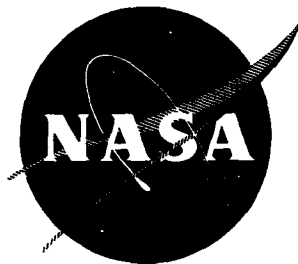


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**FINITE-ELEMENT NONLINEAR TRANSIENT RESPONSE
COMPUTER PROGRAMS PLATE 1 AND CIVM-PLATE 1
FOR THE ANALYSIS OF PANELS SUBJECTED TO
IMPULSE OR IMPACT LOADS**

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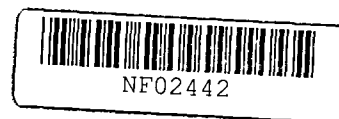
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16 Abstract <p>Described in this report are two computer programs for predicting the transient large-deflection elastic-viscoplastic responses of thin single-layer initially-flat unstiffened or integrally-stiffened Kirchhoff-Love ductile-metal panels. The PLATE 1 program pertains to structural responses produced by prescribed externally-applied transient loading or prescribed initial-velocity distributions. The CIVM-PLATE 1 program concerns structural responses produced by impact of an idealized nondeformable fragment. Finite elements are used to represent the structure in both programs. Strain-hardening and strain-rate effects of initially-isotropic material are taken into account.</p> <p>An appropriate analysis involving impulse-momentum relations is used to predict the after-impact velocity components of the fragment and of the impact-affected region of the panel from each impact; the procedure is termed the collision-imparted velocity method (CIVM). Local fragment-panel impact may be treated as perfectly-elastic, perfectly-plastic, or intermediate between these two extremes. Also, the effects of friction between the fragment and the impacted panel are taken into account. The imparted-velocity information is used in conjunction with a finite-element structural response code to predict the resulting transient structural response in small increments Δt in time. Similarly, the equations of motion for the fragment are solved in small steps in time.</p> <p>Illustrative examples for both PLATE 1 and CIVM-PLATE 1 are described, input data are shown, and example solution data are given to enable the user to check the adaptation of these computer programs to his particular computing facilities.</p>			
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FOREWORD

This research was carried out by the Aeroelastic and Structures Research Laboratory, Department of Aeronautics and Astronautics, Massachusetts Institute of Technology, Cambridge, Massachusetts under NASA Grant No. NGR 22-009-339 from the Lewis Research Center, National Aeronautics and Space Administration, Cleveland, Ohio as a part of the NASA Rotor Burst Protection Program. The work described herein was carried out over several years, and was monitored by Arthur G. Holms, Solomon Weiss, and Christos C. Chamis of NASA-LeRC. The valuable advice and guidance from these individuals is acknowledged most gratefully.

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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 are two computer programs for predicting the transient large-deflection elastic-viscoplastic responses of thin single-layer initially-flat unstiffened or integrally-stiffened Kirchhoff-Love ductile-metal panels. The PLATE 1 program pertains to structural responses produced by prescribed externally-applied transient loading or prescribed initial-velocity distributions. The CIVM-PLATE 1 program concerns structural responses produced by impact of an idealized nondeformable fragment. Finite elements are used to represent the structure in both programs. Strain-hardening and strain-rate effects of initially-isotropic material are taken into account.

An approximate analysis involving impulse-momentum relations is used to predict the after-impact velocity components of the fragment and of the impact-affected region of the panel from each impact; the procedure is termed the collision-imparted velocity method (CIVM). Local fragment-panel impact may be treated as perfectly-elastic, perfectly-plastic, or intermediate between these two extremes. Also, the effects of friction between the fragment and the impacted panel are taken into account. The imparted-velocity information is used in conjunction with a finite-element structural response code to predict the resulting transient structural response in small increments Δt in time. Similarly, the equations of motion for the fragment are solved in small steps in time.

Illustrative examples for both PLATE 1 and CIVM-PLATE 1 are described, input data are shown, and example solution data are given to enable the user to check the adaptation of these computer programs to his particular computing facilities.

SECTION 1

INTRODUCTION

The PLATE and CIVM-PLATE computer programs are the first of a proposed series of codes which are intended to be made available to the aircraft industry for possible use in analyzing three-dimensional (3-d) structural response problems such as initially-flat plates subjected to prescribed initial velocity distributions and/or external forcing functions, or subjected to impact by an idealized rigid fragment. In particular, the CIVM-PLATE code may be used for the analysis of containment/deflection structures intended to cope with engine rotor-burst fragments. This computer program may also be applicable to crash-worthiness problems which are of interest to the automobile and nuclear power plant industries.

The computer programs, written in FORTRAN IV, permit one to analyze the large, three-dimensional, elastic-plastic responses of longeron-stiffened or unstiffened initially-flat single-layer thin plates. In actuality, elastic-viscoplastic behavior is treated in this report since strain-rate effects are taken into account; hereafter in this report, this behavior is termed simply elastic-plastic for convenience. The PLATE code is designed to predict the response of plates subjected to prescribed initial velocity distributions and/or prescribed externally-applied forces. The CIVM-PLATE code is designed to predict the response of plates subjected to impact by a single idealized rigid spherical fragment. The plate may be subjected to a variety of restraint conditions, and linear-elastic line restoring springs may be specified. The plate element used in these programs is restricted to a rectangular planform; hence, the geometrical shape of the plate is restricted to a planform which can be modeled by rectangular elements. The material behavior may be elastic strain-hardening, and/or strain-rate sensitive.

The assumed-displacement finite-element model is used to obtain the spatial properties of the plate, and the temporal solution is accomplished by using the Houbolt finite-difference operator. For predicting the transient responses of plates to rigid-fragment impact (CIVM-PLATE code), 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

plate segments. The presence of fragment/plate surface friction is taken into account. The collision-imparted-velocity method (CIVM) was originally developed for use in the CIVM-JET series of codes [1, 2, 3, 4]* for the analysis of 2-d ring structures subjected to fragment impact; the CIVM approach has been extended to 3-d impact analyses for the CIVM-PLATE code. The pertinent analytical development and the solution methods upon which the PLATE and CIVM-PLATE codes** are based are presented in Appendices A and B, respectively.

Section 2 contains a general description of the organization and capabilities of the PLATE and CIVM-PLATE codes including (1) plate geometry, supports, elastic restraints, and material properties, (2) external loading options and solution procedure for the PLATE code, and (3) fragment/plate collision interaction analysis and solution procedure used for the CIVM-PLATE code. Section 3 contains a description of the main program and subprograms associated with the PLATE and CIVM-PLATE codes, and a description of the flow/usage of these subprograms. The input data, user-prepared subprograms, and output information for the PLATE and CIVM-PLATE codes are presented in Sections 4 and 5, respectively. A complete FORTRAN IV listing of the two codes is given in Section 6. Illustrative examples, including input data and the resulting solution data, using the PLATE and CIVM-PLATE codes are given in Sections 7 and 8, respectively. Finally, Appendices A and B summarize the equations on which these programs are based.

* Numbers in square brackets [] denote references included in the reference list.

** Throughout this report, the terms PLATE and CIVM-PLATE are used for simplicity rather than their correct names PLATE 1 and CIVM-PLATE 1; these codes accommodate large deflections and elastic-inelastic material behavior but various implementation features restrict their applicabilities to small strain. Later, finite-strain versions called PLATE 2 and CIVM-PLATE 2 will be prepared and released.

SECTION 2

GENERAL DESCRIPTION OF THE PLATE AND CIVM-PLATE PROGRAMS

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

The present subsection is devoted to a general description of the capabilities of the PLATE and the CIVM-PLATE program including (1) geometry, (2) supports, (3) elastic restraints, and (4) material properties. It is important to note that the capabilities of the PLATE and CIVM-PLATE programs are identical with respect to these categories. Thus, the present discussion will be restricted to the PLATE code; any differences between the two codes will be noted. Discussions of those features of PLATE and CIVM-PLATE which differ (i.e., solution procedure and external loading) are given in Subsections 2.2 through 2.5.

The PLATE computer code treats single layer unstiffened or longeron-stiffened initially-flat plates of uniform thickness. The Kirchhoff hypothesis is employed; that is transverse shear deformation is neglected. Thus, the total thickness of the plate should be small compared with the spanwise dimensions of the plate. A global XYZ rectangular Cartesian coordinate system with associated unit vectors \hat{i} , \hat{j} , \hat{k} is employed. The initially-flat plate is assumed to lie in a plane which is parallel to the global XY plane. The unit outward-normal vector of the plate, \hat{n} , is defined by the right-hand rule as $\hat{n} = \hat{i} \times \hat{j}$; the unit-outward normal direction of the plate is thus in the direction of the positive z axis, and is automatically chosen once the directions of the unit vectors \hat{i} and \hat{j} (in the global X and Y directions, respectively) have been chosen. The choice of the positive direction for the unit vector \hat{i} and \hat{j} also serves to define the "inner" and "outer" surfaces of the plate; the positive outward-normal of the plate is directed toward the "outer" surface of the plate. For analyses using the CIVM-PLATE code, the positive outward normal direction must be chosen such that fragment impact can occur only on the "inner" surface of the plate (see Fig. 1).

In the spatial finite-element analysis, the plate is represented by an assemblage of discrete (or finite) elements compatibly joined at the nodal stations. For the present codes, the plate elements are restricted to rectangular planform and uniform thickness; the geometry and nomenclature of the present four-noded rectangular plate elements are shown in Fig. 2, where a local (element) xyz coordinate system has been adopted such that the sides of the element are parallel to the x or y axis, the origin of the local xyz system ($z=0$) is located at the geometric midsurface of the plate. The plate structure may contain void regions (cutouts), but in all cases (whether or not cutouts are present) the plate structure must be modeled by a series of rectangular elements. This restriction limits the types of plate structures which can be analyzed using the present programs; in subsequent versions of the present codes, this restriction could be relaxed by adopting a more general planform for the basic plate element.

The behavior of each finite element is characterized by a knowledge of the six generalized displacements: $u, v, w, \theta = \partial w / \partial x, \psi = \partial w / \partial y,$ and $\chi = \partial^2 w / \partial x \partial y$ at each of its four (corner) nodal stations where $u, v,$ and w are the translational displacements of the reference surface in the $x, y,$ and z directions, respectively. The displacement behavior within each finite-element is represented by a bilinear interpolation in x and y for the inplane displacements u and v and a bicubic interpolation in x and y for the transverse displacement $w,$ anchored to the generalized nodal displacements at each node (see Appendix A for further details). The geometry of each finite-element is completely defined by the side length dimensions and the thickness of the element, which is assumed to be constant.

The present analysis may be applied to integrally-stiffened flat plates. The stiffeners must be oriented in the global X and/or Y direction, are assumed to be of constant cross section over each element, and must begin and terminate only at an element boundary (i.e., each stiffener must completely span one or more rectangular plate element in the finite-element mesh). The geometry and nomenclature for a typical stiffened plate element are given in Fig. 3. In this illustration, the stiffener is located along the inner surface of the plate element and is oriented in the Y direction; however, note that stiffeners may also be located on the outer surface of the plate and may also be oriented in the X direction.

The formulation of the spatial properties for the X and/or Y direction stiffeners follows the formulation used in Ref. 5 in which each stiffener is treated as a discrete structural component, with behavior similar to that of a beam element. The following assumptions have been made concerning the geometry and deformation behavior of the stiffeners:

- (1) In general, the stiffeners may be of material different from that of the plate to which it is attached; however, perfect bonding is assumed at the stiffener/plate interface. Thus, displacements are assumed to be continuous across the interfaces.
- (2) The stiffeners are characterized as being thin; that is, a typical cross-sectional dimension of the stiffener is small compared with a typical spanwise dimension of the plate, and exhibit Bernoulli-Euler behavior.
- (3) The contributions of twisting strain of the stiffener about its axial direction and bending strain of the stiffener in the plane parallel to the plate midsurface have been neglected. Only the normal strain of the stiffener in its axial direction is taken into account.

Within this framework and by considering the compatibility of displacements at the stiffener/plate interface, the displacement behavior of the stiffener can be related to the generalized degrees of freedom at the nodes of the plate element to which it is attached by employing the displacement interpolation assumption of the plate. The spatial properties of the stiffener are thus defined by a knowledge of the material properties and cross-sectional dimensions of the stiffener, and the relative location and orientation of the stiffener on the plate element. The reader is invited to consult Appendix A for further details on the formulation of stiffener spatial properties.

Two types of support conditions for the structure are included in the present programs: prescribed nodal displacement conditions and line elastic restraints. The following six prescribed displacement boundary condition options have been included (see Fig. 4a):

Constrained Degrees of Freedom

<u>Boundary Condition</u>	<u>along side Y = constant</u>	<u>along side X = constant</u>
Free	None	none
Symmetry	$v=\psi=\chi=0$	$u=\theta=\chi=0$
Ideally Clamped	$u=v=w=\theta=\psi=\chi=0$	$u=v=w=\theta=\psi=\chi=0$
Pinned-Fixed	$u=v=w=\theta=\chi=0$	$u=v=w=\psi=\chi=0$
Pinned, Free-Sliding z-direction	$u=v=\theta=\chi=0$	$u=v=\psi=\chi=0$
Pinned, Free-Sliding (inplane) normal	$u=w=\theta=\chi=0$	$v=w=\psi=\chi=0$

Elastic restraints are provided in the form of linear elastic line translation and torsional restoring springs which can be specified along any element boundary or interelement boundary. Five spring constants (three translational and two rotational) may be specified for each element boundary on which line restoring springs are present (see Fig. 4b). A global effective stiffness matrix supplied by the linear-elastic line restoring springs is evaluated, and derived from the virtual-work statement.

For the present programs, the plate structure and the stiffeners can be of different elastic, or elastic, perfectly-plastic, or elastic-strain-hardening behavior. A maximum of five different material types may be specified by the user to define the behavior of the stiffeners if different from that of the plate. The strain-rate effects of each material can also be taken into account. In the present analysis, the strain-hardening material is accounted for by using the "mechanical sublayer model" [6,7];* see Figs. A.1a-A.1c. A useful feature of this model is its accounting for nonlinear strain hardening, anisotropic strain hardening, the formation of corners on the yield surface, and the Bauschinger effect -- all of these are features that ductile metals exhibit. No other material model appears to represent these features as efficiently and faithfully as does the mechanical-sublayer model. Strain-rate effects are included as described in Subsection A.5.

2.2 External Loading Options in the PLATE Program

The PLATE computer program is designed to predict the large, elastic plastic deformation responses of stiffened or unstiffened flat plates subjected

* Also, see Subsections 3.3.3 and 3.3.4 of Ref. 14, as well as Refs. 5 and 11.

to either a prescribed initial velocity distribution or a prescribed externally-applied, time-varying force distribution. In the present finite-element scheme, initial velocity distributions are input as a vector of nodal velocities, at time $t=0$, corresponding to the generalized nodal degrees of freedom in the finite-element mesh. Prescribed externally-applied force distributions are input as a vector of nodal forces corresponding to the generalized nodal degrees of freedom in the finite-element mesh. In general, the spatial distribution of these forces can vary with time so that this vector of nodal forces must be redefined at each step of the finite-difference temporal solution.

Much of the user interaction required when using the PLATE code is in the form of preparation of input data cards; wherever possible, internal logic has been incorporated into the PLATE code to minimize the amount of user-supplied data. However, for the present plate analysis, it is impractical and computationally inefficient to attempt to provide the user with an all-inclusive set of initial velocity distribution options and prescribed force distributions (in both space and time). As a result, two computer subroutines (INCOND and EXTL) have been isolated as user-interactive subroutines for the generation of the vector of initial nodal generalized velocities and the vector of prescribed externally-applied nodal forces at each time step. The user will be required to write (in FORTRAN IV) the internal logic for these subroutines corresponding to the particular problem being considered. Clearly, some basic knowledge of computer programming and the finite-element method is required to generate these computer subroutines. Guidelines for preparation of these subroutines, including simple example subroutines, are given in Subsection 4.6.

2.3 Solution Procedure for the PLATE Program

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 plate structure which is permitted to undergo large, elastic-plastic, transient deformation. In the interest of conciseness and convenience in this report, the user is invited to consult Ref. 1 and Appendix A for a detailed derivation and discussion of the equation of motion utilized in the PLATE code. For present purposes, it suffices to note that the governing

equations of motion for the complete assembled discretized structure correspond to the conventional formulation of Ref. 1 and are written in the following form:

$$[M] \{\ddot{q}^*\} + [K] \{q^*\} + [K_s] \{q^*\} = \{F\} + \{F^{NL}\} \quad (2.1)$$

where

- $\{q^*\}$ and $\{\ddot{q}^*\}$ are the global generalized displacement vector and acceleration vector, respectively.
- $[M]$ is the mass matrix of the assembled structure.
- $[K]$ is the linear elastic stiffness matrix of the assembled structure.
- $[K_s]$ is the global effective stiffness matrix supplied by the linear-elastic line restoring springs.
- $\{F\}$ is the global generalized load vector corresponding to prescribed externally-applied forces.
- $\{F^{NL}\}$ represent equivalent "generalized loads" arising from both large deflections and plastic strains.

The matrix equations of motion are solved by employing the Houbolt finite-difference operator. In the following, the general solution process is described briefly.

First, information is provided to define the geometry of the plate and the location and geometry of the stiffeners (if any). Material constants for the plate and stiffeners are defined, and information related to the structural discretization is specified. Also defined are the time-step size, Δt , the location and elastic constants of the line restoring springs, and the prescribed displacement boundary conditions. Next, the mass matrix and stiffness matrix for the entire structure are evaluated by assembling the element mass and stiffness matrices. It should be noted that the PLATE program provides the user with the option of selecting either a lumped (diagonal matrix) mass modeling or a consistent (fully populated matrix) mass modeling.

Gaussian quadrature is used to evaluate these element matrices; the quadrature⁺ rule chosen yields an exact integration of these element matrices. Following this step, the global effective stiffness matrix supplied by the linear-elastic line restoring springs is evaluated. Then the proper prescribed displacement conditions are imposed on these assembled mass and stiffness matrices.

Before beginning the timewise solution of the equations of motion, the generalized nodal velocity vector, $\{\dot{q}^*\}_0$, at time t_0 and generalized nodal force vector corresponding to prescribed externally-applied forces $\{F\}_1$, at time t_1 , must be specified. From this information, the generalized nodal displacements and displacement increments are calculated for the first time increment Δt (i.e., from time t_0 to time t_1) from Eq. 2.1 written in the finite-difference form corresponding to the Houbolt operator. From a knowledge of the displacements, displacement increments, and current states of stress and strain, one can determine the strain increments, 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. From this information, one can calculate the equivalent generalized load vector arising from large deflections and plastic strains. Next, the generalized nodal load vector $\{F\}_2$ corresponding to prescribed externally-applied forces at time t_2 is formed. Then, the proper recurrence equations, which is the finite-difference representation of the equations of motion, are solved to obtain the generalized displacements and displacement increments of the next time increment (i.e., at time $t_2 = t_1 + \Delta t$). The process then proceeds cyclically for as many time steps as desired. For present purposes, the above general description is considered to be adequate; one may consult Appendix A for a more detailed discussion of the solution and evaluation process.

In the PLATE code, the user is required to specify the time-step size, Δt , to be used in the temporal solution of the equations of motion of the structure. The proper choice of the time-step size, Δt , requires some knowledge of the characteristics of the Houbolt operator. For linear structural analysis, the Houbolt operator is unconditionally stable; that is, no numerical instabilities will occur regardless of the value of Δt . However, as the time

⁺Numerical integration (quadrature) is employed for these evaluations since it is much more efficient and less likely to produce errors than if an analyst were to carry out and program (lengthy) expressions obtained by analytical evaluations.

step size is increased, the solution will tend to diverge from the "exact" solution because of the presence of false damping and of frequency distortion contributed by the Houbolt operator; this is a problem of "convergence". Usually, it is recommended that successive runs of the same problem be made, each with a time-step size half that of the previous run until the computed results of two successive runs are sufficiently close to each other (i.e., to represent a converged solution). For nonlinear structure analysis, where the effects of nonlinearities are included as equivalent loads (and these equivalent loads are obtained by extrapolation --- (see Appendix A), the Houbolt operator becomes conditionally stable [8,9]; that is, numerical instability will occur if the time-step size, Δt , is too large. At present, no rigorous rules exist for determining the maximum allowable Δt for nonlinear analysis using the Houbolt operator. Thus, some numerical experimentation may be necessary in order to determine an appropriate value for Δt .

To assist the user in the selection of a value for Δt , a "reference" time-step size is calculated and output by the PLATE computer program. This reference time-step size, $\Delta t_{\max}^{\text{CD}}$, is equal to the maximum time-step size which could be used if the Central Difference timewise operator were employed, and is calculated as $\Delta t_{\max}^{\text{CD}} = 0.8(2/\omega_{\max})$. In this expression, ω_{\max} is the largest natural frequency contained in the (linear) mathematical model of the structure, and $\Delta t \leq 2/\omega_{\max}$ is the stability criterion (for the Central Difference operator) of a corresponding linear dynamic system; the factor 0.8 is introduced, as in Refs. 1 through 3, to account for large-deflection effects. In the PLATE program, the value of ω_{\max} is obtained by an iteration process applied to⁺

$$\omega^2 [M] \{q^*\} = [K] \{q^*\} \quad (2.2)$$

Having obtained the value of $\Delta t_{\max}^{\text{CD}}$, the actual time-step size to be used in the PLATE program can be taken as some multiple of $\Delta t_{\max}^{\text{CD}}$ (i.e., $\Delta t = f \Delta t_{\max}^{\text{CD}}$). Again, no firm rules exist for the selection of the factor f , but results presented in Ref. 1 suggest that values of up to $f = 6$ will yield converged and stable solutions. These results are by no means conclusive, but do provide a reasonable guideline for the initial choice of Δt . To ensure

⁺The inverse power method is employed to find ω_{\max} .

convergence and/or to eliminate instabilities, subsequent computer runs can be made using a value of Δt half that of the previous run.

2.4 Fragment/Plate Collision Interaction Analysis for the CIVM-PLATE Program

The CIVM-PLATE computer program is designed to predict the large-deflection, elastic-plastic, transient responses of initially-flat stiffened or unstiffened plates subjected to impact by a single fragment. For analyzing the collision-induced transient responses of containment and/or deflector plates and fragment motions, the fragment is idealized as a non-deformable fragment of spherical configuration (Fig. 5). The modeled-fragment radius, 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), previously developed for the 2-d ring/fragment collision interaction analysis of Refs. 1 through 4, has been extended for the present 3-d collision-interaction analysis. In this procedure, 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 plate. 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 plate. The impact-affected zone is defined as the fraction of the plate that responds to fragment impact instantaneously with momentum changes. The size of the impact affected zone is estimated from the speed of a longitudinal elastic wave in the material and the computational time increment size Δt , or from alternate means (see Appendix B).
- (2) In an overall sense, the fragment is treated as being rigid, but at the "immediate contact region" between the fragment and the impacted plate the collision 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 plate 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 tangential directions.
- (4) Although fragment/plate collision will, in general, occur during a time step, Δt (rather than at the beginning or end of a time cycle), the impact-induced velocity changes of the fragment and the impact-affected zone of the plate are imposed at the beginning of the cycle in which the collision occurs. This assumption eliminates the need to extrapolate displacement and velocity data between time steps.
- (5) For the purpose of calculating the impact-induced velocity changes of the fragment and the impact-affected zone of the plate, the contact forces are the only ones considered to act on the impact-affected zone of the plate and in an anti-parallel fashion on the fragment. Any internal forces which the plate segments adjacent to the impact-affected zone may exert on that zone 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". However, these internal forces are included in the calculation of the post-impact displacement of the plate.
- (6) To avoid unduly complicating the analysis and to maintain program efficiency, each rectangular plate element is divided into two triangular plate elements in the

derivation of the impact inspections and equations; the global coordinates of the three corners of the triangle define the plane in which collision may occur (see Fig. 6). However, for transient response predictions, the plate continues to be modeled as a series of rectangular elements, and general 3-d plate deformation behavior is assumed.

- (7) For the analysis of stiffened plates, only the geometry of the plate elements is considered in the impact inspection procedure. If impact occurs at a location on the plate occupied by a stiffener, the impact is still considered to occur at the inner surface of the plate. However, stiffener mass contributions have been included in the calculation of the post-impact velocity changes of the fragment and impact-affected zone of the plate. Thus, the subsequent motion of the plate and fragment is affected by the presence of stiffeners.
- (8) To minimize the special options in impact inspection, all impacts must occur at the inner surface of the plate.

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 plate are predicted and the (tentative) region of space occupied by each body at the end of a given time cycle 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 in time at which the body locations were known (beginning of the present time cycle) to the present instant in time at which the body-location data are sought. A collision is determined to have occurred if the (tentative) regions

of space occupied by the plate and the fragment overlap. 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 a collision-interaction calculation.

3. 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_{fx} , v_{fy} , v_{fz} (translational) and ω_{fx} , ω_{fy} , ω_{fz} (rotational) of the fragment and (b) the nodal velocities of the plate impact-affected elements. These velocity changes are imposed at the beginning of the present time cycle in which impact was determined to have occurred. Steps 1 and 2 are then repeated for the present time cycle until no plate/fragment overlap is found at the end of the present time cycle; the resulting plate and fragment locations are then the corrected-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 B.

2.5 Solution Procedure for the CIVM-PLATE Program

The global solution procedure employed in the CIVM-PLATE computer program is essentially the same as that employed in the PLATE computer program except that initial velocity distributions and prescribed, externally-applied forces are not included in the CIVM-PLATE program; these loading options are "replaced" by the collision inspection-interaction analysis. The governing equation of motion for the complete assembled discretized plate structure is thus obtained by dropping the external nodal loading vector from Eq. 2.1 and is given by

$$[M] \{\ddot{q}^*\} + [K] \{q^*\} + [K_g] \{q^*\} = \{F^{NL}\} \quad (2.3)$$

where the definition of the terms in Eq. 2.3 are the same as those given in Subsection 2.3.

In the present procedure, a diagonal "lumped" mass matrix is employed;

the use of a consistent (fully populated) mass matrix is not permitted in the CIVM-PLATE program. Lumped mass modeling is chosen as a consequence of the present collision-interaction analysis in which the element (and structure) mass properties are assumed to be lumped at the nodal points. Thus, for consistency, the mass properties of the plate structure used in the global time-wise solution procedure should also be nodal lumped masses; the use of a consistent mass modeling in the global timewise solution would result in an energy mismatch following each impact. In addition, the use of a lumped mass matrix results in a decrease of the highest natural frequency for the assembled structure, compared with the use of a consistent mass matrix, and thus permits one to use a larger time step, Δt , for the structural response calculations (see discussion in Subsection 2.3). 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 matrix computationally efficient.

The equations of motion are solved through the use of the Houbolt finite-difference operator whereby one obtains a recurrence equation which provides a solution step-by-step in finite time increments. The discussion of the stability of the Houbolt operator given in Subsection 2.3 also applies to the present impact analysis. However, as will be discussed in Appendix B, this operator must be modified for time cycles in which plate/fragment collision occurs. Experience to date with the CIVM-PLATE program suggest that this modified operator is less stable than the conventional Houbolt operator, and thus smaller time steps, Δt , must be used. Because (diagonalized) lumped masses are used in all runs of the CIVM-PLATE program, the reference time step size, $\Delta t_{\max}^{\text{CD}}$, discussed in Subsection 2.3 is calculated and output for each execution of the program. It is recommended that a value of $\Delta t = 2 * \Delta t_{\max}^{\text{CD}}$ be specified on the initial run of a containment/deflector analysis. A more detailed discussion of this modified operator is given in Appendix B.

The general solution process employed in the CIVM-PLATE program is essentially identical to that employed in the PLATE program in terms of input of geometric, mesh, and boundary condition information, and generation of the assembled-structure mass (lumped mass modeling only) and stiffness matrices.

Additional input is required for the CIVM-PLATE program to define the initial location and velocity components, geometry, and collision parameters of the attacking fragment. In the following, the general timewise solution process (which differs somewhat from that used in the PLATE program) is described briefly.

The plate structure is assumed to be at rest at time t_0 , and the position and velocity of the attacking fragment are known at time t_0 . From this information the generalized nodal and fragment displacements and displacement increments are computed for the first time increment, Δt . Then the fragment-plate collision inspection-and-correction procedure is carried out. If one, or more, fragment-plate collisions have occurred during this Δt , the coordinates which locate the position of the fragment and the impact-affected nodes of the plate are thereby corrected from their tentative uncorrected-for-impact locations. Next, the strain increment developed from t_0 to t_1 at every Gaussian station (or point) required over and depthwise through each finite element are calculated. From a knowledge of the previous states of stress and strain, and the strain increments, one can determine the stress increments, the stresses, and/or the plastic strains and 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 plate-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 the fragment. This process then proceeds cyclically for as many time steps as desired. It should be noted that the plate structure remains at rest until the first plate-fragment collision occurs.

For present purposes, the above general description is considered to be adequate; one may consult Appendix B for a more detailed discussion of the solution and evaluation process, including flow charts.

⁺The mechanical-sublayer material model is particularly convenient and efficient for these evaluations; see Figs. A.1a through A.1c.

SECTION 3

DESCRIPTION OF PROGRAMS AND SUBPROGRAMS

3.1 Organization of the PLATE and CIVM-PLATE Programs

The PLATE and CIVM-PLATE computer program package consists of two dummy main programs (one each for PLATE and CIVM-PLATE) and 34 subprograms. Of these 34 subprograms, 5 are used exclusively in the PLATE program, 8 are used exclusively in the CIVM-PLATE program, and the remaining 21 are used by both the PLATE and CIVM-PLATE programs.

The dummy main program and subroutines used exclusively in the PLATE program are

CMASSP	INCOND	MAINP
EXTL	MAIN	PRINT

The dummy main program and subroutines unique to the CIVM-PLATE program are

COLLSN	IMAINP	IMPSS
IFRAG	IMPACT	INTRAC
IMAIN	IMPDS	IPRINT

The 21 subroutines used by both the PLATE and CIVM-PLATE programs are

ARRT	FACT	MESHPM	RCON	SPRING
ASSEMK	GAUSS	OMULT	RPLATE	STRESA
BCONMK	LMASSP	PRTOP	SFDM	STRESC
EAROW	MESHPA	PSTRN	SOLV	STRESP
				TSTEP

A description of these main and subprograms including the definitions of calling arguments for each subprogram is given in Subsection 3.2.

The PLATE program consists, therefore, of a dummy main program (MAIN) and 26 subroutines. The dummy main program has been included only to define array

dimensions which are problem dependent, and to input those parameters used in the dimensioning process. MAIN then calls subroutine MAINP which is the master subroutine which controls the flow of the transient nonlinear analysis. The flow of subroutine MAINP with particular emphasis on subroutine usage is shown in Fig. 8. The information provided in Fig. 8 together with the description of subroutines given in Subsection 3.2 and the theoretical developments given in Appendix A, is intended to provide the user with a better understanding of the operation and execution of the PLATE program.

The CIVM-PLATE program consists of a dummy main program (IMAIN) and 29 subroutines. The dummy main program has been provided only to define array dimensions which are problem dependent, and to input those parameters used in the dimensioning process. IMAIN then calls subroutine IMAINP which controls the flow of the impact-induced transient nonlinear analysis. The flow of subroutine IMAINP with particular emphasis on subroutine usage is shown in Fig. 9. The information provided in Fig. 9, together with the description of subroutines given in Subsection 3.2 and theoretical developments given in Appendix B, is intended to provide the user with a better understanding of the operation and execution of the CIVM-PLATE program.

3.2 Program and Subprogram Descriptions

In this subsection, each of the programs/subprograms used in the PLATE and CIVM-PLATE computer codes is described. The programs/subprograms are grouped (and presented alphabetically) according to those used only in the PLATE code, those used only in the CIVM-PLATE code, and those common to both codes. In each case, the subroutine names and argument list (as it appears in that subroutine) are given; each of the subroutine arguments is defined and a description of the overall operation of the subroutine is given.

No attempt is made to describe the programming logic or to describe each programming step of each subroutine. Information of this form could be generated by a user facility by a careful comparison of programming logic and associated theory presented in Appendices A and B, as well as various programming conventions discussed throughout this report. Such a detailed understanding of the PLATE and/or CIVM-PLATE codes would facilitate modifications and/or additions to the codes, but is not necessary for effective use of the codes.

3.2.1 Main Program and Subroutines Unique to the PLATE Program

In the following, the main program and subroutines used only in the PLATE program are discussed.

SUBROUTINE CMASSP(NTYPE, XL, YL, TH, XF, SLOC, CSA, SMOI, EM, GBI, DENS)

Purpose: This subroutine computes the consistent mass matrix for a rectangular plate element, x-direction stiffener element, or y-direction stiffener element. The formation corresponds to Eqs. A.28 and A.29 (for plate elements), Eq. A.91 for x-direction stiffeners, and Eq. A.91b for y-direction stiffeners; see Figs. 10-14. Gaussian quadrature is used to compute the required integral.

Arguments:

NTYPE : Type of element
= 1 for plate element
= 2 for x-direction stiffener
= 3 for y-direction stiffener

XL : The x-direction length of the element

YL : The y-direction length of the element

TH : The plate element thickness

XF : The stiffener offset distance (see Fig. 12)

SLOC : The location of the stiffener on its corresponding element
(see Fig. 13)

CSA : The stiffener cross-sectional area

SMOI : The mass moment of inertia of the stiffener

EM(24,24) : The mass matrix of the element

GBI(24,24) : The matrix \bar{G}^{-1} given by Eq. A.19

DENS : The initial mass per unit volume of the element

SUBROUTINE EXTL(ELV,ITT,NP,NODE,XGI,YGI)

Purpose: This user-prepared subroutine is used to generate the nodal generalized forces corresponding to prescribed externally-applied forces at time $t_m (= m\Delta t)$ as described in Subsection 4.6.2 and corresponding to the development in Subsection A.1.3.4.

Arguments:

ELV(I) : The user-defined nodal force vector at time $t = ITT * DELTAT$ (where $DELTAT = \Delta t$). ELV(I) is the generalized force corresponding to the Ith generalized degree of freedom.

ITT : The cycle number

NP(I,J) : The global node number associated with the Ith element node of element J.

NODE(K) : The assembly list associating element degrees of freedom with global degrees of freedom. If K is defined as $K = 24 * (J - 1) + I$, then NODE(K) is the global degree of freedom number associated with the Ith degree of freedom of element J.

XGI(I) } The global X and Y coordinates, respectively, of the
YGI(I) } Ith global node at time zero.

SUBROUTINE INCOND(DISP,VEL,NP,NODE,XGI,YGI)

Purpose: This user-prepared subroutine is used to specify the initial (time zero) conditions on the plate nodal displacements and velocities \underline{q}_0^* and $\dot{\underline{q}}_0^*$, respectively, required for the finite-difference solution of the governing equations of motion (see Subsection A.3). Instructions for preparation of this subroutine are given in Subsection 4.6.1.

Arguments:

DISP(I) : The displacement at time zero of the Ith generalized nodal degree of freedom

VEL(I) : The velocity at time zero corresponding to the Ith
generalized nodal degree of freedom

NP(I,J) }
NODE(K) } See SUBROUTINE EXTL
XGI(I) }
YGI(I) }

MAIN

Purpose: The dummy main program of the PLATE computer code. Problem
dependent array dimensions are specified in this dummy main
program and certain of those variables used in this dimensioning
process are input. Guidelines for preparation of the array
dimensions are given in Subsection 4.5

Arguments: None

SUBROUTINE MAINP(DEL D,DIS,DISP,DISM1,DISM2,FLN,FLVA,FLVM,FLVP,ELV,VEL,ICOL,
INUM,KROW,NDEX,STOR,STF,AMASS,NP,NODE,TAUSS,TAUSE,TAUEE,EPSSI,EPSSO,EPEEI,
EPEEO,EPSEI,EPSEO,NBC,BC,RFM,ILAST,UCF1,UCF2,XG,YG,ZG,XGI,YGI,TAGSS,LNXS,XSPROP,
MATXS,TSGEE,LNYS,YSPROP,MATYS,LNRS,ISRS,SC,MAXEL,MNSL,MNSLT4,NBE,MBWE,MNXST,
MNYST,NVSA,NCON)

Purpose: The primary subroutine of the PLATE program. This subroutine
controls the flow of program input, structural response prediction,
and program output.

Arguments:

DEL D(I) } The displacement increment and displacement vectors
DIS(IP) } $\Delta q_{m+1}^* \equiv (q_{m+1}^* - q_m^*), q_{m+1}^*, q_m^*, q_{m-1}^*, q_{m-2}^*$
DISP(I) } respectively (e.g. Eq. A.110). The Ith term in
DISM1(I) } each vector corresponds to the Ith structural degree
DISM2(I) } of freedom.

FLN(I) }
 FLVA(I) }
 FLVM(I) }
 FLVP(I) } Vectors used to accumulate effective nonlinear and
 external nodal forces required to form the right-hand
 side of Eq. A.114 (corresponding to Ith structural
 degree of freedom).
 ELV(I) : See Subroutine EXTL
 VEL(I) : The velocity corresponding to the Ith structural
 degree of freedom
 ICOL(K) }
 INUM(K) }
 KROW(K) } Vectors containing pointers used to locate
 terms in the assembled stiffness matrix which is
 stored in compacted vector form (see Subsection 4.1.5)
 NDEX(K) }
 STOR(K) : Temporary vector in which the current external force
 vector is stored
 STF(J) : Assembled stiffness matrix stored in compacted vector
 form (see Subsection 4.1.5)
 AMASS(J) : The assembled (structure) mass matrix stored either
 in compacted vector form (if consistent mass option is
 used) or as a vector of the diagonal terms (if lumped
 mass is used).
 NP(I,J) }
 NODE(K) } See Subroutine EXTL
 TAUSS(I,J,K) }
 TAUEE(I,J,K) } The stresses σ_{xx} , σ_{yy} , σ_{xy} , respectively at the Jth
 TAUSE(I,J,K) } depthwise/sublayer integration station (J is a function
 of both location and sublayer) at the Kth spanwise
 Gaussian integration station of the Ith plate element
 at the current time.

EPSSI(K,I) } The strains $\tilde{\epsilon}_{xx}$, $\tilde{\epsilon}_{yy}$, and $\tilde{\epsilon}_{xy}$, respectively, at the
 EPEEI(K,I) } Kth Gaussian integration station (K=1,2, ...9)
 EPSEI(K,I) } on the inner surface of the Ith plate element.
 EPSSO(K,I) } As above, at the outer surface of the Ith plate
 EPEEO(K,I) } element
 EPSEO(K,I) }

NBC(J) } A list of the NB constrained degree-of-freedom numbers
 BC(J) } and corresponding constrained values (BC(J) = 0.0 set internally)

RFM(J,K) : Matrix used in the calculation of the reaction forces at constrained nodes, and contains the rows of the assembled stiffness matrix (from the first nonzero term to the last nonzero term in that row) corresponding to each of the constrained degrees of freedom.

ILAST(J) : For row NBC(J) of the assembled stiffness matrix, the column in which the last nonzero term is found.

UCF1(J) } Vectors containing the right-hand side of Eq. A.114
 UCF2(J) } (prior to constraint) corresponding to constrained degree of freedom NBC(J)

XG(I) } The current global (X,Y,Z) coordinates, respectively,
 YG(I) } of structural node I
 ZG(I) }

XGI(I) } See Subroutine EXTL
 YGI(I) }

TAGSS(I,J,K): The normal stress, σ_{xx} , at the Jth depthwise/sublayer integration station at the Kth spanwise Gaussian integration station of the Ith individual X-direction stiffener.

LNXS(I) : The plate element numbers to which the Ith individual X-direction stiffener is attached.

XSPROP(J,I) : Geometric and material properties of the Ith individual X-direction stiffener. See Cards 28-34 (Subsection 4.2) for definition of J = 1,2,3, ... 6.

MATXS(I) : The material type for the Ith individual X-direction stiffener.

TSGEE(I,J,K) : The normal stress, σ_{yy} , at the Jth depthwise/sublayer integration station at the Kth spanwise Gaussian integration station of the Ith individual Y-direction stiffener.

LNYS(I) } Same as above (LNXS,XSPROP,MATXS), now for individual
 YSPROP(J,I) } Y-direction stiffeners.
 MATYS(I) }

LNRS(I) } The plate element number and element side number,
 ISRS(I) } respectively, to which the Ith linear line restoring spring is attached.

SC(K,I) : The given (K = 1,2, ... 5) elastic spring constant ($K_u, K_v, K_w, K_\theta, K_\psi$) corresponding to the Ith line restoring spring.

MAXEL } Problem size and dimensioning variables input by
 MNSL } the user. See Card 1 (Subsection 4.2) for the
 NBE } definition of these parameters.
 MBWE }
 MNXST }
 MNYST }

MNSLT4 : MNSL*4 (maximum number of depthwise/sublayer integration stations).

NVSA(I) : A list of those global node numbers at which nodal average strain output is given.

NCON(J,I) : The element numbers (J = 1,2,3,4 in general) which are common to structure node number NVSA(I).

SUBROUTINE PRINT(DISP,XG,YG,ZG,EPSSI,EPSSO,EPEEI,EPEEO,EPSEI,EPSEO,XGI,YGI, NP,GBI,STDEP,NODE,RFM,NBE,MBWE,ILAST,UCF1,NBC,ICOL,NMSUB,SUBW,TAUSS,TAUEE, TAUSE,MAXEL,NZS,NXST,LNXS,MATXS,XSPROP,TAGSS,MNXST,NYST,LNYS,MATYS,YSROP, TSGEE,MNYST,NELES,LNRS,ISRS,SC,EK,IMASS,AMASS,VEL,FLVM,KROW,NDEX,WFORCE, CINETI,NNSA,NVSA,NCON)

Purpose: This subroutine controls the calculation (as necessary) and output of all quantities (displacements, strains, energies, etc.) requested by the user at regular intervals during the timewise solution for the PLATE program.

Arguments: The arguments DISP,XG,YG,ZG,EPSSI,EPSSO,EPEEI,EPEEO,EPSEI,EPSEO, XGI,YGI,NP,NODE,RFM,NBE,MBWE,ILAST,UCF1,NBC,ICOL,TAUSS,TAUEE, TAUSE,MAXEL,LNXS,MATXS,XSPROP,TAGSS,MNXST,LNYS,MATYS,YSROP, TSGEE,MNYST,LNRS,ISRS,SC,AMASS,VEL,FLVM,KROW,NDEX,NVSA, and NCON are defined in Subroutine MAINP.

GBI(24,24) : See Subroutine CMASP.

STDEP(9,24) : The matrix used to calculate strains from displacements for an element. The rows correspond to the vectors $D_1^T, D_2^T \dots D_9^T$ of Eqs. A.10 evaluated at a specified location within the element.

NMSUB(I) : The number of mechanical sublayers used to define the uniaxial stress-strain curve for material type I.

SUBW(I,K) : The sublayer weighting factors C_k (Eq. A.120b) corresponding to material type I.

NZS : 4*MNSL where MNSL is the maximum number of mechanical sublayers used to specify a material behavior and 4 depthwise integration stations are used.

NXST : The actual number of individual X-direction stiffeners.

NYST : The actual number of individual Y-direction stiffeners.

NELES : The number of element sides on which linear restoring springs are attached.

EK(24,24) : The equivalent stiffness matrix for an element corresponding to line restoring springs. The matrix is used here to calculate the energy stored in restoring springs.

IMASS : Indicates the type of mass matrix employed
= 1 for lumped (diagonalized) mass matrix
= 2 for consistent mass matrix.

WFORCE : Current value of the work done by the externally-applied forces.

CINETI : The initial kinetic energy imparted to the structure by the user-specified initial velocity distribution.

NNSA : The number of nodes at which averaged nodal strains are to be output.

3.2.2 Main Program and Subroutines Unique to the CIVM-PLATE Program

In the following, the main program and subroutines used only in the CIVM-PLATE program are discussed.

SUBROUTINE COLLSN(IOPT,XG,YG,ZG,PEN,RF,THALF,NNSR,XF,YF,ZF,XN,YN,ZN,T,NN1,NN2,NN3)

Purpose: This subroutine performs the detailed collision inspection over a triangular subregion of a plate element. If collision (plate fragment overlap) is detected, the penetration distance, location of maximum penetration distance on the element, and appropriate coordinate transformation matrix are calculated. (See Subsection B.2.1).

Arguments:

IOPT : A parameter for subroutine usage.
= 1 if the entire check process is to be followed.
= 2 if the subroutine is to be terminated after
calculation of the coordinate transformation matrix
for the triangular subregion.

XG(I) }
YG(I) } Current global X,Y,Z coordinates of the Ith structural
ZG(I) } node.

PEN(I) : The penetration distance between the fragment and the
Ith triangular subregion.

RF : The radius of the spherical fragment.

THALF : The plate half thickness.

NNSR : The current triangular subregion being inspected.

XF }
YF } The current global X,Y,Z coordinates of the center
ZF } of the spherical fragment

XN(I) }
YN(I) } The global location (x_n, y_n, z_n -- see Eq. B.12) of
ZN(I) } the point of maximum penetration for the Ith
triangular subregion.

T(3,3) : The coordinate transformation matrix used to transform
from global to local (impact) coordinates. See
Eqs. B.7 and B.8.

NN1 }
NN2 } The global node numbers of nodes 1, 2, and 3,
NN3 } respectively of the current triangular inspection
region.

SUBROUTINE IFRAG (PMASS,AMASS)

Purpose: In this subroutine the initial fragment position and velocity, fragment geometric properties, contact surface properties and any symmetry options are input and printed for verification. The fragment initial kinetic energy is calculated and the mass matrix used in impact-interaction calculations is formed.

Arguments:

PMASS(I) : The lumped (diagonal terms only) mass matrix corresponding only to translational degrees of freedom, used in impact-interaction calculations.

AMASS(I) : The lumped mass matrix for the complete plate structure.

IMAIN

Purpose: The dummy main program of the CIVM-PLATE computer code. Problem-dependent array dimensions are specified, and certain of those variables used in this dimensioning process are input. Guidelines for preparation of the array dimensions are given in Subsection 5.3.

Arguments: None.

SUBROUTINE IMAINP (DELD, DIS, DISP, DISM1, DISM2, FLN, FLVA, FLVM, FLVP, VEL, ICOL, INUM, KROW, NDEX, STF, AMASS, NP, NODE, TAUSS, TAUSE, TAUEE, EPSSI, EPSSO, EPEEI, EPEEO, EPSEI, EPSEO, NBC, BC, RFM, ILAST, UCF1, UCF2, XG, YG, ZG, XGI, YGI, TAGSS, LNXS, XSPROP, MATXS, TSGEE, LNYS, YSPROP, MATYS, LNRS, ISRS, SC, MAXEL, MNSL, MNSLT4, NBE, MBWE, MNXST, MNYST, NVSA, NCON, PMASS, VN, VNB, SI, NEFF, ALPHA, NIAN)

Purpose: The controlling main program for the CIVM-PLATE code. The flow of input, timewise calculation, and output is governed by this primary subroutine.

Arguments:

PMASS(I) : See Subroutine IFRAG

VN(J,I) : The translational velocity components in the global X,Y,Z coordinates (J = 1,2,3) for the Ith impact-affected node at the current time instant.

- VNB(J,I) : The translational velocity components in the local (\bar{x}, \bar{y}, N) impact coordinate system ($J = 1, 2, 3$) for the Ith impact-affected node at the current time instant.
- SI(I) : For the current impact interaction calculation, the distance $|s_1|$ (see Eq. B.16) from the point of impact to the Ith impact-affected node.
- NEFF(I) : For the current impact-interaction calculation the global node number of the Ith impact-affected node.
- ALPHA(I) : The proportionality factor, α_1 (see Eqs. B.19), for impulse distribution associated with the Ith impact-affected node for the current impact-interaction calculation.
- NIAN : A user estimate of the maximum number of nodes which will be affected by any impact.

The remaining arguments are as defined for Subroutine MAINP given in Subsection 3.2.1.

SUBROUTINE IMPACT(XG, YG, ZG, DELD, VEL, NP, VN, VNB, PMASS, NBC, SI, NEFF, ALPHA, IMPCT1, NIAN)

Purpose: Controlling subroutine for impact inspection and interaction calculations for general (no symmetry) impact cases). For each step time, this subroutine controls inspection for maximum plate-fragment overlap. If impact has occurred, impact-affected nodes are identified and their pre-impact velocities are updated to post-impact velocities (similarly for the fragment) via the impact-interaction calculations.

Arguments:

XG(I)	}	See Subroutine COLLSN
YG(I)		
ZG(I)		

- DELD(I) : The current vector $\Delta \tilde{q}_{m+1}^* = \tilde{q}_{m+1}^* - \tilde{q}_m^*$ of nodal displacement increments.
- VEL(I) : The velocity corresponding to the Ith degree of freedom at the beginning of the current time step (from t_m to t_{m+1}).
- IMPCT1 : Index indicating if impact has been detected during the current execution of Subroutine IMPACT.
 = 0 if no impact has been detected.
 = 1 if impact has been detected.

The remaining variables are as defined in Subroutine IMAINP.

SUBROUTINE IMPDS (XG, YG, ZG, DELD, VEL, NP, VN, VNB, PMASS, NBC, SI, NEFF, ALPHA, IMPCT1, NIAN)

Purpose: Controlling subroutine for impact inspection and interaction calculations for double-symmetry impact cases. The underlying flow and purpose are the same as Subroutine IMPACT.

Arguments: All arguments are the same as in Subroutine IMPACT.

SUBROUTINE IMPSS (XG, YG, ZG, DELD, VEL, NP, VN, VNB, PMASS, NBC, SI, NEFF, ALPHA, IMPCT1, NIAN)

Purpose: Controlling subroutine for impact inspection and interaction calculations for single-symmetry impact cases.

Arguments: See Subroutine IMPACT.

SUBROUTINE INTRACT (S1, S2, A0, B1, B3, COEFR, FRNC, PTILDA)

Purpose: The impulse coordinates $\tilde{p}_x, \tilde{p}_y, \tilde{p}_N$ at the instant of termination of the collision are calculated in this subroutine. The relations used to calculate these values correspond to Cases I through III (Eqs. B.25 through B.28) of Subsection B.2.2.

Arguments:

S1 } Interaction constants, $S_1, S_2, A_0, B_1,$ and B_3
S2 } defined by Eqs. B.22.
A0 }
B1 }
B3 }

COEFR } The coefficient of restitution, $e,$ and coefficient of
FRNC } friction, $\mu,$ respectively, between the plate and
rigid spherical fragment surfaces.

PTILDA(I) : The impulse coordinates $\tilde{p}_x, \tilde{p}_y,$ and \tilde{p}_N ($I = 1, 2, 3,$
respectively) at the instant of termination of the
collision.

SUBROUTINE IPRINT(DISP, XG, YG, ZG, EPSSI, EPSSO, EPEEL, EPEEO, EPSEI, EPSEO, XGI,
YGI, NP, GBI, STDEP, NODE, RFM, NBE, MBWE, ILAST, UCF1, NBC, ICOL, NMSUB, SUBW, TAUSS,
TAUEE, TAUSE, MAXEL, NZS, NXST, LNXS, MATXS, XSPROP, TAGSS, MNXST, NYST, LNYS, MATYS,
YSPROP, TSGEE, MNYST, NELES, LNRS, ISRS, SC, EK, AMASS, VEL, NNSA, NVSA, NCON)

Purpose: This subroutine controls the calculation and output of all
quantities (displacement, strain, energies, etc.) as requested
by the user at regular intervals during the timewise solution
for the CIVM-PLATE program.

Arguments: All arguments are as defined in Subroutine PRINT in Subsection
3.2.1.

3.2.3 Subroutines Used by both the PLATE and the CIVM-PLATE Program

In the following, the subroutines used by both the PLATE and the
CIVM-PLATE program are discussed.

SUBROUTINE ARRT(STF, AMASS, F, ICOL, INUM, KROW, NDEX, NODE, NDPE)

Purpose: In this subroutine, the mesh nodal connectivity data in NODE(I) is used to establish the pointer arrays necessary to locate terms in the assembled stiffness matrix (and mass matrix if consistent mass is used) stored in compacted vector form. The number of words of storage required for the assembled stiffness matrix is calculated, output, and compared with the user estimate; if the user estimate is too small, a message is output and the run terminated. The assembled stiffness and mass (only for lumped mass) matrices and force vector are zeroed.

Arguments:

F(I) : A force-type vector of length NDT, where NDT is the total number of degrees of freedom for the current plate structure being analyzed.

NDPE : The number of degrees of freedom per element (NDPE - 24 for the present plate elements).

All remaining arguments are as defined in Subroutine MAINP of Subsection 3.2.1.

SUBROUTINE ASSEMK(EK,STF,INUM,NDPE,NODE,N)

Purpose: Perform assembly operation of the element stiffness matrix into the assembled stiffness matrix.

Arguments:

EK(24,24) : The stiffness matrix for the current element.

STF(I) } See Subroutine MAINP of Subsection 3.2.1.

INUM(I) }

NODE(I) }

NDPE : See Subroutine ARRT.

N : The current element number being assembled.

SUBROUTINE BCONMK(STF,BC,ICOL,INUM,NBC)

Purpose: Imposes the boundary condition constraints (zero displacements) on the assembled matrix $[-\frac{2}{(\Delta t)^2} \tilde{M} + \tilde{K}]$ given in Eq. A.114, by zeroing the row and column (not including the diagonal terms) corresponding to each constrained degree of freedom.

Arguments: See Subroutine MAINP of Subsection 3.2.1.

SUBROUTINE EAROW(STF,NBC,ICOL,INUM,RFM,ILAST,NBE,MBWE)

Purpose: This subroutine extracts the rows of the assembled matrix $[-\frac{2}{(\Delta t)^2} \tilde{M} + \tilde{K}]$ (from the first nonzero term to the last nonzero term of that row) corresponding to each constrained degree of freedom (prior to constraining) and stores these values in the matrix RFM(I,J). The user estimate of maximum bandwidth at a constrained degree of freedom is checked; if the user estimate is too small, a message is output and the run is terminated.

Arguments: See Subroutine MAINP of Subsection 3.2.1.

SUBROUTINE FACT(STIFM,NCOL,KROW,NDEX,IDET,NTAPE6,IC)

Purpose: Performs triple-factorization on the assembled matrix $[-\frac{2}{(\Delta t)^2} \tilde{M} + \tilde{K}]$ in Eq. A.114, putting it in the form $\tilde{L}^T \tilde{D} \tilde{L}$ where \tilde{L} is a lower triangular matrix and \tilde{D} is a diagonal matrix. The original matrix is destroyed in this operation. Details of the triple-factoring operation may be found in numerous texts on numerical methods and finite-element methods.

Arguments:

STIFM(I)	}	These arrays correspond to arrays STF(I),ICOL(I), KROW(I),NDEX(I), and INUM(I), respectively, as defined in Subroutine MAINP of Subsection 3.2.1.
NCOL(I)		
KROW(I)		
NDEX(I)		
IC(I)		

IDET : A parameter set equal to the number of negative diagonals in the assembled matrix being factored. If the matrix is not positive definite, IDET = -1 is set

NTAPE6 : The device number used for printed output. NTAPE6=6 is used in the PLATE and CIVM-PLATE programs.

SUBROUTINE GAUSS(N,GS,GW)

Purpose: This subroutine defines the location of the Gaussian integration stations and the corresponding weighting factors in one dimensional space. The number of Gaussian stations used may be from 1 to 6.

Arguments:

N : The number of Gaussian stations to be used.

GS(I) : The location of the N Gaussian stations relative to a normalized coordinate $-1 \leq s \leq 1$.

GW(I) : The corresponding Gaussian weights at the N Gaussian stations.

SUBROUTINE LMASSP(NTYPE,XL,YL,TH,SL,CSA,SMOI,EML,DENS)

Purpose: This subroutine forms the lumped (diagonal) mass matrix for a plate or stiffener element.

Arguments:

NTYPE : Element type
 = 1 for a plate element (unstiffened)
 = 2 for an x-direction stiffener element
 = 3 for a y-direction stiffener element

XL } The x-length, y-length, and thickness, respectively,
 YL } of the plate element (if NTYPE=1), or of the plate
 TH } element to which the stiffener is attached (if
 NTYPE=2 or 3).

SL : If NTYPE=2 or 3, the normalized ξ location ($0 \leq \xi \leq 1$) of an x-direction stiffener on the plate element (NTYPE=2), or the normalized η location ($0 \leq \eta \leq 1$) of a y-direction stiffener on the plate element (NTYPE=3).

CSA }
SMOI } The stiffener cross-sectional area and mass moment of inertia, respectively (required only if NTYPE=2 or 3).

EML(24) : The lumped mass matrix for the element.

DENS : The original mass per unit volume for this element ($\text{lb-sec}^2/\text{in}^4$).

SUBROUTINE MESHPA(NP,NODE,XG,YG,ZG,NBC,BC,LNXS,LNYS,XGI,YGI,XSPROP,YSROP,NXST,NYST,IMESH,MATXS,MATYS)

Purpose: This subroutine controls input, formation, and output of mesh, stiffener, and boundary condition information when the auto-mesh generation option is chosen. A detailed discussion of this subroutine is given in Subsection 4.1.2.

Arguments:

IMESH : See Card 2 of Subsection 4.2.

NXST }
NYST } See Subroutine PRINT of Subsection 3.2.1.

All remaining arguments are as defined for Subroutine MAINP of Subsection 3.2.1.

SUBROUTINE MESHPM(NP,NODE,XG,YG,ZG,NBC,BC,LNXS,LNYS,XGI,YGI,XSPROP,YSROP,NXST,NYST,IMESH,MATXS,MATYS)

Purpose: Mesh generation subroutine (similar to MESHPA) when the manual mesh generation option is chosen. A detailed discussion of this subroutine is given in Subsection 4.1.3.

Arguments: Same as Subroutine MESHPA.

SUBROUTINE OMULT(SQVCT,RWVCT,ACC,NCOL,KROW,NDEX)

Purpose: This subroutine performs the matrix multiplication
(ACC)=(SQVCT)*(RWVCT).

Arguments:

SQVCT(I) : A square (nxn) symmetric vector stored in lower
triangle compacted vector form, in a fashion consistent
with the pointers established in Subroutine ARR.

RWVCT(I) : A vector of length n of known quantities.

ACC(I) : The vector product (ACC)=(SQVCT)*(RWVCT) of length n.

NCOL(I) : Pointer array corresponding to ICOL(I) in Subroutine
MAINP.

KROW(I) } See Subroutine MAINP in Subsection 3.2.1.
NDEX(I) }

SUBROUTINE PRTOP(NNSA,NVSA,NCON,NP)

Purpose: In this subroutine, the print options to be executed at regular
user-specified time intervals are established. Relevant data
corresponding to various of these options is also defined. Those
options available and the associated input are given on Cards 51
through 62 in Subsection 4.2.

Arguments:

NNSA : See Card 61 in Subsection 4.2.

NVSA(I) }
NCON(I,J) } See Subroutine MAINP in Subsection 3.2.1.
NP(I,J) }

SUBROUTINE PSTRN(G11,G22,G12,S,D)

Purpose: The maximum principal strain and associated direction (in degrees,
with respect to the X axis) are calculated. Only principal
tensile strains are considered.

Arguments:

G11 } The strain components $\tilde{\epsilon}_{xx}$, $\tilde{\epsilon}_{yy}$, and $\tilde{\epsilon}_{xy}$, respectively,
G22 } at a point on the plate structure.
G12 }

S : The maximum principal tensile strain.

D : The direction (degrees) of the maximum principal
tensile strain (with respect to the X axis).

SUBROUTINE RCON(F,NBC)

Purpose: Subroutine which applies boundary constraints to the force vector.
Terms in the force vector corresponding to constrained degrees of
freedom are zeroed (it is assumed that all prescribed displacements
are zero).

Arguments:

F(I) : Force vector.

NBC(I) : List of those degrees of freedom which are constrained.

SUBROUTINE RPLATE(NTYPE,ANU,XL,YL,TH,SL,CSA,SLAM,SMOI,KT,GBI,YMOD)

Purpose: The stiffness matrix for an unstiffened rectangular plate element
(NTYPE=1), or an x-direction stiffener element (NTYPE=2), or a
y-direction stiffener element (NTYPE=3) are formed in this
subroutine. The pertinent theoretical basis for the plate element
is found in Subsection A.1.3.3. The theoretical basis for
stiffener elements is found in Subsection A.2.3.

Arguments:

NTYPE : See Subroutine LMASSP.

ANU : Poisson's ratio, ν , for the element material type.

XL }
YL }
TH } See Subroutine LMASSP.
SL }
CSA }

- SLAM : The distance (in the z direction) from the centerline of the stiffener to the midsurface of the plate (for NTYPE=2 or 3).
- SMOI : See Subroutine LMASSP.
- KT(24,24) : The calculated element stiffness matrix.
- GBI(24,24) : The matrix \bar{G}^{-1} relating generalized displacement parameters $\bar{\alpha}$ to normalized nodal degrees of freedom \bar{q} ; see Eq. A.19.
- YMOD : Young's modulus for the element material type.

SUBROUTINE SFDM(SL,EL,XL,YL,GBI,STD)

Purpose: This subroutine generates the row matrices $D_{\sim 1}^T, D_{\sim 2}^T, \dots, D_{\sim 9}^T$ of Eqs. A.10 used to evaluate strain components (or increments in strain) at a specified location within an element in terms of the element nodal generalized displacements.

Arguments:

SL } The normalized location $\xi = \frac{x}{a}, \eta = \frac{y}{b}$, respectively,
 EL } at which $D_{\sim 1}^T, D_{\sim 2}^T, \dots, D_{\sim 9}^T$ are to be evaluated.

XL } The dimensions a and b of the element in the x and
 YL } y directions, respectively.

GBI(24,24) : See Subroutine RPLATE.

STD(9,24) : The strain in terms of displacement matrix. The rows correspond to $D_{\sim 1}^T, D_{\sim 2}^T, \dots, D_{\sim 9}^T$ of Eqs. A.10 and the column correspond to $q_1, q_2, q_3, \dots, q_{24}$ (the element generalized degrees of freedom).

SUBROUTINE SOLV(STIFM,G,SOL,NCOL,KROW,NDEX)

Purpose: This subroutine performs the forward and backward substitution operations required to complete the solution of a system of linear simultaneous equations by the triple-factoring method. This subroutine must be used in conjunction with Subroutine FACT.

Arguments:

- STIFM(I) : The factored coefficient matrix obtained from Subroutine FACT.
- G(I) : The right-hand side vector (known) of the system of equations.
- SOL(I) : The solution vector of the system of equations.
- NCOL(I) }
KROW(I) } See Subroutine FACT.
NDEX(I) }

SUBROUTINE SPRING(EK,SS,ISIDE,XL,YL)

Purpose: This subroutine calculates the effective element stiffness matrix corresponding to line translational and torsional linear restoring springs applied along the side of a rectangular plate element. The theoretical basis for these calculations is given in Subsection A.1.3.5.

Arguments:

- EK(24,24) : The effective element stiffness matrix corresponding to line restoring springs applied to an element.
- SS(5) : The five elastic spring constants ($K_u, k_v, k_w, k_\theta, k_\psi$) of the line restoring springs.
- ISIDE : The element side number (1,2,3, or 4) to which the line restoring springs are attached.
- XL }
YL } The x and y dimensions, respectively, of the plate element to which the line springs are attached.

SUBROUTINE STRESA(DISP,DELD,FLVA,ITT,NODE,MAXEL,MAX2,TSCEE,PLASTW,XGI,YGI, NP,STDEA,GBI,NMSUB,DSR,PSR,SUBW,SNOM,NXST,XSPROP,LNXS,MATXS,NZS)

Purpose: This subroutine calculates the effective nodal force vector for an x-direction stiffener element corresponding to nonlinear geometric and material effects. The expression for this vector is given by Eq. A.97.

Arguments:

- DISP(I) : The displacement vector q_{m+1}^* at the current time step
- DELD(I) : The vector of displacement increments $\Delta q_{m+1}^* = q_{m+1}^* - q_m^*$
- FLVA(I) : The vector of equivalent nodal forces for the structure corresponding to geometric and material nonlinear effects.
- ITT : The current cycle number.
- NODE(I) }
MAXEL } See Subroutine MAINP in Subsection 3.2.1.
- MAX2 : Corresponds to MNXST on Card 1 of Subsection 4.2.
- TSGEE(I,J,K) : Matrix to store current stress values at Gaussian integration (sublayer stations, corresponding to matrix TAGSS(I,J,K) of Subroutine MAINP in Subsection 3.2.1.
- PLASTW : A scalar corresponding to plastic work contributions.
- XGI(I) }
YGI(I) } See Subroutine MAINP in Subsection 3.2.1.
NP(I,J) }
- STDEA(9,24) : Strains in terms of displacement matrix corresponding to STD(9,24) of Subroutine SFDM.
- GBI(24,24) : See Subroutine RPLATE.
- NMSUB(I) : See Subroutine PRINT in Subsection 3.2.1.
- DSR(I) }
PSR(I) } The strain-rate parameters, D and p, respectively, (see Eq. A.122) of the Ith material type.
- SUBW(I,K) : See Subroutine PRINT in Subsection 3.2.1.
- SNOM(I,K) : The static yield stress σ_{o_k} for the kth mechanical sublayer of the Ith material type.
- NXST : See Subroutine PRINT of Subsection 3.2.1.

XSPROP(J,I) }
 LNXS(I) } See Subroutine MAINP in Subsection 3.2.1.
 MATXS(I) }

NZS : See Subroutine PRINT in Subsection 3.2.1.

SUBROUTINE STRESC(DISP,DELD,FLVA,ITT,NODE,MAXEL,MAX2,TSGEE,PLASTW,XGI,YGI,
 NP,STDEC,GBI,NMSUB,DSR,PSR,SUBW,SNOM,NYST,YSPROP,LNYS,MATYS,NZS)

Purpose: Calculates the effective nodal force vector for a y-direction
 stiffener element corresponding to nonlinear geometric and
 material effects (Eq. A.98).

Arguments: Many of the arguments are identical to those of Subroutine STRESA.
 Only those which are different are defined here.

MAX2 : Corresponds to MNYST on Card 1 of Subsection 4.2.

TSGEE(I,J,K) : See Subroutine MAINP in Subsection 3.2.1.

STDEC(9,24) : Strains in terms of displacement matrix corresponding
 to STD(9,24) of Subroutine SFDM.

NYST : See Subroutine PRINT in Subsection 3.2.1.

YSPROP(J,I) }
 LNYS(I) } See Subroutine MAINP in Subsection 3.2.1.
 MATYX(I) }

SUBROUTINE STRESP(DISP,DELD,FLVA,ITT,NODE,MAXEL,TAUSS,TAUEE,TAUSE,EPSSI,
 EPSSO,EPEEI,EPEEO,EPSEI,EPSEO,PLASTW,XGI,YGI,NP,STDEP,GBI,NMSUB,DSR,PSR,
 SUBW,SNOM,NZS)

Purpose: Calculates the effective nodal force vector for a plate element
 corresponding to geometric and material nonlinear effects (Eq. A.35).
 The theoretical basis for these calculations is given in Subsection
 A.1.3.2.

Arguments:

DISP(I)	}	See Subroutine STRESA
DELD(I)		
FLVA(I)		
ITT		
NODE(I)	}	See Subroutine MAINP in Subsection 3.2.1.
MAXEL		
TAUSS(I,J,K)		
TAUEE(I,J,K)		
TAUSE(I,J,K)		
EPSSI(K,I)		
EPSSO(K,I)		
EPEEI(K,I)		
EPEEO(K,I)		
EPSEI(K,I)		
EPSEO(K,I)		
PLASTW	:	See Subroutine STRESA.
XGI(I)	}	See Subroutine MAINP in Subsection 3.2.1.
YGI(I)		
NP(I,J)		
STDEP(9,24)	:	Strains in terms of displacement matrix corresponding to STD(9,24) of Subroutine SFDM.
GBI(24,24)	:	See Subroutine RPLATE.
NMSUB(I)	:	See Subroutine PRINT in Subsection 3.2.1.
DSR(I)	}	See Subroutine STRESA
PSR(I)		
SUBW(I,K)	:	See Subroutine PRINT in Subsection 3.2.1.
SNOM(I,K)	:	See Subroutine STRESA.
NZS:	:	See Subroutine PRINT in Subsection 3.2.1.

SUBROUTINE TSTEP(STF,AMASS,NBC,BC,ICOL,INUM,KROW,NDEX,TRIAL,SOLN)

Purpose: Subroutine used to calculate a reference time-step bound for the Houbolt operator. The maximum natural frequency ω_{\max} of the system is calculated from $\omega^2 [M] \{q^*\} = [K] \{q^*\}$ using an iterative technique.⁺ The central-difference time-step bound $\Delta t_{\max}^{\text{CD}} = 2/\omega_{\max}$ corresponding to linear systems is calculated and output. To account for nonlinear effects, a reference time-step bound of $0.8(\Delta t_{\max}^{\text{CD}})$ is calculated and output. See Subsection 2.3 for a discussion of the use of these reference time-step bounds.

Arguments:

STF(J) : The assembled stiffness matrix stored in compacted vector form (see Subsection 4.1.5).

AMASS(I) : The assembled mass matrix for the structure, stored as a vector.

NBC(J) }
BC(J) }
ICOL(K) } See Subroutine MAINP in Subsection 3.2.1.
INUM(K) }
KROW(K) }
NDEX(K) }

TRIAL(I) } Trial and updated eigenvector solutions used in the
SOLN(I) } iteration scheme.

⁺The inverse power method is used to calculate ω_{\max} .

SECTION 4

USE OF THE PLATE PROGRAM

4.1 Discussion of Conventions Adopted in the PLATE Program

The PLATE program is designed to predict the large-deflection, elastic-plastic, transient responses of stiffened or unstiffened flat plates subjected to prescribed initial velocity distributions and/or prescribed externally-applied time-varying load distributions. The user-interaction required to execute a run of the PLATE code falls into three categories:

- (1) Preparation of input data cards
- (2) Assigning of array dimensions in the dummy MAIN program
- (3) Preparation of internal logic for subroutines INCOND and EXTL.

Instructions for preparation of input cards are given in Subsections 4.2 through 4.4, for array dimensioning in Subsection 4.5, and for preparation of subroutines INCOND and EXTL in Subsection 4.6.

The PLATE program provides the user with the option of generating structural discretization information by using an automated mesh generation procedure or a manual mesh generation procedure. If the automated mesh generation procedure is employed, substantially less input data are required, and bookkeeping tasks such as nodal and element numbering, generation of constrained degrees of freedom, etc. are performed internally according to well-defined conventions. The purpose of the present subsection is to define those problems for which automated mesh generation can be employed, and to discuss the numbering conventions used when automated mesh generation is employed. Also discussed are the schemes adopted for internal renumbering of stiffeners and storage of the assembled stiffness matrix.

4.1.1 Use of Auto-Mesh Generation vs. Use of Manual Mesh Generation

An automated mesh generation procedure has been provided in the PLATE

program in an attempt to simplify the preparation of input data; this should, in turn, result in fewer input data card errors. However, the auto-mesh generation procedure can be used only when all of the following conditions are met:

- (1) The planform of the plate structure must be rectangular (or square)
- (2) The plate must have no void regions (or cutouts)
- (3) Prescribed (zero) displacement boundary conditions must be imposed only along the outer boundaries of the rectangular plate structure
- (4) Only one boundary condition option (i.e., free, or clamped, etc.) may be specified on each side of the rectangular plate structure, and the specified boundary condition must apply along the entire side of the rectangular plate structure

If one or more of these conditions is not met, then the manual mesh-generation procedure must be employed. In either case, it should be noted again that the basic plate element used in the PLATE program is of rectangular planform; when using either the automated or manual mesh generation procedure, the plate structure must be modeled by a series of compatibly-connected rectangular elements.

4.1.2 Conventions Adopted in the Auto-Mesh Generation Procedure

When the auto-mesh generation procedure is employed, the numbering of element nodes, global nodes, elements, and plate sides is performed internally according to well-defined conventions; these conventions are illustrated in Fig. 10. The rectangular plate lies in the global X-Y plane, with the X-axis to the right and the Y-axis up, so that the global Z-axis would be out of the paper. The four sides of the plate structure are numbered sequentially in a counterclockwise fashion beginning with the side of the plate having the minimum Y=constant value. Note also that the sides of the plate structure and the sides of all plate elements are parallel to the X or Y axis. Elements and nodes are numbered sequentially beginning at the lower, left-hand corner

of the plate; the first row of nodes (elements) is numbered left to right, followed by the second row of nodes (elements) numbered left to right, the third row of nodes (elements) numbered left to right, etc. until all rows of nodes (elements) have been processed. When this process is completed, the number assigned to the node at the upper right-hand corner of the plate structure will be equal to the total number of nodes in the finite-element mesh. Similarly, the number assigned to the element in the upper, right-hand corner of the plate structure will be equal to the total number of elements in the finite-element mesh.

Once the global node numbers have been assigned, the global degree-of-freedom numbers are assigned by taking $(u, v, w, \theta, \psi, \chi)$ at global node number 1, followed by $(u, v, w, \theta, \psi, \chi)$ at global node number 2, etc., until all global nodes have been processed. The total number of degrees of freedom in the finite-element mesh, NDT, is thus given by $NDT=6*NNT$, where NNT is the total number of nodes in the finite-element mesh. As an example of the correspondence between global degree-of-freedom number and displacement parameter, the global degree-of-freedom number (NDF) assigned to the w displacement parameter at global node number 9 would be $NDF=(9-1)*6+3=51$. In general, the global degree-of-freedom number assigned to displacement parameter J (J=1,2,3, ... 6 corresponding to u, v, w, θ , ψ , and χ at a node, respectively) at global node number I is given by $NDF=(I-1)*6+J$.

For purposes of assembling element matrices (stiffness, mass, loads, etc.) into the global (system) matrices, certain "nodal connectivity" information is required. In particular, the auto-mesh procedure determines for each element the global node number associated with each of the four element nodes. As shown in Fig. 10, the element nodes are numbered counterclockwise 1 through 4 beginning with the element node in the lower left-hand corner of the element. As an example, the nodal connectivity information for element 5 of Fig. 10 would be as follows:

ELEMENT	NODE NUMBER	GLOBAL NODE NUMBER
	1	6
	2	7
	3	11
	4	10

This nodal connectivity information is internally generated in the auto-mesh procedure. However, as will be discussed shortly, when the manual mesh generation procedure is employed, the user is required to input this nodal connectivity information.

A thorough understanding of the above discussed numbering conventions is essential for the accurate preparation of input data cards, dimensioning of arrays, and preparation of subroutines INCOND and EXTL. The numbers assigned to global nodes, elements, degrees of freedom, plate sides, etc. are never modified in the PLATE program. Thus, all input and output refers to this original numbering scheme.

Two types of meshes can be generated using the auto-mesh procedure: (1) meshes for which the side lengths of elements in the mesh differ (non-uniform mesh), and (2) meshes for which all elements in the mesh have the same side dimensions (uniform mesh). The significance of this "option" is in terms of the generation of the global (X,Y) coordinates of each node, and the location of the origin of the global X-Y axis system. If a uniform mesh is employed, the origin of the global X-Y axis system is automatically chosen to be at global node number 1 (i.e., global node number 1 has (X,Y) coordinates of (0,0)), and the coordinates of each node are automatically generated by knowing the number of element subdivisions and the plate dimensions along sides 1 and 4 of the plate. If a non-uniform mesh is employed, the origin of the global X-Y axis system is chosen by the user, and in order to generate the global X-Y coordinates of each node in the finite element mesh, the user is required to input the global X coordinate of each node along side 1 of the plate structure and the global Y coordinate of each node along side 4 of the plate structure.

For the auto-mesh procedure, prescribed displacement boundary conditions are generated by choosing a boundary condition option (see Subsections 2.1 and 4.2) for each side of the plate. A list of constrained degrees of freedom is then internally generated by processing each of the plate sides in order and identifying those degrees of freedom at each node of side 1, including the end nodes of side 1, which are constrained as a result of the boundary condition option selected for side 1 of the plate. In general, this list of

constrained degrees of freedom will contain duplicates because the corner nodes of the plate are processed twice (e.g., if side 1 of the plate is ideally clamped and side 2 of the plate is pin-fixed, then the degree of freedom numbers corresponding to displacement parameters u , v , w , ψ , and χ at the node where sides 1 and 2 meet will appear twice in the list of constrained degrees of freedom). Thus, a sorting procedure is applied to this original list of constrained degrees of freedom, such that the final list of constrained degrees of freedom contains no duplicates and the constrained degree of freedom numbers appear in ascending order.

The previous discussion pertains to the auto-mesh generation procedure only; a similar discussion pertaining to the manual-mesh generation procedure is given in the next subsection. Also, no mention has been made of stiffeners in the present subsection; a discussion of conventions for stiffeners for both auto and manual mesh generation procedures is given in Subsection 4.1.4.

4.1.3 Discussion of the Manual Mesh Generation Procedure

The manual mesh generation procedure has been included in the PLATE code to accommodate as general a plate structure as possible. The only restrictions are that (1) the plate be of uniform thickness, (2) the plate be modeled by compatibly-connected rectangular elements, (3) the plate be initially flat, and (4) the plate lie initially in a plane parallel to the global X-Y plane. The price to be paid for this somewhat more general analysis capability is the increased effort required to prepare the input data. In particular, the user must assign element and global node numbers, input the nodal connectivity information, input the global coordinates of each node in the mesh, and input each constrained degree of freedom. Each of these areas will now be discussed.

The user is required first to define the mesh pattern chosen for the plate structure under consideration. Then the elements are numbered (from 1 to NET, where NET is the total number of elements in the finite-element mesh) using any convenient scheme. Global node numbers (from 1 to NNT, where NNT is the total number of nodes in the finite-element mesh) are then assigned to each node on the plate structure. Note that in order to minimize

the computer core storage requirements for the assembled stiffness matrix and mass matrix (if consistent mass modeling is chosen), the global nodes should be numbered in such a way as to minimize the average semi-bandwidth of the assembled stiffness matrix (see Subsection 4.1.5 for a discussion of the storage of the assembled stiffness matrix). Having defined the element and global node numbers, the nodal connectivity information for each element in the finite-element mesh may be prepared; that is, the global node number associated with the I th element node ($I = 1,2,3,4$) is defined. It is important to note that the element nodal numbering convention discussed in Subsection 4.1.2 and shown in Fig. 10 must be used when the manual mesh generation is employed. Global degree-of-freedom numbers are assigned internally as is done in the auto-mesh generation procedure; that is, by taking (u,v,w,θ,ψ,χ) at global node 1, followed by (u,v,w,θ,ψ,χ) at global node 2, etc. until all global nodes have been processed.

The user is also required to input the global X and Y coordinates of each global node in the finite-element mesh. The origin of the global XYZ coordinate system may be conveniently chosen by the user. The positive coordinate directions must be chosen so that (1) when viewing the finite-element-modeled plate from the top, the global X direction is to the right and the global Y direction is up and (2) all element sides are parallel to either the global X or Y axis.

Prescribed displacement constraint conditions on the plate structure are defined by specifying the global degree-of-freedom number associated with each generalized nodal displacement parameter which is to be constrained (i.e., zero displacement). The global degree-of-freedom numbering convention is related to the global node numbering scheme chosen by the user as previously discussed. Any degree of freedom at any node of the structure may be constrained. The list of constrained displacement parameters corresponding to various physical constraint conditions, presented in Subsection 2.1, may be of assistance to the user. The user is required to input the constrained degree of freedom numbers in ascending numerical order with no duplicates.

The preceding discussion is intended as a general overview of the

manual mesh generation procedure. Detailed information regarding the use of the manual mesh procedure is given in Subsection 4.3. Also, the topic of stiffeners has not been discussed in the present subsection; a unified discussion of stiffener conventions for both the auto-mesh and manual mesh generation procedures is presented in the next subsection.

4.1.4 Numbering Convention for Stiffeners

The PLATE computer program accommodates the analysis of integrally-stiffened flat plates where the stiffeners are required to be in directions parallel to the global X or Y axis. These stiffeners are designated as being either "complete" or "additional" stiffeners. Both complete and additional stiffeners may be specified when using the auto-mesh generation procedure, whereas only additional stiffeners may be specified when using the manual mesh generation procedure.

In order for a stiffener to be designated a complete stiffener, it must (1) span the plate completely, (2) be of uniform cross section, and (3) be made of a single material. Illustrative examples of complete stiffeners are given in Fig. 11. The properties of a complete stiffener are characterized by a knowledge of the global location of the centerline of the stiffener, its cross-sectional dimensions, the distance from the midplane of the plate to the neutral axis of the stiffener (offset distance), and the material properties of the stiffener (see Figs. 3, 11, and 12). In order for a stiffener to be designated an additional stiffener it must (1) completely span one element in the finite-element mesh, (2) be of uniform cross section, and (3) be made of a single material. Input information required for additional stiffeners includes cross-sectional dimensions, offset distance, material type, element on which the stiffener is located, and the relative position of the stiffener on the element (see Fig. 13).

In the PLATE program, the numbering of X-direction stiffeners is performed independently of the Y-direction stiffeners; i.e., the X-direction stiffeners are numbered from 1 to the total number of X-direction stiffeners and the Y-direction stiffeners are numbered from 1 to the total number of Y-direction stiffeners. In subsequent discussions in this subsection

of stiffener numbering, conventions for only X-direction stiffeners will be considered; however, the user should note that the discussion applies equally to Y-direction stiffeners.

As discussed in Subsection 2.1, a stiffener is modeled as a beam-type "element" compatibly attached to a flat plate element along lines parallel to the global X or Y axes. The stiffness and mass properties (as well as equivalent loads in the timewise solution) of the stiffeners are obtained by evaluating the element stiffness and mass matrices for each individual stiffener spanning a single plate element. The element matrices are then assembled into the global stiffness and mass matrices. The positioning of the stiffener element matrices in the global matrices corresponds exactly to the positioning in the global matrices of the element stiffness and mass matrices of the plate element to which the stiffener is attached.

As a result of the above procedure, all stiffeners (complete and additional) are redefined as "individual" stiffeners and assigned individual stiffener numbers; this redefining and renumbering of stiffeners is performed internally in the PLATE program. The properties of an individual stiffener are identical to those for an additional stiffener (i.e., completely span one plate element, be of uniform cross section, and be made of a single material). Thus, a complete stiffener (spanning the plate structure) may be considered to be a series of individual stiffeners. The convention used for renumbering stiffeners as individual stiffeners will be discussed next, first for the auto-mesh procedure and then for the manual mesh generation procedure. It is essential that the user understand this renumbering procedure because subsequent input data, various array dimensions, and all program output refers to the individual stiffeners. Again, note that the following discussion refers only to X-direction stiffeners, but applies equally to Y-direction stiffeners.

When using the auto-mesh generation procedure, both complete and additional X-direction stiffeners may be specified. Complete stiffeners are implicitly user-numbered (from 1 to NAST, where NAST is the total number of complete X-direction stiffeners) by the order in which the input data for complete stiffeners are specified. Similarly, additional stiffeners are

specified. Similarly, additional stiffeners are implicitly user-numbered (from 1 to NAXS, where NAXS is the total number of additional X-direction stiffeners) by the order in which the input data for additional stiffeners are specified. The following notation will be useful in the discussion of the stiffener renumbering procedure:

CSn = nth complete X-direction stiffener
ASn = nth additional X-direction stiffener
ISn = nth individual X-direction stiffener
NEAD = total number of plate elements in X-direction

The numbering convention for individual stiffeners is illustrated in Fig. 14 and is defined as follows. First CS1 is subdivided into a series of NEAD individual stiffeners numbered left to right from 1 through NEAD. Next, CS2 is subdivided into a series of NEAD individual stiffeners numbered left to right from (NEAD+1) to 2*NEAD. This process is repeated until each of the NAST complete X-direction stiffeners has been subdivided into individual stiffeners. In general, jth subdivision (j=1,2,3 ... NEAD) of the kth complete X-direction stiffener (k=1,2,3, ... NAST) will be assigned the individual stiffener number $ISn=(CSk-1)*NEAD+j$. After the processing of all complete X-direction stiffeners, individual stiffener numbers from 1 through (NAST*NEAD) will have been assigned. Next, the additional X-direction stiffeners (recall that additional stiffeners have the same properties as individual stiffeners) are processed in the order in which input data for additional stiffeners have been specified. That is, the numbering of individual stiffeners continues beginning with AS1, then AS2, etc., until all NAXS additional X-direction stiffeners have been renumbered. In general, the kth additional X-direction stiffener is assigned the individual stiffener number $ISn=(NAST*NEAD)+k$. The numbering of individual X-direction stiffeners is completed once all additional X-direction stiffeners have been processed. The total number of individual X-direction stiffeners (NXST) is thus given by $NXST=NAST*NEAD+NAXS$.

The above discussion applies equally to Y-direction stiffeners with NEAD replaced by NECD (the total number of plate elements in the Y-direction), NAST replaced by NCST (total number of complete stiffeners in the Y-direction),

and NAXS replaced by NAYS (total number of additional stiffeners in the Y-direction). Also, CSn, ASn, and ISn are now assumed to correspond to Y-direction stiffeners. The renumbering of Y-direction stiffeners results in the assigning of individual Y-direction stiffener numbers from 1 through NYST, where NYST is the total number of individual Y-direction stiffeners and is given by $NYST = NCST * NECD + NAYS$.

When the manual mesh generation procedure is used, only additional X and/or Y-direction stiffeners may be specified (i.e., the option for complete stiffeners is not included in the manual mesh generation procedure). Also, it should be recalled that the definitions of additional and individual stiffeners are identical. As a result, there is no need for internal renumbering of stiffeners when the manual mesh generation procedure is employed. The numbering of individual X-direction stiffeners is identical to the user-numbering scheme for additional X-direction stiffeners implicitly chosen by the order in which the data for stiffeners are input; the same is true for individual Y-direction stiffeners. Thus, the user is directly providing input data for the individual X and/or Y-direction stiffeners when using the manual mesh generation procedure.

4.1.5 Storage of the Assembled Stiffness Matrix

A brief description of the manner in which the assembled stiffness matrix, K is stored is presented in this subsection. An understanding of this storage technique is required in order to provide the correct dimensions for the assembled stiffness matrix and assembled mass matrix (if consistent mass modeling is chosen).

The assembled stiffness matrix is formed in such a manner that the i th row of this matrix corresponds to the i th global degree of freedom, and the j th column of this matrix corresponds to the j th global degree-of-freedom number. In all cases the assembled stiffness matrix is symmetric, so that only the lower triangular portion of K need be stored. In general, this matrix is also banded and sparsely populated. A portion of a hypothetical assembled stiffness matrix is shown in Fig. 15a; the left-hand boundary of the shaded area represents the first nonzero entry in each row and the

right-hand boundary of the shaded area represents the last nonzero in each row. For present purposes the total bandwidth of the i th row in \tilde{K} is defined as the total number of entries in the i th row between the first nonzero entry and the last nonzero entry (inclusive), and the semi-bandwidth of the i th row in \tilde{K} is defined as the total number of entries in the i th row between the first nonzero entry and the diagonal term (inclusive). In the PLATE program, the assembled stiffness matrix is stored as a vector (one-dimensional array) by rows, in order, beginning in each row with the first nonzero entry and ending with the diagonal term (i.e., the semi-bandwidth entries of each row are stored, row by row, in a vector; the leading zero terms in each row are not stored). For example, the storage of the hypothetical \tilde{K} matrix of Fig. 15a is shown in Fig. 15b.

In order to dimension the vector containing the assembled stiffness matrix properly, the user must obtain an estimate of, for example, the average semi-bandwidth. This requires some knowledge of the "assembly" process in the finite-element method (see, for example, Ref. 10). Alternatively, an abbreviated run of the PLATE program can be made to obtain the exact storage requirements for the assembled stiffness matrix; guidelines are provided in Subsection 4.8.

4.2 Input Information and Procedure for the PLATE 1 Code Using

Auto-Mesh Generation

The information required to punch a set of data cards for a run of the PLATE 1 computer program is presented in a step-by-step manner in this section. The variables to be punched on the n th 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. The notation "Card" implies that only one card is required to input the data; the notation "card(s)" implies that one or more cards may be required to input the data.

Card 1	FORMAT
MAXEL, MNSL, MNXST, MNYST, NBE, MBWE, MNC	8I10

where

MAXEL The total number of elements in the finite-element mesh.

MNSL The maximum number of mechanical sublayers employed to model the material nonlinear behavior. Note that the maximum number of mechanical sublayers permitted per material type is 5.

MNXST The maximum number of individual X-direction stiffeners employed. Note that the total number of individual X-direction stiffeners is defined to be the number of X-direction stiffeners spanning the plate times the number of elements in the X-direction, plus the number of additional X-direction stiffeners spanning individual elements. If no X-direction stiffeners are present, set MNXST=1.

MNYST Same as MNXST, except referring to Y-direction stiffeners.

NBE If reaction force output is requested (i.e., IOP5=1 on Card 51), set this variable equal to the estimated total number of constrained degrees of freedom after all duplicates have been eliminated. If no reaction force output is requested (i.e., IOP5=0 on Card 51), then set NBE=1.

MBWE If IOP5=1 (on Card 51), set this variable equal to the estimated maximum total bandwidth of the assembled stiffness matrix at a constrained degree of freedom. For a particular row of the assembled stiffness matrix, this number is equal to the number of terms (including zeros) in that row starting with the first non-zero term and ending with the last non-zero term of that row (see Sub-section 4.1.5). If IOP5=0, set MBWE=1.

MNC The estimated total number of words of storage required for the assembled stiffness matrix

stored as the lower triangle from the first nonzero term to and including the diagonal term of each row (see Subsection 4.1.5).

Card 2

IMESH, IMASS, IMCONT, IPUNCH

2014

where

IMESH Indicates the type of mesh being employed

- =0 For a structure whose planform is rectangular (with no voids) and for which a mesh of non-uniform elements is employed.
- =1 For a structure whose planform is rectangular (with no voids) and for which a mesh of uniform (equal-size) elements is employed.
- =2 For all plate structures having non-rectangular planform and/or containing voids.

If IMESH=0 or 1 is specified, the automatic mesh-generation subroutine is employed, and the following input cards are followed (Cards 3 through 43).

If IMESH=2, the manual mesh-generation subroutine is employed; Cards 3 through 43 are replaced by the input cards given in Subsection 4.3.

IMASS Indicates the type of mass matrix to be employed

- =1 For lumped (diagonal) mass matrix
- =2 For consistent (fully populated) mass matrix.

IMCONT Indicates whether present run is a continuation of a previous run.

- =0 if present run is not a continuation run.
- =1 if present run is a continuation run.

IPUNCH Control parameter which indicates whether or not a deck of continuation cards is to be punched following the final cycle of the present run.

=0 if no continuation deck is desired.

=1 if continuation deck is desired.

Card 3

NEAD, NECD

2014

where

NEAD The number of elements in the X-direction

NECD The number of elements in the Y-direction

Card 4a

EPAN, ANUP, DENSP, TH, XDIST

5D16.7

Card 4b

YDIST, ZPOS

where

EPAN SIG(1)/EPS(1) given on cards 46 and 47 for the plate material (psi).

ANUP Poisson's ratio of the plate material.

DENSP Mass per unit volume of the plate material (lb-sec²/in⁴)

TH Total thickness of the plate (in)

XDIST The dimension of the plate in the X-direction (in).

YDIST The dimension of the plate in the Y-direction (in).

ZPOS The Z-location of the plate midsurface (in)

If IMESH=1, skip Cards 5 and 6.

Card(s) 5

XG(I), I=1, (NEAD+1)⁺

5D16.7

where

XG(I) The global X coordinates of the first row of nodes in the X-direction, left to right (plate side 1).

Card(s) 6

YG(I), I=1, (NECD+1)

5D16.7

⁺The input notation XG(I), I=1, (NEAD+1) indicates that Card(s) 5 should contain the values of XG(1), XG(2), XG(3) ... XG(NEAD), XG(NEAD+1). This notation is employed throughout the description of input.

where

YG(I) The global Y coordinates of the first column of nodes in the Y-direction, bottom to top (plate side 4).

Card 7

NCSB(1), NCSB(2), NCSB(3), NCSB(4) 20I4

where

NCSB(I) The displacement boundary condition applied to the Ith side of the plate (sides are numbered counterclockwise beginning with the side parallel to the X axis having the lowest Y=constant value as discussed in Subsection 4.1.2).

=0 Free

=1 Symmetry

=2 Ideally clamped

=3 Pinned, fixed

=4 Pinned, free sliding Z-direction
tangent to boundary

=5 Pinned, free sliding normal (inplane) to
boundary

A list of the nodal degrees of freedom constrained as a result of each of the options is given in Subsection 2.1.

Card 8

NAST, NCST 20I4

where

NAST The total number of complete stiffeners spanning the plate in the X-direction (a maximum of 30 such stiffeners is permitted).

NCST The total number of complete stiffeners spanning the plate in the Y direction (a maximum of 30 such stiffeners is permitted).

If NAST=0 (no X-direction stiffeners spanning the plate), skip Cards 9 through 16. If NCST=0 (no Y-direction stiffeners spanning the plate), skip Cards 17 through 24.

Card(s) 9

APCST(I), I=1, NAST

5D16.7

where

APCST(I) The global Y location of the centerline of the Ith complete X-direction stiffener which spans the plate (subsequently referred to as the Ith complete stiffener). Note that if IMESH=1 (uniform mesh) the origin of the global axis system is automatically located at the first global node of the plate structure (Fig. 11).

Card(s) 10

RHC(I), I=1, NAST

5D16.7

where

RHC(I) The total thickness (1n) of the Ith complete X-direction stiffener (Fig. 12).

Card(s) 11

RWC(I), I=1, NAST

5D16.7

where

RWC(I) The width (1n) of the Ith complete X-direction stiffener (Fig. 12).

Card(s) 12

ECS(I), I=1, NAST

5D16.7

where

ECS(I) Young's modulus (ψ_1) of the Ith complete X-direction stiffener.⁺

Card(s) 13

ANUCS(I), I=1, NAST

5D16.7

where

ANUCS(I) Poisson's ratio of the Ith complete X-direction stiffener

Card(s) 14

DENCS(I), I=1, NAST

5D16.7

⁺The user must for consistency and correctness provide a value for ECS(I) which equals SIG(1)/EPS(1) for the material of which the stiffener is composed.

where

DENCS(I) The mass per unit initial volume of the Ith complete X-direction stiffener ($\text{lb-sec}^2/\text{in}^4$).

Card(s) 15

XFCST(I), I=1, NAST 5D16.7

where

XFCST(I) The distance (in) from the centroid of the Ith stiffener to the plate midsurface. If the direction of the vector from the stiffener centroid to the plate midsurface is the same as the direction of the global Z axis, then the sign of this quantity is positive. If the direction of the vector is opposite, the sign of this quantity is negative (Fig. 12).

Card(s) 16

MATCS(I), I=1, NAST 2014

where

MATCS(I) The material type for the Ith complete X-direction stiffener (an integer value from 1 through 5). Note that the user will specify up to 5 different material types (and their associated linear or nonlinear material behavior) on Cards 45 through 48; the value of MATCS(I) indicates which of these (user-numbered) material descriptions applies to the Ith complete X-direction stiffener.

Card(s) 17

APCST(I), I=1, NCST 5D16.7

Card(s) 18

RHC(I), I=1, NCST 5D16.7

Card(s) 19

RWC(I), I=1, NCST 5D16.7

Card(s) 20

ECS(I), I=1, NCST

5D16.7

Card(s) 21

ANUCS(I), I=1, NCST

5D16.7

Card(s) 22

DENCS(I), I=1, NCST

5D16.7

Card(s) 23

XFCST(I), I=1, NCST

5D16.7

Card(s) 24

MATCS(I), I=1, NCST

2014

where

APCST(I)

RHC(I)

RWC(I)

ECS(I)

ANUCS(I)

DENCS(I)

XFCST(I)

MATCS(I)

The geometric and material properties of the Ith complete Y-direction stiffener.

The definitions of these quantities are those given in Cards 9 through 16, except that they now refer to complete Y-direction stiffeners.

Card 25

NAXS, NAYS

2014

where

NAXS

The total number of additional (see Sub-section 4.1.4) X-direction stiffeners to be located on individual user-specified elements. Note that each of these individual X-direction stiffeners is assumed to span the individual user-specified element on which it is located.

NAYS

The total number of additional Y-direction stiffeners to be located on individual user-specified elements.

If both NAXS and NAYS are greater than zero, Cards 26 through 43 are required next. If NAXS=0, then Cards 26 through 34 are skipped. If NAYS=0, then Cards 35 through 43 are skipped.

Card(s) 26

LNXS(I), I=1, NAXS 20I4

where

LNXS(I) The element number on which the Ith additional X-direction stiffener is located.

Card(s) 27

MATXS(I), I=1, NAXS 20I4

where

MATXS(I) The material type for the Ith additional X-direction stiffener (see note for Card 16).

Card(s) 28

XSPROP(1,I), I=1, NAXS 5D16.7

Card(s) 29

XSPROP(2,I), I=1, NAXS 5D16.7

Card(s) 30

XSPROP(3,I), I=1, NAXS 5D16.7

Card(s) 31

XSPROP(4,I), I=1, NAXS 5D16.7

Card(s) 32

XSPROP(5,I), I=1, NAXS 5D16.7

Card(s) 33

XSPROP(6,I), I=1, NAXS 5D16.7

Card(s) 34

XSPROP(7,I), I=1, NAXS 5D16.7

where

XSPROP(J,I) The geometric and material properties for the Ith additional X-direction stiffener.

J=1 Thickness (in)
 J=2 Width (in)
 J=3 Young's modulus (psi) ⁺
 J=4 Poisson's ratio
 J=5 Mass per unit initial volume (lb-sec²/in⁴)
 J=6 The normalized location, η_s , of the stiffener centerline on the user-specified element (a value from 0.0 to 1.0 inclusive). Note that for the present calculation a local x-y axis system is chosen whose origin is at element node number 1. The value of η_s is calculated as the location y_s of the stiffener centerline in the local x-y system divided by the dimension of the element in the Y-direction (Fig. 13)
 J=7 The distance (in) from the centroid of the Ith additional X-direction stiffener to the plate midsurface. See Card 15 for definition of sign convention.

Card(s) 35

LNYS(I), I=1, NAYS 2014

where

LNYS(I) The element number on which the Ith additional Y-direction stiffener is located

Card(s) 36

MATYS(I), I=1, NAYS 2014

where

MATYS(I) The material type for the Ith additional Y-direction stiffener (see note for Card 16).

⁺Footnote on page 59 applies.

Card(s) 37		
	YSPROP(1,I), I=1, NAYS	5D16.7
Card(s) 38		
	YSPROP(2,I), I=1, NAYS	5D16.7
Card(s) 39		
	YSPROP(3,I), I=1, NAYS	5D16.7
Card(s) 40		
	YSPROP(4,I), I=1, NAYS	5D16.7
Card(s) 41		
	YSPROP(5,I), I=1, NAYS	5D16.7
Card(s) 42		
	YSPROP(6,I), I=1, NAYS	5D16.7
Card(s) 43		
	YSPROP(7,I), I=1, NAYS	5D16.7

where

YSPROP(J,I)	The geometric and material properties for the Ith additional Y-direction stiffener.
J=1	Thickness (in)
J=2	Width (in)
J=3	Young's modulus (psi) [†]
J=4	Poisson's ratio
J=5	Mass density (lb-sec ² /in ⁴)
J=6	Normalized location, ξ_s , of the stiffener centerline on the user-specified element. The value of ξ_s is calculated as the location, x_s , of the stiffener centerline in the <u>local</u> x-y system divided by the dimension of the <u>element</u> in the X-direction.
J=7	The distance (in) from the centroid of the stiffener to the plate midsurface. See Card 15 for definition of sign convention.

[†]Footnote on page 59 applies.

Card 44

NMAT

20I4

where

NMAT

The total number of material types to be utilized in the present run. A maximum of 5 different materials is allowed.

Card 45

NSUB

20I4

where

NSUB

The number of mechanical sublayers used to model the uniaxial stress-strain behavior of the first type of material. A maximum of 5 mechanical sublayers is allowed.

Card 46

SIG(J), J=1, NSUB

5D16.7

Card 47

EPS(J), J=1, NSUB

5D16.7

where

SIG(J)

EPS(J)

} The Jth coordinate pair of the stress, σ , and strain, ϵ , respectively, which is used to define the polygonal approximation of the uniaxial stress-strain diagram (see Appendix A) for the first material type. The units for SIG(J) are psi, and for EPS(J) are in/in. The number of values appearing on each of Cards 46 and 47 should be equal to the number of mechanical sublayers, NSUB, defined on Card 45.

Card 48

DSR(1), PSR(1)

5D16.7

where

DSR(1)

PSR(1)

} The values of the constants D and p, respectively, used in the strain-rate sensitivity formula (see Appendix A) for the first material type. If no

strain-rate sensitivity is required, set these parameters equal to zero.

Cards 45 through 48 are repeated for each of the NMAT (Card 44) material types to be defined (i.e., material type number 1 is defined by the first set of Cards 45 through 48, material type number 2 is defined by the second set of Cards 45 through 48, etc.). It is important to note that the plate material must always correspond to material type number 1; the material type of each of the complete and/or individual stiffeners is specified by the user (see Cards 16, 24, 27, and 31). It should also be noted that the value of MNSL specified on Card 1 is equal to the maximum value of NSUB used to define the various materials.

Card 49

ITIMEF, INCRT, IOUT 2014

where

ITIMEF The time-step number (or cycle number) at which the present run will terminate.

INCRT The number of cycles between regular printout (i.e., print every INCRT cycles).

IOUT A print parameter which is numerically equal to the value of INCRT.

Card 50

DELTAT, TIMEF 5D16.7

where

DELTAT The time-step size, Δt (seconds), used in the timewise solution.⁺

TIMEF The time (seconds) at which the present run will terminate.

Note that a run of the PLATE computer code will terminate when either the cycle number exceeds the value of ITIMEF (Card 49) or the time exceeds the value of TIMEF (Card 50).

Card 51

IOP1, IOP2, IOP3, IOP4, IOP5, IOP6, IOP7, IOP8 2014

⁺See Subsections 2.4 and 4.8.2 for guidance in selecting an appropriate Δt .

The value of these parameters governs the type of output to be given at every regular printout cycle (i.e., every INCRT cycles). A value of 0 indicates that the particular print option is to be skipped; a value of 1 indicates that a particular print option is to be exercised. The output associated with each of these print options is as follows:

- | | |
|------|--|
| IOP1 | Displacements and current (global) X,Y coordinates for each node. |
| IOP2 | Strain components, principal (tensile) strain and direction at the upper and lower surfaces evaluated at the spanwise centroid of each element. |
| IOP3 | Strain components, principal (tensile) strain and direction at the nine Gaussian spanwise stations (evaluated at upper and lower surfaces at each spanwise location) for user-specified element numbers. |
| IOP4 | Strain components, principal (tensile) strain and direction, and elongations (in user-specified directions) at additional spanwise locations (evaluated at upper and lower surface at each spanwise location) specified by the user. |
| IOP5 | Reaction forces at all nodes where displacement constraint conditions have been imposed. |
| IOP6 | Normal strain at the upper and lower surfaces at the three Gaussian spanwise locations for user-specified X- and/or Y-direction stiffeners. |
| IOP7 | System energies (i.e., work input to structure, structure kinetic energy, structure elastic energy, structure plastic energy, and energy stored in elastic restoring springs). |
| IOP8 | Strain components, principal (tensile) strain and direction at the upper and lower plate surfaces at user-specified <u>nodes</u> . Note that these quantities are calculated by nodal averaging. |

Some or all of Cards 52 through 62 will be required if any of options IOP3, IOP4, IOP6, or IOP8 are to be exercised (i.e., if any of these parameters are input equal to 1). However, Cards 52 and 53 should be skipped if IOP3=0, Cards 54 through 57 should be skipped if IOP4=0, Cards 58 through 60 should be skipped if IOP6=0, and Cards 61 and 62 should be skipped if IOP8=0.

Card 52

NEGS 20I4

where

NEGS The total number of plate elements for which Gaussian station strain output is desired. The value of NEGS cannot exceed 200.

Card(s) 53

LNGS(I), I=1, NEGS 20I4

where

LNGS(I) A vector containing the element numbers for which Gaussian station strain output is desired (NEGS element numbers must be specified).

Card 54

NASP

where

NASP The total number of additional spanwise locations on the plate structure where strain printout is requested. A maximum of 50 additional spanwise strain points is permitted.

Card 55

LNASP(I), SLASP(I), ELASP(I) I4,2D16.7

where

LNASP(I) The element number on which the Ith additional strain point is located.

SLASP(I) } The ξ and η coordinates, respectively, of the Ith additional strain point. The normalized coordinates are related to the local coordinates, x-y (whose origin is at node 1 of the element) by

ELASP(I) }

$$\xi = \frac{x}{a} \quad , \quad \eta = \frac{y}{b}$$

where a is the length of the element in the
 X direction
 and b is the length of the element in the
 Y direction.

Card 55 is repeated for each additional strain point until all NASP additional strain points have been processed. Note that the numbering of the additional strain points follows the order in which their element and coordinate locations are input.

Card 56

NASPE

2014

where

NASPE

The total number of additional strain points at which the directions for calculation of elongation are to be specified by the user ($NASPE \leq NASP$). Note that elongations in the directions 0° and 90° (in the X and Y directions, respectively) are automatically calculated and output for each additional strain point. The purpose of Cards 56 and 57 is to allow the user to specify other directions for elongation calculation, if desired, at some or all of the additional strain points.

If NASPE=0, skip Card 57.

Card 57

NSP, DIR1, DIR2

I4,2D16.7

where

NSP

The number of the additional strain point at which the directions for calculations of elongations are to be specified.

DIR1 }
 DIR2 } The two directions (degrees) in which elongations
 are to be calculated at the NSPth additional
 strain point. Angles are measured from the X
 axis to the direction desired, with counter-
 clockwise rotations being positive.

Card 57 is repeated for each of the NASPE additional strain points at which the directions in which elongations are calculated are specified by the user.

Card 58

NXSS, NYSS 2014

where

NXSS }
 NYSS } The total number of individual X-direction and
 Y-direction stiffeners, respectively, for which
 Gaussian station strain output is desired.
 (Note: the values of NXSS and/or NYSS cannot
 exceed 200.)

Card(s) 59 (skip if NXSS=0)

INXSS(I), I=1, NXSS 2014

where

INXSS(I) The X-direction stiffener numbers for which strain
 output is desired.

Card(s) 60 (skip if NYSS=0)

INYSS(I), I=1, NYSS 2014

where

INYSS(I) The Y-direction stiffener numbers for which strain
 output is desired.

Note: The data input on Cards 58 through 60 must corres-
 pond to the stiffeners as renumbered internally
 (e.g., each stiffener defined as spanning the

plate is now treated as a series of individual stiffeners spanning individual elements). The rules used for the internal renumbering of stiffeners are described in Subsection 4.1.4.

Card 61

NNSA 2014

where

NNSA The total number of nodes at which strain output is desired.

If the value of NNSA is set equal to the total number of nodes in the finite-element mesh, NNT, then Card 62 is skipped. If NNSA is less than NNT, then Card 62 must be input.

Card 62

NVSA(I), I=1, NNSA 2014

where

NVSA(I) The global node numbers at which strain output will be given.

Card 63

NELES 2014

where

NELES The total number of element boundaries on which linear-elastic line restoring springs are located.

If NELES=0, skip Cards 64 and 65.

Card 64

LNUM, ISIDE 2014

where

LNUM }
ISIDE } The global element number and local element side number (see Fig. 10) on which linear-elastic line restoring springs are located.

Card 65

SS(1), SS(2), SS(3), SS(4), SS(5)

5D16.7

where

SS(I) The five elastic spring constants ($k_u, k_v, k_w, k_\theta, k_\psi$) corresponding to the line restoring springs located on side ISIDE of element INUM. The displacement direction and units for each of these constants is as follows:

I=1 Translation u in X direction (lb/in per in. of span)

I=2 Translation v in Y direction (lb/in per in. of span)

I=3 Translation w in Z direction (lb/in per in. of span)

I=4 Rotation $\partial w/\partial x$ (in-lb/rad per in. of span)

I=5 Rotation $\partial w/\partial y$ (in-lb/rad per in. of span)

Cards 64 and 65 are repeated for each of the NELES element boundaries on which line restoring springs are located. Note that the distribution of spring stiffnesses along an element boundary is assumed to be constant, and that line restoring springs which span entire sides of the plate, or large portions of a side (encompassing a number of consecutive element boundaries) must be treated as a series of restoring springs spanning individual elements.

The preceding input cards (1 through 65) apply to plate structures having rectangular planform and no voids, and to runs which are not continuations of previous runs. The input modifications required for plate structures having non-rectangular planform and/or voids is given in Subsection 4.3. The additional input required for continuation runs is discussed in Subsection 4.4.

4.3 Modification to Input when Using Manual Mesh Generation

The description of input given in Subsection 4.2 applies to stiffened or unstiffened flat plate structures with rectangular planform and with no void regions (e.g. cutouts). For such structures, the generation of mesh, geometry, and boundary constraint information has been automated (subroutine MESHPA) to minimize the amount of input information which must be prepared by the user. However, for flat plate structures having non-rectangular planform and/or containing void regions, an alternate scheme (subroutine MESHPM) has been employed in which the user is required to input directly nodal connectivity, nodal coordinate, and constrained degree of freedom information. Although input preparation is more cumbersome for such cases, this scheme does provide the user with the flexibility to analyze more general plate structures.

Before preparing the input data, the user is required to assign a global element number to each element in the finite-element mesh, and a global node number to each node in the finite-element mesh. Also, a global XYZ coordinate system should be conveniently located. The value of IMESH on Card 2 of Subsection 4.2 should be defined as IMESH=2. The following input cards (3' through 28') replace cards 3 through 43 of Subsection 4.2. For convenience, a prime is used for the card numbers presented in this subsection.

Card 3' FORMAT
NNT, NET 20I4

where

NNT The total number of nodes in the finite-element mesh
NET The total number of elements in the finite element
 mesh.

Card 4'

EPAN, ANUP, DENSP, TH, ZPOS 5D16.7

where

EPAN SIG(1)/EPS(1) given on cards 46 and 47 for the
 plate material (ps₁).
ANUP Poisson's ratio of the plate material.

Card(s) 17'		
	XSPROP(5,I), I=1, NXST	5D16.7
Card(s) 18'		
	XSPROP(6,I), I=1, NXST	5D16.7
Card(s) 19'		
	XSPROP(7,I), I=1, NXST	5D16.7
where		
LNXS(I)	The geometric and material properties of the	
MATXS(I)	Ith individual X-direction stiffener; the	
XSPROP(J,I)	definition of these quantities is identical	
	to that given in Subsection 4.2, Cards 26	
	through 34.	
Card(s) 20'		
	LNYS(I), I=1, NYST	20I4
Card(s) 21'		
	MATYS(I), I=1, NYST	20I4
Card(s) 22'		
	YSPROP(1,I), I=1, NYST	5D16.7
Card(s) 23'		
	YSPROP(2,I), I=1, NYST	5D16.7
Card(s) 24'		
	YSPROP(3,I), I=1, NYST	5D16.7
Card(s) 25'		
	YSPROP(4,I), I=1, NYST	5D16.7
Card(s) 26'		
	YSPROP(5,I), I=1, NYST	5D16.7

Card(s) 27'

YSPROP(6,I), I=1, NYST 5D16.7

Card(s) 28'

YSPROP(7,I), I=1, NYST 5D16.7

where

LNYS(I)	}	The geometric and material properties of the Ith individual Y-direction stiffener; the definition of these quantities is identical to that given in Subsections 4.2, Cards 35 through 43.
MATYS(I)		
YSPROP(J,I)		

Note: When using the manual mesh generation option, all stiffeners are treated as individual stiffeners located on individual user-specified elements. As a result, no internal renumbering of stiffeners is done, and any future reference to stiffener numbers should correspond to the numbering scheme chosen by the user in preparation of data Cards 11' through 19' (for X-direction stiffeners) and Cards 20' through 28' (for Y-direction stiffeners).

This completes those input modifications required when using the manual mesh generation option (IMESH=2). The remaining cards follow exactly those given in Subsection 4.2 starting with Card 44.

4.4 Additional Input Required for Continuation Runs

An option has been provided in the PLATE code which allows the user to terminate a computer run at a specified time step, and continue the analysis in a subsequent computer run beginning with the time cycle at which the previous run was terminated. This continuation option allows the user to carry out long-time analyses in a series of continuation runs (without starting each run from time zero) with the opportunity to scan the data provided by each run before continuing the analysis, if desired.

In order to continue a previous run, a deck of continuation cards must be punched when the previous run terminates. This continuation deck

is obtained by setting IPUNCH=1 on input card number 1 (see Subsection 4.2), and is used as input for the continuation run (as described below). The parameter IMCONT is set to IMCONT=1 on input card number 1 to indicate that the present run is a continuation of a previous run.

If a continuation run is being made, the deck of continuation input cards should follow immediately after Card 65 of Subsection 4.2. It is important to note that input Cards 1 through 65 should be identical to those used in the previous run (which is being continued) with the following exceptions:

1. ITIMEF on Card 49 must be set equal to the final cycle number for the present continuation run. Note that the cycle number is not reset to zero for a continuation run, but, rather, is initialized to the value at the end of the previous run.
2. INCRT and IOUT on Card 49 may be changed to obtain printout at intervals different from the previous run.
3. TIMEF on Card 50 must be set equal to the final time for the present continuation run.
4. The parameters on Card 51 which govern the type of output to be given every regular printout cycle may be redefined (except for the option IOP5, which must have the same value as in the previous run). The information given in data cards 52 through 62 must also be altered to reflect any changes made on Card 51.

The continuation deck starts with Card 66 and contains the following information:

Card 66	Format
ITT, CINETI, WFORCE, POWMP1	I6,3D15.7

where

- ITT The cycle number at which the previous run was terminated.
- CINETI The kinetic energy imparted to the plate by the

prescribed initial velocity distribution at time zero.

WFORCE The work input to the structure.

POWMP1 The power = $F_{\sim n} \dot{q}_n$ at time t_n .

Card(s) 67

DIS(I), I=1, NDT 5D15.7

where

DIS(I) The total displacement (or rotation) of degree of freedom I at time cycle ITT.

Card(s) 68

DISP(I), I=1, NDT 5D15.7

where

DISP(I) The total displacement (or rotational) of degree of freedom I at time cycle (ITT-1).

Card(s) 69

VEL(I), I=1, NDT 5D15.7

where

VEL(I) The velocity of the Ith degree of freedom at time cycle ITT.

Card(s) 70

FLVA(I), I=1, NDT 5D15.7

where

FLVA(I) The equivalent load, corresponding to nonlinear effects, applied to degree of freedom I at time cycle ITT.

If IOP5=0, Card(s) 71 are skipped.

Card(s) 71

UCF2(I), I=1, NB 5D15.7

where

UCF2(I) The force applied to the Ith constrained degree of freedom at time cycle ITT.

Card(s) 72

STOR(I), I=1, NDT 5D15.7

where

STOR(I) The prescribed externally-applied force at degree of freedom I at time cycle ITT.

Card(s) 73

TAUSS(I,J,K), (I=1, NET), (J=1, MNSLT4), (K=1,9) 5D15.7

Card(s) 74

TAUEE(I,J,K) 5D15.7

Card(s) 75

TAUSE(I,J,K) 5D15.7

where

TAUSS(I,J,K) }
TAUEE(I,J,K) } The stresses σ_{xx} , σ_{yy} , σ_{xy} , respectively at
TAUSE(I,J,K) } the Jth depthwise/sublayer integration station (J is a function of both location and sublayer) at the Kth spanwise Gaussian integration station of the Ith element at time cycle ITT.

If no X-direction stiffeners are present, Card(s) 76 will not be included.

Card(s) 76

TAGSS(I,J,K), (I=1, NXST), (J=1, MNSLT4), (K=1,3) 5D15.7

where

TAGSS(I,J,K) The normal stress, σ_{xx} , at the Jth depthwise/sublayer integration station at the Kth spanwise Gaussian integration station of the Ith individual X-direction stiffener at time cycle ITT.

If no Y-direction stiffeners are present, Card(s) 77 will not be included.

Card(s) 77

TSGEE(I,J,K), (I=1, NYST), (J=1, MNSLT4), (K=1,3) 5D15.7

where

TSGEE(I,J,K) The normal stress, σ_{yy} , at the Jth
depthwise/sublayer integration station at
Kth spanwise Gaussian integration station
of the Ith individual Y-direction stiffener
at time cycle ITT.

4.5 Guidelines for User-Prepared Array Dimensions

In addition to providing input data cards for the PLATE program, the user is required to provide appropriate dimensions in the dummy main program for a number of vectors and arrays used in the program. The sole purpose of the dummy main program is to provide dimensions for those arrays and vectors which are variably dimensioned in subroutines of the PLATE program. The dummy main program then calls subroutine MAINP which is the main controlling subroutine for PLATE program flow.

The justification for the variable dimensioning of arrays and the corresponding need to provide fixed dimensions in the present dummy main program is based on program efficiency. Computer core storage requirements contribute, along with computer execution time, to the total cost of a run. In general, those vectors and arrays which contribute most to the computer core storage requirements have dimensions which are based on certain problem parameters (e.g. number of elements, number of nodes, number of mechanical sublayers, etc.) and, thus, are problem dependent. For 3-d plate analyses, where the dimensions and thus storage requirements grow rapidly as the number of elements is increased, maximum program efficiency (in terms of computer core storage) is obtained by providing dimensions for these arrays (vectors) which correspond exactly to the pertinent parameters of the plate structure being analyzed.

A complete listing of the dummy main program for the PLATE program is given on the following pages. The user need be concerned only with that (first) portion of the dummy main program related to array (vector) dimensioning. Shown

are the names and associated dimensions (given as variables and constants where appropriate) of those arrays which must be user-dimensioned. The definition of each dimension variable is given directly below the full list of arrays (vectors) to be dimensioned.

The user is required to prepare a FORTRAN IV DIMENSION statement which contains all of the arrays and vectors shown with the appropriate numerical dimensions substituted in place of dimension variables. This DIMENSION statement should be inserted after the list of dimension variable definitions as shown in the program listing. The dimension variables NNT, NPT, MAXEL, MNSL, MNXST, MNYST, NRSS, and MNNSA may be determined exactly, whereas the dimension variables MNC, NB, NBE, and MBWE (which are more difficult to determine exactly) may be over-estimated on the first run of a given problem and then adjusted to the correct values in subsequent runs of the same problem.

In no case may a dimension variable be set equal to zero; the minimum value for a dimension variable (all dimension variables are integers) is 1. Thus, for example, if no X-direction stiffeners are present then the dimension variable MNXST (maximum number of individual X-direction stiffeners) is set equal to MNXST=1 (rather than zero). There is no restriction on the maximum value which can be assigned to a dimension variable.

Seven of the dimension variables, namely MAXEL, MNSL, MNXST, MNYST, NBE, MBWE, and MNC, are given as input to the PLATE program (see Card 1 of Subsection 4.2). The values specified for these variables on Card 1 of the input data cards must be the same as the values assigned to these variables for dimensioning purposes.

Finally, the user should be aware of the fact that improperly dimensioned arrays (vectors) can be a chief source of anomalous results for structural response. In particular, if the value of a dimension variable is smaller than the correct value, then data from the corresponding array or vector may be incorrectly accessed during program execution. In such cases, program execution often proceeds without apparent error, but response predictions will generally be incorrect. Thus, great care should be taken by the user in preparing the DIMENSION statement for the dummy main program. Examples of proper DIMENSION statements may be found in the sample problems of Section 7.

C	PLATE 1 COMPUTER CODE.	MAIN0000
C		MAIN0001
C	ASRL TR 154-14.....ORIGINAL REPORT VERSION OF PROGRAM	MAIN0002
C		MAIN0003
C	COPYRIGHT (C) MASSACHUSETTS INSTITUTE OF TECHNOLOGY 1980	MAIN0004
C		MAIN0005
C	THIS IS THE SMALL STRAIN VERSION.	MAIN0006
C		MAIN0007
C	ILLUSTRATIVE EXAMPLE FOR PLATE PROGRAM - FULL MODEL.	MAIN0008
C		MAIN0009
C	THIS DUMMY MAIN PROGRAM FOR THE PLATE PROGRAM REQUIRES SUBROUTINES:	MAIN0010
C	ARRT,ASSEMK,BCONMK,CMASSP,EAROW,EXTL,FACT,GAUSS,	MAIN0011
C	INCOND,LMASSP,MAINP,MESHPA,MESHPM,OMULT,PRINT,	MAIN0012
C	PRTOP,PSTRN,RCON,RPLATE,SFDM,SOLV,SPRING,STRESA,	MAIN0013
C	STRESC,STRESP,TSTEP.	MAIN0014
C		MAIN0015
C	DUMMY MAIN PROGRAM WHICH PROVIDES DIMENSIONS FOR THOSE ARRAYS	MAIN0016
C	(VECTORS) WHOSE DIMENSIONS ARE PROBLEM DEPENDENT.	MAIN0017
C	THE FOLLOWING ARRAYS MUST BE DIMENSIONED BY THE USER AS SHOWN;	MAIN0018
C	DIMENSION DELD(NDT),DIS(NDT),DISP(NDT),DISM1(NDT),DISM2(NDT),	MAIN0019
C	FLN(NDT),FLVA(NDT),FLVM(NDT),FLVP(NDT),ELV(NDT),VEL(NDT),ICOL(NDT)	MAIN0020
C	,INUM(NDT),KROW(NDT),NDEX(NDT),STOR(NDT),STF(MNC),AMASS(MDIM),	MAIN0021
C	NP(4,MAXEL),NODE(24*MAXEL),TAUSS(MAXEL,4*MNSL,9),	MAIN0022
C	TAUSE(MAXEL,4*MNSL,9),TAUEE(MAXEL,4*MNSL,9),EPSSI(9,MAXEL),	MAIN0023
C	EPSSO(9,MAXEL),EPEEI(9,MAXEL),EPEEO(9,MAXEL),EPSEI(9,MAXEL),	MAIN0024
C	EPSEO(9,MAXEL),NBC(NB),BC(NB),RFM(NBE,MBWE),ILAST(NBE),UCF1(NBE),	MAIN0025
C	UCF2(NBE),XG(NNT),YG(NNT),ZG(NNT),XGI(NNT),YGI(NNT),	MAIN0026
C	TAGSS(MNXST,4*MNSL,3),LNXS(MNXST),XSPROP(7,MNXST),MATXS(MNXST),	MAIN0027
C	TSGEE(MNYST,4*MNSL,3),LNYS(MNYST),YSPROP(7,MNYST),MATYS(MNYST),	MAIN0028
C	LNRS(NRSS),ISRS(NRSS),SC(5,NRSS),NVSA(MNNSA),NCON(4,MNNSA)	MAIN0029
C		MAIN0030
C	WHERE,	MAIN0031
C	NNT ▪ TOTAL NUMBER OF NODES IN THE ASSEMBLED FINITE-ELEMENT	MAIN0032
C	MODEL.	MAIN0033
C	NDT ▪ TOTAL NUMBER OF DEGREES OF FREEDOM IN THE ASSEMBLED	MAIN0034
C	FINITE-ELEMENT MODEL = 6*NNT.	MAIN0035
C	MNC ▪ ESTIMATED NUMBER OF WORDS OF STORAGE FOR THE ASSEMBLED	MAIN0036
C	STIFFNESS MATRIX (LOWER TRIANGLE STORED BY ROWS FROM FIRST	MAIN0037
C	NONZERO TERM).	MAIN0038
C	MDIM ▪ DIMENSION OF ASSEMBLED MASS MATRIX.	MAIN0039
C	▪ NDT IF LUMPED MASS OPTION IS CHOSEN.	MAIN0040
C	▪ MNC IF CONSISTENT MASS OPTION IS CHOSEN.	MAIN0041
C	MAXEL ▪ NUMBER OF ELEMENTS IN FINITE-ELEMENT MODEL.	MAIN0042
C	MNSL ▪ MAXIMUM NUMBER OF MECHANICAL SUBLAYERS EMPLOYED.	MAIN0043
C	NOTE-- MNSL MUST BE LESS THAN OR EQUAL TO 5.	MAIN0044
C	NB ▪ ESTIMATED NUMBER OF CONSTRAINED DEGREES OF FREEDOM PRIOR	MAIN0045
C	TO ELIMINATION OF DUPLICATES.	MAIN0046
C	NDE ▪ ESTIMATED NUMBER OF CONSTRAINED DEGREES OF FREEDOM AFTER	MAIN0047
C	ALL DUPLICATES HAVE BEEN ELIMINATED (IF IOP5 = 1).	MAIN0048
C	▪ 1 IF IOP5 = 0	MAIN0049
C	MBWE ▪ ESTIMATED MAXIMUM BANDWIDTH OF ASSEMBLED STIFFNESS MATRIX	MAIN0050
C	AT A CONSTRAINED DEGREE OF FREEDOM (IF IOP5 = 1).	MAIN0051
C	▪ 1 IF IOP5 = 0	MAIN0052


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C MNXST = MAXIMUM NUMBER OF X-DIRECTION STIFFENERS. MAIN0053
C = 1 IF NO X-DIRECTION STIFFENERS. MAIN0054
C MNYST = MAXIMUM NUMBER OF Y-DIRECTION STIFFENERS. MAIN0055
C = 1 IF NO Y-DIRECTION STIFFENERS. MAIN0056
C NRSS = TOTAL NUMBER OF ELEMENT SIDES ON WHICH LINE RESTORING MAIN0057
C SPRINGS ARE LOCATED. MAIN0050
C = 1 IF NO RESTORING SPRINGS ARE PRESENT. MAIN0059
C MNSLT4 = 4*MNSL MAIN0060
C MNNSA = MAXIMUM NUMBER OF NODES REQUESTED FOR STRAIN OUTPUT (IF MAIN0061
C IOPB=1). = 1 IF IOPB = 0 MAIN0062
C MAIN0063
C IMPLICIT REAL*8(A-H,O-Z) MAIN0064
C DIMENSION DELD(390),DIS(390),DISP(390),DISM1(390),DISM2(390), MAIN0065
C 2FLN(390),FLVA(390),FLVM(390),FLVP(390),ELV(390),VEL(390),ICOL(390) MAIN0066
C 3,INUM(390),KROW(390),NDEX(390),STOR(390),STF(14037),AMASS(14037), MAIN0067
C 4NP(4,40),NODE(1152),TAUSS(48,12,9),TAUSE(48,12,9),TAUEE(48,12,9), MAIN0068
C 5EPSSI(9,48),EPSSO(9,48),EPEEI(9,48),EPEEO(9,48),EPSEI(9,48), MAIN0069
C 6EPSEO(9,48),NBC(60),BC(60),RFM(60,60),ILAST(60),UCF1(60),UCF2(60), MAIN0070
C 7XG(65),YG(65),ZG(65),XGI(65),YGI(65),TAGSS(1,12,3),LNXS(1), MAIN0071
C 8XSPROP(7,1),MATXS(1),TSGEE(1,12,3),LNYS(1),YSPROP(7,1),MATYS(1), MAIN0072
C 9LNRS(1),ISRS(1),SC(5,1),NVSA(6),NCON(4,6) MAIN0073
C COMMON/BAS/NDT,NET,MN,NB,NIRREG,MNC MAIN0074
C COMMON /INOUT/ MREAD,MWRITE,MPUNCH MAIN0075
C DEFINE CARD READER, LINE PRINTER AND CARD PUNCH UNIT NUMBERS. MAIN0076
C MREAD = 5 MAIN0077
C MWRITE = 6 MAIN0078
C MPUNCH = 7 MAIN0079
C READ(MREAD,500)MAXEL,MNSL,MNXST,MNYST,NBE,MBWE,MNC MAIN0080
500 FORMAT(8I10) MAIN0081
C WRITE(MWRITE,600) MAIN0082
C WRITE(MWRITE,610) MAXEL MAIN0083
C WRITE(MWRITE,620) MNSL MAIN0084
C WRITE(MWRITE,630) MNXST MAIN0085
C WRITE(MWRITE,640) MNYST MAIN0086
C WRITE(MWRITE,650) NBE MAIN0087
C WRITE(MWRITE,660) MBWE MAIN0088
C WRITE(MWRITE,670) MNC MAIN0089
600 FORMAT('1 PLATE 1 COMPUTER CODE (SMALL STRAIN THEORY) : USER INPUT MAIN0090
C + FOR ARRAY DIMENSIONS') MAIN0091
610 FORMAT(' ', 'MAXEL =', I10) MAIN0092
620 FORMAT(' ', 'MNSL =', I10) MAIN0093
630 FORMAT(' ', 'MNXST =', I10) MAIN0094
640 FORMAT(' ', 'MNYST =', I10) MAIN0095
650 FORMAT(' ', 'NBE =', I10) MAIN0096
660 FORMAT(' ', 'MBWE =', I10) MAIN0097
670 FORMAT(' ', 'MNC =', I10) MAIN0098
C MNSLT4=MNSL*4 MAIN0099
C CALL MAINP(DELD,DIS,DISP,DISM1,DISM2,FLN,FLVA,FLVM,FLVP,ELV, MAIN0100
C 2VEL,ICOL,INUM,KROW,NDEX,STOR,STF,AMASS,NP,NODE,TAUSS,TAUSE,TAUEE, MAIN0101
C 3EPSSI,EPSSO,EPEEI,EPEEO,EPSEI,EPSEO,NBC,BC,RFM,ILAST,UCF1,UCF2, MAIN0102
C 4XG,YG,ZG,XGI,YGI,TAGSS,LNXS,XSPROP,MATXS,TSGEE,LNYS,YSPROP,MATYS, MAIN0103
C 5LNRS,ISRS,SC,MAXEL,MNSL,MNSLT4,NBE,MBWE,MNXST,MNYST,NVSA,NCON) MAIN0104
C CALL EXIT MAIN0105

```

END

- NOTE:
1. The dimension 6400 for arrays STF and AMASS was obtained by the procedure described in items 1 through 4 on page 100. Also, see Figs. 16 and 17a.
 2. For detailed instructions on establishing dimensions and input data, see the example problems discussed in Section 7.

4.6 Guidelines for User-Prepared Subprograms

The timewise solution of the governing equations of motion for the structure (Eq. 2.1) is accomplished by employing the Houbolt finite-difference operator. As shown in detail in Appendix A, this results in the following matrix recurrence equation

$$\left[\frac{2}{(\Delta t)^2} \tilde{M} + \tilde{K} + \tilde{K}_S \right] \tilde{q}_{m+1}^* = \tilde{F}_{m+1} + \tilde{F}_{m+1}^{NL} + \frac{2}{\Delta t} \tilde{M} (\dot{\tilde{q}}_m^* + \frac{1}{\Delta t} \tilde{q}_m^*) \quad (4.1)$$

where \tilde{M} , \tilde{K} , \tilde{K}_S , \tilde{F} , \tilde{F}^{NL} , and \tilde{q}^* are defined in Subsection 2.3, and $\dot{\tilde{q}}^*$ is the vector of nodal generalized velocities. The subscripts $m+1$ and m refer to quantities evaluated at discrete time instants $t_{m+1} = (m+1) \Delta t$ and $t_m = m \Delta t$, where m is the time step number. The matrices \tilde{M} , \tilde{K} , \tilde{K}_S , and vector \tilde{F}^{NL} are internally generated and are assumed to be known.⁺ However, the vector \tilde{F}_{m+1} , which is the vector of prescribed externally-applied nodal loads at time t_{m+1} must be provided by the user to represent the spatial and temporal distribution of the external load being applied to the plate structure.

In general, the displacement vector \tilde{q}_m^* is known from the solution of Eq. 4.1 at time t_m , and the velocity vector, $\dot{\tilde{q}}_m^*$ is calculated from the Houbolt finite-difference expression and is thus also known. However, values of the displacement and velocity vector at time zero, \tilde{q}_0^* and $\dot{\tilde{q}}_0^*$, required for the solution of displacements \tilde{q}_1^* at time t_1 are not known and must be provided by the user as initial conditions on the governing matrix equation of motion (which is a second-order differential equation). These initial (time zero) conditions on the displacement and velocity vectors must correspond to the spatial distribution of displacement and velocity for the problem under consideration.

Subroutines INCOND and EXTL have been included in the PLATE program to provide, respectively, the values of \tilde{q}_0^* and $\dot{\tilde{q}}_0^*$ (initial conditions), and the external loading vector, \tilde{F}_{m+1} , at each time step. Because of the many feasible spatial distributions for \tilde{q}_0^* , $\dot{\tilde{q}}_0^*$, and \tilde{F}_{m+1} and temporal distribution of \tilde{F} , the writing of self-contained, automated logic for subroutines INCOND and EXTL has been deemed inefficient and impractical. Instead, the user is required to

⁺The vector \tilde{F}_{m+1}^{NL} is estimated by linear extrapolation from earlier known values (\tilde{F}_m^{NL} and \tilde{F}_{m-1}^{NL}) by $\tilde{F}_{m+1}^{NL} \doteq 2 \tilde{F}_m^{NL} - \tilde{F}_{m-1}^{NL}$.

write the internal logic for these two subroutines corresponding to the problem under consideration.

Guidelines for the preparation of subroutines INCOND and EXTL are given in Subsections 4.6.1 and 4.6.2, respectively. Both subroutines must be prepared for each execution of the PLATE program even if the values of \ddot{q}_0^* , \dot{q}_0^* and/or F are zero. For the sake of simplicity, no READ statements should appear in either subroutine; all data should be specified in the user-prepared internal logic. FORTRAN IV WRITE statements should, however, be included in these subroutines to verify input data. A simple example of internal logic is given in each of Subsections 4.6.1 and 4.6.2; additional examples may be found in the sample problem of Section 7.

It is assumed that the user has a working knowledge of the FORTRAN IV computer language and thus no specific discussion of the programming language has been included. Although maximum flexibility has been maintained by requiring the user to prepare these subroutines, automated versions of subroutines INCOND and EXTL could be prepared by the user (or programming personnel) to accommodate a variety of initial condition and external loading options often encountered in a given analysis or design group.

4.6.1 User-Prepared Subroutine INCOND (PLATE Program)

The user is required to write (in FORTRAN IV) a subroutine which generates the initial velocity for each degree of freedom, VEL(I), I=1, NDT, and the initial displacement, DISP(I), I=1, NDT, for each degree of freedom in the finite-element mesh. This subroutine is called prior to the first time cycle for each run of the PLATE code. The subroutine should be prepared as follows:

```
SUBROUTINE INCOND(DISP,VEL,NP,NODE,XGI,YGI)
  IMPLICIT REAL*8(A-H,O-Z)
  DIMENSION DISP(1),VEL(1), NP(4),NODE(1), XGI(1),YGI(1)
  COMMON/BAS/NDT,NET,MN,NB,NIRREG,MNC
      Insert User-Code to generate
      VEL(I),I=1,NDT
      DISP(I),I=1,NDT
  RETURN
  END
```

The first four cards and final two cards of subroutine INCOND must be as shown.

The arrays NP, NODE, XGI, and YGI, and variables NDT, NET are available to the user and contain the following information:

NP(I,J)	The <u>global</u> node number associated with the Ith <u>element</u> node of element J.
NODE(K)	The assembly list associating element degrees of freedom with global degrees of freedom. If K is defined as $K = 24*(J-1)+I$, then NODE (K) is the global degree of freedom number associated with the Ith element degree of freedom of element J.
XGI(I) } YGI(I) }	The global X and Y coordinates, respectively, of the Ith global node at time zero.
NDT	The total number of degrees of freedom in the finite-element mesh.
NET	The total number of elements in the finite-element mesh.

The information in these arrays may be used as required but must not be altered by the user-supplied internal logic.

The user should note that the conventions adopted for global node numbering are preserved for the present subroutine. Also note that in most cases (such as impulsively-loaded plates) the vector DISP(I), I=1,NDT is set equal to zero (zero initial displacement) and certain of the degrees of freedom are given an initial velocity. For example, the following set of statements generates zero initial displacement for all degrees of freedom, and an initial velocity of 2794 in/sec for the transverse w degree of freedom for nodes 1 through 9:

```
DO 10 I=1,NDT
  DISP(I) = 0.0D0
10  VEL(I) = 0.0D0
```

```

DO 20 I=1,9
II      = (I-1)*6+3
20  VEL(II) = 0.2794D+04

```

4.6.2 User-Prepared External-Loading Subroutine EXTL (PLATE Program)

The user is required to write a computer subroutine which generates the vector of prescribed externally-applied forces (ELV(I), I=1,NDT) applied to each global degree of freedom at time t_m . It should be emphasized that this vector of externally-applied (time-dependent) nodal forces corresponds to the total load applied at that instant of time. This subroutine is called for each cycle starting with the first cycle in the timewise solution. Thus, the user is required to define the spatial distribution of the external forces at each time instant (i.e., at each time $t = ITT*DELTAT$, where ITT is the current cycle number and DELTAT is the time step size, Δt). The subroutine should be prepared as follows:

```

SUBROUTINE EXTL (ELV,ITT,NP,NODE,XGI,YGI)
IMPLICIT REAL*8(A-H,O-Z)
DIMENSION ELV(1), NP(4,1), NODE(1), XGI(1), YGI(1)
COMMON/BAS/NDT,NET,MN,NB,NIRREG,MNC
COMMON/TIM/DELTAT,TIMEF,ITIMEF,INCR,IOUT,TIME,ITIME
      Insert user-code to generate the spatial distribution
      of the external forces, ELV(I), I=1, NDT, at time
      t=ITT*DELTAT. Note that if no external forces are
      present in the current run of the PLATE code, the
      vector ELV(I), I=1, NDT must be set equal to zero.

RETURN
END

```

The arrays (vectors) NP,NODE,XGI, and YGI, and variables NDT and NET retain the definitions given in Subsection 4.6.1 (it should be emphasized, however, that XGI(I) and YGI(I) are the global X and Y coordinates, respectively, of the Ith global node at time zero) and the parameters ITT and DELTAT have been defined in the preceding discussion. It should also be noted that the contents of the vector ELV(I), I=1, NDT are modified after the call to subroutine EXTL.

As an example, assume that a nodal force, F , of constant amplitude, but varying in time, of the form

$$F = 100 \sin(25t)$$

is applied to the transverse w degree of freedom at nodes 1 through 5. The following set of statements could be inserted in subroutine EXTL to generate the necessary external loading vector at each time step:⁺

```
      DO 10 I=1,NDT
10     ELV(I)      = 0.0D0
      DO 20 I=1,5
      II=(I-1)*6+3
20     ELV(II)=100.0D0*SIN(25.0D0*ITT*DELTAT)
```

4.7 Description of the Output

The printed output begins with a reiteration of the program input which defines the problem being solved. Although portions of the output associated with mesh generation are different for the auto-mesh versus manual mesh options, sufficient information is given so that the user can verify the accuracy of the input data provided. The initial output which is generated on each run of the PLATE program is summarized in the following categories:

Dimension Parameter Data

The variables input on Card 1 are output to verify these dimension parameters.

Finite Element Mesh Information (Auto-Mesh Generation)

Geometric and material data for the plate and general mesh subdivision information is first reiterated. Next, the nodal connectivity information (which is the set of global node numbers assigned to the 4 nodes of each element) is output. The user-selected boundary condition for each side of the plate is then printed, and the specific constrained degrees of freedom are output in ascending order with no duplicates. Finally, if X and/or Y direction stiffeners are present, data for each stiffener are printed. These data are given in terms of each individual (as renumbered -- see Subsection 4.1.4)

⁺This information could be supplied in any other allowable FORTRAN form.

stiffener and include the element number on which the stiffener is located, material type, thickness, width, Young's modulus, Poisson's ratio, material density, normalized location on the element, and the offset distance of the stiffener.

Finite-Element Mesh Information (Manual-Mesh Generation)

This output is similar in form to that obtained when the auto-mesh generation procedure is employed. In this case, however, most of the output is simply a reiteration of data input by the user. This output should be used to verify the accuracy of the user-prepared input data.

Mass Modeling Chosen

A message is printed indicating which mass model (lumped or consistent) has been chosen by the user.

Storage of Global Stiffness Matrix

The actual number of words of storage required for the assembled stiffness is output. If too little storage has been allowed by the user, the run is terminated and a message indicating this is printed.

Stress-Strain Data for Each Material Type

The total number of material types selected by the user is output and the following data are then printed for each material type: the coordinate pairs (stress, strain) which define the piecewise linear approximation to the actual stress-strain curve, the yield stress of each mechanical sublayer, and the strain rate parameters for that material type.

Time-Step Information

The time-step size, Δt , final time and final increment number, and the number of cycles between regular printouts for the present run are output.

Print Options

A list is printed of those quantities which will be output at each regular print cycle. This information corresponds to those print options exercised by the user as well as all pertinent data necessary for any given option. For example, if option IOP3 is exercised, a list is printed of

plate element numbers for which Gaussian station strain output is requested.

Line Restoring Spring Data

If line restoring springs are present, input data corresponding to each linear-elastic line restoring spring is reiterated. These data include the element number and element side number on which the line restoring spring is located, and the five spring constants input by the user.

Reference Time-Step Size

An eigen-analysis is performed and the following reference data are generated and output: the highest natural frequency, ω_{\max} , for the equivalent linear finite-element model, a reference time step size, $(\Delta t)_{\text{Ref.}} = 2/\omega_{\max}$ (which is the stability criterion for the Central Difference operator) of a corresponding linear dynamic system, and finally a reference time-step size, $(\Delta t_{\max}^{\text{CD}})_{\text{Ref}} = 0.8(\Delta t)_{\text{Ref}}$; the factor 0.8 is introduced to account for large-deflection effects when using the Central Difference operator [1-3]. The PLATE program, however, utilizes the Houbolt finite-difference operator, and this final reference time step size, $(\Delta t_{\max}^{\text{CD}})_{\text{Ref}}$, may be used to choose the actual time-step size as discussed in Subsections 2.3 and 4.8.2.

Dimensions Related to Reaction Force Output (If Applicable)

If reaction force output has been selected (IOP5), an operation is performed which extracts and stores in array RFM the rows of assembled stiffness matrix corresponding to the constrained degrees of freedom. During this operation, the extracted row of the assembled stiffness matrix which has the largest bandwidth is identified. This row number (which must correspond to a constrained degree of freedom number) and the corresponding bandwidth are printed. If the calculated maximum bandwidth at a constrained degree of freedom (printed) is larger than the user estimates (MBWE on data input Card 1; also used to dimension array RFM) of this quantity, the run is terminated and a message to this effect is printed; the user should make appropriate changes to MBWE on Card 1 of input data and to the dimension of RFM.

This completes the initial output generated by the PLATE program. All other output is in the form of structural response data at user-specified intervals; these data are also output prior to the first time cycle to verify initial geometry and displacement conditions, and at the end of the first time cycle. The data output corresponds to those output options selected by the user, and only that output selected by the user will appear. However, for the sake of completeness, the output generated by each of the print options is shown. The following output is generated every INCRT time cycles:

```

*** INCR. NO. =          TIME =          SEC.
NODE   U    V    W    PSIX   PSIY   TWIST   X-POS.   Y-POS.   Z-POS.
  1
  2
  3
  .
  .
  .

```

REACTION FORCES AT CONSTRAINED NODES⁺

```

NODE   RX(LBS)   RY(LBS)   RZ(LBS)   MX(LBS-IN)   MY(LBS-IN)   MXY(IN-IN-LBS)
  4
 13
 24
  .
  .
  .
  .

```

⁺Note that the "reaction force" MXY multiplied by its associated generalized displacement χ results in a quantity with units of energy:IN-LB.

STRAIN COMPONENTS, PRINCIPAL(TENSILE) STRAIN AND DIRECTION AT CENTROID OF EACH ELEMENT

ELEM.	EPS-X STRAIN		EPS-Y STRAIN		SHEAR STRAIN		PRINC.STRAIN(T)		DIRECTION(DEG)	
	INNER	OUTER	INNER	OUTER	INNER	OUTER	INNER	OUTER	INNER	OUTER

1
2
3
.
.
.

STRAIN COMPONENTS, PRINCIPAL(TENSILE) STRAIN AND DIRECTION AT USER-SPECIFIED NODES

NODE	EPS-X STRAIN		EPS-Y STRAIN		SHEAR STRAIN		PRINC.STRAIN(T)		DIRECTION(DEG.)	
	INNER	OUTER	INNER	OUTER	INNER	OUTER	INNER	OUTER	INNER	OUTER

7
10
14
18
.
.
.

STRAIN COMPONENTS, PRINCIPAL(TENSILE) STRAIN AND DIRECTION AT GAUSSIAN STATIONS

FOR SELECTED ELEMENTS

RESULTS FOR ELEMENT NUMBER [LNUM]

STA.	EPS-X STRAIN		EPS-Y STRAIN		SHEAR STRAIN		PRINC. STRAIN(T)		DIRECTION(DEG.)	
	INNER	OUTER	INNER	OUTER	INNER	OUTER	INNER	OUTER	INNER	OUTER

1
2
3
.
.
.

(This set of statements is repeated for each user-specified element.)

STRAIN COMPONENTS, PRINCIPAL(TENSILE) STRAIN AND DIRECTION, AND ELONGATIONS AT SPECIFIED ADDITIONAL POINTS

POINT NO.	SURFACE	EPS-X STRAIN	EPS-Y STRAIN	SHEAR STRAIN	ELONG. (DIR.1)	ELONG. (DIR.2)	PRINC.STRN(T)	DIRECTION(DEG)
1	INNER							
1	OUTER							
2	INNER							
2	OUTER							
3	INNER							
.								
.								
.								

STRAIN, EPS-XX, AT GAUSSIAN STATIONS ON SPECIFIED X-DIRECTION STIFFENERS

STIFFENER NUMBER	STATION 1		STATION 2		STATION 3	
	INNER	OUTER	INNER	OUTER	INNER	OUTER
16						
18						
21						
.						
.						
.						

STRAIN, EPS-YY, AT GAUSSIAN STATION ON SPECIFIED Y-DIRECTION STIFFENERS

STIFFENER NUMBER	STATION 1		STATON 2		STATION 3	
	INNER	OUTER	INNER	OUTER	INNER	OUTER
2						
3						
10						
13						
.						
.						
.						

SYSTEM ENERGIES (IN-LB)

WORK INPUT TO STRUCTURE = [EWORK]
 STRUCTURE KINETIC ENERGY = [CINET]
 STRUCTURE ELASTIC ENERGY = [ELAST]
 STRUCTURE PLASTIC ENERGY = [PLASTW]
 ENERGY STORED IN ELASTIC RESTRAINTS = [SPREN]

where

INCR. NO. = Current cycle number
 TIME = Current time in seconds
 NODE = Global node number at which the quantity is being evaluated. For displacement output, all nodes are processed; for reaction force output, those nodes which are constrained are processed; and for nodal-average strain output, only those nodes specified by the user are processed.

U	}	= The current displacement $u, v, w, \theta = \partial w / \partial x, \psi = \partial w / \partial y,$ and $\chi = \partial^2 w / \partial x \partial y,$ respectively, at the node.
V		
W		
PSIX		
PSIY		
TWIST		
X-POS	}	= The current global X, Y, and Z coordinates of a node.
Y-POS		
Z-POS		
RX (LBS)	}	= The generalized reaction forces, $R_x, R_y,$ and $R_z,$ and moments, $M_x, M_y,$ and M_{xy} at a constrained node.
RY (LBS)		
RZ (LBS)		
MX (LBS-IN)		
MY (LBS-IN)		
MX (LBS-IN-IN)	}	

EPS-X }
 EPS-Y } = The strain components $\tilde{\epsilon}_{xx}$, $\tilde{\epsilon}_{yy}$, and $\tilde{\epsilon}_{xy}$, respectively;
 SHEAR } the printed shear strain $\tilde{\epsilon}_{xy}$ is the engineering value
 -- which is twice its tensorial counterpart.

PRINC.STRAIN(T) = The (maximum) principal tensile strain component.
 If all principal strains are compressive, a value
 of 0.0 is printed.

DIRECTION(DEG.) = The direction in degrees, measured from the positive
 global X direction, of the maximum principal tensile
 strain.

INNER = Indicates strain component is evaluated at the inner
 surface of the plate (or stiffener).

OUTER = Indicates strain component is evaluated at the outer
 surface of the plate (or stiffener).

LNUM = Element number for which Gaussian station strain
 output is given.

STA. = Gaussian station number at which strain data is
 output. A 3 by 3 spanwise Gaussian integration rule
 is used and the strains are printed at each of these
 nine Gaussian stations. The location of these sta-
 tions on an element is given in terms of normalized
 coordinates ξ and η and the local (element) x, y
 coordinate locations (assuming element node number 1
 has local coordinates (x,y) = (0,0) can be obtained
 from the formulas

$$x = a(1+\xi)/2$$

$$y = b(1+\eta)/2$$

where a and b are the x and y dimensions of the ele-
 ment ξ and η take on the following values at
 each station:

<u>STATION NUMBER</u>	<u>ξ VALUE</u>	<u>η VALUE</u>
1	-0.774597	-0.774597
2	0.0	-0.774597
3	0.774597	-0.774597
4	-0.774597	0.0
5	0.0	0.0
6	0.774597	0.0
7	-0.774597	0.774597
8	0.0	0.774597
9	0.774597	0.774597

- POINT NO. = The number of the additional strain point; this number is implicitly assigned by the user by the order in which additional-strain point information is input.
- ELONG. (DIR. 1) }
 ELONG. (DIR. 2) } = The relative elongation in the two user-specified directions
- STIFFENER NUMBER = The user-specified individual X or Y-direction stiffener number for which strain data are output.
- STATION 1 }
 STATION 2 }
 STATION 3 } = Spanwise Gaussian station on the X or Y-direction stiffener at which strain is calculated.
- ework = Work input to the structure.
- CINET = Current kinetic energy stored in the structure.
- ELAST = Current elastic strain energy stored in the structure
- PLAST = Total plastic work done on the structure (mechanical work dissipated during plastic flow).
- SPREN = Total energy stored in linear elastic restoring springs.

If continuation cards have been requested, a message is printed at the conclusion of the run indicating that a continuation deck has been punched and also indicating the cycle number at which the continuation will begin.

4.8 Guides and Restrictions for Code Usage

The sequence of steps necessary to run the PLATE program (i.e., preparation of input data cards, dimensioning of arrays in the dummy main program, and writing of internal logic for subroutines INCOND and EXTL) have been discussed earlier in this section. In principle, this information is sufficient to execute the PLATE program. However, in practice, use of the PLATE program may be unnecessarily costly unless the options and features of the PLATE program are used efficiently.

The purpose of the present subsection is twofold: first, to discuss various techniques for efficient code usage in terms of computation time, computer core storage, and program cost, and second, to discuss the proper interpretation of program output. The present discussion is intended only to point out certain key areas for efficient code usage; additional areas will be identified by the user through experience.

4.8.1 Dimension of the Assembled Stiffness Matrix

The largest single block of storage required in the PLATE program is for the assembled stiffness matrix, \underline{K} . If consistent mass modeling is employed, an additional block of storage equal to that required for \underline{K} , is also required for the assembled mass matrix, \underline{M} .

The manner in which the assembled stiffness matrix is stored has been discussed in Subsection 4.1.5. The total storage requirements for \underline{K} are directly proportional to the total number of nodes in the finite-element mesh and the average semi-bandwidth of the assembled stiffness matrix. The total number of nodes can be reduced by using fewer elements in the mesh; generally, the mesh size will be dictated by geometry and accuracy considerations. However, the user should be alerted to the fact that an excessively-refined mesh will lead to excessive computer core storage requirements and computation time (the amount of computation time per time cycle is directly related to the total number of elements).

For a fixed mesh arrangement, the total storage requirements for \underline{K} can be reduced by minimizing the average semi-bandwidth of \underline{K} . For a rectangular

plate, this is accomplished by numbering the global nodes so that the difference between the lowest and highest global node number assigned to any given element is minimized. When the auto-mesh generation routine is used, global nodes are numbered sequentially left to right for the first row of nodes, then left to right for the second row of nodes, etc. Thus, the global nodes are numbered "fast" in the X-direction and "slow" in the Y-direction. The average semi-bandwidth will be minimized if the "fast" numbering direction has fewer nodes than the "slow" numbering direction. When using the auto-mesh generation routine, the side of the rectangular plate having the fewest nodes should always be aligned parallel to the global X-direction (the fast numbering direction).⁺ A similar argument can be made when using the manual mesh generation routine; number global nodes sequentially choosing the direction with fewest nodes as the "fast" numbering direction.⁺

The dimension, MNC, of K (vector STF in the PLATE program) can be estimated if the user has a knowledge of the assembly process in the finite-element method. Alternately, the PLATE program can be used directly to obtain the exact value of MNC for each new analysis as follows:

1. Prepare all input data, internal logic for subroutines INCOND and EXTL, and dimensions in the dummy main program for the analysis being considered, except
2. Set the value of MNC on input Card 1 equal to 1 and dimension STF(1) (and AMASS(1) if consistent mass modeling is elected).
3. Next run the PLATE program. The exact value of MNC will be calculated and output, and the run will terminate since the correct value of MNC is larger than the specified value (of 1 as per step 2) of MNC.
4. Change the value of MNC on Card 1 and the dimension of STF (and AMASS if consistent mass modeling is elected) to the correct value as calculated on the abbreviated run. Then proceed with the desired analysis.

If the user provides an estimate of MNC which is larger than the correct value, the analysis will proceed and the run will not be terminated. However,

⁺These guidelines have been followed in the present examples; see, for example, Figs. 17 and 19.

the correct value of MNC will always be calculated and printed as output so that the value of MNC used on Card 1 and for the dimension of STF (and AMASS if IMASS = 2) can be adjusted to the correct value for subsequent runs. Use of the correct value for MNC is advised to minimize storage requirements.

4.8.2 Selection of Time-Step Size

The total computation time is directly related to the number of time cycles, which is in turn related to the time step size Δt ; as Δt is decreased, more time cycles will be required to obtain solutions up to a given final time. Alternatively, the value of Δt cannot be set arbitrarily large because of solution convergence and stability considerations (see Subsection 2.3).

To aid the user in the selection of Δt , the PLATE program will calculate and output a reference value for Δt . For each new structural analysis or each new mesh arrangement of the same structure, it is recommended that an abbreviated run of the PLATE program be made to obtain the reference Δt as follows:

1. Prepare all input data cards, internal logic for subroutines INCOND and EXTL, and dimensions in the dummy main program for the actual analysis, except
2. Set ITIMEF=1 on Card 49 so that the program will terminate after one cycle of execution. The value of Δt (DELTAT on Card 50) can be set equal to any value.
3. When the PLATE program is run, the reference value of Δt will be calculated and printed as output. In subsequent runs, this value of Δt can be used as a reference; ITIMEF on Card 49 and DELTAT on Card 50 should be set equal to the desired values for the actual analysis.

The significance of the calculated reference Δt and its relation to "allowable" values of Δt has been discussed in Subsection 2.3. For initial runs of a given problem, it is recommended that the actual value of Δt used be between 2 and 6 times the reference Δt . In most cases, some numerical

experimentation will be necessary to determine if the solution has converged. It is recommended that the larger factor be used on the initial run, followed by a run using half the previous value of Δt . This process is repeated until the solution has converged. This convergence check can be carried out over only a portion of the desired analysis time to save computing costs, and the full time analysis can be carried out once a suitable value of Δt has been found.

Experience gained by the user with the PLATE program will help to minimize the amount of numerical experimentation necessary in later analyses. It is recommended that a record be kept of calculated vs. converged (allowable) Δt values. For example, experience gained to date suggests that for impulsively-loaded plates, a value of Δt four times the reference value will yield converged solutions.

4.8.3 Use of Lumped Mass vs. Use of Consistent Mass

The PLATE program provides an option for using either lumped or consistent mass modeling. The choice of mass modeling is not arbitrary and the user should understand the relative advantages and disadvantages of each.

Consistent mass modeling is, as indicated by its name, the more consistent approach from a variational standpoint. The kinetic energy of the plate element is approximated by employing an interpolation polynomial for the nodal velocities which is identical to that used for the nodal displacements. As shown in Appendix A, this approach leads to an element mass matrix which is in general fully populated; i.e., the kinetic energy includes coupling effects between various nodal velocities. The important fact is that the kinetic energy is based on an interpolation of velocities which is consistent with the interpolation of displacements used to define the potential energy.

On the other hand, lumped mass modeling is based on average element velocities rather than on interpolated element velocities. The average element velocities are calculated from a weighted average of the nodal velocities and a lumped (diagonal) mass matrix result. In effect, the total mass and mass moment of inertia of the element are calculated and then lumped at each node, the proportions going to each node being determined generally by element

geometry. For the present uniform-thickness, rectangular plate elements, equal portions (one-quarter of the total) are given to each node (see Appendix A for a detailed derivation).

The more important considerations, however, are computational efficiency and accuracy. The computer core storage requirement for an assembled consistent mass matrix is identical to that of the assembled stiffness matrix (i.e., MNC words of storage) whereas the assembled lumped mass matrix requires only NDT words of storage to store the diagonal entries.

In terms of computation time, slightly more time is required to perform operations with the banded assembled consistent mass matrix than is required with the diagonal assembled lumped mass matrix. Also, the reference Δt is inversely proportional to the maximum frequency in the assembled finite-element model. The maximum frequency when using consistent mass modeling is larger than that calculated when using the present lumped mass modeling.⁺ This could, in effect, reduce the maximum allowable time-step size for convergence and/or stability and thereby increase computation costs.

Because of its relative efficiency, lumped mass modeling is often used and comparative studies (e.g., Refs. 1 and 19-23) suggest that little or no loss in solution accuracy will be observed. Generally, computer core storage limitations dictate that lumped mass modeling be used. Theoretical-experimental correlation studies carried out using the PLATE program suggest that lumped mass modeling is both accurate and adequate when using relatively refined meshes. However, if computer storage limitations permit, the user may wish to carry out a series of comparative studies to assess the relative merits of the two mass models.

4.8.4 Selection of Output Options

Numerous useful options have been provided for the user which calculate and print displacement, strain, reaction force, and system energy information at user-specified intervals. The definition of these eight options (IOP1, IOP2, ... IOP8) is given on Card 51 of Subsection 4.2. Each option is useful, but not always necessary, and the user should be aware of the cost vs. value of each option before it is specified. The purpose of the present subsection is to discuss the implications of each option in terms of lines of output,

⁺ See Subsection 2.5.3 of Ref. 11 and Refs. 19-23.

computation time, and core storage. The question of the relative value of the output options (in particular for strain output) will be taken up in the next subsection.

In some installations, a portion of the cost of computing is related to the number of lines (or pages) of printout generated. In the following table, the number of lines of output generated by each output option at each printout cycle is given (note that these figures do not include headings):

<u>OPTION</u>	<u>DESCRIPTION</u>	<u>LINES/QUANTITY</u>
IOP1	Nodal displacements and current location	1/Node
IOP2	Element centroidal strains	1/Element
IOP3	Gaussian station strains on user-specified elements	9/Specified Element
IOP4	Strains at user-specified loca- tions	2/Specified Location
IOP5	Reaction forces at constrained nodes	1/Constrained Node
IOP6	Gaussian station strains on user-specified stiffeners	3/Specified Stiffener
IOP7	System energies	5 lines
IOP8	Strains at user-specified nodes	1/Specified Node

In terms of computer core storage requirements, only Options IOP5 and IOP8 require additional storage (see Subsection 4.5); Option IOP8 requires $5 \cdot \text{MNNSA}$ additional words of storage and Option IOP5 requires $\text{NBE} \cdot (\text{MBWE} + 3)$ additional words of storage, where the variables MNNSA, NBE, and MBWE are defined in Subsection 4.5. The use of Option IOP5 will require significantly more additional core storage than the use of Option IOP8.

The information printed when Options IOP1, IOP2, and IOP3 are exercised is available at the time of output and no additional computations are required. However, the information required for Options IOP4 through IOP8 must be calculated at each printout cycle before it can be printed; thus, additional computation time will be required if any of these options is exercised.

Experience to date suggests that these options do not add a significant amount of computation time, particularly if the number of printout cycles is only a small percentage of the total number of cycles (e.g. 1 printout cycle every 5 time cycles).

Total lines of printout and total additional computation time will be dependent on both the options selected as well as the total number of printout cycles requested. Both will often be dictated by the type of response information being sought and the degree of definition required in the time response. In general, it is recommended that displacement (IOP1) and system energy (IOP7) output be obtained for each run of the PLATE program. In view of increased storage and computation time, reaction force output (IOP5) should be sought only when necessary. Some form of strain output (IOP2, IOP3, IOP4, IOP6, and IOP8) should be obtained for each run of the PLATE program. A discussion of strain calculation and interpretation is given in the next subsection; it is important that the user understand these areas so that efficient use may be made of the strain output options.

4.8.5 Comments on Strain Calculation

The PLATE program provides options which allow the user to obtain strain output at element centroids, element Gaussian stations, nodal points, stiffener Gaussian stations, as well as other user-specified locations. This flexibility can be of great value to the user but care should be taken in the selection and interpretation of these strain results.

The strain-displacement relation employed for the present rectangular plate elements is given in Appendix A. Some nonlinear terms have been included in the membrane strains, but only linear terms are included in the bending behavior. Thus, the membrane nonlinearities have been assumed to be more significant than bending nonlinearities. The calculated distribution of strain may be quite different from element to element and in general will be different than the "exact" distribution; 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 strain distribution may agree with the exact distribution at one or more points within

an element, the location of these "best" points for monitoring strains cannot be readily determined. Also, strains will not be continuous along interelement boundaries or at nodes where two or more elements are joined.

Because of these facts, certain precautions should be taken by the user when assessing strain distributions in space and/or time. The type and amount of strain output will depend on the problem being considered and the region of the structure under closest scrutiny. If general strain distribution information is sought over a large portion of the structure. If detailed stress distribution information at various time instants is sought over a small region of the structure, then both nodal average strains and Gaussian station strains for elements in this small region could be employed. In either case, 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.

If strain time-history information is required at various points on the structure, these points may be specified as additional strain points (if the point does not already fall at or near a nodal point or element centroid) and the time histories can be obtained directly. Two recommendations should, however, be followed whenever strain time-history data are sought. First, 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. Second, if a point of interest falls near a node, nodal average strain information at that node should be preferred over the strain information obtained near the node (which is not averaged); in general, for elements (such as those in the PLATE program) exhibiting discontinuous strains at interelement boundaries (and therefore also at nodes), average strain values at nodes (or interelement boundaries) should

be preferred over the strain values evaluated near the node (or interelement boundary) using only the strain distribution from one element. 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. The actual strain level at which the "small strain" assumption becomes invalid has been examined and discussed in Ref. 14; the reader is referred to Ref. 14 for further information and guidance.

SECTION 5
USE OF THE CIVM-PLATE PROGRAM

5.1 Introduction

The CIVM-PLATE computer program is designed to predict the large-deflection, elastic-plastic, transient responses of initially-flat stiffened or unstiffened plates subjected to impact by a single idealized rigid spherical fragment. Much of the programming logic used in the CIVM-PLATE computer program is identical to that used in the PLATE program, as evidenced by the large number of computer subroutines common to both programs (Section 3).

The two key differences between the PLATE code and the CIVM-PLATE code are: (1) the PLATE program is designed to predict transient responses of initially-flat plate structures subjected to prescribed initial velocity distributions and/or prescribed externally-applied forces, whereas the CIVM-PLATE program is designed to predict transient responses of initially-flat plates subjected only to single fragment impact, and (2) the PLATE program allows the user to choose either consistent or diagonalized lumped mass modelling, whereas the CIVM-PLATE program uses only a diagonalized lumped mass model.

User interaction with the CIVM-PLATE program is reduced (by comparison with that required for the PLATE program) to the following two tasks:

- (1) Preparation of input data cards
- (2) Dimensioning of arrays in the dummy main program.

These two tasks are essentially identical to the corresponding tasks required when using the PLATE program. In the PLATE program, the user is required to prepare internal logic for subroutines INCOND and EXTL to define the initial velocity distribution and externally-applied force distribution. These types of loading are not included in the CIVM-PLATE program and thus no preparation of internal logic is required to use the CIVM-PLATE program; instead, the user is required to prepare additional input data cards (as described in Subsection 5.2) to define the geometry, initial position, and initial velocity components of the rigid spherical fragment, and several collision parameters.

With respect to structural geometry, nomenclature, and numbering conventions, material properties, time-step information, and output options, the CIVM-PLATE program is identical to the PLATE program. The discussions in Subsection 4.1 on the use of auto-mesh generation versus the use of manual mesh generation, conventions adopted in the auto-mesh and manual-mesh generation subroutines, numbering convention for stiffeners, and storage of the assembled stiffness matrix apply equally to the CIVM-PLATE program; the user may wish to review this information before attempting to run the CIVM-PLATE code. Also, a general overview of the collision-interaction analysis and solution procedure is given in Subsections 2.4 and 2.5, and the equations on which the CIVM-PLATE program is based are developed and discussed in Appendix B.

5.2 Input Information and Procedure

The structural geometry, nomenclature, material properties, output options and time step input required for a run of the CIVM-PLATE code is identical to that required for a run of the PLATE code. For a run of the CIVM-PLATE code using the auto-mesh generation procedure, cards 1 through 65 of Subsection 4.2 are input exactly as given in Subsection 4.2 with the following modifications/additions:

- (1) Cards 1 and 2 of Subsection 4.2 are modified as shown below.
- (2) Cards 66 through 72 are added following card 65 of Subsection 4.2

If the manual mesh generation procedure is used, the input data presented in Subsection 4.2 are modified exactly as described in Subsection 4.3; the above modifications/additions required for the CIVM-PLATE program still apply. 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 below.

Card 1 (Replaces Card 1 of Subsection 4.2)	<u>Format</u>
MAXEL, MNSL, MNXST, MNYST, NBE, MBWE, MNC, NIAN	8I10

where

MAXEL	}	Array dimension parameters as defined on Card 1 of Subsection 4.2
MNSL		
MNXST		
MNYST		
NBE		
MBWE		
MNC		
NIAN		An array dimension parameter used in the dummy main program and defined as the estimated maximum number of nodes which will be affected by a single impact.

Card 2 (Replaces Card 2 of Subsection 4.2) 20I4

IMESH, IMCONT, IPUNCH

where

IMESH	}	Mesh, continuation, and punched output options as defined on Card 2 of Subsection 4.2
IMCONT		
IPUNCH		

Card 66 (Follows Card 65 of Subsection 4.2)

XF, YF, ZF 5D16.7

where

XF	}	The global X, Y, and Z coordinates respectively, of the centroid of the spherical fragment at time zero. These coordinates must be chosen so that no plate/ fragment overlap occurs at time zero.
YF		
ZF		

Card 67

VF(1), VF(2), VF(3) 5D16.7

where

VF(1)	}	The translational velocity components (in/sec) of the fragment in the global X, Y, and Z directions, respectively, at time zero.
VF(2)		
VF(3)		

Card 68

OMEGF(1), OMEGF(2), OMEGF(3) 5D16.7

where

OMEGF(1)	}	The rotational velocity components (rad/sec) of the fragment about the global X, Y, and Z directions, respectively, at time zero.
OMEGF(2)		
OMEGF(3)		

Card 69

RF, FMASS, FMOI 5D16.7

where

RF	The radius of the spherical fragment (in).
FMASS	The total mass of the spherical fragment (lb-sec ² /in).
FMOI	The mass moment of inertia of the fragment about its c.g. (lb-sec ² -in).

Card 70

COEFR, FRNC, LEFF 5D16.7

where

COEFR	The coefficient of restitution between the fragment and the impacted plate inner surface; $0 \leq \text{COEFR} \leq 1$, 1 for perfectly elastic, 0 for perfectly inelastic, $0 < \text{COEFR} < 1$ for intermediate.
FRNC	The coefficient of friction between the fragment and the plate inner surface.
LEFF	The radius of a circle from the point of impact on the plate by the fragment to the "boundary of the impact-affected region for a single impact".

= 0 means that L_{eff} is assumed to be $[\frac{E}{\rho_0(1-\nu^2)}]^{1/2} \Delta t$

and is calculated internally, where E is the elastic modulus, ν is the Poisson ratio, ρ_0 is the mass per unit initial volume of the plate material, and Δt is the time-step size.

= a specified value that is used in place of and supersedes the above estimate for L_{eff} ; as argued in Subsection 2.5.2 of Ref. 11, a physically

plausible value is $L_{\text{eff}} = nh$ independent of the time step size, where h is the plate thickness and n may be specified as some positive number such as 2, 2.5 ... or some other selected value ($n=2$ is often used). Any other prescribed value could be selected by the user.

Card 71

NSYM, IPSS, ICUT

2014

where

NSYM A parameter which indicates the type of symmetry option elected for the present impact analysis
= 0 if no symmetry option is employed.
= 1 if the single symmetry option is employed.
= 2 if the double symmetry option is employed.

IPSS A parameter used in conjunction with the single symmetry option (if NSYM=1) to denote the plate side number which is a line of symmetry.
= 0 if NSYM=0 or NSYM=2 is employed
= 1 if plate side number 1 (i.e. the global X-axis) is the line of single symmetry.
= 4 if plate side number 4 (i.e. the global Y-axis) is the line of single symmetry.

ICUT A parameter which indicates whether or not impact inspection and correction is to be followed for the entire response history.
= 0 if impact inspection and correction is to be followed at all time instants.
= 1 if impact inspection and correction is to be terminated once the fragment kinetic energy is less than a specified fraction of the fragment kinetic energy at time zero.

The single symmetry option (i.e. NSYM=1) can be exercised only when the following conditions are satisfied:

- (1) The plate is rectangular (or square) with no cutouts, and half of the plate is modeled (i.e. the analysis is carried out for one half of the plate with one boundary of the half-plate model being a symmetry boundary).
- (2) Initial and subsequent fragment/plate collisions occur along the line of symmetry (plate side 1 if IPSS=1, or plate side 4 if IPSS=4).
- (3) The initial position and velocity components for the fragment must be specified in a fashion consistent with the assumption of motion which is symmetric with respect to the global X axis (if IPSS=1) or with respect to the global Y axis (if IPSS=4).

These conditions and other conventions adopted in the CIVM-PLATE code dictate some of the input which must be specified as follows (if NSYM=1 on Card 71):

- (1) IMESH on Card 2 must be set equal to 0 or 1 so that the auto-mesh generation subroutine is exercised.
- (2) If IMESH=0 is specified, then the global X and Y coordinates of node 1 of the structure must be specified to be 0.0 (locating the origin of the global X-Y system at node 1). This is accomplished by setting XG(1)=0.0 on Card 5 and YG(1)=0.0 on Card 6.
- (3) The symmetry boundary condition must be chosen for the plate side which is the line of symmetry. This is accomplished by setting NCSB(1)=1 on Card 7 if IPSS=1 (global X axis is the line of symmetry) or by setting NCSB(4)=1 on Card 7 if IPSS=4.
- (4) The centroid of the fragment must be located along the line of symmetry. Thus, YF=0.0 must be specified on Card 66 if IPSS=1 or XF=0.0 must be specified on Card 66 if IPSS=4.
- (5) The translational velocity components of the fragment must be consistent with the single symmetry option. If IPSS=1 (global X axis is the line of symmetry) then the Y-component must be zero; this is accomplished by setting VF(2)=0.0 on Card 67. If IPSS=4

(global Y axis is the line of symmetry) then the X-component must be zero; this is accomplished by setting VF(1)=0.0 on Card 67.

- (6) The rotational velocity components of the fragment must also be consistent with the single symmetry option. If IPSS=1 then the components of angular velocity about the X and Z axis must be zero -- set OMEGF(1)=0.0 and OMEGF(3)=0.0 on Card 68. If IPSS=4 then the components of angular velocity about the Y and Z axes must be zero -- set OMEGF(2)=0.0 and OMEGF(3)=0.0 on Card 68.

It should be noted that the fragment mass, FMASS, and fragment mass moment of inertia, FMOI, input on Card 69 still correspond to the whole fragment. If NSYM=1, FMASS and FMOI are internally reduced for the half-plate (single symmetry) impact analysis.

The double-symmetry option (i.e. NSYM=2) can be exercised only when the following conditions are satisfied:

- (1) The plate is rectangular (or square) with no cutouts, and a quarter of the plate is modeled (i.e. a doubly-symmetric finite-element mesh is used to model the plate).
- (2) Initial and subsequent fragment/plate collisions occur at the center of the plate.
- (3) The only nonzero velocity component of the fragment is the translational velocity in the global Z direction.

These conditions and other conventions adopted in the CIVM-PLATE code dictate some of the input which must be specified (when NSYM=2) as follows:

- (1) IMESH on Card 2 must be set equal to 0 or 1 so that the auto-mesh generation subroutine is exercised.
- (2) If IMESH=0 is specified, then the global X and Y coordinates of node 1 of the structure must be specified to be 0.0 (the origin of the global X-Y coordinates must be located at node number 1, which is the center of the plate). This is accomplished by setting XG(1)=0.0 on Card 5 and YG(1)=0.0 on Card 6.

- (3) The symmetry boundary condition option must be chosen for plate sides 1 and 4; this is consistent with the convention of choosing node number 1 as the center of the plate. This is accomplished by setting NCSB(1)=1 and NCSB(4)=1 on Card 7.
- (4) The global X and Y coordinates of the fragment centroid at time zero (XF, YF on Card 66) must be set equal to zero (i.e. the fragment is located directly below structural node number 1).
- (5) The translational velocity components of the fragment in the X and Y directions (i.e. VF(1) and VF(2) on Card 67) must be set equal to zero; the only nonzero component of velocity is VF(3) in the Z-direction.
- (6) The rotational velocity components of the fragment, OMEGF(1), OMEGF(2), and OMEGF(3) on Card 68 must be set equal to zero.

It should be noted that the fragment mass, FMASS, input on Card 69 still corresponds to the whole fragment. If NSYM=2, FMASS is internally reduced for the quarter model (doubly symmetric) impact analysis.

Card 72 (skip if ICUT=0)

CUTR

D16.7

where

CUTR

A factor which, when multiplied times the initial fragment kinetic energy, determines when the impact inspection and correction process is to be terminated. That is, when the fragment kinetic energy at a particular instant of time is less than CUTR times the initial fragment kinetic energy, then no further impact inspection/correction calculations will be made. Note, however, that transient structural response calculations may be continued beyond final impact inspection/correction (additional discussions of this feature is given in Subsection 5.5.2).

The above input is complete for runs of the CIVM-PLATE which are not a continuation of a previous run (i.e. for cases when IMCONT=0 is specified

on Card 2). For runs which are a continuation of a previous run (i.e. IMCONT=1 is specified on Card 2), the punched deck of continuation cards from the previous run (obtained by setting IPUNCH=1 on Card 2 for the previous run) follows immediately after Card 72 (or Card 71 if ICUT=0 is specified on Card 71).

Some additional comments related to continuation runs should be observed. The discussion (in Subsection 4.4) of input data which must (or may) be changed for continuation runs of the PLATE code should also be followed for continuation runs of the CIVM-PLATE code. In addition, the following rules should be observed when preparing input data Cards 66 through 72 for continuation runs of the CIVM-PLATE program:

- (1) Input data on Cards 66 through 70 must be identical to that used on the initial run of the present analysis (in which the deck of continuation cards was punched). This is necessary so that the initial (time zero) kinetic energy of the fragment may be calculated correctly. Input data provided in the deck of continuation cards will then update the fragment position and velocity components to the correct values prior to the first solution time cycle of the continuation run.
- (2) The values of NSYM and IPSS on Card 71 must not be altered for continuation runs.
- (3) The value of ICUT on Card 71 and/or the value of CVTR on Card 72 may be changed for continuation runs. The implications of and possible reasons for such a change are discussed in Subsection 5.5.2.

5.3 Guidelines for User-Prepared Array Dimensions

The second (and final) task required to run the CIVM-PLATE program is the assigning of fixed dimensions to arrays in the dummy main program associated with the CIVM-PLATE code. This task is essentially identical to the dimensioning task associated with the PLATE code, and the user should consult Subsection 4.5 for a general discussion of guidelines to be followed in the preparation of array dimensions.

A listing of a dummy main program for the CIVM-PLATE program is given on the next page. The arrays to be dimensioned are shown and their dimensions are given in terms of a set of problem-dependent parameters. The definitions of these parameters are also shown in the listing. The user is required to prepare a FORTRAN IV DIMENSION statement including all arrays shown in the sample DIMENSION statement; problem dependent parameters are replaced by the fixed value of each parameter for the problem being considered.

The user will note that all parameters, except NIAN, have also been used in the dummy main program associated with the PLATE program (again as a result of the general similarity between the two codes). Some additional discussion of the parameter NIAN is perhaps necessary. As indicated in the listing, the parameter NIAN is defined as the estimated maximum number of nodes which will be affected by a single impact, and may be estimated as follows. When plate/fragment impact occurs, the coordinates of the point of impact on the plate are determined. The impact-affected region of the plate is then defined as that region falling within a circle of radius L_{eff} . All nodes which fall within this circle of radius L_{eff} are considered to be impact-affected nodes (see Appendix B for additional details).

In general, the precise location of all impacts is not known a priori. Thus, the user should first select L_{eff} (see Card 70) and then assume that an impact will occur in the region of the plate having the most dense population of nodes (i.e. that region having the most highly refined mesh). The number of nodes falling within the impact-affected region for this hypothetical (worst-case) plate/fragment impact may be used as a base value for NIAN. Those nodes falling near to the impact-affected region could also be included in the estimate of NIAN to provide a liberal estimate of this parameter; in all cases, the value of NIAN should be overestimated. During each cycle in which impact occurs, the value of NIAN is checked against the actual number of impact-affected nodes. If the value of NIAN is less than the actual number of nodes affected, a message is printed and the run is terminated; the actual number of impact-affected nodes (for the cycle in which the run is terminated) is included in the printed message.

