with a portion of the impact-induced impulse being absorbed by the constraint, and no impulse being felt at nodes beyond the constrained node. However, it should be recognized that, although no impulse information is passed through the constrained node by the impact interaction analysis, the impact information will propogate through the constrained node, if physically possible, in the global timewise structural response solution.

For the case where impact occurs directly on a constrained node, only that constrained node is assumed to lie within the impact-affected region. Following the equations in Subsection A.2 and employing Eq. A.104, the fragment will simply rebound (as if impacting a rigid wall) and the ring structure will experience no momentum changes for this impact.

Finally, it should be noted that the present approach is an interim measure, and further effort is required to develop a more comprehensive approach for treating impact near a constrained node. However, the present method is believed to be sufficiently general, within the current overall assumptions of the analysis, to yield reasonable results for current engineering applications.

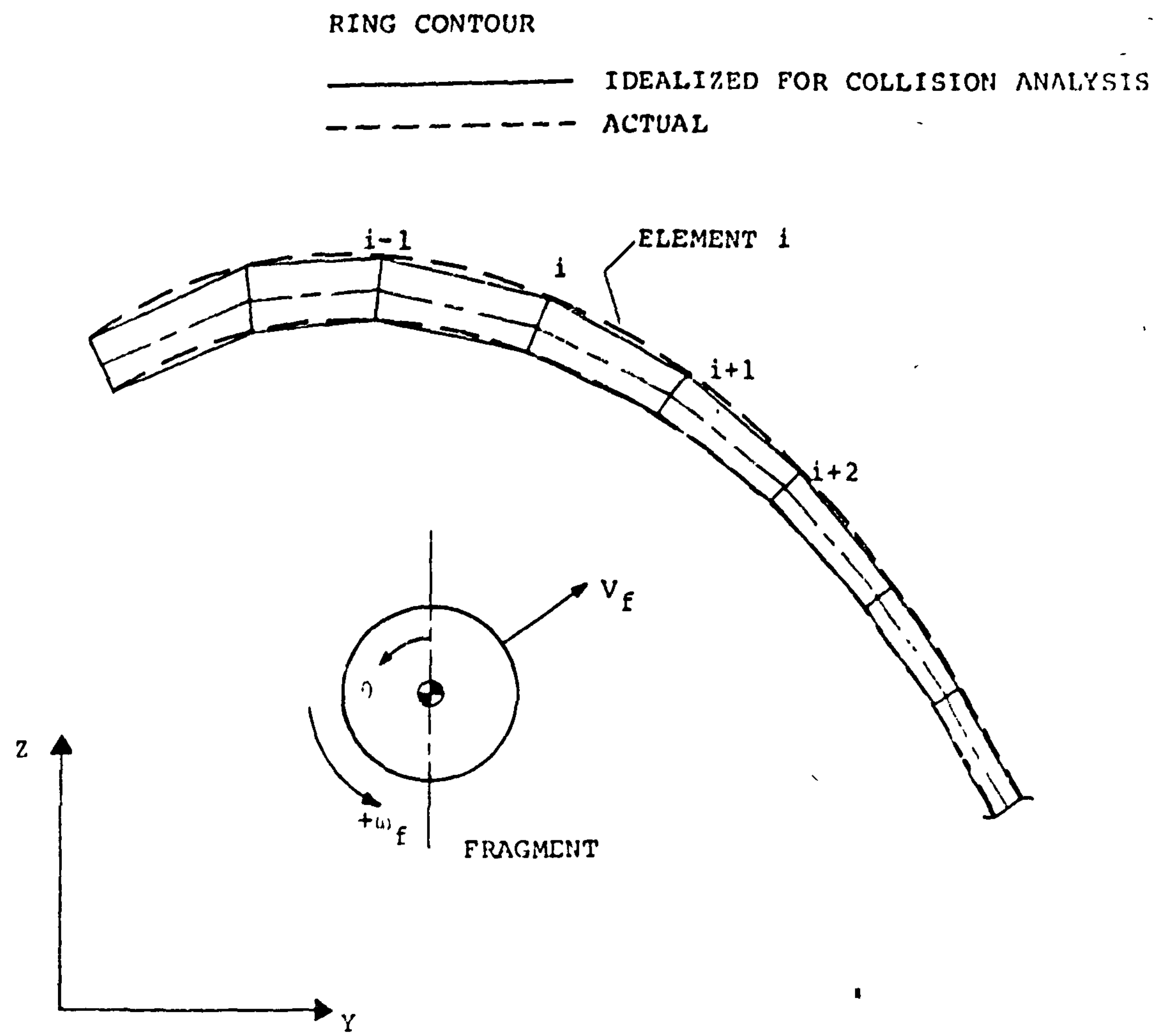


FIG. A.1 IDEALIZATION OF RING CONTOUR FOR COLLISION ANALYSIS

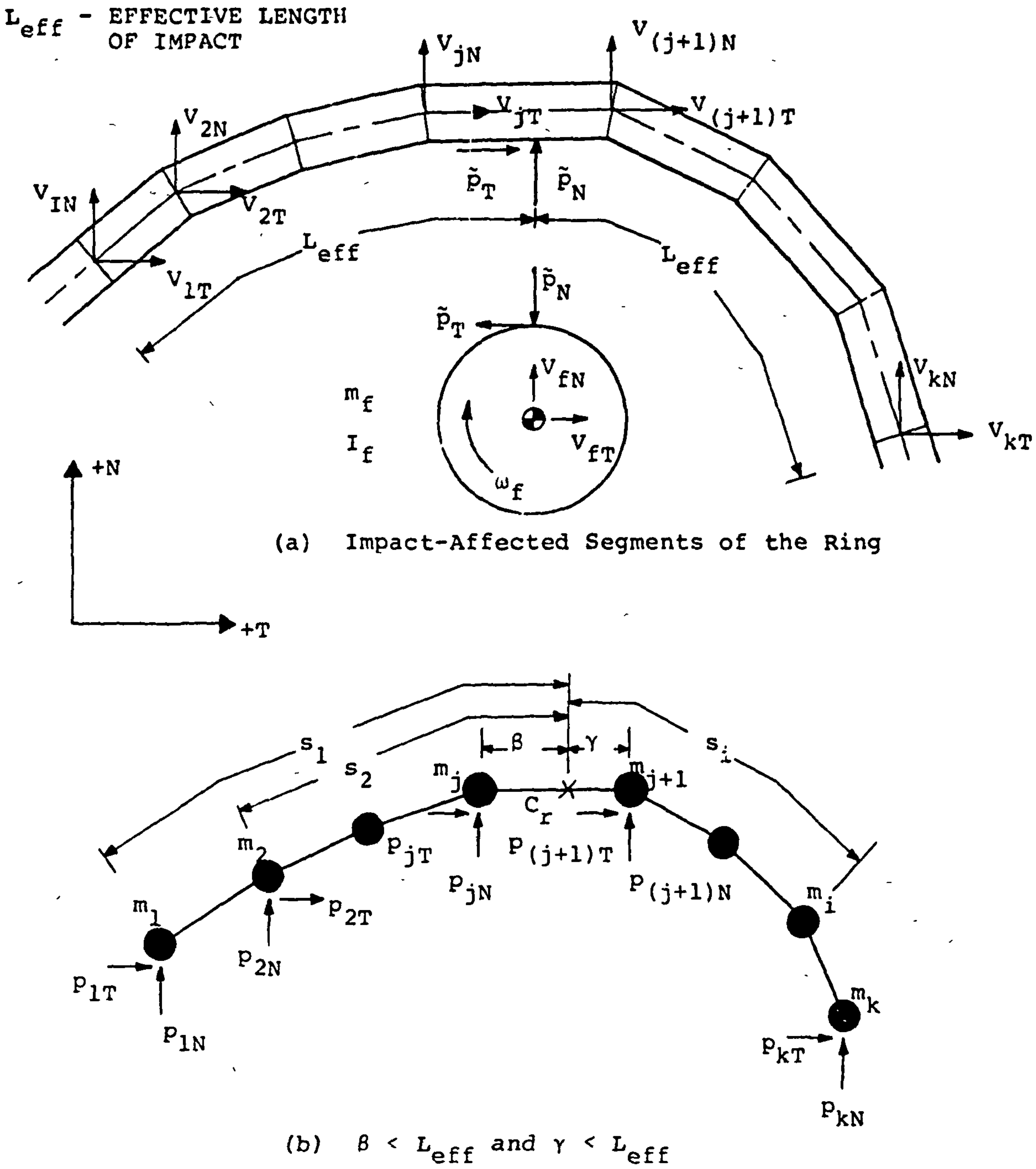
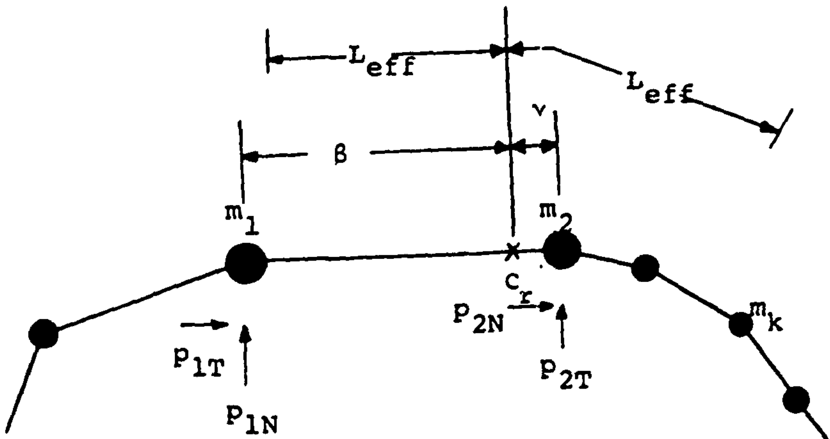


