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SSME STRUCTURAL COMPUTER PROGRAM DEVELOPMENT

BOPACE USER MANUAL

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1.0 INTRODUCTION

BOPACE is the acronym for the Boeing Plastic Analysis Capability for Engines. BOPACE was developed by Boeing/Huntsville to meet the evident need for an advanced thermal-elastic-plastic-creep structural analyzer. Although BOPACE development has been strongly influenced by the requirements for structural analysis of engines, in particular the space shuttle main engine, its capabilities have been kept quite general and it is applicable to many types of nonlinear structures.

The philosophy for program development was based on the following requirements.

1) Analysis of very high temperature and large plastic-creep effects.
2) Treatment of cyclic thermal and mechanical loads.
3) Improved material constitutive theory which closely follows actual behavior under variable temperature conditions.
4) A stable numerical solution approach which avoids cumulative errors.
5) Capability for handling up to 1000 degrees of freedom with moderate computation cost.

Although the finite-element method was first applied to plasticity in the early 1960's, and several good programs for nonlinear analysis have since been developed, numerous improvements were indicated in order to satisfy the above requirements. For example, some other available

1.0 (Continued)

programs assume linear plastic hardening, accumulate errors by failing to satisfy equilibrium at each step, or do not completely account for the effects of variable temperature on the elastic and plastic relations. The stated requirements have been effectively met by the current BOPACE program version. In addition, the research and development effort has led to an improved hardening theory for cyclic plasticity, a method for representing general cases of load reversal, and advanced techniques for improving the accuracy and controlling convergence of highly nonlinear solutions.

Two versions of the current BOPACE program are available. The first is a 300-DOF version developed for fast analysis of small size problems within moderate core-storage limitations. The second is the basic 1000-DOF version. In addition, a low-core modification of the 1000-DOF version has been accomplished through the use of overlays and dynamic storage of arrays. BOPACE is written in FORTRAN IV and has been extensively run on both the IBM 360 and UNIVAC 1108 computer systems. Documentation consists of three volumes: Theoretical Manual, User Manual (including example problems), and Programmer Manual.

The BOPACE development and programming effort has been performed at Boeing/Huntsville by Dr. R. G. Vos, with suggestions and review by W. H. Armstrong. A. H. Spring assisted with many analyses and program checkout. J. L. Ballinger of Boeing Computer Services modified and

1.0 (Continued)

programmed the Gauss wavefront solution method. Recognition is also due to N. L. Schlemmer, L. Salter and R. Hurford at the NASA Marshall Space FLight Center, and L. Johnston of Brown Engineering Co., for their suggestions and support of the program development.

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2.0 SUMMARY OF BOPACE INPUT DATA

A pictorial of the BOPACE input deck is shown in Figure 2.0-1. The input data consists of the following three general types:

Type C: Data on the usual card file. These are data which are needed for each start or restart.

Type I: Data on File I. These are basic structural data for a given problem, such as material properties and mesh data. They are the same for all load increments and are needed only when starting.

Type II: Data on File II. These are incremental thermal-load and z-load data which are needed for each start or restart.

The data included on each file are described below. Formats are consistent with FORTRAN IV conventions.

C-1. Start-restart code and data file numbers:

a. "START" if new problem, or "RESTART" if restarting.

b. If starting give unit number for file I.

c. Unit number for file II.

d. Unit number for output file (e.g. printer).

2.0 (Continued)

e. If restarting give load increment number from the end of which a restart is to be made.

f. If restarting give input restart-tape unit number.

g. If data is to be saved for future restart give output restart-tape unit number.

Format (A4,6X,6I5)

C-2. Problem I.D. title.
Format (20A4).

C-3. Program control constants (any constant left blank is assigned a default value):

a. Code for system matrix decomposition and solution. This code controls only the method of iteration and convergence, and does not affect final computed results.

Code 1 = use only elastic matrix with no updating.
2 = update elastic matrix.
3 = update plastic matrix.
4 = update total Jacobian (elastic+plastic) matrix.
5 = update both elastic and total Jacobian matrices.

The default code is 5.

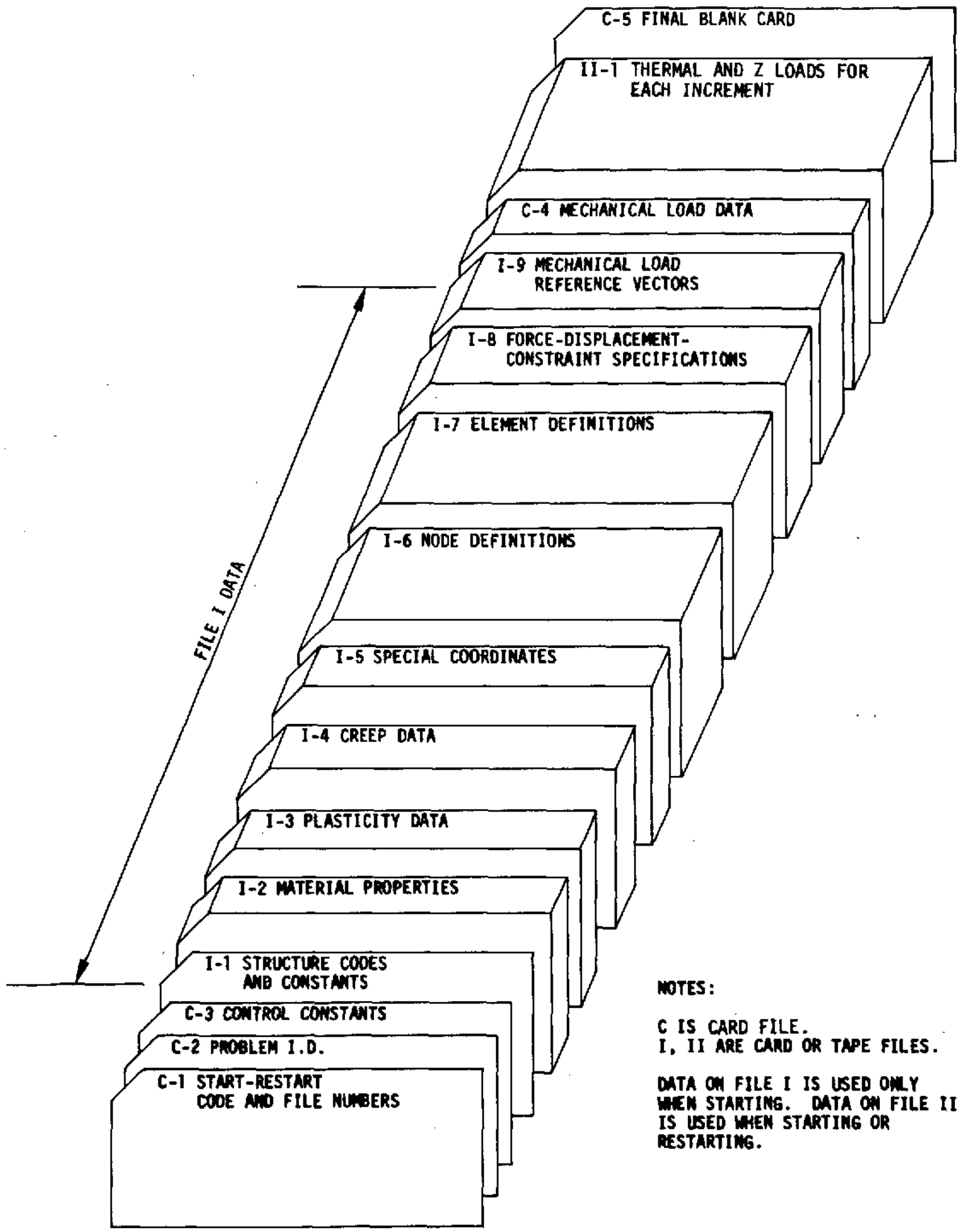

FIGURE 2.0-1: BOPACE INPUT DECK SETUP

2.0 (Continued)

b. Maximum number of stiffness updates per load increment (in order to achieve convergence to within allowable error norm). Default = 1.

c. Maximum number of residual-force iterations per stiffness update. Default = 10.

d. Maximum number of initial iterations using elastic matrix (to account for possible unloading). Default = 2.

e. Maximum allowable magnitude for elastic-plastic sum code YCODE1. Default = 2.

f. Maximum number of cuts to be performed (giving new solution with a fraction of previously used displacement corrections) if error norm is not decreasing. Default = 0.

g. Cutting fraction (displacement correction = previous correction times cutting fraction). Default = 0.5.

h. Maximum allowable error norm. Default = 0.001.

i. Fraction from end of increment to evaluate stress vs. plastic-strain slope in forming plastic stiffness. Default = 0.1.

Format (6I5,3F10.0)

I-1. Plane-stress code (0) or plane-strain code (1), number of materials, default thickness, fabrication temperature.
Format (2I5,2F10.0)

2.0 (Continued)

I-2. Material property data for each consecutive material.

a. Material number

Format (I10)

b. Three consecutive temperature-dependent property curves (thermal strain, elastic modulus, Poisson's ratio). For each curve point give temperature and value, with points in order of increasing temperature. User has option of from 1 to 4 points per card.

Format (8F10.0)

Blank card after last point of each curve.

I-3. Plasticity data for each consecutive material.

a. Material number, plasticity type, kinematic code.

Type 1 = strain hardening

2 = work hardening

Code 0 = kinematic hardening is function of one parameter

1 = kinematic hardening is function of two parameters

Format (3I10)

b. Temperature-parameter-hardening data, in order of low to high temperatures. For each temperature:

2.0 (Continued)

Material number, temperature.

Format (I10,F10.0)

Three consecutive hardening curves (cumulative hardening parameter vs. isotropic hardening, i.e. yield surface size; kinematic parameter vs. kinematic hardening shape; cumulative parameter vs. kinematic hardening factor). Bauschinger hardening is computed as kinematic hardening shape times hardening factor. If kinematic code = 0, curve of kinematic factors is not given and all factors are taken as 1.0. For each point give parameter and hardening value. User has option of from 1 to 4 points per card. First point on each curve must be yield point (parameter = 0.0).

Format (8F10.0)

Insert blank card after each input curve.

Blank card after all temperatures for a given material.

I-4. Creep data for each consecutive material.

a. Material number, creep type.

Type 1 = age hardening

2 = strain hardening

3 = work hardening

Format (2I10)

2.0 (Continued)

b. Reference creep curve. For each point, the time and creep strain, in order of increasing time. User has the option of from 1 to 4 points per card.
Format (8F10.0)

Blank card after last point of curve.

c. Table of creep factors, in order of low to high temperatures. Creep is computed as factor (function of temperature and stress) times reference creep curve.
For each temperature:

Material number, temperature
Format (I10,F10.0)

For each point given at this temperature, the stress and creep factor, in order of increasing stress. User has option of from 1 to 4 points per card.
Format (8F10.0)

Blank card after all points for a given temperature.

Blank card after all temperatures for a given material.

I-5. For each special Cartesian coordinate system: the identification number (integer $\geq$ 2) and counter-clockwise angle (degrees) from basic system X-axis to special system x-axis.
Format (I10,F10.0)

2.0 (Continued)

Blank card after last coordinate system.

I-6. For each node: Node I.D. number, identification number of coordinate system to define location, X and Y (or R and θ), identification number of coordinate system to define displacements. (Coordinate identification number 0 implies the basic Cartesian system, 1 implies the basic cylindrical system). Order of nodes in data deck is internal order used to form system matrix. Format (2I5,2F10.0, I5)

Blank card after last node.

I-7. For each element: element I.D. number, material number, thickness, three node I.D. numbers (counter-clockwise order). If thickness is left blank, default value from I-1 is used. Format (2I5,F10.0,3I5).

Blank card after last element.

I-8. For each degree of freedom with a specified force, displacement or constraint: give node I.D. number, component number (1 or 2), and code. The code to be given is:

1. For specified force, the node I.D. number

2. For specified displacement, the negative of the node I.D. number.

2.0 (Continued)

3. For dependent constrained DOF, the node I.D. number of the independent DOF in constraint.

The default code is specified force. User has option of from one to four DOF per card.
Format (4(3I5,5X))

Blank card after last force-displacement-constraint DOF.

I-9. Mechanical load reference vectors

Number of vectors (for current program version must be 2)
Format (I10)

For each non-zero component of load vector: node I.D. number, component number (1 = X or R, 2 = Y or θ), value. User has option of from 1 to 4 values per card.
Format (4(2I5,F10.0))

Blank card after last value of each vector.

C-4. Incremental mechanical load data.

Number of load increments
Format (I10)

For each load increment: maximum iterations per stiffness update (if left blank, value from C-3 is used), the cumulative factors to be applied to load reference vectors (for current version of

2.0 (Continued)

program two factors must be given), creep time increment (if left blank, no creep calculations are made).
Format (I10,3F10.0)

II-1. Incremental thermal and z-direction load data.

a. Increment I.D. title
Format (20A4)

b. Element thermal loads. For each specified component of load: element I.D. number, temperature at end of increment. Non-specified temperatures are taken to be the fabrication temperature for the first increment; for later increments they are taken to be the temperature of the preceding increment. User has option of from one to four values per card.
Format (4(I10,F10.0))

Blank card after last specified value of thermal load for each load increment.

c. Element z-stress (for a plane-stress problem) or z-strain (for a plane-strain problem). Plane-stress or plane-strain condition is defined by code in data item I-1. For each specified element z-load: element I.D. number, stress or strain at the end of increment. Non-specified z-loads are taken to be zero for the first increment; for later increments they are taken to be the z-load of the preceding increment. User has option

2.0 (Continued)

of from one to four values per card.

Format (4(I10,F10.0))

Blank card after last specified value of z-load for each load increment.

C-5. Blank card after last problem.

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3.0 SUMMARY OF OUTPUT

A discussion of BOPACE output is conveniently divided into two parts. The first covers output which is primarily an echo check of the input data, and the second covers output results for each load increment.

3.1 ECHO CHECK OF INPUT DATA

Initial Output - The first page of BOPACE output for a problem is essentially an echo check of input items C-1, C-2, C-3 and I-1. An indication is given as to whether the problem is being started or restarted. If it is restarted then the previous increment number is given, from the end of which the restart is progressing. Next the problem I.D. title is printed, followed by the various control constants which are determined from their default values or from input values C-3. Finally the input data from I-1 are printed.

Material Properties - For each material the three curves (thermal strain, elastic modulus and Poisson's ratio) input in data item I-2 are printed.

Plasticity Data - For each material the plasticity data input in data item I-3 are printed. These include the plasticity hardening type (1 = strain hardening, 2 = work hardening) and the kinematic hardening code (0, 1 for one, two parameter hardening, respectively). Following are groups of two or three curves given at each temperature (surface size $\bar{\sigma}$ - $\bar{\alpha}$ vs. cumulative hardening parameter κ, kinematic hardening curve shape vs. kinematic shape parameter κ^k, and kinematic curve magnitude vs. κ if given). The

3.1 (Continued)

hardening curves are input and output by order of associated low to high temperature. Abscissas of the curves in the first (lowest temperature) group are used as the basis for tabulating all curves, i.e., curve points of higher temperatures are interpolated to the low-temperature abscissas. These interpolated hardening curves are printed following printing of the input hardening curves.

Creep Data - For each material the creep data input in data item I-4 are printed. These include the creep hardening type (1, 2, 3 for age, strain, work hardening, respectively), and the reference creep curve shape of creep strain vs. time. Following are the creep factors for each combination of temperature and stress, grouped by low to high temperature. Stress values in the first (lowest temperature) group are used as the basis for tabulating all groups, i.e., creep factors at higher temperatures are interpolated to the low-temperature stress values. The interpolated hardening factors are printed following printing of the input hardening factors.

Special Coordinate Systems - These are the user-defined direction (special Cartesian) systems of input data item I-5. Quantities printed are the system I.D. number, and counter-clockwise angle (in degrees) from the basic X axis to the special-system x axis.

Node Definitions - The information given in input item I-6 is printed. Values are the node number, node I.D., location coordinate system number (0 = basic Cartesian, 1 = basic cylindrical), X or R coordinate, Y or θ

3.1 (Continued)

(degrees) coordinate, direction coordinate system number (0 = basic Cartesian, 1 = basic cylindrical, >1 = I.D. of special system).

Element Definitions - The information given in input item I-7 is printed. Values are the element number, element I.D., material number, element thickness, the three element node I.D. numbers in counter-clockwise order, and the computed element area.

Force-Displacement-Constraint Prescriptions - These are the codes given in input data item I-8. Quantities printed are the node I.D., the component number, and code for each degree of freedom with a user-specified force, displacement or constraint.

Mechanical Load Reference Vectors - For each input component of the two load vectors from input item I-9, the node I.D., component number, and load are printed.

Incremental Mechanical Load Data - Quantities related to input data item C-4 are printed. First is printed the number of load increments to be run. Then for each increment is given the increment number, input or default value for maximum number of iterations per increment, factors to be applied to the two load reference vectors, and the creep time increment.

3.2 RESULTS FOR EACH LOAD INCREMENT

Thermal and Z Loads - The cumulative values of thermal load and Z-direction mechanical load for each element, given in input item II-1, are printed. A heading gives the increment number, and is followed by the input I.D. title for the increment. Then the element I.D., cumulative temperature and cumulative Z load are printed, by groups of ten elements.

Iterative Error Values - An error norm computed at the end of each iteration is printed. The error norm is obtained by a ratio of unbalanced (residual) forces to "total" forces. The total forces are computed by summing a stress quantity times the thickness of each element, multiplied by the square root of the element area. This gives a meaningful error norm even if the applied loads do not include any forces.

Increment Heading - The load increment number is printed, along with the increment I.D. title given in input item II-1. Following this are the creep time increment, the number of elastic and plastic elements at the end of the increment, the number of elements which have changed elastic to plastic and plastic to elastic during the increment, the maximum allowable number of Jacobian updates and the number performed during this increment, the maximum allowable number of iterations per update and the number performed since the last update, and the maximum allowable error norm and the error norm actually obtained.

Cumulative Forces and Displacements - These are the cumulative internal forces (corresponding to computed element stresses) and displacements for

3.2 (Continued)

each node. The node number and node I.D. are printed, followed by the U and V components of force and displacement. U and V are in the directions defined by the node direction coordinate system (X-Y, R-θ, or special coordinate system).

Thermal and Elastic Strains - These are incremental and cumulative values of the thermal and elastic strains for each element. The element number and element I.D. are printed, followed by the thermal strains and components of the elastic strains. All strain components are referred to the element base coordinate system (an x-y right-hand Cartesian system with origin at node 1, and x axis along the nodal line 1-2).

Plasticity Results - For each element the number and I.D. are printed, followed by the incremental and cumulative plastic work and components of plastic strain. All strains are again given in the element base coordinate system.

Creep Results - These are printed only if the creep time increment (input in data item C-4) is greater than zero. Printed creep results correspond to those for plasticity.

Stress Results - For each element the number and I.D. are printed, followed by the values of cumulative effective stress center $\bar{\alpha}$ and effective stress $\bar{\sigma}$, and the components of stress center and stress referred to the element base coordinate system.

3.2 (Continued)

Summarized Element Quantities - For each element the number and I.D. are printed, followed by the elastic-plastic "code" and "sum code." The code is 0, -1 or +1, respectively, according to whether the element condition has remained unchanged, gone from plastic to elastic (unloaded), or gone from elastic to plastic (yielded) during the increment. The sum code gives the value for the program variable YCODE1, and is + or -, respectively, according to whether the element condition is plastic or elastic at the end of the increment. Its magnitude is an indication of the iterative tendency for the element to remain in that condition. Next are given the total temperature and the yield surface size $(\bar{\sigma} - \bar{\alpha})$ at the end of the increment. Finally are printed, for both plastic and creep strains, three values of effective strain (incremental $\Delta\bar{\varepsilon}$, sum of incremental $\Sigma\Delta\bar{\varepsilon}$, and cumulative $\bar{\varepsilon}$).

4.0 SIZE LIMITATIONS

4.1 GENERAL SIZE LIMITATIONS

The following variables are used to specify maximum size limitations in BOPACE. The values set for these variables in the 300-DOF and 1000-DOF program versions are given in Table 4.1-1.

NSTOR	=	core words allocated to Gauss wavefront storage
NMAX1	=	maximum number of materials
NMAX2	=	maximum number of nodes
NMAX3	=	maximum number of elements
NMAX4	=	maximum node I.D. number
NMAX5	=	maximum element I.D. number
NMAX6	=	maximum number of points in a material property curve
NMAX7	=	maximum number of temperature plasticity curves per material
NMAX8A	=	maximum number of points per isotropic hardening curve
NMAX8B	=	maximum number of points per kinematic hardening shape curve
NMAX8C	=	maximum number of points per kinematic hardening factor curve
NMAX9	=	maximum number of points in a creep reference curve
NMAX10	=	maximum number of creep-factor temperatures per material
NMAX11	=	maximum number of creep-factor stresses per temperature
NMAX12	=	maximum number of special coordinate systems
NMAX13	=	maximum (required) number of mechanical load reference vectors

4.1 (Continued)

NMAX14 = maximum number of load increments per run

TABLE 4.1-1: MAXIMUM SIZE LIMITATIONS

Maximum	300 DOF	1000 DOF
NSTOR	2000	5000
NMAX1	5	5
NMAX2	150	500
NMAX3	200	800
NMAX4	500	2000
NMAX5	1000	3000
NMAX6	20	20
NMAX7	6	6
NMAX8A	30	30
NMAX8B	20	20
NMAX8C	30	30
NMAX9	10	10
NMAX10	6	6
NMAX11	10	10
NMAX12	50	50
NMAX13	2	2
NMAX14	60	60

4.2 LINEAR EQUATION SOLVER LIMITATIONS

The linear equations solution routines have one user controlled limitation. This is the maximum bandwidth of active nodes during the decomposition of the stiffness matrix. The bandwidth is defined as the number of nodes following the node being processed which have non-zero terms associated with the node being processed. Melosh and Bamford [1] discuss this in some detail as the wavefront analysis concept. Whetstone [2] also discusses this concept and gives rules and procedures which can be used to keep the bandwidth as small as possible by proper numbering of the nodes.

BOPACE uses the maximum active bandwidth (wavefront) to determine core storage requirements during decomposition.

Let

K = the amount of storage available (K = 2000 for the 300 DOF version, K = 5000 for the 1000 DOF version)

N = the number of DOF per node (a constant for each node in the analysis)

B = the maximum active bandwidth

$T = B + B * N^2 + 4$

$M = B * (B+1)/2$

4.2 (Continued)

Then the following two equations must be satisfied:

$$T \leq 420 \tag{4.2-1}$$

$$K \geq B + M + 2*N^2*M + 6*N^2 + T \tag{4.2-2}$$

5.0 DETAILED INPUT AND STORAGE OF DATA

5.1 DETAILED INPUT DESCRIPTION

This section provides a definition of BOPACE input variables, and a detailed description of the input data and their use within the program. Data are discussed in the order in which they are read, with data item numbers corresponding to those given in Section 2.0.

Input Files - In addition to the usual card file (unit number 5), BOPACE uses files I and II for which the user defines unit numbers. Because the data on these files may become rather lengthy for a large-size problem, the user may wish to define them as tape files which are automatically generated by special subroutines. (See for example Appendix A, for a description of the INPUTB interpolation-data-generator program.) File I data define the basic problem, mesh and material properties. These data cannot be redefined during solution of the problem, so that they are independent of any particular load increment and are used only when starting a new problem.

C-1. Start-Restart Code and Data File Numbers - These data are read by subroutine READRS from the usual card file (unit number 5):

a. START = start-restart code

b. UIN1 = unit number for input file I

c. UIN2 = unit number for input file II

d. UOUT = unit number for output file (e.g., printer)

5.1 (Continued)

e. INCR = previous increment number from the end of which a restart is to be made

f. UINRS = unit number for input restart tape

g. UOUTRS = unit number for output restart tape

A "RESTART" code specified in item (a) means that an input restart tape is being provided (item f), which contains the initial Jacobian and its decomposition, the basic problem, mesh and material data, and previous incremental results including those for increment INCR (e) from which a restart is to be made. If INCR = 0, the problem is started from the initial conditions, but the reading of the file I data and the formation and decomposition of the initial Jacobian are avoided. If neither "START" nor "RESTART" is specified, it is assumed that the blank card of input item C-5 (see Section 2.0) has been read, and the program exits in the normal mode with a STOP 9999 code.

The file unit number (b) is required when starting. Unit numbers (c) and (d) are required in all cases. If the current run is a restart, the unit number (f) is required. If results are to be saved for a future restart, the unit number (g) is required.

C-2. Problem I.D. Title - The title is read by subroutine READO:

IDENT = problem I.D. title

The title consists of any 80 characters used to describe the current run.

5.1 (Continued)

C-3. Program Control Constants - These constants are read by subroutine READO:

a.	SCODE	=	code for system matrix (Jacobian) updating
b.	MAXUP	=	maximum number of updates per increment
c.	MAXIT	=	maximum number of iterations per update
d.	MAXIE	=	maximum number of initial elastic iterations
e.	MAXYC	=	maximum allowable magnitude for YCODE1
f.	MAXCUT	=	maximum number of cuts
g.	CUT	=	cutting fraction
h.	ERRMAX	=	maximum allowable error norm
i.	AFACT	=	increment fraction for evaluating hardening slope

The value of SCODE (item a) is the code for updating the Jacobian and its component matrices. It allows various options for the basic solution approach, depending on the amount of nonlinearity expected in the problem. It affects only the rate of convergence and the effectiveness of the iterative process. It does not alter the manner in which unbalanced forces are iteratively computed, nor does it affect the final computed results so long as convergence is achieved. A discussion of the effects of each option for various types of problems is given in Section 4.4 of the BOPACE Theoretical Manual. Item (b) gives the maximum number of Jacobian updates per load increment. An update is performed if the maximum number of iterations specified in (c) has been reached without achieving convergence.

5.1 (Continued)

Generally a maximum of one update per increment is sufficient, unless very large changes in the elastic properties, slope of the stress-strain curve, or direction of loading, have occurred.

Item (d) gives the maximum number of iterations to be performed at the start of the increment, using the current elastic matrix. These initial iterations are performed in order to account for the possible occurrence of large-scale unloading within the structure.

MAXYC (item e) gives the maximum absolute value for the elastic-plastic sum code, YCODE1. The current value of YCODE1 for each element determines whether it is to be treated as elastic or plastic in the calculation of unbalanced forces and in the formation of the Jacobian stiffness matrix (0 or - denotes elastic condition, + denotes plastic condition). YCODE1 is changed by -1 or +1 after each iteration, depending on whether the condition was determined to be elastic or plastic, respectively, but its absolute value is not allowed to exceed MAXYC. If the value of YCODE1 reaches 0, the element condition is considered to have changed and YCODE1 is set to an initial value of ±2 (±2 is used instead of ±1 because it prevents oscillation between elastic and plastic conditions in certain cases). The purpose of YCODE1 is essentially to denote the element condition and to provide a stabilizing influence on the iterative process. Higher specified values of MAXYC could increase the stability but might require larger convergence times.

5.1 (Continued)

Items (f) and (g) (MAXCUT and CUT) relate to a common method for increasing the stability of iterative processes. If a computed displacement correction in the BOPACE iteration does not result in a decreased error norm, then the error norm is computed for another configuration based on some fraction of the displacement correction. If the error norm still has not decreased, the fraction is squared and again applied to the displacement correction, etc. MAXCUT gives the maximum number of such "cuts" to be performed, and CUT gives the fraction to be used.

Item (h) gives the maximum allowable error norm. The actual error norm is computed essentially as a ratio of unbalanced forces to applied forces.

AFACT (item i) relates to evaluation of the plastic hardening slope for each element, used in forming the Jacobian matrix. The best location for evaluating this slope for the Jacobian update is a point at the end of the current increment. The actual slope is determined in BOPACE using two interpolated values from the hardening tables. The second corresponds to the estimated value of the hardening parameter at the end of the increment, while the first is at a small distance prior to the second and is determined by subtracting the fraction AFACT times the incremental change in the hardening parameter.

I-1. Basic Constants and Default Values - These items are read by subroutine READ1:

5.1 (Continued)

PCODE	=	plane-stress or plane-strain code
NMAT	=	number of materials
THICK	=	default thickness
TEMPO	=	fabrication temperature

The code for plane-stress or plane-strain holds for all elements and defines the type of problem being run. The default thickness defines the thickness of all elements, unless it is overidden by the element values given in I-7. The fabrication temperature defines the initial temperature of the structure, at which thermal strains are considered to be zero. It is also the default temperature for all elements during the first load increment, unless it is overridden by the element values given in II-1b.

I-2. Material Property Data - These data are read by subroutine READTM:

NTHERM(I)	=	number of points in thermal-strain curve for material I
THERMX(J,I)	=	Jth temperature value of thermal-strain curve for material I
THERMY(J,I)	=	Jth thermal strain value for material I
NEMOD(I)	=	number of points in elastic-modulus curve for material I

5.1 (Continued)

EMODX(J,I)	=	Jth temperature value of elastic-modulus curve for material I
EMODY(J,I)	=	Jth elastic-modulus value for material I
NPRAT(I)	=	number of points in Poisson's ratio curve for material I
PRATX(J,I)	=	Jth temperature value of Poisson's ratio curve for material I
PRATY(J,I)	=	Jth Poisson's ratio value for material I

The property data are given consecutively for each material. The zero-strain point of the thermal-strain curve is arbitrary, because the curve is used only to obtain the increment of thermal strain corresponding to a given temperature increment. All interpolation performed later from the thermal-strain, elastic-modulus and Poisson's ratio curves is accomplished by the linear interpolation routine YVAL.

I-3. Plasticity Data - The plasticity data are given consecutively for each material. The data are read by subroutine READTP:

PTYPE(I)	=	plastic hardening type for material I
KTYPE(I)	=	kinematic hardening code for material I
NTABY(I)	=	number of temperature values for hardening tables for material I

5.1 (Continued)

TABY(J,I) = Jth temperature value for hardening tables for material I

NITABX(I) = number of κ values for isotropic hardening table for material I

ITABX(J,I) = Jth κ value for isotropic hardening table for material I

ISTAB(K,J,I) = value of isotropic hardening table for Kth temperature value and Jth κ value for material I

NKTABX(I) = number of κ^k values for kinematic hardening shape table for material I

KTABX(J,I) = Jth κ^k value for kinematic hardening shape table for material I

KSTAB(K,J,I) = value of kinematic hardening shape table for Kth temperature value and Jth κ^k value for material I

NFTABX(I) = number of κ values for kinematic hardening factor table for material I

FTABX(J,I) = Jth κ value for kinematic hardening factor table for material I

FSTAB(K,J,I) = value of kinematic hardening factor table for Kth temperature value and Jth κ value for material I.

5.1 (Continued)

PTYPE defines for each material whether it is a strain-hardening or work-hardening material. KTYPE defines whether the kinematic hardening for each material is to be taken as a function of only the parameter κ^k, or of both κ^k and κ. Two-parameter kinematic hardening accounts for change in magnitude of the Bauschinger effect with continued cycling, i.e., with increase in value of κ.

Hardening is defined by values stored in the three hardening tables ISTAB, KSTAB and FSTAB. ISTAB gives the size of the yield surface $(\overline{\sigma} - \overline{\alpha})$. KSTAB gives the shape of the kinematic hardening $(\overline{\alpha})$ curve, and FSTAB gives the factor to be applied to this shape in order to define the variable Bauschinger effect. The values in these 2-dimensional tables (for each material) represent a series of hardening curves at various temperature levels. TABY defines the temperature series which is used for all three hardening tables. However, each table has its own set of values for hardening parameter, defined by the respective vectors ITABX, KTABX and FTABX for each material. When, for example, the κ-parameter ITABX and the temperature value TABY are given for a particular material, the corresponding size of the yield surface is determined by double interpolation from the table ISTAB.

The hardening curves are input in order of associated low to high temperature. The curve at each temperature may have its own series of κ or κ^k parameters. However, a single series of these parameters (defined

5.1 (Continued)

by ITABX, KTABX or FTABX) is needed for each hardening table. This series is taken as that given for the low-temperature curve of the table, and curves for other temperatures are interpolated to these basic values. Therefore the low-temperature curve input for each table should cover the range of parameter values used in all curves input for that table, in order to avoid losing any points in the initial interpolation and forming of the table. Later interpolation from the plastic hardening tables is accomplished by the double linear interpolation routine ZVAL.

For KTYPE = 0, kinematic hardening is determined using only the KSTAB table, and the FSTAB table and associated data are not read. For KTYPE = 1, kinematic hardening is determined as a product of values from the shape table KSTAB and the factor table FSTAB. A more detailed description of the BOPACE plastic hardening method is given in Section 2.3 of the Theoretical Manual.

<u>I-4. Creep Data</u> - The creep data are given consecutively for each material. The data are read by subroutine READTC:

CTYPE(I)	=	creep hardening type for material I
NCREEP(I)	=	number of points in reference creep curve for material I
CREEPX(J,I)	=	Jth time value of reference creep curve for material I
CREEPY(J,I)	=	Jth creep-strain value of reference creep curve for material I

5.1 (Continued)

NCTABX(I)	=	number of stress values for creep factor table for material I
NCTABY(I)	=	number of temperature values for creep factor table for material I
CTABX(J,I)	=	Jth stress value for creep factor table for material I
CTABY(J,I)	=	Jth temperature value for creep factor table for material I
CTAB(K,J,I)	=	value of creep factor table for Kth temperature value and Jth stress value for material I

CTYPE defines for each material whether it is an age-hardening, strain-hardening or work-hardening material with respect to creep.

Shape of the creep curve is defined by the vectors CREEPX and CREEPY for each material. Creep factors are stored in the 2-dimensional table CTAB. CTABY defines the temperatures associated with these factors, and CTABX defines the stress levels. Later interpolation from the CTAB factor table is accomplished by the double linear interpolation routine ZVAL. Interpolation from the shape vector CREEPY is accomplished by the linear incremental interpolation routine DYVAL, which gives the increment of strain on the reference creep curve corresponding to given initial and final values of time. The actual increment of effective creep strain is determined as a product of the CTAB factor and the CREEPY shape increment.