```

C   CIVM-PLATE 1 COMPUTER CODE.                                IMAN0000
C                                                                 IMAN0001
C THIS DUMMY MAIN PROGRAM FOR THE CIVM PLATE PROGRAM REQUIRES IMAN0002
C THESE SUBROUTINES:                                          IMAN0003
C   ARRT,ASSMKN,DCONMK,COLLSN,EAROW,FACT,GAUSS,I FRAG,        IMAN0004
C   IMAINP,IMPACT,IMPDS,IMPSS,INTRAC,IPRINI,LMASSP,          IMAN0005
C   MESHPA,MESHPM,OMULT,PROTOP,PSTRN,RCON,RPLATE,SFDM,       IMAN0006
C   SOLV,SPRING,STRLSA,STRESC,STRESP,ISTEP.                 IMAN0007
C                                                                 IMAN0008
C ILLUSTRATIVE EXAMPLE FOR CIVM PLATE PROGRAM - FULL MODEL. IMAN0009
C                                                                 IMAN0010
C SMALL STRAIN FORMULATION VERSION WRITTEN BY R. L. SPILKER  IMAN0011
C                                                                 IMAN0012
C   ASRL TR 154-14.....ORIGINAL REPORT VERSION OF PROGRAM  IMAN0013
C COPYRIGHT (C) MASSACHUSETTS INSTITUTE OF TECHNOLOGY 1980 IMAN0014
C                                                                 IMAN0015
C DUMMY MAIN PROGRAM WHICH PROVIDES DIMENSIONS FOR THOSE ARRAYS IMAN0016
C (VECTORS) WHOSE DIMENSIONS ARE PROBLEM DEPENDENT.         IMAN0017
C THE FOLLOWING ARRAYS MUST BE DIMENSIONED BY THE USER AS SHOWN; IMAN0018
C   DIMENSION DELD(NDT),DIS(NDT),DISP(NDT),DISM1(NDT),DISM2(NDT), IMAN0019
C   FLN(NDT),FLVA(NDT),FLVM(NDT),FLVP(NDT),VEL(NDT),ICOL(NDT), IMAN0020
C   INUM(NDT),KROW(NDT),NDEX(NDT),STF(MNC),AMASS(NDT),NP(4,MAXEL), IMAN0021
C   NODE(24*MAXEL),TAUSS(MAXEL,4*MNSL,9),TAUSE(MAXEL,4*MNSL,9), IMAN0022
C   TAUEE(MAXEL,4*MNSL,9),EPSSI(9,MAXEL),EPSSO(9,MAXEL),EPEEI(9,MAXEL) IMAN0023
C   ,EPEEO(9,MAXEL),EPSEI(9,MAXEL),EPSEO(9,MAXEL),NBC(NB),BC(NB), IMAN0024
C   RFM(NBE,MBWE),ILAST(NBE),UCF1(NBE),UCF2(NBE),XG(NNT),YG(NNT), IMAN0025
C   ZG(NNT),XGI(NNT),YGI(NNT),                                IMAN0026
C   TAGSS(MNXST,4*MNSL,3),LNXS(MNXST),XSPROP(7,MNXST),MATXS(MNXST), IMAN0027
C   TSGEE(MNYST,4*MNSL,3),LNYS(MNYST),YSPROP(7,MNYST),MATYS(MNYST), IMAN0028
C   LNRS(NRSS),ISRS(NRSS),SC(5,NRSS),NVSA(MNNSA),NCON(4,MNNSA), IMAN0029
C   PMASS(NNT),VN(3,NIAN),VNB(3,NIAN),SI(NIAN),NEFF(NIAN),ALPHA(NIAN) IMAN0030
C                                                                 IMAN0031
C WHERE,                                                       IMAN0032
C   NNT   = TOTAL NUMBER OF NODES IN THE ASSEMBLED FINITE-ELEMENT MODEL IMAN0033
C   NDT   = TOTAL NUMBER OF DEGREES OF FREEDOM IN THE ASSEMBLED FINITE- IMAN0034
C           ELEMENT MODEL = 6*NNT.                               IMAN0035
C   MNC   = ESTIMATED NUMBER OF WORDS OF STORAGE FOR THE ASSEMBLED IMAN0036
C           STIFFNESS MATRIX (LOWER TRIANGLE STORED BY ROWS FROM FIRST IMAN0037
C           NONZERO TERM).                                       IMAN0038
C   MAXEL = NUMBER OF ELEMENTS IN FINITE-ELEMENT MODEL.         IMAN0039
C   MNSL  = MAXIMUM NUMBER OF MECHANICAL SUBLAYERS EMPLOYED.    IMAN0040
C           NOTE-- MNSL MUST BE LESS THAN OR EQUAL TO 5.        IMAN0041
C   NB    = ESTIMATED NUMBER OF CONSTRAINED DEGREES OF FREEDOM PRIOR IMAN0042
C           TO ELIMINATION OF DUPLICATES.                       IMAN0043
C   NBE   = ESTIMATED NUMBER OF CONSTRAINED DEGREES OF FREEDOM AFTER IMAN0044
C           ALL DUPLICATES HAVE BEEN ELIMINATED (IF IOP5 = 1).  IMAN0045
C           = 1 IF IOP5 = 0                                       IMAN0046
C   MBWE  = ESTIMATED MAXIMUM BANDWIDTH OF ASSEMBLED STIFFNESS MATRIX IMAN0047
C           AT A CONSTRAINED DEGREE OF FREEDOM (IF IOP5 = 1).  IMAN0048
C           = 1 IF IOP5 = 0                                       IMAN0049
C   MNXST = MAXIMUM NUMBER OF X-DIRECTION STIFFENERS.           IMAN0050
C           = 1 IF NO X-DIRECTION STIFFENERS.                   IMAN0051
C   MNYST = MAXIMUM NUMBER OF Y-DIRECTION STIFFENERS.           IMAN0052

```

```

C      = 1 IF NO Y-DIRECTION STIFFENERS.                                IMAN0053
C  NRSS = TOTAL NUMBER OF ELEMENT SIDES ON WHICH LINE RESTORING        IMAN0054
C      SPRINGS ARE LOCATED.                                           IMAN0055
C      = 1 IF NO RESTORING SPRINGS ARE PRESENT.                       IMAN0056
C  MNSLT4 = 4*MNSL                                                    IMAN0057
C  MNNSA = MAXIMUM NUMBER OF NODES REQUESTED FOR STRAIN OUTPUT        IMAN0058
C      = (IF IOP8=1)                                                  IMAN0059
C  NIAN  = ESTIMATED MAXIMUM NUMBER OF NODES WHICH WILL BE AFFECTED  IMAN0060
C      BY A SINGLE IMPACT.                                           IMAN0061
C      IMPLICIT REAL*8(A-H,O-Z)                                       IMAN0062
C      DIMENSION DELD(450),DIS(450),DISP(450),DISM1(450),DISM2(450),  IMAN0063
C      2FLN(450),FLVA(450),FLVM(450),FLVP(450),VEL(450),ICOL(450),  IMAN0064
C      3INUM(450),KROW(450),NDEX(450),STF(16335),AMASS(450),        IMAN0065
C      4NP(4,56),NODE(1344),TAUSS(56,12,9),TAUSE(56,12,9),TAUEE(56,12,9), IMAN0066
C      5EPSSI(9,56),EPSSO(9,56),EPEEI(9,56),EPEEO(9,56),EPSEI(9,56), IMAN0067
C      6EPSEO(9,56),NBC(60),BC(60),RFM(1,1),ILAST(1),UCF1(1),UCF2(1), IMAN0068
C      7XG(75),YG(75),ZG(75),XGI(75),YGI(75),TAGSS(1,12,3),LNXS(1),  IMAN0069
C      8XSPROP(7,1),MATXS(1),TSGEE(28,12,3),LNYS(28),YSPROP(7,28),MATYS(28) IMAN0070
C      9),LNRS(28),ISRS(28),SC(5,28),NVSA(8),NCON(4,8),PMASS(75),VN(3,75), IMAN0071
C      A VNB(3,75),SI(75),NEFF(75),ALPHA(75)                        IMAN0072
C      COMMON/BAS/NDT,NET,MN,NB,NIRREG,MNC                          IMAN0073
C      COMMON /INOUT/ MREAD,MWRITE,MPUNCH                          IMAN0074
C  DEFINE CARD READER, LINE PRINTER AND CARD PUNCH UNIT NUMBERS.    IMAN0075
C      MREAD = 5                                                    IMAN0076
C      MWRITE = 6                                                  IMAN0077
C      MPUNCH = 7                                                 IMAN0078
C      READ(MREAD,500)MAXEL,MNSL,MNXST,MNYST,NBE,MBWE,MNC,NIAN     IMAN0079
C      FORMAT(B110)                                               IMAN0080
C      WRITE(MWRITE,600)                                           IMAN0081
C      WRITE(MWRITE,610) MAXEL                                     IMAN0082
C      WRITE(MWRITE,620) MNSL                                     IMAN0083
C      WRITE(MWRITE,630) MNXST                                   IMAN0084
C      WRITE(MWRITE,640) MNYST                                   IMAN0085
C      WRITE(MWRITE,650) NBE                                     IMAN0086
C      WRITE(MWRITE,660) MBWE                                   IMAN0087
C      WRITE(MWRITE,670) MNC                                    IMAN0088
C      WRITE(MWRITE,680) NIAN                                    IMAN0089
C      600 FORMAT('1 CIVM-PLATE 1 COMPUTER CODE (SMALL STRAIN THEORY) : USER IMAN0090
C      +INPUT FOR ARRAY DIMENSIONS')                               IMAN0091
C      610 FORMAT(' ', 'MAXEL  =', I10)                            IMAN0092
C      620 FORMAT(' ', 'MNSL   =', I10)                            IMAN0093
C      630 FORMAT(' ', 'MNXST  =', I10)                            IMAN0094
C      640 FORMAT(' ', 'MNYST  =', I10)                            IMAN0095
C      650 FORMAT(' ', 'NBE    =', I10)                            IMAN0096
C      660 FORMAT(' ', 'MBWE   =', I10)                            IMAN0097
C      670 FORMAT(' ', 'MNC    =', I10)                            IMAN0098
C      680 FORMAT(' ', 'NIAN   =', I10)                            IMAN0099
C      MNSLT4=MNSL*4                                             IMAN0100
C      CALL IMAINP(DELD,DIS,DISP,DISM1,DISM2,FLN,FLVA,FLVM,FLVP,  IMAN0101
C      2VEL,ICOL,INUM,KROW,NDEX, STF,AMASS,NP,NODE,TAUSS,TAUSE,TAUEE, IMAN0102
C      3EPSSI,EPSSO,EPEEI,EPEEO,EPSEI,EPSEO,NBC,BC,RFM,ILAST,UCF1,UCF2, IMAN0103
C      4XG,YG,ZG,XGI,YGI,TAGSS,LNXS,XSPROP,MATXS,TSGEE,LNYS,YSPROP,MATYS, IMAN0104
C      5LNRS,ISRS,SC,MAXEL,MNSL,MNSLT4,NBE,MBWE,MNXST,MNYST,NVSA,NCON, IMAN0105

```

```
6PMASS,VN,VNB,SI,NEFF,ALPHA,NIAN)  
CALL EXIT  
END
```

```
IMAN0106  
IMAN0107  
IMAN0108
```

- NOTE:
1. The dimension 3000 for array STF and the dimension 84 for AMASS were obtained by the procedure described in items 1 through 4 on page 100. Also, see Figs. 19a and 19b.
 2. For detailed instructions on establishing dimensions and input data, see the example problems discussed in Section 8.

5.4 Description of the Output

The printed output generated by the CIVM-PLATE program (as with the PLATE program) falls into two general categories: (1) initial output which reiterates user-supplied input and defines additional internally-generated data regarding geometry, material properties, boundary conditions, output options, and timewise solution parameters, and (2) solution output generated at user-specified time intervals and corresponding to those output options exercised by the user. In both of these categories, the output generated is essentially identical to that generated by the PLATE program; only those differences between the output generated by the two codes will be discussed.

All of the initial output generated by the PLATE program is also automatically generated by the CIVM-PLATE program. The reader should refer to Subsection 4.7 for a complete description of this initial output. In addition, the initial output now reiterates the data supplied for the fragment geometry, properties, initial location, and initial velocity components, as well as the collision parameters specified by the user. Also, the initial kinetic energy of the fragment is calculated and output. The user should note that a reference time step size will always be calculated and output because the CIVM-PLATE code always uses a diagonalized lumped mass model.

Solution data output at user-specified time intervals and consisting of that data requested by the user through the appropriate selection of output options is also essentially identical to that generated by the PLATE program; the user should consult Subsection 4.7 for a description of this output. In addition to the user-selected output data, the following data are printed at each regularly-scheduled print cycle:

FRAGMENT GLOBAL LOCATION AND VELOCITY COMPONENTS

X-LOC	Y-LOC	Z-LOC	VEL-X	VEL-Y	VEL-Z	OMEGA-X	OMEGA-Y	OMEGA-Z
[XF]	[YF]	[ZF]	[VF(1)]	[VF(2)]	[VF(3)]	[OMEGF(1)]	[OMEGF(2)]	[OMEGF(3)]

where

XF	}	The current global X, Y, and Z components, respectively, which locate the c.g. of the spherical fragment.
YF		
ZF		

VF (1)	}	The current translational velocity components in the global X, Y, and Z direction, respectively, of the fragment.
VF (2)		
VF (3)		
OMEGF (1)	}	The current angular velocity components about the global X, Y, and Z axes, respectively, of the fragment.
OMEGF (2)		
OMEGF (3)		

The system energy output generated by the CIVM-PLATE code is slightly different from that generated by the PLATE code and appears as follows:

SYSTEM ENERGIES (IN-LB)

FRAG TRANSLATIONAL KINETIC ENERGY	=	[CINFTN]
FRAG ROTATIONAL KINETIC ENERGY	=	[CINFRT]
WORK INPUT TO STRUCTURE	=	[EWORK]
STRUCTURE KINETIC ENERGY	=	[CINET]
STRUCTURE ELASTIC ENERGY	=	[ELAST]
STRUCTURE PLASTIC ENERGY	=	[PLASTW]
ENERGY STORED IN ELASTIC RESTRAINTS	=	[SPREN]

The parameters EWORK, CINET, ELAST, PLASTW, and SPREN are defined in Subsection 4.7, and the parameters CINFTN and CINFRT are defined, respectively, as the translational and the rotational kinetic energy of the fragment at the current time. Note that for the present impact analysis the current total work input to the plate structure is the difference between the initial (time zero) kinetic energy of the fragment and the current kinetic energy of the fragment. Also the total plastic work done on the structure is calculated indirectly by $PLASTW = EWORK - (CINET + ELAST + SPREN)$. Thus, if the coefficient of restitution, e , has been assigned a value in the range $0 < e < 1$ (corresponding to an inelastic collision), then the energy loss in each inelastic collision will be included in the total plastic work which is output.

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

The output options available in the CIVM-PLATE code are identical to those available in the PLATE program. The discussion of output options presented in Subsection 4.8.4 should be followed in the selection of output options for the CIVM-PLATE program. It is recommended that displacement, system energy, and some form of strain output be selected for each run.

Strain calculation in the CIVM-PLATE program is identical to that of the PLATE program and the discussion in Subsection 4.8.5 should be followed. The recommendations in Subsection 4.8.5 should be followed more carefully when strain data are sought near the region of plate/fragment impact. Severe strain gradients will generally be found in this region; strain distributions in this region at various time instants should be used to supplement strain time-history data sought at locations in this region.

The technique outlined in Subsection 4.8.1 for determining the dimension, MNC, of the assembled stiffness matrix, STF, should again be used with the CIVM-PLATE program. Note, however, that this dimension now applies only to the assembled stiffness matrix (array STF) and does not apply to the assembled mass matrix since only lumped mass modeling is used in the CIVM-PLATE program.

5.5.2 Selection of a Time-Step Size

The selection of a suitable time-step size, Δt , in the CIVM-PLATE program is somewhat more involved as a result of the process used to impose impact-induced velocity changes on the plate structure and on the fragment. Since it is the velocity changes imposed on the structure which affect the choice of Δt , attention will be restricted to the plate structure in the present discussion.

As shown in Appendix B, the CIVM-PLATE program, in effect, employs two different timewise operators. For time cycles in which no plate-fragment impact occurs, the Houbolt operator is employed. For time cycles in which plate-fragment impact does occur, the nodal velocities in the impact-affected region of the plate are redefined to be the post-impact velocities (calculated by using impulse-momentum -- see Appendix B) and a modified operator is used; this modified operator may be viewed as a version of that in the Generalized Acceleration Method. In both cases, the equivalent loads corresponding to

large deflection and plasticity effects are approximated by using a linear extrapolation of their values at the previous two time instants.

To assess the stability of this modified operator compared with that of the Houbolt operator, a simple one degree-of-freedom cubic-hardening spring-mass system subjected to a prescribed initial velocity was analyzed using each of these operators; linear extrapolation was used to estimate the nonlinear equivalent loads. For the particular problem being considered, the solution obtained by using the modified operator became unstable for a Δt value approximately half that of the Δt value at which the solution using the Houbolt operator became unstable.⁺ Quantitatively, these results suggest that for the same plate structure, an analysis by the CIVM-PLATE program will require a smaller Δt than an equivalent analysis by the PLATE program.

Problems of stability of the modified operator are most likely to occur if the modified operator is used every cycle for many cycles (i.e. if impact occurs on many successive cycles). Such instabilities have been observed during theoretical-experimental correlation studies using the CIVM-PLATE code. Spurious oscillations in the predicted strain time-histories at several locations along a narrow plate subjected to normal impact at its center were observed at a time just prior to fragment rebound. In this case, impacts had occurred during each of approximately 200 time cycles prior to instability. Once impacts stopped (following fragment rebound), the strain time-histories stabilized, probably as a result of the improved stability of the Houbolt operator.

Additional study of the probable sources of this instability is needed. Although not conclusive, experience to date suggests that a value of Δt no larger than twice the reference time step size which is calculated and output will yield stable solutions (recall that lumped mass modeling is used in the CIVM-PLATE program, and thus a reference time step size is calculated and output on each run of the program). However, the user should monitor the solution output, particularly strain data, to determine if an instability has occurred. If so, a smaller value of Δt should be used, until the instability is removed.

⁺Note, however, that no iterations are being carried out within a given time step Δt to achieve convergence.

An alternate, but less appealing, approach for eliminating this instability has also been included in the CIVM-PLATE program. If desired, the parameters ICUT on Card 71 and CUTR on Card 72 (see Subsection 5.2) can be specified such that impact inspection and correction will be terminated (also terminating the use of the modified operator) once the fragment kinetic energy is less than CUTR times the initial fragment kinetic energy. This approach is based on experience to date in which instabilities are generally found to occur when only approximately 5% of the initial kinetic energy is left in the fragment (just prior to fragment rebound). In principle, it could be argued that one is neglecting only 5% (for example) of the energy input to the plate structure and that, in fact, a portion of this energy is returned to the fragment as the plate and fragment rebound and the plate imparts kinetic energy to the fragment. However, when a value of CUTR = 0.05 was used on the previously-mentioned impact analysis where instability was observed, it was found that the predicted permanent strain levels, although stable, were substantially less than the experimentally determined strain levels; when a stable Δt value was used instead of the cut-off option, predicted strain levels were found to be in essential agreement with experimentally-determined strain levels.

As a general rule, instabilities should be eliminated by reducing the value of Δt . As a last resort, the cut-off option can be exercised to advance the solution beyond the point of instability; however, in this case the analyst should be alerted to the possible error in predicted transient strain levels (after the option is imposed in the timewise solution) and permanent strain levels.

SECTION 6

COMPLETE FORTRAN IV LISTING OF THE
PLATE AND CIVM-PLATE PROGRAMS

6.1 Subprograms Common to both Codes

The following 21 subprograms (or subroutines) are common to both the
PLATE and the CIVM-PLATE program:

ARRT	FACT	MESHPM	RCON	SPRING
ASSEMK	GAUSS	OMULT	RPLATE	STRESA
BCONMK	LMASSP	PRTOP	SFDM	STRESC
EAROW	MESHPA	PSTRN	SOLV	STRESP
				TSTEP

A FORTRAN IV listing of each follows.

```

SUBROUTINE ARRT(STF,AMASS,F,ICOL,INUM,KROW,NDEX,NODE,NDPE)
IMPLICIT REAL*8(A-H,O-Z)
C
C ASRL TR 154-14.... ORIGINAL REPORT VERSION OF PROGRAM
C COPYRIGHT (C) MASSACHUSETTS INSTITUTE OF TECHNOLOGY 1980
C THIS SUBROUTINE IS USED BY BOTH THE PLATE AND THE CIVM PLATE PROGRAMS.
C
C DIMENSION AMASS(1)
C DIMENSION STF(1),F(1),ICOL(1),INUM(1),KROW(1),NDEX(1),NODE(1)
C COMMON/BAS/NDT,NET,MN,NBD,NIRREG,MNC
C COMMON /INOUT/ MREAD,MWRITE,MPUNCH
C
C IN THIS SUBROUTINE, THE MESH NODAL CONNECTIVITY DATA IN NODE(1) IS
C USED TO ESTABLISH THE POINTER ARRAYS NECESSARY TO LOCATE TERMS IN
C THE ASSEMBLED STIFFNESS MATRIX (AND MASS MATRIX IF CONSISTENT MASS
C IS USED) STORED IN COMPACTED VECTOR FORM THE NUMBER OF WORDS OF
C STORAGE REQUIRED FOR THE ASSEMBLED STIFFNESS MATRIX IS CALCULATED,
C OUTPUT, AND COMPARED WITH THE USER ESTIMATE, IF THE USER ESTIMATE IS
C TOO SMALL, A MESSAGE IS OUTPUT AND THE RUN IS TERMINATED
C THE ASSEMBLED STIFFNESS AND MASS (ONLY FOR LUMPED MASS) MATRICES AND
C FORCE VECTOR ARE ZEROED.
C
C DO 598 I=1,NDT
598 ICOL(I)=NDT
C DO 500 I=1,NET
C NA=NDT
C II=(I-1)*NDPE
128 DO 5300 J=1,NDPE
C IIJ=II+J
C NZ=NODE(IIJ)
5300 IF(NA .GT. NZ) NA=NZ
C DO 500 J=1,NDPE
C IIJ=II+J
C NIIJ=NODE(IIJ)
500 IF(ICOL(NIIJ).GT.NA) ICOL(NIIJ)=NA
5601 INUM(1)=1
C DO 599 I=2,NDT
599 INUM(I)=I-ICOL(I-1)+INUM(I-1)
C DO 591 I=1,NDT
591 INUM(I)=INUM(I)-ICOL(I)
C MN=INUM(NDT)+NDT
C WRITE(MWRITE,515) MN
515 FORMAT(/2X,' MAX SIZE IS ',I6)
C IF(MN-MNC) 521,521,5211
5211 WRITE(MWRITE,520) MN
520 FORMAT(/2X,'MN=',I6,' THE DIM OF STIF IS TOO SMALL')
C GO TO 9999
521 CONTINUE
C NIRREG=0
C INDEX=0
C ISET=1
C DO 116 I=1,NDT
C L=ICOL(I)
C IF(ICOL(I)-ISET) 117,116,119
119 ISET=ICOL(I)
C GO TO 116
117 NIRREG=NIRREG+1
C IF(NIRREG-NDT/2) 711,711,712

```

```

ARRT0000
ARRT0001
ARRT0002
ARRT0003
ARRT0004
ARRT0005
ARRT0006
ARRT0007
ARRT0008
ARRT0009
ARRT0010
ARRT0011
ARRT0012
ARRT0013
ARRT0014
ARRT0015
ARRT0016
ARRT0017
ARRT0018
ARRT0019
ARRT0020
ARRT0021
ARRT0022
ARRT0023
ARRT0024
ARRT0025
ARRT0026
ARRT0027
ARRT0028
ARRT0029
ARRT0030
ARRT0031
ARRT0032
ARRT0033
ARRT0034
ARRT0035
ARRT0036
ARRT0037
ARRT0038
ARRT0039
ARRT0040
ARRT0041
ARRT0042
ARRT0043
ARRT0044
ARRT0045
ARRT0046
ARRT0047
ARRT0048
ARRT0049
ARRT0050
ARRT0051
ARRT0052
ARRT0053
ARRT0054
ARRT0055
ARRT0056
ARRT0057
ARRT0058

```

```

711 KROW(NIRREG)=I
NDEX(NIRREG)=INDEX
116 IINDEX=INDEX+I-L
712 CONTINUE
DO 20 I=1,MN
20 STF(I)=0.0
DO 10 I=1,NDT
AMASS(I)=0.0
10 F(I)=0.0
9999 RETURN
END
SUBROUTINE ASSEMK(EK, STF, INUM,NDPE,NODE,N)
IMPLICIT REAL*8(A-H,O-Z)
C
C ASRL TR 154-14.... ORIGINAL REPORT VERSION OF PROGRAM
C COPYRIGHT (C) MASSACHUSETTS INSTITUTE OF TECHNOLOGY 1980
C
C THIS SUBROUTINE IS USED BY BOTH THE PLATE AND THE CIVM PLATE PROGRAMS.
C
C DIMENSION STF(1),INUM(1),EK(NDPE,NDPE),NODE(1)
COMMON/BAS/NDT,NET,MN,NBD,NIRREG,MNC
C
C THIS SUBROUTINE ASSEMBLES THE ELEMENT STIFFNESS MATRIX INTO THE ASSEMBLED
C STIFFNESS MATRIX
C
C NN=(N-1)*NDPE
DO 100 I=1,NDPE
KMA=NODE(NN+I)
DO 100 II=1,I
KNA=NODE(NN+II)
KA=INUM(KMA)+KNA
IF(KNA.GT.KMA)KA=INUM(KNA)+KMA
STF(KA)=STF(KA)+EK(I,II)
100 CONTINUE
RETURN
END
SUBROUTINE BCONMK(STF, BC,ICOL,INUM,NBC)
IMPLICIT REAL*8(A-H,O-Z)
C
C ASRL TR 154-14. .... ORIGINAL REPORT VERSION OF PROGRAM
C COPYRIGHT (C) MASSACHUSETTS INSTITUTE OF TECHNOLOGY 1980
C
C THIS SUBROUTINE IS USED BY BOTH THE PLATE AND THE CIVM PLATE PROGRAMS.
C
C DIMENSION STF(1), BC(1),ICOL(1),INUM(1),NBC(1)
COMMON/BAS/NDT,NET,MN,NB,NIRREG,MNC
C
C THIS SUBROUTINE IMPOSES THE BOUNDARY CONDITION CONSTRAINTS (ZERO
C DISPLACEMENTS) ON THE ASSEMBLED MATRIX (2M/(DELTA T SQUARED)+K)
C GIVEN IN EQUATION A 114, BY ZEROING THE ROW AND COLUMN (NOT
C INCLUDING THE DIAGONAL TERM) CORRESPONDING TO EACH CONSTRAINED
C DEGREE OF FREEDOM
C
C IF(NB.EQ.0)RETURN
DO 100 I=1,NB
K=NBC(I)
KA=K+1
IF(NBC(I).GE.NDT)GO TO 10
DO 200 J=KA,NDT

```

```

ARRT0059
ARRT0060
ARRT0061
ARRT0062
ARRT0063
ARRT0064
ARRT0065
ARRT0066
ARRT0067
ARRT0068
ARRT0069
ASMK0000
ASMK0001
ASMK0002
ASMK0003
ASMK0004
ASMK0005
ASMK0006
ASMK0007
ASMK0008
ASMK0009
ASMK0010
ASMK0011
ASMK0012
ASMK0013
ASMK0014
ASMK0015
ASMK0016
ASMK0017
ASMK0018
ASMK0019
ASMK0020
ASMK0021
ASMK0022
ASMK0023
ASMK0024
BCMk0000
BCMk0001
BCMk0002
BCMk0003
BCMk0004
BCMk0005
BCMk0006
BCMk0007
BCMk0008
BCMk0009
BCMk0010
BCMk0011
BCMk0012
BCMk0013
BCMk0014
BCMk0015
BCMk0016
BCMk0017
BCMk0018
BCMk0019
BCMk0020
BCMk0021
BCMk0022

```

	IF(ICOL(J) GT K)GO TO 200	BCMK0023
	KK=NBC(I)+INUM(J)	BCMK0024
	STF(KK)=0.0	BCMK0025
200	CONTINUE	BCMK0026
10	KA=K-1	BCMK0027
	IF((NBC(I).LE.1) OR.(ICOL(K).GT.KA))GO TO 100	BCMK0028
	MCO=ICOL(K)	BCMK0029
	DO 500 J=MCO,KA	BCMK0030
	KK=J+INUM(K)	BCMK0031
	STF(KK)=0.0	BCMK0032
500	CONTINUE	BCMK0033
100	CONTINUE	BCMK0034
	RETURN	BCMK0035
	END	BCMK0036
	SUBROUTINE EROW(STF,NBC,ICOL,INUM,RFM,ILAST,NBE,MBWE)	EROW0000
	IMPLICIT REAL*8(A-H,O-Z)	EROW0001
C		EROW0002
C	ASRL TR 154-14.... ..ORIGINAL REPORT VERSION OF PROGRAM	EROW0003
C	COPYRIGHT (C) MASSACHUSETTS INSTITUTE OF TECHNOLOGY 1980	EROW0004
C		EROW0005
C	THIS SUBROUTINE IS USED BY BOTH THE PLATE AND THE CIVM PLATE PROGRAMS.	EROW0006
C		EROW0007
	DIMENSION STF(1),NBC(1),ICOL(1),INUM(1),ILAST(1),RFM(NBC,MBWE)	EROW0008
	COMMON/BAS/NDT,NET,MN,NB,NIRREG,MNC	EROW0009
	COMMON /INOUT/ MREAD,MWRITE,MPUNCH	EROW0010
C		EROW0011
C	THIS SUBROUTINE EXTRACTS THE ROWS OF THE ASSEMBLED MATRIX, STF	EROW0012
C	(STORED BY ROWS FROM THE FIRST NONZERO TERM TO THE DIAGONAL)	EROW0013
C	CORRESPONDING TO EACH CONSTRAINED D.O.F.. THE MATRIX RFM(K,J)	EROW0014
C	CONTAINS THE K-TH ROW OF STF, AND IS USED TO COMPUTE REACTION FORCES	EROW0015
C	IT IS ASSUMED THAT THE CONSTRAINED D.O.F. LIST CONTAINS NO	EROW0016
C	DUPLICATES	EROW0017
C		EROW0018
	IF(NB EQ.0)RETURN	EROW0019
	MEW=0	EROW0020
	LNM=0	EROW0021
	DO 50 INB=1,NB	EROW0022
	K=NBC(INB)	EROW0023
	NN=0	EROW0024
C	EXTRACT TERMS IN K-TH ROW FROM FIRST NONZERO TERM TO DIAGONAL TERM.	EROW0025
	KA=ICOL(K)	EROW0026
	DO 10 J=KA,K	EROW0027
	NN=NN+1	EROW0028
	KK=J+INUM(K)	EROW0029
10	RFM(INB,NN)=STF(KK)	EROW0030
C	FIND ROW WHICH HAS LAST NONZERO TERM IN COL. K.	EROW0031
	IL=K	EROW0032
	IF(K.EQ.NDT)GO TO 30	EROW0033
	KA=K+1	EROW0034
	DO 20 I=KA,NDT	EROW0035
	IF(K GE.ICOL(I))IL=I	EROW0036
20	CONTINUE	EROW0037
30	ILAST(INB)=IL	EROW0038
	MM=ILAST(INB)-ICOL(K)+1	EROW0039
	IF(MM.LT.MBW)GO TO 32	EROW0040
	MBW=MM	EROW0041
	LNM=K	EROW0042
32	CONTINUE	EROW0043
	IF(K.EQ.NDT)GO TO 50	EROW0044

	III=NCOL(I)	FACT0039
	INDEX=INDEX+I-III	FACT0040
	IF (IM1-III) 150,140,140	FACT0041
C	DIAGONAL TERMS	FACT0042
140	DO 104 J=III,IM1	FACT0043
	IJ=INDEX+J	FACT0044
	ICJJ=IC(J)+J	FACT0045
104	SUM=SUM+STIFM(IJ)+STIFM(IJ)*STIFM(ICJJ)	FACT0046
150	II=INDEX+I	FACT0047
	SUM=STIFM(II)-SUM	FACT0048
	IF(SUM) 151,122,105	FACT0049
151	IDET=IDET+1	FACT0050
105	TES=DABS(SUM/STIFM(II))	FACT0051
	IF(TES-TEST) 106,107,107	FACT0052
106	TEST=TES	FACT0053
	IROW=I	FACT0054
107	STIFM(II)=SUM	FACT0055
C	OFF DIAGONAL TERMS	FACT0056
	IF (I-NROWS) 108,121,121	FACT0057
108	KNDEX=INDEX	FACT0058
109	DO 116 K=IP1,NROWS	FACT0059
	KK=NCOL(K)	FACT0060
	KNDEX=KNDEX+K-KK	FACT0061
	SUM=0.0	FACT0062
	IF (KK-III) 110,130,130	FACT0063
110	KK=III	FACT0064
130	IF (IM1-KK) 112,131,131	FACT0065
131	DO 111 J=KK,IM1	FACT0066
	IJ=INDEX+J	FACT0067
	KJ=KNDEX+J	FACT0068
	ICJJ=IC(J)+J	FACT0069
111	SUM=SUM+STIFM(IJ)+STIFM(KJ)*STIFM(ICJJ)	FACT0070
112	IF (I-KK) 114,115,115	FACT0071
114	IF(NIRREG .LE. 0) GO TO 121	FACT0072
	IF(NIRREG .GT. NROWS/2) GO TO 116	FACT0073
	GO TO 190	FACT0074
115	KI=KNDEX+I	FACT0075
	STIFM(KI)=(STIFM(KI)-SUM)/STIFM(II)	FACT0076
116	CONTINUE	FACT0077
	GO TO 121	FACT0078
190	NCK=NCK+1	FACT0079
	IF(NIRREG LT. NCK) GO TO 121	FACT0080
	IP1=KROV(NCK)	FACT0081
	IF(I LT. NCOL(IP1)) GO TO 190	FACT0082
	IF(IP1 LT. K) GO TO 190	FACT0083
	KNDEX=NDEX(NCK)	FACT0084
	GO TO 109	FACT0085
121	CONTINUE	FACT0086
	WRITE(NTAPE6,1000) IROW,TEST,IDET	FACT0087
1000	FCRMT (42HOROUNDING ERROR PARAMETER IN FACTORING ROW, I4,2H =,F12.	FACT0088
	18,5X,'NO OF NEGATIVE DIAG=',I5)	FACT0089
	RETURN	FACT0090
122	WRITE(NTAPE6,1001) I	FACT0091
	IDET=-1	FACT0092
1001	FORMAT (37H1 MATRIX NOT POSITIVE DEFINITE IN ROW,I4)	FACT0093
	WRITE(NTAPE6,1002) SUM	FACT0094
1002	FORMAT (2X,'SQR DIAG TERM=',D15.8,/2X,'PART FACT K',//)	FACT0095
	RETURN	FACT0096
	END	FACT0097

```

SUBROUTINE GAUSS(N,GS,GW)
IMPLICIT REAL*8(A-H,O-Z)
C
C
C ASRL TR 154-14. . . ORIGINAL REPORT VERSION OF PROGRAM
C COPYRIGHT (C) MASSACHUSETTS INSTITUTE OF TECHNOLOGY 1980
C
C THIS SUBROUTINE IS USED BY BOTH THE PLATE AND THE CIVM PLATE PROGRAMS.
C
C THIS SUBROUTINE DEFINES THE LOCATION OF THE GAUSSIAN INTEGRATION
C STATIONS AND THE CORRESPONDING WEIGHTING FACTORS IN ONE DIMENSIONAL
C SPACE. THE NUMBER OF GAUSSIAN STATIONS USED MAY BE FROM 1 TO 6.
C
DIMENSION GS(6),GW(6)
GO TO(10,20,30,40,50,60),N
10 GS(1)=0.0D0
GW(1)=2.0D0
RETURN
20 GS1=-0.577350269189626D+00
GS(1)=GS1
GS(2)=-GS1
CW(1)=1.0D0
CW(2)=1.0D0
RETURN
30 GS1=-.774596669241483D+00
GS(1)=GS1
GS(2)=0.000000000000000D+00
GS(3)=-GS1
GW1=.5555555555555556D+00
GW(1)=GW1
GW(2)=.888888888888889D+00
GW(3)=GW1
RETURN
40 GS1=-.861136311594053D+00
GS2=-.339981043584656D+00
GS(1)=GS1
GS(2)=GS2
GS(3)=-GS2
GS(4)=-GS1
GW1=.347854845137454D+00
GW2=.652145154862546D+00
GW(1)=GW1
GW(2)=GW2
GW(3)=GW2
GW(4)=GW1
RETURN
50 GS1=-0.906179845938664D+00
GS2=-.538469310105683D+00
GS(1)=GS1
GS(2)=GS2
GS(3)=0.0D0
GS(4)=-GS2
GS(5)=-GS1
GW1=.236926885056189D+00
GW2=.4756286670499366D+00
GW(1)=GW1
GW(2)=GW2
GW(3)=.568888888888889D+00
GW(4)=GW2

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GAUS0000
GAUS0001
GAUS0002
GAUS0003
GAUS0004
GAUS0005
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GAUS0041
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GAUS0044
GAUS0045
GAUS0046
GAUS0047
GAUS0048
GAUS0049
GAUS0050
GAUS0051
GAUS0052
GAUS0053
GAUS0054
GAUS0055
GAUS0056
GAUS0057
GAUS0058

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133

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      GW(5)= GW1
      RETURN
C0      GS1=-.932469514203152D+00
      GS2=-.661209386466265D+00
      GS(1)=GS1
      GS(2)=GS2
      GS3=-.238619186083197D+00
      GS(3)=GS3
      GS(4)=- GS3
      GS(5)=- GS2
      GS(6)=- GS1
      GW1=.171324492379170D+00
      GW2=.360761573048139D+00
      GW3= 467913934572691D+00
      GW(1)=GW1
      GW(2)=GW2
      GW(3)=GW3
      GW(4)= GW3
      GW(5)= GW2
      GW(6)= GW1
      RETURN
      END
      SUBROUTINE LMASSP(NTYPE,XL,YL,TH,SL,CSA,SMOI,EML,DENS)
      IMPLICIT REAL*8(A-H,O-Z)
C
C   ASRL TR 154-14 .. ..ORIGINAL REPORT VERSION OF PROGRAM
C   COPYRIGHT (C) MASSACHUSETTS INSTITUTE OF TECHNOLOGY 1980
C
C   THIS SUBROUTINE IS USED BY BOTH THE PLATE AND THE CIVM PLATE PROGRAMS.
C
C   DIMENSION EML(1)
C
C   THIS SUBROUTINE FORMS THE LUMPED (DIAGONAL) MASS MATRIX FOR A PLATE
C   OR STIFFENER ELEMENT
C   GO TO(10,50,70),NTYPE
C   LUMPED MASS FOR PLATE
C10  AM1=XL*YL*TH
      AM2=AM1*TH*TH/12.0
      DO 40 I=1,4
      INC=6+(I-1)
      DO 20 J=1,3
      JJ=INC+J
C20  EML(JJ)=AM1/4.0
      DO 30 J=4,5
      JJ=INC+J
C30  EML(JJ)=AM2/4.0
C40  EML(INC+6)=0.0
      GO TO 90
C   LUMPED MASS FOR X-DIRECTION STIFFENER
C50  AM1=CSA*XL
      AM2=SMOI*XL
      D1=1.0-SL
      D2=SL
      DO 60 I=1,4
      FCT=D2
      IF(I EQ 1 OR I EQ 2)FCT=D1
      INC=6+(I-1)
      EML(INC+1)=AM1*FCT/2.0
      EML(INC+2)=EML(INC+1)
      GAUS0059
      GAUS0060
      CAUS0001
      GAUS0062
      GAUS0063
      GAUS0064
      GAUS0065
      GAUS0066
      GAUS0067
      GAUS0068
      GAUS0069
      GAUS0070
      GAUS0071
      GAUS0072
      GAUS0073
      GAUS0074
      GAUS0075
      GAUS0076
      GAUS0077
      GAUS0078
      GAUS0079
      GAUS0080
      LMSP0000
      LMSP0001
      LMSP0002
      LMSP0003
      LMSP0004
      LMSP0005
      LMSP0006
      LMSP0007
      LMSP0008
      LMSP0009
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      LMSP0032
      LMSP0033
      LMSP0034
      LMSP0035
      LMSP0036

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EML(INC+3)=EML(INC+1)
EML(INC+4)=AM2+FCT/2.0
EML(INC+5)=EML(INC+4)
60 EML(INC+6)=0.0
GO TO 90
C LUMPED MASS FOR Y-DIRECTION STIFFENER
70 AM1=CSA*YL
AM2=SMOI*YL
D1=1.0-SL
D2=SL
DO 80 I=1,4
FCT=D2
IF(I.EQ.1.OR.I.EQ.4)FCT=D1
INC=6*(I-1)
EML(INC+1)=AM1*FCT/2.0
EML(INC+2)=EML(INC+1)
EML(INC+3)=EML(INC+1)
EML(INC+4)=AM2+FCT/2.0
EML(INC+5)=EML(INC+4)
80 EML(INC+6)=0.0
90 CONTINUE
C MULTIPLY BY DENSITY FOR THIS ELEMENT.
DO 100 I=1,24
100 EML(I)=EML(I)*DENS
RETURN
END
SUBROUTINE MESHPA(NP,NODE,XG,YG,ZG,NBC,BC,LNXS,LNYS,XGI,YGI,
2,XSPROP,YSPROP,NXST,NYST,IMESH,MATXS,MATYS)
IMPLICIT REAL*8(A-H,O-Z)
INTEGER TY,PE,TY1,PE1,TY2,PE2
C ASRL TR 154-14 .. ORIGINAL REPORT VERSION OF PROGRAM
C COPYRIGHT (C) MASSACHUSETTS INSTITUTE OF TECHNOLOGY 1980
C THIS SUBROUTINE IS USED BY BOTH THE PLATE AND THE CIVM PLATE PROGRAMS.
C
C DIMENSION NP(4,1),NODE(1),XG(1),YG(1),ZG(1),NBC(1),BC(1),NCSB(4),
2NC(6),XSPROP(7,1),YSPROP(7,1),NSC(6,5),NEC(6,5),NBCSC(5),
3NBCEC(5),XGI(1),YGI(1),LNXS(1),LNYS(1),RHC(30),RWC(30),ECS(30),
4ANUCS(30),DENCS(30),SLCS(30),XFCST(30),APCST(30),MATCS(30),
5MATXS(1),MATYS(1)
DATA NSC/1,4,6,3*0,1,2,3,4,5,6,1,2,3,5,6,0,1,2,5,6,2*0,2,3,5,6,
@2*0/
DATA NEC/2,5,6,3*0,1,2,3,4,5,6,1,2,3,4,6,0,1,2,4,6,2*0,1,3,4,6,
@2*0/
DATA NBCEC/3,6,5,4,4/
DATA NBCSC/3,6,5,4,4/
DATA TY1,TY2,PE1,PE2/'SIN','DOU','GLE','BLE'/
COMMON/PLATE/XDIST,YDIST,TH,HXL,HYL,NEAD,NECD,DENSP,EPAN,ANUP,
2THALF
COMMON/BAS/NDT,NET,MN,NB,NIRREG,MNC
COMMON/INOUT/MREAD,MWRITE,MPUNCH
C THIS ROUTINE FORMS MESH, BOUNDARY CONDITION, AND STIFFENER
C INFORMATION FOR FLAT PLATE PROBLEM. THE STIFFENERS ARE
C ASSUMED TO BE ORIENTED IN THE X AND Y DIRECTIONS, SPANNING THE
C ENTIRE PLATE AT PRESENT A MAXIMUM OF 30 STIFFENERS IN EACH
C DIRECTION IS PERMITTED THE MESH IS MADE UP OF RECTANGULAR
C PLATE BENDING ELEMENTS, IN A UNIFORM OR NONUNIFORM PATTERN.

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LMSPC037
LMSP0038
LMSP0039
LMSP0040
LMSP0041
LMSP0042
LMSP0043
LMSP0044
LMSP0045
LMSP0046
LMSP0047
LMSP0048
LMSP0049
LMSP0050
LMSP0051
LMSP0052
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LMSP0059
LMSP0060
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LMSP0062
MSPA0000
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MSPA0030
MSPA0031
MSPA0032

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135

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C PLATE IS OF UNIFORM THICKNESS.
C
C IF IMESH=0 , A NONUNIFORM MESH IS ASSUMED.
C IF IMESH=1 , A UNIFORM MESH IS ASSUMED.
C GENERAL MESH INFORMATION
  READ(MREAD,500)NEAD,NECD
  READ(MREAD,510)EPAN,ANUP,DENSP,TH,XDIST,YDIST,ZPOS
  THALF=TH/2.0D0
  NET=NEAD*NECD
  NDPE=24
  NDPN=6
  NXST=0
  NYST=0
  NEAD1=NEAD+1
  NECD1=NECD+1
  NDT=NEAD1*NECD1*NDPN
  NNT=NEAD1*NECD1
C FORM NP(I,J), I=LOCAL NODE NUMBER, J=ELEMENT NO.
C X-DIR FIRST, Y-DIR. NEXT
  LNUM=0
  DO 10 NE=1,NECD
    INCE=(NE-1)*NEAD1
    DO 10 NS=1,NEAD
      LNUM=LNUM+1
      NP(1,LNUM)=INCE+NS
      NP(2,LNUM)=NP(1,LNUM)+1
      NP(3,LNUM)=NP(2,LNUM)+NEAD1
      NP(4,LNUM)=NP(3,LNUM)-1
10
C FORM NODE VECTOR--- ASSEMBLY LIST
  DO 30 I=1,NET
    INCI=(I-1)*NDPE
    DO 30 J=1,4
      INCJ=(J-1)*NDPN
      DO 30 K=1,NDPN
        INCIJK=INCI+INCJ+K
30
C SPACE COORDINATES OF NODES.
  IF(IMESH EQ.1)GO TO 32
C FOR NONUNIFORM MESH, READ Y=0 NODAL COORDS. AND X=0 NODAL COORDS.
  READ(MREAD,510) (XG(I), I=1,NEAD1)
  I2=NECD*NEAD1+1
  READ(MREAD,510) (YG(I), I=1,I2,NEAD1)
  GO TO 38
C FOR UNIFORM MESH GENERATE THIS INFO AUTOMATICALLY
C ASSUMING FIRST NODE AT (0,0)
32
  DX=XDIST/NEAD
  DY=YDIST/NECD
  HXL=DX/2 0
  HYL=DY/2 0
  DO 34 I=1,NEAD1
34
  XG(I)=(I-1)*DX
  DO 36 I=1,NECD1
  I2=NEAD1*I-NEAD
36
  YG(I2)=(I-1)*DY
C FILL OUT XG, YG, ZG
38
  DO 40 IY=1,NECD1
  INCY=(IY-1)*NEAD1
  DO 40 IX=1,NEAD1
  I2=INCY+IX

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MSPA0033
MSPA0034
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MSPA0089
MSPA0090
MSPA0091

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XG(I2)=XG(IX)
YG(I2)=YG(INCY+1)
^0 ZG(I2)=ZPOS
DO 41 I=1, NNT
XGI(I)=XG(I)
41 YGI(I)=YG(I)
C BOUNDARY CONDITIONS
C CONVENTION FOR FLAT-PLATE BOUNDARY CONDITION OPTIONS, NCBS(SIDE)
C 0 - FREE
C 1 - SYMMETRY
C 2 - IDEALLY CLAMPED
C 3 - PINNED-FIXED
C 4 - PINNED-FREE SLIDING Z-DIRECTION
C 5 - PINNED-FREE SLIDING/NORMAL (INPLANE)
READ(MREAD,500)(NCSB(I), I=1,4)
NBT=0
C SIDE 1---Y=0, VARY X
IF(NCSB(1).EQ 0) GO TO 50
MM=NCSB(1)
NN=NBCEC(MM)
DO 42 NS=1, NEAD1
INS=(NS-1)*NDPN
DO 42 I=1, NN
NBT=NBT+1
42 NBC(NBT)=INS+NEC(I,MM)
C SIDE 2---X=ADIST, VARY Y
50 IF(NCSB(2).EQ.0)GO TO 60
MM=NCSB(2)
NN=NBCSC(MM)
DO 52 NE=1, NECD1
INE=NE*NEAD1+NDPN-NDPN
DO 52 I=1, NN
NBT=NBT+1
52 NBC(NBT)=INE+NSC(I,MM)
C SIDE 3---Z=ADIST, VARY X
60 IF(NCSB(3).EQ 0)GO TO 70
MM=NCSB(3)
NN=NBCEC(MM)
DO 62 NS=1, NEAD1
INS=NEAD1+NECD*NDPN+(NS-1)*NDPN
DO 62 I=1, NN
NBT=NBT+1
62 NBC(NBT)=INS+NEC(I,MM)
C SIDE 4---X=0, VARY Y
70 IF(NCSB(4).EQ.0)GO TO 80
MM=NCSB(4)
NN=NBCSC(MM)
DO 72 NE=1, NECD1
INE=(NE-1)*NEAD1*NDPN
DO 72 I=1, NN
NBT=NBT+1
72 NBC(NBT)=INE+NSC(I,MM)
80 CONTINUE
C SORT CONSTRAINED D.O.F., LOWEST TO HIGHEST, ELIMINATING DUPLICATES.
IF(NBT.EQ.0)ND=0
IF(NBT.EQ.0)GO TO 850
C REMOVE DUPLICATE CONSTRAINED D.O.F.
NB=1
DO 820 I=2, NBT

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MSPA0092
MSPA0093
MSPA0094
MSPA0095
MSPA0096
MSPA0097
MSPA0098
MSPA0099
MSPA0100
MSPA0101
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MSPA0103
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MSPA0150

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	NI=NBC(I)	MSPA0151
	DO 810 J=1,NB	MSPA0152
	IF(NBC(J) EQ NI)GO TO 820	MSPA0153
810	CONTINUE	MSPA0154
	NB=NB+1	MSPA0155
	NBC(NB)=NI	MSPA0156
820	CONTINUE	MSPA0157
C	REARRANGE, LOWEST TO HIGHEST.	MSPA0158
	NBT=0	MSPA0159
830	NBT=NBT+1	MSPA0160
	NMIN=NDT+1	MSPA0161
	DO 840 II=NBT,NB	MSPA0162
	IF(NBC(II).GT NMIN)GO TO 840	MSPA0163
	NMIN=NBC(II)	MSPA0164
	NI=II	MSPA0165
840	CONTINUE	MSPA0166
	NSTOR=NBC(NBT)	MSPA0167
	NBC(NBT)=NBC(NI)	MSPA0168
	NBC(NI)=NSTOR	MSPA0169
	IF(NBT LT NB)GO TO 830	MSPA0170
	DO 845 I=1,NB	MSPA0171
845	BC(I)=0.000	MSPA0172
850	CONTINUE	MSPA0173
C	INFORMATION FOR STIFFENERS. FOR PRESENT ANALYSIS, EACH AXIAL AND/ OR CIRC STIFFENER SPANS ENTIRE DIMENSION OF STRUCTURE.	MSPA0174
	READ(MREAD,500)NAST,NCST	MSPA0175
C	INFORMATION FOR X-DIRECTION STIFFENERS SPANNING PLATE.	MSPA0176
	IF(NAST EQ 0)GO TO 100	MSPA0177
	READ(MREAD,510)(APCST(I),I=1,NAST)	MSPA0178
	READ(MREAD,510)(RHC(I),I=1,NAST)	MSPA0179
	READ(MREAD,510)(RWC(I),I=1,NAST)	MSPA0180
	READ(MREAD,510)(ECS(I),I=1,NAST)	MSPA0181
	READ(MREAD,510)(ANUCS(I),I=1,NAST)	MSPA0182
	READ(MREAD,510)(DENC(S),I=1,NAST)	MSPA0183
	READ(MREAD,510)(XFCST(I),I=1,NAST)	MSPA0184
	READ(MREAD,500)(MATCS(I),I=1,NAST)	MSPA0185
	NN=0	MSPA0186
	DO 115 NES=1,NAST	MSPA0187
	DO 105 I=1,NECD	MSPA0188
	I2=NEAD1*I+1	MSPA0189
	APOS=YG(I2)	MSPA0190
	IF(APOS GE APCST(NES))NROW=I	MSPA0191
	IF(APOS GE.APCST(NES))GO TO 110	MSPA0192
105	CONTINUE	MSPA0193
110	I1=NEAD1*(NROW-1)+1	MSPA0194
	I2=NEAD1*NROW+1	MSPA0195
	SLCS(NES)=(2 DO*APCST(NES)-YG(I1)-YG(I2))/(YG(I2)-YG(I1))	MSPA0196
	DO 115 NS=1,NEAD	MSPA0197
	NN=NN+1	MSPA0198
115	LNXS(NN)=(NROW-1)+NEAD+NS	MSPA0199
	NN=0	MSPA0200
	DO 116 I=1,NAST	MSPA0201
	DO 116 J=1,NEAD	MSPA0202
	NN=NN+1	MSPA0203
	MATXS(NN)=MATCS(I)	MSPA0204
	XSPROP(1,NN)=RHC(I)	MSPA0205
	XSPROP(2,NN)=RWC(I)	MSPA0206
	XSPROP(3,NN)=ECS(I)	MSPA0207
	XSPROP(4,NN)=ANUCS(I)	MSPA0208
		MSPA0209

```

XSPROP(5,NN)=DENC(S(I)
XSPROP(6,NN)=(SLCS(I)+1.000)/2.000
116 XSPROP(7,NN)=XFCST(I)
NXST=NAST*NEAD
C INFORMATION FOR Y-DIRECTION STIFFENERS SPANNING PLATE.
100 IF(NCST EQ 0)GO TO 120
READ(MREAD,510)(APCST(I),I=1,NCST)
READ(MREAD,510)(RHC(I),I=1,NCST)
READ(MREAD,510)(RWC(I),I=1,NCST)
READ(MREAD,510)(ECS(I),I=1,NCST)
READ(MREAD,510)(ANUCS(I),I=1,NCST)
READ(MREAD,510)(DENC(S(I),I=1,NCST)
READ(MREAD,510)(XFCST(I),I=1,NCST)
READ(MREAD,500)(MATCS(I),I=1,NCST)
NN=0
DO 95 NES=1,NCST
DO 85 I=1,NEAD
POS=XG(I+1)
IF(POS.GE.APCST(NES))NCOL=I
IF(POS.GE.APCST(NES))GO TO 90
85 CONTINUE
90 SLCS(NES)=(2.00+APCST(NES)-XG(NCOL+1)-XG(NCOL))/(XG(NCOL+1)-
&XG(NCOL))
DO 95 NE=1,NECD
NN=NN+1
95 LKYS(NN)=NCOL+NEAD*(NE-1)
NN=0
DO 96 I=1,NCST
DO 96 J=1,NECD
NN=NN+1
139 MATYS(NN)=MATCS(I)
YSPROP(1,NN)=RHC(I)
YSPROP(2,NN)=RWC(I)
YSPROP(3,NN)=ECS(I)
YSPROP(4,NN)=ANUCS(I)
YSPROP(5,NN)=DENC(S(I)
YSPROP(6,NN)=(SLCS(I)+1.000)/2.000
96 YSPROP(7,NN)=XFCST(I)
NYST=NCST*NECD
120 CONTINUE
J1=NXST+1
J2=NXST+NAXS
C INFORMATION FOR ADDITIONAL STIFFENERS ON INDIVIDUAL ELEMENTS.
READ(MREAD,500)NAXS,NAYS
IF(NAXS.EQ 0)GO TO 125
READ(MREAD,500)(LNXS(J),J=J1,J2)
READ(MREAD,500)(MATXS(J),J=J1,J2)
DO 122 I=1,7
122 READ(MREAD,510)(XSPROP(I,J),J=J1,J2)
125 IF(NAYS EQ 0)GO TO 128
J1=NYST+1
J2=NYST+NAYS
READ(MREAD,500)(LNYS(J),J=J1,J2)
READ(MREAD,500)(MATYS(J),J=J1,J2)
DO 127 I=1,7
127 READ(MREAD,510)(YSPROP(I,J),J=J1,J2)
128 NXST=NXST+NAXS
NYST=NYST+NAYS
C PRINT INFORMATION

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MSPA0210
MSPA0211
MSPA0212
MSPA0213
MSPA0214
MSPA0215
MSPA0216
MSPA0217
MSPA0218
MSPA0219
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MSPA0221
MSPA0222
MSPA0223
MSPA0224
MSPA0225
MSPA0226
MSPA0227
MSPA0228
MSPA0229
MSPA0230
MSPA0231
MSPA0232
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MSPA0240
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MSPA0250
MSPA0251
MSPA0252
MSPA0253
MSPA0254
MSPA0255
MSPA0256
MSPA0257
MSPA0258
MSPA0259
MSPA0260
MSPA0261
MSPA0262
MSPA0263
MSPA0264
MSPA0265
MSPA0266
MSPA0267
MSPA0268

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WRITE(MWRITE,600)
WRITE(MWRITE,605)XDIST,YDIST,ZPOS,TH,EPAN,ANUP,DENSP,NEAD,NECD,
2NDPE,NET,NDT,NXST,NYST
WRITE(MWRITE,625)
WRITE(MWRITE,626)
DO 130 I=1,NET
130 WRITE(MWRITE,627)I,(NP(J,I),J=1,4)
WRITE(MWRITE,700)
WRITE(MWRITE,701)
I=0
DO 135 NSIDE-1,4
NN=NCSB(NSIDE)
IF(NN EQ 0)WRITE(MWRITE,900)NSIDE
IF(NN EQ 1)WRITE(MWRITE,901)NSIDE
IF(NN EQ 2)WRITE(MWRITE,902)NSIDE
IF(NN EQ 3)WRITE(MWRITE,903)NSIDE
IF(NN EQ 4)WRITE(MWRITE,904)NSIDE
IF(NN EQ 5)WRITE(MWRITE,905)NSIDE
IF(NN .EQ. 1) I=I+1
135 CONTINUE
IF(I EQ 0) GO TO 13503
NG=2*I
IF(I .EQ. 2) GO TO 13501
TY=TY1
PE=PE1
GO TO 13502
13501 TY=TY2
PE=PE2
13502 WRITE(MWRITE,634) NO,TY,PE
13503 CONTINUE
IF(NB EQ 0)GO TO 136
WRITE(MWRITE,635)NB
WRITE(MWRITE,636)(NBC(I),I=1,NB)
136 CONTINUE
IF(NXST.EQ 0)GO TO 150
WRITE(MWRITE,650)
WRITE(MWRITE,651)
DO 140 I=1,NXST
140 WRITE(MWRITE,655)I,LNXS(I),MATXS(I),(XSPROP(J,I),J=1,7)
150 IF(NYST.EQ 0)GO TO 170
WRITE(MWRITE,660)
WRITE(MWRITE,661)
DO 160 I=1,NYST
160 WRITE(MWRITE,655)I,LNYS(I),MATYS(I),(YSPROP(J,I),J=1,7)
170 CONTINUE
500 FORMAT(20I4)
510 FORMAT(5D16 7)
600 FORMAT('0','AUTO-GENERATED FINITE-ELEMENT MESH INFORMATION FOR STIFFENED OR UNSTIFFENED FLAT-PLATE PROBLEM')
605 FORMAT(///
25X,'X-LENGTH(IN)          =',D15.7/
35X,'Y-LENGTH(IN)          =',D15.7/
45X,'Z-POSITION(IN)         =',D15.7/
55X,'THICKNESS(IN)         =',D15.7/
65X,'YOUNGS MODULUS(PSI)    =',D15.7/
75X,'POISSONS RATIO         =',D15.7/
85X,'DENSITY(LB-SEC**2/IN**4) =',D15.7/
95X,'NO. OF ELEM. IN X-DIRECTION =',I15/
A5X,'NO. OF ELEM. IN Y-DIRECTION =',I15/

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MSPA0269
MSPA0270
MSPA0271
MSPA0272
MSPA0273
MSPA0274
MSPA0275
MSPA0276
MSPA0277
MSPA0278
MSPA0279
MSPA0280
MSPA0281
MSPA0282
MSPA0283
MSPA0284
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MSPA0286
MSPA0287
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MSPA0290
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MSPA0300
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MSPA0315
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MSPA0319
MSPA0320
MSPA0321
MSPA0322
MSPA0323
MSPA0324
MSPA0325
MSPA0326
MSPA0327

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      B5X,'NO OF D O F /ELEM          =' ,I15/           MSPA0328
      C5X,'TOTAL NO. OF ELEMENTS      =' ,I15/           MSPA0329
      D5X,'TOTAL NO OF D O F          =' ,I15/           MSPA0330
      E5X,'NO. OF X-DIR STIFFENERS    =' ,I15/           MSPA0331
      F5X,'NO. OF Y-DIR. STIFFENERS   =' ,I15/           MSPA0332
625  FORMAT(' ', 'THE GLOBAL NODE NUMBERS ASSOCIATED WITH EACH ELEMENT A
      2RE AS FOLLOWS ')                                MSPA0333
626  FORMAT(' ', '5X, 'ELEMENT', 5X, 'GLOBAL NODE NUMBERS') MSPA0334
627  FORMAT(' ', '5X, I6, 5X, 4I6)                    MSPA0335
700  FORMAT('0', 'BOUNDARY CONDITIONS (SEE WRITEUP FOR CONVENTION FOR SIM
      2DE NUMBER AND BOUNDARY CONDITION)')            MSPA0336
701  FORMAT('0', 'SIDE NUMBER', 5X, 'BOUNDARY CONDITION') MSPA0338
900  FORMAT(' ', I6, 10X, 'FREE')                      MSPA0340
901  FORMAT(' ', I6, 10X, 'SYMMETRY')                  MSPA0341
902  FORMAT(' ', I6, 10X, 'IDEALLY CLAMPED')           MSPA0342
903  FORMAT(' ', I6, 10X, 'PINNED-FIXED')              MSPA0343
904  FORMAT(' ', I6, 10X, 'PINNED-FREE SLIDING Z-DIRECTION') MSPA0344
905  FORMAT(' ', I6, 10X, 'PINNED-FREE SLIDING/NORMAL (INPLANE)') MSPA0345
650  FORMAT('0', 'INFORMATION FOR X-DIRECTION STIFFENERS') MSPA0346
651  FORMAT('0', 'STIFF NO.', 2X, 'ON ELEM ', 1X, 'MAT. NO.', 3X, 'THICKNESS'
      2, 10X, 'WIDTH', 4X, 'YOUNGS MOD.', 2X, 'POISSON RATIO', 8X, 'DENSITY', 7X,
      3 'ETA-LOC.', 6X, 'OFFSET, ZF')                    MSPA0348
655  FORMAT(' ', I7, 5X, I5, I6, 3X, 7D15.5)           MSPA0349
660  FORMAT('0', 'INFORMATION FOR Y-DIRECTION STIFFENERS') MSPA0351
661  FORMAT('0', 'STIFF. NO ', 2X, 'ON ELEM. ', 1X, 'MAT. NO.', 3X, 'THICKNESS'
      2, 10X, 'WIDTH', 4X, 'YOUNGS MOD.', 2X, 'POISSON RATIO', 8X, 'DENSITY', 7X,
      3 'PSI-LOC.', 6X, 'OFFSET, ZF')                    MSPA0354
634  FORMAT(3X, '(SYSTEM ENERGIES ARE 1/ ', I1, ' THEIR ACTUAL VALUES BECAUM
      +SE OF THE', 2A4, 'SYMMETRY CONDITION)')        MSPA0355
635  FORMAT('0', 'THE FOLLOWING', I6, 2X, 'DEGREES OF FREEDOM ARE CONSTRAIN
      2ED')                                             MSPA0358
636  FORMAT(' ', 20I5)                                MSPA0359
      RETURN                                           MSPA0360
      END                                             MSPA0361
      SUBROUTINE MESHFM(NP, NODE, XG, YG, ZG, NBC, BC, LNXS, LNYS, XGI, YGI,
      2XSPROP, YSPROP, NXST, NYST, IMESH, MATXS, MATYS) MSPM0000
      IMPLICIT REAL*8(A-H, O-Z)                        MSPM0001
C                                           MSPM0002
C                                           MSPM0003
C ASRL TR 154-14. . . ORIGINAL REPORT VERSION OF PROGRAM MSPM0004
C COPYRIGHT (C) MASSACHUSETTS INSTITUTE OF TECHNOLOGY 1980 MSPM0005
C                                           MSPM0006
C THIS SUBROUTINE IS USED BY BOTH THE PLATE AND THE CIVM PLATE PROGRAMS. MSPM0007
C                                           MSPM0008
      DIMENSION NP(4,1), NODE(1), XG(1), YG(1), ZG(1), NBC(1), BC(1), LNXS(1),
      2LNYS(1), XGI(1), YGI(1), XSPROP(7,1), YSPROP(7,1), MATXS(1), MATYS(1) MSPM0009
      COMMON /BAS/NDT, NET, MN, NB, NIRREG, MNC          MSPM0010
      COMMON /PLATE/XDIST, YDIST, TH, HXL, HYL, NEAD, NECD, DENSP, EPAN, ANUP,
      2THALF                                             MSPM0011
      COMMON /INOUT/ MREAD, MWRITE, MPUNCH              MSPM0012
C MANUAL MESH GENERATION FOR FLAT-PLATE STRUCTURES HAVING NON-RECTANG- MSPM0013
C ULAR PLANFORM, VOIDS, OR REQUIRING SPECIAL CONSIDERATIONS NOT MSPM0014
C INCLUDED IN AUTO- GENERATION ROUTINE.                MSPM0015
C                                           MSPM0016
C                                           MSPM0017
C                                           MSPM0018
      READ(MREAD, 500) NNT, NET                          MSPM0019
      READ(*READ, 510) EPAN, ANUP, DENSP, TH, ZPOS      MSPM0020
      NDT=NNT*6                                         MSPM0021
      NDPE=24                                           MSPM0022
      NDPN=G                                             MSPM0023
      THALF=TH/2.0                                       MSPM0024

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C	READ IN NODAL CONNECTIVITY INFORMATION.	MSPM0025
	DO 10 I=1,NET	MSPM0026
10	READ(MREAD,500)(NP(J,I),J=1,4)	MSPM0027
	DO 20 I=1,NET	MSPM0028
	INCI=(I-1)*NDPE	MSPM0029
	DO 20 J=1,4	MSPM0030
	INCJ=(J-1)*NDPN	MSPM0031
	DO 20 K=1,NDPN	MSPM0032
	INCIJK=INCI+INCJ+K	MSPM0033
20	NODE(INCIJK)=NP(J,I)*NDPN-NDPN+K	MSPM0034
C	READ IN NODAL X AND Y COORDINATES.	MSPM0035
	READ(MREAD,510)(XG(I),I=1,NNT)	MSPM0036
	READ(MREAD,510)(YG(I),I=1,NNT)	MSPM0037
	DO 30 I=1,NNT	MSPM0038
	XGI(I)=XG(I)	MSPM0039
	YGI(I)=YG(I)	MSPM0040
30	ZG(I)=ZPOS	MSPM0041
C	READ IN CONSTRAINED DEGREES OF FREEDOM IN ASCENDING ORDER, NO	MSPM0042
C	DUPLICATES	MSPM0043
	READ(MREAD,500)NB	MSPM0044
	IF(NB EQ 0)GO TO 45	MSPM0045
	READ(MREAD,500)(NBC(I),I=1,NB)	MSPM0046
	DO 40 I=1,NB	MSPM0047
40	BC(I)=0 0	MSPM0048
45	CONTINUE	MSPM0049
C	READ IN INFORMATION FOR STIFFENERS.	MSPM0050
	READ(MREAD,500)NXST,NYST	MSPM0051
C	PROPERTIES FOR X-DIRECTION STIFFENERS.	MSPM0052
	IF(NXST EQ 0)GO TO 60	MSPM0053
142	READ(MREAD,500)(LNXS(I),I=1,NXST)	MSPM0054
	READ(MREAD,500)(MATXS(I),I=1,NXST)	MSPM0055
	DO 50 I=1,7	MSPM0056
50	READ(MREAD,510)(XSPROP(I,J),J=1,NXST)	MSPM0057
60	CONTINUE	MSPM0058
C	PROPERTIES FOR Y-DIRECTION STIFFENERS.	MSPM0059
	IF(NYST EQ 0)GO TO 80	MSPM0060
	READ(MREAD,500)(LNYS(I),I=1,NYST)	MSPM0061
	READ(MREAD,500)(MATYS(I),I=1,NYST)	MSPM0062
	DO 70 I=1,7	MSPM0063
70	READ(MREAD,510)(YSPROP(I,J),J=1,NYST)	MSPM0064
80	CONTINUE	MSPM0065
C	PRINT INFORMATION.	MSPM0066
	WRITE(MWRITE,600)	MSPM0067
	WRITE(MWRITE,605)EPAN,ANUP,DENSP,TH,ZPOS,NDPE,NET,NDT,NXST,NYST	MSPM0068
	WRITE(MWRITE,625)	MSPM0069
	WRITE(MWRITE,626)	MSPM0070
	DO 130 I=1,NET	MSPM0071
130	WRITE(MWRITE,627)I,(NP(J,I),J=1,4)	MSPM0072
	IF(NB EQ 0)GO TO 136	MSPM0073
	WRITE(MWRITE,635)NB	MSPM0074
	WRITE(MWRITE,636)(NBC(I),I=1,NB)	MSPM0075
136	CONTINUE	MSPM0076
	IF(NXST EQ 0)GO TO 150	MSPM0077
	WRITE(MWRITE,650)	MSPM0078
	WRITE(MWRITE,651)	MSPM0079
	DO 140 I=1,NXST	MSPM0080
140	WRITE(MWRITE,655)I,LNXS(I),MATXS(I),(XSPROP(J,I),J=1,7)	MSPM0081
150	IF(NYST EQ 0)GO TO 170	MSPM0082
	WRITE(MWRITE,660)	MSPM0083

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        WWRITE(MWRITE,661)
        DO 160 I=1,NYST
*80  WRITE(MWRITE,655)I,LNYS(I),MATYS(I),(YSPROP(J,I),J=1,7)
170  CONTINUE
500  FORMAT(20I4)
510  FORMAT(5D16.7)
600  FORMAT('0','USER-GENERATED FINITE-ELEMENT MESH INFORMATION FOR STIFFENED OR UNSTIFFENED FLAT-PLATE PROBLEM')
605  FORMAT(///
65X,'YOUNGS MODULUS(PSI)          =' ,D15.7/
75X,'POISSONS RATIO              =' ,D15.7/
85X,'DENSITY(LB-SEC**2/IN**4)    =' ,D15.7/
55X,'THICKNESS(IN)              =' ,D15.7/
45X,'Z-POSITION(IN)             =' ,D15.7/
85X,'NO OF D O F /ELEM.         =' ,I15/
65X,'TOTAL NO. OF ELEMENTS      =' ,I15/
D5X,'TOTAL NO. OF D O F.        =' ,I15/
E5X,'NO. OF X-DIR. STIFFENERS   =' ,I15/
F5X,'NO. OF Y-DIR. STIFFENERS   =' ,I15)
625  FORMAT(' ','THE GLOBAL NODE NUMBERS ASSOCIATED WITH EACH ELEMENT ARE AS FOLLOWS .')
626  FORMAT(' ',5X,'ELEMENT',5X,'GLOBAL NODE NUMBERS')
627  FORMAT(' ',5X,I6.5X,4I6)
650  FORMAT('0','INFORMATION FOR X-DIRECTION STIFFENERS')
651  FORMAT('0','STIFF NO.',2X,'ON ELEM.',1X,'MAT. NO.',3X,'THICKNESS',2,10X,'WIDTH',4X,'YOUNGS MOD.',2X,'POISSON RATIO',8X,'DENSITY',7X,3'ETA-LOC.',6X,'OFFSET,ZF')
655  FORMAT(' ',17,5X,I6,3X,7D15.5)
660  FORMAT('0','INFORMATION FOR Y-DIRECTION STIFFENERS')
661  FORMAT('0','STIFF NO.',2X,'ON ELEM.',1X,'MAT. NO.',3X,'THICKNESS',2,10X,'WIDTH',4X,'YOUNGS MOD.',2X,'POISSON RATIO',8X,'DENSITY',7X,3'PSI-LOC.',6X,'OFFSET,ZF')
635  FORMAT('0','THE FOLLOWING',16,2X,'DEGREES OF FREEDOM ARE CONSTRAINED')
636  FORMAT(' ',20I5)
        RETURN
        END
        SUBROUTINE OMLT(SQVCT,RWVCT,ACC,NCOL,KROW,NDEX)
        IMPLICIT REAL*8(A-H,O-Z)
C
C  ASRL TR 154-14 .. .. ORIGINAL REPORT VERSION OF PROGRAM
C  COPYRIGHT (C) MASSACHUSETTS INSTITUTE OF TECHNOLOGY 1980
C
C  THIS SUBROUTINE IS USED BY BOTH THE PLATE AND THE CIVM PLATE PROGRAMS.
C
        DIMENSION SQVCT(1),RWVCT(1),NCOL(1),ACC(1),KROW(1),NDEX(1)
        COMMON/BAS/NROWS,NET,MN,NB,NIRREG,MNC
        COMMON /INOUT/ MREAD,MWRITE,MPUNCH
C
C  TO FIND ACC OF (SQVCT)*(RWVCT)=(ACC)
C
        INDEX=0
        NROWM=NROWS-1
        IF (NIRREG .GT. 0) GO TO 200
        HIGH SPEED PRODUCT FOR REGULAR MATRICES
        DO 100 NN=1,NROWM
        SUM=0.0
        IP1=NN+1
        KST=NCOL(NN)

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MSPM0084
MSPM0085
MSPM0086
MSPM0087
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MSPM0090
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MSPM0100
MSPM0101
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OMLT0020
OMLT0021

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INDEX=INDEX+NN-KST
DO 101 KPL=KST,NN
IJ=INDEX+KPL
101 SUM=SUM+SQVCT(IJ)*RWVCT(KPL)
C NOW FOR THE COLUMN ELEMENTS
JNDEX=IJ
DO 102 KPL=IP1,NROWS
IF(NN.LT.NCOL(KPL))GO TO 100
JNDEX=JNDEX+KPL-NCOL(KPL)
102 SUM=SUM+SQVCT(JNDEX)*RWVCT(KPL)
100 ACC(NN)=ACC(NN)+SUM
C NOW FOR THE LAST ROW
104 KADD=NCOL(NROWS)
SUM=0 0
INDEX=INDEX+NROWS-KADD
DO 103 KPL=KADD,NROWS
IJ=INDEX+KPL
103 SUM=SUM+SQVCT(IJ)*RWVCT(KPL)
ACC(NROWS)=ACC(NROWS)+SUM
RETURN
C MEDIUM SPEED PRODUCT FOR NIRREG .LE. NROWS/2
200 IF (NIRREG .GT. NROWS/2) GO TO 201
DO 105 NN=1,NROWM
IP1=NN+1
KST=NCOL(NN)
INDEX=INDEX+NN-KST
SUM=0 0
DO 106 KPL=KST,NN
IJ=INDEX+KPL
106 SUM=SUM+SQVCT(IJ)*RWVCT(KPL)
NCK=0
JNDEX=IJ
107 DO 108 KPL=IP1,NROWS
IF(NN.LT.NCOL(KPL))GO TO 109
JNDEX=JNDEX+KPL-NCOL(KPL)
108 SUM=SUM+SQVCT(JNDEX)*RWVCT(KPL)
GO TO 105
109 NCK=NCK+1
IF (NCK .GT. NIRREG) GO TO 105
IF (KPL GE KROW(NCK)) GO TO 109
IP1=KPOW(NCK)
JNDEX=NDEX(NCK)+NN
GO TO 107
105 ACC(NN)=ACC(NN)+SUM
GO TO 104
201 DO 503 NN=1,NROWM
IP1=NN+1
K=NCOL(NN)
INDEX=INDEX+NN-K
SUM=0 0
DO 502 KRX=K,NN
IJ=INDEX+KRX
502 SUM=SUM+SQVCT(IJ)*RWVCT(KRX)
JNDEX=IJ
DO 504 KRX=IP1,NROWS
K=NCOL(KPX)
JNDEX=JNDEX+KRX-K
IF (.IN.LT.K) GO TO 504
SUM=SUM+SQVCT(JNDEX)*RWVCT(KRX)

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OMLT0022
OMLT0023
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OMLT0080

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504 CONTINUE
503 ACC(NN)=ACC(NN)+SUM
      GO TO 104
      END
      SUBROUTINE PRTOP(NNSA,NVSA,NCON,NP)
      IMPLICIT REAL*8(A-H,O-Z)
C
C ASRL TR 154-14. . ORIGINAL REPORT VERSION OF PROGRAM
C COPYRIGHT (C) MASSACHUSETTS INSTITUTE OF TECHNOLOGY 1980
C
C THIS SUBROUTINE IS USED BY BOTH THE PLATE AND THE CIVM PLATE PROGRAMS.
C
      DIMENSION NVSA(1),NCON(4,1),NP(4,1)
      COMMON /BAS/NDT,NET,MN,NB,NIRREG,MNC
      COMMON /ASP/SLASP(50),ELASP(50),EDIR(2,50),NASP,LNASP(50)
      COMMON /PRNT/IOP1,IOP2,IOP3,IOP4,IOP5,IOP6,IOP7,IOP8
      COMMON /GSOUT/NEGS,LNGS(200)
      COMMON /SSOUT/NXSS,NYSS,INXSS(200),INYSS(200)
      COMMON /INOUT/ MREAD,MWRITE,MPUNCH
C PRINT CONTROL FOR PROGPAW (0=NO, 1=YES)
C IOP1 NODAL DISPLACEMENTS AND LOCATION
C IOP2 ELEMENT CENTROID STRAINS, PRINCIPAL STRAIN AND DIRECTION.
C IOP3 STRAINS, PRINCIPAL STRAIN AND DIRECTION AT G.S. OF SPEC.
C ELEMENTS.
C IOP4 STRAINS, PRINC STRAIN AND DIR., AND ELONGATION IN SPECIFIED
C DIRECTIONS AT ADDITIONAL LOCATIONS
C IOP5 REACTION FORCES AT CONSTRAINED NODES.
C IOP6 STRAIN AT GAUSSIAN STATIONS FOR SPECIFIED X- AND/OR Y-
C DIRECTION STIFFENERS.
C IOP7 SYSTEM ENERGIES.
C IOP8 STRAIN COMPONENTS, PRINCIPAL STRAIN AND DIRECTION AT SPECIFIED
C NODES (USING NODAL AVERAGING).
C
      READ(MREAD,500)IOP1,IOP2,IOP3,IOP4,IOP5,IOP6,IOP7,IOP8
C IF IOP3=1, READ IN ELEMENTS SPECIFIED FOR G.S. STRAIN OUTPUT.
      IF(IOP3 EQ 0)GO TO 10
      READ(MREAD,500)NEGS
      READ(MREAD,500)(LNGS(I),I=1,NEGS)
10 CONTINUE
C IF IOP4=1, READ IN INFO FOR ADDITIONAL POINTS.
      IF(IOP4 EQ 0)GO TO 50
      READ(MREAD,500)NASP
      DO 20 I=1,NASP
20 READ(MREAD,520)LNASP(I),SLASP(I),ELASP(I)
      DO 30 I=1,NASP
      EDIR(1,I)=0.000
30 EDIR(2,I)=90.000
      READ(MREAD,500)NASPE
      IF(NASPE EQ 0)GO TO 50
      DO 40 I=1,NASPE
      READ(MREAD,520)NSP,DIR1,DIR2
      EDIR(1,NSP)=DIR1
40 EDIR(2,NSP)=DIR2
50 CONTINUE
C IF IOP6=1, READ IN STIFFENER NUMBERS FOR STRAIN OUTPUT.
      IF(IOP6 EQ 0)GO TO 51
      READ(MREAD,500)NXSS,NYSS
      IF(NXSS GT 0)READ(MREAD,500)(INXSS(J),J=1,NXSS)
      IF(NYSS GT 0)READ(MREAD,500)(INYSS(J),J=1,NYSS)

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OMLT0081
OMLT0082
OMLT0083
OMLT0084
PRT00000
PRT00001
PRT00002
PRT00003
PRT00004
PRT00005
PRT00006
PRT00007
PRT00008
PRT00009
PRT00010
PRT00011
PRT00012
PRT00013
PRT00014
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PRT00016
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PRT00054
PRT00055

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51	CONTINUE	PRT00055
C	IF IOP8=1, READ IN NODE NOS. FOR NODAL AVERAGE STRAIN CALCULATION.	PRT00056
	IF(IOP8 EQ 0)GO TO 58	PRT00057
	READ(MREAD,500)NNSA	PRT00058
C	IF NNSA=NNT, THEN ALL NODES ARE INCLUDED AUTOMATICALLY	PRT00059
	NNT=NDT/6	PRT00060
	IF(NNSA EQ NNT)GO TO 53	PRT00061
	READ(MREAD,500)(NVSA(I),I=1,NNSA)	PRT00062
	GO TO 55	PRT00063
53	CONTINUE	PRT00064
	DO 54 I=1,NNT	PRT00065
54	NVSA(I)=I	PRT00066
55	CONTINUE	PRT00067
C	DEFINE ELEMS. CONNECTED AT EACH REQUESTED NODE.	PRT00068
	DO 57 I=1,NNSA	PRT00069
	NN=NVSA(I)	PRT00070
	DO 57 J=1,4	PRT00071
	NCON(J,I)=0	PRT00072
	DO 56 K=1,NET	PRT00073
	IF(NP(J,K) NE NN)GO TO 56	PRT00074
	NCON(J,I)=K	PRT00075
	GO TO 57	PRT00076
56	CONTINUE	PRT00077
57	CONTINUE	PRT00078
58	CONTINUE	PRT00079
	WRITE(MWRITE,600)	PRT00080
	WRITE(MWRITE,610)	PRT00081
	IF(IOP1 EQ 1)WRITE(MWRITE,620)	PRT00082
	IF(IOP5 EQ 1)WRITE(MWRITE,625)	PRT00083
	IF(IOP5 EQ 2)WRITE(MWRITE,630)	PRT00084
	IF(IOP8 EQ 0)GO TO 59	PRT00085
	WRITE(MWRITE,635)NNSA	PRT00086
	WRITE(MWRITE,650)(NVSA(I),I=1,NNSA)	PRT00087
59	CONTINUE	PRT00088
	IF(IOP3 EQ 0)GO TO 60	PRT00089
	WRITE(MWRITE,640)NEGS	PRT00090
	WRITE(MWRITE,650)(LNCS(I),I=1,NEGS)	PRT00091
60	CONTINUE	PRT00092
	IF(IOP4 EQ 0)GO TO 80	PRT00093
	WRITE(MWRITE,660)NASP	PRT00094
	WRITE(MWRITE,670)	PRT00095
	DO 70 I=1,NASP	PRT00096
70	WRITE(MWRITE,680)I, LNASP(I), SLASP(I), ELASP(I), EDIR(1,I), EDIR(2,I)	PRT00097
80	CONTINUE	PRT00098
	IF(IOP6 EQ 0)GO TO 84	PRT00099
	IF(NXSS EQ 0)GO TO 82	PRT00100
	WRITE(MWRITE,700)NXSS	PRT00101
	WRITE(MWRITE,650)(INXSS(J),J=1,NXSS)	PRT00102
82	CONTINUE	PRT00103
	IF(NYSS EQ 0)GO TO 84	PRT00104
	WRITE(MWRITE,710)NYSS	PRT00105
	WRITE(MWRITE,650)(INYSS(J),J=1,NYSS)	PRT00106
84	CONTINUE	PRT00107
	IF(IOP7 EQ 1)WRITE(MWRITE,690)	PRT00108
500	FORMAT(20I4)	PRT00109
520	FORMAT(14,2D16.7)	PRT00110
600	FORMAT('0','***** OUTPUT CONTROL INFORMATION *****')	PRT00111
610	FORMAT('0','THE FOLLOWING RESULTS WILL BE GIVEN AT EVERY REGULAR P	PRT00112
	2RINTOUT CYCLE.')	PRT00113

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620 FORMAT(' ',5X,'NODAL DISPLACEMENTS AND LOCATION')          PRT00114
625 FORMAT(' ',5X,'REACTION FORCES AT CONSTRAINED NODES')      PRT00115
630 FORMAT(' ',5X,'STRAIN COMPONENTS, PRINCIPAL STRAIN AND DIRECTION' PRT00116
      2T CENTROID OF EACH ELEMENT')                              PRT00117
635 FORMAT(' ',5X,'STRAIN COMPONENTS, PRINCIPAL STRAIN AND DIRECTION' PRT00118
      2T THE FOLLOWING',15,2X,'NODES (OBTAINED BY NODAL AVERAGING):') PRT00119
640 FORMAT(' ',5X,'STRAIN COMPONENTS, PRINCIPAL STRAIN AND DIRECTION' PRT00120
      2T EACH GAUSSIAN STATION FOR EACH OF THE FOLLOWING',15,2X,'ELEMENTS' PRT00121
      3 ')                                                       PRT00122
650 FORMAT(' ',10X,20I5)                                         PRT00123
660 FORMAT(' ',5X,'STRAIN COMPONENTS, ELONGATION IN SPECIFIED DIRECTION' PRT00124
      2NS, PRINCIPAL STRAIN AND DIRECTION AT THE FOLLOWING',15,2X,'ADDTL.' PRT00125
      3 POINTS ')                                               PRT00126
670 FORMAT(' ',5X,'ADDTL POINT',2X,'ON ELEM.',4X,'PSI-LOCATION',4X, PRT00127
      2 EIA-LOCATION',2X,'ELONG. DIR.-1(DEG)',2X,'ELONG. DIR.-2(DEG)') PRT00128
680 FORMAT(' ',5X,19,5X,16,2X,2D16.7,4X,D16.7,4X,D16.7)        PRT00129
690 FORMAT(' ',5X,'SYSTEM ENERGIES')                             PRT00130
700 FORMAT(' ',5X,'STRAIN AT GAUSSIAN STATIONS FOR THE FOLLOWING',15, PRT00131
      22X,'X-DIRECTION STIFFENERS.')                            PRT00132
710 FORMAT(' ',5X,'STRAIN AT GAUSSIAN STATIONS FOR THE FOLLOWING',15, PRT00133
      22X,'Y-DIRECTION STIFFENERS.')                            PRT00134
      RETURN                                                    PRT00135
      END                                                        PRT00136
      SUBROUTINE PSTRN(G11,G22,G12,S,D)                          PSTN0000
      IMPLICIT REAL*8(A-H,O-Z)                                  PSTN0001
C
C ASRL TR 154-14 .. ORIGINAL REPORT VERSION OF PROGRAM        PSTN0002
C COPYRIGHT (C) MASSACHUSETTS INSTITUTE OF TECHNOLOGY 1980  PSTN0003
C
C THIS SUBROUTINE IS USED BY BOTH THE PLATE AND THE CIVM PLATE PROGRAMS. PSTN0004
C
C CALCULATE MAX PRINCIPAL STRAIN (TENSILE ONLY) AND CORRESPONDING PSTN0005
C DIRECTION WITH RESPECT TO X-AXIS (IN DEGREES).              PSTN0006
      C=DSQRT((G11-C22)**2+G12*G12)                             PSTN0007
      A1=(G11+G22+C)*0.5                                       PSTN0008
      A2=(G11+G22-C)*0.5                                       PSTN0009
      S=0.0                                                       PSTN0010
      IF(A1.GT.S)S=A1                                           PSTN0011
      IF(A2.GT.S)S=A2                                           PSTN0012
      IF(G11.NE.G22)GD TO 10                                     PSTN0013
      D=45.0                                                       PSTN0014
      RETURN                                                       PSTN0015
C
C CONTINUE                                                    PSTN0016
      X1=G11-G22                                                 PSTN0017
      D=DATAN2(G12,X1)                                           PSTN0018
C DIVISION OF D BY 2 AND CONVERSION TO DEGREES                PSTN0019
      D=D*28.64789D+00                                          PSTN0020
      IF(S.EQ.0.0)D=0.0                                          PSTN0021
      RETURN                                                       PSTN0022
      END                                                        PSTN0023
      SUBROUTINE RCON(F,NBC)                                     PSTN0024
      IMPLICIT REAL*8(A-H,O-Z)                                  PSTN0025
C
C ASRL TR 154-14.. ORIGINAL REPORT VERSION OF PROGRAM        RCON0000
C COPYRIGHT (C) MASSACHUSETTS INSTITUTE OF TECHNOLOGY 1980  RCON0001
C
C THIS SUBROUTINE IS USED BY BOTH THE PLATE AND THE CIVM PLATE PROGRAMS. RCON0002
C
C DIMENSION F(1),NBC(1)                                       RCON0003

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COMMON/BAS/NDT,NET,MN,NBD,NIRREG,MNC
C
C THIS SUBROUTINE APPLIES BOUNDARY CONSTRAINTS TO THE FORCE VECTOR
C TERMS IN THE FORCE VECTOR CORRESPONDING TO CONSTRAINED DEGREES OF
C FREEDOM ARE ZEROED (IT IS ASSUMED THAT ALL PRESCRIBED DISPLACEMENTS
C ARE ZERO).
C
C ZEROING OF RHS ASSUMING FIXED CONDITIONS
  IF(NBD EQ 0)RETURN
  DO 100 I=1,NBD
  NN=NBC(I)
100  F(NN)=0 0
  RETURN
  END
  SUBROUTINE RPLATE(NTYPE,ANU,XL,YL,TH,SL,CSA,SLAM,SMOI,KT,GBI,YMOD)
  IMPLICIT REAL*8(A-H,O-Z)
  DOUBLE PRECISION KT
C
C ASRL TR 154-14. . . ORIGINAL REPORT VERSION OF PROGRAM
C COPYRIGHT (C) MASSACHUSETTS INSTITUTE OF TECHNOLOGY 1980
C
C THIS SUBROUTINE IS USED BY BOTH THE PLATE AND THE CIVM PLATE PROGRAMS.
C
  DIMENSION GBI(24,24),KTLXS(10),KTLYS(10),CB1(4,4),D1(4,13),GS(6),
  2GW(6),STOR1(4,13),STOR2(24,24),KT(24,24),T(24)
C
C THE STIFFNESS MATRIX FOR AN UNSTIFFENED RECTANGULAR PLATE ELEMENT
C (NTYPE=1), OR AN X-DIRECTION STIFFENER ELEMENT (NTYPE=2), OR A
C Y-DIRECTION STIFFENER ELEMENT (NTYPE=3) ARE FORMED IN THIS
C SUBROUTINE THE PERTINENT THEORETICAL BASIS FOR THE PLATE ELEMENT
148 C IS FOUND IN SUBSECTION A 1 3 3. THE THEORETICAL BASIS FOR STIFFENER
C ELEMENTS IS FOUND IN SUBSECTION A.2.3.
C
  DATA KTLXS/2,4,13,15,17,18,20,22,23,24/
  DATA KTLYS/7,8,14,16,17,19,21,23,22,24/
  DO 5 I=1,24
  DO 5 J=1,24
  KT(I,J)=0.0
5
C FORMATION OF K-TILDA FOR PLATE
  IF(NTYPE NE 1)GO TO 160
C INPLANE CONTRIBUTIONS TO K-TILDA
C FORM C-BAR
  DO 10 I=1,4
  DO 10 J=1,4
10  CB1(I,J)=0 0
  CB1(1,1)=1.0/(XL*XL)
  CB1(1,2)=ANU/(XL*YL)
  CB1(2,1)=CB1(1,2)
  CB1(2,2)=1 0/(YL*YL)
  CB1(3,3)=(1 0-ANU)/(2.0*YL*YL)
  CB1(3,4)=CB1(3,3)*YL/XL
  CB1(4,3)=CB1(3,4)
  CB1(4,4)=(1 0-ANU)/(2.0*XL*XL)
  DO 20 I=1,4
  DO 20 J=1,4
20  CB1(I,J)=CB1(I,J)*TH/(1 0-ANU+ANU)
  NGS=2
  DO 30 I=1,4
  DO 30 J=1,8
  RCON0009
  RCON0010
  RCON0011
  RCON0012
  RCON0013
  RCON0014
  RCON0015
  RCON0016
  RCON0017
  RCON0018
  RCON0019
  RCON0020
  RCON0021
  RCON0022
  RPLT0000
  RPLT0001
  RPLT0002
  RPLT0003
  RPLT0004
  RPLT0005
  RPLT0006
  RPLT0007
  RPLT0008
  RPLT0009
  RPLT0010
  RPLT0011
  RPLT0012
  RPLT0013
  RPLT0014
  RPLT0015
  RPLT0016
  RPLT0017
  RPLT0018
  RPLT0019
  RPLT0020
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  RPLT0028
  RPLT0029
  RPLT0030
  RPLT0031
  RPLT0032
  RPLT0033
  RPLT0034
  RPLT0035
  RPLT0036
  RPLT0037
  RPLT0038
  RPLT0039
  RPLT0040
  RPLT0041
  RPLT0042
  RPLT0043
  RPLT0044

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30  D1(I,J)=0.0
    CALL GAUSS(NCS,GS,GW)
    DO 35 II=1,NGS
      GS(II)=(1.0+GS(II))/2.0
35  GW(II)=GW(II)/2.0
C   LOOP OVER GAUSS STATIONS
    DO 70 NY=1,NGS
      DO 70 NX=1,NGS
        D1(1,2)=1.0
        D1(1,4)=GS(NY)
        D1(2,7)=1 0
        D1(2,8)=GS(NX)
        D1(3,3)=1 0
        D1(3,4)=GS(NX)
        D1(4,6)=1.0
        D1(4,8)=GS(NY)
        DO 40 I=1,4
          DO 40 J=1,8
            STOR1(I,J)=0.0
            DO 40 K=1,4
              40  STOR1(I,J)=STOR1(I,J)+CB1(I,K)*D1(K,J)
                DO 50 I=1,8
                  DO 50 J=1,8
                    STOR2(I,J)=0 0
                    DO 50 K=1,4
                      50  STOR2(I,J)=STOR2(I,J)+D1(K,I)*STOR1(K,J)
                        DO 60 I=1,8
                          DO 60 J=1,8
                            60  KT(I,J)=KT(I,J)+STOR2(I,J)*GW(NX)*GW(NY)
70  CONTINUE
14C BENDING CONTRIBUTIONS TO K-TILDA
    DO 80 I=1,3
      DO 80 J=1,3
80  CB1(I,J)=0 0
      CB1(1,1)=1 0/XL**4
      CB1(1,2)=ANU/(XL*XL+YL*YL)
      CB1(2,1)=CB1(1,2)
      CB1(2,2)=1 0/YL**4
      CB1(3,3)=(1.0-ANU)/(2.0*XL*XL+YL*YL)
      DO 90 I=1,3
        DO 90 J=1,3
90  CB1(I,J)=CB1(I,J)+TH**3/(12.0*(1.0-ANU*ANU))
      NGS-4
      DO 100 I=1,3
        DO 100 J=1,13
100 D1(I,J)=0 0
      CALL GAUSS(NGS,GS,GW)
      DO 105 II=1,NGS
        GS(II)=(1.0-GS(II))/2.0
105 GW(II)=GW(II)/2.0
C   LOOP OVER GAUSS STATIONS
    DO 140 NY=1,NGS
      DO 140 NX=1,NGS
        D1(1,2)=2 0
        D1(1,4)=2 0*GS(NY)
        D1(1,6)=2 0*GS(NY)*GS(NY)
        D1(1,7)=6 0*GS(NX)
        D1(1,9)=D1(1,7)+GS(NY)
        D1(1,11)=D1(1,9)*GS(NY)

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RPLT0045
RPLT0046
RPLT0047
RPLT0048
RPLT0049
RPLT0050
RPLT0051
RPLT0052
RPLT0053
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RPLT0055
RPLT0056
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RPLT0058
RPLT0059
RPLT0060
RPLT0061
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RPLT0064
RPLT0065
RPLT0066
RPLT0067
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RPLT0070
RPLT0071
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RPLT0097
RPLT0098
RPLT0099
RPLT0100
RPLT0101
RPLT0102
RPLT0103

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```

D1(1,12)=D1(1,6)*GS(NY)
D1(1,13)=D1(1,11)*GS(NY)
D1(2,3)=2 0
D1(2,5)=2.0*GS(NX)
D1(2,6)=D1(2,5)*GS(NX)
D1(2,8)=6.0*GS(NY)
D1(2,10)=D1(2,8)*GS(NX)
D1(2,11)=D1(2,6)*CS(NX)
D1(2,12)=D1(2,10)*GS(NX)
D1(2,13)=D1(2,12)*GS(NX)
D1(3,1)=2 0
D1(3,4)=4 0*CS(NX)
D1(3,5)=4 0*GS(NY)
D1(3,6)=8 0*CS(NX)*GS(NY)
D1(3,9)=6.0*GS(NX)*GS(NX)
D1(3,10)=6 0*GS(NY)*GS(NY)
D1(3,11)=D1(3,9)+2.0*GS(NY)
D1(3,12)=D1(3,10)+2 0*GS(NX)
D1(3,13)=D1(3,9)+D1(3,10)/2.0
DO 110 I=1,3
DO 110 J=1,13
STOR1(I,J)=0 0
DO 110 K=1,3
110 STOR1(I,J)=STOR1(I,J)+CB1(I,K)*D1(K,J)
DO 120 I=1,13
DO 120 J=1,13
STOR2(I,J)=0 0
DO 120 K=1,3
120 STOR2(I,J)=STOR2(I,J)+D1(K,I)*STOR1(K,J)
DO 130 I=1,13
DO 130 J=1,13
130 KT(I+11,J+11)=KT(I+11,J+11)+STOR2(I,J)*GW(NX)*GW(NY)
140 CONTINUE
DO 150 I=1,24
DO 150 J=1,24
150 KT(I,J)=KT(I,J)*XL*YL
C THIS COMPLETES FORMATION OF K-TILDA FOR PLATE
GO TO 270
160 CONTINUE
C FORM BASIC BLOCK (10 BY 10) FOR K-TILDA OF STIFFENERS
DO 170 I=1,10
DO 170 J=1,10
170 STOR2(I,J)=0 0
STOR2(1,1)=1 0
STOR2(1,2)=SL
STOR2(1,3)=2 0
STOR2(1,4)=2 0*SL
STOR2(1,5)=2 0*SL*SL
STOR2(1,6)=3 0
STOR2(1,7)=3 0*SL
STOR2(1,8)=3 0*SL*SL
STOR2(1,9)=STOR2(1,5)*SL
STOR2(1,10)=3 0*SL**3
DO 180 J=1,10
STOR2(2,J)=STOR2(1,J)*SL
STOR2(3,J)=STOR2(1,J)*2.0
STOR2(4,J)=STOR2(3,J)*SL
180 STOR2(5,J)=STOR2(4,J)*SL
STOR2(6,6)=12 0
RPLT0104
RPLT0105
RPLT0106
RPLT0107
RPLT0108
RPLT0109
RPLT0110
RPLT0111
RPLT0112
RPLT0113
RPLT0114
RPLT0115
RPLT0116
RPLT0117
RPLT0118
RPLT0119
RPLT0120
RPLT0121
RPLT0122
RPLT0123
RPLT0124
RPLT0125
RPLT0126
RPLT0127
RPLT0128
RPLT0129
RPLT0130
RPLT0131
RPLT0132
RPLT0133
RPLT0134
RPLT0135
RPLT0136
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RPLT0156
RPLT0157
RPLT0158
RPLT0159
RPLT0160
RPLT0161
RPLT0162

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```

STOR2(6,7)=12 0*SL
STOR2(6,8)=12 0*SL*SL
STOR2(6,9)=5 0*SL**3
STOR2(6,10)=2 0*STOR2(6,9)
DO 190 J=7,10
STOR2(7,J)=STOR2(6,J)*SL
STOR2(8,J)=STOR2(7,J)*SL
190 STOR2(9,J)=STOR2(5,J)*SL
STOR2(10,10)=STOR2(8,10)*SL
DO 200 I=1,10
DO 200 J=I,10
200 STOR2(J,I)=STOR2(I,J)
IF(NTYPE EQ.2)DL=XL
IF(NTYPE.EQ.3)DL=YL
C1=CSA/DL
C2=C1*SLAM/DL
C3=SMDI/(DL**3)
DO 210 I=1,2
DO 210 J=1,2
210 STOR2(I,J)=STOR2(I,J)*C1
DO 220 I=1,2
DO 220 J=3,10
STOP2(I,J)=STOP2(I,J)*C2
220 STOR2(J,I)=STOR2(I,J)
DO 230 I=3,10
DO 230 J=3,10
230 STOR2(I,J)=STOR2(I,J)*C3
C EXPAND TO K-TILDA FOR X-DIRECTION STIFFENERS
IF(NTYPE EQ.3)GO TO 250
DO 240 I=1,10
DO 240 J=1,10
1S1 NI=KTLXS(I)
NJ=KTLXS(J)
240 KT(NI,NJ)=STOR2(I,J)
GO TO 270
C THIS COMPLETES FORMATION OF K-TILDA FOR X-DIR. STIFFENER.
250 CONTINUE
C EXPAND TO K-TILDA FOR Y-DIRECTION STIFFENERS
DO 260 I=1,10
DO 260 J=1,10
NI=KTLYS(I)
NJ=KTLYS(J)
260 KT(NI,NJ)=STOR2(I,J)
C THIS COMPLETES FORMATION OF K-TILDA FOR Y-DIR. STIFFENER
270 CONTINUE
C FORM K-BAR FOR ELEMENT
DO 280 I=1,24
DO 280 J=1,24
STOR2(I,J)=0.0
DO 280 K=1,24
280 STOR2(I,J)=STOR2(I,J)+KT(I,K)*GBI(K,J)
DO 290 I=1,24
DO 290 J=1,24
KT(I,J)=0.0
DO 290 K=1,24
290 KT(I,J)=KT(I,J)+GBI(K,I)*STOR2(K,J)
C FORM SCALING VECTOR FOR NODAL DOF
T(1)=1.0
T(2)=1.0

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RPLT0163
RPLT0164
RPLT0165
RPLT0166
RPLT0167
RPLT0168
RPLT0169
RPLT0170
RPLT0171
RPLT0172
RPLT0173
RPLT0174
RPLT0175
RPLT0176
RPLT0177
RPLT0178
RPLT0179
RPLT0180
RPLT0181
RPLT0182
RPLT0183
RPLT0184
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RPLT0186
RPLT0187
RPLT0188
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RPLT0191
RPLT0192
RPLT0193
RPLT0194
RPLT0195
RPLT0196
RPLT0197
RPLT0198
RPLT0199
RPLT0200
RPLT0201
RPLT0202
RPLT0203
RPLT0204
RPLT0205
RPLT0206
RPLT0207
RPLT0208
RPLT0209
RPLT0210
RPLT0211
RPLT0212
RPLT0213
RPLT0214
RPLT0215
RPLT0216
RPLT0217
RPLT0218
RPLT0219
RPLT0220
RPLT0221

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T(3)=1 0
T(4)=XL
T(5)=YL
T(6)=XL*YL
DO 300 I=1,6
T(I+6)=T(I)
T(I+12)=T(I)
300 T(I+18)=T(I)
C SCALE STIFFNESS MATRIX
DO 310 I=1,24
DO 310 J=1,24
310 KT(I,J)=KT(I,J)*T(I)*T(J)*YMOD
RETURN
END
SUBROUTINE SOLV(STIFM,G,SOL,NCOL,KROW,NDEX)
IMPLICIT REAL*8(A-H,O-Z)
C
C ASRL TR 154-13... .ORIGINAL REPORT VERSION OF PROGRAM
C COPYRIGHT (C) MASSACHUSETTS INSTITUTE OF TECHNOLOGY 1980
C
C THIS SUBROUTINE IS USED BY BOTH THE PLATE AND THE CIVM PLATE PROGRAMS.
C
C DIMENSION STIFM(1),G(1),KROW(1) NDFX(1) SOL(1),NCOL(1)
COMMON/BAS/NROWS,NET,MN,NBD,NIRREG,MNC
C
C THIS SUBROUTINE PERFORMS THE FORWARD AND BACKWARD SUBSTITUTION
C OPERATIONS REQUIRED TO COMPLETE THE SOLUTION OF A SYSTEM OF LINEAR
C SIMULTANEOUS EQUATIONS BY THE TRIPLE-FACTORING METHOD. THIS
C SUBROUTINE MUST BE USED IN CONJUNCTION WITH SUBROUTINE FACT.
C
C SOLVE (LL*)(SOL)=(FORCE) FOR DISPLACEMENTS (SOL)
15C INTERMEDIATE SOLUTION USING THE LOWER TRIANGLE
100 INDEX=0
SOL(1)=G(1)
DO 104 I=2,NROWS
IM1=I-1
SUM=0 0
K=NCOL(I)
INDEX=INDEX+I-K
IF (IM1-K) 103,101,101
101 DO 102 J=k,IM1
IJ=INDEX+J
SU=SOL(J)
102 SUM=SUM+STIFM(IJ)*SU
103 II=INDEX+I
104 SOL(I)=G(I)-SUM
C SOL CONTAINS THE INTERMEDIATE SOLUTION
C COMPLETE THE SOLUTION USING THE UPPER TRIANGLE
SOL(NROWS)=SOL(NROWS)/STIFM(II)
INDEX=INDEX-NROWS+NCOL(NROWS)
IF(NIRREG GT 0) GO TO 111
DO 109 KK=2,NROWS
I=NROWS+1-KK
IP1=I+1
SUM=0 0
INDEX=INDEX+I
DO 107 J=IP1,NROWS
K=NCOL(J)
IF (I-K) 108,106,106
RPLT0222
RPLT0223
RPLT0224
RPLT0225
RPLT0226
RPLT0227
RPLT0228
RPLT0229
RPLT0230
RPLT0231
RPLT0232
RPLT0233
RPLT0234
RPLT0235
SOLV0000
SOLV0001
SOLV0002
SOLV0003
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SOLV0031
SOLV0032
SOLV0033
SOLV0034
SOLV0035
SOLV0036
SOLV0037
SOLV0038
SOLV0039
SOLV0040
SOLV0041
SOLV0042
SOLV0043
SOLV0044

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106 JNDEX=JNDEX+J-K
    SU=SOL(J)
107 SUM=SUM+STIFM(JNDEX)*SU
108 II=INDEX+I
    SOL(I)=SOL(I)/STIFM(II)-SUM
109 INDEX=INDEX-I+NCOL(I)
    RETURN
111 IF(NIRREG-NROWS/2) 116,116,112
C   TOO MANY IRREGULAR ROWS FOR ACCELERATED SOLUTION
112 DO 115 KK=2,NROWS
    I=NROWS+1-KK
    IP1=I+1
    JNDEX=INDEX+I
    SUM=0.0
    JNDEX=INDEX+I
    DO 114 J=IP1,NROWS
        K=NCOL(J)
        JNDEX=JNDEX+J-K
        IF (I-K) 114,113,113
113 SU=SOL(J)
    SUM=SUM+STIFM(JNDEX)*SU
114 CONTINUE
    II=INDEX+1
    SOL(I)=SOL(I)/STIFM(II)-SUM
115 INDEX=INDEX-I+NCOL(I)
    RETURN
C   ACCELERATED SOLUTION FOR CASE WITH IRREGULAR ROWS
116 DO 125 KK=2,NROWS
    I=NROWS+1-KK
    IP1=I+1
    SUM=0.0
    NCK=0
    JNDEX=INDEX+I
117 DO 119 J=IP1,NROWS
    K=NCOL(J)
    IF (I-K) 120,118,118
118 JNDEX=JNDEX+J-K
    SU=SOL(J)
119 SUM=SUM+STIFM(JNDEX)*SU
    GO TO 124
120 NCK=NCK+1
    IF(NIRREG-NCK) 124,121,121
121 IP1=KROW(NCK)
    IF (I-NCOL(IP1)) 120,122,122
122 IF (IP1-J) 120,123,123
123 JNDEX=NDEX(NCK)+I
    GO TO 117
124 II=INDEX+I
    SOL(I)=SOL(I)/STIFM(II)-SUM
125 INDEX=INDEX-I+NCOL(I)
    RETURN
END
SUBROUTINE SPRING(EA,SS,ISIDE,XL,YL)
IMPLICIT REAL*8(A-H,O-Z)
C
C   ASRL TR 154-14 . . . ORIGINAL REPORT VERSION OF PROGRAM
C   COPYRIGHT (C) MASSACHUSETTS INSTITUTE OF TECHNOLOGY 1980
C
C THIS SUBROUTINE IS USED BY BOTH THE PLATE AND THE CIVM PLATE PROGRAMS.

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SOLV0045
SOLV0046
SOLV0047
SOLV0048
SOLV0049
SOLV0050
SOLV0051
SOLV0052
SOLV0053
SOLV0054
SOLV0055
SOLV0056
SOLV0057
SOLV0058
SOLV0059
SOLV0060
SOLV0061
SOLV0062
SOLV0063
SOLV0064
SOLV0065
SOLV0066
SOLV0067
SOLV0068
SOLV0069
SOLV0070
SOLV0071
SOLV0072
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SOLV0075
SOLV0076
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SOLV0078
SOLV0079
SOLV0080
SOLV0081
SOLV0082
SOLV0083
SOLV0084
SOLV0085
SOLV0086
SOLV0087
SOLV0088
SOLV0089
SOLV0090
SOLV0091
SOLV0092
SOLV0093
SOLV0094
SOLV0095
SOLV0096
SPNG0000
SPNG0001
SPNG0002
SPNG0003
SPNG0004
SPNG0005
SPNG0006

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C          DIMENSION EK(24,24),SS(5),SK(12,12),LIST(12,4),T(24)          SPNG0007
          DATA LIST/1,2,3,4,5,6,7,8,9,10,11,12,7,9,9,10,11,12,13,14,15,16,   SPNG0008
          B17,18,19,20,21,22,23,24,13,14,15,16,17,18,1,2,3,4,5,6,19,20,21,   SPNG0009
          C22,23,24/          SPNG0010
C SUBROUTINE TO CALCULATE THE EFFECTIVE ELEMENT STIFFNESS MATRIX,          SPNG0011
C EK(24,24), CORRESPONDING TO LINE TRANSLATIONAL AND TORSIONAL LINEAR          SPNG0012
C RESTORING SPRINGS APPLIED ALONG THE SIDE (ISIDE) OF THE RECTANGULAR          SPNG0013
C PLATE ELEMENT, RPLATE.          SPNG0014
C THE SPRING CONSTANTS, SS(I),I=1,5 CORRESPOND, RESPECTIVELY, TO          SPNG0015
C TRANSLATIONAL SPRINGS (LB/IN) IN THE U, V, AND W DISPLACEMENT          SPNG0016
C DIRECTIONS AND ROTATIONAL SPRINGS (IN-LB/IN) IN THE W,X AND W,Y          SPNG0017
C ROTATION DIRECTIONS          SPNG0018
C SIDE NOTATION ,          SPNG0019
C          ISIDE=1 ALONG SIDE Y=0.          SPNG0020
C          ISIDE=2 ALONG SIDE X=XL.          SPNG0021
C          ISIDE=3 ALONG SIDE Y=YL.          SPNG0022
C          ISIDE=4 ALONG SIDE X=0.          SPNG0023
C          SPNG0024
C          SPNG0025
C          SPNG0026
          DD 10 I=1,12          SPNG0027
          DD 10 J=1,12          SPNG0028
          SK(I,J)=0.0          SPNG0029
          DD 20 I=1,24          SPNG0030
          DD 20 J=1,24          SPNG0031
          EK(I,J)=0.0          SPNG0032
C ASSIGN TERMS WHICH ARE COMMON TO ALL SIDES.          SPNG0033
          SK(1,1)=SS(1)/3.0          SPNG0034
          SK(2,2)=SS(2)/3.0          SPNG0035
          SK(7,1)=SS(1)/6.0          SPNG0036
          SK(7,7)=SS(1)/3.0          SPNG0037
          SK(8,2)=SS(2)/6.0          SPNG0038
          SK(8,8)=SS(2)/3.0          SPNG0039
C ASSIGN TERMS FOR SIDES 1 OR 3.          SPNG0040
          IF(ISIDE.EQ 2 OR ISIDE EQ 4)GO TO 30          SPNG0041
          SL=XL          SPNG0042
          SK(3,3)=13.0*SS(3)/35.0+6.0*SS(4)/(5.0*XL*XL)          SPNG0043
          SK(4,3)=11.0*SS(3)/210.0+SS(4)/(10.0*XL*XL)          SPNG0044
          SK(4,4)=SS(3)/105.0+2.0*SS(4)/(15.0*XL*XL)          SPNG0045
          SK(5,5)=13.0*SS(5)/(35.0*YL*YL)          SPNG0046
          SK(6,5)=11.0*SS(5)/(210.0*YL*YL)          SPNG0047
          SK(6,6)=SS(5)/(105.0*YL*YL)          SPNG0048
          SK(9,3)=SS(3)/70.0-6.0*SS(4)/(5.0*XL*XL)          SPNG0049
          SK(9,4)=13.0*SS(3)/420.0-SS(4)/(10.0*XL*XL)          SPNG0050
          SK(9,9)=SK(3,3)          SPNG0051
          SK(10,3)=-SK(9,4)          SPNG0052
          SK(10,4)=-SS(3)/140.0-SS(4)/(30.0*XL*XL)          SPNG0053
          SK(10,9)=-SK(4,3)          SPNG0054
          SK(10,10)=SK(4,4)          SPNG0055
          SK(11,5)=SS(5)/(70.0*YL*YL)          SPNG0056
          SK(11,6)=13.0*SS(5)/(420.0*YL*YL)          SPNG0057
          SK(11,11)=SK(5,5)          SPNG0058
          SK(12,5)=-SK(11,6)          SPNG0059
          SK(12,6)=-SK(11,5)/2.0          SPNG0060
          SK(12,11)=-SK(6,5)          SPNG0061
          SK(12,12)=SK(6,6)          SPNG0062
          GO TO 40          SPNG0063
C ASSIGN TERMS FOR SIDE 2 OR 4.          SPNG0064
          SL=YL          SPNG0065

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	SK(3,3)=13 0+SS(3)/35.0+6.0*SS(5)/(5.0*YL*YL)	SPNG0066
	SK(4,4)=13 0+SS(4)/(35 0*XL*XL)	SPNG0067
	SK(5,3)=11.0+SS(3)/210 0 SS(5)/(10 0*YL*YL)	SPNG0068
	SK(5,5)=SS(3)/105 0+2.0*SS(5)/(15.0*YL*YL)	SPNG0069
	SK(6,4)=11 0+SS(4)/(210.0*XL*XL)	SPNG0070
	SK(6,6)=SS(4)/(105.0*XL*YL)	SPNG0071
	SK(9,3)=SS(3)/70 0-6 0+SS(5)/(5.0*YL*YL)	SPNG0072
	SK(9,5)=13 0+SS(3)/420 0-SS(5)/(10.0*YL*YL)	SPNG0073
	SK(9,9)=SK(3,3)	SPNG0074
	SK(10,4)=SS(4)/(70.0*XL*XL)	SPNG0075
	SK(10,6)=13 0+SS(4)/(420 0*XL*XL)	SPNG0076
	SK(10,10)=SK(4,4)	SPNG0077
	SK(11,3)=-SK(9,5)	SPNG0078
	SK(11,5)=-SS(3)/140.0-SS(5)/(30.0*YL*YL)	SPNG0079
	SK(11,9)=-SK(5,3)	SPNG0080
	SK(11,11)=SK(5,5)	SPNG0081
	SK(12,4)=-SK(10,6)	SPNG0082
	SK(12,6)=-SS(4)/(140.0*XL*XL)	SPNG0083
	SK(12,10)=-SK(6,4)	SPNG0084
	SK(12,12)=SK(6,6)	SPNG0085
40	CONTINUE	SPNG0086
C	FORM UPPER TRIANGLE AND MULTIPLY BY SIDE LENGTH.	SPNG0087
	DO 50 I=1,12	SPNG0088
	DO 50 J=1,I	SPNG0089
	SK(I,J)=SK(I,J)+SL	SPNG0090
50	SK(J,I)=SK(I,J)	SPNG0091
C	ASSEMBLE INTO APPROPRIATE LOCATIONS IN 24 BY 24 STIFFNESS MATRIX.	SPNG0092
	DO 60 I=1,12	SPNG0093
	IR=LIST(I,ISIDE)	SPNG0094
	DO 60 J=1,12	SPNG0095
	IC=LIST(J,ISIDE)	SPNG0096
60	EK(IR,IC)=SK(I,J)	SPNG0097
C	FORM TRANSFORMATION VECTOR.	SPNG0098
	DO 70 I=1,24	SPNG0099
70	T(I)=1.0	SPNG0100
	DO 80 I=4,22,6	SPNG0101
	T(I)=XL	SPNG0102
	T(I+1)=YL	SPNG0103
80	T(I+2)=XL*YL	SPNG0104
C	SCALE STIFFNESS MATRIX.	SPNG0105
	DO 90 I=1,24	SPNG0106
	DO 90 J=1,24	SPNG0107
90	EK(I,J)=EK(I,J)-T(I)*T(J)	SPNG0108
	RETURN	SPNG0109
	END	SPNG0110

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SUBROUTINE SFDM(SL,EL,XL,YL,GBI,STD)
IMPLICIT REAL*8(A-H,O-Z)
C
C ASRL TR 154-14... ORIGINAL REPORT VERSION OF PROGRAM
C COPYRIGHT (C) MASSACHUSETTS INSTITUTE OF TECHNOLOGY 1980
C
C THIS SUBROUTINE IS USED BY BOTH THE PLATE AND THE CIVM PLATE PROGRAMS.
C SMALL STRAIN FORMULATION VERSION WRITTEN BY R. L. SPILKER
  DIMENSION D(9,24),STD(9,24),GBI(24,24)
C SUBROUTINE TO CALCULATE MATRIX WHICH DETERMINES STRAIN
C COMPONENTS FROM NODAL DISPL.. ORDER IS U,X V,Y U,Y+V,X W,XX
C W,YY 2*W,XY W,X W,Y 0.5*(U,Y-V,X)
  DO 10 I=1,9
  DO 10 J=1,24
10 D(I,J)=0
  D(1,2)=1 0/XL
  D(1,4)=EL/XL
  D(2,7)=1 0/YL
  D(2,8)=SL/YL
  D(3,3)=1 0/YL
  D(3,4)=SL/YL
  D(3,6)=1 0/XL
  D(3,8)=EL/XL
  D(4,13)=2 0
  D(4,15)=2 0*EL
  D(4,17)=D(4,15)*EL
  D(4,18)=6.0*SL
  D(4,20)=D(4,18)*EL
  D(4,22)=D(4,20)*EL
  D(4,23)=D(4,17)*EL
  D(4,24)=D(4,22)*EL
  D(5,14)=2 0
  D(5,16)=2 0*SL
  D(5,17)=D(5,16)*SL
  D(5,19)=6 0*EL
  D(5,21)=D(5,19)*SL
  D(5,22)=D(5,17)*SL
  D(5,23)=D(5,21)*SL
  D(5,24)=D(5,23)*SL
  D(6,12)=2 0
  D(6,15)=4 0*SL
  D(6,16)=4 0*EL
  D(6,17)=8 0*SL*EL
  D(6,20)=6 0*SL*SL
  D(6,21)=6 0*EL*EL
  D(6,22)=12 0*SL*SL*EL
  D(6,23)=12 0*SL*EL*EL
  D(6,24)=18 0*SL*SL*EL*EL
  D(7,10)=1 0
  D(7,12)=EL
  D(7,13)=2 0*SL
  D(7,15)=D(7,13)*EL
  D(7,16)=EL*EL
  D(7,17)=D(7,15)*EL
  D(7,18)=3 0*SL*SL
  D(7,20)=D(7,18)*EL
  D(7,21)=D(7,16)*EL
  D(7,22)=D(7,20)*EL
  D(7,23)=D(7,17)*EL

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SFDM0000
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SFDM0055
SFDM0056
SFDM0057
SFDM0058

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D(7,24)=D(7,22)*EL
D(8,11)=1 0
D(8,12)=SL
D(8,14)=2 0*EL
D(8,15)=SL*SL
D(8,16)=D(8,14)*SL
D(8,17)=D(8,16)*SL
D(8,19)=3.0*EL*EL
D(8,20)=D(8,15)*SL
D(8,21)=D(8,19)*SL
D(8,22)=D(8,16)*SL*SL
D(8,23)=D(8,21)*SL
D(8,24)=D(8,23)*SL
D(9,3)=1.0/(2.0*YL)
D(9,4)=SL/(2.0*YL)
D(9,6)=-1 0/(2.0*XL)
D(9,8)=-EL/(2 0*XL)
DO 20 J=10,24
D(7,J)=D(7,J)/XL
D(8,J)=D(8,J)/YL
D(6,J)=D(6,J)/(XL*YL)
D(4,J)=D(4,J)/(XL*XL)
20 D(5,J)=D(5,J)/(YL*YL)
DO 30 I=1,9
DO 30 J=1,24
STD(I,J)=0.0
DO 30 K=1,24
30 STD(I,J)=STD(I,J)+D(I,K)*GBI(K,J)
DO 40 J=4,22,2
DO 40 I=1,9
157 STD(I,J)=STD(I,J)*XL
STD(I,J+1)=STD(I,J+1)*YL
40 STD(I,J+2)=STD(I,J+2)*XL*YL
RETURN
END
SUBROUTINE STRESA(DISP,DELD,FLVA,ITT,NODE,MAXEL,MAX2,
2TSGEE,PLASTW,XGI,YGI,NP,STDEA,GBI,NMSUB,DSR,PSR,SUBW,SNOM,NXST,
3XSPROP,LNXS,MATXS,NZS)
IMPLICIT REAL*8(A-H,O-Z)
C
C ASRL TR 154-14. ORIGINAL REPORT VERSION OF PROGRAM
C COPYRIGHT (C) MASSACHUSETTS INSTITUTE OF TECHNOLOGY 1980
C
C THIS SUBROUTINE IS USED BY BOTH THE PLATE AND THE CIVM PLATE PROGRAMS.
C
C SMALL STRAIN FORMULATION VERSION WRITTEN BY R. L. SPILKER
C
DIMENSION DISP(1),DELD(1),FLVA(1),SNL(9),EQNL(36),EP(9),DEP(9),
2ELFP(36),NODE(1), TSGEE(MAX2,NZS,3)
DIMENSION XCI(1),YGI(1),NP(4,1),STDEA(9,24),GBI(24,24)
DIMENSION NMSUB(1),DSR(1),PSR(1),SUBW(5,1),SNOM(5,1),ZGAUS(6),
2ZGAUW(6),AGAUS(6),AGAUW(6),RFL(4),RZETA(4),RWEGH(20),SNO(5),
3XSPROP(7,1),LNXS(1),MATXS(1)
COMMON/PLATE/XDIST,YDIST,TH,SLE,ELE,NEAD,NECD,DENSP,EPAN,ANUP,
2THALF
COMMON/BAS/NDT,NET,MN,NB,NIRREG,MNC
COMMON/TIM/DELTAT,TIMEF,TIME,ITIMEF,INCRT,IOUT,ITIME
C
C THIS SUBROUTINE CALCULATES THE EFFECTIVE NODAL FORCE VECTOR FOR AN

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SFDM0059
SFDM0060
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C X-DIRECTION STIFFENER ELEMENT CORRESPONDING TO NONLINEAR GEOMETRIC
 C AND MATERIAL EFFECTS THE EXPRESSION FOR THIS VECTOR IS GIVEN
 C BY EQUATION A.97

C
 NA=3
 NZ=4
 CALL GAUSS(NA, AGAUS, AGAUW)
 CALL GAUSS(NZ, ZGAUS, ZGAUW)
 DO 50 NST=1, NXST
 RH=XSPROP(1, NST)
 RW=XSPRCP(2, NST)
 YOUNG=XSPROP(3, NST)
 HNU=XSPROP(4, NST)
 EL=XSPROP(6, NST)
 XF=XSPROP(7, NST)
 LNUMR=LNXS(NST)
 LNUM=NST
 MAT=MATXS(NST)
 D=DSR(MAT)
 P=PSR(MAT)
 NSUBL=NMSUB(MAT)
 DO 10 LZ=1, NZ
 RFL(LZ)=0.5*RH*ZGAUW(LZ)
 10 RZETA(LZ)=0.5*RH*ZGAUS(LZ)-XF
 DO 11 LZ=1, NZ
 DO 11 LS=1, NSUBL
 JZ=LZ+(LS-1)*NZ
 11 RWEHG(JZ)=RFL(LZ)*SUBW(MAT, LS)
 DO 12 LS=1, NSUBL
 12 SNO(LS)=SNOM(MAT, LS)
 CC5=0 0
 CC6=0 0
 IF(D EQ 0.0) GO TO 13
 CC5=1.0/P
 CC6=1.0/D/DELTA
 13 CONTINUE
 NNN1=NP(1, LNUM)
 NNN2=NP(2, LNUM)
 NNN4=NP(4, LNUM)
 SLE=(XGI(NNN2)-XGI(NNN1))/2.0
 ELE=(YGI(NNN4)-YGI(NNN1))/2.0
 XL=2.0*SLE
 YL=2.0*ELE
 DO 99 J=1, 24
 99 ELFP(J)=0 0
 PLAST2=0.0
 DO 100 KS=1, 1
 SW=RW
 DO 100 KE=1, NA
 SL=(AGAUS(KE)+1.0)/2.0
 CALL SFDM(SL, EL, XL, YL, GBI, STDEA)
 EW=SLE*AGAUS(KE)
 SWEW=SW*EW
 JA=KE+(KS-1)*NA
 DO 60 J=1, 9
 EP(J)=0.0
 DEP(J)=0 0
 DO 60 K=1, 24
 NNN=(LNUMR-1)*24+K

STRA0024
 STRA0025
 STRA0026
 STRA0027
 STRA0028
 STRA0029
 STRA0030
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 STRA0075
 STRA0076
 STRA0077
 STRA0078
 STRA0079
 STRA0080
 STRA0081
 STRA0082

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INDEX=NODE(NNN)
EP(J)=EP(J)+STDEA( J,K)*DISP(INDEX)
DEP(J)=DEP(J)+STDEA( J,K)*DELD(INDEX)
60 CONTINUE
EPEEM=EP(1)+EP(7)**2/2.
DEPEEM=DEP(1)+EP(7)*DEP(7)-DEP(7)**2/2.
BPNEE=0.0
BPMEE=0.0
PLAST1=0.0
DO 150 LZ=1,NZ
EPEEZ=EPEEM-RZETA(LZ)*EP(4)
DEPEEZ=DEPEEM-RZETA(LZ)*DEP(4)
GPEE=YOUNG*EPEEZ
PTEE=0.0
FACTOR=1.
IF(D EQ 0.0) GO TO 152
FACTOR=1.+(CC6*DABS(DEPEEZ))**CC5
152 DO 155 LS=1,NSUBL
JZ=LZ+(LS-1)*NZ
SNY=SNO(LS)*FACTOR
TAE=TSGEE(LNUM, JZ, JA)
DSNEE=YOUNG*DEPEEZ
TMEE=TAE+DSNEE
IF(TMEE-SNY) 20,45,21
21 TAE=SNY
PSS1=(TMEE-SNY)/YOUNG
PLAST1=PLAST1+PSS1*TAE*RWEGH(JZ)
GO TO 156
20 IF(TMEE+SNY) 22,45,45
22 TAE=-SNY
PSS1=(TMEE+SNY)/YOUNG
PLAST1=PLAST1+PSS1*TAE*RWEGH(JZ)
GO TO 156
45 CONTINUE
TAE=TMEE
156 CONTINUE
TSGEE(LNUM, JZ, JA)=TAE
PLAEE=GPEE-TSGEE(LNUM, JZ, JA)
PTEE=PTEE+PLAEE*RWEGH(JZ)
155 CONTINUE
BPNEE=BPNEE+PTEE
BPMEE=BPMEE-PTEE+RZETA(LZ)
150 CONTINUE
DO 163 J=1,9
163 SNL(J)=0.0
SNL(1)=YOUNG*RH*EP(7)**2/2.-BPNEE
SNL(4)=YOUNG*RH*XF*EP(7)**2/2.-BPMEE
SNL(7)=(YOUNG*RH*(EPEEM+XF*EP(4))-BPNEE)*EP(7)
DO 164 J=1,9
164 SNL(J)=SNL(J)*SWEW
DO 165 J=1,24
EQNL(J)=0.0
DO 165 K=1,9
165 EQNL(J)=EQNL(J)+STDEA( K,J)*SNL(K)
DO 166 J=1,24
166 ELFP(J)=ELFP(J)+EQNL(J)
PLAST2=PLAST2+PLAST1*SWEW
100 CONTINUE
DO 201 J=1,24

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STRA0083
STRA0084
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STRA0141

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      NNN=(LNUMR-1)*24+J
      M=NODE(NNN)
201  FLVA(M)=FLVA(M)-ELFP(J)
      PLASTW=PLASTW+PLAST2
50   CONTINUE
      RETURN
      END
      SUBROUTINE STRESC(DISP,DELD,FLVA,ITT,NODE,MAXEL,MAX2,
2TSGEE,PLASTW,XGI,YGI,NP,STDEC,GBI,NMSUB,DSR,PSR,SUBW,SNOM,NYST,
3YSPROP,LNYS,MATYS,NZS)
      IMPLICIT REAL*8(A-H,O-Z)
C
C   ASRL TR 154-14. ORIGINAL REPORT VERSION OF PROGRAM
C   COPYRIGHT (C) MASSACHUSETTS INSTITUTE OF TECHNOLOGY 1980
C
C   THIS SUBROUTINE IS USED BY BOTH THE PLATE AND THE CIVM PLATE PROGRAMS.
C
C   SMALL STRAIN FORMULATION VERSION WRITTEN BY R. L. SPILKER
C
      DIMENSION DISP(1),DELD(1),FLVA(1),SNL(9),EQNL(36),EP(9),DEP(9),
2ELFP(36),NODE(1), TSGEE(MAX2,NZS,3)
      DIMENSION XGI(1),YGI(1),NP(4,1),STDEC(9,24),GBI(24,24)
      DIMENSION NMSUB(1),DSR(1),PSR(1),SUBW(5,1),SNOM(5,1),ZGAUS(6),
2ZGAUW(6),AGAUS(6),AGA UW(6),RFL(4),RZETA(4),RWEHG(20),SNO(5),
3YSPROP(7,1),LNYS(1),MATYS(1)
      COMMON/PLATE/XDIST,YDIST,TH,SLE,ELE,NEAD,NECD,DENSP,EPAN,ANUP,
2THALF
      COMMON/BAS/NDT,NET,MN,NB,NIRREG,MNC
      COMMON/TIM/DELTAT,TIMEF,TIME,ITIMEF,INCRT,IOUT,ITIME
C
160 C THIS SUBROUTINE CALCULATES THE EFFECTIVE NODAL FORCE VECTOR FOR A
C Y-DIRECTION STIFFENER ELEMENT CORRESPONDING TO NONLINEAR GEOMETRIC
C AND MATERIAL EFFECTS. THE EXPRESSION FOR THIS VECTOR IS GIVEN
C BY EQUATION A.98.
C
      NA=3
      NZ=4
      CALL GAUSS(NA,AGAUS,AGA UW)
      CALL GAUSS(NZ,ZGAUS,ZGAUW)
      DO 50 NST=1,NYST
      RH=YSPROP(1,NST)
      RW=YSPROP(2,NST)
      YDUNC=YSPROP(3,NST)
      HNU=YSPROP(4,NST)
      SL=YSPROP(6,NST)
      XF=YSPROP(7,NST)
      LNUMR=LNYS(NST)
      LNUM=NST
      MAT=MATYS(NST)
      D=DSR(MAT)
      P=PSR(MAT)
      NSUBL=NMSUB(MAT)
      DO 10 LZ=1,NZ
      RFL(LZ)=0.5*RH+ZGAUW(LZ)
10  RZETA(LZ)=0.5*RW-ZGAUS(LZ)-XF
      DO 11 LZ=1,NZ
      DO 11 LS=1,NSUBL
      JZ=LZ+(LS-1)*NZ
11  RWEHG(JZ)=RFL(LZ)*SUBW(MAT,LS)

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STRA0142
STRA0143
STRA0144
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STRC0000
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STRC0044
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STRC0046
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STRC0048
STRC0049
STRC0050
STRC0051

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	DO 12 LS=1,NSUBL	STRC0052
12	SND(LS)=SNOM(MAT,LS)	STRC0053
	CC5=0.0	STRC0054
	CC6=0.0	STRC0055
	IF(D EQ 0.0)GO TO 13	STRC0056
	CC5=1.0/P	STRC0057
	CC6=1.0/D/DELTAT	STRC0058
13	CONTINUE	STRC0059
	NNN1=NP(1,LNUM)	STRC0060
	NNN2=NP(2,LNUM)	STRC0061
	NNN4=NP(4,LNUM)	STRC0062
	SLE=(XGI(NNN2)-XGI(NNN1))/2.0	STRC0063
	ELE=(YGI(NNN4)-YGI(NNN1))/2.0	STRC0064
	XL=2.0*SLE	STRC0065
	YL=2.0*ELE	STRC0066
99	DO 99 J=1,24	STRC0067
	ELFP(J)=0.0	STRC0068
	PLAST2=0.0	STRC0069
	DO 100 KS=1,1	STRC0070
	SW=RW	STRC0071
	DO 100 KE=1,NA	STRC0072
	EL=(AGAUW(KE)+1.0)/2.0	STRC0073
	CALL SFDM(SL,EL,XL,YL,GBI,STDEC)	STRC0074
	EW=ELE*AGAUW(KE)	STRC0075
	SWEW=SW*EW	STRC0076
	JA=KE+(KS-1)*NA	STRC0077
	DO 60 J=1,9	STRC0078
	EP(J)=0.0	STRC0079
	DEP(J)=0.0	STRC0080
	DO 60 K=1,24	STRC0081
	NNN=(LNUMR-1)*24+K	STRC0082
	INDEX=NODE(NNN)	STRC0083
	EP(J)=EP(J)+STDEC(J,K)*DISP(INDEX)	STRC0084
	DEP(J)=DEP(J)+STDEC(J,K)*DELD(INDEX)	STRC0085
CO	CONTINUE	STRC0086
	EPEEM=EP(2)+EP(8)**2/2.	STRC0087
	DEPEEM=DEP(2)+EP(8)*DEP(8)-DEP(8)**2/2.	STRC0088
	BPNEE=0.0	STRC0089
	BPMEE=0.0	STRC0090
	PLAST1=0.0	STRC0091
	DO 150 LZ=1,NZ	STRC0092
	EPEEZ=EPEEM-RZETA(LZ)*EP(5)	STRC0093
	DEPEEZ=DEPEEM-RZETA(LZ)*DEP(5)	STRC0094
	GPEE=YOUNG*EPEEZ	STRC0095
	PTEE=0.0	STRC0096
	FACTOR=1.	STRC0097
	IF(D.EQ.0.0)GO TO 152	STRC0098
	FACTOR=1+(CC6*DABS(DEPEEZ))**CC5.	STRC0099
152	DO 155 LS=1,NSUBL	STRC0100
	JZ=LZ+(LS-1)*NZ	STRC0101
	SNY=SND(LS)*FACTOR	STRC0102
	TAAE=TSGEE(LNUM,JZ,JA)	STRC0103
	DSNEE=YOUNG*DEPEEZ	STRC0104
	TMEE=TAAE+DSNEE	STRC0105
	IF(TMEE-SNY)20,45,21	STRC0106
21	TAAE=SNY	STRC0107
	PSS1=(TMEE-SNY)/YOUNG	STRC0108
	PLAST1=PLAST1+PSS1*TAAE*RWEGH(JZ)	STRC0109
	GO TO 156	STRC0110

20	IF(TMEE+SNY) 22,45,45	STRC0111
22	TAAE=-SNY	STRC0112
	PSS1=(TMEE+SNY)/YOUNG	STRC0113
	PLAST1=PLAST1+PSS1*TAAE*RWEGH(JZ)	STRC0114
	GO TO 156	STRC0115
45	CONTINUE	STRC0116
	TAAE=TMEE	STRC0117
156	CONTINUE	STRC0118
	TSGEE(LNUM ,JZ,JA)=TAAE	STRC0119
	PLAEE=GPEE-TSGEE(LNUM ,JZ,JA)	STRC0120
	PTEE=PTEE+PLAEE*RWEGH(JZ)	STRC0121
155	CONTINUE	STRC0122
	BPNEE=BPNEE+PTEE	STRC0123
	BPMEE=BPMEE-PTEE*RZETA(LZ)	STRC0124
150	CONTINUE	STRC0125
	DO 163 J=1,9	STRC0126
163	SNL(J)=0 0	STRC0127
	SNL(2)=YOUNG*RH*EP(8)**2/2.-BPNEE	STRC0128
	SNL(5)=YOUNG*RH*XF*EP(8)**2/2.-BPMEE	STRC0129
	SNL(8)=(YOUNG*RH*(EPEEM+XF*EP(5))-BPNEE)*EP(8)	STRC0130
	DO 164 J=1,9	STRC0131
164	SNL(J)=SNL(J)*SWEW	STRC0132
	DO 165 J=1,24	STRC0133
	EQNL(J)=0 0	STRC0134
	DO 165 K=1,9	STRC0135
165	EQNL(J)=EQNL(J)+STDEC(K,J)*SNL(K)	STRC0136
	DO 166 J=1,24	STRC0137
166	ELFP(J)=ELFP(J)+EQNL(J)	STRC0138
	PLAST2=PLAST2+PLAST1*SWEW	STRC0139
100	CONTINUE	STRC0140
	DO 201 J=1,24	STRC0141
	NNN=(LNUMR-1)*24+J	STRC0142
	M=NODE(NNN)	STRC0143
201	FLVA(M)=FLVA(M)-ELFP(J)	STRC0144
	PLASTW=PLASTW+PLAST2	STRC0145
50	CONTINUE	STRC0146
	RETURN	STRC0147
	END	STRC0148

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SUBROUTINE STRESP(DISP,DELD,FLVA,ITT,NODE,MAXEL,TAUSS,TAUEE,TAUSE,STRP0000
2EPSSI,EPSSO,EPEEI,EPEEO,EPSEI,EPSEO,PLASTW,XGI,YGI,NP,STDEP,GBI,STRP0001
3NMSUB,DSR,PSR,SUBW,SNOM,NZS)STRP0002
IMPLICIT REAL*8(A-H,O-Z)STRP0003
CSTRP0004
C ASRL TR 154-14..... ORIGINAL REPORT VERSION OF PROGRAMSTRP0005
C COPYRIGHT (C) MASSACHUSETTS INSTITUTE OF TECHNOLOGY 1980STRP0006
CSTRP0007
C THIS SUBROUTINE IS USED BY BOTH THE PLATE AND THE CIVM PLATE PROGRAMS.STRP0008
CSTRP0009
C SMALL STRAIN FORMULATION VERSION WRITTEN BY R. L. SPILKERSTRP0010
CSTRP0011
DIMENSION DISP(1),DELD(1),FLVA(1),SNL(9),EQNL(36),EP(9),DEP(9),STRP0012
2ELFP(36),NODE(1),TAUSS(MAXEL,NZS,9),TAUEE(MAXEL,NZS,9),TAUSE(MAXEL,STRP0013
3,NZS,9),EPSSI(9,1),EPSSO(9,1),EPEEI(9,1),EPEEO(9,1),EPSEI(9,1),STRP0014
4EPSEO(9,1)STRP0015
DIMENSION XGI(1),YGI(1),NP(4,1),STDEP(9,24),GBI(24,24)STRP0016
DIMENSION NMSUB(1),DSR(1),PSR(1),SUBW(5,1),SNOM(5,1),ZGAUS(6),STRP0017
2ZGAUW(6),GFL(4),GZETA(4),GWEGH(20),SNO(5),AGAUS(6),AGAUW(6)STRP0018
COMMON/PLATE/XDIST,YDIST,TH,SLE,ELE,NEAD,NECD,DENS,YOUNG,HNU,THALFSTRP0019
COMMON/BAS/NDT,NET,MN,NB,NIRREG,MNCSTRP0020
COMMON/TIM/DELTAT,TIMEF,TIME,I TIMEF,INCRT,IOUT,ITIMESTRP0021
COMMON /INOUT/ MREAD,MWRITE,MPUNCHSTRP0022
CSTRP0023
C THIS SUBROUTINE CALCULATES THE EFFECTIVE NODAL FORCE VECTOR FOR ASTRP0024
C PLATE ELEMENT CORRESPONDING TO NONLINEAR GEOMETRIC AND MATERIALSTRP0025
C EFFECTS THE THEORETICAL BASIS FOR THESE CALCULATIONS IS GIVEN INSTRP0026
C SUBSECTION A.1.3.A.STRP0027
CSTRP0028
163 CON1=(1.0+HNU)/(3.0+YOUNG)STRP0029
NA=3STRP0030
NZ=4STRP0031
NSUBL=NMSUB(1)STRP0032
D=DSR(1)STRP0033
P=PSR(1)STRP0034
CALL GAUSS(NA,AGAUS,AGAUW)STRP0035
CALL GAUSS(NZ,ZGAUS,ZGAUW)STRP0036
DO 10 LZ=1,NZSTRP0037
GFL(LZ)=0.5*TH*ZGAUW(LZ)STRP0038
10 GZETA(LZ)=0.5*TH*ZGAUS(LZ)STRP0039
DO 20 LZ=1,NZSTRP0040
DO 20 LS=1,NSUBLSTRP0041
JZ=LZ+(LS-1)*NZSTRP0042
20 GWEGH(JZ)=GFL(LZ)*SUBW(1,LS)STRP0043
CC5=0.0STRP0044
CC6=0.0STRP0045
IF(D EQ.0.0)GO TO 30STRP0046
CC5=1.0/PSTRP0047
CC6=1.0/D/DELTATSTRP0048
30 EE1=YOUNG/(1.0-HNU+HNU)STRP0049
EE2=HNU*EE1STRP0050
EE3=YOUNG/2.0/(1.0+HNU)STRP0051
HNU1=(1.0-2.0*HNU)/3.0/(1.0-HNU)STRP0052
DO 35 LS=1,NSUBLSTRP0053
35 SNO(LS)=SNOM(1,LS)STRP0054
DO 50 LNUM=1,NETSTRP0055
NNN1=NP(1,LNUM)STRP0056
NNN2=NP(2,LNUM)STRP0057
NNN4=NP(4,LNUM)STRP0058
SLE=(XGI(NNN2)-XGI(NNN1))/2.0D0STRP0059
ELE=(YGI(NNN4)-YGI(NNN1))/2.0D0STRP0060
DO 99 J=1,24STRP0061
99 ELFP(J)=0.0STRP0062

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	DO 100 KS=1,NA	STRP0063
	SW=SLE*AGAUM(KS)	STRP0064
	DO 100 KE=1,NA	STRP0065
	SL=(AGAU(KS)+1.0)/2.0	STRP0066
	EL=(AGAU(KE)+1.0)/2.0	STRP0067
	XL=2 0*SLE	STRP0068
	YL=2 0*ELE	STRP0069
	CALL SFDM(SL,EL,XL,YL,GBI,STDEP)	STRP0070
	EW=ELE*AGAUM(KE)	STRP0071
	SWEW=SW*EW	STRP0072
	PLAST3=0 0	STRP0073
	JA=KE+(KS-1)*NA	STRP0074
	DO 60 J=1,9	STRP0075
	EP(J)=0.0	STRP0076
	DEP(J)=0.0	STRP0077
	DO 60 K=1,24	STRP0078
	NNN=(LNUM-1)*24+K	STRP0079
	INDEX=NODE(NNN)	STRP0080
	EP(J)=EP(J)+STDEP(J,K)*DISP(INDEX)	STRP0081
	DEP(J)=DEP(J)+STDEP(J,K)*DELD(INDEX)	STRP0082
60	CONTINUE	STRP0083
	EPSSM=EP(1)+EP(7)**2/2.	STRP0084
	EP(9)2/2.	STRP0085
	EPEEM=EP(2)+EP(8)**2/2.	STRP0086
	EP(9)2/2.	STRP0087
	EPSEM=EP(3)+EP(7)*EP(8)	STRP0088
	DEPSSM=DEP(1)+EP(7)*DEP(7)-DEP(7)**2/2.	STRP0089
	EP(9)+DEP(9)-DEP(9)2/2.	STRP0090
	DEPEEM=DEP(2)+EP(8)*DEP(8)-DEP(8)**2/2.	STRP0091
	EP(9)+DEP(9)-DEP(9)2/2	STRP0092
	DEPSEM=DEP(3)+EP(7)*DEP(8)+DEP(7)*EP(8)-DEP(7)*DEP(8)	STRP0093
	LN=LNUM	STRP0094
	EPSSI(JA, LN)=EPSSM+THALF*EP(4)	STRP0095
	EPEE1(JA, LN)=EPEEM+THALF*EP(5)	STRP0096
	EPSE1(JA, LN)=EPSEM+THALF*EP(6)	STRP0097
	EPSSO(JA, LN)=EPSSM-THALF*EP(4)	STRP0098
	EPEEO(JA, LN)=EPEEM-THALF*EP(5)	STRP0099
	EPSEO(JA, LN)=EPSEM-THALF*EP(6)	STRP0100
61	BPNSS=0 0	STRP0101
	BPNEE=0 0	STRP0102
	BPHSE=0 0	STRP0103
	BPMSS=0 0	STRP0104
	BPMEE=0 0	STRP0105
	BPMSE=0.0	STRP0106
	DO 150 LZ=1,NZ	STRP0107
	PLAST2=0.0	STRP0108
	EPSSZ=EPSSM-GZETA(LZ)*EP(4)	STRP0109
	EPEEZ=EPEEM-GZETA(LZ)*EP(5)	STRP0110
	EPSEZ=EPSEM-GZETA(LZ)*EP(6)	STRP0111
	DEPSSZ=DEPSSM-GZETA(LZ)*DEP(4)	STRP0112
	DEPEEZ=DEPEEM-GZETA(LZ)*DEP(5)	STRP0113
	DEPSEZ=DEPSEM-GZETA(LZ)*DEP(6)	STRP0114
	GPSS=EE1*EPSSZ+EE2*EPEEZ	STRP0115
	GPSE=EE2*EPSSZ+EE1*EPEEZ	STRP0116
	GPSE=EE3*EPSEZ	STRP0117
	PTSS=0 0	STRP0118
	PTEE=0 0	STRP0119
	PTSE=0 0	STRP0120
	FACTOR=1.	STRP0121
	IF(D EQ.0.0) GO TO 152	STRP0122
	SECINV=DEPSSZ**2+DEPEEZ**2-DEPSSZ*DEPEEZ+.75D0*DEPSEZ**2	STRP0123
	SECINV=SECINV*2 DO/3.D0	STRP0124
	IF(SECINV .LT. 0.0D0) WRITE(MWRITE,151) NNC,ITT	STRP0125
151	FORMAT(1H0,'SECOND INVARIANT OF DEVIATORIC STRAIN RATE IS NEGATIVE	STRP0126
	+ AT SUBINCREMENT',13,' AT TIME STEP',110/20X,'STOP IN SUBROUTINE \$	STRP0127
	2TRESP.')	STRP0128

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61

	IF(SECINV.LT.0.0) CALL EXIT	STRP0129
	FACTOR=1.+(CC6*DSQRT(SECINV))*CC5	STRP0130
152	DO 155 LS=1, NSUBL	STRP0131
	SIGMSQ=(SND(LS)*FACTOR)**2	STRP0132
	JZ=LZ+(LS-1)*NZ	STRP0133
	NNN=1	STRP0134
	SNN=1.	STRP0135
40	CONTINUE	STRP0136
	PLAST1=0 0	STRP0137
	NNC=1	STRP0138
	TASS=TAUSS(LNUM ,JZ,JA)	STRP0139
	TAE=TAUEE(LNUM ,JZ,JA)	STRP0140
	TASE=TAUSE(LNUM ,JZ,JA)	STRP0141
	DSNSS=(EE1*DEPSSZ+EE2*DEPEEZ)/SNN	STRP0142
	DSNEE=(EE2*DEPSSZ+EE1*DEPEEZ)/SNN	STRP0143
	DSNSE=EE3*DEPSEZ/SNN	STRP0144
41	CONTINUE	STRP0145
	TMSS=TASS+DSNSS	STRP0146
	TME=TAEE+DSNEE	STRP0147
	TMSE=TASE+DSNSE	STRP0148
	CZ=TMSS*2+TME**2-TMSS*TME+3.*TMSE**2-SIGMSQ	STRP0149
	IF(CZ LE. 0.0) GO TO 45	STRP0150
	TAUM=TASS+TAE	STRP0151
	TCSS=TASS-HNU1*TAUM	STRP0152
	TCEE=TAE-HNU1*TAUM	STRP0153
	TCSE=TASE	STRP0154
159	AZ=TCSS**2-TCSS*TCEE+TCEE**2+3.*TCSE**2	STRP0155
C		STRP0156
	BZ=TMSS+TCSS+TME+TCEE-(TMSS+TCEE+TCSS+TME)/2.+3.*TMSE+TCSE	STRP0157
	DISCR=BZ*BZ-AZ*CZ	STRP0158
	IF(DISCR LT 0 0) GO TO 157	STRP0159
	HLAMD2=BZ+DSQRT(DISCR)	STRP0160
	IF(HLAM2 .LE 0.0) GO TO 157	STRP0161
165	HLAMDA=CZ/HLAMD2	STRP0162
	PSS1=HLAMDA*CON1*(2 0+TASS-TAE)	STRP0163
	PSS2=HLAMDA*CON1*(2.0+TAE-TASS)	STRP0164
	PSS3=HLAMDA*CON1*6 0+TASE	STRP0165
	PLAST1=PLAST1+PSS1+TASS+PSS2+TAE+PSS3+TASE	STRP0166
	TASS=TMSS-HLAMDA*TCSS	STRP0167
	TAE=TMEE-HLAMDA*TCEE	STRP0168
	TASE=INSE-HLAMDA*TCSE	STRP0169
	GO TO 46	STRP0170
45	TASS=TMSS	STRP0171
	TAE=TMEE	STRP0172
	TASE=TMSE	STRP0173
46	IF(NNC.EQ NNN) GO TO 156	STRP0174
	NNC=NNC+1	STRP0175
	GO TO 41	STRP0176
157	NNN=NNN+1	STRP0177
	SNN=NNN	STRP0178
	IF(NNN-99) 40,40,44	STRP0179
44	WRITE(MWRITE,49)ITT	STRP0180
49	FORMAT(' SUBINCREMENT IN PLASTICITY RELATION .GT.99 AT IT=',15)	STRP0181
	CALL EXIT	STRP0182
156	TAUSS(LNUM ,JZ,JA)=TASS	STRP0183
	TAUEE(LNUM ,JZ,JA)=TAE	STRP0184
	TAUSE(LNUM ,JZ,JA)=TASE	STRP0185
	PLASS=GPSS-TAUSS(LNUM ,JZ,JA)	STRP0186
	PLAEE=GPEE-TAUEE(LNUM ,JZ,JA)	STRP0187
	PLASE=GPSE-TAUSE(LNUM ,JZ,JA)	STRP0188
	PTSS=PTSS+PLASS*GWEGH(JZ)	STRP0189
	PTEE=PTEE+PLAEE*GWEGH(JZ)	STRP0190
	PTSE=PTSE+PLASE*GWEGH(JZ)	STRP0191
	PLAST2=PLAST2+PLAST1*GWEGH(JZ)	STRP0192
155	CONTINUE	STRP0193
	BPNSS=BPNSS+PTSS	STRP0194

	BPNEE =BPNEE +PTEE	STRP0195
	BPNSE =BPNSE +PTSE	STRP0196
	BPMSS =BPMSS -PTSS +GZETA (LZ)	STRP0197
	BPMEE =BPMEE -PTEE +GZETA (LZ)	STRP0198
	BPMSE =BPMSE -PTSE +GZETA (LZ)	STRP0199
	PLAST3 =PLAST3 +PLAST2	STRP0200
150	CONTINUE	STRP0201
	SNL (1) = (EE1 * EP (7) ** 2 / 2 . + EE2 * EP (8) ** 2 / 2 .) * TH - BPNSS	STRP0202
	** ((EE1 + EE2) * EP (9) ** 2 / 2 .) * TH	STRP0203
	SNL (2) = (EE2 * EP (7) ** 2 / 2 . + EE1 * EP (8) ** 2 / 2 .) * TH - BPNEE	STRP0204
	** ((EE1 + EE2) * EP (9) ** 2 / 2 .) * TH	STRP0205
	SNL (3) = (EE3 * EP (7) * EP (8)) * TH - BPNSE	STRP0206
	SNL (4) = -BPMSS	STRP0207
	SNL (5) = -BPMEE	STRP0208
	SNL (6) = -BPMSE	STRP0209
	SNL (7) = ((EE1 * EPSSM + EE2 * EPEEM) * TH - BPNSS) * EP (7)	STRP0210
	** (EE3 * EPSEM * TH - BPNSE) * EP (8)	STRP0211
	SNL (8) = ((EE2 * EPSSM + EE1 * EPEEM) * TH - BPNEE) * EP (8)	STRP0212
	** (EE3 * EPSEM * TH - BPNSE) * EP (7)	STRP0213
	SNL (9) = ((EE1 * EPSSM + EE2 * EPEEM) * TH - BPNSS) * EP (9)	STRP0214
	** ((EE2 * EPSSM + EE1 * EPEEM) * TH - BPNEE) * EP (9)	STRP0215
	DO 164 J = 1 , 9	STRP0216
164	SNL (J) = SNL (J) * SWEW	STRP0217
	DO 165 J = 1 , 24	STRP0218
	EQNL (J) = 0 0	STRP0219
	DO 165 K = 1 , 9	STRP0220
165	EQNL (J) = EQNL (J) + STDEP (K , J) * SNL (K)	STRP0221
	DO 166 J = 1 , 24	STRP0222
166	ELFP (J) = ELFP (J) + EQNL (J)	STRP0223
	PLASTW = PLASTW + PLAST3 * SWEW	STRP0224
100	CONTINUE	STRP0225
	DO 201 J = 1 , 24	STRP0226
	NNNN = (LNUM - 1) * 24 + J	STRP0227
	M = NODE (NNNN)	STRP0228
166	201 FLVA (M) = FLVA (M) + ELFP (J)	STRP0229
50	CONTINUE	STRP0230
	RETURN	STRP0231
	END	STRP0232

```

SUBROUTINE TSTEP(STF,AMASS,NBC,BC,ICOL,INUM,KROW,NDEX,TRIAL,SOLN) TSTP0000
IMPLICIT REAL*8(A-H,O-Z) TSTP0001
C TSTP0002
C ASRL TR 154-14..... ORIGINAL REPORT VERSION OF PROGRAM TSTP0003
C COPYRIGHT (C) MASSACHUSETTS INSTITUTE OF TECHNOLOGY 1980 TSTP0004
C THIS SUBROUTINE IS USED BY BOTH THE PLATE AND THE CIVM PLATE PROGRAMS. TSTP0005
C TSTP0006
C DIMENSION STF(1),AMASS(1),BC(1),NBC(1),ICOL(1),INUM(1),KROW(1), TSTP0007
2NDEX(1),TRIAL(1),SOLN(1) TSTP0008
COMMON/BAS/NDT,NET,MN,NB,NIRREG,MNC TSTP0009
COMMON/PLATE/XD,YD,TH,HX,HY,NEA,NEC,DENS,EPAN,AN,THF TSTP0010
COMMON /INOUT/ MREAD,MWRITE,MPUNCH TSTP0011
COMMON /MASSM/ IMASS TSTP0012
C TSTP0013
C SUBROUTINE TO CALCULATE THE CENTRAL-DIFFERENCE TIME-STEP BOUND. TSTP0014
C ITERATION IS USED TO CALCULATE THE HIGHEST NATURAL FREQUENCY OF THE TSTP0015
C ASSEMBLED STRUCTURE. NOTE-- HOUBOLT OPERATOR TSTP0016
C USED IN PRESENT PROGRAM. CALCULATED BOUND SERVES ONLY AS A TSTP0017
C REFERENCE NO TSTP0018
C TSTP0019
C GENERATE INITIAL GUESS TSTP0020
C DO 20 I=1,NDT TSTP0021
20 TRIAL(I)=1.0D0 TSTP0022
C CONSTRAIN ASSEMBLED STIFFNESS MATRIX TSTP0023
CALL BCONMK(STF,BC,ICOL,INUM,NBC) TSTP0024
IF(IMASS.EQ.2) GO TO 28 TSTP0025
DO 25 I=1,NB TSTP0026
KK=NBC(I) TSTP0027
25 TRIAL(KK)=0.0D0 TSTP0028
DO 27 I=1,NDT TSTP0029
IF(AMASS(I).EQ.0.0)TRIAL(I)=0.0D0 TSTP0030
27 CONTINUE TSTP0031
GO TO 29 TSTP0032
C CONSTRAIN CONSISTENT MASS MATRIX. TSTP0033
28 CALL BCONMK(AMASS,BC,ICOL,INUM,NBC) TSTP0034
C NORMALIZE SO TRIAL VECTOR IS A UNIT VECTOR TSTP0035
29 SUM=0.0D0 TSTP0036
DO 30 I=1,NDT TSTP0037
30 SUM=SUM+TRIAL(I)*TRIAL(I) TSTP0038
SUM=DSQRT(SUM) TSTP0039
DO 35 I=1,NDT TSTP0040
35 TRIAL(I)=TRIAL(I)/SUM TSTP0041
EPS=1.0D-7 TSTP0042
BOLD=1.0D0 TSTP0043
NNN=0 TSTP0044
C FOR CONSISTENT MASS MATRIX, REPLACE M BY FACTORED M. TSTP0045
IF(IMASS.EQ.2) CALL FACT(AMASS,ICOL,KROW,NDEX,IDET,MWRITE,INUM) TSTP0046
C BEGIN ITERATION LOOP TSTP0047
DO 100 ITER=1,200 TSTP0048
NNN=NNN+1 TSTP0049
C ZERO OUT SOLUTION VECTOR TSTP0050
DO 40 I=1,NDT TSTP0051
10 SOLN(I)=0.0D0 TSTP0052
C MULTIPLY STIFFNESS TIMES TRIAL TSTP0053
CALL OMULT(STF,TRIAL,SOLN,ICOL,KROW,NDEX) TSTP0054
IF(IMASS.EQ.2) GO TO 46 TSTP0055
C MULTIPLY PRODUCT BY MASS-INVERSE TSTP0056
DO 45 I=1,NDT TSTP0057
45 TRIAL(I)=SOLN(I)/AMASS(I) TSTP0058
CONTINUE TSTP0059
GO TO 47 TSTP0060
TSTP0061
TSTP0062

```

46	CALL SOLV(AMASS,SOLN,TRIAL,ICOL,KROW,NDEX)	TSTP0063
47	BNEW=-1 DO	TSTP0064
C	SEARCH FOR MAX VALUE IN TRIAL VECTOR.	TSTP0065
	IHOLD=0	TSTP0066
	DO 48 I=1,NDT	TSTP0067
	CHECK=DABS(TRIAL(I))	TSTP0068
	IF(BNEW .GT. CHECK) GO TO 48	TSTP0069
	BNEW=CHECK	TSTP0070
	IHOLD=I	TSTP0071
48	CONTINUE	TSTP0072
	IF(IHOLD .NE. 0) BNEW=TRIAL(IHOLD)	TSTP0073
C	NORMALIZE SO TRIAL VECTOR IS A UNIT VECTOR	TSTP0074
	DO 55 I=1,NDT	TSTP0075
	IF(TRIAL(I) .EQ. 0.DO) GO TO 55	TSTP0076
	IF(DABS(10.0DO*TRIAL(I)/BNEW) .GT. 1.D-76) GO TO 55	TSTP0077
	TRIAL(I)=0.DO	TSTP0078
55	TRIAL(I)=TRIAL(I)/BNEW	TSTP0079
C	IF THIS IS FIRST ITERATION, SKIP CONVERGENCE CHECK	TSTP0080
	IF(ITER EQ 1)GO TO 100	TSTP0081
	CRATIO=DABS(1.000-BNEW/BOLD)	TSTP0082
	IF(CRATIO.LE.EPS)GO TO 110	TSTP0083
C	IF NOT CONVERGED CONTINUE ITERATION	TSTP0084
	BOLD=BNEW	TSTP0085
100	CONTINUE	TSTP0086
C	CONVERGENCE FOUND OR MORE THAN 200 ITERATIONS TAKEN	TSTP0087
110	BONE=BNEW	TSTP0088
	BONE=DSQRT(BONE)	TSTP0089
	WRITE(MWRITE,600)BONE	TSTP0090
C	PRINT OUT FINAL VALUE OF EIGENVECTOR.	TSTP0091
	NNT=NDT/6	TSTP0092
	WRITE(MWRITE,114)	TSTP0093
	DO 112 NN=1,NNT	TSTP0094
	J1=(NN-1)*6+1	TSTP0095
	J2=J1+5	TSTP0096
112	WRITE(MWRITE,116) NN, (TRIAL(J),J=J1,J2)	TSTP0097
114	FORMAT(1H0,23X,'HIGHEST EIGENVECTOR NORMALIZED BY LARGEST VALUE'/	TSTP0098
	1 1H0,10X, 'NODE',6X,'U',12X,'V',12X,'W',11X,'PSIX',9X,'PSIY',9X,	TSTP0099
	2 'TWIST')	TSTP0100
116	FORMAT(11X,I4,6D13.5)	TSTP0101
	WRITE(MWRITE,610)NNN,CRATIO	TSTP0102
	STS=2.0DO/BONE	TSTP0103
	WRITE(MWRITE,620) STS	TSTP0104
	STS=0 8DO*STS	TSTP0105
	WRITE(MWRITE,630)STS	TSTP0106
600	FORMAT('0','HIGHEST NATURAL FREQUENCY(RAD/SEC)=' ,D15.7)	TSTP0107
610	FORMAT(' ','AFTER',I4,2X,'ITERATIONS, CONVERGENCE RATIO=' ,D15.7)	TSTP0108
620	FORMAT(' ','CENTRAL-DIFFERENCE BOUND ON TIME-STEP(SEC) FOR LINEAR	TSTP0109
	2SYSTEM=' ,D15.7)	TSTP0110
630	FORMAT(' ','ACTUAL TIME-STEP BOUND (SEC) WOULD BE=' ,D15.7)	TSTP0111
	RETURN	TSTP0112
	END	TSTP0113

6.2 Subprograms Unique to the PLATE Code

The following 6 subprograms (or subroutines) are unique to the PLATE program:

CMASSP	INCOND	MAINP
EXTL	MAIN	PRINT

These specific versions of Subprograms EXTL, INCOND, and MAIN given in this subsection are principally for illustration, but are also those used for the illustrative example given in Subsection 7.2.1 for the complete plate. The user must write his own versions of these programs consistent with his problem data if he wishes to analyze any other example problem.

A FORTRAN IV listing of these 6 subprograms follows.

