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OAK RIDGE NATIONAL LABORATORY

GAS-COOLED REACTOR PROGRAMS

HTGR BASE TECHNOLOGY PROGRAM
(Activity AG 25 05 000)

Prestressed Concrete Nuclear Pressure Vessel Development
(Task No. 01331)

CREEP80 AXISYMMETRIC FINITE ELEMENT PROGRAM FOR CREEP ANALYSIS OF AGING CONCRETE STRUCTURES AT VARIABLE TEMPERATURE

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Date Published - August 1981

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CREEP80

AXISYMMETRIC FINITE ELEMENT PROGRAM FOR CREEP ANALYSIS OF AGING CONCRETE STRUCTURES AT VARIABLE TEMPERATURE

by

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Report No. 81-8A

to

Oak Ridge National Laboratory
Oak Ridge, Tennessee

Operated by

Union Carbide Corporation

for the

Department of Energy

Kenilworth, Illinois

August, 1981

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ABSTRACT

A new finite element program for the analysis of creep effects in concrete structures, is briefly described. The program, known as CREEP80, may be used independently or as an added feature of the general purpose finite element code NONSAP developed at the University of California at Berkeley. The program uses a rate-type creep law based on expanding the relaxation function in Dirichlet series. The creep law is linear, the aging is accounted for, and the temperature effects on creep rate as well as the rate of aging are considered. Material properties can be input either as empirical creep test data or as the double power law for creep. The program can automatically set up the creep parameters from partial empirical information. The program uses a step-by-step integration in time. Applications are envisaged chiefly for nuclear structures.

INTRODUCTION

With the increasing public concern about the safety of nuclear reactors, it is becoming imperative to evaluate the strengths and deformations of nuclear reactor vessels and containments very carefully and realistically, taking into account the actual inelastic behavior of the material. In concrete reactor containments as well as vessels acting as energy-absorbing barriers, the major source of inelastic behavior during the service life is the creep of concrete. During the past decade the knowledge of this phenomenon advanced tremendously and methods that allow an accurate and realistic analysis on the service conditions have been developed.

A general purpose finite element code for the creep analysis of nuclear concrete structures has recently been developed by Anderson and coworkers [1,7,10]. This program utilizes a rate-type creep law proposed in 1971 by Bažant [3]. which is based on expanding the compliance function for aging concrete (also called creep function) into a series of real exponentials, called Dirichlet series. Subsequently, it was found, however, [8] that this formulation has some theoretical disadvantages from the point of view of thermodynamic restrictions resulting from the aging of concrete. Although the general form of the creep constitutive relation is correct from the thermodynamic viewpoint, when the experimental creep data for concrete are fitted some parameters of the model can be negative while according to thermodynamic limitations they should be positive. This is not necessarily incorrect, since these are internal variables while the thermodynamic restrictions must be satisfied only in total by the ensemble of the internal variables. However, such a feature is a matter of concern and it appears therefore safer to use a constitutive relation where the fulfillment of the thermodynamic restrictions is assured. This appears to be the case for an analogous rate-type formulation which is based on a Dirichlet series expansion of the relaxation function rather than the compliance function and is modeled by an aging Maxwell chain model [2,4,5,6].

The foregoing formulation has been implemented in the present two programs.

This report presents a complete description of the mathematical basis, input and program structure for the CREEP80 program and the NONSAP form of the program. The report is conceptually divided into four parts. The first part is a general description of the programs with a discussion of the essential features of their mathematical and theoretical basis. The second part gives a detailed description of CREEP80 along with the input for the program. The third part is a detailed description of the NONSAP version of the program with an input description. Finally the listing of input, output and results of several test problems for CREEP80 and the NONSAP version is presented. A list of references is included at the end of the report.

The CREEP80 program and the NONSAP form of the program are intended for use in obtaining the response of axially symmetrical concrete structures. The program accommodates structures with reinforcing steel, prestressing steel and axially symmetrical thin shell elements (with no bending behavior), called liner elements. Structures may be subjected to external static time-dependent loads and temperature changes. Temperature changes may have either fixed or variable spatial distributions with time in the structure. The concrete may be plain or reinforced, with or without prestressing steel. A fixed time and spatial distribution of relative humidity in the concrete is permitted.

CONSTITUTIVE RELATION FOR CREEP

The creep law is assumed to be linear, i.e., following the principle of superposition [2]. The linearity assumption is acceptable for concrete only at stresses less than about one-half of the strength, which is typical of nuclear vessels and containments under service conditions. Even within this range, significant deviations from linearity are observed upon unloading and in a regime with decreasing strains. In such cases, the program cannot yield very good results. Another phenomenon which spoils the linearity even within the service

stress range is the simultaneous drying; however, this is not severe for nuclear concrete structures because they are massive and also protected by the steel liner on the interior face.

The aging of concrete, particularly the gradual change of creep properties as a function of age, is taken into account. This phenomenon causes the parameters of Dirichlet series expansion of the relaxation function, representing the elastic moduli of the Maxwell chain model, to be dependent on the age of concrete.

The effect of temperature variations (limited to temperatures under 80^0C) upon the creep behavior is taken into account. This includes both (a) the increase of the creep rate due to heating, and (b) the acceleration of aging, as modeled by the equivalent hydration period (maturity) [4,2]. Both of these effects are modeled using the activation energy concept, with different activation energies for the creep rate and for the process of aging (hydration).

The creep formulation used in the program is not capable of handling the general effects of time-variable pore humidity in concrete. These effects bring about a major complication of the constitutive relation [2] and require many additional variables to be used to characterize partial stresses in solid and water components, and they also require a good model for tensile cracking due to hygral stresses. Nevertheless, omission of moisture effects appears to be admissible for massive structures such as nuclear vessels and containments. This is because of their thickness, as well as the use of the steel liner on the interior face, which does not permit any significant drying to occur except in a narrow layer near the exterior surface.

An approximate consideration of the humidity effect which does not cause any major complication of the mathematical formulation, is, however, possible with the present program. The user is allowed to specify for each finite element the mean ambient humidity (not the pore humidity in concrete, and not a time-variable quantity). The coefficients of the creep law are then adjusted to give a creep function that corresponds to concrete cylinders exposed to this environmental humidity, kept constant for the duration of the creep test. The approximate practical creep

prediction model given in parts I and III of Ref. 7 is used for this purpose. As for the definition of shrinkage, the program can use the formulas from Ref. 7 or a set of experimentally observed shrinkage values can be specified. It must be remembered that the foregoing consideration of humidity effects is very crude and yields realistic values only for the overall internal force resultants caused by humidity effects within the cross section of the structure. The method does not permit evaluating the distribution of the stresses produced by humidity effects throughout the cross section.

NUMERICAL ALGORITHM

As has been clearly demonstrated before [e.g., 2], a rate-type creep law allows a much more efficient finite element analysis than the integral-type creep law based directly on the principle of superposition. As already mentioned, the present program uses a rate-type creep law based on expanding the relaxation function of concrete into a series of real exponentials called Dirichlet series. This creep formulation may be visualized by the Maxwell chain model, the elastic moduli of which depend on the age of concrete, more precisely the equivalent hydration period. This creep formulation is completely specified by a set of relaxation times, which are automatically selected in the program according to the rules given in Refs. 2 and 5, and by the age-dependent elastic moduli of the Maxwell chain. These moduli are automatically generated from the relaxation function, which itself is automatically determined from the compliance function (creep function). The program also makes a check by reproducing the creep curve on the basis of the Maxwell chain model (as presented in Ref. 6).

The rate-type creep law [6,2] consists of a set of first-order differential equations for the partial stresses of the Maxwell chain and for the total strain of the Maxwell chain. It has been shown before that the usual step-by-step methods for ordinary differential equations cannot be applied to this system of equations. This is because either

a numerical instability or a gross loss of accuracy results when the time step of these methods greatly exceeds the shortest relaxation time, which is a necessity when the long-time values, corresponding for example to a 40-year service lifetime, are to be reached. The problem is completely avoided by the so-called exponential algorithm [4,5,2], which is based on an exact solution of the differential equations for the Maxwell chain under the assumption that all parameters are constant within the time-step. This exponential algorithm was proven and demonstrated to be unconditionally stable, and highly accurate even for very long time steps. This allows increasing the time-step roughly in a geometric progression, keeping it approximately constant in the log-time scale. Experimentation with the program confirms, however, that good results are also obtained using other types of time step variation.

FLOW CHART OF THE PROGRAM

Instead of exhibiting the flow chart graphically, it is sufficient to describe it as follows.

The program implements a step-by-step stable integration procedure. A typical time step consists of estimates of the incremental quantities for the step computed using the material properties at the midstep. The flow of the program is outlined below (the subroutines involved in each step of the program are mentioned in the parentheses):

1. Read and check the input data (INPUT, MATPAR).
2. Compute the material parameters for the Maxwell chain model (MATPAR, PRINT1).
3. Initialize and set the step number to zero (MAINC).
4. Increment the step number and check whether the final step is completed. If it is, the final output is printed and the program ends (MAINC, PRINT2)
5. For the current time step, the age of the concrete, applied external loads and temperature are determined at midstep time (MAINC, CONSTI).

6. The material properties are established based on the mid-step age of concrete (CONSTI, TEMHUM, DIFFUS, EMUF).
7. The instantateous stiffness matrix is established for each element. (ASREEK).
8. The incremental inelastic strains and the corresponding load vector are evaluated for each element (ASREEO).
9. The linear equation system for the nodal displacement increments of the structure and the load vector are assembled. (MERGE).
10. The prescribed boundary constraints are imposed and the equation system is solved for the incremental displacements (BOCOND, BANSOL).
11. The incremental strains and stresses, as well as the total stresses, strains and displacements, are computed and selective output is printed. The program then returns to step 4. (RETRCK, STRESS, PRINT2)

The foregoing flow chart is, of course, routine, used in many inelastic computer programs.

DETERMINATION OF CREEP PROPERTIES

The creep properties are determined by the following subroutine (MATPAR), calling for further subroutines as specified.

1. Read the number of decades in log-time scale to be considered, the number of steps per decade, the number of elements in Maxwell chain, the time for the start of the first time step and the first relaxation time.
2. Read the input option number and read the corresponding material data from which the characterization of the compliance function is developed. When the case of drying is specified, read also the characteristics for shrinkage and drying creep.
3. Compute the discrete values of the relaxation function for various strain deviations and various ages at the start of relaxation. (This consists in direct numerical solution of a linear Volterra integral equation.) (RELAX).

4. Compute the discrete values of the Maxwell chain moduli at all discrete ages (MAXWL1).
5. As a check, compute discrete values of the compliance function from the discrete values of Maxwell chain moduli for various ages (CRCURV). Print the resulting values of the compliance function and of their deviations from the initially specified values of the compliance function. Also calculate and print the coefficient of variation of these deviations.

During the determination of the relaxation function, a subroutine for the compliance function is repeatedly called. This subroutine has three options to be specified by the user.

1. The compliance function is evaluated by interpolation from a given array of discrete values. The interpolation is linear in the logarithm of creep duration and in the logarithm of the age at loading. For durations and ages falling outside the range, extrapolation is automatically used.
2. The compliance function is evaluated from a formula corresponding to the double power law [7].
3. If drying is specified, the compliance function is evaluated from a formula consisting of the double power law enhanced by a drying term [7] .

The ultimate result obtained in the subroutine MATPAR is the array of the discrete variables of the moduli of the Maxwell chain. For any specified age, the value of the Maxwell chain moduli is computed from the discrete values (in subroutine function EMUF) by a linear interpolation in the logarithm of the age of concrete. For arguments falling outside the time range, a linear extrapolation from the two values at the end of the array is used.

INPUT OPTIONS FOR MATERIAL CHARACTERIZATION

MATPAR:

1. The compliance function is specified as an array of discrete values for various load durations and various ages at loading. No drying is considered.

2. Drying is considered, and the mean compliance function for the cross section is specified as in option 1. Also, the values of the mean shrinkage strain of the cross section are specified for various durations of drying and the given age at the start of drying.
3. The compliance function is given by the double power law, for which all of its five parameters are read. No drying is considered.
4. Same as option 3 but all double power law parameters except the 28-day elastic modulus are generated from the given strength and composition parameters of concrete (the mix ratio of water, cement, sand, and gravel, the cement-type, and the unit weight of concrete).
5. Same as option 4 except that the 28-day elastic modulus is also predicted from the strength and composition parameters.
6. Drying is specified and the compliance function is defined by the double power law enhanced by the term for the creep increase due to drying [7]. A formula for the shrinkage strain evolution in time (according to Ref. 7) is also specified. And all parameters in these formulas are read.
7. Same as option 6 but all material parameters except the 28-day elastic modulus and the final shrinkage strain are predicted from the strength and the composition parameters of concrete (and also from the given ambient humidity).
8. Same as 6 but all parameters except the 28-day elastic modulus are predicted from the strength and composition of concrete.
9. Same as option 6 but all parameters are predicted from the strength and composition of concrete.
10. Two of the five double power law parameters (namely, E_o and ϕ_1, see Ref. 7) are determined so as to obtain the best fit (in the least-square sense) of the given array of discrete values of the compliance function at various load durations and various ages. The remaining three double power law parameters are given. This option is used when the given array of discrete values for the compliance function is of limited range in time and/or age. No drying is considered in this

option. As a check, the coefficient of variation for the deviations of the formula from the given limited array of values for the compliance function is automatically computed and printed.

11. Same as option 10 but the remaining three double power law parameters are not specified; they are predicted from the given strength and composition of concrete.
12. Same as option 10 but drying is considered.
13. Same as option 11 but drying is considered.

The user selects his input option depending on the amount of information available to him before the analysis. If sufficient test data have been obtained, as is frequently done for nuclear concrete structures, then the measured discrete values of the compliance function should be used. However, if the range of these available data is too limited, it is preferable to approximate these values by the double power law. If no experimental information is available the double power law parameters are predicted from the strength and composition of concrete. However, if there exists some information on the double law parameters for a similar concrete, an adjustment of some of its parameters is appropriate [11]. Moreover, if the short-time deformation (elastic modulus) is measured, it should be also used to improve the parameters of the double power law. The choice of the proper input option has a great effect on the accuracy in representing the concrete properties.

MATHEMATICAL DESCRIPTION

The concrete is assumed to be a homogeneous and isotropic material with time and temperature dependent properties. It is assumed in the analysis that concrete does not crack. Mathematical details of the model are found in [4,5], but pertinent equations describing the behavior of the concrete are given below. Instantaneous values of the elastic constants at any point in the structure are obtained from the incremental bulk modulus K" and the incremental shear modus G" for the given time step. These values are evaluated as

$$K'' = \sum_{\mu} \lambda_{\mu} K_{\mu} \tag{1}$$

and

$$G'' = \sum_{\mu} \lambda_{\mu} G_{\mu} \tag{2}$$

in which

$$\lambda_{\mu} = \frac{1-e^{-\phi_{\mu}\Delta t}}{\phi_{\mu}\Delta t} \tag{3}$$

$$\phi_{\mu} = (10^{-a_{\mu}\sqrt{1-h}})\ \phi_T \tag{4}$$

$$a_{\mu} = 3.6 - 0.095\ (\mu-1)^2 \tag{5}$$

$$G = \frac{E_{\mu}(t_e)}{2(1+\upsilon)} \tag{6}$$

$$K_{\mu} = \frac{E_{\mu}(t_e)}{3(1-2\upsilon)} \tag{7}$$

$$\phi_T = \exp\left[\frac{U_{\mu}}{R}\left(\frac{1}{T_0} - \frac{1}{T}\right)\right] \tag{8}$$

$$\Delta t = t_r - t_{r-1} \tag{9}$$

and t_e is the equivalent time at which the properties are computed. This time is computed by the expression

$$t_e = \beta_h \int_0^{t_r} \phi_T dt \tag{10}$$

where

$$\beta_h = [1 + (3.5 - 3.5h)^4]^{-1} \tag{11}$$

and h is the relative humidity in the pores of the concrete at the point in the structure being considered. In absence of drying (h=1), which may be assumed for massive structures, one has $\phi_{\mu} = \phi_T$, $t_e = \int \phi_T dt$. The parameter U_{μ} is the activation energy of creep, which is

usually constant although it could depend on μ. R is the gas constant and T the absolute temperature, with T_0 being the initial or reference temperature. The subscript μ refers to the μth unit in the Maxwell chain with all properties of the units defined by the input option of the users.

The solution is marched out in time logarithmically [4], with the properties of the concrete evaluated at a time that is at the midpoint of the time increment Δt. The midpoint time $t_{r-\frac{1}{2}}$ (in log scale) is given by

$$t_{r-\frac{1}{2}} = t' + \sqrt{(t_r - t')\ (t_{r-1} - t')}$$

where t' is the age at which the first loading occurs. Since the solution is incremental, the total displacement and stresses are given by

$$u_r = u_{r-1} + \Delta u_r \tag{13}$$

$$\sigma_r^V = \sigma_{r-1}^V + \Delta\sigma_r^V \tag{14}$$

$$\sigma_r^D = \sigma_{r-1}^D + \Delta\sigma_r^D \tag{15}$$

where

$$\Delta\sigma_r^V = 3K''\ (\Delta\varepsilon_r^V - \Delta\varepsilon_r^{V''}) \tag{16}$$

$$\Delta\sigma_r^D = 2G''\ (\Delta\varepsilon_r^D - \Delta\varepsilon_r^{D''}) \tag{17}$$

and the inelastic strains are given by

$$\Delta\varepsilon_r^{V''} = \frac{1}{3K} \sum_\mu (1-e^{-\phi_\mu \Delta\tau})\sigma_{\mu_{r-1}}^V \tag{18}$$

$$\Delta\varepsilon_r^{D''} = \frac{1}{2G''} \sum_\mu (1-e^{-\phi_\mu \Delta t})\ \sigma_{\mu_{r-1}}^D \tag{19}$$

The total and incremental stresses must be summed from the corresponding stresses for each unit in the Maxwell chain.

COMPUTATIONAL FLOW OF THE PROGRAM

Both this program CREEP80 and the NONSAP program have the same computational flow. The general flow chart is shown in Figure 1. In Figure 2 the flow chart for the program CREEP80 is shown with all routines listed in the manner in which they are called. Figure 3 shows the storage allocation scheme for CREEP80 with the size of arrays shown on the right side of each box.

PROGRAM ROUTINE DESCRIPTIONS FOR CREEP80

The functions of individual programs and the mathematical basis for each is described below.

ASREEK The instantaneous axially symmetrical triangular element stiffness matrix is established by this subroutine.

ASREEØ This subroutine establishes the B matrix for the triangular element and calculates the vector of nodal forces due to inelastic and temperature strains.