5.1 (Continued)

Each input creep hardening factor has an associated temperature and stress level. The factors are input in temperature groups, in order of low to high temperature, and within each group are ordered from low to high stress level. Although each temperature group may have its own input stress-level series, the stress-level series defined by CTABX is used for all temperatures during later interpolation. CTABX is taken as the stress series given for the low-temperature group of factors, and other groups are interpolated to these basic values. Thus the input low-temperature group should cover the range of stress values input for all groups, in order to avoid losing any points in the initial interpolation and forming of the factor table.

I-5. Special Coordinate Systems - The special coordinate systems are read by subroutine READC:

COORDA(I) = angle for special coordinate system I

These systems provide special nodal direction coordinates which can be used to specify components of force or displacement in a particular direction.

I-6. Nodal Data - These data are read and computed by subroutine READM:

NOD = number of nodes in problem

COORD(J,I) = Jth (X or Y) coordinate for node I

GCOS(J,I) = Jth direction Cosine for node I

5.1 (Continued)

NODE(I) = node I.D. for node I

NODI(I) = node number for node I.D. I

The value of NOD is determined by the program from counting the input nodal data. When the two coordinates for a node are read, they are converted to basic Cartesian (X-Y) coordinates and stored in the COORD array. The GCOS direction Cosines are the Cosine and Sine, respectively, of the angle from the basic X axis to the nodal direction coordinate system X axis. The GCOS array is computed and stored in double precision, so as to avoid loss of accuracy. This precision is required in problems such as those involving a small cylindrical segment of an engine wall, where quantities involving the Sine and Cosine of very small angles are important.

The node I.D. is supplied by the user, and actual internal node numbers are assigned consecutively in the order in which nodes are read in the input data deck. Since the internal numbers are used in all operations including formation and solution of the linear equations, the user should attempt to place the nodes in the data deck in an efficient order, i.e., an order which avoids as much as possible the connection of nodes having greatly different internal node numbers.

I-7. Element Data - These data are read and computed by subroutine READM:

NEL = number of elements in problem

IMAT(I) = material number for element I

5.1 (Continued)

T(I)	=	thickness of element I
ELNO(J,I)	=	Jth node number for element I
NELE(I)	=	element I.D. for element I
NELI(I)	=	element number for element I.D. I

The value of NEL is determined by the program from counting the input element data. The ELNO array stores the three internal node numbers for each element in counter-clockwise order.

The element I.D. is supplied by the user, and actual internal element numbers are assigned consecutively in the same manner as for nodes. In order to increase the efficiency of the global matrix formations, it is best to have the order of elements in the data deck follow approximately the order of the nodes to which they are connected.

<u>I-8. Force-Displacement-Constraint Specifications</u> - These data are read by subroutine READ2:

KFD(I) = force-displacement-constraint code for degree of freedom I

The degrees of freedom are ordered by node number, e.g., KFD(5) is the code for the first degree of freedom at node 3 (2 DOF per node). Each DOF has either a specified force or displacement. For the usual type of structure, most will be specified forces. For a constrained DOF,

5.1 (Continued)

i.e., a dependent DOF whose displacement is set equal to that of some independent DOF, the program makes its code agree with that of the independent DOF. Thus if the independent DOF has a specified force, the dependent DOF will have a specified (perhaps zero value of) force; if the independent DOF has a specified displacement, the dependent DOF by definition has the same displacement.

A DOF may not be constrained with a dependent (already constrained) DOF. Also, the present BOPACE equation-solver routines do not allow constraints between two nodes on the same element.

<u>I-9. Mechanical Load Reference Vectors</u> - These data are read by subroutine READ3:

PREF(J,I) = load component of Jth (1st or 2nd) load reference vector for DOF I

The load components are given in the directions defined by the node direction coordinate systems. The current version of BOPACE employs two load reference vectors. In order to simplify input, the cumulative loads (specified forces and displacements) at the end of each load increment are computed as the sum of the two load factors times their respective load vectors. Thus the two load vectors remain constant throughout the entire problem. For engine problems, the two vectors typically define the pressure distributions in the chamber and coolant tubes, respectively.

5.1 (Continued)

Although the present program does not allow the load distribution within a load vector to vary from one increment to the next, the two load factors may of course vary independently of one another.

C-4. Incremental Mechanical Load Data - These data are read by subroutine READ4:

NINCR	=	number of load increments to be run
NITER(I)	=	maximum number of iterations for increment I
PFACT(J,I)	=	load factor to be applied to load reference vector J during Ith increment
CTIME(I)	=	creep time increment for load increment I

II-1. Thermal and Z-Direction Loads - These data are read by subroutine READ5:

TIDENT	=	increment I.D. title
T1(I)	=	cumulative (total) temperature at end of increment for element I
ZS1(I)	=	cumulative Z load at end of increment for element I

The increment title consists of any 80 characters used to describe the current load increment. Before the thermal and Z loads are read for an increment, T1 and ZS1 are set equal to their values at the beginning of the increment (T0 and ZS0, respectively). This provides default loads (unchanged from those of the previous increment) for those elements for

5.1 (Continued)

which the user does not specify a load value. The thermal and Z loads are then read according to data items II-1b and c, in any desired element order.

5.2 I/O AND STORAGE FILES

The following are descriptions of files used in the BOPACE program, listed by unit number.

5

Input card file.

6

Output printer file.

UIN1

UIN1 is the user-defined unit number for type I input data.

UIN2

UIN2 is the user-defined unit number for type II input data.

UOUT

UOUT is the user-defined unit number for the major output data file.

UINRS

UINRS is the user-defined unit number for the input restart data file.

5.2 (Continued)

UOUTRS

UOUTRS is the user-defined unit number for the output restart data file.

UNITE1 = 11

File for storing the merged elastic stiffness matrix.

UNITE2 = 12

File for storing the decomposed elastic stiffness matrix.

UNITP1 = 13

File for storing the merged total Jacobian matrix. It is used only when the input variable SCODE is equal to 3, 4 or 5.

UNITP2 = 14

File for storing the decomposed total Jacobian matrix. It is used only when the input variable SCODE is equal to 3, 4 or 5.

UNITS1 = 15

Scratch file used for temporary storage by the Gauss wavefront merge and decomposition routines.

UNITS2 = 16

Same as UNITS1.

6.0 PROGRAM FLOW AND RESTART OPTIONS

The major steps accomplished during a BOPACE run are shown in the program flow summary of Figure 6.0-1.

Steps 3-7 accomplish the initialization of basic variables (program control constants, material data, mesh, and load vectors) and incremental variables, and the formation of merged and decomposed elastic stiffness matrices. These steps follow from reading of input data in the case where a new problem is being started, or from reading of the input restart tape in the case of a restart. If data is to be saved for a future restart, steps 9-10 write the basic variables and elastic merged and decomposed matrices onto the output restart tape. In step 11 the incremental mechanical load data, including load factors and creep time increment for each load increment to be run, are read.

The remaining steps involve the incremental and iterative calculations. Updating of the Jacobian matrices in step 23 is performed only when convergence slows down, and in general this occurs only once per increment or once every several increments.

In step 26 the computed incremental variables are written onto the output restart tape, if a future restart is provided for. This allows the user to request a restart from the end of any previously run load increment.

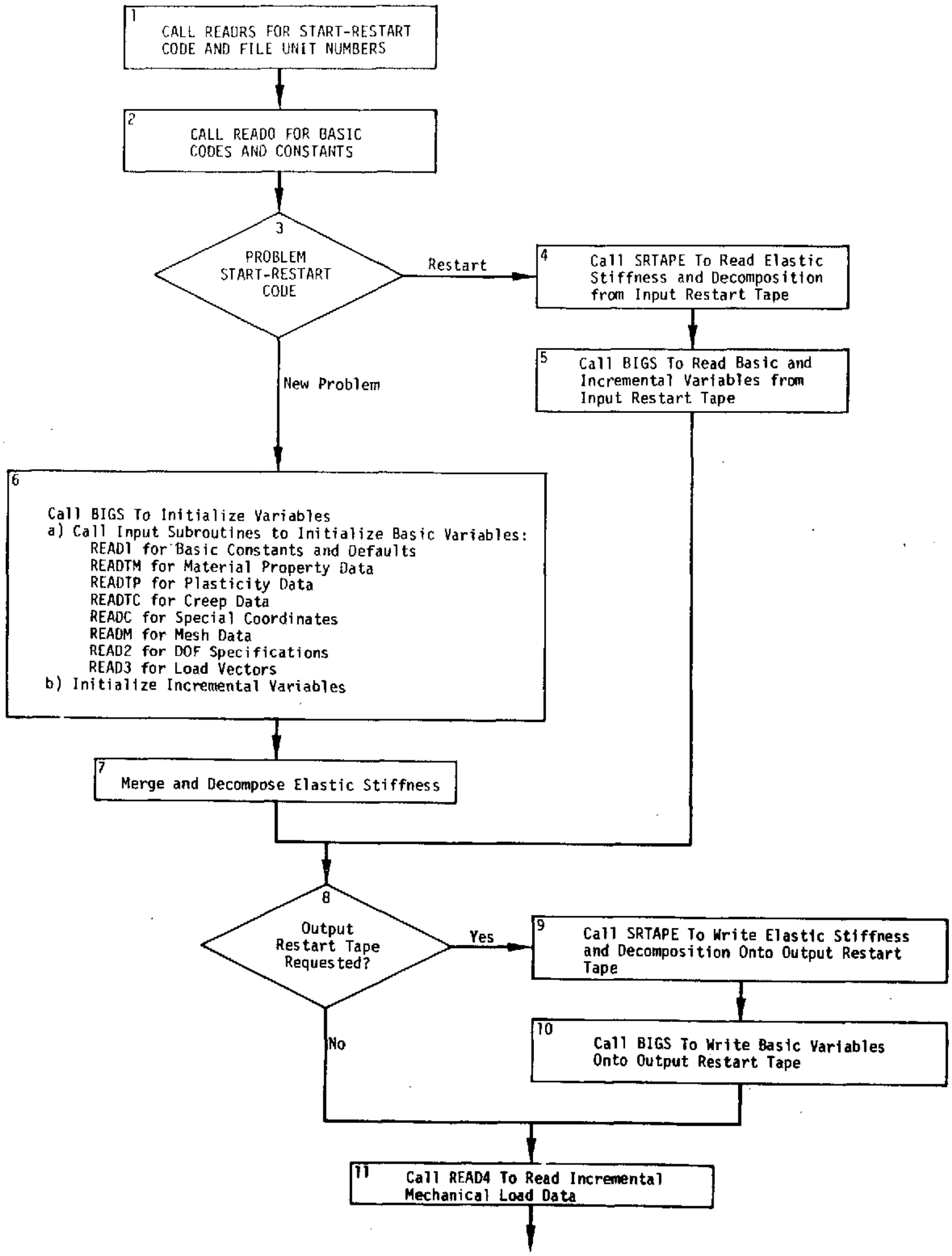

Figure 6.0-1: PROGRAM FLOW

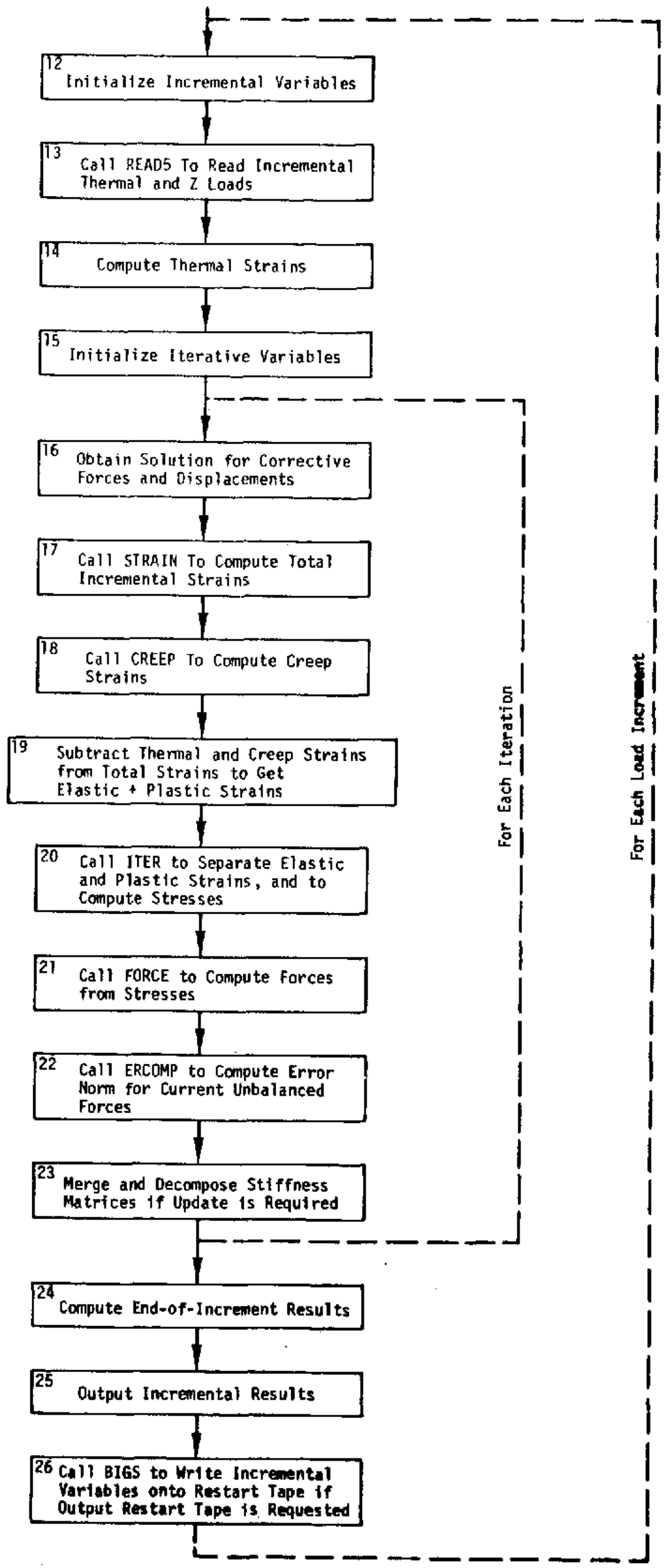

Figure 6.0-1: PROGRAM FLOW (CONTINUED)

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7.0 BOPACE ERROR MESSAGES

BOPACE uses the FORTRAN STOP codes described in this section to indicate error conditions which may occur during execution of the program. Certain errors also generate a printed error message, in order to aid the user in locating the source of the error.

Errors fall into two categories, those due to the problem definition or user input data, and those caused by a program or machine malfunction. Errors due to a machine malfunction rarely occur and in these cases a rerun of the problem will usually eliminate the error. If an error recurs and help is needed in correcting the problem, contact a BOPACE programmer for aid. Have available a listing of the input data, the printouts of the runs which failed, the input data deck, and a description of the problem.

The following are explanations of the BOPACE error STOP codes, listed by subroutine in which they occur.

READRS

9999 Normal program exit caused by reading final blank card after all problems are run.

101 Non-positive value input for a required file unit number.

READ1

201 Plane stress-strain code input not equal to 0 or 1.

202 Illegal value input for number of materials.

7.0 (Continued)

READTM

301	Wrong material number input on material property card.
302	Number of points input for material property curve exceeds maximum
303	Non-positive value input for modulus of elasticity.
304	Value input for Poisson's ratio is 0.49 or greater in plane-strain problem.
305	No points input for a required material property curve.

READTP

401	Wrong material number input on plasticity type-code card.
402	Illegal plasticity type input.
403	Illegal kinematic hardening code input.
404	Wrong material number input on plasticity temperature card.
405	Plasticity temperatures not in ascending order.
406	Number of temperatures for a material exceeds maximum.
407	Hardening point defines non-positive yield-surface size, or negative kinematic value.

7.0 (Continued)

READTP

408 Number of points input for a curve exceeds maximum.

409 No points input for a required curve.

410 First point input on a curve has non-zero abscissa.

411 No curves input for a required hardening description of a material.

READTC

501 Wrong material number input on creep type card.

502 Illegal creep type input.

503 Number of points input for a creep reference curve exceeds maximum.

504 No points input on the creep reference curve for a material.

505 Wrong material number input on creep temperature card.

506 Creep temperatures not in ascending order.

507 Number of creep temperature factors for a material exceeds maximum.

508 Number of creep stress factors at a temperature exceeds maximum.

7.0 (Continued)

READTC

509 No creep stress factors input at a temperature.

510 No creep temperatures input for a material.

READC

601 I.D. of special coordinate system exceeds maximum.

READM

701 Mesh node I.D. exceeds maximum.

702 I.D. of a node location coordinate system not equal to 0 or 1.

703 I.D. of a node displacement coordinate system exceeds maximum.

704 Number of input nodes exceeds maximum.

705 No nodes input.

711 Element I.D. exceeds maximum.

712 Illegal value input for element material number.

713 Illegal node I.D. on an element.

714 Number of input elements exceeds maximum.

715 No elements input.

7.0 (Continued)

READ2

801 Illegal node I.D. for a force-displacement-constraint specification.

802 Illegal component number (not equal to 1 or 2)

803 Illegal force-displacement-constraint code.

804 Constraint specified with dependent (already constrained) DOF.

805 Constraint specified between DOF on same element.

READ3

901 Number of input mechanical load reference curves not equal to 2.

902 Illegal node I.D. on a mechanical load.

903 Illegal component number (not equal to 1 or 2) on a mechanical load.

904 Load input on dependent DOF constrained to DOF with specified displacement.

READ4

1001 Number of load increments exceeds maximum per run.

7.0 (Continued)

READ5

1101 Illegal element I.D. on a thermal load.

1102 Illegal element I.D. on a z-load.

Linear Equation-Solver Routines

5011 I/O Error during merge. Program or machine malfunction during the merging of the elemental stiffness matrices to form the global stiffness matrix.

5021 Bandwidth too large for decomposition save array. The bandwidth is too large for the amount of core storage allocated (see Equation 4.2-1). Corrective action: renumber the nodes to reduce the bandwidth.

5023 No decomposition partitions available. Program or machine malfunction during decomposition.

5024 Decomposition node not in active node array. Program or machine malfunction during decomposition.

5031 Scratch array too small for solution work. Program or machine malfunction during forward and backward substitution.

5041 Illegal save tape I/O operation command. Program or machine malfunction in reading or writing the checkpoint tape.

7.0 (Continued)

Linear Equation-Solver Routines

5042 Illegal matrix type. Program or machine malfunction in reading or writing the checkpoint tape.

5043 Illegal save tape defined for save operation. Program or machine malfunction in reading or writing the checkpoint tape.

5051 Large decomposition not available. The bandwidth is too large to solve the problem using in-core decomposition. See Equation 4.2-2. Corrective action: Reduce the bandwidth by renumbering the nodes or reducing the problem size.

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8.0 REFERENCES

1. R. J. Melosh and R. M. Bamford, "Efficient Solution of Load-Deflection Equations," Journal of the Structural Division, ASCE, April 1969.

2. W. D. Whetstone, "Computer Analysis of Large Linear Frames," Journal of the Structural Division, ASCE, November 1969.

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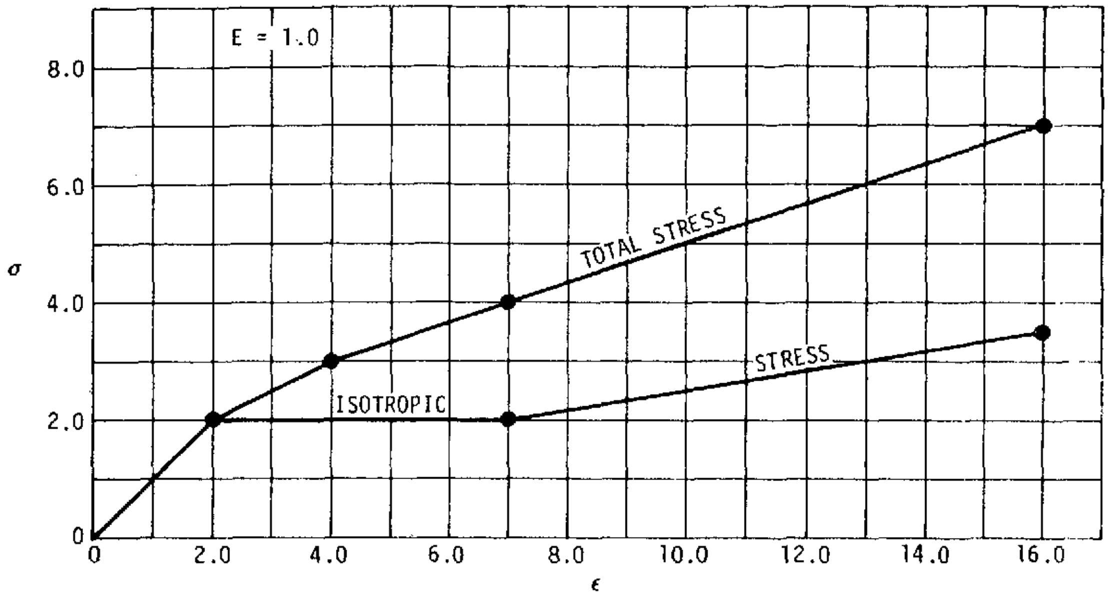
9.0 EXAMPLE PROBLEMS

Four example problems are provided here in order to demonstrate the BOPACE program capabilities and to aid the user in setting up his problems. The examples in Section 9.1 serve to demonstrate and check out various program options, including temperature-dependent elasticity, creep and prescribed normal loads. Section 9.2 illustrates a thermal ratchet behavior, which must be considered as a possible important effect during any combined mechanical loading and high-temperature thermal cycling. Section 9.3 illustrates the procedure for using actual cyclic test data to determine the isotropic and kinematic portions of hardening, and gives an indication of the test-analysis match which is possible with the BOPACE combined hardening approach. Section 9.4 gives an example of the required input data for a typical engine analysis, involving a relatively coarse finite-element mesh but with several different materials.

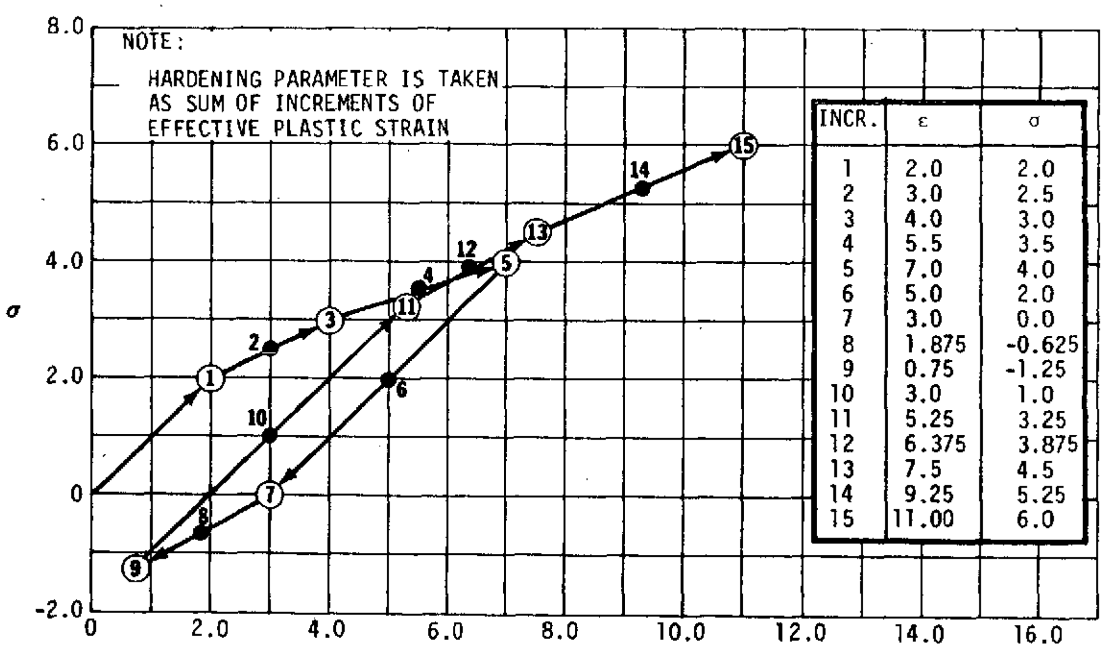
9.1 PROGRAM CHECKOUT PROBLEMS

Plane Stress with Combined Hardening - The basic characteristics of BOPACE combined hardening are shown in Figure 9.1-1 for a uniaxial (special case of a plane-stress) problem. Figure 9.1-1A gives the assumed monotonic stress-strain hardening curves. The size of the yield surface is defined by the isotropic stress, while the Bauschinger kinematic hardening is defined by the difference between the total stress and the isotropic stress. Thus the hardening is completely kinematic out to a strain value of 7.0 (plastic strain of 3.0), after which there are equal amounts of isotropic and kinematic hardening.

A resulting cyclic stress-strain curve is given in Figure 9.1-1B. The 15 load increments were chosen so as to result in the exact σ-ε points given in the figure insert table. Note that the hardening parameters (κ and κ^k) in this example were based on effective plastic strain rather than on plastic work, because it makes the relationship between the monotonic and cyclic curves more readily apparent.



(A) MATERIAL STRESS-STRAIN CURVES



INCR.	ε	σ
1	2.0	2.0
2	3.0	2.5
3	4.0	3.0
4	5.5	3.5
5	7.0	4.0
6	5.0	2.0
7	3.0	0.0
8	1.875	-0.625
9	0.75	-1.25
10	3.0	1.0
11	5.25	3.25
12	6.375	3.875
13	7.5	4.5
14	9.25	5.25
15	11.00	6.0

(B) STRESS-STRAIN PATH UNDER LOADING

FIGURE 9.1-1: UNIAXIAL TEST PROBLEM FOR CYCLIC COMBINED HARDENING

9.1 (Continued)

Plane-Strain with Additional Options - The plane-stress problem just described was altered to illustrate the use of several additional BOPACE options, including temperature-dependent elasticity, creep and prescribed normal loads.

A BOPACE plane-strain checkout analysis was performed using the finite-element mesh and loading given in Figure 9.1-2. A listing of the input data and the printed output results are included at the end of this section.

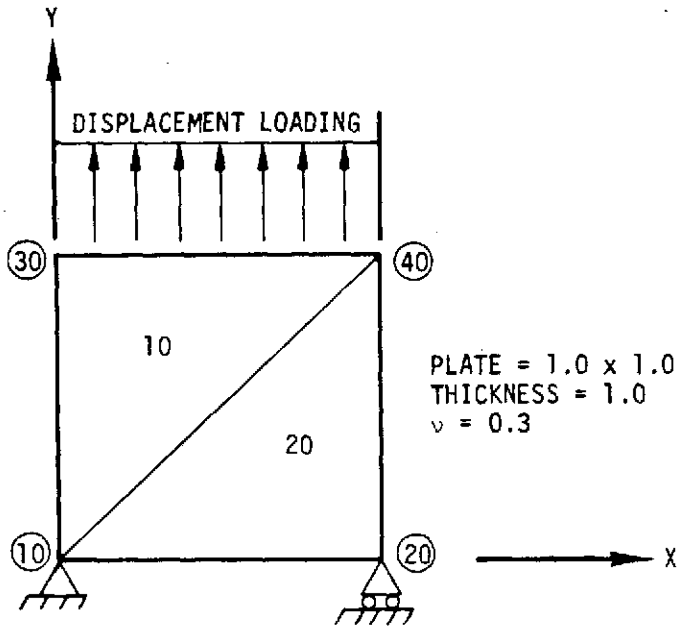


FIGURE 9.1-2: PLANE-STRAIN CHECKOUT PROBLEM

9.1 (Continued)

A summary of the problem is provided by Table 9.1-1. The 15 increments correspond to those of the previous plane-stress problem. The values of incremental plastic strain, stress, effective stress center, and yield-surface size given in columns 2-5 of Table 9.1-1 were kept the same as those of the plane-stress problem. The stress is equal to the product of the temperature-dependent elastic modulus (column 6) and the elastic strain (column 7).

The creep strain listed in column 9 results from the material creep definition of Figure 9.1-3. There the reference creep curve for a strain-hardening material is assumed as shown in (A), while (B) defines the creep factor F^c as a function of average stress level during the increment. The creep strain may be determined using the average stress level (column 10 of Table 9.1-1), the creep factor (column 11) and the specified creep time increment (column 12).

In addition, the Z-load strains given in column 13 and thermal strains in column 14 were imposed. In order to keep the results simple and exact (all numbers in Table 9.1-1 are given exactly), the Z-load and thermal-strain values were selected so as to give zero normal stress in each increment. For example, in increment 11 we have:

9.1 (Continued)

$$\varepsilon^{e}_{ZZ} = -0.3$$

$$\varepsilon^{p}_{ZZ} = -1.0$$

$$\varepsilon^{c}_{ZZ} = -0.5$$

$$\underline{\varepsilon^{t}_{ZZ} = 1.5}$$

$$\Sigma\varepsilon_{ZZ} = -0.3$$

Because the imposed Z-load strain also equals -0.3, a zero value results for the normal stress σ_{ZZ}. Thus it may be noted that this example can be used for either a plane-stress or a plane-strain checkout run.