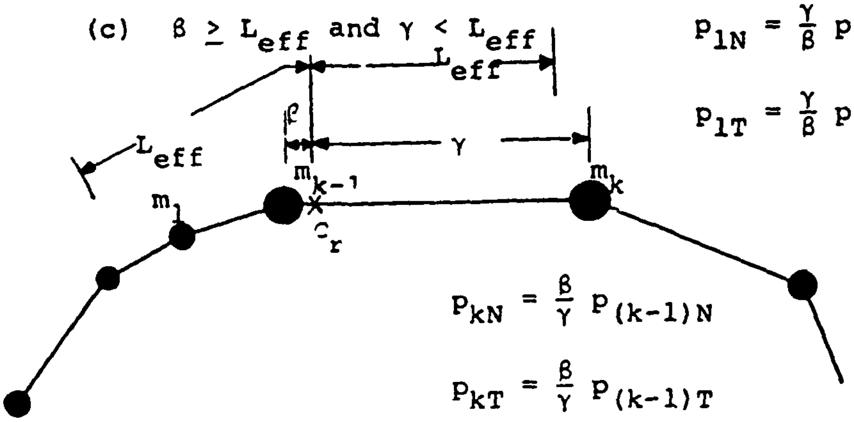
FIG. A.2 EXPLODED SCHEMATICS OF THE LUMPED-MASS COLLISION MODELS



(c) $\beta \geq L_{eff}$ and $\gamma < L_{eff}$

$$p_{1N} = \frac{\gamma}{\beta}\, p_{2N}$$

$$p_{1T} = \frac{\gamma}{\beta}\, p_{2T}$$



$$p_{kN} = \frac{\beta}{\gamma}\, p_{(k-1)N}$$

$$p_{kT} = \frac{\beta}{\gamma}\, p_{(k-1)T}$$

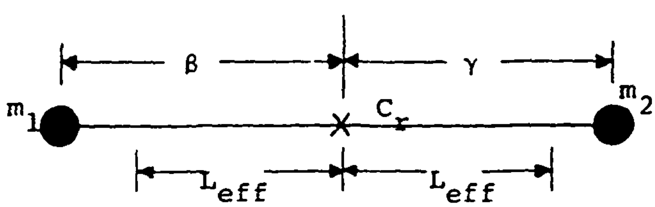
(d) $\beta < L_{eff}$ and $\gamma \geq L_{eff}$