ASREEP This subroutine computes the incremental strains due to incremental displacements.

ASTR Axially symmetrical linear element stresses are computed by this subroutine.

BANSØL This subroutine solves a set of banded symmetric equations.

BØCØND The specified zero displacement conditions are incorporated into the final set of equations by this subroutine.

BSTR Bar and loop element stresses are computed by this subroutine.

CONSTI This subroutine establishes the instantaneous constitutive relations and the inelastic strains for axially symmetrical concrete elements. See page 11 for mathematical details.

CRCURV For a check, it computes the discrete values of compliance function J(t,t') from the previously calculated discrete values of EMU.

CREEP Calculates values of compliance function J(t,t') as a function of stress duration X = t-t' and age at loading Y = t'.

CREEPA Accomplishes the purpose of CREEP by double interpolation or extrapolation from given adjacent discrete values J(t,t'). The interpolation is linear in transformed scales log (t-t') and log (t').

CREEPB Accomplishes the purpose of CREEP by evaluating the double power law (without or with the drying creep terms) from the given material parameters and specified value of stress duration X = t-t' and age at loading Y = t'.

CREEP80 The arrangement and dynamic assignment of storage for each problem is computed by routine. The storage map is shown on page 77 with definitions of storage arrays given on page 17

DIFFUS The rate coefficients $\phi_\mu^V = \phi_\mu^D$ and the thermal strain for each element of the Maxwell chain are computed by this subroutine.

DRTERM Calculates from given material parameters the drying creep term to be added to the double power law.

EMUF The time dependent value of elastic modulus E_μ for each unit of the Maxwell chain is computed by interpolation from an array (table) by this function routine.

EXPS This subroutine calculates e^{-x} and $(1 - e^{-x})/x$ for a large range of positive x.

IBANDW Maximum bandwidth is calculated by this routine.

INPUT Structural geometry, element connectivity, loads, boundary conditions, time steps, load and temperature factor and selective output information is read in by this subroutine.

INCSSR The instantaneous constitutive relation is established for each element by this subroutine.

MAINC Overall control of the flow of the program and establishment of the temperature and load conditions for each step of the solution process is affected by this subroutine.

MATPAR Generates creep and shrinkage properties from given data and calculates discrete values of relaxation moduli EMU

MAXWLI Computes the relaxation spectra for various ages at loading and various stress duration.

MERGE This subroutine controls the establishment of the instantaneous stiffness matrix of the structure.

PRINT1 Input data is printed out by this subroutine.

PRINT2 Selective or final values of displacements, stresses and strains are printed out by this subroutine.

RELAX Computes the discrete values of the relaxation function from the discrete values of the compliance function

RETRCK This subroutine controls the calculation of the incremental stresses and strains for each time step.

SHRDAT Computes the shrinkage strain for given drying duration $T = t-t_0$ by interpolation or extrapolation using a prescribed array of discrete shrinkage values for various times.

SHRINK Computes the shrinkage strain for given drying duration $T = t - t_0$, using either the square-root hyperbolic law with specified material parameters, or the discrete shrinkage values for which subroutine SHRDAT is called.

SHSTF The stiffness matrix and temperature nodal force vector is established by this subroutine for axially symmetrical shell elements (calling parameter N = 0), bar elements (N = 2) and hoop elements (N = 1).

STØR This subroutine superimposes the element stiffness matrices into the global stiffness matrix.

STRESS The incremental stress in the concrete elements is computed at the centroid by this subroutine.

TEMHUM The average temperature and humidity in each element, the coefficients β_t and β_h and shrinkage strains are computed by this subroutine.

TEMDIL Computes thermal dilatation as function of temperature TEM

DICTIONARY OF MAJOR VARIABLES

Index and Control Parameters

NBAND	Half bandwidth of equations
NBØUND	Number of nodes with specified zero displacements.
NDIS	Number of nodes selected for displacement output
NEPS	Number of concrete elements selected for strain output
NLØAD	Number of nodes with specified nodal loads.
NØBE	Number of bar and hoop elements
NØLE	Number of axially symmetrical liner elements
NSTEP	Number of time steps
NSTR	Number of concrete elements selected for stress output.
NTØT	Total number of equations
NUMEL	Number of concrete triangular elements
NUMNP	Number of nodal points

Arrays in Dynamic Storage

AREA	Liner, bar and hoop element areas
B	Concrete element B matrices
CHDAT	Maxwell chain properties
CØNST	Material constants and reinforcing steel ratios
DTIME	Time increments
ETM	Element centroid equivalent times
GLØBCØ	Nodal coordinates
IBØUND	Specified zero displacement conditions
IEG	Concrete element connectivity
IEPS	Element number of selected strains
ILØAD	Node numbers of loaded nodes
IDIS	Node numbers of selected displacements
ISE	Liner, bar and hoop element connectivity
ISTR	Element number of selected stresses
PØPR	Nodal humidity
RFAC	Load factor for each time increment
RLØAD	Nodal loads
RREF	Reference load vector

SDR	Load vector/displacement vector
SIGMA	Concrete element stresses for each Maxwell chain unit
SKI	Global stiffness matrix
SR	Total displacement vector
STRAIN	Concrete element strains
TEMP	Beginning and ending nodal temperatures in each time step
TFAC	Temperature factor for each time increment

INPUT FOR CREEP80

Group I Control Cards

Card 1 1015

1- 5	(NDIS)	No. of selected displacements
6-10	(NSTR)	No. of selected stresses
11-15	(NEPS)	No. of selected strains
16-20		Step no. of prestressing steel. (See Note 1)
21-25		Printing of input data. (=0 no printing)
26-30		Print switch (0 to 11) IPSW (See Note 2)
31-35		Data check (=0 data read and checked only)
36-40		Step at which user supplied temperatures are entered (=0 set to NSTEP+1) (See Note 3)

Card 2 1015

1- 5	(NSTEP)	No. of time steps
6-10		
11-15		Time step in real (=0) or log (=1) time

Card 3 1015

1- 5	(NUMNP)	Number of nodal points
6-10	(NUMEL)	Number of concrete elements
11-15	(NLØAD)	Number of loaded nodes
16-20	(NBØUND)	Number of nodes with specified displacement
21-25	(NPEL)	Number of nodes per element (=3)
26-30	(NDF)	Number of degrees of freedom per node (=2)
31-35	(NØLE)	Number of liner elements.
36-40	(NØBE)	Number of bar and hoop elements.

Card 4 1015

1- 5		
6-10		
11-15		
16-20		
21-25	(NMU)	No. of units in Maxwell chain

Group II Element Cards (16I5)

NUMEL cards in this group in numerical order

1- 5	Element No.
6-10	I Node
11-15	J Node
16-20	K Node

II(A) Liner Elements (3I5, F10.3) (Skip if NØLE = 0) (See Note 4)

1- 5	Element No. (NØLE Cards)
6-10	I Node
11-15	J Node
16-25	Area (in square inches)

II(B) Bar and hoop elements (skip if NØBE = 0)

1- 5	Element No. (NØBE cards)
6-10	I Node
11-15	J Node (=0 hoop element)
16-25	Area (in square inches)

Group III Coordinate Cards (I5,2(5X,E15.7)

NUMNP cards in this group in numerical order

1- 5	Node No.
11-25	R Coordinate (in inches)
31-45	Z Coordinate (in inches)

Group IV Boundary Condition Cards (16I5)

NBØUND cards in this group

1- 5	Node No.
6-10	R Boundary (1=fixed,0=free)
11-15	Z Boundary (1=fixed,0=free)

Group V Load Cards (I5,2(5X,E15.7)

NLØAD Cards in this group (See Note 5)

1- 5	Loaded Node No.
11-25	R Load (in pounds)
31-45	Z Load (in pounds)

Group VI Thermal Expansion Cards (8E10.3)

There are NMU (see Card 4 of control group) fields.

1-10	Coefficient of thermal expansion for Maxwell chain Unit 1
11-20	Coefficient of thermal expansion for Maxwell chain Unit 2
	etc.

Group VII Material Properties Cards (8E10.3)

Card 1

1-10	T_o Initial temperature of concrete (See Note 6)
11-20	α Second Material temperature coefficient (See Note 7)
21-30	PR Second Material Poisson's ratio.
31-40	
41-50	Entropy Density adsorbed water
51-60	U Activation energy of hydration
61-70	R. Gas constant

Card 2

2-10	
11-20	ν Poisson's ratio
21-20	
31-40	Radial Steel ratio (ρ_R) (See Note 8)
41-50	Axial Steel Ratio (ρ_Z) (See Note 8)
51-60	Hoop Steel Radio (ρ_H) (See Note 8)
61-70	Second Material Modulus in pounds per square inch (See Note 7)
71-80	T_{ref} Reference temperature for uniform temperature changes (See Note 9)

Card 3

1-10	H_{ref}
11-20	First age at loading (in days) (See Note 10)

Group VIII MATPAR input

Card 1 = Card A (16^I5) (= a card for which READ statement is marked as A in the program)

1- 5	(JOPT) input option
6-10	(NDEC) No. of decades in log (t-t') for calculation of relaxation function in RELAX
11-15	(JDEC) No. of steps per decade for calculation of relaxation function

16-20 (NA) No. of decades in log (t-t') for characterizing the creep compliance function J(t,t')

21-25 (JA) No. of steps per decade for characterizing the creep compliance function J(t,t')

26-30 (NMU) No. of Maxwell units in the chain model

30-36 (NTSHR) No. of discrete values to specify the shrinkage variation in time. For input options with no drying use any dummy value on input, e.g., 0.

Card 2 = Card B(5F10.3)

1-10 (T1) Smallest load duration for which creep representation is desired

11-20 (TP1) Age at loading

21-30 (TAU1) Smallest relaxation time of Maxwell chain

31-40 (W1)

41-50 (W2) Weights used for optimizing the fits by Maxwell chain (Values W1 = 0.01, W2 = 0.1 are usually suitable).

Card 3 = Card C (8F10.3)

1-10 ALFTEM Coefficient of thermal dilation of concrete used by TEMDIL. (Alternatively, the user may supply his subroutine TEMDIL, and then some dummy value may be used here for TEMDIL.)

The subsequent data cards for MATPAR depend on input option JOPT assigned above

```
For JOPT = 1:    Use Card 4 = Card D
                     Card 5 = Card E
                     Cards 6 to Card (6+NJ) = Card F...NJ-times

For JOPT = 2:    Use Card 4 = Card D
                     Card 5        E
                     Cards 6 to Card (6 +NJ) = Card F...NJ-times
                     Card (7+NJ)             = Card G
                     Card (8+NJ)             = Card H

For JOPT = 3:    Use Card 4 = Card I

For JOPT = 4:    Use Card 4 = Card I
                     Card 5 = Card K

For JOPT = 5:    Use Card 4 = Card K

For JOPT = 6:    Use Card 4 = Card I
                     Card 5 = Card J

For JOPT = 7:    Use Card 4 = Card I
                     Card 5 = Card J
                     Card 6 = Card K
                     Card 7 = Card L

For JOPT = 8:        Card 4 = Card I
                     Card 5 = Card J
                     Card 6 = Card K
                     Card 7 = Card L

For JOPT = 9:        Card 4 = Card J
                     Card 5 = Card K
                     Card 6 = Card L
```

For JOPT = 10:

Card 4 = Card D

Card 5 = Card E

Cards 6 to (6+NJ) - Card F...NJ-times

Card (7+NJ) = Card I

For JOPT = 11:

Card 4 = Card D

Card 5 = Card E

Cards 6 to (6+NJ) = Card F...NJ times

Card (7+NJ) = Card I

Card (8+NJ) = Card K

For JOPT = 12:

Card 4 = Card D

Card 5 = Card E

Cards 6 to (6+NJ) = Card F...NJ-times

Card (7+NJ) = Card G

Card (8+NJ) = Card H

Card (9+NJ) = Card I

Card (10+N) = Card J

Card (11+N) = Card K

For JOPT = 13:

Card 4 = Card D

Card 5 = Card E

Cards 6 to (6+NJ) = Card F...NJ-times

Card (7+NJ) = Card G

Card (8+NJ) = Card H

Card (9+NJ) = Card I

Card (10+NJ) = Card J

Card (11+NJ) = Card K

Card (12+NJ) = Card L

Card D (I10, (7F10.0))

1-10	NI	No. of load durations (t-t') for values of compliance function J(t,t')
11-20	AT(1)	Discrete load durations (t-t') for values of compliance function J(t,t')
21-30	AT(2)	
31-40	AT(3)	
etc.		possibly continue on a second card if there are more than 8 values to be read

Card E (I10, (7F10.1)

1-10	NJ	No. of Ages at loading t' for values of compliance function J(t,t').
11-20	ATP(1)	Discrete Ages at loading t' for values of compliance function J(t,t').
21-30	ATP(2)	
31-40	ATP(3)	
etc.		possibly again continue on a second card if needed

Card F (8F10.1)

1-10	AJ(1,1)	values of compliance function J(t,t')
11-20	AJ(2,1)	
21-30	AJ(3,1)	
etc.		

2nd Card F (8F10.1)

1-10	AJ(2,1)	same
11-20	AJ(2,2)	
21-30	AJ(2,3)	
etc.		

....

NJ-th Card F (8F10.1)

1-10	AJ(1,JN)	same
11-20	AJ(2,NJ)	
21-30	AJ(3,JN)	
etc.		

Card G (I2,1XF7.1,(7F10.1))

1-2	NTSHR	No. of discrete times TSHR(I)
3-10	TSHR(1)	discrete times (drying durations for specifying shrinkage values SHR(I) - in days
11-20	TSHR(2)	
21-30	TSHR(3)	
etc.		

Card H (8E10.3)

1-10	SHR(1)	specified shrinkage values at various times, TSHR(I)
11-20	SHR(2)	
21-20	SHR(3)	
etc.		

Card I (E10.2,4F10.1) Coeff. for double power law

1-10	E28 Young's elastic modulus at age 28 days
11-20	EOE28 = EO/E28=Ratio of asymptotic modulus EO to E28, typically 1.5
21-30	EXPN = n = exponent of double power law
31-40	EXPM = m = exponent on age in double power law
41-50	ALFA = α = coeff. of double power law

Note: For JOPT = 4 and 7 only E28 is needed; use dummy values for the rest. For JOPT = 10 to 14, only EXPN, EXPM and ALFA are needed; use some dummy values for E28 and EOE28.

Card J (9F8.1) Coeff. for additional creep due to drying

1- 8	DRYSTA = Age at start of drying (in days)
9-16	FINSHR = Final shrinkage strain
17-24	AVHUM = average relative humidity of the environment, ($0 \leq$ AVHUM ≤ 1)
25-32	AKS* = k_s = cross section shape coefficient
33-40	VS = v/s = volume-to=surface ratio in mm
41-48	C7* = C_7 = diffusivity in mm^2/day
49-56	PHID* = ϕ_d
57-64	CD* = c_d
65-72	CP* = c_p

parameters for drying creep term

Note: For JOPT=7,8,9-C7, PHID, CP are not needed-use dummy values. For JOPT=8,9 FINSHR not needed, use dummy value.

*If unsure input zero for these, and the program will then assign suitable values automatically.

Card K (5F10.1,I10) Strength and composition parameters

1-10	FCP	= f'_c = standard cylinder strength of concrete at age 28 days.
11-20	WC	= w/c = water-cement ratio by weight in the mix
21-30	AC	= a/c = aggregate cement ratio by weight in the mix
31-40	SC	= s/c = sand-cement ratio by weight in the mix
41-50	RØ	= ρ = unit mass of concrete in lb./ft^3
51-60	ITYPE	= ASTM type of cement (1,2,3, or 4)

Card L (F8.1)

1-8 CEM = c = cement content in kg per m^3 of concrete

Group IX Time Step Cards (8F10.3) (See Note 11)

1-10 Δt for time step 1 (in days)

11-20 Δt for time step 2

.

.

.

NSTEP values read in. (see group 1 card 2)

Group X Load Factor Card (8F10.3) (See Note 12)

1-10 Load factor for time step 1

11-20 Load factor for time step 2

.

.

.

NSTEP VALUES

Group XI Temperature Factor Cards (8F10.5) (See Note 13)

1-10 Temperature factor for time step 1

11-20 Temperature factor for time step 2

.

.

.

NSTEP VALUES

Group XII Selected Nodal Displacements (16I5)

his group included only if IPSW=1,7,8,9,10 or 11 and NDIS $\neq$ 0

Card 1

1- S Node No. of First Selected Nodal displacement

6-10 Node No. of Second Selected Nodal displacement

.

.

.

NDIS VALUES

GROUP XIII Selected Element Stresses (16I5)

This group included only if IPSW=3,7 or 9 and NSTR $\neq$ 0

Card 1

1 - 15	Element No. of first selected element
6 - 10	Element No. of second selected element

.

.

.

NSTR VALUES

GROUP XIV Selected element strains (16I5)

This group included only if IPSW=5,8 or 9 and NEPS $\neq$ 0

Card 1

1 - 15	Element No. of first selected element
6 - 10	Element No. of second selected element

.

.

.

NEPS VALUES

Notes on the input

Group I

Note 1: The step number prestressing steel is entered as the step following the application of the prestressing forces to the structure

Note 2: The following values of IPSW will cause printing of selected quantities at each time step.

IPSW=

1. Selected nodal displacements
2. All nodal displacements
3. Selected element stresses
4. All element stresses
5. Selected element strains
6. All element strains
7. Selected nodal displacements and element stresses
8. Selected nodal displacements and element strains
9. Selected nodal displacements, element stresses and strains
10. Selected nodal displacements and all element stresses
11. Selected nodal displacements, all element stresses and strains

Note 3: The step at which user supplied temperatures are entered is used when spacial and temporal variation of temperature is arbitrary. The temperatures are entered through TAPE 7, one temperature for each node by means of a FORTRAN binary read. There must be a set of nodal temperatures for each step of the analysis from the step number specified until the end of the analysis.

Group II

Note 4: The liner elements are the axially symmetrical elements described and the bar and hoop elements are the prestressing steel elements. The liner elements are assembled with the initial step of the analysis with the bar and hoop elements being assembled at the step number specified for the prestressing steel. Areas of liner, bar and hoop elements are numbered sequentially from 1 to NØLE + NØBE.

Group V

Note 5: The load cards appear for loaded nodes only, and the load components are calculated for a one radian sector of the structure.

Group VII

Note 6: The initial temperature is based on the absolute temperature scale (Kelvin)

Note 7: The second material refers to the reinforcing steel.

Note 8: The steel ratios are given by area.

Note 9: The reference temperature is the temperature that is multiplied by the temperature factor input in Group XI cards and added to the temperature existing in all elements in the previous time step. Thus, temperatures of the concrete which vary with time but which do not change in spacial variations may be conveniently treated.