The prescribed displacements shown in column 15 were determined from the various components of the total strain. For example, again in increment 11:

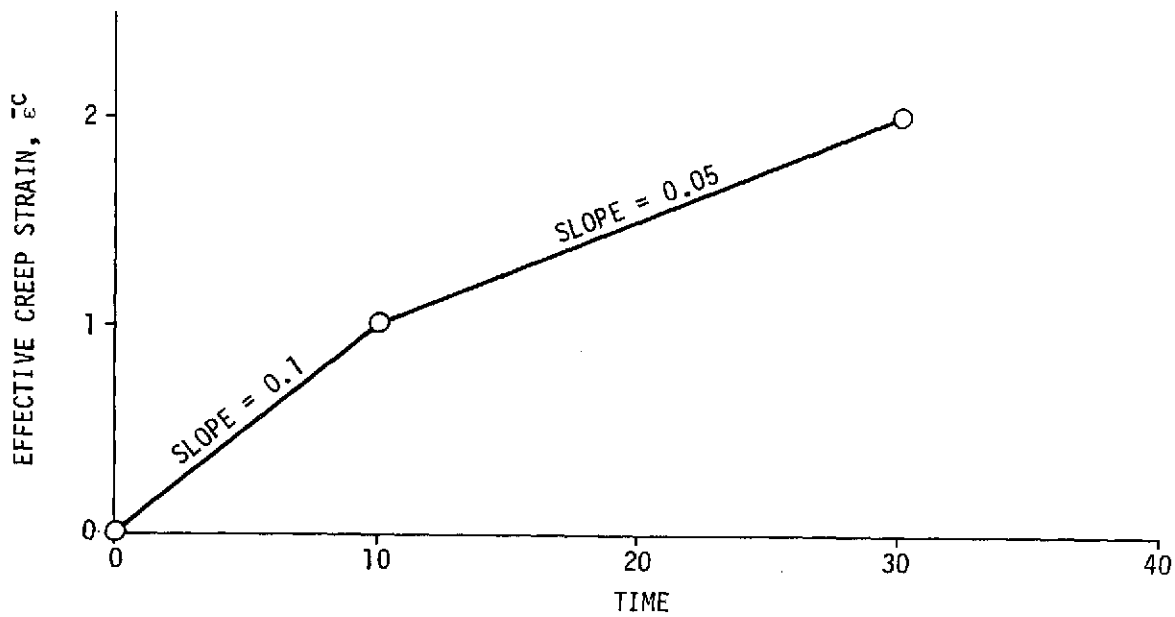
$$\varepsilon^{e}_{YY} = 1.0$$

$$\varepsilon^{p}_{YY} = 2.0$$

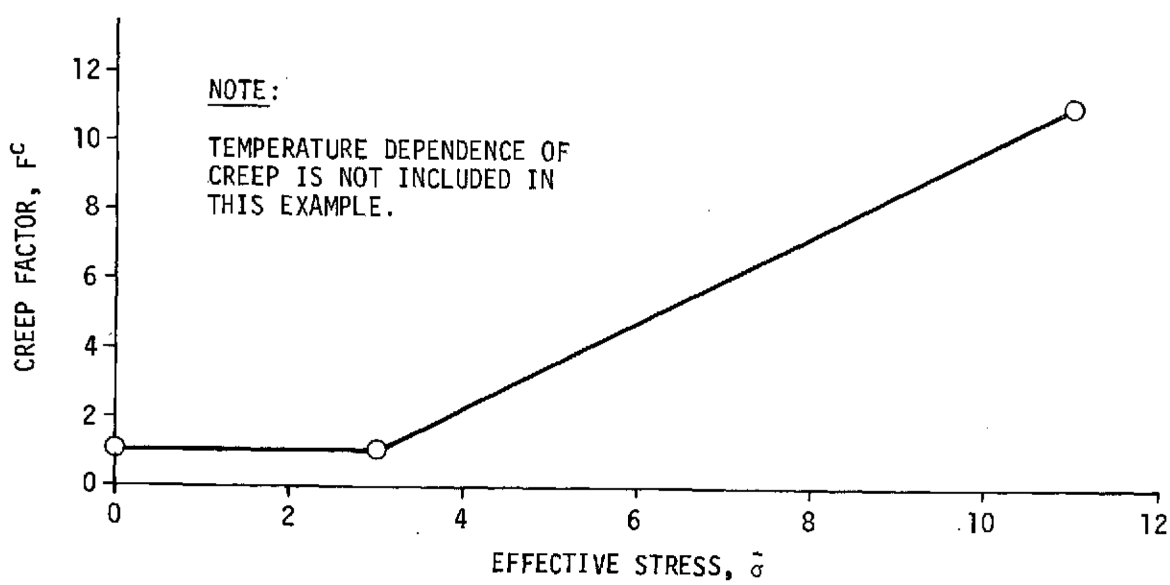
$$\varepsilon^{c}_{YY} = 1.0$$

$$\underline{\varepsilon^{t}_{YY} = 1.5}$$

$$Q_{YY} = \Sigma\varepsilon_{YY} = 5.5$$



(A) ASSUMED SHAPE FOR REFERENCE CREEP CURVE



(B) ASSUMED DEPENDENCE OF CREEP FACTOR ON STRESS

FIGURE 9.1-3: CREEP DEFINITION FOR PLANE-STRAIN CHECKOUT PROBLEM

TABLE 9.1-1: RESULTS FOR PLANE STRAIN WITH Z-LOADS AND CREEP

(1) Incr.	(2) $\Delta\epsilon^p_{YY}$	(3) σ_{YY}	(4) $\frac{3}{2}\alpha_{YY}$	(5) $\lvert\bar{\sigma}-\bar{\alpha}\rvert$	(6) E^1	(7) ϵ^e_{YY}	(8) ϵ^p_{YY}	(9) ϵ^c_{YY}	(10) $\bar{\sigma}_{ave}$	(11) F^c	(12) Δt^c	(13) z-load strain	(14) ϵ^t	(15) Q_{YY}	(16) Temp.
0	-	0	0	2.0	1.0	0	0	0	-	-	-	0	0	0	1.0
1	0	2.0	0	2.0	2.0	1.0	0	0	1.0	1.0	0	0	0.3	1.3	2.0
2	0.5	2.5	0.5	2.0	2.5	1.0	0.5	0.5	2.25	1.0	5.0	0	0.8	2.8	3.0
3	0.5	3.0	1.0	2.0	3.0	1.0	1.0	0.5	2.75	1.0	0	0	1.05	3.55	4.0
4	1.0	3.5	1.5	2.0	3.5	1.0	2.0	1.0	3.25	1.25	4.0	0	1.8	5.8	5.0
5	1.0	4.0	2.0	2.0	4.0	1.0	3.0	1.0	3.75	1.75	0	0	2.3	7.3	6.0
6	0	2.0	2.0	2.0	2.0	1.0	3.0	1.0	3.0	1.0	0	0	2.3	7.3	7.0
7	0	0	2.0	2.0	1.0	0	3.0	1.0	1.0	1.0	0	0	2.0	6.0	5.4
8	-0.5	-0.625	1.5	2.125	1.25	-0.5	2.5	1.0	0.3125	1.0	0	-0.6	1.0	4.0	8.0
9	-0.5	-1.25	1.0	2.25	1.25	-1.0	2.0	0	0.9375	1.0	10.0	-0.2	0.5	1.5	9.0
10	0	1.0	1.0	2.25	2.0	0.5	2.0	0	0.125	1.0	0	0	1.15	3.65	10.0
11	0	3.25	1.0	2.25	3.25	1.0	2.0	1.0	2.125	1.0	10.0	-0.3	1.5	5.5	4.5
12	0.5	3.875	1.5	2.375	3.875	1.0	2.5	1.0	3.5625	1.5625	0	0	2.05	6.55	12.0
13	0.5	4.5	2.0	2.5	4.5	1.0	3.0	1.0	4.1875	2.1875	0	0.2	2.5	7.5	13.0
14	1.0	5.25	2.5	2.75	5.25	1.0	4.0	1.0	4.875	2.875	0	0	2.8	8.8	14.0
15	1.0	6.0	3.0	3.0	3.0	2.0	5.0	4.125	5.625	3.625	10.0	0	5.1625	16.2875	15.0

```
 START          5     5     6
 BOPACE GENERAL CHECK (PLANE STRAIN WITH Z-LOADS, ELASTIC-PLASTIC-CREEP) 06/08/73
     5     3                        1 0.5          .00001
        1    1 1.0        1.0
             1
 1.0         0.0          2.0       0.3        3.0        0.3        4.0        1.05
 4.5         1.5          5.0       1.8        6.0        2.3        7.0        2.3
 8.0         1.0          9.0       0.5        10.0       1.15       12.0       2.05
 13.0        2.5          14.0      2.8        15.0       5.1525

 1.0         1.0          2.0       2.0        3.0        2.5        4.0        3.0
 5.0         3.5          5.4       1.0        6.0        4.0        7.0        2.0
 8.0         1.25         9.0       1.25       10.0       2.0        12.0       3.375
 13.0        4.5          14.0      5.25       15.0       3.0

 0.0         0.3

             1            1
             1 0.
 0.0         2.0          3.0       2.0        9.0        3.5

 0.0         0.0          1.0       1.0        3.0        2.0        9.0        2.5


             1            2
 0.0         0.0          10.0      1.0        30.0       2.0

             1 0.0
 0.0         1.0          3.0       1.0        11.0       9.0


      30       0.0        1.0
      40       1.0        1.0
      10       0.0        0.0
      20       1.0        0.0

      20     1             20    40    10
      10     1             10    40    30

      10     1  -10        10    2   -10        20     2  -20
      30     2  -30        40    2   -40

             2
      30     2 1.0
      40     2 1.0


            15
             1.3                 0.0
             2.8                 5.0
             3.55                0.0
             5.8                 4.0
             7.3                 0.0
             7.3                 0.0
             6.0                 0.0
             4.0                 0.0
             1.5                 10.0
             3.65                0.0
             5.5                 10.0
```

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```
        6.55                  0.0
        7.5                   C.0
        8.8                   C.0
        16.2875               10.0
INCREMENT           1
      10 2.0                20 2.0

INCREMENT           2
      10 3.0                20 3.0

INCREMENT           3
      10 4.0                20 4.0

INCREMENT           4
      10 5.0                20 5.0

INCREMENT           5
      10 6.0                20 6.0

INCREMENT           6
      10 7.0                20 7.0

INCREMENT           7
      10 5.4                20 5.4

INCREMENT           8
      10 8.0                20 8.0

      10 -0.6               20 -0.6

INCREMENT           9
      10 9.0                20 9.0

      10 -0.2               20 -0.2

INCREMENT          10
      10 10.0               20 10.0

      10 0.0                20 0.0

INCREMENT          11
      10 4.5                20 4.5

      10 -0.3               20 -0.3

INCREMENT          12
      10 12.0               20 12.0

      10 0.0                20 0.0

INCREMENT          13
      10 13.0               20 13.0
```

```
          10 0.2              20 0.2
INCREMENT             14
          10 14.0             20 14.0
          10 0.0              20 0.0
INCREMENT             15
          10 15.0             20 15.0
```

```
STARTING PROBLEM

BOPACE GENERAL CHECK (PLANE STRAIN WITH Z-LOADS, ELASTIC-PLASTIC-CREEP) 06/08/73

SOLUTION METHOD CODE =           5
MAXIMUM NO. STIFFNESS UPDATES PER INCREMENT =          3
MAXIMUM TOTAL ITERATIONS PER INCREMENT =          10
MAXIMUM ELASTIC ITERATIONS PER INCREMENT =          2
MAXIMUM MAGNITUDE FOR ELASTIC-PLASTIC SUM CODE =          2
MAXIMUM REDUCTIONS =          1
CONVERGENCE REDUCTION FACTOR =  0.50000E 00
MAXIMUM SPECIFIED ERROR NORM =  0.10000E-04
FRACTION FROM END OF INCREMENT TO EVALUATE SLOPE = 0.10000E 00

PLANE-STRAIN PROBLEM
NO. OF MATERIALS =          1
DEFAULT THICKNESS =  0.10000E 01
FABRICATION TEMPERATURE =  0.10000E 01

MATERIAL NO.    1 TEMPERATURE DEPENDENT PROPERTIES

 TEMPERATURE   THERMAL STRAIN
  0.1000E 01     0.0
  0.2000E 01     0.3000E 00
  0.3000E 01     0.8000E 00
  0.4000E 01     0.1050E 01
  0.4500E 01     0.1500E 01
  0.5000E 01     0.1800E 01
  0.6000E 01     0.2300E 01
  0.7000E 01     0.2300E 01
  0.8000E 01     0.1000E 01
  0.9000E 01     0.5000E 00
  0.1000E 02     0.1150E 01
  0.1200E 02     0.2050E 01
  0.1300E 02     0.2500E 01
  0.1400E 02     0.2800E 01
  0.1500E 02     0.5162E 01

 TEMPERATURE   ELASTIC MOD.
  0.1000E 01     0.1000E 01
  0.2000E 01     0.2000E 01
  0.3000E 01     0.2500E 01
  0.4000E 01     0.3000E 01
  0.5000E 01     0.3500E 01
  0.5400E 01     0.1000E 01
  0.6000E 01     0.4000E 01
  0.7000E 01     0.2000E 01
  0.8000E 01     0.1250E 01
  0.9000E 01     0.1250E 01
  0.1000E 02     0.2000E 01
  0.1200E 02     0.3875E 01
  0.1300E 02     0.4500E 01
  0.1400E 02     0.5250E 01
  0.1500E 02     0.3000E 01

 TEMPERATURE   POISSONS RATIO
  0.0            0.3000E 00
```


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```
MATERIAL NO.    1,PLASTICITY TYPE    1,KINEMATIC CODE    0

MATERIAL NO.    1, TEMPERATURE =  0.0

PARAMETER    ISOTROPIC STRESS
 0.0           0.20000E 01
 0.30000E 01   0.20000E 01
 0.90000E 01   0.35000E 01

PARAMETER    KINEMATIC SHAPE
 0.0           0.0
 0.10000E 01   0.10000E 01
 0.30000E 01   0.20000E 01
 0.90000E 01   0.35000E 01

TEMPERATURE =  0.0

PARAMETER    ISOTROPIC STRESS
 0.0           0.20000E 01
 0.30000E 01   0.20000E 01
 0.90000E 01   0.35000E 01

PARAMETER    KINEMATIC SHAPE
 0.0           0.0
 0.10000E 01   0.10000E 01
 0.30000E 01   0.20000E 01
 0.90000E 01   0.35000E 01
```

```
MATERIAL NO.    1,CREEP TYPE    2

    TIME       CREEP STRAIN
  0.0          0.0
  0.1000E 02   0.1000E 01
  0.3000E 02   0.2000E 01

MATERIAL NO.    1, TEMPERATURE =  0.0
    STRESS     CREEP FACTOR
  0.0          0.1000E 01
  0.3000E 01   0.1000E 01
  0.1100E 02   0.9000E 01

MATERIAL NO.    1, TEMPERATURE =  0.0
    STRESS     CREEP FACTOR
  0.0          0.1000E 01
  0.3000E 01   0.1000E 01
  0.1100E 02   0.9000E 01
```

CARTESIAN COORDINATE SYSTEMS DEFINED
NUMBER X-AXIS ANGLE

** NODE **

NO.	I.D.	LCOORD	X (R)	Y (THETA)	DCOORD
1	30	0	0.0	0.10000D 01	0
2	40	0	0.10000D 01	0.10000D 01	0
3	10	0	0.0	0.0	0
4	20	0	0.10000D 01	0.0	0

ELEMENT

NO.	I.D.	MATERIAL	THICKNESS	NODE 1	NODE 2	NODE 3	AREA
1	20	1	0.1000D 01	20	40	10	0.5000E 00
2	10	1	0.1000D 01	10	40	30	0.5000E 00

SPECIFIED FORCE-DISPLACEMENT-CONSTRAINT DOF

NODE I.D.	COMPONENT	CODE
10	1	-10
10	2	-10
20	2	-20
30	2	-30
40	2	-40

NC. CF LCAC REFERENCE CURVES = 2

LCAC REFERENCE CURVE NO. 1

NCDE	COMPCNENT	LCAC
30	2	C.10000E C1
40	2	C.10000E C1

LCAC REFERENCE CURVE NC. 2

NODE	CCMPCNENT	LCAC

NC. OF LCAC INCREMENTS = 15

INCREMENT	MAX. ITERATICNS	MECHANICAL CURVE FACTORS		CREEP TIME
1	10	0.13000E 01	C.C	0.0
2	10	0.28000E 01	0.0	0.50000E 01
3	10	0.35500E 01	C.C	0.0
4	10	0.58000E 01	0.0	C.40000E 01
5	10	0.73000E 01	C.C	0.0
6	10	C.73000E 01	C.C	0.0
7	10	0.60000E 01	0.0	0.0
8	10	0.40000E 01	C.C	0.0
9	10	C.15000E 01	0.0	0.10000E 02
10	10	0.36500E 01	0.0	0.0
11	10	C.55000E 01	C.C	0.10000E 02
12	10	0.65500E 01	C.C	0.0
13	10	0.75000E 01	C.C	0.0
14	10	C.88000E 01	C.0	0.0
15	10	C.16287E 02	0.0	0.10000E 02

```
CUMULATIVE THERMAL LOADS AND Z-LOADS FOR LOAD INCREMENT     1
INCREMENT            1

ELEMENT I.D.      20          10
TEMP.       0.20000E 01 0.20000E 01
Z-LOAD      0.0         0.0

ITERATIVE ERROR =  0.74557E 00
ITERATIVE ERROR =  0.51221E 00
ITERATIVE ERROR =  0.74557E 00
ITERATIVE ERROR =  0.20911E-06
ITERATIVE ERROR =  0.18029E-06


                    E N D   O F   L O A D   I N C R E M E N T    1

INCREMENT            1
MECHANICAL LOAD CURVE FACTORS =    0.1300E 01,   0.0
CREEP TIME INCREMENT =  0.0
NO. ELASTIC ELEMENTS =     1, NO. PLASTIC ELEMENTS =     1
      1  ELEMENTS HAVE CHANGED ELASTIC TO PLASTIC,     0  ELEMENTS PLASTIC TO ELASTIC DURING THIS INCREMENT
SPECIFIED MAX. NO. STIFFNESS UPDATES =      3, NO. UPDATES PERFORMED =      0
SPECIFIED MAX. NO. ITERATIONS PER UPDATE =     10, NO. ITERATIONS PERFORMED SINCE LAST UPDATE =      5
SPECIFIED MAX. UNBALANCED-FORCE ERROR =  0.1000E-04, ACTUAL ERROR =  0.1803E-06

              *******  CUMULATIVE INTERNAL FORCES AND DISPLACEMENTS  ********
** NODE **    *********  FORCES  *********         *****  DISPLACEMENTS  ******
 NO.  I.D.      U              V                    U              V

   1   30     0.2384166E-06  0.9999990E 00        0.1721911E-06  0.1299999E 01
   2   40    -0.1976633E-06  0.1000000E 01        0.3848754E-06  0.1299999E 01
   3   10    -0.1146242E-06 -0.9999990E 00        0.0            0.0
   4   20     0.7386905E-07 -0.1000000E 01        0.5888560E-06  0.0
```

ELEMENT NO.	I.C.	*** THERMAL STRAINS *** INCREMENTAL	CUMULATIVE	ELASTIC STRAINS — INCREMENTAL XX	YY	ZZ	XY	ELASTIC STRAINS — CUMULATIVE XX	YY	ZZ	XY
1	20	0.3000E 00	0.3000E 00	0.1000E 01	-0.3000E 00	-0.3000E 00	0.1020E-06	0.1000E 01	-0.3000E 00	-0.3000E 00	0.1020E-06
2	10	0.3000E 00	0.3000E 00	0.3500E 00	0.3500E 00	-0.3000E 00	0.6500E 00	0.3500E 00	0.3500E 00	-0.3000E 00	0.6500E 00

ELEMENT NO.	I.C.	***** PLASTIC WORK **** INCREMENTAL	CUMULATIVE	PLASTIC STRAINS — INCREMENTAL XX	YY	ZZ	XY	PLASTIC STRAINS — CUMULATIVE XX	YY	ZZ	XY
1	20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

ELEMENT NO.	I.C.	EFFECTIVE CENTER	EFFECTIVE STRESS	CUMULATIVE STRESS QUANTITIES — STRESS CENTER XX	YY	ZZ	XY	STRESS XX	YY	ZZ	XY
1	20	0.0	0.2000E 01	0.0	0.0	0.0	0.0	0.2000E 01	-0.9170E-08	-0.4677E-06	0.1569E-06
2	10	0.0	0.2000E 01	0.0	0.0	0.0	0.0	0.1000E 01	0.1000E 01	-0.6877E-06	0.1000E 01

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ELEMENT NO.	I.D.	E-P CODE	SUM CODE	INCREMENTAL TEMPERATURE	TOTAL TEMPERATURE	SURFACE YIELD SIZE	**** EFFECTIVE PLASTIC STRAINS *** INCREMENTAL	SUM INCR.	CUMULATIVE	***** EFFECTIVE CREEP STRAINS **** INCREMENTAL	SUM INCR.	CUMULATIVE
1	20	1	1	0.1000E 01	0.2000E 01	0.2000E 01	0.0	0.0	0.0	0.0	0.0	0.0
2	10	0	-2	0.1000E 01	0.2000E 01	0.2000E 01	0.0	0.0	0.0	0.0	0.0	0.0

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CUMULATIVE THERMAL LOADS AND Z-LOADS FOR LOAD INCREMENT 2

```
INCREMENT          2

ELEMENT I.D.      20            10
TEMP.        0.30000E 01  0.30000E 01
Z-LOAD       0.0            0.0

ITERATIVE ERROR =  0.92167E 00
ITERATIVE ERROR =  0.82814E 00
ITERATIVE ERROR =  0.88914E 00
ITERATIVE ERROR =  0.58787E 00
ITERATIVE ERROR =  0.61647E 00
ITERATIVE ERROR =  0.88986E 00
ITERATIVE ERROR =  0.98201E 00
ITERATIVE ERROR =  0.81647E 00
ITERATIVE ERROR =  0.88986E 00
ITERATIVE ERROR =  0.98201E 00
ITERATIVE ERROR =  0.61647E 00
ITERATIVE ERROR =  0.65049E 00
ITERATIVE ERROR =  0.76448E 00
ITERATIVE ERROR =  0.44035E 00
ITERATIVE ERROR =  0.36214E-01
ITERATIVE ERROR =  0.35867E-02
ITERATIVE ERROR =  0.34599E-03
ITERATIVE ERROR =  0.33219E-04
ITERATIVE ERROR =  0.37867E-05
ITERATIVE ERROR =  0.92718E-06
```

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E N D   O F   L O A D   I N C R E M E N T   2

```
INCREMENT          2
MECHANICAL LOAD CURVE FACTORS =    0.2800E 01,  0.0
CREEP TIME INCREMENT =  0.5000E 01
NO. ELASTIC ELEMENTS =      0, NO. PLASTIC ELEMENTS =     2
     1  ELEMENTS HAVE CHANGED ELASTIC TO PLASTIC,     0  ELEMENTS PLASTIC TO ELASTIC DURING THIS INCREMENT
SPECIFIED MAX. NO. STIFFNESS UPDATES =      3, NO. UPDATES PERFORMED =      1
SPECIFIED MAX. NO. ITERATIONS PER UPDATE =      10, NO. ITERATIONS PERFORMED SINCE LAST UPDATE =     10
SPECIFIED MAX. UNBALANCED-FORCE ERROR =  0.1000E-04, ACTUAL ERROR =  0.9272E-06
```

******* CUMULATIVE INTERNAL FORCES AND DISPLACEMENTS ********

** NODE **		********* FORCES *********		***** DISPLACEMENTS ******	
NO.	I.D.	U	V	U	V
1	30	-0.4172325E-06	0.1249999E 01	0.2061823E-06	0.2799999E 01
2	40	0.7219438E-07	0.1249999E 01	0.7573697E-06	0.2799999E 01
3	10	0.5112241E-06	-0.1249999E 01	0.0	0.0
4	20	-0.1661860E-06	-0.1250000E 01	0.8945562E-06	0.0

ELEMENT NC.	I.C.	*** THERMAL STRAINS *** INCREMENTAL	CUMULATIVE	ELASTIC STRAINS: INCREMENTAL XX	YY	ZZ	XY	CUMULATIVE XX	YY	ZZ	XY
1	20	0.5000E 00	C.8000E 0C	C.7749E-06	-C.8345E-06	0.4172E-06	0.8894E-08	0.1000E C1	-0.3000E 00	-C.300CE C0	0.1109E-06
2	10	0.5000E CC	0.8000E 00	-0.1788E-C6	C.4768E-C6	0.0	C.2384E-06	C.3500E C0	0.3500F 00	-0.3000E 00	0.6500E 00

ELEMENT NC.	I.C.	***** PLASTIC WORK **** INCREMENTAL	CUMULATIVE	PLASTIC STRAINS: INCREMENTAL XX	YY	ZZ	XY	CUMULATIVE XX	YY	ZZ	XY
1	20	0.1125E 01	0.1125E 01	C.5000E C0	-C.2500E C0	-0.2500E 00	-0.2585E-07	C.5000E 00	-0.25C0E C0	-0.2500E 00	-0.2585E-07
2	10	0.1125E 01	0.1125E 01	0.1250E C0	C.1250E C0	-0.2500E 00	0.3750E 00	0.1250E 00	0.1250E 00	-0.2500E 00	0.3750E 00

ELEMENT NO.	I.C.	****** CREEP WORK ***** INCREMENTAL	CUMULATIVE	CREEP STRAINS: INCREMENTAL XX	YY	ZZ	XY	CUMULATIVE XX	YY	ZZ	XY
1	20	0.1125E 01	0.1125E 01	0.5000E 00	-C.2500E 00	-0.2500E 00	-0.1644E-07	C.5000E 00	-0.2500E 00	-0.2500E 00	-0.1644E-07
2	10	0.1125E C1	C.1125E 01	C.1250E 00	C.1250E 00	-0.2500E 00	0.3750E 00	0.1250E 00	0.1250E 00	-C.2500E 00	0.3750E 00

ELEMENT NC.	I.C.	EFFECTIVE CENTER	EFFECTIVE STRESS	CUMULATIVE STRESS QUANTITIES: STRESS CENTER XX	YY	ZZ	XY	STRESS XX	YY	ZZ	XY
1	20	0.5000F CC	0.2500E 01	0.3333E 00	-C.1667E 00	-0.1667E 0C	-0.1723E-07	C.2500E 01	-0.5456E-06	0.132CE-05	C.2132E-06
2	10	0.5000E CC	0.2500E 01	C.8333E-01	C.8333E-01	-0.1667E 00	0.2500E 00	C.1250E 01	0.1250E 01	-C.1284E-05	0.1250E 01

ELEMENT NO.	I.C.	E-P CODE	SUM CODE	INCREMENTAL TEMPERATURE	TOTAL TEMPERATURE	SURFACE YIELD SIZE	**** EFFECTIVE PLASTIC STRAINS *** INCREMENTAL	SUM INCR.	CUMULATIVE	***** EFFECTIVE CREEP STRAINS **** INCREMENTAL	SUM INCR.	CUMULATIVE
1	20	0	2	C.1000E 01	0.3000E 01	0.2000E 01	0.5000F C0	0.500CE 00	0.5000E 00	0.5000E 00	C.5000F 00	C.5000E 00
2	10	1	2	0.1000F 01	C.3CC0E 01	0.20C0E 01	0.5000E C0	0.5000E 00	0.5000E 00	0.5000E 00	C.50CCE 00	0.5000E 00

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```
                    CUMULATIVE THERMAL LOADS AND Z-LOADS FOR LOAD INCREMENT    3
INCREMENT           3

ELEMENT I.D.     20          10
TEMP.       0.40000E 01 0.40000E 01
Z-LOAD      0.0         0.0

ITERATIVE ERROR =  0.81160E 00
ITERATIVE ERROR =  0.79893E 00
ITERATIVE ERROR =  0.52446E 00
ITERATIVE ERROR =  0.34059E 00
ITERATIVE ERROR =  0.16222E 00
ITERATIVE ERROR =  0.46823E-01
ITERATIVE ERROR =  0.16448E-01
ITERATIVE ERROR =  0.52084E-02
ITERATIVE ERROR =  0.17755E-02
ITERATIVE ERROR =  0.56927E-03
ITERATIVE ERROR =  0.28329E-04
ITERATIVE ERROR =  0.20166E-05
ITERATIVE ERROR =  0.17412E-05


                         E N D   O F   L O A D   I N C R E M E N T   3

INCREMENT           3
MECHANICAL LOAD CURVE FACTORS =   0.3550E 01,  0.0
CREEP TIME INCREMENT =  0.0
NO. ELASTIC ELEMENTS =     0, NO. PLASTIC ELEMENTS =     2
   0  ELEMENTS HAVE CHANGED ELASTIC TO PLASTIC,     0  ELEMENTS PLASTIC TO ELASTIC DURING THIS INCREMENT
SPECIFIED MAX. NO. STIFFNESS UPDATES =      3, NO. UPDATES PERFORMED =      1
SPECIFIED MAX. NO. ITERATIONS PER UPDATE =     10, NO. ITERATIONS PERFORMED SINCE LAST UPDATE =      3
SPECIFIED MAX. UNBALANCED-FORCE ERROR =  0.1000E-04, ACTUAL ERROR =  0.1741E-05


              *******  CUMULATIVE INTERNAL FORCES AND DISPLACEMENTS  ********
** NODE **    *********  FORCES  *********        *****  DISPLACEMENTS  ******
 NO.  I.D.         U                V                   U               V

   1   30     0.5960470E-07  0.1499999E 01        0.1926832E-06  0.3549599E 01
   2   40    -0.4837949E-06  0.1499999E 01       -0.9204579E-06  0.3549599E 01
   3   10    -0.2636358E-06 -0.1499999E 01        0.0            0.0
   4   20     0.6878261E-06 -0.1500000E 01       -0.6157362E-06  0.0
```

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ELEMENT NO.	I.C.	*** THERMAL STRAINS *** INCREMENTAL	CUMULATIVE	ELASTIC STRAINS — INCREMENTAL XX	YY	ZZ	XY	CUMULATIVE XX	YY	ZZ	XY
1	20	0.2500E 00	0.1050E 01	0.5960E-06	-0.2384E-06	0.2980E-06	0.5012E-07	0.1000E 01	-0.3000E 00	-0.3000E 00	0.1610E-06
2	10	0.2500E 00	0.1050E 01	-0.2384E-06	-0.1788E-06	0.8345E-06	0.7153E-06	0.3500E 00	0.3500E 00	-0.3000E 00	0.6500E 00

ELEMENT NO.	I.C.	***** PLASTIC WORK **** INCREMENTAL	CUMULATIVE	PLASTIC STRAINS — INCREMENTAL XX	YY	ZZ	XY	CUMULATIVE XX	YY	ZZ	XY
1	20	0.1375E 01	0.2500E 01	0.5000E 00	-0.2500E 00	-0.2500E 00	0.3365E-07	0.1000E 01	-0.5000E 00	-0.5000E 00	0.7799E-08
2	10	0.1375E 01	0.2500E 01	0.1250E 00	0.1250E 00	-0.2500E 00	0.3750E 00	0.2500E 00	0.2500E 00	-0.5000E 00	0.7500E 00

ELEMENT NO.	I.C.	EFFECTIVE CENTER	EFFECTIVE STRESS	CUMULATIVE STRESS QUANTITIES — STRESS CENTER XX	YY	ZZ	XY	STRESS XX	YY	ZZ	XY
1	20	0.1000E 01	0.3000E 01	0.6667E 00	-0.3333E 00	-0.3333E 00	0.5199E-08	0.3000E 01	0.1004E-05	0.4420E-05	0.3715E-06
2	10	0.1000E 01	0.3000E 01	0.1667E 00	0.1667E 00	-0.3333E 00	0.5000E 00	0.1500E 01	0.1500E 01	0.6236E-06	0.1500E 01

ELEMENT NO.	I.C.	E-P CODE	SUM CODE	INCREMENTAL TEMPERATURE	TOTAL TEMPERATURE	SURFACE YIELD SIZE	**** EFFECTIVE PLASTIC STRAINS *** INCREMENTAL	SUM INCR.	CUMULATIVE	***** EFFECTIVE CREEP STRAINS **** INCREMENTAL	SUM INCR.	CUMULATIVE
1	20	0	2	0.1000E 01	0.4000E 01	0.2000E 01	0.5000E 00	0.1000E 01	0.1000E 01	0.0	0.5000E 00	0.5000E 00
2	10	0	2	0.1000E 01	0.4000E 01	0.2000E 01	0.5000E 00	0.1000E 01	0.1000E 01	0.0	0.5000E 00	0.5000E 00

```
                         CUMULATIVE THERMAL LOADS AND Z-LOADS FOR LOAD INCREMENT    4
INCREMENT             4

ELEMENT I.D.       20           10
TEMP.       0.50000E 01 0.50000E 01
Z-LOAD      0.0          0.0

ITERATIVE ERROR =  0.50061E 00
ITERATIVE ERROR =  0.50270E 00
ITERATIVE ERROR =  0.61026E 00
ITERATIVE ERROR =  0.80980E 00
ITERATIVE ERROR =  0.78010E 00
ITERATIVE ERROR =  0.58597E 00
ITERATIVE ERROR =  0.30772E 00
ITERATIVE ERROR =  0.60747E-01
ITERATIVE ERROR =  0.14590E-01
ITERATIVE ERROR =  0.27986E-02
ITERATIVE ERROR =  0.66289E-04
ITERATIVE ERROR =  0.65623E-05
ITERATIVE ERROR =  0.60714E-05


                    E N D   O F   L O A D   I N C R E M E N T    4

INCREMENT             4
MECHANICAL LOAD CURVE FACTORS =    0.5800E 01,   0.0
CREEP TIME INCREMENT =  0.4000E 01
NO. ELASTIC ELEMENTS =     0, NO. PLASTIC ELEMENTS =     2
     0  ELEMENTS HAVE CHANGED ELASTIC TO PLASTIC,     0  ELEMENTS PLASTIC TO ELASTIC DURING THIS INCREMENT
SPECIFIED MAX. NO. STIFFNESS UPDATES =      3, NO. UPDATES PERFORMED =      1
SPECIFIED MAX. NO. ITERATIONS PER UPDATE =     10, NO. ITERATIONS PERFORMED SINCE LAST UPDATE =      3
SPECIFIED MAX. UNBALANCED-FORCE ERROR =  0.1000E-04, ACTUAL ERROR =  0.6071E-05


                  *******  CUMULATIVE INTERNAL FORCES AND DISPLACEMENTS  ********
** NODE **        *********   FORCES   *********          *****  DISPLACEMENTS  ******
  NO.  I.D.        U                V                      U                V

   1    30       0.1490116E-05  0.1749996E 01       -0.5040766E-06   0.5799959E 01
   2    40      -0.2461763E-05  0.1749997E 01       -0.1485283E-05   0.5799959E 01
   3    10       0.6304343E-06 -0.1749995E 01        0.0             0.0
   4    20       0.3412134E-06 -0.1749999E 01       -0.7957215E-06   0.0
```


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ELEMENT NO.	I.C.	*** THERMAL STRAINS *** INCREMENTAL	CUMULATIVE	ELASTIC STRAINS: INCREMENTAL XX	YY	ZZ	XY	CUMULATIVE XX	YY	ZZ	XY
1	20	0.7500E 00	0.1800E 01	0.2384E-06	-0.6557E-06	0.2384E-06	0.2066E-06	0.1000E 01	-0.3000E 00	-0.3000E 00	0.3676E-06
2	10	0.7500E 00	0.1800E 01	-0.2980E-06	-0.2980E-06	-0.3576E-06	0.3576E-06	0.3500E 00	0.3500E 00	-0.3000E 00	0.6500E 00

ELEMENT NO.	I.C.	***** PLASTIC WORK **** INCREMENTAL	CUMULATIVE	PLASTIC STRAINS: INCREMENTAL XX	YY	ZZ	XY	CUMULATIVE XX	YY	ZZ	XY
1	20	0.3250E 01	0.5750E 01	0.1000E 01	-0.5000E 00	-0.5000E 00	-0.1982E-07	0.2000E 01	-0.1000E 01	-0.1000E 01	-0.1202E-07
2	10	0.3250E 01	0.5750E 01	0.2500E 00	0.2500E 00	-0.5000E 00	0.7500E 00	0.5000E 00	0.5000E 00	-0.1000E 01	0.1500E 01

ELEMENT NO.	I.C.	****** CREEP WORK ***** INCREMENTAL	CUMULATIVE	CREEP STRAINS: INCREMENTAL XX	YY	ZZ	XY	CUMULATIVE XX	YY	ZZ	XY
1	20	0.1625E 01	0.2750E 01	0.5000E 00	-0.2500E 00	-0.2500E 00	0.5669E-08	0.1000E 01	-0.5000E 00	-0.5000E 00	-0.1077E-07
2	10	0.1625E 01	0.2750E 01	0.1250E 00	0.1250E 00	-0.2500E 00	0.3750E 00	0.2500E 00	0.2500E 00	-0.5000E 00	0.7500E 00

ELEMENT NO.	I.C.	EFFECTIVE CENTER	EFFECTIVE STRESS	CUMULATIVE STRESS QUANTITIES: STRESS CENTER XX	YY	ZZ	XY	STRESS XX	YY	ZZ	XY
1	20	0.1500E 01	0.3500E 01	0.1000E 01	-0.5000E 00	-0.5000E 00	-0.1408E-08	0.3500E 01	-0.3072E-06	0.4062E-05	0.9896E-06
2	10	0.1500E 01	0.3500E 01	0.2500E 00	0.2500E 00	-0.5000E 00	0.7500E 00	0.1750E 01	0.1750E 01	-0.1880E-05	0.1750E 01

ELEMENT NO.	I.C.	E-P CODE	SUM CODE	INCREMENTAL TEMPERATURE	TOTAL TEMPERATURE	SURFACE YIELD SIZE	**** EFFECTIVE PLASTIC STRAINS *** INCREMENTAL	SUM INCR.	CUMULATIVE	***** EFFECTIVE CREEP STRAINS **** INCREMENTAL	SUM INCR.	CUMULATIVE
1	20	0	2	0.1000E 01	0.5000E 01	0.2000E 01	0.1000E 01	0.2000E 01	0.2000E 01	0.5000E 00	0.1000E 01	0.1000E 01
2	10	0	2	0.1000E 01	0.5000E 01	0.2000E 01	0.1000E 01	0.2000E 01	0.2000E 01	0.5000E 00	0.1000E 01	0.1000E 01

```
                    CUMULATIVE THERMAL LOADS AND Z-LOADS FOR LOAD INCREMENT    5
INCREMENT          5

ELEMENT I.C.     20          10
TEMP.       C.60000E 01 0.60000E 01
Z-LOAD      C.0         C.0

ITERATIVE ERROR =  0.85454E 00
ITERATIVE ERROR =  0.61964E 00
ITERATIVE ERROR =  0.93655E 00
ITERATIVE ERROR =  0.63288E 00
ITERATIVE ERROR =  0.29106E 00
ITERATIVE ERROR =  0.38299E-01
ITERATIVE ERROR =  0.60396E-02
ITERATIVE ERROR =  0.52193E-03
ITERATIVE ERROR =  0.14100E-03
ITERATIVE ERROR =  0.21530E-04
ITERATIVE ERROR =  0.45713E-06
ITERATIVE ERROR =  0.34204E-05