$$p_{1N} = \frac{\gamma}{\beta+\gamma}\, \tilde{p}_N$$

$$p_{1T} = \frac{\gamma}{\beta+\gamma}\, \tilde{p}_T$$

$$p_{2N} = \frac{\beta}{\beta+\gamma}\, \tilde{p}_N$$

$$p_{2T} = \frac{\beta}{\beta+\gamma}\, \tilde{p}_T$$



(e) $\beta \geq L_{eff}$ and $\gamma \geq L_{eff}$

FIG. A.2 CONCLUDED

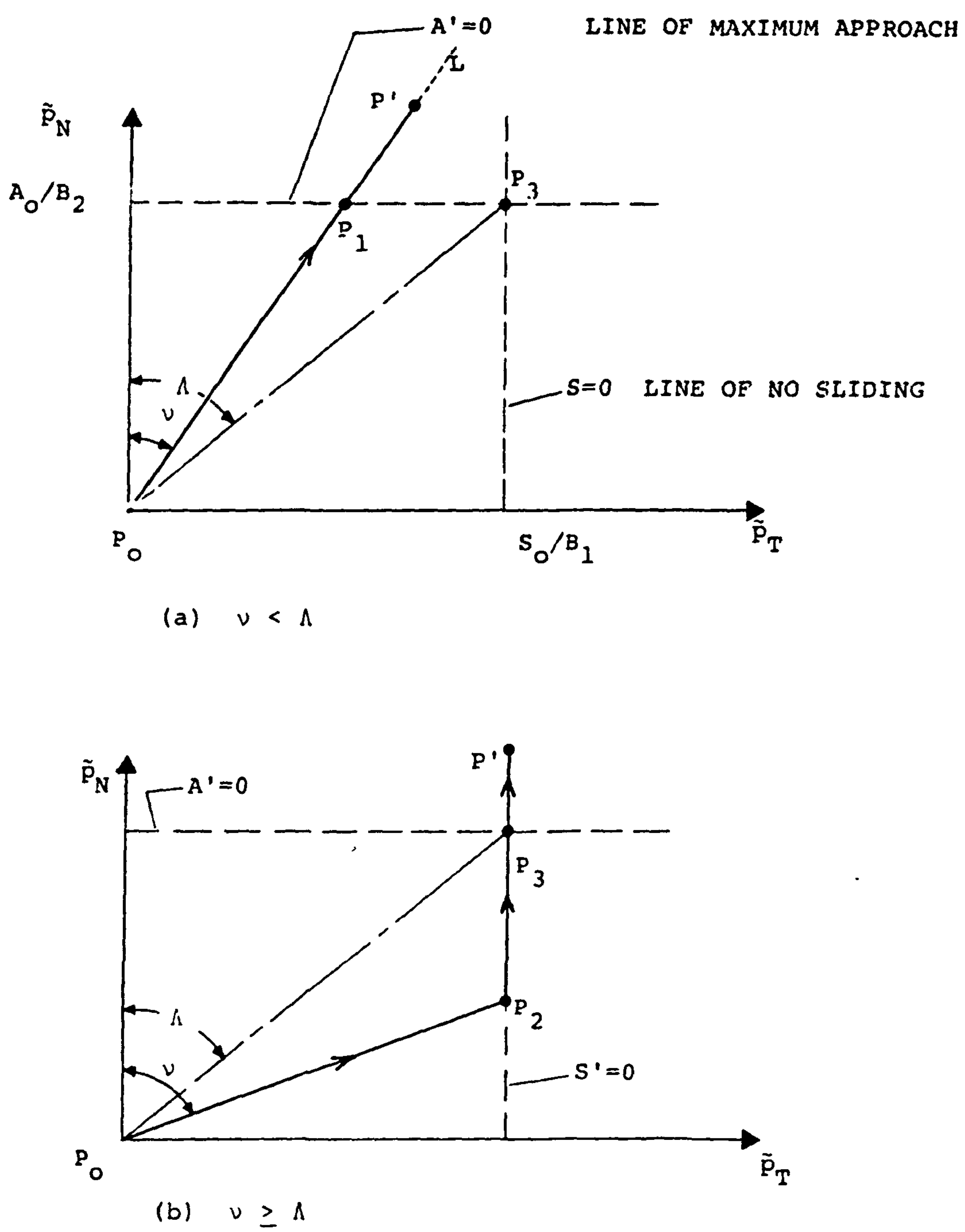


FIG. A.3 THE TRAJECTORY OF THE IMAGE POINT $\bar{P}$ IN THE $\tilde{p}_N$, $\tilde{p}_T$ PLANE TO DESCRIBE THE STATE AT EACH CONTACT INSTANT