Note 10: The age of first loading refers to t' in the theory and is the age of the concrete at the first time step.

Group IX

Note 11: The time steps may be input in real time (card 2 of Group I) or log time. The times entered are the lengths of time or Δt for each time step.

Group X

Note 12: The load factors multiply the load vector entered in Group V to obtain the incremental load for each time step.

Group XI

Note 13: The temperature factors multiply the reference temperature in Group VII to obtain the incremental temperature change for each time step.

NØNSAP Version of CREEP80

Implementation of CREEP80 into NØNSAP requires very few changes. The program CREEP80 becomes the main program for an additional segment, link or overlay depending on the computer operating system being used. The existing NØNSAP program is only slightly modified, with the modifications listed in the Appendix of this report.

Input to the NØNSAP program for a CREEP80 run is now a combination of the two programs. Since CREEP80 is used for long time variation analysis it cannot be used for dynamic analysis in NØNSAP. It can be used with other linear and, with certain restrictions, nonlinear elements of the NØNSAP program that are used for static axially symmetrical analysis.

The input separates into two phases. The first follows the input as listed in the NØNSAP manual (2) which includes control information, nodal coordinates and boundary conditions, nodal loads and element group information. The second phase provides the additional information necessary for the CREEP80 program which includes additional control information, material parameters, time step, temperature, load, selective printing and element definition information.

The complete input for a CREEP80 run is listed for the convenience of the user below. Notes on input in the NØNSAP manual (2) and at the end of this listing should be referred to by the user when preparing a run.

NONSAP INPUT

I Heading Card (12A6)

II Master Control Card Group

Card 1, (I5, 6I1, I4, 3I5, 2F100, 2I5)

(1-5) NUMNP

6 IDØF(1) = 1

7 IDØF(2) = 0

8 IDØF(#) = 0

9 IDØF(4) = 1

10 IDØF(5) = 1

11 IDØF(6) = 1

12-15 NEGL Number of linear element groups

16-20 NEGNL Number of nonlinear element groups

21-25 MØDEX Flag indicating situation mode

26-30 NSTE Number of solution time steps

31-40 DT Time increment = 1.0

41-50 Blank

51-55 IPRI (= NSTE)

Card 2 (4I5) Blank

Card 3 (I5) Blank

Card 4 (4I5, E10.4)

1-5 ISREF (=1)

6-10 NUMREF (=0)

11-15 IEQUIT Set equal to NSTE+1

16-20 Blank

21-30 Blank

Card 5 (I10, 2F10.0) Blank

Card 6 (4I5) Blank

Card 7 (16I5) Balnk

III Nodal Point Data Group

(A1, I4, A1, I4, 5I5, 3F10.0, I5)

1 CT Blank

2- 5 N Node Number

6 PSF Blank

7-10 ID(1,N) Blank

11-15	ID(2,N)	R Translation code
16-20	ID(3,N)	Z Translation code
21-25	ID(4,N)	Blank
26-30	ID(5,N)	Blank
31-35	ID(6,N)	Blank
36-45		Blank
46-55	R(N)	R Coordinate
56-65	Z(N)	Z Coordinate
66-70	RN	Node number increment for node data generation

IV Applied Loads Data Group

<u>Card 1</u> (3I5)

1- 5	NLØAD	Number of load cards
6-10	NLCUR	(=1)
11-15	NPTM	(=2)

<u>Card 2</u> (2I5)

1- 5	NTF	(=1)
6-10	NPTS	(=2)

<u>Card 3</u> (8F10.0)

1-10	Blank
11-20	1.0
21-30	Set equal to (NSTE+1)*1.0
31-40	1.0

Nodal loads group (3I5, F10.0).

There are NLØAD Cards in this group.

If NLØADS = 0 no cards are input.

1- 5	NØD	Node number to which load is applied
6-10	IDIRN	=2 for R direction
		=3 for Z direction
11-15	NCUR	=1
16-25	FAC	magnitude and direction (±) of load.

Card 4 (I5)

ICON 0

V Creep Element Group Control Card (20I4)

1- 4	NPAR(1)	=4
5- 8	NPAR(2)	= NUMEL
9-12	NPAR(3)	=1
13-16	NPAR(4)	=NØLE
17-20	NPAR(S)	=NØBE
21-14	NPAR(6)	=NDIS
25-28	NPAR(7)	=3 No.of nodes/element
29-32	NPAR(8)	= NSTR
33-36	NPAR(9)	=NEPS
37-40	NPAR(10)	=NMU
41-44	NPAR(11)	=JØPT
45-48	NPAR(12)	=NDEC
49-52	NPAR(13)	=JDEC
53-56	NPAR(14)	=NA
57-60	NPAR(15)	=JA
61-64	NPAR(16)	=NTSHR
65-68	NPAR(17)	=Step No. Pre St. Steel)
69-72	NPAR(18)	=IPSW
73-76	NPAR(19)	=Step No. of user supplied temp.
77-80	NPAR(20)	=Time steps in real or log time.

VI Element cards (16I5)

NUMEL Cards in this group in numerical order

1- 5	Element No.	
6-10	I	Node
11-15	J	Node
16-20	K	Node

VI(A) Linear Elements (3I5, F20.3)

1- 5	Element No	(NØLE Cards)
6-10	I Node	
11-15	J Node	
16-25	Area	

VI(B) Bar and Hoop Elements

1- 5	Element No	(NØBE Cards)
6-10	I Node	
11-15	J Node	(=0 hoop element)
16-25	Area	

VII Material Properties Card (8E10.3)

There are NMU fields. Enter coefficient of linear temperature expansion for each unit of Maxwell chain.

VIII Material Properties Cards (8E10.3)

<u>Card 1</u>

1-10	T_0	Initial temperature of concrete
11-20	α	Second material temperature coefficient
21-30	PR	Second material Poisson's ratio
31-40		
41-50		Entropy density of adsorbed water
51-60	U	Activation energy of hydration
61-70	R	Gas constant

<u>Card 2</u>

1-10		Blank
11-20	υ	Poisson's ratio
21-30		Blank
31-40	(ρ_R)	Radial steel ratio
41-50	(ρ_Z)	Axial steel ratio
51-60	(ρ_H)	Hoop steel radio
61-70	T_{ref}	Reference temperature for uniform temperature changes.

Card 3

1-10	H ref
11-20	First age at loading

IX MATPAR input (option 3 input is listed. See P. 21 for other options)

Card 1 (5F10.3)

1-10	(T1)	Smallest load duration
11-20	(TP1)	Age at loading
21-30	(TAU1)	Smallest relaxation time
31-40	W1	Weights for fitting Maxwell chain
41-50	W2	

Card 3 (8F10.3)

1-10	ALFTEMP

Card 4 (E10.3, 4F10.1)

1-10	(E28)
11-10	(EOE28)
21-30	(EXPN)
31-40	(EXPM)
41-50	(ALFA)

X Time step cards (8F10.3)

1-10	Δt for time step 1
11-20	Δt for time step 2

,

,

,

NSTE values read in

XI Load factor card (8F10.3)

1-10	Load factor for time step #1
11-20	Load factor for time step #1

,

,

,

,

NSTE Values

XII Temperature factor cards (8F10.5)

1-10 Temperature factor for time step #1

11-20 Temperature factor for time step #2

'

'

'

NSTE Values

XIII Selected Nodal displacements (16I5)

This group included only if IPSW = 1, 7, 8, 9, 10, 11 and NDIS $\neq$ 0

Card 1

1- 5 Node No. of first selected element

6-10 Node No. of second selected elenent

'

'

'

NDIS values

XIV Selected element stresses (16I5)

This group included only if NSTR $\neq$ 0)

1- 5 Element No. of first selected element

6-10 Element No. of second selected element

'

'

'

NSTR Values

XV Selected element strains

This group included only if (NEPS $\neq$ 0)

1- 5 Element No. of first selected element

6-10 Element No. of second selected element

'

'

'

NEPS VALUES

Notes on NØNSAP Input

Group II Master Control Cards.

The time increment is artifically set to 1 since the incrementing time is controlled by the CREEP80 portion of the program. This permits the variable time steps required for efficient use of the program.

The variable IEQUIT is set equal to the total number of time steps plus one since equilibrium iteration is not needed.

Group IV Applied Loads Data.

Only a single load curve is introduced. This load curve is equivalent to a constant value of the applied nodal loads. Since the time increment has been set to 1 (DT=1.0), the second and last point of the load curve is at the fictitious time of (number of time steps + 1) X D T.

Group V Creep Element Input

The card for the NPAR array lists control parameters for both the NØNSAP and CREEP80 portions of the program. NPAR(1) = 4 since this represents a new element type in NØNSAP. The remaining input on this card is described in detail in the CREEP80 portion of this report.

Group IX MATPAR Input

Option 3 input is listed here. Refer to pages 21 to 30 for detailed input description for all 13 options.

TEST PROBLEMS

A series of simple test problems and one large reactor problem are used to illustrate the program capabilities. The small problems have been run on both the NØNSAP and CREEP80 versions of the program while the reactor problem has only been run on the CREEP80 version. The test problems are listed in order of increasing sophistication with the results of some of the problems plotted for presentation. The listing of complete input and selcted output is also included.

Test Problem 1

Axially loaded thin cylinder.

The structure is a thin cylinder of internal radius 100", wall thickness 1" and height 1". It is assumed to be very long and is loaded with an axial compressive load of 1000 psi. The material is input under option 3 double power law with 28 day modulus of 4×10^6 psi and age of loading of 5 days. (see Fig 4) for other material parameters).

This problem is run for three different conditions.

1. Axial load only. This loading reproduces the creep function for the material which is listed as part of the basic material property output from MATPAR. The time steps are nonuniform and yield times of loading that coincide with creep function values reported. The displacements are plotted in Figure 5. Stresses in the elements are constant (σ_z = 1000 psi, $\sigma_r = \sigma_\theta = 0$) and strains follow the creep function for ε_z ($\varepsilon_r = \varepsilon_\theta = -\upsilon\varepsilon_z$ and $\gamma_{rz} = 0$).
2. Axial load with temperature change, no hydration effects. This problem is the same as the first, but a $+100^{\circ}C$ temperature change occurs at age 6 days (1 day after loading). The activation energy of hydration (U) is set to zero which uncouples the effect of hydration on rate of creep. The net result is simply a displacement of the creep curve equal to the temperature strain. Results are plotted in Fig. 5.

3. Axial load with temperature change and hydration effects. The effect of temperature on rate of creep is shown in Fig. 5. The value of U is 5400 cal.

Test Problem 2

Radially loaded thin cylinder.

The structure is the same as test problem 1, but the loading is a radial pressure load of 10 psi. The results for stresses and strain are exact but are not plotted but only listed for this problem.

Test Problem 3

Concrete test cylinder (6 x 12)

This problem is not used for comparison with exact results but rather as a means of testing various options of the program against hand computations. Symmetry of the problem permits the use of only one quadrant of the cylinder as shown in Fig. 6. With only 4 nodes and 2 elements the number of equations to be solved is only 4. This permits the use of hand computations to check various features of the element formulation and stiffness matrix for the structure. The test problem has been run for the following conditions, all of which have an axial compressive load of 2000 psi.

a) Concrete elements only
b) Concrete elements with reinforcing steel

c) Concrete elements with axially symmetrical steel liner elements on the outside and bar at the center along Z axis.
d) Concrete elements with reinforcing bar elements at center and outside and hoop reinforcing elements on outside.

The elements of these problems were compared with hand calculations and are not plotted. Summaries of the results of C are given in the output. Additional runs were made with this test problem with temperature changes, but are not reported.

Large Problem - Reactor Vessel

The vessel dimensions, finite element grid, load and temperature history are shown in Figures 7 to 16. All length units are meters, force units meganewtons and pressure units megapascals. The model consists of 270 concrete elements, 22 axially symmetrical liner elements, 15 bars and 16 hoop prestressing steel elements and 168 nodes. There are 19 time steps in the analysis covering a period of time of concrete age of 180 days (when prestressed) to 9220 days. The time steps are nonuniform with values of 1 hour (.0416 days), 1 day and 2 days at the time of temperature change. The initial temperature of this vessel is ambient and the internal temperature of the vessel changes by 75° at 730 days. The time and spacial variation of the temperature in the reactor wall and top are calculated from the exact solution for a rectangular body with insulated sides subjected to a step temperature change on one side. The coefficient of conductivity is taken as .0022 Cal./sec./cm./$^{\circ}$C. At the junction of the top and vertical wall of the reactor a linear interpolation in polar coordinates for the time and spacial variation of temperature is made between the two rectangular bodies. The temporal and spacial variation of the temperatures in the vessel were entered by means of the tape 7 option in the program.

The results of the analysis are presented in Figures 10 to 16 and are generally self explanatory. Deflections are exaggerated for clarity and stresses at the sections are obtained by averaging the stresses in the pair of triangular elements making up a rectangular region. Temperature and stress profiles are shown for the three time steps associated with the temperature shock at 730 days in Figures 10 and 11.

ACKNOWLEDGMENT

Thanks are due to Mehran Salehi for help in debugging the program and running test examples. Some of the subroutines are partly based on previous coding of Geir Horrigmoe of Narvik, Norway.

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APPENDIX A

Implementation of CREEP80 into NØNSAP Program

Implementation of CREEP80 into NØNSAP

Very few changes to the NØNSAP program are needed to implement CREEP80. The routines ELCAL, ELEMNT and NEWDAV require a few changes and the NØNSAP main program requires changes in size of storage for large problems. A listing of changes in the routines and a description of each is given below. The CREEP80 program is implemented as a new overlay (link or segment) in the NØNSAP program. Changes in NØNSAP are given in terms of the CDC operating system, but similar changes on other operating systems can easily be made.

The structure of Blank Common in NØNSAP reserves the first NUMEST locations for use with element development. This area of core is saved during the remaining of a program on tape units 2 or 9 to provide a continuity of flow of computations for each element group. The size of this core area is defined by NUMEST at the beginning of a run, and then reset to the largest size needed by any element type during execution. The size and structure of this area of Common is shown in Fig. 17. All variables have been defined previously except NSTE the number of time steps in the solution, RZ number array for the elements. Note that, as before, NUMEL refers to the number of concrete elements. The size of NUMEST increases significantly for large problems, and consequently the initial size of NUMEST should be increased in the main program of NØNSAP before attemting to run.

Changes in NØNSAP routines for CREEP80 are described below.

ELCAL

After the statement READ (5,1000) NPAR add the statement

```
IF (NPAR (1) . EQ . 4) GØ TØ 11
```

The second statement after statement 10 becomes

```
11 IF (NUMMAT . EQ . 0) NUMMAT  = 1
```

Finally, the statement GØ TØ (1,2,3), NPAR1 is replaced with

```
GØ TØ (1,2,3,20), NPAR1
```

ELEMNT

At the beginning replace the statement GØ TØ (1,2,3), NPAR1 with the statement

```
GØ TØ (1,2,3,4), NPAR1
```

Finally, add the following two statements just before the END card.

```
4    CALL ØVERLAY (4HNSAP, 6, 0, 6HRECALL)
     RETURN
```

The modification of these two routines is required to implement the new overlay (link or segment). The following routine is modified to enable the computation of incremental stresses and strains needed in CREEP80 and to initiate the selective output option.

NEWDAV

The following two Common statements must be added:

```
CØMMØN/TAPES/NREAD,NWRITE
CØMMØN A(1)
```

Following statement 40 DISP(I) = DISP(I) + DISPI(I) and before statement 70 RETURN, the following ten statements must be added.

```
      REWIND NREAD
      REWIND NWRITE
      DØ 65 N = 1,NEGNL
      READ(NREAD) NUMEST, NPAR, (A(I),I = 1,NUMEST)
      IF (NPAR(1).NE.4) GØ TØ 65
      CALL ELEMNT
   65 WRITE(NWRITE) NUMEST,NPAR,(A(I),I = 1,NUMEST
      M = NWRITE
      NWRITE = NREAD
      NREAD = M
```

Use of NØNSAP and CREEP80 Elements in Analysis CREEP80 deals with nonlinear static problems only and may not be used with dynamic options in NØNSAP. The elements in CREEP80 can be used with those elements in NØNSAP that are compatible with axially symmetrical or plane strain analysis i.e., the plane truss element and the 2-d continuum element. For compatibility of displacements, the 4 node 2-d element should be used. CREEP80 is compatible with these elements if they are linear with no initial strains. CREEP80 can be used with nonlinear forms of these elements if both of the following two conditions are met:

a) No equilibirum iteration is performed, i.e., the stiffness matrix is reformed at each time step based on instantaneous values of material properties; and

b) CREEP80 elements are the <u>first</u> group of nonlinear elements.

The errors in analysis for the nonlinear element groups which require equilibrium iteration are minimized if time steps are chosen such that incremental strains are small. This condition is fairly easy to meet in most creep problems since the inelastic creep strains proceed at a slow pace.

APPENDIX B

Listing of Sample Input and Output for Sample Problems

Input for Two Element Creep Problem with Two Liner Elements and One Bar Element

```
  4    2    2    1    1    9    1
 10    1    0
  4    2    2    2    3    2    2    1
  0    0    0    0    7    0
  1    1    2    3
  2    3    4    2
  1    3    4   .043
  2    2    4   .045
  3    1    3   .0225
  1                 0.0                  0.0
  2                 3.0                  0.0
  3                 0.0                  6.0
  4                 3.0                  6.0
  1    1    1
  2    0    1
  3    1    0
  3                 0.0       -2250.
  4                 0.0       -6750.
  .1E-4     .1E-4     .1E-4     .1E-4     .1E-4     .1E-4     .1E-4
 .298E3     .1E-4     .3E0      1.0E0     1.0E0     .54E4     .2E1      .1E
            .2E0                                                .3E8      .25E2
   .1E1     .3E2
  3    5    5    7    4    7    6
 .1         5.0       0.0       0.010     0.080
 12.0
  4.0E0     1.5       0.135     0.33      0.05
   0.1      0.5       1.0       5.0       10.0      100.0     500.0     1000.0
 5000.0    10000.0
   1.0      0.0       1.0       0.0       0.0       0.0       0.0       0.0
   0.0      0.0
   0.0      0.0       1.0       0.0       0.0       0.0       0.0       0.0
   0.0      0.0
  1    2    3    4
  1    2
  1    2    3    4    0
```

LQ17 #333 RECRFA* //// END OF LIST //// 2 PAGES.