                         E N D  O F  L O A D  I N C R E M E N T   5

INCREMENT          5
MECHANICAL LOAD CURVE FACTORS =   0.730OE 01,  0.0
CREEP TIME INCREMENT =  0.0
NO. ELASTIC ELEMENTS =     C, NO. PLASTIC ELEMENTS =    2
     0  ELEMENTS HAVE CHANGED ELASTIC TO PLASTIC,     0  ELEMENTS PLASTIC TO ELASTIC DURING THIS INCREMENT
SPECIFIED MAX. NO. STIFFNESS UPDATES =      3, NO. UPDATES PERFORMED =      1
SPECIFIED MAX. NO. ITERATIONS PER UPDATE =     10, NO. ITERATIONS PERFORMED SINCE LAST UPDATE =     2
SPECIFIED MAX. UNBALANCED-FORCE ERROR =  0.1000E-04, ACTUAL ERROR =  0.3420E-05




                ******* CUMULATIVE INTERNAL FORCES AND DISPLACEMENTS ********
** NODE **      *********  FORCES  *********        *****  DISPLACEMENTS  ******
 NO.  I.C.       U                V                   U                 V

   1   30   -0.4172325E-06  0.1999995E 01      -0.1782309E-05  0.7299999E 01
   2   40   -0.8503912E-06  C.1999996E 01      -0.1966750E-05  0.7299999E 01
   3   1C    0.2418570E-05 -0.1999994E 01       0.0             0.0
   4   20   -0.1150946E-05 -0.1999998E 01      -0.1236942E-05  0.0
```

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ELEMENT NO.	I.D.	*** THERMAL STRAINS *** INCREMENTAL	CUMULATIVE	ELASTIC STRAINS — INCREMENTAL XX	YY	ZZ	XY	ELASTIC STRAINS — CUMULATIVE XX	YY	ZZ	XY
1	20	0.5000E 00	0.2300E 01	0.1788E-06	-0.9537E-06	0.3576E-06	0.1464E-06	0.1000E 01	-0.3000E 00	-0.3000E 00	0.5140E-06
2	10	0.5000E 00	0.2300E 01	0.8345E-06	0.7153E-06	-0.8345E-06	0.5960E-07	0.3500E 00	0.3500E 00	-0.3000E 00	0.6500E 00

ELEMENT NO.	I.D.	***** PLASTIC WORK **** INCREMENTAL	CUMULATIVE	PLASTIC STRAINS — INCREMENTAL XX	YY	ZZ	XY	PLASTIC STRAINS — CUMULATIVE XX	YY	ZZ	XY
1	20	0.3750E 01	0.9500E 01	0.1000E 01	-0.5000E 00	-0.5000E 00	-0.1263E-06	0.3000E 01	-0.1500E 01	-0.1500E 01	-0.1383E-06
2	10	0.3750E 01	0.9500E 01	0.2500E 00	0.2500E 00	-0.5000E 00	0.7500E 00	0.7500E 00	0.7500E 00	-0.1500E 01	0.2250E 01

ELEMENT NO.	I.D.	EFFECTIVE CENTER	EFFECTIVE STRESS	CUMULATIVE STRESS QUANTITIES — STRESS CENTER XX	YY	ZZ	XY	STRESS XX	YY	ZZ	XY
1	20	0.2000E 01	0.4000E 01	0.1333E 01	-0.6667E 00	-0.6667E 00	-0.4351E-07	0.4000E 01	-0.3883E-05	0.6208E-05	0.1582E-05
2	10	0.2000E 01	0.4000E 01	0.3333E 00	0.3333E 00	-0.6667E 00	0.1000E 01	0.2000E 01	0.2000E 01	-0.3906E-05	0.2000E 01

ELEMENT NO.	I.D.	E-P CODE	SUM CODE	INCREMENTAL TEMPERATURE	TOTAL TEMPERATURE	SURFACE YIELD SIZE	**** EFFECTIVE PLASTIC STRAINS *** INCREMENTAL	SUM INCR.	CUMULATIVE	***** EFFECTIVE CREEP STRAINS **** INCREMENTAL	SUM INCR.	CUMULATIVE
1	20	0	2	0.1000E 01	0.6000E 01	0.2000E 01	0.1000E 01	0.3000E 01	0.3000E 01	0.0	0.1000E 01	0.1000E 01
2	10	0	2	0.1000E 01	0.6000E 01	0.2000E 01	0.1000E 01	0.3000E 01	0.3000E 01	0.0	0.1000E 01	0.1000E 01

CUMULATIVE THERMAL LOADS AND Z-LOADS FOR LOAD INCREMENT 6

INCREMENT 6

ELEMENT I.D. 20 10
TEMP. 0.70000E 01 0.70000E 01
Z-LOAD 0.0 0.0

ITERATIVE ERROR = 0.17055E-05

E N D O F L O A D I N C R E M E N T 6

INCREMENT 6
MECHANICAL LOAD CURVE FACTORS = 0.7300E 01, 0.0
CREEP TIME INCREMENT = 0.0
NO. ELASTIC ELEMENTS = 2, NO. PLASTIC ELEMENTS = 0
0 ELEMENTS HAVE CHANGED ELASTIC TO PLASTIC, 2 ELEMENTS PLASTIC TO ELASTIC DURING THIS INCREMENT
SPECIFIED MAX. NO. STIFFNESS UPDATES = 3, NO. UPDATES PERFORMED = 0
SPECIFIED MAX. NO. ITERATIONS PER UPDATE = 10, NO. ITERATIONS PERFORMED SINCE LAST UPDATE = 1
SPECIFIED MAX. UNBALANCED-FORCE ERROR = 0.1000E-04, ACTUAL ERROR = 0.1706E-05

9.7-25

******* CUMULATIVE INTERNAL FORCES AND DISPLACEMENTS ********

** NODE **		********* FORCES *********		***** DISPLACEMENTS ******	
NO.	I.D.	U	V	U	V
1	30	-0.1370907E-05	0.9999952E 00	-0.7318404E-06	0.7299999E 01
2	40	0.1086090E-05	0.9999962E 00	-0.7711196E-06	0.7299999E 01
3	10	-0.2082174E-05	-0.9999943E 00	0.0	0.0
4	20	0.2366952E-05	-0.9999971E 00	-0.6387505E-06	0.0

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ELEMENT NO.	I.C.	*** THERMAL STRAINS *** INCREMENTAL	CUMULATIVE	ELASTIC STRAINS – INCREMENTAL XX	YY	ZZ	XY	ELASTIC STRAINS – CUMULATIVE XX	YY	ZZ	XY
1	20	0.0	0.2300E 01	0.0	0.5982E-06	0.0	-0.2987E-06	0.1000E 01	-0.3000E 00	-0.3000E 00	0.2153E-06
2	10	0.0	0.2300E 01	0.5978E-06	-0.4527E-06	0.0	-0.7258E-07	0.3500E 00	0.3500E 00	-0.3000E 00	0.6500E 00

ELEMENT NO.	I.C.	***** PLASTIC WORK **** INCREMENTAL	CUMULATIVE	PLASTIC STRAINS – INCREMENTAL XX	YY	ZZ	XY	PLASTIC STRAINS – CUMULATIVE XX	YY	ZZ	XY
1	20	0.0	0.9500E 01	0.0	0.0	0.0	0.0	0.3000E 01	-0.1500E 01	-0.1500E 01	-0.1383E-06
2	10	0.0	0.9500E 01	0.0	0.0	0.0	0.0	0.7500E 00	0.7500E 00	-0.1500E 01	0.2250E 01

ELEMENT NO.	I.C.	EFFECTIVE CENTER	EFFECTIVE STRESS	CUMULATIVE STRESS QUANTITIES – STRESS CENTER XX	YY	ZZ	XY	STRESS XX	YY	ZZ	XY
1	20	0.2000E 01	0.2000E 01	0.1333E 01	-0.6667E 00	-0.6667E 00	-0.4351E-07	0.2000E 01	0.4403E-05	0.6898E-05	0.3312E-06
2	10	0.2000E 01	0.2000E 01	0.3333E 00	0.3333E 00	-0.6667E 00	0.1000E 01	0.1000E 01	0.1000E 01	-0.1832E-05	0.1000E 01

ELEMENT NO.	I.C.	E-P CODE	SUM CODE	INCREMENTAL TEMPERATURE	TOTAL TEMPERATURE	SURFACE YIELD SIZE	**** EFFECTIVE PLASTIC STRAINS *** INCREMENTAL	SUM INCR.	CUMULATIVE	***** EFFECTIVE CREEP STRAINS **** INCREMENTAL	SUM INCR.	CUMULATIVE
1	20	-1	-1	0.1000E 01	0.7000E 01	0.2000E 01	0.0	0.3000E 01	0.3000E 01	0.0	0.1000E 01	0.1000E 01
2	10	-1	-1	0.1000E 01	0.7000E 01	0.2000E 01	0.0	0.3000E 01	0.3000E 01	0.0	0.1000E 01	0.1000E 01

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CUMULATIVE THERMAL LOADS AND Z-LOADS FOR LOAD INCREMENT 7

INCREMENT 7

ELEMENT I.D. 20 10
TEMP. C.54000E 01 C.54000E 01
Z-LOAD C.0 C.0

ITERATIVE ERRCR = 0.42622E 00
ITERATIVE ERRCR = 0.30171E 00
ITERATIVE ERRCR = 0.23360E 00
ITERATIVE ERRCR = 0.17C19E 00
ITERATIVE ERRCR = 0.12406E C0
ITERATIVE ERRCR = 0.90581E-01
ITERATIVE ERRCR = 0.66250E-01
ITERATIVE ERRCR = 0.48530E-01
ITERATIVE ERRCR = 0.35597E-01
ITERATIVE ERRCR = 0.26137E-01
ITERATIVE ERRCR = 0.12619E-02
ITERATIVE ERRCR = 0.11159E-03
ITERATIVE ERRCR = 0.12630E-05
ITERATIVE ERRCR = 0.34315E-06

END OF LOAD INCREMENT 7

9.1-27

INCREMENT 7
MECHANICAL LOAD CURVE FACTORS = 0.6000E 01, 0.0
CREEP TIME INCREMENT = 0.0
NO. ELASTIC ELEMENTS = 0, NO. PLASTIC ELEMENTS = 2
2 ELEMENTS HAVE CHANGED ELASTIC TO PLASTIC, 0 ELEMENTS PLASTIC TO ELASTIC DURING THIS INCREMENT
SPECIFIED MAX. NO. STIFFNESS UPDATES = 3, NO. UPDATES PERFORMED = 1
SPECIFIED MAX. NO. ITERATIONS PER UPDATE = 10, NO. ITERATIONS PERFORMED SINCE LAST UPDATE = 4
SPECIFIED MAX. UNBALANCED-FORCE ERROR = 0.1000E-04, ACTUAL ERROR = 0.3431E-06

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******* CUMULATIVE INTERNAL FORCES AND DISPLACEMENTS ********

** NODE **		********* FORCES *********		***** DISPLACEMENTS ******	
NO.	I.D.	U	V	U	V
1	30	-0.4172326E-06	-0.3516674E-05	-0.6971468E-06	C.6C00000E 01
2	40	0.4987565E-06	-0.2861023E-05	-0.5336210E-05	C.6000000E 01
3	1C	-0.1361004E-06	0.4053116E-05	0.0	0.0
4	20	0.5457656E-07	0.2324581E-05	-0.6988167E-05	0.0

ELEMENT NO.	I.C.	*** THERMAL STRAINS *** INCREMENTAL	CUMULATIVE	ELASTIC STRAINS — INCREMENTAL XX	YY	ZZ	XY	ELASTIC STRAINS — CUMULATIVE XX	YY	ZZ	XY
1	20	-0.3000E 00	0.2000E 01	-0.1000E 01	0.3000E 00	0.3000E 00	-0.8922E-06	0.4172E-05	-0.7808E-05	0.1311E-05	-0.6769E-06
2	10	-0.3000E 00	0.2000E 01	-0.3500E 00	-0.3500E 00	0.3000E 00	-0.6500E 00	0.1788E-06	-0.4768E-06	0.1192E-06	0.4530E-05

ELEMENT NO.	I.C.	***** PLASTIC WORK **** INCREMENTAL	CUMULATIVE	PLASTIC STRAINS — INCREMENTAL XX	YY	ZZ	XY	PLASTIC STRAINS — CUMULATIVE XX	YY	ZZ	XY
1	20	0.0	0.9500E 01	-0.2264E-05	0.1132E-05	0.1132E-05	-0.8163E-12	0.3000E 01	-0.1500E 01	-0.1500E 01	-0.1383E-06
2	10	0.0	0.9500E 01	-0.3509E-06	-0.3509E-06	0.7019E-06	-0.1053E-05	0.7500E 00	0.7500E 00	-0.1500E 01	0.2250E 01

ELEMENT NO.	I.C.	EFFECTIVE CENTER	EFFECTIVE STRESS	CUMULATIVE STRESS QUANTITIES — STRESS CENTER XX	YY	ZZ	XY	STRESS XX	YY	ZZ	XY
1	20	0.2000E 01	0.7867E-05	0.1333E 01	-0.6667E 00	-0.6667E 00	-0.4351E-07	-0.3338E-05	0.6298E-06	0.5665E-05	-0.5207E-06
2	10	0.2000E 01	0.4907E-05	0.3333E 00	0.3333E 00	-0.6667E 00	0.1000E 01	-0.2444E-05	-0.1729E-05	-0.3357E-06	-0.2623E-05

ELEMENT NO.	I.C.	E-P CODE	SUM CODE	INCREMENTAL TEMPERATURE	TOTAL TEMPERATURE	SURFACE YIELD SIZE	**** EFFECTIVE PLASTIC STRAINS *** INCREMENTAL	SUM INCR.	CUMULATIVE	***** EFFECTIVE CREEP STRAINS **** INCREMENTAL	SUM INCR.	CUMULATIVE
1	20	1	2	-0.1600E 01	0.5400E 01	0.2000E 01	0.2264E-05	0.3000E 01	0.3000E 01	0.0	0.1000E 01	0.1000E 01
2	10	1	2	-0.1600E 01	0.5400E 01	0.2000E 01	0.1404E-05	0.3000E 01	0.3000E 01	0.0	0.1000E 01	0.1000E 01

```
                 CUMULATIVE THERMAL LOADS AND Z-LOADS FOR LOAD INCREMENT    8
 INCREMENT           8

 ELEMENT I.D.      20          10
 TEMP.       0.80000E 01 0.80000E 01
 Z-LOAD     -0.60000E 00-0.60000E 00

 ITERATIVE ERROR =  0.95620E 00
 ITERATIVE ERROR =  0.78952E 00
 ITERATIVE ERROR =  0.81256E 00
 ITERATIVE ERROR =  0.26832E 00
 ITERATIVE ERROR =  0.10396E 00
 ITERATIVE ERROR =  0.29551E-01
 ITERATIVE ERROR =  0.91452E-02
 ITERATIVE ERROR =  0.27538E-02
 ITERATIVE ERROR =  0.83604E-03
 ITERATIVE ERROR =  0.25289E-03
 ITERATIVE ERROR =  0.10876E-04
 ITERATIVE ERROR =  0.12559E-05
 ITERATIVE ERROR =  0.59506E-06


                      E N D   O F   L O A D   I N C R E M E N T    8

 INCREMENT           8
 MECHANICAL LOAD CURVE FACTORS =   0.4000E 01,  0.0
 CREEP TIME INCREMENT =  0.0
 NO. ELASTIC ELEMENTS =     0, NO. PLASTIC ELEMENTS =     2
     0  ELEMENTS HAVE CHANGED ELASTIC TO PLASTIC,     0  ELEMENTS PLASTIC TO ELASTIC DURING THIS INCREMENT
 SPECIFIED MAX. NO. STIFFNESS UPDATES =      3, NO. UPDATES PERFORMED =     1
 SPECIFIED MAX. NO. ITERATIONS PER UPDATE =     10, NO. ITERATIONS PERFORMED SINCE LAST UPDATE =      3
 SPECIFIED MAX. UNBALANCED-FORCE ERROR =  0.1000E-04, ACTUAL ERROR =  0.5951E-06


             *******  CUMULATIVE INTERNAL FORCES AND DISPLACEMENTS  ********
 ** NODE **    *********  FORCES  *********          *****  DISPLACEMENTS  ******
  NO.  I.D.     U                 V                   U                V

    1   30   -0.2980233E-06 -0.3125035E 00     -0.1033893E-05  0.4000000E 01
    2   40    0.7596191E-07 -0.3125043E 00     -0.6000021E 00  0.4000000E 01
    3   10    0.3740451E-06  0.3125044E 00      0.0             0.0
    4   20   -0.1519833E-06  0.3125035E 00     -0.6000034E 00  0.0
```

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ELEMENT NO.	I.D.	*** THERMAL STRAINS *** INCREMENTAL	CUMULATIVE	ELASTIC STRAINS: INCREMENTAL XX	YY	ZZ	XY	CUMULATIVE XX	YY	ZZ	XY
1	20	-0.1000E 01	0.1000E 01	-0.5000E 00	0.1500E 00	0.1500E 00	0.2709E-06	-0.5000E 00	0.1500E 00	0.1500E 00	-0.4059E-06
2	10	-0.1000E 01	0.1000E 01	-0.1750E 00	-0.1750E 00	0.1500E 00	-0.3250E 00	-0.1750E 00	-0.1750E 00	0.1500E 00	-0.3250E 00

ELEMENT NO.	I.D.	***** PLASTIC WORK **** INCREMENTAL	CUMULATIVE	PLASTIC STRAINS: INCREMENTAL XX	YY	ZZ	XY	CUMULATIVE XX	YY	ZZ	XY
1	20	0.1563E 00	0.9656E 01	-0.5000E 00	0.2500E 00	0.2500E 00	-0.9211E-07	0.2500E 01	-0.1250E 01	-0.1250E 01	-0.2304E-06
2	10	0.1563E 00	0.9656E 01	-0.1250E 00	-0.1250E 00	0.2500E 00	-0.3750E 00	0.6250E 00	0.6250E 00	-0.1250E 01	0.1875E 01

ELEMENT NO.	I.D.	EFFECTIVE CENTER	EFFECTIVE STRESS	CUMULATIVE STRESS QUANTITIES: STRESS CENTER XX	YY	ZZ	XY	STRESS XX	YY	ZZ	XY
1	20	0.1500E 01	0.6250E 00	0.1000E 01	-0.5000E 00	-0.5000E 00	-0.1049E-06	-0.6250E 00	0.8637E-07	0.2201E-05	-0.3903E-06
2	10	0.1500E 01	0.6250E 00	0.2500E 00	0.2500E 00	-0.5000E 00	0.7500E 00	-0.3125E 00	-0.3125E 00	-0.3228E-05	-0.3125E 00

ELEMENT NO.	I.D.	E-P CODE	SUM CODE	INCREMENTAL TEMPERATURE	TOTAL TEMPERATURE	SURFACE YIELD SIZE	**** EFFECTIVE PLASTIC STRAINS *** INCREMENTAL	SUM INCR.	CUMULATIVE	***** EFFECTIVE CREEP STRAINS **** INCREMENTAL	SUM INCR.	CUMULATIVE
1	20	0	2	0.2600E 01	0.8000E 01	0.2125E 01	0.5000E 00	0.3500E 01	0.2500E 01	0.0	0.1000E 01	0.1000E 01
2	10	0	2	0.2600E 01	0.8000E 01	0.2125E 01	0.5000E 00	0.3500E 01	0.2500E 01	0.0	0.1000E 01	0.1000E 01

CUMULATIVE THERMAL LOADS AND Z-LOADS FOR LOAD INCREMENT 9

```
INCREMENT          9

ELEMENT I.D.       20          10
TEMP.        0.90000E 01 0.90000E 01
Z-LOAD      -0.20000E 00-0.20000E 00

ITERATIVE ERROR =  0.82428E 00
ITERATIVE ERROR =  0.74455E 00
ITERATIVE ERROR =  0.40413E 00
ITERATIVE ERROR =  0.14128E-01
ITERATIVE ERROR =  0.69163E-02
ITERATIVE ERROR =  0.12068E-02
ITERATIVE ERROR =  0.29664E-03
ITERATIVE ERROR =  0.64185E-04
ITERATIVE ERROR =  0.14244E-04
ITERATIVE ERROR =  0.41961E-05
ITERATIVE ERROR =  0.61726E-05
```

E N D   O F   L O A D   I N C R E M E N T   9

```
INCREMENT          9
MECHANICAL LOAD CURVE FACTORS =   0.1500E 01,  0.0
CREEP TIME INCREMENT =  0.1000E 02
NO. ELASTIC ELEMENTS =     0, NO. PLASTIC ELEMENTS =     2
     0  ELEMENTS HAVE CHANGED ELASTIC TO PLASTIC,     0  ELEMENTS PLASTIC TO ELASTIC DURING THIS INCREMENT
SPECIFIED MAX. NO. STIFFNESS UPDATES =      3, NO. UPDATES PERFORMED =      1
SPECIFIED MAX. NO. ITERATIONS PER UPDATE =     10, NO. ITERATIONS PERFORMED SINCE LAST UPDATE =      1
SPECIFIED MAX. UNBALANCED-FORCE ERROR =  0.1000E-04, ACTUAL ERROR =  0.6173E-05
```

******* CUMULATIVE INTERNAL FORCES AND DISPLACEMENTS ********

** NODE **		********* FORCES *********		***** DISPLACEMENTS ******	
NO.	I.D.	U	V	U	V
1	30	-0.2205371E-05	-0.6250015E 00	-0.3952121E-05	0.1500000E 01
2	40	0.1439869E-05	-0.6250042E 00	-0.2000027E 00	0.1500000E 01
3	10	0.2576102E-05	0.6250030E 00	0.0	0.0
4	20	-0.1810600E-05	0.6250029E 00	-0.2000050E 00	0.0

ELEMENT NO.	I.C.	*** THERMAL STRAINS *** INCREMENTAL	CUMULATIVE	ELASTIC STRAINS — INCREMENTAL XX	YY	ZZ	XY	CUMULATIVE XX	YY	ZZ	XY
1	20	-0.5000E 00	0.5000E 00	-0.5000E 00	0.1500E 00	0.1500E 00	0.1456E-07	-0.1000E 01	0.3000E 00	0.3000E 00	-0.3914E-06
2	10	-0.5000E 00	0.5000E 00	-0.1750E 00	-0.1750E 00	0.1500E 00	-0.3250E 00	-0.3500E 00	-0.3500E 00	0.3000E 00	-0.6500E 00

ELEMENT NO.	I.C.	***** PLASTIC WORK **** INCREMENTAL	CUMULATIVE	PLASTIC STRAINS — INCREMENTAL XX	YY	ZZ	XY	CUMULATIVE XX	YY	ZZ	XY
1	20	0.4688E 00	0.1012E 02	-0.5000E 00	0.2500E 00	0.2500E 00	-0.5287E-07	0.2000E 01	-0.1000E 01	-0.1000E 01	-0.2833E-06
2	10	0.4688E 00	0.1012E 02	-0.1250E 00	-0.1250E 00	0.2500E 00	-0.3750E 00	0.5000E 00	0.5000E 00	-0.1000E 01	0.1500E 01

ELEMENT NO.	I.C.	****** CREEP WORK ***** INCREMENTAL	CUMULATIVE	CREEP STRAINS — INCREMENTAL XX	YY	ZZ	XY	CUMULATIVE XX	YY	ZZ	XY
1	20	0.9375E 00	0.3688E 01	-0.1000E 01	0.5000E 00	0.5000E 00	-0.4683E-06	0.2384E-06	0.2384E-06	-0.4768E-06	-0.4791E-06
2	10	0.9375E 00	0.3688E 01	-0.2500E 00	-0.2500E 00	0.5000E 00	-0.7500E 00	0.4768E-06	0.1073E-05	-0.1550E-05	-0.5960E-07

ELEMENT NO.	I.C.	EFFECTIVE CENTER	EFFECTIVE STRESS	CUMULATIVE STRESS QUANTITIES — STRESS CENTER XX	YY	ZZ	XY	STRESS XX	YY	ZZ	XY
1	20	0.1000E 01	0.1250E 01	0.6667E 00	-0.3333E 00	-0.3333E 00	-0.1402E-06	-0.1250E 01	-0.3245E-05	0.1969E-05	-0.3763E-06
2	10	0.1000E 01	0.1250E 01	0.1667E 00	0.1667E 00	-0.3333E 00	0.5000E 00	-0.6250E 00	-0.6250E 00	-0.1036E-05	-0.6250E 00

ELEMENT NO.	I.C.	E-P CODE	SUM CODE	INCREMENTAL TEMPERATURE	TOTAL TEMPERATURE	SURFACE YIELD SIZE	**** EFFECTIVE PLASTIC STRAINS *** INCREMENTAL	SUM INCR.	CUMULATIVE	***** EFFECTIVE CREEP STRAINS **** INCREMENTAL	SUM INCR.	CUMULATIVE
1	20	0	2	0.1000E 01	0.9000E 01	0.2250E 01	0.5000E 00	0.4000E 01	0.2000E 01	0.1000E 01	0.2000E 01	0.7304E-06
2	10	0	2	0.1000E 01	0.9000E 01	0.2250E 01	0.5000E 00	0.4000E 01	0.2000E 01	0.1000E 01	0.2000E 01	0.1589E-05

```
                           CUMULATIVE THERMAL LOADS AND Z-LOADS FOR LOAD INCREMENT   10
INCREMENT          10

ELEMENT I.D.      20          10
TEMP.       0.10000E 02 0.10000E 02
Z-LOAD      0.0         0.0


ITERATIVE ERROR =  0.93606E 00
ITERATIVE ERROR =  0.53202E 00
ITERATIVE ERROR =  0.64905E 00
ITERATIVE ERROR =  0.10034E 00
ITERATIVE ERROR =  0.81599E-01
ITERATIVE ERROR =  0.58229E-01
ITERATIVE ERROR =  0.45810E-01
ITERATIVE ERROR =  0.33456E-01
ITERATIVE ERROR =  0.25834E-01
ITERATIVE ERROR =  0.19124E-01
ITERATIVE ERROR =  0.25747E-06
ITERATIVE ERROR =  0.11579E-06


                         E N D   O F   L O A D   I N C R E M E N T   10

INCREMENT          10
MECHANICAL LOAD CURVE FACTORS =    0.3650E 01,  0.0
CREEP TIME INCREMENT =  0.0
NO. ELASTIC ELEMENTS =     2, NO. PLASTIC ELEMENTS =      0
    0  ELEMENTS HAVE CHANGED ELASTIC TO PLASTIC,     2  ELEMENTS PLASTIC TO ELASTIC DURING THIS INCREMENT
SPECIFIED MAX. NO. STIFFNESS UPDATES =      3, NO. UPDATES PERFORMED =      1
SPECIFIED MAX. NO. ITERATIONS PER UPDATE =     10, NO. ITERATIONS PERFORMED SINCE LAST UPDATE =      2
SPECIFIED MAX. UNBALANCED-FORCE ERROR =  0.1000E-04, ACTUAL ERROR =  0.1158E-06


                  *******  CUMULATIVE INTERNAL FORCES AND DISPLACEMENTS  ********
** NODE **        *********  FORCES  *********           *****  DISPLACEMENTS  ******
 NO.  I.D.         U                V                      U                V

    1   30     0.1788139E-06  0.4999576E 00         -0.5417178E-06  0.3650000E 01
    2   40    -0.1528397E-06  0.4999986E 00          0.4172325E-06  0.3650000E 01
    3   10     0.1081207E-07 -0.4999970E 00          0.0             0.0
    4   20    -0.3678633E-07 -0.5000000E 00         -0.1192093E-05   0.0
```

ELEMENT NO.	I.D.	*** THERMAL STRAINS *** INCREMENTAL	CUMULATIVE	ELASTIC STRAINS — INCREMENTAL XX	YY	ZZ	XY	ELASTIC STRAINS — CUMULATIVE XX	YY	ZZ	XY
1	20	0.6500E 00	0.1150E 01	0.1500E 01	-0.4500E 00	-0.4500E 00	0.3576E-06	0.5000E 00	-0.1500E 00	-0.1500E 00	-0.3376E-07
2	10	0.6500E 00	0.1150E 01	0.5250E 00	0.5250E 00	-0.4500E 00	0.9750E 00	0.1750E 00	0.1750E 00	-0.1500E 00	0.3250E 00

ELEMENT NO.	I.D.	***** PLASTIC WORK **** INCREMENTAL	CUMULATIVE	PLASTIC STRAINS — INCREMENTAL XX	YY	ZZ	XY	PLASTIC STRAINS — CUMULATIVE XX	YY	ZZ	XY
1	20	0.0	0.1012E 02	0.0	0.0	0.0	0.0	0.2000E 01	-0.1000E 01	-0.1000E 01	-0.2833E-06
2	10	0.0	0.1012E 02	0.0	0.0	0.0	0.0	0.5000E 00	0.5000E 00	-0.1000E 01	0.1500E 01

ELEMENT NO.	I.D.	EFFECTIVE CENTER	EFFECTIVE STRESS	CUMULATIVE STRESS QUANTITIES — STRESS CENTER XX	YY	ZZ	XY	CUMULATIVE STRESS QUANTITIES — STRESS XX	YY	ZZ	XY
1	20	0.1000E 01	0.1000E 01	0.6667E 00	-0.3333E 00	-0.3333E 00	-0.1402E-06	0.1000E 01	-0.2163E-07	0.4120E-05	-0.5195E-07
2	10	0.1000E 01	0.1000E 01	0.1667E 00	0.1667E 00	-0.3333E 00	0.5000E 00	0.5000E 00	0.5000E 00	-0.2540E-05	0.5000E 00

ELEMENT NO.	I.D.	E-P CODE	SUM CODE	INCREMENTAL TEMPERATURE	TOTAL TEMPERATURE	SURFACE YIELD SIZE	**** EFFECTIVE PLASTIC STRAINS *** INCREMENTAL	SUM INCR.	CUMULATIVE	***** EFFECTIVE CREEP STRAINS **** INCREMENTAL	SUM INCR.	CUMULATIVE
1	20	-1	-2	0.1000E 01	0.1000E 02	0.2250E 01	0.0	0.4000E 01	0.2000E 01	0.0	0.2000E 01	0.7304E-06
2	10	-1	-2	0.1000E 01	0.1000E 02	0.2250E 01	0.0	0.4000E 01	0.2000E 01	0.0	0.2000E 01	0.1589E-05

CUMULATIVE THERMAL LOADS AND Z-LOADS FOR LOAD INCREMENT 11

```
INCREMENT        11

ELEMENT I.D.     20          10
TEMP.       0.45000E 01 0.45000E 01
Z-LOAD     -0.30000E 00-0.30000E 00

ITERATIVE ERROR =  0.17452E 00
ITERATIVE ERROR =  0.53866E 00
ITERATIVE ERROR =  0.56949E 00
ITERATIVE ERROR =  0.15193E 00
ITERATIVE ERROR =  0.10629E 00
ITERATIVE ERROR =  0.62319E-01
ITERATIVE ERROR =  0.40663E-01
ITERATIVE ERROR =  0.24767E-01
ITERATIVE ERROR =  0.15738E-01
ITERATIVE ERROR =  0.57363E-02
ITERATIVE ERROR =  0.17456E-06
ITERATIVE ERROR =  0.25041E-05
```

E N D O F L O A D I N C R E M E N T 11

```
INCREMENT        11
MECHANICAL LOAD CURVE FACTORS =   0.5500E 01,  0.0
CREEP TIME INCREMENT =  0.1000E 02
NO. ELASTIC ELEMENTS =     0, NO. PLASTIC ELEMENTS =     2
     2  ELEMENTS HAVE CHANGED ELASTIC TO PLASTIC,     0  ELEMENTS PLASTIC TO ELASTIC DURING THIS INCREMENT
SPECIFIED MAX. NO. STIFFNESS UPDATES =     3, NO. UPDATES PERFORMED =     1
SPECIFIED MAX. NO. ITERATIONS PER UPDATE =     10, NO. ITERATIONS PERFORMED SINCE LAST UPDATE =     2
SPECIFIED MAX. UNBALANCED-FORCE ERROR =  0.1000E-04, ACTUAL ERROR =  0.2504E-05
```

******* CUMULATIVE INTERNAL FORCES AND DISPLACEMENTS ********

** NODE **		********* FORCES *********		***** DISPLACEMENTS ******	
NO.	I.D.	U	V	U	V
1	30	-0.2205371E-05	0.1624999E 01	-0.1476912E-05	0.5500000E 01
2	40	0.1914858E-05	0.1624997E 01	-0.2999985E 00	0.5500000E 01
3	10	0.4138433E-05	-0.1624998E 01	0.0	0.0
4	20	-0.3847920E-05	-0.1624999E 01	-0.3000008E 00	0.0

9.1-35

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ELEMENT NO.	I.C.	*** THERMAL STRAINS *** INCREMENTAL	CUMULATIVE	ELASTIC STRAINS — INCREMENTAL XX	YY	ZZ	XY	CUMULATIVE XX	YY	ZZ	XY
1	20	0.3500E 00	0.1500E 01	0.5000E 00	-0.1500E 00	-0.1500E 00	-0.1153E-06	0.1000E 01	-0.3000E 00	-0.3000E 00	-0.1491E-06
2	10	0.3500E 00	0.1500E 01	0.1750E 00	0.1750E 00	-0.1500E 00	0.3250E 00	0.3500E 00	0.3500E 00	-0.3000E 00	0.6500E 00

ELEMENT NO.	I.C.	***** PLASTIC WORK **** INCREMENTAL	CUMULATIVE	PLASTIC STRAINS — INCREMENTAL XX	YY	ZZ	XY	CUMULATIVE XX	YY	ZZ	XY
1	20	0.0	0.1012E 02	0.0	0.0	0.0	0.0	0.2000E 01	-0.1000E 01	-0.1000E 01	-0.2833E-06
2	10	0.0	0.1012E 02	0.0	0.0	0.0	0.0	0.5000E 00	0.5000E 00	-0.1000E 01	0.1500E 01

9.1-36

ELEMENT NO.	I.C.	****** CREEP WORK ***** INCREMENTAL	CUMULATIVE	CREEP STRAINS — INCREMENTAL XX	YY	ZZ	XY	CUMULATIVE XX	YY	ZZ	XY
1	20	0.2125E 01	0.5813E 01	0.1000E 01	-0.5000E 00	-0.5000E 00	-0.2423E-06	0.1000E 01	-0.5000E 00	-0.5000E 00	-0.7214E-06
2	10	0.2125E 01	0.5813E 01	0.2500E 00	0.2500E 00	-0.5000E 00	0.7500E 00	0.2500E 00	0.2500E 00	-0.5000E 00	0.7500E 00

D5-17266-2

ELEMENT NO.	I.C.	EFFECTIVE CENTER	EFFECTIVE STRESS	CUMULATIVE STRESS QUANTITIES — STRESS CENTER XX	YY	ZZ	XY	STRESS XX	YY	ZZ	XY
1	20	0.1000E 01	0.3250E 01	0.6667E 00	-0.3333E 00	-0.3333E 00	-0.1402E-06	0.3250E 01	-0.7323E-05	0.1765E-05	-0.3726E-06
2	10	0.1000E 01	0.3250E 01	0.1667E 00	0.1667E 00	-0.3333E 00	0.5000E 00	0.1625E 01	0.1625E 01	-0.1571E-05	0.1625E 01

ELEMENT NO.	I.C.	E-P CODE	SUM CODE	INCREMENTAL TEMPERATURE	TOTAL TEMPERATURE	SURFACE YIELD SIZE	**** EFFECTIVE PLASTIC STRAINS *** INCREMENTAL	SUM INCR.	CUMULATIVE	***** EFFECTIVE CREEP STRAINS **** INCREMENTAL	SUM INCR.	CUMULATIVE
1	20	1	2	-0.5500E 01	0.4500E 01	0.2250E 01	0.0	0.4000E 01	0.2000E 01	0.1000E 01	0.3000E 01	0.1000E 01
2	10	1	2	-0.5500E 01	0.4500E 01	0.2250E 01	0.0	0.4000E 01	0.2000E 01	0.1000E 01	0.3000E 01	0.1000E 01

CUMULATIVE THERMAL LOADS AND Z-LOADS FOR LOAD INCREMENT 12

INCREMENT 12