```

SUBROUTINE CMASSP(NTYPE,XL,YL,TH,XF,SLOC,CSA,SMOI,EM,GBI,DENS)
IMPLICIT REAL*8(A-H,O-Z)
C
C ASRL TR 154-14. . . ORIGINAL REPORT VERSION OF PROGRAM
C COPYRIGHT (C) MASSACHUSETTS INSTITUTE OF TECHNOLOGY 1980
C
C THIS SUBROUTINE IS USED EXCLUSIVELY BY THE PLATE PROGRAM.
C
C DIMENSION EM(24,24),GBI(24,24),AMT(5,5),GS(6),GW(6),P(5,24),
C 2STOR1(5,24),STOR2(24,24),T(24)
C
C THIS SUBROUTINE COMPUTES THE CONSISTENT MASS MATRIX FOR A
C RECTANGULAR PLATE ELEMENT, X-DIRECTION STIFFENER ELEMENT, OR
C Y-DIRECTION STIFFENER ELEMENT. THE FORMULATION CORRESPONDS TO
C EQUATIONS A.29 AND A.29 (FOR PLATE ELEMENTS), EQUATION A.91A FOR
C X-DIRECTION STIFFENERS, AND EQUATION A.91B FOR Y-DIRECTION
C STIFFENERS. A GAUSSIAN QUADRATURE IS USED TO COMPUTE THE REQUIRED
C INTEGRAL
C
C NGS=4
C CALL GAUSS(NGS,GS,GW)
C DO 5 I=1,NGS
C CS(I)=(1.0+CS(I))/2.0
C GW(I)=GW(I)/2.0
C NGX=NGS
C NGY=NGS
C DO 10 I=1,5
C DO 10 J=1,5
C 10 AMT(I,J)=0.0
C DO 20 I=1,5
C DO 20 J=1,24
C 20 P(I,J)=0.0
C DO 25 I=1,24
C DO 25 J=1,24
C 25 EM(I,J)=0.0
C GO TO(30,40,40),NTYPE
C M-TILDA FOR PLATE ELEMENT
C 30 AMT(1,1)=TH
C AMT(2,2)=TH
C AMT(3,3)=TH
C AMT(4,4)=TH*3/(12.0D0*XL*XL)
C AMT(5,5)=TH*3/(12.0D0*YL*YL)
C GO TO 50
C M-TILDA FOR STIFFENERS.
C 40 AMT(1,1)=CSA
C AMT(2,2)=CSA
C AMT(3,3)=CSA
C AMT(4,4)=SMOI/(XL*XL)
C AMT(5,5)=SMOI/(YL*YL)
C AMT(4,1)=-CSA*XF/XL
C AMT(1,4)=AMT(4,1)
C AMT(5,2)=-CSA*XF/YL
C AMT(2,5)=AMT(5,2)
C IF(NTYPE EQ 2)NGY=1
C IF(NTYPE EQ 3)NGX=1
C 50 CCNTINUE
C LOOP OVER GAUSS STATIONS.
C DO 100 NY=1,NGY
C DO 100 NX=1,NGX

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CMSP0000
CMSP0001
CMSP0002
CMSP0003
CMSP0004
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CMSP0047
CMSP0048
CMSP0049
CMSP0050
CMSP0051
CMSP0052
CMSP0053
CMSP0054
CMSP0055
CMSP0056
CMSP0057
CMSP0058

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SL=GS(NX)
EL=GS(NY)
GWX=GW(NX)
GWY=GW(NY)
IF(NTYPE.EQ.2)EL=SLOC
IF(NTYPE.EQ.2)GWY=1.0
IF(NTYPE.EQ.3)SL=SLOC
IF(NTYPE.EQ.3)GWX=1.0
P(1,1)=1.0
P(1,2)=SL
P(1,3)=EL
P(1,4)=EL*SL
P(2,5)=1.0
P(2,6)=SL
P(2,7)=EL
P(2,8)=SL*EL
P(3,9)=1.0
P(3,10)=SL
P(3,11)=EL
P(3,12)=SL*EL
P(3,13)=SL*SL
P(3,14)=EL*EL
P(3,15)=SL*SL*EL
P(3,16)=SL*EL*EL
P(3,17)=SL*SL*EL*EL
P(3,18)=SL**3
P(3,19)=EL**3
P(3,20)=P(3,18)*EL
P(3,21)=SL*P(3,19)
P(3,22)=P(3,20)*EL
P(3,23)=P(3,21)*SL
P(3,24)=P(3,18)*P(3,19)
P(4,10)=1.0
P(4,12)=EL
P(4,13)=2.0*SL
P(4,15)=2.0*SL*EL
P(4,16)=EL*EL
P(4,17)=P(4,15)*EL
P(4,18)=3.0*SL*SL
P(4,20)=P(4,18)*EL
P(4,21)=P(4,16)*EL
P(4,22)=P(4,20)*EL
P(4,23)=P(4,17)*EL
P(4,24)=P(4,22)*EL
P(5,11)=1.0
P(5,12)=SL
P(5,14)=2.0*EL
P(5,15)=SL*SL
P(5,16)=2.0*SL*EL
P(5,17)=P(5,16)*SL
P(5,19)=3.0*EL*EL
P(5,20)=P(5,15)*SL
P(5,21)=P(5,19)*SL
P(5,22)=P(5,17)*SL
P(5,23)=P(5,21)*SL
P(5,24)=P(5,23)*SL
DO 60 I=1,5
DO 60 J=1,24
STOR1(I,J)=0.0

```

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CMSP0059
CMSP0060
CMSP0061
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CMSP0112
CMSP0113
CMSP0114
CMSP0115
CMSP0116
CMSP0117

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	DO 60 K=1,5	CMSP0118
60	STOR1(I,J)=STOR1(I,J)+AMT(I,K)*P(K,J)	CMSP0119
	DO 70 I=1,24	CMSP0120
	DO 70 J=1,24	CMSP0121
	STOR2(I,J)=0.0	CMSP0122
	DO 70 K=1,5	CMSP0123
70	STOR2(I,J)=STOR2(I,J)+P(K,I)*STOR1(K,J)	CMSP0124
	DO 80 I=1,24	CMSP0125
	DO 80 J=1,I	CMSP0126
80	EM(I,J)=EM(I,J)+STOR2(I,J)*GWX*GWY*DENS	CMSP0127
100	CONTINUE	CMSP0128
	DO 110 I=1,24	CMSP0129
	DO 110 J=1,I	CMSP0130
	EM(I,J)=EM(I,J)*XL*YL	CMSP0131
110	EM(J,I)=EM(I,J)	CMSP0132
C	PRE- AND POST-MULTIPLY BY G-BAR-INVERSE MATRIX.	CMSP0133
	DO 120 I=1,24	CMSP0134
	DO 120 J=1,24	CMSP0135
	STOR2(I,J)=0.0	CMSP0136
	DO 120 K=1,24	CMSP0137
120	STOR2(I,J)=STOR2(I,J)+EM(I,K)*GBI(K,J)	CMSP0138
	DO 130 I=1,24	CMSP0139
	DO 130 J=1,24	CMSP0140
	EM(I,J)=0.0	CMSP0141
	DO 130 K=1,24	CMSP0142
130	EM(I,J)=EM(I,J)+GBI(K,I)*STOR2(K,J)	CMSP0143
C	FORM SCALING MATRIX FOR NODAL D.O.F..	CMSP0144
	DO 140 I=1,24	CMSP0145
140	T(I)=1.0	CMSP0146
	DO 150 I=4,22,6	CMSP0147
	T(I)=XL	CMSP0148
	T(I+1)=YL	CMSP0149
150	T(I+2)=XL*YL	CMSP0150
C	SCALE MASS MATRIX.	CMSP0151
	DO 160 I=1,24	CMSP0152
	DO 160 J=1,24	CMSP0153
160	EM(I,J)=EM(I,J)*T(I)*T(J)	CMSP0154
	RETURN	CMSP0155
	END	CMSP0156

```

SUBROUTINE EXTL(ELV,ITT,NP,NODE,XGI,YGI,GBI)
IMPLICIT REAL*8(A-H,O-Z)
C
C ASRL TR 154-14. . .ORIGINAL REPORT VERSION OF PROGRAM
C COPYRIGHT (C) MASSACHUSETTS INSTITUTE OF TECHNOLOGY 1980
C THIS SUBROUTINE IS USED EXCLUSIVELY BY THE PLATE PROGRAM.
C THIS VERSION IS FOR THE EXAMPLE OF A RECTANGULAR PLATE, CLAMPED
C ON THE TOP AND BOTTOM EDGES, FREE ON THE OTHER TWO EDGES WITH AN
C IMPULSIVE LOAD APPLIED SYMMETRICALLY TO ITS CENTRAL REGION.
C   DIMENSION ELV(1),NP(4,1),NODE(1),XGI(1),YGI(1),GBI(24,24)
C THIS USER-PREPARED SUBROUTINE IS USED TO GENERATE THE NODAL
C GENERALIZED FORCES CORRESPONDING TO PRESCRIBED EXTERNALLY-APPLIED
C FORCES AT TIME T SUB M (=M*DELTA T) AS DESCRIBED IN SUBSECTION 4.6.2
C AND CORRESPONDING TO THE DEVELOPMENT IN SUBSECTION A.1.3.4.
C DEFINE SIZE OF VECTOR CONTAINING UNIT LOAD OVER ALL DOF IN CENTRAL
C REGION OF PLATE. WIDTH OF LOADED REGION IS 1.497 IN.,LENGTH IS 1.8 IN.
C   DIMENSION ALOAD(150),AL1(72),AL2(78)
C   EQUIVALENCE (AL1(1),ALOAD(1)),(AL2(1),ALOAD(73))
C
COMMON /BAS/ NDT,NET,MN,NB,NIRREG,MNC
COMMON /TIM/ DELTAT,TIMEF,TIME,ITIMEF,INCRT,IOUT,ITIME
COMMON /INDJ/ MREAD,MWRITE,MPUNCH
C DEFINE TIME AT WHICH LOAD DROPS TO ZERO AND MAX VALUE OF IMPULSE.
C   DATA TEND/25.D-6/AMAXP/21934.4D0/
C DEFINE FIRST AND LAST DOF IN LOADED REGION.
C   DATA IDOF/121/,LDOF/270/
C DEFINE VALUES OF UNIT LOAD AT EACH DOF IN LOADED REGION
C   DATA AL1/2*0.D0, 4210312D-1, .2626182D-2, .3157734D-2, .1969637D-3/
1  ,2*0.D0, 8420625D-1, .0000000D+0, .6315468D-2, .0000000D+0/
2  ,2*0.D0, 8420625D-1, .0000000D+0, .6315468D-2, .0000000D+0/
3  ,2*0.D0, 8420625D-1, .0000000D+0, .6315468D-2, .0000000D+0/
4  ,2*0.D0, 4210312D-1, -.2626182D-2, .3157734D-2, -.1969637D-3/
5  ,2*0.D0, 8420625D-1, .5252365D-2, .0000000D+0, .0000000D+0/
6  ,2*0.D0, .1684125D+0, .0000000D+0, .0000000D+0, .0000000D+0/
7  ,2*0.D0, .1684125D+0, .0000000D+0, .0000000D+0, .0000000D+0/
8  ,2*0.D0, .1684125D+0, .0000000D+0, .0000000D+0, .0000000D+0/
9  ,2*0.D0, .8420625D-1, -.5252365D-2, .0000000D+0, .0000000D+0/
A  ,2*0.D0, 8420625D-1, .5252365D-2, .0000000D+0, .0000000D+0/
B  ,2*0.D0, 1684125D+0, .0000000D+0, .0000000D+0, .0000000D+0/
C   DATA AL2/2*0.D0, .1684125D+0, .0000000D+0, .0000000D+0, .0000000D+0/
1  ,2*0.D0, .1684125D+0, .0000000D+0, .0000000D+0, .0000000D+0/
2  ,2*0.D0, 8420625D-1, -.5252365D-2, .0000000D+0, .0000000D+0/
3  ,2*0.D0, 8420625D-1, .5252365D-2, .0000000D+0, .0000000D+0/
4  ,2*0.D0, .1684125D+0, .0000000D+0, .0000000D+0, .0000000D+0/
5  ,2*0.D0, .1684125D+0, .0000000D+0, .0000000D+0, .0000000D+0/
6  ,2*0.D0, .1684125D+0, .0000000D+0, .0000000D+0, .0000000D+0/
7  ,2*0.D0, 8420625D-1, -.5252365D-2, .0000000D+0, .0000000D+0/
8  ,2*0.D0, 4210312D-1, .2626182D-2, -.3157734D-2, -.1969637D-3/
9  ,2*0.D0, 8420625D-1, .0000000D+0, -.6315468D-2, .0000000D+0/
A  ,2*0.D0, 8420625D-1, .0000000D+0, -.6315468D-2, .0000000D+0/
B  ,2*0.D0, 8420625D-1, .0000000D+0, -.6315468D-2, .0000000D+0/
C  ,2*0.D0, 4210312D-1, -.2626182D-2, -.3157734D-2, .1969637D-3/
C ZERO OUT LOAD VECTOR.
DO 1 I=1,NDT
1 ELV(I)=0.0D0

```

EXTL0000
EXTL0001
EXTL0002
EXTL0003
EXTL0004
EXTL0005
EXTL0006
EXTL0007
EXTL0008
EXTL0009
EXTL0010
EXTL0011
EXTL0012
EXTL0013
EXTL0014
EXTL0015
EXTL0016
EXTL0017
EXTL0018
EXTL0019
EXTL0020
EXTL0021
EXTL0022
EXTL0023
EXTL0024
EXTL0025
EXTL0026
EXTL0027
EXTL0028
EXTL0029
EXTL0030
EXTL0031
EXTL0032
EXTL0033
EXTL0034
EXTL0035
EXTL0036
EXTL0037
EXTL0038
EXTL0039
EXTL0040
EXTL0041
EXTL0042
EXTL0043
EXTL0044
EXTL0045
EXTL0046
EXTL0047
EXTL0048
EXTL0049
EXTL0050
EXTL0051
EXTL0052
EXTL0053
EXTL0054
EXTL0055
EXTL0056
EXTL0057
EXTL0058

```

C IF THIS TIME STEP IS BEYOND LAST TIME OF IMPULSE RETURN WITH
C EXTERNAL LOAD VECTOR SET TO ZERO.
  TYM=(ITT-1)*DELTAT
  IF(TYM GT. TEND) RETURN
C INTERPOLATE TO FIND MAGNITUDE OF IMPULSE AT THIS TIME.
  AMULT=AMAXP*(TEND-TYM)/TEND
C FILL IN VALUES OF LOAD IN CENTRAL REGION OF PLATE.
  DO 2 I=IDOF,LDOF
    J=I-IDOF+1
    2 ELV(I)=AMULT*ALOAD(J)
C OUTPUT LOADS IF THIS IS A REGULAR PRINTING CYCLE.
  III=ITIME/INCRT*INCRT-ITIME
  IF(III.NE.0) RETURN
  NNT=NDT/6
  WRITE(MWRITE,100) TYM ,(J,J=1,6)
100  FORMAT(1H0/1H0,10X,'TIME=',D16.6,' SEC./1H ,33(1H.),'EXTERNALLY A
  +PLIED USER SPECIFIED LOADING',33(1H.)/1H ,6X,'NODE',6(7X,'DOF#',
  & I1,3X)/8X,3(10X,'(LBS)'),1X,3(7X,'(IN-LBS)'))
  I1=1
  DO 3 I=1,NNT
    I2=6*I
    WRITE(MWRITE,101) I,(ELV(J),J=I1,I2)
    I1=I2+1
  3  CONTINUE
101  FORMAT(6X,I3,2X,6D15.6)
  RETURN
  END
  SUBROUTINE INCOND(DISP,VEL,NP,NODE,XGI,YGI)
  IMPLICIT REAL*8(A-H,O-Z)
C
C ASRL TR 154-14. ... ORIGINAL REPORT VERSION OF PROGRAM
C COPYRIGHT (C) MASSACHUSETTS INSTITUTE OF TECHNOLOGY 1980
C
C THIS SUBROUTINE IS USED EXCLUSIVELY BY THE PLATE PROGRAM.
C
  DIMENSION DISP(1),VEL(1),NP(4,1),NODE(1),XGI(1),YGI(1)
  COMMON/BAS/NDT,NET,MN,NB,NIRREG,MNC
C
C THIS USER-PREPARED SUBROUTINE IS USED TO SPECIFY THE INITIAL (TIME
C ZERO) CONDITIONS ON THE PLATE NODAL DISPLACEMENT AND VELOCITIES,
C (Q ZERO)* AND (Q DOT ZERO)*, RESPECTIVELY, REQUIRED FOR THE FINITE-
C DIFFERENCE SOLUTION OF THE GOVERNING EQUATIONS OF MOTION (SEE
C SUBSECTION A 3).
C
C DUMMY ROUTINE - SETS VELOCITY AND DISPLACEMENT TO ZERO INITIALLY.
C
  DO 10 I=1,NDT
    DISP(I)=0.0D0
10  VEL(I)=0.0D0
  RETURN
  END
EXTL0059
EXTL0060
EXTL0061
EXTL0062
EXTL0063
EXTL0064
EXTL0065
EXTL0066
EXTL0067
EXTL0068
EXTL0069
EXTL0070
EXTL0071
EXTL0072
EXTL0073
EXTL0074
EXTL0075
EXTL0076
EXTL0077
EXTL0078
EXTL0079
EXTL0080
EXTL0081
EXTL0082
EXTL0083
EXTL0084
EXTL0085
INCD0000
INCD0001
INCD0002
INCD0003
INCD0004
INCD0005
INCD0006
INCD0007
INCD0008
INCD0009
INCD0010
INCD0011
INCD0012
INCD0013
INCD0014
INCD0015
INCD0016
INCD0017
INCD0018
INCD0019
INCD0020
INCD0021
INCD0022
INCD0023

```

C	PLATE 1 COMPUTER CODE.	MAIN0000
C		MAIN0001
C	ASRL TR 154-14.....ORIGINAL REPORT VERSION OF PROGRAM	MAIN0002
C		MAIN0003
C	COPYRIGHT (C) MASSACHUSETTS INSTITUTE OF TECHNOLOGY 1980	MAIN0004
C		MAIN0005
C	THIS IS THE SMALL STRAIN VERSION.	MAIN0006
C		MAIN0007
C	ILLUSTRATIVE EXAMPLE FOR PLATE PROGRAM - FULL MODEL.	MAIN0008
C		MAIN0009
C	THIS DUMMY MAIN PROGRAM FOR THE PLATE PROGRAM REQUIRES SUBROUTINES:	MAIN0010
C	ARRT,ASSEMK,BCONMK,CMASSP,EAROW,EXTL,FACT,GAUSS,	MAIN0011
C	INCOND,LMASSP,MAINP,MESHPA,MESHPM,OMULT,PRINT,	MAIN0012
C	PRTOP,PSTRN,RCON,RPLATE,SFDM,SOLV,SPRING,STRESA,	MAIN0013
C	STRESC,STRESP,TSTEP.	MAIN0014
C		MAIN0015
C	DUMMY MAIN PROGRAM WHICH PROVIDES DIMENSIONS FOR THOSE ARRAYS	MAIN0016
C	(VECTORS) WHOSE DIMENSIONS ARE PROBLEM DEPENDENT.	MAIN0017
C	THE FOLLOWING ARRAYS MUST BE DIMENSIONED BY THE USER AS SHOWN;	MAIN0018
C	DIMENSION DELD(NDT),DIS(NDT),DISP(NDT),DISM1(NDT),DISM2(NDT),	MAIN0019
C	FLN(NDT),FLVA(NDT),FLVM(NDT),FLVP(NDT),ELV(NDT),VEL(NDT),ICOL(NDT)	MAIN0020
C	,INUM(NDT),KROW(NDT),NDEX(NDT),STOR(NDT),STF(MNC),AMASS(MDIM),	MAIN0021
C	NP(4,MAXEL),NODE(24*MAXEL),TAUSS(MAXEL,4*MNSL,9),	MAIN0022
C	TAUSE(MAXEL,4*MNSL,9),TAUEE(MAXEL,4*MNSL,9),EPSSI(9,MAXEL),	MAIN0023
C	EPSSO(9,MAXEL),EPEEI(9,MAXEL),EPEEO(9,MAXEL),EPSEI(9,MAXEL),	MAIN0024
C	EPSEO(9,MAXEL),NBC(NB),BC(NB),RFM(NBE,MBWE),ILAST(NBE),UCF1(NBE),	MAIN0025
C	UCF2(NBE),XG(NNT),YG(NNT),ZG(NNT),XGI(NNT),YGI(NNT),	MAIN0026
C	TAGSS(MNXST,4*MNSL,3),LNXS(MNXST),XSPROP(7,MNXST),MATXS(MNXST),	MAIN0027
C	TSGEE(MNYST,4*MNSL,3),LNYS(MNYST),YSPROP(7,MNYST),MATYS(MNYST),	MAIN0028
C	LNRS(NRSS),ISRS(NRSS),SC(5,NRSS),NVSA(MNNSA),NCON(4,MNNSA)	MAIN0029
C		MAIN0030
C	WHERE,	MAIN0031
C	NNT = TOTAL NUMBER OF NODES IN THE ASSEMBLED FINITE-ELEMENT	MAIN0032
C	MODEL.	MAIN0033
C	NDT = TOTAL NUMBER OF DEGREES OF FREEDOM IN THE ASSEMBLED	MAIN0034
C	FINITE-ELEMENT MODEL = 6*NNT.	MAIN0035
C	MNC = ESTIMATED NUMBER OF WORDS OF STORAGE FOR THE ASSEMBLED	MAIN0036
C	STIFFNESS MATRIX (LOWER TRIANGLE STORED BY ROWS FROM FIRST	MAIN0037
C	NONZERO TERM).	MAIN0038
C	MDIM = DIMENSION OF ASSEMBLED MASS MATRIX.	MAIN0039
C	= NDT IF LUMPED MASS OPTION IS CHOSEN.	MAIN0040
C	= MNC IF CONSISTENT MASS OPTION IS CHOSEN.	MAIN0041
C	MAXEL = NUMBER OF ELEMENTS IN FINITE-ELEMENT MODEL.	MAIN0042
C	MNSL = MAXIMUM NUMBER OF MECHANICAL SUBLAYERS EMPLOYED.	MAIN0043
C	NOTE-- MNSL MUST BE LESS THAN OR EQUAL TO 5.	MAIN0044
C	NB = ESTIMATED NUMBER OF CONSTRAINED DEGREES OF FREEDOM PRIOR	MAIN0045
C	TO ELIMINATION OF DUPLICATES.	MAIN0046
C	NDE = ESTIMATED NUMBER OF CONSTRAINED DEGREES OF FREEDOM AFTER	MAIN0047
C	ALL DUPLICATES HAVE BEEN ELIMINATED (IF IOP5 = 1).	MAIN0048
C	= 1 IF IOP5 = 0	MAIN0049
C	MBWE = ESTIMATED MAXIMUM BANDWIDTH OF ASSEMBLED STIFFNESS MATRIX	MAIN0050
C	AT A CONSTRAINED DEGREE OF FREEDOM (IF IOP5 = 1).	MAIN0051
C	= 1 IF IOP5 = 0	MAIN0052

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C MNXST = MAXIMUM NUMBER OF X-DIRECTION STIFFENERS. MAIN0053
C      = 1 IF NO X-DIRECTION STIFFENERS. MAIN0054
C MNYST = MAXIMUM NUMBER OF Y-DIRECTION STIFFENERS. MAIN0055
C      = 1 IF NO Y-DIRECTION STIFFENERS. MAIN0056
C NRSS  = TOTAL NUMBER OF ELEMENT SIDES ON WHICH LINE RESTORING MAIN0057
C        SPRINGS ARE LOCATED. MAIN0058
C      = 1 IF NO RESTORING SPRINGS ARE PRESENT. MAIN0059
C MNSLT4 = 4*MNSL MAIN0060
C MNNSA  = MAXIMUM NUMBER OF NODES REQUESTED FOR STRAIN OUTPUT (IF MAIN0061
C        IOP0=1). = 1 IF IOP0 = 0 MAIN0062
C
C      IMPLICIT REAL*8(A-H,O-Z) MAIN0064
C      DIMENSION DELD(390),DIS(390),DISP(390),DISM1(390),DISM2(390), MAIN0065
C      2FLN(390),FLVA(390),FLVM(390),FLVP(390),ELV(390),VEL(390),ICOL(390) MAIN0066
C      3,INUM(390),KROW(390),NDEX(390),STOR(390),STF(14037),AMASS(14037), MAIN0067
C      4NP(4,40),NODE(1152),TAUSS(40,12,9),TAUSE(40,12,9),TAUEE(40,12,9), MAIN0068
C      5EPSSI(9,40),EPSSO(9,40),EPEEI(9,40),EPEEO(9,40),EPSEI(9,40), MAIN0069
C      6EPSEO(9,40),NBC(60),BC(60),RFM(60,60),ILAST(60),UCF1(60),UCF2(60), MAIN0070
C      7XG(65),YG(65),ZG(65),XGI(65),YGI(65),TAGSS(1,12,3),LNXS(1), MAIN0071
C      8XSPROP(7,1),MATXS(1),TSGEE(1,12,3),LNYS(1),YSPROP(7,1),MATYS(1), MAIN0072
C      9LNRS(1),ISRS(1),SC(5,1),NVSA(6),NCON(4,6) MAIN0073
C      COMMON/BAS/NOT,NET,MN,NB,NIRRCG,MNC MAIN0074
C      COMMON /INOUT/ MREAD,MWRITE,MPUNCH MAIN0075
C DEFINE CARD READER, LINE PRINTER AND CARD PUNCH UNIT NUMBERS. MAIN0076
C      MREAD = 5 MAIN0077
C      MWRITE = 6 MAIN0078
C      MPUNCH = 7 MAIN0079
C      READ(MREAD,500)MAXEL,MNSL,MNXST,MNYST,NBE,MBWE,MNC MAIN0080
500  FORMAT(B110) MAIN0081
C      WRITE(MWRITE,600) MAIN0082
C      WRITE(MWRITE,610) MAXEL MAIN0083
C      WRITE(MWRITE,620) MNSL MAIN0084
C      WRITE(MWRITE,630) MNXST MAIN0085
C      WRITE(MWRITE,640) MNYST MAIN0086
C      WRITE(MWRITE,650) NBE MAIN0087
C      WRITE(MWRITE,660) MBWE MAIN0088
C      WRITE(MWRITE,670) MNC MAIN0089
600  FORMAT('1 PLATE 1 COMPUTER CODE (SMALL STRAIN THEORY) : USER INPUT MAIN0090
C      + FOR ARRAY DIMENSIONS') MAIN0091
610  FORMAT(' ', 'MAXEL = ', I10) MAIN0092
620  FORMAT(' ', 'MNSL = ', I10) MAIN0093
630  FORMAT(' ', 'MNXST = ', I10) MAIN0094
640  FORMAT(' ', 'MNYST = ', I10) MAIN0095
650  FORMAT(' ', 'NBE = ', I10) MAIN0096
660  FORMAT(' ', 'MBWE = ', I10) MAIN0097
670  FORMAT(' ', 'MNC = ', I10) MAIN0098
C      MNSLT4=MNSL*4 MAIN0099
C      CALL MAINP(DELD,DIS,DISP,DISM1,DISM2,FLN,FLVA,FLVM,FLVP,ELV, MAIN0100.
C      2VEL,ICOL,INUM,KROW,NDEX,STOR,STF,AMASS,NP,NODE,TAUSS,TAUSE,TAUEE, MAIN0101
C      3EPSSI,EPSSO,EPEEI,EPEEO,EPSEI,EPSEO,NBC,BC,RFM,ILAST,UCF1,UCF2, MAIN0102
C      4XG,YG,ZG,XGI,YGI,TAGSS,LNXS,XSPROP,MATXS,TSGEE,LNYS,YSPROP,MATYS, MAIN0103
C      5LNRS,ISRS,SC,MAXEL,MNSL,MNSLT4,NBE,MBWE,MNXST,MNYST,NVSA,NCON) MAIN0104
C      CALL EXIT MAIN0105
C      END

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SUBROUTINE MAINP(DELD,DIS,DISP,DISM1,DISM2,FLN,FLVA,FLVM,FLVP,ELV,MANP0000
2VEL,ICOL,INUM,KROW,NDEX,STOR,STF,AMASS,NP,NODE,TAUSS,TAUSE,TAUEE,MANP0001
3EPSSI,EPSSO,EPEEI,EPEEO,EPSEI,EPSEO,NBC,BC,RFM,ILAST,UCF1,UCF2,MANP0002
4XG,YG,ZG,XGI,YGI,TAGSS,LNXS,XSPROP,MATXS,TSGEE,LNYS,YSPROP,MATYS,MANP0003
5LNRS,ISRS,SC,MAXEL,MNSLT4,NBE,MBWE,MNXST,MNYST,NVSA,NCON)MANP0004
IMPLICIT REAL*(A-H,O-Z)MANP0005
C
C ASRL TR 154-14..... ORIGINAL REPORT VERSION OF PROGRAMMANP0007
C COPYRIGHT (C) MASSACHUSETTS INSTITUTE OF TECHNOLOGY 1980MANP0008
C
C SMALL STRAIN FORMULATION VERSION WRITTEN BY R L. SPILKERMANP0010
C
C THIS SUBROUTINE IS USED EXCLUSIVELY BY THE PLATE PROGRAMMANP0012
C
C
C DIMENSION DELD(1),DIS(1),DISP(1),DISM1(1),DISM2(1),FLN(1),FLVA(1),MANP0014
2FLVM(1),FLVP(1),ELV(1),VEL(1),ICOL(1),INUM(1),KROW(1),NDEX(1),MANP0015
3STOR(1),STF(1),AMASS(1),NP(4,1),NODE(1),TAUSS(MAXEL,MNSLT4,9),MANP0016
4TAUSE(MAXEL,MNSLT4,9),TAUEE(MAXEL,MNSLT4,9),EPSSI(9,1),EPSSO(9,1)MANP0017
5,EPEEI(9,1),EPEEO(9,1),EPSEI(9,1),EPSEO(9,1),NBC(1),BC(1),RFM(NBE,MANP0018
6MBWE),ILAST(1),UCF1(1),UCF2(1),XG(1),YG(1),ZG(1),XGI(1),YGI(1),MANP0019
7TAGSS(MNXST,MNSLT4,3),LNXS(1),XSPROP(7,1),MATXS(1),TSGEE(MNYST,MANP0020
8MNSLT4,3),LNYS(1),YSPROP(7,1),MATYS(1),LNRS(1),ISRS(1),SC(5,1)MANP0021
9,NVSA(1),NCON(4,1)MANP0022
C
C
C THE FOLLOWING DIMENSION STATEMENTS ARE FIXED FOR ALL COMPUTER RUNS.MANP0024
C
C DIMENSION SIG(5),EPS(5),DSR(5),PSR(5),ES(6),SUBW(5,5),SNO(5,4),MANP0025
2NMSUB(5),EK(24,24),GBI(24,24),EML(24),STDE(9,24),EM(24,24),SS(5)MANP0026
DATA GBI/1 0,-1 0,-1 0,1 0,24*0.0,1 0,-1 0,-1.0,1 0,24*0 0,1.0,MANP0027
23*0 0,-3 0,-3 0,2*0 0,9.0,2 0,2 0,2*0 0,-6.0,-6 0,4 0,9*0 0,1.0,MANP0028
32*0 0,-2 0,2*0 0,-3 0,6.0,1 0,2*0 0,2 0,-3.0,-4 0,2.0,10*0.0,1.0,MANP0029
42*0 0,-2.0,-3 0,0.0,6 0,0 0,1.0,2.0,0.0,-4.0,-3 0,2 0,11*0.0,1.0,MANP0030
52*0.0,-2 0,-2 0,4 0,2*0.0,2*1 0,-2.0,-2.0,1 0,0.0,1.0,0 0,-1 0,MANP0031
C25*0 0,1 0,0 0,-1 0,MANP0032
628*0 0,3 0,3*0.0,-9 0,-2.0,3*0 0,6.0,6 0,-4 0,12*0.0,-1 0,3*0.0,MANP0033
73 0,1.0,3*0 0,-3 0,-2.0,2.0,14*0 0,3 0,0 0,-6 0,2*0 0,-2 0,0 0,MANP0034
84 0,3.0,-2 0,14*0 0,-1.0,0 0,2 0,2*0 0,1 0,0 0,-2.0,-1.0,1.0,3*0 0MANP0035
9,1.0,27*0 0,1 0,32*0 0,9 0,4*0.0,-6 0,-6.0,4 0,16*0.0,-3 0,4*0 0,MANP0036
A3 0,2.0,-2 0,16*0 0,-3 0,4*0 0,2.0,3 0,-2.0,16*0 0,1 0,4*0 0,-1.0,MANP0037
B-1 0,1 0,2*0 0,1 0,-1.0,26*0 0,1.0,-1.0,29*0.0,3.0,2*0.0,-9 0,0.0,MANP0038
C-2 0,2*0 0,6 0,6 0,-4 0,15*0.0,3 0,-6 0,3*0 0,-2.0,3.0,MANP0039
D4 0,-2 0,13*0 0,-1 0,2*0.0,3 0,0 0,1.0,2*0.0,-2 0,-3 0,2.0,15*0.0,MANP0040
E-1 0,2 0,3*0.0,1 0,-1.0,-2 0,1.0/
COMMON/PLATE/XDIST,YDIST,TH,HXL,HYL,NEAD,NECD,DENSP,EPAN,ANUP,MANP0041
2THALFMANP0013
COMMON/BAS/NDT,NET,MN,NB,NIRREG,MNCMANP0044
COMMON/TIM/DELTAT,TIMEF,TIME,ITIMEF,INCRIT,IOUT,ITIMEMANP0045
COMMON/PRNT/IOP1,IOP2,IOP3,IOP4,IOP5,IOP6,IOP7,IOP8MANP0046
COMMON /INOUT/ MREAD,MWRITE,MPUNCHMANP0047
COMMON /MASS/ IMASSMANP0048
C
C PLATE COMPUTER CODE.MANP0049
C
C CONTROLLING ROUTINE FOR ELASTIC-PLASTIC, LARGE DEFLECTION TRANSIENTMANP0050
C ANALYSIS OF STIFFENED AND/OR UNSTIFFENED FLAT PLATESMANP0052
C
C
C IPASS=1MANP0054
C NDPE=24MANP0055
C READ(MREAD,500)IMESH,IMASS,IMCONT,IPUNCHMANP0056
C
C
C MESH GENERATIONMANP0057
C
C IF(IMESH EQ.0 OR IMESH EQ.1)CALL MESHPA(NP,NODE,XG,YG,ZG,NBC,BC,MANP0058
2LNXS,LNYS,XGI,YGI,XSPROP,YSPROP,NXST,NYST,IMESH,MATXS,MATYS)MANP0060
C IF(IMESH EQ.2)CALL MESHPM(NP,NODE,XG,YG,ZG,NBC,BC,LNXS,LNYS,XGI,MANP0061
2YGI,XSPROP,YSPROP,NXST,NYST,IMESH,MATXS,MATYS)MANP0062

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      IF(IMASS.EQ.1)WRITE(MWRITE,700)
      IF(IMASS.EQ.2)WRITE(MWRITE,710)
700  FORMAT('0','PRESENT RUN USES LUMPED MASS MATRIX')
710  FORMAT('0','PRESENT RUN USES CONSISTENT MASS MATRIX')
C
C  SETUP OF STORAGE
      CALL ARRT(STF,AMASS,FLVA,ICOL,INUM,KROW,NDEX,NODE,NDPE)
      IF(IMASS.EQ.1)GO TO 8
      DO 7 I=1,MNC
7    AMASS(I)=0.0
8    CONTINUE
C
C  STRESS-STRAIN INFORMATION FOR EACH MATERIAL.
C  NOTE-- PLATE MATERIAL IS ASSUMED TO CORRESPOND TO FIRST MATERIAL.
      NA=3
      NZ=4
      READ(MREAD,500)NMAT
      WRITE(MWRITE,600)
      CON1=2 DO*(1 DO+ANUP)/3.DO
      CON2=2.DO*(0.5DO-ANUP)/3.DO
      DO 60 I=1,NMAT
      READ(MREAD,500)NSUB
      READ(MREAD,510)(SIG(J),J=1,NSUB)
      READ(MREAD,510)(EPS(J),J=1,NSUB)
      READ(MREAD,510)DSR(I),PSR(I)
      ES(1)=SIG(1)/EPS(1)
C  DEFINE VALUE OF YOUNGS MODULUS BASED ON EPS(1) AND SIG(1) .
      IF(1 EQ 1) EPAR=ES(1)
      IF(NSUB-1)30,30,10
10   DO 20 LS=2,NSUB
20   ES(LS)=(SIG(LS)-SIG(LS-1))/(EPS(LS)-EPS(LS-1))
30   ES(NSUB+1)=0 0
      CON3=ES(1)*(0.5DO-ANUP)/(1.0DO+ANUP)
      AI=0 0DO
      ASUM=0 0DO
      EI=0 0DO
      ESUM=0 0DO
      DO 40 LS=1,NSUB
      ASUM=ASUM+AI
      AI=1 DO-CON1*ES(LS+1)/(ES(1)-CON2*ES(LS+1))-ASUM
      SUBW(I,LS)=AI
      ESUM=ESUM+EI
      IF(LS NE NSUB) EI=(1.DO-ES(LS+1)/ES(1))*(EPS(LS+1)-EPS(LS))
      SNO(I,LS)=ES(1)*EPS(LS)+CON3*ESUM
40  CONTINUE
      NMSUB(I)=NSUB
      WRITE(MWRITE,610)I
      WRITE(MWRITE,615)
      DO 50 J=1,NSUB
50  WRITE(MWRITE,620)J,SIG(J),EPS(J),SNO(I,J),SUBW(I,J)
      WRITE(MWRITE,630)DSR(I),PSR(I)
60  CONTINUE
500  FORMAT(2014)
510  FORMAT(5D16.7)
600  FORMAT('0','PROPERTIES FOR USER-SPECIFIED MATERIALS')
610  FORMAT('0','PROPERTIES FOR MATERIAL NUMBER',I3)
615  FORMAT(' ','SUBLAYER',5X,'STRESS POINT',5X,'STRAIN POINT',5X,
        2'YIELD STRESS',2X,'WEIGHTING FACTOR')
620  FORMAT(' ',15,4X,D16.7,1X,D16.7,1X,D16.7,1X,D16.7)
630  FORMAT(' ','STRAIN RATE PARAMETERS: D=',D16.7,2X,'P=',D16.7)
C  TIME-STEP INFORMATION
      READ(MREAD,500)ITIMEF,INCR,IQUT
      READ(MREAD,510)DELTAT,TIMEF
      WRITE(MWRITE,640)
      WRITE(MWRITE,650)DELTAT
      WRITE(MWRITE,660)TIMEF,ITIMEF

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	WRITE(MWRITE,670)INCR	MANP0129
640	FORMAT('0','TIMEWISE SOLUTION PARAMETERS')	MANP0130
650	FORMAT(' ','TIME-STEP SIZE=',D16.7,2X,'SEC.')	MANP0131
660	FORMAT(' ','RUN WILL TERMINATE AT TIME =',D16.7,2X,'SEC. OR AT CYC	MANP0132
	2LE NUMBER',18)	MANP0133
670	FORMAT(' ','REGULAR PRINTOUT WILL BE GIVEN EVERY',15,2X,'CYCLES')	MANP0134
C		MANP0135
C	ESTABLISH PRINT OPTIONS	MANP0136
	CALL PRTOP(NNSA,NVSA,NCON,NP)	MANP0137
	IF(MN .GT MNC) WRITE(MWRITE,675) MN,MNC	MANP0138
675	FORMAT(1H0,10(1H+),'ASSEMBLED K REQUIRES',17,' ENTRIES.USER HAS DI	MANP0139
	*MENTIONED FOR ONLY',17,'. CALL EXIT.')	MANP0140
	IF(MN GT MNC)CALL EXIT	MANP0141
C		MANP0142
C	INITIALIZATION	MANP0143
	NZSUBL=NZ*MNSL	MANP0144
	NASQ=NA*NA	MANP0145
	DO 200 I=1,9	MANP0146
	DO 200 J=1,NET	MANP0147
	EPSSI(I,J)=0.0	MANP0148
	EPSSO(I,J)=0.0	MANP0149
	EPEEI(I,J)=0.0	MANP0150
	EPEEO(I,J)=0.0	MANP0151
	EPSEI(I,J)=0.0	MANP0152
200	EPSEO(I,J)=0.0	MANP0153
	DO 201 I=1,NET	MANP0154
	DO 201 JZ=1,NZSUBL	MANP0155
	DO 201 JA=1,NASQ	MANP0156
	TAUSS(I,JZ,JA)=0.0	MANP0157
	TAUEE(I,JZ,JA)=0.0	MANP0158
201	TAUSE(I,JZ,JA)=0.0	MANP0159
C		MANP0160
	DO 301 I=1,MNYST	MANP0161
	DO 301 JZ=1,NZSUBL	MANP0162
	DO 301 JA=1,NA	MANP0163
179 C	301 TSGEE(I,JZ,JA)=0.0	MANP0164
		MANP0165
	DO 303 I=1,MNXST	MANP0166
	DO 303 JZ=1,NZSUBL	MANP0167
	DO 303 JA=1,NA	MANP0168
303	TAGSS(I,JZ,JA)=0.0	MANP0169
C		MANP0170
	PLASTW=0.0	MANP0171
	TIME=0.0	MANP0172
	ITIME=0	MANP0173
C		MANP0174
C	FORMATION AND ASSEMBLY OF STIFFNESS AND MASS MATRICES	MANP0175
C	FOR PLATE ELEMENTS	MANP0176
304	NTYPE=1	MANP0177
	SL=0.0	MANP0178
	CSA=0.0	MANP0179
	SLAM=0.0	MANP0180
	DO 220 LNUM=1,NET	MANP0181
	NNN1=NP(1,LNUM)	MANP0182
	NNN2=NP(2,LNUM)	MANP0183
	NNN4=NP(4,LNUM)	MANP0184
	XL=XGI(NNN2)-XGI(NNN1)	MANP0185
	YL=YGI(NNN4)-YGI(NNN1)	MANP0186
C	IF DURING THIS PASS ONLY THE CONSISTENT MASS MATRIX IS BEING REFORMED,	MANP0187
C	BYPASS OTHER UNNECESSARY CALCULATIONS.	MANP0188
	IF(IPASS .EQ 2) GO TO 214	MANP0189
	CALL RPLATE(NTYPE,ANUP,XL,YL,TH,SL,CSA,SLAM,SMOI,EK,GB1,EPAN)	MANP0190
	CALL ASSEMK(EK,STF,INUM,NDPE,NODE,LNUM)	MANP0191
	GO TO(204,214),IMASS	MANP0192
204	CALL LMASSP(NTYPE,XL,YL,TH,SL,CSA,SMOI,EML,DENSP)	MANP0193
	LL=(LNUM-1)*NDPE	MANP0194

	DO 210 I=1,24	MANP0195
	LLI=LL+I	MANP0196
	NN=NODE(LLI)	MANP0197
210	AMASS(NN)=AMASS(NN)+EML(I)	MANP0198
	GO TO 220	MANP0199
214	CALL CMASSP(NTYPE,XL,YL,TH,XF,SL,CSA,SMOI,EM,GBI,DENSP)	MANP0200
	CALL ASSEMK(EM,AMASS,INUM,NDPE,NODE,LNUM)	MANP0201
220	CONTINUE	MANP0202
C	FOR X-DIRECTION STIFFENERS	MANP0203
	IF(NXST EQ 0)GO TO 250	MANP0204
	NTYPE=2	MANP0205
	DO 240 NN=1,NXST	MANP0206
	SL=XSPROP(6,NN)	MANP0207
	XF=XSPROP(7,NN)	MANP0208
	ANUS=XSPROP(4,NN)	MANP0209
	RW=XSPROP(2,NN)	MANP0210
	LNUM=LNXS(NN)	MANP0211
	RH=XSPROP(1,NN)	MANP0212
	YM=XSPROP(3,NN)	MANP0213
	DEN=XSPROP(5,NN)	MANP0214
	CSA=RW*RH	MANP0215
	SMOI=RH+RW*XF+XF+RW*RH**3/12.0	MANP0216
	XL=XGI(NP(2,LNUM))-XGI(NP(1,LNUM))	MANP0217
	YL=YGI(NP(4,LNUM))-YGI(NP(1,LNUM))	MANP0218
C	IF DURING THIS PASS ONLY THE CONSISTENT MASS MATRIX IS BEING REFORMED,	MANP0219
C	BYPASS OTHER UNNECESSARY CALCULATIONS.	MANP0220
	IF(IPASS EQ 2) GO TO 234	MANP0221
	CALL RPLATE(NTYPE,ANUS,XL,YL,RH,SL,CSA,XF,SMOI,EK,GBI,YM)	MANP0222
	CALL ASSEMK(EK,STF,INUM,NDPE,NODE,LNUM)	MANP0223
	GO TO(224,234),IMASS	MANP0224
224	CALL LMASSP(NTYPE,XL,YL,RH,SL,CSA,SMOI,EML,DEN)	MANP0225
	LL=(LNUM-1)*NOPE	MANP0226
	DO 230 I=1,24	MANP0227
	NNN=NODE(LL+I)	MANP0228
180 230	AMASS(NNN)=AMASS(NNN)+EML(I)	MANP0229
	GO TO 240	MANP0230
234	CALL CMASSP(NTYPE,XL,YL,TH,XF,SL,CSA,SMOI,EM,GBI,DEN)	MANP0231
	CALL ASSEMK(EM,AMASS,INUM,NDPE,NODE,LNUM)	MANP0232
240	CONTINUE	MANP0233
250	CONTINUE	MANP0234
C	FOR Y-DIRECTION STIFFENERS	MANP0235
	IF(NYST EQ 0)GO TO 280	MANP0236
	NTYPE=3	MANP0237
	DO 270 NN=1,NYST	MANP0238
	RH=YSPROP(1,NN)	MANP0239
	RW=YSPROP(2,NN)	MANP0240
	YM=YSPROP(3,NN)	MANP0241
	ANUS=YSPROP(4,NN)	MANP0242
	DEN=YSPROP(5,NN)	MANP0243
	SL=YSPROP(6,NN)	MANP0244
	XF=YSPROP(7,NN)	MANP0245
	CSA=RW*RH	MANP0246
	SMOI=RH+RW*XF+XF+RW*RH**3/12.0	MANP0247
	LNUM=LNYS(NN)	MANP0248
	NNN1=NP(1,LNUM)	MANP0249
	NNN2=NP(2,LNUM)	MANP0250
	NNN4=NP(4,LNUM)	MANP0251
	XL=XGI(NNN2)-XGI(NNN1)	MANP0252
	YL=YGI(NNN4)-YGI(NNN1)	MANP0253
C	IF DURING THIS PASS ONLY THE CONSISTENT MASS MATRIX IS BEING REFORMED,	MANP0254
C	BYPASS OTHER UNNECESSARY CALCULATIONS.	MANP0255
	IF(IPASS EQ 2) GO TO 264	MANP0256
	CALL RPLATE(NTYPE,ANUS,XL,YL,RH,SL,CSA,XF,SMOI,EK,GBI,YM)	MANP0257
	CALL ASSEMK(EK,STF,INUM,NDPE,NODE,LNUM)	MANP0258
	GO TO(254,264),IMASS	MANP0259
254	CALL LMASSP(NTYPE,XL,YL,RH,SL,CSA,SMOI,EML,DEN)	MANP0260

	LL=(LNUM-1)*NDPE	MANP0261
	DO 260 I=1,24	MANP0262
	NNN=NODE(LL+I)	MANP0263
260	AMASS(NNN)=AMASS(NNN)+EML(I)	MANP0264
	GO TO 270	MANP0265
264	CALL CMASSP(NTYPE,XL,YL,TH,XF,SL,CSA,SMOI,EM,GBI,DEN)	MANP0266
	CALL ASSEMK(EM,AMASS,INUM,NDPE,NODE,LNUM)	MANP0267
270	CONTINUE	MANP0268
280	CONTINUE	MANP0269
C	IF DURING THIS PASS ONLY THE CONSISTENT MASS MATRIX IS BEING REFORMED,	MANP0270
C	BYPASS OTHER UNNECESSARY CALCULATIONS.	MANP0271
	IF(IPASS .EQ 2) GO TO 920	MANP0272
	IF(IPASS EQ 3 .AND. NELES .EQ. 0) GO TO 920	MANP0273
	IF(IPASS EQ 3) GO TO 741	MANP0274
C	FORMATION AND ASSEMBLY OF EQUIVALENT STIFFNESS MATRIX FOR LINE	MANP0275
C	TRANSLATIONAL AND TORSIONAL LINEAR RESTORING SPRINGS APPLIED TO	MANP0276
C	SIDES OF ELEMENTS	MANP0277
	READ(MREAD,500) NELES	MANP0278
	IF(NELES EQ 0)GO TO 289	MANP0279
	WRITE(MWRITE,720)	MANP0280
	WRITE(MWRITE,730)	MANP0281
	DO 288 I=1,NELES	MANP0282
	READ(MREAD,500)LNUM,ISIDE	MANP0283
	READ(MREAD,510)(SS(J),J=1,5)	MANP0284
	LNRS(I)=LNUM	MANP0285
	ISRS(I)=ISIDE	MANP0286
	DO 285 K=1,5	MANP0287
285	SC(K,I)=SS(K)	MANP0288
	WRITE(MWRITE,740)LNUM,ISIDE,(SS(J),J=1,5)	MANP0289
	NNN1=NP(1,LNUM)	MANP0290
	NNN2=NP(2,LNUM)	MANP0291
	NNN4=NP(4,LNUM)	MANP0292
	XL=XGI(NNN2)-XGI(NNN1)	MANP0293
	YL=YGI(NNN4)-YGI(NNN1)	MANP0294
	CALL SPRING(EK,SS,ISIDE,XL,YL)	MANP0295
288	CALL ASSEMK(EK,STF,INUM,NDPE,NODE,LNUM)	MANP0296
720	FORMAT('0',' LOCATION AND PROPERTIES OF LINE TRANSLATIONAL AND ROTATIONAL LINEAR RESTORING SPRINGS')	MANP0297
730	FORMAT('0','ELEM NO ',2X,'ELEM. SIDE',8X,'KX(LB/IN/IN)',8X, 2'KY(LB/IN/IN)',8X,'KZ(LB/IN/IN)',2X,'K-THETA(IN-LB/RAD/IN)',2X, 3'K-PSI(IN-LB/RAD/IN)')	MANP0298 MANP0299 MANP0300
740	FORMAT(' ',15,6X,15,5X,5D20.7)	MANP0301
	GO TO 289	MANP0302
C	RESTORE THE SPRING STIFFNESS MATRICES.	MANP0303
741	DO 743 I=1,NELES	MANP0304
	LNUM=LNRS(I)	MANP0305
	ISIDE=ISRS(I)	MANP0306
	DO 742 KAY=1,5	MANP0307
742	SS(KAY)=SC(KAY,I)	MANP0308
	NNN1=NP(1,LNUM)	MANP0309
	NNN2=NP(2,LNUM)	MANP0310
	NNN4=NP(4,LNUM)	MANP0311
	XL=XGI(NNN2)-XGI(NNN1)	MANP0312
	YL=YGI(NNN4)-YGI(NNN1)	MANP0313
	CALL SPRING(EK,SS,ISIDE,XL,YL)	MANP0314
743	CALL ASSEMK(EK,STF,INUM,NDPE,NODE,LNUM)	MANP0315
289	CONTINUE	MANP0316
	IF(INCONT EQ 1)GO TO 334	MANP0317
	IF(IPASS GT 1) GO TO 920	MANP0318
C	GENERATE PLATE INITIAL CONDITIONS (POS. AND VELOCITY)	MANP0319
	CALL INCOND(DISP,VEL,NP,NODE,XGI,YGI)	MANP0320
C	CONSTRAIN INITIAL CONDITIONS.	MANP0321
	CALL RCON(VEL,NBC)	MANP0322
		MANP0323

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CALL RCON(DISP,NBC)
C CALCULATE KINETIC ENERGY IMPARTED TO PLATE BY INITIAL VELOCITY
C DISTRIBUTION.
  CINETI=0.0
  GO TO (291,293),IMASS
291 CONTINUE
  DO 292 I=1,NDT
292 CINETI=CINETI+AMASS(I)*VEL(I)*VEL(I)/2.0
  GO TO 296
293 CONTINUE
  DO 294 I=1,NDT
294 FLVM(I)=0.0
  CALL OMULT(AMASS,VEL,FLVM,ICOL,KROW,NDEX)
  DO 295 I=1,NDT
295 CINETI=CINETI+VEL(I)*FLVM(I)/2.0
C WORK AT INITIAL TIME IS ZERO.
296 WFORCE=0.0
334 CONTINUE
  HDT=0.500*DELTAT
C CALCULATE TIME STEP BOUND.
  IF(IPASS EQ 1)CALL TSTEP(STF,AMASS,NBC,BC,ICOL,INUM,KROW,NDEX,
  1 FLN,DELD)
  IF(IPASS EQ 3 .AND. IMCONT.EQ.1) GO TO 290
  IF(IMCONT EQ 1) GO TO 2891
C CALCULATE USER EXTERNAL LOAD VECTOR AT INITIAL TIME.
  ITT=1
  CALL EXTL(ELV,ITT,NP,NODE,XGI,YGI,GBI)
C CALCULATE POWER AT INITIAL TIME STEP.
  POWMP=0.0
  DO 8999 I=1,NDT
8999 POWMP=POWMP+ELV(I)*VEL(I)
C SET UP EQ A 117 FOR THE INITIAL TIME AND SOLVE FOR ACCELERATIONS.
C ALSO SET INITIAL EQUIVALENT FORCES TO ZERO.
182 DO 900 I=1,NDT
  STOR(I)=0.0
  FLN(I)=0.0
900 FLVM(I)=ELV(I)+FLN(I)
  CALL OMULT(STF,VEL,STOR,ICOL,KROW,NDEX)
C FINISH FORMING R H S OF EQUATION
  DO 902 I=1,NDT
902 FLVM(I)=FLVM(I)-STOR(I)
C SOLVE FOR ACCELERATIONS AT INITIAL TIME.
  GO TO (904,908),IMASS
C FOR LUMPED MASS MATRIX OPTION
904 DO 906 I=1,NDT
  IF(AMASS(I) .EQ. 0.0) STOR(I)=0.0
  IF(AMASS(I) EQ 0.0) GO TO 906
  STOR(I)=FLVM(I)/AMASS(I)
906 CONTINUE
  GO TO 910
C FOR CONSISTENT MASS MATRIX OPTION.
908 CALL SOLV(AMASS,FLVM,STOR,ICOL,KROW,NDEX)
910 CONTINUE
C PRINTOUT FOR INITIAL VALUES
  IF(IOP5 EQ 0.0 OR NB EQ 0.0) GO TO 320
  DO 319 I=1,NB
319 UCF1(I)=0.0
320 CONTINUE
C ZERO OUT VECTOR FLVM FOR USE IN PRINT.
  DO 911 I=1,NDT
911 FLVM(I)=0.0
  CALL PRINT(DISP,XG,YG,ZG,EPSSI,EPSSO,EPEE1,EPEEO,EPSE1,EPSEO,XGI,
  2YGI,NP,GBI,STDE,NODE,RFM,NBE,MBWE,ILAST,UCF1,NBC,ICOL,NMSUB,SUBW,MANP0386
  3TAUSS,TAUEE,TAUSE,MAXEL,NZSUBL,NXST,LNXS,MATXS,XSPROP,TAGSS,MNXST,MANP0387
  4NYST,LNYS,MATYS,YSPROP,ISGEE,MNYST,NELES,LNRS,ISRS,SC,EK,IMASS,MANP0388
  5AMASS,VEL,FLVM,KROW,NDEX,WFORCE,CINETI,NNSA,NVSA,NCON)MANP0389

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IF(IMASS.EQ.1) GO TO 920	MANP0390
C MUST RECREATE THE CONSISTENT MASS MATRIX.	MANP0391
IPASS=2	MANP0392
DO 914 I=1,MN	MANP0393
914 AMASS(I)=0 DO	MANP0394
GO TO 304	MANP0395
920 CONTINUE	MANP0396
IF(IPASS EQ 3) GO TO 290	MANP0397
ITT=ITT+1	MANP0398
C CALCULATE USER EXTERNAL LOAD VECTOR AT SECOND TIME STEP.	MANP0399
CALL EXTL(ELV,ITT,NP,NODE,XGI,YGI,GBI)	MANP0400
ITT=ITT-1	MANP0401
C FIND DISPLACEMENTS AT SECOND TIME STEP BY SOLVING EQ. A.116.	MANP0402
CONA=6 DO/DELTAT	MANP0403
CONB=CONA/DELTAT	MANP0404
DO 922 I=1,NDT	MANP0405
FLVM(I)=2 DO*STOR(I)+CONA*VEL(I)+CONB*DISP(I)	MANP0406
922 FLVA(I)=ELV(I)+FLN(I)	MANP0407
GO TO (924,930), IMASS	MANP0408
C LUMPED MASS	MANP0409
924 DO 926 I=1,NB	MANP0410
KK=NBC(I)	MANP0411
926 AMASS(KK)=0 DO	MANP0412
DO 928 I=1,NDT	MANP0413
L=I+INUM(I)	MANP0414
FLVA(I)=FLVA(I)+AMASS(I)+FLVM(I)	MANP0415
928 STF(L)=STF(L)+CONB*AMASS(I)	MANP0416
GO TO 938	MANP0417
930 CALL BCONMK(AMASS,BC,ICOL,INUM,NBC)	MANP0418
CALL OMULT(AMASS,FLVM,FLVA,ICOL,KROW,NDEX)	MANP0419
DO 932 I=1,MN	MANP0420
932 STF(I)=STF(I)+CONB*AMASS(I)	MANP0421
938 CALL FACT(STF,ICOL,KROW,NDEX,IDET,MWRITE,INUM)	MANP0422
CALL SOLV(STF,FLVA,DIS,ICOL,KROW,NDEX)	MANP0423
DT2=DELTAT**2	MANP0424
CONC=0 5DO/DELTAT	MANP0425
C EVALUATE LEFT SIDE OF EQS. A.115C AND OF A.118.	MANP0426
DO 940 I=1,NDT	MANP0427
DISM1(I)=DT2*STOR(I)+2 ODO*DISP(I)-DIS(I)	MANP0428
940 VEL(I)=CONC*(3 DO*DIS(I)-4 ODO*DISP(I)+DISM1(I))	MANP0429
C CALCULATE POWER FOR SECOND TIME STEP.	MANP0430
POWMP1=0.DO	MANP0431
DO 942 I=1,NDT	MANP0432
942 POWMP1=POWMP1+ELV(I)*VEL(I)	MANP0433
WFORCE=WFORCE+HDT*(POWMP+POWMP1)	MANP0434
C GO BACK AND RECREATE ASSEMBLED M AND ASSEMBLED K.	MANP0435
2891 DO 2892 I=1,MNC	MANP0436
2892 STF(I)=0 ODO	MANP0437
IPASS=3	MANP0438
C DEFINE NUMBER OF TERMS IN MASS MATRIX.	MANP0439
2893 IF(IMASS EQ. 1) IMEND=NDT	MANP0440
IF(IMASS EQ 2) IMEND=MNC	MANP0441
DO 2894 I=1, IMEND	MANP0442
2894 AMASS(I)=0 ODO	MANP0443
GO TO 304	MANP0444
920 CONTINUE	MANP0445
DO 333 I=1,NDT	MANP0446
333 STOR(I)=ELV(I)	MANP0447
IF(IMASS.EQ 2)GO TO 322	MANP0448
DO 321 I=1,NDT	MANP0449
321 FLVM(I)=ELV(I)+2.0*AMASS(I)*(VEL(I)+DISP(I)/DELTAT)/DELTAT	MANP0450
GO TO 325	MANP0451
322 CONTINUE	MANP0452
DO 323 I=1,NDT	MANP0453
323 FLVM(I)=2 O*(VEL(I)+DISP(I)/DELTAT)/DELTAT	MANP0454
CALL OMULT(AMASS,FLVM,ELV,ICOL,KROW,NDEX)	MANP0455

	DO 324 I=1,NDT	MANP0456
324	FLVM(I)=ELV(I)	MANP0457
325	CONTINUE	MANP0458
	IF(IOP5 EQ 0.OR.NB.EQ.0)GO TO 329	MANP0459
	DO 327 I=1,NB	MANP0460
	II=NBC(I)	MANP0461
327	UCF2(I)=FLVM(II)	MANP0462
329	DO 330 I=1,NDT	MANP0463
330	FLVA(I)=0.0	MANP0464
	COND=2 DO/DT2	MANP0465
C	FORM LHS	MANP0466
	GO TO(297,310),IMASS	MANP0467
297	CONTINUE	MANP0468
	DO 307 II=1,NDT	MANP0469
	L=II+INUM(II)	MANP0470
307	STF(L)=STF(L)+COND*AMASS(II)	MANP0471
	GO TO 318	MANP0472
310	CONTINUE	MANP0473
	DO 315 II=1,MN	MANP0474
315	STF(II)=STF(II)+COND*AMASS(II)	MANP0475
318	CONTINUE	MANP0476
	IF(IOP5.EQ.1)CALL EAROW(STF,NBC,ICOL,INUM,RFM,ILAST,NBE,MBWE)	MANP0477
C		MANP0478
C	CONSTRAIN LHS	MANP0479
	CALL BCONMK(STF,BC,ICOL,INUM,NBC)	MANP0480
C		MANP0481
C	FACTOR LHS	MANP0482
	CALL FACT(STF,ICOL,KROW,NDEX,IDET,MWRITE,INUM)	MANP0483
	IF(IMCONT EQ 0)GO TO 340	MANP0484
C	INPUT FOR CONTINUATION RUN	MANP0485
335	READ(MREAD,800)ITT,CINETI,WFORCE,POWMP1	MANP0486
	READ(MREAD,810)(DIS(I),I=1,NDT)	MANP0487
	READ(MREAD,810)(DISP(I),I=1,NDT)	MANP0488
	READ(MREAD,810)(VEL(I),I=1,NDT)	MANP0489
	READ(MREAD,810)(FLVA(I),I=1,NDT)	MANP0490
	IF(IOP5 EQ 1 AND NB GT 0)READ(MREAD,810)(UCF2(I),I=1,NB)	MANP0491
	READ(MREAD,810)(STOR(I),I=1,NDT)	MANP0492
	READ(MREAD,810)((TAUSS(I,J,K),I=1,NET),J=1,MNSLT4),K=1,9)	MANP0493
	READ(MREAD,810)((TAUEE(I,J,K),I=1,NET),J=1,MNSLT4),K=1,9)	MANP0494
	READ(MREAD,810)((TAUSE(I,J,K),I=1,NET),J=1,MNSLT4),K=1,9)	MANP0495
	IF(NXST EQ 0)GO TO 336	MANP0496
	READ(MREAD,810)((TAGSS(I,J,K),I=1,NXST),J=1,MNSLT4),K=1,3)	MANP0497
336	CONTINUE	MANP0498
	IF(NYST EQ 0)GO TO 337	MANP0499
	READ(MREAD,810)((TSGEE(I,J,K),I=1,NYST),J=1,MNSLT4),K=1,3)	MANP0500
337	NNT=NDT/6	MANP0501
	DO 338 I=1,NNT	MANP0502
	NN=(I-1)*6	MANP0503
	XG(I)=XGI(I)+DISP(NN+1)	MANP0504
	YG(I)=YGI(I)+DISP(NN+2)	MANP0505
	ZG(I)=ZGI(I)+DISP(NN+3)	MANP0506
338		MANP0507
C	BEGIN LOOP OVER TIME STEPS	MANP0508
340	ITT=ITT+1	MANP0509
	DO 350 J=1,NDT	MANP0510
	DELD(J)=DIS(J)-DISP(J)	MANP0511
	DISM(J)=DISP(J)	MANP0512
	DISP(J)=DIS(J)	MANP0513
	FLN(J)=FLVA(J)	MANP0514
	FLVM(J)=0.0	MANP0515
350	FLVA(J)=0.0	MANP0516
	POWM=POWMP1	MANP0517
	NNT=NDT/6	MANP0518
	DO 351 J=1,NNT	MANP0519
	NN=(J-1)*6	MANP0520
		MANP0521

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      XG(J)=XG(J)+DELD(NN+1)
      YG(J)=YG(J)+DELD(NN+2)
351  ZC(J)=ZG(J)+DELD(NN+3)
      IF(10P5.EQ 0.OR.NB.EQ.0)GO TO 353
      DO 352 I=1,NB
352  UCF1(I)=UCF2(I)
353  CONTINUE
C    CALCULATE WORK OF EXTERNAL FORCES.
      POWMP1=0 DO
      DO 355 I=1,NDT
355  POWMP1=POWMP1+STOR(I)+VEL(I)
      WFORCE=WFORCE+HDT*(POWM+POWMP1)
C    CALCULATE EQUIVALENT LOADS
C    FOR PLATE ELEMENT
C    CALCULATE EQUIVALENT LOADS FOR PLATE ELEMENT
      CALL STRESP(DISP,DELD,FLVA,ITT,NODE,MAXEL,TAUSS,TAUEE,TAUSE,
2EPSSI,EPSSO,EPEE1,EPEEO,EPSE1,EPSEO,PLASTW,XGI,YGI,NP,STDE,GBI,
3NMSUB,DSR,PSR,SUBW,SNO,NZSUBL)
C    FOR X-DIRECTION STIFFENERS
      IF(NXST EQ 0)GO TO 360
      CALL STRESA(DISP,DELD,FLVA,ITT,NODE,MAXEL,MNXST,TAGSS,PLASTW,XGI,
2YGI,NP,STDE,GBI,NMSUB,DSR,PSR,SUBW,SNO,NXST,XSPROP,LNXS,MATXS,
3NZSUBL)
360  CONTINUE
C    FOR Y-DIRECTION STIFFENERS
      IF(NYST.EQ 0)GO TO 370
      CALL STRESC(DISP,DELD,FLVA,ITT,NODE,MAXEL,MNYST,TSGEE,PLASTW,XGI,
2YGI,NP,STDE,GBI,NMSUB,DSR,PSR,SUBW,SNO,NYST,YSROP,LNYS,MATYS,
3NZSUBL)
370  CONTINUE
C    PRINT OUTPUT
      ITIME=ITT-1
      TIME=ITIME*DELTAT
      CALL PRINT(DISP,XG,YG,ZG,EPSSI,EPSSO,EPEE1,EPEEO,EPSE1,EPSEO,XGI,
2YGI,NP,GBI,STDE,NODE,RFM,NBE,M3VE,ILAST,UCF1,NBC,ICOL,NMSUB,SUBW,
3TAUSS,TAUEE,TAUSE,MAXEL,NZSUBL,NXST,LNXS,MATXS,XSPROP,TAGSS,MNXST,
4NYST,LNYS,MATYS,YSROP,TSGEE,MNYST,NELES,LNRS,ISRS,SC,EK,IMASS,
5AMASS,VEL,FLVM,KROW,NDEX,WFORCE,CINETI,NNSA,NVSA,NCON)
C    CALC EXTERNAL LOADING VECTOR
      CALL EXTL(ELV,ITT+1,NP,NODE,XGI,YGI,GBI)
      DO 375 I=1,NDT
375  STOR(I)=ELV(I)
C    FORM RHS
      IF(IMASS EQ 2)GO TO 382
      DO 380 I=1,NDT
380  FLVM(I)=-((2.0*FLVA(I)-FLN(I))+ELV(I)+2.0*AMASS(I)*(VEL(I)+DISP(I)
2/DELTAT)/DELTAT)
      GO TO 387
382  CONTINUE
      DO 384 I=1,NDT
      FLVM(I)=2.0*(VEL(I)+DISP(I)/DELTAT)/DELTAT
384  ELV(I)=ELV(I)-((2.0*FLVA(I)-FLN(I)))
      CALL OMULT(AMASS,FLVM,ELV,ICOL,KROW,NDEX)
      DO 386 I=1,NDT
386  FLVM(I)=ELV(I)
387  CONTINUE
      IF(10P5 EQ 0 OR.NB.EQ.0)GO TO 389
      DO 388 I=1,NB
      II=NBC(I)
388  UCF2(I)=FLVM(II)
C    CONSTRAIN RHS
389  CALL RCON(FLVM,NBC)
C    SOLVE FOR DISPLACEMENTS
      CALL SOLV(STF,FLVM,DIS,ICOL,KROW,NDEX)
C    CALCULATE VELOCITY
      DO 390 I=1,NDT

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390 VEL(I)=(3 0*DIS(I)-4.0*DISP(I)+DISM(I))/(2.0*DELTAT)
C CHECK FOR CONTINUATION
  IF(ITIME LT ITIMEF.AND.TIME.LT.TIMEF)GO TO 340
  IF(IPUNCH EQ 0)GO TO 420
  WRITE(MPUNCH,800) ITT,CINETI,WFORCE,POWMP1
  WRITE(MPUNCH,810)(DIS(I),I=1,NDT)
  WRITE(MPUNCH,810)(DISP(I),I=1,NDT)
  WRITE(MPUNCH,810)(VEL(I),I=1,NDT)
  WRITE(MPUNCH,810)(FLVA(I),I=1,NDT)
  IF(IOP5.EQ 1 AND NB.GT 0)WRITE(MPUNCH,810)(UCF2(I),I=1,NB)
  WRITE(MPUNCH,810)(STOR(I),I=1,NDT)
  WRITE(MPUNCH,810)((TAUSS(I,J,K),I=1,NET),J=1,MNSLT4),K=1,9)
  WRITE(MPUNCH,810)((TAUEE(I,J,K),I=1,NET),J=1,MNSLT4),K=1,9)
  WRITE(MPUNCH,810)((TAUSE(I,J,K),I=1,NET),J=1,MNSLT4),K=1,9)
  IF(NXST EQ 0)GO TO 400
  WRITE(MPUNCH,810)((TAGSS(I,J,K),I=1,NXST),J=1,MNSLT4),K=1,3)
400 CONTINUE
  IF(NYST EQ 0)GO TO 410
  WRITE(MPUNCH,810)((TSGEE(I,J,K),I=1,NYST),J=1,MNSLT4),K=1,3)
410 WRITE(MWRITE,820)ITT
420 RETURN
800 FORMAT(I6,3D15.7)
810 FORMAT(5D15.7)
820 FORMAT('0','CONTINUATION CARDS HAVE BEEN PUNCHED AT ITT=',I7)
END
  SUBROUTINE PRINT(DISP,XG,YG,ZG,EPSSI,EPSSO,EPEEI,EPEED,EPSEI,
2EPSEO,XGI,YGI,NP,GBI,STDEP,NODE,RFM,NBE,MBWE,ILAST,UCF1,NBC,ICOL,
3NMSUB,SUBW,TAUSS,TAUEE,TAUSE,MAXEL,NZS,NXST,LNXS,MATXS,XSPROP,
4TAGSS,MNAST,NYST,LNYS,MATYS,YSROP,TSGEE,MNYST,NELES,LNRS,ISRS,SC,
5EK,IMASS,AMASS,VEL,FLVM,KROW,NDEX,WFORCE,CINETI,NNSA,NVSA,NCON)
C ASRL TR 154-14... ..ORIGINAL REPORT VERSION OF PROGRAM
C COPYRIGHT (C) MASSACHUSETTS INSTITUTE OF TECHNOLOGY 1980
C SMALL STRAIN FORMULATION VERSION WRITTEN BY R. L. SPILKER
C THIS SUBROUTINE IS USED EXCLUSIVELY BY THE PLATE PROGRAM.
C
  IMPLICIT REAL*8(A-H,O-Z)
C
  DIMENSION DISP(1),XG(1),YG(1),ZG(1),EPSSI(9,1),EPSSO(9,1),EPEEI(9
2,1),EPEED(9,1),EPSEI(9,1),EPSEO(9,1),XGI(1),YGI(1),NP(4,1),GBI(24
3,24),STDEP(9,24),NODE(1),EP(9),ELONG(2),RFM(NBE,MBWE),ILAST(1),
4UCF1(1),NBC(1),ICOL(1),RF(6),NMSUB(1),AGAU(6),AGAUW(6),ZGAUS(6),
5ZGAUW(6),SUBW(5,1),TAUSS(MAXEL,NZS,9),TAUFF(MAXEL,NZS,9),TAUSF
6(MAXEL,NZS,9),LNYS(1),MATXS(1),XSPROP(7,1),TAGSS(MNXST,NZS,3),
7LNYS(1),MATYS(1),YSROP(7,1),TSGEE(MNYST,NZS,3),LNRS(1),ISRS(1),
8SC(5,1),SS(5),EK(24,24),EQ(24),STOR(24),AMASS(1),VEL(1),FLVM(1),
9KROW(1),NDEX(1),NVSA(1),NCON(4,1)
  COMMON /PLATE/XDIS,YDIS,TH,HX,HY,NEAD,NECD,DSP,EPAN,ANUP,THALF
  COMMON /BAS/NDT,NET,MN,NB,NIRREG,MNC
  COMMON /TIM/DELTAT,TIMEF,TIME,ITIMEF,INCRT,IOUT,ITIME
  COMMON /ASP/SLASP(50),ELASP(50),EDIR(2,50),NASP,LNASP(50)
  COMMON /PRNT/IOP1,ICP2,IOP3,IOP4,IOP5,IOP6,IOP7,IOP8
  COMMON /GSOUT/NEGS,LNGS(200)
  COMMON /SSOUT/NXSS,NYSS,INXSS(200),INYSS(200)
  COMMON /IOUT/MPEAD,MWRITE,MPUNCH
C THIS SUBROUTINE CONTROLS THE CALCULATION (AS NECESSARY) AND OUTPUT
C OF ALL QUANTITIES (DISPLACEMENTS, STRAINS, ENERGIES, ETC.) REQUESTED
C BY THE USER AT REGULAR INTERVALS DURING THE TIMEWISE SOLUTION FOR
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C THE PLATE PROGRAM.
C
  IF(ITIME LE.1)GO TO 10
  III=ITIME/INCRT*INCRT-ITIME
  IF(III NE.0)GO TO 500
10  CONTINUE
  WRITE(MWRITE,600)ITIME,TIME
C  NODAL DISPLACEMENTS AND LOCATION.
  IF(IOP1.EQ.0)GO TO 30
  WRITE(MWRITE,610)
  NNT=NDT/6
  DO 20 NN=1,NNT
  JJ=(NN-1)*6
  J1=JJ+1
  J2=JJ+6
20  WRITE(MWRITE,620)NN,(DISP(J),J=J1,J2),XG(NN),YG(NN),ZG(NN)
30  CONTINUE
C  REACTIC'N FORCES AT CONSTRAINED NODES.
  IF(IOP5 EQ 0.OR NB.EQ.0)GO TO 39
  WRITE(MWRITE,550)
  WRITE(MWRITE,560)
C  DETERMINE NODE NO. OF FIRST CONSTRAINED D.O.F..
  NC=NBC(1)
  NN1=(NC-1)/6+1
  DO 31 I=1,5
31  RF(I)=0 0
C  LOOP OVER CONSTRAINED D.O.F..
  DO 38 INB=1,NB
C  DETERMINE NODE NO. OF PRESENT CONSTRAINED D.O.F..
  NC=NBC(INB)
  NN2=(NC-1)/6+1
187 C  IF NN2 NE.NN1, CALC. OF RF FOR NODE NN1 IS COMPLETE--PRINT OUT
C  VALUES
  IF(NN2 EQ.NN1)GO TO 33
  WRITE(MWRITE,570)NN1,(RF(J),J=1,6)
  NN1=NN2
  DO 32 I=1,6
32  RF(I)=0.0
33  CC=-UCF1(INB)
  NN=0
  IB=ICOL(NC)
  IE=ILAST(INB)
  DO 34 I=IE,IB
  NN=NN+1
34  CC=CC+RFM(INB,NN)*DISP(I)
  NDF=NC-(NN1-1)*6
  RF(NDF)=CC
38  CONTINUE
  WRITE(MWRITE,570)NN1,(RF(J),J=1,6)
39  CONTINUE
C  CENTROIDAL STRAIN INFORMATION.
  IF(IOP2 EQ 0)GO TO 50
  WRITE(MWRITE,630)
  WRITE(MWRITE,640)
  WRITE(MWRITE,644)
  DO 40 LNUM=1,NET
  G11=EPSSI(5,LNUM)
  G22=EPSEI(5,LNUM)
  G12=EPSEI(5,LNUM)

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CALL PSTRN(G11,G22,G12,SI,DIRI)
G11=EPSSO(5,LNUM)
G22=EPEEO(5,LNUM)
G12=EPSEO(5,LNUM)
CALL PSTRN(G11,G22,G12,SO,DIRO)
40 WRITE(MWRITE,650)LNUM,EPSSI(5,LNUM),EPSSO(5,LNUM),EPEEI(5,LNUM),
50 2EPEEO(5,LNUM),EPSEI(5,LNUM),EPSEO(5,LNUM),SI,SO,DIRI,DIRO
CONTINUE
C NODAL AVERAGE STRAINS.
IF(IOP8.EQ 0)GO TO 55
WRITE(MWRITE,900)
WRITE(MWRITE,640)
WRITE(MWRITE,920)
DO 53 II=1,NNSA
G11U=0.0
G11L=0.0
G22U=0.0
G22L=0.0
G12U=0.0
G12L=0.0
NNUM=NNSA(II)
DENOM=0.000
DO 52 JJ=1,4
IF(NCON(JJ,II).EQ.0)GO TO 52
DENOM=DENOM+1.000
LNUM=NCON(JJ,II)
NNN1=NP(1,LNUM)
NNN2=NP(2,LNUM)
NNN4=NP(4,LNUM)
XL=XGI(NNN2)-XGI(NNN1)
YL=YGI(NNN4)-YGI(NNN1)
SL=0.0
EL=0.0
IF(JJ.EQ.2.OR.JJ.EQ.3)SL=1.0
IF(JJ.EQ.3.OR.JJ.EQ.4)EL=1.0
CALL SFDM(SL,EL,XL,YL,GBI,STDEP)
DO 51 J=1,9
EP(J)=0.0
DO 51 K=1,24
NNN=(LNUM-1)*24+K
NN=NODE(NNN)
51 EP(J)=EP(J)+STDEP(J,K)*DISP(NN)
EPSSM=EP(1)+EP(7)*EP(7)/2.0+EP(9)*EP(9)/2.0
EPEEM=EP(2)+EP(8)*EP(8)/2.0+EP(9)*EP(9)/2.0
EPSEM=EP(3)+EP(7)*EP(2)
G11L=G11L+EPSSM+THALF*EP(4)
G11U=G11U+EPSSM-THALF*EP(4)
G22L=G22L+EPEEM+THALF*EP(5)
G22U=G22U+EPEEM-THALF*EP(5)
G12L=G12L+EPSEM+THALF*EP(6)
G12U=G12U+EPSEM-THALF*EP(6)
52 CONTINUE
G11L=G11L/DENOM
G11U=G11U/DENOM
G22L=G22L/DENOM
G22U=G22U/DENOM
G12L=G12L/DENOM
G12U=G12U/DENOM
CALL PSTRN(G11L,G22L,G12L,SI,DIRI)
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      CALL PSTRN(G11U,G22U,G12U,SO,DIRO)
53  WRITE(MWRITE,650)NNUM,G11L,G11U,G22L,G22U,G12L,G12U,SI,SO,DIRI,
    + DIRO
55  CONTINUE
C   GAUSS STATION STRAIN PRINTOUT.
    IF(IOP3.EQ.0)GO TO 70
    WRITE(MWRITE,660)
    DO 60 NN=1,NEGS
    LNUM=LNGS(NN)
    WRITE(MWRITE,670) LNUM
    WRITE(MWRITE,640)
    WRITE(MWRITE,645)
    DO 60 NG=1,9
    G11=EPSSI(NG,LNUM)
    G22=EPEEI(NG,LNUM)
    G12=EPSCI(NG,LNUM)
    CALL PSTRN(G11,G22,G12,SI,DIRI)
    G11=EPSSO(NG,LNUM)
    G22=EPEEO(NG,LNUM)
    G12=EPSEO(NG,LNUM)
    CALL PSTRN(G11,G22,G12,SO,DIRO)
60  WRITE(MWRITE,650)NG,EPSSI(NG,LNUM),EPSSO(NG,LNUM),EPEEI(NG,LNUM),
    2EPEEO(NG,LNUM),EPSEI(NG,LNUM),EPSEO(NG,LNUM),SI,SO,DIRI,DIPO
70  CONTINUE
C   ADDITIONAL STRAIN POINTS.
    IF(IOP4.EQ.0)GO TO 110
    WRITE(MWRITE,690)
    WRITE(MWRITE,695)
    DO 100 KK=1,NASP
    LNUM=LNASP(KK)
    SL=SLASP(KK)
    EL=ELASP(KK)
    NNN1=NP(1,LNUM)
    NNN2=NP(2,LNUM)
    NNN4=NP(4,LNUM)
    XL=XGI(NNN2)-XGI(NNN1)
    YL=YGI(NNN4)-YGI(NNN1)
    CALL SFDM(SL,EL,XL,YL,GBI,STDEP)
    DO 80 J=1,9
    EP(J)=0.0
    DO 80 K=1,24
    NNN=(LNUM-1)*24+K
    NN=NODE(NNN)
80  EP(J)=EP(J)+STDEP(J,K)*DISP(NN)
    EPSSM=EP(1)+EP(7)*EP(7)/2.0+EP(9)*EP(9)/2.0
    EPEEM=EP(2)+EP(8)*EP(8)/2.0+EP(9)*EP(9)/2.0
    EPSEM=EP(3)+EP(7)*EP(8)
    DO 100 II=1,2
    FCT=1.0D0
    IF(II.EQ.2)FCT=-1.0D0
    G11=EPSSM+FCT*THALF*EP(4)
    G22=EPEEM+FCT*THALF*EP(5)
    G12=EPSEM+FCT*THALF*EP(6)
    CALL PSTRN(G11,G22,G12,SI,DIRI)
    DO 20 I=1,2
    THET=EDIR(I,KK)*.1745329251994330D-01
    CT=DCOS(THET)
    ST=DSIN(THET)
    ELONG(I)=G11*CT*CT+G22*ST*ST+G12*CT*ST

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90  ELONG(I)=DSQRT(1.0+2.0*ELONG(I))-1.0          PRNT0213
    IF (I1.EQ.1)WRITE(MWRITE,700)KK,G11,G22,G12,ELONG(1),ELONG(2),SI,DI PRNT0214
    +RI                                             PRNT0215
    IF (I1.EQ.2)WRITE(MWRITE,710)KK,G11,G22,G12,ELONG(1),ELONG(2),SI,DI PRNT0216
    +RI                                             PRNT0217
100 CONTINUE                                       PRNT0218
110 CONTINUE                                       PRNT0219
C  CALCULATION AND PRINTOUT OF GAUSS STATION STRAINS ON STIFFENERS. PRNT0220
    IF (IOP6.EQ.0)GO TO 190                        PRNT0221
    NA=3                                             PRNT0222
    CALL GAUSS(NA,AGAUS,AGAUW)                     PRNT0223
C  FOR X-DIRECTION STIFFENERS                     PRNT0224
    IF (NXSS.EQ.0)GO TO 150                       PRNT0225
    WRITE(MWRITE,780)                              PRNT0226
    WRITE(MWRITE,785)                              PRNT0227
    WRITE(MWRITE,790)                              PRNT0228
    DO 140 NX=1,NXSS                               PRNT0229
    NST=I1XSS(NX)                                  PRNT0230
    LNUM=LNXS(NST)                                 PRNT0231
    NNN1=NP(1,LNUM)                                PRNT0232
    NNN2=NP(2,LNUM)                                PRNT0233
    NNN4=NP(4,LNUM)                                PRNT0234
    XL=XCI(NNN2)-XCI(NNN1)                         PRNT0235
    YL=YGI(NNN4)-YGI(NNN1)                         PRNT0236
    EL=XSPROP(6,NST)                               PRNT0237
    DO 130 NG=1,NA                                  PRNT0238
    SL=(1.0+AGAUS(NG))/2.0                          PRNT0239
    CALL SFDM(SL,EL,XL,YL,GBI,STDEP)                PRNT0240
    EP(1)=0.0                                       PRNT0241
    EP(4)=0.0                                       PRNT0242
    EP(7)=0.0                                       PRNT0243
06I DO 120 K=1,24                                   PRNT0244
    NNN=(LNUM-1)*24+K                               PRNT0245
    NN=NODE(NNN)                                    PRNT0246
    EP(1)=EP(1)+STDEP(1,K)*DISP(NN)                PRNT0247
    EP(4)=EP(4)+STDEP(4,K)*DISP(NN)                PRNT0248
120 EP(7)=EP(7)+STDEP(7,K)*DISP(NN)              PRNT0249
    NN=(NG-1)*2+1                                   PRNT0250
    STOR(NN)=EP(1)+EP(7)*EP(7)/2.0+(0.5*XSPROP(1,NST)+XSPROP(7,NST)) PRNT0251
    2*EP(4)                                          PRNT0252
    STOR(NN+1)=EP(1)+EP(7)*EP(7)/2.0+(XSPROP(7,NST)-0.5*XSPROP(1,NST)) PRNT0253
    2*EP(4)                                          PRNT0254
130 CONTINUE                                       PRNT0255
140 WRITE(MWRITE,800)NST,(STOR(J),J=1,6)          PRNT0256
150 CONTINUE                                       PRNT0257
C  FOR Y-DIRECTION STIFFENERS.                   PRNT0258
    IF (NYSS.EQ.0)GO TO 190                        PRNT0259
    WRITE(MWRITE,810)                              PRNT0260
    WRITE(MWRITE,785)                              PRNT0261
    WRITE(MWRITE,790)                              PRNT0262
    DO 180 NY=1,NYSS                               PRNT0263
    NST=INYSS(NY)                                  PRNT0264
    LNUM=LNYS(NST)                                 PRNT0265
    NNN1=NP(1,LNUM)                                PRNT0266
    NNN2=NP(2,LNUM)                                PRNT0267
    NNN4=NP(4,LNUM)                                PRNT0268
    XL=XGI(NNN2)-XGI(NNN1)                         PRNT0269
    YL=YGI(NNN4)-YGI(NNN1)                         PRNT0270
    SL=YSPROP(6,NST)                               PRNT0271

```

```

DO 170 NG=1,NA
EL=(1 0+AGAUS(NG))/2.0
CALL SFDM(SL,EL,XL,YL,CB1,STDEP)
EP(2)=0.0
EP(5)=0.0
EP(8)=0.0
DO 160 K=1,24
NNN=(LNUM-1)*24+K
NN=NODE(NNN)
EP(2)=EP(2)+STDEP(2,K)*DISP(NN)
EP(5)=EP(5)+STDEP(5,K)*DISP(NN)
160 EP(8)=EP(8)+STDEP(8,K)*DISP(NN)
NN=(NG-1)*2+1
STOR(NN)=EP(2)+EP(8)*EP(8)/2.0+(0.5*YSPROP(1,NST)+YSPROP(7,NST))
2*EP(5)
STOR(NN+1)=EP(2)+EP(8)*EP(8)/2.0+(YSPROP(7,NST)-0.5*YSPROP(1,NST))
2*EP(5)
170 CONTINUE
180 WRITE(MWRITE,800)NST,(STOR(J),J=1,6)
190 CONTINUE
C CALCULATION AND PRINTOUT OF SYSTEM ENERGIES.
IF(IOP7.EQ.0)GO TO 440
C ELASTIC STRAIN ENERGY STORED IN STRUCTURE.
C FOR PLATE ELEMENTS.
NA=3
NZ=4
NSUBL=NMSUB(1)
CALL GAUSS(NA,AGAUS,AGAUW)
CALL GAUSS(NZ,ZGAUS,ZGAUW)
ELAST=0 0
S1=1 0/EPAN
S2=-ANUP*S1
S3=2.0*(1 0+ANUP)/EPAN
DO 240 LNUM=1,NET
NNN1=NP(1,LNUM)
NNN2=NP(2,LNUM)
NNN4=NP(4,LNUM)
HXL=(XGI(NNN2)-XGI(NNN1))/2.0
HYL=(YGI(NNN4)-YGI(NNN1))/2.0
DO 240 KS=1,NA
SW=HXL*AGAUW(KS)
DO 240 KE=1,NA
EW=HYL*AGAUW(KE)
JA=KE+(KS-1)*NA
STOR1=0 0
DO 230 LZ=1,NZ
ST1=0 0
ST2=0.0
ST3=0 0
DO 220 LS=1,NSUBL
JZ=LZ+(LS-1)*NZ
ST1=ST1+SUBW(1,LS)+TAUSS(LNUM,JZ,JA)
ST2=ST2+SUBW(1,LS)+TAUEE(LNUM,JZ,JA)
220 ST3=ST3+SUBW(1,LS)+TAUSE(LNUM,JZ,JA)
PROD=S1*(ST1*ST1+ST2*ST2)+2 0*S2*ST1*ST2+S3*ST3*ST3
230 STOR1=STOR1+PROD*0.5+TH*ZGAUW(LZ)
240 ELAST=ELAST+STOR1+SW*EW/2.0
C ELASTIC ENERGY IN X-DIRECTION STIFFENERS.
IF(NXST.EQ.0)GO TO 280

```

```

PRNT0272
PRNT0273
PRNT0274
PRNT0275
PRNT0276
PRNT0277
PRNT0278
PRNT0279
PRNT0280
PRNT0281
PRNT0282
PRNT0283
PRNT0284
PRNT0285
PRNT0286
PRNT0287
PRNT0288
PRNT0289
PRNT0290
PRNT0291
PRNT0292
PRNT0293
PRNT0294
PRNT0295
PRNT0296
PRNT0297
PRNT0298
PRNT0299
PRNT0300
PRNT0301
PRNT0302
PRNT0303
PRNT0304
PRNT0305
PRNT0306
PRNT0307
PRNT0308
PRNT0309
PRNT0310
PRNT0311
PRNT0312
PRNT0313
PRNT0314
PRNT0315
PRNT0316
PRNT0317
PRNT0318
PRNT0319
PRNT0320
PRNT0321
PRNT0322
PRNT0323
PRNT0324
PRNT0325
PRNT0326
PRNT0327
PRNT0328
PRNT0329
PRNT0330

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```

DD 270 NST=1,NXST
LNUM=LNXS(NST)
NNN1=NP(1,LNUM)
NNN2=NP(2,LNUM)
HXL=(XGI(NNN2)-XGI(NNN1))/2.0
MAT=MATXS(NST)
NSUBL=NMSUB(MAT)
S1=1 0/XSPROP(3,NST)
EW=XSPROP(2,NST)
DD 270 KE=1,NA
SW=HXL*AGAUW(KE)
STOR1=0 0
DD 260 LZ=1,NZ
ST1=0.0
DD 250 LS=1,NSUBL
JZ=LZ+(LS-1)*NZ
250 ST1=ST1+SUBW(MAT,LS)*TAGSS(NST,JZ,KE)
PROD=S1*ST1*ST1
260 STOR1=STOR1+PROD+0.5*XSPROP(1,NST)*ZGAUW(LZ)
270 ELAST=ELAST+STOR1*EW*SW/2.0
280 CONTINUE
C ELASTIC ENERGY STORED IN Y-DIRECTION STIFFENERS.
IF(NYST.EQ 0)GO TO 320
DD 310 NST=1,NYST
LNUM=LNYS(NST)
NNN1=NP(1,LNUM)
NNN4=NP(4,LNUM)
HYL=(YGI(NNN4)-YGI(NNN1))/2.0
MAT=MATYS(NST)
NSUBL=NMSUB(MAT)
S1=1 0/YSPROP(3,NST)
SW=YSPROP(2,NST)
DD 310 KS=1,NA
EW=HYL*AGAUW(KS)
STOR1=0 0
DD 300 LZ=1,NZ
ST1=0 0
DD 290 LS=1,NSUBL
JZ=LZ+(LS-1)*NZ
290 ST1=ST1+SUBW(MAT,LS)*TSGEE(NST,JZ,KS)
PROD=S1*ST1*ST1
300 STOR1=STOR1+PROD+0.5*YSPROP(1,NST)*ZGAUW(LZ)
310 ELAST=ELAST+STOR1*EW*SW/2.0
320 CONTINUE
C CALCULATION OF ENERGY STORED IN ELASTIC RESTORING SPRINGS.
SPREN=0.0
IF(NELES.EQ.0)GO TO 380
DD 370 NS=1,NELES
LNUM=LNRS(NS)
ISIDE=ISRS(NS)
NNN1=NP(1,LNUM)
NNN2=NP(2,LNUM)
NNN4=NP(4,LNUM)
XL=XGI(NNN2)-XGI(NNN1)
YL=YGI(NNN4)-YGI(NNN1)
DD 330 I=1,5
330 SS(I)=SC(I,NS)
CALL SPRING(EK,SS,ISIDE,XL,YL)
L=(LNUM-1)*24

```

```

PRNT0331
PRNT0332
PRNT0333
PRNT0334
PRNT0335
PRNT0336
PRNT0337
PRNT0338
PRNT0339
PRNT0340
PRNT0341
PRNT0342
PRNT0343
PRNT0344
PRNT0345
PRNT0346
PRNT0347
PRNT0348
PRNT0349
PRNT0350
PRNT0351
PRNT0352
PRNT0353
PRNT0354
PRNT0355
PRNT0356
PRNT0357
PRNT0358
PRNT0359
PRNT0360
PRNT0361
PRNT0362
PRNT0363
PRNT0364
PRNT0365
PRNT0366
PRNT0367
PRNT0368
PRNT0369
PRNT0370
PRNT0371
PRNT0372
PRNT0373
PRNT0374
PRNT0375
PRNT0376
PRNT0377
PRNT0378
PRNT0379
PRNT0380
PRNT0381
PRNT0382
PRNT0383
PRNT0384
PRNT0385
PRNT0386
PRNT0387
PRNT0388
PRNT0389

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```

DO 340 I=1,24
LL=NODE(L+I)
340 EQ(I)=DISP(LL)
DO 350 I=1,24
STOR(I)=0.0
DO 350 K=1,24
350 STOR(I)=STOR(I)+EK(I,K)*EQ(K)
STOR1=0.0
DO 360 I=1,24
360 STOR1=STOR1+EQ(I)*STOR(I)
370 SPREN=SPREN+STOR1/2.0
380 CONTINUE
C CALCULATE KINETIC ENERGY OF THE STRUCTURE.
CINET=0.0
GO TO(390,410),IMASS
390 CONTINUE
DO 400 I=1,NDT
400 CINET=CINET+AMASS(I)*VEL(I)*VEL(I)/2.0
GO TO 430
410 CALL OMULT(AMASS,VEL,FLVM,ICOL,KROW,NDEX)
DO 420 I=1,NDT
420 CINET=CINET+VEL(I)*FLVM(I)/2.0
C CALCULATE WORK INPUT TO STRUCTURE AS SUM OF CURRENT WORK OF EXTER-
C NAL FORCES PLUS KINETIC ENERGY OF INITIAL VELOCITY DISTRIBUTION.
430 EWORK=WFORCE+CINET
C CALCULATE PLASTIC WORK BY SUBTRACTION.
PLASTW=EWORK-ELAST-SPREN-CINET
C PRINTOUT ENERGIES
WRITE(MWRITE,720)
WRITE(MWRITE,730) EWORK
WRITE(MWRITE,740) CINET
WRITE(MWRITE,750) ELAST
WRITE(MWRITE,760) PLASTW
WRITE(MWRITE,770) SPREN
^40 CONTINUE
500 CONTINUE
550 FORMAT('0','REACTION FORCES AT CONSTRAINED NODES')
560 FORMAT('0',2X,'NODE',4X,'RX(LBS)',8X,'RY(LBS)',8X,'RZ(LBS)',7X,
2'MX(LBS-IN)',5X,'MY(LBS-IN)',5X,'MXY(LBS-IN-IN)')
570 FORMAT(' ',16,6D15.5)
600 FORMAT('0','***** INCR. NO =',I5,2X,'TIME=',D12.4,1X,'SEC.')
```

610	FORMAT('0','NODE',6X,'U',12X,'V',12X,'W',11X,'PSIX',9X,'PSIY',9X,	PRNT0431
	2'TJIST',7X,'Y-POS',7X,'Y-POS.',7X,'Z-POS.')	PRNT0432
620	FORMAT(' ',14,9D13.5)	PRNT0433
630	FORMAT('0','STRAIN COMPONENTS, PRINCIPAL(TENSILE) STRAIN AND DIREC	PRNT0434
	TION AT CENTROID OF EACH ELEMENT')	PRNT0435
640	FORMAT('0',14X,'EPS-X STRAIN',12X,'EPS-Y STRAIN',12X,'SHEAR STRAIN	PRNT0436
	2',12X,'PRINC. STRAIN(T)',10X,'DIRECTION(DEG.)')	PRNT0437
644	FORMAT(' ','ELEM.',5(7X,'INNER',7X,'OUTER'))	PRNT0438
645	FORMAT(' ','STA.',5(7X,'INNER',7X,'OUTER'))	PRNT0439
650	FORMAT(' ',14,1X,10D12.4)	PRNT0440
660	FORMAT('0','STRAIN COMPONENTS, PRINCIPAL(TENSILE) STRAIN AND DIREC	PRNT0441
	TION AT GAUSS STATIONS FOR SELECTED ELEMENTS')	PRNT0442
670	FORMAT('0','RESULTS FOR ELEMENT NUMBER',I5)	PRNT0443
690	FORMAT('0','STRAIN COMPONENTS, PRINCIPAL(TENSILE) STRAIN AND DIREC	PRNT0444
	TION, AND ELONGATIONS AT SPECIFIED ADDITIONAL POINTS')	PRNT0445
695	FORMAT('0','POINT NO.',2X,'SURFACE',2X,'EPS-X STRAIN',2X,'EPS-Y STR	PRNT0446
	AIN',2X,'SHEAR STRAIN',1X,'ELONG.(DIR.1)',1X,'ELONG.(DIR.2)',1X,	PRNT0447
	3'PRINC. STRN(T)',1X,'DIRECTION(DEG.)')	PRNT0448

```

700 FORMAT(' ',17,5X,'INNER',1X,7D14.5) PRNT0449
710 FORMAT(' ',17,5X,'OUTER',1X,7D14.5) PRNT0450
720 FORMAT('0','SYSTEM ENERGIES(INN-LO)') PRNT0451
730 FORMAT(' ',5X,'WORK INPUT TO STRUCTURE =',D15.7) PRNT0452
740 FORMAT(' ',5X,'STRUCTURE KINETIC ENERGY =',D15.7) PRNT0453
750 FORMAT(' ',5X,'STRUCTURE ELASTIC ENERGY =',D15.7) PRNT0454
760 FORMAT(' ',5X,'STRUCTURE PLASTIC ENERGY =',D15.7) PRNT0455
770 FORMAT(' ',5X,'ENERGY STORED IN ELASTIC RESTRAINTS=',D15.7) PRNT0456
780 FORMAT('0','STRAIN, EPS-XX, AT GAUSSIAN STATIONS ON SPECIFIED X-DI PRNT0457
2RECTION STIFFENERS') PRNT0458
785 FORMAT('0','STIFFENER',14X,'STATION 1',15X,'STATION 2',15X, PRNT0459
2'STATION 3') PRNT0460
790 FORMAT(' ',1,'NUMBER',5X,3(7X,'INNER',7X,'OUTER')) PRNT0461
800 FORMAT(' ',15,7X,6D12.4) PRNT0462
810 FORMAT('0','STRAIN, EPS-YY, AT GAUSSIAN STATIONS ON SPECIFIED Y-DI PRNT0463
2RECTION STIFFENERS') PRNT0464
900 FORMAT('0','STRAIN COMPONENTS, PRINCIPAL (TENSILE) STRAIN AND DIRE PRNT0465
2CTION AT USER-SPECIFIED NODES') PRNT0466
920 FORMAT(' ',1,'NODE ',5(7X,'INNER',7X,'OUTER')) PRNT0467
RETURN PRNT0468
END PRNT0469

```

6.3 Subprograms Unique to the CIVM-PLATE Code

The following 9 subprograms (or subroutines) are unique to the CIVM-PLATE program:

COLLSN	IMAINP	IMPSS
IFRAG	IMPACT	INTRAC
IMAIN	IMPDS	IPRINT

This version of IMAIN is provided principally for illustration, but also is appropriate for the illustrative example given in Subsection 8.2.1 for the complete plate. The user must write his own version consistent with his particular problem data if he wishes to analyze any other example problem.

A FORTRAN IV listing of these 9 subprograms follows.


```

SUBROUTINE COLLSN(IOPT,XG,YG,ZG,PEN,RF,THALF,NNSR,XF,YF,ZF,XN,YN, ZLN0000
2ZN,T,NN1,NN2,NN3) CLSN0001
IMPLICIT PEAL*8(A-H,O-Z) CLSN0002
C CLSN0003
C ASRL TR 154-14.... ORIGINAL REPORT VERSION OF PROGRAM CLSN0004
C COPYRIGHT (C) MASSACHUSETTS INSTITUTE OF TECHNOLOGY 1980 CLSN0005
C CLSN0006
C THIS SUBROUTINE IS USED EXCLUSIVELY BY THE CIVM PLATE PROGRAM. CLSN0007
C CLSN0008
C DIMENSION XG(1),YG(1),ZG(1),PEN(1),XN(1),YN(1),ZN(1),T(3,3) CLSN0009
C CLSN0010
C THIS ROUTINE PERFORMS DETAILED COLLISION INSPECTION OVER A CLSN0011
C TRIANGULAR SUBREGION OF THE PLATE, CALCULATING THE PENETRATION CLSN0012
C DISTANCE, PEN(I), AND LOCATION, XN(I), YN(I), ZN(I), OF THE CLSN0013
C CONTACT POINT, ON THE SURFACE, IF COLLISION OCCURS WITHIN THE CLSN0014
C TRIANGULAR SUBREGION CLSN0015
C IF IOPT=1, THE ENTIRE CHECK IS FOLLOWED. CLSN0016
C IF IOPT=2, THE PROCESS IS TERMINATED AFTER CALCULATION OF THE CLSN0017
C COORDINATE TRANSFORMATION MATRIX FOR THE TRIANGULAR CLSN0018
C SUBREGION. CLSN0019
C CLSN0020
C FOR PRESENT, UNIFORM THICKNESS IS ASSUMED IN THE TRIANGULAR REGION. CLSN0021
C CLSN0022
C DEFINE COMPONENTS OF A,B,C OF VECTOR IN Z-BAR DIRECTION CLSN0023
C X21=XG(NN2)-XG(NN1) CLSN0024
C Y21=YG(NN2)-YG(NN1) CLSN0025
C Z21=ZG(NN2)-ZG(NN1) CLSN0026
C X31=XG(NN3)-XG(NN1) CLSN0027
C Y31=YG(NN3)-YG(NN1) CLSN0028
C Z31=ZG(NN3)-ZG(NN1) CLSN0029
C A=Y21*Z31-Y31*Z21 CLSN0030
C B=X31*Z21-X21*Z31 CLSN0031
C C=X21*Y31-X31*Y21 CLSN0032
C AL3=DSQRT(A*A+B*B+C*C) CLSN0033
C CALCULATE DISTANCE BETWEEN FRAGMENT CENTROID AND PLATE MIDSURFACE. CLSN0034
C IF DFP IS NEGATIVE FRAGMENT CENTROID IS BELOW MIDSURFACE. CLSN0035
C DFP=(A*(XF-XG(NN1))+B*(YF-YG(NN1))+C*(ZF-ZG(NN1)))/AL3 CLSN0036
C CALC. PENETRATION DISTANCE (ASSUMING UNIFORM THICKNESS AND CLSN0037
C PENETRATION IN DIRECTION OF NORMAL FROM FRAGMENT CENTROID TO CLSN0038
C REFERENCE SURFACE) CLSN0039
C PEN(NNSR)=RF+THALF+DFP CLSN0040
C IF PENETRATION DIST. IS LESS THAN OR EQUAL TO ZERO, RETURN TO CLSN0041
C CALLING ROUTINE CLSN0042
C IF(PEN(NNSR) LE 0 0)RETURN CLSN0043
C FIND COORDS OF INTERSECTION OF NORMAL (FROM FRAG TO SURFACE) WITH CLSN0044
C THE SURFACE. CLSN0045
C XN(NNSR)=XF-A*DFP/AL3 CLSN0046
C YN(NNSR)=YF-C*DFP/AL3 CLSN0047
C ZN(NNSR)=ZF-C*DFP/AL3 CLSN0048
C ESTABLISH TRANSFORMATION MATRIX ; (BAR)=T*(GLOBAL). CLSN0049
C Z-BAR IS NORMAL TO THE PLANE AND DIRECTED TOWARD THE OUTER SURFACE CLSN0050
C OF THE PLATE X-BAR IS IN THE DIRECTION FROM TRIANGLE NODE 1 TO CLSN0051
C TRIANGLE NODE 2 CLSN0052
C AL1=DSQRT(X21*X21+Y21*Y21+Z21*Z21) CLSN0053
C T(1,1)=X21/AL1 CLSN0054
C T(1,2)=Y21/AL1 CLSN0055
C T(1,3)=Z21/AL1 CLSN0056
C T(2,1)=(B*Z21-C*Y21)/(AL1*AL3) CLSN0057
C T(2,2)=(C*X21-A*Z21)/(AL1*AL3) CLSN0058

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```

T(2,3)=(A+Y21-B*X21)/(AL1*AL3)
T(3,1)=A/AL3
T(3,2)=B/AL3
T(3,3)=C/AL3
C IF THIS ROUTINE HAS BEEN CALLED ONLY TO CALCULATE T, RETURN
  IF(IOPT EQ.2)RETURN
C FIND X-Y COORDS OF NODES AND INTERSECTION POINT IN BARRED SYSTEM
XB1=XG(NN1)*T(1,1)+YG(NN1)*T(1,2)+ZG(NN1)*T(1,3)
YB1=XG(NN1)*T(2,1)+YG(NN1)*T(2,2)+ZG(NN1)*T(2,3)
XB2=XG(NN2)*T(1,1)+YG(NN2)*T(1,2)+ZG(NN2)*T(1,3)
YB2=XG(NN2)*T(2,1)+YG(NN2)*T(2,2)+ZG(NN2)*T(2,3)
XB3=XG(NN3)*T(1,1)+YG(NN3)*T(1,2)+ZG(NN3)*T(1,3)
YB3=XG(NN3)*T(2,1)+YG(NN3)*T(2,2)+ZG(NN3)*T(2,3)
XBN=XN(NNSR)*T(1,1)+YN(NNSR)*T(1,2)+ZN(NNSR)*T(1,3)
YBN=XN(NNSR)*T(2,1)+YN(NNSR)*T(2,2)+ZN(NNSR)*T(2,3)
C DEFINE TRIANGULAR (AREA) COORDINATE PARAMETERS FOR THIS SUBREGION.
AREA2=XB2*YB3+XB1*YB2+XB3*YB1-XB2*YB1-XB3*YB2-XB1*YB3
A1=XB2*YB3-XB3*YB2
A2=XB3*YB1-XB1*YB3
A3=XB1*YB2-XB2*YB1
B1=YB2-YB3
B2=YB3-YB1
B3=YB1-YB2
C1=XB3-XB2
C2=XB1-XB3
C3=XB2-XB1
C EVALUATE TRIANGULAR COORDS (L1, L2, L3) AT FRAGMENT/NORMAL
C INTERSECTION POINT (POINT OF CONTACT)
CL1=(A1+B1*XBN+C1*YBN)/AREA2
CL2=(A2+B2*XBN+C2*YBN)/AREA2
CL3=(A3+B3*XBN+C3*YBN)/AREA2
C FOR CONTACT POINT TO LIE IN TRIANGULAR SUBREGION, CL1, CL2, AND CL3
C MUST ALL BE BETWEEN 0 AND 1 (INCLUSIVE). IF NOT, SET PENETRATION
C DISTANCE TO A LARGE NEGATIVE NUMBER.
C USE A NEGATIVE EPSILON AND 1 - EPSILON INSTEAD OF AN EXACT 0. AND 1.
C TO AVOID INACCURACIES WITH COMPUTER ROUND OFF.
  ZIP=-1.D-10
  ONE=1.D0-ZIP
  IF(CL1.LT.ZIP.OR.CL2.LT.ZIP.OR.CL3.LT.ZIP.OR.CL1.GT.ONE.OR.CL2.
2GT.ONE.OR.CL3.GT.ONE)PEN(NNSR)=-1.0D10
  RETURN
  END
SUBROUTINE IFRAG(PMASS,AMASS)
  IMPLICIT REAL*8(A-H,O-Z)
C
C ASRL TR 154-14... ..ORIGINAL REPORT VERSION OF PROGRAM
C COPYRIGHT (C) MASSACHUSETTS INSTITUTE OF TECHNOLOGY 1980
C
C THIS SUBROUTINE IS USED EXCLUSIVELY BY THE CIVM PLATE PROGRAM.
C
  DIMENSION PMASS(1),AMASS(1)
  COMMON/FRAG/XF,YF,ZF,DELF(3),VF(3),DTHETF(3),OMEGF(3),RF,FMASS,
2FMOI,FKEO,FKEC
  COMMON/PROPC/COEFR,FRNC,USEF,NSYM,IPSS,IUSEF
  COMMON/PLATE/XD,YD,THP,VAL,HVL,NEAD,NECD,DENSP,EPAN,ANUP,THALF
  COMMON/BAS/NDT,NET,MN,NB,NIRREG,MNC
  COMMON/INOUT/MREAD,MWRITE,MPUNCH
C
C IN THIS SUBROUTINE THE INITIAL FRAGMENT POSITION AND VELOCITY,

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CLSN0059
CLSN0060
CLSN0061
CLSN0062
CLSN0063
CLSN0064
CLSN0065
CLSN0066
CLSN0067
CLSN0068
CLSN0069
CLSN0070
CLSN0071
CLSN0072
CLSN0073
CLSN0074
CLSN0075
CLSN0076
CLSN0077
CLSN0078
CLSN0079
CLSN0080
CLSN0081
CLSN0082
CLSN0083
CLSN0084
CLSN0085
CLSN0086
CLSN0087
CLSN0088
CLSN0089
CLSN0090
CLSN0091
CLSN0092
CLSN0093
CLSN0094
CLSN0095
CLSN0096
CLSN0097
CLSN0098
CLSN0099
CLSN0100
IFRG0000
IFRG0001
IFRG0002
IFRG0003
IFRG0004
IFRG0005
IFRG0006
IFRG0007
IFRG0008
IFRG0009
IFRG0010
IFRG0011
IFRG0012
IFRG0013
IFRG0014
IFRG0015
IFRG0016

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C FRAGMENT GEOMETRIC PROPERTIES, CONTACT SURFACE PROPERTIES          IFRG0017
C AND ANY SUMMETRY OPTIONS ARE INPUT AND PRINTED FOR VERIFICATION.    IFRG0018
C THE FRAGMENT INITIAL KINETIC ENECY IC CALCULATED AND THE MASS MATRIX IFRG0019
C USED IN IMPACT INTERACTION CALCULATION IS FORMED.                   IFRG0020
C                                                                        IFRG0021
C      NNT=NDT/6                                                         IFRG0022
C READ IN FRAGMENT INITIAL LOCATION, VELOCITIES, AND PROPERTIES      IFRG0023
C      READ(MREAD,500)XF,YF,ZF                                         IFRG0024
C      READ(MREAD,500)(VF(I),I=1,3)                                    IFRG0025
C      READ(MREAD,500)(OMEGF(I),I=1,3)                                IFRG0026
C      READ(MREAD,500)RF,FMASS,FMOI                                     IFRG0027
C READ IN CONTACT SURFACE PROPERTIES                                  IFRG0028
C      READ(MREAD,500)COEFR,FRNC                                       IFRG0029
C      READ(MREAD,510)NSYM,IPSS,ICUT,IUSEF                             IFRG0030
C      IF(NSYM.EQ.2)FMASS=FMASS/4.0D0                                  IFRG0031
C      IF(NSYM.EQ.1) FMASS=FMASS/2.0D0                                  IFRG0032
C      IF(NSYM.EQ.1) FMOI=FMOI/2.0D0                                    IFRG0033
C      CUTR=.0D0                                                        IFRG0034
C      IF(ICUT.EQ.1)READ(MREAD,500)CUTR                                 IFRG0035
C      IF(IUSEF.EQ.1) READ(MREAD,500) USEF                              IFRG0036
C FRAGMENT INITIAL KINETIC ENERGY                                   IFRG0037
C      FKED=0.0                                                         IFRG0038
C      DO 15 I=1,3                                                       IFRG0039
15      FKED=FKED+0.5*(FMASS*VF(I)*VF(I)+FMOI*OMEGF(I)*OMEGF(I))    IFRG0040
C      FKEC=FKED*CUTR                                                  IFRG0041
C PRINT OUT THIS INFORMATION                                         IFRG0042
C      WRITE(MWRITE,600)                                               IFRG0043
C      WRITE(MWRITE,601) XF                                           IFRG0044
C      WRITE(MWRITE,602) YF                                           IFRG0045
C      WRITE(MWRITE,603) ZF                                           IFRG0046
C      WRITE(MWRITE,604) VF(1)                                         IFRG0047
C      WRITE(MWRITE,605) VF(2)                                         IFRG0048
C      WRITE(MWRITE,606) VF(3)                                         IFRG0049
C      WRITE(MWRITE,607) OMEGF(1)                                       IFRG0050
C      WRITE(MWRITE,608) OMEGF(2)                                       IFRG0051
C      WRITE(MWRITE,609) OMEGF(3)                                       IFRG0052
C      WRITE(MWRITE,610) RF                                             IFRG0053
C      WRITE(MWRITE,611) FMASS                                          IFRG0054
C      WRITE(MWRITE,612) FMOI                                          IFRG0055
C      WRITE(MWRITE,630) FKED                                           IFRG0056
C      WRITE(MWRITE,613)                                               IFRG0057
C      WRITE(MWRITE,614) COEFR                                          IFRG0058
C      WRITE(MWRITE,615) FRNC                                           IFRG0059
C      WRITE(MWRITE,616) NSYM                                           IFRG0060
C      IF(NSYM.EQ.1 AND IPSS.EQ.1) WRITE(MWRITE,617)                  IFRG0061
C      IF(NSYM.EQ.1 AND IPSS.EQ.4) WRITE(MWRITE,618)                  IFRG0062
C      IF(NSYM.EQ.1) WRITE(MWRITE,619)                                  IFRG0063
C      IF(NSYM.EQ.2) WRITE(MWRITE,620)                                  IFRG0064
C      IF(ICUT.EQ.0)GO TO 18                                           IFRG0065
C      WRITE(MWRITE,640)                                               IFRG0066
C      WRITE(MWRITE,650) CUTR                                          IFRG0067
C      WRITE(MWRITE,660) FKEC                                          IFRG0068
C      WRITE(MWRITE,670)                                               IFRG0069
18      CONTINUE                                                       IFRG0070
C      IF(IUSEF.EQ.0) WRITE(MWRITE,700)                                 IFRG0071
C      IF(IUSEF.EQ.1) WRITE(MWRITE,710) USEF                            IFRG0072
500      FORMAT(5D16.7)                                               IFRG0073
510      FORMAT(20I4)                                                 IFRG0074
600      FORMAT('0','FRAGMENT LOCATION, VELOCITY, AND PROPERTIES AT TIME=0. IFRG0075

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20 SEC. ')
601 FORMAT(' ',5X,'X-LOCATION(IN)           =',D15.7)          IFRG0076
602 FORMAT(' ',5X,'Y-LOCATION(IN)           =',D15.7)          IFRG0077
603 FORMAT(' ',5X,'Z-LOCATION(IN)           =',D15.7)          IFRG0078
604 FORMAT(' ',5X,'X-VELOCITY(IN/SEC)      =',D15.7)          IFRG0079
605 FORMAT(' ',5X,'Y-VELOCITY(IN/SEC)      =',D15.7)          IFRG0080
606 FORMAT(' ',5X,'Z-VELOCITY(IN/SEC)      =',D15.7)          IFRG0081
607 FORMAT(' ',5X,'OMEGA-X(RAD/SEC)        =',D15.7)          IFRG0082
608 FORMAT(' ',5X,'OMEGA-Y(RAD/SEC)        =',D15.7)          IFRG0083
609 FORMAT(' ',5X,'OMEGA-Z(RAD/SEC)        =',D15.7)          IFRG0084
610 FORMAT(' ',5X,'FRAGMENT RADIUS(IN)     =',D15.7)          IFRG0085
611 FORMAT(' ',5X,'FRAGMENT MASS(LB-SEC*SEC/IN) =',D15.7)        IFRG0086
612 FORMAT(' ',5X,'FRAG. MOM INERT(IN-LB-SEC*SEC) =',D15.7)      IFRG0087
613 FORMAT('0','CONTACT SURFACE PROPERTIES') IFRG0088
614 FORMAT(' ',5X,'COEF. OF RESTITUTION=' ,D15.7) IFRG0089
615 FORMAT(' ',5X,'FRICTION COEFFICIENT=' ,D15.7) IFRG0090
616 FORMAT(' ',5X,'NO. OF SYMMETRIES =',I4) IFRG0091
617 FORMAT(' ',5X,'THE GLOBAL X AXIS IS THE LINE OF SYMMETRY') IFRG0092
618 FORMAT(' ',5X,'THE GLOBAL Y AXIS IS THE LINE OF SYMMETRY') IFRG0093
619 FORMAT(' ',5X,'(FRAGMENT MASS, MASS MOMENT OF INERTIA AND KINETIC ENERGY ARE ONE-HALF THEIR ACTUAL VALUES BECAUSE OF SINGLE SYMMETRY)') IFRG0094
620 FORMAT(' ',5X,'(FRAGMENT MASS AND KINETIC ENERGY ARE ONE-QUARTER OF THEIR ACTUAL VALUES BECAUSE OF DOUBLE SYMMETRY)') IFRG0095
630 FORMAT(' ',5X,'KINETIC ENERGY(IN-LB) =',D15.7) IFRG0096
640 FORMAT('0','IMPACT INSPECTION/CORRECTION WILL BE TERMINATED WHEN') IFRG0097
650 FORMAT(' ',5X,'THE CURRENT FRAGMENT KINETIC ENERGY IS LESS THAN', IFRG0098
2D16.7,2X,'TIMES THE INITIAL FRAGMENT KINETIC ENERGY.') IFRG0099
660 FORMAT(' ',5X,'THIS CUT-OFF POINT CORRESPONDS TO A FRAGMENT KINETIC IFRG0100
2C ENERGY OF',D16.7,2X,'IN-LB.') IFRG0101
670 FORMAT(' ',5X,'NOTE THAT STRUCTURAL RESPONSE CALCULATIONS WILL CONTINUE IFRG0102
BEYOND TERMINATION OF IMPACT INSPECTION/CORRECTION.') IFRG0103
700 FORMAT('0','EFFECTIVE LENGTH WILL BE CALCULATED INTERNALLY') IFRG0104
710 FORMAT('0','USER SPECIFIED EFFECTIVE LENGTH=' ,D15.7) IFRG0105
C CALCULATE NODAL POINT MASSES FOR IMPACT/INTERACTION USE. THIS IFRG0106
C EXTRACTED FROM SYSTEM LUMPED MASS VECTOR BY NEGLECTING ROTARY IFRG0107
C INERTIA CONTRIBUTIONS. EFFECTS OF POSSIBLE NONUNIFORM MESH IFRG0108
C AND STIFFENERS INCLUDED AUTOMATICALLY. FOR PLATE ANALYSIS ONLY IFRG0109
NDPN=6 IFRG0110
DO 20 I=1,NNT IFRG0111
PMASS(I)=0.0 IFRG0112
DO 30 I=1,NNT IFRG0113
INC=(I-1)*NDPN+1 IFRG0114
J0 PMASS(I)=AMASS(INC) IFRG0115
RETURN IFRG0116
END IFRG0117

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SUBROUTINE IMPACT(XG,YG,ZG,DELD,VEL ,NP,VN,VNB,PMASS,NBC,SI,NEFF, IMPT0000
2ALPHA,IMPCT1 ,NIAN) IMPT0001
IMPLICIT REAL*8(A-H,O-Z) IMPT0002
C IMPT0003
C ASRL TR 154-14.....ORIGINAL REPORT VERSION OF PROGRAM IMPT0004
C COPYRIGHT (C) MASSACHUSETTS INSTITUTE OF TECHNOLOGY 1980 IMPT0005
C IMPT0006
C THIS SUBROUTINE IS USED EXCLUSIVELY BY THE CIVM PLATE PROGRAM. IMPT0007
C IMPT0008
DIMENSION XG(1),YG(1),ZG(1),DELD(1),VEL(1) ,NP(4,1),LNC(4),PEN(8), IMPT0009
2XN(8),YN(8),ZN(8),T(3,3),SI(1),NEFF(1),ALPHA(1),VN(3,1),VNB(3,1), IMPT0010
3OMEGFB(3),VFB(3),PMASS(1),PTILDA(3),NBC(1),LRP(8) IMPT0011
COMMON/PLATE/XD,YD,THP,HXL,HYL,NEAD,NECD,DENSP,EPAN,ANUP,THALF IMPT0012
COMMON/BAS/NDT,NET,MN,NB,NIRREG,MNC IMPT0013
COMMON/TIM/DELTAT,TIMEF,TIME,ITIMEF,INCRT,IOUT,ITIME IMPT0014
COMMON /PROPC/ COEFR,FRNC,USEF,NSYM,IPSS,IUSEF IMPT0015
COMMON/FRAG/XF,YF,ZF,DELF(3),VF(3),DTHETF(3),OMEGF(3),RF,FMASS, IMPT0016
2FMOI,FKED,FKEC IMPT0017
COMMON /INOUT/ MREAD,MWRITE,MPUNCH IMPT0018
C IMPT0019
C CONTROLLING ROUTINE FOR COLLISION INSPECTION/IMPACT INTERACTION IMPT0020
C ANALYSIS INCLUDING FRICTION. IF IMPACT HAS OCCURED, THE NODAL IMPT0021
C VELOCITIES, VEL, AND FRAGMENT VELOCITIES, VF AND OMEGF, ARE UPDATED IMPT0022
C TO THEIR POST-IMPACT VALUE. NODAL AND FRAGMENT DISPLACEMENTS AND IMPT0023
C LOCATIONS ARE NOT MODIFIED IN THIS SUBROUTINE. IMPT0024
C PRESENT ANALYSIS ASSUMES UNIFORM THICKNESS PLATE, AND SINGLE IMPT0025
C FRAGMENT. EFFECTS OF MAXIMUM PENETRATION ONLY ARE INCLUDED. IMPT0026
C IMPT0027
C UPDATE GLOBAL COORDINATES TO TRIAL VALUES IMPT0028
IMPCT1=0 IMPT0029
NDPN=6 IMPT0030
NNT=NDT/6 IMPT0031
DO 1 I=1,NNT IMPT0032
NNI=(I-1)+NDPN IMPT0033
XG(I)= XG(I)+DELD(NNI+1) IMPT0034
YG(I)= YG(I)+DELD(NNI+2) IMPT0035
ZG(I)= ZG(I)+DELD(NNI+3) IMPT0036
1
C UPDATE FRAGMENT POSITION ASSUMING SAME INCREMENTAL QUANT. AS PREV. IMPT0037
XF=XF+VF(1)*DELTAT IMPT0038
YF=YF+VF(2)*DELTAT IMPT0039
ZF=ZF+VF(3)*DELTAT IMPT0040
DO 7 I=1,3 IMPT0041
DTHETF(I)=DELTAT*OMEGF(I) IMPT0042
7 DELF(I)=DELTAT*VF(I) IMPT0043
C FIND MINIMUM DISTANCE SQUARED FROM FRAGMENT TO NODE IMPT0044
9 DMIN=1.0D10 IMPT0045
DO 10 I=1,NNT IMPT0046
DIST=(XF-XG(I))**2+(YF-YG(I))**2+(ZF-ZG(I))**2 IMPT0047
IF(DIST.LT.DMIN)NC=I IMPT0048
IF(DIST.LT.DMIN)DMIN=DIST IMPT0049
10 CONTINUE IMPT0050
C SEARCH NODAL CONNECTIONS FOR ELEMENTS CONNECTED TO NODE NC IMPT0051
NEC=0 IMPT0052
DO 20 I=1,NET IMPT0053
DO 20 J=1,4 IMPT0054
IF(NP(J,I).EQ.NC)NEC=NEC+1 IMPT0055
IF(NP(J,I).EQ.NC)LNC(NEC)=I IMPT0056
IF(NEC.EQ.4)GO TO 30 IMPT0057
20 CONTINUE IMPT0058
30 CONTINUE IMPT0059
C CHECK FOR PENETRATION IN EACH TRIANGULAR SUBREGION OF THE NEC ELEMS. IMPT0060
NRP=0 IMPT0061

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	AA=0.0	IMPT0062
	BA=0.0	IMPT0063
	CA=0.0	IMPT0064
	XA=0.0	IMPT0065
	YA=0.0	IMPT0066
	ZA=0.0	IMPT0067
	DO 50 I=1,NEC	IMPT0068
	LNUM=LNC(I)	IMPT0069
	DO 50 NSR=1,2	IMPT0070
	NNSR=(I-1)*2+NSR	IMPT0071
	NN1=NP(I,LNUM)	IMPT0072
	NN2=NP(NSR+1,LNUM)	IMPT0073
	NN3=NP(NSR+2,LNUM)	IMPT0074
49	CALL COLLN(1,XG,YG,ZG,PEN,RF,THALF,NNSR,XF,YF,ZF,XN,YN,ZN,T,	IMPT0075
	2NN1,NN2,NN3)	IMPT0076
	IF(PEN(NNSR) LE.0.0) GO TO 50	IMPT0077
	NRP=NRP+1	IMPT0078
	LRP(NRP)=NNSR	IMPT0079
	LSP=NNSR	IMPT0080
	PENM=PEN(NNSR)	IMPT0081
	LNMP=LNUM	IMPT0082
	AA=AA+T(3,1)	IMPT0083
	BA=BA+T(3,2)	IMPT0084
	CA=CA+T(3,3)	IMPT0085
	XA=XA+XN(NNSR)	IMPT0086
	YA=YA+YN(NNSR)	IMPT0087
	ZA=ZA+ZN(NNSR)	IMPT0088
50	CONTINUE	IMPT0089
C	SKIP OUT IF NO PENETRATION	IMPT0090
	IF(NRP EQ 0) GO TO 300	IMPT0091
C	CALC RADIUS OF REGION OF INFLUENCE, EFLN	IMPT0092
C	FOR PRESENT ASSUME DELTAT=STAR*DELTAT	IMPT0093
	EFLN=DSQRT(EPAN/DENSP/(1.00-ANUP**2))*DELTAT	IMPT0094
	IF(IUSEF.EQ.1) EFLN=USEF	IMPT0095
C	CALCULATION OF TRANS. AND EFFECTIVE POINT OF IMPACT WHEN MORE THAN	IMPT0096
C	ONE OVERLAP IS FOUND.	IMPT0097
201	IF(NRP EQ 1) GO TO 65	IMPT0098
	AL3=DSQRT(AA*AA+BA*BA+CA*CA)	IMPT0099
	DA=(AA+BA)/CA	IMPT0100
	AL1=DSQRT(2.000+DA*DA)	IMPT0101
	AL2=AL1+AL3	IMPT0102
	T(1,1)=1.0/AL1	IMPT0103
	T(1,2)=1.0/AL1	IMPT0104
	T(1,3)=-DA/AL1	IMPT0105
	T(2,1)=-{BA*DA+CA}/AL2	IMPT0106
	T(2,2)={CA+AA*DA}/AL2	IMPT0107
	T(2,3)=(AA-BA)/AL2	IMPT0108
	T(3,1)=AA/AL3	IMPT0109
	T(3,2)=BA/AL3	IMPT0110
	T(3,3)=CA/AL3	IMPT0111
	LSR=LRP(I)	IMPT0112
	XN(LSP)=XA/DFLOAT(NRP)	IMPT0113
	YN(LSP)=YA/DFLOAT(NRP)	IMPT0114
	ZN(LSP)=ZA/DFLOAT(NRP)	IMPT0115
65	CONTINUE	IMPT0116
C	DETERMINE WHICH NODES FALL IN THIS CIRCULAR REGION	IMPT0117
	NK=0	IMPT0118
	DO 70 I=1,NNT	IMPT0119
	DIST=DSQRT((XN(LSP)-XG(I))**2+(YN(LSP)-YG(I))**2+(ZN(LSP)-ZG(I))	IMPT0120
	2**2)	IMPT0121
	IF(DIST.GT.EFLN)GO TO 70	IMPT0122
	NK=NK+1	IMPT0123
	SI(NK)=DIST	IMPT0124
	NEFF(NK)=1	IMPT0125
	ALPHA(NK)=1.000-DIST/EFLN	IMPT0126
70	CONTINUE	IMPT0127

<pre> C IF USER ESTIMATE OF NK IS TOO SMALL, TERMINATE RUN. IF(NIAN .GE. NK) GO TO 73 WRITE(MWRITE,640) ITIME WRITE(MWRITE,650) NIAN WRITE(MWRITE,660) NK WRITE(MWRITE,670) CALL EXIT 73 CONTINUE C TEMPORARY UPDATE OF EFLN IF NK=0. IF(NK GT 0) GO TO 74 NN3=NP(LNMP,3) NN1=NP(LNMP,1) EFLN=DSQRT((XG(NN3)-XG(NN1))*2+(YG(NN3)-YG(NN1))*2 2+(ZG(NN3)-ZG(NN1))*2) WRITE(MWRITE,730) ITIME WRITE(MWRITE,740) EFLN GO TO 65 74 CONTINUE C CALC CONSTANT, CONST, ASSUMING TOTAL IMPULSE APPLIED TO NODES IS EQUAL TO TOTAL IMPARTED IMPULSE. C FOR PRESENT, ASSUME IMPULSE IS ZERO AT EFLN. CONST=0.0 DO 80 I=1,NK 80 CONST=CONST+ALPHA(I) CONST=1.0/CONST C CALC ALPHA(I)=CONST*ALPHA(I) DO 90 I=1,NK 90 ALPHA(I)=ALPHA(I)*CONST C ESTABLISH TRANSFORMATION MATRIX, T, CORRESPONDING TO TRIANGULAR SUBREGION WHERE IMPACT HAS OCCURED. C NOTE THAT TRANS IS IN THE FORM XYZ-BAR=T*XYZ C IF MORE THAN ONE OVERLAP, SKIP (USE T ABOVE). IF(NRP GT 1) GO TO 95 NN=(LSP+1)/2 LNMP=LNC(NN) NSR=LSP-2*(NN-1) NN1=NP(1, LNMP) NN2=NP(NSR+1, LNMP) NN3=NP(NSR+2, LNMP) CALL COLLSN(2,XG,YG,ZG,PEN,RF,THALF,LSP,XF,YF,ZF,XN,YN,ZN,T, 2NN1,NN2,NN3) 95 CONTINUE C EXTRACT NODAL VELOCITIES IN IMPACT AFFECTED REGION. DO 100 I=1,NK NNI=(NEFF(I)-1)*NDPN DO 100 J=1,3 K=NNI+J 100 VN(J,I)=VEL(K) C TRANSFORM NODAL VELOCITIES INTO BAR SYSTEM DO 110 I=1,NK DO 110 J=1,3 VNB(J,I)=0.0 DO 110 K=1,3 110 VNB(J,I)=VNB(J,I)+T(J,K)*VN(K,I) C CALC. ASSUMED PRE-IMPACT VELOCITIES OF FRAGMENT C TRANSFORM THESE QUANTITIES INTO BAR SYSTEM DO 130 I=1,3 OMEGFB(I)=0.0 VFB(I)=0.0 DO 130 K=1,3 OMEGFB(I)=OMEGFB(I)+T(I,K)*OMEGF(K) 130 VFB(I)=VFB(I)+T(I,K)*VF(K) C CALC. IMPULSE INTERACTION CONSTANTS, S1,S2,A0,B1,B3 S1=VFB(1)+RF*OMEGFB(2) S2=VFB(2)-RF*OMEGFB(1) A0=VFB(3) </pre>	<pre> IMPT0128 IMPT0129 IMPT0130 IMPT0131 IMPT0132 IMPT0133 IMPT0134 IMPT0135 IMPT0136 IMPT0137 IMPT0138 IMPT0139 IMPT0140 IMPT0141 IMPT0142 IMPT0143 IMPT0144 IMPT0145 IMPT0146 IMPT0147 IMPT0148 IMPT0149 IMPT0150 IMPT0151 IMPT0152 IMPT0153 IMPT0154 IMPT0155 IMPT0156 IMPT0157 IMPT0158 IMPT0159 IMPT0160 IMPT0161 IMPT0162 IMPT0163 IMPT0164 IMPT0165 IMPT0166 IMPT0167 IMPT0168 IMPT0169 IMPT0170 IMPT0171 IMPT0172 IMPT0173 IMPT0174 IMPT0175 IMPT0176 IMPT0177 IMPT0178 IMPT0179 IMPT0180 IMPT0181 IMPT0182 IMPT0183 IMPT0184 IMPT0185 IMPT0186 IMPT0187 IMPT0188 IMPT0189 IMPT0190 IMPT0191 IMPT0192 IMPT0193 </pre>
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202

B1=1.0/FMASS+RF*RF/FMOI	IMPT0194
B3=1.0/FMASS	IMPT0195
DO 140 I=1,NK	IMPT0196
S1=S1-ALPHA(I)*VNB(1,I)	IMPT0197
S2=S2-ALPHA(I)*VNB(2,I)	IMPT0198
A0=A0-ALPHA(I)*VNB(3,I)	IMPT0199
AM=PMASS(NEFF(I))	IMPT0200
B1=B1+ALPHA(I)*ALPHA(I)/AM	IMPT0201
140 B3=B3+ALPHA(I)*ALPHA(I)/AM	IMPT0202
C IF A0 LE 0 0, NO COLLISION CAN OCCUR	IMPT0203
IF(A0 LE 0 000)GO TO 300	IMPT0204
C SET IMPACT INDEX TO INDICATE IMPACT HAS OCCURED.	IMPT0205
IMPCTI=1	IMPT0206
C CALC POST-IMPACT MOMENTUM COORDINATES IN BAR SYSTEM	IMPT0207
CALL INTRAC(S1,S2,A0,B1,B3,COEFR,FRNC,PTILDA)	IMPT0208
C CALC POST-IMPACT VELOCITY DIFFERENCES OF NODES IN BAR SYSTEM	IMPT0209
C (I E. V-PRIME MINUS V)	IMPT0210
DO 180 I=1,NK	IMPT0211
K=NEFF(I)	IMPT0212
AM=PMASS(K)	IMPT0213
DO 180 J=1,3	IMPT0214
180 VNB(J,I)=ALPHA(I)*PTILDA(J)/AM	IMPT0215
C CALC. POST-IMPACT VELOCITY DIFFERENCES OF FRAGMENT IN BAR SYSTEM	IMPT0216
DO 190 I=1,3	IMPT0217
190 VFB(I)=-PTILDA(I)/FMASS	IMPT0218
OMEGFB(1)=PTILDA(2)*RF/FMOI	IMPT0219
OMEGFB(2)=-PTILDA(1)*RF/FMOI	IMPT0220
OMEGFB(3)=0 DO	IMPT0221
C TRANSFORM POST-IMPACT NODAL VELOCITY DIFFERENCES BACK TO XYZ SYSTEM	IMPT0222
DO 200 I=1,NK	IMPT0223
DO 200 J=1,3	IMPT0224
VN(J,I)=0 0	IMPT0225
DO 200 K=1,3	IMPT0226
200 VN(J,I)=VN(J,I)+T(K,J)*VNB(K,I)	IMPT0227
C TRANS. POST-IMPACT VELOCITY DIFFERENCES OF FRAGMENT TO GLOBAL	IMPT0228
C SYSTEM AND ADD TO PRE-IMPACT VELOCITIES TO GET POST-IMPACT FRAG.	IMPT0229
C VELOCITIES	IMPT0230
DO 210 I=1,3	IMPT0231
DO 210 K=1,3	IMPT0232
OMEGF(I)=OMEGF(I)+T(K,I)*OMEGFB(K)	IMPT0233
210 VF(I)=VF(I)+T(K,I)*VFB(K)	IMPT0234
C UPDATE NODAL VELOCITIES TO POST-IMPACT VALUES.	IMPT0235
DO 230 I=1,NK	IMPT0236
NNI=(NEFF(I)-1)*NDPN	IMPT0237
DO 230 J=1,3	IMPT0238
K=NNI+J	IMPT0239
230 VEL(K)=VEL(K)+VN(J,I)	IMPT0240
C CONSTRAIN VEL	IMPT0241
CALL RCON(VEL ,NBC)	IMPT0242
IF(NRP EQ.1) GO TO 250	IMPT0243
WRITE(MWRITE,700) ITIME	IMPT0244
WRITE(MWRITE,710) (LRP(I),I=1,NRP)	IMPT0245
WRITE(MWRITE,720) XN(LSP),YN(LSP),ZN(LSP)	IMPT0246
GO TO 300	IMPT0247
250 WRITE(MWRITE,600)ITIME,LNMP,NSR	IMPT0248
WRITE(MWRITE,610)XN(LSP),YN(LSP),ZN(LSP)	IMPT0249
WRITE(MWRITE,620)PEN(LSP)	IMPT0250
300 CONTINUE	IMPT0251
C REDUCE FRAGMENT POSITION TO PRE-IMPACT VALUE	IMPT0252
XF=XF-DELF(1)	IMPT0253
YF=YF-DELF(2)	IMPT0254
ZF=ZF-DELF(3)	IMPT0255
C REDUCE NODAL COORDS. TO PRE-IMPACT VALUES	IMPT0256
DO 220 I=1,NNT	IMPT0257
NNI=(I-1)*NDPN	IMPT0258
XG(I)=XG(I)-DELD(NNI+1)	IMPT0259


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      YG(I)=YG(I)-DELD(NNI+2)
220  ZG(I)=ZG(I)-DELD(NNI+3)
600  FORMAT('0',10X,'IMPACT CYCLE=',I10,2X,'ELEMENT=',I5,2X,'SUBREGION
      2=',I3)
610  FORMAT(' ',10X,'GLOBAL IMPACT LOCATION (XN,YN,ZN)=' ,3D15.7)
620  FORMAT(' ',10X,'PENETRATION DISTANCE(IN.)=' ,D15.7)
640  FORMAT('0','***** USER ESTIMATE OF NUMBER OF IMPACT-AFFECTED NODES
      1 TOO SMALL AT CYCLE NUMBER',I7)
650  FORMAT(' ',5X,'USER ESTIMATE (PARAMETER NIAN IN DUMMY MAIN PROGRAM
      1)=' ,I5)
660  FORMAT(' ',5X,'ACTUAL NUMBER OF IMPACT AFFECTED NODES=' ,I7)
670  FORMAT(' ',5X,'RUN HAS BEEN TERMINATED')
700  FORMAT('0',10X,'IMPACT CYCLE=' ,I10)
710  FORMAT('0',10X,'SUBREGIONS PENETRATED:' ,BI4)
720  FORMAT('0',10X,'POINT OF EFFECTIVE IMPACT(XA,YA,ZA)=' ,3D15.7)
730  FORMAT('0','** TEMPORARY UPDATE OF EFFECTIVE LENGTH AT CYCLE'
      2,I5)
740  FORMAT(' ', 'EFFECTIVE LENGTH=' ,D15.7)
      RETURN
      END

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IMPT0260
IMPT0261
IMPT0262
IMPT0263
IMPT0264
IMPT0265
IMPT0266
IMPT0267
IMPT0268
IMPT0269
IMPT0270
IMPT0271
IMPT0272
IMPT0273
IMPT0274
IMPT0275
IMPT0276
IMPT0277
IMPT0278
IMPT0279

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SUBROUTINE IMPDS(XG,YG,ZG,DELD,VEL,NP,VN,VNB,PMASS,NBC,S1,NEFF,
1ALPHA,IMPCT1,NIAN)
IMPLICIT REAL*8(A-H,O-Z)
C
C ASRL TR 154-14.... ORIGINAL REPORT VERSION OF PROGRAM
C COPYRIGHT (C) MASSACHUSETTS INSTITUTE OF TECHNOLOGY 1980
C THIS SUBROUTINE IS USED EXCLUSIVELY BY THE CIVM PLATE PROGRAM.
C
C DIMENSION XG(1),YG(1),ZG(1),DELD(1),VEL(1),NP(4,1),LNC(4),PEN(8),
2XN(8),YN(8),ZN(8),T(3,3),S1(1),NEFF(1),ALPHA(1),VN(3,1),VNB(3,1),
3OMEGFB(3),VFB(3),PMASS(1),PTILDA(3),NBC(1)
COMMON/PLATE/XD,YD,THP,HXL,HYL,NEAD,NECD,DENSP,EPAN,ANUP,THALF
COMMON/BAS/NDT,NET,MN,NB,NIRREG,MNC
COMMON/TIM/DELTAT,TIMEF,TIME,ITIMEF,INCRT,IOUT,ITIME
COMMON /PROP/ COEFR,FRNC,USEF,NSYM,IPSS,IUSEF
COMMON/FRAG/XF,YF,ZF,DELF(3),VF(3),DTHETF(3),OMEGF(3),RF,FMASS,
2FMDI,FKED,FKEC
COMMON /INOUT/ MREAD,MWRITE,MPUNCH
C
C CONTROLLING ROUTINE FOR COLLISION/IMPACT INTERACTIONS
C ANALYSIS INCLUDING FRICTION, ASSUMING DOUBLE-SYMMETRY
C OPTION IS EXERCISED.
C IMPACT CAN OCCUR ONLY WITH ELEMENT NUMBER ONE (IMPACT IS
C ASSUMED TO BE CENTERED AT GLOBAL NODE NUMBER 1).
C
C UPDATE NODAL GLOBAL COORDINATES TO TRIAL VALUES.
C
C IMPCT1=0
C NDPN=6
C NNT=NDT/6
C DO 1 I=1,NNT
C NNI=(I-1)*NDPN
C XG(I)=XG(I)+DELD(NNI+1)
C YG(I)=YG(I)+DELD(NNI+2)
C 1 ZG(I)=ZG(I)+DELD(NNI+3)
C
C UPDATE FRAGMENT POSITIONS IN Z-DIRECTION.
C
C DELF(3)=VF(3)*DELTAT
C ZF=ZF+DELF(3)
C
C CHECK FOR PENETRATION IN EACH TRIANGULAR SUBREGION OF ELEM. #1.
C
C DO 50 NSR=1,2
C NNSR=NSR
C NN1=NP(1,1)
C NN2=NP(NSR+1,1)
C NN3=NP(NSR+2,1)
C 50 CALL COLL5N(1,XG,YG,ZG,PEN,RF,THALF,NNSR,XF,YF,ZF,XN,YN,
1ZN,T,NN1,NN2,NN3)
C
C SEARCH FOR MAXIMUM PENETRATION
C
C PENM=0.0E0
C IF (PEN(1).GT.0.0) LSP=1
C IF (PEN(1).GT.0.0) PENM=PEN(1)
C IF (PEN(2).GT.PENM) LSP=2
C IF (PEN(2).GT.PENM) PENM=PEN(2)
C
C SKIP OUT IF NO PENETRATION.
C
C IF(PENM.EQ.0.000) GO TO 300

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C		IMDS0063
C	CALCULATE RADIUS OF REGION OF INFLUENCE, EFLN.	IMDS0064
C		IMDS0065
	EFLN=DSQRT(EPAN/DENSP)*DELTA	IMDS0066
	IF(IUSEF.EQ.1) EFLN=USEF	IMDS0067
C		IMDS0068
C	IMPACT IS ASSUMED CENTERED AT X=0, Y=0.	IMDS0069
C	DETERMINE WHICH NODES FALL IN THIS REGION.	IMDS0070
C		IMDS0071
	65 CONTINUE	IMDS0072
	NK=0	IMDS0073
	DO 70 I=1,NNT	IMDS0074
	DIST=DSQRT(XG(I)*XG(I)+YG(I)*YG(I)+(ZG(1)-ZG(I))**2)	IMDS0075
	IF (DIST.GT.EFLN) GO TO 70	IMDS0076
	NK=NK+1	IMDS0077
	S1(NK)=DIST	IMDS0078
	NEFF(NK)=1	IMDS0079
	ALPHA(NK)=1.000-DIST/EFLN	IMDS0080
	70 CONTINUE	IMDS0081
C		IMDS0082
C	IF USER ESTIMATES OF NK IS TOO SMALL, TERMINATE PROGRAM.	IMDS0083
C		IMDS0084
	IF (NIAN.GE.NK) GO TO 73	IMDS0085
	WRITE(MWRITE,640) ITIME	IMDS0086
	WRITE(MWRITE,650) NIAN	IMDS0087
	WRITE(MWRITE,660) NK	IMDS0088
	WRITE(MWRITE,670)	IMDS0089
	CALL EXIT	IMDS0090
	73 CONTINUE	IMDS0091
C	TEMPORARY UPDATE OF EFLN IF NK=0.	IMDS0092
	IF(NK GT 0) GO TO 74	IMDS0093
	NN3=NP(LNMP,3)	IMDS0094
	NN1=NP(LNMP,1)	IMDS0095
	EFLN=DSQRT((XG(NN3)-XG(NN1))**2+(YG(NN3)-YG(NN1))**2	IMDS0096
	+((ZG(NN3)-ZG(NN1))**2)	IMDS0097
206	WRITE(MWRITE,730) ITIME	IMDS0098
	WRITE(MWRITE,740) EFLN	IMDS0099
	GO TO 65	IMDS0100
	74 CONTINUE	IMDS0101
		IMDS0102
C		IMDS0103
C	CALCULATE ALPHAS FOR WHOLE PLATE.	IMDS0104
C		IMDS0105
	NEAD1=NEAD+1	IMDS0106
	NECD1=NECD+1	IMDS0107
	DO 75 I=1,NK	IMDS0108
	NN=NEFF(I)	IMDS0109
	IF (NN EQ 1) GO TO 75	IMDS0110
	NROW=(NN-1)/NEAD1	IMDS0111
	IF (NROW EQ 0) ALPHA(I)=2.000*ALPHA(I)	IMDS0112
	NCOLM=NN-NROW*NEAD1-1	IMDS0113
	IF (NCOLM EQ 0) ALPHA(I)=2.000*ALPHA(I)	IMDS0114
	IF (NROW GT 0.AND.NCOLM.GT.0) ALPHA(I)=4.000*ALPHA(I)	IMDS0115
	75 CONTINUE	IMDS0116
	CONST=0.000	IMDS0117
	DO 80 I=1,NK	IMDS0118
	80 CONST=CONST+ALPHA(I)	IMDS0119
	CONST=1.000/CONST	IMDS0120
	DO 90 I=1,NK	IMDS0121
	90 ALPHA(I)=ALPHA(I)*CONST	IMDS0122
C		IMDS0123
C	EXTRACT NODAL Z-DIRECTION VELOCITIES IN IMPACT-AFFECTED REGION.	IMDS0124
C		IMDS0125
	DO 100 I=1,NK	IMDS0126
	NNI=(NEFF(I)-1)*NDPN	IMDS0127
100	VN(3,I)=VEL(NNI+3)	IMDS0128
C		

C	CALCULATE INTERACTION CONSTANTS A0 AND B3.	IMDS0129
C	A0=VF(3)	IMDS0130
	B3=1.000/FMASS	IMDS0131
	DO 140 I=1,NK	IMDS0132
	A0=A0-ALPHA(I)*VN(3,I)	IMDS0133
	J=NEFF(I)	IMDS0134
	140 B3=B3+ALPHA(I)*ALPHA(I)/PMASS(J)	IMDS0135
C	IF (A0.LE.0.000) NO COLLISION CAN OCCUR.	IMDS0136
C	IF (A0 LE 0.000) GO TO 300	IMDS0137
C	SET IMPACT INDEX TO INDICATE IMPACT HAS OCCURED.	IMDS0138
C	IMPCT1=1	IMDS0139
C	CALCULATE Z-DIRECTION IMPULSE.	IMDS0140
C	PTILDA(3)=(1.000+COEFR)*A0/B3	IMDS0141
C	CALCULATE POST-IMPACT Z-DIRECTION VELOCITIES AT IMPACT	IMDS0142
C	AFFECTED NODES.	IMDS0143
C	DO 150 I=1,NK	IMDS0144
	J=NEFF(I)	IMDS0145
	NNI=(J-1)*NDPN	IMDS0146
	150 VEL(NNI+3)=VEL(NNI+3)+ALPHA(I)*PTILDA(3)/PMASS(J)	IMDS0147
C	CALCULATE POST-IMPACT Z-DIRECTION VELOCITY OF FRAGMENT.	IMDS0148
C	VF(3)=VF(3)-PTILDA(3)/FMASS	IMDS0149
C	PRINT MESSAGE.	IMDS0150
C	WRITE (MWRITE,600) ITIME,NSR	IMDS0151
	WRITE (MWRITE,610)XN(1),YN(1),ZN(1)	IMDS0152
	WRITE (MWRITE,620) PENM	IMDS0153
	WRITE (MWRITE,630)	IMDS0154
207	300 CONTINUE	IMDS0155
C	REDUCE FRAGMENT Z-POSITION TO PRE-IMPACT VALUE.	IMDS0156
C	ZF=ZF-DELF(3)	IMDS0157
C	REDUCE NODAL COORDINATES TO PRE-IMPACT VALUES.	IMDS0158
C	DO 220 I=1,NNT	IMDS0159
	NNI=(I-1)*NDPN	IMDS0160
	XG(I)=XG(I)-DELD(NNI+1)	IMDS0161
	YG(I)=YG(I)-DELD(NNI+2)	IMDS0162
	220 ZG(I)=ZG(I)-DELD(NNI+3)	IMDS0163
	600 FORMAT ('0',10X,'IMPACT IT=',I10,2X,'ELEMENT=1,	IMDS0164
	1 SUBREGION=',I3)	IMDS0165
	610 FORMAT (' ',10X,'GLOBAL IMPACT LOCATION (XN,YN,ZN)=' ,3D15.7)	IMDS0166
	620 FORMAT (' ',10X,'PENETRATION DISTANCE(IN.)=' ,D15.7)	IMDS0167
	630 FORMAT (' ',10X,'DOUBLE SYMMETRY OPTION IN EFFECT')	IMDS0168
	640 FORMAT ('0', '***** USER ESTIMATE OF NUMBER OF IMPACT-AFFECTED ',	IMDS0169
	1'NODES TOO SMALL AT CYCLE NUMBER ',I7)	IMDS0170
	650 FORMAT (' ', 5X,'USER ESTIMATE(PARAMETER NIAN IN DUMMY MAIN PROGRA	IMDS0171
	1M)=' ,I5)	IMDS0172
	660 FORMAT (' ',5X,'ACTUAL NUMBER OF IMPACT AFFECTED NODES = ',I7)	IMDS0173
	670 FORMAT (' ',5X,'RUN HAS BEEN TERMINATED')	IMDS0174
	730 FORMAT ('0', '*** TEMPORARY UPDATE OF EFFECTIVE LENGTH AT CYCLE'	IMDS0175
	2,I5)	IMDS0176
	740 FORMAT (' ', 'EFFECTIVE LENGTH=' ,D15.7)	IMDS0177
	RETURN	IMDS0178
	END	IMDS0179
		IMDS0180
		IMDS0181
		IMDS0182
		IMDS0183
		IMDS0184
		IMDS0185
		IMDS0186
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		IMDS0193
		IMDS0194

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SUBROUTINE IMPSS(XG,YG,ZG,DELD,VEL,NP,VN,VNB,PMASS,NBC,SI,NEFF, IMSS0000
1ALPHA,IMPCT1,NIAM) IMSS0001
IMPLICIT REAL*8(A-H,O-Z) IMSS0002
C IMSS0003
C ASRL TR 154-14. ... ORIGINAL REPORT VERSION OF PROGRAM IMSS0004
C COPYRIGHT (C) MASSACHUSETTS INSTITUTE OF TECHNOLOGY 1980 IMSS0005
C THIS SUBROUTINE IS USED EXCLUSIVELY BY THE CIVM PLATE PROGRAM. IMSS0006
C IMSS0007
C IMSS0008
DIMENSION XG(1),YG(1),ZG(1),DELD(1),VEL(1),NP(4,1),LNC(4),PEN(8), IMSS0009
2XN(8),YN(8),ZN(8),T(3,3),SI(1),NEFF(1),ALPHA(1),VN(3,1),VNB(3,1), IMSS0010
3OMEGFB(3),VFB(3),PMASS(1),PTILDA(3),NBC(1) IMSS0011
COMMON/PLATE/XD,YD,THP,HXL,HYL,NEAD,NECD,DENSP,EPAN,ANUP,TPALF IMSS0012

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COMMON/BAS/NDT,NET,MN,NB,NIRREG,MNC
COMMON/TIM/DELTAT,TIMEF,TIME,ITIMEF,INCRT,IOUT,ITIME
COMMON /PPOPC/ COEFP,FRNC,USEF,MSYM,IPSS,IUSEF
COMMON/FRAG/XF,YF,ZF,DELF(3),VF(3),DTHETF(3),OMEGF(3),RF,FMASS,
2FMOI,FKEO,FKEC
COMMON /INOUT/ MREAD,MWRITE,MPUNCH
C
C CONTROLLING ROUTINE FOR COLLISION INSPECTION/IMPACT INTERACTION
C ANALYSIS INCLUDING FRICTION, ASSUMING SINGLE-SYMMETRY OPTION IS
C EXERCISED. IMPACT CAN OCCUR ONLY ALONG PLATE SIDE NUMBER 1 IF
C IPSS=1, OR PLATE SIDE NUMBER 4 IF IPSS=4
C
C UPDATE NODAL GLOBAL COORDINATES TO TRIAL VALUES.
C
    IMPC(1)=0
    NEAD1=NEAD+1
    NECD1=NECD+1
    NOPN=6
    NNT=NDT/6
    DO 1 I=1,NNT
    NNI=(I-1)+NDPN
    XG(I)=XG(I)+DELD(NNI+1)
    YG(I)=YG(I)+DELD(NNI+2)
    1 ZG(I)=ZG(I)+DELD(NNI+3)
C
C UPDATE FRAGMENT POSITION.
C
    DO 7 I=1,3
    DTHETF(I)=OMEGF(I)*DELTAT
    7 DELF(I)=VF(I)*DELTAT
    XF=XF+DELF(1)
    YF=YF+DELF(2)
    ZF=ZF+DELF(3)
C
C DETERMINE WHICH ELEMENTS ARE TO BE CHECKED FOR POSSIBLE IMPACT.
C
    IF (IPSS.EQ 4) GO TO 14
C
C FOR CASE WHERE SIDE 1 (X-AXIS) IS LINE OF SYMMETRY,
C FIND MINIMUM DISTANCE SQUARED FROM FRAGMENT TO NODE.
C
    DMIN=1 OD10
    DO 10 I=1,NEAD1
    DIST=(XF-XG(I))**2+(YF-YG(I))**2+(ZF-ZG(I))**2
    IF (DIST.LT.DMIN) NC=I
    IF (DIST.LT.DMIN) DMIN=DIST
    10 CONTINUE
C
C DETERMINE ELEMENT NUMBERS CONNECTED TO NODE NC.
C
    NEC=0
    IF (NC.EQ.1) GO TO 12
    NEC=NEC+1
    LNC(NEC)=NC-1
    12 CONTINUE
    IF (NC.EQ.NEAD1) GO TO 20
    NEC=NEC+1
    LNC(NEC)=NC
    GO TO 20

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IMSS0070
IMSS0071

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C		IMSS0072
C	FOR CASE WHERE SIDE 4 (Y-AXIS) IS LINE OF SYMMETRY.	IMSS0073
C		IMSS0074
	14 CONTINUE	IMSS0075
	DMIN=1 OD10	IMSS0076
	DO 16 I=1,NNT,NEAD1	IMSS0077
	DIST=(XF-XG(I))*2+(YF-YG(I))*2+(ZF-ZG(I))*2	IMSS0078
	IF (DIST.LT.DMIN) NC=I	IMSS0079
	IF (DIST.LT.DMIN) DMIN=DIST	IMSS0080
	16 CONTINUE	IMSS0081
C		IMSS0082
C	DETERMINE ELEMENT NUMBERS CONNECTED TO NODE NC.	IMSS0083
C		IMSS0084
	NEC=0	IMSS0085
	NROW=(NC-1)/NEAD1+1	IMSS0086
	IF (NROW EQ.1) GO TO 18	IMSS0087
	NEC=NEC+1	IMSS0088
	LNC(NEC)=(NROW-2)*NEAD+1	IMSS0089
	18 CONTINUE	IMSS0090
	IF (NROW.EQ.NECD1) GO TO 20	IMSS0091
	NEC=NEC+1	IMSS0092
	LNC(NEC)=(NROW-1)*NEAD+1	IMSS0093
	20 CONTINUE	IMSS0094
C		IMSS0095
C	CHECK FOR PENETRATION IN EACH TRIANGULAR SUBREGION OF	IMSS0096
C	THE NEC ELEMENTS.	IMSS0097
C		IMSS0098
	DO 50 I=1,NEC	IMSS0099
	LNUM=LNC(I)	IMSS0100
	DO 50 NSR=1,2	IMSS0101
	NNSR=(I-1)*2+NSP	IMSS0102
	NN1=NP(1,LNUM)	IMSS0103
	NN2=NP(NSR+1,LNUM)	IMSS0104
	NN3=NP(NSR+2,LNUM)	IMSS0105
	50 CALL COLLN(1,XG,YG,ZG,PEN,RF,THALF,NNSR,XF,YF,ZF,XN,YN,ZN,T,NN1,	IMSS0106
	1NN2,NN3)	IMSS0107
C		IMSS0108
C	SEARCH FOR MAXIMUM PENETRATION.	IMSS0109
C		IMSS0110
	NEC2=NEC+2	IMSS0111
	PENM=0.0D0	IMSS0112
	DO 60 I=1,NEC2	IMSS0113
	IF (PEN(I) GT.PENM) LSP=I	IMSS0114
	IF (PEN(I).GT.PENM) PENM=PEN(I)	IMSS0115
	60 CONTINUE	IMSS0116
C		IMSS0117
C	SKIP OUT IF NO PENETRATION	IMSS0118
C		IMSS0119
	IF (PENM EQ.0 0) GO TO 300	IMSS0120
C		IMSS0121
C	CALCULATE RADIUS OF REGION OF INFLUENCE, EFLN	IMSS0122
C		IMSS0123
	EFLN=DSQRT(EPAN/DENSP)*DELTA	IMSS0124
	IF(IUSEF.EQ.1) EFLN=USEF	IMSS0125
C		IMSS0126
C	POINT OF CONTACT MUST FALL ON LINE OF SYMMETRY.	IMSS0127
C		IMSS0128
	IF (IPSS.EQ.1) YN(LSP)=0 0D0	IMSS0129
	IF (IPSS.EQ.4) XN(LSP)=0.0D0	IMSS0130

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C		IMSS0131
C	DETERMINE WHICH NODES FALL IN THIS REGION OF INFLUENCE.	IMSS0132
C		IMSS0133
	65 CONTINUE	IMSS0134
	NK=0	IMSS0135
	DO 70 I=1,NNT	IMSS0136
	DIST=DSQRT(((XN(LSP)-XG(I))**2+(YN(LSP)-YG(I))**2	IMSS0137
	1+(ZN(LSP)-ZG(I))**2)	IMSS0138
	IF (DIST GT.EFLN) GO TO 70	IMSS0139
	NK=NK+1	IMSS0140
	SI(NK)=DIST	IMSS0141
	NEFF(NK)=I	IMSS0142
	ALPHA(NK)=1.000-DIST/EFLN	IMSS0143
	70 CONTINUE	IMSS0144
C		IMSS0145
C	IF USER ESTIMATES OF NK IS TOO SMALL, TERMINATE PROGRAM.	IMSS0146
C		IMSS0147
	IF (NIAN.GE.NK) GO TO 73	IMSS0148
	WRITE(MWRITE,650) ITIME	IMSS0149
	WRITE(MWRITE,660) NIAN	IMSS0150
	WRITE(MWRITE,670) NK	IMSS0151
	WRITE(MWRITE,680)	IMSS0152
	CALL EXIT	IMSS0153
	73 CONTINUE	IMSS0154
C	TEMPORARY UPDATE OF EFLN IF NK=0.	IMSS0155
	IF(NK GT 0) GO TO 74	IMSS0156
	NN3=NP(LNMP,3)	IMSS0157
	NN1=NP(LNMP,1)	IMSS0158
	EFLN=DSQRT(((XG(NN3)-XG(NN1))**2+(YG(NN3)-YG(NN1))**2	IMSS0159
	2+(ZG(NN3)-ZG(NN1))**2)	IMSS0160
	WRITE(MWRITE,730) ITIME	IMSS0161
	WRITE(MWRITE,740) EFLN	IMSS0162
	GO TO 65	IMSS0163
211	74 CONTINUE	IMSS0164
C		IMSS0165
C	CALCULATE AND SCALE ALPHAS FOR PRESENT SINGLE SYMMETRY ANALYSIS.	IMSS0166
C		IMSS0167
	DO 75 I=1,NK	IMSS0168
	NN=NCF(I)	IMSS0169
	NROW=(NN-1)/NEAD1	IMSS0170
	NCOLM=NN-NROW*NEAD1-1	IMSS0171
	IF (IPSS EQ.1 AND.NROW.EQ.0) GO TO 75	IMSS0172
	IF (IPSS EQ.4 AND.NCOLM.EQ.0) GO TO 75	IMSS0173
	ALPHA(I)=2.0000*ALPHA(I)	IMSS0174
	75 CONTINUE	IMSS0175
	CONST=0.000	IMSS0176
	DO 80 I=1,NK	IMSS0177
	80 CONST=CONST+ALPHA(I)	IMSS0178
	CONST=1.000/CONST	IMSS0179
	DO 90 I=1,NK	IMSS0180
	90 ALPHA(I)=ALPHA(I)*CONST	IMSS0181
C		IMSS0182
C	ESTABLISH COORDINATE TRANSFORMATION MATRIX, T, IN	IMSS0183
C	FORM (XYZ-BAR)=T*(XYZ).	IMSS0184
C		IMSS0185
	DO 92 I=1,3	IMSS0186
	DO 92 J=1,3	IMSS0187
	92 T(I,J)=0.000	IMSS0188
	NN=(LSP+1)/2	IMSS0189

	LNMP=LNC(NN)	IMSS0190
	NSR=LSP-2+(NN-1)	IMSS0191
	IF (IPSS EQ 4) GO TO 94	IMSS0192
C		IMSS0193
C	TRANSFORMATION WHEN X-AXIS IS LINE OF SYMMETRY.	IMSS0194
C		IMSS0195
	NN1=NP(1, LNMP)	IMSS0196
	NN2=NP(2, LNMP)	IMSS0197
	ESL=DSQRT((XG(NN2)-XG(NN1))**2+(ZG(NN2)-ZG(NN1))**2)	IMSS0198
	SINB=(ZG(NN2)-ZG(NN1))/ESL	IMSS0199
	COSB=(XG(NN2)-XG(NN1))/ESL	IMSS0200
	T(1,1)=COSB	IMSS0201
	T(1,3)=SINB	IMSS0202
	T(2,2)=1.000	IMSS0203
	T(3,1)=-SINB	IMSS0204
	T(3,3)=COSB	IMSS0205
	CO TO 96	IMSS0206
	94 CONTINUE	IMSS0207
C		IMSS0208
C	TRANSFORMATION WHEN Y-AXIS IS LINE OF SYMMETRY.	IMSS0209
C		IMSS0210
	NN1=NP(1, LNMP)	IMSS0211
	NN2=NP(4, LNMP)	IMSS0212
	ESL=DSQRT((YG(NN2)-YG(NN1))**2+(ZG(NN2)-ZG(NN1))**2)	IMSS0213
	SINB=(ZG(NN2)-ZG(NN1))/ESL	IMSS0214
	COSB=(YG(NN2)-YG(NN1))/ESL	IMSS0215
	T(1,1)=1.000	IMSS0216
	T(2,2)=COSB	IMSS0217
	T(2,3)=SINB	IMSS0218
	T(3,2)=-SINB	IMSS0219
	T(3,3)=COSB	IMSS0220
	96 CONTINUE	IMSS0221
C		IMSS0222
C	EXTRACT NODAL VELOCITIES IN IMPACT-AFFECTED REGION.	IMSS0223
C		IMSS0224
	DO 100 I=1, NK	IMSS0225
	NNI=(NEFF(I)-1)*NDPN	IMSS0226
	DO 100 J=1, 3	IMSS0227
	K=NNI+J	IMSS0228
	100 VN(J, I)=VEL(K)	IMSS0229
C	TRANSFORM NODAL VELOCITIES INTO BAR SYSTEM.	IMSS0230
C		IMSS0231
	DO 110 I=1, NK	IMSS0232
	DO 110 J=1, 3	IMSS0233
	VNB(J, I)=0.000	IMSS0234
	DO 110 K=1, 3	IMSS0235
	110 VNB(J, I)=VNB(J, I)+T(J, K)*VN(K, I)	IMSS0236
C		IMSS0237
C	TRANSFORM FRAGMENT VELOCITIES INTO BAR SYSTEM	IMSS0238
C		IMSS0239
	DO 130 I=1, 3	IMSS0240
	OMEGFB(I)=0.000	IMSS0241
	VFB(I)=0.000	IMSS0242
	DO 130 K=1, 3	IMSS0243
	OMEGFB(I)=OMEGFB(I)+T(I, K)*OMEGF(K)	IMSS0244
	130 VFB(I)=VFB(I)+T(I, K)*VF(K)	IMSS0245
C		IMSS0246
C	CALCULATE IMPULSE INTERACTION CONSTANTS.	IMSS0247
C		IMSS0248

	S1=VFB(1)+RF*OMEGFB(2)	IMSS0249
	S2=VFB(2)-RF*OMEGFB(1)	IMSS0250
	A0=VFB(3)	IMSS0251
	B3=1.000/FMASS	IMSS0252
	DO 140 I=1,NK	IMSS0253
	S1=S1-ALPHA(I)*VNB(1,I)	IMSS0254
	S2=S2-ALPHA(I)*VNB(2,I)	IMSS0255
	A0=A0-ALPHA(I)*VNB(3,I)	IMSS0256
	J=NEFF(I)	IMSS0257
140	B3=B3+ALPHA(I)*ALPHA(I)/PMASS(J)	IMSS0258
	B1=B3+RF*RF/FMOI	IMSS0259
C		IMSS0260
C	IF A0 IS NON-POSITIVE, THEN NO COLLISIONS CAN OCCUR.	IMSS0261
C		IMSS0262
	IF (A0.LE.0.0) GO TO 300	IMSS0263
C		IMSS0264
C	SET IMPACT INDEX TO INDICATE THAT IMPACT HAS OCCURED.	IMSS0265
C		IMSS0266
	IMPCT1=1	IMSS0267
C		IMSS0268
C	MODIFY S1 OR S2 FOR SINGLE SYMMETRY IMPACT.	IMSS0269
C		IMSS0270
	IF (IPSS.EQ.1) S2=0.000	IMSS0271
	IF (IPSS.EQ.4) S1=0.000	IMSS0272
C		IMSS0273
C	CALCULATE POST-IMPACT MOMENTUM COORDINATES IN BAR SYSTEM.	IMSS0274
C		IMSS0275
	CALL INTRAC(S1,S2,A0,B1,B3,COEFR,FRNC,PTILDA)	IMSS0276
C		IMSS0277
C	CALCULATE POST-IMPACT VELOCITY DIFFERENCE OF NODES AND FRAGMENT	IMSS0278
C	IN BAR SYSTEM (I.E. V-PRIME MINUS V).	IMSS0279
	DO 180 I=1,NK	IMSS0280
	K=NEFF(I)	IMSS0281
	AM=PMASS(K)	IMSS0282
	DO 180 J=1,3	IMSS0283
180	VNB(J,I)=ALPHA(I)*PTILDA(J)/AM	IMSS0284
	DO 190 I=1,3	IMSS0285
190	VFB(I)=-PTILDA(I)/FMASS	IMSS0286
	OMEGFB(1)=PTILDA(2)*RF/FMOI	IMSS0287
	OMEGFB(2)=-PTILDA(1)*RF/FMOI	IMSS0288
	OMEGFB(3)=0.00	IMSS0289
C	TRANSFORM POST-IMPACT NODAL VELOCITY DIFFERENCE BACK TO XYZ SYSTEM.	IMSS0290
C		IMSS0291
	DO 200 I=1,NK	IMSS0292
	DO 200 J=1,3	IMSS0293
	VN(J,I)=0.000	IMSS0294
	DO 200 K=1,3	IMSS0295
200	VN(J,I)=VN(J,I)+T(K,J)*VNB(K,I)	IMSS0296
C		IMSS0297
C	TRANSFORM POST-IMPACT VELOCITY DIFFERENCE OF FRAGMENT TO GLOBAL	IMSS0298
C	SYSTEM AND ADD TO PRE-IMPACT VELOCITIES TO GET POST-IMPACT	IMSS0299
C	FRAGMENT VELOCITIES.	IMSS0300
C		IMSS0301
	DO 210 I=1,3	IMSS0302
	DO 210 K=1,3	IMSS0303
	OMEGF(I)=OMEGF(I)+T(K,I)*OMEGFB(K)	IMSS0304
210	VF(I)=VF(I)+T(K,I)*VFB(K)	IMSS0305
C		IMSS0306
C	UPDATE NODAL VELOCITIES TO POST-IMPACT VALUES.	IMSS0307

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C          DO 230 I=1,NK
          NNI=(NEFF(I)-1)*NDPN
          DO 230 J=1,3
          K=NNI+J
230      VEL(K)=VEL(K)+VN(J,I)
C      CONSTRAIN VELOCITY
C
C          CALL RCON(VEL,NBC)
C
C      PRINT MESSAGES.
C
C          WRITE(MWRITE,600)ITIME, LNMP,NSR
          WRITE(MWRITE,610)XN(LSP),YN(LSP),ZN(LSP)
          WRITE(MWRITE,620)PEN(LSP)
          IF (IPSS.EQ.1) WRITE(MWRITE,630)
          IF (IPSS.EQ.4) WRITE(MWRITE,640)
300      CONTINUE
C
C      REDUCE FRAGMENT POSITION TO PRE-IMPACT VALUE.
C
C          XF=XF-DELF(1)
          YF=YF-DELF(2)
          ZF=ZF-DELF(3)
C
C      REDUCE NODAL COORDINATES TO PRE-IMPACT VALUES.
C
C          DO 220 I=1,NNT
          NNI=(I-1)*NDPN
          XG(I)=XG(I)-DELD(NNI+1)
          YG(I)=YG(I)-DELD(NNI+2)
220      ZG(I)=ZG(I)-DELD(NNI+3)
214 600      FORMAT('0',10X,'IMPACT IT=',I10,2X,'ELEMENT=',I5,2X,'SUBREGION=',
          1I3)
          610 FORMAT(' ',10X,'GLOBAL IMPACT LOCATION(XN,YN,ZN)=' ,3D15.7)
          620 FORMAT(' ',10X,'PENETRATION DISTANCE(IN.)=' ,D15.7)
          630 FORMAT(' ',10X,'SINGLE SYMMETRY OPTION IN EFFECT ALONG X-AXIS')
          640 FORMAT(' ',10X,'SINGLE SYMMETRY OPTION IN EFFECT ALONG Y-AXIS')
          650 FORMAT('0', '***** USER ESTIMATE OF NUMBER OF IMPACT-AFFECTED ',
          1'NODES TOO SMALL AT CYCLE NUMBER ',I7)
          660 FORMAT(' ', 5X,'USER ESTIMATE(PARAMETER NIAN IN DUMMY MAIN PROGRA
          1M)= ',I5)
          670 FORMAT(' ',5X,'ACTUAL NUMBER OF IMPACT AFFECTED NODES - ',I7)
          680 FORMAT(' ',5X,'RUN HAS BEEN TERMINATED')
          730 FORMAT('0', '** TEMPORARY UPDATE OF EFFECTIVE LENGTH AT CYCLE'
          2,I5)
          740 FORMAT(' ', 'EFFECTIVE LENGTH=' ,D15.7)
          RETURN
          END
          SUBROUTINE INTRAC(S1,S2,A0,B1,B3,COEFR,FRNC,PTILDA)
          IMPLICIT REAL*8(A-H,O-Z)
C
C      ASRL TR 154-14 . . . ORIGINAL REPORT VERSION OF PROGRAM
C      COPYRIGHT (C) MASSACHUSETTS INSTITUTE OF TECHNOLOGY 1980
C
C      THIS SUBROUTINE IS USED EXCLUSIVELY BY THE CIVM PLATE PROGRAM.
C
C          DIMENSION PTILDA(3)
C
C

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IMSS0308
IMSS0309
INTC0001
IMSS0311
IMSS0312
IMSS0313
IMSS0314
IMSS0315
IMSS0316
IMSS0317
IMSS0318
IMSS0319
IMSS0320
IMSS0321
IMSS0322
IMSS0323
IMSS0324
IMSS0325
IMSS0326
IMSS0327
IMSS0328
IMSS0329
IMSS0330
IMSS0331
IMSS0332
IMSS0333
IMSS0334
IMSS0335
IMSS0336
IMSS0337
IMSS0338
IMSS0339
IMSS0340
IMSS0341
IMSS0342
IMSS0343
IMSS0344
IMSS0345
IMSS0346
IMSS0347
IMSS0348
IMSS0349
IMSS0350
IMSS0351
IMSS0352
IMSS0353
IMSS0354
IMSS0355
IMSS0356
INTC0000
INTC0001
INTC0002
INTC0003
INTC0004
INTC0005
INTC0006
INTC0007
INTC0008
INTC0009

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C	THIS SUBROUTINE CALCULATES THE POST-IMPACT MOMENTUM COORDINATES	INTC0010
C	IN 3-D MOMENTUM SPACE A GRAPHICAL SOLUTION TECHNIQUE WAS USED TO	INTC0011
C	DETERMINE THE ANALYTIC EXPRESSIONS USED IN THIS ROUTINE. THE	INTC0012
C	PARAMETERS S1, S2, AND B1 DEFINE THE LINE OF NO SLIDING, AND A0	INTC0013
C	AND B3 DEFINE THE PLANE OF MAXIMUM APPROACH. COEFR IS THE	INTC0014
C	COEFFICIENT OF RESTITUTION AND FRNC IS THE COEFFICIENT OF FRICTION	INTC0015
C	BETWEEN THE CONTACTING SURFACES. PTILDA(I) IS THE VECTOR OF	INTC0016
C	POST-IMPACT MOMENTUM COORDINATES (OUTPUT) IN THE X-BAR, Y-BAR,	INTC0017
C	AND Z-BAR (NORMAL) DIRECTIONS RESPECTIVELY.	INTC0018
C		INTC0019
C	CALC. TANL=TANGENT(LAMBDA)	INTC0020
	CONST1=DSQRT(S1*S1+S2*S2)	INTC0021
	TANL=B3*CONST1/(A0*B1)	INTC0022
C	CONSIDER PERFECTLY SMOOTH CONTACT SURFACES	INTC0023
	IF(FRNC.GT 0.0)GO TO 10	INTC0024
	PTILDA(1)=0.000	INTC0025
	PTILDA(2)=0.000	INTC0026
	PTILDA(3)=(1.000+COEFR)*A0/B3	INTC0027
	RETURN	INTC0028
10	CONTINUE	INTC0029
	IF(FRNC.GE.TANL)GO TO 20	INTC0030
C	CASE WHERE FRNC LESS THAN TANL	INTC0031
	COSTB=S1/CONST1	INTC0032
	SINTB=S2/CONST1	INTC0033
	PN1=A0/B3	INTC0034
	PTILDA(1)=COSTB*FRNC*(1.000+COEFR)*PN1	INTC0035
	PTILDA(2)=SINTB*FRNC*(1.000+COEFR)*PN1	INTC0036
	PTILDA(3)=(1.000+COEFR)*PN1	INTC0037
	RETURN	INTC0038
20	CONTINUE	INTC0039
C	CASE WHERE FRNC GREATER THAN OR EQUAL TO TANL	INTC0040
215	ALSO CASE OF PERFECTLY ROUGH CONTACT SURFACES	INTC0041
	PTILDA(3)=(1.000+COEFR)*A0/B3	INTC0042
	PTILDA(1)=S1/B1	INTC0043
	PTILDA(2)=S2/B1	INTC0044
	RETURN	INTC0045
	END	INTC0046

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SUBROUTINE IMAINP(DELD,DIS,DISP,DISM1,DISM2,FLN,FLVA,FLVM,FLVP, IMNP0000
2VEL,ICOL,INUM,KROW,NDEX, STF,AMASS,NP,NODE,TAUSS,TAUSE,TAUEE, IMNP0001
3EPSI,EPSSO,EPEEI,EPEEO,EPSEI,EPSEO,NBC,BC,RFM,ILAST,UCF1,UCF2, IMNP0002
4XG,YG,ZG,XGI,YGI,TAGSS,LNXS,XSPROP,MATXS,TSGEE,LNYS,YSROP,MATYS, IMNP0003
5LNRS,ISRS,SC,MAXEL,MNSL,MNSLT4,NBE,MBWE,MNXST,MNYST,NVSA,NCON, IMNP0004
6PMASS,VN,VNB,SI,NEFF,ALPHA,NIAN) IMNP0005
IMPLICIT REAL*8(A-H,O-Z) IMNP0006
C IMNP0007
C ASRL TR 154-14 ..... ORIGINAL REPORT VERSION OF PROGRAM IMNP0008
C COPYRIGHT (C) MASSACHUSETTS INSTITUTE OF TECHNOLOGY 1980 IMNP0009
C IMNP0010
C THIS SUBROUTINE IS USED EXCLUSIVELY BY THE CIVM PLATE PROGRAM. IMNP0011
C IMNP0012
C SMALL STRAIN FORMULATION VERSION WRITTEN BY R. L. SPILKER IMNP0013
C IMNP0014
DIMENSION DELD(1),DIS(1),DISP(1),DISM1(1),DISM2(1),FLN(1),FLVA(1), IMNP0015
2FLVM(1),FLVP(1), VEL(1),ICOL(1),INUM(1),KROW(1),NDEX(1), IMNP0016
3 STF(1),AMASS(1),NP(4,1),NODE(1),TAUSS(MAXEL,MNSLT4,9), IMNP0017
4TAUSE(MAXEL,MNSLT4,9),TAUEE(MAXEL,MNSLT4,9),EPSI(9,1),EPSSO(9,1) IMNP0018
5,EPEEI(9,1),EPEEO(9,1),EPSEI(9,1),EPSEO(9,1),NBC(1),BC(1),RFM(NBE, IMNP0019
6MBWE),ILAST(1),UCF1(1),UCF2(1),XG(1),YG(1),ZG(1),XGI(1),YGI(1), IMNP0020
7TAGSS(MNXST,MNSLT4,3),LNXS(1),XSPROP(7,1),MATXS(1),TSGEE(MNYST, IMNP0021
8MNSLT4,3),LNYS(1),YSROP(7,1),MATYS(1),LNRS(1),ISRS(1),SC(5,1) IMNP0022
9,NVSA(1),NCON(4,1),PMASS(1),VN(3,1),VNB(3,1),SI(1),NEFF(1), IMNP0023
1ALPHA(1) IMNP0024
C IMNP0025
C THE FOLLOWING DIMENSION STATEMENTS ARE FIXED FOR ALL COMPUTER RUNS. IMNP0026
DIMENSION SIG(5),EPS(5),DSR(5),PSR(5),ES(6),SUBW(5.5),SNO(5.5), IMNP0027
2NMSUB(5),EK(24,24),GBI(24,24),EML(24),STDE(9,24),SS(5) IMNP0028
DATA GBI/1 0,-1 0,-1 0,1 0,24*0.0,1.0,-1 0,-1 0,1 0,24*0.0,1.0, IMNP0029
23*0.0,-3 0,-3.0,2*0 0,9 0,2 0,2 0,2*0 0,-6.0,-6.0,4 0,9*0 0,1 0, IMNP0030
32*0 0,-2 0,2*0 0,-3 0,6 0,1 0,2*0 0,2 0,-3 0,-4 0,2 0,10*0.0,1.0, IMNP0031
42*0.0,-2 0,-3 0,0 0,6 0,0 0,1 0,2 0,0 0,-4.0,-3.0,2.0,11*0.0,1.0, IMNP0032
52*0 0,-2 0,-2 0,4 0,2*0 0,2*1 0,-2 0,-2.0,1 0,0.0,1 0,0 0,-1.0, IMNP0033
C25*0 0,1 0,0.0,-1 0, IMNP0034
628*0 0,3 0,3*0 0,-9 0,-2 0,3*0.0,6.0,6 0,-4.0,12*0 0,-1 0,3*0 0, IMNP0035
73 0,1 0,3*0.0,-3.0,-2 0,2 0,14*0.0,3 0,0 0,-6 0,2*0.0,-2 0,0.0, IMNP0036
84 0,3.0,-2 0,14*0 0,-1 0,0,2.0,2*0 0,1 0,0 0,-2 0,-1.0,1 0,3*0.0 IMNP0037
9,1 0,27*0 0,1.0,32*0.0,9.0,4*0.0,-6 0,-6 0,4 0,16*0.0,-3 0,4*0.0, IMNP0038
A3 0,2 0,-2 0,16*0 0,-3.0,4*0 0,2.0,3 0,-2 0,16*0 0,1 0,4*0 0,-1.0, IMNP0039
B-1 0,1 0,2*0 0,1 0,-1 0,26*0 0,1 0,-1 0,29*0 0,3 0,2*0.0,-9.0,0.0, IMNP0040
C-2 0,2*0 0,6.0,6 0,-4 0,15*0 0,3 0,-6 0,3*0 0,-2.0,3.0, IMNP0041
D4 0,-2 0,13*0 0,-1.0,2*0 0,3 0,0.0,1.0,2*0.0,-2 0,-3.0,2.0,15*0.0, IMNP0042
E-1 0,2 0,3*0 0,1 0,-1 0,-2 0,1 0/ IMNP0043
COMMON/PLATE/XDIST,YDIST,TH ,HXL,HYL,NEAD,NECD,DENSP,EPAN,ANUP, IMNP0044
2THALF IMNP0045
COMMON/BAS/NDT,NET,MN,NB,NIRREG,MNC IMNP0046
COMMON/TIM/DELTA,TIMEF,TIME,ITIMEF,INCRT,IOUT,ITIME IMNP0047
COMMON/PRNT/IOP1,IOP2,IOP3,IOP4,IOP5,IOP6,IOP7,IOP8 IMNP0048
COMMON/FRAG/XF,YF,ZF,DELTF(3),VTF(3),DTHETF(3),OMEGF(3),RF,FMASS, IMNP0049
2FMOI,FKEO,FKEC IMNP0050
COMMON /PROPC/ COEFR,FRNC,USEF,NSYM,IPSS,IUSEF IMNP0051
COMMON /INOUT/ MREAD,MWRITE,MPUNCH IMNP0052
COMMON /MASS/ IMASS IMNP0053
C CIVM-PLATE 1 COMPUTER CODE IMNP0054
C CONTROLLING ROUTINE FOR ELASTIC-PLASTIC, LARGE DEFLECTION TRANSIENT IMNP0055
C ANALYSIS OF STIFFENED AND/OR UNSTIFFENED FLAT PLATES SUBJECTED TO IMNP0056
C IMPACT BY A SINGLE FRAGMENT. IMNP0057
C IMNP0058
IPASS=1 IMNP0059
IMASS=1 IMNP0060
NDPE=24 IMNP0061
READ(MREAD,500)IMESH,IMCONT,IPUNCH IMNP0062

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C
C MESH GENERATION
  IF(IMESH.EQ.0.OR.IMESH.EQ.1)CALL MESHPA(NP,NODE,XG,YG,ZG,NBC,BC,
  2LNXS,LNYS,XGI,YGI,XSPROP,YSPROP,NXST,NYST,IMESH,MATXS,MATYS)
  IF(IMESH.EQ.2)CALL MESHPM(NP,NODE,XG,YG,ZG,NBC,BC,LNXS,LNYS,XGI,
  2YGI,XSPROP,YSPROP,NXST,NYST,IMESH,MATXS,MATYS)
C
C SETUP OF STORAGE
  CALL ARRT(STF,AMASS,FLVA,ICOL,INUM,KROW,NDEX,NODE,NDPE)
C
C STRESS-STRAIN INFORMATION FOR EACH MATERIAL.
C NOTE-- PLATE MATERIAL IS ASSUMED TO CORRESPOND TO FIRST MATERIAL.
  NA=3
  NZ=4
  READ(MREAD,500)NMAT
  WRITE(MWRITE,600)
  CON1=2.00*(1.00+ANUP)/3.00
  CON2=2.00*(0.500-ANUP)/3.00
  DO 60 I=1,NMAT
  READ(MREAD,500)NSUB
  READ(MREAD,510)(SIG(J),J=1,NSUB)
  READ(MREAD,510)(EPS(J),J=1,NSUB)
  READ(MREAD,510)DSR(I),PSR(I)
  ES(1)=SIG(1)/EPS(1)
C DEFINE VALUE OF YOUNGS MODULUS BASED ON EPS(1) AND SIG(1) .
  IF(I.EQ.1)EPAN=ES(1)
  IF(NSUB-1)30,30,10
10 DO 20 LS=2,NSUB
20 ES(LS)=(SIG(LS)-SIG(LS-1))/(EPS(LS)-EPS(LS-1))
30 ES(NSUB+1)=0.0
  CON3=ES(1)*(0.500-ANUP)/(1.000+ANUP)
  A1=0.000
  ASUM=0.000
  E1=0.000
  ESUM=0.000
  DO 40 LS=1,NSUB
  ASUM=ASUM+A1
  A1=1.00-CON1*ES(LS+1)/(ES(1)-CON2*ES(LS+1))-ASUM
  SUBW(1,LS)=A1
  ESUM=ESUM+E1
  IF(LS.NE.NSUB)E1=(1.00-ES(LS+1)/ES(1))*(EPS(LS+1)-EPS(LS))
  SNO(I,LS)=ES(1)*EPS(LS)+CON3*ESUM
40 CONTINUE
  NMSUB(1)=NSUB
  WRITE(MWRITE,610) I
  WRITE(MWRITE,615)
  DO 50 J=1,NSUB
50 WRITE(MWRITE,620)J,SIG(J),EPS(J),SNO(1,J),SUBW(1,J)
  WRITE(MWRITE,630)DSR(I),PSR(I)
60 CONTINUE
500 FORMAT(20I4)
510 FORMAT(5D16.7)
600 FORMAT('0','PROPERTIES FOR USER-SPECIFIED MATERIALS')
610 FORMAT('0','PROPERTIES FOR MATERIAL NUMBER',I3)
615 FORMAT(' ','SUBLAYER',5X,'STRESS POINT',5X,'STRAIN POINT',5X,
  2'YIELD STRESS',2X,'WEIGHTING FACTOR')
620 FORMAT(' ',15,4X,D16.7,1X,D16.7,1X,D16.7,1X,D16.7)
630 FORMAT(' ','STRAIN RATE PARAMETERS: D=',D16.7,2X,'P=',D16.7)
C TIME-STEP INFORMATION
  READ(MREAD,500)ITIMEF,INCR,IOUT
  READ(MREAD,510)DELTAT,TIMEF
  WRITE(MWRITE,640)
  WRITE(MWRITE,650)DELTAT
  WRITE(MWRITE,660)TIMEF,ITIMEF
  WRITE(MWRITE,670)INCR
640 FORMAT('0','TIMewise SOLUTION PARAMETERS')

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IMNP0063
IMNP0064
IMNP0065
IMNP0066
IMNP0067
IMNP0068
IMNP0069
IMNP0070
IMNP0071
IMNP0072
IMNP0073
IMNP0074
IMNP0075
IMNP0076
IMNP0077
IMNP0078
IMNP0079
IMNP0080
IMNP0081
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IMNP0111
IMNP0112
IMNP0113
IMNP0114
IMNP0115
IMNP0116
IMNP0117
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IMNP0119
IMNP0120
IMNP0121
IMNP0122
IMNP0123
IMNP0124
IMNP0125
IMNP0126
IMNP0127
IMNP0128

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650 FORMAT(' ','TIME-STEP SIZE=',D16.7,2X,'SEC.') IMNPO129
660 FORMAT(' ','RUN WILL TERMINATE AT TIME =',D16.7,2X,'SEC. OR AT CYC IMNPO130
    2LE NUMBER',1B) IMNPO131
670 FORMAT(' ','REGULAR PRINTOUT WILL BE GIVEN EVERY',15,2X,'CYCLES') IMNPO132
C IMNPO133
C ESTABLISH PRINT OPTIONS IMNPO134
    CALL PRTOP(NNSA,NVSA,NCON,NP) IMNPO135
    IF(MN .GT. MNC) WRITE(MWRITE,675) MN,MNC IMNPO136
675 FORMAT(1H0,10(1H*),'ASSEMBLED K REQUIRES',17,' ENTRIES.USER HAS DI IMNPO137
    *MENTIONED FOR ONLY',17,'. CALL EXIT.') IMNPO138
    IF(MN GT MNC)CALL EXIT IMNPO139
C IMNPO140
C INITIALIZATION IMNPO141
    NZSUBL=NZ*MNSL IMNPO142
    NASQ=NA*NA IMNPO143
    DO 200 I=1,9 IMNPO144
    DO 200 J=1,NET IMNPO145
    EPSSI(I,J)=0.0 IMNPO146
    EPSSO(I,J)=0.0 IMNPO147
    EPEEI(I,J)=0.0 IMNPO148
    EPEEO(I,J)=0 0 IMNPO149
    EPSEI(I,J)=0.0 IMNPO150
200 EPSEO(I,J)=0 0 IMNPO151
    DO 201 I=1,NET IMNPO152
    DO 201 JZ=1,NZSUBL IMNPO153
    DO 201 JA=1,NASQ IMNPO154
    TAUSS(I,JZ,JA)=0.0 IMNPO155
    TAUEE(I,JZ,JA)=0.0 IMNPO156
201 TAUSE(I,JZ,JA)=0 0 IMNPO157
C IMNPO158
    DO 301 I=1,MNYST IMNPO159
    DO 301 JZ=1,NZSUBL IMNPO160
    DO 301 JA=1,NA IMNPO161
301 TSGEE(I,JZ,JA)=0.0 IMNPO162
C IMNPO163
    DO 303 I=1,MNXST IMNPO164
    DO 303 JZ=1,NZSUBL IMNPO165
    DO 303 JA=1,NA IMNPO166
303 TAGSS(I,JZ,JA)=0.0 IMNPO167
C IMNPO168
    PLASTW=0.0 IMNPO169
    TIME=0.0 IMNPO170
    ITIME=0 IMNPO171
C IMNPO172
C FORMATION AND ASSEMBLY OF STIFFNESS AND MASS MATRICES IMNPO173
C FOR PLATE ELEMENTS IMNPO174
304 NTYPE=1 IMNPO175
    DO 220 LNUM=1,NET IMNPO176
    NN1=NP(1,LNUM) IMNPO177
    NN2=NP(2,LNUM) IMNPO178
    NN4=NP(4,LNUM) IMNPO179
    XL=XGI(NN2)-XGI(NN1) IMNPO180
    YL=YGI(NN1)-YGI(NN1) IMNPO181
    CALL RPLATE(NTYPE,ANUP,XL,YL,TH,0 DO,0.DO,0.DO,0.DO,EK,GBI,EPAN) IMNPO182
    CALL ASSENK(EK,STF,INUM,NDPE,NODE,LNUM) IMNPO183
    CALL LMASSP(NTYPE,XL,YL,TH,SL,CSA,SMOI,EML,DENSP) IMNPO184
    LL=(LNUM-1)*NDPE IMNPO185
    DO 210 I=1,24 IMNPO186
    NN=NODE(LL+I) IMNPO187
210 AMASS(NN)=AMASS(NN)+EML(I) IMNPO188
220 CONTINUE IMNPO189
C FOR X-DIRECTION STIFFENERS IMNPO190
    IF(NXST EQ 0)GO TO 250 IMNPO191
    NTYPE=2 IMNPO192
    DO 240 NN=1,NXST IMNPO193
    SL=XSPROP(6,NN) IMNPO194