CONTROL PARAMETERS :
****

NO. OF SELECTED NODE DISP.	:	4
NO. OF SELECTED ELEMENT STRESSES	:	2
NO. OF SELECTED ELEMENT STRAINS	:	2
STEP NO. FOR PRESTRESS STEEL	:	1
PRINTING OF INPUT DATA	:	1
PRINT SWITCH	:	9
DATA CHECK	:	1
NO. OF TIME STEPS	:	10
STEP NO. OF USER SUPPLIED TEMP. DIST.	:	11
MAXIMUM NO. OF SUBDIVISIONS	:	1
TIME STEPS IN REAL/LOG. SCALE	:	0
NO. OF NODAL POINTS	:	4
NO. OF ELEMENTS	:	2
NO. OF LINER ELEMENTS	:	2
NO. OF BAR AND HOOP ELEMENTS	:	1
NO. OF LOADED NODAL POINTS	:	2
NO. OF RESTRAINED NODAL POINTS	:	3
NO. OF NODAL POINTS PER ELEMENT	:	3
NO. OF D.O.F. PER NODAL POINT	:	2
NO. OF UNITS IN MAXWELL CHAIN	:	7

ELEMENT CONNECTIONS :
****

	1	2	3
ELEMENT NO. 1 :	1	2	3
ELEMENT NO. 2 :	3	4	2

LINER ELEMENTS :
****

LINER ELEMENT 1 :	3	4	AREA :	.0430000
LINER ELEMENT 2 :	2	4	AREA :	.0450000

BAR/HOOP ELEMENTS :
****

BAR/HOOP ELEMENT 3 :	1	3	AREA :	.0225000

NODAL COORDINATES :
****

	R	Z
NODE NO. 1 :	0.	0.
NODE NO. 2 :	.300000E+01	0.
NODE NO. 3 :	0.	.600000E+01
NODE NO. 4 :	.300000E+01	.600000E+01

RESTRAINED NODAL POINTS :
****

	U	V
NODE NO. 1 :	1	1
NODE NO. 2 :	0	1
NODE NO. 3 :	1	0

PRESCRIBED EXTERNAL LOADING :
****

	R-COMP	Z-COMP
NODE NO. 3 :	0.	-.225000E+04
NODE NO. 4 :	0.	-.675000E+04

MATERIAL PARAMETERS :
****

REFERENCE TEMPERATURE	: TO	=	.298000E+03
ENTROPY DENSITY (HIND. ADSB. WATER)	: SW	=	.100000E+01
ACTIVATION ENERGY OF HYDRATION	: U	=	.540000E+04
GAS CONSTANT	: R	=	.2[illegible]E+01
POISSON'S RATIO	: FR	=	.200000E+00
RADIAL STEEL RATIO	: RHOR	=	0.
AXIAL STEEL RATIO	: RHOZ	=	0.
HOOP STEEL RATIO	: RHOH	=	0.
SECOND MATERIAL MODULUS	: E2	=	.300000E+0[illegible]
SECOND MATERIAL TEMP. COEF.	: ALFA	=	.1[illegible]E-04
SECOND MATERIAL POISSON'S RATIO	: FR	=	.300000E+00
CHOSEN REFERENCE VALUE OF T	: TREF	=	.250000E+02
CHOSEN REFERENCE VALUE OF H	: HREF	=	.1[illegible]E+01

INPUT DATA FOLLOW

JOPT= 3 NDEC= 5 JDEC= 5 NA= 7 JA= 4 NML= 7 NTSHR= 6

INPUT DATA FOLLOW

T1= .10000 TP1= 5.00000 TAU1= 0.00000 W1= .010

INPUT DATA FOLLOW

COEF. OF THERMAL DIL. ALFTEM= 12.000

NT= 25 TMAX= .6310E+04

```
***   WARNING FROM MATPAR   ***

SMALLEST RELAXATION TIME UNASSIGNED.CHOOSE - TAU1=   .333E+00

***   WARNING FROM MATPAR   ***

HIGHEST RELAXATION TIME : TAUM =   .333E+05

NOTE : FOR GIVEN RELAXATION TIMES,CREEP CAN BE
REPRESENTED ONLY FROM T1=  .167E+00  TO TMAX=  .167E+05
MAKE SURE THAT THE SMALLEST AGE TP1 IS .GE.  .300E+00
OR ELSE AGING OF YOUNG CONCRETE DISTORTS LONG-TIME
RESPONSE

INPUT DATA FOR OPTION JOPT=  3  FOLLOW

GIVEN DOUBLE POWER LAW PARAMETERS

28-DAY EL.MODULUS E28=     .40000E+07 PSI

   EOE28=  1.5000     EXPN=  .1350     EXPM=  .3300     ALFA=  .05000

CALCULATED EO =     .60000E+07          PHI1= 1.78146

END OF INPUT AND OF GENERATION OF INPUT PARAMETERS

TABLE OF CALCULATED RELAXATION FUNCTION ER(IT,IA)
      TP(IA)=   .500E+01   .6691E+01   .1581E+02   .2812E+02   .5000E+02   .8891E+
```

IT	T(IT)	ER(IT,1)	ER(IT,2) ...				
1	.100	.3274E+07	.3529E+07	.3773E+07	.4002E+07	.4213E+07	.4405E+
2	.158	.3171E+07	.3430E+07	.3678E+07	.3912E+07	.4129E+07	.4327E+
3	.251	.3073E+07	.3334E+07	.3586E+07	.3823E+07	.4045E+07	.4246E+
4	.398	.2977E+07	.3239E+07	.3493E+07	.3735E+07	.3961E+07	.4169E+
5	.631	.2880E+07	.3144E+07	.3400E+07	.3645E+07	.3875E+07	.4088E+
6	1.000	.2784E+07	.3048E+07	.3306E+07	.3554E+07	.3788E+07	.4005E+
7	1.585	.2687E+07	.2952E+07	.3212E+07	.3462E+07	.3699E+07	.3921E+
8	2.512	.2588E+07	.2855E+07	.3116E+07	.3369E+07	.3609E+07	.3835E+
9	3.981	.2488E+07	.2757E+07	.3020E+07	.3275E+07	.3518E+07	.3747E+
10	6.310	.2385E+07	.2657E+07	.2922E+07	.3179E+07	.3425E+07	.3658E+
11	10.000	.2279E+07	.2554E+07	.2822E+07	.3082E+07	.3332E+07	.3567E+
12	15.849	.2168E+07	.2448E+07	.2720E+07	.2983E+07	.3236E+07	.3474E+
13	25.119	.2052E+07	.2337E+07	.2615E+07	.2882E+07	.3138E+07	.3382E+
14	39.811	.1929E+07	.2221E+07	.2505E+07	.2778E+07	.3038E+07	.3284E+
15	63.096	.1799E+07	.2099E+07	.2390E+07	.2669E+07	.2935E+07	.3185E+
16	100.000	.1661E+07	.1971E+07	.2269E+07	.2556E+07	.2828E+07	.3084E+
17	158.489	.1515E+07	.1834E+07	.2142E+07	.2437E+07	.2717E+07	.2980E+
18	251.189	.1360E+07	.1693E+07	.2008E+07	.2312E+07	.2600E+07	.2870E+
19	398.107	.1196E+07	.1538E+07	.1866E+07	.2181E+07	.2478E+07	.2755E+
20	630.957	.1023E+07	.1376E+07	.1717E+07	.2042E+07	.2349E+07	.2637E+
21	1000.000	.8399E+06	.1206E+07	.1559E+07	.1896E+07	.2214E+07	.2512E+
22	1584.893	.6467E+06	.1026E+07	.1392E+07	.1742E+07	.2071E+07	.2380E+
23	2511.886	.4433E+06	.8374E+06	.1217E+07	.1580E+07	.1922E+07	.2242E+
24	3981.072	.2296E+06	.6368E+06	.1033E+07	.1409E+07	.1763E+07	.2097E+
25	6309.573	.5450E+04	.4305E+06	.8402E+06	.1231E+07	.1600E+07	.1945E+

```
WEIGHTS USED IN MAXWELL ARE W1=    .0100    AND W2=    .0600

RELAXATION TIMES TAU(MU)=     .3333E+00     .3333E+01     .3333E+02     .3333E+03

MAXWELL CHAIN MODULI FOR TIME RANGE FROM     .166E+00 TO    .833E+04 (UNITS PSI)
```

IA	TP(IA)	EMU(1,IA)	EMU(2,IA) ...					
1	5.000	.487E+06	.479E+06	.563E+06	.766E+06	.102E+07	.126E+07	-.1
2	8.891	.485E+06	.472E+06	.526E+06	.714E+06	.950E+06	.117E+07	-.6
3	15.811	.475E+06	.464E+06	.512E+06	.665E+06	.878E+06	.106E+07	-.1
4	28.117	.458E+06	.454E+06	.492E+06	.620E+06	.810E+06	.993E+06	.2
5	50.000	.434E+06	.441E+06	.475E+06	.580E+06	.747E+06	.937E+06	.7
6	88.914	.407E+06	.424E+06	.458E+06	.546E+06	.689E+06	.828E+06	.1
7	158.114	.378E+06	.404E+06	.441E+06	.515E+06	.636E+06	.754E+06	.1

```
     TP(IA)=     .500E+01     .889E+01     .158E+02     .281E+02     .500E+02     .889E+0
CREEP FUNCTION VALUES COMPUTED FROM MAXWELL CHAIN MODULI EMU
```

IT	T(IT)	AJ(IT,1)	AJ(IT,2) ...					
1	.100	.302E-06	.280E-06	.262E-06	.247E-06	.235E-06	.225E-	
2	.158	.309E-06	.286E-06	.267E-06	.252E-06	.239E-06	.228E-	
3	.251	.318E-06	.294E-06	.274E-06	.257E-06	.244E-06	.232E-	
4	.398	.330E-06	.304E-06	.282E-06	.265E-06	.250E-06	.238E-	
5	.631	.342E-06	.315E-06	.291E-06	.272E-06	.257E-06	.243E-	
6	1.000	.355E-06	.325E-06	.300E-06	.280E-06	.263E-06	.249E-	
7	1.585	.367E-06	.335E-06	.309E-06	.287E-06	.269E-06	.254E-	
8	2.512	.379E-06	.345E-06	.317E-06	.294E-06	.275E-06	.259E-	
9	3.981	.393E-06	.357E-06	.327E-06	.303E-06	.282E-06	.266E-	
10	6.310	.409E-06	.371E-06	.339E-06	.312E-06	.290E-06	.272E-	
11	10.000	.425E-06	.384E-06	.350E-06	.322E-06	.298E-06	.279E-	
12	15.849	.441E-06	.397E-06	.361E-06	.331E-06	.306E-06	.286E-	
13	25.119	.458E-06	.411E-06	.373E-06	.341E-06	.315E-06	.293E-	
14	39.811	.477E-06	.428E-06	.387E-06	.353E-06	.325E-06	.301E-	
15	63.096	.498E-06	.446E-06	.402E-06	.366E-06	.336E-06	.311E-	
16	100.000	.520E-06	.464E-06	.417E-06	.379E-06	.347E-06	.320E-	
17	158.489	.541E-06	.481E-06	.432E-06	.391E-06	.358E-06	.329E-	
18	251.189	.564E-06	.501E-06	.449E-06	.405E-06	.369E-06	.340E-	
19	398.107	.591E-06	.523E-06	.468E-06	.421E-06	.383E-06	.351E-	
20	630.957	.620E-06	.546E-06	.488E-06	.439E-06	.398E-06	.364E-	
21	1000.000	.648E-06	.571E-06	.508E-06	.455E-06	.412E-06	.376E-	
22	1584.893	.675E-06	.594E-06	.527E-06	.472E-06	.426E-06	.388E-	
23	2511.886	.704E-06	.618E-06	.546E-06	.489E-06	.441E-06	.401E-	
24	3981.072	.736E-06	.645E-06	.570E-06	.508E-06	.457E-06	.414E-	
25	6309.573	.769E-06	.673E-06	.594E-06	.528E-06	.473E-06	.428E-	

```
COMPARE CREEP FUNCTION VALUES AS ORIGINALLY GIVEN

HERE T(IT)= CURRENT TIME MINUS T-PRIME*STRESS DURATION , TP(IA) = T-PRIME = AGE AT
```

1	.100	.305E-06	.283E-06	.265E-06	.250E-06	.237E-06	.227E-

2	.158	.314E-06	.291E-06	.271E-06	.255E-06	.242E-06	.231E-06
3	.251	.324E-06	.299E-06	.278E-06	.261E-06	.247E-06	.235E-06
4	.398	.334E-06	.307E-06	.285E-06	.267E-06	.252E-06	.239E-06
5	.631	.345E-06	.316E-06	.293E-06	.273E-06	.257E-06	.244E-06
6	1.000	.356E-06	.326E-06	.301E-06	.280E-06	.263E-06	.249E-06
7	1.585	.366E-06	.336E-06	.310E-06	.288E-06	.269E-06	.254E-06
8	2.512	.381E-06	.347E-06	.319E-06	.295E-06	.276E-06	.260E-06
9	3.981	.395E-06	.359E-06	.328E-06	.304E-06	.283E-06	.266E-06
0	6.310	.411E-06	.371E-06	.339E-06	.312E-06	.290E-06	.272E-06
1	10.000	.425E-06	.384E-06	.350E-06	.322E-06	.298E-06	.279E-06
2	15.849	.442E-06	.398E-06	.362E-06	.332E-06	.307E-06	.286E-06
3	25.119	.459E-06	.413E-06	.374E-06	.342E-06	.316E-06	.294E-06
4	39.811	.478E-06	.428E-06	.387E-06	.353E-06	.325E-06	.302E-06
5	63.096	.496E-06	.445E-06	.402E-06	.365E-06	.336E-06	.311E-06
6	100.000	.519E-06	.463E-06	.417E-06	.378E-06	.346E-06	.320E-06
7	158.489	.542E-06	.482E-06	.433E-06	.392E-06	.358E-06	.330E-06
8	251.189	.566E-06	.502E-06	.450E-06	.406E-06	.370E-06	.340E-06
9	398.107	.592E-06	.524E-06	.468E-06	.422E-06	.383E-06	.351E-06
0	630.957	.619E-06	.547E-06	.487E-06	.438E-06	.397E-06	.363E-06
1	1000.000	.648E-06	.571E-06	.508E-06	.455E-06	.412E-06	.376E-06
2	1584.893	.679E-06	.597E-06	.530E-06	.474E-06	.428E-06	.389E-06
3	2511.886	.712E-06	.625E-06	.553E-06	.493E-06	.444E-06	.404E-06
4	3981.072	.747E-06	.654E-06	.576E-06	.514E-06	.462E-06	.419E-06
5	6309.573	.784E-06	.685E-06	.604E-06	.537E-06	.481E-06	.435E-06

DEVIATIONS DIVIDED BY MEAN OF GIVEN J VALUES

1	.100	-.00973	-.00893	-.00816	-.00739	-.00662	-.00586
2	.158	-.01499	-.01305	-.01139	-.00993	-.00865	-.00753
3	.251	-.01537	-.01300	-.01106	-.00944	-.00808	-.00691
4	.398	-.01150	-.00939	-.00772	-.00641	-.00538	-.00456
5	.631	-.00621	-.00470	-.00356	-.00277	-.00221	-.00181
6	1.000	-.00350	-.00237	-.00157	-.00105	-.00073	-.00056
7	1.585	-.00463	-.00344	-.00255	-.00190	-.00146	-.00111
8	2.512	-.00601	-.00478	-.00376	-.00294	-.00231	-.00188
9	3.981	-.00424	-.00340	-.00266	-.00202	-.00149	-.00110
0	6.310	-.00083	-.00059	-.00038	-.00015	.00008	.00028
1	10.000	.00015	.00015	.00011	.00012	.00019	.00023
2	15.849	-.00237	-.00208	-.00197	-.00182	-.00162	-.00133
3	25.119	-.00437	-.00361	-.00351	-.00327	-.00296	-.00255
4	39.811	-.00250	-.00213	-.00203	-.00198	-.00188	-.00161
5	63.096	.00089	.00095	.00077	.00051	.00029	.00011
6	100.000	.00104	.00125	.00126	.00102	.00078	.00065
7	158.489	-.00272	-.00183	-.00132	-.00106	-.00099	-.00101
8	251.189	-.00504	-.00377	-.00293	-.00240	-.00212	-.00202
9	398.107	-.00223	-.00139	-.00088	-.00061	-.00055	-.00066
0	630.957	.00165	.00190	.00193	.00184	.00161	.00122
1	1000.000	-.00067	-.00005	.00029	.00047	.00048	.00022
2	1584.893	-.01059	-.00843	-.00682	-.00560	-.00473	-.00421
3	2511.886	-.02122	-.01742	-.01449	-.01220	-.01045	-.00921
4	3981.072	-.02865	-.02373	-.01992	-.01692	-.01461	-.01291
5	6309.573	-.03984	-.03322	-.02804	-.02395	-.02074	-.01821

DEFF. OF VARIATION FOR THE DEVIATIONS FROM GIVEN J-VALUES IS .0364

RELAXATION TIMES :

.333E+00	.333E+01	.333E+02	.333E+03	.333E+04	.333E+05	.10E

STARTING VALUES :
****

FIRST TIME STEP : .100000E+00
FIRST AGE AT LOADING : .300000E+02
FIRST RELAXATION TIME : .333333E+00

MAXWELL CHAIN DATA :
****

	MU= 1	MU= 2	MU= 3	MU= 4	MU= 5	MU= 6
ALFA-S :	.100E-04	.100E-04	.100E-04	.100E-04	.100E-04	.100E-04
TAUMU :	.333E+00	.333E+01	.333E+02	.333E+03	.333E+04	.333E+05

TIME STEPS
****

	DT	LOAD FACT	TEMP FACT
TIME STEP NO. : , 1	.100	1.000	0.000
TIME STEP NO. : , 2	.500	0.000	0.000
TIME STEP NO. : , 3	1.000	0.000	0.000
TIME STEP NO. : , 4	5.000	0.000	0.000
TIME STEP NO. : , 5	10.000	0.000	0.000
TIME STEP NO. : , 6	100.000	0.000	0.000
TIME STEP NO. : , 7	500.000	0.000	0.000
TIME STEP NO. : , 8	1000.000	0.000	0.000
TIME STEP NO. : , 9	5000.000	0.000	0.000
TIME STEP NO. : , 10	10000.000	0.000	0.000

TIME STEP NO. : 1
****

SIZE OF TIME STEP	:	.100
TOTAL TIME	:	.100
LOAD INCREMENT	:	1.000
TEMP. INCREMENT	:	0.000

SELECTIVE NODAL DISPLACEMENTS
****

	R-DISPLACEMENT	Z-DISPLACEMENT
NODAL POINT NO. 1 :	0.	0.
NODAL POINT NO. 2 :	.265976E-03	0.
NODAL POINT NO. 3 :	0.	-.254335E-02
NODAL POINT NO. 4 :	.268632E-03	-.273476E-02

SELECTIVE ELEMENT STRESSES
**********/

	SIGMA-R	SIGMA-Z	SIGMA-TH
ELEMENT NO. 1 :	.219E+02	-.172E+04	.219E+02
ELEMENT NO. 2 :	.243E+02	-.165E+04	.115E+02

SELECTIVE ELEMENT STRAINS
****

	EPS-R	EPS-Z	EPS-TH
ELEMENT NO. 1 :	.687E-04	-.424E-03	.887E-04
ELEMENT NO. 2 :	.962E-04	-.456E-03	.924E-04

TIME STEP NO. : 10
****

SIZE OF TIME STEP : 10000.000

TOTAL TIME : 16616.600

LOAD INCREMENT : 0.000

TEMP. INCREMENT : 0.000

DISPLACEMENT VECTOR
****

	R-DISPLACEMENT	Z-DISPLACEMENT
NODAL POINT NO. 1 :	0.	0.
NODAL POINT NO. 2 :	.625659E-03	0.
NODAL POINT NO. 3 :	0.	-.539743E-02
NODAL POINT NO. 4 :	.569096E-03	-.566021E-02

ELEMENT STRESSES
****

	SIGMA-R	SIGMA-Z	SIGMA-TH
ELEMENT NO. 1 :	.928E+02	-.154E+04	.928E+02
REINF ST STR :	0.	0.	0.
ELEMENT NO. 2 :	.106E+00	-.162E+04	.257E+02
REINF ST STR :	0.	0.	0.