```
ELEMENT I.C.      20            10
TEMP.      0.12000E 02  0.12000E 02
Z-LOAD     0.0           0.0

ITERATIVE ERROR =  0.93777E 00
ITERATIVE ERROR =  0.80830E 00
ITERATIVE ERROR =  0.67054E 00
ITERATIVE ERROR =  0.59180E-01
ITERATIVE ERROR =  0.63850E-02
ITERATIVE ERROR =  0.65916E-03
ITERATIVE ERROR =  0.69355E-04
ITERATIVE ERROR =  0.76921E-05
ITERATIVE ERROR =  0.50321E-05
```

E N D O F L O A D I N C R E M E N T 12

```
INCREMENT 12
MECHANICAL LOAD CURVE FACTORS =  0.6550E 01,  0.0
CREEP TIME INCREMENT =  0.0
NO. ELASTIC ELEMENTS =    0, NO. PLASTIC ELEMENTS =    2
    0  ELEMENTS HAVE CHANGED ELASTIC TO PLASTIC,    0  ELEMENTS PLASTIC TO ELASTIC DURING THIS INCREMENT
SPECIFIED MAX. NO. STIFFNESS UPDATES =     3, NO. UPDATES PERFORMED =     0
SPECIFIED MAX. NO. ITERATIONS PER UPDATE =    10, NO. ITERATIONS PERFORMED SINCE LAST UPDATE =     9
SPECIFIED MAX. UNBALANCED-FORCE ERROR =  0.1000E-04, ACTUAL ERROR =  0.5032E-05
```

9.1-37

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******* CUMULATIVE INTERNAL FORCES AND DISPLACEMENTS ********

** NODE **		********* FORCES *********		***** DISPLACEMENTS ******	
NO.	I.D.	U	V	U	V
1	30	-0.1728534E-05	0.1937495E 01	-0.4172507E-06	0.6549999E 01
2	40	0.2162575E-05	0.1937495E 01	0.1251698E-05	0.6549999E 01
3	10	-0.9906980E-06	-0.1937495E 01	0.0	0.0
4	20	0.5566571E-06	-0.1937496E 01	-0.6556511E-06	0.0

ELEMENT NO.	I.C.	*** THERMAL STRAINS *** INCREMENTAL	CUMULATIVE	ELASTIC STRAINS — INCREMENTAL XX	YY	ZZ	XY	ELASTIC STRAINS — CUMULATIVE XX	YY	ZZ	XY
1	20	0.5500E 00	0.2050E 01	0.5960E-06	0.9537E-06	0.1192E-06	0.1778E-06	0.1000E 01	-0.3000E 00	-0.3000E 00	0.2872E-07
2	10	0.5500E 00	0.2050E 01	0.2384E-06	-0.8345E-06	0.7153E-06	0.4768E-06	0.3500E 00	0.3500E 00	-0.3000E 00	0.6500E 00

ELEMENT NO.	I.C.	***** PLASTIC WORK **** INCREMENTAL	CUMULATIVE	PLASTIC STRAINS — INCREMENTAL XX	YY	ZZ	XY	PLASTIC STRAINS — CUMULATIVE XX	YY	ZZ	XY
1	20	0.1781E 01	0.1191E 02	0.5000E 00	-0.2500E 00	-0.2500E 00	0.3084E-07	0.2500E 01	-0.1250E 01	-0.1250E 01	-0.2525E-06
2	10	0.1781E 01	0.1191E 02	0.1250E 00	0.1250E 00	-0.2500E 00	0.3750E 00	0.6250E 00	0.6250E 00	-0.1250E 01	0.1875E 01

ELEMENT NO.	I.C.	EFFECTIVE CENTER	EFFECTIVE STRESS	CUMULATIVE STRESS QUANTITIES — STRESS CENTER XX	YY	ZZ	XY	STRESS XX	YY	ZZ	XY
1	20	0.1500E 01	0.3875E 01	0.1000E 01	-0.5000E 00	-0.5000E 00	-0.1196E-06	0.3875E 01	0.1028E-05	0.1006E-04	0.8559E-07
2	10	0.1500E 01	0.3875E 01	0.2500E 00	0.2500E 00	-0.5000E 00	0.7500E 00	0.1938E 01	0.1938E 01	0.4662E-05	0.1937E 01

ELEMENT NO.	I.C.	E-P CODE	SUM CODE	INCREMENTAL TEMPERATURE	TOTAL TEMPERATURE	SURFACE YIELD SIZE	**** EFFECTIVE PLASTIC STRAINS *** INCREMENTAL	SUM INCR.	CUMULATIVE	***** EFFECTIVE CREEP STRAINS **** INCREMENTAL	SUM INCR.	CUMULATIVE
1	20	0	2	0.7500E 01	0.1200E 02	0.2375E 01	0.5000E 00	0.4500E 01	0.2500E 01	0.0	0.3000E 01	0.1000E 01
2	10	0	2	0.7500E 01	0.1200E 02	0.2375E 01	0.5000E 00	0.4500E 01	0.2500E 01	0.0	0.3000E 01	0.1000E 01

CUMULATIVE THERMAL LOADS AND Z-LOADS FOR LOAD INCREMENT 13

INCREMENT 13

```
ELEMENT I.D.      20             10
TEMP.        0.13000E 02 0.13000E 02
Z-LOAD       0.20000E 00 0.20000E 00

ITERATIVE ERROR =  0.52380E 00
ITERATIVE ERROR =  0.61836E 00
ITERATIVE ERROR =  0.58817E 00
ITERATIVE ERROR =  0.59557E 00
ITERATIVE ERROR =  0.43190E 00
ITERATIVE ERROR =  0.59985E-01
ITERATIVE ERROR =  0.32527E-01
ITERATIVE ERROR =  0.90488E-02
ITERATIVE ERROR =  0.27425E-02
ITERATIVE ERROR =  0.78102E-03
ITERATIVE ERROR =  0.32732E-04
ITERATIVE ERROR =  0.15091E-05
ITERATIVE ERROR =  0.12363E-05
```

END OF LOAD INCREMENT 13

```
INCREMENT 13
MECHANICAL LOAD CURVE FACTORS =   0.7500E 01,  0.0
CREEP TIME INCREMENT =  0.0
NO. ELASTIC ELEMENTS =     0, NO. PLASTIC ELEMENTS =    2
    0 ELEMENTS HAVE CHANGED ELASTIC TO PLASTIC,    0 ELEMENTS PLASTIC TO ELASTIC DURING THIS INCREMENT
SPECIFIED MAX. NO. STIFFNESS UPDATES =     3, NO. UPDATES PERFORMED =     1
SPECIFIED MAX. NO. ITERATIONS PER UPDATE =    10, NO. ITERATIONS PERFORMED SINCE LAST UPDATE =     3
SPECIFIED MAX. UNBALANCED-FORCE ERROR =  0.1000E-04, ACTUAL ERROR =  0.1236E-05
```

******* CUMULATIVE INTERNAL FORCES AND DISPLACEMENTS ********

** NODE **		********* FORCES *********		***** DISPLACEMENTS ******	
NO.	I.D.	U	V	U	V
1	30	0.1788148E-06	0.2249992E 01	-0.4548076E-07	0.7500000E 01
2	40	0.3175164E-06	0.2249993E 01	0.2000019E 00	0.7500000E 01
3	10	0.1000672E-06	-0.2249993E 01	0.0	0.0
4	20	-0.5963975E-06	-0.2249993E 01	0.2000000E 00	0.0

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ELEMENT NO.	I.C.	*** THERMAL STRAINS *** INCREMENTAL	CUMULATIVE	ELASTIC STRAINS — INCREMENTAL XX	YY	ZZ	XY	ELASTIC STRAINS — CUMULATIVE XX	YY	ZZ	XY
1	20	0.4500E 00	0.2500E 01	-0.7153E-06	0.5364E-06	-0.7153E-06	-0.3998E-07	0.1000E 01	-0.3000E 00	-0.3000E 00	-0.1126E-07
2	10	0.4500E 00	0.2500E 01	-0.6557E-06	-0.4172E-06	-0.2980E-06	-0.5960E-06	0.3500E 00	0.3500E 00	-0.3000E 00	0.6500E 00

ELEMENT NO.	I.C.	***** PLASTIC WORK **** INCREMENTAL	CUMULATIVE	PLASTIC STRAINS — INCREMENTAL XX	YY	ZZ	XY	PLASTIC STRAINS — CUMULATIVE XX	YY	ZZ	XY
1	20	0.2094E 01	0.1400E 02	0.5000E 00	-0.2500E 00	-0.2500E 00	0.3998E-07	0.3000E 01	-0.1500E 01	-0.1500E 01	-0.2125E-06
2	10	0.2094E 01	0.1400E 02	0.1250E 00	0.1250E 00	-0.2500E 00	0.3750E 00	0.7500E 00	0.7500E 00	-0.1500E 01	0.2250E 01

ELEMENT NO.	I.C.	EFFECTIVE CENTER	EFFECTIVE STRESS	CUMULATIVE STRESS QUANTITIES — STRESS CENTER XX	YY	ZZ	XY	STRESS XX	YY	ZZ	XY
1	20	0.2000E 01	0.4500E 01	0.1333E 01	-0.6667E 00	-0.6667E 00	-0.9295E-07	0.4500E 01	-0.1154E-05	0.5253E-05	-0.3899E-07
2	10	0.2000E 01	0.4500E 01	0.3333E 00	0.3333E 00	-0.6667E 00	0.1000E 01	0.2250E 01	0.2250E 01	-0.1525E-05	0.2250E 01

ELEMENT NO.	I.C.	E-P CODE	SUM CODE	INCREMENTAL TEMPERATURE	TOTAL TEMPERATURE	SURFACE YIELD SIZE	**** EFFECTIVE PLASTIC STRAINS *** INCREMENTAL	SUM INCR.	CUMULATIVE	***** EFFECTIVE CREEP STRAINS **** INCREMENTAL	SUM INCR.	CUMULATIVE
1	20	0	2	0.1000E 01	0.1300E 02	0.2500E 01	0.5000E 00	0.5000E 01	0.3000E 01	0.0	0.3000E 01	0.1000E 01
2	10	0	2	0.1000E 01	0.1300E 02	0.2500E 01	0.5000E 00	0.5000E 01	0.3000E 01	0.0	0.3000E 01	0.1000E 01

CUMULATIVE THERMAL LOADS AND Z-LOADS FOR LOAD INCREMENT 14

INCREMENT 14

ELEMENT I.C.	20	10
TEMP.	0.14000E 02	0.14000E 02
Z-LOAD	0.0	0.0

ITERATIVE ERROR = 0.72649E 00
ITERATIVE ERROR = 0.81608E 00
ITERATIVE ERROR = 0.92921E 00
ITERATIVE ERROR = 0.58297E 00
ITERATIVE ERROR = 0.25604E 00
ITERATIVE ERROR = 0.39645E-01
ITERATIVE ERROR = 0.72418E-02
ITERATIVE ERROR = 0.12782E-02
ITERATIVE ERROR = 0.22749E-03
ITERATIVE ERROR = 0.40927E-04
ITERATIVE ERROR = 0.10559E-05
ITERATIVE ERROR = 0.93568E-05

E N D O F L O A D I N C R E M E N T 14

INCREMENT 14
MECHANICAL LOAD CURVE FACTORS = 0.8800E 01, 0.0
CREEP TIME INCREMENT = 0.0
NO. ELASTIC ELEMENTS = 0, NO. PLASTIC ELEMENTS = 2
0 ELEMENTS HAVE CHANGED ELASTIC TO PLASTIC, 0 ELEMENTS PLASTIC TO ELASTIC DURING THIS INCREMENT
SPECIFIED MAX. NO. STIFFNESS UPDATES = 3, NO. UPDATES PERFORMED = 1
SPECIFIED MAX. NO. ITERATIONS PER UPDATE = 10, NO. ITERATIONS PERFORMED SINCE LAST UPDATE = 2
SPECIFIED MAX. UNBALANCED-FORCE ERROR = 0.1000E-04, ACTUAL ERROR = 0.9357E-05

******* CUMULATIVE INTERNAL FORCES AND DISPLACEMENTS ********

** NODE **		********* FORCES *********		***** DISPLACEMENTS ******	
NO.	I.D.	U	V	U	V
1	30	-0.4112720E-05	0.2624991E 01	0.5436887E-06	0.8799959E 01
2	40	0.4693330E-05	0.2624992E 01	0.1668930E-05	0.8799999E 01
3	10	-0.1698906E-05	-0.2624992E 01	0.0	0.0
4	20	0.1118256E-05	-0.2624992E 01	-0.6556511E-06	0.0

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ELEMENT NO.	I.C.	*** THERMAL STRAINS *** INCREMENTAL	CUMULATIVE	ELASTIC STRAINS — INCREMENTAL XX	YY	ZZ	XY	CUMULATIVE XX	YY	ZZ	XY
1	20	0.3000E 00	0.2800E 01	0.0	0.5960E-06	0.2980E-06	0.7794E-07	0.1000E 01	-0.3000E 00	-0.3000E 00	0.6668E-07
2	10	0.3000E 00	0.2800E 01	0.6557E-06	0.5960E-06	-0.5960E-06	-0.1013E-05	0.3500E 00	0.3500E 00	-0.3000E 00	0.6500E 00

ELEMENT NO.	I.C.	***** PLASTIC WORK **** INCREMENTAL	CUMULATIVE	PLASTIC STRAINS — INCREMENTAL XX	YY	ZZ	XY	CUMULATIVE XX	YY	ZZ	XY
1	20	0.4875E 01	0.1887E 02	0.1000E 01	-0.5000E 00	-0.5000E 00	-0.2866E-06	0.4000E 01	-0.2000E 01	-0.2000E 01	-0.4991E-06
2	10	0.4875E 01	0.1887E 02	0.2500E 00	0.2500E 00	-0.5000E 00	0.7500E 00	0.1000E 01	0.1000E 01	-0.2000E 01	0.3000E 01

ELEMENT NO.	I.C.	EFFECTIVE CENTER	EFFECTIVE STRESS	CUMULATIVE STRESS QUANTITIES — STRESS CENTER XX	YY	ZZ	XY	STRESS XX	YY	ZZ	XY
1	20	0.2500E 01	0.5250E 01	0.1667E 01	-0.8333E 00	-0.8333E 00	-0.1885E-06	0.5250E 01	0.1967E-05	0.1028E-04	0.2693E-06
2	10	0.2500E 01	0.5250E 01	0.4167E 00	0.4167E 00	-0.8333E 00	0.1250E 01	0.2625E 01	0.2625E 01	-0.8315E-06	0.2625E 01

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ELEMENT NO.	I.C.	E-P CODE	SUM CODE	INCREMENTAL TEMPERATURE	TOTAL TEMPERATURE	SURFACE YIELD SIZE	**** EFFECTIVE PLASTIC STRAINS *** INCREMENTAL	SUM INCR.	CUMULATIVE	***** EFFECTIVE CREEP STRAINS **** INCREMENTAL	SUM INCR.	CUMULATIVE
1	20	0	2	0.1000E 01	0.1400E 02	0.2750E 01	0.1000E 01	0.6000E 01	0.4000E 01	0.0	0.3000E 01	0.1000E 01
2	10	0	2	0.1000E 01	0.1400E 02	0.2750E 01	0.1000E 01	0.6000E 01	0.4000E 01	0.0	0.3000E 01	0.1000E 01

```
                    CUMULATIVE THERMAL LOADS AND Z-LOADS FOR LOAD INCREMENT   15
INCREMENT          15

ELEMENT I.D.      20          10
TEMP.      0.15000E 02 0.15000E 02
Z-LOAD     0.0          0.0

ITERATIVE ERROR =  0.94681E 00
ITERATIVE ERROR =  0.11170E 00
ITERATIVE ERROR =  0.70383E 00
ITERATIVE ERROR =  0.49096E-01
ITERATIVE ERROR =  0.85154E 00
ITERATIVE ERROR =  0.90057E 00
ITERATIVE ERROR =  0.90364E 00
ITERATIVE ERROR =  0.56701E 00
ITERATIVE ERROR =  0.93310E 00
ITERATIVE ERROR =  0.50647E 00
ITERATIVE ERROR =  0.69358E 00
ITERATIVE ERROR =  0.78188E 00
ITERATIVE ERROR =  0.42414E 00
ITERATIVE ERROR =  0.26775E 00
ITERATIVE ERROR =  0.97388E-01
ITERATIVE ERROR =  0.46999E-01
ITERATIVE ERROR =  0.20906E-01
ITERATIVE ERROR =  0.10267E-01
ITERATIVE ERROR =  0.48489E-02
ITERATIVE ERROR =  0.24238E-02
ITERATIVE ERROR =  0.37040E-03
ITERATIVE ERROR =  0.18710E-03
ITERATIVE ERROR =  0.79042E-04
ITERATIVE ERROR =  0.41894E-04
ITERATIVE ERROR =  0.17000E-04
ITERATIVE ERROR =  0.66029E-05
ITERATIVE ERROR =  0.99181E-05

                    E N D   O F   L O A D   I N C R E M E N T   15

INCREMENT          15
MECHANICAL LOAD CURVE FACTORS =    0.1629E 02,  0.0
CREEP TIME INCREMENT =  0.1000E 02
NO. ELASTIC ELEMENTS =     0, NO. PLASTIC ELEMENTS =     2
    0  ELEMENTS HAVE CHANGED ELASTIC TO PLASTIC,     0  ELEMENTS PLASTIC TO ELASTIC DURING THIS INCREMENT
SPECIFIED MAX. NO. STIFFNESS UPDATES =      3, NO. UPDATES PERFORMED =      2
SPECIFIED MAX. NO. ITERATIONS PER UPDATE =     10, NO. ITERATIONS PERFORMED SINCE LAST UPDATE =      7
SPECIFIED MAX. UNBALANCED-FORCE ERROR =  0.1000E-04, ACTUAL ERROR =  0.9918E-05

               *******  CUMULATIVE INTERNAL FORCES AND DISPLACEMENTS  ********
** NODE **     *********  FORCES  *********         *****  DISPLACEMENTS  ******
 NO.  I.D.     U                V                   U                V

   1   30   -0.2682209E-05  0.2999987E 01      0.8409859E-06  0.1628749E 02
   2   40    0.3983378E-05  0.2999991E 01      0.1060135E-04  0.1628749E 02
   3   10    0.2552869E-05 -0.2999989E 01      0.0              0.0
   4   20   -0.3854057E-05 -0.2999990E 01      0.4021342E-05  0.0
```

ELEMENT NO.	I.C.	*** THERMAL STRAINS *** INCREMENTAL	CUMULATIVE	ELASTIC STRAINS — INCREMENTAL XX	YY	ZZ	XY	CUMULATIVE XX	YY	ZZ	XY
1	20	0.2363E 01	0.5162E 01	0.1000E 01	-0.3000E 00	-0.3000E 00	0.1492E-05	0.2000E 01	-0.6000E 00	-0.6000E 00	0.1559E-05
2	10	0.2363E 01	0.5162E 01	0.3500E 00	0.3500E 00	-0.3000E 00	0.6500E 00	0.7000E 00	0.7000E 00	-0.6000E 00	0.1300E 01

ELEMENT NO.	I.C.	***** PLASTIC WORK **** INCREMENTAL	CUMULATIVE	PLASTIC STRAINS — INCREMENTAL XX	YY	ZZ	XY	CUMULATIVE XX	YY	ZZ	XY
1	20	0.5625E 01	0.2450E 02	0.1000E 01	-0.5000E 00	-0.5000E 00	-0.1347E-05	0.5000E 01	-0.2500E 01	-0.2500E 01	-0.1846E-05
2	10	0.5625E 01	0.2450E 02	0.2500E 00	0.2500E 00	-0.5000E 00	0.7500E 00	0.1250E 01	0.1250E 01	-0.2500E 01	0.3750E 01

ELEMENT NO.	I.C.	****** CREEP WORK ***** INCREMENTAL	CUMULATIVE	CREEP STRAINS — INCREMENTAL XX	YY	ZZ	XY	CUMULATIVE XX	YY	ZZ	XY
1	20	0.1758E 02	0.2339E 02	0.3125E 01	-0.1562E 01	-0.1562E 01	-0.2273E-05	0.4125E 01	-0.2062E 01	-0.2062E 01	-0.2994E-05
2	10	0.1758E 02	0.2339E 02	0.7812E 00	0.7812E 00	-0.1562E 01	0.2344E 01	0.1031E 01	0.1031E 01	-0.2062E 01	0.3094E 01

ELEMENT NO.	I.C.	E-P CODE	SUM CODE	INCREMENTAL TEMPERATURE	TOTAL TEMPERATURE	SURFACE YIELD SIZE	**** EFFECTIVE PLASTIC STRAINS *** INCREMENTAL	SUM INCR.	CUMULATIVE	***** EFFECTIVE CREEP STRAINS **** INCREMENTAL	SUM INCR.	CUMULATIVE
1	20	0	2	0.1000E 01	0.1500E 02	0.3000E 01	0.1000E 01	0.7000E 01	0.5000E 01	0.3125E 01	0.6125E 01	0.4125E 01
2	10	0	2	0.1000E 01	0.1500E 02	0.3000E 01	0.1000E 01	0.7000E 01	0.5000E 01	0.3125E 01	0.6125E 01	0.4125E 01

ELEMENT NO.	I.C.	EFFECTIVE CENTER	EFFECTIVE STRESS	CUMULATIVE STRESS QUANTITIES — STRESS CENTER XX	YY	ZZ	XY	STRESS XX	YY	ZZ	XY
1	20	0.3000E 01	0.6000E 01	0.2000E 01	-0.1000E 01	-0.1000E 01	-0.6373E-06	0.6000E 01	-0.1130E-04	0.6546E-05	0.3597E-05
2	10	0.3000E 01	0.6000E 01	0.5000E 00	0.5000E 00	-0.1000E 01	0.1500E 01	0.3000E 01	0.3000E 01	-0.1220E-04	0.3000E 01

9.2 THERMAL RATCHET

This is a thermal ratchet problem, involving thermal cycling in conjunction with a sustained mechanical load. The finite-element idealization and mechanical loading are shown in Figure 9.2-1. The thermal loading consists of an alternate heating and cooling of the left half of the structure (elements 1 and 2).

Because the stresses and thermal strains differ in the left and right halves of the structure, the BOPACE nodal-constraint option was used to allow vertical slip at the center. Thus the displacements at nodes 3-11 and 4-12 are constrained to be equal in the X direction, but are allowed to have different values in the Y direction. Poisson's ratio is taken as 0.5 so as to avoid small errors which would otherwise be induced by intermediate yielding within an increment.

Results are summarized in Table 9.2-1 for six increments, and the BOPACE input listing and printed output results are included at the end of this section. The mechanical loading is applied during the first increment and it then remains on the structure. In the second increment the thermal heating load is applied, and it results in plastic flow within the right side of the structure. Each succeeding heating and cooling cycle (two increments) results in continuing plastic flow and an increase of 0.5 in displacement. Note that this occurs even though a part of the structure is always elastic, because yielding occurs during alternate increments in the left and right sides. This type of behavior must be considered in thermal-mechanical cycling of engines.

PLATE = 2.0 x 1.0
THICKNESS = 10.0
TENSILE YIELD POINT = 1.0
THERMAL COEFFICIENT
OF EXPANSION = 1.0
E = 1.0
ν = 0.5

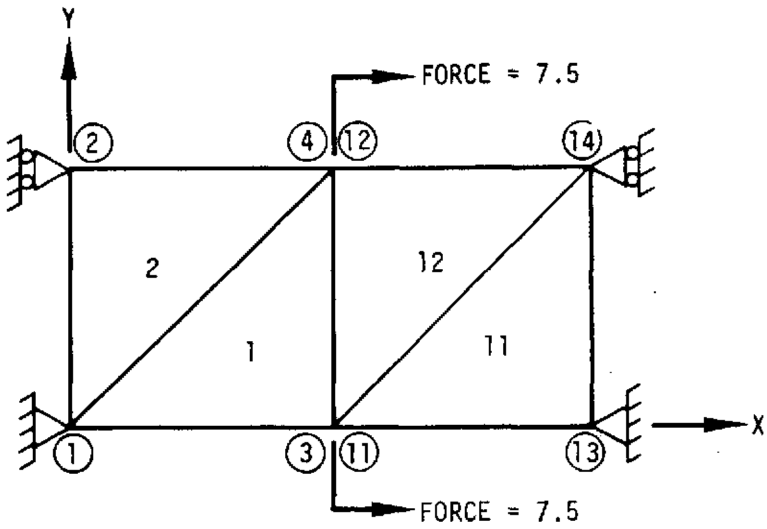

FIGURE 9.2-1: THERMAL RATCHET PROBLEM

TABLE 9.2-1: THERMAL RATCHET DATA

INCREMENT	DISPLACEMENT	TEMP. 1 & 2	TEMP. 11 & 12
1	0.75	0	0
2	2.0	1.5	0
3	1.5	0	0
4	2.5	1.5	0
5	2.0	0	0
6	3.0	1.5	0

```
START              5     5     6
THERMAL RATCHET PROBLEM (WITH CONSTRAINED DOF)                         R. VOS 05/23/73
     3     2                         1          .00001
     0     1 10.0       0.0
           1
0.0        0.0         10.0       10.0

0.0        1.0

0.0        0.5

           1           2
           1 0.
0.0        1.0        100.0       1.0

0.0        0.0        100.0       0.0


           1           1
0.0        0.0         1.0        1.0

           1 0.
1.0        0.0


     1     0.0         0.0
     2     0.0         1.0
     3     1.0         0.0
     4     1.0         1.0
    11     1.0         0.0
    12     1.0         1.0
    13     2.0         0.0
    14     2.0         1.0

     1     1              1     3     4
     2     1              4     2     1
    11     1             11    13    14
    12     1             14    12    11

     1     1   -1         1     2    -1          2     1    -2
    13     1  -13        13     2   -13         14     1   -14
    11     1    3        12     1     4

           2
     3     1 7.5          4     1 7.5


           6
             1.0
             1.0
             1.0
             1.0
             1.0
             1.0
INCREMENT 1 (COLD)
           1 0.0                2 0.0

INCREMENT 2 (HOT)
```

1 1.5	2 1.5

INCREMENT 3 (COLD)

1 0.0	2 0.0

INCREMENT 4 (HOT)

1 1.5	2 1.5

INCREMENT 5 (COLD)

1 0.0	2 0.0

INCREMENT 6 (HOT)

1 1.5	2 1.5

STARTING PROBLEM

THERMAL RATCHET PROBLEM (WITH CONSTRAINED DOF)   P. VOS 05/23/72

```
SOLUTION METHOD CODE =            3
MAXIMUM NO. STIFFNESS UPDATES PER INCREMENT =            2
MAXIMUM TOTAL ITERATIONS PER INCREMENT =          10
MAXIMUM ELASTIC ITERATIONS PER INCREMENT =          2
MAXIMUM MAGNITUDE FOR ELASTIC-PLASTIC SUM CODE =          2
MAXIMUM REDUCTIONS =          1
CONVERGENCE REDUCTION FACTOR =  0.50000E 00
MAXIMUM SPECIFIED ERROR NORM =  0.10000E-04
FRACTION FROM END OF INCREMENT TO EVALUATE SLOPE = 0.10000E 00

PLANE-STRESS PROBLEM
NO. OF MATERIALS =          1
DEFAULT THICKNESS =  0.10000E 02
FABRICATION TEMPERATURE =  0.0
```

MATERIAL NO.   1 TEMPERATURE DEPENDENT PROPERTIES

TEMPERATURE	THERMAL STRAIN
0.0	0.0
0.1000E 02	0.1000E 02

TEMPERATURE	ELASTIC MOD.
0.0	0.1000E 01

TEMPERATURE	POISSONS RATIO
0.0	0.5000E 00

```
MATERIAL NO.      1,PLASTICITY TYPE     2,KINEMATIC CODE      0

MATERIAL NO.      1, TEMPERATURE =   0.0

PARAMETER      ISOTROPIC STRESS
 0.0               0.10000E 01
 0.10000E 03       0.10000E 01

PARAMETER      KINEMATIC SHAPE
 0.0               0.0
 0.10000E 03       0.0

TEMPERATURE =   0.0

PARAMETER      ISOTROPIC STRESS
 0.0               0.10000E 01
 0.10000E 03       0.10000E 01

PARAMETER      KINEMATIC SHAPE
 0.0               0.0
 0.10000E 03       0.0
```

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```
MATERIAL NO.      1,CREEP TYPE     1

   TIME        CREEP STRAIN
  0.0           0.0
  0.1000E 01    0.1000E 01

MATERIAL NO.      1, TEMPERATURE =   0.0
   STRESS      CREEP FACTOR
  0.1000E 01    0.0

MATERIAL NO.      1, TEMPERATURE =   0.0
   STRESS      CREEP FACTOR
  0.1000E 01    0.0
```

CARTESIAN COORDINATE SYSTEMS DEFINED

NUMBER X-AXIS ANGLE

** NODE **

NO.	I.D.	LCOORD	X (R)	Y (THETA)	DCOORD
1	1	0	0.0	0.0	0
2	2	0	0.0	0.10000D 01	0
3	3	0	0.10000D 01	0.0	0
4	4	0	0.10000D 01	0.10000D 01	0
5	11	0	0.10000D 01	0.0	0
6	12	0	0.10000D 01	0.10000D 01	0
7	13	0	0.20000D 01	0.0	0
8	14	0	0.20000D 01	0.10000D 01	0

ELEMENT

NO.	I.D.	MATERIAL	THICKNESS	NODE 1	NODE 2	NODE 3	AREA
1	1	1	0.1000D 02	1	3	4	0.5000E 00
2	2	1	0.1000D 02	4	2	1	0.5000E 00
3	11	1	0.1000D 02	11	13	14	0.5000E 00
4	12	1	0.1000D 02	14	12	11	0.5000E 00

SPECIFIED FORCE-DISPLACEMENT-CONSTRAINT DOF

NODE I.D.	COMPONENT	CODE
1	1	-1
1	2	-1
2	1	-2
13	1	-13
13	2	-13
14	1	-14
11	1	3
12	1	4

NO. OF LOAD REFERENCE CURVES = 2

LOAD REFERENCE CURVE NO. 1

NODE	COMPONENT	LOAD
3	1	0.75000E 01
4	1	0.75000E 01

LOAD REFERENCE CURVE NO. 2

NODE	COMPONENT	LOAD

NO. OF LOAD INCREMENTS = 6

INCREMENT	MAX. ITERATIONS	MECHANICAL CURVE FACTORS		CREEP TIME
1	10	0.10000E 01	0.0	0.0
2	10	0.10000E 01	0.0	0.0
3	10	0.10000E 01	0.0	0.0
4	10	0.10000E 01	0.0	0.0
5	10	0.10000E 01	0.0	0.0
6	10	0.10000E 01	0.0	0.0

CUMULATIVE THERMAL LOADS AND Z-LOADS FOR LOAD INCREMENT 1

INCREMENT 1 (COLD)

ELEMENT I.D.	1	2	11	12
TEMP.	0.0	0.0	0.0	0.0
Z-LOAD	0.0	0.0	0.0	0.0

ITERATIVE ERROR = 0.74366E-06

E N D   O F   L O A D   I N C R E M E N T   1

INCREMENT 1 (COLD)
MECHANICAL LOAD CURVE FACTORS = 0.1000E 01, 0.0
CREEP TIME INCREMENT = 0.0
NO. ELASTIC ELEMENTS = 4, NO. PLASTIC ELEMENTS = 0
0 ELEMENTS HAVE CHANGED ELASTIC TO PLASTIC, 0 ELEMENTS PLASTIC TO ELASTIC DURING THIS INCREMENT
SPECIFIED MAX. NO. STIFFNESS UPDATES = 2, NO. UPDATES PERFORMED = 0
6-2-9 SPECIFIED MAX. NO. ITERATIONS PER UPDATE = 10, NO. ITERATIONS PERFORMED SINCE LAST UPDATE = 1
SPECIFIED MAX. UNBALANCED-FORCE ERROR = 0.1000E-04, ACTUAL ERROR = 0.7437E-06