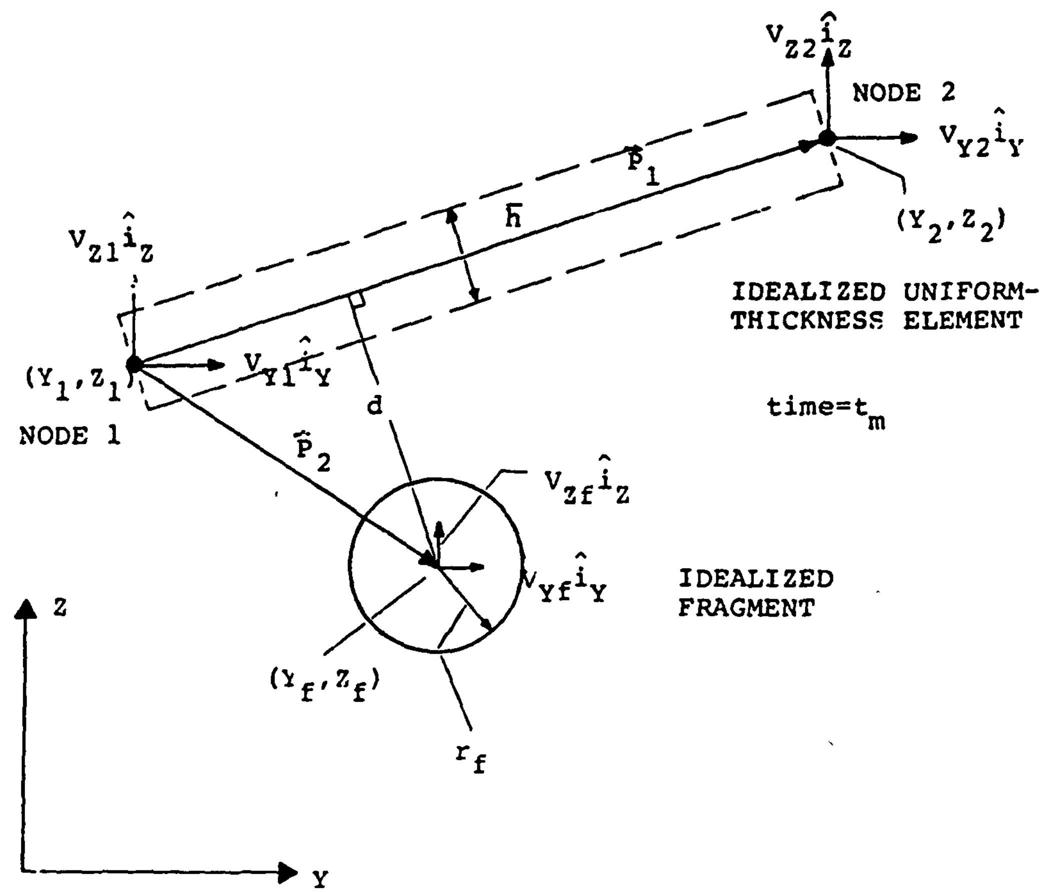


FIG. A.4 IDEALIZATIONS AND DEFINITIONS FOR CALCULATION OF TIME OF RING-FRAGMENT CONTACT