AXISYMMETRIC LINER ELEMENT STRESSES
****

EL.NO.	NA	NB	SIGMA	SIGMA-TH
1	3	4	.813E+04	.813E+04
2	2	4	-.291E+05	-.276E+04

BAR AND HOOP ELEMENT STRESSES
****

EL.NO.	NA	NB	SIGMA
3	1	3	-.270E+05

ELEMENT STRAINS
****

	EPS-R	EPS-Z	EPS-TH
ELEMENT NO. 1 :	.209E-03	-.900E-03	.209E-03
ELEMENT NO. 2 :	.190E-03	-.943E-03	.199E-03

*** MAXIMUM NO. OF TIME STEPS REACHED ***

```
TWO ELEMENT CONCRETE CYLINDER WITH STRESS OF 2000 PSI, 2 NONSAP BAR AND 1 HOOP
   4100111   1   1   1  10   1.0                    10


  1   0  11


  1   0   1   1                          0.0       0.0
  2   0   0   1                          3.0       0.0
  3   0   1   0                          0.0       6.0
  4   0   0                              3.0       6.0
  2   1   2
  1   2
 0.0       1.0       11.0       1.0
  3   3   1  -2250.
  4   3   1  -6750.

  1   2                                                    1   2
  1
30000000.    .0225
  2
30000000.    .045
  1   1   3   1                1
  2   2   4   2                1
  4   2   1   0   1   4   3   2   2   7   3   5   5   7   4   6   1   9
  1   1   2   3
  2   3   4   2
  1   4   0   .043
   .1E-4     .1E-4     .1E-4     .1E-4     .1E-4     .1E-4     .1E-4
  .298E3     .1E-4      .3E0     1.0E0     1.0E0     .54E4      .2E1      0.E0
   0.E0      .2E0      0.0E0     0.0E0     0.0E0     0.0E0     .3E08    .25E02
   .1E1      .3E2
   .1        5.0       0.0       0.010     0.080
 12.0
  4.0E6      1.5       0.135     0.33      0.05
  0.1        0.5       1.0        5.0      10.0      100.0     500.0    1000.0
 5000.0    10000.0
  1.0


  1   2   3   4
  1   2
  1   2

LR16    #999     RECRFA*  //// END OF LIST ////        2    PAGES.
```

TWO ELEMENT CONCRETE CYLINDER WITH STRESS OF 2000 PSI, 2 NONSAP BAR AND

C O N T R O L I N F O R M A T I O N

```
NUMBER OF NODAL POINTS . . . . . . . . . . (NUMNP)   =   4

MASTER X-TRANSLATION CODE . . . . . . . . . (IDOF(1)) =   1

MASTER Y-TRANSLATION CODE . . . . . . . . . (IDOF(2)) =   0

MASTER Z-TRANSLATION CODE . . . . . . . . . (IDOF(3)) =   0

MASTER X-ROTATION    CODE . . . . . . . . . (IDOF(4)) =   1

MASTER Y-ROTATION    CODE . . . . . . . . . (IDOF(5)) =   1

MASTER Z-ROTATION    CODE . . . . . . . . . (IDOF(6)) =   1

NUMBER OF LINEAR ELEMENT GROUPS . . . . . . (NEGL)   =   1

NUMBER OF NONLINEAR ELEMENT GROUPS  . . . . (NEGNL)  =   1

SOLUTION MODE . . . . . . . . . . . . . . . (MODEX)  =   1
   EQ.0, DATA CHECK
   EQ.1, EXECUTION
   EQ.2, RESTART

NUMBER OF TIME STEPS  . . . . . . . . . . . (NSTE)   =  10

TIME STEP INCREMENT . . . . . . . . . . . . (DT)  =  .1000E+01

TIME AT SOLUTION START  . . . . . . . . . . (TSTART)= 0.

PRINTING INTERVAL . . . . . . . . . . . . . (IPRI)   =  10

MASS MATRIX CODE  . . . . . . . . . . . . . (IMASS)  =   0
   EQ.0, NO MASS EFFECTS
   EQ.1, LUMPED MASS
   EQ.2, CONSISTENT MASS

DAMPING MATRIX CODE . . . . . . . . . . . . (IDAMP)  =   0
   EQ.0, NO RAYLEIGH DAMPING
   EQ.1, RAYLEIGH DAMPING

NUMBER OF NODAL MASSES  . . . . . . . . . . (IMASSN) =   0

NUMBER OF NODAL DAMPERS . . . . . . . . . . (IDAMPN) =   0

FREQUENCIES SOLUTION CODE . . . . . . . . . (IEIG)   =   0
   EQ.0, NO FREQUENCIES SOLUTION
   EQ.1, FREQUENCIES AND MODE SHAPES
         ARE DETERMINED

NUMBER OF TIME STEPS BETWEEN REFORMING
  EFFECTIVE STIFFNESS MATRIX  . . . . . . . (ISREF)  =   1

NUMBER OF ALLOWABLE STIFFNESS REFORMATIONS
  IN EACH TIME STEP . . . . . . . . . . . . (NUMREF) =   0

NUMBER OF TIME STEPS BETWEEN
  EQUILIBRIUM ITERATIONS  . . . . . . . . . (IEQUIT) =  11

MAXIMUM NUMBER OF EQUILIBRIUM
  ITERATIONS PERMITTED  . . . . . . . . . . (ITEMAX) =  15

CONVERGENCE TOLERANCE . . . . . . . . . . . (RTOL)=  .10E-02
```

A N A L Y S I S T Y P E

```
TIME DEPENDENCY CODE  . . . . . . . . . . . (ISTAT)  =   0
   EQ.0, STATIC ANALYSIS
   EQ.1, DYNAMIC ANALYSIS

NONLINEARITY CODE . . . . . . . . . . . . . (KLIN)   =   1
   EQ.0, LINEAR ANALYSIS
   EQ.1, NONLINEAR ANALYSIS
```

D I S P / V E L / A C C P R I N T O U T C O D E

```
NUMBER OF BLOCKS OF NODAL PRINTOUT  . . . . . . (NPB) =   1

DISPLACEMENT PRINTOUT CODE  . . . . . . . . . . (IDC) =   1
   EQ.0, NO PRINTING OF DISPLACEMENTS
   EQ.1, PRINT DISPLACEMENTS

VELOCITY PRINTOUT CODE  . . . . . . . . . . . . (IVC) =   1
   EQ.0, NO PRINTING OF VELOCITIES
   EQ.1, PRINT VELOCITIES

ACCELERATION PRINTOUT CODE  . . . . . . . . . . (IAC) =   1
   EQ.0, NO PRINTING OF ACCELERATIONS
   EQ.1, PRINT ACCELERATIONS

BLOCK  1

   FIRST NODE OF THIS BLOCK  . . . . . (IPNODE(1,1) =   1

   LAST NODE OF THIS BLOCK  . . . . . . (IPNODE(2,1) =   4
```

L O A D S

NUMBER OF LOADS = 2
NUMBER OF LOAD CURVES = 1
MAX NUMBER OF POINTS IN LOAD CURVES = 2

LOAD FUNCTION NUMBER = 1
NUMBER OF TIME POINTS = 2

TIME VALUE	FUNCTION
0.00000	.1000E+01
11.00000	.1000E+01

CONCENTRATED LOADS

NODE	DIRECTION	LOAD CURVE	LOAD CURVE MULTIPL
3	3	1	-.2250E+04
4	3	1	-.6750E+04

N O D A L P O I N T D A T A

INPUT NODAL DATA

NODE	BOUNDARY CONDITION CODES						NODAL POINT COORDINATES		
	X	Y	Z	XX	YY	ZZ	X	Y	Z
1	0	1	1	0	0	0	0.000	0.000	0.000
2	0	0	1	0	0	0	0.000	3.000	0.000
3	0	1	0	0	0	0	0.000	0.000	6.000
4	0	0	0	0	0	0	0.000	3.000	6.000

GENERATED NODAL DATA

NODE	BOUNDARY CONDITION CODES						NODAL POINT COORDINATES		
	X	Y	Z	XX	YY	ZZ	X	Y	Z
1	1	1	1	1	1	1	0.000	0.000	0.000
2	1	0	1	1	1	1	0.000	3.000	0.000
3	1	1	0	1	1	1	0.000	0.000	6.000
4	1	0	0	1	1	1	0.000	3.000	6.000

EQUATION NUMBERS

N	X	Y	Z	XX	YY	ZZ
1	0	0	0	0	0	0
2	0	1	0	0	0	0
3	0	0	2	0	0	0
4	0	3	4	0	0	0

```
E L E M E N T   G R O U P   D A T A

E L E M E N T   G R O U P ........................... =    1    ( LINEAR )

E L E M E N T   D E F I N I T I O N

ELEMENT TYPE  . . . . . . . . . . . . .( NPAR(1) ). . =    1
    EQ.1, TRUSS ELEMENTS
    EQ.2, 2-DIM ELEMENTS
    EQ.3, 3-DIM ELEMENTS

NUMBER OF ELEMENTS. . . . . . . . . . .( NPAR(2) ). . =    2

TYPE OF NONLINEAR ANALYSIS. . . . . . .( NPAR(3) ). . =    1
    EQ.1, MATERIALLY NONLINEAR ONLY
    EQ.2, UPDATED LAGRANGIAN FORMULATION

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

MATERIAL MODEL. . . . . . . . . . . . .( NPAR(15)). . =    1
   EQ.1,   LINEAR ELASTIC
   EQ.2,   NONLINEAR ELASTIC
           (STRESS-STRAIN LAW SPECIFIED)

NUMBER OF DIFFERENT SETS OF MATERIAL
   CONSTANTS . . . . . . . . . . . . .( NPAR(16)). . =    2

NUMBER OF MATERIAL CONSTANTS PER SET. .( NPAR(17)). . =    0

TYPE            E          AREA            DEN          STRAI

   1   .3000000E+08   .2250000E-01  0.            0.

   2   .3000000E+08   .4500000E-01  0.            0.

E L E M E N T   I N F O R M A T I O N

   N     I     J  TYPE       PRESTRESSING FORCE       IPS

   1     1     3     1              0.                 1
   2     2     4     2              0.                 1
```

```
E L E M E N T   G R O U P ........................... =    2    ( NONLINEAR )
```

```
CONTROL PARAMETERS :
********************

NO. OF SELECTED NODE DISP.                  :  4
NO. OF SELECTED ELEMENT STRESSES            :  2
NO. OF SELECTED ELEMENT STRAINS             :  2
STEP NO. FOR PRESTRESS STEEL                :  1
PRINTING OF INPUT DATA                      :  1
PRINT SWITCH                                :  9
DATA CHECK                                  :  1
NO. OF TIME STEPS                           : 10
STEP NO. OF USER SUPPLIED TEMP. DIST.       : 11
TIME STEPS IN REAL/LOG. SCALE               :  0
NO. OF ELEMENTS                             :  2
NO. OF LINER ELEMENTS                       :  0
NO. OF BAR AND HOOP ELEMENTS                :  1
NO. OF NODAL POINTS PER ELEMENT             :  3
NO. OF D.O.F. PER NODAL POINT               :  2
NO. OF UNITS IN MAXWELL CHAIN               :  7

ELEMENT CONNECTIONS :
*********************

                      1          2          3

ELEMENT NO.  1 :      1          2          3
ELEMENT NO.  2 :      3          4          2

BAR/HOOP ELEMENTS   :
*************************
BAR/HOOP ELEMENT   1 :       4       0    AREA :    .0430000

MATERIAL PARAMETERS :
*********************
REFERENCE TEMPERATURE                  : TO    =    .298000E+03
ENTROPY DENSITY (HIND. ADSB. WATER)    : SW    =    .100000E+01
ACTIVATION ENERGY OF HYDRATION         : U     =    .540000E+04
GAS CONSTANT                           : R     =    .200000E+01
POISSON'S RATIO                        : PR    =    .200000E+00
RADIAL STEEL RATIO                     : RHOR  =   0.
AXIAL STEEL RATIO                      : RHOZ  =   0.
HOOP STEEL RATIO                       : RHOH  =   0.
SECOND MATERIAL MODULUS                : E2    =    .300000E+08
SECOND MATERIAL TEMP. COEF.            : ALFA  =    .100000E-04
SECOND MATERIAL POISSON'S RATIO        : PR    =    .300000E+00
CHOSEN REFERENCE VALUE OF T            : TREF  =    .250000E+02
CHOSEN REFERENCE VALUE OF H            : HREF  =    .100000E+01

INPUT DATA FOLLOW
```

```
INPUT DATA FOLLOW

T1=      .10000        TP1=     5.00000        TAU1=     0.00000        W1=     .010

INPUT DATA FOLLOW

ALFTEM=    12.000

NT=  25          TMAX=  .6310E+04

      ***   WARNING FROM MATPAR   ***

      SMALLEST RELAXATION TIME UNASSIGNED.CHOOSE - TAU1=   .333E+00

      ***   WARNING FROM MATPAR   ***

      HIGHEST RELAXATION TIME : TAUM =   .333E+05

      NOTE : FOR GIVEN RELAXATION TIMES,CREEP CAN BE
      REPRESENTED ONLY FROM T1=  .100E+00  TO TMAX=  .167E+05
      MAKE SURE THAT THE SMALLEST AGE TP1 IS .GE.      .300E+00
      OR ELSE AGING OF YOUNG CONCRETE DISTORTS LONG-TIME
      RESPONSE

INPUT DATA FOR OPTION JOPT=  3  FOLLOW

GIVEN DOUBLE POWER LAW PARAMETERS

28-DAY ELMODULUS E26=      .40000E+07 PSI

    E0E28=  1.5000     EXPN=  .1350     EXPM=  .3300     ALFA=  .05000

 CALCULATED E0 =      .60000E+07          PHI1= 1.78146

 END OF INPUT AND GENERATION OF INPUT PARAMETERS

TABLE OF CALCULATED RELAXATION FUNCTION ER(IT,IA)
      TP(IA)=   .5000E+01   .8891E+01   .1581E+02   .2812E+02   .5000E+02   .8891E
IT    T(IT)     ER(IT,1)    ER(IT,2) ...
 1     .100     .3274E+07   .3529E+07   .3773E+07   .4002E+07   .4213E+07   .4405E
 2     .159     .3171E+07   .3430E+07   .3678E+07   .3912E+07   .4129E+07   .4327E
 3     .251     .3073E+07   .3334E+07   .3586E+07   .3823E+07   .4045E+07   .4248E
```

4	.398	.2477E+07	.2639E+07	.2793E+07	.2939E+07	.3081E+07	.4169E
5	.631	.2880E+07	.3144E+07	.3400E+07	.3642E+07	.3875E+07	.4088E
6	1.000	.2784E+07	.3048E+07	.3306E+07	.3554E+07	.3788E+07	.4005E
7	1.585	.2687E+07	.2952E+07	.3212E+07	.3462E+07	.3699E+07	.3921E
8	2.512	.2586E+07	.2855E+07	.3116E+07	.3369E+07	.3609E+07	.3835E
9	3.981	.2488E+07	.2757E+07	.3020E+07	.3275E+07	.3518E+07	.3747E
10	6.310	.2385E+07	.2657E+07	.2922E+07	.3179E+07	.3425E+07	.3658E
11	10.000	.2279E+07	.2554E+07	.2822E+07	.3082E+07	.3331E+07	.3567E
12	15.849	.2168E+07	.2448E+07	.2720E+07	.2983E+07	.3236E+07	.3474E
13	25.119	.2052E+07	.2337E+07	.2615E+07	.2882E+07	.3138E+07	.3380E
14	39.811	.1929E+07	.2221E+07	.2505E+07	.2778E+07	.3038E+07	.3284E
15	63.096	.1799E+07	.2099E+07	.2390E+07	.2669E+07	.2935E+07	.3186E
16	100.000	.1661E+07	.1971E+07	.2269E+07	.2556E+07	.2828E+07	.3084E
17	158.489	.1515E+07	.1834E+07	.2142E+07	.2437E+07	.2717E+07	.2980E
18	251.189	.1360E+07	.1690E+07	.2008E+07	.2312E+07	.2600E+07	.2870E
19	398.107	.1196E+07	.1538E+07	.1866E+07	.2181E+07	.2478E+07	.2756E
20	630.957	.1023E+07	.1376E+07	.1717E+07	.2042E+07	.2349E+07	.2637E
21	1000.000	.8399E+06	.1206E+07	.1559E+07	.1896E+07	.2214E+07	.2512E
22	1584.893	.6467E+06	.1026E+07	.1392E+07	.1742E+07	.2071E+07	.2380E
23	2511.886	.4433E+06	.8374E+06	.1217E+07	.1580E+07	.1922E+07	.2242E
24	3981.072	.2296E+06	.6388E+06	.1033E+07	.1409E+07	.1765E+07	.2097E
25	6309.573	.5450E+04	.4305E+06	.8402E+06	.1231E+07	.1600E+07	.1945E

WEIGHTS USED IN MAXWL1 ARE W1= .0100 AND W2= .0800

RELAXATION TIMES TAU(MU)= .3333E+00 .3333E+01 .3333E+02 .3333E+03

RELAXATION MODULI FOR TIME RANGE FROM .100E+00 TO .631E+04

IA	TP(IA)	EMU(1,IA)	EMU(2,IA) ...					
1	5.000	.487E+06	.479E+06	.563E+06	.766E+06	.102E+07	.126E+07	-.
2	8.891	.485E+06	.472E+06	.536E+06	.714E+06	.950E+06	.117E+07	-.
3	15.811	.475E+06	.464E+06	.512E+06	.665E+06	.878E+06	.108E+07	-.
4	28.117	.458E+06	.454E+06	.492E+06	.620E+06	.810E+06	.993E+06	.
5	50.000	.434E+06	.441E+06	.475E+06	.580E+06	.747E+06	.907E+06	.
6	88.914	.407E+06	.424E+06	.458E+06	.546E+06	.689E+06	.828E+06	.
7	158.114	.378E+06	.404E+06	.441E+06	.515E+06	.636E+06	.754E+06	.