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******* CUMULATIVE INTERNAL FORCES AND DISPLACEMENTS ********

** NODE **		********* FORCES *********		***** DISPLACEMENTS ******	
NO.	I.D.	U	V	U	V
1	1	-0.3749999E 01	-0.1390774E-05	0.0	0.0
2	2	-0.3749997E 01	0.1192092E-05	0.0	-0.3749996E 00
3	3	0.3749998E 01	0.1788138E-05	0.7500002E 00	0.7152557E-06
4	4	0.3749997E 01	-0.1589457E-05	0.7499996E 00	-0.3749996E 00
5	11	0.3750001E 01	0.3973642E-06	0.7500002E 00	-0.2384186E-06
6	12	0.3749996E 01	-0.2980232E-06	0.7499996E 00	0.3749995E 00
7	13	-0.3750001E 01	0.2781549E-05	0.0	0.0
8	14	-0.3749996E 01	-0.2880890E-05	0.0	0.3749998E 00

ELEMENT NO.	I.D.	*** THERMAL STRAINS *** INCREMENTAL	CUMULATIVE	PLASTIC STRAINS INCREMENTAL XX	YY	ZZ	XY	PLASTIC STRAINS CUMULATIVE XX	YY	ZZ	XY
1	1	0.0	0.0	0.7500E 00	-0.3750E 00	-0.3750E 00	0.5960E-07	0.7500E 00	-0.3750E 00	-0.3750E 00	0.5960E-07
2	2	0.0	0.0	0.7500E 00	-0.3750E 00	-0.3750E 00	0.0	0.7500E 00	-0.3750E 00	-0.3750E 00	0.0
3	11	0.0	0.0	-0.7500E 00	0.3750E 00	0.3750E 00	0.1192E-06	-0.7500E 00	0.3750E 00	0.3750E 00	0.1192E-06
4	12	0.0	0.0	-0.7500E 00	0.3750E 00	0.3750E 00	-0.1490E-06	-0.7500E 00	0.3750E 00	0.3750E 00	-0.1490E-06

ELEMENT NO.	I.D.	***** PLASTIC WORK **** INCREMENTAL	CUMULATIVE	PLASTIC STRAINS INCREMENTAL XX	YY	ZZ	XY	PLASTIC STRAINS CUMULATIVE XX	YY	ZZ	XY
1	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

9.2-10

ELEMENT NO.	I.D.	EFFECTIVE CENTER	EFFECTIVE STRESS	CUMULATIVE STRESS QUANTITIES: STRESS CENTER XX	YY	ZZ	XY	STRESS XX	YY	ZZ	XY
1	1	0.0	0.7500E 00	0.0	0.0	0.0	0.0	0.7500E 00	-0.3179E-06	0.0	0.3974E-07
2	2	0.0	0.7500E 00	0.0	0.0	0.0	0.0	0.7500E 00	0.2384E-06	0.0	0.0
3	11	0.0	0.7500E 00	0.0	0.0	0.0	0.0	-0.7500E 00	-0.4763E-06	0.0	0.7947E-07
4	12	0.0	0.7500E 00	0.0	0.0	0.0	0.0	-0.7500E 00	-0.1589E-06	0.0	-0.9934E-07

D5-17266-2

ELEMENT NO.	I.D.	E-P CODE	SUM CODE	INCREMENTAL TEMPERATURE	TOTAL TEMPERATURE	SURFACE YIELD SIZE	**** EFFECTIVE PLASTIC STRAINS *** INCREMENTAL	SUM INCR.	CUMULATIVE	***** EFFECTIVE CREEP STRAINS **** INCREMENTAL	SUM INCR.	CUMULATIVE
1	1	0	-1	0.0	0.0	0.1000E 01	0.0	0.0	0.0	0.0	0.0	0.0
2	2	0	-1	0.0	0.0	0.1000E 01	0.0	0.0	0.0	0.0	0.0	0.0
3	11	0	-1	0.0	0.0	0.1000E 01	0.0	0.0	0.0	0.0	0.0	0.0
4	12	0	-1	0.0	0.0	0.1000E 01	0.0	0.0	0.0	0.0	0.0	0.0

CUMULATIVE THERMAL LOADS AND Z-LOADS FOR LOAD INCREMENT 2

INCREMENT 2 (HOT)

ELEMENT I.D.	1	2	11	12
TEMP.	0.15000E 01	0.15000E 01	0.0	0.0
Z-LOAD	0.0	0.0	0.0	0.0

ITERATIVE ERROR = 0.12500E 01
ITERATIVE ERROR = 0.62744E-05
ITERATIVE ERROR = 0.35355E 00
ITERATIVE ERROR = 0.35356E 00
ITERATIVE ERROR = 0.35356E 00
ITERATIVE ERROR = 0.23570E 00
ITERATIVE ERROR = 0.14142E 00
ITERATIVE ERROR = 0.78574E-01
ITERATIVE ERROR = 0.41599E-01
ITERATIVE ERROR = 0.21435E-01
ITERATIVE ERROR = 0.54369E-05
ITERATIVE ERROR = 0.32200E-05

E N D O F L O A D I N C R E M E N T 2

INCREMENT 2 (HOT)
MECHANICAL LOAD CURVE FACTORS = 0.1000E 01, 0.0
9.2-11 CREEP TIME INCREMENT = 0.0 D5-17266-2
NO. ELASTIC ELEMENTS = 2, NO. PLASTIC ELEMENTS = 2
2 ELEMENTS HAVE CHANGED ELASTIC TO PLASTIC, 0 ELEMENTS PLASTIC TO ELASTIC DURING THIS INCREMENT
SPECIFIED MAX. NO. STIFFNESS UPDATES = 2, NO. UPDATES PERFORMED = 1
SPECIFIED MAX. NO. ITERATIONS PER UPDATE = 10, NO. ITERATIONS PERFORMED SINCE LAST UPDATE = 2
SPECIFIED MAX. UNBALANCED-FORCE ERROR = 0.1000E-04, ACTUAL ERROR = 0.3220E-05

******* CUMULATIVE INTERNAL FORCES AND DISPLACEMENTS *******

** NODE ** NO.	I.D.	********* FORCES U	********* V	***** DISPLACEMENTS U	***** V
1	1	-0.2500002E 01	0.6228571E-05	0.0	0.0
2	2	-0.2499994E 01	-0.6755187E-05	0.0	0.1249999E 01
3	3	0.2500001E 01	0.5266165E-06	0.2000000E 01	-0.4165804E-07
4	4	0.2499994E 01	0.0	0.1999999E 01	0.1250000E 01
5	11	0.4999999E 01	-0.8046076E-06	0.2000000E 01	-0.3463335E-06
6	12	0.4999996E 01	0.1162290E-05	0.1999999E 01	0.9999996E 00
7	13	-0.4999998E 01	0.3625893E-05	0.0	0.0
8	14	-0.4999997E 01	-0.3983575E-05	0.0	0.9999996E 00

ELEMENT NO.	I.D.	*** THERMAL STRAINS *** INCREMENTAL	CUMULATIVE	PLASTIC STRAINS — INCREMENTAL XX	YY	ZZ	XY	CUMULATIVE XX	YY	ZZ	XY
1	1	0.1500E 01	0.1500E 01	-0.2500E 00	0.1250E 00	0.1250E 00	-0.3785E-06	0.5000E 00	-0.2500E 00	-0.2500E 00	-0.3189E-06
2	2	0.1500E 01	0.1500E 01	-0.2500E 00	0.1250E 00	0.1250E 00	0.4768E-06	0.5000E 00	-0.2500E 00	-0.2500E 00	0.4768E-06
3	11	0.0	0.0	-0.2500E 00	0.1250E 00	0.1250E 00	-0.2386E-07	-0.1000E 01	0.5000E 00	0.5000E 00	0.9535E-07
4	12	0.0	0.0	-0.2500E 00	0.1250E 00	0.1250E 00	-0.5364E-07	-0.1000E 01	0.5000E 00	0.5000E 00	-0.2027E-06

ELEMENT NO.	I.D.	***** PLASTIC WORK **** INCREMENTAL	CUMULATIVE	PLASTIC STRAINS — INCREMENTAL XX	YY	ZZ	XY	CUMULATIVE XX	YY	ZZ	XY
1	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	11	0.1000E 01	0.1000E 01	-0.1000E 01	0.5000E 00	0.5000E 00	0.7782E-07	-0.1000E 01	0.5000E 00	0.5000E 00	0.7782E-07
4	12	0.1000E 01	0.1000E 01	-0.1000E 01	0.5000E 00	0.5000E 00	-0.1550E-06	-0.1000E 01	0.5000E 00	0.5000E 00	-0.1550E-06

ELEMENT NO.	I.D.	EFFECTIVE CENTER	EFFECTIVE STRESS	CUMULATIVE STRESS QUANTITIES — STRESS CENTER XX	YY	ZZ	XY	STRESS XX	YY	ZZ	XY
1	1	0.0	0.5000E 00	0.0	0.0	0.0	0.0	0.5000E 00	-0.3179E-06	0.0	-0.2126E-06
2	2	0.0	0.5000E 00	0.0	0.0	0.0	0.0	0.5000E 00	-0.1033E-05	0.0	0.3179E-06
3	11	0.0	0.1000E 01	0.0	0.0	0.0	0.0	-0.1000E 01	-0.6616E-06	0.0	0.6357E-07
4	12	0.0	0.1000E 01	0.0	0.0	0.0	0.0	-0.1000E 01	0.9735E-07	0.0	-0.1351E-06

ELEMENT NO.	I.D.	E-P CODE	SUM CODE	INCREMENTAL TEMPERATURE	TOTAL TEMPERATURE	SURFACE YIELD SIZE	**** EFFECTIVE PLASTIC STRAINS *** INCREMENTAL	SUM INCR.	CUMULATIVE	***** EFFECTIVE CREEP STRAINS **** INCREMENTAL	SUM INCR.	CUMULATIVE
1	1	0	-2	0.1500E 01	0.1500E 01	0.1000E 01	0.0	0.0	0.0	0.0	0.0	0.0
2	2	0	-2	0.1500E 01	0.1500E 01	0.1000E 01	0.0	0.0	0.0	0.0	0.0	0.0
3	11	1	2	0.0	0.0	0.1000E 01	0.1000E 01	0.1000E 01	0.1000E 01	0.0	0.0	0.0
4	12	1	2	0.0	0.0	0.1000E 01	0.1000E 01	0.1000E 01	0.1000E 01	0.0	0.0	0.0

CUMULATIVE THERMAL LOADS AND Z-LOADS FOR LOAD INCREMENT 3

INCREMENT 3 (COLD)

ELEMENT I.D.	1	2	11	12
TEMP.	0.0	0.0	0.0	0.0
Z-LOAD	0.0	0.0	0.0	0.0

```
ITERATIVE ERROR =  0.12500E 01
ITERATIVE ERROR =  0.14142E 00
ITERATIVE ERROR =  0.12266E-05
ITERATIVE ERROR =  0.99194E-06
```

E N D O F L O A D I N C R E M E N T 3

```
INCREMENT 3 (COLD)
MECHANICAL LOAD CURVE FACTORS =   0.1000E 01,  0.0
CREEP TIME INCREMENT =  0.0
NO. ELASTIC ELEMENTS =     2, NO. PLASTIC ELEMENTS =     2
    2  ELEMENTS HAVE CHANGED ELASTIC TO PLASTIC,    2  ELEMENTS PLASTIC TO ELASTIC DURING THIS INCREMENT
SPECIFIED MAX. NO. STIFFNESS UPDATES =      2, NO. UPDATES PERFORMED =      0
SPECIFIED MAX. NO. ITERATIONS PER UPDATE =     10, NO. ITERATIONS PERFORMED SINCE LAST UPDATE =      4
SPECIFIED MAX. UNBALANCED-FORCE ERROR =  0.1000E-04, ACTUAL ERROR =  0.9919E-06
```

******* CUMULATIVE INTERNAL FORCES AND DISPLACEMENTS *******

** NODE ** NO.	I.D.	FORCES U	FORCES V	DISPLACEMENTS U	DISPLACEMENTS V
1	1	-0.5000001E 01	0.2688557E-07	0.0	0.0
2	2	-0.4999999E 01	-0.1132491E-05	0.0	-0.7500000E 00
3	3	0.5000000E 01	-0.3404473E-05	0.1500000E 01	0.2530946E-06
4	4	0.4999999E 01	0.4510080E-05	0.1500000E 01	-0.7499990E 00
5	11	0.2500003E 01	-0.3394331E-07	0.1500000E 01	-0.1223534E-06
6	12	0.2500003E 01	0.6953815E-07	0.1500000E 01	0.7500002E 00
7	13	-0.2500002E 01	0.7368089E-07	0.0	0.0
8	14	-0.2500004E 01	-0.1092749E-06	0.0	0.7500004E 00

ELEMENT NO.	I.D.	THERMAL STRAINS INCREMENTAL	THERMAL STRAINS CUMULATIVE	ELASTIC STRAINS INCREMENTAL XX	YY	ZZ	XY	ELASTIC STRAINS CUMULATIVE XX	YY	ZZ	XY
1	1	-0.1500E 01	0.0	0.5000E 00	-0.2500E 00	-0.2500E 00	0.2631E-06	0.1000E 01	-0.5000E 00	-0.5000E 00	-0.5575E-07
2	2	-0.1500E 01	0.0	0.5000E 00	-0.2500E 00	-0.2500E 00	-0.8941E-07	0.1000E 01	-0.5000E 00	-0.5000E 00	0.3874E-06
3	11	0.0	0.0	0.5000E 00	-0.2500E 00	-0.2500E 00	-0.1120E-06	-0.5000E 00	0.2500E 00	0.2500E 00	-0.1664E-07
4	12	0.0	0.0	0.5000E 00	-0.2500E 00	-0.2500E 00	0.2086E-06	-0.5000E 00	0.2500E 00	0.2500E 00	0.5960E-08

ELEMENT NO.	I.D.	PLASTIC WORK INCREMENTAL	PLASTIC WORK CUMULATIVE	PLASTIC STRAINS INCREMENTAL XX	YY	ZZ	XY	PLASTIC STRAINS CUMULATIVE XX	YY	ZZ	XY
1	1	0.5000E 00	0.5000E 00	0.5000E 00	-0.2500E 00	-0.2500E 00	-0.5612E-07	0.5000E 00	-0.2500E 00	-0.2500E 00	-0.5612E-07
2	2	0.5000E 00	0.5000E 00	0.5000E 00	-0.2500E 00	-0.2500E 00	0.8941E-07	0.5000E 00	-0.2500E 00	-0.2500E 00	0.8941E-07
3	11	0.0	0.1000E 01	0.0	0.0	0.0	0.0	-0.1000E 01	0.5000E 00	0.5000E 00	0.7782E-07
4	12	0.0	0.1000E 01	0.0	0.0	0.0	0.0	-0.1000E 01	0.5000E 00	0.5000E 00	-0.1550E-06

ELEMENT NO.	I.D.	EFFECTIVE CENTER	EFFECTIVE STRESS	CUMULATIVE STRESS QUANTITIES STRESS CENTER XX	YY	ZZ	XY	STRESS XX	YY	ZZ	XY
1	1	0.0	0.1000E 01	0.0	0.0	0.0	0.0	0.1000E 01	0.4437E-06	0.0	-0.3717E-07
2	2	0.0	0.1000E 01	0.0	0.0	0.0	0.0	0.1000E 01	0.3179E-07	0.0	0.2583E-06
3	11	0.0	0.5000E 00	0.0	0.0	0.0	0.0	-0.5000E 00	-0.2583E-07	0.0	-0.1109E-07
4	12	0.0	0.5000E 00	0.0	0.0	0.0	0.0	-0.5000E 00	0.1788E-07	0.0	0.3974E-08

ELEMENT NO.	I.D.	E-P CODE	SUM CODE	INCREMENTAL TEMPERATURE	TOTAL TEMPERATURE	SURFACE YIELD SIZE	EFFECTIVE PLASTIC STRAINS INCREMENTAL	SUM INCR.	CUMULATIVE	EFFECTIVE CREEP STRAINS INCREMENTAL	SUM INCR.	CUMULATIVE
1	1	1	2	-0.1500E 01	0.0	0.1000E 01	0.5000E 00	0.5000E 00	0.5000E 00	0.0	0.0	0.0
2	2	1	2	-0.1500E 01	0.0	0.1000E 01	0.5000E 00	0.5000E 00	0.5000E 00	0.0	0.0	0.0
3	11	-1	-2	0.0	0.0	0.1000E 01	0.0	0.1000E 01	0.1000E 01	0.0	0.0	0.0
4	12	-1	-2	0.0	0.0	0.1000E 01	0.0	0.1000E 01	0.1000E 01	0.0	0.0	0.0

9.2-14

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CUMULATIVE THERMAL LOADS AND Z-LOADS FOR LOAD INCREMENT 4

INCREMENT 4 (HOT)

ELEMENT I.D.	1	2	11	12
TEMP.	0.15000E 01	0.15000E 01	0.0	0.0
Z-LOAD	0.0	0.0	0.0	0.0

ITERATIVE ERROR = 0.12500E 01
ITERATIVE ERROR = 0.36616E-05
ITERATIVE ERROR = 0.14142E 00
ITERATIVE ERROR = 0.14143E 00
ITERATIVE ERROR = 0.14143E 00
ITERATIVE ERROR = 0.10874E-05
ITERATIVE ERROR = 0.17333E-05

E N D O F L O A D I N C R E M E N T 4

INCREMENT 4 (HOT)
MECHANICAL LOAD CURVE FACTORS = 0.1000E 01, 0.0
CREEP TIME INCREMENT = 0.0
NO. ELASTIC ELEMENTS = 2, NO. PLASTIC ELEMENTS = 2
2 ELEMENTS HAVE CHANGED ELASTIC TO PLASTIC, 2 ELEMENTS PLASTIC TO ELASTIC DURING THIS INCREMENT
SPECIFIED MAX. NO. STIFFNESS UPDATES = 2, NO. UPDATES PERFORMED = 0
SPECIFIED MAX. NO. ITERATIONS PER UPDATE = 10, NO. ITERATIONS PERFORMED SINCE LAST UPDATE = 7
SPECIFIED MAX. UNBALANCED-FORCE ERROR = 0.1000E-04, ACTUAL ERROR = 0.1733E-05

******* CUMULATIVE INTERNAL FORCES AND DISPLACEMENTS *******

** NODE **		********* FORCES *********		***** DISPLACEMENTS ******	
NO.	I.D.	U	V	U	V
1	1	-0.2499999E 01	0.7309890E-05	0.0	0.0
2	2	-0.2499997E 01	-0.7490318E-05	0.0	0.9999990E 00
3	3	0.2499999E 01	0.2028176E-05	0.2500000E 01	-0.3020122E-06
4	4	0.2499997E 01	-0.1847749E-05	0.2500000E 01	0.1000000E 01
5	11	0.4999999E 01	-0.1561245E-05	0.2500000E 01	-0.2905017E-07
6	12	0.4999996E 01	0.2296018E-05	0.2500000E 01	0.1250000E 01
7	13	-0.4999997E 01	-0.2820906E-07	0.0	0.0
8	14	-0.4999998E 01	-0.7065628E-06	0.0	0.1250000E 01

ELEMENT NO.	I.D.	*** THERMAL STRAINS *** INCREMENTAL	CUMULATIVE	ELASTIC STRAINS — INCREMENTAL XX	YY	ZZ	XY	ELASTIC STRAINS — CUMULATIVE XX	YY	ZZ	XY
1	1	0.1500E 01	0.1500E 01	-0.5000E 00	0.2500E 00	0.2500E 00	-0.2776E-06	0.5000E 00	-0.2500E 00	-0.2500E 00	-0.3333E-06
2	2	0.1500E 01	0.1500E 01	-0.5000E 00	0.2500E 00	0.2500E 00	0.0	0.5000E 00	-0.2500E 00	-0.2500E 00	0.3874E-06
3	11	0.0	0.0	-0.5000E 00	0.2500E 00	0.2500E 00	-0.3057E-07	-0.1000E 01	0.5000E 00	0.5000E 00	-0.4721E-07
4	12	0.0	0.0	-0.5000E 00	0.2500E 00	0.2500E 00	-0.1792E-06	-0.1000E 01	0.5000E 00	0.5000E 00	-0.1732E-06

ELEMENT NO.	I.D.	***** PLASTIC WORK **** INCREMENTAL	CUMULATIVE	PLASTIC STRAINS — INCREMENTAL XX	YY	ZZ	XY	PLASTIC STRAINS — CUMULATIVE XX	YY	ZZ	XY
1	1	0.0	0.5000E 00	0.0	0.0	0.0	0.0	0.5000E 00	-0.2500E 00	-0.2500E 00	-0.5612E-07
2	2	0.0	0.5000E 00	0.0	0.0	0.0	0.0	0.5000E 00	-0.2500E 00	-0.2500E 00	0.8941E-07
3	11	0.5000E 00	0.1500E 01	-0.5000E 00	0.2500E 00	0.2500E 00	-0.1608E-07	-0.1500E 01	0.7500E 00	0.7500E 00	0.6173E-07
4	12	0.5000E 00	0.1500E 01	-0.5000E 00	0.2500E 00	0.2500E 00	-0.2943E-07	-0.1500E 01	0.7500E 00	0.7500E 00	-0.1844E-06

9.2-16

ELEMENT NO.	I.D.	EFFECTIVE CENTER	EFFECTIVE STRESS	CUMULATIVE STRESS QUANTITIES — STRESS CENTER XX	YY	ZZ	XY	STRESS XX	YY	ZZ	XY
1	1	0.0	0.5000E 00	0.0	0.0	0.0	0.0	0.5000E 00	-0.6278E-06	0.0	-0.2222E-06
2	2	0.0	0.5000E 00	0.0	0.0	0.0	0.0	0.5000E 00	-0.1240E-05	0.0	0.2583E-06
3	11	0.0	0.1000E 01	0.0	0.0	0.0	0.0	-0.1000E 01	-0.2583E-07	0.0	-0.3147E-07
4	12	0.0	0.1000E 01	0.0	0.0	0.0	0.0	-0.1000E 01	0.3437E-06	0.0	-0.1155E-06

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ELEMENT NO.	I.D.	E-P CODE	SUM CODE	INCREMENTAL TEMPERATURE	TOTAL TEMPERATURE	SURFACE YIELD SIZE	**** EFFECTIVE PLASTIC STRAINS *** INCREMENTAL	SUM INCR.	CUMULATIVE	***** EFFECTIVE CREEP STRAINS **** INCREMENTAL	SUM INCR.	CUMULATIVE
1	1	-1	-2	0.1500E 01	0.1500E 01	0.1000E 01	0.0	0.5000E 00	0.5000E 00	0.0	0.0	0.0
2	2	-1	-2	0.1500E C1	0.1500E 01	0.1000E 01	0.0	0.5000E 00	0.5000E 00	0.0	0.0	0.0
3	11	1	2	0.0	0.0	0.1000E 01	0.5000E 00	0.1500E 01	0.1500E 01	0.0	0.0	0.0
4	12	1	2	0.0	0.0	0.1000E 01	0.5000E 00	0.1500E 01	0.1500E 01	0.0	0.0	0.0

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                    CUMULATIVE THERMAL LOADS AND Z-LOADS FOR LOAD INCREMENT     5
INCREMENT 5 (COLD)

ELEMENT I.D.         1            2            11           12
TEMP.         0.0          0.0          0.0          0.0
Z-LOAD        0.0          0.0          0.0          0.0

ITERATIVE ERROR =  0.12500E 01
ITERATIVE ERROR =  0.14142E 00
ITERATIVE ERROR =  0.10633E-05
ITERATIVE ERROR =  0.83051E-06