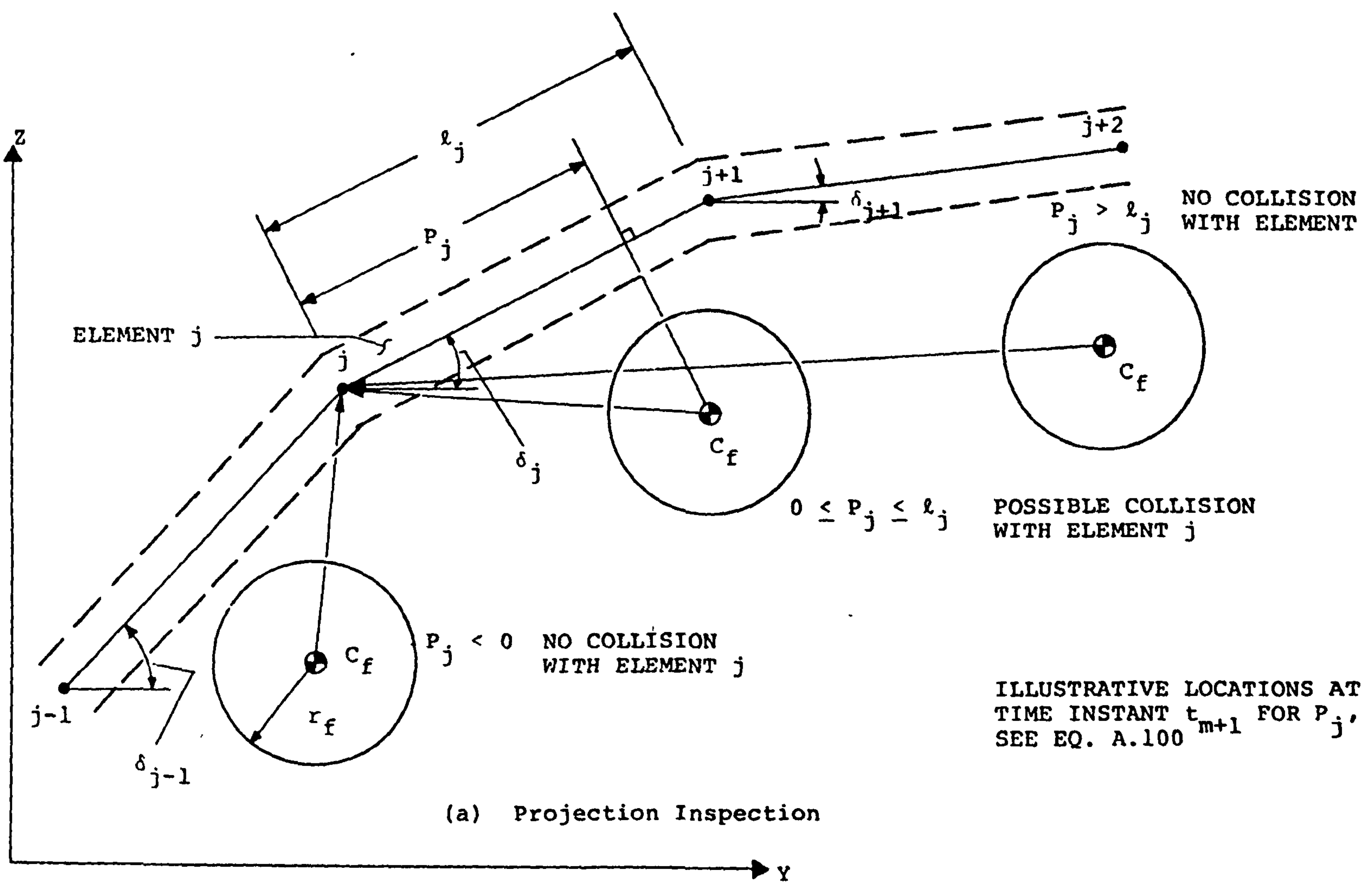
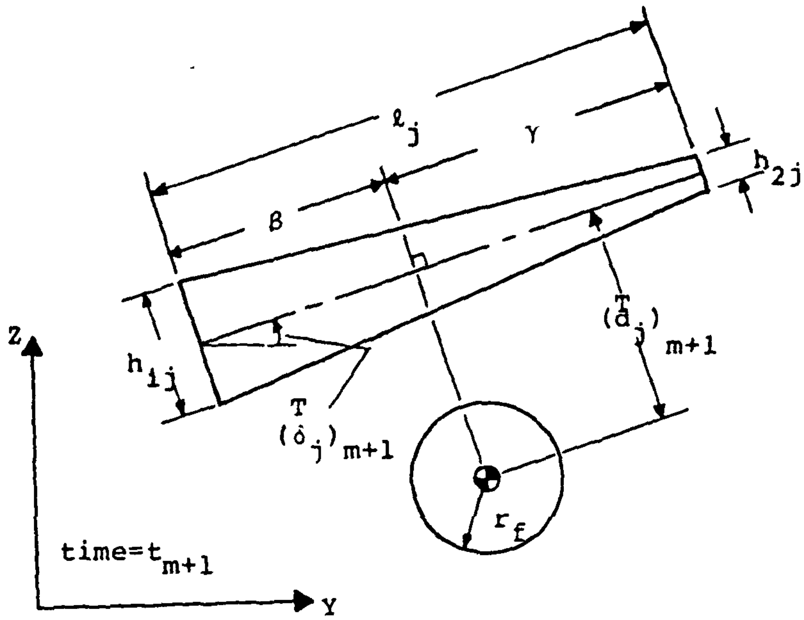
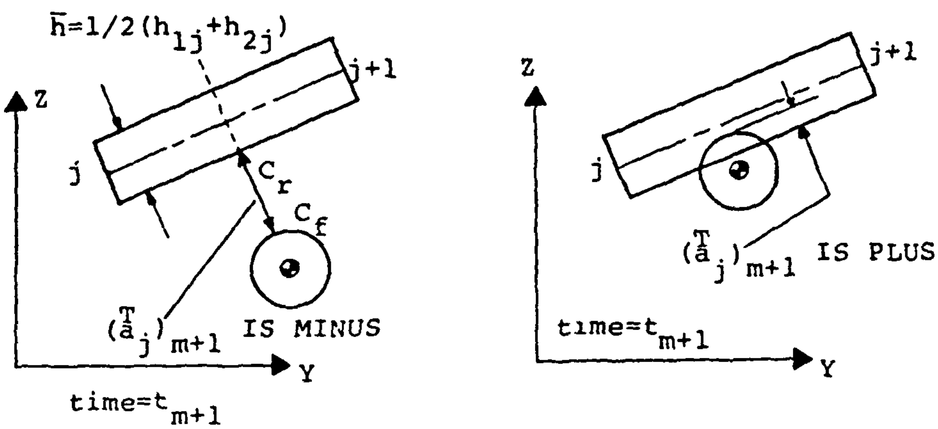


FIG. A.5 INSPECTION FOR DETERMINING A COLLISION OF THE FRAGMENT WITH THE RING



IDEALIZED UNIFORM-THICKNESS ELEMENT



(b) Penetration Inspection

FIG. A.5 CONCLUDED