TP(IA)= .500E+01 .158E+02 .500E+02 .158E+03

CREEP FUNCTION VALUES COMPUTED FROM MAXWELL CHAIN MODULI EMU

IT	T(IT)	AJ(IT,1)	AJ(IT,2) ...		
1	.100	.302E-06	.262E-06	.235E-06	.217E-06
2	.158	.309E-06	.267E-06	.239E-06	.219E-06
3	.251	.318E-06	.274E-06	.244E-06	.223E-06
4	.398	.330E-06	.282E-06	.250E-06	.228E-06
5	.631	.342E-06	.291E-06	.257E-06	.233E-06
6	1.000	.355E-06	.300E-06	.263E-06	.237E-06
7	1.585	.367E-06	.309E-06	.269E-06	.242E-06
8	2.512	.379E-06	.317E-06	.275E-06	.246E-06
9	3.981	.393E-06	.327E-06	.282E-06	.252E-06
10	6.310	.409E-06	.339E-06	.290E-06	.257E-06
11	10.000	.425E-06	.350E-06	.298E-06	.263E-06
12	15.849	.441E-06	.361E-06	.306E-06	.269E-06
13	25.119	.458E-06	.373E-06	.315E-06	.275E-06
14	39.811	.477E-06	.387E-06	.325E-06	.282E-06
15	63.096	.498E-06	.402E-06	.336E-06	.290E-06
16	100.000	.520E-06	.417E-06	.347E-06	.298E-06
17	158.489	.541E-06	.432E-06	.358E-06	.306E-06
18	251.189	.564E-06	.449E-06	.369E-06	.315E-06
19	398.107	.591E-06	.468E-06	.383E-06	.325E-06
20	630.957	.620E-06	.486E-06	.398E-06	.336E-06
21	1000.000	.648E-06	.508E-06	.412E-06	.346E-06
22	1584.893	.675E-06	.527E-06	.426E-06	.356E-06
23	2511.886	.704E-06	.548E-06	.440E-06	.367E-06
24	3981.072	.736E-06	.570E-06	.457E-06	.379E-06
25	6309.573	.769E-06	.594E-06	.473E-06	.391E-06

COMPARE CREEP FUNCTION VALUES AS ORIGINALLY GIVEN

1	.100	.305E-06	.265E-06	.237E-06	.218E-06
2	.158	.314E-06	.271E-06	.242E-06	.222E-06
3	.251	.324E-06	.278E-06	.247E-06	.225E-06
4	.398	.334E-06	.285E-06	.252E-06	.229E-06
5	.631	.345E-06	.293E-06	.257E-06	.233E-06
6	1.000	.356E-06	.301E-06	.263E-06	.237E-06
7	1.585	.368E-06	.310E-06	.269E-06	.242E-06
8	2.512	.381E-06	.319E-06	.276E-06	.247E-06
9	3.981	.395E-06	.326E-06	.283E-06	.252E-06
10	6.310	.410E-06	.339E-06	.290E-06	.257E-06
11	10.000	.425E-06	.350E-06	.298E-06	.263E-06
12	15.849	.442E-06	.362E-06	.307E-06	.269E-06
13	25.119	.459E-06	.374E-06	.316E-06	.276E-06
14	39.811	.478E-06	.387E-06	.325E-06	.283E-06
15	63.096	.498E-06	.402E-06	.336E-06	.290E-06
16	100.000	.519E-06	.417E-06	.346E-06	.298E-06
17	158.489	.542E-06	.433E-06	.358E-06	.307E-06
18	251.189	.566E-06	.450E-06	.370E-06	.316E-06
19	398.107	.592E-06	.468E-06	.383E-06	.325E-06
20	630.957	.619E-06	.487E-06	.397E-06	.335E-06
21	1000.000	.648E-06	.508E-06	.412E-06	.346E-06
22	1584.893	.679E-06	.530E-06	.428E-06	.358E-06
23	2511.886	.712E-06	.553E-06	.444E-06	.370E-06
24	3981.072	.747E-06	.578E-06	.462E-06	.383E-06
25	6309.573	.784E-06	.604E-06	.481E-06	.397E-06

DEVIATIONS DIVIDED BY MEAN OF GIVEN J VALUES

1	.100	-.00965	-.00809	-.00656	-.00511
2	.158	-.01486	-.01129	-.00858	-.00647
3	.251	-.01524	-.01096	-.00801	-.00593
4	.398	-.01140	-.00766	-.00533	-.00386
5	.631	-.00616	-.00355	-.00219	-.00152
6	1.000	-.00348	-.00156	-.00073	-.00046
7	1.585	-.00459	-.00253	-.00145	-.00098
8	2.512	-.00596	-.00373	-.00229	-.00150
9	3.981	-.00420	-.00264	-.00148	-.00079
10	6.310	-.00082	-.00037	.00007	.00036
11	10.000	.00015	.00011	.00016	.00034
12	15.849	-.00235	-.00195	-.00161	-.00112
13	25.119	-.00433	-.00348	-.00293	-.00221
14	39.811	-.00246	-.00201	-.00187	-.00149
15	63.096	.00089	.00076	.00029	.00002
16	100.000	.00103	.00119	.00078	.00022
17	158.489	-.00270	-.00131	-.00098	-.00128
18	251.189	-.00500	-.00290	-.00211	-.00227
19	398.107	-.00221	-.00087	-.00055	-.00114
20	630.957	.00164	.00191	.00159	.00048
21	1000.000	-.00066	.00029	.00047	-.00035
22	1584.893	-.01050	-.00676	-.00469	-.00427
23	2511.886	-.02104	-.01437	-.01036	-.00864

25	6309.573	-.03950	-.02760	-.02056	-.01666

COEFF. OF VARIATION FOR THE DEVIATIONS FROM GIVEN J-VALUES IS .0086

RELAXATION TIMES :

.333E+00 .333E+01 .333E+02 .333E+03 .333E+04 .333E+05 .1001

STARTING VALUES :
****

FIRST TIME STEP : .100000E+00
FIRST AGE AT LOADING : .300000E+02
FIRST RELAXATION TIME : .333333E+00

MAXWELL CHAIN DATA :
****

	MU= 1	MU= 2	MU= 3	MU= 4	MU= 5	MU= 6
ALFA-S :	.100E-04	.100E-04	.100E-04	.100E-04	.100E-04	.100E-04
TAUMU :	.333E+00	.333E+01	.333E+02	.333E+03	.333E+04	.333E+05

TIME STEPS
****

	DT	LOAD FACT	TEMP FACT
TIME STEP NO. : , 1	.100	1.000	0.000
TIME STEP NO. : , 2	.500	0.000	0.000
TIME STEP NO. : , 3	1.000	0.000	0.000
TIME STEP NO. : , 4	5.000	0.000	0.000
TIME STEP NO. : , 5	10.000	0.000	0.000
TIME STEP NO. : , 6	100.000	0.000	0.000
TIME STEP NO. : , 7	500.000	0.000	0.000
TIME STEP NO. : , 8	1000.000	0.000	0.000
TIME STEP NO. : , 9	5000.000	0.000	0.000
TIME STEP NO. : , 10	10000.000	0.000	0.000

INITIAL CONDITIONS

DISPLACEMENTS

NODE	X-DISPLACEMENT	Y-DISPLACEMENT	Z-DISPLACEMENT	X-ROTAT
1	0.	0.	0.	0.
2	0.	0.	0.	0.
3	0.	0.	0.	0.
4	0.	0.	0.	0.

TIME STEP NO. : 1
****

SIZE OF TIME STEP	:	.100
TOTAL TIME	:	.100
LOAD INCREMENT	:	1.000
TEMP. INCREMENT	:	0.000

SELECTIVE NODAL DISPLACEMENTS
****

	R-DISPLACEMENT	Z-DISPLACEMENT
NODAL POINT NO. 1 :	0.	0.
NODAL POINT NO. 2 :	.225579E-03	0.
NODAL POINT NO. 3 :	0.	-.250712E-02
NODAL POINT NO. 4 :	.297117E-03	-.272317E-02

SELECTIVE ELEMENT STRESSES
**********/

	SIGMA-R	SIGMA-Z	SIGMA-TH
ELEMENT NO. 1 :	-.474E+02	-.172E+04	-.474E+02
ELEMENT NO. 2 :	.333E+02	-.184E+04	-.719E+01

SELECTIVE ELEMENT STRAINS
****

	EPS-R	EPS-Z	EPS-TH
ELEMENT NO. 1 :	.752E-04	-.418E-03	.752E-04
ELEMENT NO. 2 :	.990E-04	-.454E-03	.871E-04

P R I N T O U T F O R T I M E S T E P 10

NO EQUILIBRIUM ITERATION ON THIS TIME STEP
STIFFNESS REFORMED FOR THIS TIME STEP

TIME STEP NO. : 10
****

SIZE OF TIME STEP : 10000.000

TOTAL TIME : 16616.600

LOAD INCREMENT : 0.000

TEMP. INCREMENT : 0.000

D I S P L A C E M E N T S

NODE	X-DISPLACEMENT	Y-DISPLACEMENT	Z-DISPLACEMENT	X-ROTAT
1	0.	0.	0.	0.
2	0.	.468087E-03	0.	0.
3	0.	0.	-.525662E-02	0.
4	0.	.601360E-03	-.561231E-02	0.

S T R E S S C A L C U L A T I O N S F O R E L E M E N T G R O U P 1 (

ELEMENT	FORCE	STRESS
1	-.591370E+03	-.262831E+05
2	-.126277E+04	-.280615E+05

ELEMENT STRESSES
****

	SIGMA-R	SIGMA-Z	SIGMA-TH
ELEMENT NO. 1 :	-.462E+02	-.154E+04	-.482E+02
REINF ST STR :	0.	0.	0.
ELEMENT NO. 2 :	.177E+02	-.161E+04	-.126E+02
REINF ST STR :	0.	0.	0.

BAR AND HOOP ELEMENT STRESSES
****

EL.NO.,	NA	NB	SIGMA
1	4		.601E+04

ELEMENT STRAINS
****

	EPS-R	EPS-Z	EPS-TH
ELEMENT NO. 1 :	.156E-03	-.876E-03	.156E-03
ELEMENT NO. 2 :	.200E-03	-.935E-03	.178E-03

```
FOUR ELEMENT CONCRETE CYLINDER WITH STRESS OF 1000 PSI
   5100111   0   1   1   8   1.0                    8


   1   0   9


   1         0   1                          100.0       0.
   2         0   1                          101.0       0.
   3         0   0                          100.5       0.5
   4         0   0                          100.0       1.0
   5         0   0                          101.0       1.0
   2   1     2
   1   2
 0.0       1.0       9.0       1.0
   4   3   1-.502486E5
   5   3   1-.502486E5

  4   4   1   0   0   5   3   4   4   7   1   5   5   7   4   6  11   9
   1   1   4   3
   2   1   3   2
   3   2   3   5
   4   3   4   5
  .1E-4     .1E-4     .1E-4     .1E-4     .1E-4     .1E-4     .1E-4
 .298E3     .1E-4      .3E0     1.0E0     1.0E0     .54E4      .2E1      0.E
   0.E0      .2E0     0.0E0     0.0E0     0.0E0     0.0E0     .3E08    .25E0
  .1E1      .5E1
  .1        5.0       0.0       0.010     0.050
12.0
        5   .01       1.0       10.0      100.0    3000.0
        3   7.0       90.0      730.0
 .26E-6    .45E-6    .59E-6    .77E-6    1.1E-6
 .18E-6    .29E-6    .37E-6    .47E-6    .71E-6
 .12E-6    .20E-6    .26E-6    .33E-6    .48E-6
 0.1       0.9       9.0       90.0      900.0  1511.886  1469.186  2328.501
 1.0

   1   2   3   4   5
   1   2   3   4
   1   2   3   4

LR16    #555     RECREA*  //// END OF LIST ////        2    PAGES.
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```
FOUR ELEMENT CONCRETE CYLINDER WITH STRESS OF 1000 PSI

C O N T R O L   I N F O R M A T I O N

   NUMBER OF NODAL POINTS . . . . . . . . . . . (NUMNP)   =    5

   MASTER X-TRANSLATION CODE . . . . . . . . . (IDCF(1)) =    1

   MASTER Y-TRANSLATION CODE . . . . . . . . . (IDCF(2)) =    0

   MASTER Z-TRANSLATION CODE . . . . . . . . . (IDCF(3)) =    0

   MASTER X-ROTATION    CODE . . . . . . . . . (IDCF(4)) =    1

   MASTER Y-ROTATION    CODE . . . . . . . . . (IDCF(5)) =    1

   MASTER Z-ROTATION    CODE . . . . . . . . . (IDCF(6)) =    1

   NUMBER OF LINEAR ELEMENT GROUPS . . . . . . (NEGL)    =    0

   NUMBER OF NONLINEAR ELEMENT GROUPS . . . . . (NEGNL)   =    1

   SOLUTION MODE . . . . . . . . . . . . . . . (MODEX)   =    1
      EQ.0, DATA CHECK
      EQ.1, EXECUTION
      EQ.2, RESTART

   NUMBER OF TIME STEPS . . . . . . . . . . . (NSTE)    =    8

   TIME STEP INCREMENT . . . . . . . . . . . . (DT)     =  .1000E+01

   TIME AT SOLUTION START . . . . . . . . . . (TSTART)= 0.

   PRINTING INTERVAL . . . . . . . . . . . . . (IPRI)    =    8

   MASS MATRIX CODE . . . . . . . . . . . . . (IMASS)   =    0
      EQ.0, NO MASS EFFECTS
      EQ.1, LUMPED MASS
      EQ.2, CONSISTENT MASS

   DAMPING MATRIX CODE . . . . . . . . . . . . (IDAMP)   =    0
      EQ.0, NO RAYLEIGH DAMPING
      EQ.1, RAYLEIGH DAMPING

   NUMBER OF NODAL MASSES . . . . . . . . . . (IMASSN)  =    0

   NUMBER OF NODAL DAMPERS . . . . . . . . . (IDAMPN)   =    0

   FREQUENCIES SOLUTION CODE . . . . . . . . . (IEIG)    =    0
      EQ.0, NO FREQUENCIES SOLUTION
      EQ.1, FREQUENCIES AND MODE SHAPES
            ARE DETERMINED

   NUMBER OF TIME STEPS BETWEEN REFORMING
     EFFECTIVE STIFFNESS MATRIX . . . . . . . (ISPEF)    =    1

   NUMBER OF ALLOWABLE STIFFNESS REFORMATIONS
     IN EACH TIME STEP . . . . . . . . . . . . (NUMREF)   =    0

   NUMBER OF TIME STEPS BETWEEN
     EQUILIBRIUM ITERATIONS . . . . . . . . . (IEQUIT)   =    9

   MAXIMUM NUMBER OF EQUILIBRIUM
     ITERATIONS PERMITTED . . . . . . . . . . (ITEMAX)   =   15

   CONVERGENCE TOLERANCE . . . . . . . . . . . (RTOL)=  .10E-02

A N A L Y S I S   T Y P E

   TIME DEPENDENCY CODE . . . . . . . . . . . (ISTAT)    =    0
      EQ.0, STATIC ANALYSIS
      EQ.1, DYNAMIC ANALYSIS

   NONLINEARITY CODE . . . . . . . . . . . . . (KLIN)    =    1
      EQ.0, LINEAR ANALYSIS
      EQ.1, NONLINEAR ANALYSIS

D I S P / V E L / A C C   P R I N T O U T   C O D E

   NUMBER OF BLOCKS OF NODAL PRINTOUT . . . . . . (NPB) =    1

   DISPLACEMENT PRINTOUT CODE . . . . . . . . . . . (IDC) =    1
      EQ.0, NO PRINTING OF DISPLACEMENTS
      EQ.1, PRINT DISPLACEMENTS

   VELOCITY PRINTOUT CODE . . . . . . . . . . . . (IVC) =    1
      EQ.0, NO PRINTING OF VELOCITIES
      EQ.1, PRINT VELOCITIES

   ACCELERATION PRINTOUT CODE . . . . . . . . . . (IAC) =    1
      EQ.0, NO PRINTING OF ACCELERATIONS
      EQ.1, PRINT ACCELERATIONS

   BLOCK 1

      FIRST NODE OF THIS BLOCK . . . . . (IPNODE(1,1) =    1

      LAST NODE OF THIS BLOCK . . . . . . (IPNODE(2,1) =    5
```

N O D A L P O I N T D A T A

INPUT NODAL DATA

NODE	BOUNDARY CONDITION CODES						NODAL POINT COORDINATES		
	X	Y	Z	XX	YY	ZZ	X	Y	Z
1	0	0	1	0	0	0	0.000	100.000	0.000
2	0	0	1	0	0	0	0.000	101.000	0.000
3	0	0	0	0	0	0	0.000	100.500	.500
4	0	0	0	0	0	0	0.000	100.000	1.000
5	0	0	0	0	0	0	0.000	101.000	1.000

GENERATED NODAL DATA

NODE	BOUNDARY CONDITION CODES						NODAL POINT COORDINATES		
	X	Y	Z	XX	YY	ZZ	X	Y	Z
1	1	0	1	1	1	1	0.000	100.000	0.000
2	1	0	1	1	1	1	0.000	101.000	0.000
3	1	0	0	1	1	1	0.000	100.500	.500
4	1	0	0	1	1	1	0.000	100.000	1.000
5	1	0	0	1	1	1	0.000	101.000	1.000