                    E N D  O F  L O A D  I N C R E M E N T    5

INCREMENT 5 (COLD)
MECHANICAL LOAD CURVE FACTORS =   0.1000E 01,  0.0
CREEP TIME INCREMENT =  0.0
NO. ELASTIC ELEMENTS =    2, NO. PLASTIC ELEMENTS =    2
    2  ELEMENTS HAVE CHANGED ELASTIC TO PLASTIC,    2  ELEMENTS PLASTIC TO ELASTIC DURING THIS INCREMENT
SPECIFIED MAX. NO. STIFFNESS UPDATES =      2, NO. UPDATES PERFORMED =      0
SPECIFIED MAX. NO. ITERATIONS PER UPDATE =     10, NO. ITERATIONS PERFORMED SINCE LAST UPDATE =      4
SPECIFIED MAX. UNBALANCED-FORCE ERROR =  0.1000E-04, ACTUAL ERROR =  0.8305E-06
```

9.2-17

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           *******  CUMULATIVE INTERNAL FORCES AND DISPLACEMENTS  ********
** NODE **   *********  FORCES  *********           *****  DISPLACEMENTS  ******
 NO.  I.D.       U                V                   U                 V

    1    1   -0.5000000E 01 -0.8030302E-06     0.0              0.0
    2    2   -0.4999999E 01 -0.2111092E-06     0.0             -0.1000000E 01
    3    3    0.4999999E 01 -0.1889095E-05     0.2000000E 01 -0.9106533E-07
    4    4    0.5000000E 01  0.2903234E-05     0.2000001E 01 -0.9999999E 00
    5   11    0.2500004E 01  0.4372123E-07     0.2000000E 01 -0.1974433E-07
    6   12    0.2500004E 01  0.1117496E-07     0.2000001E 01  0.1000000E 01
    7   13   -0.2500002E 01 -0.4371877E-07     0.0              0.0
    8   14   -0.2500006E 01 -0.1117536E-07     0.0              0.1000000E 01
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ELEMENT NO.	I.D.	*** THERMAL STRAINS *** INCREMENTAL	CUMULATIVE	ELASTIC STRAINS — INCREMENTAL XX	YY	ZZ	XY	CUMULATIVE XX	YY	ZZ	XY
1	1	-0.1500E 01	0.0	0.5000E 00	-0.2500E 00	-0.2500E 00	0.3060E-06	0.1000E 01	-0.5000E 00	-0.5000E 00	-0.2731E-07
2	2	-0.1500E 01	0.0	0.5000E 00	-0.2500E 00	-0.2500E 00	-0.5588E-07	0.1000E 01	-0.5000E 00	-0.5000E 00	0.3316E-06
3	11	0.0	0.0	0.5000E 00	-0.2500E 00	-0.2500E 00	-0.4653E-08	-0.5000E 00	0.2500E 00	0.2500E 00	-0.5196E-07
4	12	0.0	0.0	0.5000E 00	-0.2500E 00	-0.2500E 00	0.2086E-06	-0.5000E 00	0.2500E 00	0.2500E 00	0.3539E-07

ELEMENT NO.	I.D.	***** PLASTIC WORK **** INCREMENTAL	CUMULATIVE	PLASTIC STRAINS — INCREMENTAL XX	YY	ZZ	XY	CUMULATIVE XX	YY	ZZ	XY
1	1	0.5000E 00	0.1000E 01	0.5000E 00	-0.2500E 00	-0.2500E 00	-0.2171E-07	0.1000E 01	-0.5000E 00	-0.5000E 00	-0.7783E-07
2	2	0.5000E 00	0.1000E 01	0.5000E 00	-0.2500E 00	-0.2500E 00	0.5538E-07	0.1000E 01	-0.5000E 00	-0.5000E 00	0.1453E-06
3	11	0.0	0.1500E 01	0.0	0.0	0.0	0.0	-0.1500E 01	0.7500E 00	0.7500E 00	0.6173E-07
4	12	0.0	0.1500E 01	0.0	0.0	0.0	0.0	-0.1500E 01	0.7500E 00	0.7500E 00	-0.1844E-06

9.2-18

ELEMENT NO.	I.D.	EFFECTIVE CENTER	EFFECTIVE STRESS	CUMULATIVE STRESS QUANTITIES — STRESS CENTER XX	YY	ZZ	XY	STRESS XX	YY	ZZ	XY
1	1	0.0	0.1000E 01	0.0	0.0	0.0	0.0	0.1000E 01	0.3596E-06	0.0	-0.1821E-07
2	2	0.0	0.1000E 01	0.0	0.0	0.0	0.0	0.1000E 01	0.1798E-06	0.0	0.2210E-06
3	11	0.0	0.5000E 00	0.0	0.0	0.0	0.0	-0.5000E 00	-0.2583E-07	0.0	-0.3457E-07
4	12	0.0	0.5000E 00	0.0	0.0	0.0	0.0	-0.5000E 00	0.2583E-07	0.0	0.2359E-07

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ELEMENT NO.	I.D.	E-P CODE	SUM CODE	INCREMENTAL TEMPERATURE	TOTAL TEMPERATURE	SURFACE YIELD SIZE	**** EFFECTIVE PLASTIC STRAINS *** INCREMENTAL	SUM INCR.	CUMULATIVE	***** EFFECTIVE CREEP STRAINS **** INCREMENTAL	SUM INCR.	CUMULATIVE
1	1	1	2	-0.1500E 01	0.0	0.1000E 01	0.5000E 00	0.1000E 01	0.1000E 01	0.0	0.0	0.0
2	2	1	2	-0.1500E 01	0.0	0.1000E 01	0.5000E 00	0.1000E 01	0.1000E 01	0.0	0.0	0.0
3	11	-1	-2	0.0	0.0	0.1000E 01	0.0	0.1500E 01	0.1500E 01	0.0	0.0	0.0
4	12	-1	-2	0.0	0.0	0.1000E 01	0.0	0.1500E 01	0.1500E 01	0.0	0.0	0.0

CUMULATIVE THERMAL LOADS AND Z-LOADS FOR LOAD INCREMENT 6

INCREMENT 6 (HOT)

ELEMENT I.D.	1	2	11	12
TEMP.	0.15000E 01	0.15000E 01	0.0	0.0
Z-LOAD	0.0	0.0	0.0	0.0

ITERATIVE ERROR = 0.12500E 01
ITERATIVE ERROR = 0.39608E-05
ITERATIVE ERROR = 0.14142E 00
ITERATIVE ERROR = 0.14143E 00
ITERATIVE ERROR = 0.14143E 00
ITERATIVE ERROR = 0.12657E-05
ITERATIVE ERROR = 0.19410E-05

E N D O F L O A D I N C R E M E N T 6

INCREMENT 6 (HOT)
MECHANICAL LOAD CURVE FACTORS = 0.1000E 01, 0.0
CREEP TIME INCREMENT = 0.0
NO. ELASTIC ELEMENTS = 2, NO. PLASTIC ELEMENTS = 2
2 ELEMENTS HAVE CHANGED ELASTIC TO PLASTIC, 2 ELEMENTS PLASTIC TO ELASTIC DURING THIS INCREMENT
SPECIFIED MAX. NO. STIFFNESS UPDATES = 2, NO. UPDATES PERFORMED = 0
SPECIFIED MAX. NO. ITERATIONS PER UPDATE = 10, NO. ITERATIONS PERFORMED SINCE LAST UPDATE = 7
SPECIFIED MAX. UNBALANCED-FORCE ERROR = 0.1000E-04, ACTUAL ERROR = 0.1941E-05

******* CUMULATIVE INTERNAL FORCES AND DISPLACEMENTS ********

** NODE ** NO.	I.D.	********* FORCES ********* U	V	***** DISPLACEMENTS ****** U	V
1	1	-0.2499998E 01	0.6237953E-05	0.0	0.0
2	2	-0.2499997E 01	-0.6568932E-05	0.0	0.7499990E 00
3	3	0.2499998E 01	0.3785571E-05	0.3000000E 01	-0.5009626E-06
4	4	0.2499998E 01	-0.3454593E-05	0.3000001E 01	0.7500000E 00
5	11	0.4999999E 01	-0.1719393E-05	0.3000000E 01	0.3210380E-07
6	12	0.4999995E 01	0.2121707E-05	0.3000001E 01	0.1500000E 01
7	13	-0.4999996E 01	-0.6647882E-06	0.0	0.0
8	14	-0.4999998E 01	0.2624780E-06	0.0	0.1500000E 01

ELEMENT NO.	I.D.	*** THERMAL STRAINS *** INCREMENTAL	CUMULATIVE	ELASTIC STRAINS INCREMENTAL XX	YY	ZZ	XY	CUMULATIVE XX	YY	ZZ	XY
1	1	0.1500E 01	0.1500E 01	-0.5000E 00	0.2500E 00	0.2500E 00	-0.2049E-06	0.5000E 00	-0.2500E 00	-0.2500E 00	-0.2323E-06
2	2	0.1500E 01	0.1500E 01	-0.5000E 00	0.2500E 00	0.2500E 00	0.0	0.5000E 00	-0.2500E 00	-0.2500E 00	0.3316E-06
3	11	0.0	0.0	-0.5000E 00	0.2500E 00	0.2500E 00	-0.1547E-08	-0.1000E 01	0.5000E 00	0.5000E 00	-0.5341E-07
4	12	0.0	0.0	-0.5000E 00	0.2500E 00	0.2500E 00	-0.1027E-06	-0.1000E 01	0.5000E 00	0.5000E 00	-0.6729E-07

ELEMENT NO.	I.D.	***** PLASTIC WORK **** INCREMENTAL	CUMULATIVE	PLASTIC STRAINS INCREMENTAL XX	YY	ZZ	XY	CUMULATIVE XX	YY	ZZ	XY
1	1	0.0	0.1000E 01	0.0	0.0	0.0	0.0	0.1000E 01	-0.5000E 00	-0.5000E 00	-0.7783E-07
2	2	0.0	0.1000E 01	0.0	0.0	0.0	0.0	0.1000E 01	-0.5000E 00	-0.5000E 00	0.1453E-06
3	11	0.5000E 00	0.2000E 01	-0.5000E 00	0.2500E 00	0.2500E 00	-0.2438E-07	-0.2000E 01	0.1000E 01	0.1000E 01	0.3735E-07
4	12	0.5000E 00	0.2000E 01	-0.5000E 00	0.2500E 00	0.2500E 00	0.1327E-07	-0.2000E 01	0.1000E 01	0.1000E 01	-0.1711E-06

ELEMENT NO.	I.D.	EFFECTIVE CENTER	EFFECTIVE STRESS	CUMULATIVE STRESS QUANTITIES STRESS CENTER XX	YY	ZZ	XY	STRESS XX	YY	ZZ	XY
1	1	0.0	0.5000E 00	0.0	0.0	0.0	0.0	0.5000E 00	-0.9120E-06	0.0	-0.1548E-06
2	2	0.0	0.5000E 00	0.0	0.0	0.0	0.0	0.5000E 00	-0.1093E-05	0.0	0.2210E-06
3	11	0.0	0.1000E 01	0.0	0.0	0.0	0.0	-0.1000E 01	0.9735E-07	0.0	-0.3560E-07
4	12	0.0	0.1000E 01	0.0	0.0	0.0	0.0	-0.1000E 01	0.2795E-06	0.0	-0.4486E-07

ELEMENT NO.	I.D.	E-P CODE	SUM CODE	INCREMENTAL TEMPERATURE	TOTAL TEMPERATURE	SURFACE YIELD SIZE	**** EFFECTIVE PLASTIC STRAINS *** INCREMENTAL	SUM INCR.	CUMULATIVE	***** EFFECTIVE CREEP STRAINS **** INCREMENTAL	SUM INCR.	CUMULATIVE
1	1	-1	-2	0.1500E 01	0.1500E 01	0.1000E 01	0.0	0.1000E 01	0.1000E 01	0.0	0.0	0.0
2	2	-1	-2	0.1500E 01	0.1500E 01	0.1000E 01	0.0	0.1000E 01	0.1000E 01	0.0	0.0	0.0
3	11	1	2	0.0	0.0	0.1000E 01	0.5000E 00	0.2000E 01	0.2000E 01	0.0	0.0	0.0
4	12	1	2	0.0	0.0	0.1000E 01	0.5000E 00	0.2000E 01	0.2000E 01	0.0	0.0	0.0

9.3 STAINLESS STEEL HYSTERESIS LOOPS

This example is intended to aid the user in reducing cyclic test data into a form suitable for BOPACE input. The stainless steel specimen used in the example exhibits a pronounced variation in isotropic and kinematic hardening as the cycling progresses, and thus provides a severe test of the BOPACE capability for combined hardening.

The cyclic test data are shown in Figure 9.3-1 by the solid lines.* The plotted points and dashed lines represent the analytical results obtained from a BOPACE run. The hysteresis loops are denoted by dash numbers, with the first number denoting the cycle number and the second denoting the 1st and 2nd half of the cycle.

Because of the obvious variation in magnitude of kinematic hardening over the test cycles, the BOPACE option for variable kinematic hardening was employed in addition to the usual combined isotropic and kinematic hardening. The assumed hardening curves are given in Figure 9.3-2, and the BOPACE input data are listed at the end of this section. A summary of the analytical results is shown in Table 9.3-1.

The test/analysis correlation is quite good, and could be further improved if one were willing to accept some amount of non-smoothness in the input hardening curves of Figure 9.3-2. An exact match would require hardening curves with discontinuous slopes at points corresponding to the strain

* The test hysteresis loops were furnished by Dr. R. H. Mallett of the Advanced Reactor Division, Westinghouse Electric Corp.

9.3 (Continued)

range used in the cyclic test. This is not justifiable in general, because a proper test/analysis match would not result for other strain ranges. Although the test/analysis correlation is considered to be very satisfactory, cyclic results for other strain ranges would have to be compared before any definite conclusions can be drawn.

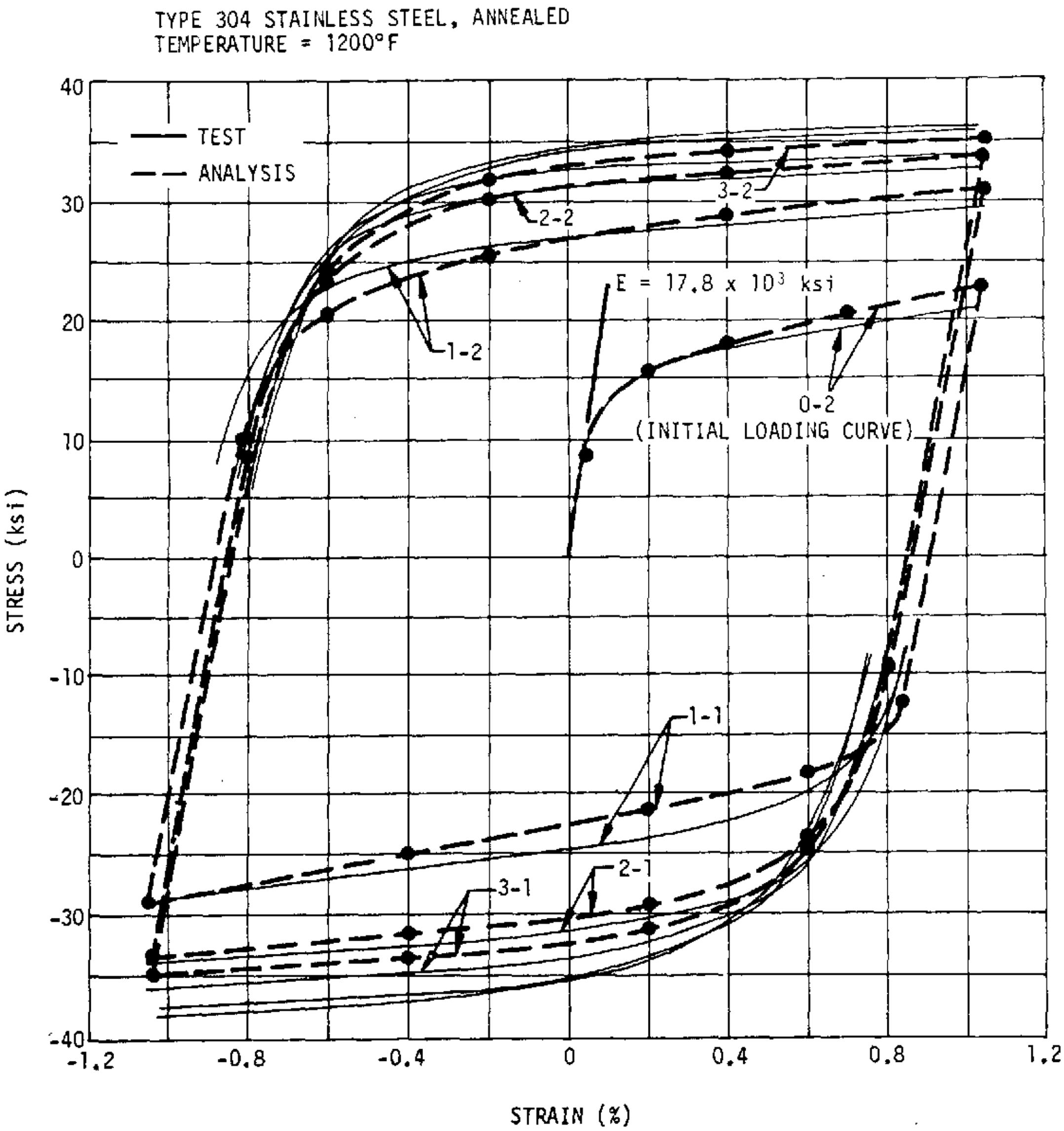

FIGURE 9.3-1: CYCLIC TEST/ANALYSIS CORRELATION FOR STAINLESS STEEL

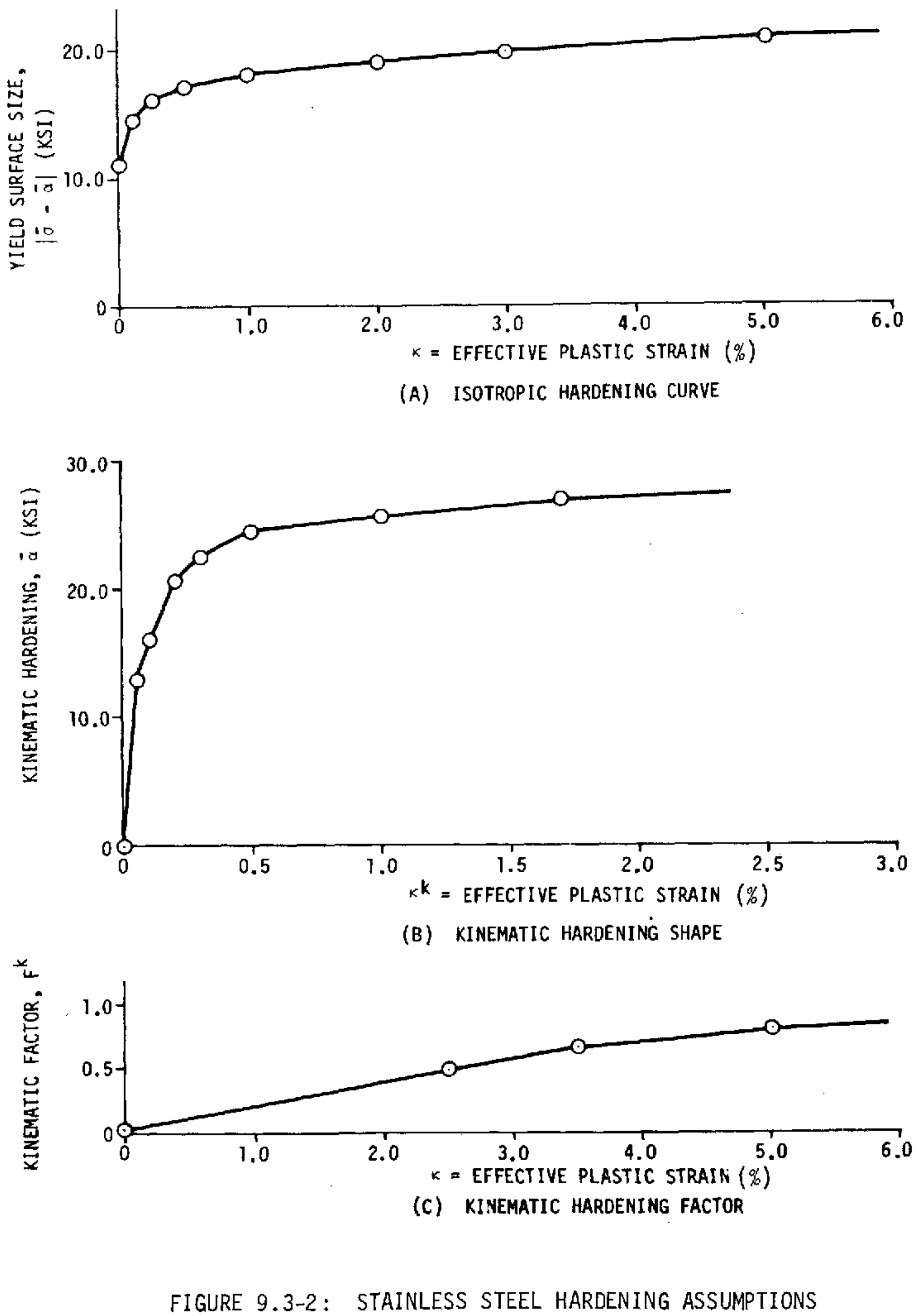

FIGURE 9.3-2: STAINLESS STEEL HARDENING ASSUMPTIONS

TABLE 9.3-1: RESULTS FOR STAINLESS STEEL HARDENING

INCR.	CYCLE	DISPLACEMENT	$\frac{3}{2}\alpha_{XX}$	σ_{XX}	$\lvert\bar{\sigma}-\bar{\alpha}\rvert$	ITERATIONS
1	0-2	.05	0.00	8.90	11.00	1
2	0-2	.2	0.70	15.33	14.64	13
3	0-2	.4	1.74	17.94	16.20	8
4	0-2	.7	3.27	20.44	17.17	7
5	0-2	1.04	4.97	22.80	17.82	7
6	1-1	.9	4.97	-2.12	17.82	1
7	1-1	.8	3.38	-14.50	17.88	9
8	1-1	.6	0.10	-18.02	18.12	8
9	1-1	.2	-2.66	-21.17	18.50	7
10	1-1	-.4	-5.95	-25.01	19.06	7
11	1-1	-1.04	-9.48	-28.97	19.49	7
12	1-2	-.9	-9.48	-4.05	19.49	1
13	1-2	-.8	-7.84	11.65	19.50	7
14	1-2	-.6	1.05	20.65	19.60	9
15	1-2	-.2	5.89	25.69	19.82	8
16	1-2	.4	8.59	28.70	20.11	7
17	1-2	1.04	10.83	31.25	20.42	7
18	2-1	.9	10.83	6.33	20.42	1
19	2-1	.8	9.85	-10.57	20.42	7
20	2-1	.6	-2.58	-23.07	20.49	9
21	2-1	.2	-8.64	-29.31	20.67	8
22	2-1	-.4	-10.54	-31.43	20.89	7
23	2-1	-1.04	-12.34	-33.45	21.11	7
24	2-2	-.9	-12.34	-8.53	21.11	1
25	2-2	-.8	-12.06	9.05	21.11	5
26	2-2	-.6	2.28	23.43	21.15	10
27	2-2	-.2	9.10	30.38	21.27	7
28	2-2	.4	11.00	32.46	21.46	7
29	2-2	1.04	12.35	33.97	21.63	7
30	3-1	.9	12.35	9.06	21.63	1
31	3-1	.8	12.35	-8.74	21.63	1
32	3-1	.6	-2.80	-24.45	21.66	11
33	3-1	.2	-9.98	-31.73	21.76	8
34	3-1	-.4	-11.71	-33.62	21.91	7
35	3-1	-1.04	-13.09	-35.17	22.08	7
36	3-2	-.9	-13.09	-10.25	22.08	1
37	3-2	-.8	-13.09	7.55	22.08	1
38	3-2	-.6	2.25	24.36	22.11	12
39	3-2	-.2	9.83	32.03	22.20	8
40	3-2	.4	11.49	33.79	22.30	7
41	3-2	1.04	12.70	35.10	22.40	7

```
START          5    5    6
BOPACE COMBINED HARDENING (STAINLESS STEEL DATA)             R. VOS    05/2[illegible]/73
   3                                       .0001
     0     1 1.0      1200.
           1
0.0        0.0        1.0        1.0

1200.      178.

1200.      0.3

           1          1          1
           1 1200.
0.0        11.0       .10        14.5       .25        16.0       .5         17.0
1.0        18.0       2.0        19.0       3.0        19.7       5.0        20.7
7.0        21.4       10.0       22.2       15.0       23.0       20.0       23.5
100.0      23.5

0.0        0.0        0.05       13.0       0.1        16.0       0.2        20.5
0.3        22.5       0.5        24.5       1.0        25.7       1.7        27.0
3.0        28.0

0.0        0.02       2.5        0.5
3.5        0.67       5.0        0.9        7.0        0.9        10.0       0.95
20.0       1.0        100.0      1.0


           1          1
0.0        0.0        1.0        1.0

           1 0.
1.0        0.0


     1       0.0        0.0
     2       1.0        0.0
     3       0.0        1.0
     4       1.0        1.0

     1     1                 3    1    4
     2     1                 2    4    1

     1     1  -1             1    2   -1        2    2   -2
     3     2  -3             4    2   -4

           2
     3     2 1.0
     4     2 1.0


         41
           .05
           .2
           .4
           .7
           1.04
           .9
           .8
           .6
```

9.3-6

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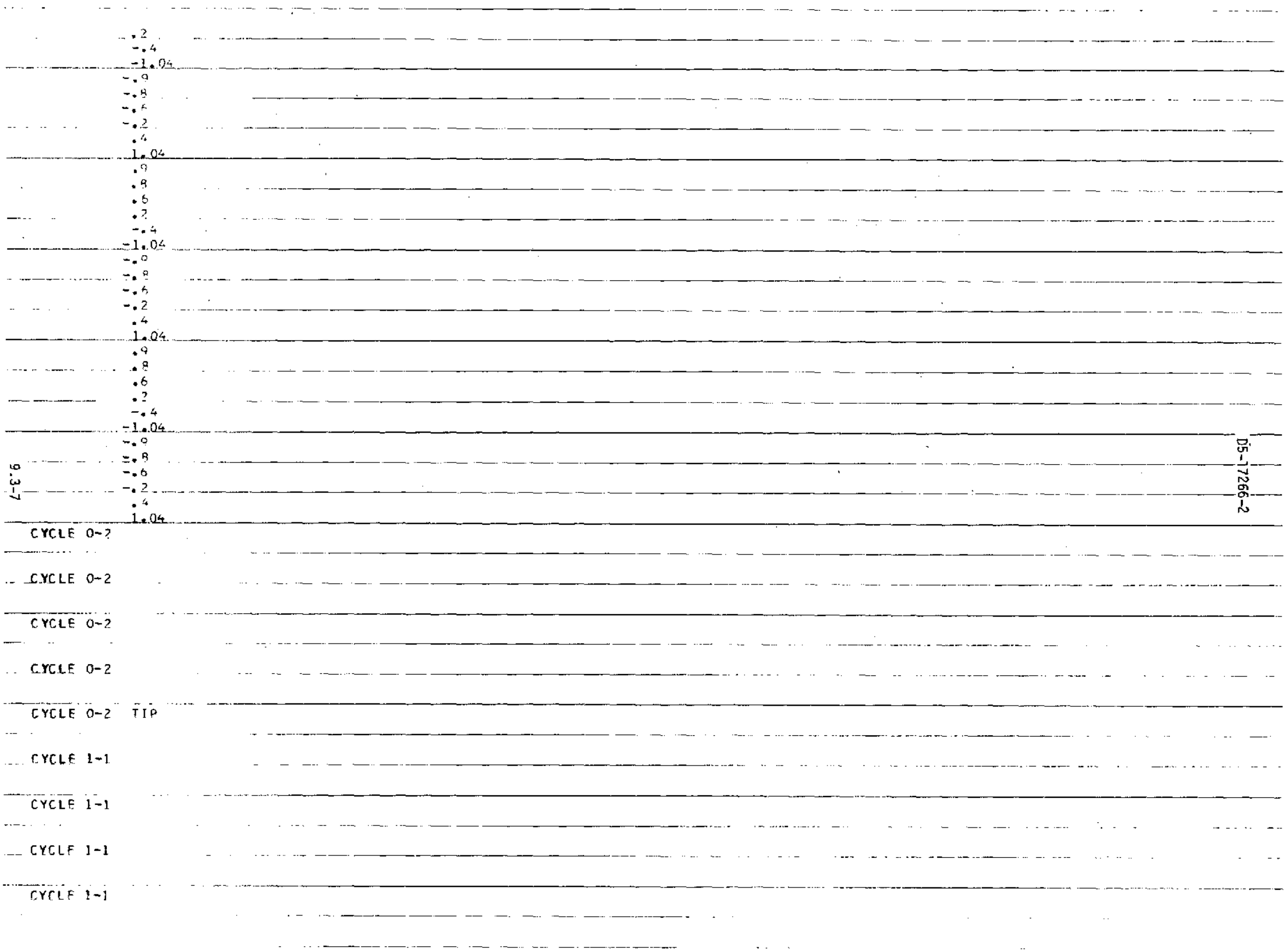
.2
-.4
-1.04
-.9
-.8
-.6
-.2
.4
1.04
.9
.8
.6
.2
-.4
-1.04
-.9
-.8
-.6
-.2
.4
1.04
.9
.8
.6
.2
-.4
-1.04
-.9
-.8
-.6
-.2
.4
1.04
CYCLE 0-2
CYCLE 0-2
CYCLE 0-2
CYCLE 0-2
CYCLE 0-2 TIP
CYCLE 1-1
CYCLE 1-1
CYCLE 1-1
CYCLE 1-1

D5-17266-2

CYCLE 1-1

CYCLE 1-1 TIP

CYCLE 1-2

CYCLE 1-2

CYCLE 1-2

CYCLE 1-2

CYCLE 1-2

CYCLE 1-2 TIP

CYCLE 2-1

CYCLE 2-1

CYCLE 2-1

CYCLE 2-1

CYCLE 2-1

CYCLE 2-1 TIP

CYCLE 2-2

CYCLE 2-2

CYCLE 2-2

CYCLE 2-2

CYCLE 2-2

CYCLE 2-2 TIP

CYCLE 3-1

CYCLE 3-1

CYCLE 3-1

CYCLE 3-1

CYCLE 3-1

CYCLE 3-1 TIP

CYCLE 3-2

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CYCLE 3-2

CYCLE 3-2

CYCLE 3-2

CYCLE 3-2 TIP

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9.4 TYPICAL ENGINE ANALYSIS

The BOPACE program has been directed toward thermo-structural analysis of thrust chamber liners in the Space Shuttle Main Engine (SSME) and in other scale model engines. This section describes a typical analysis for the SSME.

Figure 9.4-1 shows a cross section of the SSME 470K thrust chamber. For the present demonstration a generalized plane-strain analysis is performed for a radial segment at a station 25.4 mm (1.0 inch) upstream of the throat. Details of this segment are given in Figure 9.4-2. The finite element model is shown in Figure 9.4-3. Because this is a demonstration problem and because several loading cycles are analyzed, the selected mesh is fairly crude (only about 250 degrees of freedom). However the results appear to be quite good and indicate that a very fine mesh may not be needed for this type of analysis.

The demonstration problem is summarized as follows.

1. Three cycles at the given station in the SSME 470K engine are analyzed.

2. Each cycle is defined by a start transient, sustained burn and shutdown. Sustained burn will last 500 seconds and shutdown is defined in the detailed report of the demonstration problem (Document D5-17266-3).

3. For demonstration purposes, the following are included.

9.4 (Continued)

a. Creep behavior based on Boeing test data for NARLOY-Z.

b. Estimated cyclic behavior of NARLOY-Z.

c. Specified variation of z-strain from the inside of the liner to the outside of the structural jacket.

d. Local tangential slip is allowed between the liner and Inconel jacket.

A listing of the input data is included at the end of this section. In order to avoid unnecessary duplication, the listing includes thermal and z-load data for only the 1st increment (involving only thermal loads) and the 5th increment (involving both thermal and imposed z-strain loads).

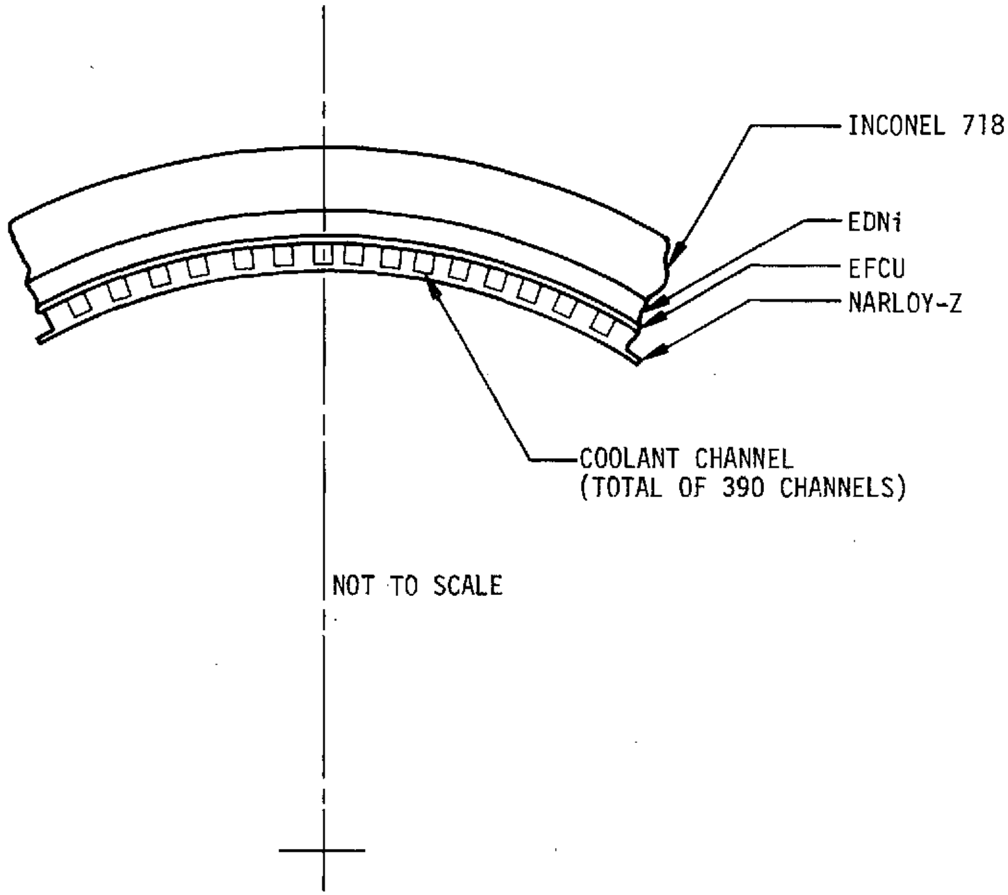

FIGURE 9.4-1: SSME 470K THRUST CHAMBER CROSS SECTION

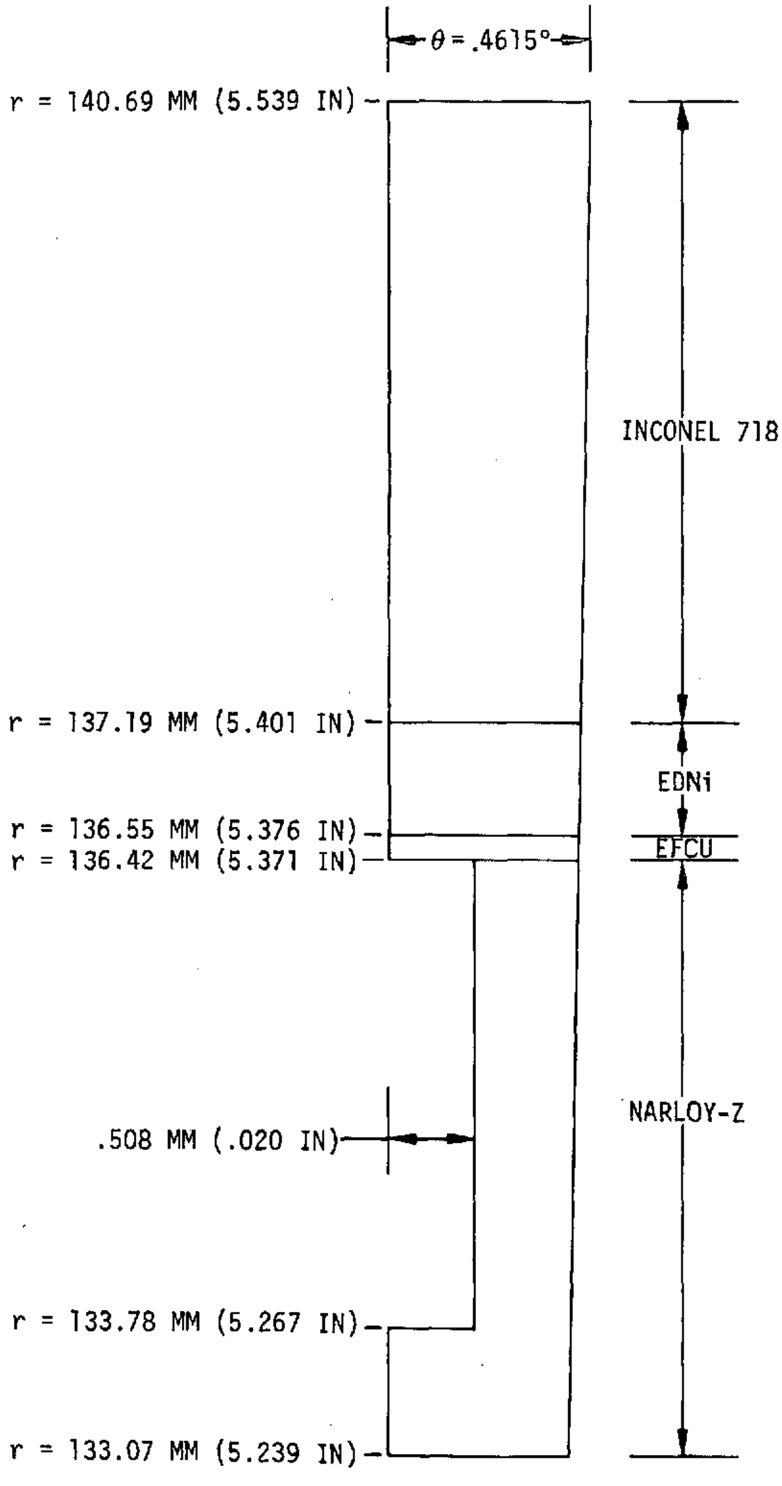

FIGURE 9.4-2: THRUST CHAMBER SEGMENT FOR ANALYSIS

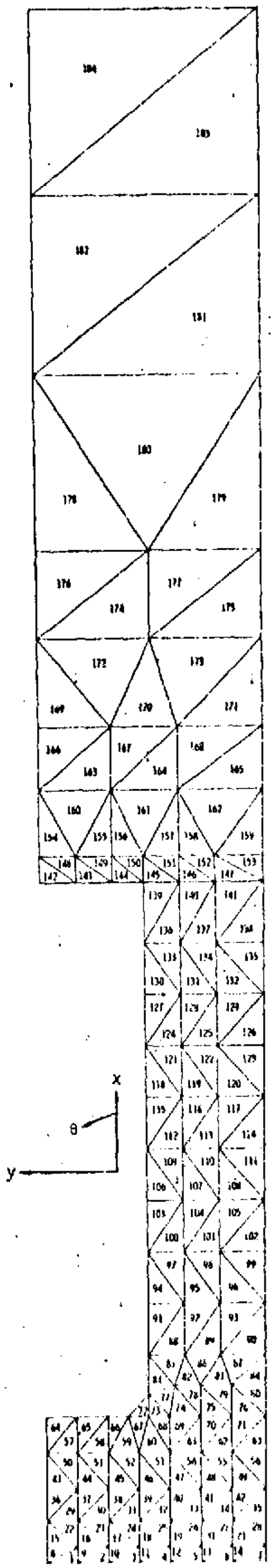

FIGURE 9.4-3: FINITE ELEMENT MODEL

```
START          5    5    6    0    0   22                                              START/RESTART CODE AND DATA FILE NUMBERS
SSME DEMONSTRATION PROBLEM FOR NAS8-29821 INCREMENTS 1-20                                PROBLEM I.D. TITLE
                                                                                         PROGRAM CONTROL CONSTANTS (BLANK CARD)
   1      4 1.0        255.                                                              PLANE STRAIN, 4 MATERIALS, DEFAULT THICK., FAB. TEMP.
          1
 33.15      -.0038     255.4      0.         477.6      .0038     699.8      .0078
 922.        .0122
                                                                                         MATERIAL PROPERTY DATA
 33.15      143.4  +3 255.4      130.3  +3 477.6       117.2  +3 699.8      108.2  +3      (NARLOY-Z)
 922.       56.5   +3

 33.15      .33        922.       .33

          2
 33.        -.0022     144.       -.0014     294.       .0018     478.       .0038
                                                                                         MATERIAL PROPERTY DATA
 33.        147.   +3 144.       139.   +3 294.        130.   +3 478.       121.   +3       (EFCU)

 33.        .36        478.       .36

          3
 144.       -.002      294.       .0004
                                                                                         MATERIAL PROPERTY DATA
 144.       185.   +3 294.       181.   +3                                                 (EDNi)

 144.       .34        294.       .34

          4
 144.       -.001      294.       .0006
                                                                                         MATERIAL PROPERTY DATA
 144.       207.   +3 294.       207.   +3                                                 (INCONEL 718)

 144.       .315       294.       .293

          1          1          1
          1 33.
 0.        172.4      .00365     174.4      .00853     176.5      .00184     182.
.0283      187.5      .0481      199.       .07        199.       .10        199.

 0.        0.         .00365     43.1       .00853     53.1       .0184      57.6
.0283      60.7       .0481      67.2       .07        72.4       .10        79.3

 0.        .23        .00365     .432       .00853     .636       .0184      .79
.0283      .887       .0481      1.0        .07        1.0        .10        1.0

          1 294.
 0.        137.9      .00368     139.3      .00853     141.       .0184      143.4
.0283      146.2      .0482      151.3      .0680      151.7      .10        151.7

 0.        0.         .00368     63.8       .00853     78.6       .0184      82.7
.0283      87.6       .0482      96.5       .0680      106.2      .10        113.8

 0.        .4         .00368     .465       .00853     .60        .0184      .685
.0283      .772       .0482      .88        .068       1.0        .10        1.0

          1 700.
 0.         106.9      .00381     107.8      .00870     109.       .01855     111.
 .02847     113.2      .04837     117.1      .0683      117.6      .10        117.6

 0.         0.         .00381     38.6       .00870     49.2       .01855     50.3
```

.02847	53.1	.04837	59.98	.0683	63.78	.10	66.38
0.	.45	.00381	.55	.00870	.695	.01855	.90
.02847	.98	.04837	.99	.0683	1.0	.10	1.0
	1 811.						
0.	80.7	.00383	81.3	.00866	82.1	.01858	83.7
.02851	85.4	.04842	88.3	.07	88.8	.10	88.8
0.	0.	.00383	24.13	.00866	29.44	.01858	32.06
.02851	33.09	.04842	37.58	.07	38.82	.10	39.
0.	.22	.00383	.52	.00866	.845	.01858	.94
.02851	.96	.04842	1.0	.07	1.0	.10	1.0
	1 922.						
0.	44.8	.00395	45.3	.00883	45.5	.01868	46.5
.02857	47.4	.04853	49.0	.06852	49.3	.10	49.3
0.	0.	.00395	21.24	.00883	24.82	.01868	29.37
.02857	33.23	.04853	33.78	.06852	34.13	.10	34.13
0.	.5	.00395	.66	.00883	.83	.01868	.95
.02857	1.0	.04853	1.0	.06852	1.0	.10	1.0

	2	1	0				
	2 33.						
0.	62.1	.10	62.1				
0.	0.	.0011	68.9	.004	81.4	.00895	92.4
.0189	103.4	.0486	137.9	.0685	162.0	.10	163.0
	2 144.						
0.	48.3	.10	48.3				
0.	0.	.00121	62.1	.00413	73.1	.00906	82.0
.019	91.0	.0488	119.3	.0687	137.9	.10	140.
	2 294.						
0.	41.4	.10	41.4				
0.	0.	.00133	44.8	.00425	55.2	.0092	62.1
.0192	68.9	.049	91.	.0689	106.2	.10	107.
	2 478.						
0.	34.5	.10	34.5				
0.	0.	.00157	17.9	.00451	25.5	.00946	31.
.0194	34.5	.0494	44.1	.0693	49.6	.10	50.

PLASTICITY DATA (EFCu)

	3	1	0				
	3 144.						
0.	310.	.10	310.				
0.	0.	.0028	103.	.0075	155.	.0271	224.
.0469	262.	.10	262.				
	3 294.						

PLASTICITY DATA (EDNi)

```
0.        276.      .10       276.