```

	XXF=XSPROP(7,NN)	IMNP0195
	ANUS=XSPROP(4,NN)	IMNP0196
	RW=XSPROP(2,NN)	IMNP0197
	LNUM=LNXS(NN)	IMNP0198
	RH=XSPROP(1,NN)	IMNP0199
	YM=XSPROP(3,NN)	IMNP0200
	DEN=XSPROP(5,NN)	IMNP0201
	CSA=RW*RH	IMNP0202
	SMOI=RH*RW*XXF*XXF+RW*RH**3/12.0	IMNP0203
	NN1=NP(1,LNUM)	IMNP0204
	NN2=NP(2,LNUM)	IMNP0205
	NN4=NP(4,LNUM)	IMNP0206
	XL=XGI(NN2)-XGI(NN1)	IMNP0207
	YL=YGI(NN4)-YGI(NN1)	IMNP0208
	CALL RPLATE(NTYPE,ANUS,XL,YL,RH,SL,CSA,XXF,SMOI,EK,GBI,YM)	IMNP0209
	CALL ASSEM(K,EK,STF,INUM,NDPE,NODE,LNUM)	IMNP0210
	CALL LMASSP(NTYPE,XL,YL,RH,SL,CSA,SMOI,EML,DEN)	IMNP0211
	LL=(LNUM-1)*NDPE	IMNP0212
	DO 230 I=1,24	IMNP0213
	J=LL+I	IMNP0214
	NNN=NODE(J)	IMNP0215
230	AMASS(NNN)=AMASS(NNN)+EML(I)	IMNP0216
240	CONTINUE	IMNP0217
250	CONTINUE	IMNP0218
C	FOR Y-DIRECTION STIFFENERS	IMNP0219
	IF(NYST.EQ.0)GO TO 280	IMNP0220
	NTYPE=3	IMNP0221
	DO 270 NN=1,NYST	IMNP0222
	RH=YSPROP(1,NN)	IMNP0223
	RW=YSPROP(2,NN)	IMNP0224
	YM=YSPROP(3,NN)	IMNP0225
	ANUS=YSPROP(4,NN)	IMNP0226
	DEN=YSPROP(5,NN)	IMNP0227
	SL=YSPROP(6,NN)	IMNP0228
	XXF=YSPROP(7,NN)	IMNP0229
	CSA=RW*RH	IMNP0230
219	SMOI=RH*RW*XXF*XXF+RW*RH**3/12.000	IMNP0231
	LNUM=LNYS(NN)	IMNP0232
	NNN1=NP(1,LNUM)	IMNP0233
	NNN2=NP(2,LNUM)	IMNP0234
	NNN4=NP(4,LNUM)	IMNP0235
	XL=XGI(NNN2)-XGI(NNN1)	IMNP0236
	YL=YGI(NNN4)-YGI(NNN1)	IMNP0237
	CALL RPLATE(NTYPE,ANUS,XL,YL,RH,SL,CSA,XXF,SMOI,EK,GBI,YM)	IMNP0238
	CALL ASSEM(K,EK,STF,INUM,NDPE,NODE,LNUM)	IMNP0239
	CALL LMASSP(NTYPE,XL,YL,RH,SL,CSA,SMOI,EML,DEN)	IMNP0240
	LL=(LNUM-1)*NDPE	IMNP0241
	DO 260 I=1,24	IMNP0242
	J=LL+I	IMNP0243
	NNN=NODE(J)	IMNP0244
260	AMASS(NNN)=AMASS(NNN)+EML(I)	IMNP0245
270	CONTINUE	IMNP0246
280	CONTINUE	IMNP0247
	IF(IPASS.EQ.3 AND.NELES.EQ.0)GO TO 290	IMNP0248
	IF(IPASS.EQ.2)GO TO 741	IMNP0249
C	FORMATION AND ASSEMBLY OF EQUIVALENT STIFFNESS MATRIX FOR LINE	IMNP0250
C	TRANSLATIONAL AND TORSIONAL LINEAR RESTORING SPRINGS APPLIED TO	IMNP0251
C	SIDES OF ELEMENTS	IMNP0252
	READ(MREAD,500)NELES	IMNP0253
	IF(NELES.EQ.0)GO TO 289	IMNP0254
	WRITE(MWRITE,720)	IMNP0255
	WRITE(MWRITE,730)	IMNP0256
	DO 288 I=1,NELES	IMNP0257
	READ(MREAD,500)LNUM,ISIDE	IMNP0258
	READ(MREAD,510)(SS(J),J=1,5)	IMNP0259
	LNRS(I)=LNUM	IMNP0260

	ISRS(1)=ISIDE	IMNP0261
	DO 285 K=1,5	IMNP0262
285	SC(K,I)=SS(K)	IMNP0263
	WRITE(MWRITE,740)LNUM,ISIDE,(SS(J),J=1,5)	IMNP0264
	NNN1=NP(1,LNUM)	IMNP0265
	NNN2=NP(2,LNUM)	IMNP0266
	NNN4=NP(4,LNUM)	IMNP0267
	XL=XGI(NNN2)-XGI(NNN1)	IMNP0268
	YL=YGI(NNN4)-YGI(NNN1)	IMNP0269
	CALL SPRING(EK,SS,ISIDE,XL,YL)	IMNP0270
288	CALL ASSEM(K,EK,STF,INUM,NDPE,NODE,LNUM)	IMNP0271
720	FORMAT('0',' LOCATION AND PROPERTIES OF LINE TRANSLATIONAL AND ROTATIONAL LINEAR RESTORING SPRINGS')	IMNP0272
730	FORMAT('0','ELEM. NO ',2X,'ELEM. SIDE',8X,'KX(LB/IN/IN)',8X,2'KY(LB/IN/IN)',8X,'KZ(LB/IN/IN)',2X,'K-THETA(IN-LB/RAD/IN)',2X,3'K-PSI(IN-LB/RAD/IN)')	IMNP0273
740	FORMAT(' ',15,6X,15,5X,5D20.7)	IMNP0274
	GO TO 289	IMNP0275
741	DO 743 I=1,NELES	IMNP0276
	LNUM=LNRS(I)	IMNP0277
	ISIDE=ISRS(I)	IMNP0278
	DO 742 KAY=1,5	IMNP0279
742	SS(KAY)=SC(KAY,I)	IMNP0280
	NNN1=NP(1,LNUM)	IMNP0281
	NNN2=NP(2,LNUM)	IMNP0282
	NNN4=NP(4,LNUM)	IMNP0283
	XL=XGI(NNN2)-XGI(NNN1)	IMNP0284
	YL=YGI(NNN4)-YGI(NNN1)	IMNP0285
	CALL SPRING(EK,SS,ISIDE,XL,YL)	IMNP0286
743	CALL ASSEM(K,EK,STF,INUM,NDPE,NODE,LNUM)	IMNP0287
	GO TO 290	IMNP0288
289	CONTINUE	IMNP0289
C	CALCULATE TIME STEP BOUND (FOR REFERENCE ONLY).	IMNP0290
	CALL TSTEP(STF,AMASS,NBC,BC,ICOL,INUM,KROW,NDEX,DISP,DELDT)	IMNP0291
	IF(IOP5 EQ 0 .OR. NB .EQ. 0) GO TO 290	IMNP0292
	IPASS=2	IMNP0293
2891	DO 2892 I=1,MNC	IMNP0294
2892	STF(I)=0 ODO	IMNP0295
	DO 2894 I=1,NDT	IMNP0296
2894	AMASS(I)=0 ODO	IMNP0297
	GO TO 304	IMNP0298
290	CONTINUE	IMNP0299
C	GENERATE INITIAL CONDITIONS ON FRAGMENT.	IMNP0300
	CALL IFRAG(PMASS,AMASS)	IMNP0301
	NIMPCT=0	IMNP0302
	ITT=0	IMNP0303
	DO 291 I=1,NDT	IMNP0304
	DIS(I)=0.0	IMNP0305
	DISP(I)=0 0	IMNP0306
	FLVA(I)=0.0	IMNP0307
291	VEL(I)=0 0	IMNP0308
C	FORM LHS	IMNP0309
	DO 307 II=1,NDT	IMNP0310
	L=II+INUM(II)	IMNP0311
307	STF(L)=STF(L)+2.0D0* AMASS(II)/(DELTAT*DELTAT)	IMNP0312
	IF(IOP5 EQ 1)CALL EAROW(STF,NBC,ICOL,INUM,RFM,ILAST,NBE,MBWE)	IMNP0313
C	CONSTRAIN LHS	IMNP0314
	CALL BCDNMK(STF,BC,ICOL,INUM,NBC)	IMNP0315
C	FACTOR LHS	IMNP0316
	CALL FACT(STF,ICOL,KROW,NDEX,IDET,MWRITE,INUM)	IMNP0317
	IF(IMCONT EQ 1)GO TO 335	IMNP0318
C	PRINTOUT FOR INITIAL VALUES	IMNP0319
	IF(IOP5 EQ 0 .OR. NB .EQ. 0)GO TO 320	IMNP0320
	DO 319 I=1,NB	IMNP0321
319	UCF(I)=0.0	IMNP0322
320	CONTINUE	IMNP0323
		IMNP0324
		IMNP0325
		IMNP0326

	NOCHK=0	IMNP0327
	GO TO 340	IMNP0328
C	INPUT FOR CONTINUATION RUN	IMNP0329
335	READ(MREAD,800)ITT,NIMPCT	IMNP0330
	READ (MREAD,810){DIS(I),I=1,NDT}	IMNP0331
	READ (MREAD,810){DISP(I),I=1,NDT}	IMNP0332
	READ (MREAD,810){VEL(I),I=1,NDT}	IMNP0333
	READ (MREAD,810){FLVA(I),I=1,NDT}	IMNP0334
	IF(IOP5 EQ 1 AND NB GT 0)READ (MREAD,810){UCF2(I),I=1,NB}	IMNP0335
	READ (MREAD,810){(TAUSS(I,J,K),I=1,NET),J=1,MNSLT4,K=1,9}	IMNP0336
	READ (MREAD,810){(TAUEE(I,J,K),I=1,NET),J=1,MNSLT4,K=1,9}	IMNP0337
	READ (MREAD,810){(TAUSE(I,J,K),I=1,NET),J=1,MNSLT4,K=1,9}	IMNP0338
	IF(NXST EQ 0)GO TO 336	IMNP0339
	READ ((MREAD,810){(TAGSS(I,J,K),I=1,NXST),J=1,MNSLT4,K=1,3}	IMNP0340
336	CONTINUE	IMNP0341
	IF(NYST EQ 0)GO TO 337	IMNP0342
	READ (MREAD,810){(TSGEE(I,J,K),I=1,NYST),J=1,MNSLT4,K=1,3}	IMNP0343
337	READ(MREAD,810)XF,YF,ZF,(VF(J),J=1,3),(OMEGF(II),II=1,3)	IMNP0344
	NNT=NDT/6	IMNP0345
	DO 338 I=1,NNT	IMNP0346
	NN=(I-1)*6	IMNP0347
	XG(I)=XGI(I)+DISP(NN+1)	IMNP0348
	YG(I)=YGI(I)+DISP(NN+2)	IMNP0349
338	ZG(I)=ZG(I)+DISP(NN+3)	IMNP0350
	NOCHK=0	IMNP0351
	FKE=0 0	IMNP0352
	DO 339 I=1,3	IMNP0353
339	FKE=FKE+0.5D0*(FMASS*VF(I)+VF(I)+FMOI*OMEGF(I)+OMEGF(I))	IMNP0354
	IF(FKE LT.FKEC)NOCHK=1	IMNP0355
C	BEGIN LOOP OVER TIME STEPS	IMNP0356
340	ITT=ITT+1	IMNP0357
	NSINC=0	IMNP0358
	DO 350 J=1,NDT	IMNP0359
221	DELD(J)=DIS(J)-DISP(J)	IMNP0360
	DISM1(J)=DISP(J)	IMNP0361
	DISP(J)=DIS(J)	IMNP0362
	FLN(J)=FLVA(J)	IMNP0363
	FLVM(J)=0 0	IMNP0364
350	FLVA(J)=0 0	IMNP0365
	NNT=NDT/6	IMNP0366
	DO 351 J=1,NNT	IMNP0367
	NN=(J-1)*6	IMNP0368
	XG(J)=XG(J)+DELD(NN+1)	IMNP0369
	YG(J)=YG(J)+DELD(NN+2)	IMNP0370
351	ZG(J)=ZG(J)+DELD(NN+3)	IMNP0371
	IF(NOCHK EQ 1 .OR. ITT .EQ. 1) GO TO 343	IMNP0372
	XF=XF+VF(1)*DELTAT	IMNP0373
	YF=YF+VF(2)*DELTAT	IMNP0374
	ZF=ZF+VF(3)*DELTAT	IMNP0375
343	CONTINUE	IMNP0376
	IF(IOP5 EQ 0 .OR NB .EQ. 0)GO TO 353	IMNP0377
	DO 352 I=1,NB	IMNP0378
352	UCF1(I)=UCF2(I)	IMNP0379
353	CONTINUE	IMNP0380
C	CALCULATE EQUIVALENT LOADS	IMNP0381
C	FOR PLATE ELEMENT	IMNP0382
	CALL STRESP(DISP,DELD,FLVA,ITT,NODE,MAXEL,TAUSS,TAUEE,TAUSE,	IMNP0383
	2EPS1,EPSS0,EPEE1,EPEE0,EPSE1,EPSE0,PLASTW,XGI,YGI,NP,STDE,GB1,	IMNP0384
	3NMSUB,DSR,PSR,SUBW,SNO ,NZSUBL)	IMNP0385
C	FOR X-DIRECTION STIFFENERS	IMNP0386
	IF(NXST EQ 0)GO TO 360	IMNP0387
	CALL STRESA(DISP,DELD,FLVA,ITT,NODE,MAXEL,MNXST,TAGSS,PLASTW,XGI,	IMNP0388
	2YGI,NP,STDE,GB1,NMSUB,DSR,PSR,SUBW,SNO ,NXST,XSPROP,LNKS,MATXS,	IMNP0389
	3NZSUBL)	IMNP0390
360	CONTINUE	IMNP0391
C	FOR Y-DIRECTION STIFFENERS	IMNP0392

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IF(NYST.EQ 0)GO TO 370
CALL STRESC(DISP,DELD,FLVA,ITT,NODE,MAXEL,MNYST,TSGEE,PLASTW,XGI,
2YGI,NP,STDE,GBI,NMSUB,DSR,PSR,SUBW,SND,NYST,YSPROP,LNYS,MATYS,
3NZSUBL)
370 CONTINUE
C PRINT OUTPUT
ITIME=ITT-1
TIME=ITIME*DELTAT
CALL IPRINT(DISP,XG,YG,ZG,EPSSI,EPSSO,EPEEI,EPEED,EPSEI,EPSEO,XGI,
2YGI,NP,GBI,STDE,NODE,RFM,NBE,MBWE,ILAST,UCF1,NBC,ICOL,NMSUB,SUBW,
3TAUSS,TAUEE,TAUSE,MAXEL,NZSUBL,NXST,LNXS,MATXS,XSPROP,TAGSS,MNXST,
4NYST,LNYS,MATYS,YSPROP,TSGEE,MNYST,NELES,LNRS,ISRS,SC,EK,
5AMASS,VEL,NNSA,NVSA,NCON)
C FORM RHS
372 CONTINUE
NSINC=NSINC+1
IF(NSINC GT 20)WRITE(MWRITE,900)
IF(NSINC GT 20)RETURN
900 FORMAT('0','MORE THAN 20 ITERATIONS REQUIRED TO CONVERGE AN IMPACT
2 SOLUTION--RUN HAS BEEN TERMINATED')
DO 380 I=1,NDT
380 FLVM(I)=-{2.000*FLVA(I)-F(LN(I)) +2.000*AMASS(I)*(VEL(I)+DISP(I)
2/DELTAT)/DELTAT
IF(IOP5 EQ 0 OR NB EQ.0)GO TO 389
DO 388 I=1,NB
II=NBC(I)
388 UCF2(I)=FLVM(II)
C CONSTRAIN RHS
389 CALL RCON(FLVM,NBC)
C SOLVE FOR DISPLACEMENTS
CALL SOLV(STF,FLVM,DIS,ICOL,KROW,NDEX)
DO 390 I=1,NDT
390 DELD(I)-DIS(I)-DISP(I)
C CHECK FOR SKIP OF IMPACT INSPECTION/CORRECTION ROUTINE.
IMPCT1=0
IF(NOCHK EQ 1)GO TO 394
C CHECK FOR IMPACT
IF(NSYM EQ 0)CALL IMPACT(XG,YG,ZG,DELD,VEL,NP,VN,VNB,PMASS,NBC,SI,
1 NEFF,ALPHA,IMPCT1,NIAN)
IF(NSYM EQ 1) CALL IMPSS(XG,YG,ZG,DELD,VEL,NP,VN,VNB,PMASS,NBC,
1SI,NEFF,ALPHA,IMPCT1,NIAN)
IF(NSYM EQ 2) CALL IMPDS(XG,YG,ZG,DELD,VEL,NP,VN,VNB,PMASS,NBC,
1SI,NEFF,ALPHA,IMPCT1,NIAN)
C IF IMPCT1=1, IMPACT HAS OCCURED. CALCULATE NEW TRIAL DISPLACEMENT,
C DIS
IF(IMPCT1 EQ 1)GO TO 372
C IF IMPCT1=0, THEN NO IMPACTS. TRIAL DIS IS CORRECT. PROCEED TO
C NEXT TIME
IF(NSINC.GT.1)NIMPCT=NIMPCT+1
IF(NSINC GT 1)WRITE(MWRITE,830)NIMPCT
IF(NSINC EQ.1)GO TO 394
C SPECIAL CALCULATION OF VELOCITY IF IMPACT HAS OCCURED.
DO 392 I=1,NDT
392 VEL(I)=2.000*(DIS(I)-DISP(I))/DELTAT-VEL(I)
GO TO 398
394 CONTINUE
C NORMAL UPDATE OF VELOCITY.
DO 396 I=1,NDT
396 VEL(I)={3.000*DIS(I)-4.000*DISP(I)+DISM1(I)}/(2.000*DELTAT)
398 CONTINUE
FKE=0.0
DO 399 I=1,3
399 FKE=FKE+0.500*(FMASS*VF(I)*VF(I)+FMOI*OMEGF(I)*OMEGF(I))
IF(FKE.LT.FKEC)NOCHK=1
C CHECK FOR CONTINUATION
IF(1TIME.LT.1TIMEF.AND.TIME.LT.TIMEF)GO TO 340

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IMNP0393
IMNP0394
IMNP0395
IMNP0396
IMNP0397
IMNP0398
IMNP0399
IMNP0400
IMNP0401
IMNP0402
IMNP0403
IMNP0404
IMNP0405
IMNP0406
IMNP0407
IMNP0408
IMNP0409
IMNP0410
IMNP0411
IMNP0412
IMNP0413
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IMNP0438
IMNP0439
IMNP0440
IMNP0441
IMNP0442
IMNP0443
IMNP0444
IMNP0445
IMNP0446
IMNP0447
IMNP0448
IMNP0449
IMNP0450
IMNP0451
IMNP0452
IMNP0453
IMNP0454
IMNP0455
IMNP0456
IMNP0457
IMNP0458

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IF(IPUNCH.EQ.0)GO TO 420
WRITE(MPUNCH,800)ITT,NIMPCT
WRITE(MPUNCH,810)(DIS(I),I=1,NDT)
WRITE(MPUNCH,810)(DISP(I),I=1,NDT)
WRITE(MPUNCH,810)(VEL(I),I=1,NDT)
WRITE(MPUNCH,810)(FLVA(I),I=1,NDT)
IF(IOP5.EQ.1.AND.NB.GT.0)WRITE(MPUNCH,810)(UCF2(I),I=1,NB)
WRITE(MPUNCH,810)((TAUSS(I,J,K),I=1,NET),J=1,MNSLT4),K=1,9)
WRITE(MPUNCH,810)((TAUEE(I,J,K),I=1,NET),J=1,MNSLT4),K=1,9)
WRITE(MPUNCH,810)((TAUSE(I,J,K),I=1,NET),J=1,MNSLT4),K=1,9)
IF(NXST.EQ.0)GO TO 400
WRITE(MPUNCH,810)((TAGSS(I,J,K),I=1,NXST),J=1,MNSLT4),K=1,3)
400 CONTINUE
IF(NYST.EQ.0)GO TO 410
WRITE(MPUNCH,810)((TSGEE(I,J,K),I=1,NYST),J=1,MNSLT4),K=1,3)
410 WRITE(MPUNCH,810)XF,YF,ZF,(VF(J),J=1,3),(OMEGF(II),II=1,3)
WRITE(MWRITE,820)ITT
420 RETURN
800 FORMAT(2I10)
810 FORMAT(SD15.7)
820 FORMAT('0','CONTINUATION CARDS HAVE BEEN PUNCHED AT ITT=',I7)
830 FORMAT(' ',10X,'THIS IS IMPACT NUMBER',I7)
END
SUBROUTINE IPRINT(DISP,XG,YG,ZG,EPSSI,EPSSO,EPEEI,EPEEO,EPSEI,
2EPSEO,XGI,YGI,NP,GBI,STDEP,NODE,RFM,NBE,MBWE,ILAST,UCF1,NBC,ICOL,
3NMSUB,SUBW,TAUSS,TAUEE,TAUSE,MAXEL,NZS,NXST,LNXS,MATXS,XSPROP,
4TAGSS,MNXST,NYST,LNYS,MATYS,YSPROP,TSGEE,MNYST,NELES,LNRS,ISRS,SC,
5EK,AMASS,VEL,'NSA,NVSA,NCON)
IMPLICIT REAL*8(A-H,O-Z)
IPRT0000
IPRT0001
IPRT0002
IPRT0003
IPRT0004
IPRT0005
IPRT0006
IPRT0007
IPRT0008
IPRT0009
IPRT0010
IPRT0011
IPRT0012
IPRT0013
IPRT0014
IPRT0015
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C THIS SUBROUTINE IS USED EXCLUSIVELY BY THE CIVM PLATE PROGRAM.
C SMALL STRAIN FORMULATION VERSION WRITTEN BY R. L. SPILKER
C DIMENSION DISP(1),XG(1),YG(1),ZG(1),EPSSI(9,1),EPSSO(9,1),EPEEI(9
2,1),EPEEO(9,1),EPSEI(9,1),EPSEO(9,1),XGI(1),YGI(1),NP(4,1),GBI(24

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3,24),STDEP(9,24),NODE(1),EP(9),ELONG(2),RFM(NBE,MBWE),ILAST(1),
4UCF1(1),NBC(1),ICOL(1),RF(6),NMSUB(1),AG AUS(6),AGAUW(6),ZGAUS(6),
5ZCAUW(6),SUBW(5,1),TAUSS(MAXEL,NZS,9),TAUEE(MAXEL,NZS,9),TAUC
6(MAXEL,NZS,9),LNXS(1),MATXS(1),XSPROP(7,1),TAGSS(MNXST,NZS,3),
7LNYS(1),MATYS(1),YSPROP(7,1),TSGEE(MNYS,NZS,3),LNRS(1),ISRS(1),
8SC(5,1),SS(5),EK(24,24),EQ(24),STOR(24),AMASS(1),VEL(1),NVSA(1),
9NCON(4,1)
COMMON/PLATE/XDIS,YDIS,T4,HX,HY,NEAD,NECD,DSP,EPAN,ANUP,THALF
COMMON/BAS/NDT,NET,MN,NB,NIRREG,MNC
COMMON/TIM/DELTAT,TIMEF,TIME,ITIMEF,INCRT,IOUT,ITIME
COMMON/ASP/SLASP(50),ELASP(50),EDIR(2,50),NASP,LNASP(50)
COMMON/PRNT/IOP1,IOP2,IOP3,IOP4,IOP5,IOP6,IOP7,IOP8
COMMON/GSOUT/NEGS,LNGS(200)
COMMON/SSOUT/NXSS,NYSS,INXSS(200),INYSS(200)
COMMON/FRAG/XF,YF,ZF,DELF(3),VF(3),DTHETF(3),OMEGF(3),RADF,FMASS,
2FMOI,FKEO,FKEC
COMMON /INOUT/ MREAD,MWRITE,MPUNCH
C
C THIS SUBROUTINE CONTROLS THE CALCULATION AND OUTPUT OF ALL QUANTITIES
C (DISPLACEMENTS, STRAINS, ENERGIES, ETC.) AS REQUESTED BY THE USER AT
C REGULAR INTERVALS DURING THE TIMewise SOLUTION.
C
IF(ITIME LE.1)GO TO 10
III=ITIME/INCRT*INCRT-ITIME
IF(III.NE.0)GO TO 500
10 CONTINUE
WRITE(MWRITE,600)ITIME,TIME
C NODAL DISPLACEMENTS AND LOCATION.
IF(IOP1.EQ.0)GO TO 30
WRITE(MWRITE,610)
NNT=NDT/6
DO 20 NN=1,NNT
JJ=(NN-1)*6
J1=JJ+1
J2=JJ+6
20 WRITE(MWRITE,620)NN,(DISP(I),I=J1,J2),XG(NN),YG(NN),ZG(NN)
30 CONTINUE
WRITE(MWRITE,940)
WRITE(MWRITE,950)
WRITE(MWRITE,960)XF,YF,ZF,(VF(I),I=1,3),(OMEGF(J),J=1,3)
C REACTION FORCES AT CONSTRAINED NODES.
IF(IOP5.EQ.0 OR NB.EQ.0)GO TO 39
WRITE(MWRITE,550)
WRITE(MWRITE,560)
C DETERMINE NODE NO. OF FIRST CONSTRAINED D.O.F..
NC=NBC(1)
NN1=(NC-1)/6+1
DO 31 I=1,6
31 RF(I)=0.000
C LOOP OVER CONSTRAINED D.O.F..
DO 38 INB=1,NB
C DETERMINE NODE NO. OF PRESENT CONSTRAINED D.O.F..
NC=NBC(INB)
NN2=(NC-1)/6+1
C IF NN2.NC.NN1, CALC. OF RF FOR NODE NN1 IS COMPLETE--PRINT OUT
C VALUES
IF(NN2.EQ.NN1)GO TO 33
WRITE(MWRITE,570)NN1,(RF(J),J=1,6)
NN1=NN2
IPRT0016
IPRT0017
IPRT0018
IPRT0019
IPRT0020
IPRT0021
IPRT0022
IPRT0023
IPRT0024
IPRT0025
IPRT0026
IPRT0027
IPRT0028
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IPRT0040
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IPRT0050
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IPRT0054
IPRT0055
IPRT0056
IPRT0057
IPRT0058
IPRT0059
IPRT0060
IPRT0061
IPRT0062
IPRT0063
IPRT0064
IPRT0065
IPRT0066
IPRT0067
IPRT0068
IPRT0069
IPRT0070
IPRT0071
IPRT0072
IPRT0073
IPRT0074

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DO 32 I=1,6
32 RF(I)=0.000
33 CC=-UCF1(INB)
   NN=0
   IB=ICOL(NC)
   IE=ILAST(INB)
   DO 34 I=IB,IE
   NN=NN+1
34 CC=CC+RFM(INB,NN)*DISP(I)
   NDF=NC-(NN1-1)*6
   RF(NDF)=CC
38 CONTINUE
   WRITE(MWRITE,570)NN1,(RF(J),J=1,6)
39 CONTINUE
C   CENTROIDAL STRAIN INFORMATION.
   IF(IOP2.EQ 0)GO TO 50
   WRITE(MWRITE,630)
   WRITE(MWRITE,640)
   WRITE(MWRITE,644)
   DO 40 LNUM=1,NET
   G11=EPSSI(5,LNUM)
   G22=EPEEI(5,LNUM)
   G12=EPSEI(5,LNUM)
   CALL PSTRN(G11,C22,G12,SI,DIRI)
   G11=EPSSO(5,LNUM)
   G22=EPEEO(5,LNUM)
   G12=EPSEO(5,LNUM)
   CALL PSTRN(G11,G22,G12,SO,DIRO)
40 WRITE(MWRITE,650)LNUM,EPSSI(5,LNUM),EPSSO(5,LNUM),EPEEI(5,LNUM),
   2EPEEO(5,LNUM),EPSEI(5,LNUM),EPSEO(5,LNUM),SI,SO,DIRI,DIRO
50 CONTINUE
C   NODAL AVERAGE STRAINS.
225 IF(IOP3.EQ 0)GO TO 55
   WRITE(MWRITE,900)
   WRITE(MWRITE,940)
   WRITE(MWRITE,920)
   DO 53 II=1,NNSA
   G11U=0.000
   G11I=0.000
   G22U=0.000
   G22L=0.000
   G12U=0.000
   G12L=0.000
   NNUM=NVS(A(II))
   DENOM=0.000
   DO 52 JJ=1,4
   IF(NCON(JJ,II).EQ 0)GO TO 52
   DENOM=DENOM+1.000
   LNUM=NCON(JJ,II)
   NNN1=NP(1,LNUM)
   NNN2=NP(2,LNUM)
   NNN4=NP(4,LNUM)
   XL=XGI(NNN2)-XGI(NNN1)
   YL=YGI(NNN4)-YGI(NNN1)
   SL=0.000
   EL=0.000
   IF(JJ.EQ 2.OR.JJ.EQ 3)SL=1.000
   IF(JJ.EQ 3.OR.JJ.EQ 4)EL=1.000
   CALL SFDM(SL,EL,XL,YL,GBI,STDEP)

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IPRT0080
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IPRT0088
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IPRT0090
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IPRT0121
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IPRT0125
IPRT0126
IPRT0127
IPRT0128
IPRT0129
IPRT0130
IPRT0131
IPRT0132
IPRT0133

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DO 51 J=1,9
EP(J)=0.000
DO 51 K=1,24
NNN=(LNUM-1)*24+K
NN=NODE(NNN)
51 EP(J)=EP(J)+STDEP(J,K)*DISP(NN)
EPSSM=EP(1)+EP(7)*EP(7)/2.000+EP(9)*EP(9)/2.000
EPEEM=EP(2)+EP(8)*EP(8)/2.000+EP(9)*EP(9)/2.000
EPSEM=EP(3)+EP(7)*EP(8)
G11L=G11L+EPSSM+THALF*EP(4)
G11U=G11U+EPSSM-THALF*EP(4)
G22L=G22L+EPEEM+THALF*EP(5)
G22U=G22U+EPEEM-THALF*EP(5)
G12L=G12L+EPSEM+THALF*EP(6)
G12U=G12U+EPSEM-THALF*EP(6)
52 CONTINUE
G11L=G11L/DENOM
G11U=G11U/DENOM
G22L=G22L/DENOM
G22U=G22U/DENOM
G12L=G12L/DENOM
G12U=G12U/DENOM
CALL PSTRN(G11L,G22L,G12L,SI,DIRI)
CALL PSTRN(G11U,G22U,G12U,SO,DIRO)
53 WRITE(MWRITE,650)NNUM,G11L,G11U,G22L,G22U,G12L,G12U,SI,SO,DIRI,
+ DIRO
55 CONTINUE
C GAUSS STATION STRAIN PRINTOUT.
IF(IOP3.EQ.0)GO TO 70
WRITE(MWRITE,660)
DO 60 NN=1,NEGS
LNUM=LNGS(NN)
226 WRITE(MWRITE,670) LNUM
WRITE(MWRITE,640)
WRITE(MWRITE,645)
DO 60 NG=1,9
G11=EPSSI(NG,LNUM)
G22=EPEEI(NG,LNUM)
G12=EPSEI(NG,LNUM)
CALL PSTRN(G11,G22,G12,SI,DIRI)
G11=EPSSO(NG,LNUM)
G22=EPSEE(NG,LNUM)
G12=EPSEO(NG,LNUM)
CALL PSTRN(G11,G22,G12,SO,DIRO)
60 WRITE(MWRITE,650)NG,EPSSI(NG,LNUM),EPSSO(NG,LNUM),EPEEI(NG,LNUM),
2EPEEO(NG,LNUM),EPSEI(NG,LNUM),EPSEO(NG,LNUM),SI,SO,DIRI,DIRO
70 CONTINUE
C ADDITIONAL STRAIN POINTS.
IF(IOP4.EQ.0)GO TO 110
WRITE(MWRITE,690)
WRITE(MWRITE,695)
DO 100 KK=1,NASP
LNUM=LNASP(KK)
SL=SLASP(KK)
EL=ELASP(KK)
NNN1=NP(1,LNUM)
NNN2=NP(2,LNUM)
NNN4=NP(4,LNUM)
XL=XGI(NNN2)-XGI(NNN1)

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IPRT0186
IPRT0187
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IPRT0189
IPRT0190
IPRT0191
IPRT0192

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YL=YGI (NNN4) -YGI (NNN1)
CALL SFDM(SL,EL,XL,YL,GBI,STDEP)
DO 80 J=1,9
EP(J)=0.00
DO 80 K=1,24
NNN=(LNUM-1)*24+K
NN=NODE(NNN)
80 EP(J)=EP(J)+STDEP(J,K)*DISP(NN)
EPSSM=EP(1)+EP(7)*EP(7)/2.0+EP(9)*EP(9)/2.0
EPEEM=EP(2)+EP(8)*EP(8)/2.0+EP(9)*EP(9)/2.0
EPSEM=EP(3)+EP(7)*EP(8)
DO 100 II=1,2
FCT=1.000
IF(II EQ 2)FCT=-1.000
G11=EPSSM+FCT*THALF*EP(4)
G22=EP ELM+FCT*THALF*EP(5)
G12=EPSEM+FCT*THALF*EP(6)
CALL PSTRN(G11,G22,G12,SI,DIRI)
DO 90 I=1,2
THET=EDIR(I, KK)*0.1745329251994D-01
CT=DCOS(THET)
ST=DSIN(THET)
ELONG(I)=G11*CT+CT+G22*ST*ST+G12*CT*ST
90 ELONG(I)=DSQRT(1.0+2.0*ELONG(I))-1.0
IF(II EQ 1)WRITE(MWRITE,700)KK,G11,G22,G12,ELONG(1),ELONG(2),SI,
+ DIRI
IF(II EQ 2)WRITE(MWRITE,710)KK,G11,G22,G12,ELONG(1),ELONG(2),SI,
+ DIRI
100 CONTINUE
110 CONTINUE
C CALCULATION AND PRINTOUT OF GAUSS STATION STRAINS ON STIFFENERS.
IF(IOP6.EQ 0)GO TO 190
NA=3
CALL GAUSS(NA,AGAUS,AGAUW)
C FOR X-DIRECTION STIFFENERS.
IF(NXSS EQ 0)GO TO 150
WRITE(MWRITE,780)
WRITE(MWRITE,785)
WRITE(MWRITE,790)
DO 140 NX=1,NXSS
NST=INXSS(NX)
LNUM=LNXS(NST)
NNN1=NP(1,LNUM)
NNN2=NP(2,LNUM)
NNN4=NP(4,LNUM)
XL=XGI(NNN2)-XGI(NNN1)
YL=YGI(NNN4)-YGI(NNN1)
EL=XSPROP(6,NST)
DO 130 NC=1,NA
SL=(1.0000+AGAUS(NG))/2.000
CALL SFDM(SL,EL,XL,YL,GBI,STDEP)
EP(1)=0.0
EP(4)=0.0
EP(7)=0.0
DO 120 K=1,24
NNN=(LNUM-1)*24+K
NN=NODE(NNN)
EP(1)=EP(1)+STDEP(1,K)*DISP(NN)
EP(4)=EP(4)+STDEP(4,K)*DISP(NN)

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IPRT0193
IPRT0194
IPRT0195
IPRT0196
IPRT0197
IPRT0198
IPRT0199
IPRT0200
IPRT0201
IPRT0202
IPRT0203
IPRT0204
IPRT0205
IPRT0206
IPRT0207
IPRT0208
IPRT0209
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IPRT0236
IPRT0237
IPRT0238
IPRT0239
IPRT0240
IPRT0241
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IPRT0243
IPRT0244
IPRT0245
IPRT0246
IPRT0247
IPRT0248
IPRT0249
IPRT0250
IPRT0251

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120 EP(7)=EP(7)+STDEP(7,K)*DISP(NN)          IPRT0252
    NN=(NG-1)*2+1                            IPRT0253
    STOR(NN)=EP(1)+EP(7)*EP(7)/2.0+(0.5*XSPROP(1,NST)+XSPROP(7,NST)) IPRT0254
    2*EP(4)                                    IPRT0255
    STOR(NN+1)=EP(1)+EP(7)*EP(7)/2.0+(XSPROP(7,NST)-0.5*XSPROP(1,NST)) IPRT0256
    2*EP(4)                                    IPRT0257
130 CONTINUE                                  IPRT0258
140 WRITE(MWRITE,800)NST,(STOR(J),J=1,6)      IPRT0259
150 CONTINUE                                  IPRT0260
C FOR Y-DIRECTION STIFFENERS.                 IPRT0261
    IF(NYSS EQ 0)GO TO 190                     IPRT0262
    WRITE(MWRITE,810)                           IPRT0263
    WRITE(MWRITE,785)                           IPRT0264
    WRITE(MWRITE,790)                           IPRT0265
    DO 180 NY=1,NYSS                             IPRT0266
    NST=INYSS(NY)                                IPRT0267
    LNUM=LNYS(NST)                               IPRT0268
    NNN1=JP(1,LNUM)                              IPRT0269
    NNN2=NP(2,LNUM)                              IPRT0270
    NNN4=NP(4,LNUM)                              IPRT0271
    XL=XGI(NNN2)-XGI(NNN1)                       IPRT0272
    YL=YGI(NNN4)-YGI(NNN1)                       IPRT0273
    SL=YSPROP(6,NST)                             IPRT0274
    DO 170 NG=1,NA                               IPRT0275
    EL=(1.0+AG AUS(NG))/2.0                     IPRT0276
    CALL SFDM(SL,EL,XL,YL,GBI,STDEP)             IPRT0277
    EP(2)=0 0                                    IPRT0278
    EP(5)=0 0                                    IPRT0279
    EP(8)=0 0                                    IPRT0280
    DO 160 k=1,24                                IPRT0281
    NNN=(LNUM-1)*24+k                           IPRT0282
    NN=NODE(NNN)                                 IPRT0283
    EP(2)=EP(2)+STDEP(2,k)*DISP(NN)             IPRT0284
    EP(5)=EP(5)+STDEP(5,k)*DISP(NN)             IPRT0285
    EP(8)=EP(8)+STDEP(8,k)*DISP(NN)             IPRT0286
    NN=(NG-1)*2+1                                IPRT0287
    STOR(NN)=EP(2)+EP(8)*EP(8)/2.0+(0.5*YSPROP(1,NST)+YSPROP(7,NST)) IPRT0288
    2*EP(5)                                       IPRT0289
    STOR(NN+1)=EP(2)+EP(8)*EP(8)/2.0+(YSPROP(7,NST)-0.5*YSPROP(1,NST)) IPRT0290
    2*EP(5)                                       IPRT0291
170 CONTINUE                                  IPRT0292
180 WRITE(MWRITE,800)NST,(STOR(J),J=1,6)      IPRT0293
190 CONTINUE                                  IPRT0294
C CALCULATION AND PRINTOUT OF SYSTEM ENERGIES. IPRT0295
    IF(IOP7 EQ 0)GO TO 440                     IPRT0296
C ELASTIC STRAIN ENERGY STORED IN STRUCTURE. IPRT0297
C FOR PLATE ELEMENTS.                         IPRT0298
    NA=3                                         IPRT0299
    NZ=4                                         IPRT0300
    NSUBL=NMSUB(1)                              IPRT0301
    CALL GAUSS(NA,AG AUS,AG AUW)                 IPRT0302
    CALL GAUSS(NZ,ZGAUS,ZGAUW)                 IPRT0303
    ELAST=0 0                                    IPRT0304
    S1=1.0/EPAN                                  IPRT0305
    S2=-ANUP*S1                                  IPRT0306
    S3=2 0*(1.0+ANUP)/EPAN                     IPRT0307
    DO 240 LNUM=1,NET                            IPRT0308
    NNN1=NP(1,LNUM)                              IPRT0309
    NNN2=NP(2,LNUM)                              IPRT0310

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NNN4=NP(4,LNUM)
HXL=(XGI(NNN2)-XGI(NNN1))/2.000
HYL=(YGI(NNN4)-YGI(NNN1))/2.000
DO 240 KS=1,NA
SW=HXL*AGAUW(KS)
DO 240 KE=1,NA
EW=HYL*AGAUW(KE)
JA=KE+(KS-1)*NA
STOR1=0.0
DO 230 LZ=1,NZ
ST1=0.0
ST2=0.0
ST3=0.0
DO 220 LS=1,NSUBL
JZ=LZ+(LS-1)*NZ
ST1=ST1+SUBW(1,LS)*TAUSS(LNUM,JZ,JA)
ST2=ST2+SUBW(1,LS)*TAUEE(LNUM,JZ,JA)
220 ST3=ST3+SUBW(1,LS)*TAUSE(LNUM,JZ,JA)
PROD=S1*(ST1+ST1+ST2+ST2)+2.0*S2*ST1*ST2+S3*ST3*ST3
230 STOR1=STOR1+PROD*0.5*TH*ZGAUW(LZ)
240 ELAST=ELAST+STOR1*SW*EW/2.0
C ELASTIC ENERGY IN X-DIRECTION STIFFENERS.
IF(NXST.EQ.0)GO TO 280
DO 270 NST=1,NXST
LNUM=LNXS(NST)
NNN1=NP(1,LNUM)
NNN2=NP(2,LNUM)
HXL=(XGI(NNN2)-XGI(NNN1))/2.000
MAT=MATXS(NST)
NSUBL=NMSUB(MAT)
S1=1.0/XSPROP(3,NST)
229 EW=XSPROP(2,NST)
DO 270 KE=1,NA
SW=HXL*AGAUW(KE)
STOR1=0.0
DO 260 LZ=1,NZ
ST1=0.0
DO 250 LS=1,NSUBL
JZ=LZ+(LS-1)*NZ
250 ST1=ST1+SUBW(MAT,LS)*TAGSS(NST,JZ,KE)
PROD=S1*ST1*ST1
260 STOR1=STOR1+PROD*0.5*XSPROP(1,NST)*ZGAUW(LZ)
270 ELAST=ELAST+STOR1*EW*SW/2.0
260 CONTINUE
C ELASTIC ENERGY STORED IN Y-DIRECTION STIFFENERS.
IF(NYST.EQ.0)GO TO 320
DO 310 NST=1,NYST
LNUM=LNYS(NST)
NNN4=NP(4,LNUM)
HYL=(YGI(NNN4)-YGI(NNN1))/2.000
MAT=MATYS(NST)
NSUBL=NMSUB(MAT)
S1=1.0/YSPROP(3,NST)
SW=YSPROP(2,NST)
DO 310 KS=1,NA
EW=HYL*AGAUW(KS)
STOR1=0.0
DO 300 LZ=1,NZ
ST1=0.0

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IPRT0370

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DO 290 LS=1, NSUBL
JZ=LZ+(LS-1)*NZ
290 ST1=ST1+SU3W(MAT,LS)+TSGEE(NST,JZ,KS)
PROD=S1*ST1*ST1
300 STOR1=STOR1+PRCD*0.5*YSPROP(1,NST)*ZGAUW(LZ)
310 ELAST=ELAST+STOR1+EW*SW/2.0
320 CONTINUE
C CALCULATION OF ENERGY STORED IN ELASTIC RESTORING SPRINGS.
SPREN=0.0
IF(NELES.EQ.0)GO TO 380
DO 370 NS=1, NELES
LNUM=LNRS(NS)
ISIDE=ISRS(NS)
NNN1=NP(1,LNUM)
NNN2=NP(2,LNUM)
NNN4=NP(4,LNUM)
XL=XGI(NNN2)-XGI(NNN1)
YL=YGI(NNN4)-YGI(NNN1)
DO 330 I=1,5
330 SS(I)=SC(I,NS)
CALL SPRING(EK,SS,ISIDE,XL,YL)
L=(LNUM-1)*24
DO 340 I=1,24
LPI=L+I
LL=NODE(LPI)
340 EQ(I)=DISP(LL)
DO 350 I=1,24
STOR(I)=0.0
DO 350 K=1,24
350 STOR(I)=STOR(I)+EK(I,K)*EQ(K)
STOR1=0.0
DO 360 I=1,24
360 STOR1=STOR1+EQ(I)*STOR(I)
370 SPREN=SPREN+STOR1/2.0
380 CONTINUE
C CALCULATE KINETIC ENERGY OF THE STRUCTURE.
CINET=0.0
DO 400 I=1,NDT
400 CINET=CINET+AMASS(I)*VEL(I)*VEL(I)/2.0
C CALCULATE KINETIC ENERGY OF THE FRAGMENT.
CINFRT=0.00
CINFNT=0.00
DO 420 I=1,3
CINFRT=CINFRT+0.500*FMOI*OMEGF(I)*OMEGF(I)
420 CINFNT=CINFNT+0.500*FMAS+VF(I)*VF(I)
C WORK INPUT TO STRUCTURE EQUAL TO DIFFERENCE BETWEEN INITIAL
C AND CURRENT FRAGMENT ENERGIES.
EWORK=FKEO-CINFRT-CINFNT
C CALCULATE PLASTIC WORK BY SUBTRACTION.
PLASTW=EWORK-ELAST-SPREN-CINET
C PRINTOUT ENERGIES.
WRITE(MWRITE,720)
WRITE(MWRITE,725) CINFNT
WRITE(MWRITE,726) CINFRT
WRITE(MWRITE,730) EWORK
WRITE(MWRITE,740) CINET
WRITE(MWRITE,750) ELAST
WRITE(MWRITE,760) PLASTW
WRITE(MWRITE,770) SPREN
IPRT0371
IPRT0372
IPRT0373
IPRT0374
IPRT0375
IPRT0376
IPRT0377
IPRT0378
IPRT0379
IPRT0380
IPRT0381
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IPRT0384
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IPRT0397
IPRT0398
IPRT0399
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IPRT0422
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IPRT0424
IPRT0425
IPRT0426
IPRT0427
IPRT0428
IPRT0429

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440 CONTINUE                                IPRT0430
500 CONTINUE                                IPRT0431
550 FORMAT('0','REACTION FORCES AT CONSTRAINED NODES') IPRT0432
560 FORMAT('0',2X,'NODE',4X,'RX(LBS)',8X,'RY(LBS)',8X,'RZ(LBS)',7X, IPRT0433
      2'MX(LBS-IN)',5X,'MY(LBS-IN)',5X,'MXY(LBS-IN-IN)') IPRT0434
570 FORMAT(' ',I6,6D15.5) IPRT0435
600 FORMAT('0','***** INCR NO.=',I5,2X,'TIME=',D12.4,1X,'SEC.') IPRT0436
610 FORMAT('0','NODE',6X,'U',12X,'V',12X,'W',11X,'PSIX',9X,'PSIY',9X, IPRT0437
      2'TWIST',7X,'X-POS',7X,'Y-POS.',7X,'Z-POS.') IPRT0438
620 FORMAT(' ',I4,9D13.5) IPRT0439
630 FORMAT('0','STRAIN COMPONENTS, PRINCIPAL(TENSILE) STRAIN AND DIREC IPRT0440
      2TION AT CENTROID OF EACH ELEMENT') IPRT0441
640 FORMAT('0',14X,'EPS-X STRAIN',12X,'EPS-Y STRAIN',12X,'SHEAR STRAIN IPRT0442
      2',12X,'PRINC. STRAIN(T)',10X,'DIRECTION(DEG.)') IPRT0443
644 FORMAT(' ',ELEM',5(7X,'INNER',7X,'OUTER')) IPRT0444
645 FORMAT(' ',STA.',5(7X,'INNER',7X,'OUTER')) IPRT0445
650 FORMAT(' ',I4,1X,10D12.4) IPRT0446
660 FORMAT('0','STRAIN COMPONENTS, PRINCIPAL(TENSILE) STRAIN AND DIREC IPRT0447
      2TION AT GAUSS STATIONS FOR SELECTED ELEMENTS') IPRT0448
670 FORMAT('0','RESULTS FOR ELEMENT NUMBER',I5) IPRT0449
690 FORMAT('0','STRAIN COMPONENTS, PRINCIPAL(TENSILE) STRAIN AND DIREC IPRT0450
      2TION, AND ELONGATIONS AT SPECIFIED ADDITIONAL POINTS') IPRT0451
695 FORMAT('0','POINT NO.',2X,'SURFACE',2X,'EPS-X STRAIN',2X,'EPS-Y ST IPRT0452
      2RAIN',2X,'SHEAR STRAIN',1X,'ELONG.(DIR.1)',1X,'ELONG.(DIR.2)',1X, IPRT0453
      3'PRINC. STRN(T)',1X,'DIRECTION(DEG.)') IPRT0454
700 FORMAT(' ',I7,5X,'INNER',1X,7D14.5) IPRT0455
710 FORMAT(' ',I7,5X,'OUTER',1X,7D14.5) IPRT0456
720 FORMAT('0','SYSTEM ENERGIES(IN-LB)') IPRT0457
725 FORMAT(' ',5X,'FRAG. TRANSLATIONAL KINETIC ENERGY =',D15.7) IPRT0458
726 FORMAT(' ',5X,'FRAG. ROTATIONAL KINETIC ENERGY =',D15.7) IPRT0459
730 FORMAT(' ',5X,'WORK INPUT TO STRUCTURE =',D15.7) IPRT0460
740 FORMAT(' ',5X,'STRUCTURE KINETIC ENERGY =',D15.7) IPRT0461
750 FORMAT(' ',5X,'STRUCTURE ELASTIC ENERGY =',D15.7) IPRT0462
760 FORMAT(' ',5X,'STRUCTURE PLASTIC ENERGY =',D15.7) IPRT0463
770 FORMAT(' ',5X,'ENERGY STORED IN ELASTIC RESTRAINTS=',D15.7) IPRT0464
780 FORMAT('0','STRAIN, EPS-XX, AT GAUSSIAN STATIONS ON SPECIFIED X-DI IPRT0465
      2RECTION STIFFENERS') IPRT0466
785 FORMAT('0','STIFFENER',14X,'STATION 1',15X,'STATION 2',15X, IPRT0467
      2'STATION 3') IPRT0468
790 FORMAT(' ',NUMBER',5X,3(7X,'INNER',7X,'OUTER')) IPRT0469
800 FORMAT(' ',I5,7X,6D12.4) IPRT0470
810 FORMAT('0','STRAIN, EPS-YY, AT GAUSSIAN STATIONS ON SPECIFIED Y-DI IPRT0471
      2RECTION STIFFENERS') IPRT0472
900 FORMAT('0','STRAIN COMPONENTS, PRINCIPAL (TENSILE) STRAIN AND DIRE IPRT0473
      2CTION AT USER-SPECIFIED NODES') IPRT0474
920 FOPMAT(' ',NODE',5(7X,'INNER',7X,'OUTER')) IPRT0475
940 FORMAT('0','FRAGMENT GLOBAL LOCATION AND VELOCITY COMPONENTS') IPRT0476
950 FORMAT(' ',9X,'X-LOC',9X,'Y-LOC',9X,'Z-LOC',9X,'VEL-X',9X,'VEL-Y', IPRT0477
      29X,'VEL-Z',7X,'OMEGA-X',7X,'OMEGA-Y',7X,'OMEGA-Z') IPRT0478
960 FORMAT(' ',9D14.6) IPRT0479
      RETURN IPRT0480
      END IPRT0481

```

C	CIVM-PLATE 1 COMPUTER CODE.	IMAN0000
C		IMAN0001
C	THIS DUMMY MAIN PROGRAM FOR THE CIVM PLATE PROGRAM REQUIRES	IMAN0002
C	THESE SUBROUTINES:	IMAN0003
C	ARRT, ASSEM, DCONMK, COLLSN, CAROW, FACT, GAUSS, IFRAG,	IMAN0004
C	IMAINP, IMPACT, IMPDS, IMPSS, INTRAC, IPRINT, LMASSP,	IMAN0005
C	MESHPA, MESHPM, OMULT, PROTOP, PSTRN, RCON, RPLATE, SFDM,	IMAN0006
C	SOLV, SPRING, STRLSA, STRESC, STRESP, TSTEP.	IMAN0007
C		IMAN0008
C	ILLUSTRATIVE EXAMPLE FOR CIVM PLATE PROGRAM - FULL MODEL.	IMAN0009
C		IMAN0010
C	SMALL STRAIN FORMULATION VERSION WRITTEN BY R. L. SPILKER	IMAN0011
C		IMAN0012
C	ASRL TR 154-14.....ORIGINAL REPORT VERSION OF PROGRAM	IMAN0013
C	COPYRIGHT (C) MASSACHUSETTS INSTITUTE OF TECHNOLOGY 1980	IMAN0014
C		IMAN0015
C	DUMMY MAIN PROGRAM WHICH PROVIDES DIMENSIONS FOR THOSE ARRAYS	IMAN0016
C	(VECTORS) WHOSE DIMENSIONS ARE PROBLEM DEPENDENT.	IMAN0017
C	THE FOLLOWING ARRAYS MUST BE DIMENSIONED BY THE USER AS SHOWN;	IMAN0018
C	DIMENSION DELD(NDT), DIS(NDT), DISP(NDT), DISM1(NDT), DISM2(NDT),	IMAN0019
C	FLN(NDT), FLVA(NDT), FLVM(NDT), FLVP(NDT), VEL(NDT), ICOL(NDT),	IMAN0020
C	INUM(NDT), KROW(NDT), NDEX(NDT), STF(MNC), AMASS(NDT), NP(4, MAXEL),	IMAN0021
C	NODE(24*MAXEL), TAUSS(MAXEL, 4*MNSL, 9), TAUSE(MAXEL, 4*MNSL, 9),	IMAN0022
C	TAUEE(MAXEL, 4*MNSL, 9), EPSSI(9, MAXEL), EPSSO(9, MAXEL), EPEEI(9, MAXEL)	IMAN0023
C	, EPEEO(9, MAXEL), EPSEI(9, MAXEL), EPSEO(9, MAXEL), NBC(NB), BC(NB),	IMAN0024
C	RFM(NBE, MBWE), ILAST(NBE), UCF1(NBE), UCF2(NBE), XG(NNT), YG(NNT),	IMAN0025
C	ZG(NNT), XGI(NNT), YGI(NNT).	IMAN0026
C	TAGSS(MNXST, 4*MNSL, 3), LNXS(MNXST), XSPROP(7, MNXST), MATXS(MNXST),	IMAN0027
C	TSGEE(MNYST, 4*MNSL, 3), LNYS(MNYST), YSPROP(7, MNYST), MATYS(MNYST),	IMAN0028
C	LNRS(NRSS), ISRS(NRSS), SC(5, NRSS), NVSA(MNNSA), NCON(4, MNNSA),	IMAN0029
C	PMASS(NNT), VN(3, NIAN), VNB(3, NIAN), SI(NIAN), NEFF(NIAN), ALPHA(NIAN)	IMAN0030
C		IMAN0031
C	WHERE,	IMAN0032
C	NNT = TOTAL NUMBER OF NODES IN THE ASSEMBLED FINITE-ELEMENT MODEL	IMAN0033
C	NDT = TOTAL NUMBER OF DEGREES OF FREEDOM IN THE ASSEMBLED FINITE-	IMAN0034
C	ELEMENT MODEL = 6*NNT.	IMAN0035
C	MNC = ESTIMATED NUMBER OF WORDS OF STORAGE FOR THE ASSEMBLED	IMAN0036
C	STIFFNESS MATRIX (LOWER TRIANGLE STORED BY ROWS FROM FIRST	IMAN0037
C	NONZERO TERM).	IMAN0038
C	MAXEL = NUMBER OF ELEMENTS IN FINITE-ELEMENT MODEL.	IMAN0039
C	MNSL = MAXIMUM NUMBER OF MECHANICAL SUBLAYERS EMPLOYED.	IMAN0040
C	NOTE-- MNSL MUST BE LESS THAN OR EQUAL TO 5.	IMAN0041
C	NB = ESTIMATED NUMBER OF CONSTRAINED DEGREES OF FREEDOM PRIOR	IMAN0042
C	TO ELIMINATION OF DUPLICATES.	IMAN0043
C	NBE = ESTIMATED NUMBER OF CONSTRAINED DEGREES OF FREEDOM AFTER	IMAN0044
C	ALL DUPLICATES HAVE BEEN ELIMINATED (IF IOP5 = 1).	IMAN0045
C	= 1 IF IOP5 = 0	IMAN0046
C	MBWE = ESTIMATED MAXIMUM BANDWIDTH OF ASSEMBLED STIFFNESS MATRIX	IMAN0047
C	AT A CONSTRAINED DEGREE OF FREEDOM (IF IOP5 = 1).	IMAN0048
C	= 1 IF IOP5 = 0	IMAN0049
C	MNXST = MAXIMUM NUMBER OF X-DIRECTION STIFFENERS.	IMAN0050
C	= 1 IF NO X-DIRECTION STIFFENERS.	IMAN0051
C	MNYST = MAXIMUM NUMBER OF Y-DIRECTION STIFFENERS.	IMAN0052

```

C      = 1 IF NO Y-DIRECTION STIFFENERS. IMAN0053
C NRSS = TOTAL NUMBER OF ELEMENT SIDES ON WHICH LINE RESTORING IMAN0054
C      SPRINGS ARE LOCATED. IMAN0055
C      = 1 IF NO RESTORING SPRINGS ARE PRESENT. IMAN0056
C MNSLT4 = 4*MNSL IMAN0057
C MNNSA = MAXIMUM NUMBER OF NODES REQUESTED FOR STRAIN OUTPUT IMAN0058
C      = (IF IOPB=1). IMAN0059
C NIAN = ESTIMATED MAXIMUM NUMBER OF NODES WHICH WILL BE AFFECTED IMAN0060
C      BY A SINGLE IMPACT. IMAN0061
      IMPLICIT REAL*8(A-H,O-Z) IMAN0062
      DIMENSION DELD(450),DIS(450),DISP(450),DISM1(450),DISM2(450), IMAN0063
      2FLN(450),FLVA(450),FLVM(450),FLVP(450),VEL(450),ICOL(450), IMAN0064
      3INUM(450),KROW(450),NDEX(450),STF(16335),AMASS(450), IMAN0065
      4NP(4,56),NODE(1344),TAUSS(56,12,9),TAUSE(56,12,9),TAUEE(56,12,9), IMAN0066
      5EPSSI(9,56),EPSSO(9,56),EPEEI(9,56),EPEEO(9,56),EPSEI(9,56), IMAN0067
      6EPSEO(9,56),NBC(60),BC(60),RFM(1,1),ILAST(1),UCF1(1),UCF2(1), IMAN0068
      7XG(75),YG(75),ZG(75),XGI(75),YGI(75),TAGSS(1,12,3),LNXS(1), IMAN0069
      8XSPROP(7,1),MATXS(1),TSGEE(28,12,3),LNYS(28),YSPROP(7,28),MATYS(28 IMAN0070
      9),LNRS(28),ISRS(28),SC(5,28),NVSA(8),NCON(4,8),PMASS(75),VN(3,75), IMAN0071
      A VNB(3,75),SI(75),NEFF(75),ALPHA(75) IMAN0072
      COMMON/BAS/NOT,NET,MN,NB,NIRREG,MNC IMAN0073
      COMMON /INOUT/ MREAD,MWRITE,MPUNCH IMAN0074
C DEFINE CARD READER, LINE PRINTER AND CARD PUNCH UNIT NUMBERS. IMAN0075
      MREAD = 5 IMAN0076
      MWRITE = 6 IMAN0077
      MPUNCH = 7 IMAN0078
      READ(MREAD,500)MAXEL,MNSL,MNXST,MNYST,NBE,MBWE,MNC,NIAN IMAN0079
500  FORMAT(BI10) IMAN0080
      WRITE(MWRITE,600) IMAN0081
      WRITE(MWRITE,610) MAXEL IMAN0082
      WRITE(MWRITE,620) MNSL IMAN0083
      WRITE(MWRITE,630) MNXST IMAN0084
      WRITE(MWRITE,640) MNYST IMAN0085
      WRITE(MWRITE,650) NBE IMAN0086
      WRITE(MWRITE,660) MBWE IMAN0087
      WRITE(MWRITE,670) MNC IMAN0088
      WRITE(MWRITE,680) NIAN IMAN0089
600  FORMAT('1 CIVM-PLATE 1 COMPUTER CODE (SMALL STRAIN THEORY) : USER' IMAN0090
      +INPUT FOR ARRAY DIMENSIONS') IMAN0091
610  FORMAT(' ', 'MAXEL = ', I10) IMAN0092
620  FORMAT(' ', 'MNSL = ', I10) IMAN0093
630  FORMAT(' ', 'MNXST = ', I10) IMAN0094
640  FORMAT(' ', 'MNYST = ', I10) IMAN0095
650  FORMAT(' ', 'NBE = ', I10) IMAN0096
660  FORMAT(' ', 'MBWE = ', I10) IMAN0097
670  FORMAT(' ', 'MNC = ', I10) IMAN0098
680  FORMAT(' ', 'NIAN = ', I10) IMAN0099
      MNSLT4=MNSL+4 IMAN0100
      CALL IMAINP(DELD,DIS,DISP,DISM1,DISM2,FLN,FLVA,FLVM,FLVP, IMAN0101
      2VEL,ICOL,INUM,KROW,NDEX, STF,AMASS,NP,NODE,TAUSS,TAUSE,TAUEE, IMAN0102
      3EPSSI,EPSSO,EPEEI,EPCEO,EPSEI,EPSEO,NBC,BC,RFM,ILAST,UCF1,UCF2, IMAN0103
      4XG,YG,ZG,XGI,YGI,TAGSS,LNXS,XSPROP,MATXS,TSGEE,LNYS,YSPROP,MATYS, IMAN0104
      5LNRS,ISRS,SC,MAXEL,MNSL,MNSLT4,NBE,MBWE,MNXST,MNYST,NVSA,NCON, IMAN0105

```

6PMASS, VN, VNB, SI, NEFF, ALPHA, NIAN)
CALL EXIT
END

IMANO106
IMANO107
IMANO108

SECTION 7

PLATE 1 CODE EXAMPLE: TRANSIENTLY-LOADED NARROW RECTANGULAR PLATE

To illustrate the use of the PLATE 1 computer program, a narrow rectangular plate with both ends clamped is analyzed.* The plate is subjected to a prescribed distributed vertical-direction transient external loading. Three alternate finite-element modelings are described, and the associated input data for each are shown. However, for conciseness, solution output data are given for only one of these models; these results can be employed by the user to check the adaptation of PLATE 1 to his particular computing facilities.

7.1 Problem Description

A narrow rectangular uniform-thickness aluminum plate with both ends ideally clamped and both sides free is subjected to a uniform w-direction triangular time-pulse pressure loading $F_z^A \equiv p_z \equiv p_0 = 21,934.4$ psi for a 25-microsecond duration, as depicted in Fig. 16. This pressure loading covers the entire width of the plate and a 1.80-in spanwise region centered at the midspan station. This plate is of 0.102-in thickness, 1.497-in width, and 8.00-in span.

The initial mass per unit volume ρ_0 of this plate material is assumed to be 0.25384×10^{-3} (lb-sec²)/in⁴. The uniaxial stress-strain (σ, ϵ) properties of the plate material are represented by a 3-sublayer version of the mechanical-sublayer material model, defined by $\sigma_1, \epsilon_1 = 44,200$ psi, 0.00442 in/in; $\sigma_2, \epsilon_2 = 49,200$ psi, 0.0760; and $\sigma_3, \epsilon_3 = 76,400$ psi, 0.615; this behavior is described as elastic, strain hardening (EL-SH). In addition, it is assumed that this material yields in a rate-dependent fashion with the strain-rate constants assumed to be $d = 6500$ sec⁻¹ and $p = 4$; this material is thus described concisely as of EL-SH-SR type where SR denotes that the material is strain-rate sensitive. Also, it is assumed that this initially-isotropic material has an elastic (Young's) modulus of 10×10^6 psi and a Poisson ratio of 1/3.

* Additional examples and transient response predictions obtained by using the PLATE 1 program are described in Subsection 7.2 of Ref. 14 as the "small strain" calculations.

The generalized nodal loads for a plate element of dimensions $(x,y) = (a,b)$ subjected to externally-applied loads $F_x^L = F_y^L = F_z^L = F_x^B = F_y^B = F_z^B = F_x^A = F_y^A = F_z^A = 0$ and $F_z^A \equiv p_0$ (psi) -- (see Subsection A.1.3.4 and Eqs. A.54) -- can be shown for the present LLC plate element to be:

Node	Degree of Freedom (DOF) ⁺					
	u	v	w	$\frac{\partial w}{\partial x}$	$\frac{\partial w}{\partial y}$	$\frac{\partial^2 w}{\partial x \partial y}$
1	0	0	$\frac{ab}{4}$	$\frac{a^2 b}{24}$	$\frac{ab^2}{24}$	$\frac{a^2 b^2}{144}$
2	0	0	$\frac{ab}{4}$	$-\frac{a^2 b}{24}$	$\frac{ab^2}{24}$	$-\frac{a^2 b^2}{144}$
3	0	0	$\frac{ab}{4}$	$-\frac{a^2 b}{24}$	$-\frac{ab^2}{24}$	$\frac{a^2 b^2}{144}$
4	0	0	$\frac{ab}{4}$	$\frac{a^2 b}{24}$	$-\frac{ab^2}{24}$	$-\frac{a^2 b^2}{144}$

These values apply for a unit value of uniform pressure loading p_0 ; hence, if $p_0 = p_0(t)$, the appropriate corresponding element nodal loads are obtained by multiplying the above values by $p_0(t)$.

For each of the three modelings employed, it is necessary to provide a specific version each of subroutines EXTL (prescribed transient external loading) and INCOND (initial conditions). A listing of the subroutines for each of these three example modelings follows.

⁺ See Fig. 2 for definitions and signs of these generalized displacements; the positive generalized loads are defined consistent with these directions.

Subroutines for the Full-Plate Model

```

SUBROUTINE EXTL(ELV,ITT,NP,NODE,XGI,YGI,GBI)
IMPLICIT REAL*8(A-H,O-Z)
C
C ASRL TR 154-14.....ORIGINAL REPORT VERSION OF PROGRAM
C COPYRIGHT (C) MASSACHUSETTS INSTITUTE OF TECHNOLOGY 1980
C THIS SUBROUTINE IS USED EXCLUSIVELY BY THE PLATE PROGRAM.
C THIS VERSION IS FOR THE EXAMPLE OF A RECTANGULAR PLATE, CLAMPED
C ON THE TOP AND BOTTOM EDGES, FREE ON THE OTHER TWO EDGES WITH AN
C IMPULSIVE LOAD APPLIED SYMMETRICALLY TO ITS CENTRAL REGION.
  DIMENSION ELV(1),NP(4,1),NODE(1),XGI(1),YGI(1),GBI(24,24)
C
C THIS USER-PREPARED SUBROUTINE IS USED TO GENERATE THE NODAL
C GENERALIZED FORCES CORRESPONDING TO PRESCRIBED EXTERNALLY-APPLIED
C FORCES AT TIME T SUB M (=M*DELTA T) AS DESCRIBED IN SUBSECTION 4.6.2
C AND CORRESPONDING TO THE DEVELOPMENT IN SUBSECTION A.1.3.4.
C
C DEFINE SIZE OF VECTOR CONTAINING UNIT LOAD OVER ALL DOF IN CENTRAL
C REGION OF PLATE. WIDTH OF LOADED REGION IS 1.497 IN.,LENGTH IS 1.8 IN.
  DIMENSION ALOAD(150),AL1(72),AL2(78)
  EQUIVALENCE (AL1(1),ALOAD(1)),(AL2(1),ALOAD(73))
C
COMMON /BAS/ NDT,NET,MN,NB,NIRREG,MNC
COMMON/TIM/DELTAT,TIMEF,TIME,ITIMEF,INCRT,IOUT,ITIME
COMMON /INOUT/ MREAD,MWRITE,MPUNCH
C DEFINE TIME AT WHICH LOAD DROPS TO ZERO AND MAX VALUE OF IMPULSE.
  DATA TEND/25.D-6/,AMAXP/219344DO/
C DEFINE FIRST AND LAST DOF IN LOADED REGION.
  DATA IDOF/121/,LODF/270/
C DEFINE VALUES OF UNIT LOAD AT EACH DOF IN LOADED REGION.
  DATA AL1/2*0.D0,.4210312D-1,.2626182D-2,.3157734D-2,.1969637D-3/
  1 ,2*0.D0,.8420625D-1,.0000000D+0,.6315468D-2,.0000000D+0/
  2 ,2*0.D0,.8420625D-1,.0000000D+0,.6315468D-2,.0000000D+0/
  3 ,2*0.D0,.8420625D-1,.0000000D+0,.6315468D-2,.0000000D+0/
  4 ,2*0.D0,.4210312D-1,-.2626182D-2,.3157734D-2,-.1969637D-3/
  5 ,2*0.D0,.8420625D-1,.5252365D-2,.0000000D+0,.0000000D+0/
  6 ,2*0.D0,.1684125D+0,.0000000D+0,.0000000D+0,.0000000D+0/
  7 ,2*0.D0,.1684125D+0,.0000000D+0,.0000000D+0,.0000000D+0/
  8 ,2*0.D0,.1684125D+0,.0000000D+0,.0000000D+0,.0000000D+0/
  9 ,2*0.D0,.8420625D-1,-.5252365D-2,.0000000D+0,.0000000D+0/
  A ,2*0.D0,.8420625D-1,.5252365D-2,.0000000D+0,.0000000D+0/
  B ,2*0.D0,.1684125D+0,.0000000D+0,.0000000D+0,.0000000D+0/
  DATA AL2/2*0.D0,.1684125D+0,.0000000D+0,.0000000D+0,.0000000D+0/
  1 ,2*0.D0,.1684125D+0,.0000000D+0,.0000000D+0,.0000000D+0/
  2 ,2*0.D0,.8420625D-1,-.5252365D-2,.0000000D+0,.0000000D+0/
  3 ,2*0.D0,.8420625D-1,.5252365D-2,.0000000D+0,.0000000D+0/
  4 ,2*0.D0,.1684125D+0,.0000000D+0,.0000000D+0,.0000000D+0/
  5 ,2*0.D0,.1684125D+0,.0000000D+0,.0000000D+0,.0000000D+0/
  6 ,2*0.D0,.1684125D+0,.0000000D+0,.0000000D+0,.0000000D+0/
  7 ,2*0.D0,.8420625D-1,-.5252365D-2,.0000000D+0,.0000000D+0/
  8 ,2*0.D0,.4210312D-1,.2626182D-2,-.3157734D-2,-.1969637D-3/
  9 ,2*0.D0,.8420625D-1,.0000000D+0,-.6315468D-2,.0000000D+0/
  A ,2*0.D0,.8420625D-1,.0000000D+0,-.6315468D-2,.0000000D+0/
  B ,2*0.D0,.8420625D-1,.0000000D+0,-.6315468D-2,.0000000D+0/
  C ,2*0.D0,.4210312D-1,-.2626182D-2,-.3157734D-2,.1969637D-3/
C ZERO OUT LOAD VECTOR.
  DO 1 I=1,NDT
  1 ELV(I)=0.000

```

```

EXTL0000
EXTL0001
EXTL0002
EXTL0003
EXTL0004
EXTL0005
EXTL0006
EXTL0007
EXTL0008
EXTL0009
EXTL0010
EXTL0011
EXTL0012
EXTL0013
EXTL0014
EXTL0015
EXTL0016
EXTL0017
EXTL0018
EXTL0019
EXTL0020
EXTL0021
EXTL0022
EXTL0023
EXTL0024
EXTL0025
EXTL0026
EXTL0027
EXTL0028
EXTL0029
EXTL0030
EXTL0031
EXTL0032
EXTL0033
EXTL0034
EXTL0035
EXTL0036
EXTL0037
EXTL0038
EXTL0039
EXTL0040
EXTL0041
EXTL0042
EXTL0043
EXTL0044
EXTL0045
EXTL0046
EXTL0047
EXTL0048
EXTL0049
EXTL0050
EXTL0051
EXTL0052
EXTL0053
EXTL0054
EXTL0055
EXTL0056
EXTL0057
EXTL0058

```

```

C IF THIS TIME STEP IS BEYOND LAST TIME OF IMPULSE RETURN WITH
C EXTERNAL LOAD VECTOR SET TO ZERO.
      TYM=(ITT-1)*DELTAT
      IF(TYM .GT. TEND) RETURN
C INTERPOLATE TO FIND MAGNITUDE OF IMPULSE AT THIS TIME.
      AMULT=AMAXP*(TEND-TYM)/TEND
C FILL IN VALUES OF LOAD IN CENTRAL REGION OF PLATE.
      DO 2 I=1DOF,LDOF
        J=I-IDOF+1
        2 ELV(I)=AMULT*ALOAD(J)
C OUTPUT LOADS IF THIS IS A REGULAR PRINTING CYCLE.
      III=ITIME/INCRT*INCRT-ITIME
      IF(III.NE.0) RETURN
      NNT=NDT/6
      WRITE(MWRITE,100) TYM ,(J,J=1,6)
100  FORMAT(1H0/1H0,10X,'TIME=',D16.6,' SEC./1H ,33(1H.),'EXTERNALLY A
+PLIED USER SPECIFIED LOADING',33(1H.)/1H ,6X,'NODE',6(7X,'DOF#',
& I1,3X)/8X,3(10X,'(LBS)'),1X,3(7X,'(IN-LBS)'))
      I1=1
      DO 3 I=1,NNT
        I2=G*I
        WRITE(MWRITE,101) I,(ELV(J),J=I1,I2)
        I1=I2+1
      3  CONTINUE
101  FORMAT(6X,I3,2X,6D15.6)
      RETURN
      END
      SUBROUTINE INCOND(DISP,VEL,NP,NODE,XGI,YGI)
      IMPLICIT REAL*8(A-H,O-Z)
C
C   ASRL TR 154-14.....ORIGINAL REPORT VERSION OF PROGRAM
C   COPYRIGHT (C) MASSACHUSETTS INSTITUTE OF TECHNOLOGY 1980
C
C   THIS SUBROUTINE IS USED EXCLUSIVELY BY THE PLATE PROGRAM.
C
      DIMENSION DISP(1),VEL(1),NP(4,1),NODE(1),XGI(1),YGI(1)
      COMMON/BAS/NDT,NET,MN,NB,NIRREG,MNC
C
C   THIS USER-PREPARED SUBROUTINE IS USED TO SPECIFY THE INITIAL (TIME
C   ZERO) CONDITIONS ON THE PLATE NODAL DISPLACEMENT AND VELOCITIES,
C   (Q ZERO)* AND (Q DOT ZERO)*, RESPECTIVELY, REQUIRED FOR THE FINITE-
C   DIFFERENCE SOLUTION OF THE GOVERNING EQUATIONS OF MOTION (SEE
C   SUBSECTION A.3).
C
C   DUMMY ROUTINE - SETS VELOCITY AND DISPLACEMENT TO ZERO INITIALLY.
C
      DO 10 I=1,NDT
        DISP(I)=0.0D0
        VEL(I)=0.0D0
      10  RETURN
      END

```

```

EXTL0059
EXTL0060
EXTL0061
EXTL0062
EXTL0063
EXTL0064
EXTL0065
EXTL0066
EXTL0067
EXTL0068
EXTL0069
EXTL0070
EXTL0071
EXTL0072
EXTL0073
AEXTL0074
EXTL0075
EXTL0076
EXTL0077
EXTL0078
EXTL0079
EXTL0080
EXTL0081
EXTL0082
EXTL0083
EXTL0084
EXTL0085
INCD0000
INCD0001
INCD0002
INCD0003
INCD0004
INCD0005
INCD0006
INCD0007
INCD0008
INCD0009
INCD0010
INCD0011
INCD0012
INCD0013
INCD0014
INCD0015
INCD0016
INCD0017
INCD0018
INCD0019
INCD0020
INCD0021
INCD0022
INCD0023

```

Subroutines for the Half-Plate Model

```

SUBROUTINE EXTL(ELV,ITT,NP,NODE,XGI,YGI,GBI)
IMPLICIT REAL*8(A-H,O-Z)
EXTL1000
C
C ASRL TR 154-14.....ORIGINAL REPORT VERSION OF PROGRAM
EXTL1001
C COPYRIGHT (C) MASSACHUSETTS INSTITUTE OF TECHNOLOGY 1980
EXTL1002
C
C THIS SUBROUTINE IS USED EXCLUSIVELY BY THE PLATE PROGRAM.
EXTL1003
C
C THIS VERSION IS FOR THE EXAMPLE OF A RECTANGULAR PLATE, CLAMPED
EXTL1004
C ON THE TOP AND BOTTOM EDGES, FREE ON THE OTHER TWO EDGES WITH AN
EXTL1005
C IMPULSIVE LOAD APPLIED SYMMETRICALLY TO ITS CENTRAL REGION.
EXTL1006
C
C ONLY THE RIGHT HALF OF THE PLATE IS MODELLED USING THE SYMMETRY
EXTL1007
C CONDITION ON THE LEFT EDGE. THIS IS THE SINGLE SYMMETRY CASE.
EXTL1008
C
C DIMENSION ELV(1),NP(4,1),NODE(1),XGI(1),YGI(1),GBI(24,24)
EXTL1009
EXTL1010
EXTL1011
C
C THIS USER-PREPARED SUBROUTINE IS USED TO GENERATE THE NODAL
EXTL1012
C GENERALIZED FORCES CORRESPONDING TO PRESCRIBED EXTERNALLY-APPLIED
EXTL1013
C FORCES AT TIME T SUB M (=M*DELTA T) AS DESCRIBED IN SUBSECTION 4.6.2
EXTL1014
C AND CORRESPONDING TO THE DEVELOPMENT IN SUBSECTION A.1.3.4.
EXTL1015
EXTL1016
C
C DEFINE SIZE OF VECTOR CONTAINING UNIT LOAD OVER ALL DOF IN CENTRAL
EXTL1017
C REGION OF PLATE. WIDTH OF LOADED REGION IS .7485 IN, LENGTH IS 1.8 IN.
EXTL1018
C
C DIMENSION ALOAD(90)
EXTL1019
COMMON /BAS/ NDT,NET,MN,NB,NIRREG,MNC
EXTL1020
COMMON /TIM/ DELTAT,TIMEF,TIME,ITIMEF,INCR,T,OUT,ITIME
EXTL1021
COMMON /INOUT/ MREAD,MWRITE,MPUNCH
EXTL1022
C
C USE DATA STATEMENTS FOR VALUES WHICH WILL NOT CHANGE THROUGHOUT RUN.
EXTL1023
EXTL1024
EXTL1025
C
C DEFINE TIME AT WHICH LOAD DROPS TO ZERO AND MAX VALUE OF IMPULSE.
EXTL1026
DATA TEND/25.D-6/,AMAXP/21934.400/
EXTL1027
C
C DEFINE FIRST AND LAST DOF IN LOADED REGION.
EXTL1028
DATA IDOF/73/, LOOF/162/
EXTL1029
C
C DEFINE VALUES OF UNIT LOAD AT EACH DOF IN LOADED REGION.
EXTL1030
DATA ALOAD/2*0 D0,.4210312D-1, .2626182D-2,.3157734D-2,.1969637D-3
EXTL1031
1 .2*0 D0,.8420625D-1, .0000000D+0, .6315468D-2, .0000000D+0
EXTL1032
2 .2*0 D0, .4210312D-1,-.2626182D-2, .3157734D-2,-.1969637D-3
EXTL1033
3 .2*0 D0,.8420625D-1, .5252365D-2, .0000000D+0, .0000000D+0
EXTL1034
4 .2*0 D0,.1684125D+0, .0000000D+0, .0000000D+0, .0000000D+0
EXTL1035
5 .2*0 D0,.8420625D-1,-.5252365D-2, .0000000D+0, .0000000D+0
EXTL1036
6 .2*0 D0, .8420625D-1, .5252365D-2, .0000000D+0, .0000000D+0
EXTL1037
7 .2*0 D0,.1684125D+0, .0000000D+0, .0000000D+0, .0000000D+0
EXTL1038
8 .2*0 D0, .8420625D-1,-.5252365D-2, .0000000D+0, .0000000D+0
EXTL1039
9 .2*0 D0, .8420625D-1, .5252365D-2, .0000000D+0, .0000000D+0
EXTL1040
A .2*0 D0, .1684125D+0, .0000000D+0, .0000000D+0, .0000000D+0
EXTL1041
B .2*0 D0,.8420625D-1,-.5252365D-2, .0000000D+0, .0000000D+0
EXTL1042
C .2*0 D0, .4210312D-1, .2626182D-2,-.3157734D-2,-.1969637D-3
EXTL1043
D .2*0 D0, .8420625D-1, .0000000D+0,-.6315468D-2, .0000000D+0
EXTL1044
E .2*0 D0,.4210312D-1,-.2626182D-2,-.3157734D-2, .1969637D-3/
EXTL1045
C
C ZERO OUT LOAD VECTOR.
EXTL1050
DO 1 I=1,NDT
EXTL1051
1 ELV(I)=0.000
EXTL1052
TYM=(ITT-1)*DELTAT
EXTL1053
C
C IF THIS TIME STEP IS BEYOND LAST TIME OF IMPULSE RETURN WITH
EXTL1054
C EXTERNAL LOAD VECTOR SET TO ZERO.
EXTL1055
IF(TYM GT. TEND) RETURN
EXTL1056
C
C INTERPOLATE TO FIND MAGNITUDE OF IMPULSE AT THIS TIME.
EXTL1057
AMULT=AMAXP*(TEND-TYM)/TEND
EXTL1058

```

C	FILL IN VALUES OF LOAD IN CENTRAL REGION OF PLATE.	EXTL1059
	DO 2 I=IDOF, LDOF	EXTL1060
	J=I-IDOF+1	EXTL1061
	2 ELV(I)=AMULT*ALOAD(J)	EXTL1062
C	OUTPUT LOADS IF THIS IS A REGULAR PRINTING CYCLE.	EXTL1063
	III=ITIME/INCR+INCR-ITIME	EXTL1064
	IF(III.NE.0) RETURN	EXTL1065
	NNT=NDT/6	EXTL1066
	WRITE(MWRITE,100) TYM ,(J,J=1,6)	EXTL1067
100	FORMAT(1H0/1H0,10X,'TIME=',D16.6,' SEC.'/1H,33(1H.),'EXTERNALLY APPLIED USER SPECIFIED LOADING',33(1H.)/1H,6X,'NODE',6(7X,'DOF#',	EXTL1068
	& 11,3X)/8X,3(10X,'(LBS)'),1X,3(7X,'(IN-LBS)')	EXTL1069
	I1=1	EXTL1070
	DO 3 I=1,NNT	EXTL1071
	I2=6*I	EXTL1072
	WRITE(MWRITE,101) I,(ELV(J),J=I1,I2)	EXTL1073
	I1=I2+1	EXTL1074
3	CONTINUE	EXTL1075
101	FORMAT(6X,13,2X,6D15.6)	EXTL1076
	RETURN	EXTL1077
	END	EXTL1078
	SUBROUTINE INCOND(DISP,VEL,NP,NODE,XGI,YGI)	EXTL1079
	IMPLICIT REAL*8(A-H,O-Z)	INCD1000
C		INCD1001
C	ASRL TR 154-14.....ORIGINAL REPORT VERSION OF PROGRAM	INCD1002
C		INCD1003
C	COPYRIGHT (C) MASSACHUSETTS INSTITUTE OF TECHNOLOGY 1980	INCD1004
C		INCD1005
C	THIS SUBROUTINE IS USED EXCLUSIVELY BY THE PLATE PROGRAM.	INCD1006
C		INCD1007
C		INCD1008
	DIMENSION DISP(1),VEL(1),NP(4,1),NODE(1),XGI(1),YGI(1)	INCD1009
	COMMON/BAS/NDT,NET,MN,NB,NIRREG,MNC	INCD1010
C		INCD1011
C	THIS USER-PREPARED SUBROUTINE IS USED TO SPECIFY THE INITIAL (TIME	INCD1012
C	ZERO) CONDITIONS ON THE PLATE NODAL DISPLACEMENT AND VELOCITIES,	INCD1013
C	(Q ZERO)* AND (Q DOT ZERO)*, RESPECTIVELY, REQUIRED FOR THE FINITE-	INCD1014
C	DIFFERENCE SOLUTION OF THE GOVERNING EQUATIONS OF MOTION (SEE	INCD1015
C	SUBSECTION A.3).	INCD1016
C		INCD1017
C	DUMMY ROUTINE - SETS VELOCITY AND DISPLACEMENT TO ZERO INITIALLY.	INCD1018
C		INCD1019
	DO 10 I=1,NDT	INCD1020
	DISP(I)=0.0D0	INCD1021
10	VEL(I)=0.0D0	INCD1022
	RETURN	INCD1023
	END	INCD1024

Subroutines for the Quarter-Plate Model

```

SUBROUTINE EXTL(ELV,ITT,NP,NODE,XGI,YGI,GEI)
IMPLICIT REAL*8(A-H,O-Z)
C
C ASRL TR 154-14.....ORIGINAL REPORT VERSION OF PROGRAM
C COPYRIGHT (C) MASSACHUSETTS INSTITUTE OF TECHNOLOGY 1980
C
C THIS SUBROUTINE IS USED EXCLUSIVELY BY THE PLATE PROGRAM.
C
C THIS VERSION IS FOR THE EXAMPLE OF A RECTANGULAR PLATE, CLAMPED
C ON THE TOP AND BOTTOM EDGES, FREE ON THE OTHER TWO EDGES WITH AN
C IMPULSIVE LOAD APPLIED SYMMETRICALLY TO ITS CENTRAL REGION.
C
C ONLY THE UPPER RIGHT QUADRANT IS MODELLED USING THE SYMMETRY CONDITION
C ONE BOTH THE BOTTOM AND LEFT EDGES. THIS IS THE DOUBLE SYMMETRY CASE.
C DIMENSION ELV(1),NP(4,1),NODE(1),XGI(1),YGI(1),GBI(24,24)
C
C THIS USER-PREPARED SUBROUTINE IS USED TO GENERATE THE NODAL
C GENERALIZED FORCES CORRESPONDING TO PRESCRIBED EXTERNALLY-APPLIED
C FORCES AT TIME T SUB M (*M*DELTA T) AS DESCRIBED IN SUBSECTION 4.6.2
C AND CORRESPONDING TO THE DEVELOPMENT IN SUBSECTION A.1.3.4.
C
C DEFINE SIZE OF VECTOR CONTAINING UNIT LOAD OVER ALL DOF IN CENTRAL
C REGION OF PLATE WIDTH OF LOADED REGION IS .7485 IN. LENGTH IS .9 IN.
C DIMENSION ALOAD(54)
C
COMMON /BAS/ NDT,NET,MN,NB,NIRREG,MNC
COMMON /TIM/DELTA T,TIMEF,TIME,ITIMEF,INCRT,IOUT,ITIME
COMMON /INOUT/ MREAD,MWRITE,MPUNCH
C
C USE DATA STATEMENTS FOR VALUES WHICH WILL NOT CHANGE THROUGHOUT RUN.
C
C DEFINE TIME AT WHICH LOAD DROPS TO ZERO AND MAX VALUE OF IMPULSE.
DATA TEND/25.D-6/,AMAXP/21934.4DO/
C DEFINE FIRST AND LAST DOF IN LOADED REGION.
DATA IDOF/1/,LOOF/54/
C DEFINE VALUES OF UNIT LOAD AT EACH DOF IN LOADED REGION.
DATA ALOAD/2*0 DO,.4210312D-1,.2626182D-2,.3157734D-2,.1969637D-3
1 .2*0 DO,.8420625D-1,.0000000D+0,.6315468D-2,.0000000D+0
2 .2*0 DO,.4210312D-1,-.2626182D-2,.3157734D-2,-.1969637D-3
3 .2*0 DO,.8420625D-1,.5252365D-2,.0000000D+0,.0000000D+0
4 .2*0 DO,.1684125D+0,.0000000D+0,.0000000D+0,.0000000D+0
5 .2*0 DO,.8420625D-1,-.5252365D-2,.0000000D+0,.0000000D+0
6 .2*0 DO,.4210312D-1,.2626182D-2,-.3157734D-2,-.1969637D-3
7 .2*0 DO,.8420625D-1,.0000000D+0,-.6315468D-2,.0000000D+0
8 .2*0 DO,.4210312D-1,-.2626182D-2,-.3157734D-2,.1969637D-3/
C ZERO OUT LOAD VECTOR.
DO 1 I=1,NDT
1 ELV(I)=0 DOO
C IF THIS TIME STEP IS BEYOND LAST TIME OF IMPULSE RETURN WITH
C EXTERNAL LOAD VECTOR SET TO ZERO.
TYM=(ITT-1)*DELTA T
IF(TYM GT. TEND) RETURN
C INTERPOLATE TO FIND MAGNITUDE OF IMPULSE AT THIS TIME.
AMULT=AMAXP*(TEND-TYM)/TEND
C FILL IN VALUES OF LOAD IN CENTRAL REGION OF PLATE.
DO 2 I=IDOF,LOOF
J=I-IDOF+1
2 ELV(I)=AMULT*ALOAD(J)
C OUTPUT LOADS IF THIS IS A REGULAR PRINTING CYCLE.

```

```

EXTL2000
EXTL2001
EXTL2002
EXTL2003
EXTL2004
EXTL2005
EXTL2006
EXTL2007
EXTL2008
EXTL2009
EXTL2010
EXTL2011
EXTL2012
EXTL2013
EXTL2014
EXTL2015
EXTL2016
EXTL2017
EXTL2018
EXTL2019
EXTL2020
EXTL2021
EXTL2022
EXTL2023
EXTL2024
EXTL2025
EXTL2026
EXTL2027
EXTL2028
EXTL2029
EXTL2030
EXTL2031
EXTL2032
EXTL2033
EXTL2034
EXTL2035
EXTL2036
EXTL2037
EXTL2038
EXTL2039
EXTL2040
EXTL2041
EXTL2042
EXTL2043
EXTL2044
EXTL2045
EXTL2046
EXTL2047
EXTL2048
EXTL2049
EXTL2050
EXTL2051
EXTL2052
EXTL2053
EXTL2054
EXTL2055
EXTL2056
EXTL2057
EXTL2058

```

```

      III=ITIME/INCRT*INCRT-ITIME
      IF(III.NE.0) RETURN
      NNT=NDT/6
      WRITE(MWRITE,100) TYM ,(J,J=1,6)
100  FORMAT(1H0/1H0,10X,'TIME=',D16.6,' SEC. '/1H ,33(1H.),' EXTERNALLY A
      +PPLIED USER SPECIFIED LOADING',33(1H.)/1H ,6X,'NODE',6(7X,'DOF#',
      & I1,3X)/8X,3(10X,'(LBS)'),1X,3(7X,'(IN-LBS)'))
      I1=1
      DO 3 I=1,NNT
      I2=6*I
      WRITE(MWRITE,101) I,(ELV(J),J=I1,I2)
      I1=I2+1
      3  CONTINUE
101  FORMAT(6X,I3,2X,6D15.6)
      RETURN
      END
      SUBROUTINE INCOND(DISP,VEL,NP,NODE,XGI,YGI)
      IMPLICIT REAL*8(A-H,O-Z)
C
C   ASRL TR 154-14.....ORIGINAL REPORT VERSION OF PROGRAM
C   COPYRIGHT (C) MASSACHUSETTS INSTITUTE OF TECHNOLOGY 1980
C
C   THIS SUBROUTINE IS USED EXCLUSIVELY BY THE PLATE PROGRAM
C
      DIMENSION DISP(1),VEL(1),NP(4,1),NODE(1),XGI(1),YGI(1)
      COMMON/BAS/NDT,NET,MN,NB,NIRREG,MNC
C
C   THIS USER-PREPARED SUBROUTINE IS USED TO SPECIFY THE INITIAL (TIME
C   ZERO) CONDITIONS ON THE PLATE NODAL DISPLACEMENT AND VELOCITIES,
C   (Q ZERO)* AND (Q DOT ZERO)*, RESPECTIVELY, REQUIRED FOR THE FINITE-
C   DIFFERENCE SOLUTION OF THE GOVERNING EQUATIONS OF MOTION (SEE
C   SUBSECTION A.3).
C
C   DUMMY ROUTINE - SETS VELOCITY AND DISPLACEMENT TO ZERO INITIALLY.
      DO 10 I=1,NDT
      DISP(I)=0.000
10   VEL(I)=0.000
      RETURN
      END

```

```

EXTL2059
EXTL2060
EXTL2061
EXTL2062
EXTL2063
EXTL2064
EXTL2065
EXTL2066
EXTL2067
EXTL2068
EXTL2069
EXTL2070
EXTL2071
EXTL2072
EXTL2073
EXTL2074
INCD2000
INCD2001
INCD2002
INCD2003
INCD2004
INCD2005
INCD2006
INCD2007
INCD2008
INCD2009
INCD2010
INCD2011
INCD2012
INCD2013
INCD2014
INCD2015
INCD2016
INCD2017
INCD2018
INCD2019
INCD2020
INCD2021
INCD2022

```

The FORTRAN listing of the main program for the full plate example is given on pages 175 and 176. For the half plate and the quarter plate models, the associated main programs are the same except for the following DIMENSION statement:

```

DIMENSION DELD(390),DIS(390),DISP(390),DISM1(390),DISM2(390),      MAIN0065
2FLN(390),FLVA(390),FLVM(390),FLVP(390),ELV(390),VEL(390),ICOL(390) MAIN0066
3,INUM(390),KROW(390),NDEX(390),STOR(390),STF(14037),AMASS(14037), MAIN0067
4NP(4,48),NODE(1152),TAUSS(48,12,9),TAUSE(48,12,9),TAUEE(48,12,9), MAIN0068
5EPSSI(9,48),EPSSO(9,48),EPEEI(9,48),EPEEO(9,48),EPSEI(9,48),      MAIN0069
6EPSEO(9,48),NBC(60),BC(60),RFM(60,60),ILAST(60),UCF1(60),UCF2(60), MAIN0070
7XG(65),YG(65),ZG(65),XGI(65),YGI(65),TAGSS(1,12,3),LNXS(1),      MAIN0071
8XSPROP(7,1),MATXS(1),TSGEE(1,12,3),LNYS(1),YSPROP(7,1),MATYS(1), MAIN0072
9LNRS(1),ISRS(1),SC(5,1),NVSA(6),NCON(4,6)                          MAIN0073

```

For the half-plate example, replace the original above DIMENSION statement with this DIMENSION statement:

```

DIMENSION DELD(234),DIS(234),DISP(234),DISM1(234),DISM2(234),      MAIN1067
2FLN(234),FLVA(234),FLVM(234),FLVP(234),ELV(234),VEL(234),ICOL(234) MAIN1068
3,INUM(234),KROW(234),NDEX(234),STOR(234),STF(5643),AMASS(5643),      MAIN1069
4NP(4,24),NODE(576),TAUSS(24,12,9),TAUSE(24,12,9),TAUEE(24,12,9), MAIN1070
5EPSSI(9,24),EPSSO(9,24),EPEEI(9,24),EPEEO(9,24),EPSEI(9,24),      MAIN1071
6EPSEO(9,24),NBC(75),BC(75),RFM(69,48),ILAST(69),UCF1(69),UCF2(69), MAIN1072
7XG(39),YG(39),ZG(39),XGI(39),YGI(39),TAGSS(1,12,3),LNXS(1),      MAIN1073
8XSPROP(7,1),MATXS(1),TSGEE(1,12,3),LNYS(1),YSPROP(7,1),MATYS(1), MAIN1074
9LNRS(1),ISRS(:),SC(5,1),NVSA(6),NCON(4,6)                          MAIN1075

```

For the quarter-plate example, replace the original DIMENSION statement with this DIMENSION statement:

```

DIMENSION DELD(126),DIS(126),DISP(126),DISM1(126),DISM2(126),      MAIN2065
2FLN(126),FLVA(126),FLVM(126),FLVP(126),ELV(126),VEL(126),ICOL(126) MAIN2066
3,INUM(126),KROW(126),NDEX(126),STOR(126),STF(2889),AMASS(2889),      MAIN2067
4NP(4,12),NODE(288),TAUSS(12,12,9),TAUSE(12,12,9),TAUEE(12,12,9), MAIN2068
5EPSSI(9,12),EPSSO(9,12),EPEEI(9,12),EPEEO(9,12),EPSEI(9,12),      MAIN2069
6EPSEO(9,24),NBC(75),BC(75),RFM(44,48),ILAST(44),UCF1(44),UCF2(44), MAIN2070
7XG(21),YG(21),ZG(21),XGI(21),YGI(21),TAGSS(1,12,3),LNXS(1),      MAIN2071
8XSPROP(7,1),MATXS(1),TSGEE(1,12,3),LNYS(1),YSPROP(7,1),MATYS(1), MAIN2072
9LNRS(1),ISRS(1),SC(5,1),NVSA(6),NCON(4,6)                          MAIN2073

```


7.2 Modeling and Input Data

For illustrative purposes, three different structural models of the narrow-plate specimen depicted in Fig. 16 are described in the following. First, the entire plate is modeled by 48 LLC plate elements as shown in Fig. 17. Next, since symmetry exists about the y axis, the half-plate is modeled with the same basic finite-element breakdown, with symmetry about the y axis invoked; this results in a 24-element model (Fig. 17). Finally, advantage is taken of the fact that there are, in fact, two axes of symmetry; hence, the third model is the 12-element quarter-plate model shown also in Fig. 17. For each of these three models, the selected numbering of elements and nodes is shown in Fig. 17.

Pilot calculations show that the largest natural frequency in the linear-system mathematical model of the whole plate is $\omega_{\max} = 3,052,755$ rad/sec. Hence, if the timewise central-difference model were used to predict the linear transient response of this model, a Δt not exceeding $\Delta t = 2/\omega_{\max} = 0.655$ μ sec would be required. However, since the PLATE 1 program employs the Houbolt operator, a reasonable choice is $\Delta t = 2.5$ μ sec, as discussed in Subsection 4.8.2; reasonable behavior for $\Delta t \lesssim 6[0.8(2/\omega_{\max})] \doteq 3.14$ μ sec would be expected.

Solution output data will be requested at the end of every 10 time steps or cycles; however, for conciseness these data will be included here only for the end of time cycles (or time steps) 0, 1, 2, 10, 20, 140, and 150 (last). The desired solution output data are indicated as the following print options (Card 51 of Subsection 4.2):

- | | |
|------|--|
| IOP1 | Displacements and current (global) X,Y,Z coordinates for each node. |
| IOP2 | Strain (Green) components as well as principal (tensile) strain and direction at the upper and lower surface evaluated at the centroid of each element. |
| IOP4 | Strain (Green) components, principal (tensile) strain and direction, and elongations (in user-specified directions) at <u>additional</u> spanwise locations (evaluated at both upper and lower surfaces at each spanwise location) as specified by the user. |

- IOP5 Reaction forces at all nodes where displacement constraint conditions have been imposed.
- IOP7 System energies (i.e., work input to structure, structure kinetic energy, structure elastic energy, structure plastic energy, and energy stored in elastic restoring springs).
- IOP8 Strain (Green) components, principal (tensile) strain and direction at the upper and lower plate surfaces at user-specified nodes (by nodal averaging).

Print options IOP3 and IOP6 are not desired; hence, set these quantities equal to 0 on Card 51 (of Subsection 4.2). Summarized concisely as follows are the affected element or node numbers for each of the three finite-element models (see Fig. 17):

Output Option	Full-Plate Model	Half-Plate Model	Quarter-Plate Model
IOP1	All Nodes	All Nodes	All Nodes
IOP2	All Elements	All Elements	All Elements
IOP4	Elements 2,6,10,14, 26,34,38,42 and 46	Elements 1,3,5,7, 11,17,19,21 and 23	Elements 1,5,7, 9 and 11
IOP5	Degrees of Freedom 1 through 30 inclusive and 361 through 390 inclusive	Degrees of Freedom 1 through 19 inclusive, 22,24, 37,40,42,55,58,60, 73,76,78,91,94,96, 109,112,114,127, 130,132,145,148, 150,163,166,168, 181,184,186,199, 202,204, and 217 through 234 inclusive	Degrees of Freedom ⁺ 1,2,4,5,6,8,11,12, 14,17,18,19,22,24, 37,40,42,55,58,60, 73,76,78,91,94,96, and 109 through 126 inclusive

⁺See Fig. 17c.

	Full-Plate Model	Half-Plate Model	Quarter-Plate Model
IOP7	Entire Structure	Entire Structure	Entire Structure
IOP8	Nodes 33,35,38,40, 48,50	Nodes 19,21,22,24, 28,30	Nodes 1,3,4,6,10, 12

The associated input data on each card are described for the full-plate, the half-plate, and the quarter-plate model in Subsections 7.2.1, 7.2.2, and 7.2.3, respectively. However, solution output data are presented in Subsection 7.3 only for the full-plate model.

7.2.1 Input Data for the Full-Plate Model

The values to be punched on the data cards are as follows (see Fig. 17a):

Card 1		8I10
MAXEL	= 48	
MNSL	= 3	
MXST	= 1 ⁺	
MNST	= 1 ⁺	
NBE	= 1 ⁺	
MBWE	= 1 ⁺	
MNC	= 14037	
Card 2		20I4
IMESH	= 0	
IMASS	= 2	
IMCONT	= 0	
IPUNCH	= 0	
Card 3		20I4
NEAD	= 4	
NECD	= 12	
Card 4a		5D16.7
EPAN	= 0.1D8	
ANUP	= .3333333DO	

⁺As noted on page 82, these quantities must be set equal to 1 in accordance with FORTRAN rules because they are used as dimensioning variables; they must not be set equal to zero.

DENSP	=	0.25384D-3	
TH	=	0.102D0	
XDIST	=	1.4970D0	
Card 4b			5D16.7
YDIST	=	8.0D0	
ZPOS	=	0.0D0	
Card 5			5D16.7
XG(1)	=	0.0D0	
XG(2)	=	.37425D0	
XG(3)	=	.7485D0	
XG(4)	=	1.12275D0	
XG(5)	=	1.4970D0	
Card 6a			5D16.7
YG(1)	=	0.0D0	
YG(2)	=	.775D0	
YG(3)	=	1.55D0	
YG(4)	=	2.325D0	
YG(5)	=	3.1D0	
Card 6b			5D16.7
YG(6)	=	3.55D0	
YG(7)	=	4.0D0	
YG(8)	=	4.45D0	
YG(9)	=	4.9D0	
YG(10)	=	5.675D0	
Card 6c			5D16.7
YG(11)	=	6.45D0	
YG(12)	=	7.225D0	
YG(13)	=	8.0D0	
Card 7			20I4
NCSB(1)	=	2	
NCSB(2)	=	0	
NCSB(3)	=	2	
NCSB(4)	=	0	

Card 8		20I4
	NAST = 0	
	NCST = 0	
Card 25*		20I4
	NAXS = 0	
	NAYS = 0	
Card 44*		20I4
	NMAT = 1	
Card 45		20I4
	NSUB = 3	
Card 46		5D16.7
	SIG(1) = 44.2D3	
	SIG(2) = 49.2D3	
	SIG(3) = 76.4D3	
Card 47		5D16.7
	EPS(1) = .00442D0	
	EPS(2) = .0760D0	
	EPS(3) = 0.615D0	
Card 48		5D16.7
	DSR(1) = 6500.D0	
	PSR(1) = 4.0D0	
Card 49		20I4
	ITIMEF = 150	
	INCRT = 1	
	IOUT = 1	
Card 50		5D16.7
	DELTAT = 2.5D-06	
	TIMEF = 3.75D-04	
Card 51		20I4
	IOP1 = 1	
	IOP2 = 1	

* For omitted cards, see page 251.

IOP3	= 0	
IOP4	= 1	
IOP5	= 1	
IOP6	= 0	
IOP7	= 1	
IOP8	= 1	
Card 54*		20I4
NASP	= 11	
Card 55a		I4,2D16.7
LNASP(1)	= 2	
SLASP(1)	= 1.0D0	
ELASP(1)	= 0.0D0	
Card 55b		I4,2D16.7
LNASP(2)	= 2	
SLASP(2)	= 1.0D0	
ELASP(2)	= .2580645D0	
Card 55c		I4,2D16.7
LNASP(3)	= 6	
SLASP(3)	= 1.0D0	
ELASP(3)	= .2903226D0	
Card 55d		I4,2D16.7
LNASP(4)	= 10	
SLASP(4)	= 1.0D0	
ELASP(4)	= .3225806D0	
Card 55e		I4,2D16.7
LNASP(5)	= 14	
SLASP(5)	= 1.0D0	
ELASP(5)	= .3548387D0	
Card 55f		I4,2D16.7
LNASP(6)	= 26	
SLASP(6)	= 1.0D0	
ELASP(6)	= 0.0D0	

* For omitted cards, see page 251.

Card 55g		I4,2D16.7
LNASP(7) = 34		
SLASP(7) = 1.0D0		
ELASP(7) = .6451613D0		
Card 55h		I4,2D16.7
LNASP(8) = 38		
SLASP(8) = 1.0D0		
ELASP(8) = .6774194D0		
Card 55i		I4,2D16.7
LNASP(9) = 42		
SLASP(9) = 1.0D0		
ELASP(9) = .7096774D0		
Card 55j		I4,2D16.7
LNASP(10) = 46		
SLASP(10) = 1.0D0		
ELASP(10) = .7419355D0		
Card 55k		I4,2D16.7
LNASP(11) = 46		
SLASP(11) = 1.0D0		
ELASP(11) = 1.0D0		
Card 56		20I4
NASPE = 0		
Card 61*		20I4
NNSA = 6		
Card 62		20I4
NVSA(1) = 33		
NVSA(2) = 35		
NVSA(3) = 38		
NVSA(4) = 40		
NVSA(5) = 48		
NVSA(6) = 50		
Card 63		20I4
NELES = 0		

* For omitted cards, see page 251.

Cards 9 through 16 are omitted because NAST on Card 8 is zero (that is, there are no complete X-direction stiffeners).

Cards 17 through 24 are omitted because NCST on Card 8 is zero (that is, there are no complete Y-direction stiffeners).

Cards 26 through 34 are omitted because NAXS on Card 24 is zero (that is, there are no additional X-direction stiffeners).

Cards 35 through 43 are omitted because NAYS on Card 24 is zero (that is, there are no additional Y-direction stiffeners).

Cards 52 and 53 are omitted because IOP3 = 3 on Card 51.

Card 57 is omitted because NASPE = 0 on Card 55. Cards 58 through 60 are omitted because IOP5 = 0 on Card 51.

The following is the complete input deck for this example:

```

      48      3      1      1      1      1      14037
0  2  0  0
4 12
      0.108      .333333300      .253840-3      .10200      1.497000
      8 000      0.000
      0.000      .3742500      .748500      1.1227500      1.497000
      0 000      .775000      1.5500      2.32500      3.100
      3.5500      4.000      4.4500      4.900      5.67500
      6.4500      7.22500      8.000
2  0  2  0
0  0
0  0
1
3
      44.203      49.203      76.403
      .0044200      .076000      0.61500
      6500.00      4.000
150 1  1
      2.5  0-06      3.750-04
1  1  0  1  1  0  1  1
11
2      1.000      0 000
2      1.000      .258064500
6      1 000      .290322600
10     1 000      .322580600
14     1.000      .354838700
26     1 000      0.000
34     1.000      .645161300
38     1.000      .677419400
42     1.000      .709677400
46     1.000      .741935500
46     1.000      1.000
0
6
33 35 38 40 48 50
0

```


7.2.2 Input Data for the Half-Plate Model*

The values to be punched on the data cards are as follows (see Fig. 17b):

Card 1		8I10
MAXEL	= 24	
MNSL	= 3	
MNXST	= 1	
MNYST	= 1	
NBE	= 1	
MBWE	= 1	
MNC	= 5643	
Card 2		20I4
IMESH	= 0	
IMASS	= 2	
IMCONT	= 0	
IPUNCH	= 0	
Card 3		20I4
NEAD	= 2	
NECD	= 12	
Card 4a		5D16.7
EPAN	= 0.1D8	
ANUP	= .3333333D0	
DENSP	= 0.25384D-3	
TH	= 0.102D0	
XDIST	= 1.4970D0	
Card 4b		5D16.7
YDIST	= 8.0D0	
ZPOS	= 0.0D0	
Card 5		5D16.7
XG(1)	= 0.0D0	
XG(2)	= .37425D0	
XG(3)	= .7485D0	

* Certain input cards are omitted; see page 251.

Card 6a		5D16.7
YG(1)	= 0.0D0	
YG(2)	= .775D0	
YG(3)	= 1.55D0	
YG(4)	= 2.325D0	
YG(5)	= 3.1D0	
Card 6b		5D16.7
YG(6)	= 3.55D0	
YG(7)	= 4.0D0	
YG(8)	= 4.45D0	
YG(9)	= 4.9D0	
YG(10)	= 5.675D0	
Card 6c		5D16.7
YG(11)	= 6.45D0	
YG(12)	= 7.225D0	
YG(13)	= 8.0D0	
Card 7		20I4
NCSB(1)	= 2	
NCSB(2)	= 0	
NCSB(3)	= 2	
NCSB(4)	= 1	
Card 8		20I4
NAST	= 0	
NCST	= 0	
Card 25		20I4
NAYS	= 0	
NAYS	= 0	
Card 44		20I4
NMAT	= 1	
Card 45		20I4
NSUB	= 3	

Card 46		5D16.7
	SIG(1) = 44.2D3	
	SIG(2) = 49.2D3	
	SIG(3) = 76.4D3	
Card 47		5D16.7
	EPS(1) = .00442D0	
	EPS(2) = .0760D0	
	EPS(3) = 0.615D0	
Card 48		5D16.7
	DSR(1) = 6500.D0	
	PSR(1) = 4.0D0	
Card 49		20I4
	ITIMEF = 150	
	INCR1 = 1	
	IOUT = 1	
Card 50		5D16.7
	DELTAT = 2.5D-06	
	TIMEF = 3.75D-04	
Card 51		20I4
	IOP1 = 1	
	IOP2 = 1	
	IOP3 = 0	
	IOP4 = 1	
	IOP5 = 1	
	IOP6 = 0	
	IOP7 = 1	
	IOP8 = 1	
Card 54		20I4
	NASP = 11	
Card 55a		I4,2D16.7
	LNASP(1) = 1	
	SLASP(1) = 0.0D0	
	ELASP(1) = 0.0D0	

Card 55b I4,2D16.7
LNASP(2) = 1
SLASP(2) = 0.0D0
ELASP(2) = .2580645D0

Card 55c I4,2D16.7
LNASP(3) = 3
SLASP(3) = 0.0D0
ELASP(3) = .2903226D0

Card 55d I4,2D16.7
LNASP(4) = 5
SLASP(4) = 0.0D0
ELASP(4) = .3225806D0

Card 55e I4,2D16.7
LNASP(5) = 7
SLASP(5) = 0.0D0
ELASP(5) = .3548387D0

Card 55f I4,2D16.7
LNASP(6) = 11
SLASP(6) = 0.0D0
ELASP(6) = 1.0D0

Card 55g I4,2D16.7
LNASP(7) = 17
SLASP(7) = 0.0D0
ELASP(7) = .6451613D0

Card 55h I4,2D16.7
LNASP(8) = 19
SLASP(8) = 0.0D0
ELASP(8) = .6774194D0

Card 55i I4,2D16.7
LNASP(9) = 21
SLASP(9) = 0.0D0
ELASP(9) = .7096774D0

Card 55j		I4,2D16.7
LNASP(10) = 23		
SLASP(10) = 0.0D0		
ELASP(10) = .7419355D0		
Card 55k		I4,2D16.7
LNASP(11) = 23		
SLASP(11) = 0.0D0		
ELASP(11) = 1.0D0		
Card 56		20I4
NASPE = 0		
Card 61		20I4
NNSA = 6		
Card 62		20I4
NVSA(1) = 19		
NVSA(2) = 21		
NVSA(3) = 22		
NVSA(4) = 24		
NVSA(5) = 28		
NVSA(6) = 30		
Card 63		20I4
NELES = 0		

The following is the complete input deck for this example:

```

      24      3      1      1      1      1      5643
0  2  0  0
2  12
      0.108      .333333300      .253840-3      .10200      .7485000
      8.000      0.000
      0.000      .3742500      .748500
      0.000      .775000      1.5500      2.32500      3.100
      3.5500      4.000      4.4500      4.900      5.67500
      6.4500      7.22500      8.000
2  0
0  0
0  0
1
3
      44 203      49.203      76.403
      0044200      .076000      0.61500
      6500.00      4.000
150 1 1
      2.5      0-06      3.750-04
1  1  0  1  1  0  1  1
11
1      .000      0.000
1      .000      .258064500
3      .000      .290322600
5      .000      .322580600
7      .000      .354838700
11     .000      1 000
17     .000      645161300
19     .000      .677419400
21     .000      .709677400
23     .000      .741935500
23     .000      1.000
0
6
19 21 22 24 28 30
0

```

7.2.3 Input Data for the Quarter-Plate Model*

The values to be punched on the data cards are as follows (see Fig. 17c):

Card 1		8I10
MAXEL	= 12	
MNSL	= 3	
MXST	= 1	
MNST	= 1	
NBE	= 1	
MBWE	= 1	
MNC	= 2889	
Card 2		20I4
IMESH	= 0	
IMASS	= 2	
IMCONT	= 0	
IPUNCH	= 0	
Card 3		20I4
NEAD	= 2	
NECD	= 6	
Card 4a		5D16.7
EPAN	= 0.1D8	
ANUP	= .3333333D0	
DENSP	= 0.25384D-3	
TH	= 0.102D0	
XDIST	= .74850D0	
Card 4b		5D16.7
YDIST	= 4.0D0	
ZPOS	= 0.0D0	
Card 5		5D16.7
XG(1)	= 0.0D0	
XG(2)	= .37425D0	
XG(3)	= .7485D0	

* Certain input cards are omitted; see page 251.

Card 6a		5D16.7
YG(1)	= 0.0D0	
YG(2)	= .4500D0	
YG(3)	= 0.90D0	
YG(4)	= 1.675D0	
YG(5)	= 2.45D0	
Card 6b		5D16.7
YG(6)	= 3.225D0	
YG(7)	= 4.0D0	
Card 7		20I4
NCSB(1)	= 1	
NCSB(2)	= 0	
NCSB(3)	= 2	
NCSB(4)	= 1	
Card 8		20I4
NAST	= 0	
NCST	= 0	
Card 25		20I4
NAXS	= 0	
NAYS	= 0	
Card 44		20I4
NMAT	= 1	
Card 45		20I4
NSUB	= 3	
Card 46		5D16.7
SIG(1)	= 44.2D3	
SIG(2)	= 49.2D3	
SIG(3)	= 76.4D3	
Card 47		5D16.7
EPS(1)	= .00442D0	
EPS(2)	= .0760D0	
EPS(3)	= 0.615D0	

Card 48		5D16.7
DSR(1)	= 6500.D0	
PSR(1)	= 4.0D0	
Card 49		20I4
ITIMEF	= 150	
INCRT	= 1	
IOUT	= 1	
Card 50		5D16.7
DELTAT	= 2.5D-06	
TIMEF	= 3.75D-04	
Card 51		20I4
IOP1	= 1	
IOP2	= 1	
IOP3	= 0	
IOP4	= 1	
IOP5	= 1	
IOP6	= 0	
IOP7	= 1	
IOP8	= 1	
Card 54		20I4
NASP	= 6	
Card 55a		I4,2D16.7
LNASP(1)	= 1	
SLASP(1)	= 0.0D0	
ELASP(1)	= 0.0D0	
Card 55b		I4,2D16.7
LNASP(2)	= 5	
SLASP(2)	= 0.0D0	
ELASP(2)	= .6451613D0	
Card 55c		I4,2D16.7
LNASP(3)	= 7	
SLASP(3)	= 0.0D0	
ELASP(3)	= .6774194D0	

Card 55d		I4,2D16.7
LNASP(4)	= 9	
SLASP(4)	= 0.0D0	
ELASP(4)	= .7096774D0	
Card 55e		I4,2D16.7
LNASP(5)	= 11	
SLASP(5)	= 0.0D0	
ELASP(5)	= .7419355D0	
Card 55f		I4,2D16.7
LNASP(6)	= 11	
SLASP(6)	= 0.0D0	
ELASP(6)	= 1.0D0	
Card 56		20I4
NASPE	= 0	
Card 61		20I4
NNSA	= 6	
Card 62		20I4
NVSA(1)	= 1	
NVSA(2)	= 3	
NVSA(3)	= 4	
NVSA(4)	= 6	
NVSA(5)	= 10	
NVSA(6)	= 12	
Card 63		20I4
NELES	= 0	

The following is the complete input deck for this example:

```

0      12      3      1      1      1      1      2889
2      6
      0.108      .333333300      .253840-3      .10200      .7485000
      4.000      0.000
      0.000      .3742500      .748500
      0.000      .450000      0.9000      1.67500      2.4500
      3.22500      4.000
1      0      2      1
0      0
0      0
1
3
      44.203      49.203      76.403
      .0044200      .076000      0.61500
      6500.00      4.000
150  1      1
      2.5      D-06      3.75D-04
1      1      0      1      1      0      1      1
6
1      0 000      0 000
5      0.000      .645161300
7      0.000      .677419400
9      0.000      .709677400
11     0.000      .741935500
11     0.000      1.000
0
6
1      3      4      6      10      12
0

```

7.3 Solution Output Data for the Full-Plate Model

The following is the output for 150 cycles (375 μ sec) of response of the transiently-loaded narrow plate specimen depicted in Fig. 16, for the full-plate finite-element model shown in Fig. 17.

The first segment of the output describes the initial geometry, material properties and boundary conditions of the plate as well as element numbers and global node numbers of the finite elements used to model the structure. Noted also are the constrained degrees of freedom and the properties of each sublayer of the mechanical-sublayer material model: (a) stress, (b) strain, (c) yield stress, and (d) weighting factor.

The next segment describes the output to be given at every regular printout cycle. This output consists of (a) the generalized displacements of and the global location of each nodal station, (b) the reaction forces at each constrained node, (c) the strain components as well as the principal (tensile) strain and direction at the centroid of each element, (d) strain components as well as principal strains and associated direction at 6 nodes as described, (e) strain components, elongations in specified directions, and principal strain and associated direction at each of 11 identified "additional locations", and (f) a tabulation of the various energies of the system. Also given are the generalized nodal forces from the externally-applied loading whenever those forces are non-zero.

In the interest of conciseness, only a portion of the called-for output is shown. Included are: (1) all input-verification information and (2) scheduled output at the end of time cycles 0, 1, 2, 10, 20, 140, and 150 (last).⁺ This output listing is intended for use in verifying the (successful) adaptation of the PLATE 1 program to a user's computing facility.

⁺An auxiliary computer run was made with printout every cycle to give the output shown at the end of time steps 1 and 2.

PLATE 1 COMPUTER CODE (SMALL STRAIN THEORY) : USER INPUT FOR ARRAY DIMENSIONS

MAXEL = 48
MNSL = 3
MNXST = 1
MNYST = 1
NBE = 60
NBVE = 60
MNC = 14037

AUTO-GENERATED FINITE-ELEMENT MESH INFORMATION FOR STIFFENED OR UNSTIFFENED FLAT-PLATE PROBLEM

X-LENGTH(IN) = 0.1497000D+01
Y-LENGTH(IN) = 0.8000000D+01
Z-POSITION(IN) = 0.0
THICKNESS(IN) = 0.1020000D+00
YOUNGS MODULUS (PSI) = 0.1000000D+08
POISSONS RATIO = 0.333333D+00
DENSITY(LB-SEC**2/IN**4) = 0.2538400D-03
NO OF ELEM IN X-DIRECTION = 4
NO OF ELEM IN Y-DIRECTION = 12
NO OF D O F /ELEM = 24
TOTAL NO OF ELEMENTS = 48
TOTAL NO OF D O F = 390
NO OF X-DIR STIFFENERS = 0
NO OF Y-DIR STIFFENERS = 0

THE GLOBAL NODE NUMBERS ASSOCIATED WITH EACH ELEMENT ARE AS FOLLOWS :

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ELEMENT	GLOBAL NODE NUMBERS			
1	1	2	7	6
2	2	3	8	7
3	3	4	9	8
4	4	5	10	9
5	6	7	12	11
6	7	8	13	12
7	8	9	14	13
8	9	10	15	14
9	11	12	17	16
10	12	13	18	17
11	13	14	19	18
12	14	15	20	19
13	16	17	22	21
14	17	18	23	22
15	18	19	24	23
16	19	20	25	24
17	21	22	27	26
18	22	23	28	27
19	23	24	29	28
20	24	25	30	29
21	26	27	32	31
22	27	28	33	32
23	28	29	34	33
24	29	30	35	34
25	31	32	37	36
26	32	33	38	37
27	33	34	39	38
28	34	35	40	39
29	36	37	42	41
30	37	38	43	42
31	38	39	44	43
32	39	40	45	44
33	41	42	47	46
34	42	43	48	47

35	43	44	49	48
36	44	45	50	49
37	46	47	52	51
38	47	48	53	52
39	48	49	54	53
40	49	50	55	54
41	51	52	57	56
42	52	53	58	57
43	53	54	59	58
44	54	55	60	59
45	56	57	62	61
46	57	58	63	62
47	58	59	64	63
48	59	60	65	64

BOUNDARY CONDITIONS (SEE WRITEUP FOR CONVENTION FOR SIDE NUMBER AND BOUNDARY CONDITION)

SIDE NUMBER	BOUNDARY CONDITION
1	IDEALLY CLAMPED
2	FREE
3	IDEALLY CLAMPED
4	FREE

THE FOLLOWING 60 DEGREES OF FREEDOM ARE CONSTRAINED

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
21	22	23	24	25	26	27	28	29	30	361	362	363	364	365	366	367	368	369	370
371	372	373	374	375	376	377	378	379	380	381	382	383	384	385	386	387	388	389	390

PRESENT RUN USES CONSISTENT MASS MATRIX

MAX SIZE IS 14037

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PROPERTIES FOR USER-SPECIFIED MATERIALS

PROPERTIES FOR MATERIAL NUMBER 1

SUBLAYER	STRESS POINT	STRAIN POINT	YIELD STRESS	WEIGHTING FACTOR
1	0 4420000D+05	0.4420000D-02	0.4420000D+05	0.9937861D+00
2	0 4920000D+05	0.7600000D-01	0.8488500D+06	0.1725692D-02
3	0 7640000D+05	0.6150000D+00	0.6909200D+07	0.4488190D-02

STRAIN RATE PARAMETERS D= 0 6500000D+04 P= 0.4000000D+01

TIMWISE SOLUTION PARAMETERS

TIME-STEP SIZE= 0 2500000D-05 SEC
 RUN WILL TERMINATE AT TIME = 0 3750000D-03 SEC. OR AT CYCLE NUMBER 150
 REGULAR PRINTOUT WILL BE GIVEN EVERY 10 CYCLES

***** OUTPUT CONTROL INFORMATION *****

THE FOLLOWING RESULTS WILL BE GIVEN AT EVERY REGULAR PRINTOUT CYCLE:

NODAL DISPLACEMENTS AND LOCATION

REACTION FORCES AT CONSTRAINED NODES

STRAIN COMPONENTS, PRINCIPAL STRAIN AND DIRECTION AT THE FOLLOWING 6 NODES (OBTAINED BY NODAL AVERAGING):

33 35 38 40 49 50

STRAIN COMPONENTS, ELONGATION IN SPECIFIED DIRECTIONS, PRINCIPAL STRAIN AND DIRECTION AT THE FOLLOWING 11 ADDTL. POINTS:

ADDTL. POINT	ON ELEM.	PSI-LOCATION	ETA-LOCATION	ELONG DIR.-1(DEG)	ELONG DIR -2(DEG)
1	2	0 1000000D+01	0 0	0 0	0.9000000D+02
2	2	0.1000000D+01	0.2580645D+00	0 0	0 9000000D+02
3	6	0 1000000D+01	0 2903226D+00	0 0	0 9000000D+02
4	10	0 1000000D+01	0 3225006D+00	0 0	0 9000000D+02
5	14	0.1000000D+01	0 3548387D+00	0 0	0.9000000D+02
6	26	0 1000000D+01	0 0	0 0	0.9000000D+02
7	34	0 1000000D+01	0 6451613D+00	0.0	0 9000000D+02
8	38	0 1000000D+01	0 6774194D+00	0 0	0.9000000D+02
9	42	0 1000000D+01	0.7096774D+00	0 0	0 9000000D+02
10	46	0.1000000D+01	0 7419355D+00	0 0	0.9000000D+02
11	46	0.1000000D+01	0 1000000D+01	0.0	0.9000000D+02

SYSTEM ENERGIES

ROUNDING ERROR PARAMETER IN FACTORING ROW 150 = 0.11560148 NO OF NEGATIVE DIAG= 0

HIGHEST NATURAL FREQUENCY(RAD/SEC)= 0.3052755D+07

HIGHEST EIGENVECTOR NORMALIZED BY LARGEST VALUE

NODE	U	V	W	PSIX	PSIY	TWIST
1	0.0	0.0	0 0	0 0	0.0	0.0
2	0 0	0.0	0 0	0.0	0 0	0 0
3	0 0	0 0	0 0	0 0	0 0	0 0
4	0 0	0 0	0 0	0 0	0.0	0 0
5	0 0	0 0	0 0	0 0	0 0	0.0
6	0 33785D-39	-0 15059D-39	-0 14396D-04	0.42661D-03	-0.16797D-03	0.49778D-02
7	-0 32374D-39	0 49596D-40	-0 19032D-05	0.18869D-03	-0 22206D-04	0 22019D-02
8	0 32202D-39	0.91215D-52	-0 20335D-10	0.15294D-03	-0.23733D-09	0.17849D-02
9	-0 32374D-39	-0 49596D-40	0 19031D-05	0.18868D-03	0 22205D-04	0.22019D-02
10	0 33785D-39	0 15059D-39	0 14396D-04	0 42661D-03	0 16797D-03	0 49778D-02
11	-0 10874D-38	0.38119D-39	-0 36548D-04	0 10842D-02	-0 62817D-03	0.18624D-01
12	0 10623D-38	-0 12626D-39	-0 48299D-05	0 48067D-03	-0 83031D-04	0 82463D-02
13	-0 10593D-38	-0 37017D-51	-0 51892D-10	0 38994D-03	-0 88945D-09	0.66869D-02
14	0 10623D-38	0 12626D-39	0 48298D-05	0 48066D-03	0.83029D-04	0 82462D-02
15	-0 10874D-38	-0 38119D-39	0 36548D-04	0.10842D-02	0 62816D-03	0 18624D-01
16	0 30294D-38	-0 81416D-39	-0 11186D-03	0 33205D-02	-0 19494D-02	0 57840D-01
17	-0 29977D-38	0 26985D-39	-0 14781D-04	0.14712D-02	-0 25762D-03	0 25650D-01
18	0 29940D-38	0 11917D-50	-0 15931D-09	0 11965D-02	-0 27697D-08	0 20811D-01
19	-0 29977D-38	-0 26985D-39	0 14780D-04	0 14742D-02	0 25762D-03	0 25650D-01
20	0 30294D-38	0 81418D-39	0 11185D-03	0 33205D-02	0 19494D-02	0 57839D-01
21	-0 81171D-38	0 15157D-38	-0 57385D-03	0.17021D-01	-0 73302D-02	0.21748D+00
22	0 81067D-38	-0 50439D-39	-0 75851D-04	0 75436D-02	-0 96878D-03	0 96441D-01
23	-0 81060D-38	-0 35006D-50	-0 81410D-09	0 61188D-02	-0 10413D-07	0 78243D-01
24	0 81067D-38	0 50439D-39	0 75849D-04	0 75435D-02	0 96875D-03	0 96440D-01
25	-0 81171D-38	-0 15157D-38	0 57384D-03	0 17021D-01	0 73301D-02	0.21748D+00
26	0 18540D-37	-0 16502D-38	-0 45469D-03	0 13474D-01	-0 25868D-01	0 76705D+00
27	-0 18642D-37	0 55309D-39	-0 60132D-04	0 59584D-02	-0 34198D-02	0 33971D+00
28	0 18656D-37	0 85192D-50	-0 64189D-09	0 48292D-02	-0 36641D-07	0 27548D+00
29	-0 18642D-37	-0 55309D-39	0 60131D-04	0 59584D-02	0 34197D-02	0 33971D+00
30	0 18540D-37	0 16502D-38	0 45468D-03	0.13474D-01	0 25868D-01	0 76704D+00
31	-0 22625D-37	-0 87298D-50	0 16310D-12	-0 48016D-11	-0 33729D-01	0 10000D+01
32	0 22901D-37	0 10055D-49	0 21428D-13	-0 21355D-11	-0 44595D-02	0 44272D+00
33	-0 22826D-37	-0 10604D-49	0 32050D-15	-0 17284D-11	-0 47737D-07	0.35897D+00
34	0 22801D-37	0 10072D-49	-0 20312D-13	-0 21070D-11	0 44594D-02	0 44272D+00
35	-0 22625D-37	-0 87759D-50	-0 15775D-12	-0 46809D-11	0 33729D-01	0 99999D+00
36	0 18540D-37	0 16502D-38	0 45469D-03	-0 13474D-01	-0 25868D-01	0 76705D+00
37	-0 18642D-37	-0 55309D-39	0 60132D-04	-0 59584D-02	-0 34198D-02	0.33971D+00
38	0 18653D-37	0 84830D-50	0 64189D-09	-0 48292D-02	-0 36641D-07	0 27548D+00
39	-0 18642D-37	0 55309D-39	-0 60131D-04	-0 59584D-02	0 34197D-02	0.33971D+00
40	0 18540D-37	0 16502D-38	-0 45468D-03	0 13474D-01	0 25868D-01	0 76704D+00
41	-0 81171D-38	-0 15157D-38	0 57385D-03	-0 17021D-01	-0 73302D-02	0 21748D+00
42	0 81067D-38	0 50439D-39	0 75851D-04	-0 75436D-02	-0 96878D-03	0 96441D-01
43	-0 81060D-38	-0 34672D-50	0 81410D-09	-0 61188D-02	-0 10413D-07	0 78243D-01
44	0 81067D-38	-0 50439D-39	-0 75849D-04	-0 75435D-02	0 96875D-03	0 96440D-01
45	-0 81171D-38	0 15157D-38	-0 57384D-03	-0 17021D-01	0 73301D-02	0 21748D+00
46	0 30294D-38	0 81418D-39	0 11186D-03	-0 33205D-02	-0 19494D-02	0 57840D-01
47	-0 29977D-38	-0 26945D-39	0 14781D-04	-0 14712D-02	-0 25762D-03	0 25650D-01
48	0 29940D-38	0 11731D-50	-0 15931D-09	-0 11965D-02	-0 27697D-08	0 20811D-01
49	-0 29977D-38	0 26985D-39	-0 14780D-04	-0 14742D-02	0 25762D-03	0 25650D-01
50	0 30294D-38	-0 81418D-39	-0 11185D-03	-0 33205D-02	0 19494D-02	0 57839D-01
51	-0 10874D-38	-0 38119D-39	0 36548D-04	-0 10842D-02	-0.62817D-03	0 18624D-01
52	0 10623D-38	0 12626D-39	0 48299D-05	-0.48067D-03	-0.83031D-04	0.82463D-02
53	-0 10593D-38	-0 36061D-51	0 51892D-10	-0 38994D-03	-0 88944D-09	0 66869D-02
54	0 10623D-38	-0 12626D-39	-0 48298D-05	-0 48066D-03	0 83029D-04	0 82462D-02
55	-0 10874D-38	0 38119D-39	-0 36548D-04	-0 10842D-02	0 62816D-03	0 18624D-01
56	0 33785D-39	0 15059D-39	0 14396D-04	-0 42661D-03	-0 16797D-03	0 49778D-02
57	-0 32374D-39	-0 49596D-40	0 19032D-05	-0 18868D-03	-0.22206D-04	0.22019D-02

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58 0.32202D-39 0 86867D-52 0.20335D-10 -0.15294D-03 -0.23733D-09 0.17849D-02
59 -0 32374D-39 0 49596D-40 -0.19031D-05 -0.18868D-03 0.22205D-04 0.22019D-02
60 0 33785D-39 -0.15059D-39 -0 14396D-04 -0 42661D-03 0 16797D-03 0.49778D-02
61 0 0 0.0 0 0 0 0 0.0 0.0
62 0 0 0.0 0.0 0 0 0 0 0.0
63 0.0 0.0 0 0 0 0 0 0.0
64 0.0 0 0 0 0 0 0 0.0
65 0.0 0 0 0 0 0 0 0.0

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AFTER 106 ITERATIONS, CONVERGENCE RATIO= 0 9539402D-07
CENTRAL-DIFFERENCE BOUND ON TIME-STEP(SEC) FOR LINEAR SYSTEM= 0.6551460D-06
ACTUAL TIME-STEP BOUND (SEC) WOULD BE= 0 5241168D-06

TIME= 0.0 SEC.

..... EXTERNALLY APPLIED USER SPECIFIED LOADING.....

NODE	DOF#1 (LBS)	DOF#2 (LBS)	DOF#3 (LBS)	DOF#4 (IN-LBS)	DOF#5 (IN-LBS)	DOF#6 (IN-LBS)
1	0.0	0.0	0 0	0 0	0 0	0.0
2	0.0	0.0	0 0	0 0	0 0	0.0
3	0 0	0.0	0 0	0 0	0.0	0.0
4	0.0	0.0	0.0	0 0	0.0	0.0
5	0.0	0.0	0.0	0 0	0.0	0.0
6	0 0	0.0	0.0	0 0	0 0	0 0
7	0.0	0 0	0 0	0 0	0.0	0 0
8	0 0	0 0	0 0	0 0	0 0	0 0
9	0 0	0.0	0 0	0 0	0.0	0 0
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 923507D+03	0 576037D+02	0 692630D+02	0 432028D+01
22	0.0	0.0	0 184701D+04	0 0	0 138526D+03	0 0
23	0 0	0 0	0 184701D+04	0 0	0 138526D+03	0 0
24	0 0	0 0	0 184701D+04	0 0	0 138526D+03	0 0
25	0.0	0.0	0 923507D+03	-0 576037D+02	0 692630D+02	-0 432028D+01
26	0 0	0 0	0 184701D+04	0 115207D+03	0 0	0 0
27	0.0	0 0	0 369403D+04	0 0	0 0	0 0
28	0 0	0.0	0 369403D+04	0 0	0 0	0 0
29	0 0	0 0	0 369403D+04	0.0	0 0	0 0
30	0 0	0.0	0 184701D+04	-0 115207D+03	0 0	0 0
31	0 0	0.0	0 184701D+04	0 115207D+03	0 0	0.0
32	0 0	0 0	0 369403D+04	0 0	0 0	0 0
33	0.0	0 0	0 369403D+04	0 0	0 0	0 0
34	0.0	0 0	0 369403D+04	0 0	0 0	0 0
35	0 0	0.0	0 184701D+04	-0 115207D+03	0.0	0 0
36	0 0	0 0	0 184701D+04	0 115207D+03	0 0	0 0
37	0 0	0.0	0 369403D+04	0.0	0 0	0.0
38	0.0	0 0	0 369403D+04	0 0	0 0	0 0
39	0 0	0.0	0 369403D+04	0 0	0 0	0 0
40	0.0	0 0	0 184701D+04	-0 115207D+03	0 0	0 0
41	0 0	0.0	0 923507D+03	0 576037D+02	-0 692630D+02	-0 432028D+01
42	0.0	0.0	0 184701D+04	0 0	-0 138526D+03	0 0
43	0 0	0.0	0 184701D+04	0 0	-0 138526D+03	0 0
44	0 0	0 0	0 184701D+04	0 0	-0 138526D+03	0 0
45	0 0	0.0	0 923507D+03	-0 576037D+02	-0 692630D+02	0 432028D+01
46	0 0	0 0	0 0	0 0	0 0	0 0
47	0.0	0.0	0 0	0 0	0 0	0 0
48	0.0	0.0	0 0	0 0	0.0	0.0

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49	0.0	0.0	0.0	0.0	0.0	0.0	0.0
50	0.0	0.0	0.0	0.0	0.0	0.0	0.0
51	0.0	0.0	0.0	0.0	0.0	0.0	0.0
52	0.0	0.0	0.0	0.0	0.0	0.0	0.0
53	0.0	0.0	0.0	0.0	0.0	0.0	0.0
54	0.0	0.0	0.0	0.0	0.0	0.0	0.0
55	0.0	0.0	0.0	0.0	0.0	0.0	0.0
56	0.0	0.0	0.0	0.0	0.0	0.0	0.0
57	0.0	0.0	0.0	0.0	0.0	0.0	0.0
58	0.0	0.0	0.0	0.0	0.0	0.0	0.0
59	0.0	0.0	0.0	0.0	0.0	0.0	0.0
60	0.0	0.0	0.0	0.0	0.0	0.0	0.0
61	0.0	0.0	0.0	0.0	0.0	0.0	0.0
62	0.0	0.0	0.0	0.0	0.0	0.0	0.0
63	0.0	0.0	0.0	0.0	0.0	0.0	0.0
64	0.0	0.0	0.0	0.0	0.0	0.0	0.0
65	0.0	0.0	0.0	0.0	0.0	0.0	0.0

***** INCR. NO.= 0 TIME= 0.0 SEC.

NODE	U	V	W	PSIX	PSIY	TWIST	X-POS.	Y-POS.	Z-POS.
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.37425D+00	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.74850D+00	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.11227D+01	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.14970D+01	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.77500D+00	0.0
7	0.0	0.0	0.0	0.0	0.0	0.0	0.37425D+00	0.77500D+00	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.74850D+00	0.77500D+00	0.0
9	0.0	0.0	0.0	0.0	0.0	0.0	0.11227D+01	0.77500D+00	0.0
10	0.0	0.0	0.0	0.0	0.0	0.0	0.14970D+01	0.77500D+00	0.0
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.15500D+01	0.0
12	0.0	0.0	0.0	0.0	0.0	0.0	0.37425D+00	0.15500D+01	0.0
13	0.0	0.0	0.0	0.0	0.0	0.0	0.74850D+00	0.15500D+01	0.0
14	0.0	0.0	0.0	0.0	0.0	0.0	0.11227D+01	0.15500D+01	0.0
15	0.0	0.0	0.0	0.0	0.0	0.0	0.14970D+01	0.15500D+01	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.23250D+01	0.0
17	0.0	0.0	0.0	0.0	0.0	0.0	0.37425D+00	0.23250D+01	0.0
18	0.0	0.0	0.0	0.0	0.0	0.0	0.74850D+00	0.23250D+01	0.0
19	0.0	0.0	0.0	0.0	0.0	0.0	0.11227D+01	0.23250D+01	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0	0.14970D+01	0.23250D+01	0.0
21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.31000D+01	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0	0.37425D+00	0.31000D+01	0.0
23	0.0	0.0	0.0	0.0	0.0	0.0	0.74850D+00	0.31000D+01	0.0
24	0.0	0.0	0.0	0.0	0.0	0.0	0.11227D+01	0.31000D+01	0.0
25	0.0	0.0	0.0	0.0	0.0	0.0	0.14970D+01	0.31000D+01	0.0
26	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.35500D+01	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0	0.37425D+00	0.35500D+01	0.0
28	0.0	0.0	0.0	0.0	0.0	0.0	0.74850D+00	0.35500D+01	0.0
29	0.0	0.0	0.0	0.0	0.0	0.0	0.11227D+01	0.35500D+01	0.0
30	0.0	0.0	0.0	0.0	0.0	0.0	0.14970D+01	0.35500D+01	0.0
31	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.40000D+01	0.0
32	0.0	0.0	0.0	0.0	0.0	0.0	0.37425D+00	0.40000D+01	0.0
33	0.0	0.0	0.0	0.0	0.0	0.0	0.74850D+00	0.40000D+01	0.0
34	0.0	0.0	0.0	0.0	0.0	0.0	0.11227D+01	0.40000D+01	0.0
35	0.0	0.0	0.0	0.0	0.0	0.0	0.14970D+01	0.40000D+01	0.0
36	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.44500D+01	0.0
37	0.0	0.0	0.0	0.0	0.0	0.0	0.37425D+00	0.44500D+01	0.0
38	0.0	0.0	0.0	0.0	0.0	0.0	0.74850D+00	0.44500D+01	0.0
39	0.0	0.0	0.0	0.0	0.0	0.0	0.11227D+01	0.44500D+01	0.0
40	0.0	0.0	0.0	0.0	0.0	0.0	0.14970D+01	0.44500D+01	0.0
41	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.49000D+01	0.0
42	0.0	0.0	0.0	0.0	0.0	0.0	0.37425D+00	0.49000D+01	0.0
43	0.0	0.0	0.0	0.0	0.0	0.0	0.74850D+00	0.49000D+01	0.0
44	0.0	0.0	0.0	0.0	0.0	0.0	0.11227D+01	0.49000D+01	0.0
45	0.0	0.0	0.0	0.0	0.0	0.0	0.14970D+01	0.49000D+01	0.0

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46	0 0	0.0	0.0	0.0	0.0	0.0	0.0	0 0	0.56750D+01	0.0
47	0 0	0.0	0.0	0.0	0.0	0.0	0.0	0.37425D+00	0.56750D+01	0.0
48	0 0	0.0	0.0	0.0	0.0	0.0	0.0	0.74850D+00	0.56750D+01	0.0
49	0 0	0.0	0.0	0.0	0.0	0.0	0.0	0.11227D+01	0.56750D+01	0.0
50	0 0	0.0	0.0	0.0	0.0	0.0	0.0	0.14970D+01	0.56750D+01	0.0
51	0 0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.64500D+01	0.0
52	0 0	0.0	0.0	0.0	0.0	0.0	0.0	0.37425D+00	0.64500D+01	0.0
53	0 0	0.0	0.0	0.0	0.0	0.0	0.0	0.74850D+00	0.64500D+01	0.0
54	0 0	0.0	0.0	0.0	0.0	0.0	0.0	0.11227D+01	0.64500D+01	0.0
55	0 0	0.0	0.0	0.0	0.0	0.0	0.0	0.14970D+01	0.64500D+01	0.0
56	0 0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.72250D+01	0.0
57	0 0	0.0	0.0	0.0	0.0	0.0	0.0	0.37425D+00	0.72250D+01	0.0
58	0 0	0.0	0.0	0.0	0.0	0.0	0.0	0.74850D+00	0.72250D+01	0.0
59	0 0	0.0	0.0	0.0	0.0	0.0	0.0	0.11227D+01	0.72250D+01	0.0
60	0 0	0.0	0.0	0.0	0.0	0.0	0.0	0.14970D+01	0.72250D+01	0.0
61	0 0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.80000D+01	0.0
62	0 0	0.0	0.0	0.0	0.0	0.0	0.0	0.37425D+00	0.80000D+01	0.0
63	0 0	0.0	0.0	0.0	0.0	0.0	0.0	0.74850D+00	0.80000D+01	0.0
64	0 0	0.0	0.0	0.0	0.0	0.0	0.0	0.11227D+01	0.80000D+01	0.0
65	0 0	0.0	0.0	0.0	0.0	0.0	0.0	0.14970D+01	0.80000D+01	0.0

REACTION FORCES AT CONSTRAINED NODES

NODE	RX(LBS)	RY(LBS)	RZ(LBS)	MX(LBS-IN)	MY(LBS-IN)	MXY(LBS-IN-IN)
1	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0
61	0.0	0.0	0.0	0.0	0.0	0.0
62	0.0	0.0	0.0	0.0	0.0	0.0
63	0.0	0.0	0.0	0.0	0.0	0.0
64	0.0	0.0	0.0	0.0	0.0	0.0
65	0.0	0.0	0.0	0.0	0.0	0.0

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STRAIN COMPONENTS, PRINCIPAL(TENSILE) STRAIN AND DIRECTION AT CENTROID OF EACH ELEMENT

ELEM	EPS-X STRAIN		EPS-Y STRAIN		SHEAR STRAIN		PRINC. STRAIN(T)		DIRECTION(DEG.)	
	INNER	OUTER	INNER	OUTER	INNER	OUTER	INNER	OUTER	INNER	OUTER
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
26	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
27	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02

28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
29	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
31	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
32	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
33	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
34	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
35	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
36	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
37	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
38	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
39	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
40	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
41	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
42	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
43	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
44	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
45	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
46	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
47	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
48	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02

STRAIN COMPONENTS, PRINCIPAL (TENSILE) STRAIN AND DIRECTION AT USER-SPECIFIED NODES

NODE	EPS-X STRAIN		EPS-Y STRAIN		SHEAR STRAIN		PRINC. STRAIN(T)		DIRECTION(DEG.)	
	INNER	OUTER	INNER	OUTER	INNER	OUTER	INNER	OUTER	INNER	OUTER
33	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
35	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
38	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
40	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
48	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02

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STRAIN COMPONENTS, PRINCIPAL(TENSILE) STRAIN AND DIRECTION, AND ELONGATIONS AT SPECIFIED ADDITIONAL POINTS

POINT NO.	SURFACE	EPS-X STRAIN	EPS-Y STRAIN	SHEAR STRAIN	ELONG (DIR.1)	ELONG.(DIR.2)	PRINC. STRN(T)	DIRECTION(DEG.)
1	INNER	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02
1	OUTER	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02
2	INNER	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02
2	OUTER	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02
3	INNER	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02
3	OUTER	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02
4	INNER	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02
4	OUTER	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02
5	INNER	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02
5	OUTER	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02
6	INNER	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02
6	OUTER	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02
7	INNER	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02
7	OUTER	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02
8	INNER	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02
8	OUTER	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02
9	INNER	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02
9	OUTER	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02
10	INNER	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02
10	OUTER	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02
11	INNER	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02
11	OUTER	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02

SYSTEM ENERGIES(IN-LB)

WORK INPUT TO STRUCTURE	0.0
STRUCTURE KINETIC ENERGY	0.0
STRUCTURE ELASTIC ENERGY	0.0
STRUCTURE PLASTIC ENERGY	0.0
ENERGY STORED IN ELASTIC RESTRAINTS	0.0

TIME= 0.250000D-05 SEC.

.....EXTERNALLY APPLIED USER SPECIFIED LOADING.....

NODE	DOF#1 (LBS)	DOF#2 (LBS)	DOF#3 (LBS)	DOF#4 (IN-LBS)	DOF#5 (IN-LBS)	DOF#6 (IN-LBS)
1	0 0	0.0	0 0	0 0	0.0	0.0
2	0 0	0.0	0.0	0.0	0.0	0.0
3	0 0	0.0	0.0	0.0	0.0	0.0
4	0.0	0 0	0 0	0 0	0.0	0.0
5	0.0	0.0	0 0	0 0	0 0	0 0
6	0 0	0 0	0 0	0 0	0.0	0 0
7	0 0	0 0	0 0	0 0	0 0	0 0
8	0 0	0.0	0 0	0 0	0 0	0 0
9	0 0	0.0	0 0	0 0	0 0	0 0
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 831156D+03	0 518434D+02	0 623367D+02	0 388825D+01
22	0.0	0.0	0 166231D+04	0 0	0.124673D+03	0 0
23	0 0	0 0	0 166231D+04	0 0	0 124673D+03	0 0
24	0.0	0 0	0 166231D+04	0 0	0 124673D+03	0 0
25	0 0	0.0	0 831156D+03	-0 518434D+02	0 623367D+02	-0 388825D+01
26	0.0	0.0	0 166231D+04	0 103687D+03	0.0	0 0
27	0 0	0.0	0 332462D+04	0 0	0 0	0 0
28	0 0	0 0	0 332162D+04	0 0	0.0	0 0
29	0 0	0.0	0 332462D+04	0 0	0 0	0 0
30	0 0	0.0	0 166231D+04	-0 103687D+03	0 0	0 0
31	0.0	0 0	0 166231D+04	0 103687D+03	0 0	0 0
32	0 0	0 0	0 332462D+04	0 0	0 0	0 0
33	0 0	0 0	0 332462D+04	0 0	0 0	0 0
34	0 0	0.0	0 332462D+04	0 0	0 0	0 0
35	0 0	0 0	0 166231D+04	-0 103687D+03	0 0	0 0
36	0 0	0.0	0 166231D+04	0 103687D+03	0 0	0.0
37	0.0	0.0	0.332462D+04	0.0	0 0	0 0
38	0 0	0 0	0.332462D+04	0 0	0 0	0.0
39	0.0	0 0	0 332462D+04	0.0	0 0	0 0
40	0 0	0.0	0 166231D+04	-0 103687D+03	0.0	0 0
41	0 0	0.0	0 831156D+03	0 518434D+02	-0.623367D+02	-0 388825D+01
42	0 0	0 0	0 166231D+04	0 0	-0 124673D+03	0 0
43	0 0	0.0	0 166231D+04	0 0	-0 124673D+03	0 0
44	0.0	0.0	0 166231D+04	0 0	-0 124673D+03	0 0
45	0 0	0.0	0 831156D+03	-0 518434D+02	-0 623367D+02	0 388825D+01
46	0 0	0.0	0 0	0 0	0 0	0 0
47	0 0	0.0	0 0	0 0	0 0	0.0
48	0 0	0.0	0.0	0 0	0 0	0 0
49	0 0	0.0	0 0	0 0	0 0	0.0
50	0 0	0.0	0 0	0 0	0 0	0 0
51	0 0	0.0	0 0	0 0	0.0	0 0
52	0 0	0 0	0 0	0 0	0 0	0.0
53	0 0	0 0	0 0	0 0	0.0	0 0
54	0 0	0.0	0.0	0 0	0 0	0 0
55	0 0	0.0	0 0	0 0	0.0	0 0
56	0 0	0.0	0 0	0 0	0.0	0 0
57	0.0	0.0	0 0	0 0	0 0	0.0
58	0.0	0 0	0 0	0 0	0 0	0.0
59	0.0	0.0	0.0	0.0	0 0	0.0
60	0.0	0.0	0 0	0 0	0.0	0.0

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61	0.0	0.0	0.0	0.0	0.0	0.0
62	0.0	0.0	0.0	0.0	0.0	0.0
63	0.0	0.0	0.0	0.0	0.0	0.0
64	0.0	0.0	0.0	0.0	0.0	0.0
65	0.0	0.0	0.0	0.0	0.0	0.0

ROUNDING ERROR PARAMETER IN FACTORING ROW 150 = 0.28916102 NO OF NEGATIVE DIAG= 0

MAXIMUM BANDWIDTH OF 60 IS FOUND FOR (CONSTRAINED) DEGREE-OF-FREEDOM NUMBER 372

ROUNDING ERROR PARAMETER IN FACTORING ROW 150 = 0.34295915 NO OF NEGATIVE DIAG= 0

***** INCR. NO.= 1 TIME= 0.2500D-05 SEC.

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NODE	U	V	W	PSIX	PSIY	TWIST	X-POS.	Y-POS.	Z-POS.
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.37425D+00	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.74850D+00	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.11227D+01	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.14970D+01	0.0	0.0
6	0.0	0.0	0.51519D-05	-0.14519D-04	0.55451D-04	-0.16130D-03	0.0	0.77500D+00	0.51519D-05
7	0.0	0.0	0.43962D-05	-0.14371D-05	0.47145D-04	-0.16538D-04	0.37425D+00	0.77500D+00	0.43962D-05
8	0.0	0.0	0.43375D-05	0.44170D-16	0.46477D-04	0.51387D-15	0.74850D+00	0.77500D+00	0.43375D-05
9	0.0	0.0	0.43962D-05	0.14371D-05	0.47145D-04	0.16539D-04	0.11227D+01	0.77500D+00	0.43962D-05
10	0.0	0.0	0.51519D-05	0.14519D-04	0.55451D-04	0.16130D-03	0.14970D+01	0.77500D+00	0.51519D-05
11	0.0	0.0	0.19922D-04	-0.46461D-04	0.27121D-03	-0.69738D-03	0.0	0.15500D+01	0.19922D-04
12	0.0	0.0	0.17431D-04	-0.38937D-05	0.23448D-03	-0.64409D-04	0.37425D+00	0.15500D+01	0.17431D-04
13	0.0	0.0	0.17262D-04	0.13365D-15	0.23179D-03	0.21406D-14	0.74850D+00	0.15500D+01	0.17262D-04
14	0.0	0.0	0.17431D-04	0.38937D-05	0.23448D-03	0.64409D-04	0.11227D+01	0.15500D+01	0.17431D-04
15	0.0	0.0	0.19922D-04	0.46461D-04	0.27121D-03	0.69738D-03	0.14970D+01	0.15500D+01	0.19922D-04
16	0.0	0.0	0.99179D-04	-0.19027D-03	0.12524D-02	-0.27066D-02	0.0	0.23250D+01	0.99179D-04
17	0.0	0.0	0.88537D-04	-0.12370D-04	0.11050D-02	-0.20861D-03	0.37425D+00	0.23250D+01	0.88537D-04
18	0.0	0.0	0.87982D-04	0.42699D-16	0.10959D-02	0.53380D-14	0.74850D+00	0.23250D+01	0.87982D-04
19	0.0	0.0	0.88537D-04	0.12370D-04	0.11050D-02	0.20861D-03	0.11227D+01	0.23250D+01	0.88537D-04
20	0.0	0.0	0.99179D-04	0.19027D-03	0.12524D-02	0.27066D-02	0.14970D+01	0.23250D+01	0.99179D-04
21	0.0	0.0	0.13479D-02	-0.14959D-03	0.10897D-01	-0.94515D-02	0.0	0.31000D+01	0.13479D-02
22	0.0	0.0	0.13400D-02	-0.12765D-04	0.10366D-01	-0.50944D-03	0.37425D+00	0.31000D+01	0.13400D-02
23	0.0	0.0	0.13395D-02	0.64591D-15	0.10341D-01	0.77473D-14	0.74850D+00	0.31000D+01	0.13395D-02
24	0.0	0.0	0.13400D-02	0.12765D-04	0.10366D-01	0.50944D-03	0.11227D+01	0.31000D+01	0.13400D-02
25	0.0	0.0	0.13479D-02	0.14959D-03	0.10897D-01	0.94515D-02	0.14970D+01	0.31000D+01	0.13479D-02
26	0.0	0.0	0.25893D-02	-0.45265D-04	-0.51140D-03	0.12476D-02	0.0	0.35500D+01	0.25893D-02
27	0.0	0.0	0.25857D-02	0.11586D-04	-0.42594D-03	-0.54027D-04	0.37425D+00	0.35500D+01	0.25857D-02
28	0.0	0.0	0.25861D-02	0.29626D-15	-0.42629D-03	0.27136D-13	0.74850D+00	0.35500D+01	0.25861D-02
29	0.0	0.0	0.25857D-02	-0.11586D-04	-0.42594D-03	0.54027D-04	0.11227D+01	0.35500D+01	0.25857D-02
30	0.0	0.0	0.25893D-02	0.45265D-04	-0.51140D-03	-0.12476D-02	0.14970D+01	0.35500D+01	0.25893D-02
31	0.0	0.0	0.25651D-02	-0.23795D-04	-0.21068D-14	0.60101D-13	0.0	0.40000D+01	0.25651D-02
32	0.0	0.0	0.25637D-02	-0.18478D-05	-0.54644D-16	0.36420D-13	0.37425D+00	0.40000D+01	0.25637D-02
33	0.0	0.0	0.25636D-02	-0.95735D-16	-0.25587D-15	0.31861D-13	0.74850D+00	0.40000D+01	0.25636D-02
34	0.0	0.0	0.25637D-02	0.18478D-05	-0.36634D-15	0.20534D-13	0.11227D+01	0.40000D+01	0.25637D-02
35	0.0	0.0	0.25651D-02	0.23795D-04	0.68860D-15	0.25161D-13	0.14970D+01	0.40000D+01	0.25651D-02
36	0.0	0.0	0.25893D-02	-0.45265D-04	0.51140D-03	-0.12476D-02	0.0	0.44500D+01	0.25893D-02
37	0.0	0.0	0.25857D-02	0.11586D-04	0.42594D-03	0.54027D-04	0.37425D+00	0.44500D+01	0.25857D-02
38	0.0	0.0	0.25861D-02	-0.81218D-15	0.42629D-03	0.19021D-13	0.74850D+00	0.44500D+01	0.25861D-02
39	0.0	0.0	0.25857D-02	-0.11586D-04	-0.42594D-03	-0.54027D-04	0.11227D+01	0.44500D+01	0.25857D-02
40	0.0	0.0	0.25893D-02	0.45265D-04	0.51140D-03	0.12476D-02	0.14970D+01	0.44500D+01	0.25893D-02
41	0.0	0.0	0.13479D-02	-0.14959D-03	-0.10897D-01	0.94515D-02	0.0	0.49000D+01	0.13479D-02
42	0.0	0.0	0.13400D-02	-0.12765D-04	-0.10366D-01	0.50944D-03	0.37425D+00	0.49000D+01	0.13400D-02
43	0.0	0.0	0.13395D-02	0.64591D-15	-0.10341D-01	-0.16253D-13	0.74850D+00	0.49000D+01	0.13395D-02
44	0.0	0.0	0.13400D-02	0.12765D-04	-0.10366D-01	-0.50944D-03	0.11227D+01	0.49000D+01	0.13400D-02
45	0.0	0.0	0.13479D-02	0.14959D-03	-0.10897D-01	-0.94515D-02	0.14970D+01	0.49000D+01	0.13479D-02
46	0.0	0.0	0.99179D-04	-0.19027D-03	-0.12524D-02	0.27066D-02	0.0	0.56750D+01	0.99179D-04
47	0.0	0.0	0.88537D-04	-0.12370D-04	-0.11050D-02	0.20861D-03	0.37425D+00	0.56750D+01	0.88537D-04
48	0.0	0.0	0.87982D-04	0.32499D-15	-0.10959D-02	-0.23433D-14	0.74850D+00	0.56750D+01	0.87982D-04
49	0.0	0.0	0.88537D-04	0.12370D-04	-0.11050D-02	-0.20861D-03	0.11227D+01	0.56750D+01	0.88537D-04
50	0.0	0.0	0.99179D-04	0.19027D-03	-0.12524D-02	0.27066D-02	0.14970D+01	0.56750D+01	0.99179D-04
51	0.0	0.0	0.19922D-04	-0.46461D-04	-0.27121D-03	0.69738D-03	0.0	0.64500D+01	0.19922D-04

52	0.0	0.0	0.17431D-04	-0.38937D-05	-0.23448D-03	0.64409D-04	0.37425D+00	0.64500D+01	0.17431D-04
53	0.0	0.0	0.17262D-04	0.16121D-16	-0.23179D-03	-0.54427D-15	0.74850D+00	0.64500D+01	0.17262D-04
54	0.0	0.0	0.17431D-04	0.38937D-05	-0.23448D-03	-0.64409D-04	0.11227D+01	0.64500D+01	0.17431D-04
55	0.0	0.0	0.19922D-04	0.46461D-04	-0.27121D-03	-0.69738D-03	0.14970D+01	0.64500D+01	0.19922D-04
56	0.0	0.0	0.51519D-05	-0.14519D-04	-0.55451D-04	0.16130D-03	0.0	0.72250D+01	0.51519D-05
57	0.0	0.0	0.43962D-05	-0.14371D-05	-0.47145D-04	0.16538D-04	0.37425D+00	0.72250D+01	0.43962D-05
58	0.0	0.0	0.43375D-05	0.12340D-16	-0.46477D-04	-0.81810D-16	0.74850D+00	0.72250D+01	0.43375D-05
59	0.0	0.0	0.43962D-05	0.14371D-05	-0.47145D-04	-0.16538D-04	0.11227D+01	0.72250D+01	0.43962D-05
60	0.0	0.0	0.51519D-05	0.14519D-04	-0.55451D-04	-0.16130D-03	0.14970D+01	0.72250D+01	0.51519D-05
61	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.80000D+01	0.0
62	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.80000D+01	0.0
63	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.80000D+01	0.0
64	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.80000D+01	0.0
65	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.80000D+01	0.0

REACTION FORCES AT CONSTRAINED NODES

NODE	RX (LBS)	RY (LBS)	RZ (LBS)	MX (LBS-IN)	MY (LBS-IN)	MX (LBS-IN)	MY (LBS-IN)	MX (LBS-IN)	MY (LBS-IN)	MX (LBS-IN)	MY (LBS-IN)
1	0.0	0.0	0.19108D+01	0.12929D+00	0.33697D+00	0.22568D-01					
2	0.0	0.0	0.36567D+01	0.80131D-02	0.64390D+00	0.13107D-02					
3	0.0	0.0	0.36947D+01	-0.36310D-14	0.65001D+00	-0.20456D-14					
4	0.0	0.0	0.36567D+01	-0.80131D-02	0.64390D+00	-0.13107D-02					
5	0.0	0.0	0.19108D+01	-0.12929D+00	0.33697D+00	-0.22568D-01					
61	0.0	0.0	0.19108D+01	0.12929D+00	0.33697D+00	-0.22568D-01					
62	0.0	0.0	0.36567D+01	0.80131D-02	-0.64390D+00	-0.13107D-02					
63	0.0	0.0	0.36947D+01	0.33005D-13	-0.65001D+00	-0.60392D-14					
64	0.0	0.0	0.36567D+01	-0.80131D-02	-0.64390D+00	0.13107D-02					
65	0.0	0.0	0.19108D+01	-0.12929D+00	-0.33697D+00	0.22568D-01					

STRAIN COMPONENTS, PRINCIPAL(TENSILE) STRAIN AND DIRECTION AT CENTROID OF EACH ELEMENT

ELEM.	EPS-X STRAIN		EPS-Y STRAIN		SHEAR STRAIN		PRINC. STRAIN(T)		DIRECTION(DEG.)	
	INNER	OUTER	INNER	OUTER	INNER	OUTER	INNER	OUTER	INNER	OUTER
1	-0.10200D-05	0.10200D-05	0.29300D-05	-0.29300D-05	-0.95210D-07	0.95210D-07	0.29310D-05	0.10200D-05	-0.89310D+02	0.69050D+00
2	-0.12040D-06	0.12040D-06	0.30300D-05	-0.30300D-05	-0.12640D-07	0.12640D-07	0.30300D-05	0.12040D-06	-0.89890D+02	0.11500D+00
3	-0.12040D-06	0.12040D-06	0.30300D-05	-0.30300D-05	0.12640D-07	-0.12640D-07	0.30300D-05	0.12040D-06	0.89890D+02	-0.11500D+00
4	-0.10200D-05	0.10200D-05	0.29300D-05	-0.29300D-05	0.95210D-07	-0.95210D-07	0.29310D-05	0.10200D-05	0.89310D+02	-0.69050D+00
5	-0.26530D-05	0.26530D-05	0.11760D-04	-0.11760D-04	-0.10620D-05	0.10620D-05	0.11780D-04	0.26730D-05	-0.87890D+02	0.21070D+01
6	-0.26880D-06	0.26880D-06	0.12110D-04	-0.12110D-04	-0.13800D-06	0.13800D-06	0.12120D-04	0.26910D-06	-0.89680D+02	0.31930D+00
7	-0.26880D-06	0.26880D-06	0.12110D-04	-0.12110D-04	0.13800D-06	-0.13800D-06	0.12120D-04	0.26910D-06	0.89680D+02	-0.31930D+00
8	-0.26530D-05	0.26530D-05	0.11760D-04	-0.11760D-04	0.10620D-05	-0.10620D-05	0.11780D-04	0.26730D-05	0.87890D+02	-0.21070D+01
9	-0.95980D-05	0.95980D-05	0.55200D-04	-0.55170D-04	-0.35540D-05	0.35550D-05	0.55250D-04	0.96470D-05	-0.88430D+02	0.15710D+01
10	-0.79550D-06	0.79550D-06	0.56650D-04	-0.56610D-04	-0.42190D-06	0.42200D-06	0.56650D-04	0.79630D-06	-0.89790D+02	0.21060D+00
11	-0.79550D-06	0.79550D-06	0.56650D-04	-0.56610D-04	0.42190D-06	-0.42200D-06	0.56650D-04	0.79630D-06	0.89790D+02	-0.21060D+00
12	-0.95980D-05	0.95980D-05	0.55200D-04	-0.55170D-04	0.35540D-05	-0.35550D-05	0.55250D-04	0.96470D-05	0.88430D+02	-0.15710D+01
13	-0.63630D-04	0.63630D-04	0.60230D-03	-0.60210D-03	-0.12580D-04	0.12590D-04	0.60240D-03	0.63690D-04	-0.89460D+02	0.54170D+00
14	-0.22590D-05	0.22590D-05	0.60810D-03	-0.60790D-03	-0.10850D-05	0.10850D-05	0.60810D-03	0.22590D-05	-0.89950D+02	0.50940D-01
15	-0.22590D-05	0.22590D-05	0.60810D-03	-0.60790D-03	0.10850D-05	-0.10850D-05	0.60810D-03	0.22590D-05	0.89950D+02	-0.50940D-01
16	-0.63630D-04	0.63630D-04	0.60230D-03	-0.60210D-03	0.12580D-04	-0.12590D-04	0.60210D-03	0.63690D-04	0.89460D+02	-0.54170D+00
17	0.91720D-04	-0.91720D-04	-0.12020D-02	0.12050D-02	-0.15380D-04	0.15440D-04	0.91760D-04	0.12050D-02	-0.34040D+00	0.89660D+02
18	0.35710D-05	-0.35710D-05	-0.12180D-02	0.12210D-02	-0.19210D-05	0.19230D-05	0.35720D-05	0.12210D-02	-0.45050D-01	0.89960D+02
19	0.35710D-05	-0.35710D-05	-0.12180D-02	0.12210D-02	0.19210D-05	-0.19230D-05	0.35720D-05	0.12210D-02	0.45050D-01	-0.89960D+02
20	0.91720D-04	-0.91720D-04	-0.12020D-02	0.12050D-02	0.15380D-04	-0.15440D-04	0.91760D-04	0.12050D-02	0.34040D+00	-0.89660D+02
21	-0.46080D-05	0.46080D-05	0.46220D-04	-0.46210D-04	0.11280D-05	-0.11280D-05	0.46220D-04	0.46140D-05	0.89360D+02	-0.63580D+00
22	-0.24940D-06	0.24940D-06	0.48580D-04	-0.48580D-04	0.22630D-06	-0.22630D-06	0.48580D-04	0.24960D-06	0.89870D+02	-0.13280D+00
23	-0.24940D-06	0.24940D-06	0.48580D-04	-0.48580D-04	-0.22630D-06	0.22630D-06	0.48580D-04	0.24960D-06	-0.89870D+02	0.13280D+00
24	-0.46080D-05	0.46080D-05	0.46220D-04	-0.46210D-04	-0.11280D-05	0.11280D-05	0.46220D-04	0.46140D-05	-0.89360D+02	0.63580D+00
25	-0.46080D-05	0.46080D-05	0.46220D-04	-0.46210D-04	0.11280D-05	-0.11280D-05	0.46220D-04	0.46140D-05	0.89360D+02	-0.63580D+00
26	-0.21910D-06	0.21910D-06	0.48580D-04	-0.48580D-04	-0.22630D-06	0.22630D-06	0.48580D-04	0.24960D-06	-0.89870D+02	0.13280D+00
27	-0.21910D-06	0.21910D-06	0.48580D-04	-0.48580D-04	0.22630D-06	-0.22630D-06	0.48580D-04	0.24960D-06	0.89870D+02	-0.13280D+00
28	-0.46080D-05	0.46080D-05	0.46220D-04	-0.46210D-04	0.11280D-05	-0.11280D-05	0.46220D-04	0.46140D-05	-0.89360D+02	0.63580D+00
29	0.91720D-04	-0.91720D-04	-0.12020D-02	0.12050D-02	0.15380D-04	-0.15440D-04	0.91760D-04	0.12050D-02	0.34040D+00	-0.89660D+02
30	0.35710D-05	-0.35710D-05	-0.12180D-02	0.12210D-02	-0.19210D-05	0.19230D-05	0.35720D-05	0.12210D-02	-0.45050D-01	0.89960D+02
31	0.35710D-05	-0.35710D-05	-0.12180D-02	0.12210D-02	0.19210D-05	-0.19230D-05	0.35720D-05	0.12210D-02	0.45050D-01	-0.89960D+02
32	0.91720D-04	-0.91720D-04	-0.12020D-02	0.12050D-02	-0.15380D-04	0.15440D-04	0.91760D-04	0.12050D-02	-0.34040D+00	0.89660D+02
33	-0.63630D-04	0.63630D-04	0.60230D-03	-0.60210D-03	0.12580D-04	-0.12590D-04	0.60240D-03	0.63690D-04	0.89460D+02	-0.54170D+00

34	-0.2259D-05	0.2259D-05	0.6081D-03	-0.6079D-03	0.1085D-05	-0.1085D-05	0.6081D-03	0.2259D-05	0.8995D+02	-0.5094D-01
35	-0.2259D-05	0.2259D-05	0.6081D-03	-0.6079D-03	-0.1085D-05	0.1085D-05	0.6081D-03	0.2259D-05	-0.8995D+02	0.5094D-01
36	-0.6363D-04	0.6363D-04	0.6023D-03	-0.6021D-03	-0.1258D-04	0.1259D-04	0.6024D-03	0.6369D-04	-0.8946D+02	0.5417D+00
37	-0.9598D-05	0.9598D-05	0.5520D-04	-0.5517D-04	0.3554D-05	-0.3555D-05	0.5525D-04	0.9647D-05	0.8843D+02	-0.1571D+01
38	-0.7955D-06	0.7955D-06	0.5665D-04	-0.5661D-04	0.4219D-06	-0.4220D-06	0.5665D-04	0.7963D-06	0.8979D+02	-0.2106D+00
39	-0.7955D-06	0.7955D-06	0.5665D-04	-0.5661D-04	-0.4219D-06	0.4220D-06	0.5665D-04	0.7963D-06	-0.8979D+02	0.2106D+00
40	-0.9598D-05	0.9598D-05	0.5520D-04	-0.5517D-04	-0.3554D-05	0.3555D-05	0.5525D-04	0.9647D-05	-0.8843D+02	0.1571D+01
41	-0.2653D-05	0.2653D-05	0.1176D-04	-0.1176D-04	0.1062D-05	-0.1062D-05	0.1178D-04	0.2673D-05	0.8789D+02	-0.2107D+01
42	-0.2688D-06	0.2688D-06	0.1211D-04	-0.1211D-04	0.1380D-06	-0.1380D-06	0.1212D-04	0.2691D-06	0.8968D+02	-0.3193D+00
43	-0.2688D-06	0.2688D-06	0.1211D-04	-0.1211D-04	-0.1380D-06	0.1380D-06	0.1212D-04	0.2691D-06	-0.8968D+02	0.3193D+00
44	-0.2653D-05	0.2653D-05	0.1176D-04	-0.1176D-04	-0.1062D-05	0.1062D-05	0.1178D-04	0.2673D-05	-0.8789D+02	0.2107D+01
45	-0.1020D-05	0.1020D-05	0.2930D-05	-0.2930D-05	0.9521D-07	-0.9521D-07	0.2931D-05	0.1020D-05	0.8931D+02	-0.6905D+00
46	-0.1204D-06	0.1204D-06	0.3030D-05	-0.3030D-05	0.1264D-07	-0.1264D-07	0.3030D-05	0.1204D-06	0.8989D+02	-0.1150D+00
47	-0.1204D-06	0.1204D-06	0.3030D-05	-0.3030D-05	-0.1264D-07	0.1264D-07	0.3030D-05	0.1204D-06	-0.8989D+02	0.1150D+00
48	-0.1020D-05	0.1020D-05	0.2930D-05	-0.2930D-05	-0.9521D-07	0.9521D-07	0.2931D-05	0.1020D-05	-0.8931D+02	0.6905D+00

STRAIN COMPONENTS, PRINCIPAL (TENSILE) STRAIN AND DIRECTION AT USER-SPECIFIED NODES

NODE	EPS-X STRAIN		EPS-Y STRAIN		SHEAR STRAIN		PRINC. STRAIN(T)		DIRECTION(DEG.)	
	INNER	OUTER	INNER	OUTER	INNER	OUTER	INNER	OUTER	INNER	OUTER
33	-0.2436D-06	0.2436D-06	-0.6264D-04	0.6264D-04	0.3250D-14	-0.3250D-14	0.0	0.6264D-04	0.0	-0.9000D+02
35	0.1037D-04	-0.1037D-04	-0.7935D-04	0.7935D-04	0.2566D-14	-0.2566D-14	0.1037D-04	0.7935D-04	0.8196D-09	-0.9000D+02
38	0.2445D-05	-0.2445D-05	0.2133D-03	-0.2131D-03	0.1940D-14	-0.1941D-14	0.0	0.2133D-03	0.0	0.9000D+02
40	0.1370D-04	-0.1370D-04	0.2789D-03	-0.2786D-03	0.1273D-03	-0.1272D-03	0.2934D-03	0.7851D-06	0.7718D+02	-0.1283D+02
48	-0.2160D-05	0.2160D-05	-0.3639D-03	0.3651D-03	-0.2394D-15	0.2387D-15	0.0	0.3651D-03	0.0	0.9000D+02
50	0.8385D-04	-0.8385D-04	-0.4005D-03	0.4021D-03	-0.2763D-03	0.2756D-03	0.1205D-03	0.4365D-03	-0.1485D+02	0.7521D+02

STRAIN COMPONENTS, PRINCIPAL(TENSILE) STRAIN AND DIRECTION, AND ELONGATIONS AT SPECIFIED ADDITIONAL POINTS

POINT NO.	SURFACE	EPS-X STRAIN		EPS-Y STRAIN		SHEAR STRAIN		ELONG (DIR 1)		ELONG (DIR 2)		PRINC. STRN(T)		DIRECTION(DEG.)	
		INNER	OUTER	INNER	OUTER	INNER	OUTER	1	2	1	2	1	2	1	2
1	INNER	0.0	0.0	-0.3907D-05	0.0	0.0	0.0	-0.3907D-05	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	OUTER	0.0	0.0	0.3907D-05	0.0	0.0	0.0	0.3907D-05	0.3907D-05	0.3907D-05	0.3907D-05	0.9000D+02	0.9000D+02	0.9000D+02	0.9000D+02
2	INNER	0.7312D-07	-0.7312D-07	-0.3119D-06	0.3119D-06	-0.9902D-17	0.9902D-17	0.7312D-07	-0.3119D-06	0.7312D-07	-0.3119D-06	0.7312D-07	-0.7367D-09	-0.7367D-09	-0.7367D-09
2	OUTER	-0.7312D-07	0.7312D-07	0.3120D-06	-0.3120D-06	0.9902D-17	-0.9902D-17	-0.7312D-07	0.3120D-06	0.3120D-06	0.3120D-06	0.9000D+02	0.9000D+02	0.9000D+02	0.9000D+02
3	INNER	-0.1557D-06	0.1557D-06	-0.8079D-05	0.8079D-05	-0.5221D-16	0.5221D-16	-0.1557D-06	-0.8079D-05	0.0	0.0	0.0	0.0	0.0	0.0
3	OUTER	0.1557D-06	-0.1557D-06	0.8082D-05	-0.8082D-05	0.5220D-16	-0.5220D-16	0.1557D-06	0.8082D-05	0.8082D-05	0.8082D-05	0.9000D+02	0.9000D+02	0.9000D+02	0.9000D+02
4	INNER	-0.3706D-06	0.3706D-06	-0.2332D-04	0.2332D-04	-0.1922D-15	0.1922D-15	-0.3706D-06	-0.2332D-04	0.0	0.0	0.0	0.0	0.0	0.0
4	OUTER	0.3706D-06	-0.3706D-06	0.2338D-04	-0.2338D-04	0.1922D-15	-0.1922D-15	0.3706D-06	0.2338D-04	0.2338D-04	0.2338D-04	0.9000D+02	0.9000D+02	0.9000D+02	0.9000D+02
5	INNER	-0.1096D-05	0.1096D-05	-0.1387D-03	0.1387D-03	-0.1763D-15	0.1763D-15	-0.1096D-05	-0.1387D-03	0.1387D-03	0.1387D-03	-0.9000D+02	-0.9000D+02	-0.9000D+02	-0.9000D+02
5	OUTER	0.1096D-05	-0.1096D-05	0.1372D-03	-0.1372D-03	0.1754D-15	-0.1754D-15	0.1096D-05	0.1372D-03	0.1372D-03	0.1372D-03	0.3634D-10	0.3634D-10	0.3634D-10	0.3634D-10
6	INNER	-0.2436D-06	0.2436D-06	-0.6263D-04	0.6263D-04	-0.3249D-14	0.3249D-14	-0.2436D-06	-0.6263D-04	0.0	0.0	0.0	0.0	0.0	0.0
6	OUTER	0.2436D-06	-0.2436D-06	0.6263D-04	-0.6263D-04	0.3249D-14	-0.3249D-14	0.2436D-06	0.6263D-04	0.6263D-04	0.6263D-04	-0.9000D+02	-0.9000D+02	-0.9000D+02	-0.9000D+02
7	INNER	-0.1096D-05	0.1096D-05	-0.1387D-03	0.1387D-03	-0.1763D-15	0.1763D-15	-0.1096D-05	-0.1387D-03	0.1387D-03	0.1387D-03	0.9000D+02	0.9000D+02	0.9000D+02	0.9000D+02
7	OUTER	0.1096D-05	-0.1096D-05	0.1372D-03	-0.1372D-03	0.1763D-15	-0.1763D-15	0.1096D-05	0.1372D-03	0.1372D-03	0.1372D-03	-0.9000D+02	-0.9000D+02	-0.9000D+02	-0.9000D+02
8	INNER	-0.3706D-06	0.3706D-06	-0.2332D-04	0.2332D-04	-0.2509D-16	0.2509D-16	-0.3706D-06	-0.2332D-04	0.0	0.0	0.0	0.0	0.0	0.0
8	OUTER	0.3706D-06	-0.3706D-06	0.2338D-04	-0.2338D-04	0.2508D-16	-0.2508D-16	0.3706D-06	0.2338D-04	0.2338D-04	0.2338D-04	-0.9000D+02	-0.9000D+02	-0.9000D+02	-0.9000D+02
9	INNER	-0.1557D-06	0.1557D-06	-0.8079D-05	0.8079D-05	-0.1681D-16	0.1681D-16	-0.1557D-06	-0.8079D-05	0.0	0.0	0.0	0.0	0.0	0.0
9	OUTER	0.1557D-06	-0.1557D-06	0.8082D-05	-0.8082D-05	0.1681D-16	-0.1681D-16	0.1557D-06	0.8082D-05	0.8082D-05	0.8082D-05	-0.9000D+02	-0.9000D+02	-0.9000D+02	-0.9000D+02
10	INNER	0.7312D-07	-0.7312D-07	-0.3119D-06	0.3119D-06	-0.7759D-18	0.7759D-18	0.7312D-07	-0.3119D-06	0.7312D-07	-0.3119D-06	0.7312D-07	-0.5772D-10	-0.5772D-10	-0.5772D-10
10	OUTER	-0.7312D-07	0.7312D-07	0.3120D-06	-0.3120D-06	0.7759D-18	-0.7759D-18	-0.7312D-07	0.3120D-06	0.3120D-06	0.3120D-06	0.9000D+02	0.9000D+02	0.9000D+02	0.9000D+02
11	INNER	-0.1244D-02	0.1244D-02	-0.3907D-05	0.3907D-05	-0.8691D-21	0.8691D-21	0.0	-0.3907D-05	0.0	0.0	0.0	0.0	0.0	0.0
11	OUTER	0.1244D-02	-0.1244D-02	0.3907D-05	-0.3907D-05	0.8691D-21	-0.8691D-21	0.0	0.3907D-05	0.3907D-05	0.3907D-05	-0.9000D+02	-0.9000D+02	-0.9000D+02	-0.9000D+02

SYSTEM ENERGIES(IN-LB)
 WORK INPUT TO STRUCTURE = 0.40116400+03
 STRUCTURE KINETIC ENERGY = 0.1456689D+03
 STRUCTURE ELASTIC ENERGY = 0.1127671D+01
 STRUCTURE PLASTIC ENERGY = 0.2543675D+03
 ENERGY STORED IN ELASTIC RESTRAINTS= 0.0

TIME= 0.500000D-05 SEC.
 EXTERNALLY APPLIED USER SPECIFIED LOADING.....

NODE	DOF#1 (LBS)	DOF#2 (LBS)	DOF#3 (LBS)	DOF#4 (IN-LBS)	DOF#5 (IN-LBS)	DOF#6 (IN-LBS)
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1	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0	0.0	0.0
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	0.738805D+03	0.460830D+02	0.554104D+02	0.345622D+01
22	0.0	0.0	0.147761D+04	0.0	0.110821D+03	0.0
23	0.0	0.0	0.147761D+04	0.0	0.110821D+03	0.0
24	0.0	0.0	0.147761D+04	0.0	0.110821D+03	0.0
25	0.0	0.0	0.738805D+03	-0.460830D+02	0.554104D+02	-0.345622D+01
26	0.0	0.0	0.147761D+04	0.921660D+02	0.0	0.0
27	0.0	0.0	0.295522D+04	0.0	0.0	0.0
28	0.0	0.0	0.295522D+04	0.0	0.0	0.0
29	0.0	0.0	0.295522D+04	0.0	0.0	0.0
30	0.0	0.0	0.147761D+04	-0.921660D+02	0.0	0.0
31	0.0	0.0	0.147761D+04	0.921660D+02	0.0	0.0
32	0.0	0.0	0.295522D+04	0.0	0.0	0.0
33	0.0	0.0	0.295522D+04	0.0	0.0	0.0
34	0.0	0.0	0.295522D+04	0.0	0.0	0.0
35	0.0	0.0	0.147761D+04	-0.921660D+02	0.0	0.0
36	0.0	0.0	0.147761D+04	0.921660D+02	0.0	0.0
37	0.0	0.0	0.295522D+04	0.0	0.0	0.0
38	0.0	0.0	0.295522D+04	0.0	0.0	0.0
39	0.0	0.0	0.295522D+04	0.0	0.0	0.0
40	0.0	0.0	0.147761D+04	-0.921660D+02	0.0	0.0
41	0.0	0.0	0.738805D+03	0.460830D+02	-0.554104D+02	-0.345622D+01
42	0.0	0.0	0.147761D+04	0.0	-0.110821D+03	0.0
43	0.0	0.0	0.147761D+04	0.0	-0.110821D+03	0.0
44	0.0	0.0	0.147761D+04	0.0	-0.110821D+03	0.0
45	0.0	0.0	0.738805D+03	-0.460830D+02	-0.554104D+02	0.345622D+01
46	0.0	0.0	0.0	0.0	0.0	0.0
47	0.0	0.0	0.0	0.0	0.0	0.0
48	0.0	0.0	0.0	0.0	0.0	0.0
49	0.0	0.0	0.0	0.0	0.0	0.0
50	0.0	0.0	0.0	0.0	0.0	0.0
51	0.0	0.0	0.0	0.0	0.0	0.0
52	0.0	0.0	0.0	0.0	0.0	0.0
53	0.0	0.0	0.0	0.0	0.0	0.0
54	0.0	0.0	0.0	0.0	0.0	0.0
55	0.0	0.0	0.0	0.0	0.0	0.0
56	0.0	0.0	0.0	0.0	0.0	0.0
57	0.0	0.0	0.0	0.0	0.0	0.0
58	0.0	0.0	0.0	0.0	0.0	0.0
59	0.0	0.0	0.0	0.0	0.0	0.0
60	0.0	0.0	0.0	0.0	0.0	0.0
61	0.0	0.0	0.0	0.0	0.0	0.0
62	0.0	0.0	0.0	0.0	0.0	0.0
63	0.0	0.0	0.0	0.0	0.0	0.0
64	0.0	0.0	0.0	0.0	0.0	0.0
65	0.0	0.0	0.0	0.0	0.0	0.0

***** INCR. NO.= 2 TIME= 0.5000D-05 SEC.

NODE	U	V	W	PSIX	PSIY	TWIST	X-POS.	Y-POS.	Z-POS.
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.37425D+00	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.74850D+00	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.11227D+01	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.14970D+01	0.0	0.0
6	-0.32055D-07	0.17451D-07	0.75092D-08	-0.14477D-04	-0.44967D-05	-0.15187D-03	-0.32055D-07	0.77500D+00	0.75092D-08
7	0.69323D-08	-0.13693D-07	-0.47200D-06	-0.26689D-05	-0.90374D-05	-0.30124D-04	0.37425D+00	0.77500D+00	-0.47200D-06
8	-0.47720D-21	0.86680D-08	-0.64130D-06	-0.11025D-17	-0.10875D-04	-0.36194D-16	0.74850D+00	0.77500D+00	-0.64130D-06
9	-0.69323D-08	-0.13693D-07	-0.47200D-06	0.26689D-05	-0.90374D-05	0.30124D-04	0.11227D+01	0.77500D+00	-0.47200D-06
10	0.32055D-07	0.17451D-07	0.75092D-08	0.14477D-04	-0.44967D-05	0.15187D-03	0.14970D+01	0.77500D+00	0.75092D-08
11	0.26745D-06	0.10613D-06	0.98713D-05	-0.71806D-04	0.63672D-04	-0.86432D-03	0.26745D-06	0.15500D+01	0.98713D-05
12	0.29660D-07	0.17536D-06	0.65589D-05	-0.83695D-05	0.29290D-04	-0.12722D-03	0.37425D+00	0.15500D+01	0.65589D-05
13	0.18118D-20	0.12084D-06	0.59073D-05	0.12039D-16	0.20394D-04	0.37937D-16	0.74850D+00	0.15500D+01	0.59073D-05
14	-0.29660D-07	0.17536D-06	0.65589D-05	0.83695D-05	0.29290D-04	0.12722D-03	0.11227D+01	0.15500D+01	0.65589D-05
15	-0.26745D-06	0.10613D-06	0.98713D-05	0.71806D-04	0.63672D-04	0.86432D-03	0.14970D+01	0.15500D+01	0.98713D-05
16	-0.38160D-03	0.21993D-05	0.16867D-03	-0.55483D-03	0.12984D-02	-0.56278D-02	-0.38160D-06	0.23250D+01	0.16867D-03
17	0.27500D-08	0.18533D-05	0.13247D-03	-0.34472D-04	0.97851D-03	-0.49099D-03	0.37425D+00	0.23250D+01	0.13247D-03
18	-0.87913D-20	0.19584D-05	0.12946D-03	0.25625D-16	0.93867D-03	0.61686D-15	0.74850D+00	0.23250D+01	0.12946D-03
19	-0.27500D-08	0.18533D-05	0.13247D-03	0.34472D-04	0.97851D-03	0.49099D-03	0.11227D+01	0.23250D+01	0.13247D-03
20	0.38160D-06	0.21993D-05	0.16867D-03	0.55483D-03	0.12984D-02	0.56278D-02	0.14970D+01	0.23250D+01	0.16867D-03
21	0.33972D-05	0.22839D-06	0.49834D-02	-0.21907D-03	0.34504D-01	-0.33045D-01	0.33972D-05	0.31000D+01	0.49834D-02
22	0.83089D-06	0.21707D-06	0.49715D-02	-0.18310D-04	0.32072D-01	-0.18330D-03	0.37425D+00	0.31000D+01	0.49715D-02
23	0.49570D-19	0.20695D-06	0.49703D-02	0.29664D-15	0.32119D-01	0.32110D-14	0.74850D+00	0.31000D+01	0.49703D-02
24	-0.83684D-06	0.21707D-06	0.49715D-02	0.18310D-04	0.32072D-01	0.18330D-03	0.11227D+01	0.31000D+01	0.49715D-02
25	-0.33972D-05	0.22839D-06	0.49834D-02	0.21907D-03	0.34504D-01	0.33045D-01	0.14970D+01	0.31000D+01	0.49834D-02
26	0.18129D-07	-0.28943D-05	0.10305D-01	-0.10664D-02	-0.30850D-02	0.11445D-01	0.18129D-07	0.35500D+01	0.10305D-01
27	0.22826D-06	-0.24971D-05	0.10206D-01	0.94412D-04	-0.21704D-02	-0.14922D-03	0.37425D+00	0.35500D+01	0.10206D-01
28	-0.28624D-19	-0.26217D-05	0.10219D-01	0.41368D-15	-0.22001D-02	0.18014D-13	0.74850D+00	0.35500D+01	0.10219D-01
29	-0.22826D-06	-0.24871D-05	0.10206D-01	-0.94412D-04	-0.21704D-02	0.14922D-03	0.11227D+01	0.35500D+01	0.10206D-01
30	-0.18129D-07	-0.28943D-05	0.10305D-01	0.10664D-02	-0.30850D-02	-0.11445D-01	0.14970D+01	0.35500D+01	0.10305D-01
31	0.76871D-06	0.34055D-19	0.98308D-02	0.70954D-04	-0.86302D-15	0.34514D-13	0.76871D-06	0.40000D+01	0.98308D-02
32	0.76726D-07	0.84434D-20	0.98400D-02	-0.79478D-05	0.64185D-16	0.27315D-13	0.37425D+00	0.40000D+01	0.98400D-02
33	0.17333D-19	0.58631D-20	0.98395D-02	0.64835D-16	-0.16133D-15	0.24703D-13	0.74850D+00	0.40000D+01	0.98395D-02
34	-0.78723D-07	0.11832D-19	0.98400D-02	0.79478D-05	-0.40072D-15	0.14564D-13	0.11227D+01	0.40000D+01	0.98400D-02
35	-0.76974D-06	0.18132D-20	0.98308D-02	-0.70954D-04	0.86736D-17	0.10064D-13	0.14970D+01	0.40000D+01	0.98308D-02
36	0.18129D-07	0.26943D-05	0.10305D-01	-0.10664D-02	0.30850D-02	-0.11415D-01	0.18129D-07	0.44500D+01	0.10305D-01
37	0.22826D-06	0.24871D-05	0.10206D-01	0.94412D-04	0.21704D-02	0.14922D-03	0.37425D+00	0.44500D+01	0.10206D-01
38	-0.19181D-19	0.26217D-05	0.10219D-01	-0.24069D-15	0.22001D-02	0.21647D-13	0.74850D+00	0.44500D+01	0.10219D-01
39	-0.22826D-06	0.24871D-05	0.10206D-01	-0.94412D-04	0.21704D-02	-0.14922D-03	0.11227D+01	0.44500D+01	0.10206D-01
40	-0.18129D-07	0.28313D-05	0.10305D-01	0.10664D-02	0.30850D-02	0.11445D-01	0.14970D+01	0.44500D+01	0.10305D-01
41	0.33972D-05	-0.22839D-06	0.49834D-02	-0.21907D-03	0.34504D-01	0.33045D-01	0.33972D-05	0.49000D+01	0.49834D-02
42	0.83089D-06	-0.21707D-06	0.49715D-02	-0.18310D-04	0.32072D-01	0.18330D-03	0.37425D+00	0.49000D+01	0.49715D-02
43	0.15284D-18	-0.20695D-06	0.49703D-02	-0.23581D-15	-0.32119D-01	-0.38840D-14	0.74850D+00	0.49000D+01	0.49703D-02
44	-0.83689D-06	-0.21707D-06	0.49715D-02	0.18310D-04	0.32072D-01	-0.18330D-03	0.11227D+01	0.49000D+01	0.49715D-02
45	-0.33972D-05	-0.22839D-06	0.49834D-02	0.21907D-03	0.34504D-01	0.33045D-01	0.14970D+01	0.49000D+01	0.49834D-02
46	-0.38160D-06	-0.21993D-05	0.16867D-03	-0.55483D-03	0.12984D-02	0.56278D-02	-0.38160D-06	0.56750D+01	0.16867D-03
47	0.27500D-08	-0.18533D-05	0.13247D-03	-0.34472D-04	-0.97651D-03	0.49099D-03	0.37425D+00	0.56750D+01	0.13247D-03
48	-0.36500D-19	-0.19584D-05	0.12946D-03	0.56389D-16	-0.93867D-03	0.32896D-15	0.74850D+00	0.56750D+01	0.12946D-03
49	-0.27500D-08	-0.18533D-05	0.13247D-03	0.34472D-04	-0.97851D-03	-0.49099D-03	0.11227D+01	0.56750D+01	0.13247D-03
50	0.38160D-06	-0.21993D-05	0.16867D-03	0.55483D-03	0.12984D-02	0.56278D-02	0.14970D+01	0.56750D+01	0.16867D-03
51	0.26745D-06	-0.10613D-06	0.98713D-05	-0.71806D-04	0.63672D-04	0.86432D-03	0.26745D-06	0.64500D+01	0.98713D-05
52	0.29660D-07	-0.17536D-06	0.65589D-05	-0.83695D-05	0.29290D-04	0.12722D-03	0.37425D+00	0.64500D+01	0.65589D-05
53	0.77846D-20	-0.12084D-06	0.59073D-05	-0.10963D-16	-0.20394D-04	0.33630D-15	0.74850D+00	0.64500D+01	0.59073D-05
54	-0.29660D-07	-0.17536D-06	0.65589D-05	0.83695D-05	0.29290D-04	0.12722D-03	0.11227D+01	0.64500D+01	0.65589D-05
55	-0.26745D-06	-0.10613D-06	0.95713D-05	0.71806D-04	-0.63672D-04	-0.86432D-03	0.14970D+01	0.64500D+01	0.95713D-05
56	-0.32055D-07	-0.17451D-07	0.75092D-08	-0.14477D-04	-0.44967D-05	0.15187D-03	-0.32055D-07	0.72250D+01	0.75092D-08
57	0.69323D-08	0.13693D-07	-0.47200D-06	-0.26689D-05	0.90374D-05	0.30124D-04	0.37425D+00	0.72250D+01	-0.47200D-06
58	-0.25499D-20	-0.86680D-08	-0.64130D-06	-0.81090D-17	0.10875D-04	0.57772D-16	0.74850D+00	0.72250D+01	-0.64130D-06
59	-0.69323D-08	0.13693D-07	-0.47200D-06	0.26689D-05	0.90374D-05	-0.30124D-04	0.11227D+01	0.72250D+01	-0.47200D-06
60	0.32055D-07	-0.17451D-07	0.75092D-08	0.14477D-04	-0.44967D-05	-0.15187D-03	0.14970D+01	0.72250D+01	0.75092D-08
61	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.80000D+01	0.0
62	0.0	0.0	0.0	0.0	0.0	0.0	0.37425D+00	0.80000D+01	0.0
63	0.0	0.0	0.0	0.0	0.0	0.0	0.74850D+00	0.80000D+01	0.0

64	0.0	0.0	0.0	0.0	0.0	0.0	0.11227D+01	0.80000D+01	0.0
65	0.0	0.0	0.0	0.0	0.0	0.0	0.14970D+01	0.80000D+01	0.0

REACTION FORCES AT CONSTRAINED NODES

NODE	RX(LBS)	RY(LBS)	RZ(LBS)	MX(LBS-IN)	MY(LBS-IN)	MXY(LBS-IN-IN)
1	-0.14890D-01	0.21819D-02	0.34260D+01	0.22219D+00	0.59755D+00	0.39043D-01
2	0.19712D-01	-0.12578D-01	0.65787D+01	0.12319D-01	0.11444D+01	0.21494D-02
3	-0.86649D-15	0.82524D-02	0.66355D+01	0.21157D-12	0.11548D+01	0.37984D-13
4	-0.19712D-01	-0.12578D-01	0.65787D+01	-0.12319D-01	0.11444D+01	-0.21494D-02
5	0.14890D-01	0.21819D-02	0.34260D+01	-0.22219D+00	0.59755D+00	-0.39043D-01
61	-0.14890D-01	-0.21819D-02	0.34260D+01	0.22219D+00	-0.59755D+00	-0.39043D-01
62	0.19712D-01	0.12578D-01	0.65787D+01	0.12319D-01	-0.11444D+01	-0.21494D-02
63	-0.36478D-14	-0.82524D-02	0.66355D+01	0.57668D-13	-0.11548D+01	-0.11000D-13
64	-0.19712D-01	0.12578D-01	0.65787D+01	-0.12319D-01	-0.11444D+01	0.21494D-02
65	0.14890D-01	-0.21819D-02	0.34260D+01	-0.22219D+00	-0.59755D+00	0.39043D-01

STRAIN COMPONENTS, PRINCIPAL(TENSILE) STRAIN AND DIRECTION AT CENTROID OF EACH ELEMENT

ELEM.	EPS-X STRAIN		EPS-Y STRAIN		SHEAR STRAIN		PRINC. STRAIN(T)		DIRECTION(DEG.)	
	INNER	OUTER	INNER	OUTER	INNER	OUTER	INNER	OUTER	INNER	OUTER
1	-0.7506D-06	0.8548D-06	-0.8177D-06	0.8225D-06	-0.2871D-06	0.1715D-06	0.0	0.9259D-06	0.0	0.3968D+02
2	0.2251D-06	0.2066D-06	-0.7512D-06	0.7447D-06	0.2786D-07	0.4083D-07	0.0	0.7454D-06	0.0	0.8783D+02
3	-0.2251D-06	0.2066D-06	-0.7512D-06	0.7447D-06	-0.2786D-07	-0.4083D-07	0.0	0.7454D-06	0.0	-0.8783D+02
4	-0.7506D-06	0.8548D-06	-0.8177D-06	0.8225D-06	0.2871D-06	-0.1715D-06	0.0	0.9259D-06	0.0	-0.3968D+02
5	-0.3262D-05	0.2731D-05	0.1789D-05	-0.1430D-05	-0.2375D-05	0.2893D-05	0.2054D-05	0.3184D-05	-0.7741D+02	0.1740D+02
6	-0.5785D-06	0.4803D-06	0.2185D-05	-0.1797D-05	-0.3460D-07	-0.2198D-07	0.2186D-05	0.4808D-06	-0.8964D+02	-0.2765D+00
7	-0.5785D-06	0.4803D-06	0.2185D-05	-0.1797D-05	0.3460D-07	0.2198D-07	0.2186D-05	0.4808D-06	0.8964D+02	0.2765D+00
8	-0.3262D-05	0.2731D-05	0.1789D-05	-0.1430D-05	0.2375D-05	-0.2893D-05	0.2054D-05	0.3184D-05	0.7741D+02	-0.1740D+02
9	-0.1811D-04	0.1850D-04	0.6075D-04	-0.5588D-04	-0.1082D-04	0.9203D-05	0.6112D-04	0.1878D-04	-0.8610D+02	0.3527D+01
10	-0.1927D-05	0.1940D-05	0.6259D-04	-0.5806D-04	0.5120D-06	-0.4117D-06	0.6260D-04	0.1841D-05	0.8977D+02	-0.1969D+00
11	-0.1927D-05	0.1840D-05	0.6259D-04	-0.5806D-04	-0.5120D-06	0.4117D-06	0.6260D-04	0.1841D-05	-0.8977D+02	0.1969D+00
12	-0.1811D-04	0.1850D-04	0.6075D-04	-0.5588D-04	0.1082D-04	-0.9203D-05	0.6112D-04	0.1878D-04	0.8610D+02	-0.3527D+01
13	-0.3198D-03	0.3140D-03	0.2029D-02	-0.2032D-02	0.3506D-04	-0.2965D-04	0.2029D-02	0.3141D-03	0.8957D+02	-0.3621D+00
14	0.6537D-05	-0.8780D-05	0.2048D-02	-0.2052D-02	-0.3822D-05	0.5089D-05	0.2048D-02	0.0	-0.8995D+02	0.0
15	0.6537D-05	-0.8780D-05	0.2048D-02	-0.2052D-02	0.3822D-05	-0.5089D-05	0.2048D-02	0.0	0.8995D+02	0.0
16	-0.3198D-03	0.3140D-03	0.2029D-02	-0.2032D-02	-0.3506D-04	0.2965D-04	0.2029D-02	0.3141D-03	-0.8957D+02	0.3621D+00
17	0.4304D-03	-0.4367D-03	-0.3791D-02	0.3879D-02	-0.4672D-04	0.3492D-04	0.4306D-03	0.3879D-02	-0.3170D+00	0.8977D+02
18	-0.6347D-05	0.3501D-05	-0.3841D-02	0.3929D-02	0.4160D-05	-0.5297D-05	0.0	0.3929D-02	0.0	-0.8996D+02
19	-0.6347D-05	0.3501D-05	-0.3841D-02	0.3929D-02	-0.4160D-05	0.5297D-05	0.0	0.3929D-02	0.0	0.8996D+02
20	0.4304D-03	-0.4367D-03	-0.3791D-02	0.3879D-02	0.4672D-04	-0.3492D-04	0.4306D-03	0.3879D-02	0.3170D+00	-0.8977D+02
21	-0.1580D-04	0.1452D-04	0.2425D-03	-0.2301D-03	0.3902D-04	-0.3657D-04	0.2440D-03	0.1588D-04	0.8571D+02	-0.4252D+01
22	-0.1580D-04	0.1452D-04	0.2425D-03	-0.2301D-03	-0.3902D-04	0.3657D-04	0.2440D-03	0.1588D-04	-0.8571D+02	0.4252D+01
23	-0.5158D-05	0.4337D-05	0.2544D-03	-0.2425D-03	-0.6869D-05	0.6166D-05	0.2544D-03	0.4376D-05	-0.8924D+02	0.7155D+00
24	-0.5158D-05	0.4337D-05	0.2544D-03	-0.2425D-03	0.6869D-05	-0.6166D-05	0.2544D-03	0.4376D-05	0.8924D+02	-0.7155D+00
25	-0.1580D-04	0.1452D-04	0.2425D-03	-0.2301D-03	-0.3902D-04	0.3657D-04	0.2440D-03	0.1588D-04	-0.8571D+02	0.4252D+01
26	-0.1580D-05	0.4337D-05	0.2544D-03	-0.2425D-03	0.6869D-05	-0.6166D-05	0.2544D-03	0.4376D-05	0.8924D+02	-0.7155D+00
27	-0.1580D-05	0.4337D-05	0.2544D-03	-0.2425D-03	-0.6869D-05	0.6166D-05	0.2544D-03	0.4376D-05	-0.8924D+02	0.7155D+00
28	-0.1580D-04	0.1452D-04	0.2425D-03	-0.2301D-03	0.3902D-04	-0.3657D-04	0.2440D-03	0.1588D-04	0.8571D+02	-0.4252D+01
29	0.4304D-03	-0.4367D-03	-0.3791D-02	0.3879D-02	0.4672D-04	-0.3492D-04	0.4306D-03	0.3879D-02	0.3170D+00	-0.8977D+02
30	-0.6347D-05	0.3501D-05	-0.3841D-02	0.3929D-02	-0.4160D-05	0.5297D-05	0.0	0.3929D-02	0.0	0.8996D+02
31	-0.6347D-05	0.3501D-05	-0.3841D-02	0.3929D-02	0.4160D-05	-0.5297D-05	0.0	0.3929D-02	0.0	-0.8996D+02
32	0.4304D-03	-0.4367D-03	-0.3791D-02	0.3879D-02	-0.4672D-04	0.3492D-04	0.4306D-03	0.3879D-02	-0.3170D+00	0.8977D+02
33	-0.3198D-03	0.3140D-03	0.2029D-02	-0.2032D-02	-0.3506D-04	0.2965D-04	0.2029D-02	0.3141D-03	-0.8957D+02	0.3621D+00
34	0.6537D-05	-0.8780D-05	0.2048D-02	-0.2052D-02	0.3822D-05	-0.5089D-05	0.2048D-02	0.0	0.8995D+02	0.0
35	0.6537D-05	-0.8780D-05	0.2048D-02	-0.2052D-02	-0.3822D-05	0.5089D-05	0.2048D-02	0.0	-0.8995D+02	0.0
36	-0.3198D-03	0.3140D-03	0.2029D-02	-0.2032D-02	0.3506D-04	-0.2965D-04	0.2029D-02	0.3141D-03	0.8957D+02	-0.3621D+00
37	-0.1811D-04	0.1850D-04	0.6075D-04	-0.5588D-04	0.1082D-04	-0.9203D-05	0.6112D-04	0.1878D-04	0.8610D+02	-0.3527D+01
38	-0.1927D-05	0.1840D-05	0.6259D-04	-0.5806D-04	-0.5120D-06	0.4117D-06	0.6260D-04	0.1841D-05	-0.8977D+02	0.1969D+00
39	-0.1927D-05	0.1840D-05	0.6259D-04	-0.5806D-04	0.5120D-06	-0.4117D-06	0.6260D-04	0.1841D-05	0.8977D+02	-0.1969D+00
40	-0.1811D-04	0.1850D-04	0.6075D-04	-0.5588D-04	-0.1082D-04	0.9203D-05	0.6112D-04	0.1878D-04	-0.8610D+02	0.3527D+01
41	-0.3262D-05	0.2731D-05	0.1789D-05	-0.1430D-05	0.2375D-05	-0.2893D-05	0.2054D-05	0.3184D-05	0.7741D+02	-0.1740D+02
42	-0.5785D-06	0.4803D-06	0.2185D-05	-0.1797D-05	0.3460D-07	-0.2198D-07	0.2186D-05	0.4808D-06	0.8964D+02	-0.2765D+00
43	-0.5785D-06	0.4803D-06	0.2185D-05	-0.1797D-05	-0.3460D-07	0.2198D-07	0.2186D-05	0.4808D-06	-0.8964D+02	0.2765D+00
44	-0.3262D-05	0.2731D-05	0.1789D-05	-0.1430D-05	-0.2375D-05	0.2893D-05	0.2054D-05	0.3184D-05	-0.7741D+02	0.1740D+02
45	-0.7506D-06	0.8548D-06	-0.8177D-06	0.8225D-06	0.2871D-06	-0.1715D-06	0.0	0.9259D-06	0.0	-0.3968D+02

46	-0.2251D-06	0 2066D-06	-0.7512D-06	0.7447D-06	-0.2786D-07	-0.4083D-07	0.0	0.7454D-06	0.0	-0.8783D+02
47	-0.2251D-06	0 2066D-06	-0.7512D-06	0.7447D-06	0.2786D-07	0.4083D-07	0.0	0.7454D-06	0.0	0.8783D+02
48	-0.7506D-06	0 8548D-06	-0.8177D-06	0.8225D-06	-0.2871D-06	0.1715D-06	0.0	0.9259D-06	0.0	0.3968D+02

STRAIN COMPONENTS, PRINCIPAL (TENSILE) STRAIN AND DIRECTION AT USER-SPECIFIED NODES

NODE	EPS-X STRAIN		EPS-Y STRAIN		SHEAR STRAIN		PRINC. STRAIN(T)		DIRECTION(DEG.)	
	INNER	OUTER	INNER	OUTER	INNER	OUTER	INNER	OUTER	INNER	OUTER
33	-0.1097D-05	0.6767D-06	0.8008D-04	-0.6843D-04	0.2520D-14	-0.2520D-14	0.8008D-04	0.6767D-06	0.9000D+02	-0.1045D-08
35	-0.1826D-04	0.1458D-04	0.2419D-04	-0.1132D-04	0.1026D-14	-0.1026D-14	0.2419D-04	0.1458D-04	0.9000D+02	-0.1135D-08
38	-0.1338D-05	0.1180D-06	-0.6095D-03	0.6139D-03	0.2208D-14	-0.2208D-14	0.0	0.6139D-03	0.0	-0.9000D+02
40	0.3407D-03	-0.3334D-03	-0.4646D-03	0.4736D-03	0.1169D-02	-0.1166D-02	0.6478D-03	0.7780D-03	0.2772D+02	-0.6243D+02
48	-0.2828D-05	0.2813D-05	-0.9102D-03	0.9111D-03	0.3338D-16	-0.3372D-16	0.0	0.9111D-03	0.0	-0.9000D+02
50	0.2339D-03	-0.2316D-03	-0.1075D-02	0.1081D-02	-0.5737D-03	0.5744D-03	0.2938D-03	0.1141D-02	-0.1180D+02	0.7818D+02

STRAIN COMPONENTS, PRINCIPAL(TENSILE) STRAIN AND DIRECTION, AND ELONGATIONS AT SPECIFIED ADDITIONAL POINTS

POINT NO.	SURFACE	EPS-X STRAIN	EPS-Y STRAIN	SHEAR STRAIN	ELONG. (DIR. 1)	ELONG. (DIR. 2)	PRINC. STRN(T)	DIRECTION(DEG.)
1	INNER	0.47392D-43	0.11157D-05	-0.61574D-21	0.0	0.11157D-05	0.11157D-05	-0.9000D+02
1	OUTER	0.47392D-43	-0.10934D-05	-0.61574D-21	0.0	-0.10934D-05	0.0	0.0
2	INNER	0.96753D-07	0.17628D-06	0.15419D-07	0.96753D-07	0.17628D-06	0.17703D-06	0.84514D+02
2	OUTER	-0.10631D-06	-0.15391D-06	0.15419D-07	-0.10631D-06	-0.15391D-06	0.0	0.0
3	INNER	-0.26475D-06	0.28134D-05	0.11352D-09	-0.26475D-06	0.28134D-05	0.28134D-05	0.89999D+02
3	OUTER	0.19245D-06	-0.25240D-05	0.11352D-09	0.19245D-06	-0.25240D-05	0.19245D-06	0.11972D-02
4	INNER	-0.58631D-06	0.17956D-04	-0.81300D-08	-0.58631D-06	0.17956D-04	0.17956D-04	-0.89987D+02
4	OUTER	0.47420D-06	-0.13203D-04	-0.81300D-08	0.47420D-06	-0.13203D-04	0.47420D-06	-0.17028D-01
5	INNER	0.82019D-06	0.87315D-03	0.17148D-06	0.82019D-06	0.87315D-03	0.87315D-03	0.89994D+02
5	OUTER	-0.24166D-05	-0.87317D-03	0.17148D-06	-0.24167D-05	-0.87356D-03	0.0	0.0
6	INNER	-0.10974D-05	0.80084D-04	0.25196D-14	-0.10974D-05	0.80081D-04	0.80084D-04	0.90000D+02
6	OUTER	0.67672D-06	-0.68432D-04	-0.25199D-14	0.67672D-06	-0.68435D-04	0.67672D-06	-0.10446D-08
7	INNER	0.82019D-06	0.87315D-03	-0.17148D-06	0.82019D-06	0.87277D-03	0.87315D-03	-0.89994D+02
7	OUTER	-0.24166D-05	-0.87317D-03	-0.17148D-06	-0.24167D-05	-0.87356D-03	0.0	0.0
8	INNER	-0.58631D-06	0.17956D-04	0.81300D-08	-0.58631D-06	0.17956D-04	0.17956D-04	0.89987D+02
8	OUTER	0.47420D-06	-0.13203D-04	0.81300D-08	0.47420D-06	-0.13204D-04	0.47420D-06	0.17028D-01
9	INNER	-0.26475D-06	0.28134D-05	-0.11352D-09	-0.26475D-06	0.28134D-05	0.28134D-05	-0.89999D+02
9	OUTER	0.19245D-06	-0.25240D-05	-0.11352D-09	0.19245D-06	-0.25240D-05	0.19245D-06	-0.11972D-02
10	INNER	0.96753D-07	0.17628D-06	-0.15419D-07	0.96753D-07	0.17628D-06	0.17703D-06	-0.84514D+02
10	OUTER	-0.10631D-06	-0.15391D-06	-0.15419D-07	-0.10631D-06	-0.15391D-06	0.0	0.0
11	INNER	0.64420D-22	0.11157D-05	0.48733D-20	0.0	0.11157D-05	0.11157D-05	0.90000D+02
11	OUTER	-0.64420D-22	-0.10934D-05	0.17071D-20	0.0	-0.10934D-05	0.0	0.0

SYSTEM ENERGIES(IN-LB)

WORK INPUT TO STRUCTURE = 0.7522995D+03
 STRUCTURE KINETIC ENERGY = 0.4927275D+03
 STRUCTURE ELASTIC ENERGY = 0.8634123D+01
 STRUCTURE PLASTIC ENERGY = 0.2509379D+03
 ENERGY STORED IN ELASTIC RESTRAINTS = 0.0

...

***** INCR. NO.= 10 TIME= 0.2500D-04 SEC.

NODE	U	V	W	PSIX	PSIY	TWIST	X-POS.	Y-POS.	Z-POS.
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.37425D+00	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.74850D+00	0.0	0.0

4	0 0	0.0	0.0	0 0	0 0	0.0	0.11227D+01	0 0	0.0
5	0 0	0.0	0.0	0 0	0 0	0.0	0.14970D+01	0.0	0.0
6	0 375390-03	0 11017D-02	-0.535390-03	0 697020-03	-0 68163D-02	0.11178D-01	0.375390-03	0.77610D+00	-0 535390-03
7	0 172900-03	0 100750-02	-0.437580-03	0 339850-04	-0 53111D-02	0.97021D-03	0.37442D+00	0 776010+00	-0 437580-03
8	0 328310-17	0 937810-03	-0 438050-03	0 253970-16	-0 519300-02	0.12393D-14	0.748500+00	0 776000+00	-0.438050-03
9	-0 172900-03	0 100750-02	-0 437580-03	-0.339850-04	-0.53111D 02	-0.97021D-03	0.11226D+01	0 776010+00	-0 437580-03
10	-0 375390-03	0 11017D-02	-0 535390-03	0 697020-03	-0 68163D-02	-0 11178D-01	0.14966D+01	0.776100+00	-0 535390-03
11	0 51893D-03	0 25561D-02	0 291390-02	-0 42725D-02	0 60749D-02	-0.15508D-01	0 51893D-03	0.15526D+01	0.291390-02
12	0 22141D-03	0.25025D-02	0 22386D-02	-0 56948D-03	0 35779D-02	-0.33484D-02	0 37447D+00	0.15525D+01	0.22386D-02
13	0 235310-16	0 24181D-02	0 21425D-02	-0 29177D-15	0 28233D-02	0.42387D-15	0 748500+00	0.15524D+01	0.21425D-02
14	-0 22141D-03	0 25025D-02	0 22386D-02	0 56948D-03	0 35779D-02	0 33484D-02	0 11225D+01	0.15525D+01	0.22386D-02
15	-0 51893D-03	0 25561D-02	0 291390-02	0 42725D-02	0 60749D-02	0 15508D-01	0.14965D+01	0 15526D+01	0.291390-02
16	0 62880D-03	0 47930D-02	-0 12131D-01	0 21474D-01	-0 16607D-02	0 64964D-01	0 62880D-03	0 23298D+01	-0.12131D-01
17	0 37548D-03	0 43261D-02	-0 83097D-02	0 30158D-02	0 86620D-02	0.97201D-02	0 37463D+00	0 23293D+01	-0.83097D-02
18	0 22975D-16	0 42870D-02	-0.80237D-02	-0 82876D-15	0 98036D-02	-0 93441D-14	0 748500+00	0 23293D+01	-0.80237D-02
19	-0 37548D-03	0 43261D-02	-0 83097D-02	-0 30158D-02	0 86620D-02	-0 97201D-02	0 11224D+01	0.23293D+01	-0 83097D-02
20	-0 62880D-03	0 47930D-02	-0 12131D-01	-0 21474D-01	-0 18607D-02	-0 64964D-01	0 14964D+01	0 23298D+01	-0.12131D-01
21	0 24981D-02	0 31733D-02	0 85074D-01	0 37644D-02	0 22632D+00	-0 95707D-01	0 24981D-02	0.31032D+01	0.85074D-01
22	0 97269D-03	0 27280D-02	0 85752D-01	0 45403D-03	0 20997D+00	-0.11509D-01	0 37522D+00	0.31027D+01	0 85752D-01
23	-0 88037D-16	0 27314D-02	0 85758D-01	-0 29178D-14	0 20810D+00	-0 40704D-13	0 74850D+00	0 31027D+01	0 85758D-01
24	-0 97269D-03	0 27280D-02	0 85752D-01	-0.45403D-03	0 20997D+00	0.11509D-01	0 11218D+01	0 31027D+01	0.85752D-01
25	-0 24981D-02	0 31733D-02	0 85074D-01	-0 37644D-02	0 22632D+00	0 95707D-01	0 14945D+01	0.31032D+01	0.85074D-01
26	0 15211D-02	-0 24657D-02	0 17265D+00	-0 29963D-01	0 12132D+00	-0.12969D-01	0 15211D-02	0 35475D+01	0 17265D+00
27	0 82648D-03	-0 18116D-02	0 16775D+00	-0 39461D-02	0 11668D+00	-0 25997D-02	0 37508D+00	0 35482D+01	0.16775D+00
28	-0 58625D-16	-0 19584D-02	0 16733D+00	0 18579D-14	0 11707D+00	-0 57457D-13	0.74850D+00	0 35480D+01	0.16733D+00
29	-0 82648D-03	-0 18116D-02	0 16775D+00	0 39461D-02	0 11680D+00	0 25997D-02	0 11219D+01	0.35482D+01	0.16775D+00
30	-0 15211D-02	-0 24657D-02	0 17265D+00	0 29963D-01	0 12132D+00	0 12969D-01	0 14955D+01	0.35475D+01	0 17265D+00
31	0 13316D-02	0 29346D-15	0 19546D+00	-0 23635D-01	0 24744D-13	-0 33706D-12	0 13316D-02	0 40000D+01	0.19546D+00
32	0 55316D-03	0 12620D-15	0.19089D+00	-0 29098D-02	0 25951D-14	-0 27534D-13	0 37480D+00	0 40000D+01	0.19089D+00
33	0 40732D-16	0 47325D-16	0 19075D+00	0 33220D-14	0 C8613D-15	-0 27117D-13	0 74850D+00	0 40000D+01	0.19075D+00
34	-0 55316D-03	-0 87278D-17	0 19089D+00	0 29098D-02	-0 80-91D-15	-0 53513D-13	0 11222D+01	0 40000D+01	0.19089D+00
35	-0 13316D-02	-0 10701D-15	0 19546D+00	0 23635D-01	-0 14891D-13	-0 25087D-12	0.14957D+01	0 40000D+01	0.19546D+00
36	0 15211D-02	0 24657D-02	0 17265D+00	-0 29963D-01	0 12132D+00	0 12969D-01	0 15211D-02	0 44525D+01	0.17265D+00
37	0 82648D-03	0 18116D-02	0 16775D+00	-0 39461D-02	-0 11680D+00	0 25997D-02	0 37508D+00	0 44518D+01	0.16775D+00
38	0 15428D-15	0 19584D-02	0 16733D+00	0 12551D-14	-0 11707D+00	0 63699D-14	0 74850D+00	0 44520D+01	0.16733D+00
39	-0 82648D-03	0 18116D-02	0.16775D+00	0.39461D-02	-0 11680D+00	-0.25997D-02	0.11219D+01	0 44518D+01	0.16775D+00
40	-0 15211D-02	0 24657D-02	0 17265D+00	0 29963D-01	-0 12132D 00	-0 12969D-01	0 14955D+01	0 44525D+01	0 17265D+00
41	0 24981D-02	-0 31733D-02	0 85074D-01	0 37644D-02	-0 22632D+00	0 95707D-01	0 24981D-02	0 48968D+01	0.85074D-01
42	0 97269D-03	-0 27280D-02	0 85752D-01	0 45403D-03	-0 20997D+00	0.11509D-01	0 37522D+00	0 48973D+01	0.85752D-01
43	-0 10186D-15	-0 27314D-02	0 85758D-01	-0 60256D-14	-0 20810D+00	0 80602D-13	0.74850D+00	0 48973D+01	0 85758D-01
44	-0 97269D-03	-0 27280D-02	0 85752D-01	-0 45403D-03	-0 20997D+00	-0.11509D-01	0 11218D+01	0 48973D+01	0 85752D-01
45	-0 24981D-02	-0 31733D-02	0 85074D-01	-0 37644D-02	-0 22632D+00	-0.95707D-01	0 14945D+01	0 48968D+01	0 85074D-01
46	0 62880D-03	-0 47930D-02	-0 12131D-01	0 21474D-01	0 18607D-02	-0 64964D-01	0.62880D-03	0 56702D+01	-0 12131D-01
47	0 37548D-03	-0 43261D-02	-0 83097D-02	0 30158D-02	-0 86620D-02	-0.97201D-02	0 37463D+00	0 56707D+01	-0.83097D-02
48	0 41979D-17	-0 42870D-02	-0 80237D-02	-0 94017D-15	-0 98036D-02	0 65422D-14	0.74850D+00	0 56707D+01	-0 80237D-02
49	-0 37548D-03	-0 43261D-02	-0 83097D-02	-0 30158D-02	-0 86620D-02	0.97201D-02	0.11224D+01	0 56707D+01	-0.83097D-02
50	-0 62880D-03	-0 47930D-02	-0 12131D-01	-0 21474D-01	-0 18607D-02	0 64964D-01	0 14964D+01	0 56702D+01	-0.12131D-01
51	0 51893D-03	0 25561D-02	0 29139D-02	-0 42725D-02	-0 60749D-02	0.15508D-01	0 51893D-03	0 64474D+01	0 29139D-02
52	0 22141D-03	-0 25025D-02	0.22386D-02	-0 56948D-03	0 35779D-02	0 33484D-02	0 37447D+00	0 64475D+01	0 22386D-02
53	0 38692D-17	-0 24181D-02	0 21425D-02	-0 29177D-15	0 28233D-02	0 27067D-14	0 74850D+00	0 64476D+01	0 21425D-02
54	-0 22141D-03	-0 25025D-02	0 22386D-02	0 56948D-03	-0 35779D-02	-0 33484D-02	0 11225D+01	0 64475D+01	0 22386D-02
55	-0 51893D-03	0 25561D-02	0 29139D-02	0 42725D-02	-0 60749D-02	0 15508D-01	0.14965D+01	0 64474D+01	0 29139D-02
56	0 37539D-03	0 11017D-02	-0 53539D-03	0 69702D-03	0 68163D-02	-0 11178D-01	0 37539D-03	0 72239D+01	-0.53539D-03
57	0 17290D-03	-0 10075D-02	-0.43758D-03	0 339850-04	0 53111D-02	-0 97021D-03	0.37442D+00	0 72240D+01	-0.43758D-03
58	0 34423D-17	-0 99781D-03	-0 43805D-03	-0 80377D-16	0 51930D-02	0 59252D-15	0.74850D+00	0 72240D+01	-0.43805D-03
59	-0 17290D-03	-0 10075D-02	-0 43758D-03	-0 33985D-04	0 53111D-02	0 97021D-03	0 11226D+01	0 72240D+01	-0 43758D-03
60	-0 37539D-03	-0 11017D-02	-0 53539D-03	-0 69702D-03	0 68163D-02	0.11178D-01	0 14966D+01	0 72239D+01	-0.53539D-03
61	0 0	0 0	0 0	0 0	0 0	0.0	0 0	0 80000D+01	0.0
62	0 0	0 0	0 0	0 0	0 0	0.0	0 0	0 80000D+01	0.0
63	0 0	0 0	0 0	0 0	0 0	0.0	0 37425D+00	0 80000D+01	0.0
64	0.0	0.0	0.0	0.0	0.0	0.0	0 748500+00	0 80000D+01	0.0
65	0 0	0.0	0 0	0 0	0 0	0.0	0.11227D+01	0 80000D+01	0.0
							0.14970D+01	0.80000D+01	0.0

REACTION FORCES AT CONSTRAINED NODS

NODE RX(LBS) RY(LBS) RZ(LBS) MX(LBS-IN) MY(LBS-IN) MXY(LBS-IN-IN)

1	-0.13544D+03	-0.29965D+03	-0.31238D+02	-0.24713D+01	-0.59216D+01	-0.42464D+00
2	-0.18163D+02	-0.47127D+03	-0.51304D+02	-0.13785D+00	-0.10160D+02	-0.94223D-02
3	0.16698D-12	-0.45729D+03	-0.53312D+02	-0.33618D-13	-0.10316D+02	-0.22326D-13
4	0.18163D+02	-0.47127D+03	-0.51304D+02	0.13785D+00	-0.10160D+02	0.94223D-02
5	0.13544D+03	-0.29965D+03	-0.31238D+02	0.24713D+01	-0.59216D+01	0.42464D+00
61	-0.13544D+03	0.29965D+03	-0.31238D+02	-0.24713D+01	0.59216D+01	0.42464D+00
62	-0.18163D+02	0.47127D+03	-0.51304D+02	-0.13785D+00	0.10160D+02	0.94223D-02
63	-0.85976D-12	0.45729D+03	-0.53312D+02	0.25752D-12	0.10316D+02	-0.27319D-13
64	0.18163D+02	0.47127D+03	-0.51304D+02	0.13785D+00	0.10160D+02	-0.94223D-02
65	0.13544D+03	0.29965D+03	-0.31238D+02	0.24713D+01	0.59216D+01	-0.42464D+00

STRAIN COMPONENTS, PRINCIPAL(TENSILE) STRAIN AND DIRECTION AT CENTROID OF EACH ELEMENT

ELEM.	EPS-X STRAIN		EPS-Y STRAIN		SHEAR STRAIN		PRINC. STRAIN(T)		DIRECTION(DEG.)	
	INNER	OUTER	INNER	OUTER	INNER	OUTER	INNER	OUTER	INNER	OUTER
1	-0.1809D-03	-0.3601D-03	0.9933D-03	0.1729D-02	0.1927D-03	0.2628D-03	0.1001D-02	0.1737D-02	0.8534D+02	0.8641D+02
2	-0.2205D-03	-0.2415D-03	0.9512D-03	0.1636D-02	0.9065D-04	0.1065D-03	0.9530D-03	0.1638D-02	0.8779D+02	0.8838D+02
3	-0.2205D-03	-0.2415D-03	0.9512D-03	0.1636D-02	-0.9065D-04	-0.1065D-03	0.9530D-03	0.1638D-02	-0.8779D+02	-0.8838D+02
4	-0.1809D-03	-0.3601D-03	0.9933D-03	0.1729D-02	-0.1927D-03	-0.2628D-03	0.1001D-02	0.1737D-02	-0.8534D+02	-0.8641D+02
5	-0.7561D-03	-0.5798D-03	0.2568D-02	0.1272D-02	-0.3507D-03	0.2054D-03	0.2577D-02	0.1278D-02	-0.8699D+02	0.8684D+02
6	-0.5473D-03	-0.5063D-03	0.2439D-02	0.1353D-02	-0.8980D-04	-0.9776D-04	0.2440D-02	0.1355D-02	-0.8914D+02	-0.8850D+02
7	-0.5473D-03	-0.5063D-03	0.2439D-02	0.1353D-02	0.8980D-04	0.9776D-04	0.2440D-02	0.1355D-02	0.8914D+02	0.8850D+02
8	-0.7561D-03	-0.5798D-03	0.2568D-02	0.1272D-02	0.3507D-03	-0.2054D-03	0.2577D-02	0.1278D-02	0.8699D+02	-0.8684D+02
9	-0.8508D-03	-0.6197D-03	0.3054D-02	0.2827D-02	0.1094D-02	-0.2198D-02	0.3129D-02	0.3147D-02	0.8217D+02	-0.7374D+02
10	-0.7915D-03	-0.8032D-03	0.3082D-02	0.2207D-02	0.6878D-04	-0.1841D-03	0.3082D-02	0.2210D-02	0.8949D+02	-0.8825D+02
11	-0.7915D-03	-0.8032D-03	0.3082D-02	0.2207D-02	-0.6878D-04	0.1841D-03	0.3082D-02	0.2210D-02	-0.8949D+02	0.8825D+02
12	-0.8508D-03	-0.6197D-03	0.3054D-02	0.2827D-02	-0.1094D-02	0.2198D-02	0.3129D-02	0.3147D-02	-0.8217D+02	0.7374D+02
13	-0.5634D-02	0.1014D-02	0.1991D-01	-0.7499D-02	0.7479D-03	0.2946D-02	0.1991D-01	0.1262D-02	0.8916D+02	0.9544D+01
14	-0.2317D-02	-0.1284D-02	0.1911D-01	-0.7053D-02	0.4089D-03	0.4716D-03	0.1912D-01	0.0	0.8945D+02	0.0
15	-0.2317D-02	-0.1284D-02	0.1911D-01	-0.7053D-02	-0.4089D-03	-0.4716D-03	0.1912D-01	0.0	-0.8945D+02	0.0
16	-0.5634D-02	0.1014D-02	0.1991D-01	-0.7499D-02	-0.7479D-03	-0.2946D-02	0.1991D-01	0.1262D-02	-0.8916D+02	-0.9544D+01
17	-0.8338D-03	-0.5060D-02	-0.3166D-02	0.1851D-01	-0.5171D-02	0.8464D-03	0.8365D-03	0.1852D-01	-0.3286D+02	0.8897D+02
18	-0.2097D-02	-0.2710D-02	-0.2482D-02	0.1830D-01	-0.6203D-03	-0.3695D-03	0.0	0.1830D-01	0.0	-0.8950D+02
19	-0.2097D-02	-0.2710D-02	-0.2482D-02	0.1830D-01	0.6203D-03	0.3695D-03	0.0	0.1830D-01	0.0	0.8950D+02
20	-0.8338D-03	-0.5060D-02	-0.3166D-02	0.1851D-01	0.5171D-02	-0.8464D-03	0.8365D-03	0.1852D-01	0.3286D+02	-0.8897D+02
21	-0.1371D-02	-0.5157D-02	-0.7545D-02	0.1933D-01	-0.4747D-04	-0.4016D-03	0.1371D-02	0.1933D-01	-0.1525D+00	-0.8953D+02
22	-0.1356D-02	-0.2330D-02	-0.7871D-02	0.1861D-01	-0.2614D-03	-0.7533D-03	0.0	0.1861D-01	0.0	-0.8897D+02
23	-0.1356D-02	-0.2330D-02	-0.7871D-02	0.1861D-01	0.2614D-03	0.7533D-03	0.0	0.1861D-01	0.0	0.8897D+02
24	-0.1371D-02	-0.5157D-02	-0.7545D-02	0.1933D-01	0.4747D-04	0.4016D-03	0.1371D-02	0.1933D-01	0.1525D+00	0.8953D+02
25	-0.1371D-02	-0.5157D-02	-0.7545D-02	0.1933D-01	0.4747D-04	0.4016D-03	0.1371D-02	0.1933D-01	0.1525D+00	0.8953D+02
26	-0.1356D-02	-0.2330D-02	-0.7871D-02	0.1861D-01	0.2614D-03	0.7533D-03	0.0	0.1861D-01	0.0	0.8897D+02
27	-0.1356D-02	-0.2330D-02	-0.7871D-02	0.1861D-01	-0.2614D-03	-0.7533D-03	0.0	0.1861D-01	0.0	-0.8897D+02
28	-0.1371D-02	-0.5157D-02	-0.7545D-02	0.1933D-01	-0.4747D-04	-0.4016D-03	0.1371D-02	0.1933D-01	-0.1525D+00	-0.8953D+02
29	-0.8338D-03	-0.5060D-02	-0.3166D-02	0.1851D-01	0.5171D-02	-0.8464D-03	0.8365D-03	0.1852D-01	0.3286D+02	-0.8897D+02
30	-0.2097D-02	-0.2710D-02	-0.2482D-02	0.1830D-01	-0.6203D-03	-0.3695D-03	0.0	0.1830D-01	0.0	-0.8950D+02
31	-0.2097D-02	-0.2710D-02	-0.2482D-02	0.1830D-01	0.6203D-03	0.3695D-03	0.0	0.1830D-01	0.0	0.8950D+02
32	-0.8338D-03	-0.5060D-02	-0.3166D-02	0.1851D-01	-0.5171D-02	0.8464D-03	0.8365D-03	0.1852D-01	-0.3286D+02	0.8897D+02
33	-0.5634D-02	0.1014D-02	0.1991D-01	-0.7499D-02	-0.7479D-03	-0.2946D-02	0.1991D-01	0.1262D-02	-0.8916D+02	-0.9544D+01
34	-0.2317D-02	-0.1284D-02	0.1911D-01	-0.7053D-02	-0.4089D-03	-0.4716D-03	0.1912D-01	0.0	-0.8945D+02	0.0
35	-0.2317D-02	-0.1284D-02	0.1911D-01	-0.7053D-02	0.4089D-03	0.4716D-03	0.1912D-01	0.0	0.8945D+02	0.0
36	-0.5634D-02	0.1014D-02	0.1991D-01	-0.7499D-02	0.7479D-03	0.2946D-02	0.1991D-01	0.1262D-02	0.8916D+02	0.9544D+01
37	-0.8508D-03	-0.6197D-03	0.3054D-02	0.2827D-02	-0.1031D-02	0.2198D-02	0.3129D-02	0.3147D-02	-0.8217D+02	0.7374D+02
38	-0.7915D-03	-0.8032D-03	0.3082D-02	0.2207D-02	-0.6878D-04	0.1841D-03	0.3082D-02	0.2210D-02	-0.8949D+02	0.8825D+02
39	-0.7915D-03	-0.8032D-03	0.3082D-02	0.2207D-02	0.6878D-04	-0.1841D-03	0.3082D-02	0.2210D-02	0.8949D+02	-0.8825D+02
40	-0.8508D-03	-0.6197D-03	0.3054D-02	0.2827D-02	0.1094D-02	-0.2198D-02	0.3129D-02	0.3147D-02	0.8217D+02	-0.7374D+02
41	-0.7561D-03	-0.5798D-03	0.2568D-02	0.1272D-02	0.3507D-03	-0.2054D-03	0.2577D-02	0.1278D-02	0.8699D+02	-0.8684D+02
42	-0.5473D-03	-0.5063D-03	0.2439D-02	0.1353D-02	0.8980D-04	0.9776D-04	0.2440D-02	0.1355D-02	0.8914D+02	0.8850D+02
43	-0.5473D-03	-0.5063D-03	0.2439D-02	0.1353D-02	-0.8980D-04	-0.9776D-04	0.2440D-02	0.1355D-02	-0.8914D+02	-0.8850D+02
44	-0.7561D-03	-0.5798D-03	0.2568D-02	0.1272D-02	-0.3507D-03	0.2054D-03	0.2577D-02	0.1278D-02	-0.8699D+02	0.8684D+02
45	-0.1809D-03	-0.3601D-03	0.9933D-03	0.1729D-02	-0.1927D-03	-0.2628D-03	0.1001D-02	0.1737D-02	-0.8534D+02	-0.8641D+02
46	-0.2205D-03	-0.2415D-03	0.9512D-03	0.1636D-02	-0.9065D-04	-0.1065D-03	0.9530D-03	0.1638D-02	-0.8779D+02	-0.8838D+02
47	-0.2205D-03	-0.2415D-03	0.9512D-03	0.1636D-02	0.9065D-04	0.1065D-03	0.9530D-03	0.1638D-02	0.8779D+02	0.8838D+02
48	-0.1809D-03	-0.3601D-03	0.9933D-03	0.1729D-02	0.1927D-03	0.2628D-03	0.1001D-02	0.1737D-02	0.8534D+02	0.8641D+02

STRAIN COMPONENTS, PRINCIPAL (TENSILE) STRAIN AND DIRECTION AT USER-SPECIFIED NODES

NODE	EPS-X STRAIN		EPS-Y STRAIN		SHEAR STRAIN		PRINC. STRAIN(T)		DIRECTION(DEC.)	
	INNER	OUTER	INNER	OUTER	INNER	OUTER	INNER	OUTER	INNER	OUTER
33	-0.19700D-02	-0.98630D-03	-0.44990D-02	0.13200D-01	-0.27090D-14	0.28220D-14	0.0	0.13200D-01	0.0	0.90000D+02
35	0.18810D-02	-0.54820D-02	-0.15000D-02	0.12460D-01	-0.26030D-13	0.25140D-13	0.18810D-02	0.12460D-01	-0.22060D-09	0.90000D+02
38	-0.23770D-02	-0.20390D-02	-0.16540D-01	0.24170D-01	0.50480D-15	-0.79420D-15	0.0	0.24170D-01	0.0	-0.90000D+02
40	0.53010D-02	-0.81120D-02	-0.19140D-01	0.27110D-01	-0.45060D-02	-0.18610D-02	0.55040D-02	0.27140D-01	-0.51610D+01	-0.88490D+02
48	-0.80610D-03	-0.12000D-02	0.13220D-01	-0.12720D-01	0.66840D-15	-0.66620D-15	0.13220D-01	0.0	0.90000D+02	0.0
50	-0.46230D-02	0.37330D-02	0.14500D-01	-0.13700D-01	0.66160D-02	-0.66370D-02	0.15060D-01	0.43430D-02	0.80460D+02	-0.10420D+02

STRAIN COMPONENTS, PRINCIPAL(TENSILE) STRAIN AND DIRECTION, AND ELONGATIONS AT SPECIFIED ADDITIONAL POINTS

POINT NO.	SURFACE	EPS-X STRAIN	EPS-Y STRAIN	SHEAR STRAIN	ELONG (DIR 1)	ELONG (DIR 2)	PRINC STRN(T)	DIRECTION(DEC.)	
								INNER	OUTER
1	INNER	0.224320D-35	0.174780D-02	0.423630D-17	0.0	0.174630D-02	0.174780D-02	0.90000D+02	
1	OUTER	0.224320D-35	0.827200D-03	0.423630D-17	0.0	0.826860D-03	0.827200D-03	0.90000D+02	
2	INNER	-0.117760D-03	0.133430D-02	-0.668030D-05	-0.117770D-03	0.133430D-02	0.133430D-02	-0.898680D+02	
2	OUTER	-0.120690D-03	0.124160D-02	-0.668030D-05	-0.120690D-03	0.124090D-02	0.124170D-02	-0.898600D+02	
3	INNER	-0.513660D-03	0.311130D-02	-0.838300D-04	-0.513790D-03	0.310650D-02	0.311180D-02	-0.893380D+02	
3	OUTER	-0.465580D-03	0.561250D-03	-0.838300D-04	-0.465700D-03	0.561090D-03	0.562920D-03	-0.877110D+02	
4	INNER	-0.558750D-03	0.356600D-03	-0.186450D-03	-0.518910D-03	0.356540D-03	0.366000D-03	-0.842440D+02	
4	OUTER	-0.890050D-03	0.486270D-02	-0.186450D-03	-0.890440D-03	0.487080D-02	0.488420D-02	-0.890750D+02	
5	INNER	-0.144010D-02	0.171020D-01	-0.642700D-04	-0.144120D-02	0.169580D-01	0.171020D-01	-0.899010D+02	
5	OUTER	-0.169890D-02	-0.117600D-01	-0.642700D-04	-0.170030D-02	-0.118300D-01	0.0	0.0	
6	INNER	-0.196980D-02	-0.449880D-02	-0.272440D-14	-0.147180D-02	-0.450900D-02	0.0	0.0	
6	OUTER	-0.986290D-03	0.132030D-01	0.280750D-14	-0.986780D-03	0.131170D-01	0.132030D-01	0.90000D+02	
7	INNER	-0.144010D-02	0.171020D-01	0.642700D-04	-0.144120D-02	0.169580D-01	0.171020D-01	0.899010D+02	
7	OUTER	-0.169890D-02	-0.117600D-01	0.642700D-04	-0.170030D-02	-0.118300D-01	0.0	0.0	
8	INNER	-0.558750D-03	0.356600D-03	0.186450D-03	-0.518910D-03	0.356540D-03	0.366000D-03	0.842440D+02	
8	OUTER	-0.890050D-03	0.486270D-02	0.186450D-03	-0.890440D-03	0.487080D-02	0.488420D-02	0.890750D+02	
9	INNER	-0.513660D-03	0.311130D-02	0.838300D-04	-0.513790D-03	0.310650D-02	0.311180D-02	0.893380D+02	
9	OUTER	-0.465580D-03	0.561250D-03	0.838300D-04	-0.465700D-03	0.561090D-03	0.562920D-03	0.877110D+02	
10	INNER	-0.117760D-03	0.133430D-02	0.668030D-05	-0.117770D-03	0.133430D-02	0.133430D-02	0.898680D+02	
10	OUTER	-0.120690D-03	0.124160D-02	0.668030D-05	-0.120690D-03	0.124090D-02	0.124170D-02	0.898600D+02	
11	INNER	0.298810D-20	0.174780D-02	-0.449270D-17	0.0	0.174630D-02	0.174780D-02	-0.90000D+02	
11	OUTER	-0.299810D-20	0.827200D-03	-0.439070D-17	0.0	0.826860D-03	0.827200D-03	-0.90000D+02	

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SYSTEM ENERGIES(IN-LB)

WORK INPUT TO STRUCTURE = 0.38488320D+04
STRUCTURE KINETIC ENERGY = 0.33017230D+04
STRUCTURE ELASTIC ENERGY = 0.12309500D+03
STRUCTURE PLASTIC ENERGY = 0.42401360D+03
ENERGY STORED IN ELASTIC RESTRAINTS = 0.0

***** INCR. NO.= 20 TIME= 0.5000D-04 SEC.

NODE	U	V	W	PSIX	PSIY	TWIST	X-POS.	Y-POS.	Z-POS.
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.374250D+00	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.748500D+00	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.112270D+01	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.149700D+01	0.0	0.0
6	0.282990D-02	0.704540D-02	0.381470D-02	-0.365810D-02	0.254340D-01	-0.458870D-01	0.282990D-02	0.782050D+00	0.381470D-02
7	0.137570D-02	0.622480D-02	0.299970D-02	-0.900200D-03	0.181500D-01	-0.640430D-02	0.375630D+00	0.781220D+00	0.299970D-02
8	-0.221720D-16	0.607130D-02	0.296210D-02	-0.397200D-15	0.170360D-01	-0.100360D-13	0.748500D+00	0.781070D+00	0.286210D-02
9	-0.137570D-02	0.622480D-02	0.299970D-02	0.900200D-03	0.181500D-01	0.640430D-02	0.112140D+01	0.781220D+00	0.299970D-02
10	-0.282990D-02	0.704540D-02	0.381470D-02	0.365810D-02	0.254340D-01	0.458870D-01	0.149420D+01	0.782050D+00	0.381470D-02
11	0.376070D-02	0.144700D-01	-0.135030D-01	0.937010D-02	-0.685170D-01	0.118400D+00	0.376070D-02	0.156450D+01	-0.135030D-01
12	0.176010D-02	0.146710D-01	-0.107070D-01	0.459380D-02	-0.458890D-01	0.230920D-01	0.376010D+00	0.156470D+01	-0.107070D-01
13	-0.101430D-15	0.145500D-01	-0.989220D-02	0.100400D-15	-0.422090D-01	-0.202000D-13	0.748500D+00	0.156460D+01	-0.989220D-02
14	-0.176010D-02	0.146710D-01	-0.107070D-01	-0.459380D-02	-0.458890D-01	-0.230920D-01	0.112100D+01	0.156470D+01	-0.107070D-01
15	-0.376070D-02	0.144700D-01	-0.135030D-01	0.937010D-02	-0.685170D-01	-0.118400D+00	0.149320D+01	0.156450D+01	-0.135030D-01
16	0.402930D-02	0.268910D-01	0.122020D-01	0.355730D-01	0.192710D+00	-0.647810D-01	0.402930D-02	0.235190D+01	0.122020D-01
17	0.189490D-02	0.252420D-01	0.206680D-01	0.124270D-01	0.183500D+00	-0.701830D-02	0.376140D+00	0.235020D+01	0.206680D-01
18	-0.196890D-15	0.246370D-01	0.228090D-01	0.168880D-14	0.184200D+00	-0.281010D-13	0.748500D+00	0.234980D+01	0.228090D-01
19	-0.189490D-02	0.252420D-01	0.206680D-01	-0.124270D-01	0.163500D+00	0.701830D-02	0.112090D+01	0.235020D+01	0.206680D-01
20	-0.402930D-02	0.268910D-01	0.122020D-01	-0.355730D-01	0.192710D+00	0.647810D-01	0.149300D+01	0.235190D+01	0.122020D-01
21	0.616090D-02	0.167560D-01	0.214260D+00	0.184290D-01	0.374000D+00	-0.117920D+00	0.616090D-02	0.311680D+01	0.214260D+00

22	0.27626D-02	0.14688D-01	0.21766D+00	0.37891D-02	0.34700D+00	-0.34691D-01	0.37701D+00	0.31147D+01	0.21766D+00
23	-0.32645D-15	0.14470D-01	0.21822D+00	-0.39187D-14	0.34173D+00	-0.95645D-13	0.74850D+00	0.31145D+01	0.21822D+00
24	-0.27626D-02	0.14688D-01	0.21766D+00	-0.37891D-02	0.34700D+00	-0.34691D-01	0.11200D+01	0.31147D+01	0.21766D+00
25	-0.61609D-02	0.16756D-01	0.21426D+00	-0.18429D-01	0.37400D+00	0.11792D+00	0.14908D+01	0.31168D+01	0.21426D+00
26	0.60405D-02	-0.89438D-02	0.38735D+00	-0.43702D-01	0.35418D+00	-0.19294D+00	0.60405D-02	0.35411D+01	0.38735D+00
27	0.27559D-02	-0.67665D-02	0.37680D+00	-0.14951D-01	0.31311D+00	-0.42831D-01	0.37701D+00	0.35436D+01	0.37680D+00
28	0.73984D-16	-0.62579D-02	0.37443D+00	0.18874D-14	0.30673D+00	-0.18285D-12	0.74850D+00	0.35437D+01	0.37443D+00
29	-0.27559D-02	-0.62665D-02	0.37680D+00	0.14951D-01	0.31311D+00	0.42831D-01	0.11200D+01	0.35436D+01	0.37680D+00
30	-0.60405D-02	-0.89438D-02	0.38735D+00	0.43702D-01	0.35418D+00	0.19294D+00	0.14910D+01	0.35411D+01	0.38735D+00
31	0.71232D-02	-0.10752D-14	0.46329D+00	-0.98762D-01	0.18171D-12	-0.18625D-11	0.71232D-02	0.40000D+01	0.46329D+00
32	0.26769D-02	-0.37378D-15	0.44276D+00	-0.27953D-01	0.36610D-13	-0.14765D-12	0.37693D+00	0.40000D+01	0.44276D+00
33	0.42062D-15	-0.67015D-15	0.43923D+00	0.11519D-13	0.17611D-13	-0.14384D-12	0.74850D+00	0.40000D+01	0.43923D+00
34	-0.26769D-02	-0.87349D-15	0.44276D+00	0.22953D-01	-0.17070D-14	-0.26638D-12	0.11201D+01	0.40000D+01	0.44276D+00
35	-0.71232D-02	-0.26910D-15	0.46329D+00	0.98762D-01	-0.10056D-12	-0.12605D-11	0.14899D+01	0.40000D+01	0.46329D+00
36	0.60405D-02	0.89438D-02	0.38735D+00	-0.43702D-01	-0.35418D+00	0.19294D+00	0.60405D-02	0.44589D+01	0.38735D+00
37	0.27559D-02	0.63565D-02	0.37660D+00	-0.14951D-01	-0.31311D+00	0.42831D-01	0.37701D+00	0.44564D+01	0.37660D+00
38	0.99183D-15	0.62579D-02	0.37443D+00	-0.23384D-14	-0.30673D+00	0.26049D-13	0.74850D+00	0.44563D+01	0.37443D+00
39	-0.27559D-02	0.63665D-02	0.37680D+00	0.14951D-01	-0.31311D+00	-0.42831D-01	0.11200D+01	0.44564D+01	0.37680D+00
40	-0.60405D-02	0.89438D-02	0.38735D+00	0.43702D-01	-0.35418D+00	-0.19294D+00	0.14910D+01	0.44589D+01	0.38735D+00
41	0.61609D-02	-0.16756D-01	0.21426D+00	0.18429D-01	-0.37400D+00	0.11792D+00	0.61609D-02	0.48832D+01	0.21426D+00
42	0.27626D-02	-0.14688D-01	0.21766D+00	0.37891D-02	-0.34700D+00	0.34691D-01	0.37701D+00	0.48853D+01	0.21766D+00
43	-0.69709D-15	-0.14470D-01	0.21822D+00	-0.16591D-13	-0.34173D+00	0.17160D-12	0.74850D+00	0.48855D+01	0.21822D+00
44	-0.27626D-02	-0.14688D-01	0.21766D+00	-0.37891D-02	-0.34700D+00	-0.34691D-01	0.11200D+01	0.48853D+01	0.21766D+00
45	-0.61609D-02	-0.16756D-01	0.21426D+00	-0.18429D-01	-0.37400D+00	-0.11792D+00	0.14908D+01	0.48832D+01	0.21426D+00
46	0.40293D-02	-0.26891D-01	0.12202D-01	0.35573D-01	-0.19271D+00	0.64781D-01	0.40293D-02	0.56481D+01	0.12202D-01
47	0.18949D-02	-0.25242D-01	0.20668D-01	0.12427D-01	-0.18350D+00	0.70183D-02	0.37614D+00	0.56498D+01	0.20668D-01
48	-0.37806D-15	-0.24837D-01	0.22809D-01	0.21270D-14	-0.18242D+00	-0.18621D-13	0.74850D+00	0.56502D+01	0.22809D-01
49	-0.18949D-02	-0.25242D-01	0.20668D-01	-0.12427D-01	-0.18350D+00	-0.70183D-02	0.11209D+01	0.56498D+01	0.20668D-01
50	-0.40293D-02	-0.26891D-01	0.12202D-01	-0.35573D-01	-0.19271D+00	-0.64781D-01	0.14930D+01	0.56481D+01	0.12202D-01
51	0.37607D-02	-0.14470D-01	-0.13503D-01	0.93701D-02	0.68517D-01	-0.11840D+00	0.37607D-02	0.64355D+01	-0.13503D-01
52	0.17601D-02	-0.14671D-01	-0.10707D-01	0.45938D-02	0.45889D-01	-0.23092D-01	0.37601D+00	0.64353D+01	-0.10707D-01
53	-0.19530D-15	-0.14550D-01	-0.98922D-02	0.78133D-15	0.42209D-01	-0.10312D-13	0.74850D+00	0.64354D+01	-0.98922D-02
54	-0.17601D-02	-0.14671D-01	-0.10707D-01	-0.45938D-02	0.45889D-01	0.23092D-01	0.11210D+01	0.64353D+01	-0.10707D-01
55	-0.37607D-02	-0.14470D-01	-0.13503D-01	-0.93701D-02	0.66517D-01	0.11840D+00	0.14932D+01	0.64355D+01	-0.13503D-01
56	0.28299D-02	-0.70454D-02	0.38147D-02	-0.36581D-02	-0.25434D-01	0.45887D-01	0.28299D-02	0.72180D+01	0.38147D-02
57	0.13757D-02	-0.62248D-02	0.29997D-02	-0.90020D-03	-0.18150D-01	0.64043D-02	0.37563D+00	0.72188D+01	0.29997D-02
58	-0.50258D-17	-0.60713D-02	0.28621D-02	0.40056D-15	-0.17036D-01	-0.27142D-14	0.74850D+00	0.72189D+01	0.28621D-02
59	-0.13757D-02	-0.62248D-02	0.29997D-02	0.90020D-03	-0.18150D-01	-0.64043D-02	0.11214D+01	0.72188D+01	0.29997D-02
60	-0.28299D-02	-0.70454D-02	0.38147D-02	0.36581D-02	-0.25434D-01	-0.45887D-01	0.14942D+01	0.72180D+01	0.38147D-02
61	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0.80000D+01	0 0
62	0 0	0 0	0 0	0 0	0 0	0 0	0.37425D+00	0.80000D+01	0 0
63	0 0	0 0	0 0	0 0	0 0	0 0	0.74850D+00	0.80000D+01	0 0
64	0 0	0 0	0 0	0 0	0 0	0 0	0.11227D+01	0.80000D+01	0 0
65	0 0	0 0	0 0	0 0	0 0	0 0	0.14970D+01	0.80000D+01	0 0

REACTION FORCES AT CONSTRAINED NODES

NODE	RX(LBS)	RY(LBS)	RZ(LBS)	MX(LBS-IN)	MY(LBS-IN)	MXY(LBS-IN-IN)
1	-0.75363D+03	-0.14544D+04	0.10847D+02	0.11578D+01	0.26035D+00	0.13400D+00
2	-0.69600D+02	-0.23567D+04	0.47066D+01	0.74311D-01	-0.16905D+01	-0.15812D-01
3	0.63655D-11	-0.22951D+04	0.47261D+01	0.16972D-11	-0.19659D+01	0.35318D-12
4	0.69600D+02	-0.23567D+04	0.47066D+01	-0.74311D-01	-0.16905D+01	0.15812D-01
5	0.75363D+03	-0.14544D+04	0.10847D+02	-0.11578D+01	0.26035D+00	-0.13400D+00
61	-0.75363D+03	0.14544D+04	0.10847D+02	0.11578D+01	-0.26035D+00	-0.13400D+00
62	-0.69600D+02	0.23567D+04	0.47066D+01	0.74311D-01	0.16905D+01	0.15812D-01
63	-0.60254D-11	0.22951D+04	0.47261D+01	0.50383D-12	0.19659D+01	-0.74107D-13
64	0.69600D+02	0.23567D+04	0.47066D+01	-0.74311D-01	0.16905D+01	-0.15812D-01
65	0.75363D+03	0.14544D+04	0.10847D+02	-0.11578D+01	-0.26035D+00	0.13400D+00

STRAIN COMPONENTS, PRINCIPAL(TENSILE) STRAIN AND DIRECTION AT CENTROID OF EACH ELEMENT

ELEM.	EPS-X STRAIN		EPS-Y STRAIN		SHEAR STRAIN		PRINC. STRAIN(T)		DIRECTION(DEG.)	
	INNER	OUTER	INNER	OUTER	INNER	OUTER	INNER	OUTER	INNER	OUTER
1	-0.22740D-02	-0.16080D-02	0.95770D-02	0.72520D-02	0.16090D-02	0.16260D-02	0.99300D-02	0.73260D-02	0.86230D+02	0.84800D+02
2	-0.18610D-02	-0.18150D-02	0.90720D-02	0.67960D-02	0.69110D-03	0.67400D-03	0.90830D-02	0.68090D-02	0.88190D+02	0.87760D+02
3	-0.18610D-02	-0.18150D-02	0.90720D-02	0.67960D-02	-0.69110D-03	-0.67400D-03	0.90830D-02	0.68090D-02	-0.88190D+02	-0.87760D+02

4	-0.2274D-02	-0.1608D-02	0.9877D-02	0.7252D-02	-0.1609D-02	-0.1626D-02	0.9930D-02	0.7326D-02	-0.8623D+02	-0.8480D+02
5	-0.2965D-02	-0.6249D-02	0.5680D-02	0.1525D-01	0.1051D-02	-0.8359D-03	0.5711D-02	0.1525D-01	0.8653D+02	-0.8889D+02
6	-0.4052D-02	-0.4327D-02	0.7128D-02	0.1506D-01	0.2132D-03	-0.4405D-03	0.7129D-02	0.1506D-01	0.8945D+02	-0.8935D+02
7	-0.4052D-02	-0.4327D-02	0.7128D-02	0.1506D-01	-0.2132D-03	0.4405D-03	0.7129D-02	0.1506D-01	-0.8945D+02	0.8935D+02
8	-0.2965D-02	-0.6249D-02	0.5680D-02	0.1525D-01	-0.1051D-02	0.8359D-03	0.5711D-02	0.1525D-01	-0.8653D+02	0.8889D+02
9	-0.9204D-02	-0.1358D-02	0.3079D-01	-0.5557D-03	0.7283D-03	-0.3031D-02	0.3079D-01	0.6107D-03	0.8948D+02	-0.5241D+02
10	-0.6428D-02	-0.3314D-02	0.2869D-01	-0.1003D-02	0.1990D-04	-0.9786D-03	0.2869D-01	0.0	0	0
11	-0.6428D-02	-0.3314D-02	0.2869D-01	-0.1003D-02	-0.1990D-04	0.9786D-03	0.2869D-01	0.0	-0.8998D+02	0.0
12	-0.9204D-02	-0.1358D-02	0.3079D-01	-0.5557D-03	0.7283D-03	0.3031D-02	0.3079D-01	0.6107D-03	-0.8948D+02	0.5241D+02
13	-0.1010D-01	-0.4276D-02	0.2915D-01	0.6616D-02	0.1492D-02	0.2421D-02	0.2916D-01	0.6749D-02	0.8891D+02	0.8374D+02
14	-0.7683D-02	-0.4743D-02	0.2770D-01	0.6623D-02	0.3634D-03	0.1244D-02	0.2770D-01	0.6657D-02	0.8971D+02	0.8688D+02
15	-0.7683D-02	-0.4743D-02	0.2770D-01	0.6623D-02	-0.3634D-03	-0.1244D-02	0.2770D-01	0.6657D-02	-0.8971D+02	-0.8688D+02
16	-0.1010D-01	-0.4276D-02	0.2915D-01	0.6616D-02	-0.1492D-02	-0.2421D-02	0.2916D-01	0.6749D-02	-0.8891D+02	-0.8374D+02
17	-0.8449D-02	-0.9347D-02	0.1540D-01	0.2220D-01	-0.1004D-01	0.5273D-02	0.1642D-01	0.2242D-01	-0.7858D+02	0.8526D+02
18	-0.6672D-02	-0.8069D-02	0.1443D-01	0.2232D-01	-0.2620D-02	0.8049D-03	0.1451D-01	0.2233D-01	-0.8646D+02	0.8924D+02
19	-0.6672D-02	-0.8069D-02	0.1443D-01	0.2232D-01	0.2620D-02	-0.8049D-03	0.1451D-01	0.2233D-01	0.8646D+02	-0.8924D+02
20	-0.8449D-02	-0.9347D-02	0.1540D-01	0.2220D-01	0.1004D-01	-0.5273D-02	0.1642D-01	0.2242D-01	0.7858D+02	-0.8526D+02
21	-0.1009D-02	-0.1756D-01	-0.9126D-02	0.6491D-01	-0.7724D-02	0.3362D-02	0.5347D-03	0.6494D-01	-0.2179D+02	0.8883D+02
22	-0.4316D-02	-0.1014D-01	-0.1111D-01	0.5868D-01	-0.1581D-02	-0.5242D-03	0.0	0.5868D-01	0.0	-0.8978D+02
23	-0.4316D-02	-0.1014D-01	-0.1111D-01	0.5868D-01	0.1581D-02	0.5242D-03	0.0	0.5868D-01	0.0	0.8978D+02
24	-0.1009D-02	-0.1756D-01	-0.9126D-02	0.6491D-01	0.7724D-02	-0.3362D-02	0.5347D-03	0.6494D-01	0.2179D+02	-0.8883D+02
25	-0.1009D-02	-0.1756D-01	-0.9126D-02	0.6491D-01	-0.7724D-02	0.3362D-02	0.5347D-03	0.6494D-01	0.2179D+02	-0.8883D+02
26	-0.4316D-02	-0.1014D-01	-0.1111D-01	0.5868D-01	0.1581D-02	0.5242D-03	0.0	0.5868D-01	0.0	0.8978D+02
27	-0.4316D-02	-0.1014D-01	-0.1111D-01	0.5868D-01	-0.1581D-02	-0.5242D-03	0.0	0.5868D-01	0.0	-0.8978D+02
28	-0.1009D-02	-0.1756D-01	-0.9126D-02	0.6491D-01	-0.7724D-02	0.3362D-02	0.5347D-03	0.6494D-01	-0.2179D+02	0.8883D+02
29	-0.8449D-02	-0.9347D-02	0.1540D-01	0.2220D-01	0.1004D-01	-0.5273D-02	0.1642D-01	0.2242D-01	0.7858D+02	-0.8526D+02
30	-0.6672D-02	-0.8069D-02	0.1443D-01	0.2232D-01	0.2620D-02	-0.8049D-03	0.1451D-01	0.2233D-01	0.8646D+02	-0.8924D+02
31	-0.6672D-02	-0.8069D-02	0.1443D-01	0.2232D-01	-0.2620D-02	0.8049D-03	0.1451D-01	0.2233D-01	-0.8646D+02	0.8924D+02
32	-0.8449D-02	-0.9347D-02	0.1540D-01	0.2220D-01	-0.1004D-01	0.5273D-02	0.1642D-01	0.2242D-01	-0.7858D+02	0.8526D+02
33	-0.1010D-01	-0.4276D-02	0.2915D-01	0.6616D-02	-0.1492D-02	-0.2421D-02	0.2916D-01	0.6749D-02	-0.8891D+02	-0.8374D+02
34	-0.7683D-02	-0.4743D-02	0.2770D-01	0.6623D-02	0.3634D-03	0.1244D-02	0.2770D-01	0.6657D-02	-0.8971D+02	-0.8688D+02
35	-0.7683D-02	-0.4743D-02	0.2770D-01	0.6623D-02	-0.3634D-03	-0.1244D-02	0.2770D-01	0.6657D-02	0.8971D+02	0.8688D+02
36	-0.1010D-01	-0.4276D-02	0.2915D-01	0.6616D-02	0.1492D-02	0.2421D-02	0.2916D-01	0.6749D-02	0.8891D+02	0.8374D+02
37	-0.9204D-02	-0.1358D-02	0.3079D-01	-0.5557D-03	0.7283D-03	0.3031D-02	0.3079D-01	0.6107D-03	-0.8948D+02	0.5241D+02
38	-0.6428D-02	-0.3314D-02	0.2869D-01	-0.1003D-02	-0.1990D-04	0.9786D-03	0.2869D-01	0.0	-0.8998D+02	0.0
39	-0.6428D-02	-0.3314D-02	0.2869D-01	-0.1003D-02	0.1990D-04	-0.9786D-03	0.2869D-01	0.0	0.8998D+02	0.0
40	-0.9204D-02	-0.1358D-02	0.3079D-01	-0.5557D-03	0.7283D-03	-0.3031D-02	0.3079D-01	0.6107D-03	0.8948D+02	-0.5241D+02
41	-0.2965D-02	-0.6249D-02	0.5680D-02	0.1525D-01	-0.1051D-02	0.8359D-03	0.5711D-02	0.1525D-01	-0.8653D+02	0.8889D+02
42	-0.4052D-02	-0.4327D-02	0.7128D-02	0.1506D-01	-0.2132D-03	0.4405D-03	0.7129D-02	0.1506D-01	-0.8945D+02	0.8935D+02
43	-0.4052D-02	-0.4327D-02	0.7128D-02	0.1506D-01	0.2132D-03	-0.4405D-03	0.7129D-02	0.1506D-01	0.8945D+02	-0.8935D+02
44	-0.2965D-02	-0.6249D-02	0.5680D-02	0.1525D-01	0.1051D-02	-0.8359D-03	0.5711D-02	0.1525D-01	0.8653D+02	-0.8889D+02
45	-0.2274D-02	-0.1608D-02	0.9877D-02	0.7252D-02	-0.1609D-02	-0.1626D-02	0.9930D-02	0.7326D-02	-0.8623D+02	-0.8480D+02
46	-0.1861D-02	-0.1815D-02	0.9072D-02	0.6796D-02	-0.6911D-03	-0.6740D-03	0.9083D-02	0.6809D-02	-0.8819D+02	-0.8776D+02
47	-0.1861D-02	-0.1815D-02	0.9072D-02	0.6796D-02	0.6911D-03	0.6740D-03	0.9083D-02	0.6809D-02	0.8819D+02	0.8776D+02
48	-0.2274D-02	-0.1608D-02	0.9877D-02	0.7252D-02	0.1609D-02	0.1626D-02	0.9930D-02	0.7326D-02	0.8623D+02	0.8480D+02

STRAIN COMPONENTS, PRINCIPAL (TENSILE) STRAIN AND DIRECTION AT USER-SPECIFIED NODES

NODE	EPS-X STRAIN		EPS-Y STRAIN		SHEAR STRAIN		PRINC. STRAIN(T)		DIRECTION(DEG.)	
	INNER	OUTER	INNER	OUTER	INNER	OUTER	INNER	OUTER	INNER	OUTER
33	-0.5677D-02	-0.8628D-02	-0.1448D-01	0.4230D-01	-0.1433D-13	0.1502D-13	0.0	0.4230D-01	0.0	0.9000D+02
35	0.8233D-02	-0.2224D-01	-0.1460D-01	0.5435D-01	-0.1364D-12	0.1207D-12	0.8233D-02	0.5435D-01	-0.1711D-09	0.9000D+02
38	-0.6253D-02	-0.8474D-02	0.6246D-03	0.6130D-01	0.2146D-14	-0.3172D-14	0.6246D-03	0.6130D-01	0.9000D+02	-0.9000D+02
40	-0.2975D-02	-0.1266D-01	0.1309D-01	0.7513D-01	-0.2720D-01	0.1216D-01	0.2085D-01	0.7555D-01	-0.6028D+02	0.8606D+02
48	-0.6351D-02	-0.3772D-02	0.3277D-01	0.4054D-03	-0.1918D-14	0.1850D-14	0.3277D-01	0.4054D-03	-0.9000D+02	0.9000D+02
50	-0.9348D-02	-0.7832D-03	0.3585D-01	0.4247D-02	-0.2509D-02	0.1061D-01	0.3589D-01	0.7601D-02	-0.8835D+02	0.5769D+02

STRAIN COMPONENTS, PRINCIPAL(TENSILE) STRAIN AND DIRECTION AND ELONGATIONS AT SPECIFIED ADDITIONAL POINTS

POINT NO.	SURFACE	EPS-X STRAIN	EPS-Y STRAIN	SHEAR STRAIN	ELONG.(DIR.1)	ELONG(DIR.2)	PRINC. STRN(T)	DIRECTION(DEG.)
1	INNER	0.10231D-33	0.70499D-02	-0.28609D-16	0.0	0.70252D-02	0.70499D-02	-0.90000D+02
1	OUTER	0.10231D-33	0.86179D-02	-0.28609D-16	0.0	0.85811D-02	0.86179D-02	-0.90000D+02
2	INNER	-0.96584D-03	0.80338D-02	-0.10588D-03	-0.91631D-03	0.80018D-02	0.80341D-02	-0.89663D+02
2	OUTER	-0.93142D-03	0.70353D-02	-0.10588D-03	-0.31155D-03	0.76064D-02	0.76356D-02	-0.89646D+02
3	INNER	-0.38790D-02	0.64132D-02	-0.38477D-03	-0.38865D-02	0.63927D-02	0.64168D-02	-0.88930D+02
3	OUTER	-0.40693D-02	0.15492D-01	-0.38477D-03	-0.40776D-02	0.15374D-01	0.15494D-01	-0.89437D+02

4	INNER	-0.57591D-02	0.24165D-01	-0.56794D-03	-0.5758D-02	0.23880D-01	0.24168D-01	-0.89456D+02
4	OUTER	-0.38793D-02	0.24215D-02	-0.56794D-03	-0.38669D-02	0.24186D-02	0.24343D-02	-0.87425D+02
5	INNER	-0.69399D-02	0.21350D-01	-0.90536D-03	-0.69642D-02	0.21127D-01	0.21357D-01	-0.89084D+02
5	OUTER	-0.48318D-02	0.26603D-02	-0.90536D-03	-0.48435D-02	0.26568D-02	0.26876D-02	-0.86555D+02
6	INNER	-0.56772D-02	-0.14483D-01	-0.14195D-13	-0.56934D-02	-0.14589D-01	0.0	0.0
6	OUTER	-0.86280D-02	0.42295D-01	0.15149D-13	-0.86656D-02	0.41437D-01	0.42295D-01	0.90000D+02
7	INNER	-0.69399D-02	0.21350D-01	0.90536D-03	-0.69642D-02	0.21127D-01	0.21357D-01	0.89084D+02
7	OUTER	-0.48318D-02	0.26603D-02	0.90536D-03	-0.48435D-02	0.26568D-02	0.26876D-02	0.86555D+02
8	INNER	-0.57591D-02	0.24165D-01	0.56794D-03	-0.57758D-02	0.23880D-01	0.24168D-01	0.89456D+02
8	OUTER	-0.38793D-02	0.24215D-02	0.56794D-03	-0.38869D-02	0.24186D-02	0.24343D-02	0.87425D+02
9	INNER	-0.38790D-02	0.64132D-02	0.38477D-03	-0.38865D-02	0.63927D-02	0.64168D-02	0.88930D+02
9	OUTER	-0.40693D-02	0.15492D-01	0.38477D-03	-0.40776D-02	0.15374D-01	0.15494D-01	0.89437D+02
10	INNER	-0.96584D-03	0.80338D-02	0.10588D-03	-0.96631D-03	0.80018D-02	0.80341D-02	0.89663D+02
10	OUTER	-0.93142D-03	0.76353D-02	0.10588D-03	-0.93185D-03	0.76064D-02	0.76356D-02	0.89646D+02
11	INNER	0.13844D-18	0.70499D-02	0.69117D-17	0.0	0.70252D-02	0.70499D-02	0.90000D+02
11	OUTER	-0.13844D-18	0.86179D-02	0.62386D-17	0.0	0.85811D-02	0.86179D-02	0.90000D+02

SYSTEM ENERGIES(IN-LB)

WORK INPUT TO STRUCTURE	=	0.3848832D+04
STRUCTURE KINETIC ENERGY	=	0.2381437D+04
STRUCTURE ELASTIC ENERGY	=	0.2736041D+03
STRUCTURE PLASTIC ENERGY	=	0.1193791D+04
ENERGY STORED IN ELASTIC RESTRAINTS	=	0.0

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***** INCR. NO.= 140 TIME= 0 3500D-03 SEC.

NODE	U	V	W	PSIX	PSIY	TWIST	X-POS.	Y-POS.	Z-POS.
1	0 0	0 0	0.0	0 0	0 0	0.0	0.0	0.0	0.0
2	0 0	0 0	0 0	0.0	0 0	0.0	0.37425D+00	0.0	0.0
3	0.0	0 0	0.0	0 0	0 0	0.0	0.74850D+00	0.0	0.0
4	0 0	0 0	0.0	0.0	0 0	0.0	0.11227D+01	0.0	0.0
5	0.0	0 0	0 0	0.0	0 0	0.0	0.14970D+01	0.0	0.0
6	0 11168D-01	-0 16063D-01	0 22456D+00	-0.38388D-02	0 35040D+00	0.20650D-01	0.11168D-01	0.75894D+00	0.22456D+00
7	0.53935D-02	-0.16882D-01	0 22373D+00	-0.14533D-02	0 36099D+00	0.13046D-01	0.37964D+00	0 75812D+00	0.22373D+00
8	0.39218D-12	-0 16938D-01	0.22341D+00	-0 54197D-12	0 36261D+00	-0.21121D-11	0 74850D+00	0.75806D+00	0.22341D+00
9	-0 53935D-02	-0 16882D-01	0 22373D+00	0.14533D-02	0.36099D+00	-0.13046D-01	0.11174D+01	0.75812D+00	0.22373D+00
10	-0 11168D-01	-0 16063D-01	0 22456D+00	0.38388D-02	0.35040D+00	-0.20650D-01	0.14858D+01	0.75894D+00	0.22456D+00
11	0 10482D-01	-0 47561D-01	0 51225D+00	-0 98638D-02	0 39266D+00	-0 62600D-01	0.10482D-01	0.15024D+01	0.51225D+00
12	0 53509D-02	-0 46237D-01	0 51097D+00	-0.23590D-02	0 38957D+00	0.81612D-03	0 37960D+00	0.15038D+01	0.51097D+00
13	0 10598D-11	-0 45974D-01	0 51063D+00	-0 22515D-11	0 38947D+00	-0.31344D-11	0.74850D+00	0.15040D+01	0.51063D+00
14	-0 53509D-02	-0.46237D-01	0.51097D+00	0 23590D-02	0 38957D+00	-0.81612D-03	0.11174D+01	0.15038D+01	0.51097D+00
15	-0.10482D-01	-0.47561D-01	0.51225D+00	0.98638D-02	0 39266D+00	0 62600D-01	0.14865D+01	0.15024D+01	0.51225D+00
16	0.99764D-02	-0.49729D-01	0.75111D+00	-0 20050D-01	0 33755D+00	-0.13326D+00	0.99764D-02	0.22753D+01	0.75111D+00
17	0 48527D-02	-0 47760D-01	0 74555D+00	-0 99619D-02	0 32412D+00	-0 64496D-02	0.37910D+00	0.22772D+01	0.74555D+00
18	0.12465D-11	-0 46977D-01	0.74362D+00	0 27322D-11	0 32257D+00	-0.95271D-11	0 74850D+00	0.22780D+01	0.74362D+00
19	-0 48527D-02	-0 47760D-01	0 74555D+00	0 99619D-02	0 32412D+00	0 64496D-02	0.11179D+01	0.22772D+01	0.74555D+00
20	-0 99764D-02	-0 49729D-01	0 75111D+00	0 20050D-01	0 33755D+00	0.13326D+00	0.14870D+01	0.22753D+01	0.75111D+00
21	0 82092D-02	-0 31763D-01	0.89283D+00	-0 62094D-02	0.24566D+00	-0.17556D+00	0.82092D-02	0.30682D+01	0.89283D+00
22	0 38831D-02	-0 31307D-01	0 88973D+00	-0 82074D-02	0 21480D+00	-0.36351D-01	0.37813D+00	0.30687D+01	0.88973D+00
23	0 90110D-12	-0 30898D-01	0 88810D+00	0 69554D-12	0 20897D+00	-0.42541D-12	0.74850D+00	0.30691D+01	0.88810D+00
24	-0 38831D-02	-0 31307D-01	0.88973D+00	0.82074D-02	0.21480D+00	0.36351D-01	0.11189D+01	0.30687D+01	0.88973D+00
25	-0 82092D-02	-0.31763D-01	0 89283D+00	0.62094D-02	0 24566D+00	0.17556D+00	0.14888D+01	0.30682D+01	0.89283D+00
26	0.85445D-02	-0.21497D-01	0.95626D+00	-0 30929D-01	0.13937D+00	-0.14155D+00	0.85445D-02	0.35285D+01	0.95626D+00
27	0 43943D-02	-0.21507D-01	0.94816D+00	-0.12569D-01	0.11210D+00	-0 22280D-01	0.37864D+00	0.35285D+01	0.94816D+00
28	0 47549D-12	-0 21314D-01	0 94563D+00	-0.95775D-12	0.10868D+00	-0 92713D-12	0.74850D+00	0.35287D+01	0.94563D+00
29	-0.43943D-02	-0 21507D-01	0 94816D+00	0.12569D-01	0 11210D+00	0.22280D-01	0.11184D+01	0.35285D+01	0.94816D+00
30	-0 85445D-02	-0.21497D-01	0 95626D+00	0.30929D-01	0 13937D+00	0.14155D+00	0.14885D+01	0.35285D+01	0.95626D+00
31	0.12252D-01	-0.12828D-11	0 96231D+00	-0 17867D-01	0.92588D-10	-0.54499D-09	0.12252D-01	0.40000D+01	0.96231D+00
32	0 46056D-02	0 19815D-11	0 95365D+00	-0 20740D-01	0.19522D-10	0.19140D-09	0.37886D+00	0.40000D+01	0.95365D+00
33	0 18158D-12	0 97387D-11	0.95040D+00	-0.28519D-12	-0.19881D-10	-0.26675D-10	0.74850D+00	0.40000D+01	0.95040D+00
34	-0.46056D-02	0.19362D-11	0 95365D+00	0.20740D-01	0 12620D-10	-0.18811D-09	0.11181D+01	0.40000D+01	0.95365D+00
35	-0.12252D-01	-0 26007D-12	0.96231D+00	0.17867D-01	0.66454D-10	0.39031D-09	0.14847D+01	0.40000D+01	0.96231D+00
36	0 85445D-02	0.21497D-01	0.95626D+00	-0.30929D-01	-0.13937D+00	0.14155D+00	0.85445D-02	0.44715D+01	0.95626D+00
37	0.43943D-02	0.21507D-01	0 94816D+00	-0.12569D-01	-0.11210D+00	0.22280D-01	0.37864D+00	0.44715D+01	0.94816D+00
38	-0 13822D-12	0.21314D-01	0.94563D+00	0.11766D-11	-0 10868D+00	0.95883D-12	0.74850D+00	0.44713D+01	0.94563D+00
39	-0 43943D-02	0.21507D-01	0.94816D+00	0.12569D-01	-0.11210D+00	-0.22280D-01	0.11184D+01	0.44715D+01	0.94816D+00

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40	-0.85445D-02	0.21497D-01	0.95626D+00	0.30929D-01	-0.13937D+00	-0.14155D+00	0.14885D+01	0.44715D+01	0.95626D+00
41	0.82092D-02	0.31763D-01	0.89283D+00	-0.62094D-02	-0.24566D+00	0.17556D+00	0.82092D-02	0.49318D+01	0.89283D+00
42	0.38831D-02	0.31307D-01	0.88973D+00	-0.82074D-02	-0.21480D+00	0.36351D-01	0.37813D+00	0.49313D+01	0.88973D+00
43	-0.78789D-12	0.30898D-01	0.88810D+00	0.38751D-12	-0.20837D+00	0.48970D-11	0.74850D+00	0.49309D+01	0.88810D+00
44	-0.38831D-02	0.31307D-01	0.89973D+00	0.82074D-02	-0.21480D+00	-0.36351D-01	0.11189D+01	0.49313D+01	0.89973D+00
45	-0.82092D-02	0.31763D-01	0.89283D+00	0.62094D-02	-0.24566D+00	-0.17556D+00	0.14888D+01	0.49318D+01	0.89283D+00
46	0.99764D-02	0.49729D-01	0.75111D+00	-0.20050D-01	-0.33755D+00	0.13326D+00	0.99764D-02	0.57247D+01	0.75111D+00
47	0.48527D-02	0.47760D-01	0.74555D+00	-0.99619D-02	-0.32412D+00	0.64496D-02	0.37910D+00	0.57228D+01	0.74555D+00
48	-0.17127D-11	0.46977D-01	0.74362D+00	-0.63437D-12	-0.32257D+00	-0.22217D-10	0.74850D+00	0.57220D+01	0.74362D+00
49	-0.46527D-02	0.47760D-01	0.74555D+00	0.99619D-02	-0.32412D+00	-0.64496D-02	0.11179D+01	0.57228D+01	0.74555D+00
50	-0.99764D-02	0.49729D-01	0.75111D+00	0.20050D-01	-0.33755D+00	-0.13326D+00	0.14870D+01	0.57247D+01	0.75111D+00
51	0.10482D-01	0.47561D-01	0.51225D+00	-0.98638D-02	-0.39266D+00	0.62600D-01	0.10482D-01	0.64976D+01	0.51225D+00
52	0.53509D-02	0.46237D-01	0.51097D+00	-0.23590D-02	-0.38957D+00	-0.81612D-03	0.37960D+00	0.64962D+01	0.51097D+00
53	-0.16977D-11	0.45474D-01	0.51063D+00	0.37265D-11	-0.38347D+00	-0.69404D-11	0.74850D+00	0.64960D+01	0.51063D+00
54	-0.53509D-02	0.46237D-01	0.51097D+00	0.23590D-02	-0.38957D+00	0.81612D-03	0.11174D+01	0.64962D+01	0.51097D+00
55	-0.10482D-01	0.47561D-01	0.51225D+00	0.98638D-02	-0.39266D+00	-0.62600D-01	0.14865D+01	0.64976D+01	0.51225D+00
56	0.11168D-01	0.16063D-01	0.22456D+00	-0.38388D-02	-0.35040D+00	-0.20650D-01	0.11168D-01	0.72411D+01	0.22456D+00
57	0.53935D-02	0.16882D-01	0.22373D+00	-0.14533D-02	-0.36099D+00	-0.13046D-01	0.37960D+00	0.72419D+01	0.22373D+00
58	-0.49691D-12	0.16930D-01	0.22341D+00	0.27186D-12	-0.36261D+00	-0.39224D-11	0.74850D+00	0.72419D+01	0.22341D+00
59	-0.53935D-02	0.16882D-01	0.22373D+00	0.14533D-02	-0.36099D+00	0.13046D-01	0.11174D+01	0.72419D+01	0.22373D+00
60	-0.11168D-01	0.16063D-01	0.22456D+00	-0.38388D-02	-0.35040D+00	0.20650D-01	0.14858D+01	0.72411D+01	0.22456D+00
61	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.80000D+01	0.0
62	0.0	0.0	0.0	0.0	0.0	0.0	0.37425D+00	0.80000D+01	0.0
63	0.0	0.0	0.0	0.0	0.0	0.0	0.74850D+00	0.80000D+01	0.0
64	0.0	0.0	0.0	0.0	0.0	0.0	0.11227D+01	0.80000D+01	0.0
65	0.0	0.0	0.0	0.0	0.0	0.0	0.14970D+01	0.80000D+01	0.0

REACTION FORCES AT CONSTRAINED NODES

		RX (LBS)	RY (LBS)	RZ (LBS)	MX (LBS-IN)	MY (LBS-IN)	MXY (LBS-IN-IN)
286	1	-0.20851D+03	-0.55717D+03	-0.19668D+03	-0.17373D+02	-0.39141D+02	-0.25709D+01
	2	-0.58213D+02	-0.67278D+03	-0.35976D+03	0.19649D+00	-0.67213D+02	-0.39230D-01
	3	-0.11835D-07	-0.65654D+03	-0.35882D+03	0.20692D-09	-0.68003D+02	0.97145D-10
	4	0.58213D+02	-0.67278D+03	-0.35976D+03	-0.19649D+00	-0.67213D+02	0.39230D-01
	5	0.20851D+03	-0.55717D+03	-0.19668D+03	0.17373D+02	-0.39141D+02	0.25709D+01
	61	-0.20851D+03	0.55717D+03	-0.19668D+03	-0.17373D+02	0.39141D+02	0.25709D+01
	62	-0.58213D+02	0.67278D+03	-0.35976D+03	0.19649D+00	-0.67213D+02	0.39230D-01
	63	0.11240D-08	0.65654D+03	-0.35882D+03	0.97057D-09	0.68003D+02	-0.23037D-10
	64	0.58213D+02	0.67278D+03	-0.35976D+03	-0.19649D+00	-0.67213D+02	-0.39230D-01
	65	0.20851D+03	0.55717D+03	-0.19668D+03	0.17373D+02	0.39141D+02	-0.25709D+01

STRAIN COMPONENTS, PRINCIPAL(TENSILE) STRAIN AND DIRECTION AT CENTROID OF EACH ELEMENT

ELEM.	EPS-X STRAIN		EPS-Y STRAIN		SHEAR STRAIN		PRINC STRAIN(T)		DIRECTION(DEG.)	
	INNER	OUTER	INNER	OUTER	INNER	OUTER	INNER	OUTER	INNER	OUTER
1	-0.7425D-02	-0.7951D-02	0.6157D-01	0.1471D-01	0.6811D-02	0.9373D-02	0.6174D-01	0.1564D-01	0.8717D+02	0.7876D+02
2	-0.6931D-02	-0.7475D-02	0.6051D-01	0.1281D-01	0.2883D-02	0.3404D-02	0.6054D-01	0.1295D-01	0.8878D+02	0.8524D+02
3	-0.6931D-02	-0.7475D-02	0.6051D-01	0.1281D-01	-0.2883D-02	-0.3404D-02	0.6054D-01	0.1295D-01	-0.8878D+02	-0.8524D+02
4	-0.7425D-02	-0.7951D-02	0.6157D-01	0.1471D-01	-0.6811D-02	-0.9373D-02	0.6174D-01	0.1564D-01	-0.8717D+02	-0.7876D+02
5	-0.1483D-01	-0.1430D-01	0.3126D-01	0.2703D-01	-0.3566D-03	0.1515D-02	0.3126D-01	0.2705D-01	-0.8975D+02	0.8895D+02
6	-0.1426D-01	-0.1445D-01	0.3178D-01	0.2820D-01	0.2975D-04	0.1187D-03	0.3178D-01	0.2820D-01	0.8998D+02	0.8992D+02
7	-0.1426D-01	-0.1445D-01	0.3178D-01	0.2820D-01	-0.2975D-04	-0.1187D-03	0.3178D-01	0.2820D-01	-0.8998D+02	-0.8992D+02
8	-0.1483D-01	-0.1430D-01	0.3126D-01	0.2703D-01	0.3566D-03	0.1515D-02	0.3126D-01	0.2705D-01	0.8975D+02	-0.8895D+02
9	-0.1331D-01	-0.1404D-01	0.3257D-01	0.4089D-01	-0.1241D-03	0.4098D-02	0.3257D-01	0.4097D-01	-0.8992D+02	0.8787D+02
10	-0.1288D-01	-0.1337D-01	0.3113D-01	0.4019D-01	-0.3872D-03	0.1104D-02	0.3143D-01	0.4019D-01	-0.8975D+02	0.8942D+02
11	-0.1288D-01	-0.1337D-01	0.3143D-01	0.4019D-01	0.3872D-03	-0.1104D-02	0.3143D-01	0.4019D-01	0.8975D+02	-0.8942D+02
12	-0.1331D-01	-0.1404D-01	0.3257D-01	0.4089D-01	0.1241D-03	-0.4098D-02	0.3257D-01	0.4097D-01	0.8992D+02	-0.8787D+02
13	-0.1221D-01	-0.1299D-01	0.2514D-01	0.3875D-01	0.3975D-02	-0.2944D-02	0.2554D-01	0.3880D-01	0.8699D+02	-0.8837D+02
14	-0.1082D-01	-0.1251D-01	0.2425D-01	0.3910D-01	0.1030D-02	-0.2392D-03	0.2426D-01	0.3910D-01	0.8916D+02	-0.8987D+02
15	-0.1082D-01	-0.1251D-01	0.2425D-01	0.3910D-01	-0.1030D-02	0.2392D-03	0.2426D-01	0.3910D-01	-0.8916D+02	0.8987D+02
16	-0.1221D-01	-0.1299D-01	0.2544D-01	0.3875D-01	-0.3975D-02	0.2944D-02	0.2554D-01	0.3880D-01	-0.8699D+02	0.8837D+02
17	-0.9939D-02	-0.1217D-01	0.1705D-01	0.4053D-01	-0.1002D-02	0.5740D-03	0.1706D-01	0.4053D-01	-0.8894D+02	0.8969D+02
18	-0.9517D-02	-0.1256D-01	0.1646D-01	0.3932D-01	0.3879D-03	0.9845D-03	0.1646D-01	0.3932D-01	0.8957D+02	0.8946D+02
19	-0.9517D-02	-0.1256D-01	0.1646D-01	0.3932D-01	-0.3879D-03	-0.9845D-03	0.1646D-01	0.3932D-01	-0.8957D+02	-0.8946D+02
20	-0.9939D-02	-0.1217D-01	0.1705D-01	0.4053D-01	0.1002D-02	-0.5740D-03	0.1706D-01	0.4053D-01	0.8894D+02	-0.8969D+02
21	-0.1342D-01	-0.1736D-01	0.3420D-01	0.6143D-01	0.5116D-02	0.3974D-02	0.3433D-01	0.6148D-01	0.8693D+02	0.8856D+02

22	-0.9552D-02	-0.1443D-01	0.3525D-01	0.6004D-01	0.5013D-03	0.6654D-03	0.3525D-01	0.6004D-01	0.8968D+02	0.8974D+02
23	-0.9552D-02	-0.1443D-01	0.3525D-01	0.6004D-01	-0.5013D-03	-0.6654D-03	0.3525D-01	0.6004D-01	-0.8968D+02	-0.8974D+02
24	-0.1342D-01	-0.1736D-01	0.3420D-01	0.6143D-01	-0.5116D-02	-0.3974D-02	0.3433D-01	0.6148D-01	-0.8693D+02	-0.8856D+02
25	-0.1342D-01	-0.1736D-01	0.3420D-01	0.6143D-01	-0.5116D-02	-0.3974D-02	0.3433D-01	0.6148D-01	-0.8693D+02	-0.8856D+02
26	-0.9552D-02	-0.1443D-01	0.3525D-01	0.6004D-01	-0.5013D-03	-0.6654D-03	0.3525D-01	0.6004D-01	-0.8968D+02	-0.8974D+02
27	-0.9552D-02	-0.1443D-01	0.3525D-01	0.6004D-01	0.5013D-03	0.6654D-03	0.3525D-01	0.6004D-01	0.8968D+02	0.8974D+02
28	-0.1342D-01	-0.1736D-01	0.3420D-01	0.6143D-01	-0.5116D-02	-0.3974D-02	0.3433D-01	0.6148D-01	-0.8693D+02	-0.8856D+02
29	-0.9939D-02	-0.1247D-01	0.1705D-01	0.4053D-01	0.1002D-02	-0.5740D-03	0.1706D-01	0.4053D-01	0.8894D+02	-0.8969D+02
30	-0.9517D-02	-0.1256D-01	0.1646D-01	0.3932D-01	-0.3879D-03	-0.9845D-03	0.1646D-01	0.3932D-01	-0.8957D+02	-0.8946D+02
31	-0.9517D-02	-0.1256D-01	0.1646D-01	0.3932D-01	0.3879D-03	0.9845D-03	0.1646D-01	0.3932D-01	0.8957D+02	0.8946D+02
32	-0.9939D-02	-0.1247D-01	0.1705D-01	0.4053D-01	-0.1002D-02	0.5740D-03	0.1706D-01	0.4053D-01	-0.8894D+02	0.8969D+02
33	-0.1221D-01	-0.1299D-01	0.2544D-01	0.3875D-01	-0.3975D-02	0.2944D-02	0.2554D-01	0.3880D-01	-0.8699D+02	0.8837D+02
34	-0.1082D-01	-0.1251D-01	0.2425D-01	0.3910D-01	-0.1030D-02	0.2392D-03	0.2426D-01	0.3910D-01	-0.8916D+02	0.8987D+02
35	-0.1082D-01	-0.1251D-01	0.2425D-01	0.3910D-01	0.1030D-02	-0.2392D-03	0.2426D-01	0.3910D-01	0.8916D+02	-0.8987D+02
36	-0.1221D-01	-0.1299D-01	0.2544D-01	0.3875D-01	-0.3975D-02	-0.2944D-02	0.2554D-01	0.3880D-01	-0.8699D+02	-0.8837D+02
37	-0.1331D-01	-0.1404D-01	0.3257D-01	0.4089D-01	0.1241D-03	-0.4098D-02	0.3257D-01	0.4097D-01	0.8992D+02	-0.8787D+02
38	-0.1288D-01	-0.1437D-01	0.3143D-01	0.4019D-01	-0.3872D-03	-0.1104D-02	0.3143D-01	0.4019D-01	-0.8975D+02	-0.8942D+02
39	-0.1288D-01	-0.1437D-01	0.3143D-01	0.4019D-01	-0.3872D-03	0.1104D-02	0.3143D-01	0.4019D-01	-0.8975D+02	0.8942D+02
40	-0.1331D-01	-0.1404D-01	0.3257D-01	0.4089D-01	-0.1241D-03	0.4098D-02	0.3257D-01	0.4097D-01	-0.8992D+02	0.8787D+02
41	-0.1137D-01	-0.1430D-01	0.3126D-01	0.2703D-01	0.3360D-03	-0.1515D-02	0.3126D-01	0.2705D-01	-0.8975D+02	-0.8895D+02
42	-0.1426D-01	-0.1415D-01	0.3176D-01	0.2820D-01	-0.2995D-04	-0.1187D-03	0.3178D-01	0.2820D-01	-0.8998D+02	-0.8992D+02
43	-0.1426D-01	-0.1415D-01	0.3176D-01	0.2820D-01	0.2995D-04	0.1187D-03	0.3178D-01	0.2820D-01	0.8998D+02	0.8992D+02
44	-0.1483D-01	-0.1430D-01	0.3126D-01	0.2703D-01	-0.3966D-03	0.1515D-02	0.3126D-01	0.2705D-01	-0.8975D+02	0.8895D+02
45	-0.7425D-02	-0.7951D-02	0.6157D-01	0.1471D-01	-0.6841D-02	-0.9373D-02	0.6174D-01	0.1564D-01	-0.8717D+02	-0.7876D+02
46	-0.6933D-02	-0.7175D-02	0.6051D-01	0.1281D-01	-0.2883D-02	-0.3404D-02	0.6054D-01	0.1295D-01	-0.8878D+02	-0.8524D+02
47	-0.6933D-02	-0.7475D-02	0.6051D-01	0.1281D-01	0.2883D-02	0.3404D-02	0.6054D-01	0.1295D-01	0.8878D+02	0.8524D+02
48	-0.7425D-02	-0.7951D-02	0.6157D-01	0.1471D-01	0.6841D-02	0.9373D-02	0.6174D-01	0.1564D-01	0.8717D+02	0.7876D+02

STRAIN COMPONENTS, PRINCIPAL (TENSILE) STRAIN AND DIRECTION AT USER-SPECIFIED NODES

NODE	EPS-X STRAIN		EPS-Y STRAIN		SHEAR STRAIN		PRINC. STRAIN(T)		DIRECTION(DEG.)	
	INNER	OUTER	INNER	OUTER	INNER	OUTER	INNER	OUTER	INNER	OUTER
33	-0.1085D-01	-0.1377D-01	0.6479D-01	0.2994D-01	-0.3463D-11	0.1978D-11	0.6479D-01	0.2994D-01	-0.9000D+02	0.9000D+02
35	-0.2379D-01	-0.1674D-01	0.7023D-01	0.2533D-01	0.3841D-10	-0.4121D-10	0.7023D-01	0.2533D-01	0.9000D+02	-0.9000D+02
38	-0.9632D-02	-0.1385D-01	0.2406D-01	0.5641D-01	-0.2482D-12	-0.4438D-12	0.2406D-01	0.5641D-01	-0.9000D+02	-0.9000D+02
40	-0.8025D-02	-0.1319D-01	0.2949D-01	0.6052D-01	-0.1428D-01	0.1459D-01	0.3081D-01	0.6124D-01	-0.7958D+02	0.8440D+02
48	-0.1147D-01	-0.1446D-01	0.5108D-01	0.7242D-01	-0.8344D-12	0.3698D-11	0.5108D-01	0.7242D-01	-0.9000D+02	0.9000D+02
50	-0.1200D-01	-0.1497D-01	0.5210D-01	0.8224D-01	-0.1657D-01	0.1062D-01	0.5315D-01	0.8253D-01	-0.8275D+02	0.8688D+02

STRAIN COMPONENTS, PRINCIPAL(TENSILE) STRAIN AND DIRECTION, AND ELONGATIONS AT SPECIFIED ADDITIONAL POINTS

POINT NO.	SURFACE	EPS-X STRAIN	EPS-Y STRAIN	SHEAR STRAIN	ELONG (DIR.1)	ELONG (DIR.2)	PRINC STRN(T)	DIRECTION(DEG.)
1	INNER	0.32010D-25	0.44241D-01	0.50604D-12	0.0	0.43303D-01	0.44241D-01	0.9000D+02
1	OUTER	0.32010D-25	-0.87952D-01	0.50604D-12	0.0	-0.92202D-01	0.0	0.0
2	INNER	-0.36713D-02	0.45870D-01	-0.38776D-04	-0.36780D-02	0.44864D-01	0.45870D-01	-0.89978D+02
2	OUTER	-0.37669D-02	-0.42726D-01	-0.38776D-04	-0.37740D-02	-0.43680D-01	0.0	0.0
3	INNER	-0.14141D-01	0.29537D-01	0.97338D-04	-0.14242D-01	0.29113D-01	0.29537D-01	0.89936D+02
3	OUTER	-0.14616D-01	0.27802D-01	0.97338D-04	-0.14724D-01	0.27426D-01	0.27802D-01	0.89934D+02
4	INNER	-0.13460D-01	0.30134D-01	0.11509D-02	-0.13551D-01	0.29693D-01	0.30141D-01	0.89244D+02
4	OUTER	-0.12779D-01	0.54159D-01	0.15090D-02	-0.11380D-01	0.53052D-01	0.54464D-01	0.89520D+02
5	INNER	-0.10565D-01	0.19191D-01	0.17374D-02	-0.10653D-01	0.19016D-01	0.19216D-01	0.88331D+02
5	OUTER	-0.13497D-01	0.52331D-01	0.17374D-02	-0.11590D-01	0.51029D-01	0.52342D-01	0.89244D+02
6	INNER	-0.10847D-01	0.64793D-01	0.17290D-10	-0.10900D-01	0.62820D-01	0.64793D-01	0.90000D+02
6	OUTER	-0.13766D-01	0.29937D-01	0.22737D-10	-0.13862D-01	0.29501D-01	0.29937D-01	0.90000D+02
7	INNER	-0.10596D-01	0.19191D-01	-0.17374D-02	-0.10653D-01	0.19010D-01	0.19216D-01	-0.88331D+02
7	OUTER	-0.13497D-01	0.52331D-01	-0.17374D-02	-0.11590D-01	0.51029D-01	0.52342D-01	-0.89244D+02
8	INNER	-0.13460D-01	0.30134D-01	-0.11509D-02	-0.13551D-01	0.29693D-01	0.30141D-01	-0.89244D+02
8	OUTER	-0.14277D-01	0.54459D-01	-0.11503D-02	-0.11380D-01	0.53052D-01	0.54464D-01	-0.89520D+02
9	INNER	-0.14141D-01	0.29537D-01	-0.97338D-04	-0.14242D-01	0.29113D-01	0.29537D-01	-0.89936D+02
9	OUTER	-0.14616D-01	0.27802D-01	-0.97338D-04	-0.14724D-01	0.27426D-01	0.27802D-01	-0.89934D+02
10	INNER	-0.36713D-02	0.45870D-01	0.38776D-04	-0.36780D-02	0.44864D-01	0.45870D-01	0.89978D+02
10	OUTER	-0.37669D-02	-0.42726D-01	0.38776D-04	-0.37740D-02	-0.43680D-01	0.0	0.0
11	INNER	0.35898D-18	0.44241D-01	0.64117D-12	0.0	0.43303D-01	0.44241D-01	0.9000D+02
11	OUTER	-0.35898D-18	-0.87952D-01	0.64117D-12	0.0	-0.92202D-01	0.0	0.0

SYSTEM ENERGIES(IN-LB)

WORK INPUT TO STRUCTURE = 0.3848832D+04
STRUCTURE KINETIC ENERGY = 0.8794630D+02
STRUCTURE ELASTIC ENERGY = 0.6741908D+02
STRUCTURE PLASTIC ENERGY = 0.3693466D+04
ENERGY STORED IN ELASTIC RESTRAINTS= 0.0

***** INCR. NO.= 150 TIME= 0.3750D-03 SEC.

NODE	U	V	W	PSIX	PSIY	TWIST	X-POS.	Y-POS.	Z-POS.
1	0 0	0 0	0 0	0.0	0.0	0.0	0.0	0.0	0.0
2	0 0	0 0	0 0	0 0	0 0	0.0	0.37425D+00	0.0	0.0
3	0.0	0 0	0.0	0 0	0.0	0.0	0.74850D+00	0.0	0.0
4	0 0	0 0	0.0	0 0	0 0	0.0	0.11227D+01	0 0	0.0
5	0 0	0 0	0.0	0.0	0.0	0.0	0.14970D+01	0.0	0.0
6	0.10577D-01	-0 15472D-01	0 21855D+00	-0.62583D-02	0.33756D+00	0 15768D-01	0.10577D-01	0.75953D+00	0.21855D+00
7	0 51089D-02	-0.15957D-01	0 21709D+00	-0.26210D-02	0 34761D+00	0 13124D-01	0.37936D+00	0.75904D+00	0.21709D+00
8	0 17067D-12	-0 15916D-01	0 21655D+00	-0 85720D-12	0 34926D+00	-0 29345D-11	0.74850D+00	0.75908D+00	0.21655D+00
9	-0 51089D-02	-0 15957D-01	0 21709D+00	0 26210D-02	0 34761D+00	-0.13124D-01	0.11176D+01	0.75904D+00	0.21709D+00
10	-0 10577D-01	-0 15472D-01	0 21855D+00	0 62583D-02	0 33756D+00	-0.15768D-01	0 14864D+01	0.75953D+00	0 21855D+00
11	0 99164D-02	-0 42556D-01	0 49051D+00	-0.98516D-02	0 37709D+00	-0.66297D-01	0.99164D-02	0.15074D+01	0.49051D+00
12	0 50632D-02	-0 41245D-01	0 48922D+00	-0 23659D-02	0 37439D+00	0.24323D-02	0.37931D+00	0 15088D+01	0 48922D+00
13	0 80972D-12	-0 40976D-01	0 48887D+00	-0 23143D-11	0.37460D+00	-0.23026D-11	0.74850D+00	0.15090D+01	0 48887D+00
14	-0 50632D-02	-0 41245D-01	0 48922D+00	0 23659D-02	0 37439D+00	-0.24323D-02	0.11177D+01	0 15088D+01	0 48922D+00
15	-0 99164D-02	-0 42556D-01	0 49051D+00	0 98516D-02	0.37709D+00	0.66297D-01	0 14871D+01	0 15074D+01	0.49051D+00
16	0 94630D-02	-0 42452D-01	0 71707D+00	-0.15207D-01	0 33367D+00	-0.13143D+00	0.94630D-02	0 22825D+01	0.71707D+00
17	0 46101D-02	-0 40797D-01	0.71243D+00	-0 88388D-02	0 32049D+00	-0.58165D-02	0 37886D+00	0 22842D+01	0.71243D+00
18	0 10040D-11	-0 40075D-01	0 71067D+00	0 23317D-11	0 31906D+00	-0.10914D-10	0 74850D+00	0 22849D+01	0.71067D+00
19	-0 46101D-02	-0 40797D-01	0.71243D+00	0 88388D-02	0 32049D+00	0 58165D-02	0 11181D+01	0.22842D+01	0.71243D+00
20	-0 94630D-02	-0 42452D-01	0 71707D+00	0 15207D-01	0 33367D+00	0 13143D+00	0.14875D+01	0 22825D+01	0.71707D+00
21	0 78979D-02	-0 28001D-01	0.87038D+00	-0 57092D-02	0 27058D+00	-0 17812D+00	0 78979D-02	0 30720D+01	0.87038D+00
22	0 37051D-02	-0 27512D-01	0 86704D+00	-0 91965D-02	0 23784D+00	-0 39752D-01	0.37796D+00	0 30725D+01	0.86704D+00
23	0 74222D-12	-0 27076D-01	0 86519D+00	-0 77961D-12	0 23135D+00	0 39382D-11	0.74850D+00	0 30729D+01	0.86519D+00
24	-0 37051D-02	-0 27512D-01	0 86704D+00	0 91965D-02	0 23784D+00	0.39752D-01	0 11190D+01	0 30725D+01	0 86704D+00
25	-0 78979D-02	-0 28001D-01	0.87038D+00	0 57092D-02	0 27058D+00	0 17812D+00	0 14891D+01	0 30720D+01	0 87038D+00
26	0 82257D-02	-0 20683D-01	0 94859D+00	-0 38349D-01	0 17072D+00	-0.16177D+00	0 82257D-02	0 35293D+01	0 94859D+00
27	0 41950D-02	-0 20351D-01	0 93843D+00	-0 16392D-01	0 13905D+00	-0 28622D-01	0 37844D+00	0 35296D+01	0 93843D+00
28	0 33151D-12	-0 20112D-01	0 93517D+00	-0 28075D-12	0 13443D+00	0 20816D-11	0 74850D+00	0 35299D+01	0.93517D+00
29	-0 41950D-02	-0 20351D-01	0 93843D+00	0 16392D-01	0 13905D+00	0 28622D-01	0 11186D+01	0 35296D+01	0.93843D+00
30	-0 82257D-02	-0 20683D-01	0 94859D+00	0 38349D-01	0 17072D+00	0 16177D+00	0.14888D+01	0 35293D+01	0 94859D+00
31	0 11871D-01	0 47311D-13	0 96197D+00	-0 29993D-01	0 12727D-09	-0.59200D-09	0.11871D-01	0 40000D+01	0.96197D+00
32	0 43607D-02	0 29548D-11	0 95008D+00	-0 26395D-01	0 57128D-10	0.18801D-09	0 37861D+00	0 40000D+01	0.95008D+00
33	0 16244D-12	0 10268D-10	0.94575D+00	-0 42258D-13	0 24093D-10	-0 27419D-10	0 74850D+00	0.40000D+01	0 94575D+00
34	-0 43607D-02	0 19735D-11	0 95008D+00	0 26395D-01	0 48763D-10	-0 18904D-09	0 11184D+01	0 40000D+01	0.95008D+00
35	-0 11871D-01	0 70815D-12	0 96197D+00	0 29999D-01	0 98154D-10	0 42941D-09	0 14851D+01	0 40000D+01	0 96197D+00
36	0 82257D-02	0 20683D-01	0 94859D+00	-0 38349D-01	-0 17072D+00	0 16177D+00	0 82257D-02	0 44707D+01	0.94859D+00
37	0 41950D-02	0 20351D-01	0 93843D+00	-0 16392D-01	-0 13905D+00	0 28622D-01	0 37844D+00	0.44704D+01	0 93843D+00
38	0 89324D-14	0 20112D-01	0 93517D+00	0 27328D-11	-0 13443D+00	0 95934D-11	0 74850D+00	0.44701D+01	0 93517D+00
39	-0 41950D-02	0 20351D-01	0 93843D+00	0 16392D-01	-0 13905D+00	-0 28622D-01	0 11196D+01	0 44704D+01	0.93843D+00
40	-0 82257D-02	0 20683D-01	0 94859D+00	0 38349D-01	-0 17072D+00	-0 16177D+00	0 14888D+01	0 44707D+01	0.94859D+00
41	0 78979D-02	0 28001D-01	0 87038D+00	-0 57092D-02	-0 27058D+00	0 17812D+00	0 78979D-02	0 49200D+01	0.87038D+00
42	0 37051D-02	0 27512D-01	0 86704D+00	-0 91965D-02	-0 23784D+00	0 39752D-01	0 37796D+00	0.49275D+01	0 86704D+00
43	-0 41837D-12	0 27076D-01	0 86519D+00	0 60115D-11	-0 23135D+00	0.10183D-10	0 74850D+00	0 49271D+01	0.86519D+00
44	-0 37051D-02	0 27512D-01	0 86704D+00	0 91965D-02	-0 23784D+00	-0 39752D-01	0 11190D+01	0 49275D+01	0.86704D+00
45	-0 78979D-02	0 28001D-01	0 87038D+00	0 57092D-02	-0 27058D+00	-0 17812D+00	0 14891D+01	0 49280D+01	0 87038D+00
46	0 94630D-02	0 42452D-01	0 71707D+00	-0 15207D-01	-0 33367D+00	0.13143D+00	0 94630D-02	0.57175D+01	0.71707D+00
47	0 46101D-02	0 40797D-01	0 71243D+00	-0 88388D-02	-0 32049D+00	0 58165D-02	0 37886D+00	0 57158D+01	0.71243D+00
48	-0 10255D-11	0 40675D-01	0 71067D+00	0 26425D-11	-0 31906D+00	-0 21868D-10	0 74850D+00	0 57151D+01	0.71067D+00
49	-0 46101D-02	0 40797D-01	0 71243D+00	0 88388D-02	-0 32049D+00	-0 58165D-02	0.11181D+01	0 57158D+01	0.71243D+00
50	-0 94630D-02	0 42452D-01	0 71707D+00	0 15207D-01	-0 33367D+00	-0 13143D+00	0 14875D+01	0 57175D+01	0.71707D+00
51	0 99164D-02	-0 42556D-01	0 49051D+00	-0 98516D-02	-0 37709D+00	0.66297D-01	0.99164D-02	0.64926D+01	0.49051D+00
52	0 50632D-02	0 41245D-01	0 48922D+00	-0 23659D-02	-0 37439D+00	-0.24323D-02	0 37931D+00	0 64912D+01	0.48922D+00
53	-0 11043D-11	0 40976D-01	0 48887D+00	0 63194D-11	-0 37460D+00	-0 81592D-11	0.74850D+00	0 64910D+01	0.48887D+00
54	-0 50632D-02	0 41245D-01	0 48922D+00	0 23659D-02	-0 37439D+00	0.24323D-02	0.11177D+01	0.64912D+01	0.48922D+00
55	-0 99164D-02	0 42556D-01	0 49051D+00	0 98516D-02	-0 37709D+00	-0 66297D-01	0.14871D+01	0.64926D+01	0.49051D+00
56	0 10577D-01	0.15472D-01	0 21855D+00	-0 62583D-02	0.33756D+00	-0.15768D-01	0 10577D-01	0.72405D+01	0.21855D+00
57	0 51089D-02	0.15957D-01	0 21709D+00	-0 26210D-02	-0 34761D+00	-0.13124D-01	0.37936D+00	0.72410D+01	0.21709D+00

288

58	-0.17301D-12	0.15916D-01	0.21855D+00	0.13874D-11	-0.34926D+00	-0.65051D-11	0.74850D+00	0.72409D+01	0.21655D+00
59	-0.51089D-02	0.15957D-01	0.21709D+00	0.26210D-02	-0.34761D+00	0.13124D-01	0.11176D+01	0.72410D+01	0.21709D+00
60	-0.10577D-01	0.15472D-01	0.21855D+00	0.62583D-02	-0.33756D+00	0.15768D-01	0.14864D+01	0.72405D+01	0.21855D+00
61	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.80000D+01	0.0
62	0.0	0.0	0.0	0.0	0.0	0.0	0.37425D+00	0.80000D+01	0.0
63	0.0	0.0	0.0	0.0	0.0	0.0	0.74850D+00	0.80000D+01	0.0
64	0.0	0.0	0.0	0.0	0.0	0.0	0.11227D+01	0.80000D+01	0.0
65	0.0	0.0	0.0	0.0	0.0	0.0	0.14970D+01	0.80000D+01	0.0

REACTION FORCES AT CONSTRAINED NODES

NODE	RX (LBS)	RY (LBS)	RZ (LBS)	MX (LBS-IN)	MY (LBS-IN)	MX (LBS-IN)	MY (LBS-IN)	MX (LBS-IN)	MY (LBS-IN)
1	-0.17901D+03	-0.14156D+03	-0.41818D+02	-0.59745D+01	-0.66443D+01	-0.38651D+00			
2	-0.30362D+02	-0.30566D+02	-0.75548D+02	0.28669D-01	-0.43400D+01	-0.17978D-01			
3	0.44715D-08	-0.44600D+02	-0.75675D+02	-0.60662D-09	-0.43263D+01	0.22240D-11			
4	0.30362D+02	-0.30566D+02	-0.75548D+02	-0.28669D-01	-0.43400D+01	0.17978D-01			
5	0.17901D+03	-0.14156D+03	-0.41818D+02	0.59745D+01	-0.66443D+01	0.38651D+00			
61	-0.17901D+03	0.14156D+03	-0.41818D+02	-0.59745D+01	0.66443D+01	0.38651D+00			
62	-0.30362D+02	0.30566D+02	-0.75548D+02	0.28669D-01	0.43400D+01	0.17978D-01			
63	-0.16765D-07	0.44600D+02	-0.75675D+02	0.14277D-08	0.43263D+01	-0.40298D-10			
64	0.30362D+02	0.30566D+02	-0.75548D+02	-0.28669D-01	0.43400D+01	-0.17978D-01			
65	0.17901D+03	0.14156D+03	-0.41818D+02	0.59745D+01	0.66443D+01	-0.38651D+00			

STRAIN COMPONENTS, PRINCIPAL(TENSILE) STRAIN AND DIRECTION AT CENTROID OF EACH ELEMENT

ELEM.	EPS-X STRAIN		EPS-Y STRAIN		SHEAR STRAIN		PRINC. STRAIN(T)		DIRECTION(DEC.)	
	INNER	OUTER	INNER	OUTER	INNER	OUTER	INNER	OUTER	INNER	OUTER
1	-0.6995D-02	-0.7561D-02	0.5860D-01	0.1349D-01	0.6227D-02	0.9348D-02	0.5874D-01	0.1448D-01	0.8729D+02	0.7803D+02
2	-0.6472D-02	-0.7175D-02	0.5757D-01	0.1163D-01	0.2618D-02	0.3375D-02	0.5760D-01	0.1178D-01	0.8883D+02	0.8491D+02
3	-0.6172D-02	-0.7175D-02	0.5757D-01	0.1163D-01	-0.2618D-02	-0.3375D-02	0.5760D-01	0.1178D-01	-0.8883D+02	-0.8491D+02
4	-0.6995D-02	-0.7561D-02	0.5860D-01	0.1349D-01	-0.6227D-02	-0.9348D-02	0.5874D-01	0.1448D-01	-0.8729D+02	-0.7803D+02
5	-0.1397D-01	-0.1360D-01	0.2851D-01	0.2459D-01	-0.7614D-04	0.1263D-02	0.2851D-01	0.2460D-01	-0.8995D+02	0.8905D+02
6	-0.1339D-01	-0.1379D-01	0.2906D-01	0.2569D-01	0.1305D-03	0.4685D-04	0.2906D-01	0.2569D-01	0.8991D+02	0.8997D+02
7	-0.1339D-01	-0.1379D-01	0.2906D-01	0.2569D-01	-0.1305D-03	-0.4685D-04	0.2906D-01	0.2569D-01	-0.8991D+02	-0.8997D+02
8	-0.1397D-01	-0.1360D-01	0.2851D-01	0.2459D-01	0.7614D-04	0.1263D-02	0.2851D-01	0.2460D-01	0.8995D+02	-0.8905D+02
9	-0.1276D-01	-0.1315D-01	0.3129D-01	0.3804D-01	0.3292D-03	0.3787D-02	0.3129D-01	0.3811D-01	0.8979D+02	0.8788D+02
10	-0.1227D-01	-0.1357D-01	0.3015D-01	0.3740D-01	-0.2749D-03	0.1111D-02	0.3015D-01	0.3741D-01	-0.8981D+02	0.8938D+02
11	-0.1227D-01	-0.1357D-01	0.3015D-01	0.3740D-01	0.2749D-03	0.1111D-02	0.3015D-01	0.3741D-01	0.8981D+02	-0.8938D+02
12	-0.1276D-01	-0.1315D-01	0.3129D-01	0.3804D-01	-0.3292D-03	-0.3787D-02	0.3129D-01	0.3811D-01	-0.8979D+02	-0.8788D+02
13	-0.1204D-01	-0.1210D-01	0.2533D-01	0.3500D-01	0.3120D-02	-0.2592D-02	0.2541D-01	0.3504D-01	0.8739D+02	-0.8842D+02
14	-0.1032D-01	-0.1188D-01	0.2422D-01	0.3564D-01	0.8124D-03	-0.1199D-03	0.2422D-01	0.3564D-01	0.8933D+02	-0.8993D+02
15	-0.1032D-01	-0.1188D-01	0.2422D-01	0.3564D-01	-0.8124D-03	0.1199D-03	0.2422D-01	0.3564D-01	-0.8933D+02	0.8993D+02
16	-0.1204D-01	-0.1210D-01	0.2533D-01	0.3500D-01	-0.3120D-02	0.2592D-02	0.2541D-01	0.3504D-01	-0.8739D+02	0.8842D+02
17	-0.9523D-02	-0.1212D-01	0.1556D-01	0.3801D-01	-0.2579D-02	0.1267D-02	0.1562D-01	0.3802D-01	-0.8706D+02	0.8928D+02
18	-0.8699D-02	-0.1236D-01	0.1431D-01	0.3687D-01	-0.2135D-03	0.1026D-02	0.1481D-01	0.3688D-01	-0.8974D+02	0.8940D+02
19	-0.8699D-02	-0.1236D-01	0.1431D-01	0.3687D-01	0.2135D-03	0.1026D-02	0.1481D-01	0.3688D-01	0.8974D+02	-0.8940D+02
20	-0.9523D-02	-0.1212D-01	0.1556D-01	0.3801D-01	0.2579D-02	-0.1267D-02	0.1562D-01	0.3802D-01	0.8706D+02	-0.8928D+02
21	-0.1205D-01	-0.1758D-01	0.2878D-01	0.6247D-01	0.4224D-02	0.4614D-02	0.2888D-01	0.6254D-01	0.8705D+02	0.8835D+02
22	-0.8241D-02	-0.1451D-01	0.2961D-01	0.6031D-01	0.1799D-03	0.7939D-03	0.2962D-01	0.6031D-01	0.8986D+02	0.8970D+02
23	-0.8241D-02	-0.1451D-01	0.2961D-01	0.6031D-01	-0.1799D-03	-0.7939D-03	0.2962D-01	0.6031D-01	-0.8986D+02	-0.8970D+02
24	-0.1205D-01	-0.1758D-01	0.2878D-01	0.6247D-01	-0.4224D-02	-0.4614D-02	0.2888D-01	0.6254D-01	-0.8705D+02	-0.8835D+02
25	-0.1205D-01	-0.1758D-01	0.2878D-01	0.6247D-01	0.4224D-02	0.4614D-02	0.2888D-01	0.6254D-01	0.8705D+02	0.8835D+02
26	-0.8241D-02	-0.1451D-01	0.2961D-01	0.6031D-01	-0.1799D-03	-0.7939D-03	0.2962D-01	0.6031D-01	-0.8986D+02	-0.8970D+02
27	-0.8241D-02	-0.1451D-01	0.2961D-01	0.6031D-01	0.1799D-03	0.7939D-03	0.2962D-01	0.6031D-01	0.8986D+02	0.8970D+02
28	-0.1205D-01	-0.1758D-01	0.2878D-01	0.6247D-01	0.4224D-02	0.4614D-02	0.2888D-01	0.6254D-01	0.8705D+02	0.8835D+02
29	-0.9523D-02	-0.1212D-01	0.1556D-01	0.3801D-01	0.2579D-02	-0.1267D-02	0.1562D-01	0.3802D-01	0.8706D+02	-0.8928D+02
30	-0.8699D-02	-0.1236D-01	0.1431D-01	0.3687D-01	-0.2135D-03	-0.1026D-02	0.1481D-01	0.3688D-01	-0.8974D+02	-0.8940D+02
31	-0.8699D-02	-0.1236D-01	0.1431D-01	0.3687D-01	0.2135D-03	0.1026D-02	0.1481D-01	0.3688D-01	0.8974D+02	0.8940D+02
32	-0.9523D-02	-0.1212D-01	0.1556D-01	0.3801D-01	-0.2579D-02	0.1267D-02	0.1562D-01	0.3802D-01	-0.8706D+02	0.8928D+02
33	-0.1204D-01	-0.1210D-01	0.2533D-01	0.3500D-01	-0.3120D-02	0.2592D-02	0.2541D-01	0.3504D-01	-0.8739D+02	0.8842D+02
34	-0.1032D-01	-0.1188D-01	0.2422D-01	0.3564D-01	0.8124D-03	0.1199D-03	0.2422D-01	0.3564D-01	-0.8933D+02	0.8993D+02
35	-0.1032D-01	-0.1188D-01	0.2422D-01	0.3564D-01	-0.8124D-03	-0.1199D-03	0.2422D-01	0.3564D-01	0.8933D+02	-0.8993D+02
36	-0.1204D-01	-0.1210D-01	0.2533D-01	0.3500D-01	0.3120D-02	-0.2592D-02	0.2541D-01	0.3504D-01	0.8739D+02	-0.8842D+02
37	-0.1276D-01	-0.1315D-01	0.3129D-01	0.3804D-01	-0.3292D-03	0.3787D-02	0.3129D-01	0.3811D-01	-0.8979D+02	-0.8788D+02
38	-0.1227D-01	-0.1357D-01	0.3015D-01	0.3740D-01	0.2749D-03	-0.1111D-02	0.3015D-01	0.3741D-01	0.8981D+02	-0.8938D+02
39	-0.1227D-01	-0.1357D-01	0.3015D-01	0.3740D-01	-0.2749D-03	0.1111D-02	0.3015D-01	0.3741D-01	-0.8981D+02	0.8938D+02

40	-0.1276D-01	-0.1315D-01	0.3129D-01	0.3804D-01	0.3129D-03	0.7787D-02	0.3129D-01	0.3811D-01	0.8979D+02	0.8788D+02
41	-0.1347D-01	-0.1360D-01	0.2851D-01	0.2459D-01	0.7014D-04	-0.1263D-02	0.2851D-01	0.2460D-01	0.8995D+02	-0.8905D+02
42	-0.1339D-01	-0.1379D-01	0.2906D-01	0.2569D-01	-0.1305D-03	-0.4685D-04	0.2906D-01	0.2569D-01	-0.8991D+02	-0.8997D+02
43	-0.1339D-01	-0.1379D-01	0.2906D-01	0.2569D-01	0.1305D-03	0.4685D-04	0.2906D-01	0.2569D-01	0.8991D+02	0.8997D+02
44	-0.1397D-01	-0.1360D-01	0.2051D-01	0.2459D-01	-0.7614D-04	0.1263D-02	0.2851D-01	0.2460D-01	-0.8995D+02	0.8905D+02
45	-0.6995D-02	-0.7501D-02	0.5860D-01	0.1349D-01	-0.6227D-02	-0.9348D-02	0.5874D-01	0.1448D-01	-0.8729D+02	-0.7803D+02
46	-0.6472D-02	-0.7175D-02	0.5757D-01	0.1163D-01	-0.2618D-02	-0.3375D-02	0.5760D-01	0.1178D-01	-0.8883D+02	-0.8491D+02
47	-0.6472D-02	-0.7175D-02	0.5757D-01	0.1163D-01	0.2618D-02	0.3375D-02	0.5760D-01	0.1178D-01	0.8883D+02	0.8491D+02
48	-0.6995D-02	-0.7501D-02	0.5860D-01	0.1349D-01	0.6227D-02	0.9348D-02	0.5874D-01	0.1448D-01	0.8729D+02	0.7803D+02

STRAIN COMPONENTS, PRINCIPAL (TENSILE) STRAIN AND DIRECTION AT USER-SPECIFIED NODES

NODE	EPS-X STRAIN		EPS-Y STRAIN		SHEAR STRAIN		PRINC. STRAIN(T)		DIRECTION(DEG.)	
	INNER	OUTER	INNER	OUTER	INNER	OUTER	INNER	OUTER	INNER	OUTER
33	-0.9395D-02	-0.1391D-01	0.5916D-01	0.3022D-01	-0.3371D-11	0.2223D-11	0.5916D-01	0.3022D-01	-0.9000D+02	0.9000D+02
35	-0.2203D-01	-0.1719D-01	0.6145D-01	0.2749D-01	0.4495D-10	-0.4265D-10	0.6445D-01	0.2749D-01	0.9000D+02	-0.9000D+02
38	-0.8546D-02	-0.1387D-01	0.2047D-01	0.5777D-01	0.8271D-12	-0.1130D-11	0.2047D-01	0.5777D-01	0.9000D+02	-0.9000D+02
40	-0.6847D-02	-0.1322D-01	0.2737D-01	0.6400D-01	-0.1775D-01	0.1525D-01	0.2954D-01	0.6475D-01	-0.7629D+02	0.8441D+02
48	-0.1088D-01	-0.1375D-01	0.5216D-01	0.6758D-01	-0.1291D-11	0.3782D-11	0.5216D-01	0.6758D-01	-0.9000D+02	0.9000D+02
50	-0.1228D-01	-0.1342D-01	0.5311D-01	0.7671D-01	-0.1536D-01	0.1145D-01	0.5430D-01	0.7707D-01	-0.8342D+02	0.8638D+02

STRAIN COMPONENTS, PRINCIPAL(TENSILE) STRAIN AND DIRECTION, AND ELONGATIONS AT SPECIFIED ADDITIONAL POINTS

POINT NO.	SURFACE	EPS-X STRAIN	EPS-Y STRAIN	SHEAR STRAIN	ELONG.(DIR.1)	ELONG.(DIR.2)	PRINC. STRN(T)	DIRECTION(DEG.)
1	INNER	0.60618D-26	0.43823D-01	0.22021D-12	0.0	0.42903D-01	0.43823D-01	0.9000D+02
1	OUTER	0.60618D-26	-0.84898D-01	0.22021D-12	0.0	-0.88844D-01	0.0	0.0
2	INNER	-0.34469D-02	0.44627D-01	0.28111D-04	-0.30529D-02	0.43673D-01	0.44627D-01	0.89983D+02
2	OUTER	-0.35987D-02	-0.41383D-01	0.28111D-04	-0.30529D-02	-0.42276D-01	0.0	0.0
3	INNER	-0.13241D-01	0.26606D-01	0.28584D-03	-0.11330D-01	0.26262D-01	0.26607D-01	0.89795D+02
3	OUTER	-0.13990D-01	0.26765D-01	0.28584D-03	-0.11090D-01	0.26416D-01	0.26765D-01	0.89799D+02
4	INNER	-0.12756D-01	0.27426D-01	0.11090D-02	-0.12839D-01	0.27060D-01	0.27434D-01	0.89210D+02
4	OUTER	-0.13520D-01	0.51728D-01	0.11090D-02	-0.13613D-01	0.50455D-01	0.51733D-01	0.89513D+02
5	INNER	-0.10031D-01	0.19200D-01	0.16585D-02	-0.10082D-01	0.19019D-01	0.19223D-01	0.88376D+02
5	OUTER	-0.12889D-01	0.48125D-01	0.16585D-02	-0.12973D-01	0.47020D-01	0.48137D-01	0.89221D+02
6	INNER	-0.93955D-02	0.59164D-01	0.18701D-10	-0.94400D-02	0.57511D-01	0.59164D-01	0.9000D+02
6	OUTER	-0.13908D-01	0.30221D-01	0.24294D-10	-0.11006D-01	0.29778D-01	0.30221D-01	0.9000D+02
7	INNER	-0.10031D-01	0.19200D-01	-0.16585D-02	-0.10082D-01	0.19019D-01	0.19223D-01	-0.88376D+02
7	OUTER	-0.12889D-01	0.48125D-01	-0.16585D-02	-0.12973D-01	0.47020D-01	0.48137D-01	-0.89221D+02
8	INNER	-0.12756D-01	0.27426D-01	-0.11090D-02	-0.12839D-01	0.27060D-01	0.27434D-01	-0.89210D+02
8	OUTER	-0.13520D-01	0.51728D-01	-0.11090D-02	-0.13613D-01	0.50455D-01	0.51733D-01	-0.89513D+02
9	INNER	-0.13241D-01	0.26606D-01	-0.28584D-03	-0.11330D-01	0.26262D-01	0.26607D-01	-0.89795D+02
9	OUTER	-0.13990D-01	0.26765D-01	-0.28584D-03	-0.11090D-01	0.26416D-01	0.26765D-01	-0.89799D+02
10	INNER	-0.34469D-02	0.44627D-01	-0.28111D-04	-0.30529D-02	0.43673D-01	0.44627D-01	-0.89983D+02
10	OUTER	-0.35987D-02	-0.41383D-01	-0.28111D-04	-0.30529D-02	-0.42276D-01	0.0	0.0
11	INNER	0.59735D-18	0.43823D-01	0.22324D-12	0.0	0.42903D-01	0.43823D-01	0.9000D+02
11	OUTER	-0.59735D-18	-0.84898D-01	0.22324D-12	0.0	-0.88844D-01	0.0	0.0

SYSTEM ENERGIES(IN-LB)

WORK INPUT TO STRUCTURE = 0.3848832D+04
 STRUCTURE KINETIC ENERGY = 0.1135526D+03
 STRUCTURE ELASTIC ENERGY = 0.4064170D+02
 STRUCTURE PLASTIC ENERGY = 0.3694637D+04
 ENERGY STORED IN ELASTIC RESTRAINTS= 0.0

SECTION 8

CIVM-PLATE 1 CODE EXAMPLE:

FRAGMENT-IMPACTED NARROW RECTANGULAR PLATE

To illustrate the use of the CIVM-PLATE 1 computer program, a narrow rectangular plate with both ends ideally clamped and its two sides restrained by only z-direction line elastic springs is analyzed.* The plate is subjected only to impact by a single non-deformable spherical "fragment". Two alternate finite-element modelings of the plate are described, and the associated input data for each are shown. However, for conciseness, solution output data are given for only one of these modelings; these results can be employed by the user to check the adaptation of CIVM-PLATE 1 to his particular computing facilities.

8.1 Problem Description

A narrow rectangular uniform-thickness aluminum plate (0.200 x 1.60 x 6.80 in) with an aluminum stiffener of 0.1 by 0.2 in cross section "integrally attached", located at the plate's midwidth upper-surface station, and extending for the full 6.80-in span -- as depicted in Fig. 18 -- is the example structure. Its two ends are ideally clamped. Along its other two sides there are only z-direction line springs of $k_z = 3,000 \text{ lb}/(\text{in-in of span})$; hence, $k_x = k_y = k_\theta = k_\psi = 0$.

This plate is impacted by a solid (non-deformable) steel sphere of 1-inch diameter; the initial point of impact is near the midwidth-midspan station of the plate. The pre-impact line of flight of the sphere is in the y,z "symmetry" plane and is approaching along a line at 60° from the y (spanwise) axis as shown in Fig. 18. Prior to impact the sphere is assumed to have a translational velocity of 2794 in/sec and to be rotating about the x axis with $\omega_{fx} = 1650 \text{ rad/sec}$; hence, initially $\omega_{fy} = \omega_{fz} = 0$. Also, it is assumed that a fixed value of the coefficient of friction $\mu = 0.20$ applies

* Additional examples and transient response predictions obtained by using the CIVM-PLATE 1 program are described in Subsection 7.6 of Ref. 14 as the "small strain" calculations.

during impact-interaction between the fragment and the plate. Fragment-plate impact is assumed to be perfectly-elastic; hence, $e = 1$ is used for the coefficient of restitution. Hence, the pertinent fragment data are:

$$\begin{array}{ll}
 V_{fx} = 0 & \omega_{fx} = 1650 \text{ rad/sec} \\
 V_{fy} = 1397.0 \text{ in/sec} & \omega_{fy} = 0 \\
 V_{fz} = 2419.675 \text{ in/sec} & \omega_{fz} = 0 \\
 m_f = 0.3815 \times 10^{-3} \frac{\text{lb-sec}^2}{\text{in}} & I_f = 0.3816 \times 10^{-4} \text{ in-lb-sec}^2
 \end{array}$$

Also, during an impact, the value of the impact-affected "circle radius" L_{eff} is assumed to be $L_{\text{eff}} = 0.42$ inch which is slightly greater than twice the thickness ($h = 0.20$ in) of the uniform plate.

Both the plate and the stiffener are assumed to consist of the same type of aluminum. Its mass per unit volume is assumed to be 0.25384×10^{-3} (lb-sec²)/in⁴. The uniaxial stress-strain (σ, ϵ) properties of this material are represented by a 3-sublayer version of the mechanical-sublayer material model, defined by $\sigma_1, \epsilon_1 = 44,200$ psi, 0.00442 in/in; $\sigma_2, \epsilon_2 = 49,200$ psi, 0.0760; and $\sigma_3, \epsilon_3 = 76,400$ psi, 0.615. For this example, the material is assumed to be insensitive to strain rate; hence, it is specified that $D = \nu = 0$. The material's elastic modulus and Poisson ratio are assumed to be, respectively, 10×10^6 psi and 1/3.

8.2 Modeling and Input Data

For illustrative purposes, two different structural models of the stiffened-plate specimen depicted in Fig. 18 are described in the following. First, the entire plate is modeled by 56 LLC plate elements as shown in Fig. 19. Next, since this problem involves symmetry only about the y, z plane, a 28-element half-plate model with symmetry invoked along the plate's midwidth station is used. The two models otherwise employ the same basic finite-element layout. For each of these models, the selected numbering of elements and nodes is shown in Fig. 19.

Pilot calculations showed that the largest linear-system natural frequency of the full-plate structural model is $\omega_{\text{max}} = 0.1748 \times 10^7$ rad/sec.

Hence, if the timewise central-difference model were used to predict the linear transient response of this model, a Δt not exceeding $\Delta t = 2/\omega_{\max} = 1.14$ μsec would be required. However, since the CIVM-PLATE 1 program uses the Houbolt (and a modified Houbolt) operator, a reasonable choice is $\Delta t = 2.0$ μsec , as discussed in Subsection 5.5.2.

Solution output data will be requested at the end of every 10 time steps or cycles; however, for conciseness, these data will be included here only at the end of time cycles (or time steps) 0, 1, 2, 3, 4, 140, and 150 (last).⁺ The desired solution output data are indicated as the following print options (Card 51 of Subsection 4.2):

- | | |
|------|---|
| IOP1 | Displacements and current (global) X,Y,Z coordinates of each node ⁺ . |
| IOP4 | Strain (Green) components, principal (tensile) strain and direction, and elongation (in user-specified directions) at <u>additional</u> spanwise locations (evaluated at both upper and lower surfaces at each spanwise location) as specified by the user. |
| IOP7 | System energies (i.e., work input to structure, structure kinetic energy, structure elastic energy, structure plastic energy, energy stored in elastic restoring springs, and fragment translational and rotational kinetic energies) |
| IOP8 | Strain (Green) components, principal (tensile) strain and direction at the upper and lower plate surfaces at user-specified <u>nodes</u> (by nodal averaging). |

Print options IOP2, IOP3, and IOP5 are not desired; hence, set these quantities equal to zero on Card 51 (of Subsection 4.2). Summarized concisely as follows are the affected element or node numbers for each of these two finite-element models (see Fig. 19):

⁺Automatically at each printout time, one obtains the global X,Y,Z location of the fragment as well as its translational and rotational velocity components.

Output Option	Full-Plate Model	Half-Plate Model
IOP1	All Nodes	All Nodes
IOP4	Elements 30,31,34,35	Elements 15 and 17
IOP7	Entire System	Entire System
IOP8	Nodes 38,39,43,44, 48,49,53,54	Nodes 22,23,25,26 28,29,31,32

The associated input data on each card are described for the full-plate and the half-plate model in Subsections 8.2.1 and 8.2.2, respectively. However, solution output data are presented in Subsection 8.3 only for the full-plate model.

8.2.1 Input Data for the Full-Plate Model

The values to be punched on the data cards are as follows (see Fig. 19a):

Card 1		8I10
MAXEL	= 56	
MNSL	= 3	
MNXST	= 1	
MNYST	= 28	
NBE	= 1	
MBWE	= 1	
MNC	= 16335	
NLAN	= 75	
Card 2		20I4
IMESH	= 0	
IMCONT	= 0	
IPUNCH	= 0	
Card 3		20I4
NEAD	= 4	
NECD	= 14	

Card 4a 5D16.7

EPAN = 0.1D8
ANUP = .3333333D0
DENSP = 0.25384D-3
TH = 0.200D0
XDIST = 1.600D0

Card 4b 5D16.7

YDIST = 6.8D0
ZPOS = 0.0D0

Card 5 5D16.7

XG(1) = 0.0D0
XG(2) = .400D0
XG(3) = .800D0
XG(4) = 1.200D0
XG(5) = 1.600D0

Card 6a 5D16.7

YG(1) = 0.0D0
YG(2) = 0.40D0
YG(3) = 0.80D0
YG(4) = 1.40D0
YG(5) = 2.0D0

Card 6b 5D16.7

YG(6) = 2.60D0
YG(7) = 3.0D0
YG(8) = 3.4D0
YG(9) = 3.8D0
YG(10) = 4.2D0

Card 6c 5D16.7

YG(11) = 4.80D0
YG(12) = 5.40D0
YG(13) = 6.0D0
YG(14) = 6.4D0
YG(15) = 6.8D0

Card 7		20I4
NCSB (1)	= 2	
NCSB (2)	= 0	
NCSB (3)	= 2	
NCSB (4)	= 0	
Card 8		20I4
NAST	= 0	
NCST	= 2	
Card 17*		5D16.7
APCST (1)	= 0.775D0	
APCST (2)	= 0.825D0	
Card 18		5D16.7
RHC (1)	= 0.2D0	
RHC (2)	= 0.2D0	
Card 19		5D16.7
RWC (1)	= 0.05D0	
RWC (2)	= 0.05D0	
Card 20		5D16.7
ECS (1)	= 0.1D8	
ECS (2)	= 0.1D8	
Card 21		5D16.7
ANUCS (1)	= 0.3333333D0	
ANUCS (2)	= 0.3333333D0	
Card 22		5D16.7
DENCS (1)	= 0.25384D-3	
DENCS (2)	= 0.25384D-3	
Card 23		5D16.7
XFCST (1)	= -0.2D0	
XFCST (2)	= -0.2D0	

* For omitted cards see page 308.

Card 24		20I4
	MATCS (1) = 1	
	MATCS (2) = 1	
Card 25		20I4
	NAXS = 0	
	NAYS = 0	
Card 44*		20I4
	NMAT = 1	
Card 45		20I4
	NSUB = 3	
Card 46		5D16.7
	SIG(1) = 44.2D3	
	SIG(2) = 49.2D3	
	SIG(3) = 76.4D3	
Card 47		5D16.7
	EPS (1) = .00442D0	
	EPS (2) = .0760D0	
	EPS (3) = 0.615D0	
Card 48		5D16.7
	DSR(1) = 0.0D0	
	PSR(1) = 0.0D0	
Card 49		20I4
	ITIMEF = 150	
	INCRT = 1	
	IOUT = 1	
Card 50		5D16.7
	DELTAT = 2.0D-06	
	TIMEF = 3.00D-04	

* For omitted cards see page 308.

Card 51			20I4
IOP1	=	1	
IOP2	=	0	
IOP3	=	0	
IOP4	=	1	
IOP5	=	0	
IOP6	=	0	
IOP7	=	1	
IOP8	=	1	
Card 54*			20I4
NASP	=	4	
Card 55a			I4,2D16.7
LNASP(1)	=	30	
SLASP(1)	=	0.5D0	
ELASP(1)	=	0.5D0	
Card 55b			I4,2D16.7
LNASP(2)	=	31	
SLASP(2)	=	0.5D0	
ELASP(2)	=	0.5D0	
Card 55c			I4,2D16.7
LNASP(3)	=	34	
SLASP(3)	=	0.5D0	
ELASP(3)	=	0.5D0	
Card 55d			I4,2D16.7
LNASP(4)	=	35	
SLASP(4)	=	0.5D0	
ELASP(4)	=	0.5D0	
Card 56			20I4
NASPE	=	2	

* For omitted cards see page 308.

Card 57a		I4,2D16.7
NSP	= 1	
DIR1	= 45.0D0	
DIR2	= 135.0D0	
Card 57b		I4,2D16.7
NSP	= 2	
DIR1	= 45.0D0	
DIR2	= 135.0D0	
Card 61*		20I4
NNSA	= 8	
Card 62		20I4
NVSA(1)	= 33	
NVSA(2)	= 35	
NVSA(3)	= 38	
NVSA(4)	= 40	
NVSA(5)	= 48	
NVSA(6)	= 50	
Card 63		20I4
NELES	= 28	
Card 64a		20I4
LNUM	= 4	
ISIDE	= 2	
Card 65a		5D16.7
SS(1)	= 0.0D0	
SS(2)	= 0.0D0	
SS(3)	= 0.3000D+04	
SS(4)	= 0.0D0	
SS(5)	= 0.0D0	
Card 64b		20I4
LNUM	= 8	
ISIDE	= 2	

* For omitted cards see page 308.

Card 65b			5D16.7
SS(1)	=	0.0D0	
SS(2)	=	0.0D0	
SS(3)	=	0.3000D+04	
SS(4)	=	0.0D0	
SS(5)	=	0.0D0	
Card 64c			20I4
LNUM	=	12	
ISIDE	=	2	
Card 65c			5D16.7
SS(1)	=	0.0D0	
SS(2)	=	0.0D0	
SS(3)	=	0.3000D+04	
SS(4)	=	0.0D0	
SS(5)	=	0.0D0	
Card 64d			20I4
LNUM	=	16	
ISIDE	=	2	
Card 65d			5D16.7
SS(1)	=	0.0D0	
SS(2)	=	0.0D0	
SS(3)	=	0.3000D+04	
SS(4)	=	0.0D0	
SS(5)	=	0.0D0	
Card 64e			20I4
LNUM	=	20	
ISIDE	=	2	
Card 65e			5D16.7
SS(1)	=	0.0D0	
SS(2)	=	0.0D0	
SS(3)	=	0.3000D+04	
SS(4)	=	0.0D0	
SS(5)	=	0.0D0	

Card 64f 20I4

LNUM = 24

ISIDE = 2

Card 65f 5D16.7

SS(1) = 0.0D0

SS(2) = 0.0D0

SS(3) = 0.3000D+04

SS(4) = 0.0D0

SS(5) = 0.0D0

Card 64g 20I4

LNUM = 28

ISIDE = 2

Card 65g 5D16.7

SS(1) = 0.0D0

SS(2) = 0.0D0

SS(3) = 0.3000D+04

SS(4) = 0.0D0

SS(5) = 0.0D0

Card 64h 20I4

LNUM = 32

ISIDE = 2

Card 65h 5D16.7

SS(1) = 0.0D0

SS(2) = 0.0D0

SS(3) = 0.3000D+04

SS(4) = 0.0D0

SS(5) = 0.0D0

Card 64i 20I4

LNUM = 36

ISIDE = 2

Card 65i			5D16.7
SS (1)	=	0.0D0	
SS (2)	=	0.0D0	
SS (3)	=	0.3000D+04	
SS (4)	=	0.0D0	
SS (5)	=	0.0D0	
Card 64j			20I4
LNUM	=	40	
ISIDE	=	2	
Card 65j			5D16.7
SS (1)	=	0.0D0	
SS (2)	=	0.0D0	
SS (3)	=	0.3000D+04	
SS (4)	=	0.0D0	
SS (5)	=	0.0D0	
Card 64k			20I4
LNUM	=	44	
ISIDE	=	2	
Card 65k			5D16.7
SS (1)	=	0.0D0	
SS (2)	=	0.0D0	
SS (3)	=	0.3000D+04	
SS (4)	=	0.0D0	
SS (5)	=	0.0D0	
Card 64l			20I4
LNUM	=	48	
ISIDE	=	2	
Card 65l			5D16.7
SS (1)	=	0.0D0	
SS (2)	=	0.0D0	
SS (3)	=	0.3000D+04	
SS (4)	=	0.0D0	
SS (5)	=	0.0D0	

Card 64m			20I4
LNUM	=	52	
ISIDE	=	2	
Card 65m			5D16.7
SS(1)	=	0.0D0	
SS(2)	=	0.0D0	
SS(3)	=	0.3000D+04	
SS(4)	=	0.0D0	
SS(5)	=	0.0D0	
Card 64n			20I4
LNUM	=	56	
ISIDE	=	2	
Card 65n			5D16.7
SS(1)	=	0.0D0	
SS(2)	=	0.0D0	
SS(3)	=	0.3000D+04	
SS(4)	=	0.0D0	
SS(5)	=	0.0D0	
Card 64o			20I4
LNUM	=	1	
ISIDE	=	4	
Card 65o			5D16.7
SS(1)	=	0.0D0	
SS(2)	=	0.0D0	
SS(3)	=	0.3000D+04	
SS(4)	=	0.0D0	
SS(5)	=	0.0D0	
Card 64p			20I4
LNUM	=	5	
ISIDE	=	4	

Card 65p			5D16.7
SS(1)	=	0.0D0	
SS(2)	=	0.0D0	
SS(3)	=	0.3000D+04	
SS(4)	=	0.0D0	
SS(5)	=	0.0D0	
Card 64q			20I4
LNUM	=	9	
ISIDE	=	4	
Card 65q			5D16.7
SS(1)	=	0.0D0	
SS(2)	=	0.0D0	
SS(3)	=	0.3000D+04	
SS(4)	=	0.0D0	
SS(5)	=	0.0D0	
Card 64r			20I4
LNUM	=	13	
ISIDE	=	4	
Card 65r			5D16.7
SS(1)	=	0.0D0	
SS(2)	=	0.0D0	
SS(3)	=	0.3000D+04	
SS(4)	=	0.0D0	
SS(5)	=	0.0D0	
Card 64s			20I4
LNUM	=	17	
ISIDE	=	4	
Card 65s			5D16.7
SS(1)	=	0.0D0	
SS(2)	=	0.0D0	
SS(3)	=	0.3000D+04	
SS(4)	=	0.0D0	
SS(5)	=	0.0D0	

Card 64t			20I4
LNUM	= 21		
ISIDE	= 4		
Card 65t			5D16.7
SS (1)	= 0.0D0		
SS (2)	= 0.0D0		
SS (3)	= 0.3000D+04		
SS (4)	= 0.0D0		
SS (5)	= 0.0D0		
Card 64u			20I4
LNUM	= 25		
ISIDE	= 4		
Card 65u			5D16.7
SS (1)	= 0.0D0		
SS (2)	= 0.0D0		
SS (3)	= 0.3000D+04		
SS (4)	= 0.0D0		
SS (5)	= 0.0D0		
Card 64v			20I4
LNUM	= 29		
ISIDE	= 4		
Card 65v			5D16.7
SS (1)	= 0.0D0		
SS (2)	= 0.0D0		
SS (3)	= 0.3000D+04		
SS (4)	= 0.0D0		
SS (5)	= 0.0D0		
Card 64w			20I4
LNUM	= 33		
ISIDE	= 4		

Card 65w		5D16.7
SS (1)	= 0.0D0	
SS (2)	= 0.0D0	
SS (3)	= 0.3000D+4	
SS (4)	= 0.0D0	
SS (5)	= 0.0D0	
Card 64x		20I4
LNUM	= 37	
ISIDE	= 4	
Card 65x		5D16.7
SS (1)	= 0.0D0	
SS (2)	= 0.0D0	
SS (3)	= 0.3000D+4	
SS (4)	= 0.0D0	
SS (5)	= 0.0D0	
Card 64y		20I4
LNUM	= 41	
ISIDE	= 4	
Card 65y		5D16.7
SS (1)	= 0.0D0	
SS (2)	= 0.0D0	
SS (3)	= 0.3000D+4	
SS (4)	= 0.0D0	
SS (5)	= 0.0D0	
Card 64z		20I4
LNUM	= 45	
ISIDE	= 4	
Card 65z		5D16.7
SS (1)	= 0.0D0	
SS (2)	= 0.0D0	
SS (3)	= 0.3000D+4	
SS (4)	= 0.0D0	
SS (5)	= 0.0D0	

Card 64aa		2014
LNUM	= 49	
ISIDE	= 4	
Card 65aa		5D16.7
SS (1)	= 0.0D0	
SS (2)	= 0.0D0	
SS (3)	= 0.3000D+4	
SS (4)	= 0.0D0	
SS (5)	= 0.0D0	
Card 64bb		2014
LNUM	= 53	
ISIDE	= 4	
Card 65bb		5D16.7
SS (1)	= 0.0D0	
SS (2)	= 0.0D0	
SS (3)	= 0.3000D+4	
SS (4)	= 0.0D0	
SS (5)	= 0.0D0	
Card 66		5D16.7
XF	= 0.8D0	
YF	= 3.394412D+00	
ZF	= -0.6098787D+0	
Card 67		5D16.7
VF (1)	= 0.0D0	
VF (2)	= 1397.0D+00	
VF (3)	= 2419.675D+00	
Card 68		5D16.7
OMEGF (1)	= 1650.0D0	
OMEGF (2)	= 0.0D0	
OMEGF (3)	= 0.0D0	

Card 69		5D16.7
RF	= 0.5D0	
FMASS	= 0.38153D-03	
FMOI	= 0.38160D-04	
Card 70		5D16.7
COEFR	= 1.0D0	
FRNC	= 0.2D0	
Card 71		20I4
NSYM	= 0	
IPSS	= 0	
ICUT	= 0	
IUSEF	= 1	
Card 73*		5D16.7
EFFL	= 0.42D0	

Cards 9 through 16 are omitted because NAST on Card 8 is zero (that is, there are no complete X-direction stiffeners).

Cards 26 through 34 are omitted because NAXS on Card 25 is zero (that is, there are no additional X-direction stiffeners).

Cards 35 through 43 are omitted because NAYS on Card 25 is zero (that is, there are no additional Y-direction stiffeners).

Cards 52 and 53 are omitted because IOP3 on Card 51 is zero.

Cards 58 through 60 are omitted because IOP6 on Card 51 is zero.

Card 72 is omitted because ICUT on Card 71 is zero.

The following is the computer input deck for this example:

* For omitted cards see page 308.

} } } } } } } } } } } } } } }

	56	3	1	28	1	1	16335	75
0	0	0						
4	14							
		0.108	.333333300	.253840-3		.20000		1.60000
		6.800	0 000					
		0.000	.4000000	.80000		1.200		1.600
		0 000	0.400	0.800		1.400		2.000
		2.600	3.000	3.400		3.800		4.200
		4.800	5 400	6.000		6.400		6.800
2	0	2 0						
0	2							
		.77500	.82500					
		200	.200					
		.0500	.0500					
		0.108	0.108					
0.3333333		000.33333333	00					
0.25384	D-3	0.25384	D-3					
		-0.200	-0.200					
1	1							
0	0							
1								
3								
		44 203	49 203	76.403				
		.0044200	.076000	0.61500				
		0.000	0.000					
150	1	1						
		2.00-06	3.00-04					
1	0	0 1	0 0	1 1				
4								
30		0.500	0.500					
31		0.500	0.500					
34		0.500	0.500					
35		0 500	0.500					
2								
1		45.000	135.000					
2		45 000	135.000					
8								
38	39	43 44	48 49	53 54				
28								
4	2							
		0.000	0.000	0.3000 D+04		0.000		0.000
8	2							
		0.000	0 000	0.3000 D+04		0.000		0.000
12	2							
		0.000	0.000	0.3000 D+04		0.000		0.000
16	2							
		0.000	0.000	0.3000 D+04		0.000		0.000
20	2							
		0.000	0.000	0.3000 D+04		0.000		0.000
24	2							
		0.000	0.000	0.3000 D+04		0.000		0.000

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28	2	0.000	0.000	0.3000 D+04	0.000	0.000
32	2	0.000	0.000	0.3000 D+04	0.000	0.000
36	2	0.000	0.000	0.3000 D+04	0.000	0.000
40	2	0.000	0.000	0.3000 D+04	0.000	0.000
44	2	0.000	0.000	0.3000 D+04	0.000	0.000
48	2	0.000	0.000	0.3000 D+04	0.000	0.000
52	2	0.000	0.000	0.3000 D+04	0.000	0.000
56	2	0.000	0.000	0.3000 D+04	0.000	0.000
1	4	0.000	0.000	0.3000 D+04	0.000	0.000
5	4	0.000	0.000	0.3000 D+04	0.000	0.000
9	4	0.000	0.000	0.3000 D+04	0.000	0.000
13	4	0.000	0.000	0.3000 D+04	0.000	0.000
17	4	0.000	0.000	0.3000 D+04	0.000	0.000
21	4	0.000	0.000	0.3000 D+04	0.000	0.000
25	4	0.000	0.000	0.3000 D+04	0.000	0.000
29	4	0.000	0.000	0.3000 D+04	0.000	0.000
33	4	0.000	0.000	0.3000 D+04	0.000	0.000
37	4	0.000	0.000	0.3000 D+04	0.000	0.000
41	4	0.000	0.000	0.3000 D+04	0.000	0.000
45	4	0.000	0.000	0.3000 D+04	0.000	0.000
49	4	0.000	0.000	0.3000 D+04	0.000	0.000
53	4	0.000	0.000	0.3000 D+04	0.000	0.000
		0.800	3.394412 D+00	-0.6098737 D+0		
		0.000	1397.0000	2419.675 D+00		
1650.0		D+00	0.000	0.000		
		0.500	0.381513 D-03	0.38160 D-04		
		1.000	0.200			
0	0	0.1				
		0.4200				

8.2.2 Input Data for the Half-Plate Model*

The values to be punched on the data cards are as follows (see Fig. 19b):

Card 1		8I10
MAXEL	= 28	
MNSL	= 3	
MNXST	= 1	
MNYST	= 14	
NBE	= 1	
MBWE	= 1	
MNC	= 6561	
NIAN	= 45	
Card 2		20I4
IMESH	= 0	
IMCONT	= 0	
IPUNCH	= 0	
Card 3		20I4
NEAD	= 2	
NECD	= 14	
Card 4a		5D16.7
EDAN	= 0.1D8	
ANUP	= .3333333D0	
DENSP	= 0.25384D-3	
TH	= 0.200D0	
XDIST	= 0.800D0	
Card 4b		5D16.7
YDIST	= 6.8D0	
ZPOS	= 0.0D0	
Card 5		5D16.7
XG(1)	= 0.0D0	
XG(2)	= .40000D0	
XG(3)	= .800D0	

* Certain input cards are omitted; see page 308.

Card 6a			5D16.7
YG(1)	=	0.0D0	
YG(2)	=	0.4D0	
YG(3)	=	0.8D0	
YG(4)	=	1.4D0	
YG(5)	=	2.0D0	
Card 6b			5D16.7
YG(6)	=	2.6D0	
YG(7)	=	3.0D0	
YG(8)	=	3.4D0	
YG(9)	=	3.8D0	
YG(10)	=	4.2D0	
Card 6c			5D16.7
YG(11)	=	4.8D0	
YG(12)	=	5.4D0	
YG(13)	=	6.0D0	
YG(14)	=	6.4D0	
YG(15)	=	6.8D0	
Card 7			20I4
NCSB(1)	=	2	
NCSB(2)	=	0	
NCSB(3)	=	2	
NCSB(4)	=	1	
Card 8			20I4
NAST	=	0	
NCST	=	1	
Card 17			5D16.7
APCST(1)	=	0.025D0	
Card 18			5D16.7
RHC(1)	=	0.2D0	
Card 19			5D16.7
RWC(1)	=	0.05D0	

Card 20		5D16.7
ECS(1)	= 0.1D8	
Card 21		5D16.7
ANUCS(1)	= 0.3333333D0	
Card 22		5D16.7
DENCs(1)	= 0.25384D-3	
Card 23		5D16.7
XFCST(1)	= -0.2D0	
Card 24		20I4
MATCS(1)	= 1	
Card 25		20I4
NAXS	= 0	
NAYS	= 0	
Card 44		20I4
NMAT	= 1	
Card 45		20I4
NSUB	= 3	
Card 46		5D16.7
SIG(1)	= 44.2D3	
SIG(2)	= 49.2D3	
SIG(3)	= 76.4D3	
Card 47		5D16.7
EPS(1)	= .00442D0	
EPS(2)	= .0760D0	
EPS(3)	= 0.615D0	
Card 48		5D16.7
DSR(1)	= 0.0D0	
PSR(1)	= 0.0D0	
		20I4

Card 49			20I4
	ITIMEF	= 150	
	INCRT	= 1	
	IOUT	= 1	
Card 50			5D16.7
	DELTAT	= 2.0D-06	
	TIMEF	= 3.0D-04	
Card 51			20I4
	IOP1	= 1	
	IOP2	= 0	
	IOP3	= 0	
	IOP4	= 1	
	IOP5	= 0	
	IOP6	= 0	
	IOP7	= 1	
	IOP8	= 1	
Card 54			20I4
	NASP	= 2	
Card 55a			I4,2D16.7
	LNASP(1)	= 15	
	SLASP(1)	= 0.5D0	
	ELASP(1)	= 0.5D0	
Card 55b			I4,2D16.7
	LNASP(2)	= 17	
	SLASP(2)	= 0.5D0	
	ELASP(2)	= 0.5D0	
Card 56			20I4
	NASPE	= 1	
Card 57			I4,2D16.7
	NSP	= 1	
	DIR1	= 45.0D0	
	DIR2	= 135.0D0	

Card 61 20I4
NNSA = 8

Card 62 20I4
NVSA(1) = 22
NVSA(2) = 23
NVSA(3) = 25
NVSA(4) = 26
NVSA(5) = 28
NVSA(6) = 29
NVSA(7) = 31
NVSA(8) = 32

Card 63 20I4
NELES = 14

Card 64a 20I4
LNUM = 2
ISIDE = 2

Card 65a 5D16.7
SS(1) = 0.0D0
SS(2) = 0.0D0
SS(3) = 0.3000D+04
SS(4) = 0.0D0
SS(5) = 0.0D0

Card 64b 20I4
LNUM = 4
ISIDE = 2

Card 65b 5D16.7
SS(1) = 0.0D0
SS(2) = 0.0D0
SS(3) = 0.3000D+04
SS(4) = 0.0D0
SS(5) = 0.0D0

Card 64c			20I4
	LNUM	= 6	
	ISIDE	= 2	
Card 65c			5D16.7
	SS(1)	= 0.0D0	
	SS(2)	= 0.0D0	
	SS(3)	= 0.3000D+04	
	SS(4)	= 0.0D0	
	SS(5)	= 0.0D0	
Card 64d			20I4
	LNUM	= 8	
	ISIDE	= 2	
Card 65d			5D16.7
	SS(1)	= 0.0D0	
	SS(2)	= 0.0D0	
	SS(3)	= 0.3000D+04	
	SS(4)	= 0.0D0	
	SS(5)	= 0.0D0	
Card 64e			20I4
	LNUM	= 10	
	ISIDE	= 2	
Card 65e			5D16.7
	SS(1)	= 0.0D0	
	SS(2)	= 0.0D0	
	SS(3)	= 0.3000D+04	
	SS(4)	= 0.0D0	
	SS(5)	= 0.0D0	
Card 64f			20I4
	LNUM	= 12	
	ISIDE	= 2	

Card 65f 5D16.7

SS (1) = 0.0D0
SS (2) = 0.0D0
SS (3) = 0.3000D+04
SS (4) = 0.0D0
SS (5) = 0.0D0

Card 64g 20I4

LNUM = 14
ISIDE = 2

Card 65g 5D16.7

SS (1) = 0.0D0
SS (2) = 0.0D0
SS (3) = 0.3000D+04
SS (4) = 0.0D0
SS (5) = 0.0D0

Card 64h 20I4

LNUM = 16
ISIDE = 2

Card 65h 5D16.7

SS (1) = 0.0D0
SS (2) = 0.0D0
SS (3) = 0.3000D+04
SS (4) = 0.0D0
SS (5) = 0.0D0

Card 64i 20I4

LNUM = 18
ISIDE = 2

Card 65i 5D16.7

SS (1) = 0.0D0
SS (2) = 0.0D0
SS (3) = 0.3000D+04
SS (4) = 0.0D0
SS (5) = 0.0D0

Card 64j			20I4
	LNUM	= 20	
	ISIDE	= 2	
Card 65j			5D16.7
	SS(1)	= 0.0D0	
	SS(2)	= 0.0D0	
	SS(3)	= 0.3000D+04	
	SS(4)	= 0.0D0	
	SS(5)	= 0.0D0	
Card 64k			20I4
	LNUM	= 22	
	ISIDE	= 2	
Card 65k			5D16.7
	SS(1)	= 0.0D0	
	SS(2)	= 0.0D0	
	SS(3)	= 0.3000D+04	
	SS(4)	= 0.0D0	
	SS(5)	= 0.0D0	
Card 64l			20I4
	LNUM	= 24	
	ISIDE	= 2	
Card 65l			5D16.7
	SS(1)	= 0.0D0	
	SS(2)	= 0.0D0	
	SS(3)	= 0.3000D+04	
	SS(4)	= 0.0D0	
	SS(5)	= 0.0D0	
Card 64m			20I4
	LNUM	= 26	
	ISIDE	= 2	

Card 65m		5D16.7
SS (1)	= 0.0D0	
SS (2)	= 0.0D0	
SS (3)	= 0.3000D+04	
SS (4)	= 0.0D0	
SS (5)	= 0.0D0	
Card 64n		20I4
LNUM	= 28	
ISIDE	= 2	
Card 65n		5D16.7
SS (1)	= 0.0D0	
SS (2)	= 0.0D0	
SS (3)	= 0.3000D+04	
SS (4)	= 0.0D0	
SS (5)	= 0.0D0	
Card 66		5D16.7
XF	= 0.8D0	
YF	= 3.399412D+00	
ZF	= -0.6098787D+0	
Card 67		5D16.7
VF (1)	= 0.0D0	
VF (2)	= 1397.0D+00	
VF (3)	= 2419.675D+00	
Card 68		5D16.7
OMEGF (1)	= 1650.0D0	
OMEGF (2)	= 0.0D0	
OMEGF (3)	= 0.0D0	
Card 69		5D16.7
RF	= 0.5D0	
FMASS	= 0.38153D-03	
FMOI	= 0.38160D-04	

Card 70			5D16.7
COEFR	=	1.0D0	
FRNC	=	0.2D0	
Card 71			20I4
NSYM	=	0	
IPSS	=	0	
ICUT	=	0	
IUSEF	=	1	
Card 73			5D16.7
EFFL	=	0.42D0	

The following is the complete input deck for this example:

```

      2E      3      1      14      1      1      6561      45
0  0  0
2 14
      0.108      .333333300      .253840-3      .20000      0.80000
      6.800      0 000
      0.000      .4000000      .80000
      0.000      0.400      0.800      1.400      2.000
      2.600      3 000      3.400      3.800      4.200
      4.800      5.400      6.000      6.400      6.800
2  0  2  1
0  1
      .02500
      .2000
      .0500
      0.108
0.3333333  00
0.25384  0-3
      -0.200
1
0  0
1
3
      44.203      49.203      76.403
      .0044200      .076000      0.61500
      0.000      0 000
150 1  1
      2.00-06      3.00-04
1  0  0  1  0  0  1  1
2
15      0.500      0.500
17      0 500      0.500
1
1      45.000      135.000
8
22 23 25 26 28 29 31 32
14
2  2
4  2      0.000      0.000      0.3000 D+04      0.000      0.000
6  2      0.000      0.000      0.3000 D+04      0.000      0.000
8  2      0.000      0.000      0.3000 D+04      0.000      0.000
10 2      0.000      0.000      0.3000 D+04      0.000      0.000
12 2      0 000      0 000      0.3000 D+04      0.000      0.000
14 2      0.000      0.000      0.3000 D+04      0.000      0.000
16 2      0.000      0.000      0.3000 D+04      0.000      0.000

```

18	2	0.000	0.000	0.3000 D+04	0.000	0.000
20	2	0.000	0.000	0.3000 D+04	0.000	0.000
22	2	0.000	0.000	0.3000 D+04	0.000	0.000
24	2	0.000	0.000	0.3000 D+04	0.000	0.000
26	2	0.000	0.000	0.3000 D+04	0.000	0.000
28	2	0.000	0.000	0.3000 D+04	0.000	0.000
		0.000	0.000	0.3000 D+04	0.000	0.000
		0.000	3.394412 D+00	-0.6098787 D+0		
		0.000	1397.00+00	2419.675 D+00		
1650.0		D+00	0.000	0.000		
		0.500	0.381513 D-03	0.38160 D-04		
		1.000	0.200			
1	4	0	1			
		0.4200				

The FORTRAN listing of the main program for the full CIVM plate example is given on pages 232-234. For the half-plate model, the associated main program is the same except for the following DIMENSION statement:

```

DIMENSION DELD(450),DIS(450),DISP(450),DISM1(450),DISM2(450),      IMAN0063
2FLN(450),FLVA(450),FLVM(450),FLVP(450),VEL(450),ICOL(450),      IMAN0064
3INUM(450),KROW(450),NDEX(450),STF(16335),AMASS(450),              IMAN0065
4NP(4,56),NODE(1344),TAUSS(56,12,9),TAUSE(56,12,9),TAUEE(56,12,9), IMAN0066
5EPSSI(9,56),EPSSO(9,56),EPEEI(9,56),EPEEO(9,56),EPSEI(9,56),    IMAN0067
6EPSEO(9,56),NBC(60),BC(60),RFM(1,1),ILAST(1),UCF1(1),UCF2(1),    IMAN0068
7XG(75),YG(75),ZG(75),XGI(75),YGI(75),TAGSS(1,12,3),LNXS(1),     IMAN0069
8XSPROP(7,1),MATXS(1),TSGEE(28,12,3),LNYS(28),YSPROP(7,28),MATYS(28) IMAN0070
9),LNRS(28),ISRS(28),SC(5,28),NVSA(8),NCON(4,8),PMASS(75),VN(3,75), IMAN0071
A VNB(3,75),SI(75),NEFF(75),ALPHA(75)                               IMAN0072

```

For the half-plate example, replace the original above DIMENSION statement with this DIMENSION statement:

```

DIMENSION DELD(270),DIS(270),DISP(270),DISM1(270),DISM2(270),      IMAN1064
2FLN(270),FLVA(270),FLVM(270),FLVP(270),VEL(270),ICOL(270)      IMAN1065
3,INUM(270),KROW(270),NDEX(270),STF(6561),AMASS(270),              IMAN1066
4NP(4,28),NODE(672),TAUSS(28,12,9),TAUSE(28,12,9),TAUEE(28,12,9), IMAN1067
5EPSSI(9,28),EPSSO(9,28),EPEEI(9,28),EPEEO(9,28),EPSEI(9,28),    IMAN1068
6EPSEO(9,28),NBC(81),BC(81),RFM(1,1),ILAST(1),UCF1(1),UCF2(1),    IMAN1069
7XG(45),YG(45),ZG(45),XGI(45),YGI(45),TAGSS(1,12,3),LNXS(1),     IMAN1070
8XSPROP(7,1),MATXS(1),TSGEE(14,12,3),LNYS(14),YSPROP(7,14),MATYS(14) IMAN1071
9),LNRS(14),ISRS(14),SC(5,14),NVSA(8),NCON(4,8),PMASS(45),VN(3,45), IMAN1072
A VNB(3,45),SI(45),NEFF(45),ALPHA(45)                               IMAN1073

```


8.3 Solution Output Data for the Full-Plate Model

The following is the output for 150 cycles (300 μ sec) for the fragment-impacted narrow plate specimen depicted in Fig. 18; the associated finite-element model is shown in Fig. 19.

The first segment of the output describes the initial geometry and material properties of the basic plate and the integrally attached stiffener. The element numbers and global node numbers of the finite-element model of the structure are shown. The boundary conditions employed and the associated constrained degrees of freedom are identified. Next, pertinent geometric and material properties for the stiffener are listed. Then, the properties for each sublayer of the mechanical-sublayer material model are given: (a) stress, (b) strain, (c) yield stress, and (d) sublayer weighting factor. Finally, the time-step size used and the intended calculation run time and periodic printout times are identified.

The next segment describes the output to be given at every printout cycle, the properties of all elastic restoring springs, all pre-impact fragment data, and the selected coefficient of restitution and friction coefficient for impact. This output consists of (a) the generalized displacements at and the global location of each node, (b) the global location of as well as the components of the translational and rotational velocities of the fragment, (c) strain components as well as principal (tensile) strain and direction at 8 specified nodes, (d) strain components, principal (tensile) strain and direction, and relative elongations at 4 specified additional stations, and (e) a tabulation of the various energies of the system. Also noted are the number of impacts which have occurred and the current effective impact location.

In the interest of conciseness, only a portion of the called-for output is shown. Included are: (1) all input-verification information and (2) scheduled output at the end of time cycles 0, 1, 2, 3, 140, and 150 (last)⁺. This output listing is intended for use in verifying the (successful) adaptation of the CIVM-PLATE 1 program to a user's computer facility.

⁺ An auxiliary computer run was made with printout every cycle to give the output shown at the end of cycles 1, 2, 3, and 4.

CIVM-PLATE 1 COMPUTER CODE (SMALL STRAIN THEORY) : USER INPUT FOR ARRAY DIMENSIONS

MAXEL = 56
MNSL = 3
MNXST = 1
MNYST = 28
NBE = 1
MEWE = 1
MNC = 16335
NIAN = 75

AUTO-GENERATED FINITE-ELEMENT MESH INFORMATION FOR STIFFENED OR UNSTIFFENED FLAT-PLATE PROBLEM

X-LENGTH(IN) = 0.1600000D+01
Y-LENGTH(IN) = 0.6800000D+01
Z-POSITION(IN) = 0.0
THICKNESS(IN) = 0.2000000D+00
YOUNGS MODULUS(PSI) = 0.1000000D+08
POISSONS RATIO = 0.3333333D+00
DENSITY(LB-SEC**2/IN**4) = 0.2538400D-03
NO. OF ELEM. IN X-DIRECTION = 4
NO OF ELEM IN Y-DIRECTION = 14
NO OF D O F /ELEM. = 24
TOTAL NO OF ELEMENTS = 56
TOTAL NO OF D.O F = 450
NO OF X-DIR STIFFENERS = 0
NO OF Y-DIR STIFFENERS = 28

THE GLOBAL NODE NUMBERS ASSOCIATED WITH EACH ELEMENT ARE AS FOLLOWS :

ELEMENT	GLOBAL NODE NUMBERS			
1	1	2	7	6
2	2	3	8	7
3	3	4	9	8
4	4	5	10	9
5	6	7	12	11
6	7	8	13	12
7	8	9	14	13
8	9	10	15	14
9	11	12	17	16
10	12	13	18	17
11	13	14	19	18
12	14	15	20	19
13	16	17	22	21
14	17	18	23	22
15	18	19	24	23
16	19	20	25	24
17	21	22	27	26
18	22	23	28	27
19	23	24	29	28
20	24	25	30	29
21	26	27	32	31
22	27	28	33	32
23	28	29	34	33
24	29	30	35	34
25	31	32	37	36
26	32	33	38	37
27	33	34	39	38
28	34	35	40	39
29	36	37	42	41
30	37	38	43	42
31	38	39	44	43
32	39	40	45	44
33	41	42	47	46

34	42	43	48	47
35	43	44	49	48
36	44	45	50	49
37	46	47	52	51
38	47	48	53	52
39	48	49	54	53
40	49	50	55	54
41	51	52	57	56
42	52	53	58	57
43	53	54	59	58
44	54	55	60	59
45	56	57	62	61
46	57	58	63	62
47	59	59	64	63
48	59	60	65	64
49	61	62	67	66
50	62	63	68	67
51	63	64	69	68
52	64	65	70	69
53	66	67	72	71
54	67	68	73	72
55	68	69	74	73
56	69	70	75	74

BOUNDARY CONDITIONS (SEE WRITEUP FOR CONVENTION FOR SIDE NUMBER AND BOUNDARY CONDITION)

SIDE NUMBER	BOUNDARY CONDITION
1	IDEALLY CLAMPED
2	FREE
3	IDEALLY CLAMPED
4	FREE

THE FOLLOWING 60 DEGREES OF FREEDOM ARE CONSTRAINED

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
21	22	23	24	25	26	27	28	29	30	421	422	423	424	425	426	427	428	429	430	
325	431	432	433	434	435	436	437	438	439	440	441	442	443	444	445	446	447	448	449	450

INFORMATION FOR Y-DIRECTION STIFFENERS

STIFF. NO.	ON ELEM.	MAT. NO.	THICKNESS	WIDTH	YOUNGS MOD.	POISSON RATIO	DENSITY	PSI-LOC.	OFFSET,ZF
1	2	1	0.20000D+00	0.50000D-01	0.10000D+08	0.33333D+00	0.25384D-03	0.93750D+00	-0.20000D+00
2	6	1	0.20000D+00	0.50000D-01	0.10000D+08	0.33333D+00	0.25384D-03	0.93750D+00	-0.20000D+00
3	10	1	0.20000D+00	0.50000D-01	0.10000D+08	0.33333D+00	0.25384D-03	0.93750D+00	-0.20000D+00
4	14	1	0.20000D+00	0.50000D-01	0.10000D+08	0.33333D+00	0.25384D-03	0.93750D+00	-0.20000D+00
5	18	1	0.20000D+00	0.50000D-01	0.10000D+08	0.33333D+00	0.25384D-03	0.93750D+00	-0.20000D+00
6	22	1	0.20000D+00	0.50000D-01	0.10000D+08	0.33333D+00	0.25384D-03	0.93750D+00	-0.20000D+00
7	26	1	0.20000D+00	0.50000D-01	0.10000D+08	0.33333D+00	0.25384D-03	0.93750D+00	-0.20000D+00
8	30	1	0.20000D+00	0.50000D-01	0.10000D+08	0.33333D+00	0.25384D-03	0.93750D+00	-0.20000D+00
9	34	1	0.20000D+00	0.50000D-01	0.10000D+08	0.33333D+00	0.25384D-03	0.93750D+00	-0.20000D+00
10	38	1	0.20000D+00	0.50000D-01	0.10000D+08	0.33333D+00	0.25384D-03	0.93750D+00	-0.20000D+00
11	42	1	0.20000D+00	0.50000D-01	0.10000D+08	0.33333D+00	0.25384D-03	0.93750D+00	-0.20000D+00
12	46	1	0.20000D+00	0.50000D-01	0.10000D+08	0.33333D+00	0.25384D-03	0.93750D+00	-0.20000D+00
13	50	1	0.20000D+00	0.50000D-01	0.10000D+08	0.33333D+00	0.25384D-03	0.93750D+00	-0.20000D+00
14	54	1	0.20000D+00	0.50000D-01	0.10000D+08	0.33333D+00	0.25384D-03	0.93750D+00	-0.20000D+00
15	3	1	0.20000D+00	0.50000D-01	0.10000D+08	0.33333D+00	0.25384D-03	0.62500D-01	-0.20000D+00
16	7	1	0.20000D+00	0.50000D-01	0.10000D+08	0.33333D+00	0.25384D-03	0.62500D-01	-0.20000D+00
17	11	1	0.20000D+00	0.50000D-01	0.10000D+08	0.33333D+00	0.25384D-03	0.62500D-01	-0.20000D+00
18	15	1	0.20000D+00	0.50000D-01	0.10000D+08	0.33333D+00	0.25384D-03	0.62500D-01	-0.20000D+00
19	19	1	0.20000D+00	0.50000D-01	0.10000D+08	0.33333D+00	0.25384D-03	0.62500D-01	-0.20000D+00
20	23	1	0.20000D+00	0.50000D-01	0.10000D+08	0.33333D+00	0.25384D-03	0.62500D-01	-0.20000D+00
21	27	1	0.20000D+00	0.50000D-01	0.10000D+08	0.33333D+00	0.25384D-03	0.62500D-01	-0.20000D+00
22	31	1	0.20000D+00	0.50000D-01	0.10000D+08	0.33333D+00	0.25384D-03	0.62500D-01	-0.20000D+00
23	35	1	0.20000D+00	0.50000D-01	0.10000D+08	0.33333D+00	0.25384D-03	0.62500D-01	-0.20000D+00
24	39	1	0.20000D+00	0.50000D-01	0.10000D+08	0.33333D+00	0.25384D-03	0.62500D-01	-0.20000D+00
25	43	1	0.20000D+00	0.50000D-01	0.10000D+08	0.33333D+00	0.25384D-03	0.62500D-01	-0.20000D+00
26	47	1	0.20000D+00	0.50000D-01	0.10000D+08	0.33333D+00	0.25384D-03	0.62500D-01	-0.20000D+00

27	51	1	0.20000D+00	0.50000D-01	0.10000D+08	0.33333D+00	0.25384D-03	0.62500D-01	-0.20000D+00
28	55	1	0.20000D+00	0.50000D-01	0.10000D+08	0.33333D+00	0.25384D-03	0.62500D-01	-0.20000D+00

MAX SIZE IS 16335

PROPERTIES FOR USER-SPECIFIED MATERIALS

PROPERTIES FOR MATERIAL NUMBER 1

SUBLAYER	STRESS POINT	STRAIN POINT	YIELD STRESS	WEIGHTING FACTOR
1	0.4420000D+05	0.4420000D-02	0.4420000D+05	0.9937861D+00
2	0.4920000D+05	0.7600000D-01	0.8488500D+06	0.1725692D-02
3	0.7640000D+05	0.6150000D+00	0.6909200D+07	0.4468190D-02

STRAIN RATE PARAMETERS. D= 0 0 P= 0.0

TIMewise SOLUTION PARAMETERS

TIME-STEP SIZE= 0.2000000D-05 SEC.
 RUN WILL TERMINATE AT TIME = 0.3000000D-03 SEC. OR AT CYCLE NUMBER 150
 REGULAR PRINTOUT WILL BE GIVEN EVERY 10 CYCLES

***** OUTPUT CONTROL INFORMATION *****

THE FOLLOWING RESULTS WILL BE GIVEN AT EVERY REGULAR PRINTOUT CYCLE.

NODAL DISPLACEMENTS AND LOCATION

STRAIN COMPONENTS, PRINCIPAL STRAIN AND DIRECTION AT THE FOLLOWING 8 NODES (OBTAINED BY NODAL AVERAGING):

STRAIN COMPONENTS, ELONGATION IN SPECIFIED DIRECTIONS, PRINCIPAL STRAIN AND DIRECTION AT THE FOLLOWING 4 ADDTL. POINTS:	ADDTL. POINT	ON ELEM	PSI-LOCATION	ETA-LOCATION	ELONG DIR.-1(DEG)	ELONG. DIR.-2(DEG)
1	30	0.5000000D+00	0.5000000D+00	0.4500000D+02	0.1350000D+03	
2	31	0.5000000D+00	0.5000000D+00	0.4500000D+02	0.1350000D+03	
3	34	0.5000000D+00	0.5000000D+00	0.0	0.9000000D+02	
4	35	0.5000000D+00	0.5000000D+00	0.0	0.9000000D+02	

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SYSTEM ENERGIES

LOCATION AND PROPERTIES OF LINE TRANSLATIONAL AND ROTATIONAL LINEAR RESTORING SPRINGS

ELEM. NO.	ELEM. SIDE	KX(LB/IN/IN)	KY(LB/IN/IN)	KZ(LB/IN/IN)	K-THETA(IN-LB/RAD/IN)	K-PSI(IN-LB/RAD/IN)
4	2	0.0	0.0	0.3000000D+04	0.0	0.0
8	2	0.0	0.0	0.3000000D+04	0.0	0.0
12	2	0.0	0.0	0.3000000D+04	0.0	0.0
16	2	0.0	0.0	0.3000000D+04	0.0	0.0
20	2	0.0	0.0	0.3000000D+04	0.0	0.0
24	2	0.0	0.0	0.3000000D+04	0.0	0.0
28	2	0.0	0.0	0.3000000D+04	0.0	0.0
32	2	0.0	0.0	0.3000000D+04	0.0	0.0
36	2	0.0	0.0	0.3000000D+04	0.0	0.0
40	2	0.0	0.0	0.3000000D+04	0.0	0.0
44	2	0.0	0.0	0.3000000D+04	0.0	0.0
48	2	0.0	0.0	0.3000000D+04	0.0	0.0
52	2	0.0	0.0	0.3000000D+04	0.0	0.0
56	2	0.0	0.0	0.3000000D+04	0.0	0.0
1	4	0.0	0.0	0.3000000D+04	0.0	0.0
5	4	0.0	0.0	0.3000000D+04	0.0	0.0
9	4	0.0	0.0	0.3000000D+04	0.0	0.0
13	4	0.0	0.0	0.3000000D+04	0.0	0.0
17	4	0.0	0.0	0.3000000D+04	0.0	0.0
21	4	0.0	0.0	0.3000000D+04	0.0	0.0
25	4	0.0	0.0	0.3000000D+04	0.0	0.0
29	4	0.0	0.0	0.3000000D+04	0.0	0.0
33	4	0.0	0.0	0.3000000D+04	0.0	0.0
37	4	0.0	0.0	0.3000000D+04	0.0	0.0
41	4	0.0	0.0	0.3000000D+04	0.0	0.0
45	4	0.0	0.0	0.3000000D+04	0.0	0.0
49	4	0.0	0.0	0.3000000D+04	0.0	0.0
53	4	0.0	0.0	0.3000000D+04	0.0	0.0

HIGHEST NATURAL FREQUENCY(RAD/SEC)= 0.1748652D+07

HIGHEST EIGENVECTOR NORMALIZED BY LARGEST VALUE

NODE	U	V	W	PSIX	PSIY	TWIST
1	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0
6	-0.35139D-08	0.44238D-07	0.60626D-02	0.35444D+00	0.40451D-01	0.0
7	-0.13576D-06	0.21164D-05	-0.19616D-02	0.18590D+00	-0.58777D-01	0.0
8	0.37885D-08	0.42080D-04	-0.54413D-03	0.17067D-01	-0.10436D-01	0.0
9	0.13600D-06	0.21375D-05	0.95879D-03	0.97152D-01	0.25437D-01	0.0
10	-0.62293D-08	0.58175D-07	-0.31307D-02	0.18244D+00	-0.21666D-01	0.0
11	0.29133D-07	-0.52983D-07	0.11999D-01	0.78012D+00	0.29044D+00	0.0
12	0.61814D-06	-0.26364D-06	-0.36638D-02	0.44270D+00	-0.11644D+00	0.0
13	-0.15888D-08	0.79465D-05	-0.55001D-03	0.28999D-01	-0.90483D-02	0.0
14	-0.61811D-06	-0.53482D-06	0.18047D-02	0.22150D+00	0.54841D-01	0.0
15	-0.25110D-07	-0.59877D-07	-0.59563D-02	0.38763D+00	-0.14442D+00	0.0
16	0.12572D-06	0.11263D-06	0.13334D-01	0.88039D+00	0.79973D-02	0.0
17	-0.37265D-06	-0.69987D-06	-0.43368D-02	0.50825D+00	0.61180D-02	0.0
18	-0.96771D-09	-0.32113D-05	-0.87799D-03	0.37141D-01	-0.20746D-02	0.0
19	0.37263D-06	-0.53580D-06	0.20607D-02	0.24945D+00	-0.47981D-02	0.0
20	-0.12220D-06	0.12205D-06	-0.64837D-02	0.42792D+00	-0.16486D-03	0.0
21	-0.10405D-06	-0.31909D-06	0.14576D-01	0.96134D+00	0.29907D-01	0.0
22	-0.20969D-05	-0.10832D-05	-0.47362D-02	0.55606D+00	-0.22095D-01	0.0
23	-0.19145D-08	0.36091D-04	-0.89218D-03	0.39035D-01	0.37038D-02	0.0
24	0.20968D-05	-0.12562D-05	0.21683D-02	0.26115D+00	0.11402D-01	0.0
25	0.10894D-06	-0.33092D-06	-0.66873D-02	0.44325D+00	-0.25239D-02	0.0
26	-0.35573D-06	0.13432D-06	0.15394D-01	0.10000D+01	-0.32675D+00	0.0
27	0.31068D-05	0.10414D-04	-0.44592D-02	0.56636D+00	0.14421D+00	0.0
28	0.96182D-09	0.18426D-03	0.63389D-03	0.38118D-01	0.36017D-01	0.0
29	-0.31065D-05	0.10817D-04	0.20023D-02	0.26271D+00	-0.14911D-01	0.0
30	0.35321D-06	0.15118D-06	-0.58154D-02	0.41730D+00	0.20574D+00	0.0
31	-0.54857D-06	-0.52391D-06	0.13555D-01	0.79349D+00	0.65229D-01	0.0
32	0.75411D-05	-0.91065D-05	-0.33260D-02	0.40792D+00	0.13333D+00	0.0
33	0.51831D-08	-0.18189D-03	0.12623D-02	0.36112D-01	0.12127D+00	0.0
34	-0.75407D-05	-0.93680D-05	0.25690D-02	0.23776D+00	0.12502D+00	0.0
35	0.53533D-06	-0.54911D-06	-0.56597D-02	0.38302D+00	0.20605D+00	0.0
36	0.13481D-07	0.13990D-05	0.87834D-02	0.55614D+00	0.20780D+00	0.0
37	-0.96768D-07	-0.36104D-05	-0.26440D-02	0.31527D+00	0.16864D+00	0.0
38	-0.72257D-08	-0.23212D-03	-0.75318D-04	0.32260D-01	0.15559D+00	0.0
39	0.95768D-07	-0.36104D-05	0.25080D-02	0.30066D+00	0.16864D+00	0.0
40	0.51072D-08	0.13990D-05	-0.83747D-02	0.53003D+00	0.20780D+00	0.0
41	0.54475D-06	-0.55216D-06	0.61393D-02	0.41242D+00	0.20946D+00	0.0
42	-0.75731D-05	-0.91164D-05	-0.27249D-02	0.25357D+00	0.12418D+00	0.0
43	0.51831D-08	-0.17655D-03	-0.14078D-02	0.36112D-01	0.11933D+00	0.0
44	0.75738D-05	-0.88550D-05	0.31701D-02	0.39211D+00	0.13249D+00	0.0
45	-0.55799D-06	-0.52695D-06	-0.13075D-01	0.76106D+00	0.68644D-01	0.0
46	0.35159D-06	0.14332D-06	0.63782D-02	0.45011D+00	0.21977D+00	0.0
47	-0.30172D-05	0.10805D-04	-0.27916D-02	0.28144D+00	-0.19530D-01	0.0
48	0.96182D-09	0.18597D-03	-0.75519D-03	0.38458D-01	0.34692D-01	0.0
49	0.30175D-05	0.10432D-04	0.42699D-02	0.54473D+00	0.13962D+00	0.0
50	-0.35411D-06	0.12676D-06	-0.14831D-01	0.96249D+00	-0.31272D+00	0.0
51	0.10163D-06	-0.32913D-06	0.72557D-02	0.48092D+00	-0.33111D-02	0.0
52	0.21079D-05	-0.13216D-05	-0.23594D-02	0.28316D+00	0.12210D-01	0.0
53	-0.19145D-08	0.35034D-04	0.74408D-03	0.39395D-01	0.35741D-02	0.0
54	-0.21081D-05	-0.11517D-05	0.45457D-02	0.53115D+00	-0.21286D-01	0.0
55	-0.96737D-07	-0.31730D-06	-0.14003D-01	0.92607D+00	0.29120D-01	0.0
56	-0.13250D-06	0.11861D-06	0.70205D-02	0.46342D+00	-0.25612D-03	0.0
57	0.37901D-06	-0.47404D-06	-0.22397D-02	0.26976D+00	-0.50868D-02	0.0
58	-0.96771D-09	-0.21922D-05	0.73955D-03	0.37141D-01	-0.17478D-02	0.0
59	-0.37904D-06	-0.63810D-06	0.41578D-02	0.48794D+00	0.58293D-02	0.0
60	0.13502D-06	0.10918D-06	-0.12797D-01	0.84486D+00	0.79060D-02	0.0
61	-0.27360D-07	-0.47416D-07	0.64486D-02	0.41963D+00	-0.15622D+00	0.0
62	-0.50393D-06	-0.46773D-06	-0.19562D-02	0.23958D+00	0.59828D-01	0.0

63	-0.15888D-08	0.67428D-05	0.46102D-03	0.28999D-01	-0.75916D-02	0.0
64	0.50397D-06	-0.19655D-06	0.35123D-02	0.42168D+00	-0.11145D+00	0.0
65	0.31384D-07	-0.40523D-07	0.11506D-01	0.74813D+00	0.27864D+00	0.0
66	-0.68892D-08	0.49644D-07	0.33772D-02	0.19690D+00	-0.23186D-01	0.0
67	0.11571D-06	0.17770D-05	-0.10425D-02	0.10461D+00	0.28185D-01	0.0
68	0.37885D-08	0.35011D-04	0.45399D-03	0.17067D-01	-0.87211D-02	0.0
69	-0.11548D-06	0.17560D-05	0.18779D-02	0.17844D+00	-0.56029D-01	0.0
70	-0.28540D-08	0.35707D-07	-0.58161D-02	0.33998D+00	0.38932D-01	0.0
71	0.0	0.0	0.0	0.0	0.0	0.0
72	0.0	0.0	0.0	0.0	0.0	0.0
73	0.0	0.0	0.0	0.0	0.0	0.0
74	0.0	0.0	0.0	0.0	0.0	0.0
75	0.0	0.0	0.0	0.0	0.0	0.0

AFTER 158 ITERATIONS, CONVERGENCE RATIO= 0.9623089D-07
CENTRAL-DIFFERENCE BOUND ON TIME-STEP(SEC) FOR LINEAR SYSTEM= 0.1 43738D-05
ACTUAL TIME-STEP BOUND (SEC) WOULD BE= 0.9149905D-06

FRAGMENT LOCATION, VELOCITY, AND PROPERTIES AT TIME=0.0 SEC.

X-LOCATION(IN)	=	0.8000000D+00
Y-LOCATION(IN)	=	0.3394412D+01
Z-LOCATION(IN)	=	-0.6098787D+00
X-VELOCITY(IN/SEC)	=	0.0
Y-VELOCITY(IN/SEC)	=	0.1397000D+04
Z-VELOCITY(IN/SEC)	=	0.2419675D+04
OMEGA-X(RAD/SEC)	=	0.1650000D+04
OMEGA-Y(RAD/SEC)	=	0.0
OMEGA-Z(RAD/SEC)	=	0.0
FRAGMENT RADIUS(IN)	=	0.5000000D+00
FRAGMENT MASS(LB-SEC*SEC/IN)	=	0.3815130D-03
FRAG MOMENT OF INERTIA(IN**4)	=	0.3816000D-04
KINETIC ENERGY(IN-LB)	=	0.1541074D+04

CONTACT SURFACE PROPERTIES

COEF OF RESTITUTION	=	0.1000000D+01
FRICTION COEFFICIENT	=	0.2000000D+00
NO. OF SYMMETRIES	=	0

USER SPECIFIED EFFECTIVE LENGTH= 0.4200000D+00

ROUNDING ERROR PARAMETER IN FACTORING ROW 390 = 0.52440101 NO OF NEGATIVE DIAG= 0

**** INCR. NO.= 0 TIME= 0.0 SEC.

NODE	U	V	W	PSIX	PSIY	TWIST	X-POS.	Y-POS.	Z-POS.
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.40000D+00	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.80000D+00	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.12000D+01	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.16000D+01	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.40000D+00	0.0
7	0.0	0.0	0.0	0.0	0.0	0.0	0.40000D+00	0.40000D+00	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.80000D+00	0.40000D+00	0.0
9	0.0	0.0	0.0	0.0	0.0	0.0	0.12000D+01	0.40000D+00	0.0
10	0.0	0.0	0.0	0.0	0.0	0.0	0.16000D+01	0.40000D+00	0.0
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.80000D+00	0.0
12	0.0	0.0	0.0	0.0	0.0	0.0	0.40000D+00	0.80000D+00	0.0
13	0.0	0.0	0.0	0.0	0.0	0.0	0.80000D+00	0.80000D+00	0.0
14	0.0	0.0	0.0	0.0	0.0	0.0	0.12000D+01	0.80000D+00	0.0
15	0.0	0.0	0.0	0.0	0.0	0.0	0.16000D+01	0.80000D+00	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.14000D+01	0.0
17	0.0	0.0	0.0	0.0	0.0	0.0	0.40000D+00	0.14000D+01	0.0
18	0.0	0.0	0.0	0.0	0.0	0.0	0.80000D+00	0.14000D+01	0.0
19	0.0	0.0	0.0	0.0	0.0	0.0	0.12000D+01	0.14000D+01	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0	0.16000D+01	0.14000D+01	0.0
21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.20000D+01	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0	0.40000D+00	0.20000D+01	0.0

23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.80000D+00	0.20000D+01	0.0
24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.12000D+01	0.20000D+01	0.0
25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.16000D+01	0.20000D+01	0.0
26	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.26000D+01	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.40000D+00	0.26000D+01	0.0
28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.80000D+00	0.26000D+01	0.0
29	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.12000D+01	0.26000D+01	0.0
30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.16000D+01	0.26000D+01	0.0
31	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.30000D+01	0.0
32	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.40000D+00	0.30000D+01	0.0
33	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.80000D+00	0.30000D+01	0.0
34	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.12000D+01	0.30000D+01	0.0
35	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.16000D+01	0.30000D+01	0.0
36	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.34000D+01	0.0
37	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.40000D+00	0.34000D+01	0.0
38	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.80000D+00	0.34000D+01	0.0
39	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.12000D+01	0.34000D+01	0.0
40	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.16000D+01	0.34000D+01	0.0
41	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.38000D+01	0.0
42	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.40000D+00	0.38000D+01	0.0
43	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.80000D+00	0.38000D+01	0.0
44	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.12000D+01	0.38000D+01	0.0
45	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.16000D+01	0.38000D+01	0.0
46	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.42000D+01	0.0
47	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.40000D+00	0.42000D+01	0.0
48	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.80000D+00	0.42000D+01	0.0
49	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.12000D+01	0.42000D+01	0.0
50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.16000D+01	0.42000D+01	0.0
51	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.48000D+01	0.0
52	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.40000D+00	0.48000D+01	0.0
53	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.80000D+00	0.48000D+01	0.0
54	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.12000D+01	0.48000D+01	0.0
55	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.16000D+01	0.48000D+01	0.0
56	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.54000D+01	0.0
57	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.40000D+00	0.54000D+01	0.0
58	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.80000D+00	0.54000D+01	0.0
59	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.12000D+01	0.54000D+01	0.0
60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.16000D+01	0.54000D+01	0.0
61	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.60000D+01	0.0
62	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.40000D+00	0.60000D+01	0.0
63	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.80000D+00	0.60000D+01	0.0
64	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.12000D+01	0.60000D+01	0.0
65	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.16000D+01	0.60000D+01	0.0
66	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.64000D+01	0.0
67	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.40000D+00	0.64000D+01	0.0
68	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.80000D+00	0.64000D+01	0.0
69	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.12000D+01	0.64000D+01	0.0
70	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.16000D+01	0.64000D+01	0.0
71	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.68000D+01	0.0
72	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.40000D+00	0.68000D+01	0.0
73	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.80000D+00	0.68000D+01	0.0
74	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.12000D+01	0.68000D+01	0.0
75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.16000D+01	0.68000D+01	0.0

FRAGMENT GLOBAL LOCATION AND VELOCITY COMPONENTS

X-LOC	Y-LOC	Z-LOC	VEL-X	VEL-Y	VEL-Z	OMEGA-X	OMEGA-Y	OMEGA-Z
0.800000D+00	0.339441D+01	-0.609879D+00	0.0	0.139700D+04	0.241967D+04	0.165000D+04	0.0	0.0

STRAIN COMPONENTS, PRINCIPAL (TENSILE) STRAIN AND DIRECTION AT USER-SPECIFIED NODES

NODE	EPS-X STRAIN		EPS-Y STRAIN		SHEAR STRAIN		PRINC. STRAIN(T)		DIRECTION(DEG.)	
	INNER	OUTER	INNER	OUTER	INNER	OUTER	INNER	OUTER	INNER	OUTER
38	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
39	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
43	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
44	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02

48	0.0	0.0	0.0	0.0	0 0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
49	0.0	0.0	0.0	0.0	0 0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
53	0 0	0.0	0.0	0.0	0 0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02
54	0.0	0.0	0.0	0.0	0 0	0.0	0.0	0.0	0.0	0.4500D+02	0.4500D+02

STRAIN COMPONENTS, PRINCIPAL(TENSILE) STRAIN AND DIRECTION, AND ELONGATIONS AT SPECIFIED ADDITIONAL POINTS

POINT NO.	SURFACE	EPS-X STRAIN	EPS-Y STRAIN	SHEAR STRAIN	ELONG (DIR.1)	ELONG.(DIR.2)	PRINC. STRN(T)	DIRECTION(DEG.)
1	INNER	0 0	0.0	0.0	0 0	0.0	0.0	0 45000D+02
1	OUTER	0 0	0.0	0 0	0.0	0.0	0 0	0.45000D+02
2	INNER	0.0	0.0	0 0	0 0	0.0	0.0	0 45000D+02
2	OUTER	0.0	0 0	0.0	0 0	0.0	0.0	0.45000D+02
3	INNER	0 0	0.0	0 0	0.0	0.0	0.0	0.45000D+02
3	OUTER	0 0	0.0	0.0	0.0	0.0	0.0	0.45000D+02
4	INNER	0 0	0 0	0 0	0 0	0.0	0.0	0.45000D+02
4	OUTER	0 0	0.0	0.0	0.0	0.0	0.0	0.45000D+02

SYSTEM ENERGIES(IN-LB)

FRAG. TRANSLATIONAL KINETIC ENERGY = 0.1489128D+04
FRAG. ROTATIONAL KINETIC ENERGY = 0 5194530D+02
WORK INPUT TO STRUCTURE = 0 0
STRUCTURE KINETIC ENERGY = 0.0
STRUCTURE ELASTIC ENERGY = 0 0
STRUCTURE PLASTIC ENERGY = 0 0
ENERGY STORED IN ELASTIC RESTRAINTS= 0.0

***** INCR. NO.= 1 TIME= 0.2000D-05 SEC.

NODE	U	V	W	PSIX	PSIY	TWIST	X-POS.	Y-POS.	Z-POS.
1	0.0	0 0	0 0	0 0	0.0	0.0	0.0	0.0	0.0
2	0 0	0 0	0 0	0 0	0.0	0.0	0.40000D+00	0 0	0.0
3	0 0	0.0	0.0	0 0	0 0	0.0	0.80000D+00	0 0	0.0
4	0 0	0 0	0 0	0 0	0 0	0.0	0.12000D+01	0 0	0.0
5	0 0	0 0	0.0	0 0	0.0	0.0	0.16000D+01	0 0	0.0
6	0 0	0.0	0.0	0 0	0.0	0.0	0 0	0 40000D+00	0.0
7	0 0	0 0	0 0	0 0	0.0	0.0	0 40000D+00	0 40000D+00	0.0
8	0 0	0 0	0 0	0.0	0 0	0.0	0 80000D+00	0 40000D+00	0.0
9	0 0	0.0	0.0	0 0	0 0	0.0	0 12000D+01	0.40000D+00	0.0
10	0.0	0.0	0 0	0 0	0 0	0.0	0 16000D+01	0 40000D+00	0 0
11	0 0	0.0	0 0	0 0	0 0	0.0	0 0	0 80000D+00	0.0
12	0.0	0.0	0.0	0 0	0 0	0.0	0 40000D+00	0 80000D+00	0.0
13	0 0	0 0	0 0	0 0	0.0	0.0	0 80000D+00	0 80000D+00	0.0
14	0 0	0 0	0 0	0 0	0 0	0.0	0 12000D+01	0 80000D+00	0 0
15	0 0	0 0	0 0	0 0	0 0	0.0	0 16000D+01	0 80000D+00	0.0
16	0 0	0 0	0 0	0 0	0 0	0.0	0 0	0 14000D+01	0.0
17	0.0	0 0	0 0	0 0	0 0	0.0	0.40000D+00	0 14000D+01	0 0
18	0 0	0 0	0 0	0 0	0 0	0.0	0 80000D+00	0 14000D+01	0 0
19	0 0	0 0	0.0	0 0	0 0	0.0	0 12000D+01	0 14000D+01	0 0
20	0 0	0 0	0 0	0 0	0 0	0.0	0 16000D+01	0 14000D+01	0.0
21	0 0	0.0	0 0	0 0	0 0	0.0	0 0	0 20000D+01	0 0
22	0.0	0 0	0 0	0 0	0 0	0.0	0 40000D+00	0 20000D+01	0 0
23	0.0	0 0	0 0	0 0	0 0	0.0	0 80000D+00	0 20000D+01	0.0
24	0 0	0.0	0 0	0 0	0 0	0.0	0 12000D+01	0 20000D+01	0 0
25	0.0	0 0	0.0	0 0	0 0	0.0	0.16000D+01	0 20000D+01	0.0
26	0 0	0 0	0 0	0 0	0 0	0.0	0 0	0 26000D+01	0 0
27	0.0	0.0	0 0	0 0	0.0	0.0	0 40000D+00	0 26000D+01	0.0
28	0.0	0 0	0.0	0 0	0 0	0.0	0 80000D+00	0.26000D+01	0.0
29	0.0	0.0	0 0	0 0	0 0	0.0	0 12000D+01	0 26000D+01	0 0
30	0 0	0 0	0 0	0 0	0 0	0.0	0 16000D+01	0 26000D+01	0.0
31	0.0	0 0	0 0	0 0	0 0	0.0	0 0	0 30000D+01	0.0
32	0 0	0 0	0.0	0 0	0 0	0.0	0 40000D+00	0 30000D+01	0.0
33	0 0	0 0	0 0	0 0	0 0	0.0	0 80000D+00	0 30000D+01	0.0
34	0.0	0 0	0.0	0 0	0 0	0.0	0.12000D+01	0.30000D+01	0.0
35	0.0	0.0	0.0	0 0	0 0	0.0	0.16000D+01	0 30000D+01	0.0
36	0.0	0.0	0 0	0 0	0 0	0.0	0.0	0.34000D+01	0.0
37	0.0	0.0	0 0	0.0	0.0	0.0	0.40000D+00	0.34000D+01	0.0

4 OUTER 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.45000D+02

SYSTEM ENERGIES(IN-LB)

FRAG. TRANSLATIONAL KINETIC ENERGY = 0.1489128D+04
 FRAG. ROTATIONAL KINETIC ENERGY = 0.5194530D+02
 WORK INPUT TO STRUCTURE = 0.0
 STRUCTURE KINETIC ENERGY = 0.0
 STRUCTURE ELASTIC ENERGY = 0.0
 STRUCTURE PLASTIC ENERGY = 0.0
 ENERGY STORED IN ELASTIC RESTRAINTS= 0.0

***** INCR. NO.= 2 TIME= 0.4000D-05 SEC.

NODE	U	V	W	PSIX	PSIY	TWIST	X-POS.	Y-POS.	Z-POS.
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.40000D+00	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.80000D+00	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.12000D+01	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.16000D+01	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.40000D+00	0.0
7	0.0	0.0	0.0	0.0	0.0	0.0	0.40000D+00	0.40000D+00	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.80000D+00	0.40000D+00	0.0
9	0.0	0.0	0.0	0.0	0.0	0.0	0.12000D+01	0.40000D+00	0.0
10	0.0	0.0	0.0	0.0	0.0	0.0	0.16000D+01	0.40000D+00	0.0
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.80000D+00	0.0
12	0.0	0.0	0.0	0.0	0.0	0.0	0.40000D+00	0.80000D+00	0.0
13	0.0	0.0	0.0	0.0	0.0	0.0	0.80000D+00	0.80000D+00	0.0
14	0.0	0.0	0.0	0.0	0.0	0.0	0.12000D+01	0.80000D+00	0.0
15	0.0	0.0	0.0	0.0	0.0	0.0	0.16000D+01	0.80000D+00	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.14000D+01	0.0
17	0.0	0.0	0.0	0.0	0.0	0.0	0.40000D+00	0.14000D+01	0.0
18	0.0	0.0	0.0	0.0	0.0	0.0	0.80000D+00	0.14000D+01	0.0
19	0.0	0.0	0.0	0.0	0.0	0.0	0.12000D+01	0.14000D+01	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0	0.16000D+01	0.14000D+01	0.0
21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.20000D+01	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0	0.40000D+00	0.20000D+01	0.0
23	0.0	0.0	0.0	0.0	0.0	0.0	0.80000D+00	0.20000D+01	0.0
24	0.0	0.0	0.0	0.0	0.0	0.0	0.12000D+01	0.20000D+01	0.0
25	0.0	0.0	0.0	0.0	0.0	0.0	0.16000D+01	0.20000D+01	0.0
26	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.26000D+01	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0	0.40000D+00	0.26000D+01	0.0
28	0.0	0.0	0.0	0.0	0.0	0.0	0.80000D+00	0.26000D+01	0.0
29	0.0	0.0	0.0	0.0	0.0	0.0	0.12000D+01	0.26000D+01	0.0
30	0.0	0.0	0.0	0.0	0.0	0.0	0.16000D+01	0.26000D+01	0.0
31	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.30000D+01	0.0
32	0.0	0.0	0.0	0.0	0.0	0.0	0.40000D+00	0.30000D+01	0.0
33	0.0	0.0	0.0	0.0	0.0	0.0	0.80000D+00	0.30000D+01	0.0
34	0.0	0.0	0.0	0.0	0.0	0.0	0.12000D+01	0.30000D+01	0.0
35	0.0	0.0	0.0	0.0	0.0	0.0	0.16000D+01	0.30000D+01	0.0
36	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.34000D+01	0.0
37	0.0	0.0	0.0	0.0	0.0	0.0	0.40000D+00	0.34000D+01	0.0
38	0.0	0.0	0.0	0.0	0.0	0.0	0.80000D+00	0.34000D+01	0.0
39	0.0	0.0	0.0	0.0	0.0	0.0	0.12000D+01	0.34000D+01	0.0
40	0.0	0.0	0.0	0.0	0.0	0.0	0.16000D+01	0.34000D+01	0.0
41	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.38000D+01	0.0
42	0.0	0.0	0.0	0.0	0.0	0.0	0.40000D+00	0.38000D+01	0.0
43	0.0	0.0	0.0	0.0	0.0	0.0	0.80000D+00	0.38000D+01	0.0
44	0.0	0.0	0.0	0.0	0.0	0.0	0.12000D+01	0.38000D+01	0.0
45	0.0	0.0	0.0	0.0	0.0	0.0	0.16000D+01	0.38000D+01	0.0
46	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.42000D+01	0.0
47	0.0	0.0	0.0	0.0	0.0	0.0	0.40000D+00	0.42000D+01	0.0
48	0.0	0.0	0.0	0.0	0.0	0.0	0.80000D+00	0.42000D+01	0.0
49	0.0	0.0	0.0	0.0	0.0	0.0	0.12000D+01	0.42000D+01	0.0
50	0.0	0.0	0.0	0.0	0.0	0.0	0.16000D+01	0.42000D+01	0.0
51	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.48000D+01	0.0
52	0.0	0.0	0.0	0.0	0.0	0.0	0.40000D+00	0.48000D+01	0.0

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53	0.0	0.0	0.0	0.0	0 0	0.0	0 80000D+00	0.48000D+01	0.0
54	0.0	0.0	0.0	0.0	0.0	0.0	0 12000D+01	0.48000D+01	0.0
55	0.0	0.0	0.0	0.0	0.0	0.0	0.16000D+01	0 48000D+01	0.0
56	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.54000D+01	0.0
57	0.0	0.0	0.0	0.0	0.0	0.0	0.40000D+00	0 54000D+01	0.0
58	0.0	0.0	0.0	0.0	0.0	0.0	0 80000D+00	0 54000D+01	0.0
59	0.0	0.0	0.0	0.0	0.0	0.0	0.12000D+01	0 54000D+01	0.0
60	0.0	0.0	0.0	0.0	0.0	0.0	0 16000D+01	0 54000D+01	0.0
61	0.0	0.0	0.0	0.0	0.0	0.0	0 0	0 60000D+01	0.0
62	0.0	0.0	0.0	0.0	0.0	0.0	0 40000D+00	0 60000D+01	0.0
63	0.0	0.0	0.0	0.0	0.0	0.0	0.80000D+00	0 60000D+01	0.0
64	0.0	0.0	0.0	0.0	0.0	0.0	0 12000D+01	0 60000D+01	0.0
65	0.0	0.0	0.0	0.0	0.0	0.0	0 16000D+01	0 60000D+01	0.0
66	0.0	0.0	0.0	0.0	0.0	0.0	0 0	0 64000D+01	0.0
67	0.0	0.0	0.0	0.0	0.0	0.0	0 40000D+00	0 64000D+01	0.0
68	0.0	0.0	0.0	0.0	0.0	0.0	0.80000D+00	0 64000D+01	0.0
69	0.0	0.0	0.0	0.0	0.0	0.0	0 12000D+01	0 64000D+01	0.0
70	0.0	0.0	0.0	0.0	0.0	0.0	0 16000D+01	0 64000D+01	0.0
71	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0 68000D+01	0.0
72	0.0	0.0	0.0	0.0	0.0	0.0	0.40000D+00	0 68000D+01	0.0
73	0.0	0.0	0.0	0.0	0.0	0.0	0 80000D+00	0 68000D+01	0.0
74	0.0	0.0	0.0	0.0	0.0	0.0	0.12000D+01	0.68000D+01	0.0
75	0.0	0.0	0.0	0.0	0.0	0.0	0.16000D+01	0.68000D+01	0.0

FRAGMENT GLOBAL LOCATION AND VELOCITY COMPONENTS

X-LOC	Y-LOC	Z-LOC	VEL-X	VEL-Y	VEL-Z	OMEGA-X	OMEGA-Y	OMEGA-Z
0.800000D+00	0.340000D+01	-0.600200D+00	0 0	0 139700D+04	0.241967D+04	0.165000D+04	0.0	0.0

STRAIN COMPONENTS, PRINCIPAL (TENSILE) STRAIN AND DIRECTION AT USER-SPECIFIED NODES

NODE	EPS-X STRAIN			EPS-Y STRAIN			SHEAR STRAIN			PRINC. STRAIN(T)			DIRECTION(DEG.)	
	INNER	OUTER		INNER	OUTER		INNER	OUTER		INNER	OUTER	INNER	OUTER	
38	0.0	0.0	0 0	0 0	0 0	0.0	0 0	0 0	0.0	0 0	0.0	0.4500D+02	0.4500D+02	
39	0.0	0.0	0 0	0 0	0 0	0.0	0 0	0 0	0.0	0 0	0.0	0.4500D+02	0.4500D+02	
43	0.0	0.0	0.0	0.0	0.0	0.0	0 0	0 0	0.0	0 0	0.0	0.4500D+02	0.4500D+02	
44	0.0	0.0	0.0	0.0	0.0	0.0	0 0	0 0	0.0	0 0	0.0	0.4500D+02	0.4500D+02	
48	0.0	0.0	0.0	0.0	0.0	0.0	0 0	0 0	0.0	0 0	0.0	0.4500D+02	0.4500D+02	
49	0.0	0.0	0.0	0.0	0.0	0.0	0 0	0 0	0.0	0 0	0.0	0.4500D+02	0.4500D+02	
53	0.0	0.0	0.0	0.0	0.0	0.0	0 0	0 0	0.0	0 0	0.0	0.4500D+02	0.4500D+02	
54	0.0	0.0	0.0	0.0	0.0	0.0	0 0	0 0	0.0	0 0	0.0	0.4500D+02	0.4500D+02	

STRAIN COMPONENTS, PRINCIPAL(TENSILE) STRAIN AND DIRECTION, AND ELONGATIONS AT SPECIFIED ADDITIONAL POINTS

POINT NO.	SURFACE	EPS-X STRAIN	EPS-Y STRAIN	SHEAR STRAIN	ELONG (DIR.1)	ELONG.(DIR.2)	PRINC. STRN(T)	DIRECTION(DEG.)
1	INNER	0 0	0.0	0.0	0 0	0.0	0 0	0 45000D+02
1	OUTER	0.0	0.0	0.0	0.0	0.0	0 0	0.45000D+02
2	INNER	0 0	0.0	0 0	0 0	0.0	0 0	0.45000D+02
2	OUTER	0.0	0.0	0 0	0 0	0.0	0 0	0.45000D+02
3	INNER	0 0	0.0	0 0	0 0	0.0	0 0	0.45000D+02
3	OUTER	0 0	0.0	0 0	0.0	0.0	0 0	0.45000D+02
4	INNER	0 0	0.0	0 0	0.0	0.0	0 0	0.45000D+02
4	OUTER	0 0	0.0	0 0	0.0	0.0	0 0	0.45000D+02

SYSTEM ENERGIES(IN-LB)

FRAG TRANSLATIONAL KINETIC ENERGY = 0 1489128D+04
FRAG. ROTATIONAL KINETIC ENERGY = 0 5194530D+02
WORK INPUT TO STRUCTURE = 0.0
STRUCTURE KINETIC ENERGY = 0.0
STRUCTURE ELASTIC ENERGY = 0.0
STRUCTURE PLASTIC ENERGY = 0.0
ENERGY STORED IN ELASTIC RESTRAINTS= 0.0

IMPACT CYCLE= 2

SUBREGIONNS PENETRATED: 5 8

POINT OF EFFECTIVE IMPACT(XA,YA,ZA)= 0.80000000+00 0.34027940+01 -0.15265570-15
 THIS IS IMPACT NUMBER 1

**** INCR. NO.= 3 TIME= 0.6000D-05 SEC.

NODE	U	V	W	PSIX	PSIY	TWIST	X-POS.	Y-POS.	Z-POS.
1	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
2	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
3	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
4	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
5	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
6	0.94752D-08	0.19913D-07	0.92643D-08	0.21756D-06	-0.52954D-07	0.47497D-05	0.94752D-08	0.40000D+00	0.92643D-08
7	0.96341D-09	0.18171D-07	0.51535D-08	0.66400D-07	-0.22158D-07	0.19535D-05	0.40000D+00	0.40000D+00	0.51535D-08
8	0.49631D-23	0.19127D-07	0.13548D-08	-0.54878D-19	-0.51714D-07	-0.18116D-17	0.80000D+00	0.40000D+00	0.13548D-08
9	-0.96341D-09	0.18171D-07	0.51535D-08	0.66400D-07	-0.22158D-07	-0.19535D-05	0.12000D+01	0.40000D+00	0.51535D-08
10	-0.94752D-08	0.19913D-07	0.92643D-08	-0.21756D-06	-0.52954D-07	-0.47497D-05	0.16000D+01	0.40000D+00	0.92643D-08
11	0.14279D-07	0.56708D-07	-0.38456D-07	0.24223D-06	-0.13260D-05	0.22944D-04	0.14279D-07	0.80000D+00	-0.38456D-07
12	0.80036D-08	0.92721D-07	-0.58547D-07	0.41682D-06	-0.82053D-06	0.15600D-04	0.40000D+00	0.80000D+00	-0.58547D-07
13	0.99262D-23	0.32213D-07	-0.11127D-06	-0.14385D-18	-0.71064D-06	-0.74681D-17	0.80000D+00	0.80000D+00	-0.11127D-06
14	-0.80036D-08	0.92721D-07	-0.58547D-07	0.41682D-06	-0.82053D-06	-0.15600D-04	0.12000D+01	0.80000D+00	-0.58547D-07
15	-0.14279D-07	0.56708D-07	-0.38456D-07	0.24223D-06	-0.13260D-05	-0.22944D-04	0.16000D+01	0.80000D+00	-0.38456D-07
16	-0.18393D-06	0.59656D-06	0.12512D-06	0.45564D-05	0.39544D-05	0.72683D-04	-0.18393D-06	0.14000D+01	0.12512D-06
17	-0.14255D-06	0.21974D-06	0.49536D-06	0.44973D-05	0.59962D-05	0.63308D-04	0.40000D+00	0.14000D+01	0.49536D-06
18	0.26470D-22	0.74318D-06	0.14432D-05	-0.75124D-18	0.92807D-05	-0.24510D-16	0.80000D+00	0.14000D+01	0.14432D-05
19	0.14255D-06	0.21974D-06	0.49536D-06	-0.44973D-05	0.59962D-05	-0.63308D-04	0.12000D+01	0.14000D+01	0.49536D-06
20	0.18393D-06	0.59656D-06	0.12512D-06	0.45564D-05	0.39544D-05	-0.72683D-04	0.16000D+01	0.14000D+01	0.12512D-06
21	0.31640D-05	0.62356D-05	0.26662D-05	0.13711D-04	0.21682D-04	0.85838D-04	0.31640D-05	0.20000D+01	0.26662D-05
22	-0.42689D-06	0.21997D-05	-0.30161D-05	-0.16940D-04	-0.65843D-04	0.41867D-04	0.40000D+00	0.20000D+01	-0.30161D-05
23	0.42352D-21	-0.34230D-05	-0.14840D-04	-0.28219D-17	-0.12957D-03	-0.11723D-15	0.80000D+00	0.20000D+01	-0.14840D-04
24	0.42689D-06	0.21997D-05	-0.30161D-05	0.16940D-04	-0.65843D-04	-0.41867D-04	0.12000D+01	0.20000D+01	-0.30161D-05
25	-0.31640D-05	0.62356D-05	0.26662D-05	0.13711D-04	0.21682D-04	-0.85838D-04	0.16000D+01	0.20000D+01	0.26662D-05
26	0.19751D-04	0.18194D-04	-0.16565D-04	-0.19099D-03	-0.24342D-03	0.13579D-03	0.19751D-04	0.26000D+01	-0.16565D-04
27	0.20104D-04	0.35848D-04	-0.45769D-04	0.11216D-03	-0.56973D-04	0.36136D-02	0.40002D+00	0.26000D+01	-0.45769D-04
28	0.57175D-20	-0.30321D-05	-0.47318D-04	-0.34661D-17	0.62331D-03	-0.26769D-15	0.80000D+00	0.26000D+01	-0.47318D-04
29	-0.20404D-04	0.35848D-04	-0.45769D-04	-0.11216D-03	-0.56973D-04	-0.36136D-02	0.12000D+01	0.26000D+01	-0.45769D-04
30	-0.19751D-04	0.18194D-04	-0.16565D-04	0.19099D-03	-0.24342D-03	-0.13579D-03	0.16000D+01	0.26000D+01	-0.16565D-04
31	0.24601D-04	0.10648D-04	-0.97566D-04	-0.32879D-03	-0.30127D-03	0.52317D-02	0.24601D-04	0.30000D+01	-0.97566D-04
32	0.63191D-04	0.93528D-04	0.25326D-03	0.36673D-02	0.28345D-02	0.27463D-01	0.40006D+00	0.30001D+01	0.25326D-03
33	-0.99526D-20	0.44415D-03	0.17853D-02	0.14057D-16	0.99969D-02	-0.11861D-14	0.80000D+00	0.30004D+01	0.17853D-02
34	-0.63491D-04	0.93528D-04	0.25326D-03	-0.36673D-02	0.28345D-02	-0.27463D-01	0.11999D+01	0.30001D+01	0.25326D-03
35	-0.24601D-04	0.10648D-04	-0.97566D-04	0.32879D-03	-0.30127D-03	-0.52317D-02	0.16000D+01	0.30000D+01	-0.97566D-04
36	-0.46748D-05	0.10144D-04	-0.10700D-03	0.20411D-03	-0.99241D-05	0.21569D-04	-0.46748D-05	0.34000D+01	-0.10700D-03
37	-0.17434D-04	0.89706D-04	0.12041D-02	0.91667D-02	0.10296D-03	0.84106D-03	0.39998D+00	0.34001D+01	0.12041D-02
38	0.37994D-20	0.12590D-02	0.72028D-02	0.67763D-16	0.10507D-02	-0.29907D-14	0.80000D+00	0.34013D+01	0.72028D-02
39	0.17434D-04	0.89706D-04	0.12041D-02	-0.91667D-02	0.10296D-03	-0.84106D-03	0.12000D+01	0.34010D+01	0.12041D-02
40	0.46718D-05	0.10144D-04	-0.10700D-03	0.20411D-03	-0.99241D-05	0.21569D-04	0.16000D+01	0.34000D+01	-0.10700D-03
41	-0.26528D-04	0.13732D-04	-0.10098D-03	-0.33409D-03	0.30038D-03	-0.53417D-02	-0.26528D-04	0.38000D+01	-0.10098D-03
42	-0.58531D-04	0.94139D-04	0.27637D-03	0.39348D-02	-0.29333D-02	-0.28253D-01	0.39994D+00	0.38001D+01	0.27637D-03
43	0.23929D-19	0.92132D-04	0.13534D-02	-0.39573D-16	-0.10850D-01	0.11442D-14	0.80000D+00	0.38001D+01	0.13534D-02
44	0.58531D-04	0.94139D-04	0.27637D-03	-0.39348D-02	-0.29333D-02	0.28253D-01	0.12001D+01	0.38001D+01	0.27637D-03
45	0.26528D-04	0.13732D-04	-0.10098D-03	0.33409D-03	0.30038D-03	0.53417D-02	0.16000D+01	0.38000D+01	-0.10098D-03
46	-0.14026D-04	0.18309D-04	-0.17716D-04	-0.20500D-03	0.25573D-03	-0.12006D-03	-0.14026D-04	0.42000D+01	-0.17716D-04
47	-0.46967D-05	0.22945D-04	-0.46517D-04	0.11233D-03	0.27307D-04	-0.39136D-02	0.40000D+00	0.42000D+01	-0.46517D-04
48	-0.34513D-20	0.10260D-03	-0.50330D-04	-0.96765D-17	-0.85785D-03	0.24903D-15	0.80000D+00	0.42001D+01	-0.50983D-04
49	0.46967D-05	0.22945D-04	-0.46517D-04	0.11233D-03	0.27307D-04	0.39136D-02	0.12000D+01	0.42000D+01	-0.46517D-04
50	0.14026D-04	0.18309D-04	-0.17716D-04	0.20500D-03	0.25573D-03	0.12006D-03	0.16000D+01	0.42000D+01	-0.17716D-04
51	-0.23595D-05	0.42261D-05	0.29905D-05	0.14343D-04	-0.22166D-04	-0.60475D-04	-0.23595D-05	0.48000D+01	0.29905D-05
52	-0.37416D-05	0.75080D-05	-0.40415D-05	-0.26390D-04	0.82972D-04	0.55755D-04	0.40000D+00	0.48000D+01	-0.40415D-05
53	0.59557D-21	0.16292D-04	-0.19336D-04	-0.42775D-18	0.14496D-03	0.70087D-16	0.80000D+00	0.48000D+01	-0.19336D-04
54	0.37416D-05	0.75080D-05	-0.40415D-05	0.26390D-04	0.82972D-04	-0.55755D-04	0.12000D+01	0.48000D+01	-0.40415D-05
55	0.23595D-05	0.42261D-05	0.29905D-05	-0.14343D-04	-0.22166D-04	0.60475D-04	0.16000D+01	0.48000D+01	0.29905D-05
56	-0.91199D-06	0.13593D-05	0.17932D-06	0.51849D-05	-0.53858D-05	-0.71744D-04	-0.91199D-06	0.54000D+01	0.17932D-06
57	-0.44658D-06	0.14016D-05	0.55853D-06	0.13501D-05	-0.65269D-05	-0.45528D-04	0.40000D+00	0.54000D+01	0.53853D-06
58	-0.19852D-21	0.81180D-06	0.14859D-05	-0.88752D-18	-0.11450D-04	0.35853D-16	0.80000D+00	0.54000D+01	0.14859D-05
59	0.44658D-06	0.14016D-05	0.55853D-06	-0.13501D-05	-0.65269D-05	0.45528D-04	0.12000D+01	0.54000D+01	0.55853D-06
60	0.91199D-06	0.13593D-05	0.17932D-06	-0.51849D-05	-0.53858D-05	0.71744D-04	0.16000D+01	0.54000D+01	0.17932D-06

335

61	-0 97107D-07	0.28811D-06	-0 47744D-07	0 19653D-06	0 14862D-05	-0.21553D-04	-0.97107D-07	0.60000D+01	-0.47744D-07
62	-0 21180D-07	0 18578D-06	-0 71318D-07	0.22843D-06	0.99607D-06	-0.11304D-04	0.40000D+00	0.60000D+01	-0.71318D-07
63	0.33501D-22	0 24343D-06	-0 14502D-06	-0.18677D-18	0.67754D-06	0.10526D-16	0.80000D+00	0.60000D+01	-0.14502D-06
64	0 21180D-07	0 18578D-06	-0 71318D-07	-0 22843D-06	0 99607D-06	0.11304D-04	0.12000D+01	0.60000D+01	-0.71318D-07
65	0 97107D-07	0 28811D-06	-0 47744D-07	-0 19653D-06	0 14862D-05	0.21553D-04	0.16000D+01	0.60000D+01	-0.47744D-07
66	-0 18817D-07	0 66375D-07	0 10832D-07	0 20639D-06	0 33206D-07	-0.42535D-05	-0.18817D-07	0.64000D+01	0.10832D-07
67	-0.61808D-08	0 53457D-07	0 63938D-08	0 30544D-07	0 13509D-07	-0.13561D-05	0.40000D+00	0.64000D+01	0.63938D-08
68	0.70827D-23	0 50815D-07	-0.49228D-08	-0.57315D-19	0 46282D-07	0 17750D-17	0.80000D+00	0.64000D+01	-0.49228D-08
69	0.61808D-08	0.53457D-07	0 63938D-08	-0.30544D-07	0.13509D-07	0.13561D-05	0.12000D+01	0.64000D+01	0.63938D-08
70	0 18817D-07	0 66375D-07	0 10832D-07	-0.20639D-06	0 33206D-07	0.42535D-05	0.16000D+01	0.64000D+01	0.10832D-07
71	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.68000D+01	0.0
72	0.0	0.0	0.0	0.0	0.0	0.0	0.40000D+00	0.68000D+01	0.0
73	0.0	0.0	0.0	0.0	0.0	0.0	0.80000D+00	0.68000D+01	0.0
74	0.0	0.0	0.0	0.0	0.0	0.0	0.12000D+01	0.68000D+01	0.0
75	0.0	0.0	0.0	0.0	0.0	0.0	0.16000D+01	0.68000D+01	0.0

FRAGMENT GLOBAL LOCATION AND VELOCITY COMPONENTS

X-LOC	Y-LOC	Z-LOC	VEL-X	VEL-Y	VEL-Z	OMEGA-X	OMEGA-Y	OMEGA-Z
0.800000D+00	0.340273D+01	-0 595705D+00	0.0	0 136252D+04	0.224726D+04	0.182237D+04	0.0	0.0

STRAIN COMPONENTS, PRINCIPAL (TENSILE) STRAIN AND DIRECTION AT USER-SPECIFIED NODES

NODE	EPS-X STRAIN		EPS-Y STRAIN		SHEAR STRAIN		PRINC. STRAIN(T)		DIRECTION(DEG.)	
	INNER	OUTER	INNER	OUTER	INNER	OUTER	INNER	OUTER	INNER	OUTER
38	-0.1787D-01	0.1796D-01	-0.1523D-01	0 1435D-01	-0 5985D-15	0 5967D-15	0.0	0.1796D-01	0.0	0.4740D-11
39	0 8889D-02	-0 8792D-02	-0.2079D-02	0 2082D-02	-0 1578D-02	-0.1241D-02	0.8945D-02	0.2117D-02	-0.4093D+01	-0.8674D+02
43	-0 4175D-02	0 4468D-02	0.5175D-02	-0 7948D-02	0 2290D-15	-0.2234D-15	0.5175D-02	0.4468D-02	0.9000D+02	-0.5271D-12
44	0.2394D-02	-0 2312D-02	0.1070D-02	-0 1228D-02	0 5548D-02	-0 5753D-02	0.4584D-02	0.1157D-02	0 3829D+02	-0.5033D+02
48	0.7716D-04	-0.5366D-04	0.8461D-03	-0 9638D-03	0 4937D-16	-0 4940D-16	0.8461D-03	0.0	0.9000D+02	0.0
49	0.1942D-04	0 1566D-04	-0 1982D-03	-0 5466D-05	0 6093D-03	-0 9562D-03	0.2341D-03	0.4833D-03	0.3517D+02	-0.4437D+02
53	0.5252D-04	-0 3381D-04	-0 2349D-03	0 6528D-04	0 1401D-16	-0 1402D-16	0.5252D-04	0.6528D-04	0.1396D-11	-0.9000D+02
54	-0.8953D-05	0 1486D-04	-0 4553D-04	0.9629D-05	-0 2977D-04	-0 7471D-05	0.0	0.1680D-04	0.0	-0.2751D+02

STRAIN COMPONENTS, PRINCIPAL(TENSILE) STRAIN AND DIRECTION, AND ELONGATIONS AT SPECIFIED ADDITIONAL POINTS

POINT NO.	SURFACE	EPS-X STRAIN	EPS-Y STRAIN	SHEAR STRAIN	ELONG (DIR.1)	ELONG.(DIR.2)	PRINC. STRN(T)	DIRECTION(DEG.)
1	INNER	-0 18074D-02	-0 36266D-02	-0 89513D-02	-0 72187D-02	0.17571D-02	0 18502D-02	-0.39256D+02
1	OUTER	0.21953D-02	0.63495D-03	0.11468D-01	0.72233D-02	-0.42280D-02	0.72896D-02	0 41618D+02
2	INNER	-0 18074D-02	-0 36266D-02	0.89513D-02	0 17571D-02	-0.72187D-02	0.18502D-02	0.39256D+02
2	OUTER	0 21953D-02	0 63495D-03	-0 11468D-01	-0 42280D-02	0.72233D-02	0.72896D-02	-0.41618D+02
3	INNER	-0 12130D-03	0 18511D-02	-0.25985D-02	-0.12130D-03	0.18494D-02	0.24960D-02	-0.63600D+02
3	OUTER	0.28199D-03	-0.19955D-02	0.29187D-02	0 28195D-03	-0.19975D-02	0.99429D-03	0.26017D+02
4	INNER	-0.12130D-03	0 18511D-02	0.25985D-02	-0 12130D-03	0.18494D-02	0.24960D-02	0.63600D+02
4	OUTER	0 28199D-03	-0 19955D-02	-0 29187D-02	0.28195D-03	-0.19975D-02	0.99429D-03	-0.26017D+02

SYSTEM ENERGIES(IN-LB)

FRAG TRANSLATIONAL KINETIC ENERGY	=	0 1317489D+04
FRAG ROTATIONAL KINETIC ENERGY	=	0 6336536D+02
WRK INPUT TO STRUCTURE	=	0 1602192D+03
STRUCTURE KINETIC ENERGY	=	0 6523067D+02
STRUCTURE ELASTIC ENERGY	=	0.1507899D+02
STRUCTURE PLASTIC ENERGY	=	0.7990952D+02
ENERGY STORED IN ELASTIC RESTRAINTS	=	0.3324755D-04

} } } } } } } } } } } } } } } } }

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***** INCR. NO.= 140 TIME= 0.2800D-03 SEC.

NODE	U	V	W	PSIX	PSIY	TWIST	X-POS.	Y-POS.	Z-POS.
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.40000D+00	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.80000D+00	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.12000D+01	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.16000D+01	0.0	0.0
6	0.99196D-03	0.24400D-02	0.99401D-02	0.49670D-02	0.48266D-01	-0.32008D-01	0.99196D-03	0.40244D+00	0.99401D-02
7	0.46903D-03	0.28891D-02	0.10568D-01	-0.12682D-02	0.47366D-01	0.92273D-03	0.40047D+00	0.40289D+00	0.10568D-01
8	0.89356D-04	0.46029D-02	0.99245D-02	-0.38251D-04	0.42851D-01	-0.86186D-01	0.80009D+00	0.40460D+00	0.99245D-02
9	-0.56806D-03	0.27553D-02	0.10436D-01	-0.14594D-03	0.46013D-01	-0.12171D-01	0.11994D+01	0.40276D+00	0.10436D-01
10	-0.10819D-02	0.23835D-02	0.94952D-02	-0.56482D-02	0.46630D-01	0.27413D-01	0.15989D+01	0.40238D+00	0.94952D-02
11	0.25261D-03	0.26791D-02	0.28321D-01	0.22139D-02	0.43855D-01	-0.70363D-02	0.25261D-03	0.80268D+00	0.28321D-01
12	0.46802D-01	0.31205D-02	0.29308D-01	0.25126D-02	0.41381D-01	-0.63338D-03	0.40005D+00	0.80312D+00	0.29308D-01

13	-0.64037D-04	0.38945D-02	0.29786D-01	-0.37840D-02	0.48266D-01	-0.10363D+00	0.79994D+00	0.80389D+00	0.29786D-01
14	-0.12221D-03	0.31523D-02	0.29502D-01	-0.19518D-02	0.44930D-01	-0.14778D-01	0.11999D+01	0.80315D+00	0.28502D-01
15	-0.33801D-03	0.25894D-02	0.27552D-01	-0.23488D-02	0.43731D-01	0.27290D-02	0.15997D+01	0.80259D+00	0.27552D-01
16	0.17980D-03	0.30537D-02	0.51833D-01	0.44222D-02	0.36364D-01	-0.16044D-02	0.17980D-03	0.14031D+01	0.51833D-01
17	0.64511D-04	0.30463D-02	0.53751D-01	0.44449D-02	0.39214D-01	0.85365D-02	0.40006D+00	0.14030D+01	0.53751D-01
18	0.77478D-04	0.33495D-02	0.54779D-01	-0.63504D-03	0.47665D-01	-0.12763D+00	0.80008D+00	0.14033D+01	0.54779D-01
19	0.25879D-04	0.30279D-02	0.53630D-01	-0.42469D-02	0.39875D-01	-0.13496D-01	0.12000D+01	0.14030D+01	0.53630D-01
20	-0.79804D-04	0.29718D-02	0.51869D-01	-0.39302D-02	0.38145D-01	0.14448D-02	0.15993D+01	0.14029D+01	0.51869D-01
21	0.59588D-03	0.32050D-02	0.71213D-01	0.11536D-01	0.31834D-01	-0.30163D-03	0.59588D-03	0.20032D+01	0.71213D-01
22	0.47843D-03	0.30222D-02	0.75866D-01	0.11337D-01	0.35846D-01	0.11173D-01	0.40048D+00	0.20030D+01	0.75866D-01
23	0.13487D-03	0.31389D-02	0.78876D-01	-0.67013D-03	0.45332D-01	-0.13068D+00	0.80013D+00	0.20031D+01	0.78876D-01
24	-0.22389D-03	0.29576D-02	0.76336D-01	-0.96131D-02	0.36665D-01	-0.18474D-01	0.11998D+01	0.20030D+01	0.76336D-01
25	-0.32976D-03	0.30225D-02	0.72255D-01	-0.10236D-01	0.33173D-01	-0.17539D-02	0.15997D+01	0.20030D+01	0.72255D-01
26	0.77599D-03	0.28136D-02	0.89014D-01	0.21819D-01	0.32925D-01	0.41101D-02	0.77599D-03	0.26028D+01	0.89014D-01
27	0.72531D-03	0.31157D-02	0.97296D-01	0.19304D-01	0.38622D-01	0.13858D-01	0.40073D+00	0.26031D+01	0.97296D-01
28	0.24961D-03	0.40500D-02	0.10268D+00	0.43313D-02	0.46996D-01	-0.11939D+00	0.80025D+00	0.26040D+01	0.10268D+00
29	-0.37638D-03	0.29431D-02	0.98575D-01	-0.19335D-01	0.39719D-01	-0.33544D-01	0.11996D+01	0.26029D+01	0.98575D-01
30	-0.42173D-03	0.26500D-02	0.90180D-01	-0.21056D-01	0.32795D-01	-0.80318D-02	0.15996D+01	0.26026D+01	0.90180D-01
31	0.11305D-03	0.21916D-02	0.10291D+00	0.25616D-01	0.37231D-01	-0.14363D-02	0.11305D-03	0.30022D+01	0.10291D+00
32	0.20664D-03	0.27126D-02	0.11370D+00	0.29493D-01	0.40771D-01	0.18374D-01	0.40021D+00	0.30027D+01	0.11370D+00
33	0.92122D-04	0.55840D-02	0.12366D+00	0.57339D-02	0.50325D-01	-0.70995D-01	0.80009D+00	0.30056D+01	0.12366D+00
34	0.94928D-04	0.25584D-02	0.11451D+00	-0.28709D-01	0.39588D-01	-0.31057D-01	0.12001D+01	0.30026D+01	0.11451D+00
35	0.20836D-03	0.20157D-02	0.10399D+00	-0.24741D-01	0.35098D-01	-0.17568D-02	0.16002D+01	0.30020D+01	0.10399D+00
36	-0.88932D-03	0.12373D-02	0.11666D+00	-0.23265D-01	0.28165D-01	-0.98305D-02	-0.88932D-03	0.31012D+01	0.11666D+00
37	-0.64267D-03	0.16382D-02	0.12887D+00	0.34930D-01	0.29862D-01	0.97245D-02	0.39936D+00	0.34016D+01	0.12887D+00
38	0.17079D-03	0.35595D-02	0.14051D+00	-0.61408D-07	0.32186D-01	0.42548D-02	0.80017D+00	0.34036D+01	0.14051D+00
39	0.95695D-03	0.15453D-02	0.12836D+00	-0.34992D-01	0.27951D-01	-0.18515D-01	0.12010D+01	0.34015D+01	0.12836D+00
40	0.12160D-02	0.10331D-02	0.11668D+00	-0.23070D-01	0.23858D-01	0.49471D-02	0.16012D+01	0.34010D+01	0.11668D+00
41	-0.85138D-03	-0.10775D-03	0.12054D+00	0.25948D-01	-0.76157D-02	0.12060D-01	-0.85138D-03	0.37999D+01	0.12054D+00
42	-0.64987D-03	-0.30391D-03	0.13263D+00	0.34613D-01	-0.10014D-01	-0.20471D-01	0.39935D+00	0.37997D+01	0.13263D+00
43	0.16590D-03	-0.34919D-02	0.14344D+00	-0.87462D-02	-0.17388D-01	-0.80059D-01	0.80017D+00	0.37965D+01	0.14344D+00
44	0.82773D-03	-0.58601D-03	0.13095D+00	-0.36018D-01	-0.13076D-01	0.15091D-01	0.12008D+01	0.37994D+01	0.13095D+00
45	0.90572D-03	-0.21653D-03	0.11829D+00	-0.20169D-01	-0.10894D-01	-0.12162D-01	0.16010D+01	0.37998D+01	0.11829D+00
46	-0.39103D-04	-0.66278D-03	0.11639D+00	0.23321D-01	-0.12072D-01	-0.12482D-01	-0.39103D-04	0.41993D+01	0.11639D+00
47	0.79633D-04	-0.11735D-02	0.12604D+00	0.25506D-01	-0.22013D-01	-0.40168D-01	0.40008D+00	0.41988D+01	0.12604D+00
48	0.73362D-04	-0.32488D-02	0.13220D+00	-0.72098D-02	-0.32528D-01	-0.13654D+00	0.80007D+00	0.41968D+01	0.13220D+00
49	-0.56315D-04	-0.13173D-02	0.12405D+00	-0.25893D-01	-0.19193D-01	0.26987D-01	0.11999D+01	0.41987D+01	0.12405D+00
50	0.34697D-04	-0.71851D-03	0.11409D+00	-0.24498D-01	-0.10665D-01	0.11047D-01	0.16000D+01	0.41993D+01	0.11409D+00
51	0.23015D-03	-0.13801D-02	0.10753D+00	0.39210D-02	-0.26407D-01	-0.85511D-02	0.23015D-03	0.47986D+01	0.10753D+00
52	0.29263D-03	-0.16111D-02	0.11003D+00	0.77195D-02	-0.33394D-01	-0.24254D-01	0.40029D+00	0.47984D+01	0.11003D+00
53	0.11038D-04	-0.21064D-02	0.11251D+00	0.16155D-02	-0.44457D-01	-0.16006D+00	0.80001D+00	0.47979D+01	0.11251D+00
54	-0.23905D-03	-0.15266D-02	0.10970D+00	-0.98937D-02	-0.32169D-01	0.24161D-01	0.11998D+01	0.47984D+01	0.10970D+00
55	-0.19464D-03	-0.13993D-02	0.10658D+00	-0.53561D-02	-0.32726D-01	0.91710D-02	0.15998D+01	0.47986D+01	0.10658D+00
56	0.12991D-03	-0.17241D-02	0.84849D-01	-0.46787D-02	-0.54147D-01	0.89120D-02	0.12991D-03	0.53983D+01	0.84848D-01
57	0.46674D-04	-0.21183D-02	0.84147D-01	0.40799D-04	-0.54207D-01	-0.12250D-01	0.40005D+00	0.53979D+01	0.84147D-01
58	0.34266D-04	-0.28138D-02	0.84485D-01	0.16687D-02	-0.63805D-01	-0.16006D+00	0.80003D+00	0.53972D+01	0.84485D-01
59	0.88249D-04	-0.20008D-02	0.84825D-01	0.65936D-03	-0.53411D-01	0.98318D-02	0.12001D+01	0.53980D+01	0.84825D-01
60	0.75374D-05	-0.16630D-02	0.85782D-01	0.52926D-02	-0.51338D-01	-0.73828D-02	0.16000D+01	0.53983D+01	0.85782D-01
61	0.53580D-03	-0.21328D-02	0.45790D-01	-0.66176D-03	-0.74389D-01	0.13603D-01	0.53580D-03	0.59979D+01	0.45790D-01
62	0.25468D-03	-0.29596D-02	0.45825D-01	0.53322D-03	-0.72729D-01	-0.11969D-01	0.40025D+00	0.59970D+01	0.45825D-01
63	0.14991D-03	-0.43250D-02	0.47201D-01	0.55885D-02	-0.77089D-01	-0.13376D+00	0.80015D+00	0.59957D+01	0.47201D-01
64	0.64211D-05	-0.28189D-02	0.47245D-01	-0.36087D-03	-0.72982D-01	-0.62363D-02	0.12000D+01	0.59972D+01	0.47245D-01
65	-0.27532D-03	-0.20173D-02	0.47504D-01	0.17674D-02	-0.75620D-01	-0.19804D-01	0.15997D+01	0.59980D+01	0.47504D-01
66	0.13501D-02	-0.26553D-02	0.15546D-01	0.66908D-02	-0.74475D-01	0.40837D-01	0.13501D-02	0.63973D+01	0.15546D-01
67	0.77363D-03	-0.30733D-02	0.16399D-01	-0.43493D-03	-0.72122D-01	-0.94422D-02	0.40077D+00	0.63969D+01	0.16399D-01
68	-0.92938D-04	-0.57059D-02	0.15661D-01	0.12028D-03	-0.68498D-01	-0.10592D+00	0.79991D+00	0.63943D+01	0.15661D-01
69	-0.61820D-03	-0.31794D-02	0.16704D-01	0.25726D-02	-0.74396D-01	-0.46922D-02	0.11994D+01	0.63968D+01	0.16704D-01
70	-0.11747D-02	-0.25377D-02	0.16362D-01	-0.56024D-02	-0.77524D-01	-0.43024D-01	0.15988D+01	0.63975D+01	0.16382D-01
71	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.68000D+01	0.0
72	0.0	0.0	0.0	0.0	0.0	0.0	0.40000D+00	0.68000D+01	0.0
73	0.0	0.0	0.0	0.0	0.0	0.0	0.80000D+00	0.68000D+01	0.0
74	0.0	0.0	0.0	0.0	0.0	0.0	0.12000D+01	0.68000D+01	0.0
75	0.0	0.0	0.0	0.0	0.0	0.0	0.16000D+01	0.68000D+01	0.0

FRAGMENT GLOBAL LOCATION AND VELOCITY COMPONENTS

X-LOC Y-LOC Z-LOC VEL-X VEL-Y VEL-Z OMEGA-X OMEGA-Y OMEGA-Z

2 0.0 0.0 0.0 0.0 0.0 0.0 0.400000+00 0.0 0.0
3 0.0 0.0 0.0 0.0 0.0 0.0 0.800000+00 0.0 0.0
4 0.0 0.0 0.0 0.0 0.0 0.0 0.120000+01 0.0 0.0
5 0.0 0.0 0.0 0.0 0.0 0.0 0.160000+01 0.0 0.0
6 0.932030-03 0.233000-02 0.991850-02 0.303370-02 0.473190-01 -0.364160-01 0.932030-03 0.402330+00 0.991850-02
7 0.443850-03 0.281180-02 0.994800-02 -0.224900-02 0.445170-01 -0.242450-02 0.400140+00 0.402810+00 0.994800-02
8 0.936890-04 0.448860-02 0.911590-02 0.736530-04 0.393600-01 -0.828030-01 0.800090+00 0.404490+00 0.911590-02
9 -0.534390-03 0.267470-02 0.984660-02 0.965930-03 0.432630-01 -0.714190-02 0.119950+01 0.402670+00 0.984660-02
10 -0.101100-02 0.225080-02 0.952700-02 -0.367930-02 0.459390-01 0.324800-01 0.159900+01 0.402260+00 0.952700-02
11 0.194090-03 0.250560-02 0.274740-01 -0.169260-02 0.404110-01 -0.901910-02 0.194090-03 0.802510+00 0.274740-01
12 0.230540-04 0.300310-02 0.271270-01 -0.118930-03 0.397580-01 -0.219760-02 0.400020+00 0.803000+00 0.271270-01
13 -0.527870-04 0.378480-02 0.270250-01 -0.342180-02 0.425550-01 -0.951940-01 0.799950+00 0.803780+00 0.270250-01
14 -0.749870-04 0.302110-02 0.264440-01 0.799950-03 0.403940-01 -0.107990-01 0.119990+01 0.803020+00 0.264440-01
15 -0.255490-03 0.239240-02 0.268780-01 0.166780-02 0.106800-01 0.563360-02 0.159970+01 0.802390+00 0.268780-01
16 0.117670-03 0.285670-02 0.478730-01 -0.717330-03 0.287780-01 -0.254210-03 0.117670-03 0.140290+01 0.478730-01
17 0.424550-04 0.290010-02 0.480820-01 0.119120-02 0.320400-01 0.103730-01 0.400040+00 0.140290+01 0.480820-01
18 0.101050-03 0.321590-02 0.484220-01 -0.260580-03 0.395550-01 -0.116110+00 0.800100+00 0.140320+01 0.484220-01
19 0.943090-04 0.287160-02 0.481450-01 -0.592610-03 0.327100-01 -0.135630-01 0.120010+01 0.140290+01 0.481450-01
20 0.264840-04 0.208980-02 0.482120-01 0.158970-02 0.307180-01 0.745210-03 0.160000+01 0.140270+01 0.482120-01
21 0.530860-03 0.303210-02 0.612800-01 0.909730-02 0.203160-01 0.512450-02 0.530860-03 0.200300+01 0.612800-01
22 0.455600-03 0.238020-02 0.651070-01 0.971480-02 0.263550-01 0.165390-01 0.400460+00 0.200290+01 0.651070-01
23 0.168230-03 0.296390-02 0.677820-01 -0.427630-03 0.354670-01 -0.117560+00 0.800170+00 0.200300+01 0.677820-01
24 -0.135180-03 0.281770-02 0.657400-01 -0.761660-02 0.270110-01 -0.223720-01 0.119990+01 0.200280+01 0.657400-01
25 -0.202030-03 0.285050-02 0.626520-01 -0.733320-02 0.214320-01 -0.683230-02 0.159980+01 0.200290+01 0.626520-01
26 0.763000-03 0.274540-02 0.715860-01 0.240970-01 0.206670-01 0.113140-01 0.763000-03 0.260270+01 0.715860-01
27 0.715460-03 0.302550-02 0.806530-01 0.209890-01 0.287790-01 0.199960-01 0.400720+00 0.260300+01 0.806530-01
28 0.278510-03 0.385770-02 0.864740-01 0.416840-02 0.374690-01 -0.107670+00 0.800280+00 0.260390+01 0.864740-01
29 -0.306900-03 0.287730-02 0.819740-01 -0.206220-01 0.296490-01 -0.371890-01 0.119970+01 0.260290+01 0.819740-01
30 -0.352670-03 0.261770-02 0.732410-01 -0.229670-01 0.203650-01 -0.146840-01 0.159960+01 0.260260+01 0.732410-01
31 0.195800-03 0.224250-02 0.810680-01 0.302240-01 0.275130-01 0.466100-02 0.195800-03 0.300220+01 0.810680-01
32 0.245370-03 0.270510-02 0.933620-01 0.324080-01 0.3288610-01 0.227110-01 0.400250+00 0.300270+01 0.933620-01
33 0.109720-03 0.546600-02 0.103930+00 0.557600-02 0.432080-01 -0.654670-01 0.800110+00 0.300550+01 0.103930+00
34 0.891550-04 0.257800-02 0.942060-01 -0.315120-01 0.315430-01 -0.331410-01 0.120010+01 0.300260+01 0.942060-01
35 0.156390-03 0.211390-02 0.822440-01 -0.291030-01 0.252150-01 -0.767470-02 0.160020+01 0.300210+01 0.822440-01
36 -0.700070-03 0.140010-02 0.919620-01 0.304760-01 0.238230-01 -0.387570-02 -0.700070-03 0.340140+01 0.919620-01
37 -0.559010-03 0.173710-02 0.105760+00 0.389320-01 0.266590-01 0.128960-01 0.399440+00 0.340170+01 0.105760+00
38 0.166880-03 0.356380-02 0.118670+00 -0.105820-04 0.286650-01 0.451870-02 0.800170+00 0.340360+01 0.118670+00
39 0.859530-03 0.167040-02 0.105660+00 -0.388790-01 0.246090-01 -0.202890-01 0.120090+01 0.340170+01 0.105660+00
40 0.101510-02 0.125590-02 0.918520-01 -0.300720-01 0.194050-01 -0.724000-03 0.160100+01 0.340130+01 0.918520-01
41 -0.676960-03 0.122950-03 0.959660-01 0.328970-01 -0.225830-02 0.950110-02 -0.676960-03 0.380010+01 0.959660-01
42 -0.580530-03 -0.767080-04 0.110190+00 0.382890-01 -0.524330-02 -0.204360-01 0.399420+00 0.379990+01 0.110190+00
43 0.138790-03 -0.318950-02 0.121650+00 -0.848480-02 -0.133190-01 -0.715920-01 0.800140+00 0.379680+01 0.121650+00
44 0.697100-03 -0.337490-03 0.108520+00 -0.396590-01 -0.854430-02 0.162270-01 0.120070+01 0.379970+01 0.108520+00
45 0.748810-03 0.388730-04 0.937370-01 -0.350110-01 -0.585760-02 -0.945320-02 0.160070+01 0.380000+01 0.937370-01
46 -0.192670-05 -0.425100-03 0.954860-01 0.282550-01 0.652640-03 -0.199840-01 -0.192670-05 0.419960+01 0.954860-01
47 0.779280-04 -0.889320-03 0.106690+00 0.284780-01 -0.116920-01 -0.440320-01 0.400080+00 0.419910+01 0.106690+00
48 0.293640-04 -0.279660-02 0.113610+00 -0.702760-02 -0.224520-01 -0.122540+00 0.800030+00 0.419720+01 0.113610+00
49 -0.149310-03 -0.101020-02 0.104640+00 -0.292780-01 -0.940360-02 0.337580-01 0.113990+01 0.419900+01 0.104640+00
50 -0.102090-03 -0.449770-03 0.929750-01 -0.297700-01 0.143200-02 0.186920-01 0.159990+01 0.419960+01 0.929750-01
51 0.420620-04 -0.111200-02 0.981650-01 0.249650-02 -0.916670-02 -0.181010-01 0.420620-04 0.479890+01 0.981650-01
52 0.148200-03 -0.127170-02 0.980670-01 0.675260-02 -0.199640-01 -0.318160-01 0.400150+00 0.479870+01 0.980670-01
53 -0.407060-04 -0.159620-02 0.100090+00 0.835300-03 -0.314870-01 -0.143230+00 0.799960+00 0.479840+01 0.100090+00
54 -0.193740-03 -0.122260-02 0.974020-01 -0.925150-02 -0.191370-01 0.331170-01 0.119380+01 0.479880+01 0.974020-01
55 -0.972400-04 -0.115170-02 0.945720-01 -0.469220-02 -0.713190-02 0.187720-01 0.159990+01 0.479880+01 0.945720-01
56 -0.951310-04 -0.128600-02 0.831340-01 -0.136820-01 -0.424250-01 0.329010-02 -0.951310-04 0.539870+01 0.831340-01
57 -0.136760-03 -0.181530-02 0.794600-01 -0.618140-02 -0.445820-01 -0.160110-01 0.399860+00 0.539820+01 0.794600-01
58 0.588650-05 -0.255410-02 0.781060-01 0.205030-03 -0.541370-01 -0.151520+00 0.800010+00 0.539740+01 0.781060-01
59 0.228110-03 -0.175340-02 0.795910-01 0.581790-02 -0.439930-01 0.146740-01 0.120020+01 0.539820+01 0.795910-01
60 0.194880-03 -0.132240-02 0.831340-01 0.132270-01 -0.397510-01 -0.106940-02 0.160020+01 0.539870+01 0.831340-01
61 0.410080-03 -0.163830-02 0.475310-01 -0.841420-02 -0.730340-01 0.191870-01 0.410080-03 0.599840+01 0.475310-01
62 0.160920-03 -0.276700-02 0.449050-01 -0.404600-02 -0.690460-01 -0.596630-02 0.400160+00 0.599720+01 0.449050-01
63 0.154690-03 -0.435510-02 0.449380-01 0.511330-02 -0.714290-01 -0.131430+00 0.800150+00 0.599560+01 0.449380-01
64 0.881690-04 -0.264190-02 0.459960-01 0.436470-02 -0.690710-01 -0.101410-01 0.120010+01 0.599740+01 0.459960-01
65 -0.170140-03 -0.156890-02 0.486620-01 0.893430-02 -0.737520-01 -0.240560-01 0.159980+01 0.599840+01 0.486620-01
66 0.127520-02 -0.233810-02 0.168820-01 0.246710-02 -0.772920-01 0.508310-01 0.127520-02 0.639770+01 0.168820-01
67 0.757860-03 -0.294170-02 0.163450-01 -0.301530-02 -0.712650-01 -0.106150-02 0.400760+00 0.639710+01 0.163450-01

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68	-0.10223D-03	-0.56997D-02	0.15070D-01	0.58109D-05	-0.65642D-01	-0.10663D+00	0.79990D+00	0.63943D+01	0.15070D-01
69	-0.61369D-03	-0.30584D-02	0.1E515D-01	0.47010D-02	-0.73064D-01	-0.11233D-01	0.11994D+01	0.63969D+01	0.16515D-01
70	-0.11145D-02	-0.22437D-02	0.17411D-01	-0.19308D-02	-0.79391D-01	-0.56187D-01	0.15989D+01	0.63978D+01	0.17411D-01
71	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.68000D+01	0.0
72	0.0	0.0	0.0	0.0	0.0	0.0	0.40000D+00	0.68000D+01	0.0
73	0.0	0.0	0.0	0.0	0.0	0.0	0.80000D+00	0.68000D+01	0.0
74	0.0	0.0	0.0	0.0	0.0	0.0	0.12000D+01	0.68000D+01	0.0
75	0.0	0.0	0.0	0.0	0.0	0.0	0.16000D+01	0.68000D+01	0.0

FRAGMENT GLOBAL LOCATION AND VELOCITY COMPONENTS

X-LOC	Y-LOC	Z-LOC	VEL-X	VEL-Y	VEL-Z	OMEGA-X	OMEGA-Y	OMEGA-Z
0.800126D+00	0.376221D+01	-0.478863D+00	-0.109028D+01	0.121354D+04	-0.108176D+04	0.239815D+04	-0.100262D+01	0.915274D+00

STRAIN COMPONENTS, PRINCIPAL (TENSILE) STRAIN AND DIRECTION AT USER-SPECIFIED NODES

NODE	EPS-X STRAIN		EPS-Y STRAIN		SHEAR STRAIN		PRINC. STRAIN(T)		DIRECTION(DEG.)	
	INNER	OUTER	INNER	OUTER	INNER	OUTER	INNER	OUTER	INNER	OUTER
38	-0.2735D-01	0.3090D-01	-0.1792D-01	-0.2876D-02	0.8563D-03	-0.9511D-03	0.0	0.3091D-01	0.0	-0.8064D+00
39	0.7825D-02	-0.4189D-02	-0.9437D-02	0.2759D-02	-0.7140D-02	0.9759D-03	0.8535D-02	0.2793D-02	-0.1123D+02	0.8600D+02
43	-0.2572D-01	0.2900D-01	-0.1643D-01	0.7198D-03	-0.1470D-01	0.1393D-01	0.0	0.3062D-01	0.0	0.1312D+02
44	0.5460D-02	-0.2353D-02	-0.7445D-02	0.8261D-03	0.6359D-02	-0.1321D-03	0.6201D-02	0.8274D-03	0.1312D+02	-0.8881D+02
48	-0.1562D-01	0.1511D-01	0.4081D-02	-0.5885D-03	-0.2470D-01	0.2432D-01	0.1003D-01	0.2173D-01	-0.6429D+02	0.2858D+02
49	0.9222D-03	-0.3887D-03	-0.2326D-03	-0.1710D-02	0.8865D-02	-0.4638D-02	0.4815D-02	0.1362D-02	0.4129D+02	-0.3705D+02
53	-0.5334D-02	0.4480D-02	-0.1050D-02	0.2446D-02	-0.2863D-01	0.2866D-01	0.1128D-01	0.1783D-01	-0.4925D+02	0.4297D+02
54	0.1065D-02	-0.1121D-02	-0.3486D-02	0.2613D-02	0.7671D-02	-0.5576D-02	0.3249D-02	0.4102D-02	0.2966D+02	-0.6190D+02

STRAIN COMPONENTS, PRINCIPAL(TENSILE) STRAIN AND DIRECTION, AND ELONGATIONS AT SPECIFIED ADDITIONAL POINTS

POINT NO.	SURFACE	EPS-X STRAIN	EPS-Y STRAIN	SHEAR STRAIN	ELONG.(DIR.1)	ELONG.(DIR.2)	PRINC. STRN(T)	DIRECTION(DEG.)
1	INNER	-0.76503D-02	-0.19381D-01	-0.29144D-02	-0.15087D-01	-0.12132D-01	0.0	0.0
1	OUTER	0.12709D-01	-0.19287D-02	0.36435D-03	0.55571D-02	0.51947D-02	0.12712D-01	0.71290D+00
2	INNER	-0.77716D-02	-0.21754D-01	0.52492D-03	-0.11607D-01	-0.15140D-01	0.0	0.0
2	OUTER	0.12555D-01	-0.10363D-03	0.84862D-03	0.66279D-02	0.57845D-02	0.12569D-01	0.19177D+01
3	INNER	-0.87068D-02	-0.19412D-02	-0.17577D-01	-0.87450D-02	-0.19430D-02	0.40929D-02	-0.55526D+02
3	OUTER	0.11179D-01	0.12706D-02	0.53272D-02	0.11118D-01	0.12698D-02	0.11850D-01	0.14132D+02
4	INNER	-0.65011D-02	-0.23416D-02	0.99634D-02	-0.65224D-02	-0.23443D-02	0.97710D-03	0.56330D+02
4	OUTER	0.85670D-02	0.18683D-02	0.21520D-03	0.85306D-02	0.18666D-02	0.85687D-02	0.92004D+00

SYSTEM ENERGIES(IN-LB)

FRAG. TRANSLATIONAL KINETIC ENERGY = 0.5041488D+03
FRAG. ROTATIONAL KINETIC ENERGY = 0.1097311D+03
WORK INPUT TO STRUCTURE = 0.9271939D+03
STRUCTURE KINETIC ENERGY = 0.1662348D+03
STRUCTURE ELASTIC ENERGY = 0.7717905D+02
STRUCTURE PLASTIC ENERGY = 0.6094116D+03
ENERGY STORED IN ELASTIC RESTRAINTS= 0.7436948D+02

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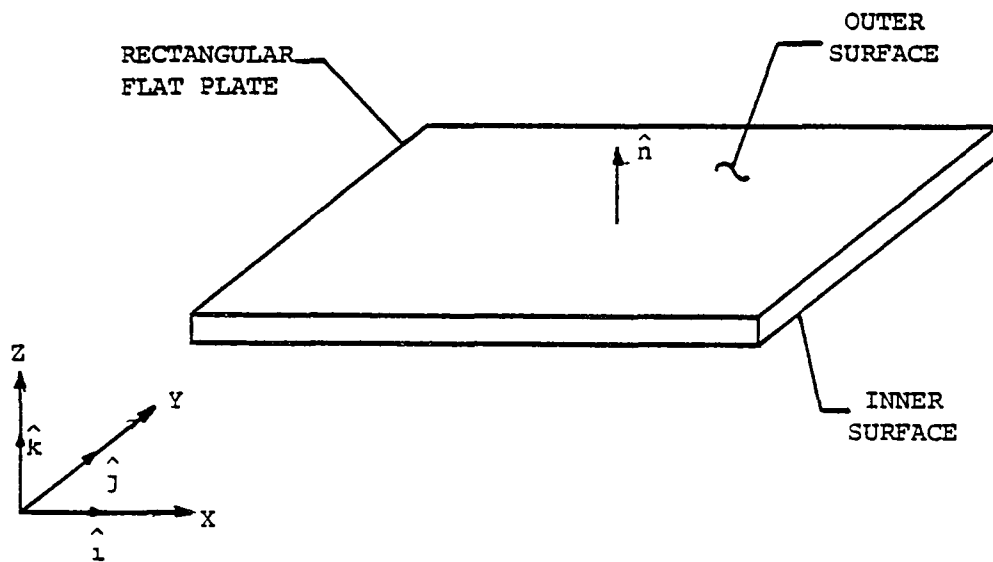
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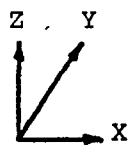
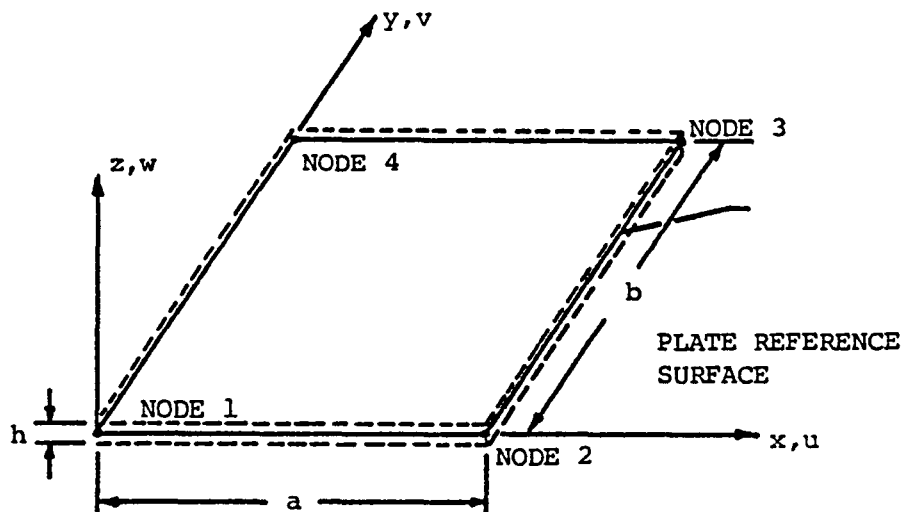


X, Y, Z -- GLOBAL RECTANGULAR
 CARTESIAN COORDINATE
 SYSTEM

$\hat{i}, \hat{j}, \hat{k}$ -- UNIT VECTORS IN THE
 GLOBAL COORDINATE
 DIRECTIONS

\hat{n} -- UNIT-OUTWARD NORMAL
 OF THE PLATE

FIG. 1 GLOBAL COORDINATES AND UNIT-OUTWARD-NORMAL DIRECTION FOR A FLAT PLATE



X, Y, Z - Global Rectangular Cartesian Coordinate System

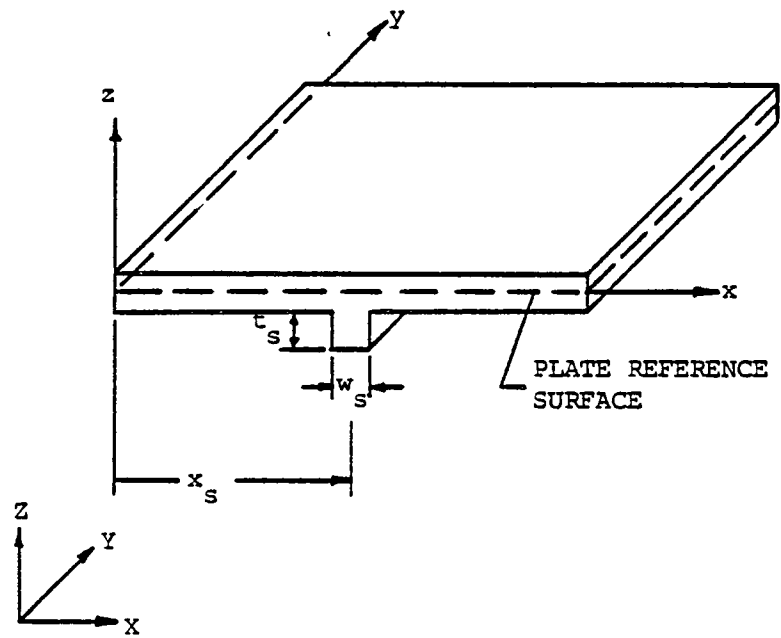
x, y, z - Local (element) Coordinate System

h - Total Element Thickness

a, b - Element Spanwise Dimension in the x and y Directions

$$\left. \begin{aligned} u, v, w \\ w_{,x} = \frac{\partial w}{\partial x} \\ w_{,y} = \frac{\partial w}{\partial y} \\ w_{,xy} = \frac{\partial^2 w}{\partial x \partial y} \end{aligned} \right\} \text{Generalized Nodal Displacements for } u, v, w: \text{ LLC Element}$$

FIG. 2 GEOMETRY AND NOMENCLATURE FOR A UNIFORM-THICKNESS RECTANGULAR PLATE ELEMENT



w_s - Width of Stiffener

t_s - Thickness of Stiffener

x_s - Local x -Location of Stiffener

FIG. 3 GEOMETRY AND NOMENCLATURE FOR A STIFFENED RECTANGULAR PLATE ELEMENT

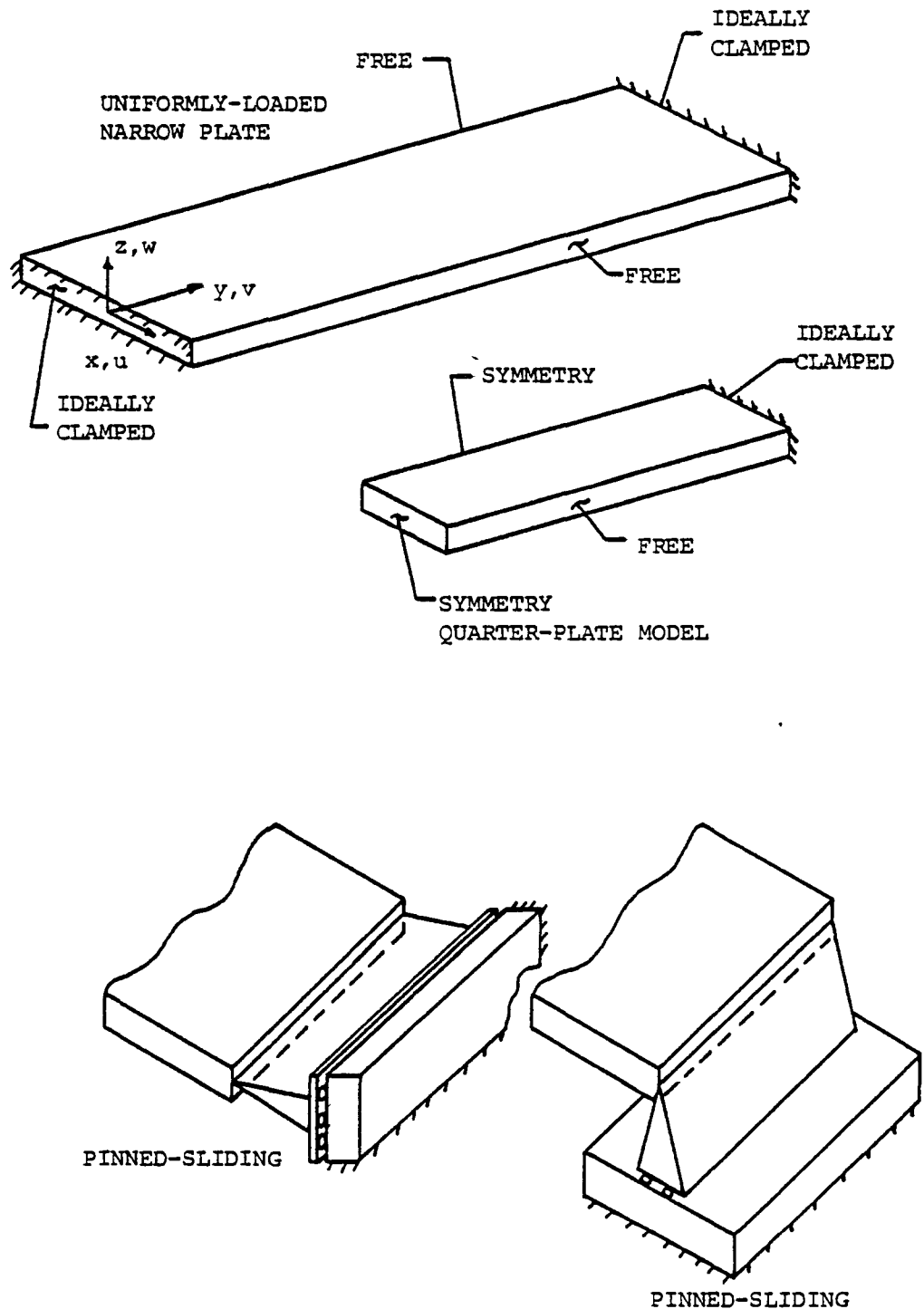
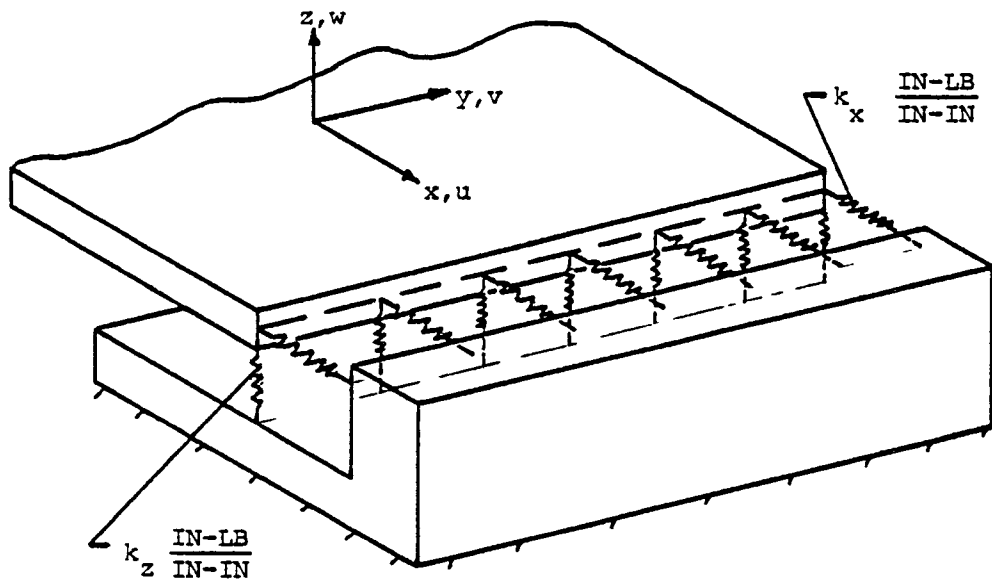
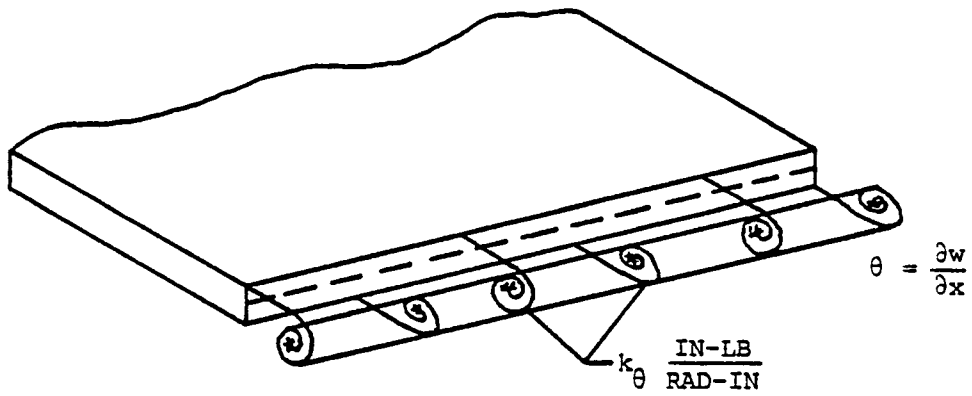


FIG. 4 SCHEMATICS OF PLATE-SIDE BOUNDARY AND ELASTIC-SPRING SUPPORT CONDITIONS

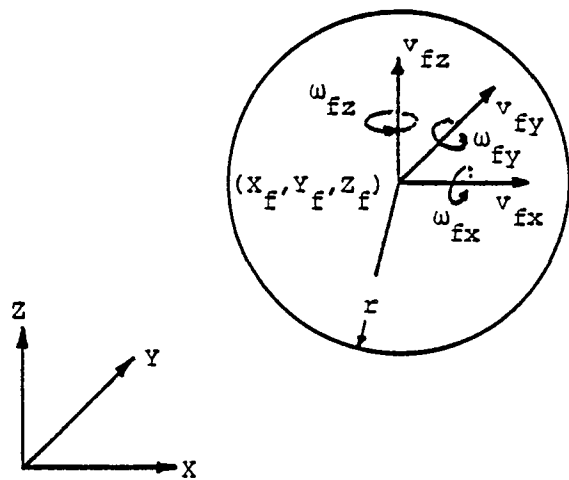


DISTRIBUTED LINE TRANSLATIONAL SPRINGS



DISTRIBUTED LINE ROTATIONAL SPRINGS

FIG. 4 CONCLUDED



X, Y, Z - Global Coordinate System.

X_f, Y_f, Z_f - Global Coordinates which
Locate the Center of Gravity
(c.g.) of the Fragment.

r - Radius of the Spherical Fragment.

v_{fx}, v_{fy}, v_{fz} - Translational Velocity Components
of the Fragment in the $X, Y,$ and Z
Directions, Respectively.

$\omega_{fx}, \omega_{fy}, \omega_{fz}$ - Rotational Velocity Components
of the Fragment in the $X, Y,$ and Z
Directions, Respectively.

FIG. 5 GEOMETRY AND NOMENCLATURE FOR AN IDEALIZED NON-DEFORMABLE SPHERICAL FRAGMENT

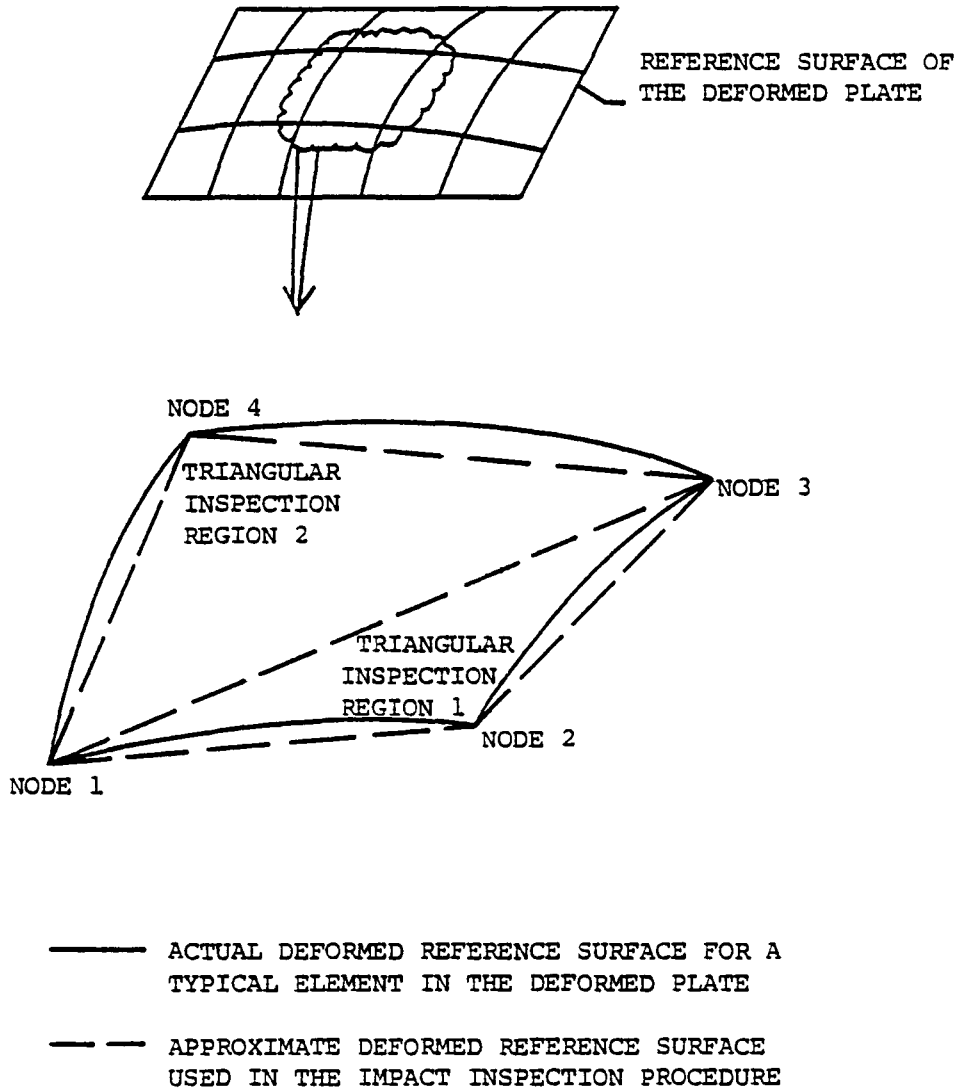


FIG. 6 IDEALIZATION OF DEFORMED PLATE FOR IMPACT INSPECTION PURPOSES

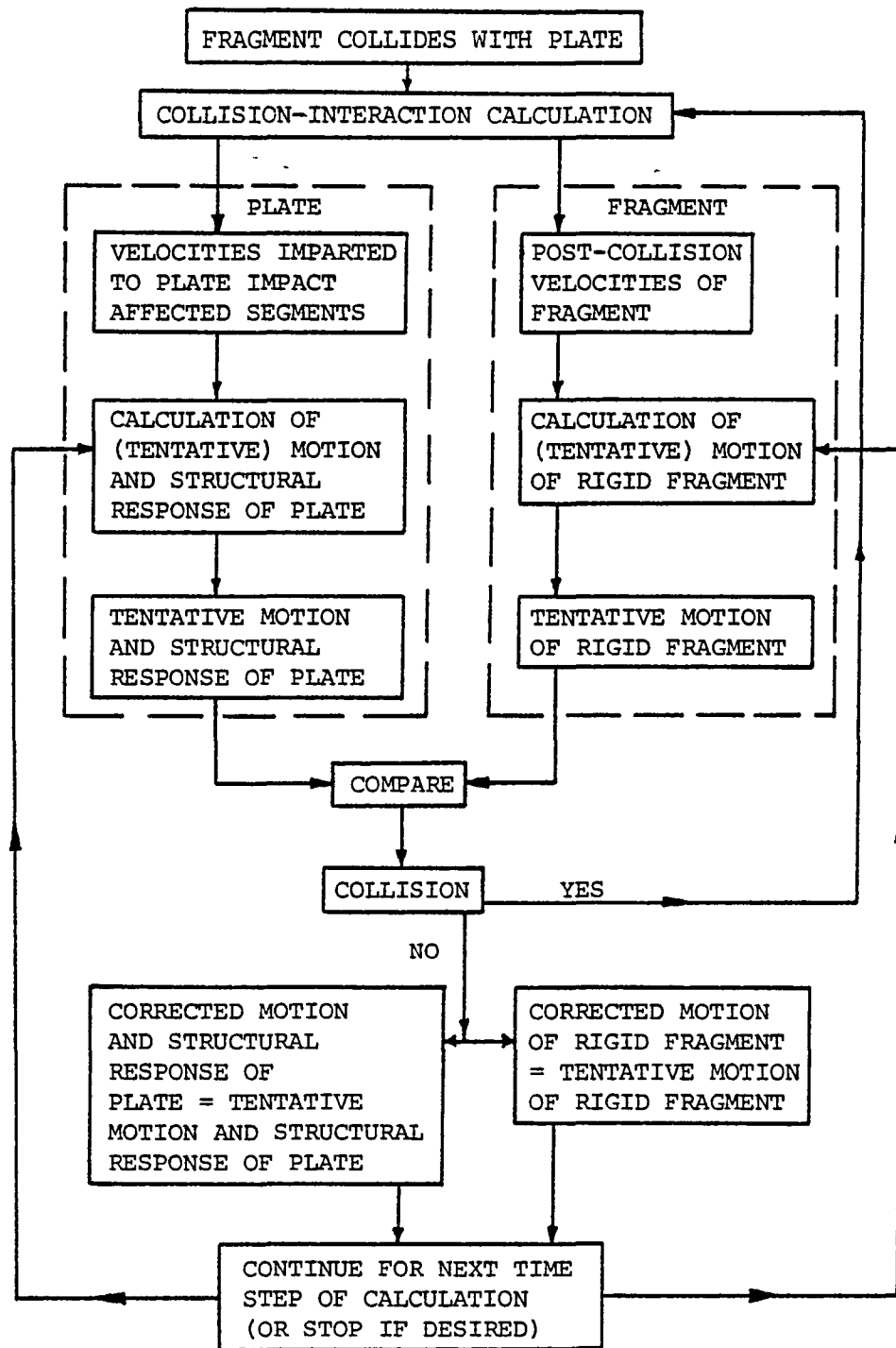


FIG. 7 INFORMATION FLOW SCHEMATIC FOR PREDICTING PLATE AND FRAGMENT MOTIONS IN THE COLLISION-IMPARTED VELOCITY METHOD

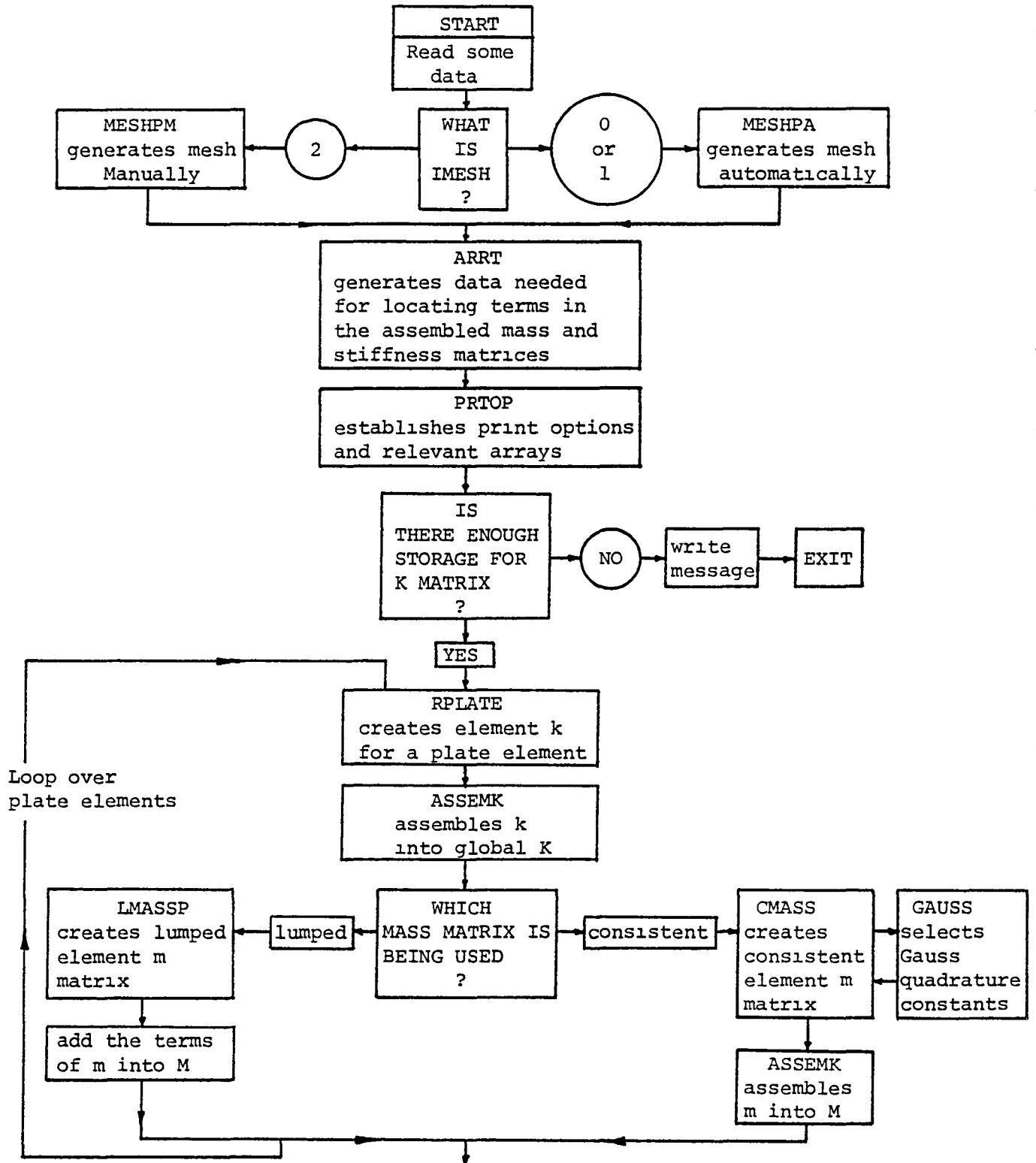


FIG. 8 FLOW CHART OF MAINP FOR THE PLATE 1 PROGRAM

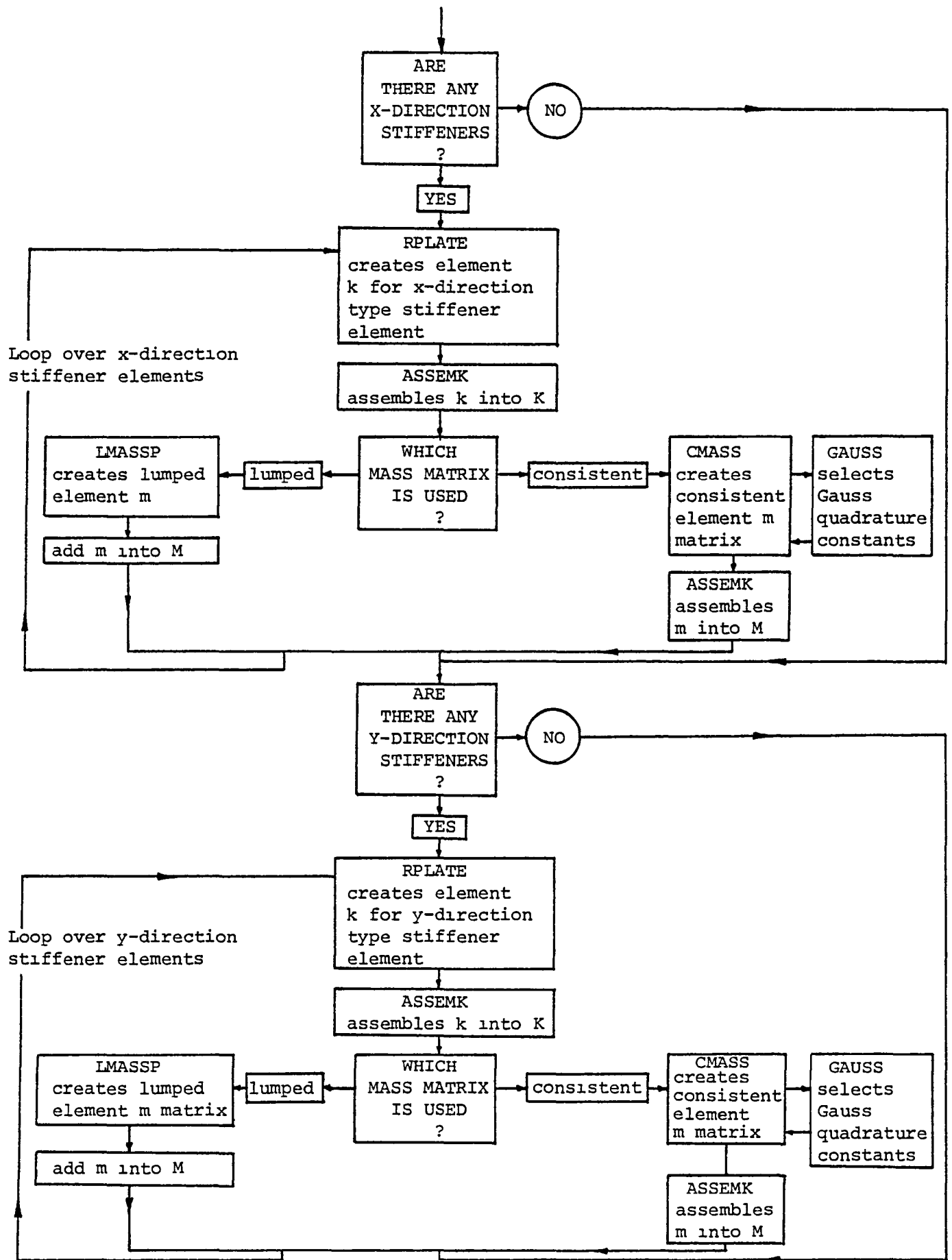


FIG. 8 CONTINUED

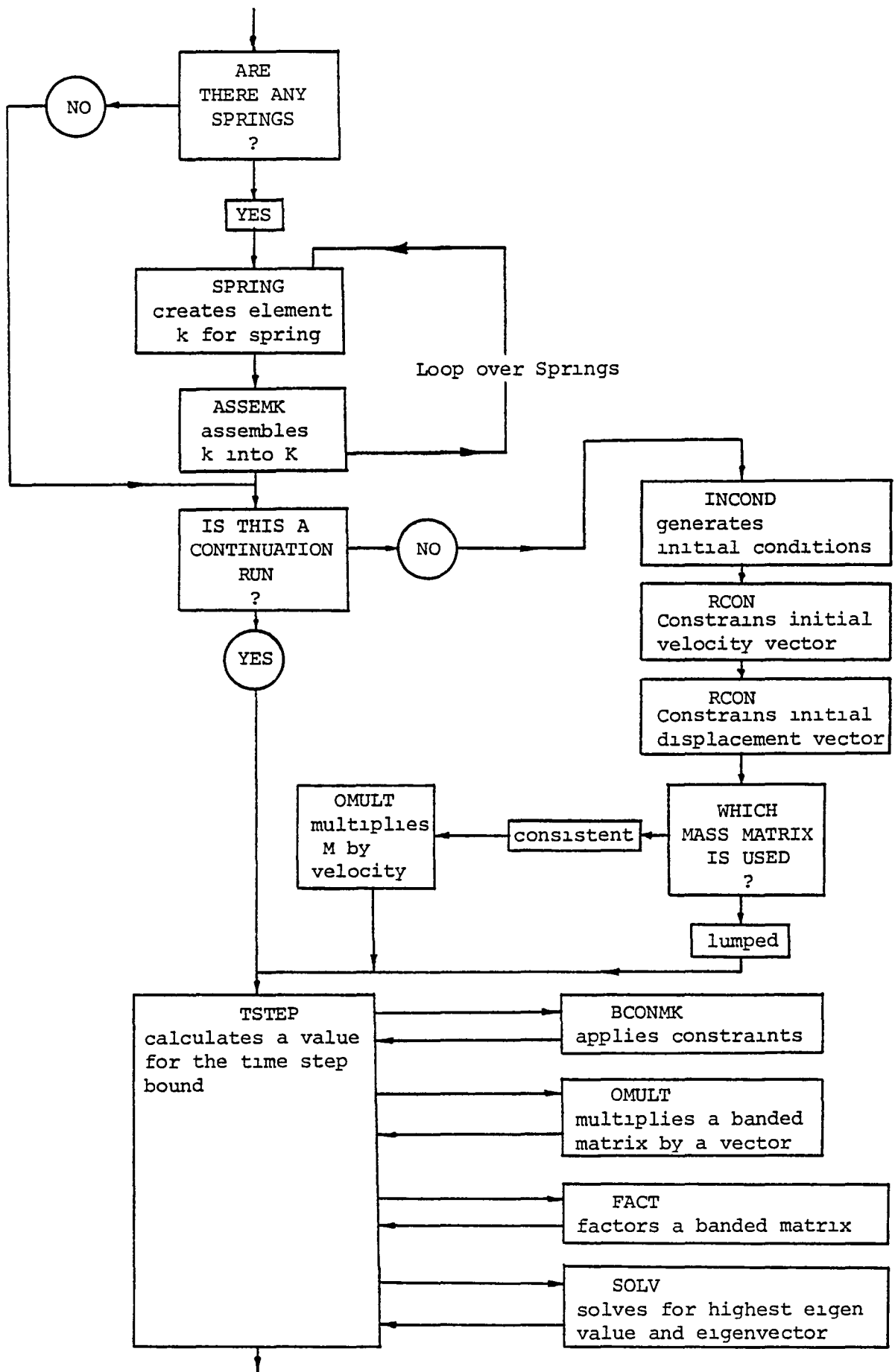


FIG. 8 CONTINUED

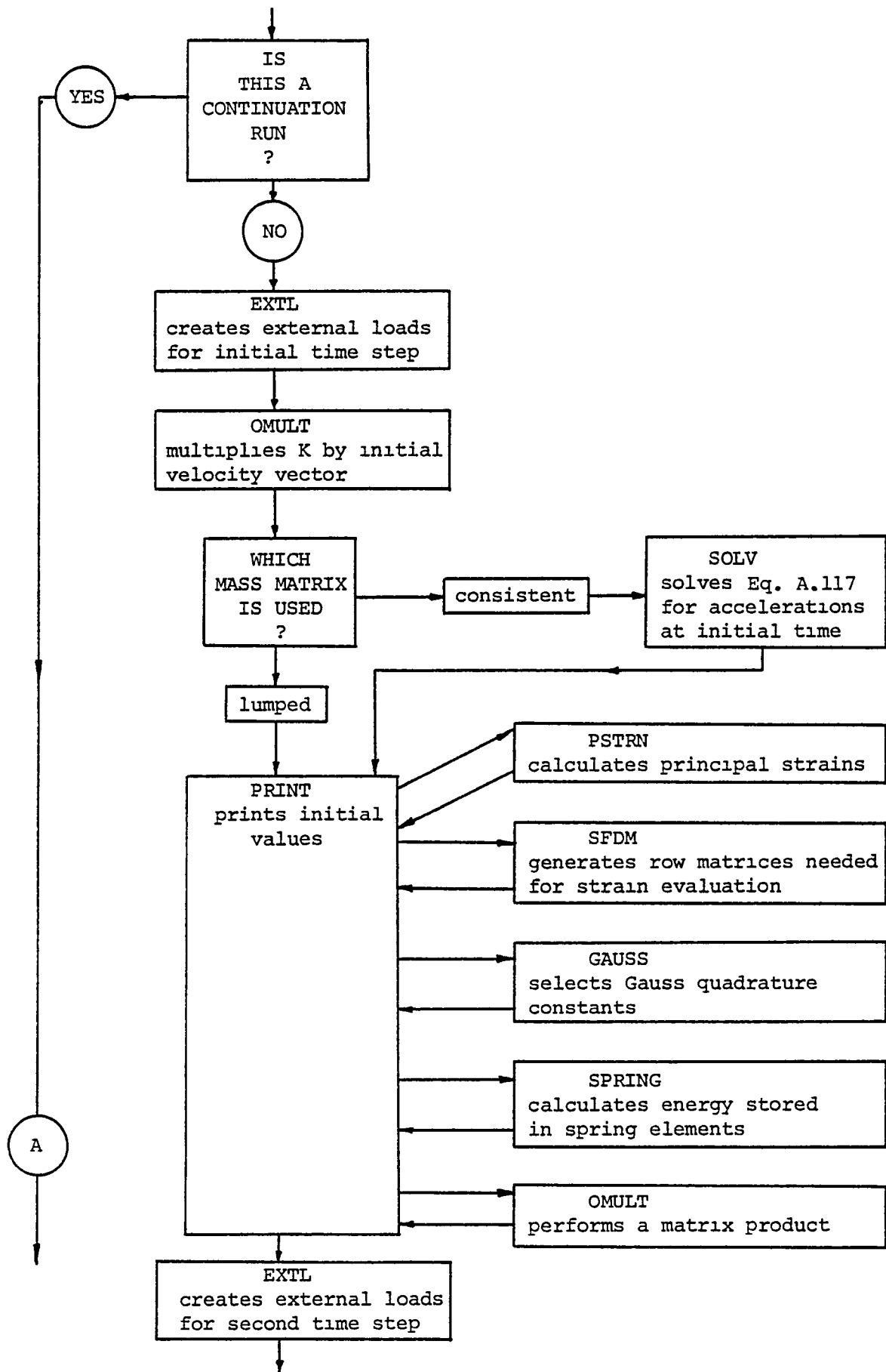


FIG. 8 CONTINUED

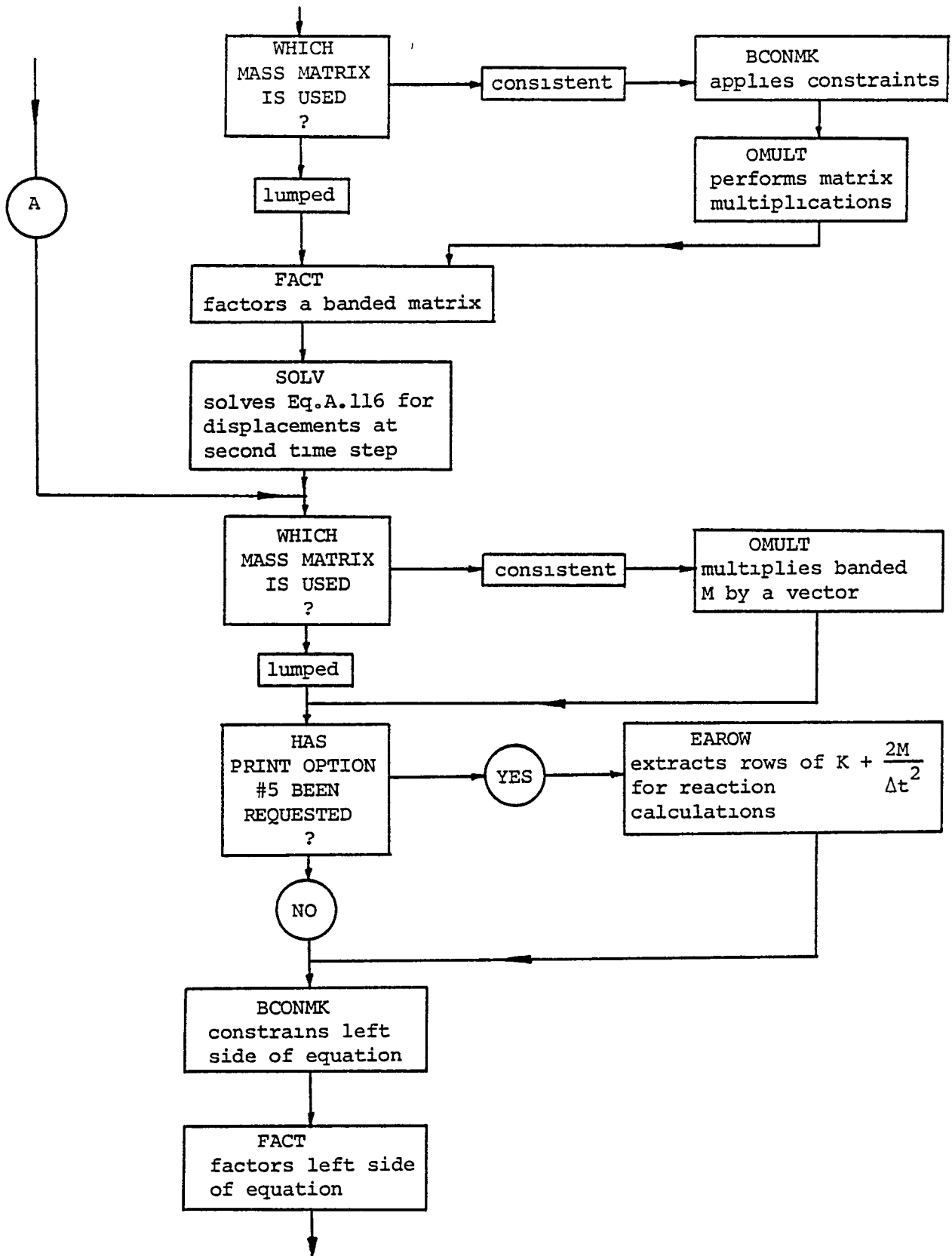


FIG. 8 CONTINUED

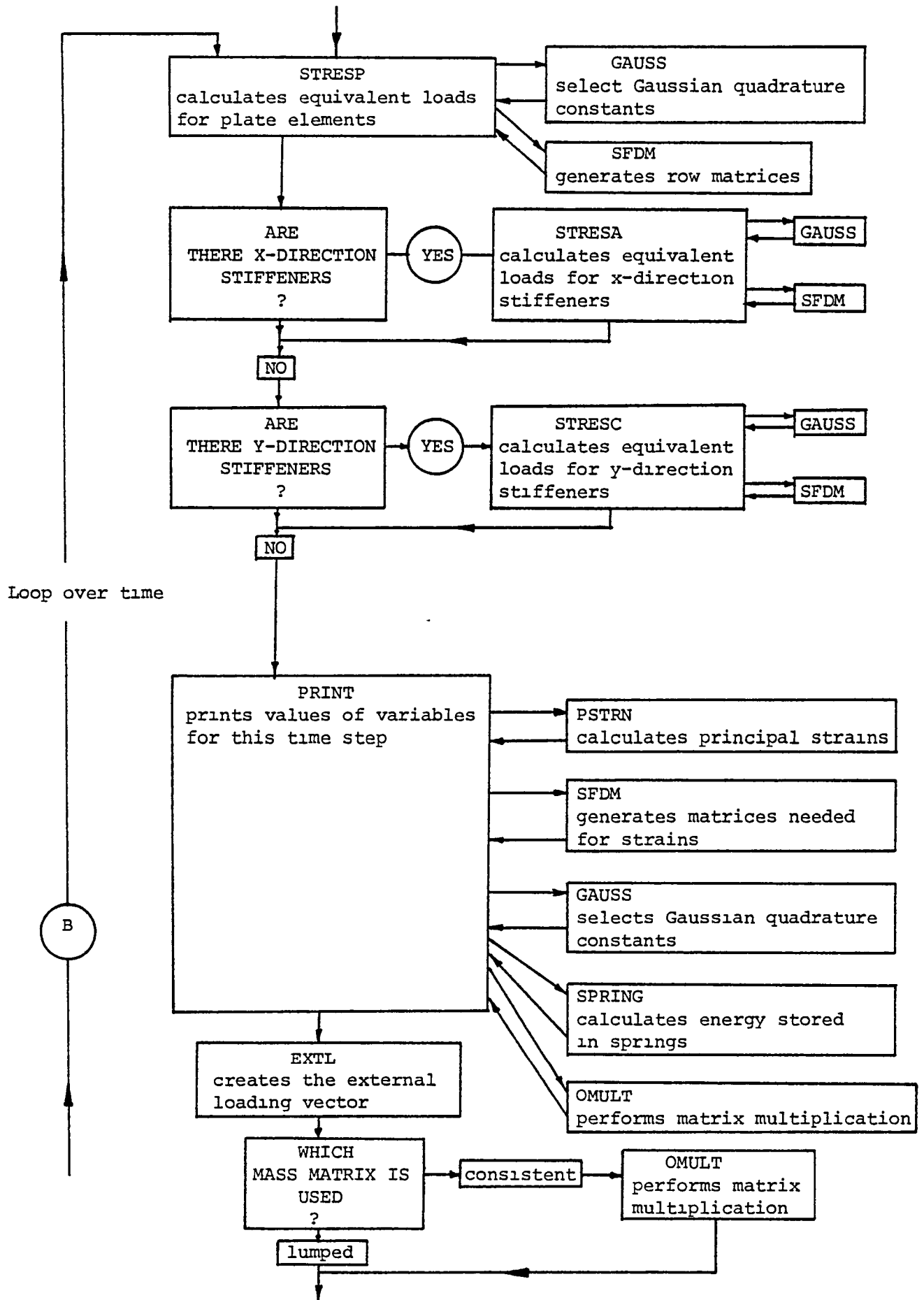


FIG. 8 (CONTINUED)

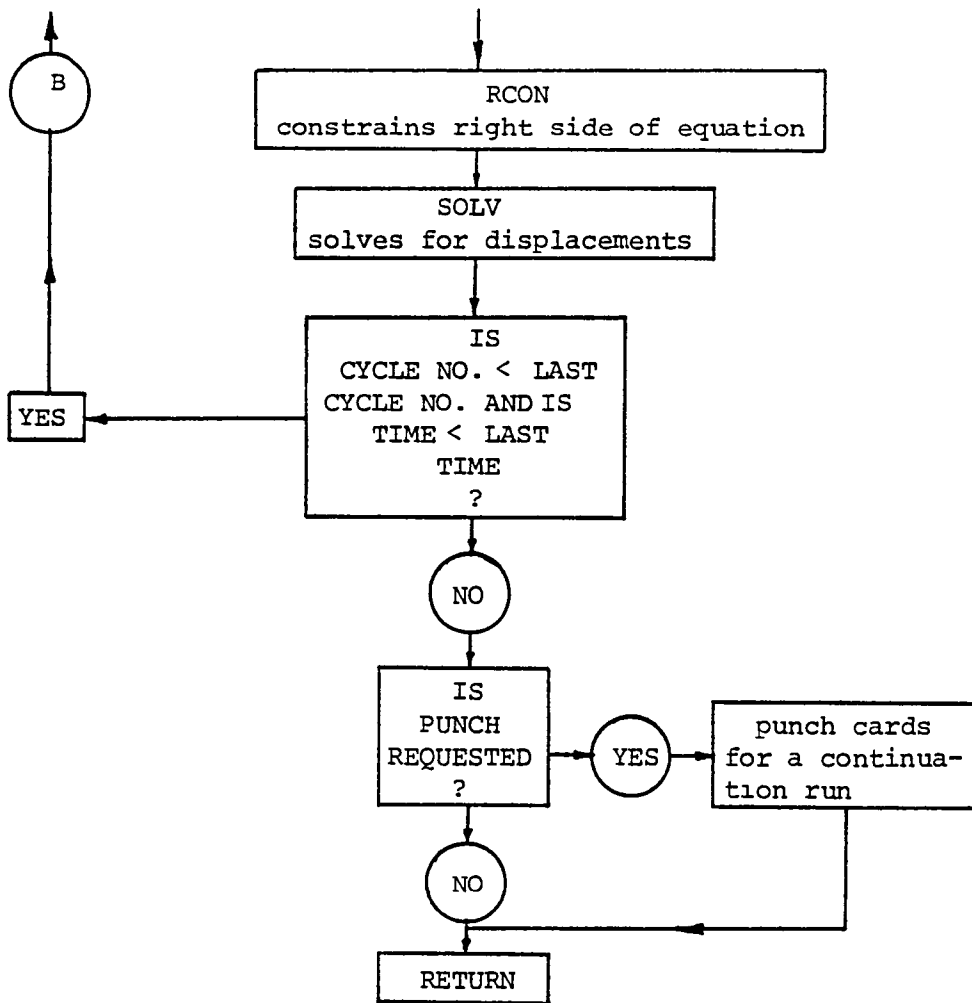


FIG. 8 CONCLUDED

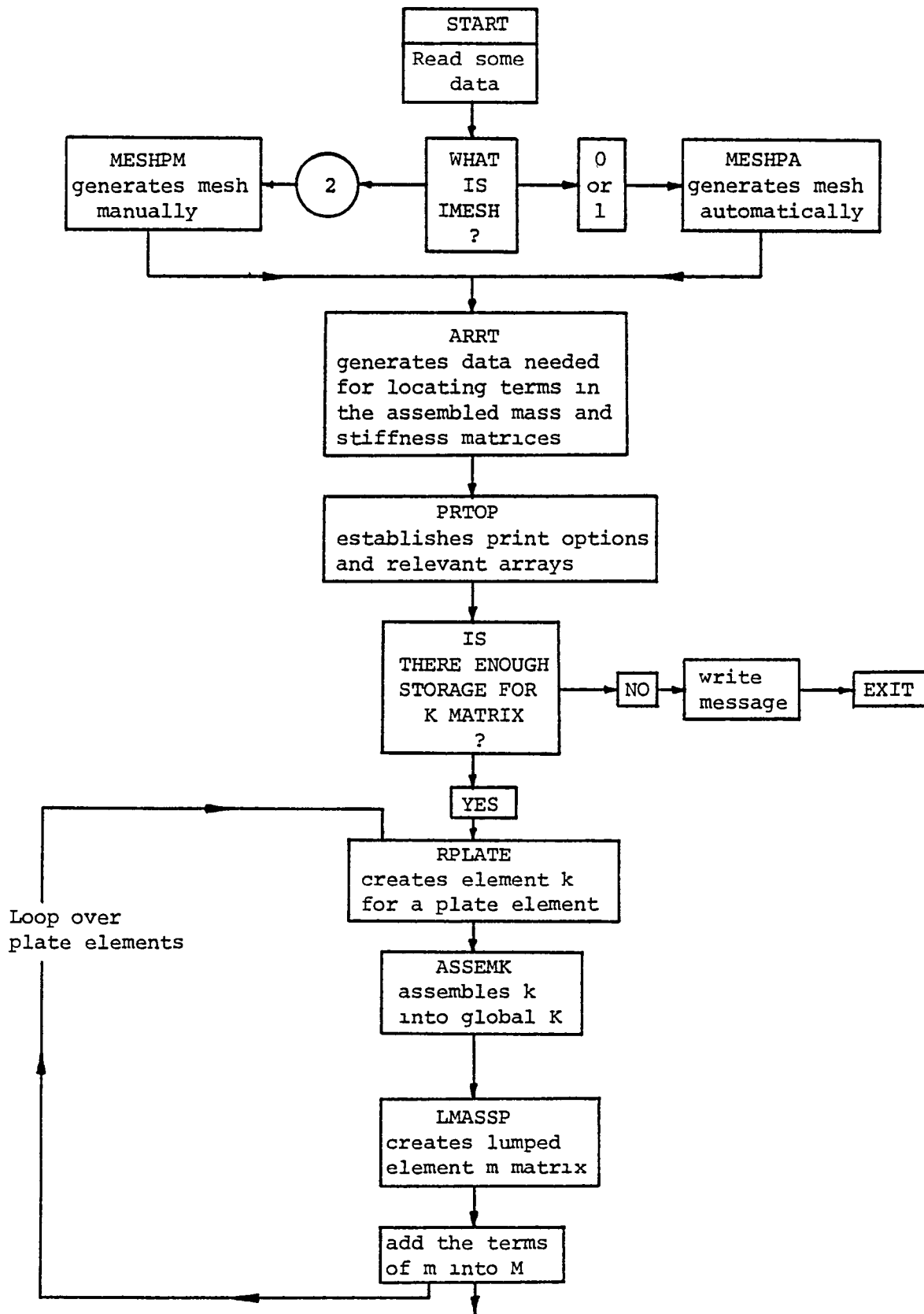


FIG. 9 FLOW CHART OF IMAINP FOR THE CIVM-PLATE 1 PROGRAM

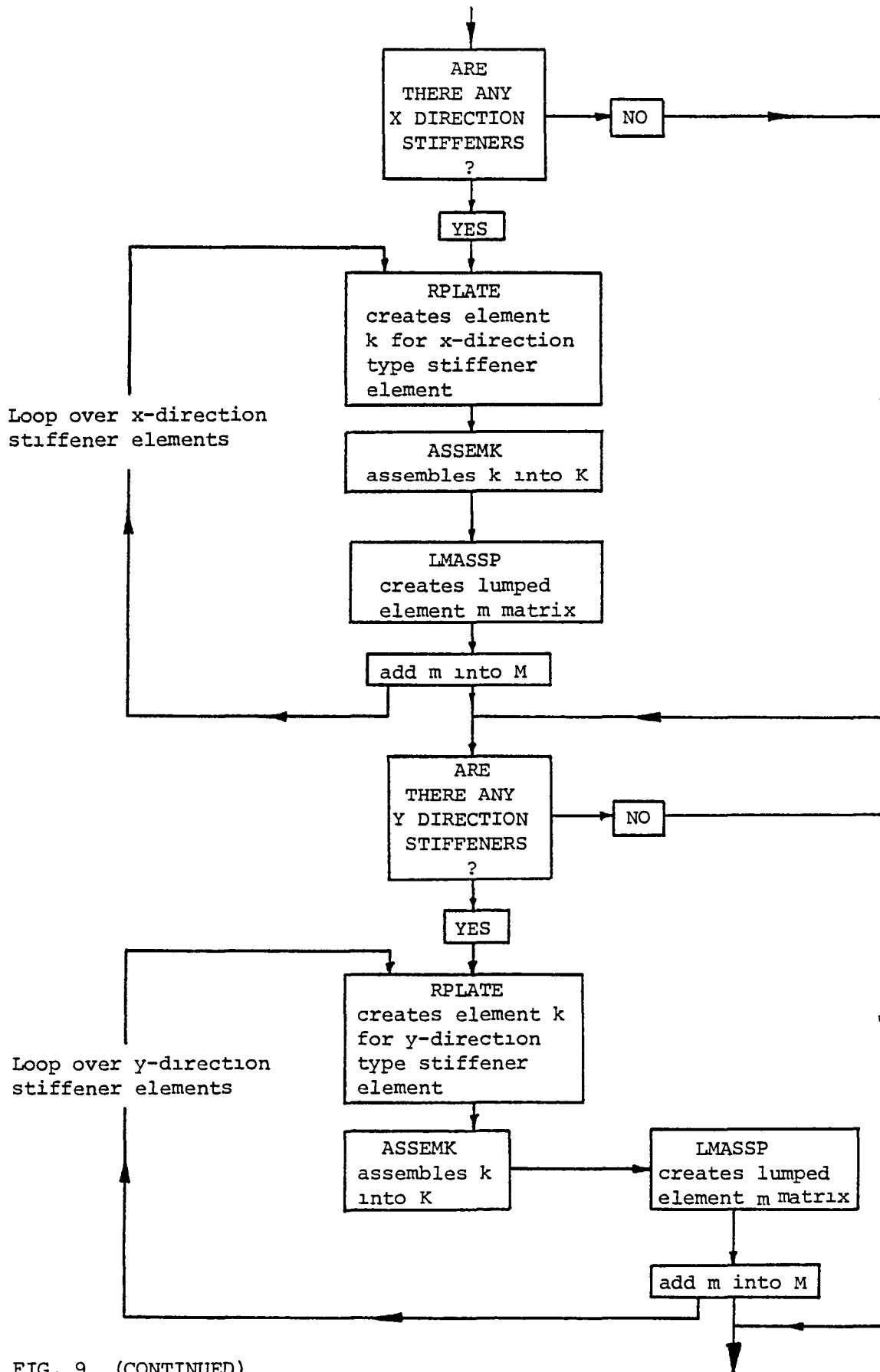


FIG. 9 (CONTINUED)

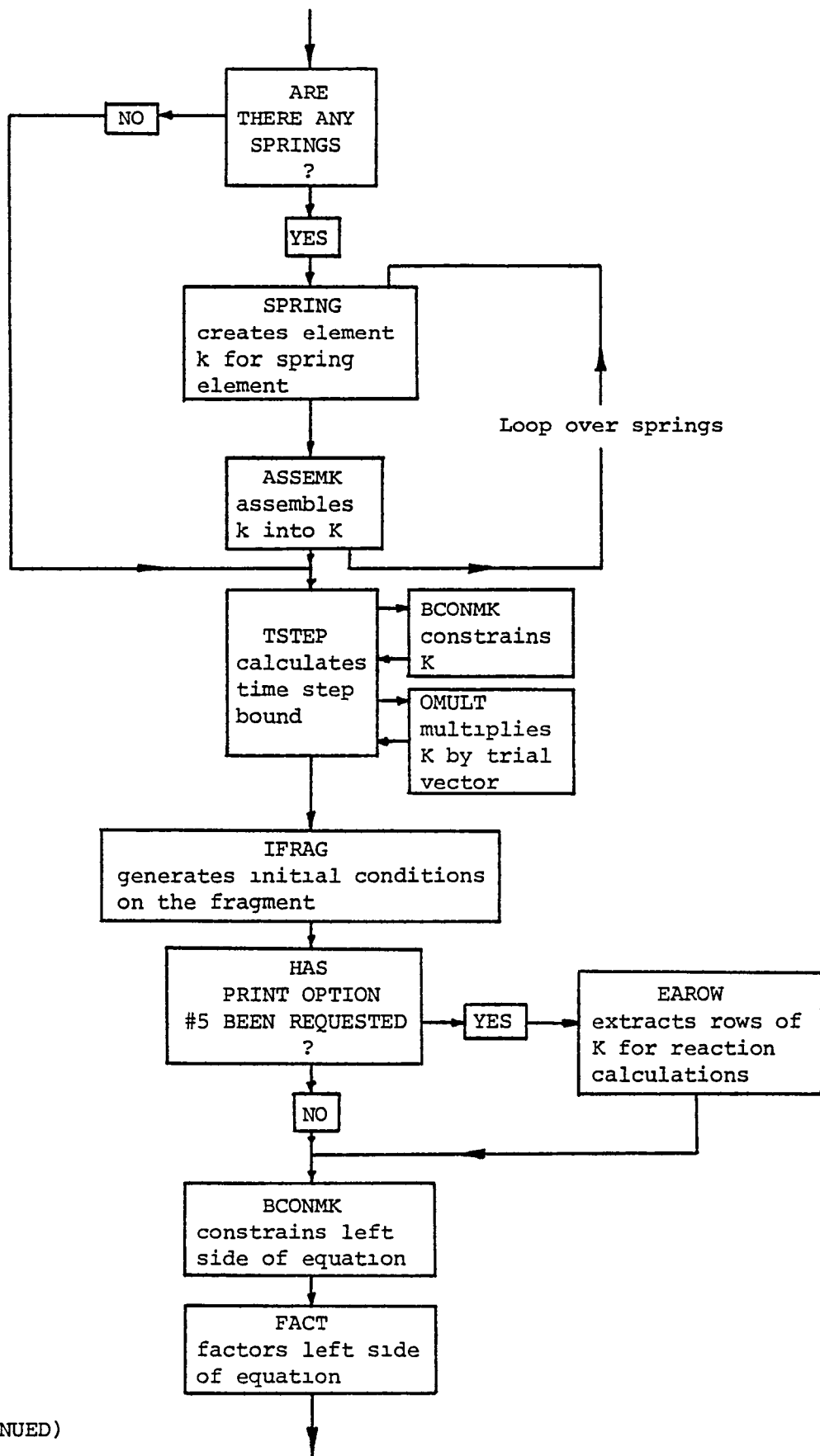


FIG. 9 (CONTINUED)

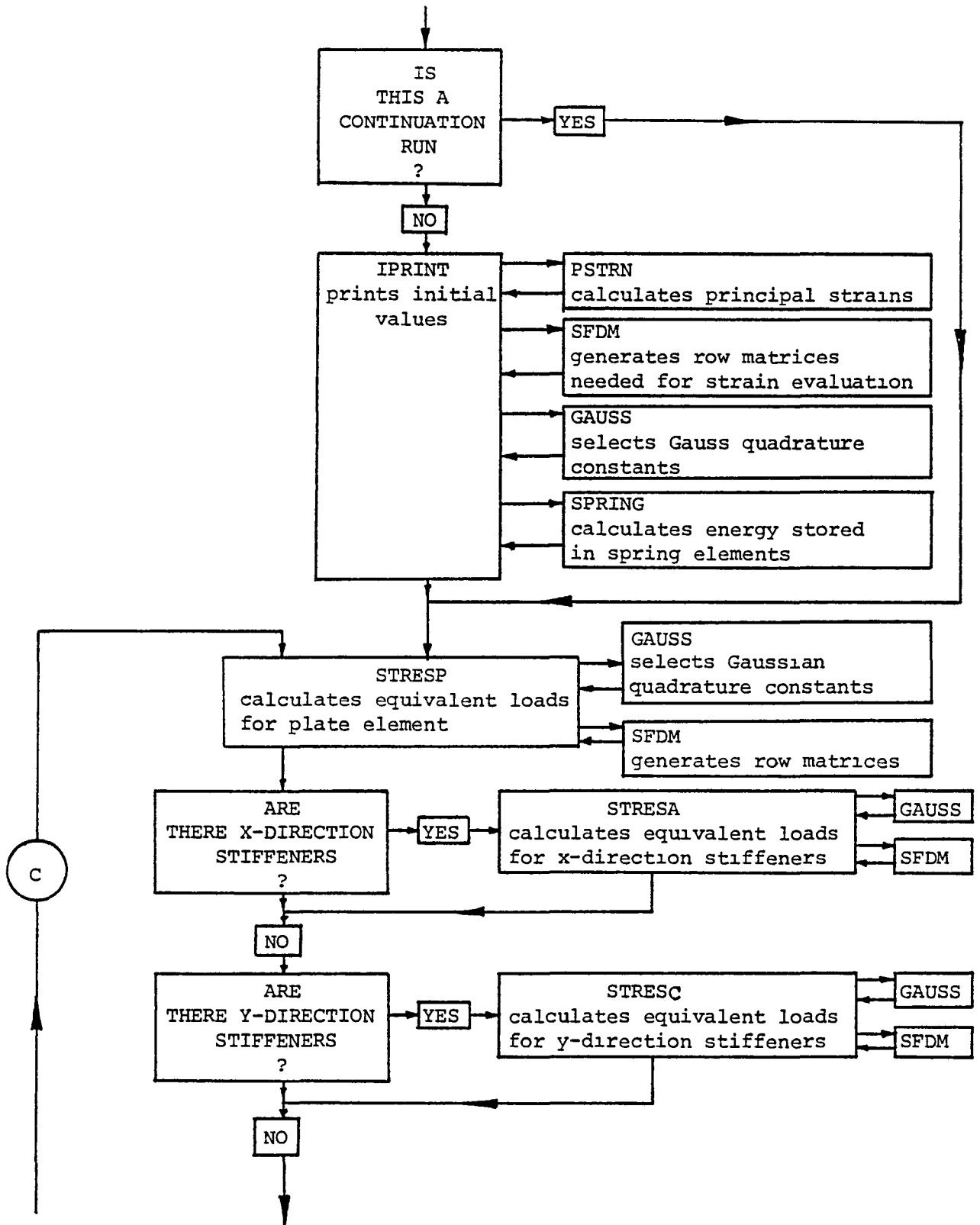


FIG. 9 (CONTINUED)

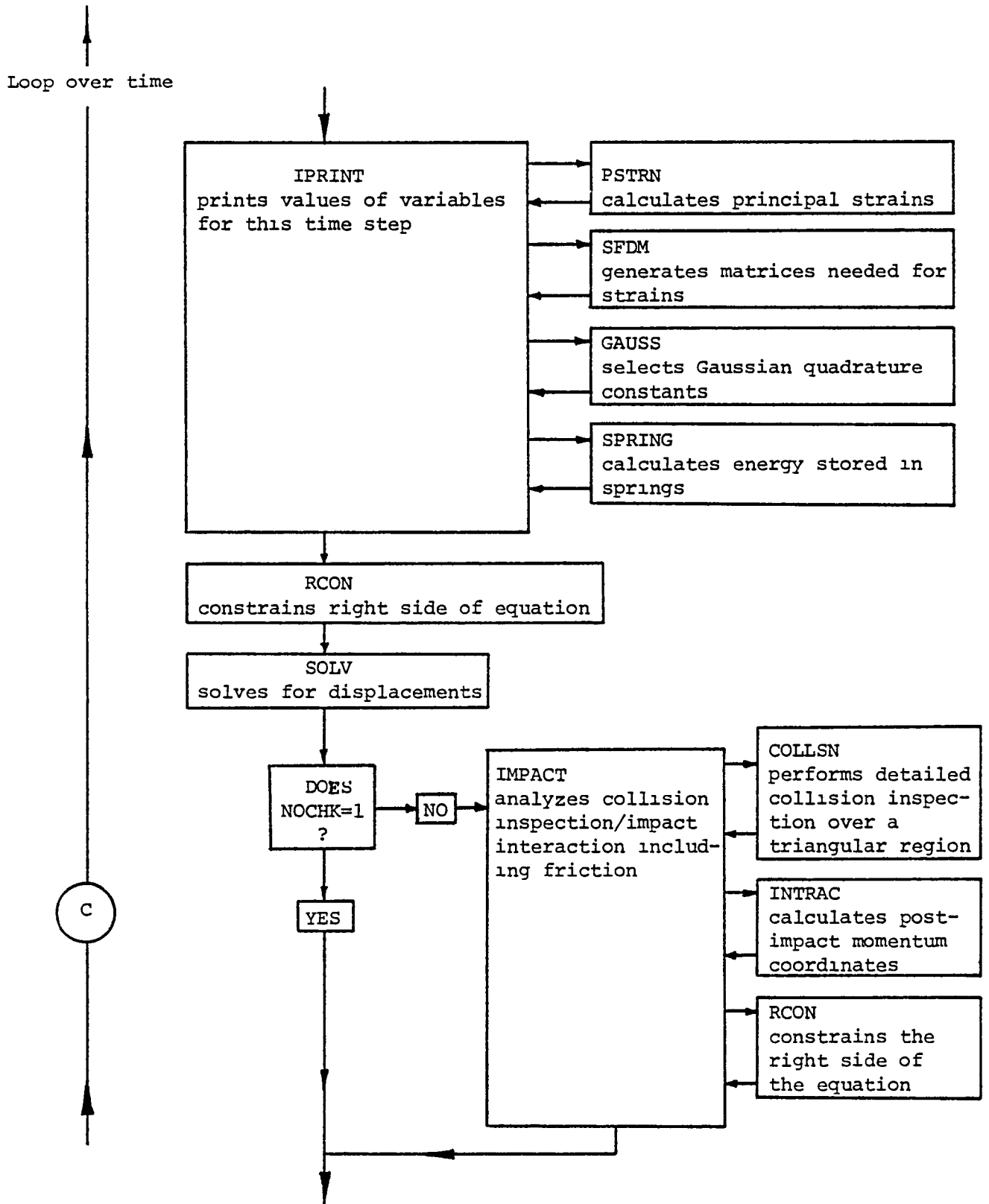


FIG. 9 (CONTINUED)

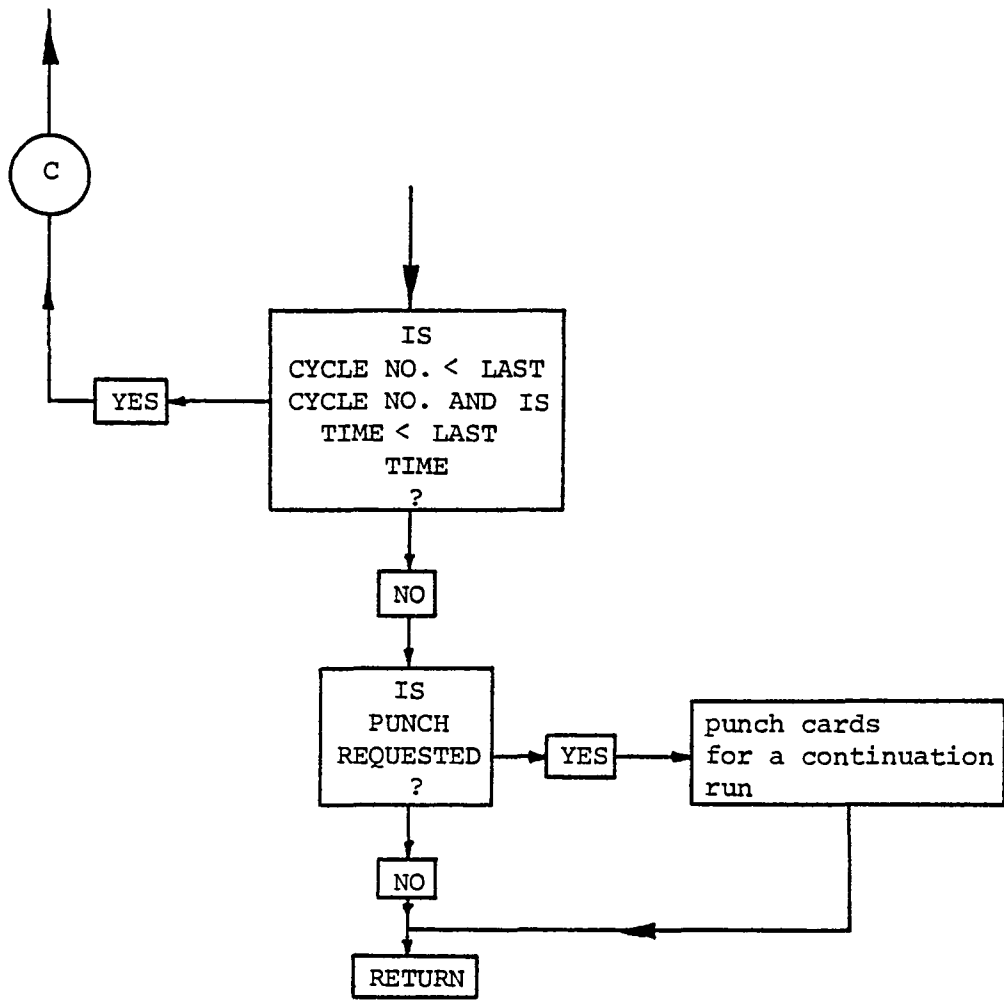
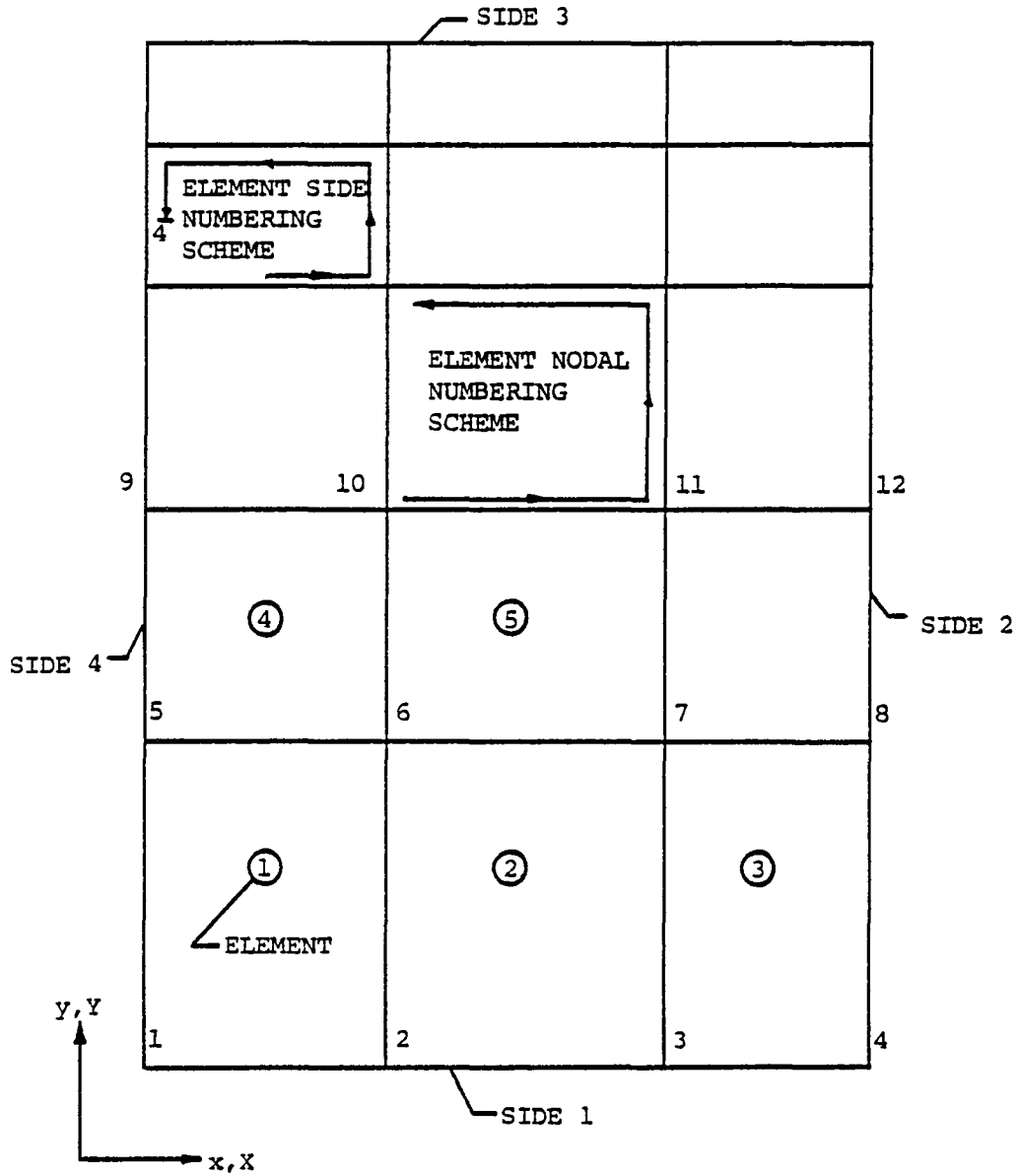


FIG. 9 (CONCLUDED)



NOTE: IF IMESH=1
 THEN COORDINATE SYSTEM
 IS AUTOMATICALLY
 ANCHORED AT STRUCTURAL
 NODE NUMBER 1

NODAL AND ELEMENT
 NUMBERING CONVENTION

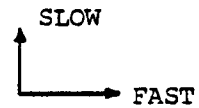


FIG. 10 NUMBERING CONVENTION ADOPTED IN THE AUTOMATED MESH GENERATION PROCEDURE

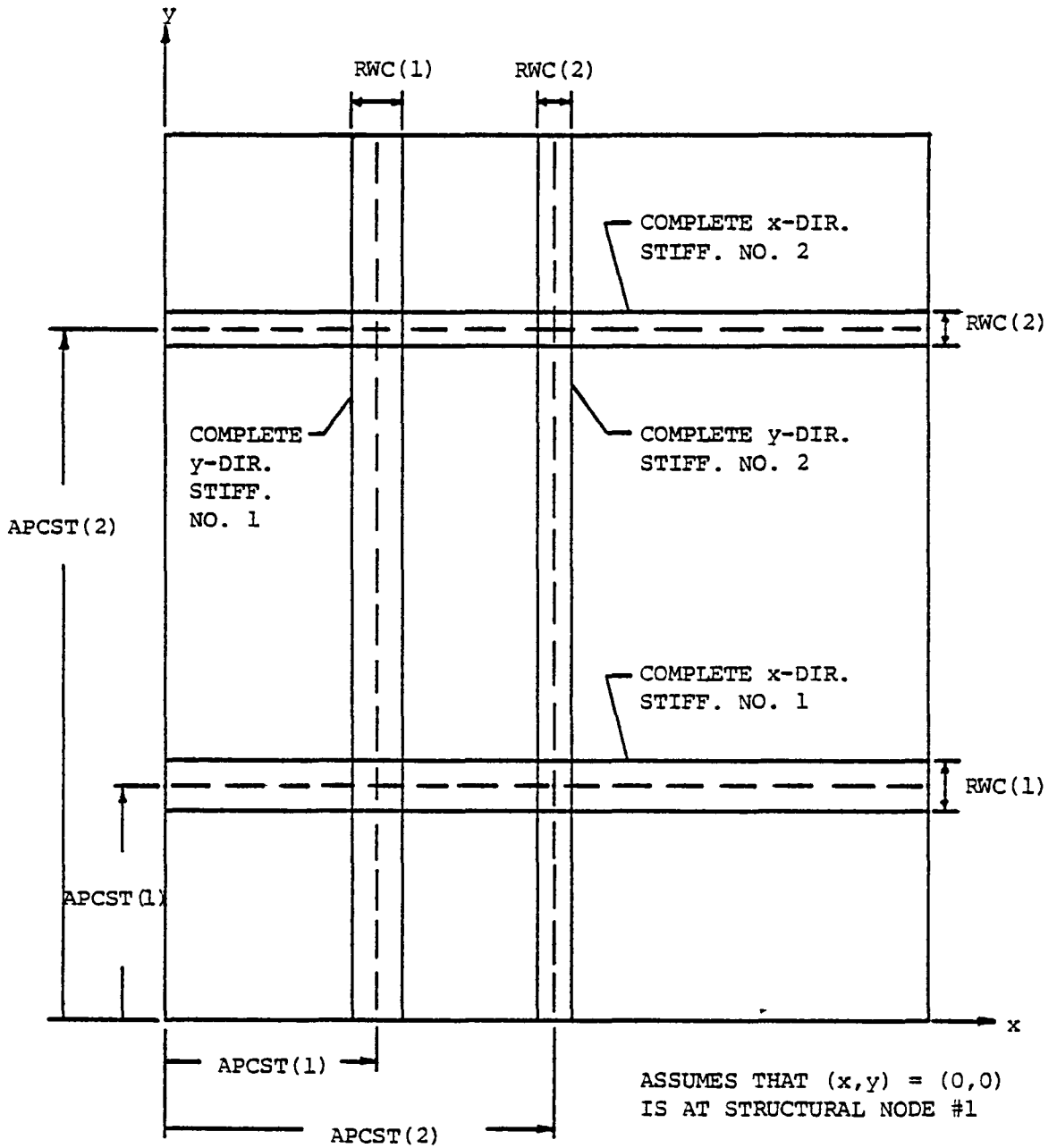
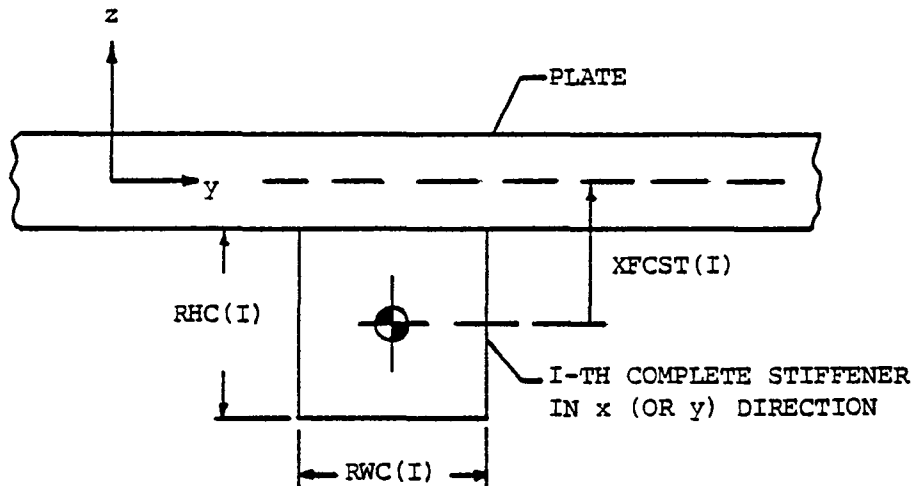


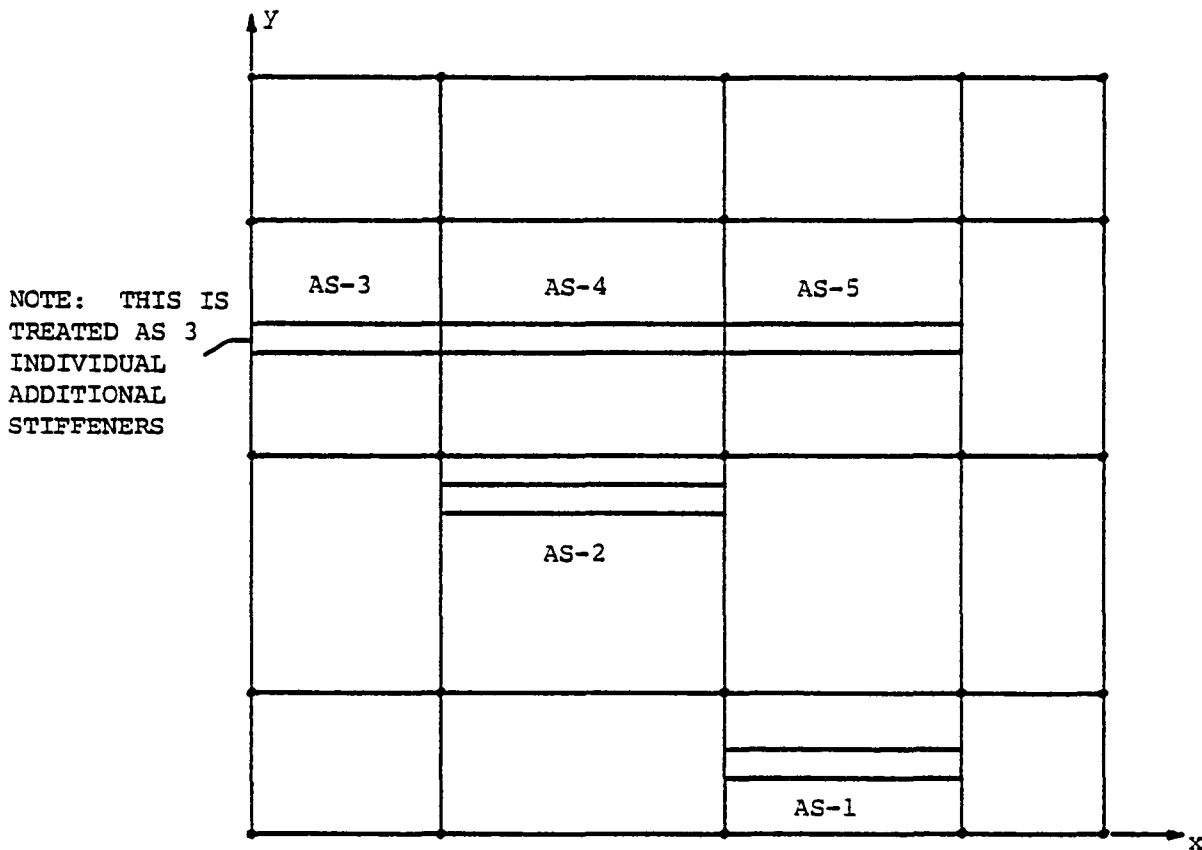
FIG. 11 ILLUSTRATIVE COMPLETE X- AND Y-DIRECTION STIFFENERS



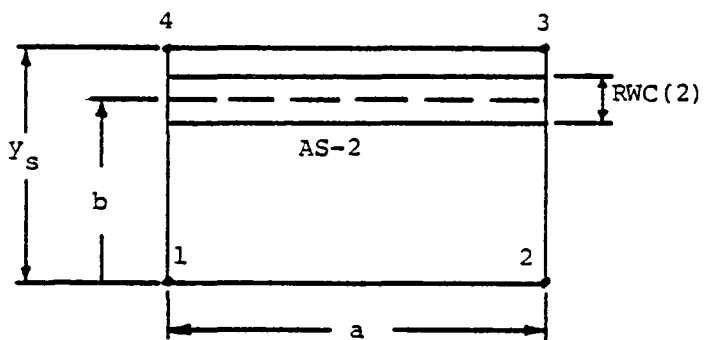
Note:

1. Stiffener has a rectangular cross-section which is constant along the stiffener.
2. If Stiffener were placed on "top" of plate, XFCST(I) would be a negative number.

FIG. 12 CROSS-SECTIONAL GEOMETRIC PROPERTIES OF STIFFENERS

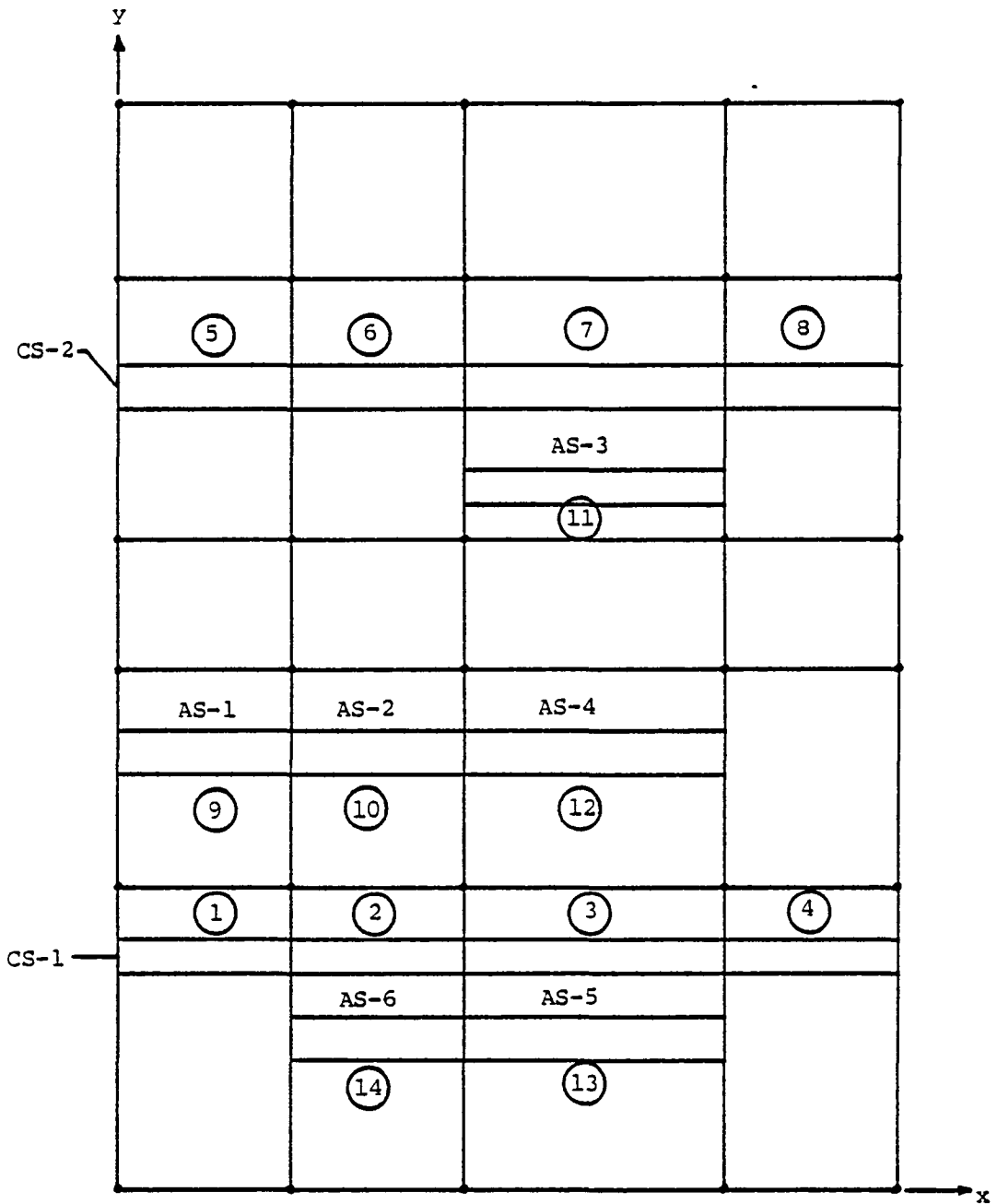


AS-n refers to Additional Stiffener Number n.



POSITION OF ADDITIONAL STIFFENER IS GIVEN IN TERMS OF THE NORMALIZED POSITION RELATIVE TO ELEMENT NODE 1: $POS = \frac{y_s}{b}$

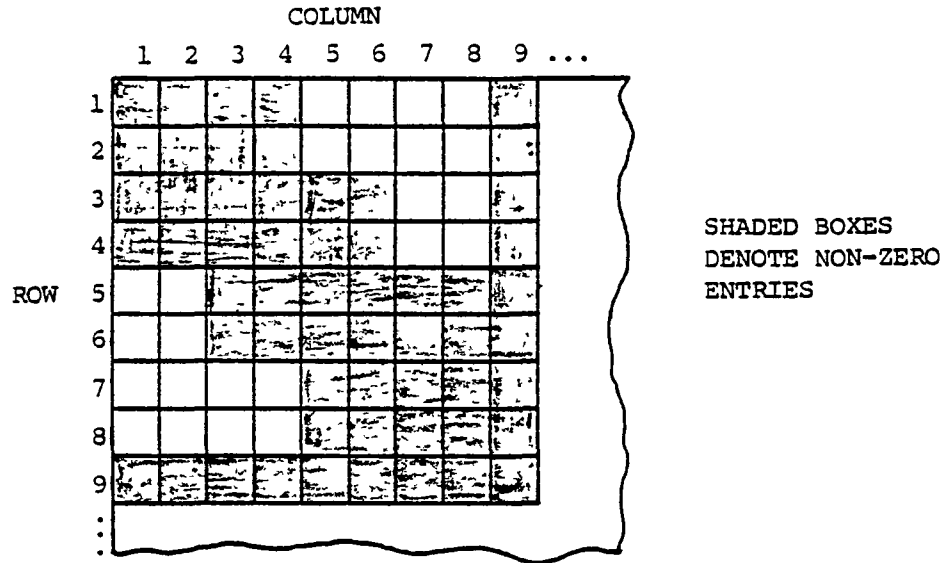
FIG. 13 ILLUSTRATIVE X-DIRECTION ADDITIONAL STIFFENERS



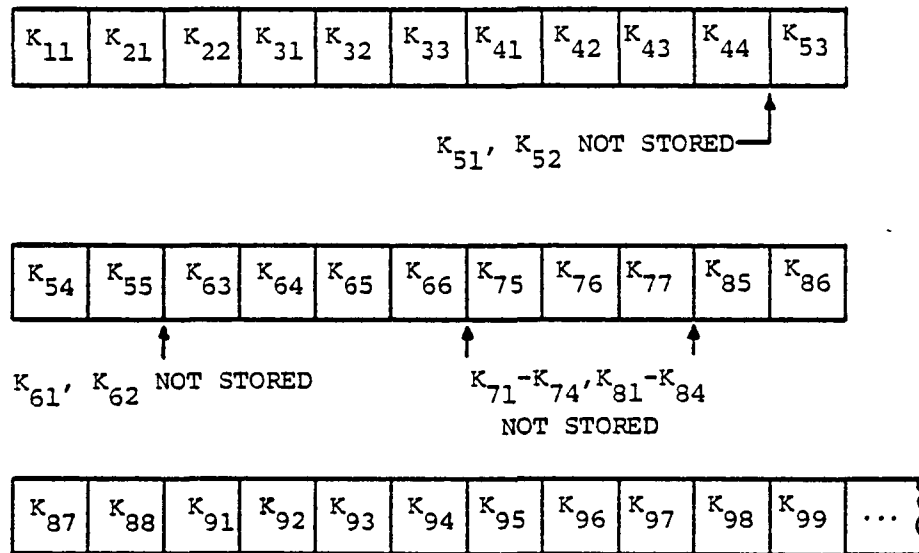
NOTATION

- CS-n : n-th stiffener defined as complete stiffener.
- AS-n : n-th stiffener defined as an additional stiffener.
- (n) : Stiffener number assigned internally to each stiffener on each element.

FIG. 14 CONVENTION USED FOR INTERNAL RENUMBERING OF STIFFENERS



a. Portion of a Hypothetical Assembled Stiffness Matrix



b. Storage of Assembled Stiffness Matrix (Lower Triangle) In Vector Form

FIG. 15 STORAGE OF THE ASSEMBLED STIFFNESS MATRIX

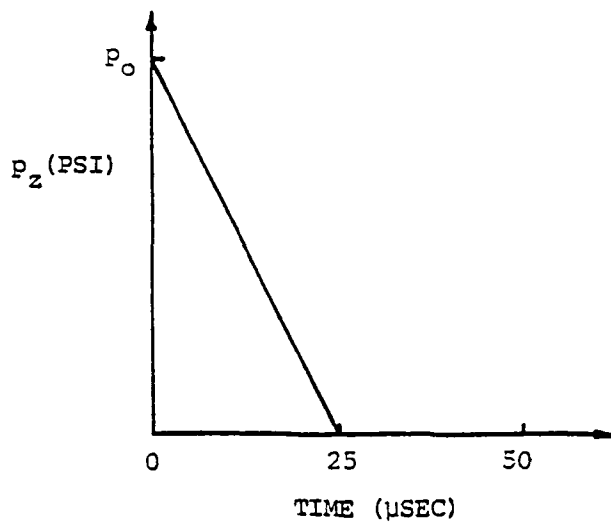
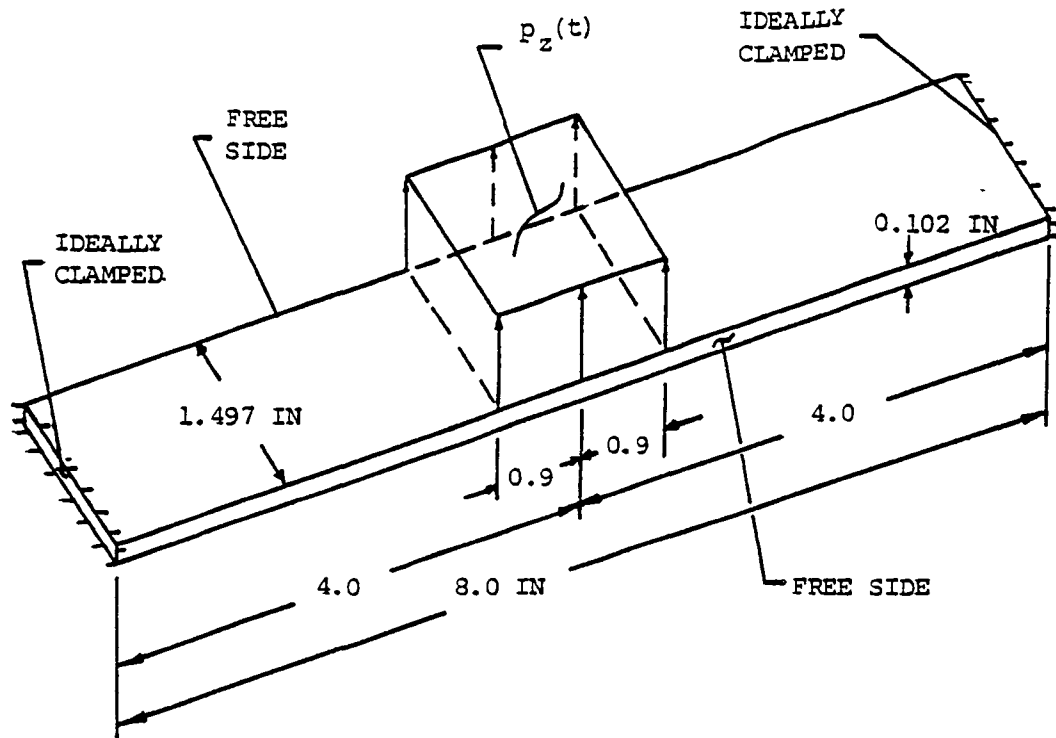


FIG. 16 SCHEMATIC OF A TRANSIENTLY-LOADED THIN NARROW PLATE

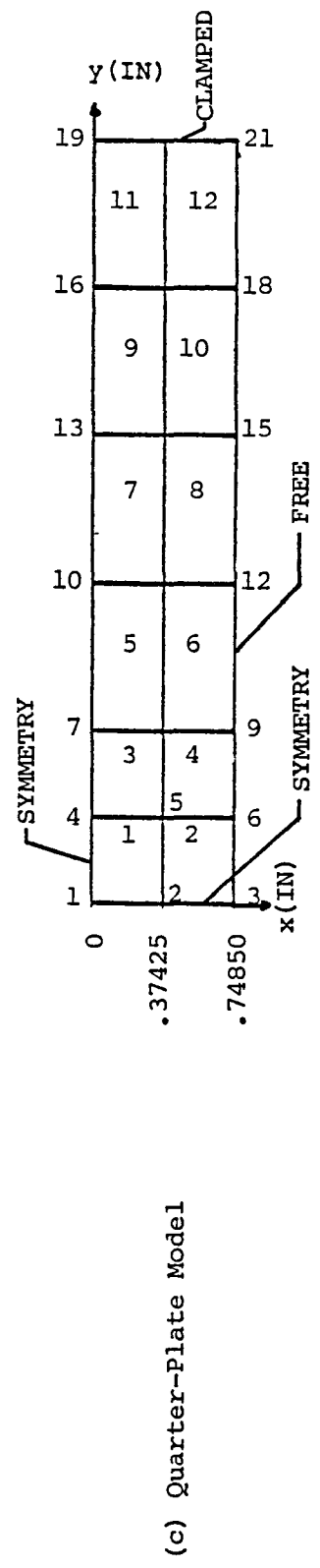
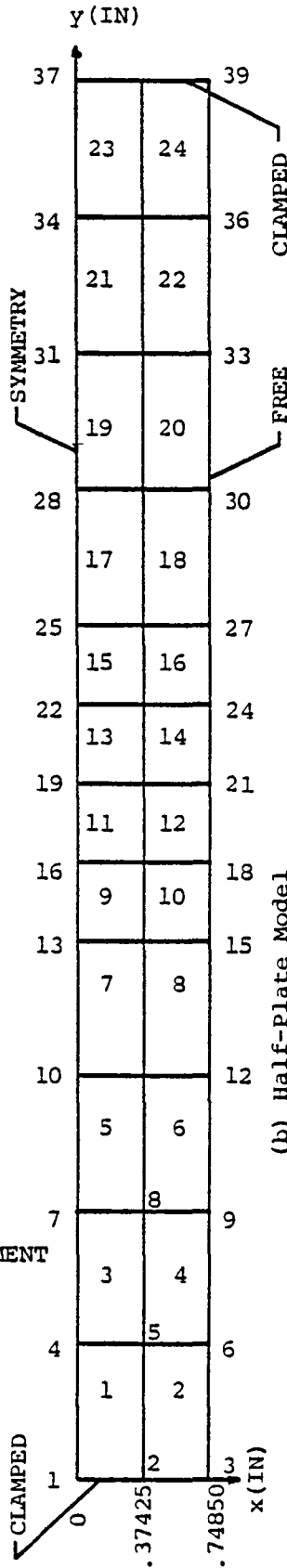
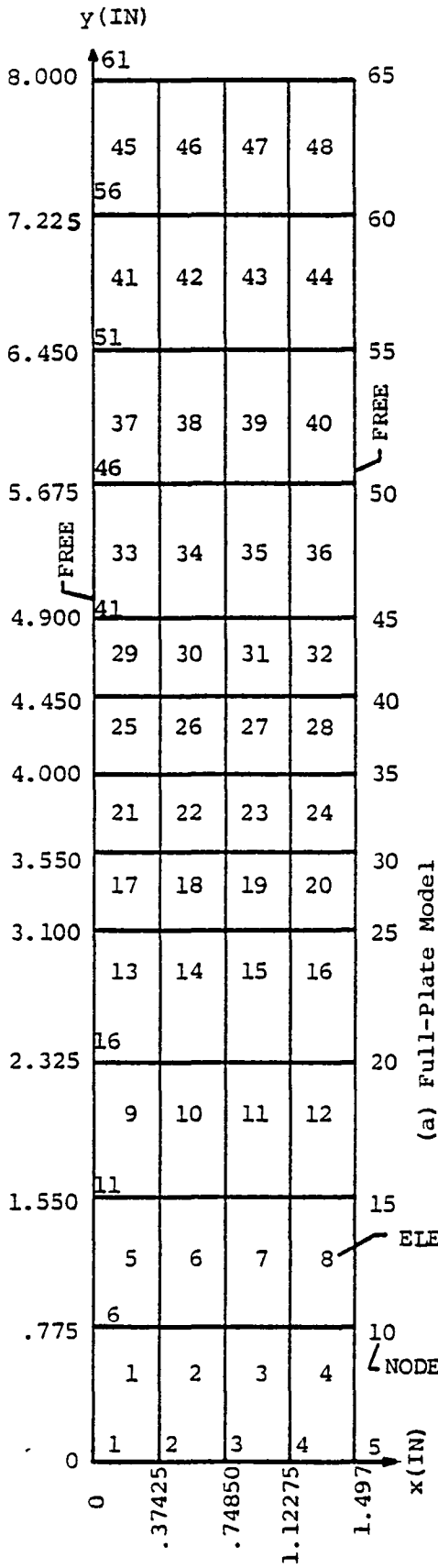
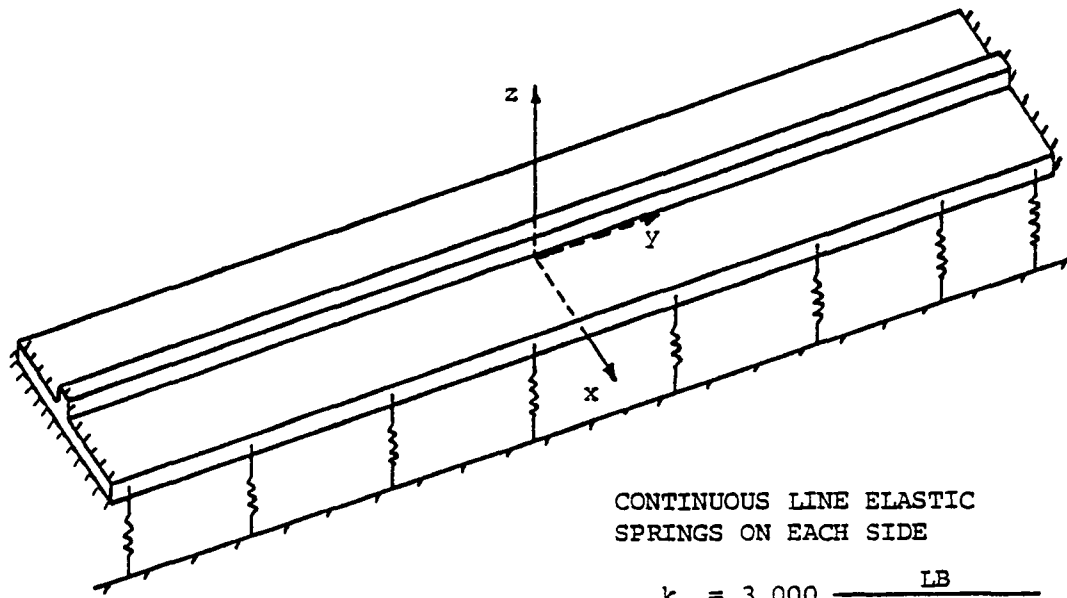


FIG. 17 FINITE-ELEMENT MODELS OF THE TRANSIENTLY-LOADED THIN NARROW PLATE



CONTINUOUS LINE ELASTIC
SPRINGS ON EACH SIDE

$$k_z = 3,000 \frac{\text{LB}}{\text{IN-IN OF SPAN}}$$

$$k_x = k_y = k_\theta = k_\psi = 0$$

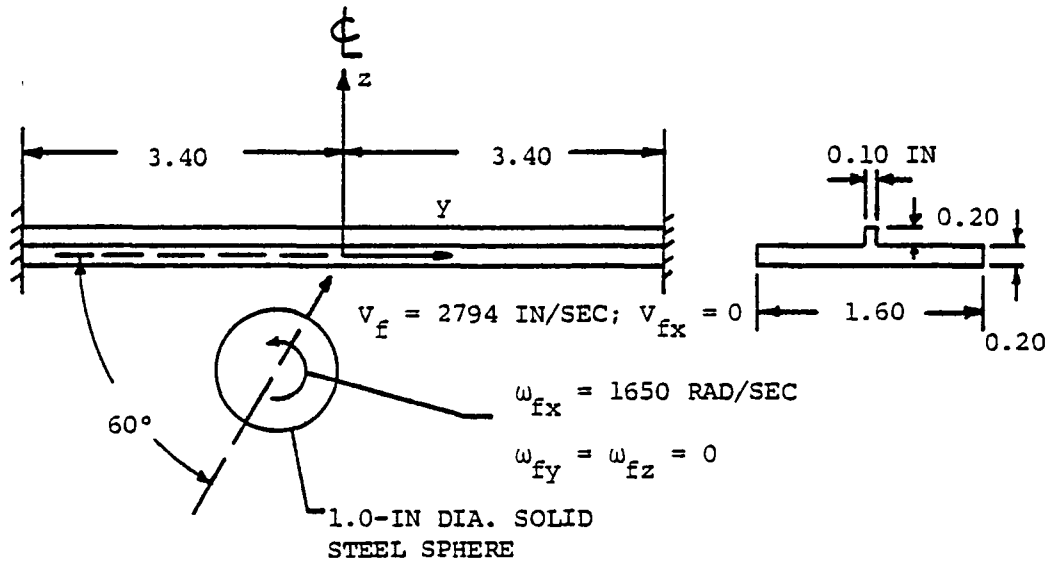


FIG. 18 SCHEMATIC OF A GEOMETRICALLY-STIFFENED SPRING-RESTRAINED THIN FLAT PLATE SUBJECTED TO STEEL-SPHERE IMPACT

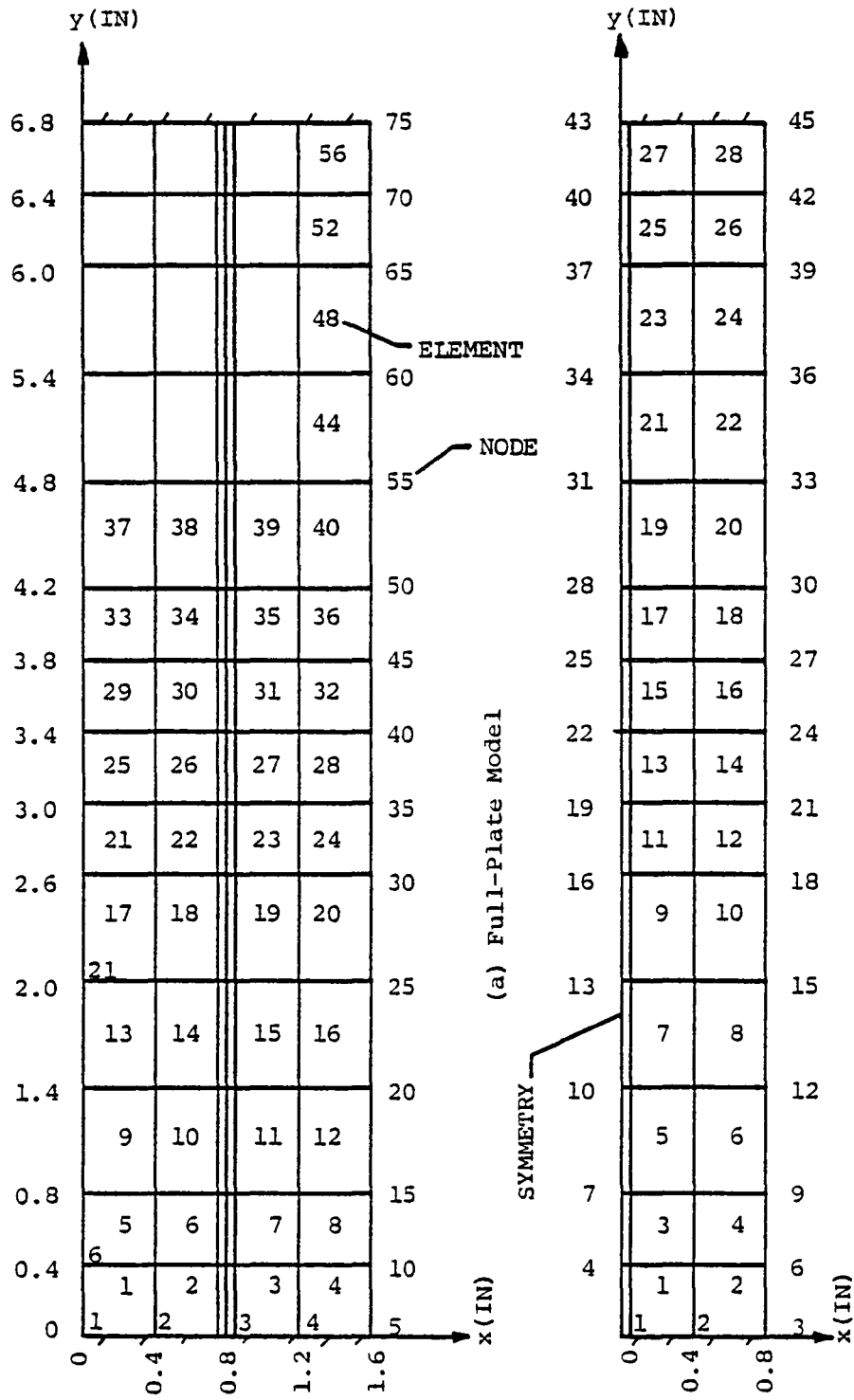


FIG. 19 FINITE-ELEMENT MODELS OF THE GEOMETRICALLY-STIFFENED SPRING-RESTRAINED THIN FLAT PLATE SUBJECTED TO STEEL-SPHERE IMPACT

APPENDIX A

GOVERNING EQUATIONS ON WHICH THE PLATE PROGRAM IS BASED

A.1 Formulation for Constant-Thickness Unstiffened

Rectangular Flat Plate Elements

A.1.1 Interpolation Functions and Strain-Displacement Relations

The PLATE program accommodates both unstiffened and longeron integrally-stiffened thin plate structures utilizing a constant-thickness plate element of rectangular planform. The present subsection deals with the unstiffened element; as discussed in Subsection A.2, a stiffened plate element is formulated by combining a "stiffener" element with the unstiffened plate element to which it is attached.

The geometry and nomenclature of a typical rectangular thin plate element are shown in Fig. 2. The element has constant thickness, h , and spanwise dimensions a and b in the x and y directions, respectively, with the origin of the element xyz coordinate system located at element node number 1.

Since the Kirchhoff hypothesis⁺ is employed, the displacement field \tilde{u} , \tilde{v} , and \tilde{w} may be approximated by the plate middle surface displacements u , v , and w and rotations θ and ψ as follows:

$$\begin{aligned}\tilde{u}(x, y, z) &= u(x, y) - z \theta(x, y) \\ \tilde{v}(x, y, z) &= v(x, y) - z \psi(x, y) \\ \tilde{w}(x, y, z) &= w(x, y)\end{aligned}\tag{A.1}$$

where

$$\begin{aligned}\theta(x, y) &= \frac{\partial w(x, y)}{\partial x} \\ \psi(x, y) &= \frac{\partial w(x, y)}{\partial y}\end{aligned}\tag{A.2}$$

The midsurface displacements u , v , and w are approximated within each element

⁺The Kirchhoff hypothesis is appropriate since attention herein is restricted to thin plates. It should be noted, however, that recently less restrictive plate bending elements have developed, based on Mindlin theory [24]; such elements employ independent interpolations for the transverse displacement w and for the rotations. These elements often suffer from excessive stiffness in the thin-plate limit; this "defect" has been remedied by the use of selective reduced numerical integration [25-27].

by assuming a bilinear interpolation for the inplane displacements u and v , and a bicubic Hermetian interpolation for the transverse displacement, w . The interpolations written in terms of element x, y, z coordinates are

$$u(x, y) = \alpha_1 + x \alpha_2 + y \alpha_3 + xy \alpha_4 \quad (\text{A.3a})$$

$$v(x, y) = \alpha_5 + x \alpha_6 + y \alpha_7 + xy \alpha_8 \quad (\text{A.3b})$$

$$\begin{aligned} w(x, y) = & \alpha_9 + x \alpha_{10} + y \alpha_{11} + xy \alpha_{12} + x^2 \alpha_{13} + y^2 \alpha_{14} \\ & + x^2 y \alpha_{15} + x y^2 \alpha_{16} + x^2 y^2 \alpha_{17} + x^3 \alpha_{18} + y^3 \alpha_{19} \\ & + x^3 y \alpha_{20} + x y^3 \alpha_{21} + x^3 y^2 \alpha_{22} + x^2 y^3 \alpha_{23} + x^3 y^3 \alpha_{24} \end{aligned} \quad (\text{A.3c})$$

where $\alpha_1, \alpha_2 \dots \alpha_{24}$ are unknown parameters which will be related to the generalized nodal displacements; the rotations θ and ψ are evaluated by substituting Eq. A.3c into Eqs. A.2.

In order to obtain a set of generalized nodal displacements which can be related to the 24 α_i 's, the generalized nodal displacements chosen are the parameters u, v, w, θ, ψ , and $\chi = (\partial^2 w / \partial x \partial y)$ at each of the four corner nodes of the element.⁺ The nodal displacement vector, \underline{q} , for the element is thus

$$\{\underline{q}\}^T = \begin{bmatrix} u_1 & v_1 & w_1 & \theta_1 & \psi_1 & \chi_1 & u_2 & v_2 & w_2 & \theta_2 & \psi_2 & \chi_2 \\ u_3 & v_3 & w_3 & \dots & \dots & \dots & \chi_4 \end{bmatrix} \quad (\text{A.4})$$

By evaluating Eqs. A.3 and $\theta(x, y)$, $\psi(x, y)$, and $\chi(x, y)$ (obtained by differentiating Eqs. A.3) at the element nodes, a unique (invertable) relation between \underline{q} and $\underline{\alpha}$ is obtained:

$$\underline{\tilde{q}} = \underline{\tilde{G}} \underline{\tilde{\alpha}} \quad (\text{A.5})$$

The 24 α_i 's can be related to the 24 q_i 's by inversion of Eq. A.5 so that

$$\underline{\tilde{\alpha}} = \underline{\tilde{G}}^{-1} \underline{\tilde{q}} \quad (\text{A.6})$$

and the displacement interpolation (Eq. A.3) can, in principle, be written in terms of nodal generalized displacements, \underline{q} ; details of the calculation of

⁺These six generalized displacements are convenient to use because of the ways in which these quantities appear in the strain-displacement relations (Eqs. A.7 and A.8) for the Kirchhoff hypothesis.

\tilde{G}^{-1} will be discussed later.

The distribution of strains $\tilde{\epsilon}_{xx}$, $\tilde{\epsilon}_{yy}$, and $\tilde{\epsilon}_{xy}$ may be represented by mid-surface inplane strain components ϵ_{xx} , ϵ_{yy} , and ϵ_{xy} and curvatures κ_{xx} , κ_{yy} , and κ_{xy} , and are written under the Kirchhoff assumption,† as

$$\begin{aligned}\tilde{\epsilon}_{xx} &= \epsilon_{xx} - z \kappa_{xx} \\ \tilde{\epsilon}_{yy} &= \epsilon_{yy} - z \kappa_{yy} \\ \tilde{\epsilon}_{xy} &= \epsilon_{xy} - z \kappa_{xy}\end{aligned}\tag{A.7}$$

For the present element, the nonlinear strain-displacement relations of Sanders [12] for moderately small rotations are used, and are given by††

$$\begin{aligned}\epsilon_{xx} &= \frac{\partial u}{\partial x} + \frac{1}{2} \left(\frac{\partial w}{\partial x} \right)^2 + \frac{1}{2} \left[\frac{1}{2} \left(\frac{\partial u}{\partial y} - \frac{\partial v}{\partial x} \right) \right]^2; \quad \kappa_{xx} = \frac{\partial^2 w}{\partial x^2} \equiv \frac{\partial \theta}{\partial x} \\ \epsilon_{yy} &= \frac{\partial v}{\partial y} + \frac{1}{2} \left(\frac{\partial w}{\partial y} \right)^2 + \frac{1}{2} \left[\frac{1}{2} \left(\frac{\partial u}{\partial y} - \frac{\partial v}{\partial x} \right) \right]^2; \quad \kappa_{yy} = \frac{\partial^2 w}{\partial y^2} \equiv \frac{\partial \psi}{\partial y} \\ \epsilon_{xy} &= \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} + \left(\frac{\partial w}{\partial x} \right) \left(\frac{\partial w}{\partial y} \right); \quad \kappa_{xy} = 2 \frac{\partial^2 w}{\partial x \partial y} \equiv 2 \chi\end{aligned}\tag{A.8}$$

When Eq. A.6 is substituted into the interpolation functions of Eqs. A.3, and the result substituted into Eqs. A.8, then Eqs. A.8 can be written in the form:

$$\begin{aligned}\epsilon_{xx} &= \underline{D}_1^T \underline{q} + \frac{1}{2} \underline{q}^T \left(\underline{D}_7 \underline{D}_7^T + \underline{D}_9 \underline{D}_9^T \right) \underline{q} \\ \epsilon_{yy} &= \underline{D}_2^T \underline{q} + \frac{1}{2} \underline{q}^T \left(\underline{D}_8 \underline{D}_8^T + \underline{D}_9 \underline{D}_9^T \right) \underline{q} \\ \epsilon_{xy} &= \underline{D}_3^T \underline{q} + \frac{1}{2} \underline{q}^T \left(\underline{D}_7 \underline{D}_8^T + \underline{D}_8 \underline{D}_7^T \right) \underline{q} \\ \kappa_{xx} &= \underline{D}_4^T \underline{q} \\ \kappa_{yy} &= \underline{D}_5^T \underline{q} \\ \kappa_{xy} &= \underline{D}_6^T \underline{q}\end{aligned}\tag{A.9}$$

†The Kirchhoff assumption reduces the number of "displacement variables" but introduces higher order derivatives in the formulation of plate and shell elements.

††Note that ϵ_{xy} is the engineering strain and κ_{xy} is the engineering twist curvature at the reference surface; these quantities are equal to twice their tensorial counterparts.

where $D_{\sim 1}, D_{\sim 2}, \dots, D_{\sim 9}$ are defined from the relations

$$\begin{aligned}
 \frac{\partial u}{\partial x} &= D_{\sim 1}^T \underline{q}_{\sim} & 2 \frac{\partial^2 w}{\partial x \partial y} &= D_{\sim 6}^T \underline{q}_{\sim} \\
 \frac{\partial v}{\partial y} &= D_{\sim 2}^T \underline{q}_{\sim} & \frac{\partial w}{\partial x} &= D_{\sim 7}^T \underline{q}_{\sim} \\
 \left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} \right) &= D_{\sim 3}^T \underline{q}_{\sim} & \frac{\partial w}{\partial y} &= D_{\sim 8}^T \underline{q}_{\sim} \\
 \frac{\partial^2 w}{\partial x^2} &= D_{\sim 4}^T \underline{q}_{\sim} & \frac{1}{2} \left(\frac{\partial u}{\partial y} - \frac{\partial v}{\partial x} \right) &= D_{\sim 9}^T \underline{q}_{\sim} \\
 \frac{\partial^2 w}{\partial y^2} &= D_{\sim 5}^T \underline{q}_{\sim} & &
 \end{aligned} \tag{A.10}$$

The nonlinear geometric behavior of the plate material will be expressed in terms of the increment in strain from time t_{m-1} to time t_m . Assuming that the displacements \underline{q}_m and the increment in nodal displacements, $\Delta \underline{q}_m$ are known, the strain increments can be calculated by

$$\begin{aligned}
 (\Delta \tilde{\epsilon}_{xx})_m &= (\Delta \epsilon_{xx})_m - z (\Delta \mathcal{K}_{xx})_m \\
 (\Delta \tilde{\epsilon}_{yy})_m &= (\Delta \epsilon_{yy})_m - z (\Delta \mathcal{K}_{yy})_m \\
 (\Delta \tilde{\epsilon}_{xy})_m &= (\Delta \epsilon_{xy})_m - z (\Delta \mathcal{K}_{xy})_m
 \end{aligned} \tag{A.11}$$

where

$$\begin{aligned}
 (\Delta \epsilon_{xx})_m &= D_{\sim 1}^T \Delta \underline{q}_m + \underline{q}_m^T (D_{\sim 7} D_{\sim 7}^T + D_{\sim 9} D_{\sim 9}^T) \Delta \underline{q}_m \\
 &\quad - \frac{1}{2} \Delta \underline{q}_m^T (D_{\sim 7} D_{\sim 7}^T + D_{\sim 9} D_{\sim 9}^T) \Delta \underline{q}_m \\
 (\Delta \epsilon_{yy})_m &= D_{\sim 2}^T \Delta \underline{q}_m + \underline{q}_m^T (D_{\sim 8} D_{\sim 8}^T + D_{\sim 9} D_{\sim 9}^T) \Delta \underline{q}_m \\
 &\quad - \frac{1}{2} \Delta \underline{q}_m^T (D_{\sim 8} D_{\sim 8}^T + D_{\sim 9} D_{\sim 9}^T) \Delta \underline{q}_m \\
 (\Delta \epsilon_{xy})_m &= D_{\sim 3}^T \Delta \underline{q}_m + \underline{q}_m^T (D_{\sim 7} D_{\sim 8}^T + D_{\sim 8} D_{\sim 7}^T) \Delta \underline{q}_m \\
 &\quad - \frac{1}{2} \Delta \underline{q}_m^T (D_{\sim 7} D_{\sim 8}^T + D_{\sim 8} D_{\sim 7}^T) \Delta \underline{q}_m
 \end{aligned} \tag{A.12}$$

$$\begin{aligned} (\Delta \mathcal{K}_{xx})_m &= D_{\sim 4}^T \Delta \mathcal{f}_{\sim m} & (\Delta \mathcal{K}_{xy})_m &= D_{\sim 6}^T \Delta \mathcal{f}_{\sim m} \\ (\Delta \mathcal{K}_{yy})_m &= D_{\sim 5}^T \Delta \mathcal{f}_{\sim m} \end{aligned}$$

and

$$\Delta \mathcal{f}_{\sim m} = \mathcal{f}_{\sim m} - \mathcal{f}_{\sim m-1} \quad (\text{A.13})$$

A.1.2 Normalized Coordinates and Nodal Degrees of Freedom

In operations related to the element matrix formulation, it is generally convenient to deal with normalized coordinates (ξ, η) where

$$\begin{aligned} \xi &= \frac{x}{a} \\ \eta &= \frac{y}{b} \end{aligned} \quad (\text{A.14})$$

Normalized nodal coordinates $(\bar{u}, \bar{v}, \bar{w}, \bar{\theta}, \bar{\psi}, \bar{\chi})$ are then defined by the relations

$$\begin{aligned} \bar{u} &= u & \bar{\theta} &= a \theta \\ \bar{v} &= v & \bar{\psi} &= b \psi \\ \bar{w} &= w & \bar{\chi} &= a b \chi \end{aligned} \quad (\text{A.15})$$

and normalized new parameters $\bar{\alpha}_i$ are defined by

$$\begin{aligned} \bar{\alpha}_1 &= \alpha_1 & \bar{\alpha}_9 &= \alpha_9 & \bar{\alpha}_{17} &= a^2 b^2 \alpha_{17} \\ \bar{\alpha}_2 &= a \alpha_2 & \bar{\alpha}_{10} &= a \alpha_{10} & \bar{\alpha}_{18} &= a^3 \alpha_{18} \\ \bar{\alpha}_3 &= b \alpha_3 & \bar{\alpha}_{11} &= b \alpha_{11} & \bar{\alpha}_{19} &= b^3 \alpha_{19} \\ \bar{\alpha}_4 &= a b \alpha_4 & \bar{\alpha}_{12} &= a b \alpha_{12} & \bar{\alpha}_{20} &= a^3 b \alpha_{20} \\ \bar{\alpha}_5 &= \alpha_5 & \bar{\alpha}_{13} &= a^2 \alpha_{13} & \bar{\alpha}_{21} &= a b^3 \alpha_{21} \\ \bar{\alpha}_6 &= a \alpha_6 & \bar{\alpha}_{14} &= b^2 \alpha_{14} & \bar{\alpha}_{22} &= a^3 b^2 \alpha_{22} \\ \bar{\alpha}_7 &= b \alpha_7 & \bar{\alpha}_{15} &= a^2 b \alpha_{15} & \bar{\alpha}_{23} &= a^2 b^3 \alpha_{23} \\ \bar{\alpha}_8 &= a b \alpha_8 & \bar{\alpha}_{16} &= a b^2 \alpha_{16} & \bar{\alpha}_{24} &= a^3 b^3 \alpha_{24} \end{aligned}$$

(A.16)

Substituting Eqs. A.14 through A.16 into Eqs. A.3 yields the following interpolations:

$$\bar{u} = \bar{\alpha}_1 + \xi \bar{\alpha}_2 + \eta \bar{\alpha}_3 + \xi \eta \bar{\alpha}_4 \quad (\text{A.17a})$$

$$\bar{v} = \bar{\alpha}_5 + \xi \bar{\alpha}_6 + \eta \bar{\alpha}_7 + \xi \eta \bar{\alpha}_8 \quad (\text{A.17b})$$

$$\begin{aligned} \bar{w} = & \bar{\alpha}_9 + \xi \bar{\alpha}_{10} + \eta \bar{\alpha}_{11} + \xi \eta \bar{\alpha}_{12} + \xi^2 \bar{\alpha}_{13} + \eta^2 \bar{\alpha}_{14} \\ & + \xi^2 \eta \bar{\alpha}_{15} + \xi \eta^2 \bar{\alpha}_{16} + \xi^2 \eta^2 \bar{\alpha}_{17} + \xi^3 \bar{\alpha}_{18} + \eta^3 \bar{\alpha}_{19} \\ & + \xi^3 \eta \bar{\alpha}_{20} + \xi \eta^3 \bar{\alpha}_{21} + \xi^3 \eta^2 \bar{\alpha}_{22} + \xi^2 \eta^3 \bar{\alpha}_{23} + \xi \eta^3 \bar{\alpha}_{24} \end{aligned} \quad (\text{A.17c})$$

$$\begin{aligned} \bar{\theta} = & \bar{\alpha}_{10} + \eta \bar{\alpha}_{12} + 2\xi \bar{\alpha}_{13} + 2\xi \eta \bar{\alpha}_{15} + \eta^2 \bar{\alpha}_{16} + 2\xi \eta^2 \bar{\alpha}_{17} \\ & + 3\xi^2 \bar{\alpha}_{18} + 3\xi^2 \eta \bar{\alpha}_{20} + \eta^3 \bar{\alpha}_{21} + 3\xi^2 \eta^2 \bar{\alpha}_{22} \\ & + 2\xi \eta^3 \bar{\alpha}_{23} + 3\xi^2 \eta^3 \bar{\alpha}_{24} \end{aligned} \quad (\text{A.17d})$$

$$\begin{aligned} \bar{\psi} = & \bar{\alpha}_{11} + \xi \bar{\alpha}_{12} + 2\eta \bar{\alpha}_{14} + \xi^2 \bar{\alpha}_{15} + 2\xi \eta \bar{\alpha}_{16} + 2\xi^2 \eta \bar{\alpha}_{17} \\ & + 3\eta^2 \bar{\alpha}_{19} + \xi^3 \bar{\alpha}_{20} + 3\xi \eta^2 \bar{\alpha}_{21} + 2\xi^3 \eta \bar{\alpha}_{22} + 3\xi^2 \eta^2 \bar{\alpha}_{23} + 3\xi \eta^3 \bar{\alpha}_{24} \end{aligned} \quad (\text{A.17e})$$

$$\begin{aligned} \bar{\chi} = & \bar{\alpha}_{12} + 2\xi \bar{\alpha}_{15} + 2\eta \bar{\alpha}_{16} + 4\xi \eta \bar{\alpha}_{17} + 3\xi^2 \bar{\alpha}_{20} + 3\eta^2 \bar{\alpha}_{21} \\ & + 6\xi^2 \eta \bar{\alpha}_{22} + 6\xi \eta^2 \bar{\alpha}_{23} + 9\xi^2 \eta^2 \bar{\alpha}_{24} \end{aligned} \quad (\text{A.17f})$$

Note that \bar{u} and \bar{v} are bilinear whereas \bar{w} is expressed as a bicubic interpolation function of ξ and η . When Eqs. A.17 are evaluated at the nodal coordinates, the normalized nodal degrees of freedom should result; these conditions define the matrix \bar{G} (see Eqs. A.5) relating \bar{q} and $\bar{\alpha}$. Because of the simple rectangular geometry of the element and the use of normalized quantities, the $\bar{\alpha}_i$'s can be obtained in terms of the \bar{q} 's in closed form. The resulting

expressions are

$$\bar{\alpha}_1 = \bar{u}_1$$

$$\bar{\alpha}_2 = -\bar{u}_1 + \bar{u}_2$$

$$\bar{\alpha}_3 = -\bar{u}_1 + \bar{u}_4$$

$$\bar{\alpha}_4 = \bar{u}_1 - \bar{u}_2 + \bar{u}_3 - \bar{u}_4$$

$$\bar{\alpha}_5 = \bar{v}_1$$

$$\bar{\alpha}_6 = -\bar{v}_1 + \bar{v}_2$$

$$\bar{\alpha}_7 = -\bar{v}_1 + \bar{v}_4$$

$$\bar{\alpha}_8 = \bar{v}_1 - \bar{v}_2 + \bar{v}_3 - \bar{v}_4$$

$$\bar{\alpha}_9 = \bar{w}_1$$

$$\bar{\alpha}_{10} = \bar{\theta}_1$$

$$\bar{\alpha}_{11} = \bar{\psi}_1$$

$$\bar{\alpha}_{12} = \bar{\chi}_1$$

$$\bar{\alpha}_{13} = 3(-\bar{w}_1 + \bar{w}_2) - (2\bar{\theta}_1 + \bar{\theta}_2)$$

$$\bar{\alpha}_{14} = 3(-\bar{w}_1 + \bar{w}_4) - (2\bar{\psi}_1 + \bar{\psi}_4)$$

$$\bar{\alpha}_{15} = 3(-\bar{\psi}_1 + \bar{\psi}_2) - (2\bar{\chi}_1 + \bar{\chi}_2)$$

$$\bar{\alpha}_{16} = 3(-\bar{\theta}_1 + \bar{\theta}_4) - (2\bar{\chi}_1 + \bar{\chi}_4)$$

$$\begin{aligned} \bar{\alpha}_{17} = & 9(\bar{w}_1 - \bar{w}_2 + \bar{w}_3 - \bar{w}_4) + 3(2\bar{\theta}_1 + \bar{\theta}_2 - \bar{\theta}_3 - 2\bar{\theta}_4) \\ & + 3(2\bar{\psi}_1 - 2\bar{\psi}_2 - \bar{\psi}_3 - \bar{\psi}_4) + (4\bar{\chi}_1 + 2\bar{\chi}_2 + \bar{\chi}_3 + 2\bar{\chi}_4) \end{aligned}$$

$$\bar{\alpha}_{18} = 2(\bar{w}_1 - \bar{w}_2) + (\bar{\theta}_1 + \bar{\theta}_2)$$

$$\bar{\alpha}_{19} = 2(\bar{w}_1 - \bar{w}_4) + (\bar{\psi}_1 + \bar{\psi}_4)$$

$$\bar{\alpha}_{20} = 2(\bar{\psi}_1 - \bar{\psi}_2) + (\bar{\chi}_1 + \bar{\chi}_2)$$

$$\bar{\alpha}_{21} = 2(\bar{\theta}_1 - \bar{\theta}_4) + (\bar{\chi}_1 + \bar{\chi}_4)$$

$$\begin{aligned} \bar{\alpha}_{22} = & 6(-\bar{w}_1 + \bar{w}_2 - \bar{w}_3 + \bar{w}_4) + 3(-\bar{\theta}_1 - \bar{\theta}_2 + \bar{\theta}_3 + \bar{\theta}_4) \\ & + 2(-2\bar{\psi}_1 + 2\bar{\psi}_2 + \bar{\psi}_3 - \bar{\psi}_4) + (-2\bar{\chi}_1 - 2\bar{\chi}_2 - \bar{\chi}_3 - \bar{\chi}_4) \end{aligned}$$

$$\begin{aligned} \bar{\alpha}_{23} = & 6(-\bar{w}_1 + \bar{w}_2 - \bar{w}_3 + \bar{w}_4) + 2(-2\bar{\theta}_1 - \bar{\theta}_2 + \bar{\theta}_3 + 2\bar{\theta}_4) \\ & + 3(-\bar{\psi}_1 + \bar{\psi}_2 + \bar{\psi}_3 - \bar{\psi}_4) + 2(-2\bar{\chi}_1 - \bar{\chi}_2 - \bar{\chi}_3 - 2\bar{\chi}_4) \end{aligned}$$

$$\begin{aligned} \bar{\alpha}_{24} = & 4(\bar{w}_1 - \bar{w}_2 + \bar{w}_3 - \bar{w}_4) + 2(\bar{\theta}_1 + \bar{\theta}_2 - \bar{\theta}_3 - \bar{\theta}_4) \\ & + 2(\bar{\psi}_1 - \bar{\psi}_2 - \bar{\psi}_3 + \bar{\psi}_4) + (\bar{\chi}_1 + \bar{\chi}_2 + \bar{\chi}_3 + \bar{\chi}_4) \end{aligned}$$

(A.18)

If Eqs. A.18 are written in matrix form, the \bar{G}^{-1} matrix is obtained:

$$\bar{\alpha} = \bar{G}^{-1} \bar{q} \quad (\text{A.19})$$

It is useful to note that \bar{G}^{-1} is independent of element geometry and may be formed once and used for all elements.

The internal energy of the plate element is defined in terms of strain components, or, more specifically, midsurface strains and curvatures. It will, therefore, be necessary to relate these strain components and curvatures to the derivatives of the normalized displacements in the normalized coordinates. It can easily be seen that

$$\begin{aligned} \frac{\partial u}{\partial x} &= \frac{1}{a} \frac{\partial \bar{u}}{\partial \xi} & \frac{\partial u}{\partial y} &= \frac{1}{b} \frac{\partial \bar{u}}{\partial \eta} \\ \frac{\partial v}{\partial x} &= \frac{1}{a} \frac{\partial \bar{v}}{\partial \xi} & \frac{\partial v}{\partial y} &= \frac{1}{b} \frac{\partial \bar{v}}{\partial \eta} \\ \frac{\partial \theta}{\partial x} &= \frac{1}{a^2} \frac{\partial \bar{\theta}}{\partial \xi} & \frac{\partial \psi}{\partial y} &= \frac{1}{b^2} \frac{\partial \bar{\psi}}{\partial \eta} \\ 2\chi &= \frac{1}{ab} (2\bar{\chi}) \end{aligned} \quad (\text{A.20})$$

from which the following matrix relation may be written

$$\begin{Bmatrix} \frac{\partial u}{\partial x} \\ \frac{\partial v}{\partial y} \\ \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} \\ \frac{\partial \theta}{\partial x} \\ \frac{\partial \psi}{\partial y} \\ 2\chi \end{Bmatrix} = \underbrace{\begin{bmatrix} \frac{1}{a} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \frac{1}{b} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \frac{1}{b} & \frac{1}{a} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{a^2} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1}{b^2} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \frac{1}{ab} \end{bmatrix}}_{\bar{A}} \begin{Bmatrix} \frac{\partial \bar{u}}{\partial \xi} \\ \frac{\partial \bar{v}}{\partial \eta} \\ \frac{\partial \bar{u}}{\partial \eta} \\ \frac{\partial \bar{v}}{\partial \xi} \\ \frac{\partial \bar{\theta}}{\partial \xi} \\ \frac{\partial \bar{\psi}}{\partial \eta} \\ 2\bar{\chi} \end{Bmatrix} \quad (\text{A.21})$$

A.1.3 Definition and Calculation of Element Property Matrices

In the previous subsections, the characteristic displacement behavior of the element and the associated strain components were defined. These interpolations/relations are now used in conjunction with the concepts of work and energy to derive the various plate element property matrices.

A.1.3.1 Element Mass Matrix

The consistent mass matrix \tilde{m}_c for a rectangular plate element is derived from the expression for the kinetic energy, $(T)_n$, for a typical (nth) element which is given by

$$\begin{aligned} T_n &= \frac{1}{2} \int_{V_n} \rho (\dot{\tilde{u}}^2 + \dot{\tilde{v}}^2 + \dot{\tilde{w}}^2) dV \\ &= \frac{1}{2} \int_0^b \int_0^a \int_{-\frac{h}{2}}^{+\frac{h}{2}} \rho [(\dot{u} - z\dot{\theta})^2 + (\dot{v} - z\dot{\psi})^2 + \dot{w}^2] dx dy dz \end{aligned} \quad (A.22)$$

with ρ taken as the mass per unit volume of the plate material. Introducing normalized coordinates (Eqs. A.14) and normalized displacements (Eqs. A.15), and integrating Eq. A.22 through the thickness of the element yields

$$T_n = \frac{1}{2} ab \int_0^1 \int_0^1 \begin{bmatrix} \dot{\tilde{u}} & \dot{\tilde{v}} & \dot{\tilde{w}} & \dot{\tilde{\theta}} & \dot{\tilde{\psi}} \end{bmatrix} [\tilde{m}] \begin{Bmatrix} \dot{\tilde{u}} \\ \dot{\tilde{v}} \\ \dot{\tilde{w}} \\ \dot{\tilde{\theta}} \\ \dot{\tilde{\psi}} \end{Bmatrix} d\xi d\eta \quad (A.23)$$

where \tilde{m} is the diagonal matrix

$$[\tilde{m}] = \begin{bmatrix} \rho h & & & & \\ & \rho h & & & \\ & & \rho h & & \\ & & & \frac{\rho h^3}{12 a^2} & \\ & & & & \frac{\rho h^3}{12 b^2} \end{bmatrix} \quad (A.24)$$

It is reasonable to assume that the spatial variation of the velocity field is the same as that of the displacement field. From Eqs. A.17a through A.17e, the velocity field is written as

$$\begin{Bmatrix} \dot{u} \\ \dot{v} \\ \dot{w} \\ \dot{\theta} \\ \dot{\psi} \end{Bmatrix} = [N(\xi, \eta)] \begin{Bmatrix} \dot{\alpha}_1 \\ \dot{\alpha}_2 \\ \vdots \\ \dot{\alpha}_{24} \end{Bmatrix} \quad (\text{A.25})$$

Substitution of Eq. A.19 (valid also for velocities) into Eq. A.25 and the result into Eq. A.23 yields,

$$T_n = \frac{1}{2} \dot{\bar{q}}^T a b (\bar{G}^{-1})^T \int_0^1 \int_0^1 N^T \tilde{m} N d\xi d\eta \bar{G}^{-1} \dot{\bar{q}} = \frac{1}{2} \dot{\bar{q}}^T \bar{m} \dot{\bar{q}} \quad (\text{A.26})$$

The \bar{m} matrix is the normalized consistent element mass matrix for the element corresponding to normalized nodal (velocity) degrees of freedom, \bar{q} . By using Eq. A.15, the normalized \bar{q} vector can be related to $\dot{\bar{q}}$ by

$$\dot{\bar{q}} = T \dot{\bar{q}} \quad (\text{A.27})$$

so that by substituting Eq. A.27 into Eq. A.26, the consistent element mass matrix \bar{m}_c is defined

$$\bar{m}_c = T^T \bar{m} T \quad (\text{A.28})$$

where

$$\bar{m} = a b (\bar{G}^{-1})^T \int_0^1 \int_0^1 N^T \tilde{m} N d\xi d\eta \bar{G}^{-1} \quad (\text{A.29})$$

The integral in Eq. A.29 is evaluated numerically. It should be noted that the matrix multiplication indicated in Eq. A.28 is accomplished simply by scaling the rows and columns of the \bar{m} matrix since T is a diagonal matrix.

A diagonal lumped mass matrix can also be formed for the rectangular plate element. In this case, the total mass properties of the element are lumped evenly at the four nodal locations, resulting in a diagonal matrix of the form

$$\tilde{m}_L = \begin{bmatrix} \hat{m} & & & \\ & \hat{m} & & \\ & & \hat{m} & \\ & & & \hat{m} \end{bmatrix} \quad (A.30)$$

where \hat{m} is the diagonal matrix;

$$\hat{m} = \rho \begin{bmatrix} \frac{abh}{4} & & & \\ & \frac{abh}{4} & & \\ & & \frac{abh}{4} & \\ & & & \frac{abh^3}{48} \\ & & & & \frac{abh^3}{48} \end{bmatrix} \quad (A.31)$$

A.1.3.2 Element Equivalent Loads Corresponding to Nonlinear Effects

For the present plane-stress case, the expression for the variation of the work of the stresses within the element is given by⁺

$$(\delta U)_n = \int_{V_n} (\sigma_{xx} \delta \tilde{\epsilon}_{xx} + \sigma_{yy} \delta \tilde{\epsilon}_{yy} + \sigma_{xy} \delta \tilde{\epsilon}_{xy}) dV \quad (A.32)$$

where σ_{xx} and σ_{yy} are the inplane normal stresses in the x and y directions and σ_{xy} is the inplane shearing stress. Considering initially-isotropic material, the elastic-plastic stress-strain relation can be expressed by

$$\begin{Bmatrix} \sigma_{xx} \\ \sigma_{yy} \\ \sigma_{xy} \end{Bmatrix} = \frac{E}{1-\nu^2} \begin{bmatrix} 1 & \nu & 0 \\ \nu & 1 & 0 \\ 0 & 0 & \frac{1-\nu}{2} \end{bmatrix} \begin{Bmatrix} \tilde{\epsilon}_{xx} - \tilde{\epsilon}_{xx}^p \\ \tilde{\epsilon}_{yy} - \tilde{\epsilon}_{yy}^p \\ \tilde{\epsilon}_{xy} - \tilde{\epsilon}_{xy}^p \end{Bmatrix} \quad (A.33a)$$

or

$$\tilde{\sigma} = \tilde{C} (\tilde{\epsilon} - \tilde{\epsilon}^p) \quad (A.33b)$$

⁺For a proper energy evaluation, the σ_{ij} stresses represent Second Piola-Kirchhoff stress components since the $\tilde{\epsilon}_{ij}$ are Green strain components [14].

When the stress-strain relation, Eq. A.33, is introduced into Eq. A.32, and then employing the strain-displacement relations of Eqs. A.7 and A.9, the expression for $(\delta U)_n$ will be in the form:

$$(\delta U)_n = \delta \tilde{q}^T \left(\tilde{k} \tilde{q} - \tilde{f}^{NL} \right) \quad (A.34)$$

in which \tilde{k} is the element linear elastic stiffness matrix and \tilde{f}^{NL} is the equivalent element force vector corresponding to nonlinear material and geometric effects, and is given by

$$\begin{aligned} \left\{ \tilde{f}^{NL} \right\} = & -\frac{E h}{2(1-\nu^2)} \int_0^a \int_0^b [D_1 D_2 D_3] \left\{ \begin{array}{l} (\theta^2 + \chi^2) + \nu(\psi^2 + \chi^2) \\ (\psi^2 + \chi^2) + \nu(\theta^2 + \chi^2) \\ (1-\nu)\theta\psi \end{array} \right\} dx dy \\ & -\frac{E h}{(1-\nu^2)} \int_0^a \int_0^b [D_7 D_8 D_9] \left\{ \begin{array}{l} \theta(\epsilon_{xx} + \nu\epsilon_{yy}) + \left(\frac{1-\nu}{2}\right)\psi\epsilon_{xy} \\ \psi(\epsilon_{yy} + \nu\epsilon_{xx}) + \left(\frac{1-\nu}{2}\right)\theta\epsilon_{xy} \\ (1+\nu)\chi(\epsilon_{xx} + \epsilon_{yy}) \end{array} \right\} dx dy \\ & + \int_0^a \int_0^b \left([D_1 D_2 D_3] \left\{ \begin{array}{l} \int_h \sigma_{xx}^p dz \\ \int_h \sigma_{yy}^p dz \\ \int_h \sigma_{xy}^p dz \end{array} \right\} - [D_4 D_5 D_6] \left\{ \begin{array}{l} \int_h z \sigma_{xx}^p dz \\ \int_h z \sigma_{yy}^p dz \\ \int_h z \sigma_{xy}^p dz \end{array} \right\} \right) dx dy \\ & + \int_0^a \int_0^b [D_7 D_8 D_9] \left\{ \begin{array}{l} \theta \int_h \sigma_{xx}^p dz + \psi \int_h \sigma_{xy}^p dz \\ \psi \int_h \sigma_{yy}^p dz + \theta \int_h \sigma_{xy}^p dz \\ \chi \int_h (\sigma_{xx}^p + \sigma_{yy}^p) dz \end{array} \right\} dx dy \end{aligned} \quad (A.35)$$

where

$$\begin{Bmatrix} \sigma_{xx}^p \\ \sigma_{yy}^p \\ \sigma_{xy}^p \end{Bmatrix} = \frac{E}{1-\nu^2} \begin{bmatrix} 1 & \nu & 0 \\ \nu & 1 & 0 \\ 0 & 0 & \frac{1-\nu}{2} \end{bmatrix} \begin{Bmatrix} \tilde{\epsilon}_{xx}^p \\ \tilde{\epsilon}_{yy}^p \\ \tilde{\epsilon}_{xy}^p \end{Bmatrix} \quad (A.36a)$$

or

$$\tilde{\sigma}^p = \tilde{C} \tilde{\epsilon}^p \quad (A.36b)$$

In Eq. A.35 the first two integrals represent equivalent nodal loads arising from large deflections, and the third and fourth integrals represent equivalent nodal loads corresponding to plastic strains and associated, respectively, with the linear and nonlinear terms in the strain-displacement relations; for convenience of presentation, all of these equivalent-load-producing nonlinear effects have been collected into a single expression.

The integrals in Eq. A.35 are evaluated for each time step in the transient response prediction process because the integrands (which are functions of displacements, strains, and plastic strains) change with time as the deformation progresses; these integrations are evaluated numerically by using Gaussian quadrature, so that the stresses, strains, and strain increments need to be evaluated at a selected number of spanwise and depthwise integration stations (monitoring points in the Gaussian quadrature).

At any instant in time t_m , the nodal generalized displacement parameters q_m can be calculated, and one may then employ the assumed displacement functions (Eqs. A.3) together with the strain-displacement relations (Eqs. A.9, and Eqs. A.11 through A.13) to obtain the strains and strain increments at any station within the element. Then the stresses and plastic strains are evaluated; the procedure is described briefly in the following.

The strain-hardening behavior of the material is accounted for by employing the mechanical-sublayer material-behavior model (see Subsection A.4). For each mechanical sublayer, the stresses σ_{m-1} at time t_{m-1} are known. Trial (superscript T) total stresses σ_m^T at time t_m may then be calculated by assuming that the strain increments $\Delta \tilde{\epsilon}_m$ from time t_{m-1} to t_m are entirely elastic

$$\sigma_m^T = \sigma_{m-1} + C \Delta \tilde{\epsilon}_m \quad (A.37)$$

The trial stresses are then substituted into the Huber-Mises-Hencky yield condition which for plane stress is

$$F_m^T = F(\sigma_m^T, \sigma_o) = \left[(\sigma_{xx}^T)_m^2 + (\sigma_{yy}^T)_m^2 - (\sigma_{xx}^T)_m (\sigma_{yy}^T)_m + 3 (\sigma_{xy}^T)_m^2 - \sigma_o^2 \right] \quad (A.38)$$

where σ_o is the known (static or strain-rate dependent) yield stress of the

mechanical sublayer being processed.

If $F_m^T < 0$, the stress state lies within or on the yield surface. In this case, no plastic flow occurs within this sublayer during this time step; the stress state at time t_m thus arises from wholly elastic behavior (in this sublayer) over the increment from t_{m-1} to t_m and thus

$$\tilde{\sigma}_m = \tilde{\sigma}_m^T \quad (\text{A.39a})$$

and

$$\tilde{\epsilon}_m^p = \tilde{\epsilon}_{m-1}^p \quad (\text{A.39b})$$

If $F_m^T \geq 0$ plastic yielding has occurred. By the flow rule of plasticity, the plastic strain increments may be related to the deviatoric stress state through a real, non-negative scalar proportionality term, $\Delta\lambda$. For the plane stress case this relation is

$$\left\{ \Delta \tilde{\epsilon}_m^p \right\} = \Delta\lambda \left\{ \begin{array}{c} 2\sigma_{xx} - \sigma_{yy} \\ 2\sigma_{yy} - \sigma_{xx} \\ 6\sigma_{xy} \end{array} \right\}_{m-1} \quad (\text{A.40})$$

In Eq. A.40, the (known) stress state at time t_{m-1} is used. The use of this stress state instead of the trial state at time t_m has been found [13] to be more accurate than the latter for finite incremental changes involving states of two-dimensional stress. The actual stresses are then calculated from

$$\tilde{\sigma}_m = \tilde{\sigma}_m^T - \Delta\lambda^* \left\{ \begin{array}{c} \sigma_{xx} - \frac{(1-2\nu)}{3(1-\nu)} (\sigma_{xx} + \sigma_{yy}) \\ \sigma_{yy} - \frac{(1-2\nu)}{3(1-\nu)} (\sigma_{xx} + \sigma_{yy}) \\ \sigma_{xy} \end{array} \right\}_{m-1} \quad (\text{A.41a})$$

or

$$\tilde{\sigma}_m = \tilde{\sigma}_m^T - \Delta\lambda^* \hat{\tilde{\sigma}}_{m-1} \quad (\text{A.41b})$$

where

$$\Delta \lambda^* = \frac{3E}{(1+\nu)} \Delta \lambda \quad (\text{A.41c})$$

The plastic flow parameter $\Delta \lambda$ or $\Delta \lambda^*$ is evaluated from the condition that the actual stress state must lie on the yield surface. Thus, the following condition must be satisfied:

$$F_m = F(\sigma_m, \sigma_o) = \left[(\sigma_{xx})_m^2 + (\sigma_{yy})_m^2 - (\sigma_{xx})_m (\sigma_{yy})_m + 3(\sigma_{xy})_m^2 - \sigma_o^2 \right] = 0 \quad (\text{A.42})$$

Substituting Eq. A.41a into Eq. A.42 yields the following relation for $\Delta \lambda^*$

$$\Delta \lambda^* = \frac{C}{B + \sqrt{B^2 - AC}} = \frac{B - \sqrt{B^2 - AC}}{A} \quad (\text{A.43a})$$

where

$$\begin{aligned} A &= (\hat{\sigma}_{xx})_{m-1}^2 + (\hat{\sigma}_{yy})_{m-1}^2 - (\hat{\sigma}_{xx})_{m-1} (\hat{\sigma}_{yy})_{m-1} + 3(\sigma_{xy})_{m-1}^2 \\ B &= (\sigma_{xx}^T)_m (\hat{\sigma}_{xx})_{m-1} + (\sigma_{yy}^T)_m (\hat{\sigma}_{yy})_{m-1} - \frac{1}{2} (\sigma_{xx}^T)_m (\hat{\sigma}_{yy})_{m-1} \\ &\quad - \frac{1}{2} (\sigma_{yy}^T)_m (\hat{\sigma}_{xx})_{m-1} + 3(\sigma_{xy}^T)_m (\sigma_{xy})_{m-1} \\ C &= F_m^T \end{aligned} \quad (\text{A.43b})$$

Also, the following requirements must be satisfied:

$$\begin{aligned} B^2 - AC &\geq 0 \\ B + \sqrt{B^2 - AC} &> 0 \end{aligned} \quad (\text{A.43c})$$

With $\Delta \lambda^*$ (and therefore $\Delta \lambda$) determined, the stress state at time t_m can be obtained from Eq. A.41a and the plastic strain increments from t_{m-1} to t_m can be obtained from Eq. A.40. This process is carried out for each mechanical sublayer at each spanwise and depthwise Gaussian station. Once the sublayer stresses and plastic strains in each mechanical sublayer have been determined, the stresses and plastic strains at that Gaussian station can be found from a weighted sum of the sublayer results; details of the mechanical sublayer model are given in Subsection A.4.

During the operation of the solution process for intense loading problems, instances of large strain increments can occur which sometimes may lead to an imaginary (or negative) value of $\Delta\lambda$; that is, the conditions of Eq. A.43c are violated. Since the time-step size for that particular instance cannot be economically reduced, a subincrement procedure to circumvent this difficulty as discussed in Ref. 13 can be and is used. The basic finite-time increment, Δt , is divided into a number, say L , of equal subincrements; the size of the subincrement is chosen to be sufficiently small so that a positive real value of $\Delta\lambda$ for each subincrement can be derived successively. The value of the finite-strain increments $(\Delta\tilde{\epsilon})_m$ as calculated by Eq. A.11 during the time interval t_{m-1} to t_m are also divided into L equal parts, $(\Delta\tilde{\epsilon})_m/L$. It is assumed that during each subincrement of length $\Delta t/L$ this change in strain is approximately correct. Then, by employing the previously mentioned procedure, a valid value for $\Delta\lambda$ along with stress increments and plastic strain increments are calculated for each subinterval, and in the meanwhile, the stresses and plastic strains are kept updated. The process is continued until either (a) the information needed at time t_m is calculated or (b) a complex (or negative) $\Delta\lambda$ is encountered. In the latter case, the process is repeated from time t_{m-1} using a larger value of L . If the stresses at time t_m can be derived successfully, the solution procedure continues with L henceforth set to unity until an imaginary $\Delta\lambda$ is again encountered.

A.1.3.3 Element Stiffness Matrix

The preceding discussion pertains to the calculation of the equivalent element nodal force vector \tilde{f}^{NL} in Eq. A.34. The remaining element property matrix defined from the variation of the work of the stresses is the linear elastic element stiffness matrix, \tilde{k} (see Eq. A.34).

By substituting Eq. A.33b into Eq. A.32, the element stiffness matrix is seen to be given from the expression

$$\delta \underline{q}^T \underline{k} \underline{q} = \int_{V_n} \delta \underline{\tilde{\epsilon}}^T \underline{C} \underline{\tilde{\epsilon}} dV \quad (\text{A.44})$$

Equation A.7 is substituted in Eq. A.44 and the integration through the thickness is performed to give

$$\delta \underline{q}^T \underline{k} \underline{q} = \int_0^a \int_0^b [\delta \underline{\tilde{\epsilon}}^T \delta \underline{\tilde{\kappa}}^T] \hat{\underline{C}} \begin{Bmatrix} \underline{\tilde{\epsilon}} \\ \underline{\tilde{\kappa}} \end{Bmatrix} dx dy \quad (\text{A.45})$$

where

$$\hat{\underline{C}} = \frac{E h}{1-\nu^2} \begin{bmatrix} 1 & & & & & & \\ & \nu & & & & & \\ & 0 & 1 & & & & \\ & 0 & 0 & \frac{1-\nu}{2} & & & \\ & 0 & 0 & 0 & \frac{h^2}{12} & & \\ & 0 & 0 & 0 & \frac{\nu h^2}{12} & \frac{h^2}{12} & \\ & 0 & 0 & 0 & 0 & 0 & \frac{(1-\nu) h^2}{24} \end{bmatrix} \quad (\text{A.46})$$

SYMMETRIC

For computational convenience and efficiency, the stiffness matrix is first formed in the normalized (barred) system and then transformed back to the original x,y coordinate system. To this end, Eq. A.21 (which represents a transformation of strains and curvatures from the x,y system to the normalized system) is substituted in Eq. A.45 to give

$$\delta \underline{q}^T \underline{k} \underline{q} = ab \int_0^1 \int_0^1 \delta \left[\frac{\partial \bar{u}}{\partial \xi} \quad \frac{\partial \bar{v}}{\partial \xi} \quad \frac{\partial \bar{u}}{\partial \eta} \quad \frac{\partial \bar{v}}{\partial \eta} \quad \frac{\partial \bar{\theta}}{\partial \xi} \quad \frac{\partial \bar{\psi}}{\partial \xi} \quad 2\bar{\chi} \right] \bar{\underline{C}} \begin{Bmatrix} \frac{\partial \bar{u}}{\partial \xi} \\ \frac{\partial \bar{v}}{\partial \xi} \\ \frac{\partial \bar{u}}{\partial \eta} \\ \frac{\partial \bar{v}}{\partial \eta} \\ \frac{\partial \bar{\theta}}{\partial \xi} \\ \frac{\partial \bar{\psi}}{\partial \xi} \\ \frac{\partial \bar{\theta}}{\partial \eta} \\ \frac{\partial \bar{\psi}}{\partial \eta} \\ 2\bar{\chi} \end{Bmatrix} \quad (\text{A.47a})$$

where

$$\bar{C} = \bar{A}^T \hat{C} \bar{A} \quad (\text{A.47b})$$

The derivatives indicated in Eq. A.47a are obtained by differentiation of the interpolation assumptions given by Eqs. A.17a through A.17f:

$$\begin{aligned} \frac{\partial \bar{u}}{\partial \xi} &= \bar{\alpha}_2 + \eta \bar{\alpha}_4 \\ \frac{\partial \bar{v}}{\partial \eta} &= \bar{\alpha}_7 + \xi \bar{\alpha}_8 \\ \frac{\partial \bar{u}}{\partial \eta} &= \bar{\alpha}_3 + \xi \bar{\alpha}_4 \\ \frac{\partial \bar{v}}{\partial \xi} &= \bar{\alpha}_6 + \eta \bar{\alpha}_8 \\ \frac{\partial \bar{\theta}}{\partial \xi} &= 2\bar{\alpha}_{13} + 2\eta \bar{\alpha}_{15} + 2\eta^2 \bar{\alpha}_{17} + 6\xi \bar{\alpha}_{18} + 6\xi\eta \bar{\alpha}_{20} + 6\xi\eta^2 \bar{\alpha}_{22} \\ &\quad + 2\eta^3 \bar{\alpha}_{23} + 6\xi\eta^3 \bar{\alpha}_{24} \\ \frac{\partial \bar{\psi}}{\partial \eta} &= 2\bar{\alpha}_{14} + 2\xi \bar{\alpha}_{16} + 2\xi^2 \bar{\alpha}_{17} + 6\eta \bar{\alpha}_{19} + 6\xi\eta \bar{\alpha}_{21} + 6\xi^3 \bar{\alpha}_{22} \\ &\quad + 6\xi^2\eta \bar{\alpha}_{23} + 6\xi^3\eta \bar{\alpha}_{24} \\ 2\bar{\chi} &= 2\bar{\alpha}_{12} + 4\xi \bar{\alpha}_{15} + 4\eta \bar{\alpha}_{16} + 8\xi\eta \bar{\alpha}_{17} + 6\xi^2 \bar{\alpha}_{20} + 6\eta^2 \bar{\alpha}_{21} \\ &\quad + 12\xi^2\eta \bar{\alpha}_{22} + 12\xi\eta^2 \bar{\alpha}_{23} + 18\xi^3\eta^2 \bar{\alpha}_{24} \end{aligned} \quad (\text{A.48})$$

Equations A.48 can be written in matrix form as

$$\begin{Bmatrix} \frac{\partial \bar{u}}{\partial \xi} \\ \frac{\partial \bar{v}}{\partial \eta} \\ \frac{\partial \bar{u}}{\partial \eta} \\ \frac{\partial \bar{v}}{\partial \xi} \\ -\frac{\partial \bar{\theta}}{\partial \xi} \\ \frac{\partial \bar{\psi}}{\partial \eta} \\ 2\bar{\chi} \end{Bmatrix} = [D] \begin{Bmatrix} \bar{\alpha}_1 \\ \bar{\alpha}_2 \\ \bar{\alpha}_3 \\ \vdots \\ \bar{\alpha}_{24} \end{Bmatrix} = \begin{bmatrix} D_1 & 0 \\ 0 & D_2 \end{bmatrix} \begin{Bmatrix} \bar{\alpha}_1 \\ \bar{\alpha}_2 \\ \vdots \\ \bar{\alpha}_8 \\ \bar{\alpha}_9 \\ \bar{\alpha}_{10} \\ \vdots \\ \bar{\alpha}_{24} \end{Bmatrix} \quad (\text{A.49})$$

where the 4 by 8 matrix \underline{D}_1 and the 3 by 16 matrix \underline{D}_2 are obtained from Eqs. A.48. Note that the first 4 columns of \underline{D}_2 are zero. When Eq. A.19 is substituted into Eq. A.49 and the result substituted into Eq. A.47a, the following expression is obtained:

$$\delta \underline{q}_{\sim}^T \hat{k}_{\sim} \underline{q}_{\sim} = \delta \underline{\bar{q}}_{\sim}^T \left(\underline{\bar{G}}^{-1T} \underbrace{\left[ab \int_0^1 \int_0^1 \underline{D}_{\sim}^T \underline{\bar{C}}_{\sim} \underline{D}_{\sim} d\xi d\eta \right]}_{\hat{k}_{\sim}} \underline{\bar{G}}^{-1} \right) \underline{\bar{q}}_{\sim} \quad (\text{A.50})$$

where \hat{k}_{\sim} may be viewed as the "kernel" stiffness matrix in terms of the generalized displacement parameters $\bar{\alpha}_1, \bar{\alpha}_2, \bar{\alpha}_3, \dots, \bar{\alpha}_{24}$ and is given by

$$\hat{k}_{\sim} = ab \int_0^1 \int_0^1 \underline{D}_{\sim}^T \underline{\bar{C}}_{\sim} \underline{D}_{\sim} d\xi d\eta \quad (\text{A.51a})$$

and \bar{k}_{\sim} is the "kernel" stiffness matrix in terms of generalized nodal displacement parameters \bar{q}_{\sim} in the normalized system and is given by

$$\bar{k}_{\sim} = (\underline{\bar{G}}^{-1})^T \hat{k}_{\sim} \underline{\bar{G}}^{-1} \quad (\text{A.51b})$$

Finally, the normalized nodal displacement \bar{q}_{\sim} can be related to the generalized nodal displacement parameters q_{\sim} in the form

$$\bar{q}_{\sim} = \underline{T}_{\sim} q_{\sim} \quad (\text{A.52a})$$

where the transformation matrix \underline{T}_{\sim} is a diagonal matrix and can be written in the form

$$\underline{T}_{\sim} = \begin{bmatrix} [t] & & & \\ & [t] & & \\ & & \bigcirc & \\ \bigcirc & & & [t] \\ & & & & [t] \end{bmatrix} \quad (\text{A.52b})$$

and the diagonal sub-matrix \underline{t}_{\sim} is obtained from Eqs. A.15 and is given by

In the second approach, the interpolated spatial distribution of the displacements is ignored; instead, the displacement behavior is assumed to be either (1) constant over each quarter (or half-side) of the plate and equal to the value of the displacement at the node associated with that quarter (or half-side) of the plate, or (2) constant over the whole plate element (or element side) and equal to the average of the four (or two) nodal values; a nodal force vector derived in this fashion will be termed a lumped force vector. The formulation of a consistent nodal force vector will be discussed first.

Three types of force distribution are evident: (1) line forces (tractions) distributed along element boundaries, (2) area forces which are distributed over the midsurface of the plate (e.g. transverse loading on a plate), and (3) volume forces which are distributed throughout the plate element. The first type is rigorously included in all statements of Virtual Work and the third type may be treated in the same fashion as a distributed body force. The second type may be included as a special case of a distributed body force in which no variation occurs through the thickness.

The work (at a discrete time t_m) of the external forces for a typical n th element, $(W)_n$, is given by

$$\begin{aligned}
 (W)_n = & \int_{S_{\sigma_n}} (F_x^L \tilde{u} + F_y^L \tilde{v} + F_z^L \tilde{w})_{t_m} dA \\
 & + \int_{A_{\sigma_n}} (F_x^A u + F_y^A v + F_z^A w)_{t_m} dA \\
 & + \int_{V_n} (F_x^B \tilde{u} + F_y^B \tilde{v} + F_z^B \tilde{w})_{t_m} dV
 \end{aligned} \tag{A.54}$$

where

F_x^L, F_y^L, F_z^L = Components of the edge (line) force in the $x, y,$ and z directions, which are in general a function of the element side coordinate and thickness (lb/in^2).

F_x^A, F_y^A, F_z^A = Components of the force acting over the plate surface in the $x, y,$ and z directions. Each component may, in general, be a function of x and y only (lb/in^2).

F_x^B, F_y^B, F_z^B = Components (in the x, y, and z directions of the body force, or any analogous force which is distributed throughout the element volume (lb/in^3)).

The distribution of the forces is assumed to be known. Equations A.1 may be substituted into Eq. A.54 and the result written in the following matrix form

$$\begin{aligned}
 (W)_n = & \int_0^{\ell} \int_{-\frac{h}{2}}^{\frac{h}{2}} [u \ v \ w \ \theta \ \psi] \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \\ -z & 0 & 0 \\ 0 & -z & 0 \end{bmatrix} \begin{Bmatrix} F_x^L \\ F_y^L \\ F_z^L \end{Bmatrix} ds dz \\
 & + \int_0^a \int_0^b [u \ v \ w] \begin{Bmatrix} F_x^A \\ F_y^A \\ F_z^A \end{Bmatrix} dx dy \\
 & + \int_0^a \int_0^b \int_{-\frac{h}{2}}^{\frac{h}{2}} [u \ v \ w \ \theta \ \psi] \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \\ -z & 0 & 0 \\ 0 & -z & 0 \end{bmatrix} \begin{Bmatrix} F_x^B \\ F_y^B \\ F_z^B \end{Bmatrix} dx dy dz
 \end{aligned} \tag{A.55}$$

where ℓ in the first integral is the length of the element side on which the force is applied. It is generally more convenient to perform calculations in the normalized coordinate system, so that Eq. A.55 should be written as

$$\begin{aligned}
 (W)_n = & \ell \int_0^1 \int_{-\frac{h}{2}}^{\frac{h}{2}} [\bar{u} \ \bar{v} \ \bar{w} \ \bar{\theta} \ \bar{\psi}] \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \\ -\frac{z}{a} & 0 & 0 \\ 0 & -\frac{z}{b} & 0 \end{bmatrix} \begin{Bmatrix} F_x^L \\ F_y^L \\ F_z^L \end{Bmatrix} ds dz \\
 & + ab \int_0^1 \int_0^1 [\bar{u} \ \bar{v} \ \bar{w}] \begin{Bmatrix} F_x^A \\ F_y^A \\ F_z^A \end{Bmatrix} d\xi d\eta \\
 & + ab \int_0^1 \int_0^1 [\bar{u} \ \bar{v} \ \bar{w} \ \bar{\theta} \ \bar{\psi}] \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \\ -\frac{z}{a} & 0 & 0 \\ 0 & -\frac{z}{b} & 0 \end{bmatrix} \begin{Bmatrix} F_x^B \\ F_y^B \\ F_z^B \end{Bmatrix} d\xi d\eta dz
 \end{aligned} \tag{A.56}$$

For the first integral in Eq. A.56, displacements along the boundary are interpolated by using Eqs. A.17a through A.17e to yield a matrix relation in the form

$$\begin{Bmatrix} \bar{u} \\ \bar{v} \\ \bar{w} \\ \bar{\theta} \\ \bar{\psi} \end{Bmatrix} = \left[N^L(s) \right] \begin{Bmatrix} \bar{\alpha}_1 \\ \bar{\alpha}_2 \\ \vdots \\ \bar{\alpha}_{24} \end{Bmatrix} \quad (\text{A.57})$$

The matrix $N^L(s)$ is obtained by evaluating the interpolation assumptions along the element boundary on which the force is applied. The following table may be used to put the interpolation of Eqs. A.17a through A.17e into the proper form:

<u>Element Side Number</u>	<u>Replace ξ by</u>	<u>Replace η by</u>
1	s	0
2	1	s
3	s	1
4	0	s

The force distribution in the first integral of Eq. A.56 must also be given as functions $F_x^L(s,z)$, $F_y^L(s,z)$, and $F_z^L(s,z)$.

The displacement in the second integral of Eq. A.56 may be expressed in terms of displacement parameters $\bar{\alpha}_1, \bar{\alpha}_2, \dots, \bar{\alpha}_{24}$ in matrix form

$$\begin{Bmatrix} \bar{u} \\ \bar{v} \\ \bar{w} \end{Bmatrix} = \left[N^3(\xi, \eta) \right] \begin{Bmatrix} \bar{\alpha}_1 \\ \bar{\alpha}_2 \\ \vdots \\ \bar{\alpha}_{24} \end{Bmatrix} \quad (\text{A.58})$$

where the interpolation matrix $N^3(\xi, \eta)$, is obtained by writing Eqs. A.17a, A.17b, and A.17c in matrix form. Also, the force distribution should be given as functions $F_x^A(\xi, \eta)$, $F_y^A(\xi, \eta)$, and $F_z^A(\xi, \eta)$.

The displacements in the final integral of Eq. A.56 may be interpolated in terms of $\bar{\alpha}_1, \bar{\alpha}_2, \dots, \bar{\alpha}_{24}$ in the matrix form

$$\begin{Bmatrix} \bar{u} \\ \bar{v} \\ \bar{w} \\ \bar{\theta} \\ \bar{\psi} \end{Bmatrix} = [N(\xi, \eta)] \begin{Bmatrix} \bar{\alpha}_1 \\ \bar{\alpha}_2 \\ \vdots \\ \bar{\alpha}_{24} \end{Bmatrix} \quad (\text{A.59})$$

where $N(\xi, \eta)$ is obtained by writing Eqs. A.17a through A.17e in matrix form. The force distributions should be given as functions $F_x^B(\xi, \eta, z)$, $F_y^B(\xi, \eta, z)$, and $F_z^B(\xi, \eta, z)$.

If Eqs. A.57, A.58, and A.59 are substituted into Eq. A.56, the work of the external forces can be put in the form

$$(W)_n = [\bar{\alpha}_1 \ \bar{\alpha}_2 \ \dots \ \bar{\alpha}_{24}] \hat{\underset{\sim}{f}} \quad (\text{A.60})$$

where the vector $\hat{\underset{\sim}{f}}$ is given by

$$\begin{aligned} \hat{\underset{\sim}{f}} = & \ell \int_0^1 \int_{-\frac{h}{2}}^{\frac{h}{2}} [N^L(s)]^T \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \\ -\frac{z}{a} & 0 & 0 \\ 0 & -\frac{z}{b} & 0 \end{bmatrix} \begin{Bmatrix} F_x^L(s, z) \\ F_y^L(s, z) \\ F_z^L(s, z) \end{Bmatrix}_{t_m} ds dz \\ & + ab \int_0^1 \int_0^1 [N^3(\xi, \eta)]^T \begin{Bmatrix} F_x^A(\xi, \eta) \\ F_y^A(\xi, \eta) \\ F_z^A(\xi, \eta) \end{Bmatrix}_{t_m} d\xi d\eta \\ & + ab \int_0^1 \int_0^1 \int_{-\frac{h}{2}}^{\frac{h}{2}} [N(\xi, \eta)]^T \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \\ -\frac{z}{a} & 0 & 0 \\ 0 & -\frac{z}{b} & 0 \end{bmatrix} \begin{Bmatrix} F_x^B(\xi, \eta, z) \\ F_y^B(\xi, \eta, z) \\ F_z^B(\xi, \eta, z) \end{Bmatrix}_{t_m} d\xi d\eta dz \quad (\text{A.61}) \end{aligned}$$

In order to transform Eq. A.60 into a form containing the generalized nodal displacements, $\underset{\sim}{q}$ the displacement parameters $\bar{\alpha}_1, \bar{\alpha}_2, \dots, \bar{\alpha}_{24}$ are first related to the normalized nodal displacements, $\bar{\underset{\sim}{q}}$, by Eq. A.19, and the normalized nodal displacements $\bar{\underset{\sim}{q}}$ are then related to the generalized nodal displacements, $\underset{\sim}{q}$, by Eq. A.52a. The final form of Eq. A.60 is then

$$(\underline{W})_n = \underline{q}^T \underline{f}_c \quad (\text{A.62})$$

where \underline{f}_c is the consistent element nodal force vector corresponding to externally-applied forces and is related to $\hat{\underline{f}}$ (Eq. A.61) by

$$\underline{f}_c = \underline{T} (\underline{\bar{G}}^{-1})^T \hat{\underline{f}} \quad (\text{A.63})$$

Once the spatial distribution of the forces over the element are known, they are substituted into Eq. A.61 and the integration performed to give $\hat{\underline{f}}$; in many cases, the force distributions will be sufficiently simple so that these integrations can be performed analytically and a simple algorithm written to generate $\hat{\underline{f}}$ for each element. Alternatively, $\hat{\underline{f}}$ may be evaluated by using numerical integration (see, for example, Ref. 10 for a detailed discussion of numerical integration applied to the finite-element method).

No mention has yet been made of the time domain. As will be shown in Subsection A.3, in order to obtain the timewise solution of the governing equations of motion for the structure, the nodal force vector corresponding to externally-applied forces must be specified at discrete time instants, t_m . Thus Eqs. A.54 through A.63 refer to the work of the externally-applied forces at a particular instant in time when the spatial distributions of the forces are $F_x^L(s,z)$, $F_y^L(s,z)$, $F_z^L(s,z)$, $F_x^A(\xi,\eta)$, $F_y^A(\xi,\eta)$, $F_z^A(\xi,\eta)$, etc. In general, these spatial distributions may change at each discrete time instant and thus \underline{f}_c must be re-evaluated for each element at each time instant using the spatial distributions of the external forces at that time instant.

Some simplification of this calculation may be realized if the spatial and temporal dependence of the external forces can be uncoupled. For simplicity, this simplification will be illustrated only for the second integral of $\hat{\underline{f}}$ (Eq. A.61); but it should be noted that the development holds for all integrals required to calculate $\hat{\underline{f}}$. Assume, for example, that

$$\left\{ \begin{array}{c} F_x^A \\ F_y^A \\ F_z^A \end{array} \right\}_t = \left[\begin{array}{ccc} g_1(t) & 0 & 0 \\ 0 & g_2(t) & 0 \\ 0 & 0 & g_3(t) \end{array} \right] \left\{ \begin{array}{c} F_x^A(\xi,\eta) \\ F_y^A(\xi,\eta) \\ F_z^A(\xi,\eta) \end{array} \right\} \quad (\text{A.64a})$$

where $g_1(t)$, $g_2(t)$, and $g_3(t)$ are specified functions of time and $F_x^A(\xi, \eta)$, $F_y^A(\xi, \eta)$, and $F_z^A(\xi, \eta)$ are independent of time. In this case, the second integral of Eq. A.61 would become

$$ab \int_0^1 \int_0^1 [N^3(\xi, \eta)]^T \begin{bmatrix} g_1(t_m) & 0 & 0 \\ 0 & g_2(t_m) & 0 \\ 0 & 0 & g_3(t_m) \end{bmatrix} \begin{Bmatrix} F_x^A(\xi, \eta) \\ F_y^A(\xi, \eta) \\ F_z^A(\xi, \eta) \end{Bmatrix} d\xi d\eta \quad (\text{A.64b})$$

The area integral need be performed only once; the result is then appropriately scaled by $g_1(t_m)$, $g_2(t_m)$, and $g_3(t_m)$ at each time instant.

The greatest simplification of the calculation of \underline{f}_c comes when the uncoupled timewise variation of the external forces is the same for all force components, i.e., when all force components may be expressed in the form

$$\begin{Bmatrix} F_x^A(\xi, \eta, t) \\ F_y^A(\xi, \eta, t) \\ F_z^A(\xi, \eta, t) \end{Bmatrix} = \begin{Bmatrix} F_x^A(\xi, \eta) \\ F_y^A(\xi, \eta) \\ F_z^A(\xi, \eta) \end{Bmatrix} g(t) \quad (\text{A.65})$$

In this case, the scalar $g(t_m)$ may be taken outside the integrals in Eq. A.61. It is easy to see that the element force vector $(\underline{f}_c)_{t_m}$ evaluated at any time instant t_m is given by

$$(\underline{f}_c)_{t_m} = g(t_m) \hat{\underline{f}}_c \quad (\text{A.66})$$

where \underline{f}_c is given by Eq. A.63 and $\hat{\underline{f}}_c$ is obtained from Eq. A.61 and need be calculated only once for each transient analysis problem. It should be noted that the use of Eq. A.65 implies that the shape of the applied force distribution is identical at all time steps, and that the magnitude of the applied force distribution varies as some prescribed function of time, $g(t)$.

The second (lumped) approach to the formulation of the nodal force vector utilizes the same force distribution as the first (consistent) approach, but a simplified assumption is used for the displacement distribution within the element; the resulting force vectors will be loosely termed lumped force vectors (as a result of the lumping or averaging schemes which will be used to describe

the displacement distributions). Two types of displacement distribution averaging, and the resulting nodal force vectors (to be denoted by $\underline{f}_{\lambda 1}$, and $\underline{f}_{\lambda 2}$), will be described. For the present development, there is no need to introduce normalized coordinates; thus, the distribution of the components of force at time t_m will be specified in the x, y, z coordinate system.

In the first lumping scheme, the displacement behavior within an element is assumed to be constant over the element and equal to the algebraic average of the current nodal displacements for the element. Thus the distribution of the displacements u, v, w, θ , and ψ in Eq. A.55 are given by

$$\begin{Bmatrix} u \\ v \\ w \\ \theta \\ \psi \end{Bmatrix} = \frac{1}{4} \sum_{i=1}^4 \begin{Bmatrix} u_i \\ v_i \\ w_i \\ \theta_i \\ \psi_i \end{Bmatrix} \quad (\text{A.67})$$

According to the nodal degree of freedom numbering scheme given in Eq. A.4, Eq. A.67 can be written in matrix form as

$$\begin{Bmatrix} u \\ v \\ w \\ \theta \\ \psi \end{Bmatrix} = \frac{1}{4} \begin{bmatrix} \underline{b} & \underline{b} & \underline{b} & \underline{b} \end{bmatrix} \{q\} = \frac{1}{4} \underline{B} \underline{q} \quad (\text{A.68})$$

where \underline{b} is the Boolean matrix

$$\underline{b} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix} \quad (\text{A.68a})$$

Equation A.68 applies to the (averaged uniform) distribution of displacements within the element and is in a form appropriate for substitution into the last integral in Eq. A.55. For the second integral in Eq. A.55, only u , v , and w are needed; in this case \underline{B} in Eq. A.68 is replaced by \underline{B}^3 where \underline{B}^3 is the first three rows of \underline{B} . For the first integral in Eq. A.55, the averaged uniform displacement distribution along the loaded element side depends only on the current displacements at the nodes along that side. In this case, the averaging factor in Eq. A.68 is $1/2$ instead of $1/4$, and the form of \underline{B}^5 (replacing \underline{B} in Eq. A.68) depends on the element side being loaded:

$$\begin{aligned}
 \text{Side 1 : } \quad \underline{B}^5 &= \begin{bmatrix} \underline{b} & \underline{b} & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \\
 \text{Side 2 : } \quad \underline{B}^5 &= \begin{bmatrix} 0 & \underline{b} & \underline{b} & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \\
 \text{Side 3 : } \quad \underline{B}^5 &= \begin{bmatrix} 0 & 0 & \underline{b} & \underline{b} \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \\
 \text{Side 4 : } \quad \underline{B}^5 &= \begin{bmatrix} \underline{b} & 0 & 0 & \underline{b} \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}
 \end{aligned} \tag{A.69}$$

Equation A.68 (or the equivalent for the first and second integrals) is substituted into the expression for the work of the external forces for a typical n th element at time t_m to give

$$\begin{aligned}
 (W)_n &= \underline{q}^T \underline{B}^5 T \frac{1}{2} \int_0^l \int_{-\frac{h}{2}}^{\frac{h}{2}} \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \\ -z & 0 & 0 \\ 0 & -z & 0 \end{bmatrix} \begin{Bmatrix} F_x^L(s,z) \\ F_y^L(s,z) \\ F_z^L(s,z) \end{Bmatrix} ds dz \\
 &+ \underline{q}^T \underline{B}^3 T \frac{1}{4} \int_0^a \int_0^b \begin{Bmatrix} F_x^A(x,y) \\ F_y^A(x,y) \\ F_z^A(x,y) \end{Bmatrix} dx dy \\
 &+ \underline{q}^T \underline{B}^T \frac{1}{4} \int_0^a \int_0^b \int_{-\frac{h}{2}}^{\frac{h}{2}} \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \\ -z & 0 & 0 \\ 0 & -z & 0 \end{bmatrix} \begin{Bmatrix} F_x^B(x,y,z) \\ F_y^B(x,y,z) \\ F_z^B(x,y,z) \end{Bmatrix} dx dy dz
 \end{aligned} \tag{A.70}$$

The following vectors may be defined

$$\hat{f}_{\sim L} = \frac{1}{2} \int_0^L \int_{-\frac{h}{2}}^{\frac{h}{2}} \left\{ \begin{array}{l} F_x^L(s, z) \\ F_y^L(s, z) \\ F_z^L(s, z) \\ -z F_x^L(s, z) \\ -z F_y^L(s, z) \end{array} \right\} ds dz \quad (A.71a)$$

$$\hat{f}_{\sim A} = \frac{1}{4} \int_0^a \int_0^b \left\{ \begin{array}{l} F_x^A(x, y) \\ F_y^A(x, y) \\ F_z^A(x, y) \end{array} \right\} dx dy \quad (A.71b)$$

$$\hat{f}_{\sim B} = \frac{1}{4} \int_0^a \int_0^b \int_{-\frac{h}{2}}^{\frac{h}{2}} \left\{ \begin{array}{l} F_x^B(x, y, z) \\ F_y^B(x, y, z) \\ F_z^B(x, y, z) \\ -z F_x^B(x, y, z) \\ -z F_y^B(x, y, z) \end{array} \right\} dz dx dy \quad (A.71c)$$

Then Eq. A.70 may be expressed in the form

$$(W)_n = \hat{g}_{\sim}^T \hat{f}_{\sim L1} \quad (A.72)$$

where $\hat{f}_{\sim L1}$ is the first type of lumped nodal load vector and is given by

$$\hat{f}_{\sim L1} = \hat{B}_{\sim}^{5T} \hat{f}_{\sim L} + \hat{B}_{\sim}^{3T} \hat{f}_{\sim A} + \hat{B}_{\sim}^T \hat{f}_{\sim B} \quad (A.73)$$

The operations shown in Eq. A.73 correspond to the proper positioning and addition of the vectors $\hat{f}_{\sim L}$, $\hat{f}_{\sim A}$, and $\hat{f}_{\sim B}$ into the nodal loads vector $\hat{f}_{\sim L1}$. The five entries in the $\hat{f}_{\sim L}$ vector are added into the five locations corresponding

to the first five degrees of freedom at each of the nodes located along this element edge. The three terms in $\hat{f}_{\sim A}$ are added into rows 1 through 3, 7 through 9, 13 through 15, and 19 through 21 in $\underline{f}_{\sim \ell 1}$ (corresponding to displacements u , v , and w at each node). The five terms in $\hat{f}_{\sim B}$ are added into rows 1 through 5, 7 through 11, 13 through 17, and 19 through 23 in $\underline{f}_{\sim \ell 1}$ (corresponding to displacements u , v , w , θ , and ψ at each node).

The second type of lumped loading is established through an alternate assumption for the displacement behavior in the element. First the undeformed rectangular plate element is subdivided into four equal-size regions; using the notation R_i to denote subregion i (associated with node i of the plate), it is now assumed that the displacements within each subregion are constant and equal to the value of the displacements at the node associated with that subregion. If one thus defines

$$\underline{F}^L = \left\{ \begin{array}{l} F_x^L(s, z) \\ F_y^L(s, z) \\ F_z^L(s, z) \\ -z F_x^L(s, z) \\ -z F_y^L(s, z) \end{array} \right\} \quad (\text{A.74a})$$

$$\underline{F}^A = \left\{ \begin{array}{l} F_x^A(x, y) \\ F_y^A(x, y) \\ F_z^A(x, y) \end{array} \right\} \quad (\text{A.74b})$$

$$\underline{F}^B = \left\{ \begin{array}{l} F_x^B(x, y, z) \\ F_y^B(x, y, z) \\ F_z^B(x, y, z) \\ -z F_x^B(x, y, z) \\ -z F_y^B(x, y, z) \end{array} \right\} \quad (\text{A.74c})$$

Next by subdividing the line, area, and volume integrals of Eq. A.55, the work of the external forces can be defined in the form

$$(W)_n = \tilde{q}^T \tilde{f}_{l2} \quad (\text{A.75})$$

where \tilde{f}_{l2} is the lumped nodal load vector of the second type and is given by

$$\tilde{f}_{l2} = \left\{ \begin{array}{c} \int_{-\frac{h}{2}}^{\frac{h}{2}} \int_{s_1} \tilde{F}^L dA \\ \hline 0 \\ \hline \int_{-\frac{h}{2}}^{\frac{h}{2}} \int_{s_2} \tilde{F}^L dA \\ \hline 0 \\ \hline \int_{-\frac{h}{2}}^{\frac{h}{2}} \int_{s_3} \tilde{F}^L dA \\ \hline 0 \\ \hline \int_{-\frac{h}{2}}^{\frac{h}{2}} \int_{s_4} \tilde{F}^L dA \\ \hline 0 \end{array} \right\} + \left\{ \begin{array}{c} \int_{R_1} \tilde{F}^A dx dy \\ \hline 0 \\ \hline 0 \\ \hline \int_{R_2} \tilde{F}^A dx dy \\ \hline 0 \\ \hline 0 \\ \hline 0 \\ \hline \int_{R_3} \tilde{F}^A dx dy \\ \hline 0 \\ \hline 0 \\ \hline 0 \\ \hline \int_{R_4} \tilde{F}^A dx dy \\ \hline 0 \\ \hline 0 \\ \hline 0 \end{array} \right\} + \left\{ \begin{array}{c} \int_{-\frac{h}{2}}^{\frac{h}{2}} \int_{R_1} \tilde{F}^B dx dy dz \\ \hline 0 \\ \hline \int_{-\frac{h}{2}}^{\frac{h}{2}} \int_{R_2} \tilde{F}^B dx dy dz \\ \hline 0 \\ \hline \int_{-\frac{h}{2}}^{\frac{h}{2}} \int_{R_3} \tilde{F}^B dx dy dz \\ \hline 0 \\ \hline \int_{-\frac{h}{2}}^{\frac{h}{2}} \int_{R_4} \tilde{F}^B dx dy dz \\ \hline 0 \end{array} \right\} \quad (\text{A.76})$$

where it should be noted that the length s_1 refers to the half-side lengths associated with node 1. Clearly the first vector corresponds to line loadings, the second vector to loading distributed over the mid-surface of the plate, and the third vector to loading distributed over the plate volume.

The difference between \tilde{f}_{l1} and \tilde{f}_{l2} may be summarized as follows: at a node, the lumped load is equal either to (1) one-quarter of the total load integrated over the whole plate (for \tilde{f}_{l1}), or (2) to the value of the load integrated over one-quarter of the plate. For a constant load (in space), these two forms are equivalent. Also, it should be expected that the second form of lumping, \tilde{f}_{l2} , will be the more accurate of the two lumping schemes.