EQUATION NUMBERS

N	X	Y	Z	XX	YY	ZZ
1	0	1	0	0	0	0
2	0	2	0	0	0	0
3	0	3	4	0	0	0
4	0	5	6	0	0	0
5	0	7	8	0	0	0

L O A D S

NUMBER OF LOADS = 2
NUMBER OF LOAD CURVES = 1
MAX NUMBER OF POINTS IN LOAD CURVES = 2

LOAD FUNCTION NUMBER = 1
NUMBER OF TIME POINTS = 2

TIME VALUE	FUNCTION
0.00000	.1000E+01
9.00000	.1000E+01

CONCENTRATED LOADS

NODE	DIRECTION	LOAD CURVE	LOAD CURVE MULTIPL
4	3	1	-.5025E+05
5	3	1	-.5025E+05

I N I T I A L C O N D I T I O N S

INITIAL CONDITIONS CODE (ICON) = 0
EQ.0, ZERO INITIAL CONDITIONS
EQ.1, INITIAL CONDITIONS ARE READ
(BUT RESTART OVER-RIDES ICON)

E L E M E N T G R O U P D A T A

E L E M E N T G R O U P ..... = 1 (NONLINEAR)

```
CONTROL PARAMETERS :
********************

NO. OF SELECTED NODE DISP.                  :   5
NO. OF SELECTED ELEMENT STRESSES            :   4
NO. OF SELECTED ELEMENT STRAINS             :   4
STEP NO. FOR PRESTRESS STEEL                :  11
PRINTING OF INPUT DATA                      :   1
PRINT SWITCH                                :   9
DATA CHECK                                  :   1
NO. OF TIME STEPS                           :   8
STEP NO. OF USER SUPPLIED TEMP. DIST.       :   9
TIME STEPS IN REAL/LOG. SCALE               :   0
NO. OF ELEMENTS                             :   4
NO. OF LINER ELEMENTS                       :   0
NO. OF BAR AND HOOP ELEMENTS                :   0
NO. OF NODAL POINTS PER ELEMENT             :   3
NO. OF D.O.F. PER NODAL POINT               :   2
NO. OF UNITS IN MAXWELL CHAIN               :   7

ELEMENT CONNECTIONS :
*********************

                          1          2          3

ELEMENT NO.  1 :          1          4          3
ELEMENT NO.  2 :          1          3          2
ELEMENT NO.  3 :          2          3          5
ELEMENT NO.  4 :          3          4          5

MATERIAL PARAMETERS :
*********************

REFERENCE TEMPERATURE                       : TC    =    .298000E+03
ENTROPY DENSITY (HIND. ADSB. WATER)         : SW    =    .100000E+01
ACTIVATION ENERGY OF HYDRATION              : U     =    .540000E+04
GAS CONSTANT                                : R     =    .200000E+01
POISSON'S RATIO                             : PR    =    .200000E+00
RADIAL STEEL RATIO                          : RHOR  =    0.
AXIAL STEEL RATIO                           : RHOZ  =    0.
HOOP STEEL RATIO                            : RHOH  =    0.
SECOND MATERIAL MODULUS                     : E2    =    .300000E+08
SECOND MATERIAL TEMP. COEF.                 : ALFA  =    .100000E-04
SECOND MATERIAL POISSON'S RATIO             : PR    =    .300000E+00
CHOSEN REFERENCE VALUE OF T                 : TREF  =    .250000E+02
CHOSEN REFERENCE VALUE OF H                 : HREF  =    .100000E+01

INPUT DATA FOLLOW

JOPT= 1     NDEC= 5     JCEC= 5     NA= 7     JA= 4     NMU= 7     NTSHR=**
```

```
INPUT DATA FOLLOW

T1=      .10000      TP1=      5.00000      TAU1=      1.00000      W1=      .0

INPUT DATA FOLLOW

COEF. OF THERMAL OIL. ALFTEM=      12.000

NT=  25          TMAX=  .6310E+04

      ***   WARNING FROM MATPAR   ***

      SMALLEST RELAXATION TIME UNASSIGNED.CHOOSE - TAU1=    .333E+00

      ***   WARNING FROM MATPAR   ***

      HIGHEST RELAXATION TIME : TAUM =    .333E+05

      NOTE : FOR GIVEN RELAXATION TIMES,CREEP CAN BE
      REPRESENTED ONLY FROM T1=  .167E+00  TO TMAX=  .167E+05
      MAKE SURE THAT THE SMALLEST AGE TP1 IS .GE.      .300E+00
      OR ELSE AGING OF YOUNG CONCRETE DISTORTS LONG-TIME
      RESPONSE

INPUT DATA FOR OPTION JOPT=  1  FOLLOW

INPUT VALUES OF CREEP FUNCTION J PER PSI

NO. OF DISCRETE TIMES FOR INPUT AND PRINT...NI =    5

NO. OF DISCRETE AGES FOR INPUT AND PRINT....NJ =    3

          AT(I)=        .0100       1.0000      10.0000     100.0000    3000.00
ATP( 1)=   7.0000      .2600E-06   .4500E-06   .5900E-06   .7700E-06    .110
ATP( 2)=  90.0000      .1800E-06   .2900E-06   .3700E-06   .4700E-06    .710
ATP( 3)= 730.0000      .1200E-06   .2000E-06   .2600E-06   .3300E-06    .480

      ***   WARNING FROM MATPAR   ***

      FINAL AGE IS BEYOND RANGE OF GIVEN CREEP DATA; TPM AX =  .631E+04          ML

END OF INPUT AND OF GENERATION OF INPUT PARAMETERS
```

7	1.585	.498E-06	.421E-06	.344E-06	.283E-06
8	2.512	.524E-06	.442E-06	.361E-06	.293E-06
9	3.981	.554E-06	.466E-06	.379E-06	.308E-06
10	6.310	.588E-06	.494E-06	.400E-06	.324E-06
11	10.000	.623E-06	.522E-06	.422E-06	.341E-06
12	15.849	.656E-06	.549E-06	.442E-06	.357E-06
13	25.119	.691E-06	.578E-06	.464E-06	.374E-06
14	39.811	.730E-06	.610E-06	.489E-06	.394E-06
15	63.096	.772E-06	.645E-06	.517E-06	.416E-06
16	100.000	.813E-06	.679E-06	.545E-06	.439E-06
17	158.489	.852E-06	.713E-06	.574E-06	.463E-06
18	251.189	.893E-06	.749E-06	.604E-06	.488E-06
19	398.107	.940E-06	.790E-06	.640E-06	.517E-06
20	630.957	.993E-06	.836E-06	.679E-06	.551E-06
21	1000.000	.105E-05	.883E-06	.720E-06	.585E-06
22	1584.893	.110E-05	.930E-06	.760E-06	.619E-06
23	2511.886	.115E-05	.978E-06	.803E-06	.654E-06
24	3981.072	.122E-05	.103E-05	.851E-06	.695E-06
25	6309.573	.128E-05	.109E-05	.904E-06	.739E-06

COMPARE CREEP FUNCTION VALUES AS ORIGINALLY GIVEN

1	.100	.371E-06	.317E-06	.263E-06	.215E-06
2	.158	.391E-06	.333E-06	.275E-06	.225E-06
3	.251	.411E-06	.350E-06	.288E-06	.235E-06
4	.398	.431E-06	.366E-06	.301E-06	.245E-06
5	.631	.451E-06	.383E-06	.314E-06	.256E-06
6	1.000	.471E-06	.399E-06	.327E-06	.266E-06
7	1.585	.501E-06	.423E-06	.346E-06	.281E-06
8	2.512	.530E-06	.447E-06	.364E-06	.296E-06
9	3.981	.561E-06	.471E-06	.383E-06	.311E-06
10	6.310	.589E-06	.496E-06	.402E-06	.325E-06
11	10.000	.619E-06	.520E-06	.421E-06	.340E-06
12	15.849	.657E-06	.551E-06	.444E-06	.359E-06
13	25.119	.695E-06	.582E-06	.468E-06	.377E-06
14	39.811	.733E-06	.612E-06	.492E-06	.396E-06
15	63.096	.771E-06	.643E-06	.515E-06	.414E-06
16	100.000	.810E-06	.674E-06	.539E-06	.432E-06
17	158.489	.856E-06	.715E-06	.574E-06	.462E-06
18	251.189	.902E-06	.756E-06	.610E-06	.491E-06
19	398.107	.948E-06	.797E-06	.645E-06	.520E-06
20	630.957	.995E-06	.837E-06	.680E-06	.549E-06
21	1000.000	.104E-05	.878E-06	.716E-06	.578E-06
22	1584.893	.109E-05	.919E-06	.751E-06	.608E-06
23	2511.886	.113E-05	.960E-06	.786E-06	.637E-06
24	3981.072	.118E-05	.100E-05	.821E-06	.666E-06
25	6309.573	.123E-05	.104E-05	.857E-06	.695E-06

DEVIATIONS DIVIDED BY MEAN OF GIVEN J VALUES

1	.100	-.00732	-.00676	-.01602	-.00523
2	.158	-.01944	-.01639	-.01326	-.01083
3	.251	-.02304	-.01895	-.01491	-.01194
4	.398	-.01824	-.01458	-.01115	-.00873
5	.631	-.00797	-.00580	-.00404	-.00288
6	1.000	.00279	.00311	.00296	.00279
7	1.585	-.00534	-.00369	-.00235	-.00146
8	2.512	-.01158	-.00925	-.00685	-.00516
9	3.981	-.01040	-.00887	-.00682	-.00532
10	6.310	-.00260	-.00300	-.00267	-.00228
11	10.000	.00628	.00385	.00203	.00106
12	15.849	-.00179	-.00267	-.00337	-.00298
13	25.119	-.00753	-.00719	-.00704	-.00565
14	39.811	-.00581	-.00484	-.00493	-.00332
15	63.096	.00116	.00233	.00236	.00378
16	100.000	.00594	.00887	.01091	.01235

TABLE OF CALCULATED RELAXATION FUNCTION ER(IT,IA)

TP(IA)=		.500E+01	.8891E+01	.2581E+02	.2812E+02	.5000E+02	.8891

IT	T(IT)	ER(IT,1)	ER(IT,2) ...				
1	.100	.2697E+07	.2909E+07	.3157E+07	.3452E+07	.3808E+07	.4245
2	.158	.2528E+07	.2731E+07	.2972E+07	.3253E+07	.3596E+07	.4020
3	.251	.2398E+07	.2594E+07	.2823E+07	.3096E+07	.3429E+07	.3840
4	.398	.2285E+07	.2473E+07	.2694E+07	.2959E+07	.3280E+07	.3680
5	.631	.2182E+07	.2364E+07	.2578E+07	.2835E+07	.3146E+07	.3535
6	1.000	.2089E+07	.2265E+07	.2473E+07	.2721E+07	.3024E+07	.3402
7	1.585	.1947E+07	.2116E+07	.2314E+07	.2551E+07	.2842E+07	.3206
8	2.512	.1831E+07	.1993E+07	.2183E+07	.2412E+07	.2691E+07	.3042
9	3.981	.1726E+07	.1884E+07	.2069E+07	.2289E+07	.2558E+07	.2898
10	6.310	.1632E+07	.1785E+07	.1965E+07	.2178E+07	.2439E+07	.2768
11	10.000	.1543E+07	.1695E+07	.1870E+07	.2077E+07	.2330E+07	.2650
12	15.849	.1423E+07	.1572E+07	.1743E+07	.1945E+07	.2191E+07	.2502
13	25.119	.1317E+07	.1466E+07	.1634E+07	.1832E+07	.2071E+07	.2377
14	39.811	.1217E+07	.1364E+07	.1531E+07	.1726E+07	.1960E+07	.2262
15	63.096	.1118E+07	.1266E+07	.1432E+07	.1624E+07	.1856E+07	.2157
16	100.000	.1019E+07	.1167E+07	.1333E+07	.1526E+07	.1757E+07	.2057
17	158.489	.8953E+06	.1037E+07	.1196E+07	.1380E+07	.1598E+07	.1880
18	251.189	.7893E+06	.9265E+06	.1081E+07	.1256E+07	.1466E+07	.1734
19	398.107	.6907E+06	.8238E+06	.9726E+06	.1143E+07	.1345E+07	.1641
20	630.957	.5953E+06	.7246E+06	.8691E+06	.1034E+07	.1229E+07	.1475
21	1000.000	.5003E+06	.6260E+06	.7662E+06	.9262E+06	.1114E+07	.1350
22	1584.893	.4028E+06	.5249E+06	.6608E+06	.8157E+06	.9974E+06	.1224
23	2511.886	.3008E+06	.4190E+06	.5506E+06	.7032E+06	.8753E+06	.1092
24	3981.072	.1909E+06	.3051E+06	.4320E+06	.5761E+06	.7443E+06	.9513
25	6309.573	.6863E+05	.1783E+06	.3003E+06	.4380E+06	.5986E+06	.7946

WEIGHTS USED IN MAXWL1 ARE W1= .0100 AND W2= .0500

RELAXATION TIMES TAU(MU)= .3333E+00 .3333E+01 .3333E+02 .3333E+03

MAXWELL CHAIN MODULI FOR TIME RANGE FROM .100E+00 TO .631E+04 (UNITS PSI)

IA	TP(IA)	EMU(1,IA)	EMU(2,IA) ...				
1	5.000	.644E+06	.540E+06	.513E+06	.512E+06	.523E+06	.539E+06 -
2	8.891	.689E+06	.564E+06	.520E+06	.527E+06	.545E+06	.567E+06 -
3	15.811	.739E+06	.596E+06	.532E+06	.545E+06	.570E+06	.598E+06 -
4	28.117	.794E+06	.636E+06	.553E+06	.569E+06	.600E+06	.631E+06 -
5	50.000	.856E+06	.685E+06	.583E+06	.602E+06	.636E+06	.670E+06 -
6	88.914	.927E+06	.740E+06	.613E+06	.649E+06	.692E+06	.731E+06
7	158.114	.103E+07	.821E+06	.660E+06	.663E+06	.685E+06	.709E+06

TP(IA)= .500E+01 .158E+02 .500E+02 .158E+03

CREEP FUNCTION VALUES COMPUTED FROM MAXWELL CHAIN MODULI EMU

IT	T(IT)	AJ(IT,1)	AJ(IT,2) ...		
1	.100	.367E-06	.313E-06	.259E-06	.212E-06
2	.158	.380E-06	.324E-06	.268E-06	.219E-06
3	.251	.398E-06	.339E-06	.280E-06	.228E-06
4	.398	.421E-06	.358E-06	.295E-06	.240E-06
5	.631	.447E-06	.379E-06	.312E-06	.254E-06
6	1.000	.473E-06	.401E-06	.329E-06	.267E-06

17	158.483	-.00673	-.00370	-.00144	.00179
18	251.189	-.01576	-.01250	-.00985	-.00525
19	398.107	-.01397	-.01153	-.00943	-.00457
20	630.957	-.00286	-.00217	-.00148	.00274
21	1000.000	.00993	.00892	.00821	.01162
22	1584.893	.02067	.01852	.01682	.01955
23	2511.886	.03617	.03260	.02953	.03085
24	3981.072	.06465	.05833	.05251	.05079
25	6309.573	.10263	.09257	.08298	.07700

COEFF. OF VARIATION FOR THE DEVIATIONS FROM GIVEN J-VALUES IS .0238

RELAXATION TIMES :

.333E+00 .333E+01 .333E+02 .333E+03 .333E+04 .333E+05 .10

STARTING VALUES :
****

FIRST TIME STEP : .100000E+00
FIRST AGE AT LOADING : .500000E+01
FIRST RELAXATION TIME : .333333E+00

MAXWELL CHAIN DATA :
****

	MU= 1	MU= 2	MU= 3	MU= 4	MU= 5	MU= 6
ALFA-S :	.100E-04	.100E-04	.100E-04	.100E-04	.100E-04	.100E-0
TAUMU :	.333E+00	.333E+01	.333E+02	.333E+03	.333E+04	.333E+0

TIME STEPS
****

		DT	LOAD FACT	TEMP FACT
TIME STEP NO. : ,	1	.100	1.000	0.000
TIME STEP NO. : ,	2	.900	0.000	0.000
TIME STEP NO. : ,	3	9.000	0.000	0.000
TIME STEP NO. : ,	4	90.000	0.000	0.000
TIME STEP NO. : ,	5	900.000	0.000	0.000
TIME STEP NO. : ,	6	1511.886	0.000	0.000
TIME STEP NO. : ,	7	1469.186	0.000	0.000
TIME STEP NO. : ,	8	2328.591	0.000	0.000

I N I T I A L C O N D I T I O N S

D I S P L A C E M E N T S

NODE	X-DISPLACEMENT	Y-DISPLACEMENT	Z-DISPLACEMENT	X-ROT
1	0.	0.	0.	0.
2	0.	0.	0.	0.
3	0.	0.	0.	0.
4	0.	0.	0.	0.
5	0.	0.	0.	0.

TIME STEP NO. : 1
****

SIZE OF TIME STEP	:	.100
TOTAL TIME	:	.100
LOAD INCREMENT	:	1.000
TEMP. INCREMENT	:	0.000

SELECTIVE NODAL DISPLACEMENTS
****

		R-DISPLACEMENT	Z-DISPLACEMENT
NODAL POINT NO. 1	:	.733357E-02	0.
NODAL POINT NO. 2	:	.740691E-02	0.
NODAL POINT NO. 3	:	.736997E-02	-.183329E-03
NODAL POINT NO. 4	:	.733257E-02	-.367661E-03
NODAL POINT NO. 5	:	.740590E-02	-.365654E-03

SELECTIVE ELEMENT STRESSES
****

		SIGMA-R	SIGMA-Z	SIGMA-TH
ELEMENT NO. 1	:	.622E+00	-.100E+04	-.415E+00
ELEMENT NO. 2	:	.129E-02	-.100E+04	.945E-02
ELEMENT NO. 3	:	-.622E+00	-.997E+03	.415E+00
ELEMENT NO. 4	:	-.602E-03	-.100E+04	-.945E-02

SELECTIVE ELEMENT STRAINS
****

		EPS-R	EPS-Z	EPS-TH
ELEMENT NO. 1	:	.738E-04	-.368E-03	.733E-04
ELEMENT NO. 2	:	.733E-04	-.367E-03	.733E-04
ELEMENT NO. 3	:	.729E-04	-.366E-03	.733E-04
ELEMENT NO. 4	:	.733E-04	-.367E-03	.733E-04

TIME STEP NO. : 8
****

SIZE OF TIME STEP : 2328.501

TOTAL TIME : 6309.573

LOAD INCREMENT : 0.000

TEMP. INCREMENT : 0.000

P R I N T O U T F O R T I M E S T E P 8

NO EQUILIBRIUM ITERATION ON THIS TIME STEP
STIFFNESS REFORMED FOR THIS TIME STEP

D I S P L A C E M E N T S

NODE	X-DISPLACEMENT	Y-DISPLACEMENT	Z-DISPLACEMENT	X-ROT
1	0.	.257251E-01	0.	0.
2	0.	.259823E-01	0.	0.
3	0.	.258529E-01	-.643094E-03	0.
4	0.	.257217E-01	-.128951E-02	0.
5	0.	.259790E-01	-.128287E-02	0.