0.        0.        .0029     103.       .0078     138.      .0274     193.
.0473     214.      .10       214.
```

```
          4         1         0
          4 294.
0.        827.      .10       827.

0.        0.        .0013     138.       .0048     248.      .0145     317.
.0441     386.      .10       400.
```

PLASTICITY DATA (INCONEL 718)

```
          1         2
0.0       0.0       20.       .00008     60.       .00020    180.      .00029
600.      .00043    1200.     .00054     1800.     .00064    3600.     .00075

          1 644.0
0.0       0.0       97.0      0.0        138.  6   0.0       207.0     0.0

          1 811.0
0.0       0.0       97.0      1.0        138.0     2.0       207.0     5.0

          1 922.0
0.0       0.0       97.0      2.0        138.0     6.0       207.0     20.0
```

CREEP DATA (NARLOY-Z)

```
          2         2
3600.     0.0

          2 922.0
207.0     0.0
```

CREEP DATA (EFCu)

```
          3         2
3600.     0.0

          3 922.0
207.0     0.0
```

CREEP DATA (EDNi)

```
          4         2
3600.     0.0

          4 922.0
207.0     0.0
```

CREEP DATA (INCONEL 718)

SPECIAL COORDINATE SYSTEMS (BLANK CARD)

```
   1      0 133.07054    0.0          1
   2      0 133.07054   -0.15240      1
   3      0 133.07054   -0.30480      1
   4      0 133.07054   -0.45720      1
   5      0 133.07054   -0.60960      1
   6      0 133.07054   -0.76200      1
   7      0 133.07054   -0.91440      1
   8      0 133.06621   -1.07192      1
   9      0 133.14674    0.0          1
  10      0 133.14674   -0.15240      1
```

11	0	133.14674	-0.30480	1
12	0	133.14674	-0.45720	1
13	0	133.14674	-0.60960	1
14	0	133.14674	-0.76200	1
15	0	133.14674	-0.91440	1
16	0	133.14241	-1.07254	1
17	0	133.27376	0.0	1
18	0	133.27376	-0.15240	1
19	0	133.27376	-0.30480	1
20	0	133.27376	-0.45720	1
21	0	133.27376	-0.60960	1
22	0	133.27376	-0.76200	1
23	0	133.27376	-0.91440	1
24	0	133.26942	-1.07356	1
25	0	133.42615	0.0	1
26	0	133.42615	-0.15240	1
27	0	133.42615	-0.30480	1
28	0	133.42615	-0.45720	1
29	0	133.42615	-0.60960	1
30	0	133.42615	-0.76200	1
31	0	133.42615	-0.91440	1
32	0	133.42181	-1.07479	1
33	0	133.60394	0.0	1
34	0	133.60394	-0.15240	1
35	0	133.60394	-0.30480	1
36	0	133.60394	-0.45720	1
37	0	133.60394	-0.60960	1
38	0	133.60394	-0.76200	1
39	0	133.60394	-0.91440	1
40	0	133.59961	-1.07622	1
41	0	133.78174	0.0	1
42	0	133.78174	-0.15240	1
43	0	133.78174	-0.30480	1
44	0	133.78174	-0.40640	1
45	0	133.78174	-0.50800	1
46	0	133.78174	-0.60960	1
47	0	133.78174	-0.76200	1
48	0	133.78174	-0.91440	1
49	0	133.77737	-1.07765	1
50	0	133.88336	-0.50800	1
51	0	133.93416	-0.63500	1
52	0	133.93416	-0.76200	1
53	0	133.93416	-0.91440	1
54	0	133.92979	-1.07888	1
55	0	134.08655	-0.50800	1
56	0	134.08655	-0.68580	1
57	0	134.08655	-0.86360	1
58	0	134.08218	-1.08011	1
59	0	134.34055	-0.50800	1
60	0	134.34055	-0.68580	1
61	0	134.34055	-0.86360	1
62	0	134.33618	-1.08215	1
63	0	134.59456	-0.50800	1
64	0	134.59456	-0.68580	1
65	0	134.59456	-0.86360	1
66	0	134.59016	-1.08420	1
67	0	134.84854	-0.50800	1
68	0	134.84854	-0.68580	1
69	0	134.84854	-0.86360	1
70	0	134.84415	-1.08624	1

NODE DEFINITIONS

71	0	135.10254	-0.50800	1
72	0	135.10254	-0.68580	1
73	0	135.10254	-0.86360	1
74	0	135.09816	-1.08829	1
75	0	135.35655	-0.50800	1
76	0	135.35655	-0.68580	1
77	0	135.35655	-0.86360	1
78	0	135.35214	-1.09034	1
79	0	135.61055	-0.50800	1
80	0	135.61055	-0.68580	1
81	0	135.61055	-0.86360	1
82	0	135.60614	-1.09238	1
83	0	135.86456	-0.50800	1
84	0	135.86456	-0.68580	1
85	0	135.86456	-0.86360	1
86	0	135.86015	-1.09443	1
87	0	136.11855	-0.50800	1
88	0	136.11855	-0.68580	1
89	0	136.11855	-0.86360	1
90	0	136.11411	-1.09648	1
91	0	136.42334	0.0	1
92	0	136.42334	-0.17780	1
93	0	136.42334	-0.35560	1
94	0	136.42334	-0.50800	1
95	0	136.42334	-0.68580	1
96	0	136.42334	-0.86360	1
97	0	136.41891	-1.09893	1
98	0	136.55034	0.0	1
99	0	136.55034	-0.17780	1
100	0	136.55034	-0.35560	1
101	0	136.55034	-0.50800	1
102	0	136.55034	-0.68580	1
103	0	136.55034	-0.86360	1
104	0	136.54591	-1.09995	1
105	0	136.88055	0.0	1
106	0	136.88055	-0.35560	1
107	0	136.88055	-0.68580	1
108	0	136.87610	-1.10261	1
109	0	137.18533	0.0	1
110	0	137.18533	-0.35560	1
111	0	137.18533	-0.68580	1
210	0	137.18533	-0.35560	1
211	0	137.18533	-0.68580	1
112	0	137.18088	-1.10507	1
113	0	137.61714	0.0	1
114	0	137.61714	-0.55880	1
115	0	137.61266	-1.10855	1
116	0	138.04895	0.0	1
117	0	138.04895	-0.55880	1
118	0	138.04446	-1.11203	1
119	0	138.91255	0.0	1
120	0	138.90805	-1.11898	1
121	0	139.77614	0.0	1
122	0	139.77159	-1.12594	1
123	0	140.69055	0.0	1
124	0	140.68597	-1.13330	1

1	1	2	10	1
2	1	3	11	2
3	1	4	12	3

4	1	5	13	4
5	1	6	14	5
6	1	7	15	6
7	1	8	16	7
8	1	9	1	10
9	1	10	2	11
10	1	11	3	12
11	1	12	4	13
12	1	13	5	14
13	1	14	6	15
14	1	15	7	16
15	1	17	9	10
16	1	18	10	11
17	1	19	11	12
18	1	20	12	13
19	1	21	13	14
20	1	22	14	15
21	1	23	15	16
22	1	10	18	17
23	1	11	19	18
24	1	12	20	19
25	1	13	21	20
26	1	14	22	21
27	1	15	23	22
28	1	16	24	23
29	1	18	26	17
30	1	19	27	18
31	1	20	28	19
32	1	21	29	20
33	1	22	30	21
34	1	23	31	22
35	1	24	32	23
36	1	25	17	26
37	1	26	18	27
38	1	27	19	28
39	1	28	20	29
40	1	29	21	30
41	1	30	22	31
42	1	31	23	32
43	1	33	25	26
44	1	34	26	27
45	1	35	27	28
46	1	36	28	29
47	1	37	29	30
48	1	38	30	31
49	1	39	31	32
50	1	26	34	33
51	1	27	35	34
52	1	28	36	35
53	1	29	37	36
54	1	30	38	37
55	1	31	39	38
56	1	32	40	39
57	1	34	42	33
58	1	35	43	34
59	1	35	36	44
60	1	36	37	45
61	1	38	47	37
62	1	39	48	38
63	1	40	49	39

64	1	41	33	42
65	1	42	34	43
66	1	43	35	44
67	1	45	44	36
68	1	37	46	45
69	1	46	37	47
70	1	47	38	48
71	1	48	39	49
72	1	45	50	44
73	1	50	45	46
74	1	46	47	51
75	1	52	47	48
76	1	53	48	49
77	1	46	51	50
78	1	47	52	51
79	1	48	53	52
80	1	49	54	53
81	1	55	50	51
82	1	51	52	56
83	1	52	53	57
84	1	54	58	53
85	1	56	55	51
86	1	57	56	52
87	1	58	57	53
88	1	56	60	55
89	1	57	61	56
90	1	58	62	57
91	1	59	55	60
92	1	60	56	61
93	1	61	57	62
94	1	63	59	60
95	1	64	60	61
96	1	65	61	62
97	1	60	64	63
98	1	61	65	64
99	1	62	66	65
100	1	64	68	63
101	1	65	69	64
102	1	66	70	65
103	1	67	63	68
104	1	68	64	69
105	1	69	65	70
106	1	71	67	68
107	1	72	68	69
108	1	73	69	70
109	1	68	72	71
110	1	69	73	72
111	1	70	74	73
112	1	72	76	71
113	1	73	77	72
114	1	74	78	73
115	1	75	71	76
116	1	76	72	77
117	1	77	73	78
118	1	79	75	76
119	1	80	76	77
120	1	81	77	78
121	1	76	80	79
122	1	77	81	80
123	1	78	82	81

ELEMENT DEFINITIONS

124	1	80	84	79
125	1	81	85	80
126	1	82	86	81
127	1	83	79	84
128	1	84	80	85
129	1	85	81	86
130	1	87	83	84
131	1	88	84	85
132	1	89	85	86
133	1	84	88	87
134	1	85	89	88
135	1	86	90	89
136	1	88	95	87
137	1	89	96	88
138	1	90	97	89
139	1	94	87	95
140	1	95	88	96
141	1	96	89	97
142	2	98	91	92
143	2	99	92	93
144	2	100	93	94
145	2	101	94	95
146	2	102	95	96
147	2	103	96	97
148	2	92	99	98
149	2	93	100	99
150	2	94	101	100
151	2	95	102	101
152	2	96	103	102
153	2	97	104	103
154	3	105	98	99
155	3	100	106	99
156	3	106	100	101
157	3	102	107	101
158	3	107	102	103
159	3	104	108	103
160	3	106	105	99
161	3	107	106	101
162	3	108	107	103
163	3	106	110	105
164	3	107	111	106
165	3	108	112	107
166	3	109	105	110
167	3	110	106	111
168	3	111	107	112
169	4	113	109	210
170	4	210	111	114
171	4	112	115	211
172	4	114	113	210
173	4	115	114	211
174	4	114	117	113
175	4	115	118	114
176	4	116	113	117
177	4	117	114	118
178	4	119	116	117
179	4	118	120	117
180	4	120	119	117
181	4	120	122	119
182	4	121	119	122
183	4	122	124	121

```
184    4             123  121  124
```

```
  1    2   -1
  9    2   -9
 17    2  -17
 25    2  -25
 33    2  -33
 41    2  -41
 91    2  -91
 98    2  -98
105    2 -105
109    2 -109
113    2 -113
116    2 -116
119    2 -119
121    2 -121
123    2 -123
  8    2   -8
 16    2  -16
 24    2  -24
 32    2  -32
 40    2  -40
 49    2  -49
 54    2  -54
 58    2  -58
 62    2  -62
 66    2  -66
 70    2  -70
 74    2  -74
 78    2  -78
 82    2  -82
 86    2  -86
 90    2  -90
 97    2  -97
104    2 -104
108    2 -108
112    2 -112
115    2 -115
118    2 -118
120    2 -120
122    2 -122
124    2 -124
```

CONSTRAINED DEGREES OF FREEDOM

```
       2
  1    1 .0762
  2    1 .1524
  3    1 .1524
  4    1 .1524
  5    1 .1524
  6    1 .1524
  7    1 .1524
  8    1 .0762

 41    1 -.0762
 42    1 -.1524
 43    1 -.127
 44    1 -.1016
 44    2 -.0508
 50    1 -.0508
 50    2 -.1524
```

MECHANICAL LOAD REFERENCE VECTORS

55	2	-.2286
59	2	-.254
63	2	-.254
67	2	-.254
71	2	-.254
75	2	-.254
79	2	-.254
83	2	-.254
87	2	-.2794
94	1	.0762
94	2	-.1524
93	1	.1651
92	1	.1778
91	1	.0889

20

.31	1.	.4
.31	1.	.4
.43	1.38	.5
1.49	4.83	.45
2.13	6.89	.25
2.98	9.65	.2
4.15	13.44	.2
5.32	17.23	.2
6.60	21.37	.2
8.31	26.89	.2
10.01	32.41	.2
11.93	38.61	.2
12.71	41.13	.2
12.71	41.13	.2
12.71	41.13	.2
12.71	41.13	.2
12.71	41.13	.2
12.71	41.13	.2
12.71	41.13	.2
12.71	41.13	.2

INCREMENTAL MECHANICAL LOAD DATA (20 INCREMENTS)

0.4000**

1	257.65	2	257.66	3	257.64	4	257.63
5	257.61	6	257.62	7	257.76	8	257.40
9	257.40	10	257.39	11	257.36	12	257.33
13	257.32	14	257.45	15	256.75	16	256.73
17	256.68	18	256.64	19	256.60	20	256.57
21	256.64	22	256.34	23	256.29	24	256.21
25	256.17	26	256.13	27	256.06	28	256.13
29	255.43	30	255.34	31	255.23	32	255.15
33	255.07	34	254.95	35	254.86	36	254.97
37	254.88	38	254.75	39	254.64	40	254.52
41	254.41	42	254.27	43	254.00	44	253.71
45	253.67	46	253.44	47	253.30	48	253.08
49	252.96	50	253.30	51	253.09	52	252.94
53	252.73	54	252.52	55	252.32	56	252.13
57	252.20	58	251.78	59	251.51	60	251.18
61	250.91	62	250.76	63	250.51	64	252.00
65	251.30	66	250.93	67	250.46	68	250.00
69	249.88	70	249.92	71	249.78	72	248.82
73	248.39	74	247.87	75	248.27	76	247.99
77	247.26	78	247.26	79	247.33	80	247.15
81	245.36	82	245.46	83	245.62	84	245.68
85	244.16	86	244.76	87	244.81	88	242.53
89	242.97	90	243.31	91	241.49	92	242.04

93	242.34	94	239.87	95	240.37	96	240.64
97	239.26	98	239.61	99	239.88	100	237.85
101	238.18	102	238.42	103	237.12	104	237.54
105	237.75	106	236.03	107	236.40	108	236.60
109	235.62	110	235.99	111	236.09	112	234.68
113	234.93	114	235.11	115	234.19	116	234.50
117	234.67	118	233.47	119	233.76	120	233.91
121	233.22	122	233.43	123	233.58	124	232.63
125	232.82	126	232.97	127	232.30	128	232.55
129	232.69	130	231.92	131	232.10	132	232.24
133	231.79	134	231.92	135	232.24	136	231.44
137	231.60	138	231.93	139	231.17	140	231.44
141	231.61	142	229.86	143	230.27	144	230.61
145	230.97	146	231.27	147	231.47	148	230.04
149	230.42	150	230.73	151	231.08	152	231.30
153	231.51	154	230.08	155	230.48	156	230.70
157	230.97	158	231.12	159	231.39	160	230.38
161	230.83	162	231.17	163	230.54	164	230.84
165	231.09	166	230.48	167	230.76	168	230.96
169	230.65	170	230.80	171	230.95	172	230.75
173	230.86	174	230.79	175	230.84	176	230.78
177	230.82	178	230.80	179	230.92	180	230.81
181	230.81	182	230.81	183	230.81	184	230.81

ELEMENT TEMPERATURES 1ST INCREMENT

ELEMENT Z-STRAINS (1ST INCREMENT)

2.0000**

1	310.94	2	310.97	3	310.91	4	310.84
5	310.76	6	310.79	7	311.78	8	309.31
9	309.27	10	309.24	11	309.11	12	308.96
13	308.92	14	309.83	15	304.99	16	304.90
17	304.66	18	304.48	19	304.26	20	304.14
21	304.75	22	302.26	23	302.02	24	301.70
25	301.50	26	301.28	27	300.93	28	301.54
29	296.28	30	295.86	31	295.39	32	295.03
33	294.60	34	294.01	35	293.55	36	293.17
37	292.76	38	292.20	39	291.70	40	291.10
41	290.53	42	289.94	43	286.61	44	285.02
45	284.98	46	283.78	47	283.39	48	282.28
49	281.66	50	281.98	51	280.91	52	280.27
53	279.40	54	278.63	55	277.59	56	276.66
57	274.39	58	272.10	59	270.91	60	269.71
61	268.80	62	268.12	63	266.85	64	272.61
65	268.62	66	266.82	67	264.74	68	263.09
69	262.65	70	262.98	71	262.39	72	255.05
73	253.26	74	250.74	75	253.16	76	251.79
77	246.89	78	247.07	79	247.70	80	246.91
81	235.24	82	236.39	83	237.54	84	238.21
85	228.41	86	232.32	87	232.92	88	219.08
89	222.18	90	224.44	91	213.04	92	216.93
93	218.93	94	204.46	95	207.78	96	209.55
97	201.34	98	203.65	99	205.37	100	193.82
101	195.90	102	197.42	103	189.87	104	192.50
105	193.84	106	184.34	107	186.60	108	187.80
109	182.39	110	183.96	111	195.15	112	177.59
113	179.02	114	180.08	115	175.05	116	176.87
117	177.80	118	171.58	119	173.17	120	174.01
121	170.43	122	171.54	123	172.38	124	167.51
125	168.52	126	169.34	127	165.91	128	167.23
129	167.95	130	164.14	131	165.06	132	165.79
133	163.57	134	164.19	135	165.90	136	161.93

ELEMENT TEMPERATURES (5TH INCREMENT)

137	162.66	138	164.29	139	160.65	140	161.88
141	162.75	142	154.66	143	156.47	144	159.01
145	159.69	146	161.13	147	162.08	148	155.46
149	157.14	150	158.58	151	160.22	152	161.24
153	162.26	154	155.69	155	157.47	156	159.48
157	159.70	158	160.41	159	161.68	160	157.03
161	159.07	162	160.67	163	157.77	164	159.13
165	160.29	166	157.49	167	158.78	168	159.70
169	158.28	170	158.95	171	159.65	172	158.73
173	159.24	174	158.91	175	159.15	176	158.86
177	159.04	178	158.93	179	159.05	180	158.99
181	159.00	182	158.99	183	159.00	184	159.00

ELEMENT Z-STRAINS (5TH INCREMENT)

1	-0.000077	2	-0.000077	3	-0.000077	4	-0.000077
5	-0.000077	6	-0.000077	7	-0.000077	8	-0.000077
9	-0.000077	10	-0.000077	11	-0.000077	12	-0.000077
13	-0.000077	14	-0.000077	15	-0.000078	16	-0.000078
17	-0.000078	18	-0.000078	19	-0.000078	20	-0.000078
21	-0.000078	22	-0.000079	23	-0.000079	24	-0.000079
25	-0.000079	26	-0.000078	27	-0.000078	28	-0.000078
29	-0.000080	30	-0.000080	31	-0.000080	32	-0.000080
33	-0.000080	34	-0.000080	35	-0.000079	36	-0.000080
37	-0.000080	38	-0.000080	39	-0.000080	40	-0.000080
41	-0.000080	42	-0.000080	43	-0.000081	44	-0.000081
45	-0.000081	46	-0.000082	47	-0.000082	48	-0.000082
49	-0.000082	50	-0.000082	51	-0.000082	52	-0.000083
53	-0.000083	54	-0.000083	55	-0.000083	56	-0.000083
57	-0.000083	58	-0.000083	59	-0.000084	60	-0.000085
61	-0.000085	62	-0.000085	63	-0.000085	64	-0.000084
65	-0.000084	66	-0.000084	67	-0.000085	68	-0.000085
69	-0.000085	70	-0.000085	71	-0.000085	72	-0.000085
73	-0.000085	74	-0.000085	75	-0.000085	76	-0.000085
77	-0.000085	78	-0.000086	79	-0.000086	80	-0.000085
81	-0.000087	82	-0.000087	83	-0.000087	84	-0.000086
85	-0.000087	86	-0.000087	87	-0.000087	88	-0.000089
89	-0.000089	90	-0.000088	91	-0.000089	92	-0.000089
93	-0.000089	94	-0.000091	95	-0.000091	96	-0.000091
97	-0.000092	98	-0.000092	99	-0.000092	100	-0.000094
101	-0.000094	102	-0.000094	103	-0.000095	104	-0.000095
105	-0.000095	106	-0.000096	107	-0.000096	108	-0.000096
109	-0.000097	110	-0.000097	111	-0.000097	112	-0.000099
113	-0.000099	114	-0.000099	115	-0.000100	116	-0.000100
117	-0.000100	118	-0.000102	119	-0.000102	120	-0.000102
121	-0.000102	122	-0.000102	123	-0.000102	124	-0.000104
125	-0.000104	126	-0.000104	127	-0.000105	128	-0.000105
129	-0.000105	130	-0.000107	131	-0.000107	132	-0.000107
133	-0.000108	134	-0.000108	135	-0.000109	136	-0.000109
137	-0.000109	138	-0.000110	139	-0.000111	140	-0.000111
141	-0.000110	142	-0.000112	143	-0.000112	144	-0.000112
145	-0.000112	146	-0.000112	147	-0.000112	148	-0.000112
149	-0.000112	150	-0.000112	151	-0.000112	152	-0.000112
153	-0.000112	154	-0.000114	155	-0.000114	156	-0.000114
157	-0.000114	158	-0.000113	159	-0.000113	160	-0.000115
161	-0.000115	162	-0.000115	163	-0.000117	164	-0.000117
165	-0.000117	166	-0.000118	167	-0.000118	168	-0.000118
169	-0.000121	170	-0.000121	171	-0.000120	172	-0.000122
173	-0.000122	174	-0.000125	175	-0.000125	176	-0.000126
177	-0.000126	178	-0.000131	179	-0.000130	180	-0.000133
181	-0.000139	182	-0.000142	183	-0.000148	184	-0.000151

NOTE: THERMAL AND Z-DIRECTION LOAD DATA SHOWN FOR 1ST AND 5TH INCREMENTS ONLY. COMPLETE SET OF DATA WOULD INCLUDE THERMAL AND Z-DIRECTION LOAD DATA FOR 20 INCREMENTS.

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A.0 INPUTB INTERPOLATION AND DATA GENERATION

Purpose - The program INPUTB was developed to serve as an interface between thermal analyzers such as BETA (Boeing Engineering Thermal Analyzer) and BOPACE. For the BETA program the structure is modeled as a network of lumped masses which in general do not correspond to the finite element nodes required for BOPACE. To expedite and automate preparation of thermal input data for BOPACE, INPUTB operates on the output from BETA to produce element temperatures for input to BOPACE. The generation of thermal data for BOPACE is shown schematically in Figure A.0-1. Note that the BETA thermal analyzer can be replaced by any other thermal analyzer (e.g., SINDA, NASTRAN).

However, INPUTB is of a general nature, and it can be used equally well for interpolation and data generation of the user-prescribed element z-direction loads. The INPUTB program will be discussed here in terms of temperature interpolation, but its use in interpolating other quantities should be obvious.

Method - If temperatures are given as functions of time for some two-dimensional mesh of points, then the temperature at any other point and time can be determined by a spatial and temporal interpolation.

The time variations of temperature are computed by a simple linear interpolation, while the spatial variations are treated with an area weighting process equivalent to linear interpolation.

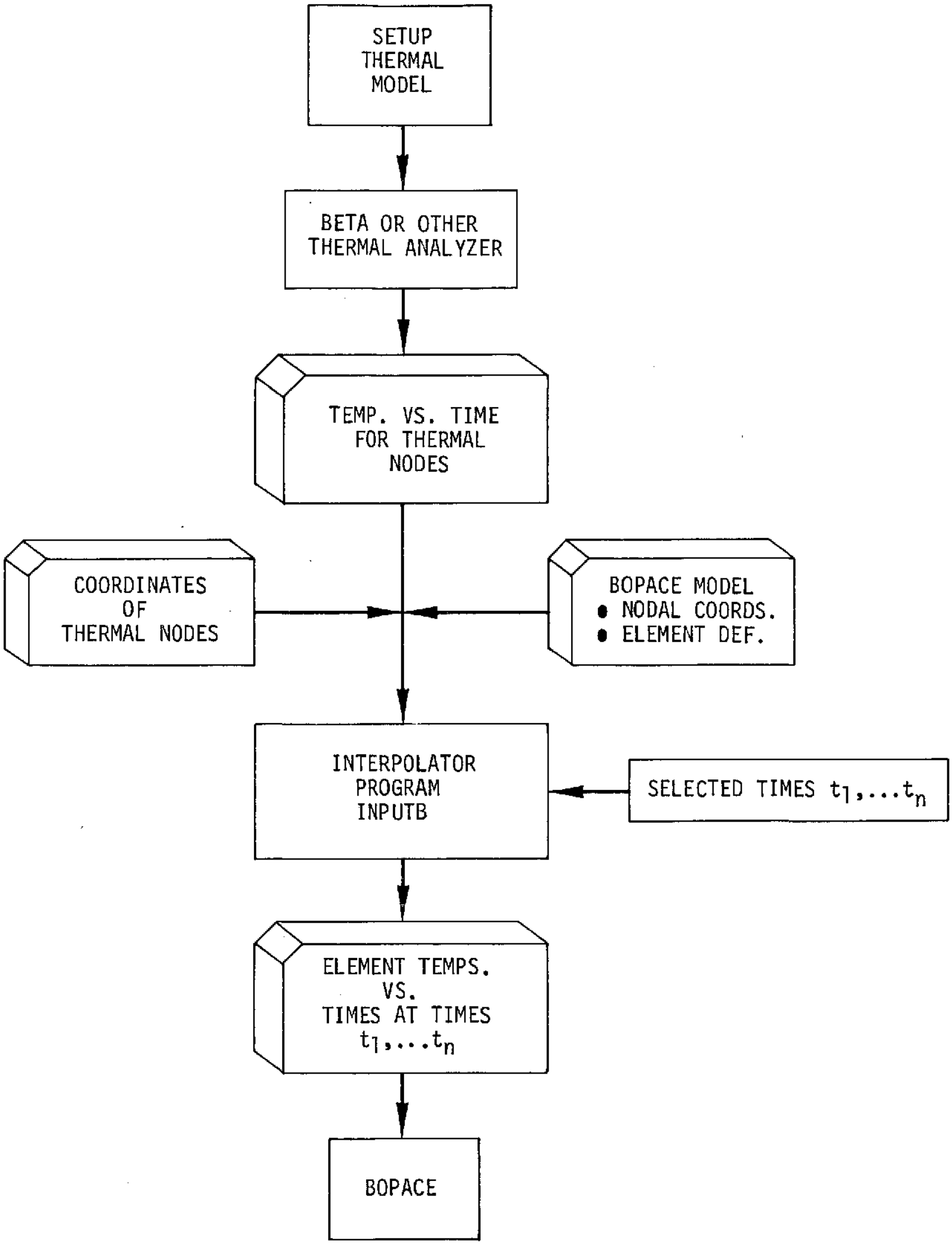

Figure A.0-1: THERMAL ANALYSIS/GENERATION OF THERMAL DATA FOR BOPACE

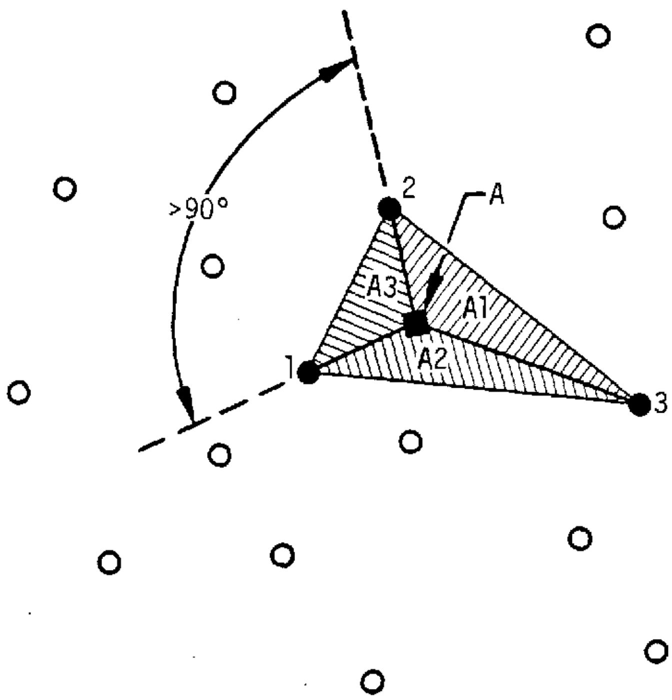

FIGURE A.0-2: SPATIAL INTERPOLATION

DECK SETUP

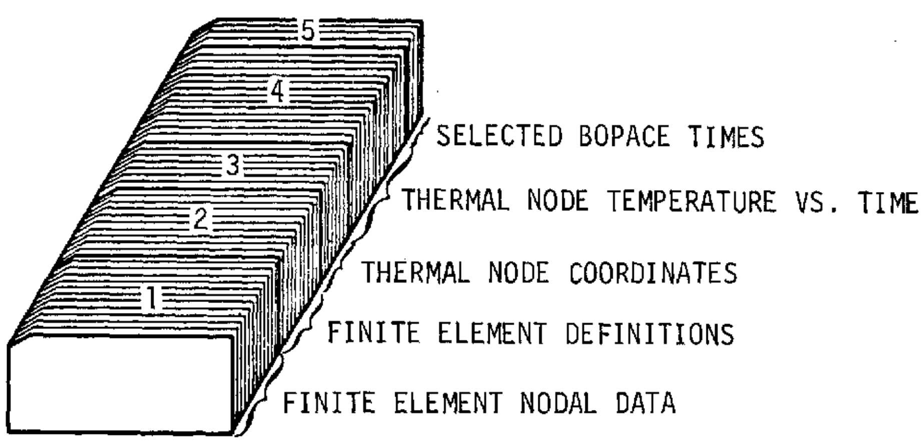

FIGURE A.0-3: INPUTB DECK SETUP

A.0 (Continued)

For the spatial interpolation, refer to Figure A.0-2. Assume that the temperature is to be computed at point A. Temperatures at all other points are known. INPUTB logic proceeds as follows.

(1) Find point 1, the point closest to A.

(2) Locate point 2 as the next closest point such that the angle between lines A-1 and A-2 is greater than 90°.

(3) Locate point 3 as the next closest point such that point A is <u>within</u> the triangle 1-2-3.

(4) The temperature at point A is determined from a weighting of the temperatures at points 1,2,3 according to areas A1, A2, A3, i.e.,

$$T_A = \frac{1}{(A1+A2+A3)} \quad (A1*T_1+A2*T_2+A3*T_3)$$

(5) Special cases may arise where no triangle can be found according to the above procedure. These special cases have been accounted for.

<u>Summary of INPUTB Data</u> - A pictorial of the INPUTB input deck is shown in Figure A.0-3. The following is a listing of the input data by item (Formats are consistent with FORTRAN IV conventions).

1. Finite Element Nodal Data (BOPACE Format)
   - For Each Node: Node I.D.

     I.D. of Coordinate System (0-Rectangular, 1-Polar)

A.0 (Continued)

Nodal Coordinates (X,Y or R,θ)

I.D. of Displacement System (0-Rectangular, 1-Polar)

(2I5,2F10.0,I5)

- Blank Card after Last Node

2. Finite Element Definitions (BOPACE Format)

- For Each Element: Element I.D.

  Material Number

  Thickness

  3 Node Numbers (CCW Order)

(2I5,F10.0,3I5)

3. Thermal Node Coordinates

- For Each Thermal Node: Node I.D., ICOORD, X(R), Y(θ)

  ICOORD = 0 -Rectangular Coordinates

  ICOORD = 1 -R,θ Coordinates

  Up to 2 Nodes per Card

  2(2I5,2F10.0)

- Blank Card After Last Thermal Node

4. Thermal Node Temperatures vs. Time

- Number of Times, Default Temperature (I10,F10.0)

A.0 (Continued)

- Time (F10.0)
- For Each Thermal Node: Node Number, Temperature
  Up to 4 Nodes Per Card 4(I10,F10.0)
- Blank Card after Last Node

Repeat for each time up to number of times.

For first time, default temperature will be assigned to unspecified nodes. For succeeding times, unspecified nodes will take on value at previous time.

5. Selected Times

For each time (BOPACE Time) at which Element Temperatures are to be Computed:

- Time, ISTOP (F10.0, I10)

  Note: ISTOP = 0, except on card following last time card set ISTOP = 9.

Note: Max Input Times = 20

Max Number of BOPACE Times = 12

Max Number of Thermal Nodes = 300 (Max I.D. = 2000)

Max Finite Element Nodes = 500 (Max I.D. = 2000)

Max Number of Finite Elements = 800 (Max I.D. = 3000)

A.0 (Continued)

Output Data - Element Numbers and Temperatures are punched for each of the selected BOPACE times specified in the input as follows.

- Time (F10.4,70(LH*))
- Element Number, Element Temperature 4(I10,F10.2)