The preceding discussion pertains only to the spatial distributions of the external force, and the forces defined should be viewed as being derived on the basis of the force distributions at a particular instant in time. The discussion of time dependence for the consistent loading vector and corresponding possible simplification also applies to the two alternate lumping schemes and is, therefore, not repeated here.

A.1.3.5 Element Stiffness Matrix Corresponding to Elastic Restoring Springs

In the PLATE program, linear elastic line restoring springs may be specified. These line restoring springs are permitted to act only along element boundaries. The variation of the work done by the restoring springs, δW_{sp} , is given by (writing $-\delta W_{sp}$ hereinafter for convenience)

$$-\delta W_{sp} = \int_{side\ i} (k_x u \delta u + k_y v \delta v + k_z w \delta w + k_\theta \theta \delta \theta + k_\psi \psi \delta \psi) ds \quad (A.77)$$

where k_x , k_y , and k_z are the line translational spring constants (units of lb/in per in of span) corresponding to springs oriented in the x, y, and z directions, respectively; k_θ and k_ψ are the line torsional spring constants (units of in-lb/radian per in of span) corresponding to rotation about the y and x axes, respectively; and the integration of Eq. A.77 extends over the i th side of the element (i=1,2,3, or 4).

For convenience, the normalized coordinate system (Subsection A.1.2) and associated normalized nodal degrees of freedom are used. Then Eq. A.77 may be written in terms of normalized quantities in the matrix form

$$-\delta W_{sp} = l_i \int_0^1 [\delta \bar{u} \delta \bar{v} \delta \bar{w} \delta \bar{\theta} \delta \bar{\psi}] \underbrace{\begin{bmatrix} k_x & & & & \\ & k_y & & & \\ & & k_z & & \\ & & & \frac{k_\theta}{a^2} & \\ & & & & \frac{k_\psi}{b^2} \end{bmatrix}}_{[\bar{C}_{sp}]} \begin{Bmatrix} \bar{u} \\ \bar{v} \\ \bar{w} \\ \bar{\theta} \\ \bar{\psi} \end{Bmatrix} \quad (A.78)$$

where l_i is the length of element side 1. The normalized displacements, \bar{u} , \bar{v} , \bar{w} , $\bar{\theta}$, and $\bar{\psi}$ must be expressed in terms of the normalized nodal generalized displacements at the two nodes (1 and $i+1$) bounding element side i . This relation for side 1 (for example) is given by

$$\begin{aligned}
 \bar{u} &= \bar{u}_1 (1-s) + \bar{u}_2 s \\
 \bar{v} &= \bar{v}_1 (1-s) + \bar{v}_2 s \\
 \bar{w} &= \bar{w}_1 (1-3s^2+2s^3) + \bar{w}_2 (3s^2-2s^3) + \bar{\theta}_1 (s-2s^2+s^3) + \bar{\theta}_2 (-s^2+s^3) \\
 \bar{\theta} &= \bar{\theta}_1 (1-4s+3s^2) + \bar{\theta}_2 (-2s+3s^2) + \bar{w}_1 (-6s+6s^2) + \bar{w}_2 (6s-6s^2) \\
 \bar{\psi} &= \bar{\psi}_1 (1-3s^2+2s^3) + \bar{\psi}_2 (3s^2-2s^3) + \bar{\chi}_1 (s-2s^2+s^3) + \bar{\chi}_2 (-s^2+s^3)
 \end{aligned} \tag{A.79}$$

and for side 4 (where $\xi=0$), the relation is

$$\begin{aligned}
 \bar{u} &= \bar{u}_1 (1-s) + \bar{u}_2 s \\
 \bar{v} &= \bar{v}_1 (1-s) + \bar{v}_4 s \\
 \bar{w} &= \bar{w}_1 (1-3s^2+2s^3) + \bar{w}_4 (3s^2-2s^3) + \bar{\psi}_1 (s-2s^2+s^3) + \bar{\psi}_4 (-s^2+s^3) \\
 \bar{\theta} &= \bar{\theta}_1 (1-3s^2+2s^3) + \bar{\theta}_4 (3s^2-2s^3) + \bar{\chi}_1 (s-2s^2+s^3) + \bar{\chi}_4 (-s^2+s^3) \\
 \bar{\psi} &= \bar{\psi}_1 (1-4s+3s^2) + \bar{\psi}_4 (-2s+3s^2) + \bar{w}_1 (-6s+6s^2) + \bar{w}_4 (6s-6s^2)
 \end{aligned} \tag{A.80}$$

In general, these relations are written in matrix form:

$$\begin{Bmatrix} \bar{u} \\ \bar{v} \\ \bar{w} \\ \bar{\theta} \\ \bar{\psi} \end{Bmatrix} = [N^i] \begin{Bmatrix} \bar{u}_i \\ \bar{v}_i \\ \vdots \\ \bar{u}_{i+1} \\ \bar{v}_{i+1} \\ \vdots \\ \bar{\psi}_{i+1} \end{Bmatrix} \tag{A.81}$$

When Eq. A.81 is substituted into Eq. A.78, $-\delta W_{sp}$ becomes

$$-\delta W_{sp} = \delta \left[\bar{u}_i \ \bar{v}_i \ \bar{w}_i \ \dots \ \bar{u}_{i+1} \ \bar{v}_{i+1} \ \dots \ \bar{\psi}_{i+1} \right] \underbrace{\int_0^1 [N^i]^T [\bar{C}_{sp}] [N^i] ds}_{[k_{sp}]} \begin{Bmatrix} \bar{u}_i \\ \bar{v}_i \\ \vdots \\ \bar{u}_{i+1} \\ \bar{v}_{i+1} \\ \vdots \\ \bar{\psi}_{i+1} \end{Bmatrix} \tag{A.82}$$

The normalized nodal generalized displacements are then expressed in terms of nodal displacements u_i, v_i, \dots as

$$\begin{Bmatrix} \bar{u}_i \\ \bar{v}_i \\ \bar{w}_i \\ \vdots \\ \bar{u}_{i+1} \\ \bar{v}_{i+1} \\ \vdots \\ \bar{\psi}_{i+1} \end{Bmatrix} = \begin{bmatrix} \tilde{t} & 0 \\ 0 & \tilde{t} \end{bmatrix} \begin{Bmatrix} u_i \\ v_i \\ w_i \\ \vdots \\ u_{i+1} \\ v_{i+1} \\ \vdots \\ \psi_{i+1} \end{Bmatrix} \equiv [T] \begin{Bmatrix} u_i \\ v_i \\ w_i \\ \vdots \\ u_{i+1} \\ v_{i+1} \\ \vdots \\ \psi_{i+1} \end{Bmatrix} \quad (\text{A.83})$$

where the diagonal matrix, \tilde{t} , is defined in Eq. A.52c. Substituting Eq. A.83 into Eq. A.82 yields

$$-\delta W_{sp} = \delta \begin{bmatrix} u_i & v_i & \dots & u_{i+1} & v_{i+1} & \dots & \psi_{i+1} \end{bmatrix} [k_{sp}^i] \begin{Bmatrix} u_i \\ v_i \\ \vdots \\ u_{i+1} \\ v_{i+1} \\ \vdots \\ \psi_{i+1} \end{Bmatrix} \quad (\text{A.84})$$

where $[k_{sp}^i]$ is the compacted stiffness matrix corresponding to line elastic restoring springs on element side i , and is given by

$$[k_{sp}] = [T]^T [\bar{k}_{sp}] [T] \quad (\text{A.85})$$

The compacted matrix $[\bar{k}_{sp}]$ has been obtained analytically and is given in Table A.1a for element sides 1 and 3, and in Table A.1b for element sides 2 and 4. The variation of work, $-\delta W_{sp}$, can be related to all of the element nodal displacements, q by

$$-\delta W_{sp} = \delta \tilde{q}^T [k_{sp}] \tilde{q} \quad (\text{A.86})$$

by "assembling" (relocating and adding in) the entries in the compacted matrices $k_{\sim sp}$ or $k_{\sim sp}^1$ into the element spring-stiffness matrix, $k_{\sim sp}$. To aid in this assembly process, the rows and columns of $\bar{k}_{\sim sp}$ given in Table A.1 are labelled with the appropriate nodal displacements.

A.2 Formulations for Stiffened Rectangular Plate Elements

The PLATE program accommodates integrally-stiffened flat plates where the stiffeners must be oriented in the x and/or y directions. Other assumptions related to geometry and deformation behavior of the stiffeners are given in Subsection 2.1.

In the PLATE program, the stiffened plate element is developed by superimposing an unstiffened plate element and a compatibly derived beam element. The formulation of straight beam elements by the assumed-displacement model is a straightforward process and is detailed in most texts on finite-element analysis methods. For the present case, the stiffener (or stiffeners) located on a particular element will be assumed to contribute only to the kinetic energy (mass matrix) and the internal work of the stresses (stiffness matrix and equivalent nodal loads corresponding to nonlinear effects). The stiffener is assumed to have no effect on the work of the external forces or the work of the line restoring springs; thus, the developments in Subsections A.1.3.4 and A.1.3.5 apply to both unstiffened and stiffened plates.

Before presenting details of the formulation of the stiffener contributions, some comments regarding the interpolation assumption for the stiffeners should be made. In order to calculate the property matrices for a stiffener, the geometry (rectangular cross-section width and height) and location of the stiffener (η_s for x-direction stiffeners, and ξ_s for y-direction stiffeners) and the z-location (top or bottom of the plate) must be known.

Because the stiffener is assumed to be perfectly bonded to the plate, the displacement interpolation assumption of Eqs. A.17 can be utilized to determine the distribution of any component of displacement within the stiffener in terms of $\bar{\alpha}_1, \bar{\alpha}_2 \dots \bar{\alpha}_{24}$. For x-direction stiffeners, $\eta = \eta_s$ and ξ is the variable; for y-direction stiffeners, $\xi = \xi_s$ and η is the variable; in both cases, the z-integrations will extend over the height of the stiffener (note that the reference $z=0$ is located at the midsurface of the plate). Once

the element stiffness and mass matrices are defined in terms of $\bar{\alpha}_1, \bar{\alpha}_2 \dots \bar{\alpha}_{24}$, Eqs. A.19 and A.52a are used to transform these into a final form which is fully compatible with the stiffness and mass matrices of the unstiffened plate element (i.e. expressed in terms of the nodal displacements of the plate element). The stiffness (or mass) matrix for the stiffened plate is then obtained by adding together the stiffness (or mass) matrices of the stiffener and the unstiffened plate element to which it is attached.

A.2.1 Stiffener Mass Matrix

The consistent mass matrix for a stiffener is derived from the expression for the kinetic energy, $(T)_s$, which for a typical stiffener element is

$$(T)_s = \int_0^l \int_{A_s} \frac{1}{2} \rho_s \left[(\dot{u} - z\dot{\theta})^2 + (\dot{v} - z\dot{\psi})^2 + \dot{w}^2 \right] dA ds \quad (A.87)$$

where A_s and ρ_s are the stiffener cross-sectional area and mass per unit volume. Introducing normalized coordinates and normalized displacements and integrating over the cross-section of the stiffener, Eq. A.87 can be written in the following matrix form:

$$(T)_s = \frac{1}{2} \rho_s l_s \int_0^1 \begin{bmatrix} \dot{u} & \dot{v} & \dot{w} & \dot{\theta} & \dot{\psi} \end{bmatrix} \begin{bmatrix} \tilde{m}^s \end{bmatrix} \begin{Bmatrix} \dot{u} \\ \dot{v} \\ \dot{w} \\ \dot{\theta} \\ \dot{\psi} \end{Bmatrix} ds \quad (A.88)$$

where l_s is the length of the stiffener (= a for x-direction stiffeners, =b for y-direction stiffeners), and

$$\begin{bmatrix} \tilde{m}^s \end{bmatrix} = \begin{bmatrix} A_s & & & & & & \\ & A_s & & & & & \\ & & A_s & & & & \\ & & & \frac{I_s}{a^2} & & & \\ & & & & \frac{I_s}{b^2} & & \\ & & & & & & \end{bmatrix} \quad (A.89)$$

In Eq. A.89, I_s is the cross-sectional area moment of inertia of the stiffener, and λ_s is the distance along the z axis from the plate reference surface to the centroid of the stiffener. It should be noted that for x-direction stiffeners, ds (Eq. A.88) is equal to $d\xi$, and is equal to $d\eta$ for y-direction stiffeners.

By substituting Eq. A.25 (evaluated at the stiffener location) into Eq. A.88 and applying Eqs. A.19 and A.27, the expression for the kinetic energy can be written in terms of the nodal generalized velocities of the plate element to which the stiffener is attached as:

$$(\dot{T})_s = \frac{1}{2} \dot{\tilde{q}}^T \tilde{m}_c^s \dot{\tilde{q}} \quad (\text{A.90})$$

where \tilde{m}_c^s is the consistent element mass matrix for the stiffener and is given by

$$\tilde{m}_c^s = \rho_s l_s A_s \tilde{T}^T (\tilde{G}^{-1})^T \int_0^l \tilde{N}^T(\xi, \eta_s) \tilde{m}^s \tilde{N}(\xi, \eta_s) d\xi \tilde{G}^{-1} \tilde{T} \quad (\text{A.91a})$$

for x-direction stiffeners and

$$\tilde{m}_c^s = \rho_s l_s A_s \tilde{T}^T (\tilde{G}^{-1})^T \int_0^l \tilde{N}^T(\xi_s, \eta) \tilde{m}^s \tilde{N}(\xi_s, \eta) d\eta \tilde{G}^{-1} \tilde{T} \quad (\text{A.91b})$$

for y-direction stiffeners.

A lumped (diagonal) mass matrix can also be formed for the stiffener element by proportionally lumping the total mass properties of the stiffener to the four corner nodes of the plate element to which it is attached. The lumped mass matrix is of the form

$$\tilde{m}_L^s = \begin{bmatrix} f_1 \hat{\tilde{m}}^s & & & \\ & f_2 \hat{\tilde{m}}^s & & \\ & & f_3 \hat{\tilde{m}}^s & \\ & & & f_4 \hat{\tilde{m}}^s \end{bmatrix} \quad (\text{A.92})$$

where

$$\hat{\mathfrak{M}}^s = \left[\begin{array}{ccc} \frac{A_s l_s}{2} & & \\ & \frac{A_s l_s}{2} & \\ & & \frac{A_s l_s}{2} \\ & & & \text{O} \\ & & & & \frac{I_s l_s}{2} \\ & & & & & \frac{I_s l_s}{2} \end{array} \right] \quad (\text{A.92a})$$

and where the multiplying factors f_1 , f_2 , f_3 , and f_4 depend on the type and location of the stiffener and are assigned values as follows:

<u>Stiffener</u>	<u>f_1</u>	<u>f_2</u>	<u>f_3</u>	<u>f_4</u>
x-direction	$(1-\eta_s)$	$(1-\eta_s)$	η_s	η_s
y-direction	$(1-\xi_s)$	ξ_s	ξ_s	$(1-\xi_s)$

A.2.2 Element Equivalent Loads Corresponding to Nonlinear Effects

For the present beam-type stiffeners, the expression for the variation of the work of the stresses within the element is

$$\delta U = w_s \int_z \int_0^{l_s} \sigma \delta \epsilon \, ds \, dz \quad (\text{A.93})$$

where w_s is the width of the stiffener and where σ and ϵ are the stress and strain in the direction of the stiffener. The corresponding stress-strain relation is

$$\sigma = E_s (\tilde{\epsilon} - \tilde{\epsilon}^p) = E_s (\epsilon - z \kappa - \tilde{\epsilon}^p) \quad (\text{A.94})$$

where E_s is Young's modulus of the sth stiffener. When Eq. A.94 is substituted into Eq. A.93, the expression for δU reads

$$\delta U = w_s \int_z \int_0^{l_s} E_s (\epsilon - z\kappa - \tilde{\epsilon}^p) \delta(\epsilon - z\kappa) ds dz \quad (\text{A.95})$$

The pertinent strain-displacement relations of Eqs. A.8 and A.9 (ϵ_{xx} and κ_{xx} for x-direction stiffeners, and ϵ_{yy} and κ_{yy} for y-direction stiffeners) are substituted into Eq. A.95 to yield

$$\delta U = \delta \tilde{q}_s^T \tilde{k}_s \tilde{q}_s - \delta \tilde{q}_s^T \tilde{f}_s^{NL} \quad (\text{A.96})$$

where \tilde{k}_s is the stiffness matrix of the s th stiffener (and is discussed in the next subsection) and \tilde{f}_s^{NL} is the vector of equivalent nodal forces for the s th stiffener corresponding to nonlinear geometric and material effects. For x-direction stiffeners \tilde{f}_s^{NL} is given by

$$\begin{aligned} \left\{ \tilde{f}_s^{NL} \right\} &= -E_s A_s \int_0^a \begin{bmatrix} D_1(\xi, \eta_s) \\ D_4(\xi, \eta_s) \\ D_7(\xi, \eta_s) \end{bmatrix}^T \left\{ \begin{array}{l} \frac{\theta^2}{2} \\ -\frac{\lambda_s \theta^2}{z} \\ \theta \epsilon_{xx} - \lambda_s \theta \kappa_{xx} \end{array} \right\} dx \\ &+ E_s w_s \int_0^a \begin{bmatrix} D_1(\xi, \eta_s) \\ D_4(\xi, \eta_s) \end{bmatrix}^T \left\{ \begin{array}{l} \int_z \tilde{\epsilon}_{xx}^p dz \\ -\int_z z \tilde{\epsilon}_{xx}^p dz \end{array} \right\} dx \\ &+ E_s w_s \int_0^a \left\{ D_7(\xi, \eta_s) \right\} \left(\theta \int_z \tilde{\epsilon}_{xx}^p dz \right) dx \end{aligned} \quad (\text{A.97})$$

and for y-direction stiffeners is given by

$$\begin{aligned} \left\{ \tilde{f}_s^{NL} \right\} &= -E_s A_s \int_0^b \begin{bmatrix} D_2(\xi_s, \eta) \\ D_5(\xi_s, \eta) \\ D_8(\xi_s, \eta) \end{bmatrix}^T \left\{ \begin{array}{l} \frac{\psi^2}{z} \\ -\frac{\lambda_s \psi^2}{z} \\ \psi \epsilon_{yy} - \lambda_s \psi \kappa_{yy} \end{array} \right\} dy \\ &+ E_s w_s \int_0^b \begin{bmatrix} D_2(\xi_s, \eta) \\ D_5(\xi_s, \eta) \end{bmatrix}^T \left\{ \begin{array}{l} \int_z \tilde{\epsilon}_{yy}^p dz \\ -\int_z z \tilde{\epsilon}_{yy}^p dz \end{array} \right\} dy \\ &+ E_s w_s \int_0^b \left\{ D_8(\xi_s, \eta) \right\} \left(\psi \int_z \tilde{\epsilon}_{yy}^p dz \right) dy \end{aligned} \quad (\text{A.98})$$

The calculation of f_s^{NL} for a stiffener follows essentially the same steps as for the plate elements except that the integrations now extend only along the stiffener direction and through-the-thickness. The reader is invited to consult Subsection A.1.3.2 for a general discussion.

A.2.3 Element Stiffness Matrix

The stiffness matrix contributions for a stiffener correspond to the term $\delta \underline{q}_s^T \underline{k}_s \underline{q}_s$ in Eq. A.96 and can be derived from the linear term in the strain-displacement relation. From Eq. A.95 and A.96

$$\delta \underline{q}_s^T \underline{k}_s \underline{q}_s = w_s \int_z \int_0^{l_s} E_s (\epsilon - z\kappa) \delta(\epsilon - z\kappa) ds dz \quad (A.99)$$

or, since E_s is assumed to be constant over the stiffener, and integrating over the stiffener thickness:

$$\delta \underline{q}_s^T \underline{k}_s \underline{q}_s = E_s \int_0^{l_s} \delta \left[\begin{array}{c} \epsilon \\ \kappa \end{array} \right] \left[\begin{array}{cc} A_s & -A_s \lambda_s \\ -A_s \lambda_s & I_s \end{array} \right] \left\{ \begin{array}{c} \epsilon \\ \kappa \end{array} \right\} ds \quad (A.100)$$

The interpolations used for the normal strain, ϵ , and curvature, κ , must be compatible with that used for the plate element since perfect bonding is assumed at the plate/stiffener interface. Thus, the strain and curvature are evaluated from the displacement interpolations of Eqs. A.17. For an x-direction stiffener:

$$\epsilon \equiv \epsilon_{xx} = \frac{\partial u}{\partial x} = \frac{1}{a} \frac{\partial \bar{u}}{\partial \xi} = \frac{\bar{\alpha}_2 + \eta_s \bar{\alpha}_4}{a} \quad (A.101a)$$

$$\begin{aligned} \kappa \equiv \kappa_{xx} = \frac{\partial \theta}{\partial x} = \frac{1}{a^2} \frac{\partial \bar{\theta}}{\partial \xi} = \frac{1}{a^2} \left(2\bar{\alpha}_{13} + 2\eta_s \bar{\alpha}_{15} + 2\eta_s^2 \bar{\alpha}_{17} \right. \\ \left. + 6\xi \bar{\alpha}_{18} + 6\xi \eta_s \bar{\alpha}_{20} + 6\xi \eta_s^2 \bar{\alpha}_{22} + 2\eta_s^3 \bar{\alpha}_{23} + 6\xi \eta_s^3 \bar{\alpha}_{24} \right) \end{aligned} \quad (A.101b)$$

and for a y-direction stiffener:

$$\epsilon \equiv \epsilon_{yy} = \frac{\partial v}{\partial y} = \frac{\partial \bar{v}}{\partial \bar{\gamma}} = \frac{\bar{\alpha}_7 + \xi_s \bar{\alpha}_8}{b} \quad (\text{A.102a})$$

$$\begin{aligned} \mathcal{K} \equiv \mathcal{K}_{yy} = \frac{\partial \psi}{\partial y} = \frac{1}{b^2} \frac{\partial \bar{\psi}}{\partial \bar{\gamma}} = \frac{1}{b^2} \left(2 \bar{\alpha}_{14} + 2 \xi_s \bar{\alpha}_{16} + 2 \xi_s^2 \bar{\alpha}_{17} \right. \\ \left. + 6 \gamma \bar{\alpha}_{19} + 6 \gamma \xi_s \bar{\alpha}_{21} + 2 \xi_s^3 \bar{\alpha}_{22} + 6 \gamma \xi_s^2 \bar{\alpha}_{23} + 6 \gamma \xi_s^3 \bar{\alpha}_{24} \right) \end{aligned} \quad (\text{A.102b})$$

or in matrix form

$$\begin{Bmatrix} \epsilon \\ \mathcal{K} \end{Bmatrix} = \underset{\sim}{D} \underset{\sim}{\bar{\alpha}} \quad (\text{A.103})$$

where $\underset{\sim}{D}$ is obtained from Eqs. A.101 for x-direction stiffeners or from Eqs. A.102 for y-direction stiffeners.

When Eq. A.103 is substituted into Eq. A.100, the resulting expression is

$$\delta \underset{\sim}{\bar{q}}^T \underset{\sim}{k}_s \underset{\sim}{\bar{q}} = \delta \underset{\sim}{\bar{\alpha}}^T \underset{\sim}{k} \underset{\sim}{\bar{\alpha}} \quad (\text{A.104})$$

where

$$\underset{\sim}{k} = E_s \int_0^{l_s} \underset{\sim}{D}^T \begin{bmatrix} A_s & -A_s \lambda_s \\ -A_s \lambda_s & I_s \end{bmatrix} \underset{\sim}{D} ds \quad (\text{A.105})$$

Finally, the stiffness matrix is obtained by relating $\underset{\sim}{\bar{q}}$ to $\underset{\sim}{q}$ through Eqs. A.19 and A.27 and is given by

$$\underset{\sim}{k}_s = \underset{\sim}{T}^T (\underset{\sim}{G}^{-1})^T \underset{\sim}{k} \underset{\sim}{G}^{-1} \underset{\sim}{T} \quad (\text{A.106})$$

The stiffness matrix for both x- and y-direction stiffeners is, therefore, related to the generalized nodal displacement parameters of the plate element to which they are attached. As a result, the stiffness matrix of a stiffened plate element can be formed by adding the stiffness matrix of the unstiffened plate and the stiffness matrix of each stiffener. Alternatively, unstiffened plate and stiffener elements can be processed separately. In the PLATE program, the latter approach is used.

A.3 Formation and Solution of the Governing Dynamic Equations for the Structure

The governing equations of motion for the discretized plate structure are obtained by applying the Principle of Virtual Work and D'Alembert's Principle to give

$$\sum_{n=1}^{n_p} \delta \underline{q}^T \left(\underline{m} \ddot{\underline{q}} + \underline{k} \underline{q} + \underline{k}_s \underline{q} - \underline{f} - \underline{f}^{NL} \right) + \sum_{n=1}^{n_s^x} \delta \underline{q}^T \left(\underline{m}_s \ddot{\underline{q}} + \underline{k}_s \underline{q} - \underline{f}_s^{NL} \right) + \sum_{n=1}^{n_s^y} \delta \underline{q}^T \left(\underline{m}_s \ddot{\underline{q}} + \underline{k}_s \underline{q} - \underline{f}_s^{NL} \right) = 0 \quad (\text{A.107})$$

where n_p , n_s^x , n_s^y are the number of plate elements, x-direction stiffeners, and y-direction stiffeners, respectively. The nodal generalized displacements, \underline{q} , (and accelerations, $\ddot{\underline{q}}$) for each element are then related to the global generalized displacements, \underline{q}^* , by

$$\underline{q} = \underline{J} \underline{q}^* \quad (\text{A.108})$$

where \underline{J} is a Boolean matrix. The indicated summations are then performed; this operation is the usual element "assembly" procedure. After assembly, the following matrix equation results, which governs the dynamic, large-deflection, elastic-plastic response of the plate structure;

$$\underline{M} \ddot{\underline{q}}^* + \underline{K} \underline{q}^* = \underline{F} + \underline{F}^{NL} \quad (\text{A.109})$$

where

- $\underline{q}^*, \ddot{\underline{q}}^*$ = vector of generalized nodal displacements and accelerations, respectively, for the assembled structure.
- \underline{M} = assembled mass matrix for the structure.
- \underline{K} = assembled elastic stiffness matrix for the structure, including the effective stiffness supplied by the line restoring springs.
- \underline{F} = vector of nodal forces for the structure corresponding to prescribed externally-applied forces.
- \underline{F}^{NL} = vector of nodal equivalent forces for the structure corresponding to geometric and material nonlinear effects.

The solution of the dynamic equation of motion (Eq. A.109) can be accomplished by applying a direct timewise integration scheme. In this scheme, the time derivatives of the nodal displacement vector ($\ddot{\underline{q}}^*$ and $\dot{\underline{q}}^*$) are expressed at a discrete time instant in terms of the nodal displacements at several nearby discrete time instants. When substituted into the governing equation of motion, a recurrence relation is obtained from which displacements can be calculated at each discrete time instant.

In the PLATE program, the (implicit) Houbolt operator is used, so that the accelerations $\ddot{\underline{q}}^*$ at time t_{m+1} are expressed by a 4-point backward-difference formula:

$$\ddot{\underline{q}}_{m+1}^* = \frac{1}{(\Delta t)^2} \left(2 \underline{q}_{m+1}^* - 5 \underline{q}_m^* + 4 \underline{q}_{m-1}^* - \underline{q}_{m-2}^* \right) + O(\Delta t^2) \quad (\text{A.110})$$

The velocities $\dot{\underline{q}}_{m+1}^*$ at time t_{m+1} can be expressed by the following 3-point backward-difference formula having the same truncation error as $\ddot{\underline{q}}_{m+1}^*$

$$\dot{\underline{q}}_{m+1}^* = \frac{1}{2 \Delta t} \left(3 \underline{q}_{m+1}^* - 4 \underline{q}_m^* + \underline{q}_{m-1}^* \right) + O(\Delta t^2) \quad (\text{A.111})$$

For convenience, (particularly, as will be seen in Appendix B, for impact analysis) the terms in Eq. A.110 can be regrouped so that $\ddot{\underline{q}}_{m+1}^*$ at time t_{m+1} can also be related to $\dot{\underline{q}}_m^*$ at time t_m :

$$\begin{aligned} \ddot{\underline{q}}_{m+1}^* &= \frac{\left[2(\underline{q}_{m+1}^* - \underline{q}_m^*) \right] + \left[-3 \underline{q}_m^* + 4 \underline{q}_{m-1}^* - \underline{q}_{m-2}^* \right]}{(\Delta t)^2} \\ &= \frac{2}{(\Delta t)^2} \left(\underline{q}_{m+1}^* - \underline{q}_m^* \right) - \frac{2}{\Delta t} \dot{\underline{q}}_m^* \end{aligned} \quad (\text{A.112})$$

Equation A.109 can be written to express dynamic equilibrium at time t_{m+1} as

$$\underline{M}_{m+1} \ddot{\underline{q}}_{m+1}^* + \underline{K}_{m+1} \underline{q}_{m+1}^* = \underline{F}_{m+1} + \underline{F}_{m+1}^{NL} \quad (\text{A.113})$$

Equation A.112 is then substituted into Eq. A.113 and the terms regrouped to give

$$\left[\frac{2}{(\Delta t)^2} \tilde{M} + \tilde{K} \right] \tilde{q}_{m+1}^* = \tilde{F}_{m+1} + \tilde{F}_{m+1}^{NL} + \frac{2}{\Delta t} \tilde{M} \left(\dot{\tilde{q}}_m^* + \frac{1}{\Delta t} \tilde{q}_m^* \right) \quad (\text{A.114})$$

The recurrence relation given by Eq. A.114 can be solved at each time step for the unknown displacements \tilde{q}_{m+1}^* at time t_{m+1} , based on the knowledge of \tilde{F}_{m+1} , \tilde{F}_{m+1}^{NL} , $\dot{\tilde{q}}_m^*$, and \tilde{q}_m^* . Once \tilde{q}_{m+1}^* is determined, the velocities, $\dot{\tilde{q}}_{m+1}^*$ can be obtained from Eq. A.111, and the solution advanced to the next time instant. This process is repeated until some specified termination point is reached.

Several comments concerning the solution by Eq. A.114 are needed. The quantities \tilde{F}_{m+1} , $\dot{\tilde{q}}_m^*$, and \tilde{q}_m^* on the right side of Eq. A.114 are known (or user specified in the case of \tilde{F}_{m+1} , $\dot{\tilde{q}}_0^*$, and \tilde{q}_0^*) at time t_{m+1} , but the vector of equivalent forces corresponding to nonlinear effects, $\tilde{F}_{m+1}^{NL} = \tilde{F}_{m+1}^{NL}(\tilde{q}_{m+1}^*)$ is a function of \tilde{q}_{m+1}^* and is thus not known. Consequently, either some form of extrapolation or extrapolation with iteration is required to calculate \tilde{F}_{m+1}^{NL} . In the PLATE program, a linear extrapolation is used with no iteration so that \tilde{F}_{m+1}^{NL} in Eq. A.114 is replaced by

$$\tilde{F}_{m+1}^{NL} \doteq 2 \tilde{F}_m^{NL} - \tilde{F}_{m-1}^{NL} \quad (\text{A.115})$$

Equation A.114 may be used for times t_{m+1} such that $m+1 \geq 2$. For earlier times, however, a starting procedure must be used; that chosen procedure is as follows [4]. Use the central-difference operator to write:

$$\ddot{\tilde{q}}_{\tilde{0}} = \frac{\tilde{q}_{\tilde{1}} - 2\tilde{q}_{\tilde{0}} + \tilde{q}_{\tilde{-1}}}{(\Delta t)^2} + O(\Delta t)^2 \quad (\text{A.115a})$$

and a mixed operator to obtain

$$\dot{\tilde{q}}_{\tilde{0}} = \frac{2\tilde{q}_{\tilde{1}} + 3\tilde{q}_{\tilde{0}} - 6\tilde{q}_{\tilde{-1}} + \tilde{q}_{\tilde{-2}}}{6\Delta t} + O(\Delta t)^2 \quad (\text{A.115b})$$

From Eq. A.115a, one obtains

$$\tilde{q}_{\tilde{-1}} = (\Delta t)^2 \ddot{\tilde{q}}_{\tilde{0}} + 2\tilde{q}_{\tilde{0}} - \tilde{q}_{\tilde{1}} \quad (\text{A.115c})$$

Applying Eq. A.115c to Eq. A.115b, one finds

$$\tilde{q}_{-2} = 6(\Delta t)^2 \ddot{\tilde{q}}_{\sim 0} + 6\Delta t \dot{\tilde{q}}_{\sim 0} + 9\tilde{q}_{\sim 0} - 8\tilde{q}_{-1} \quad (\text{A.115d})$$

Since $\ddot{\tilde{q}}_{\sim 1}$ is given by the Houbolt operator as

$$\ddot{\tilde{q}}_{\sim 1} = \frac{2\tilde{q}_{\sim 1} - 5\tilde{q}_{\sim 0} + 4\tilde{q}_{-1} - \tilde{q}_{-2}}{(\Delta t)^2} \quad (\text{A.115e})$$

one can use Eqs. A.115c, A.115d, and A.115e to write the finite-difference equations of motion at time t_1 (i.e. $m+1=1$) as

$$\begin{aligned} (6\tilde{M} + (\Delta t)^2 \tilde{K}) \tilde{q}_{\sim 1} &= (\Delta t)^2 \left(\tilde{F}_{\sim 1} + \tilde{F}_{\sim 0}^{NL} \right) \\ &+ \tilde{M} \left(2(\Delta t)^2 \ddot{\tilde{q}}_{\sim 0} + 6(\Delta t) \dot{\tilde{q}}_{\sim 0} + 6\tilde{q}_{\sim 0} \right) \end{aligned} \quad (\text{A.116})$$

where $\tilde{F}_{\sim 1}^{NL}$ has been approximated (replaced) by its value at $t=0: \tilde{F}_{\sim 0}^{NL}$ and $\ddot{\tilde{q}}_{\sim 0}$ is found from the basic equation of motion written at time $t=0$:

$$\tilde{M} \ddot{\tilde{q}}_{\sim 0} + \tilde{K} \tilde{q}_{\sim 0} = \tilde{F}_{\sim 0} + \tilde{F}_{\sim 0}^{NL} \quad (\text{A.117})$$

Since $\tilde{q}_{\sim 0}$, $\tilde{F}_{\sim 0}$ and $\tilde{F}_{\sim 0}^{NL}$ are all prescribed, one can find $\ddot{\tilde{q}}_{\sim 0}$. Then, one can calculate $\ddot{\tilde{q}}_{\sim 1}$ from Eq. A.116 since all quantities on the right-hand side of Eq. A.116 are either prescribed or otherwise known. Now one can evaluate $\tilde{F}_{\sim 1}^{NL}$. Next, one can find $\dot{\tilde{q}}_{\sim 1}$ by using the Houbolt operator:

$$\dot{\tilde{q}}_{\sim 1} = \frac{3\tilde{q}_{\sim 1} - 4\tilde{q}_{\sim 0} + \tilde{q}_{-1}}{2\Delta t} \quad (\text{A.118})$$

where \tilde{q}_{-1} is given by Eq. A.115c. This ends the starting procedure.

Thereafter one uses Eq. A.114 as modified by Eq. A.115, followed by Eq. A.111 for times t_2, t_3, t_4, \dots to obtain the transient response solution.

The matrices \underline{M} and \underline{K} , and the time-step size, Δt , are held constant throughout the timewise solution. In order to solve Eq. A.114 for \underline{q}_{m+1}^* , the triple-factoring form of Gauss-Jordan elimination is used. The matrix sum $[\frac{2}{\Delta t} \underline{M} + \underline{K}]$ is thus formed and factored prior to the first time step. At each time step, \underline{q}_{m+1}^* is obtained by a back-substitution operation. The increased computation time and storage realized when using a consistent (fully populated) element mass matrix formulation instead of a lumped (diagonal) element mass matrix formulation is also evidenced by Eq. A.114. In the case of a lumped mass formulation, the storage requirements for \underline{M} are the same as for a vector of length equal to the total number of degrees of freedom, whereas if a consistent mass formulation is used, \underline{M} requires the same storage space as \underline{K} which could be as high as 2 to 3 orders of magnitude greater than the total number of degrees of freedom. Also, the matrix product $\underline{M}\dot{\underline{q}}_m^*$, for example, will require more computation time when a consistent mass formulation is used.

A.4 Description of the Mechanical-Sublayer Material Model

In the present analysis, the strain-hardening behavior of the material is characterized by using the mechanical sublayer material model [6,7]⁺. In this model, the uniaxial stress-strain curve (tension or compression) is first approximated by (n+1) piecewise-linear segments defined at the coordinates (σ_k, ϵ_k) , $k = 1, 2, 3 \dots n$ as shown in Fig. A.1a. Next the material is conceived of as behaving at any material point as n equally-strained "sublayers" of elastic, perfectly-plastic behavior, with each sublayer having the same elastic modulus, E, but an appropriately different static yield stress, σ_{ok} , (see Fig. A.1b) given by

⁺ See page 6 for pertinent comments and additional references.

$$\sigma_{o.k} = E \epsilon_k \quad (k = 1, 2, 3, \dots, n) \quad (\text{A.119a})$$

for application to uniaxial conditions, but by

$$\sigma_{o.k} = E \epsilon_k + \frac{E(\frac{1}{2}-\nu)}{(1+\nu)} \sum_{j=1}^k \left(1 - \frac{E_j}{E}\right) [\epsilon_j - \epsilon_{j-1}] \quad (\text{A.119b})$$

for application to multiaxial conditions [7,14]. The stress value, σ_k , associated with the kth sublayer can be defined uniquely by the strain history and the value of the strain and strain-rate present at that point. The stress, σ , at that material point corresponding to strain, ϵ , is then obtained as a weighted average of the stresses $\sigma_k(\epsilon)$ in each sublayer

$$\sigma(\epsilon) = \sum_{k=1}^n C_k \sigma_k(\epsilon) \quad (\text{A.120})$$

where the weighting factor C_k for the kth sublayer for uniaxial applications is given by

$$C_k = \frac{E_k - E_{k+1}}{E} \quad (\text{A.120a})$$

and that for application to multiaxial conditions is given by

$$C_k = 1 - \frac{\frac{2}{3}(1+\nu) E_{k+1}}{E - \frac{2}{3}(\frac{1}{2}-\nu) E_{k+1}} - \sum_{j=1}^{k-1} C_j \quad (\text{A.120b})$$

and where

$$E_1 \equiv E, \quad E_k = \frac{\sigma_k - \sigma_{k-1}}{\epsilon_k - \epsilon_{k-1}} \quad (k = 2, 3, \dots, n); \quad E_{n+1} = 0 \quad (\text{A.120})$$

Two special subcases are evident; for elastic, perfectly-plastic materials only one sublayer is required, and for elastic, linear strain-hardening materials two sublayers are required with the value of the yield stress in the second sublayer taken sufficiently high so that the behavior in that sublayer remains elastic.

The relation between sublayer stresses and material point stress given by Eq. A.120 is written in terms of uniaxial stresses. For the plane-stress state in the plate elements, it is assumed that the uniaxial stresses in Eq. A.120 may be replaced by the corresponding stress vectors so that

$$\underline{\sigma} = \sum_{k=1}^n C_k \underline{\sigma}_k(\underline{\epsilon}) \quad (\text{A.121})$$

where $\underline{\sigma}_k$ is the vector of stresses in the kth sublayer and $\underline{\sigma}$ is the vector of stresses at the material point.

Strain-rate effects may also be easily accommodated in the mechanical sublayer model, by assuming that the yield stress in each sublayer follows the relation

$$\sigma_{ky} = \sigma_{ok} \left(1 + \left| \frac{\dot{\epsilon}}{D} \right|^{\frac{1}{p}} \right) \quad (\text{A.122})$$

where D and p are material constants and σ_{yk} is the current yield stress in sublayer k corresponding to a strain-rate $\dot{\epsilon}$, and σ_{ok} is the static yield stress of sublayer k. Figures A.2a and A.2b illustrate the strain-rate effects for an elastic, perfectly-plastic material, and for a strain-hardening material which is represented by the mechanical sublayer model, respectively.

It should be noted that the material strain-rate parameters D and p are assumed in the PLATE code to be identical for each mechanical sublayer for a given material type. More comprehensive strain-rate behavior could be accommodated in the future by assuming different values of D and p in each sublayer. Also, the equivalent uniaxial strain rate $\dot{\epsilon}$ for the thin plate under the Kirchhoff assumption of no transverse normal or shear strain rate is calculated by⁺

$$\dot{\epsilon} = \frac{2}{3} \frac{1}{\Delta t} \left[(\Delta \tilde{\epsilon}_{xx})^2 + (\Delta \tilde{\epsilon}_{yy})^2 - \Delta \tilde{\epsilon}_{xx} \Delta \tilde{\epsilon}_{yy} + \frac{3}{4} (\Delta \tilde{\epsilon}_{xy})^2 \right]^{\frac{1}{2}} \quad (\text{A.123})$$

where $\Delta(\)$ are the increments of () over the current time step. The value of each incremental strain can be obtained from Eqs. A.12, and the value of $\dot{\epsilon}$ calculated from Eq. A.123 is then used in Eq. A.122.

⁺See pp. 35-45 of Ref. 28.

Note, as depicted in Fig. A.1c, that unloading, reversed loading and straining, reloading, etc. are accounted for very simply and efficiently (computationally) by this model. As noted in Subsection 2.1, this mechanical-sublayer material model accounts for nonlinear strain hardening, anisotropic strain hardening, the formation of corners on the yield surface, and the Bauschinger effect -- all of these are features that ductile metals exhibit. No other material model devised to date appears to represent these features as faithfully and efficiently as does the mechanical-sublayer model.

A.5 Evaluation of the Elastic Strain Energy

The elastic strain energy per unit volume is given, in general, for isotropic material by:

$$\bar{U} = \frac{1}{2E} [\sigma_{xx}^2 + \sigma_{yy}^2 + \sigma_{zz}^2] - \frac{\nu}{E} [\sigma_{xx}\sigma_{yy} + \sigma_{yy}\sigma_{zz} + \sigma_{zz}\sigma_{xx}] + \frac{1}{2G} [\sigma_{xy}^2 + \sigma_{yz}^2 + \sigma_{zx}^2] \quad (\text{A.124})$$

A.5.1 Plate Element Evaluation

For the plane stress (plate element) state where $\sigma_{zz} = \sigma_{zx} = \sigma_{zy} = 0$, this reduces to:

$$\bar{U} = \frac{1}{2E} [\sigma_{xx}^2 + \sigma_{yy}^2] - \frac{\nu}{E} [\sigma_{xx}\sigma_{yy}] + \frac{1}{2G} [\sigma_{xy}^2] \quad (\text{A.125})$$

Hence, for a plate element of dimensions a, b, h in directions x, y, and z respectively, the elastic strain energy in the plate element becomes

$$U = \iiint \bar{U} dV = \int_{-\frac{a}{2}}^{+\frac{a}{2}} \int_{-\frac{b}{2}}^{+\frac{b}{2}} \int_{-\frac{h}{2}}^{+\frac{h}{2}} \bar{U} dx dy dz = \frac{abh}{8} \int_{-1}^{+1} \int_{-1}^{+1} \int_{-1}^{+1} \left[\frac{1}{2E} (\sigma_{xx}^2 + \sigma_{yy}^2) - \frac{\nu}{E} \sigma_{xx}\sigma_{yy} + \frac{1}{2G} \sigma_{xy}^2 \right] d\bar{x} d\bar{y} d\bar{z}$$

(A.126)

where $\bar{x} = x/(a/2)$, $\bar{y} = y/(b/2)$, and $\bar{z} = z/(h/2)$. The quantity U for each plate element is evaluated by Gaussian quadrature with 3 x-direction, 3 y-direction, and 4 depthwise Gaussian stations at each of the 9 spanwise Gaussian stations.

A.5.2 Evaluation for Stiffener Elements

Each stiffener behaves in a Bernoulli-Euler fashion. Hence, only the axial stress (σ_{xx} for an x-direction stiffener or σ_{yy} for a y-direction stiffener) contributes to the elastic strain energy. Accordingly for an x-direction stiffener of length l_s , width w_s , and height h_s , the elastic strain energy is given by

$$\begin{aligned}
 U &= \iiint \bar{U} \, dx \, dy \, dz \equiv w_s \int_{-\frac{l_s}{2}}^{+\frac{l_s}{2}} \int_{-\frac{h_s}{2}}^{+\frac{h_s}{2}} \frac{\sigma_{xx}^2}{2E} \, dx \, dz \\
 &= \frac{w_s l_s h_s}{4} \int_{-1}^{+1} \int_{-1}^{+1} \frac{\sigma_{xx}^2}{2E} \, d\bar{\xi} \, d\bar{\zeta}
 \end{aligned}$$

(A.127)

where $\bar{\xi} = x/(l_s/2)$ and $\bar{\zeta} = z/(h_s/2)$. In the computer program, U is evaluated by Gaussian quadrature by using 4 depthwise Gaussian stations at each of 3 spanwise Gaussian stations.

A.6 Comments on Estimating the Plastic Work

For calculation convenience, the plastic work in the entire structure is evaluated at each time instant in an indirect fashion. For example, if the structure were subjected to only a prescribed initial velocity distribution, one would evaluate the associated initial kinetic energy (KE_0); thereafter at any time instant, one would evaluate (a) the total kinetic energy (KE) (b) the total elastic strain energy EE. Then the Plastic Work (PW) is estimated from

$$PW = (KE)_0 - KE - EE \tag{A.128}$$

On the other hand if the structure were subjected only to a prescribed distribution and time history of externally applied forces, the work done on the structure by those forces from time zero until the present instant of time is computed and saved; this is called the work input (WI). In this case, the plastic work is estimated from:

$$PW = WI - KE - EE \quad (A.129)$$

The work input (WI) to the structure by, for example, the externally applied loads {F} may be evaluated by using

$$WI = \int_0^t [F] \{\dot{q}\} dt \quad (A.130)$$

where for evaluations up to time instant $t_n = n\Delta t$, one may use the trapezoidal rule to write

$$WI(t_n) = \frac{\Delta t}{2}(H_0 + H_1) + \frac{\Delta t}{2}(H_1 + H_2) + \dots + \frac{\Delta t}{2}(H_{n-1} + H_n) \quad (A.131)$$

where $H_0 = [F_0] \{\dot{q}_0\} =$ power input at $t=0$
 $H_1 = [F_1] \{\dot{q}_1\} =$ power input at $t = 1\Delta t$
 \vdots
 $WI(0) = 0$

This is the procedure employed in the computer program.

Side 3 →	u_4	v_4	w_4	θ_4	ψ_4	χ_4	u_3	v_3	w_3	θ_3	ψ_3	χ_3
Side 1 →	u_1	v_1	w_1	θ_1	ψ_1	χ_1	u_2	v_2	w_2	θ_2	ψ_2	χ_2
u_4, u_1	$\frac{k_x}{3}$											
v_4, v_1	0	$\frac{k_y}{3}$										
w_4, w_1	0	0	$\frac{13k_z}{35} + \frac{6k_\theta}{5a^2}$									
θ_4, θ_1	0	0	$\frac{11k_\theta}{210} + \frac{k_\theta}{10a^2}$	$\frac{k_\theta}{105} + \frac{2k_\theta}{15a^2}$								
ψ_4, ψ_1	0	0	0	0	$\frac{13k_w}{35b^2}$							
χ_4, χ_1	0	0	0	0	$\frac{11k_\psi}{210b^2}$	$\frac{k_\psi}{105b^2}$						
u_3, u_2	$\frac{k_x}{6}$	0	0	0	0	0	$\frac{k_x}{3}$					
v_3, v_2	0	$\frac{k_y}{6}$	0	0	0	0	0	$\frac{k_y}{3}$				
w_3, w_2	0	0	$\frac{k_z}{70} - \frac{6k_\theta}{5a^2}$	$\frac{13k_z}{420} - \frac{k_\theta}{10a^2}$	0	0	0	0	$\frac{13k_z}{35} + \frac{6k_\theta}{5a^2}$			
θ_3, θ_2	0	0	$\frac{-13k_\theta}{420} + \frac{k_\theta}{10a^2}$	$\frac{-k_\theta}{140} - \frac{k_\theta}{30a^2}$	0	0	0	0	$\frac{-11k_\theta}{210} - \frac{k_\theta}{10a^2} + \frac{k_\theta}{105} + \frac{2k_\theta}{15a^2}$			
ψ_3, ψ_2	0	0	0	0	$\frac{k_\psi}{70b^2}$	$\frac{13k_\psi}{420b^2}$	0	0	0	0	$\frac{13k_\psi}{35b^2}$	
χ_3, χ_2	0	0	0	0	$\frac{-13k_\psi}{420b^2}$	$\frac{-k_\psi}{140b^2}$	0	0	0	0	$\frac{-11k_\psi}{210b^2}$	$\frac{k_\psi}{105b^2}$

SYMMETRIC

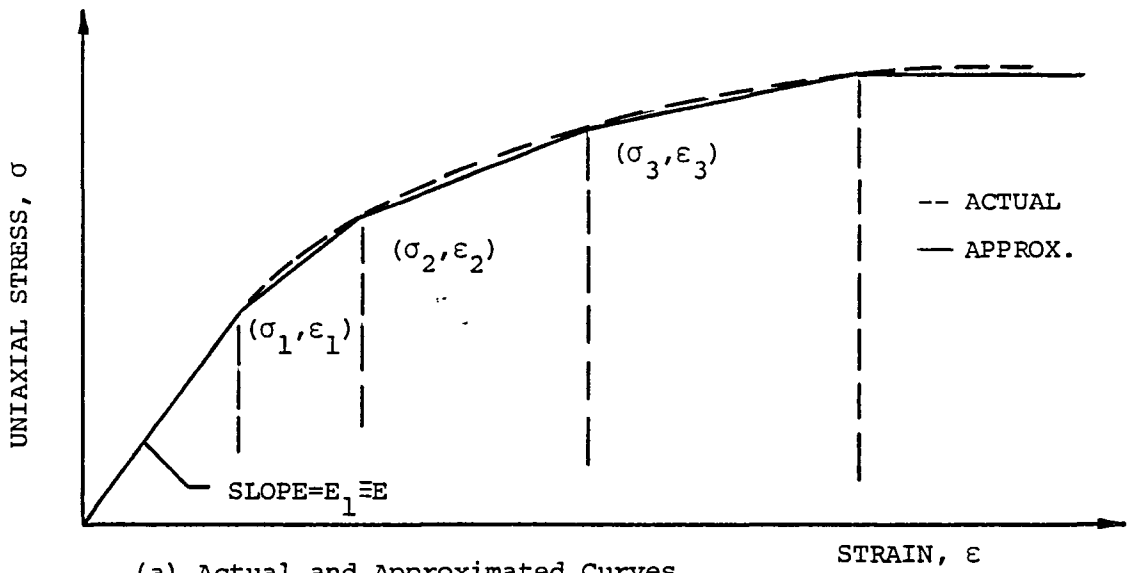
(a) $[\bar{k}_s]$ for Plate Sides 1 and 3

TABLE A.1 COMPACTED INTERMEDIATE STIFFNESS MATRIX $[\bar{k}_s]$ CORRESPONDING TO LINE ELASTIC RESTORING SPRINGS

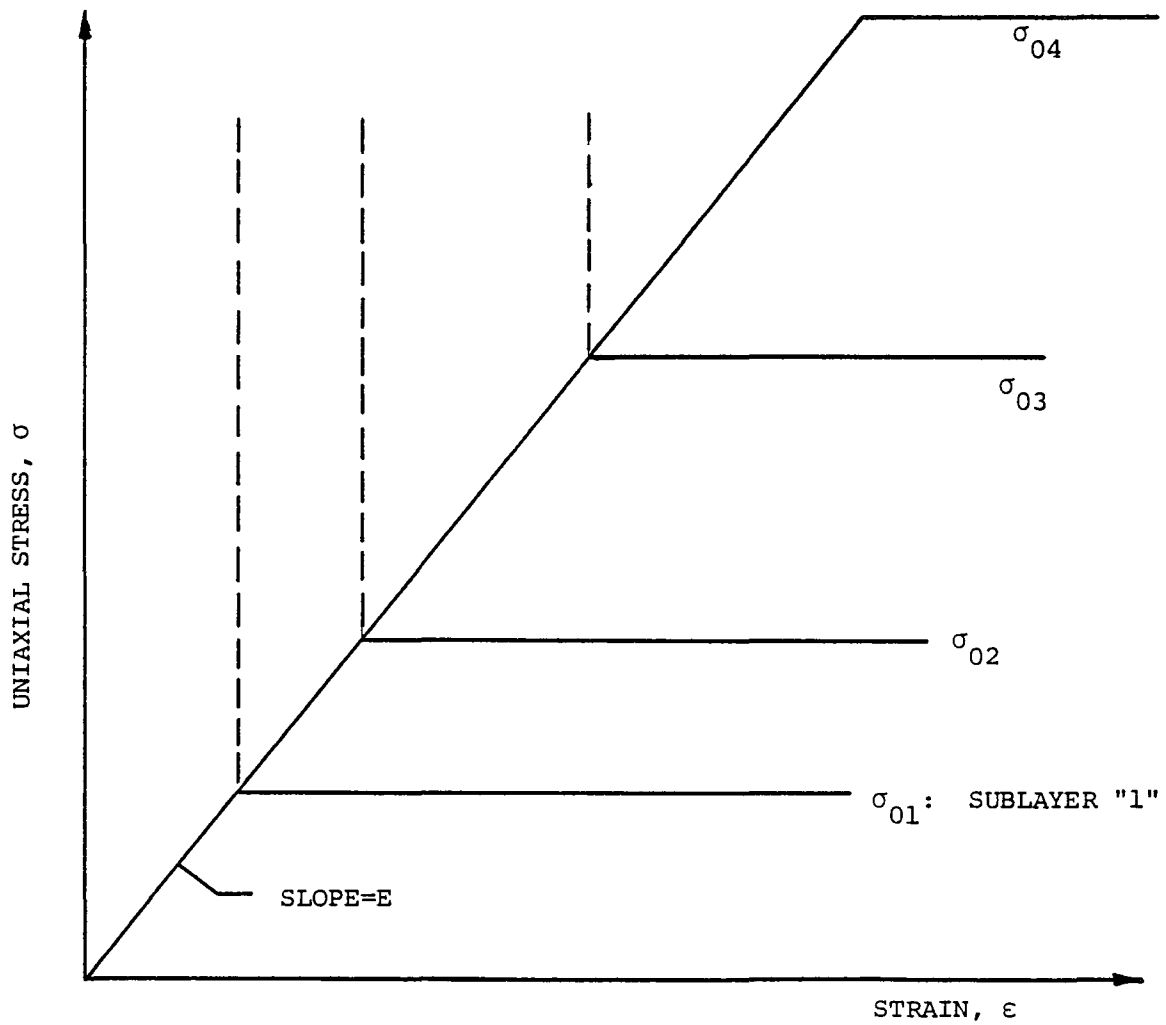
Side 2 →	u_2	v_2	w_2	θ_2	ψ_2	χ_2	u_3	v_3	w_3	θ_3	ψ_3	χ_3
Side 4 →	u_1	v_1	w_1	θ_1	ψ_1	χ_1	u_4	v_4	w_4	θ_4	ψ_4	χ_4
u_2	$\frac{k_x}{3}$											
v_2	0	$\frac{k_y}{3}$										
w_2	0	0	$\frac{13k_z}{35} + \frac{6k_y}{5b^2}$									
θ_2	0	0	0	$\frac{13k_\theta}{35a^2}$								
ψ_2	0	0	$\frac{11k_x}{210} + \frac{k_y}{10b^2}$	0	$\frac{k_z}{105} + \frac{2k_y}{15b^2}$				SYMMETRIC			
χ_2	0	0	0	$\frac{11k_\theta}{210a^2}$	0	$\frac{k_\theta}{105a^2}$						
u_3	$\frac{k_x}{6}$	0	0	0	0	0	$\frac{k_x}{3}$					
v_3	0	$\frac{k_y}{6}$	0	0	0	0	0	$\frac{k_y}{3}$				
w_3	0	0	$\frac{k_x}{20} - \frac{6k_y}{5b^2}$	0	$\frac{13k_z}{420} - \frac{k_y}{10b^2}$	0	0	0	$\frac{13k_z}{35} + \frac{6k_y}{5b^2}$			
θ_3	0	0	0	$\frac{k_\theta}{70a^2}$	0	$\frac{13k_\theta}{420a^2}$	0	0	0	$\frac{13k_\theta}{35a^2}$		
ψ_3	0	0	$\frac{-13k_x}{420} + \frac{k_y}{10b^2}$	0	$\frac{-k_z}{140} - \frac{k_y}{30b^2}$	0	0	0	$\frac{-11k_x}{210} - \frac{k_y}{10b^2}$	0	$\frac{k_z}{105} + \frac{2k_y}{15b^2}$	
χ_3	0	0	0	$\frac{-13k_\theta}{420a^2}$	0	$\frac{-k_\theta}{140a^2}$	0	0	0	$\frac{-11k_\theta}{210a^2}$	0	$\frac{k_\theta}{105a^2}$

(b) $[\bar{k}_s]$ for Plate Sides 2 and 4

TABLE A.1 CONCLUDED

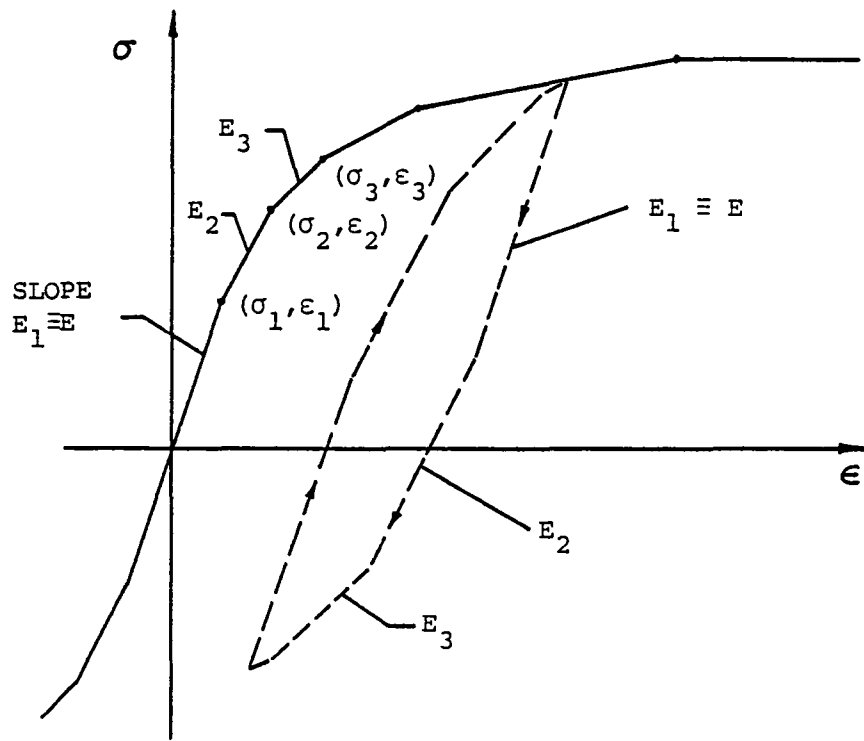


(a) Actual and Approximated Curves



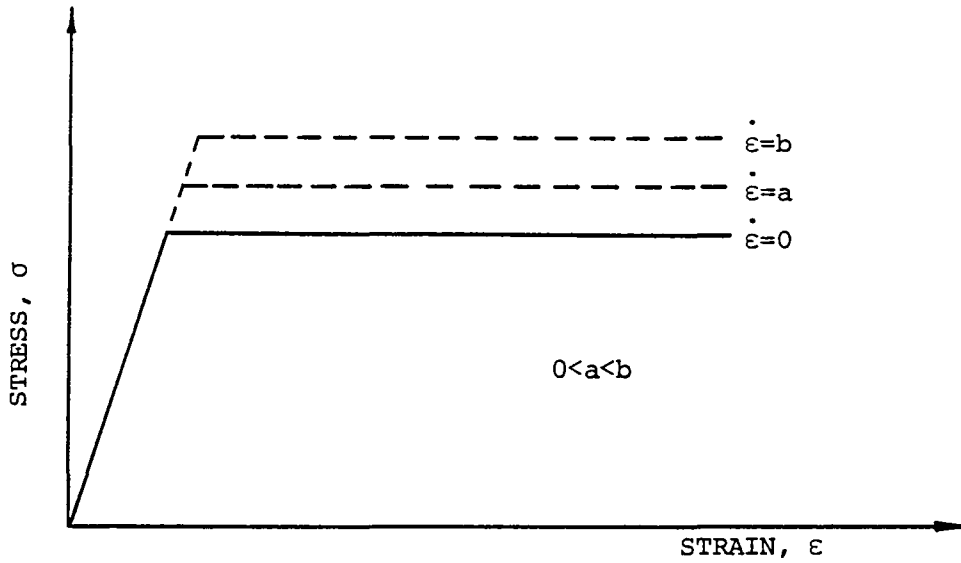
(b) Properties of the Elastic, Perfectly-Plastic Sublayers

FIG. A.1 APPROXIMATION OF A UNIAXIAL STRESS-STRAIN CURVE BY THE MECHANICAL-SUBLAYER MODEL

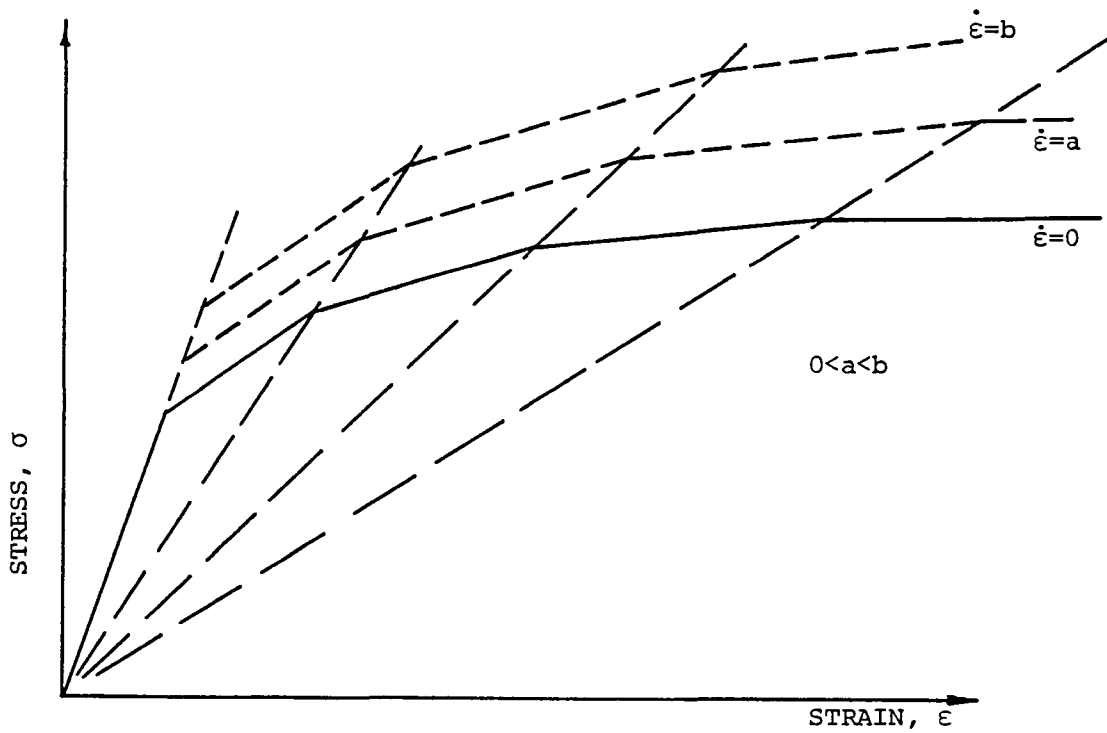


(c) Schematic of Loading, Unloading, and Reloading Paths

FIG. A.1 CONCLUDED



(a) Elastic, Perfectly-Plastic Material



(b) Special Strain Hardening Material

FIG. A.2 SCHEMATIC OF STRAIN-RATE DEPENDENT UNIAXIAL STRESS-STRAIN CURVES

APPENDIX B

GOVERNING EQUATIONS ON WHICH THE CIVM-PLATE PROGRAM IS BASED

B.1 Introduction

The CIVM-PLATE program is designed to predict the large-deflection, elastic-plastic, transient responses of stiffened and/or unstiffened initially-flat plates subjected to impact by an idealized rigid spherical fragment having specified translational and/or rotational velocity components prior to impact. Much of the theoretical basis of the CIVM-PLATE program is identical to that of the PLATE program; this is evidenced by the large number of computer subroutines shared by the PLATE and CIVM-PLATE program (see Sections 3 and 6). The key difference between the two programs is the cause of structural response. In the PLATE program, structural response is a result of prescribed initial nodal velocities or prescribed externally-applied forces. In the CIVM-PLATE program, structural response is a result of fragment/plate impact and interaction; no other form of "external loading" is permitted.

The governing equations used to formulate the element property matrices for unstiffened and stiffened plate elements also apply to the CIVM-PLATE program and the reader is invited to consult Subsections A.1 and A.2 for a discussion of these developments. However, the following exceptions should be noted. Since no externally-applied forces are allowed in the CIVM-PLATE program, the development of nodal force vectors given in Subsection A.1.3.4 is not required in the CIVM-PLATE program. Also, in order that the mass properties of the plate used in the transient structural response calculations be consistent with those assumed in the impact-interaction calculations, only lumped (diagonal) mass matrices (Eqs. A.30 and A.31, and A.92) are used in the CIVM-PLATE program.

To predict the transient response of the plate structure, programming logic must be introduced which (1) detects the time and location on the plate of a plate/fragment collision, (2) predicts the interaction between the plate and fragment during the collision, and (3) moves the transient structural

response calculations ahead in time. The formulation of the equations governing the collision inspection/interaction analysis is given in Subsection B.2, and a description of the solution of the governing dynamic equations of motion of the rigid fragment and the structure is given in Subsection B.3. Finally, the step-by-step program flow of the collision inspection/interaction analysis is discussed in Subsection B.4.

A detailed list of the assumptions which apply to the collision inspection/interaction analysis as well as a terse description of each of these procedures is given in Subsection 2.4. It is recommended that the information in that subsection as well as Fig. 7 be reviewed.

B.2 Plate/Fragment Collision Inspection/Interaction Analysis

B.2.1 Inspection for Location of Plate/Fragment Collision

The first task in the collision inspection/interaction analysis is to determine if a plate/fragment collision has occurred during the current time step and, if so, to determine the position on the plate where the collision occurs; this is a problem of geometry. Previous inspection schemes for two-dimensional beam/ring impact codes such as CIVM-JET 4B [3] and CIVM-JET 5B [4] have been based on the approximation that the deformed beam/ring element is straight (for the sake of inspection calculations only); these schemes attempt not only to determine the point of collision but also to calculate the approximate instant of the time of collision. Such techniques require a knowledge (or assumption) of the structure nodal and fragment centroidal location as a function of time within each time step.

The calculation of the instant of collision is deemed not practical at present for plate/fragment impact problems. Instead, trial positions for the plate nodes and the centroid of the spherical fragment at the end of a time step are calculated. Based on these trial positions and various simplifying assumptions on the space occupancy of the plate elements between nodes, the space occupancy of the plate elements and the spherical fragment are compared; if any overlap of the plate and fragment are detected, a collision is said to have occurred during that time step. No attempt is made to calculate the precise instant in time of plate/fragment collision. Instead, the collision

is assumed to have occurred at the beginning of the time step, and the corrections invoked as a result of the impact interaction analysis are enforced at the beginning of the time step.

The inspection for plate fragment overlap is based on current trial positions of the plate nodes and fragment centroid at the end of each time step; time as a variable does not enter into these calculations. The inspection for position (on the plate) of plate/fragment overlap can be accomplished by inspecting for overlap in each element. However, this potentially time-consuming inspection process has been simplified in the CIVM-PLATE program. First, the distance from the fragment centroid to each nodal position is calculated and the node closest to the fragment centroid is identified. The plate/fragment overlap (if any) should be found in one of the elements connected to the identified node. At most, four plate elements can be connected to the identified node and thus the inspection is carried out element by element over these four (or fewer) elements.

The inspection procedure within each element must be simplified further. Prior to initial impact each plate element is flat, of rectangular planform, and of uniform thickness. After deformation the space occupancy of a single element is complicated and is a combination of the plate initial coordinates plus the assumed deformation shapes given by Eqs. A.3. Inspection using this complicated surface has been judged to be impractical and inefficient. Instead, the following simplified geometry has been used; as discussed in Subsection 2.4, the plate element is subdivided into two triangles using the convention shown in Fig. 6. A planar triangular region is then defined by the current location of the three nodes associated with the triangle. The inspection for each element is thus divided into two inspections, each over a triangular region. The remainder of this subsection is devoted to the presentation of the equations which may be used to determine whether overlap between the spherical fragment and a triangular planar region, and, if so, to calculate the amount of this overlap.

Assume a triangular planar region of uniform thickness, h , in global x, y, z space with the midsurface defined by the coordinates (x_i, y_i) , $i=1, 2, 3$ of the corners of the triangle. The idealized rigid spherical fragment of radius R is located by the coordinates (x_f, y_f, z_f) of its centroid (Fig. 5) relative to the same global x, y, z system. The nodal numbering sequence for either triangular inspection subregion has been chosen (see Fig. B.1) in such a way that a vector, \vec{V}_n , which is normal to the triangular region (and therefore normal to the plane defined by the triangular region) can be defined by the vector cross-product

$$\vec{V}_n = \vec{V}_{12} \times \vec{V}_{13} \quad (\text{B.1})$$

where \vec{V}_{12} is the vector from node 1 to node 2 and \vec{V}_{13} is the vector from node 1 to node 3 of the triangle. The vector \vec{V}_n will be directed toward the outer surface of the plate, and it is assumed that impact always occurs on the inner surface of the plate. The vectors \vec{V}_{12} and \vec{V}_{13} can be defined in terms of the global coordinates of the nodes of the triangle. Using the notation $x_{1j} = x_1 - x_j$ etc. to define the difference between nodal coordinates, the vector \vec{V}_n can be evaluated from Eq. B.1 and is given by

$$\vec{V}_n = A \hat{i} + B \hat{j} + C \hat{k} \quad (\text{B.2})$$

where $\hat{i}, \hat{j}, \hat{k}$ are unit vectors in the global x, y , and z directions and

$$\begin{aligned} A &= y_{21} z_{31} - y_{31} z_{21} \\ B &= x_{31} z_{21} - x_{21} z_{31} \\ C &= x_{21} y_{31} - x_{31} y_{21} \end{aligned} \quad (\text{B.2a})$$

A coordinate transformation is required (for the later stages of collision inspection and for all phases of collision interaction to a system $\bar{x} \bar{y} \bar{z}$ such that the \bar{z} axis (or N axis, as used in the impact interaction analysis) is normal to plane of impact (in the triangular region where overlap occurs) and the \bar{x} and \bar{y} axes lie in the impacted plane. This coordinate transformation will now be derived.

The vector \vec{V}_n is normal to triangular plane and is directed along the \bar{z} axis. The unit vector \hat{k} in the \bar{z} direction can then be defined from Eq. B.2 as

$$\hat{k} = \frac{A}{l_3} \hat{i} + \frac{B}{l_3} \hat{j} + \frac{C}{l_3} \hat{k} \quad (\text{B.3})$$

where l_3 is the length of the vector \vec{v}_n and is given by

$$l_3 = [A^2 + B^2 + C^2]^{\frac{1}{2}} \quad (\text{B.3a})$$

In order to define the \bar{x} and \bar{y} coordinates which lie in the plane of the triangle, one of these directions may be chosen arbitrarily; in the present case, it is assumed that the \bar{x} axis is directed from node 1 to node 2 of the triangle. The vector \vec{v}_{12} is thus directed along the \bar{x} axis and the unit vector \hat{i} along the \bar{x} axis can be defined as

$$\hat{i} = \frac{x_{21}}{l_1} \hat{i} + \frac{y_{21}}{l_1} \hat{j} + \frac{z_{21}}{l_1} \hat{k} \quad (\text{B.4})$$

where l_1 is the length of the vector \vec{v}_{12} given by

$$l_1 = [x_{21}^2 + y_{21}^2 + z_{21}^2]^{\frac{1}{2}} \quad (\text{B.4a})$$

The unit vector \hat{j} along the \bar{y} axis can then be defined in terms of \hat{k} and \hat{i} by the vector cross-product

$$\hat{j} = \hat{k} \times \hat{i} \quad (\text{B.5})$$

which upon substitution of Eqs. B.3 and B.4 becomes

$$\hat{j} = \frac{(Bz_{21} - Cy_{21})}{l_1 l_3} \hat{i} + \frac{(Cx_{21} - Az_{21})}{l_1 l_3} \hat{j} + \frac{(Ay_{21} - Bx_{21})}{l_1 l_3} \hat{k} \quad (\text{B.5a})$$

The coordinate transformation matrix can now be defined. Consider any vector \vec{v} having components (v_x, v_y, v_z) in the xyz coordinate system, and components $(\bar{v}_x, \bar{v}_y, \bar{v}_z)$ in the $\bar{x} \bar{y} \bar{z}$ coordinate system. The vector \vec{v} may be written in terms of components in either coordinate system and therefore the following equality must hold:

$$\bar{v}_x \hat{i} + \bar{v}_y \hat{j} + \bar{v}_z \hat{k} = v_x \hat{i} + v_y \hat{j} + v_z \hat{k} \quad (\text{B.6})$$

The relation between components $(\bar{v}_x, \bar{v}_y, \bar{v}_z)$ and (v_x, v_y, v_z) is obtained by first dotting both sides of Eq. B.6 by \hat{i} , then dotting both sides of Eq. B.6 by \hat{j} , and finally, dotting both sides of Eq. B.6 by \hat{k} . The three equations thus obtained can be written in matrix form as

$$\begin{Bmatrix} \bar{v}_x \\ \bar{v}_y \\ \bar{v}_z \end{Bmatrix} = \begin{bmatrix} \hat{i} \cdot \hat{l} & \hat{j} \cdot \hat{l} & \hat{k} \cdot \hat{l} \\ \hat{i} \cdot \hat{f} & \hat{j} \cdot \hat{f} & \hat{k} \cdot \hat{f} \\ \hat{i} \cdot \hat{h} & \hat{j} \cdot \hat{h} & \hat{k} \cdot \hat{h} \end{bmatrix} \begin{Bmatrix} v_x \\ v_y \\ v_z \end{Bmatrix} \quad (\text{B.7})$$

or

$$\bar{\underline{v}} = \underline{T} \underline{v} \quad (\text{B.7a})$$

The matrix \underline{T} is the required transformation matrix to obtain components of a vector in the $\bar{x} \bar{y} \bar{z}$ coordinate system in terms of components in the xyz coordinate system. The inverse of Eq. B.7a can be obtained by noting that \underline{T} is an orthogonal matrix (having the property that $\underline{T}^{-1} = \underline{T}^T$) so that

$$\underline{v} = \underline{T}^T \bar{\underline{v}} \quad (\text{B.7b})$$

The unit vector dot products in Eq. B.7 can be evaluated from Eqs. B.3, B.4, and B.5a giving \underline{T} in terms of known nodal coordinates (and other previously-defined quantities related to nodal coordinates) by

$$\underline{T} = \begin{bmatrix} \frac{x_{21}}{l_1} & \frac{y_{21}}{l_1} & \frac{z_{21}}{l_1} \\ \frac{(B z_{21} - C y_{21})}{l_1 l_3} & \frac{(C x_{21} - A z_{21})}{l_1 l_3} & \frac{(A y_{21} - B x_{21})}{l_1 l_3} \\ \frac{A}{l_3} & \frac{B}{l_3} & \frac{C}{l_3} \end{bmatrix} \quad (\text{B.8})$$

The perpendicular distance, d_{fp} , between the fragment centroid and the plane of the triangle can be calculated by noting that by applying the above coordinate transformation, the triangular region now lies in a $\bar{z} = \text{constant}$

plane. The distance d_{fp} can be calculated as the difference between the \bar{z} location of the fragment centroid (obtained by transformation of the fragment centroid coordinates x_f , y_f , and z_f using the last row of \tilde{T} and Eq. B.7a) and the \bar{z} location of any triangle node (here the \bar{z} location of node 1 is used, obtained by using the last row of \tilde{T} and Eq. B.7a). Adopting the convention that a negative value of d_{fp} implies that the fragment centroid is below the plate (in a negative \bar{z} direction from the plate), d_{fp} is given by

$$\begin{aligned} d_{fp} &= \bar{z}_f - z_1 = T_{31}(x_f - x_1) + T_{32}(y_f - y_1) + T_{33}(z_f - z_1) \\ &= \frac{A(x_f - x_1) + B(y_f - y_1) + C(z_f - z_1)}{[A^2 + B^2 + C^2]^{\frac{1}{2}}} \end{aligned} \quad (\text{B.9})$$

Using the above-mentioned convention for d_{fp} , the penetration distance, d_o (amount of plate/fragment overlap), can be calculated as

$$d_o = \left(r_f + \frac{h}{2} \right) + d_{fp} \quad (\text{B.10})$$

where r_f is the radius of the rigid spherical fragment and h is the (constant) thickness of the plate.

Impact can occur only if d_o is positive. If $d_o \leq 0$, no further inspection is required; overlap cannot occur. If d_o is positive, this implies that overlap occurs at some point located by coordinates (x_n, y_n, z_n) in the plane which includes the triangular region. The coordinates (x_n, y_n, z_n) of the point on the plane which is along the normal line from (x_f, y_f, z_f) to the plane and at which the overlap d_o is obtained must be found. The vector from (x_f, y_f, z_f) to (x_n, y_n, z_n) has a magnitude of d_{fp} and is directed in the positive \bar{z} direction if d_{fp} is negative. The components of this vector in the xyz coordinate system can be obtained by applying Eq. B.7b to give

$$\begin{aligned} (d_{fp})_x &= - \frac{A d_{fp}}{l_3} \\ (d_{fp})_y &= - \frac{B d_{fp}}{l_3} \\ (d_{fp})_z &= - \frac{C d_{fp}}{l_3} \end{aligned} \quad (\text{B.11})$$

Hence, the coordinates (x_n, y_n, z_n) can be obtained by adding these components to the fragment centroidal position as

$$\begin{aligned} x_n &= x_f + (d_{fp})_x = x_f - \frac{A d_{fp}}{l_3} \\ y_n &= y_f + (d_{fp})_y = y_f - \frac{B d_{fp}}{l_3} \\ z_n &= z_f + (d_{fp})_z = z_f - \frac{C d_{fp}}{l_3} \end{aligned} \quad (\text{B.12})$$

where A, B, and C are given by Eqs. B.2a, l_3 by Eq. B.3a, and d_{fp} is calculated from Eq. B.9. An inspection must be performed to determine if the point (x_n, y_n, z_n) falls within the triangular inspection region.

The transformation given by Eq. B.7a can be applied to the coordinates of the corners of the triangle yielding $(\bar{x}_1, \bar{y}_1, \bar{z}_1)$, $(\bar{x}_2, \bar{y}_2, \bar{z}_2)$, and $(\bar{x}_3, \bar{y}_3, \bar{z}_3)$ and to the point of maximum overlap (x_n, y_n, z_n) to give $(\bar{x}_n, \bar{y}_n, \bar{z}_n)$ where $\bar{z}_1 = \bar{z}_2 = \bar{z}_3 = \bar{z}_n$. Triangular coordinates (L_1, L_2, L_3) can be defined by (see, for example, Ref. 10)

$$\begin{aligned} L_1 &= (a_1 + b_1 \bar{x} + c_1 \bar{y}) / (2A^*) \\ L_2 &= (a_2 + b_2 \bar{x} + c_2 \bar{y}) / (2A^*) \\ L_3 &= (a_3 + b_3 \bar{x} + c_3 \bar{y}) / (2A^*) \end{aligned} \quad (\text{B.13})$$

where

$$\begin{aligned} a_1 &= \bar{x}_2 \bar{y}_3 - \bar{x}_3 \bar{y}_2 & b_1 &= \bar{y}_2 - \bar{y}_3 & c_1 &= \bar{x}_3 - \bar{x}_2 \\ a_2 &= \bar{x}_3 \bar{y}_1 - \bar{x}_1 \bar{y}_3 & b_2 &= \bar{y}_3 - \bar{y}_1 & c_2 &= \bar{x}_1 - \bar{x}_3 \\ a_3 &= \bar{x}_1 \bar{y}_2 - \bar{x}_2 \bar{y}_1 & b_3 &= \bar{y}_1 - \bar{y}_2 & c_3 &= \bar{x}_2 - \bar{x}_1 \end{aligned} \quad (\text{B.13a})$$

and A^* is the area of the triangle and is given by

$$A^* = \frac{1}{2} \left(\bar{x}_2 \bar{y}_3 + \bar{x}_1 \bar{y}_2 + \bar{x}_3 \bar{y}_1 - \bar{x}_2 \bar{y}_1 - \bar{x}_3 \bar{y}_2 - \bar{x}_1 \bar{y}_3 \right) \quad (\text{B.13b})$$

It can be verified easily that for all values of (\bar{x}, \bar{y}) within the triangle, the values of the triangular coordinates (L_1, L_2, L_3) will be between 0 and 1. To check if point (\bar{x}_n, \bar{y}_n) falls inside the triangular region, the coordinates (\bar{x}_n, \bar{y}_n) are substituted into Eqs. B.13. If the point (\bar{x}_n, \bar{y}_n) is within the triangle, the following conditions must be satisfied:

$$\begin{aligned} 0 &\leq L_1(\bar{x}_n, \bar{y}_n) \leq 1 \\ 0 &\leq L_2(\bar{x}_n, \bar{y}_n) \leq 1 \\ 0 &\leq L_3(\bar{x}_n, \bar{y}_n) \leq 1 \end{aligned} \quad (\text{B.14})$$

If any of Eqs. B.14 is violated, the point of maximum plane/fragment overlap is not within the triangular region and no plate/fragment overlap occurs in this triangular inspection region.

If Eqs. B.14 are satisfied, a plate/fragment impact has occurred during the current time step at point (x_n, y_n) (or at point (x_n, y_n, z_n)) in this triangular inspection region with an overlap (penetration) of d_o given by Eq. B.10. This procedure is followed for each of the two triangular inspection regions for each element in the region of interest. As a result of this inspection, it is possible that either (a) no positive penetrations or (b) one or more positive penetrations will be found. If no positive penetrations are found (i.e. $d_o \leq 0$ or Eqs. B.14 are not satisfied for all triangular inspection regions), fragment/plate impact has not occurred during the current time cycle.

If fragment/plate impact occurs during the current cycle, one or more positive d_o (with Eqs. B.14 also satisfied) values will be found. If only one positive d_o is detected, impact is said to occur at (x_n, y_n, z_n) as described above. However, it should be recalled that no attempt is made in the present program to "subdivide" the time step, Δt , in order to identify precise times of impact, etc. Such schemes introduce unwanted complications and additional computations, as they tend to engender an excessive number of "special cases" and corresponding checks. Therefore, if more than one positive overlap is

detected during the inspection, no attempt is made to identify which "impact occurred first. Instead, the 2 or more impacts are assumed to have occurred simultaneously, and their effects are imposed (as described earlier) at the beginning of the time cycle.

The developments in this subsection have concentrated on a typical triangular inspection region. For purposes of impact correction (see the collision interaction analysis to be described in Subsection B.2.2), the point of impact and the plane of impact must be defined (along with the corresponding coordinate transformation matrix). If only one overlap occurs, the point and plane of impact, and transformation are as described earlier. If 2 or more overlaps occur, a modified definition is needed and is described in the following.

It is assumed that all points of overlap and associated planes of impact for the cycle have been identified. If more than one overlap has occurred, effective plate/fragment impact is said to occur at the location (x_a, y_a, z_a) which is computed as the algebraic average of all points of plate/fragment overlap. The effective plane of impact and associated coordinate transformation must also be defined. The unit outward normal, \hat{k}_a , to the effective plane of impact is given by

$$\hat{k}_a = \frac{1}{l_3} (A_a \hat{i} + B_a \hat{j} + C_a \hat{k}) \quad (B.15a)$$

where A_a , B_a , and C_a are the sum of the x, y, and z components, respectively, of the unit outward normals to each plane of overlap. Also,

$$l_3 = \sqrt{A_a^2 + B_a^2 + C_a^2} \quad (B.15b)$$

so that \hat{k}_a is a unit vector. Note that this is analogous to defining the "average" plane of impact.

In order to define the necessary coordinate transformation matrix (analogous to Eqs. B.7-B.8), the inplane \bar{x} - \bar{y} coordinate directions must be identified. Therefore, define a vector \bar{C}_x as

$$\bar{C}_x = (x_i - x_a) \hat{i} + (y_i - y_a) \hat{j} + (z_i - z_a) \hat{k} \quad (B.15c)$$

where (x_1, y_1, z_1) is some as yet unspecified location. Now require that \bar{C}_x define the \bar{x} direction and, therefore, lie in a plane having the unit outward normal, \hat{k}_a . Thus, (x_1, y_1, z_1) should be chosen such that

$$\hat{k}_a \cdot \bar{C}_x = 0 \quad (\text{B.15d})$$

Clearly, two of the coordinates can be chosen arbitrarily and the third determined from Eq. B.15d. The following choices satisfy Eq. B.15d:

$$\begin{aligned} (x_i - x_a) &= l \\ (y_i - y_a) &= l \\ (\bar{z}_i - \bar{z}_a) &= -\frac{(A_a + B_a)}{C_a} \equiv -d_a \end{aligned} \quad (\text{B.15e})$$

so that the unit vector, \hat{i}_a , in the \bar{x} direction is given by

$$\hat{i}_a = \frac{l}{l_1} (\hat{i} + \hat{j} - d_a \hat{k}) \quad (\text{B.15f})$$

where

$$l_1 = \sqrt{2 + d_a^2} \quad (\text{B.15g})$$

The unit vector, \hat{j}_a , in the \bar{y} direction is then given by

$$\hat{j}_a = \hat{k}_a \times \hat{i}_a = \frac{l}{l_2} \left[(-B_a d_a - C_a) \hat{i} + (C_a + A_a d_a) \hat{j} + (A_a - B_a) \hat{k} \right] \quad (\text{B.15h})$$

where

$$l_2 = l_1 l_3 \quad (\text{B.15i})$$

With the coordinate directions of the effective plane of impact defined above, the coordinate transformation matrix, \mathbb{T} , can be defined via Eqs. B.7 and B.7a with $\hat{i}, \hat{j}, \hat{k}$ in B.7 replaced by $\hat{i}_a, \hat{j}_a, \hat{k}_a$, respectively, defined in Eqs. B.15a, B.15f, and B.15h. The result is

$$\tilde{T} = \begin{bmatrix} \frac{1}{l_1} & \frac{1}{l_1} & -\frac{d_a}{l_1} \\ \frac{(-B_a d_a - C_a)}{l_2} & \frac{(C_a + A_a d_a)}{l_2} & \frac{(A_a - B_a)}{l_2} \\ \frac{A_a}{l_3} & \frac{B_a}{l_3} & \frac{C_a}{l_3} \end{bmatrix} \quad (\text{B.15j})$$

It should be noted that the identification of an effective point of impact for multiple overlaps during a time step is used only in the general whole-plate analysis. For the symmetry cases, maximum positive penetration determines the point and plane of impact. Also note that the present effective point and plane of impact reduces to the actual point and plane of impact for cases where only one overlap is found. Finally, in subsequent discussion and descriptions, the terminologies "point of maximum penetration", "point of impact", and "point of effective impact" may be used interchangeably.

B.2.2 Collision Interaction Analysis

Momentum and energy considerations are utilized to predict the interaction between the rigid fragment and the plate once a plate/fragment collision (overlap) is detected. First the region of the plate affected by the impact is defined; those nodes which fall in this region of the plate are termed the impact-affected nodes. The impact interaction analysis to be

described in this subsection is then used to predict the changes in velocity of the fragment and of the impact-affected nodes. This procedure is termed the Collision-Imparted-Velocity-Method (CIVM). The CIVM has been previously utilized in 2-D beam/ring codes [1,2,3,4], and is extended here for the present 3-D plate impact analysis.

As discussed in the previous subsection, no attempt is made to identify the precise instant in time (during the time step, Δt) at which impact occurs. Instead, when plate/fragment overlap is detected at the end of a time step, the velocity corrections (as a result of impact) are based on the positions and velocities at the beginning of the time step and corrections are imposed at the beginning of the time step.

Before calculating velocity corrections, the impact-affected region of the plate must be defined. For present purposes, the impact affected region of the plate (see Fig. B.2) is defined by a circle whose origin is at the calculated point of plate/fragment collision (maximum plate/fragment overlap). The effects of the impact are assumed to travel at the elastic longitudinal wave speed so that the radius of the circle, L_{eff} , can be defined as the distance traveled in the time step, Δt ,

$$L_{eff} = \left[\frac{E}{\rho_0 (1 - \nu^2)} \right]^{\frac{1}{2}} \Delta t \quad (B.16)$$

where E , ν , and ρ_0 are Young's modulus, the Poisson ratio, and the mass density of the plate material. Those plate nodes which fall within this circular region are the impact-affected nodes. Other estimates for L_{eff} could, of course, be selected and used (see Card 70 in Subsection 5.2).

The impulse-momentum relations will be written for the fragment and each impact-affected node in the transformed coordinate system (\bar{x}, \bar{y}, N) --- (with N replacing \bar{z} --- defined as the plane of impact (see Subsection B.2.1). Thus, components of velocity and impulse normal (N) and tangent (\bar{x}, \bar{y}) to the impact are considered.

For present purposes, a cone-shaped distribution⁺ of impulse (centered at the point of impact) is assumed over the impact-affected region of the plate.

⁺This is similar to the procedure used by Gerstle [15,16,17].

The impulse components, $p_{i\bar{x}}$, $p_{i\bar{y}}$, and p_{iN} applied at node i in the impact-affected region are then given by

$$p_{i\bar{x}} = c \left(1 - \frac{|s_i|}{L_{eff}} \right) \tilde{p}_{\bar{x}} \equiv c \alpha'_i \tilde{p}_{\bar{x}} \quad (\text{B.17a})$$

$$p_{i\bar{y}} = c \left(1 - \frac{|s_i|}{L_{eff}} \right) \tilde{p}_{\bar{y}} \equiv c \alpha'_i \tilde{p}_{\bar{y}}$$

$$p_{iN} = c \left(1 - \frac{|s_i|}{L_{eff}} \right) \tilde{p}_N \equiv c \alpha'_i \tilde{p}_N$$

where $|s_i|$ is the distance from the i th impact-affected node to the point of impact (see Fig. B.2) and it is assumed that k nodes fall in the impact-affected region. The components $\tilde{p}_{\bar{x}}$, $\tilde{p}_{\bar{y}}$, \tilde{p}_N represent the total impulse applied to the plate and in an equal but opposed fashion to the fragment. The constant, c , is determined by requiring that the sum of the nodal impulse components be equal to the total imparted impulse, i.e.

$$\sum_{i=1}^k \begin{Bmatrix} p_{i\bar{x}} \\ p_{i\bar{y}} \\ p_{iN} \end{Bmatrix} = \begin{Bmatrix} \tilde{p}_{\bar{x}} \\ \tilde{p}_{\bar{y}} \\ \tilde{p}_N \end{Bmatrix} \quad (\text{B.17b})$$

substituting any one of Eqs. B.17a into Eq. B.17b yields

$$c = \frac{1}{\sum_{i=1}^k \left(1 - \frac{|s_i|}{L_{eff}} \right)} = \frac{1}{\sum_{i=1}^k \alpha'_i} \quad (\text{B.18})$$

It is assumed that only the translational components of nodal velocity are affected. Denoting by primes the "after-impact" translational and rotational (fragment only) velocities, the following impulse-momentum relations may be written for the fragment and the impact-affected plate nodes:

\bar{x} -Direction: Translational

$$\begin{aligned}
 m_f \left[v'_{f\bar{x}} - v_{f\bar{x}} \right] &= -\tilde{p}_{\bar{x}} && \text{fragment} \\
 m_1 \left[v'_{1\bar{x}} - v_{1\bar{x}} \right] &= \alpha_1 \tilde{p}_{\bar{x}} \\
 m_2 \left[v'_{2\bar{x}} - v_{2\bar{x}} \right] &= \alpha_2 \tilde{p}_{\bar{x}} \\
 &\vdots \\
 m_k \left[v'_{k\bar{x}} - v_{k\bar{x}} \right] &= \alpha_k \tilde{p}_{\bar{x}}
 \end{aligned}
 \left. \vphantom{\begin{aligned} m_f \left[v'_{f\bar{x}} - v_{f\bar{x}} \right] &= -\tilde{p}_{\bar{x}} \\ m_1 \left[v'_{1\bar{x}} - v_{1\bar{x}} \right] &= \alpha_1 \tilde{p}_{\bar{x}} \\ m_2 \left[v'_{2\bar{x}} - v_{2\bar{x}} \right] &= \alpha_2 \tilde{p}_{\bar{x}} \\ &\vdots \\ m_k \left[v'_{k\bar{x}} - v_{k\bar{x}} \right] &= \alpha_k \tilde{p}_{\bar{x}} \end{aligned}} \right\} \text{plate impact-affected nodes}$$

(B.19a)

\bar{y} -Direction: Translational

$$\begin{aligned}
 m_f \left[v'_{f\bar{y}} - v_{f\bar{y}} \right] &= -\tilde{p}_{\bar{y}} && \text{fragment} \\
 m_1 \left[v'_{1\bar{y}} - v_{1\bar{y}} \right] &= \alpha_1 \tilde{p}_{\bar{y}} \\
 m_2 \left[v'_{2\bar{y}} - v_{2\bar{y}} \right] &= \alpha_2 \tilde{p}_{\bar{y}} \\
 &\vdots \\
 m_k \left[v'_{k\bar{y}} - v_{k\bar{y}} \right] &= \alpha_k \tilde{p}_{\bar{y}}
 \end{aligned}
 \left. \vphantom{\begin{aligned} m_f \left[v'_{f\bar{y}} - v_{f\bar{y}} \right] &= -\tilde{p}_{\bar{y}} \\ m_1 \left[v'_{1\bar{y}} - v_{1\bar{y}} \right] &= \alpha_1 \tilde{p}_{\bar{y}} \\ m_2 \left[v'_{2\bar{y}} - v_{2\bar{y}} \right] &= \alpha_2 \tilde{p}_{\bar{y}} \\ &\vdots \\ m_k \left[v'_{k\bar{y}} - v_{k\bar{y}} \right] &= \alpha_k \tilde{p}_{\bar{y}} \end{aligned}} \right\} \text{plate impact-affected nodes}$$

(B.19b)

Normal Direction: Translational

$$\begin{aligned}
 m_f \left[v'_{fN} - v_{fN} \right] &= -\tilde{p}_N && \text{fragment} \\
 m_1 \left[v'_{1N} - v_{1N} \right] &= \alpha_1 \tilde{p}_N \\
 m_2 \left[v'_{2N} - v_{2N} \right] &= \alpha_2 \tilde{p}_N \\
 &\vdots \\
 m_k \left[v'_{kN} - v_{kN} \right] &= \alpha_k \tilde{p}_N
 \end{aligned}
 \left. \vphantom{\begin{aligned} m_f \left[v'_{fN} - v_{fN} \right] &= -\tilde{p}_N \\ m_1 \left[v'_{1N} - v_{1N} \right] &= \alpha_1 \tilde{p}_N \\ m_2 \left[v'_{2N} - v_{2N} \right] &= \alpha_2 \tilde{p}_N \\ &\vdots \\ m_k \left[v'_{kN} - v_{kN} \right] &= \alpha_k \tilde{p}_N \end{aligned}} \right\} \text{plate impact-affected nodes}$$

(B.19c)

Rotational

$$\begin{aligned}
 I_f \left[\omega'_{f\bar{y}} - \omega_{f\bar{y}} \right] &= -r_f \tilde{p}_{\bar{x}} \\
 I_f \left[\omega'_{f\bar{x}} - \omega_{f\bar{x}} \right] &= -r_f \tilde{p}_{\bar{y}} \\
 \omega'_{fN} - \omega_{fN} &= 0
 \end{aligned}
 \left. \vphantom{\begin{aligned} I_f \left[\omega'_{f\bar{y}} - \omega_{f\bar{y}} \right] &= -r_f \tilde{p}_{\bar{x}} \\ I_f \left[\omega'_{f\bar{x}} - \omega_{f\bar{x}} \right] &= -r_f \tilde{p}_{\bar{y}} \\ \omega'_{fN} - \omega_{fN} &= 0 \end{aligned}} \right\} \text{fragment}$$

(B.19d)

where m_f , I_f , and r_f are the mass, mass moment of inertia, and radius of the fragment, m_i is the (diagonalized lumped) translational mass of node i , and

$\alpha_i (=c\alpha'_i)$ is the proportionality constant associated with node i . The known translational velocity components of node i are v_{ix}^- , v_{iy}^- , and v_{iN} and the known translational and rotational components of the fragment centroid are v_{fx}^- , v_{fy}^- , v_{fN} , ω_{fx}^- , ω_{fy}^- , and ω_{fN} (these are the transformed nodal and fragment velocities at the beginning of the time step). Note that the last of Eqs. B.19d simply indicates that there is no mechanism (i.e., friction, etc.) which can change the angular velocity of the fragment about the N axis. Once the impulse components \tilde{p}_x^- , \tilde{p}_y^- , and \tilde{p}_N are determined, the post-impact (primed) nodal and fragment velocities can be calculated from Eqs. B.19.

Analytic expressions for the impulse components \tilde{p}_x^- , \tilde{p}_y^- , \tilde{p}_N at the instant of termination of the impact are obtained by an extension of a graphical technique suggested by Goldsmith [18]. The motion of the system during the impact process is described by an image point, \bar{P} , in the \tilde{p}_x^- , \tilde{p}_y^- , \tilde{p}_N space (Fig. B.3). The coordinates of \bar{P} at the termination of the impact process then define the impulse imparted during impact.

The relative velocity of sliding, S' , and the relative velocity of approach, A' , between the impact-affected plate nodes and the fragment at the point of contact can be defined by

$$\begin{aligned} S' \cos \bar{\theta} &= \left[v_{fx}' - r_f \omega_{fy}' \right] - \sum_{i=1}^n \alpha_i v_{ix}' \\ S' \sin \bar{\theta} &= \left[v_{fy}' - r_f \omega_{fx}' \right] - \sum_{i=1}^n \alpha_i v_{iy}' \\ A' &= v_{fN}' - \sum_{i=1}^n \alpha_i v_{iN}' \end{aligned} \quad (B.20)$$

where $\bar{\theta}$ is the angle found by the direction of sliding with the \bar{x} axis (see Fig. B.3). Substituting the impulse-momentum relations (B.19) into Eqs. B.20 yields relations in the form

$$\begin{aligned} S' \cos \bar{\theta} &= S_1 - B_1 \tilde{p}_x^- \\ S' \sin \bar{\theta} &= S_2 - B_2 \tilde{p}_y^- \\ A' &= A_0 - B_3 \tilde{p}_N \end{aligned} \quad (B.21)$$

where A_0 , S_1 , S_2 , B_1 , B_2 , and B_3 are given by

$$\begin{aligned}
 S_1 &= S_0 \cos \bar{\theta} = \left[v_{f\bar{x}} + r_f \omega_{f\bar{y}} \right] - \sum_{i=1}^k \alpha_i v_{i\bar{x}} \\
 S_2 &= S_0 \sin \bar{\theta} = \left[v_{f\bar{y}} - r_f \omega_{f\bar{x}} \right] - \sum_{i=1}^k \alpha_i v_{i\bar{y}} \\
 A_0 &= v_{fN} - \sum_{i=1}^k \alpha_i v_{iN} \\
 B_2 &= B_1 = \left[\frac{1}{m_f} + \frac{r_f^2}{I_f} \right] + \sum_{i=1}^k \frac{\alpha_i^2}{m_i} \\
 B_3 &= \frac{1}{m_f} + \sum_{i=1}^k (\alpha_i^2 / m_i)
 \end{aligned} \tag{B.22}$$

It should be noted that, as defined, B_1 and B_3 must be non-negative. Also, the relative velocity of approach at the instant of initiation of contact, A_0 , must be non-negative; if $A_0 < 0$, the plate and fragment are moving apart and no collision occurs. If S_1 or S_2 are positive, the fragment slides initially along the plate segment; this sliding is assumed to occur at the value of limiting friction.

The no-sliding and maximum-approach conditions identify limiting conditions during the collision process. From the first two of Eqs. B.21, it is seen that the locus of no sliding, $S'=0$, is a straight line perpendicular to the \tilde{p}_x \tilde{p}_y plane, which intersects the $\tilde{p}_N=0$ plane at:

$$\tilde{p}_{\bar{x}} = \frac{S_1}{B_1} \quad , \quad \tilde{p}_{\bar{y}} = \frac{S_2}{B_1}$$

From the last of Eqs. B.21, the locus of maximum approach, $A'=0$, is seen to be a plane whose normal is in the \tilde{p}_N direction. The plane intersects the \tilde{p}_N axis at the point

$$\tilde{p}_N = \frac{A_0}{B_3}$$

Finally, the line of no sliding, $S'=0$, intersects the plane of maximum approach, $A'=0$, at the point (see Fig. B.3):

$$\tilde{p}_{\bar{x}} = \frac{S_1}{B_1} \quad , \quad \tilde{p}_{\bar{y}} = \frac{S_2}{B_1} \quad , \quad \tilde{p}_N = \frac{A_0}{B_3}$$

In order to obtain the impulse coordinates \tilde{p}_x \tilde{p}_y \tilde{p}_N at the instant of termination of the collision, the motion of the image point, \bar{P} , in \tilde{p}_x \tilde{p}_y \tilde{p}_N

space, must be followed. The existence of a value of limiting friction, μ , requires that the first stage of the path of \bar{P} be governed by the relations

$$\frac{d\tilde{p}_x}{\cos \bar{\theta}} = \frac{d\tilde{p}_y}{\sin \bar{\theta}} = \mu d\tilde{p}_N \quad (\text{B.23})$$

This condition restricts initial motion to be in the plane formed by the line $S'=0$ and the \tilde{p}_N axis, at an angle

$$\nu = \tan^{-1} \mu \quad (\text{B.24})$$

with respect to the \tilde{p}_N axis. The subsequent motion of \bar{P} will first be defined for the general case where $0 < \mu < \infty$, then for the two special cases, $\mu=0$ (perfectly smooth contact surfaces) and $\mu=\infty$ (perfectly rough contact surfaces).

Case I: $0 < \mu < \infty$

First the friction angle, ν , is defined according to Eq. B.24. Next, the angle Λ formed between the \tilde{p}_N axis and the line from the origin to the intersection of $S'=0$ and $A'=0$ (see Fig. B.4) is defined by

$$\Lambda = \tan^{-1} \left[\frac{B_3}{A_0 B_1} (S_1^2 + S_2^2)^{\frac{1}{2}} \right] \quad (\text{B.25})$$

Initially, the image point moves along the path which subtends an angle ν with the \tilde{p}_N axis. Subsequent motion is described by the following two subcases.

Subcase Ia: $\mu = \tan \nu < \tan \Lambda$

The subsequent motion of \bar{P} is shown in Fig. B.4a. The line P_0L of initial motion intersects the plane 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 termination of the approach period. This is followed by a restitution period; the process ceases at point P' (path P_0-P_1-P'), whose coordinates are

$$\begin{aligned}\tilde{p}_x &= \mu (1+e) p_{N_1} \cos \bar{\theta} \\ \tilde{p}_y &= \mu (1+e) p_{N_1} \sin \bar{\theta}\end{aligned}\tag{B.25}$$

where

$$\begin{aligned}\tilde{p}_N &= (1+e) p_{N_1} \\ \cos \bar{\theta} &= \frac{S_1}{[S_1^2 + S_2^2]^{\frac{1}{2}}} \\ \sin \bar{\theta} &= \frac{S_2}{[S_1^2 + S_2^2]^{\frac{1}{2}}}\end{aligned}\tag{B.25a}$$

$$p_{N_1} = \frac{A_o}{B_3}$$

and e is the coefficient of restitution.

Subcase Ib: $\mu = \tan \nu > \tan \lambda$

The subsequent motion of the image point \bar{P} for this subcase is illustrated in Fig. B.4b. The line P_0L of initial motion will intersect the line of no sliding, $S'=0$, first at the point P_2 which marks the end of the initial sliding phase. The image point \bar{P} will then move along the line of no sliding, through the intersection point P_3 with the plane of maximum approach, $A'=0$. This is followed by a restoration period, moving the image point to P' (path $P_0-P_2-P_3-P'$). The final impulse coordinate values are

$$\begin{aligned}\tilde{p}_x &= \frac{S_1}{B_1} \\ \tilde{p}_y &= \frac{S_2}{B_1} \\ \tilde{p}_N &= (1+e) p_{N_3} = (1+e) \frac{A_o}{B_3}\end{aligned}\tag{B.26}$$

The special subcases will now be considered.

Case II: $\mu=0$ (perfectly smooth contact surfaces)

This situation is a special case of Subcase Ia in which line P_0L coalesces with the \tilde{p}_N axis. The image point will move along the \tilde{p}_N axis through the plane $A'=0$ so that after a period of restoration, the final impulse coordinate values are

$$\tilde{p}_x = \tilde{p}_y = 0, \quad \tilde{p}_N = (1+e) \frac{A_o}{B_3}\tag{B.27}$$

Case III: $\mu=\infty$ (completely rough contact surfaces)

The motion of \bar{P} is similar to Subcase Ib except that \bar{P} moves initially in the $\tilde{p}_N = 0$ plane to the line $S'=0$. The remaining motion along the line of no sliding to the end of impact is identical to Subcase Ib. The final impulse coordinates are thus

$$\begin{aligned}\tilde{p}_x &= \frac{S_1}{B_1} \\ \tilde{p}_y &= \frac{S_2}{B_1} \\ \tilde{p}_N &= (1+e) \frac{A_0}{B_3}\end{aligned}\tag{B.28}$$

Once the values of \tilde{p}_x , \tilde{p}_y , and \tilde{p}_N are determined from Eqs. B.25, or B.26, or B.27, or B.28, the post-impact plate nodal and fragment centroidal velocity components can be calculated from the impulse-momentum relations (Eqs. B.19). For example, the normal components of post-impact velocity would be calculated as

$$\begin{aligned}v'_{fN} &= v_{fN} - \frac{\tilde{p}_N}{m_f} && \text{fragment} \\ \left. \begin{aligned}v'_{1N} &= v_{1N} + \frac{\alpha_1}{m_1} \tilde{p}_N \\ v'_{2N} &= v_{2N} + \frac{\alpha_2}{m_2} \tilde{p}_N \\ \vdots & \\ v'_{kN} &= v_{kN} + \frac{\alpha_k}{m_k} \tilde{p}_N\end{aligned} \right\} && \text{plate impact-affected nodes}\end{aligned}\tag{B.29}$$

Similar relations are found for the \bar{x} and \bar{y} components.

It should be noted that the relations in this subsection have been written in the transformed (\bar{x}, \bar{y}, N) system. When the procedure is linked with the dynamic structural response calculations, it is necessary to transform impact-affected nodal and fragment velocities to the (\bar{x}, \bar{y}, N) system before calculation of \tilde{p}_x, \tilde{p}_y , and \tilde{p}_N . After calculation of the post-impact nodal and fragment velocities, these quantities will be transformed back to the (x, y, z) coordinate system.

B.2.3 Collision Inspection/Interaction Analysis for Cases of Single and Double Symmetry

For the general case of impact on a plate, the inspection and interaction analyses discussed in Subsections B.2.1 and B.2.2 must be applied. In some

of these problems, the computation times and computer core storage requirements can become excessive. However, in a number of practical problems, the geometry of the plate, locations of plate/fragment impact, and subsequent interaction may be such that the response of the plate (and fragment) will be symmetric with respect to one or two planes. In these cases, it is necessary to model only one-half (in the case of a single symmetry) or one-quarter (in the case of a double symmetry) of the plate; as a result, considerable savings in computation time and computer core storage can be realized.

In these cases, the collision inspection is simplified and the collision interaction analysis must be modified to reflect the single- and double-symmetry conditions; that is, the resulting plate nodal and fragment centroidal post-impact velocities obtained from the symmetric analysis must be identical to those which would be obtained from the corresponding analysis of the whole plate. Details of these modifications for both single and double symmetry are given next.

B.2.3.1 Inspection/Interaction Analysis for Single Symmetry

Without loss of generality, the following two cases of single symmetry can be identified: (1) the case where the x-axis (xz plane) is the line of symmetry, and (2) where the y axis (yz plane) is the line of symmetry. The case where the x axis is the line of symmetry will be considered first.

In order that the x axis be a line of symmetry, the fragment coordinates and velocity must satisfy

$$\left. \begin{aligned} \gamma_f &= 0 \\ v_{fy} &= 0 \\ \omega_{fy} &= 0 \end{aligned} \right\} \text{ at } t = 0 \quad (\text{B.30})$$

In addition, the results obtained from the collision interaction analysis must satisfy Eqs. B.30 for all time. The collision inspection procedure used in the general case is also used here. When plate/fragment impact is detected, a specialized collision interaction analysis is followed.

In the case of single symmetry (about the xz plane) each impact may be considered as a single impact occurring along the line of symmetry at location

$(x_c, 0)$ with two points of contact located symmetrically with respect to the line of symmetry (i.e. at (x_c, y_c) and $(x_c, -y_c)$) as shown in Fig. B.5a. Once the point of effective impact is identified, a coordinate transformation is defined such that the \bar{x} axis is along the line between the nodes on the line of symmetry which bound the point of effective impact; the N coordinate is then defined as normal to the line connecting these nodes (see Fig. B.5b). The impact interaction analysis is then performed in the (\bar{x}, y, N) system.

In order to perform the impact interaction analysis in the half-plate (HP) model, the general interaction equations for the whole-plate (WP) presented in Subsection B.2.2 are first reduced to the case of symmetry about the \bar{x} axis. Denoting by a superscript "B" those plate nodes falling on the boundary (line of symmetry) and by "I" those nodes falling in the interior of the plate, and noting that \tilde{p}_y must be zero by symmetry, the impulse-momentum equations may be written

$$\left. \begin{aligned}
 m_f \left[\begin{array}{l} v'_{f\bar{x}} \\ v'_{fN} \end{array} - \begin{array}{l} v_{f\bar{x}} \\ v_{fN} \end{array} \right] &= - \begin{array}{l} \tilde{p}_{\bar{x}} \\ \tilde{p}_N \end{array} \\
 I_f \left[\omega'_{fy} - \omega_{fy} \right] &= - r_f \tilde{p}_{\bar{x}} \\
 m_i^B \left[\begin{array}{l} v_{i\bar{x}}^B \\ v_{iN}^B \end{array} - \begin{array}{l} v_{i\bar{x}} \\ v_{iN} \end{array} \right] &= \alpha_i^B \begin{array}{l} \tilde{p}_{\bar{x}} \\ \tilde{p}_N \end{array} \\
 m_i^I \left[\begin{array}{l} v_{i\bar{x}}^I \\ v_{iN}^I \end{array} - \begin{array}{l} v_{i\bar{x}} \\ v_{iN} \end{array} \right] &= \alpha_i^I \begin{array}{l} \tilde{p}_{\bar{x}} \\ \tilde{p}_N \end{array}
 \end{aligned} \right\} \begin{array}{l} \text{fragment} \\ \\ \text{ith plate boundary node} \\ \text{ith plate interior node} \end{array} \quad (B.31)$$

The impact interaction constants (A_0, S_1, S_2, \dots) will be given by

$$\begin{aligned}
 S_1 &= S_0 \cos \bar{\theta}_0 = \left[v_{f\bar{x}} + r_f \omega_{fy} \right] - \left[\sum \alpha_i^B v_{i\bar{x}}^B + \sum \alpha_i^I v_{i\bar{x}}^I \right] \\
 S_2 &= S_0 \sin \bar{\theta}_0 = \left[v_{fy} - r_f \omega_{f\bar{x}} \right] - \left[\sum \alpha_i^B v_{iy}^B + \sum \alpha_i^I v_{iy}^I \right] = 0 \\
 A_0 &= v_{fN} - \left[\sum \alpha_i^B v_{iN}^B + \sum \alpha_i^I v_{iN}^I \right] \\
 B_1 = B_2 &= \frac{1}{m_f} + \frac{r_f^2}{I_f} + \sum \frac{\alpha_i^{B2}}{m_i^B} + \sum \frac{\alpha_i^{I2}}{m_i^I} \\
 B_3 &= \frac{1}{m_f} + \sum \frac{\alpha_i^{B2}}{m_i^B} + \sum \frac{\alpha_i^{I2}}{m_i^I}
 \end{aligned} \quad (B.32)$$

The impulse coordinates \tilde{p}_x^- and \tilde{p}_N can be obtained from Cases I through III in Subsection B.2.2 by substituting $S_2=0$ and by noting that $\tilde{p}_y=0$ for all cases. By examining the resulting equations, it is seen that the solutions for \tilde{p}_x^- and \tilde{p}_N are functions of the ratios A_0/B_3 and S_1/B_1 .

It is required to perform an analysis of the half-plate model and obtain the same post-impact velocities for the fragment and impact-affected plate nodes as in the whole-plate analysis. An examination of the expressions for S_1 and A_0 (Eqs. B.32) show that

$$\begin{aligned} (S_1)_{HP} &= (S_1)_{WP} \\ (A_0)_{HP} &= (A_0)_{WP} \end{aligned} \tag{B.33}$$

provided that the α_i^I terms are multiplied by 2.0 to account for the missing lower-half interior nodes in the summation.

Consider now the parameters B_1 and B_3 in Eqs. B.32 term by term. In the half-plate analysis, the mass, m_1^B , assigned to each boundary node is half that of the corresponding node in the whole-plate analysis, so that

$$\left(\sum \frac{\alpha_i^{B^2}}{m_i^B} \right)_{HP} = 2 \left(\sum \frac{\alpha_i^{B^2}}{m_i^B} \right)_{WP} \tag{B.34}$$

The summations over the interior nodes for the half-plate will be half that of the whole plate analysis (interior node masses will be the same for half and whole plate analysis) since only the upper half plate nodes are included.

But the sum will increase by a factor of 4 as a result of the redefining of $\alpha_1^I = 2\alpha_1^I$ so that

$$\left(\sum \frac{\alpha_i^{I^2}}{m_i^I} \right)_{HP} = 2 \left(\sum \frac{\alpha_i^{I^2}}{m_i^I} \right)_{WP} \tag{B.34b}$$

If the actual fragment mass, m_f , and mass moment of inertia, I_f , are reduced by a factor of 2 for half-plate analyses, then

$$\left(\frac{l}{m_f}\right)_{HP} = 2 \left(\frac{l}{m_f}\right)_{WP} \quad (\text{B.34c})$$

$$\left(\frac{r_f^2}{I_f}\right)_{HP} = 2 \left(\frac{r_f^2}{I_f}\right)_{WP} \quad (\text{B.34d})$$

As a result of Eqs. B.34, the parameters $(B_1)_{HP}$ and $(B_3)_{HP}$ for the half-plate are related to the equivalent whole-plate values by

$$\begin{aligned} (B_1)_{HP} &= 2 (B_1)_{WP} \\ (B_3)_{HP} &= 2 (B_3)_{WP} \end{aligned} \quad (\text{B.35})$$

so that a combination of Eqs. B.33 and B.35 yields

$$\begin{aligned} \left(\frac{A_o}{B_3}\right)_{HP} &= \frac{1}{2} \left(\frac{A_o}{B_3}\right)_{WP} \\ \left(\frac{S_i}{B_1}\right)_{HP} &= \frac{1}{2} \left(\frac{S_i}{B_1}\right)_{WP} \end{aligned} \quad (\text{B.36})$$

The total imparted impulses \tilde{p}_x and \tilde{p}_N are functions of the ratios given in Eqs. B.36. Therefore, for all interaction cases where the x-axis is a line of symmetry

$$\begin{aligned} \left(\tilde{p}_x\right)_{HP} &= \frac{1}{2} \left(\tilde{p}_x\right)_{WP} \\ \left(\tilde{p}_N\right)_{HP} &= \frac{1}{2} \left(\tilde{p}_N\right)_{WP} \end{aligned} \quad (\text{B.37})$$

The post-impact plate node and fragment velocities for the case of symmetry would be calculated from Eqs. B.31 for the whole-plate analysis. However, it can be easily verified that in the half-plate analysis by redefining (scaling) α_1^I , m_f , and I_f as discussed, and as a result of the boundary plate node masses being $(m_1^B)_{HP} = \frac{1}{2}(m_1^B)_{WP}$ and the result given by Eq. B.37, all scaling factors cancel in Eqs. B.31. As a result, the post-impact plate node and fragment velocities calculated by the half-plate analysis will be the same as those obtained in the whole-plate analysis.

The relations established and programming logic used for general (whole-plate) impact interaction calculations can be used for the present single symmetry case in which the x-axis is the line of symmetry, provided the following modifications are made:

- (1) Scale the fragment mass, $m_f = \frac{1}{2}m_f$, and fragment mass moment of inertia, $I_f = \frac{1}{2}I_f$, prior to the first time step.
- (2) Calculate all α_i as if performing a whole plate analysis (Eqs. B.17a and B.18).
- (3) Scale α_i^I corresponding to interior nodes by $\alpha_i^I = 2\alpha_i^I$.
- (4) Set $S_2 = 0$.
- (5) Solve impact-interaction problem in transformed (\bar{x} -N) system, using the same logic as in the whole plate analysis. Note that the nodal velocities in the y-direction must remain unchanged and the fragment velocities must satisfy Eqs. B.30.

A second case of single symmetry is one in which the y-axis (yz plane) is the line of symmetry. In this case, the fragment coordinates and velocity must satisfy

$$\begin{aligned} x_f &= 0 \\ v_{fx} &= 0 \\ \omega_{fx} &= 0 \end{aligned} \tag{B.38}$$

at all instants of time. Each impact may be considered as a single impact occurring along the line of symmetry at location $(0, y_c)$ with two points of simultaneous contact located symmetrically with respect to the line of symmetry (i.e. at (x_c, y_c) and $(-x_c, y_c)$) as shown in Fig. B.6a, and directed normal to line of symmetry. Once the point of effective impact is identified, a coordinate transformation is defined such that the \bar{y} axis is along the line between the nodes on the line of symmetry which bounds the point of effective impact; the N direction is defined as normal to the line connecting these nodes (see Fig. B.6b). The impact interaction calculations are performed in the (x, \bar{y}, N) system.

The development of an impact interaction analysis for this case of single symmetry follows steps similar to those for the previous single symmetry case (x-axis being the line of symmetry). However, in the present case where the y-axis is the line of symmetry, the impulse \tilde{p}_x must be zero by symmetry; also, the parameter S_1 (Eq. B.22) will be zero, while S_2 will be nonzero. The impulse coordinates \tilde{p}_y and \tilde{p}_N will be obtained from Cases I through III in Subsection B.2.2 by substituting $S_1=0$ and $\tilde{p}_x=0$.

It can be shown that the relations established and the program logic used for the general impact interaction calculations can be used to obtain the post-impact fragment and plate-node velocities for the present single-symmetry case (where the y-axis is the line of symmetry) provided the following modifications are made:

- (1) Scale the fragment mass, $m_f = \frac{1}{2}m_f$, and fragment mass moment of inertia, $I_f = \frac{1}{2}I_f$, prior to the first time step.
- (2) Calculate all α_1 as if performing a whole-plate analysis (Eqs. B.17a and B.18).
- (3) Scale α_1^I corresponding to interior nodes by $\alpha_i^I = 2\alpha_i^I$.
- (4) Set $S_1=0$.
- (5) Solve the impact-interaction problem in the transformed (x, \bar{y}, N) system, using the same logic as for general impact cases. Note that nodal velocities in the x direction must remain unchanged and the fragment velocities must satisfy Eqs. B.38.

B.2.3.2 Inspection/Interaction Analysis for Double Symmetry*

In cases where both the x and y axes are lines of symmetry and where the initial and all subsequent impacts occur at the center of the plate, double symmetry exists and the analysis may be reduced to a quarter of the plate structure; in the present case it is assumed that the first quadrant (see Fig. B.7) is analyzed and that the origin of the x,y system is at the center of the original whole plate.

In the case of double-symmetry, the following assumptions/simplifications can be made:

* This implies either frictionless impact-interaction or a non-spinning spherical fragment.

- (1) Impact is treated as a single impact occurring at point (0,0) with 4 points of simultaneous contact, i.e. at (x_c, y_c) , $(-x_c, y_c)$, $(-x_c, -y_c)$, and $(x_c, -y_c)$ as shown in Fig. B.7.
- (2) The net effective normal direction for the single impact is the global z-axis.
- (3) No net impulse should be found in the global x or y directions at any plate nodes. This is based on the assumption that the impact-affected regions for each of the 4 simultaneous contact points overlap completely; in this case, the inplane x and y direction impulses must cancel exactly at all impact-affected plate nodes.
- (4) As a consequence of (3), the impulse coordinates \tilde{p}_x and \tilde{p}_y will be zero; as a result, no post-impact velocity changes in the x and y direction will occur.
- (5) The fragment coordinates and velocity must satisfy

$$\begin{array}{lll}
 x_f = 0 & v_{fx} = 0 & \omega_{fx} = 0 \\
 y_f = 0 & v_{fy} = 0 & \omega_{fy} = 0
 \end{array} \tag{B.39}$$

at all time instants.

The impact-interaction calculations are performed in the global (x,y,z) coordinate system (i.e. no transformation of coordinates is required). Since \tilde{p}_x and \tilde{p}_y are zero, only \tilde{p}_z need be considered; again, it assumed that the impulse at node 1 is given by

$$p_{i,z} = \alpha_i \tilde{p}_z \tag{B.40}$$

where the α_i are calculated as for the whole-plate analysis. Using superscripts B and I to refer to symmetry boundary and interior nodes, respectively, and noting that the center node is node number 1, the impulse-momentum relations for the double symmetry case are given as

$$\begin{aligned}
\text{Fragment} & : m_f [v_{fz}' - v_{fz}] = - \tilde{p}_z \\
\text{Center Node} & : m_1 [v_{1z}' - v_{1z}] = \alpha_1 \tilde{p}_z \\
\text{Boundary Nodes} & : m_i^B [v_{iz}^B' - v_{iz}^B] = \alpha_i^B \tilde{p}_z \\
\text{Interior Nodes} & : m_i^I [v_{iz}^I' - v_{iz}^I] = \alpha_i^I \tilde{p}_z
\end{aligned} \tag{B.41}$$

The only remaining nonzero interaction parameters are A_o and B_3 (see Eqs. B.22) and are given by

$$\begin{aligned}
A_o &= v_{fz} - \left[\alpha_1 v_{1z} + \sum \alpha_i^B v_{iz}^B + \sum \alpha_i^I v_{iz}^I \right] \\
B_3 &= \frac{1}{m_f} + \frac{\alpha_1^2}{m_1} + \sum \frac{\alpha_i^{B^2}}{m_i^B} + \sum \frac{\alpha_i^{I^2}}{m_i^I}
\end{aligned} \tag{B.42}$$

The impulse \tilde{p}_z is obtained from Cases I through III of Subsection B.2.2 with $S_1=S_2=0$, and reduces to the same expression for all cases:

$$\tilde{p}_z = (1+e) \frac{A_o}{B_3} \tag{B.43}$$

It should be noted that the value of \tilde{p}_z is independent of the coefficient of friction, μ , since no relative sliding takes place.

It is required to perform the interaction on the quarter plate model (QP) and obtain the same post-impact velocities as would be obtained in the whole-plate (WP) analysis. The effects of the quarter-plate model on A_o and B_3 must be investigated. The whole plate model would include each $\alpha_{1z}^{B^B}$ term twice and each $\alpha_{1z}^{I^I}$ term four times in A_o ; thus, if the sums in A_o apply only to the quarter-model, the α_i^B and α_i^I terms must be scaled by

$$\begin{aligned}
(\alpha_i^B) &= 2 (\alpha_i^B) \\
(\alpha_i^I) &= 4 (\alpha_i^I)
\end{aligned} \tag{B.44}$$

so that

$$(A_o)_{QP} = (A_o)_{WP} \tag{B.45}$$

Consider each term in B_3 :

$$\Sigma \frac{\alpha_i^{I2}}{m_i^I} : \quad \text{In the quarter model, the sum will be 1/4 that of the whole plate. The scaling of } \alpha_i^I = 4\alpha_i^I \text{ will increase the sum by a factor of 16, so that}$$

$$\left(\Sigma \frac{\alpha_i^{I2}}{m_i^I} \right)_{QP} = 4 \left(\Sigma \frac{\alpha_i^{I2}}{m_i^I} \right)_{WP} \quad (\text{B.46a})$$

$$\Sigma \frac{\alpha_i^{B2}}{m_i^B} : \quad \text{For the quarter model, the sum will be 1/2 that of the whole plate. Because of the scaling } \alpha_i^B = 2\alpha_i^B \text{ the sum will increase by a factor of 4. Finally, the nodal masses, } m_i^B, \text{ generated internally for boundary nodes will be 1/2 of the value for a whole plate analysis. Thus,}$$

$$\left(\Sigma \frac{\alpha_i^{B2}}{m_i^B} \right)_{QP} = 4 \left(\Sigma \frac{\alpha_i^{B2}}{m_i^B} \right)_{WP} \quad (\text{B.46b})$$

$$\frac{\alpha_1^2}{m_1} : \quad \text{In the quarter model, the internally-generated mass at node 1 is 1/4 that of the whole plate analysis, so that}$$

$$\left(\frac{\alpha_1^2}{m_1} \right)_{QP} = \left(\frac{\alpha_1^2}{m_1} \right)_{WP} \quad (\text{B.46c})$$

$$\frac{1}{m_f} : \quad \text{To achieve consistency with Eqs. B.46a - B.46c, the fragment mass used in the quarter-plate analysis is redefined to be one-quarter the actual fragment mass, so that}$$

$$\left(\frac{1}{m_f} \right)_{QP} = 4 \left(\frac{1}{m_f} \right)_{WP} \quad (\text{B.46d})$$

As a result of Eqs. B.46 through B.46d, $(B_3)_{QP}$ for the quarter-plate will be

$$(B_3)_{QP} = 4 (B_3)_{WP} \quad (\text{B.47})$$

and by substituting Eqs. B.45 and B.47 into Eq. B.43

$$\left(\tilde{\dot{p}}_z \right)_{QP} = \frac{1}{4} \left(\tilde{\dot{p}}_z \right)_{WP} \quad (\text{B.48})$$

Compare the impulse-momentum equations used to obtain post-impact velocities for the whole-plate analysis and for the quarter-plate analysis:

Whole-Plate Analysis

Quarter-Plate Analysis

$$\begin{array}{ll} m_f [v_{fz}' - v_{fz}] = -\tilde{\dot{p}}_z & \left(\frac{1}{4} m_f\right) [v_{fz}' - v_{fz}] = -\left(\frac{1}{4} \tilde{\dot{p}}_z\right) \\ m_i [v_{iz}' - v_{iz}] = \alpha_i \tilde{\dot{p}}_z & \left(\frac{1}{4} m_i\right) [v_{iz}' - v_{iz}] = \alpha_i \left(\frac{1}{4} \tilde{\dot{p}}_z\right) \\ m_i^B [v_{iz}^B' - v_{iz}^B] = \alpha_i^B \tilde{\dot{p}}_z & \left(\frac{1}{2} m_i^B\right) [v_{iz}^B' - v_{iz}^B] = (2\alpha_i^B) \left(\frac{1}{4} \tilde{\dot{p}}_z\right) \\ m_i^I [v_{iz}^I' - v_{iz}^I] = \alpha_i^I \tilde{\dot{p}}_z & m_i^I [v_{iz}^I' - v_{iz}^I] = (4\alpha_i^I) \left(\frac{1}{4} \tilde{\dot{p}}_z\right) \end{array}$$

The scaling factors in the quarter-plate analysis cancel, so the same post-impact fragment and plate nodal velocities would be found using either analysis.

Thus, the relations established and program logic used for the general impact interaction calculations can be used in the case of a quarter-plate analysis provided the following modifications are made:

- (1) Scale the fragment mass by $m_f = \frac{1}{4} m_f$.
- (2) Calculate all α_i as if performing a whole plate analysis (Eqs. B.16 and B.18).
- (3) Scale α_i^B corresponding to nodes on each symmetry boundary by $\alpha_i^B = 2\alpha_i^B$, and α_i^I corresponding to interior nodes by $\alpha_i^I = 4\alpha_i^I$.
- (4) Set $S_1 = S_2 = 0$.
- (5) Solve the impact-interaction problem in the global (x,y,z) system (no coordinate transformation), using the same logic as for the general interaction cases. Note that nodal velocities in the x and y directions will remain unchanged and that the fragment velocities will satisfy Eqs. B.39.

B.3 Timewise Solution of the Governing Equations of Motion for the Fragment and the Plate

B.3.1 Motion of the Fragment

The motion of the rigid spherical fragment is given in terms of the motion of its centroid. Neglecting the effects of gravity, the governing equations of motion for the fragment are given by

$$\begin{aligned} \ddot{x}_f &= 0 & \ddot{\theta}_x &= 0 \\ \ddot{y}_f &= 0 & \ddot{\theta}_y &= 0 \\ \ddot{z}_f &= 0 & \ddot{\theta}_z &= 0 \end{aligned} \tag{B.49}$$

Equations B.49 represent constant-velocity motion. Thus the Cartesian coordinates of the fragment at time t_{m+1} can be obtained from the Cartesian coordinates and translational velocities of the fragment at time t_m as

$$\begin{Bmatrix} x_f \\ y_f \\ z_f \end{Bmatrix}_{m+1} = \begin{Bmatrix} x_f \\ y_f \\ z_f \end{Bmatrix}_m + \Delta t \begin{Bmatrix} v_{fx} \\ v_{fy} \\ v_{fz} \end{Bmatrix} \tag{B.50a}$$

The angular position of the fragment at time t_{m+1} is given by

$$\begin{Bmatrix} \theta_x \\ \theta_y \\ \theta_z \end{Bmatrix}_{m+1} = \begin{Bmatrix} \theta_x \\ \theta_y \\ \theta_z \end{Bmatrix}_m + \Delta t \begin{Bmatrix} \omega_{fx} \\ \omega_{fy} \\ \omega_{fz} \end{Bmatrix} \tag{B.50b}$$

where $\Delta t = t_{m+1} - t_m$ is the time increment.

The fragment velocities used in Eqs. B.50a and B.50b are the current velocities at time t_m . If no impact occurs during the time t_m to t_{m+1} , these will be the same velocity values as for the previous time step. However, if impact is detected during the time t_m to t_{m+1} , the fragment velocities used in Eqs. B.50a and B.50b will be the updated post-impact fragment velocities obtained from the collision interaction analysis described in Subsection B.2.2.

B.3.2 Motion of the Plate

The governing discretized equations of motion for the plate structure have been derived in Appendix A. For impact response problems, no prescribed, externally-applied loads are present. Thus, the equations of motion of the plate for plate/fragment impact response predictions are obtained from Eq. A.109 by setting $F=0$ and are

$$\underline{M} \ddot{\underline{q}}^* + \underline{K} \underline{q}^* = \underline{F}^{NL} \quad (\text{B.51})$$

where \underline{M} , \underline{K} , $\dot{\underline{q}}^*$, \underline{q}^* , and \underline{F}^{NL} are as defined following Eq. A.109.

The solution of Eq. B.51 is accomplished by applying a direct timewise integration scheme, which results in a recurrence relation from which displacements can be calculated at each discrete time instant. The (implicit) Houbolt operator is used (as in the PLATE program). Following the steps outlined by Eqs. A.110 through A.114, the following recurrence relation (corresponding to Eq. B.51) is obtained:

$$\left[\frac{2}{(\Delta t)^2} \underline{M} + \underline{K} \right] \underline{q}_{m+1}^* = \underline{F}_{m+1}^{NL} + \frac{2}{\Delta t} \underline{M} \left[\dot{\underline{q}}_m^* + \frac{1}{\Delta t} \underline{q}_m^* \right] \quad (\text{B.52})$$

Equation B.52 is solved for the unknown displacements \underline{q}_{m+1}^* at time t_{m+1} based on the known quantities \underline{F}_{m+1}^{NL} , $\dot{\underline{q}}_m^*$, and \underline{q}_m^* . It should again be noted that $\underline{F}_{m+1}^{NL} = \underline{F}_{m+1}^{NL}(\underline{q}_{m+1}^*)$; however, linear extrapolation of this quantity is used as given in Eq. A.115 with no iteration.

The form of Eq. B.52 is particularly suited to the present impact analysis. During a time step in which plate/fragment collision occurs, the nodal velocity vector $\dot{\underline{q}}_m^*$ is updated to post-impact nodal velocities according to the collision interaction analysis described in Subsection B.2.2.

The overall solution procedure for a time step is as follows. Given \underline{q}_m^* , $\dot{\underline{q}}_m^*$, and \underline{F}_{m+1}^{NL} (evaluated by linear extrapolation, and based on \underline{q}_m^*), a trial displacement vector, \underline{q}_{m+1}^{T*} , is evaluated from Eq. B.52. Based on these trial nodal displacements (and similar trial displacements of the fragment), the collision inspection is performed. If no plate/fragment overlap is found, the trial displacements \underline{q}_{m+1}^{T*} are the correct nodal displacements. If plate/fragment overlap is detected, the collision interaction analysis is performed and the nodal velocities $\dot{\underline{q}}_m^*$ are updated to their post-impact value (as are the

fragment velocities). A new trial displacement vector, \tilde{q}_{m+1}^T , is calculated from Eq. B.52 and a collision inspection is performed. This process is repeated until no plate/fragment overlap is detected; then the trial displacements, \tilde{q}_{m+1}^* , are said to be the actual displacements.

It should be recalled at this point that the corrections resulting from a plate/fragment impact are applied at the beginning of the time step during which the impact occurs; no attempt is made to identify the precise instant of impact. The advantage of this scheme is the resulting relative simplicity of the inspection/interaction procedure; few, if any, "special cases" need be considered. Impulse-momentum and conservation of kinetic energy are utilized to calculate the instantaneous post-impact nodal (and fragment) velocities which are applied at the beginning of a time step. It can be remarked that this interaction analysis neglects all other system forces/energies in the calculation of velocity. However, since all pertinent system energies are included in Eqs. B.51 and B.52, the subsequent motion of the plate as a result of impact does include all of the system forces/energies.

Once the displacements, \tilde{q}_{m+1}^* , have been calculated, the nodal velocities, $\dot{\tilde{q}}_{m+1}^*$ (needed to calculate \tilde{q}_{m+2}^*), can be evaluated. If no impacts occurred during the time t_m to t_{m+1} , then Eq. A.11 (repeated here for convenience),

$$\dot{\tilde{q}}_{m+1}^* = \frac{1}{2\Delta t} \left(3 \tilde{q}_{m+1}^* - 4 \tilde{q}_m^* + \tilde{q}_{m-1}^* \right) \quad (\text{B.53})$$

can be used; recall that this difference formula has the same truncation error as the Houbolt expression for $\ddot{\tilde{q}}_{m+1}^*$. If impact has occurred during this time step, a modified expression must be used:

$$\dot{\tilde{q}}_{m+1}^* = \frac{2}{\Delta t} \left(\tilde{q}_{m+1}^* - \tilde{q}_m^* \right) - \dot{\tilde{q}}_m^* \quad (\text{B.54})$$

where $\dot{\tilde{q}}_m^*$ is the vector of post-impact (corrected) nodal velocities. The derivation and possible implications of the use of Eq. B.54 are now discussed.

The modified velocity expression given by Eq. B.54 can be derived in a manner analogous to the starting sequence required in the PLATE program (Eqs. A.116 - A.118). If \tilde{q}_{m+1}^* is calculated from the central difference expression for $\dot{\tilde{q}}_m^*$:

$$\dot{\tilde{q}}_m = \frac{1}{2 \Delta t} \left(\tilde{q}_{m+1}^* - \tilde{q}_{m-1}^* \right) \quad (\text{B.55})$$

and substituted into the Houbolt velocity expression (Eq. B.53) the modified velocity expression of Eq. B.54 is obtained. It should be noted that the velocity $\dot{\tilde{q}}_m^*$ in Eq. B.54 is the vector of post-impact (corrected) nodal velocities.

The unconditional stability of the Houbolt operator, represented by Eqs. A.112 and B.53, is well established for linear systems. For nonlinear systems, this operator is conditionally stable.[†] For cycles in which no plate/fragment impacts occur, the Houbolt operator is used; whereas, for cycles in which impact occurs, the modified Houbolt operator, represented by Eqs. A.112 and B.54, is used. Numerical experience with the CIVM-PLATE program shows the following trends: (1) early in the timewise response, the impacts are widely spaced in time and the Houbolt operator is, in effect, used for nearly all cycles, (2) however, as the fragment velocity decreases and nears zero (prior to rebound), impacts may be found during nearly every cycle, so that the modified Houbolt operator dominates. In view of the fact that a large segment of timewise response could be governed by the modified Houbolt operator, it is desirable to obtain some idea of the stability characteristics of this operator.

The discussion of stability of the modified Houbolt operator is simplified if the operator can be shown to be analogous to some other operator. Consider the difference expressions corresponding to the Generalized Acceleration Method [8,19] as written here, for simplicity, for a one degree-of-freedom system:

$$x_{m+1} = x_m + (\Delta t) \dot{x}_m + (\Delta t)^2 \left[\left(\frac{1}{2} - \beta \right) \ddot{x}_m + \beta \ddot{x}_{m+1} \right] \quad (\text{B.56a})$$

$$\dot{x}_{m+1} = \dot{x}_m + (\Delta t) \left[(1 - \gamma) \ddot{x}_m + \gamma \ddot{x}_{m+1} \right] \quad (\text{B.56b})$$

where β and γ are parameters to be specified. A variety of difference expressions (both explicit and implicit) can be obtained by the choice of β and γ . For the present case, substitution of $\beta=1/2$ into Eq. B.56a yields, after rearranging,

[†]This is the case if iteration is not used within a given time step Δt : iteration is not used here.

$$\ddot{x}_{m+1} = \frac{2(x_{m+1} - x_m)}{(\Delta t)^2} - \frac{2}{\Delta t} \dot{x}_m \quad (\text{B.57})$$

which is identical to Eq. A.112 of the Houbolt operator. Substituting Eq. B.57 into Eq. B.56a, with $\gamma=1$, yields after rearranging:

$$\dot{x}_{m+1} = \frac{2(x_{m+1} - x_m)}{\Delta t} - \dot{x}_m \quad (\text{B.58})$$

which is identical to the velocity expression (Eq. B.54) of the modified Houbolt operator. Thus, the modified Houbolt operator used for cycles in which impact occurs corresponds to a Generalized Acceleration Method with $\beta=1/2$ and $\gamma=1$. For linear systems, this algorithm can be shown to be unconditionally stable [19]; however, no data are available for nonlinear systems.

To obtain a comparison of the Houbolt and modified Houbolt operators for nonlinear systems, consider the one degree-of-freedom nonlinear spring/mass system with a cubic hardening spring governed by the equation

$$\ddot{x} + \omega^2 (1 + A x^2) x = 0 \quad (\text{B.59a})$$

subject to the initial conditions

$$x(0) = 0 \quad (\text{B.59b})$$

$$\dot{x}(0) = B$$

The predicted response for the displacement x versus time t for the case $\omega^2=100$, $A=10$, and $B=60$ is shown in Figs. B.8a and B.8b, for the Houbolt and modified Houbolt operators, respectively. Time step sizes of $\Delta t=0.001$, 0.01 , and 0.02 are used in each case. For comparison, the time step bound of the central-difference operator for the linear equivalent of the above system is $\Delta t_{\max}^{\text{CD}} = 2/\omega_{\max} = 0.2$.

The following observations are made on the basis of comparison of results presented in Figs. B.8a and B.8b. For the case $\Delta t=0.02$, the results

by the Houbolt operator begin to diverge, whereas the results by the modified Houbolt operator become unstable very early in the timewise response. For the case $\Delta t=0.001$, the results by the modified Houbolt operator show more artificial damping and phase shift than the results by the Houbolt operator. For the case $\Delta t=0.01$, the results obtained by the Houbolt operator are in essential agreement with the results for $\Delta t=0.001$. The results obtained by the modified Houbolt operator illustrate substantial artificial damping and phase shift compared with the results for $\Delta t=0.001$.

The result of primary interest is stability. It appears that the modified Houbolt operator may require a somewhat smaller time step size than the Houbolt operator to ensure stability. Moreover, the question of stability is complicated by the fact that the velocity \dot{q}_{m}^* in Eq. B.54 represents the post-impact velocity; thus, when impacts occur each cycle (as is characteristic of the time range near fragment rebound), a velocity increment is imposed at each time cycle. Such imposed velocity increments if sufficiently large compared with the actual (pre-impact) nodal velocities, could cause an instability. Such an instability has been observed in a test case of the CIVM-PLATE program; unrealistic and severely oscillatory strain values in the vicinity of the impact location near the time of fragment rebound have been observed. By reducing the time step size, this behavior was eliminated. In general, the guidelines suggested in Subsection 2.5 should be followed; if the above-mentioned instability is found, the time step size used should be reduced.

B.4 Collision Inspection and Solution Procedure

The collision inspection and solution procedure used in the CIVM-PLATE program will now be discussed. The discussion pertains to all impact cases including the special symmetry cases. If special operations are required for symmetry cases, they are noted in each step. Therefore, unless otherwise noted, the step is assumed to apply to all cases. For the sake of convenience, the following notation (consistent with the variables input in CIVM-PLATE) is used to denote the various symmetry cases:

- (1) NSYM=0 refers to general impact cases.
- (2) NSYM=1 and IPSS=1 refers to the single symmetry case where the x axis is the line of symmetry.
- (3) NSYM=1 and IPSS=4 refers to the single symmetry case where the y axis is the line of symmetry.
- (4) NSYM=2 refers to the double-symmetry case.

The following procedure indicated in the flow diagram of Fig. 7 may be employed to predict the motions of the plate and the rigid spherical 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 \tilde{q}_m^* , and the displacement increments $\Delta\tilde{q}_m^*$ are known. One can then calculate the strain increments $\Delta\tilde{\epsilon}_m$ at all Gaussian stations over the span and through the thickness of the plate.
- Step 2: Using a suitable constitutive relation for the plate material, the stress increments $\Delta\tilde{\sigma}_m$ and the plastic strain increments $\Delta\tilde{\epsilon}_m^P$ at corresponding Gaussian stations within each finite element can be determined from the known strain increments $\Delta\tilde{\epsilon}_m$. This information together with the appropriate linear extrapolation permits determining the equivalent force vector F_{m+1}^{NL} in Eq. B.52.
- Step 3: Solve Eq. B.52 for the trial nodal displacements, \tilde{q}_{m+1}^T , and calculate the trial fragment positions $(\tilde{x}_f^T, \tilde{y}_f^T, \tilde{z}_f^T)_{m+1}$ from Eq. B.50a. Trial displacement increments $\Delta\tilde{q}_{m+1}^T (= \tilde{q}_{m+1}^T - \tilde{q}_m^*)$ are then calculated for the plate nodes, and for the fragment (e.g. $\Delta\tilde{x}_f^T = \tilde{x}_f^T - x_{f_m}$). Since impact 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 calculate the corrected post-impact plate-node and fragment velocities at time t_m .

Step 4: The current position of the plate nodes and fragment centroid are calculated based on the positions at t_m and the trial displacement increments. The distance (squared) from the fragment centroid to each plate node is then calculated. The minimum of these distances and the corresponding node number are identified. The four elements which share the identified node will be examined for possible plate-fragment collision. For NSYM=1 only those nodes along the line of symmetry are checked and the two elements sharing the identified node are subject to collision inspection. For NSYM=2, this check is not made; instead, element number 1 is identified as the only element subject to collision inspection.

Step 4a: Following the procedure outlined in Subsection B.2.1, each of the elements subject to collision inspection is subdivided into two triangular subregions. Based on the current trial nodal and fragment positions, the penetration distance d_o (Eq. B.10) is calculated for each triangular region. If $d_o > 0$, it is determined whether or not the location of maximum overlap (x_n, y_n, z_n) from Eq. B.12 falls within the triangular inspection region. If not, d_o is assigned a negative value to indicate no plate/fragment overlap within the triangular inspection region.

Step 4b: A search is performed to identify the maximum of all d_o values calculated. If all values of d_o are less than or equal to zero, no collision has occurred and Step 7 is followed. For NSYM = 1 and NSYM = 2, if any of the d_o values are positive, the element number and triangular subregion number corresponding to the maximum value of d_o are identified. However, for NSYM = 0, an average of all detected points of overlap is used as the location of effective impact. The following sequence of steps is then followed to define the impact interaction parameters.

Step 5: The plate/fragment impact is assumed to occur at the global coordinates (x_n, y_n, z_n) where the maximum d_o value for NSYM = 1 or NSYM = 2 is calculated, or at the effective point of impact for NSYM = 0. However, if symmetry options are in effect, these values are modified according to the discussion in Subsection B.2.3, as follows.

- (1) If NSYM=1 and IPSS=1, set $y_n=0$.
- (2) If NSYM=1 and IPSS=4, set $x_n=0$.
- (3) If NSYM=2, set $x_n=0$ and $y_n=0$.

Step 5a: Calculate the distance from (x_n, y_n, z_n) to each plate node. If this distance is less than or equal to L_{eff} (Eq. B.15 or otherwise specified), the node is identified as falling within the impact-affected zone on the plate. The proportionality factor α'_1 (Eq. B.16) for each impact-affected node is calculated by

$$\alpha'_i = 1 - \frac{|s_i|}{L_{eff}} \quad (B.60)$$

where $|s_i|$ is the distance from the i th impact-affected node to (x_n, y_n, z_n) . If a symmetry option is in effect; some of the α'_i must be multiplied by a factor f (see Subsection B.2.3). Thus, each of the impact-affected nodes is inspected and the following values of f apply:

For cases where NSYM=0, no scaling is necessary ($f=1$).

For cases where NSYM=1: $f=2$ for all impact-affected nodes in the interior of the plate, and $f=1$ (no scaling) for impact-affected nodes on the symmetry boundary.

For cases where NSYM=2: $f=1$ (no scaling) for node number 1 (where lines of symmetry intersect), $f=2$ for all impact-affected nodes (except node 1) falling on a line of symmetry, and $f=4$ for all impact-affected nodes in the interior of the plate.

After all α'_i have been calculated (and scaled if necessary), the normalization factor, C , is calculated from Eq. B.18, and the impulse impulse proportionality factor α_1 (see Eqs. B.19) for each impact-affected node is calculated from

$$\alpha_i = C \alpha'_i \quad (B.61)$$

Step 5b: For NSYM=1 and NSYM=2, the coordinate transformation matrix \tilde{T} (Eq. B.7) is then defined corresponding to the triangular inspection region in which the maximum plate/fragment overlap was detected. For the cases NSYM=1, \tilde{T} is shown in Fig. B.5b (for IPSS=1) or Fig. B.6b (for IPSS=4). For the case NSYM=2, no transformation is required (or, for consistency one may define \tilde{T} to be the identity matrix, I). For the case NSYM=0, \tilde{T} is defined by Eq. B.15j if more than one impact point is detected; however, if only one location of impact occurs, \tilde{T} is evaluated from Eq. B.8.

Step 5c: The translational velocity components $(v_{x_i}, v_{y_i}, v_{z_i})$ at each impact-affected node are extracted from the nodal velocity vector \dot{q}_m^* (at time t_m) and the components $(\bar{v}_{x_i}, \bar{v}_{y_i}, \bar{v}_{z_i})$ of velocity in the transformed coordinate system (normal and tangent to the plane of impact) at each impact-affected node are calculated from Eq. B.7a, using \tilde{T} established in step 5b. The fragment translational velocity components $(v_{fx}, v_{fy}, v_{fz})_m$ and rotational velocity components $(\omega_{fx}, \omega_{fy}, \omega_{fz})_m$ at time t_m are transformed using Eq. B.7a yielding components $(\bar{v}_{fx}, \bar{v}_{fy}, \bar{v}_{fz})$ and $(\bar{\omega}_{fx}, \bar{\omega}_{fy}, \bar{\omega}_{fz})$.

Step 5d: The impact interaction constants $S_1, S_2, A_0, B_1,$ and B_3 are now calculated. For the cases NSYM=0 and NSYM=1, Eqs. B.22 are used to calculate these constants. However, when NSYM=1 and IPSS=1, S_2 must be set to zero; when NSYM=1 and IPSS=4, S_1 must be set to zero. For the case of NSYM=2, only A_0 and B_3 are nonzero and are calculated from Eqs. B.42.

Step 5e: The value of A_0 is checked. If $A_0 \leq 0$, the plate and fragment are moving apart and no collision occurs; in this situation, Step 7 is followed next. If $A_0 > 0$, the next steps are followed to calculate the post-impact nodal and fragment velocities.

Step 6: The total impulse imparted to the impact-affected nodes and to the fragment are calculated, and post-impact velocities are calculated according to the following steps.

Step 6a: The components \tilde{p}_x^- , \tilde{p}_y^- , \tilde{p}_z^- of the total imparted impulse are calculated corresponding to Case I, II, or III as presented in Subsection B.2.2. Note that if NSYM=0, the only nonzero impulse component is $\tilde{p}_z^- = \tilde{p}_z$ as given by Eq. B.43.

Step 6b: The collision-induced velocity differences (i.e. $v_{fx}^+ - v_{fx}^-$, $v_{ly}^+ - v_{ly}^-$, etc.) of the impact-affected plate nodes and the fragment are then calculated from Eqs. B.19 and transformed back to the global coordinate system by using Eq. B.7b. This yields velocity increments $(\Delta v_{x1}, \Delta v_{y1}, \Delta v_{z1})$ at each impact-affected plate node, and $(\Delta v_{fx}, \Delta v_{fy}, \Delta v_{fz})$ and $(\Delta \omega_{fx}, \Delta \omega_{fy}, \Delta \omega_{fz})$ for the fragment.

Step 6c: The velocity components of the impact-affected plate nodes and fragment are then updated to their post-impact values by

$$\begin{Bmatrix} v_{x_i} \\ v_{y_i} \\ v_{z_i} \end{Bmatrix}_m = \begin{Bmatrix} v_{x_i} \\ v_{y_i} \\ v_{z_i} \end{Bmatrix}_m + \begin{Bmatrix} \Delta v_{x_i} \\ \Delta v_{y_i} \\ \Delta v_{z_i} \end{Bmatrix} \quad (\text{B.62a})$$

$$\begin{Bmatrix} v_{fx} \\ v_{fy} \\ v_{fz} \end{Bmatrix}_m = \begin{Bmatrix} v_{fx} \\ v_{fy} \\ v_{fz} \end{Bmatrix}_m + \begin{Bmatrix} \Delta v_{fx} \\ \Delta v_{fy} \\ \Delta v_{fz} \end{Bmatrix} \quad (\text{B.62b})$$

$$\begin{Bmatrix} \omega_{fx} \\ \omega_{fy} \\ \omega_{fz} \end{Bmatrix}_m = \begin{Bmatrix} \omega_{fx} \\ \omega_{fy} \\ \omega_{fz} \end{Bmatrix}_m + \begin{Bmatrix} \Delta \omega_{fx} \\ \Delta \omega_{fy} \\ \Delta \omega_{fz} \end{Bmatrix} \quad (\text{B.62c})$$

The nodal velocity vector, \dot{q}_m^* , is then updated; the components of translational velocity in \dot{q}_m^* corresponding to impact-affected nodes are replaced by the post-impact translational velocity components at those impact-affected nodes as calculated in Eq. B.62a. It

should be emphasized that the nodal velocities, $\dot{\underline{q}}_m^*$, and fragment velocities (given by Eqs. B.62b and B.62c) at time t_m are now the updated post-impact values. It should also be noted that the effects of impact occurring in the range $t_{m-} < t < t_{m+1}$ have been accounted for as updated (modified) nodal and fragment velocities at time t_m (i.e. at the beginning of the time step).

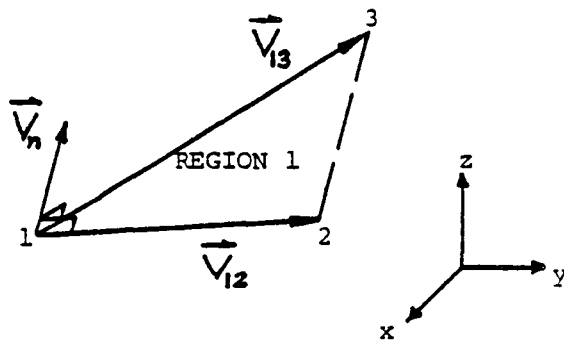
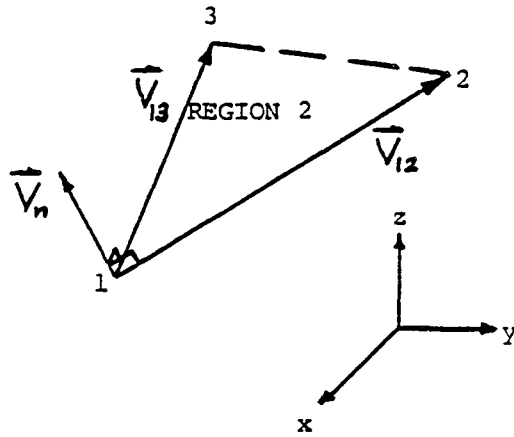
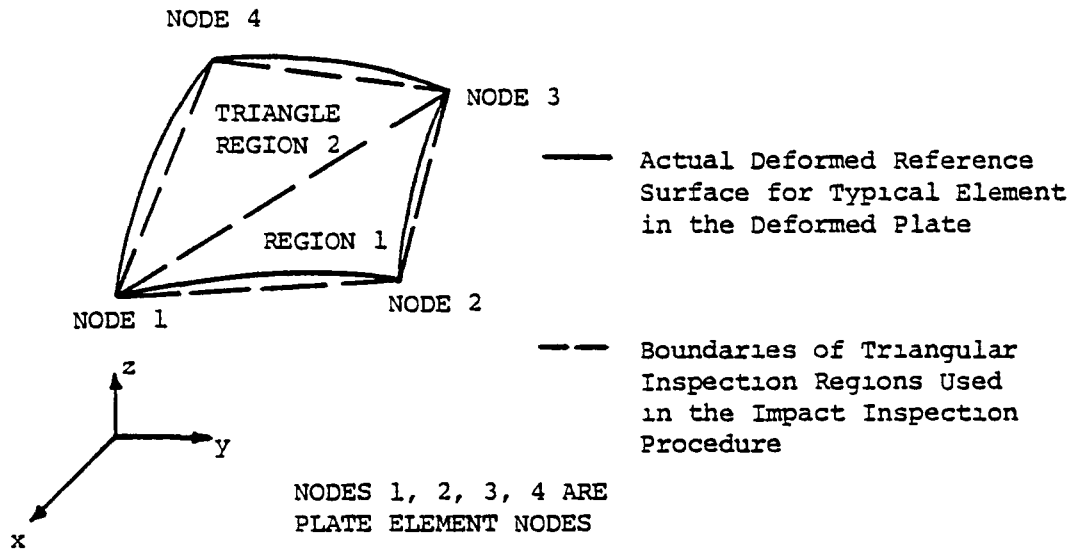
Step 7: The plate node and fragment positions are reduced back to their values at time t_m using $\Delta \underline{q}_{m+1}^T$ for the plate nodes and $(\Delta x_f^T, \Delta y_f^T, \Delta z_f^T)_{m+1}$ for the fragment.

Step 8: If no collision has been detected, Step 9 is followed next. If a plate/fragment collision has occurred, new trial nodal and fragment displacements must be calculated (now including the post-impact nodal and fragment velocities) at time t_{m+1} . Thus, steps 3 through 7 are again followed. This "iteration" process will continue until no plate/fragment overlap is detected or until a value $A_O < 0$ is found.

Step 9: This step is reached when no (further) plate/fragment collisions are detected for the current time cycle. The trial plate node and fragment displacements become the actual (corrected-for-impact) displacements and the fragment and plate node positions at time t_{m+1} are updated based on the actual displacement increments (e.g. $\Delta \underline{q}_{m+1}^* = \underline{q}_{m+1}^* - \underline{q}_m^*$).

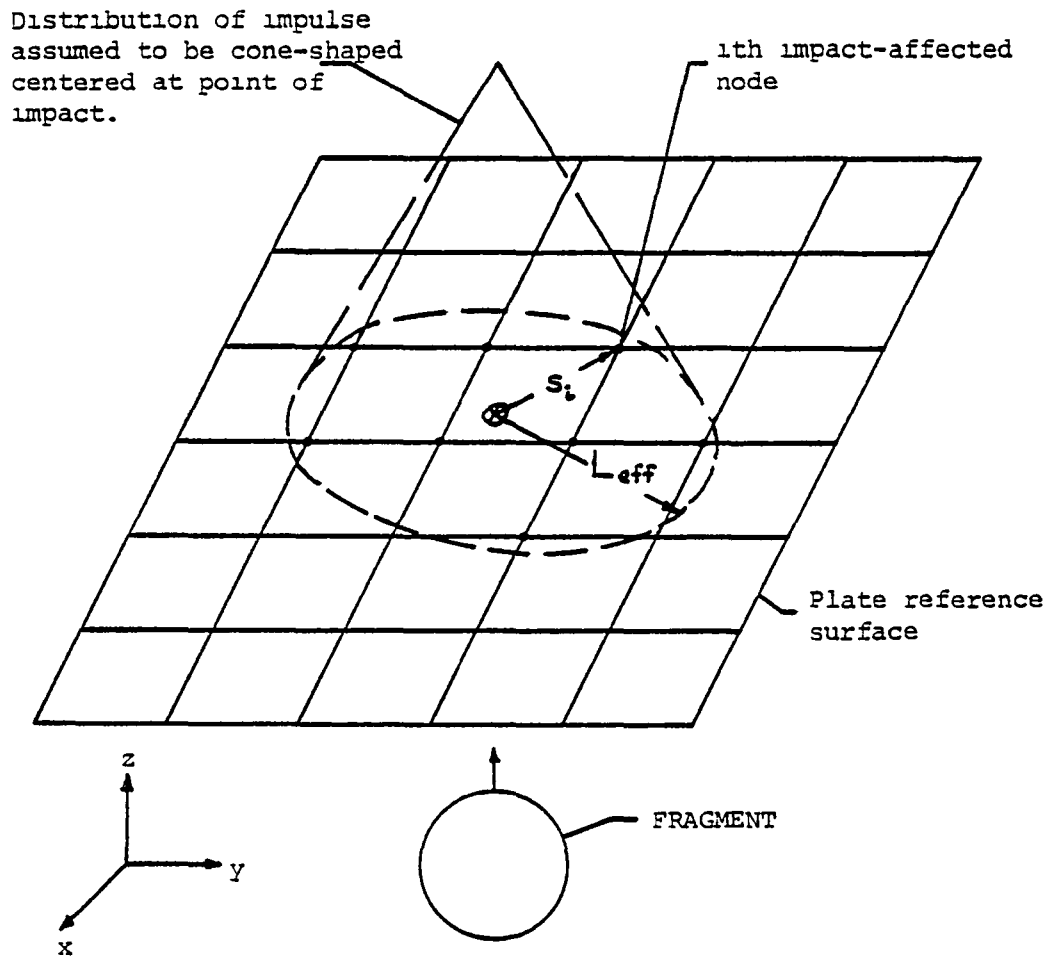
Step 10: The nodal velocity vector $\dot{\underline{q}}_{m+1}^*$ (required for the displacement solution for the next time step) is then calculated. If no impacts have occurred during the time step, Eq. B.53 is used. If one (or more) impact has occurred during the current time step, Eq. B.54 is used. The solution for the current time step is now complete; the solution for the next time step (for t_{m+2}) is obtained by proceeding to step 1 (with the indices appropriately incremented).

Steps 1 through 10 may be carried out for as many time steps as desired or may be terminated by invoking (and implementing in CIVM-PLATE) the use of a termination criterion such as, for example, the reaching of a critical value of strain at some location on the plate.



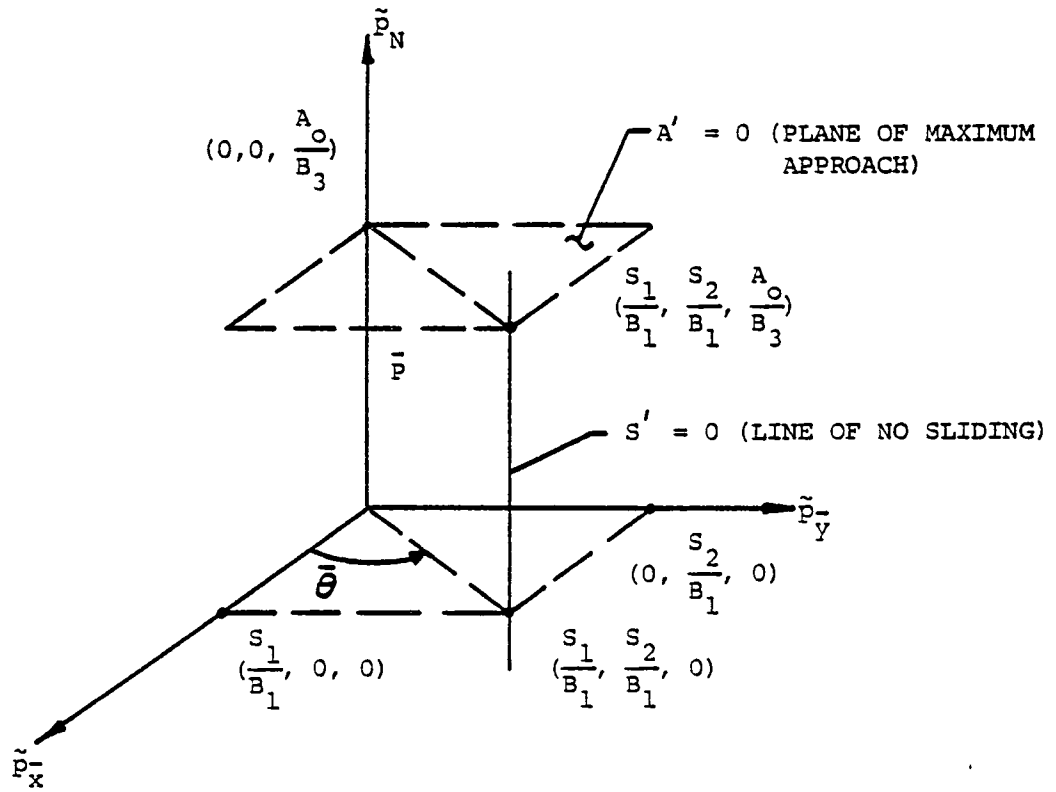
NODES 1, 2, 3 ARE TRIANGULAR INSPECTION REGION NODES

FIG. B.1 CONVENTION ADOPTED FOR TRIANGULAR COLLISION INSPECTION REGIONS



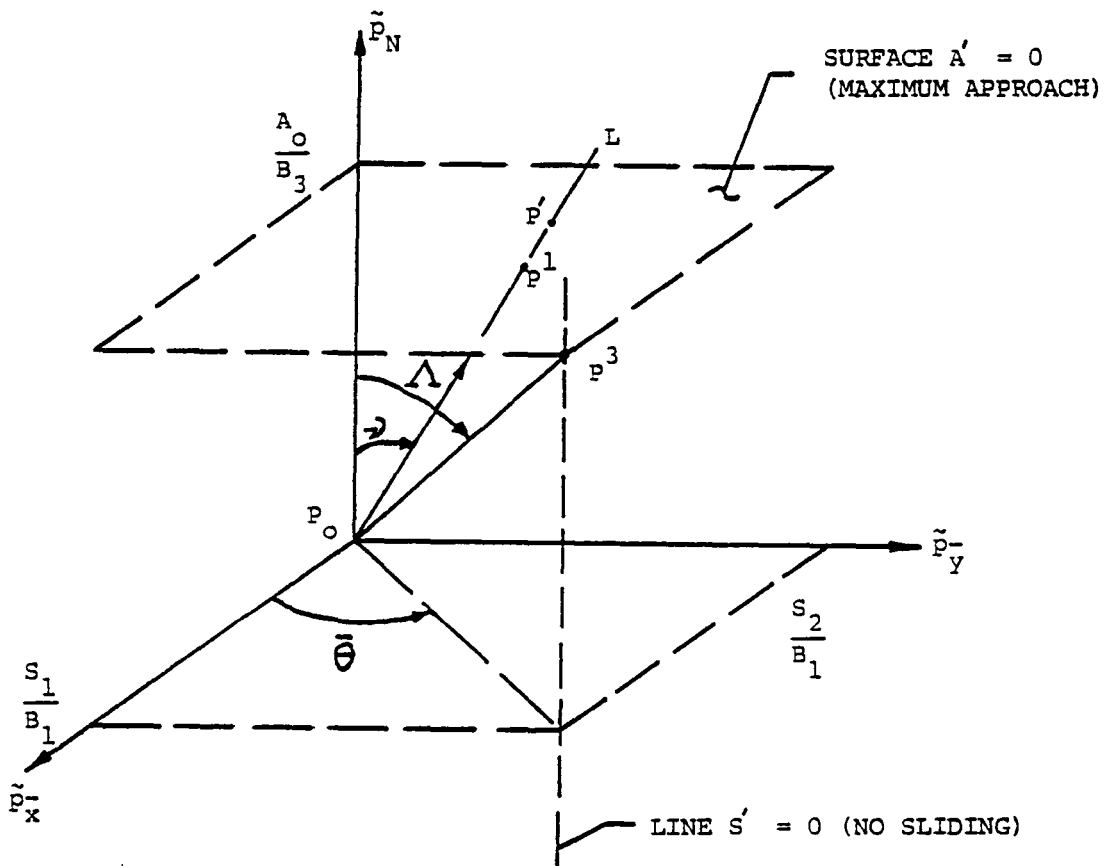
- Impact-affected nodes falling within circle of radius L_{eff} centered at point of impact
- ⊗ Point of impact (maximum plate/fragment overlap).
- s_1 Distance from point of impact to 1th impact-affected node.

FIG. B.2 IDENTIFICATION OF IMPACT-AFFECTED NODES AND ASSUMED IMPULSE DISTRIBUTION



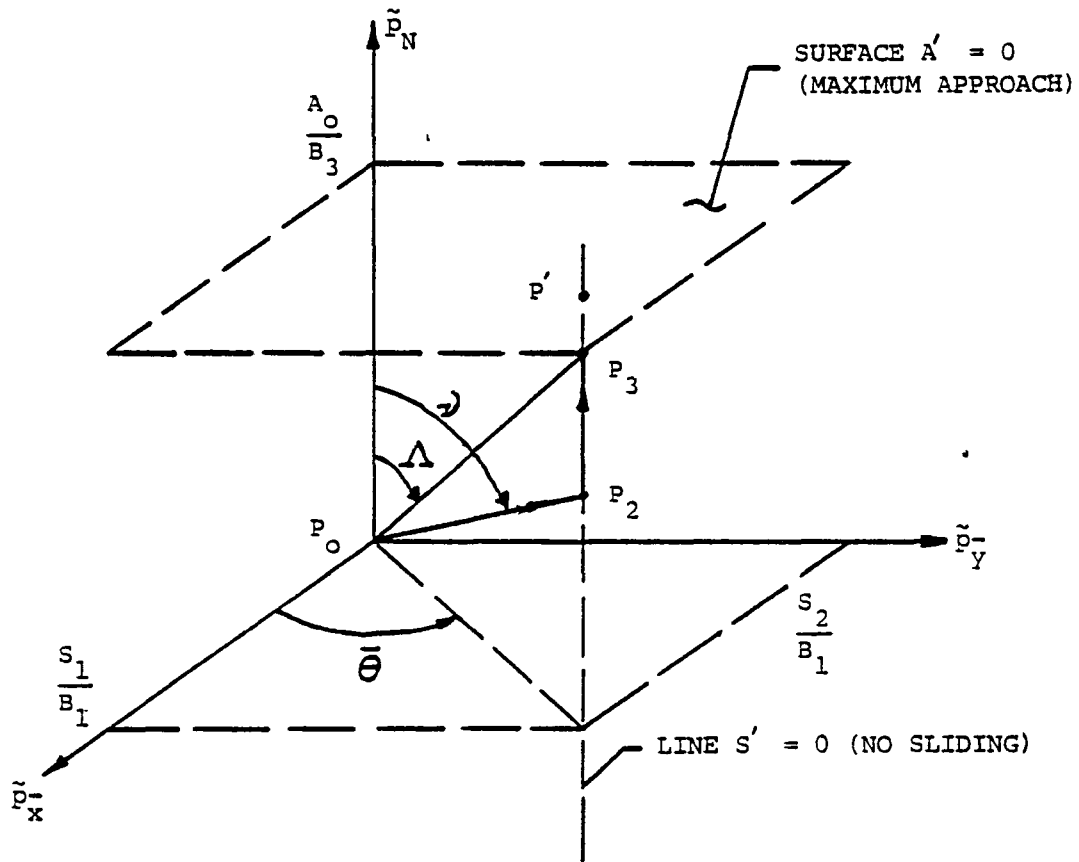
\bar{p} = IMAGE POINT IN $\tilde{p}_x, \tilde{p}_y, \tilde{p}_N$ COORDINATES

FIG. B.3 DESCRIPTION OF IMPULSE COORDINATE SPACE FOR IMPACT INTERACTION ANALYSIS



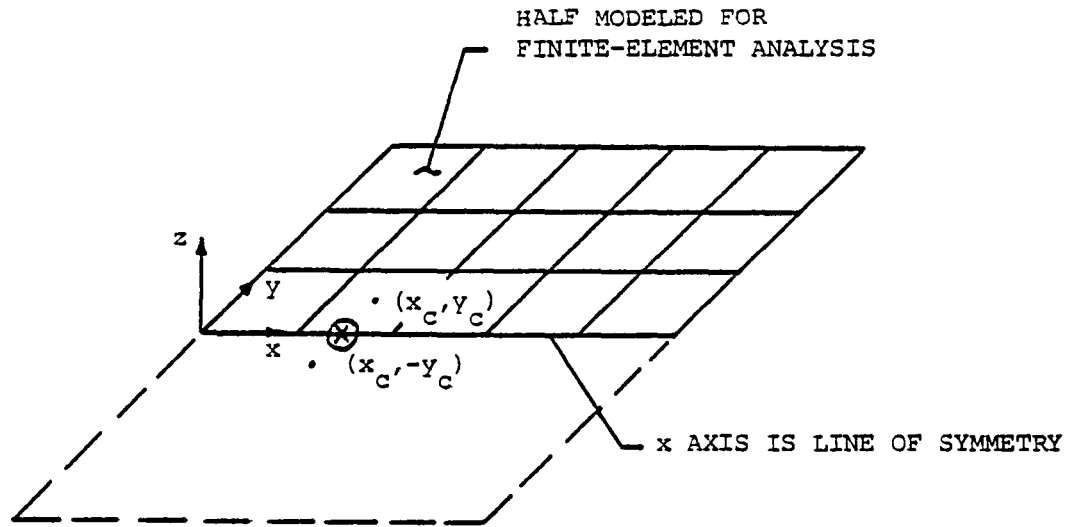
(a) For $v < \Lambda$

FIG. B.4 THE TRAJECTORY OF THE IMPAGE POINT \bar{P} IN THE $\bar{p}_x, \bar{p}_y, \bar{p}_N$ PLANE TO DESCRIBE THE IMPULSE STATE AT EACH CONTACT INSTANT



(b) For $v \geq \Lambda$

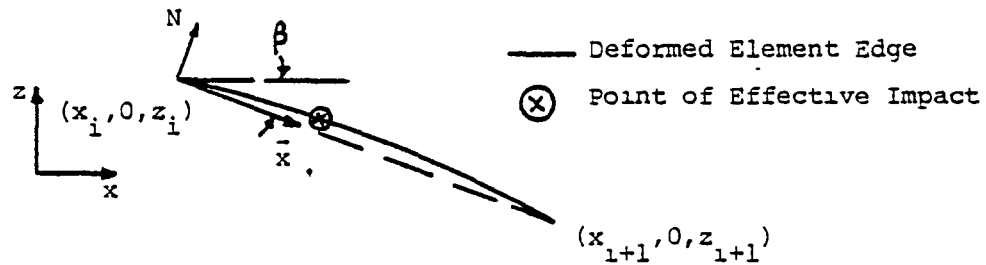
FIG. B.4 CONCLUDED



• POINTS OF SIMULTANEOUS PLATE/FRAGMENT IMPACT

⊗ POINT OF EFFECTIVE IMPACT ON LINE OF SYMMETRY

(a) Finite-Element Model and Location of Effective Point of Impact.



$$\begin{Bmatrix} \bar{x} \\ y \\ N \end{Bmatrix} = [T] \begin{Bmatrix} x \\ y \\ z \end{Bmatrix}$$

$$[T] = \begin{bmatrix} \cos \beta & 0 & \sin \beta \\ 0 & 1 & 0 \\ -\sin \beta & 0 & \cos \beta \end{bmatrix}$$

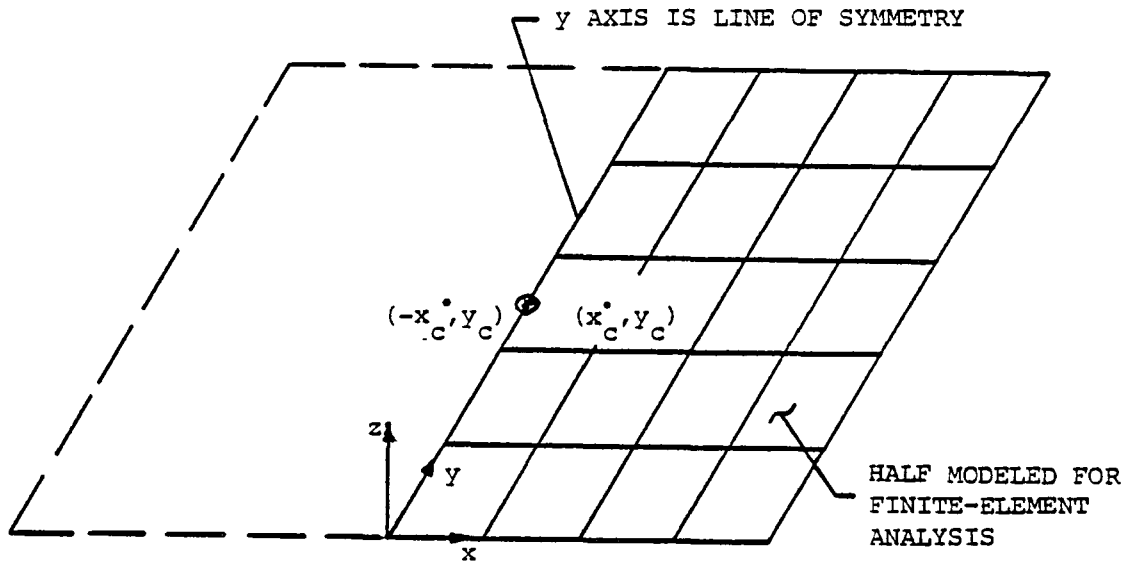
$$\sin \beta = \frac{z_{i+1} - z_i}{l}$$

$$\cos \beta = \frac{x_{i+1} - x_i}{l}$$

$$l = \left[(x_{i+1} - x_i)^2 + (z_{i+1} - z_i)^2 \right]^{\frac{1}{2}}$$

(b) Coordinate Transformation.

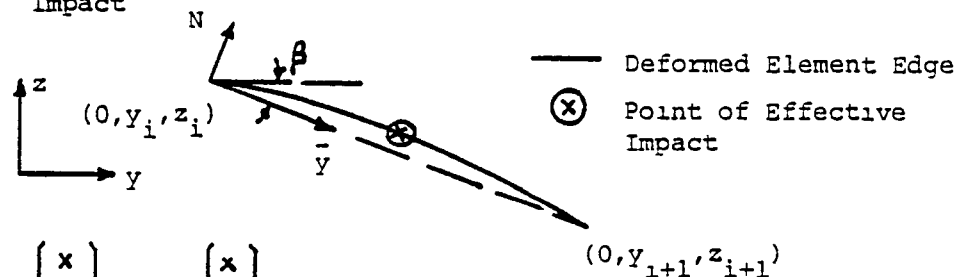
FIG. B.5 CONVENTIONS AND COORDINATE TRANSFORMATION WHEN THE x AXIS IS A LINE OF SYMMETRY



• POINTS OF SIMULTANEOUS PLATE/FRAGMENT IMPACT

⊗ POINT OF EFFECTIVE IMPACT ON LINE OF SYMMETRY

(a) Finite-Element Model and Location of Effective Point of Impact



$$\begin{Bmatrix} x \\ \bar{y} \\ N \end{Bmatrix} = [T] \begin{Bmatrix} x \\ y \\ z \end{Bmatrix}$$

$$[T] = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos \beta & \sin \beta \\ 0 & -\sin \beta & \cos \beta \end{bmatrix}$$

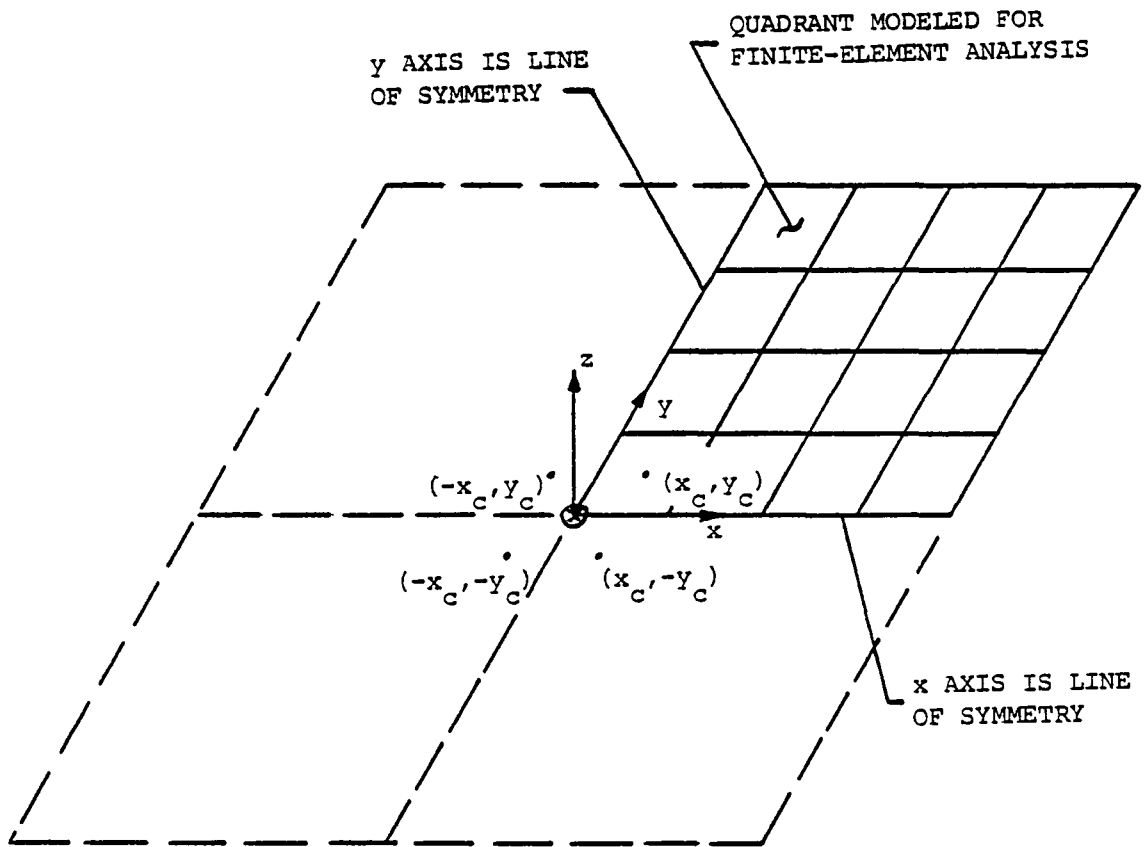
$$\sin \beta = \frac{z_{i+1} - z_i}{l}$$

$$\cos \beta = \frac{y_{i+1} - y_i}{l}$$

$$l = \left[(y_{i+1} - y_i)^2 + (z_{i+1} - z_i)^2 \right]^{1/2}$$

(b) Coordinate Transformation

FIG. B.6 CONVENTIONS AND COORDINATE TRANSFORMATION WHEN THE y AXIS IS A LINE OF SYMMETRY



• POINTS OF SIMULTANEOUS PLATE/FRAGMENT IMPACT

⊗ POINT OF EFFECTIVE IMPACT

FIG. B.7 CONVENTIONS AND MODELING FOR DOUBLE SYMMETRY IMPACT CASES

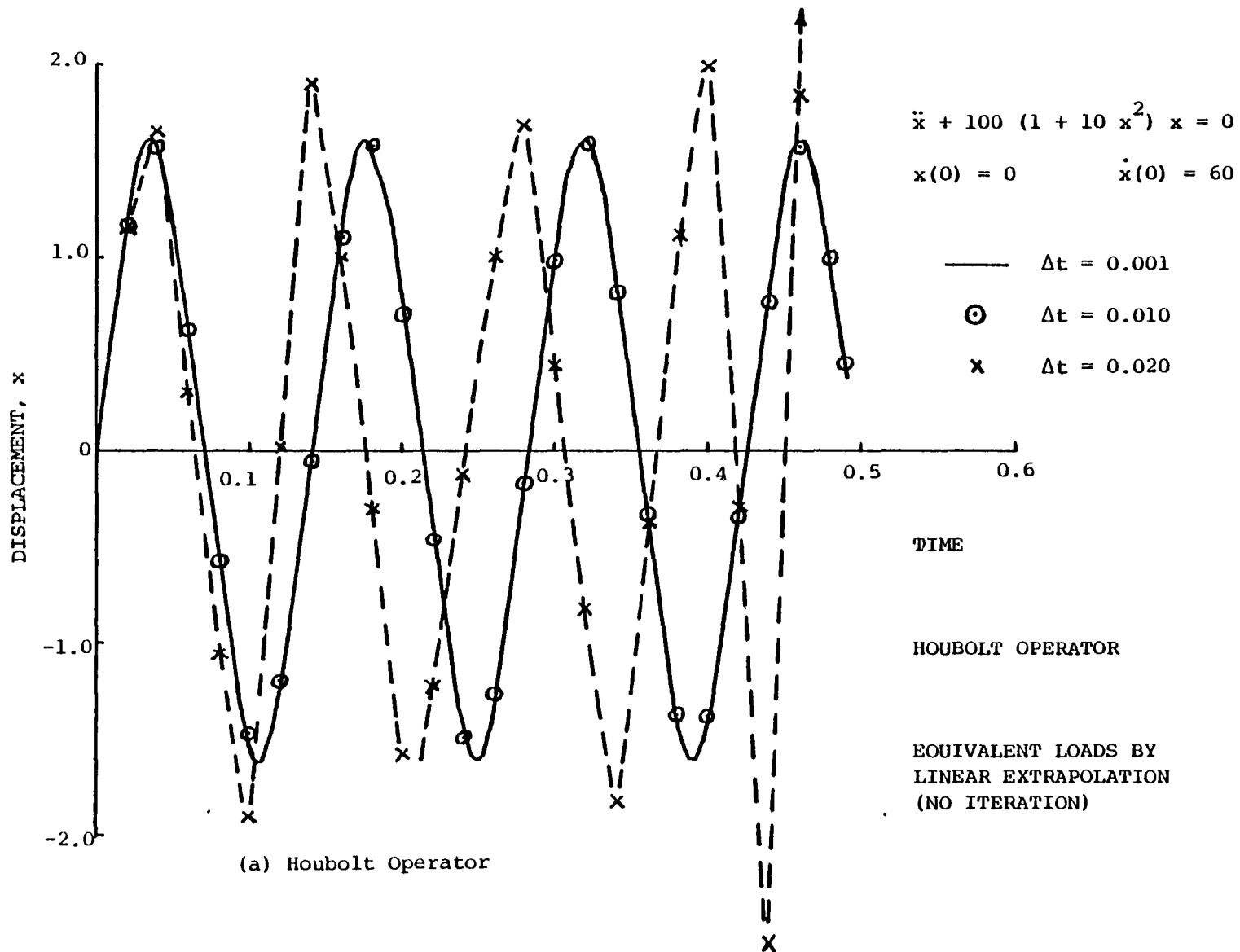


FIG. B.8 PREDICTED RESPONSE OF A ONE DEGREE-OF-FREEDOM NONLINEAR SPRING-MASS SYSTEM SUBJECTED TO AN INITIAL VELOCITY

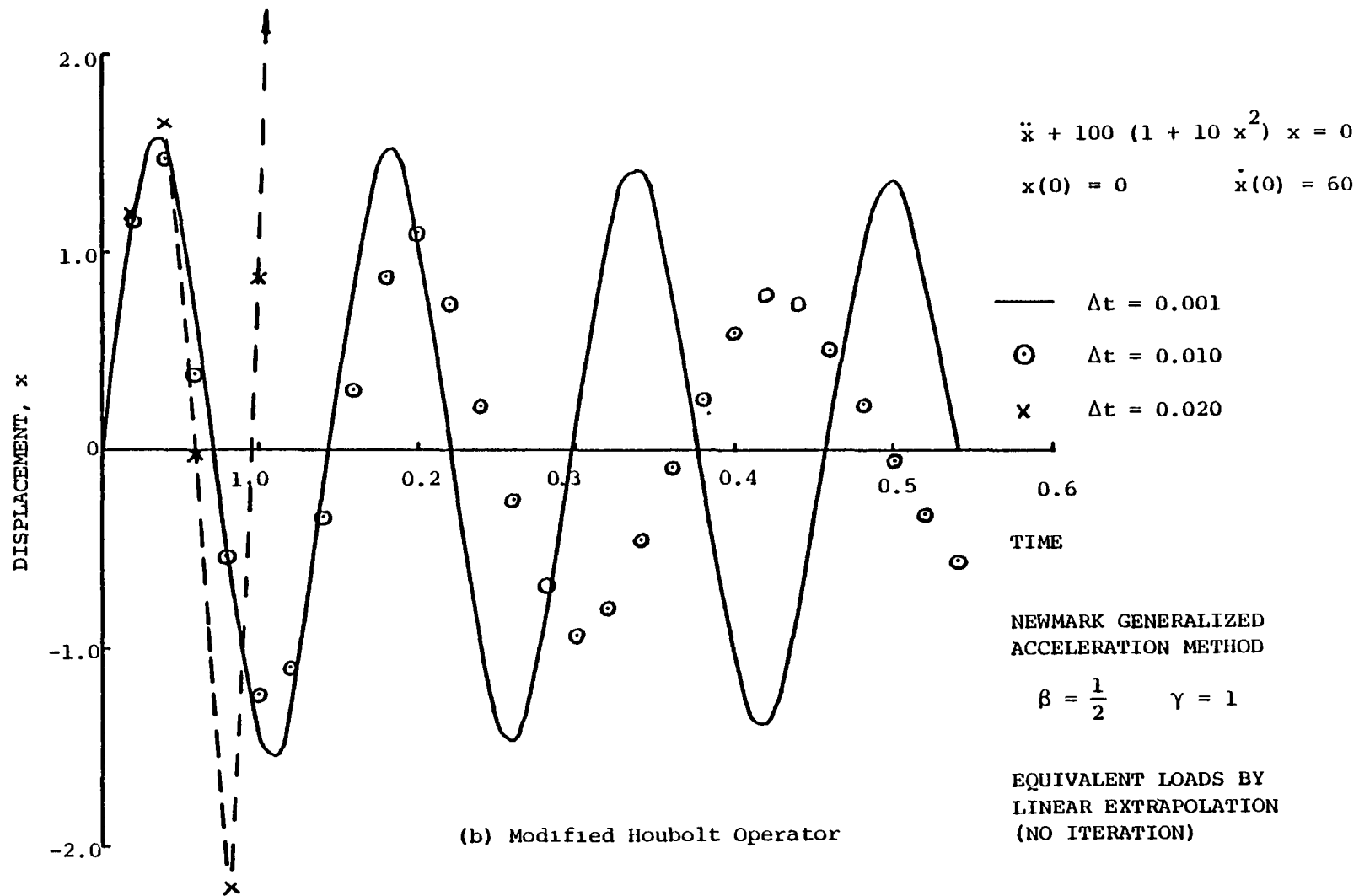


FIG. B.8 CONCLUDED

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