ELEMENT STRESSES
****

	SIGMA-R	SIGMA-Z	SIGMA-TH
ELEMENT NO. 1 :	.962E+00	-.100E+04	-.279E+00
REINF ST STR :	0.	0.	0.
ELEMENT NO. 2 :	.249E-02	-.100E+04	.881E-02
REINF ST STR :	0.	0.	0.
ELEMENT NO. 3 :	-.960E+00	-.998E+03	.279E+00
REINF ST STR :	0.	0.	0.
ELEMENT NO. 4 :	-.225E-03	-.100E+04	-.881E-02
REINF ST STR :	0.	0.	0.

ELEMENT STRAINS
****

	EPS-R	EPS-Z	EPS-TH
ELEMENT NO. 1 :	.259E-03	-.129E-02	.257E-03
ELEMENT NO. 2 :	.257E-03	-.129E-02	.257E-03
ELEMENT NO. 3 :	.259E-03	-.128E-02	.257E-03
ELEMENT NO. 4 :	.257E-03	-.129E-02	.257E-03

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COMPUTATIONAL FLOW OF ANALYSIS

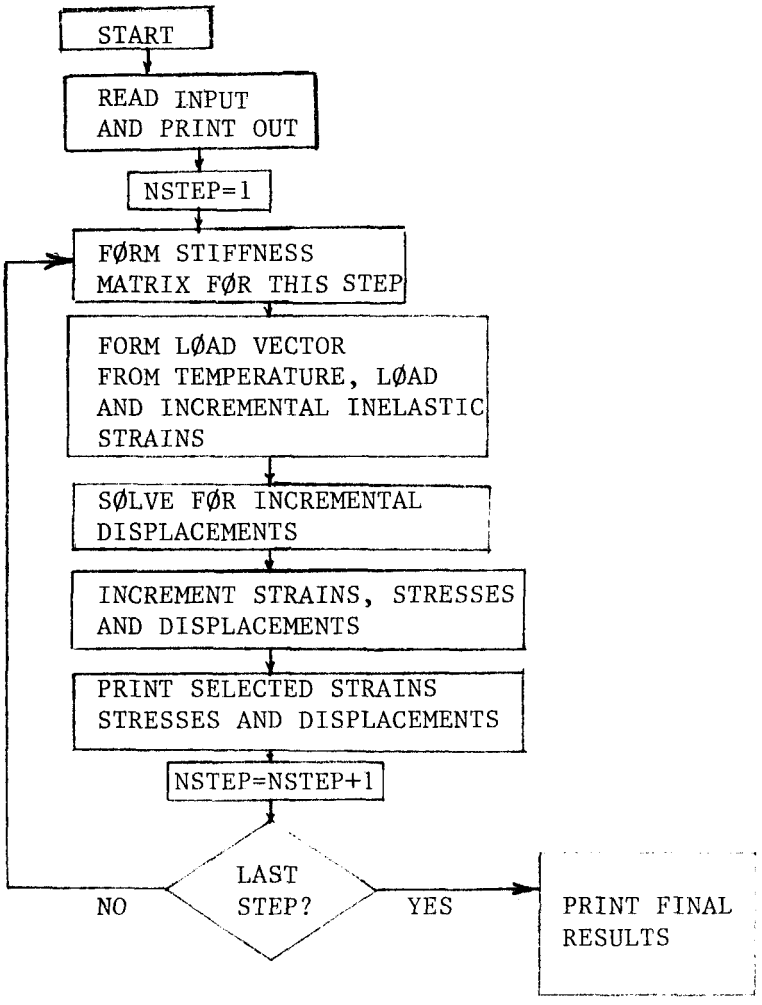

FIGURE 1

FLOW CHART

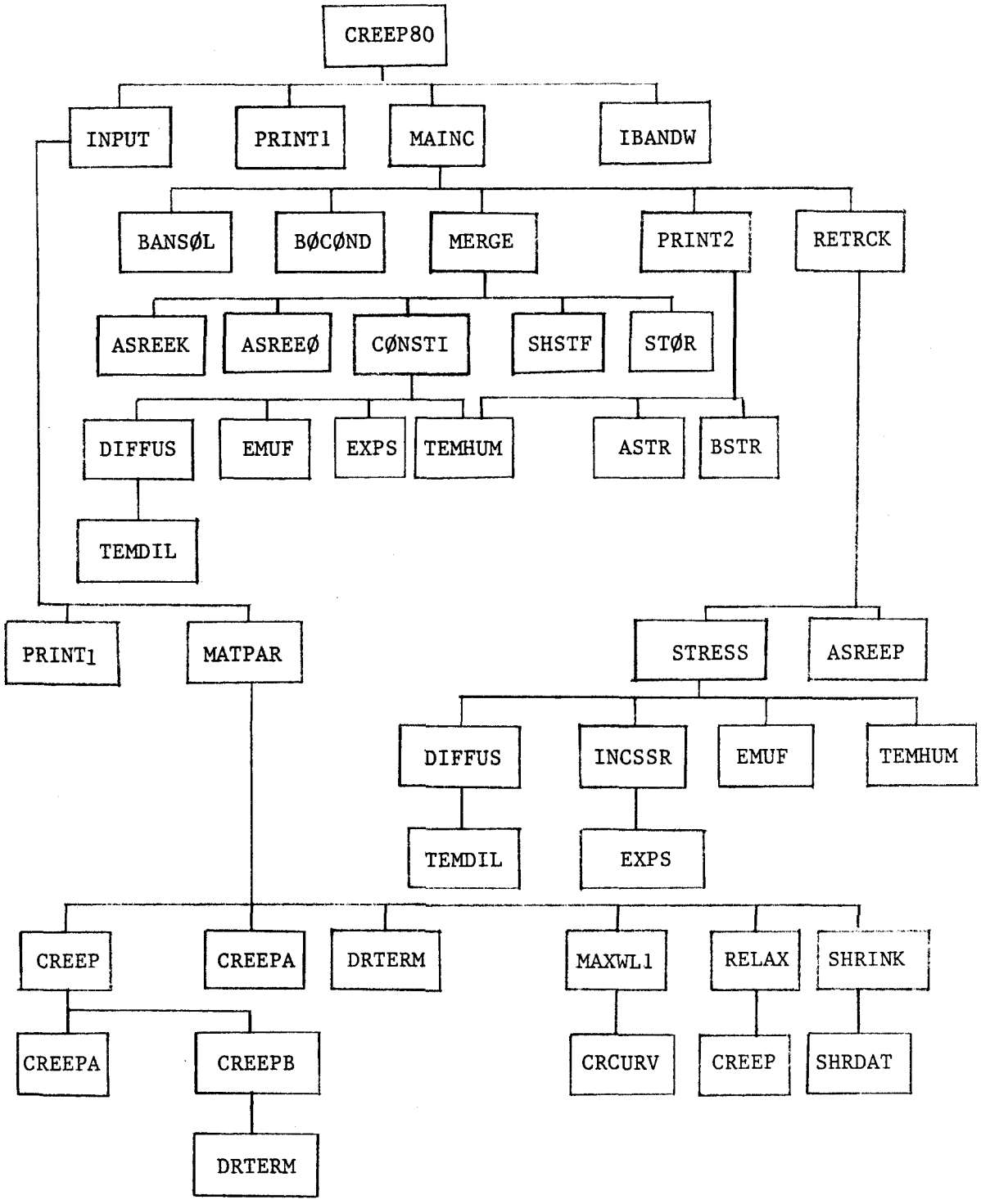

Figure 2

STORAGE ALLOCATION FOR CREEP80

1	IEG	3*NUMEL
N1	GLØBCØ	2*NUMNP
N2	IBØUND	3*NBØUND
N3	TEMP	2*NUMNP
N4	POPR	NUMNP
N5	CHDAT	20
N6	ETM	NUMEL
N7	ISE	2*(NØLE+NØBE)
N8	AREA	NØLE+NØBE
N9	CØNST	20
N10	SIGMA	28*NUMEL
N11	STRAIN	4*NUMEL
N12	ILØAD	NLØAD
N13	RLØAD	2*NLØAD
N14	DTIME	NSTEP
N15	RFAC	NSTEP
N16	TFAC	NSTEP
N17	IDIS	NDIS
N18	ISTR	NSTR
N19	IEPS	NEPS
N20	SR	NTØT
N21	SDR	NTØT
N22	RREF	NTØT
N23	B	25*NUMEL
N24	SKI	NTØT*NBAND

Figure 3

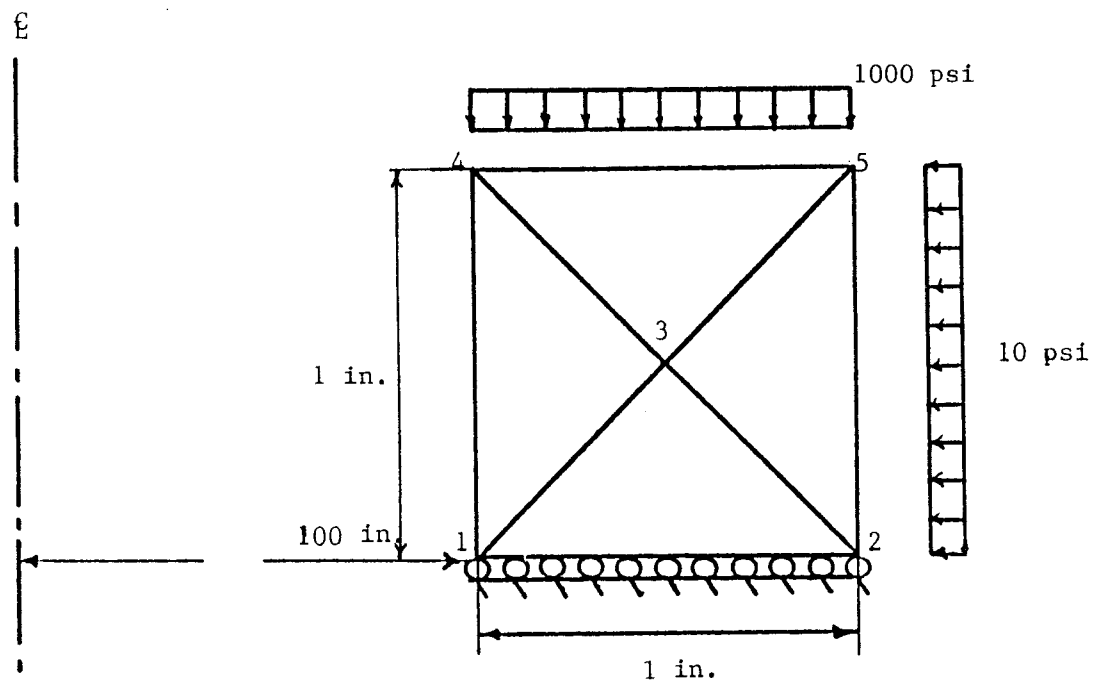

Fig. 4. Four-Element Creep Example

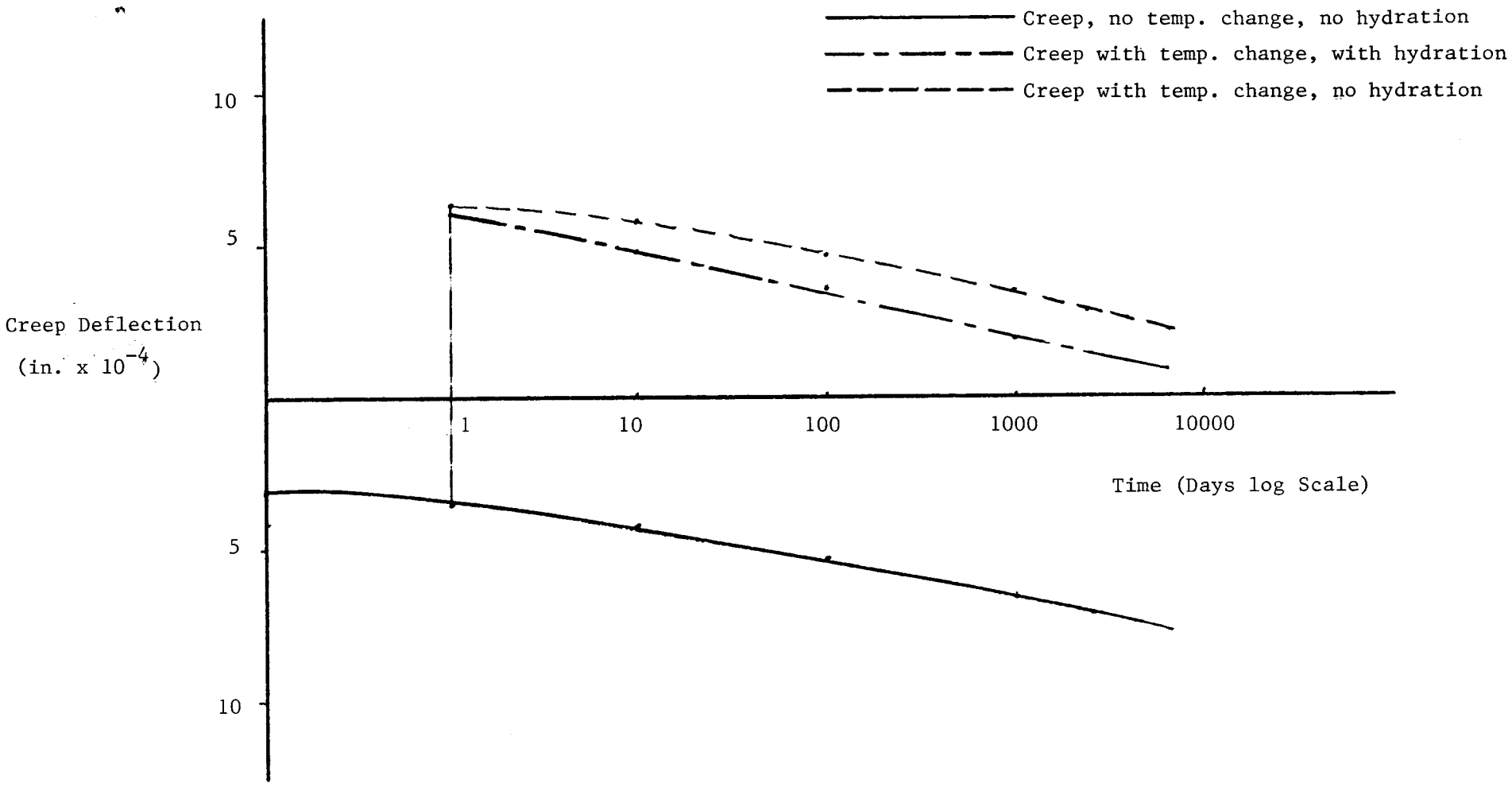

Fig. 5. Creep of Two-Element Test Problem

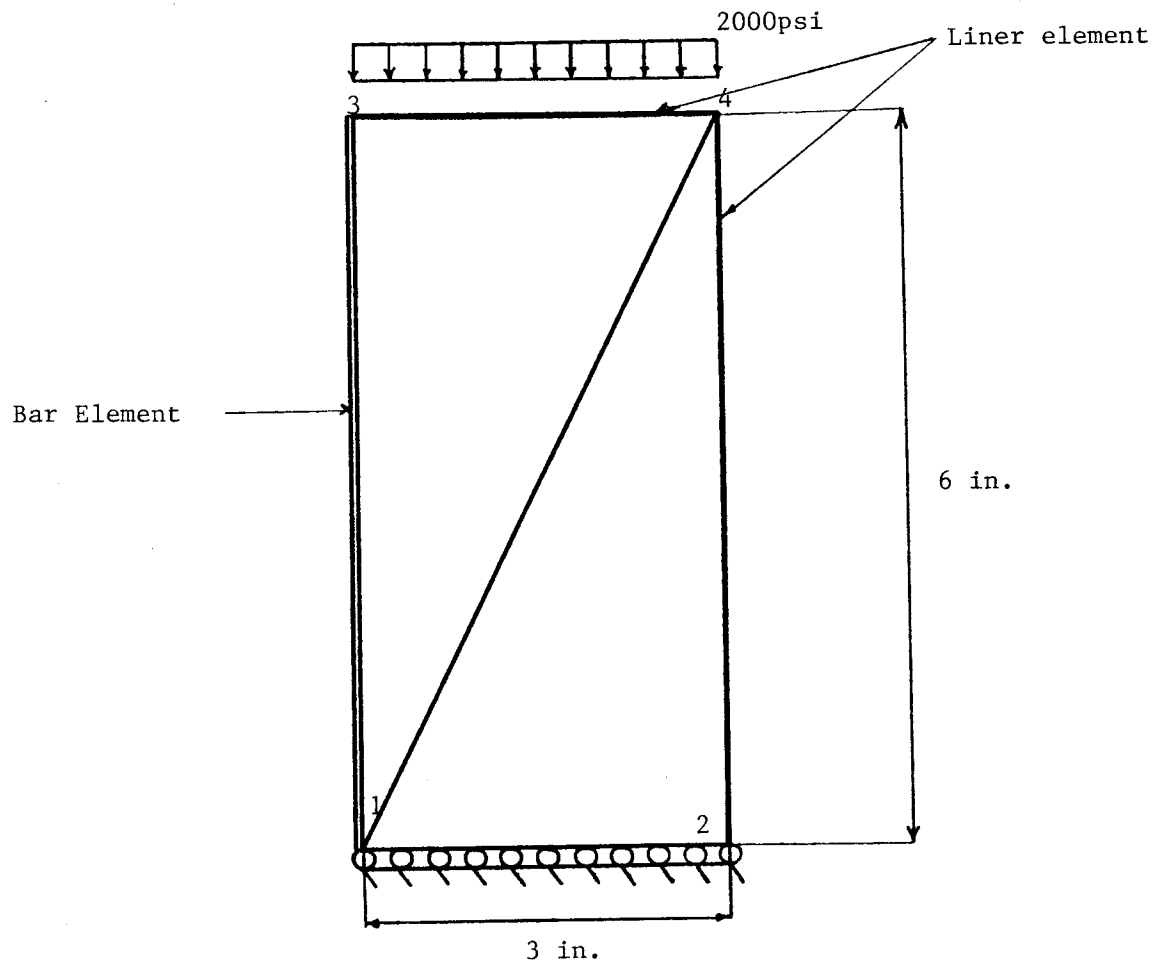

Fig. 6. Two-Element Creep Example

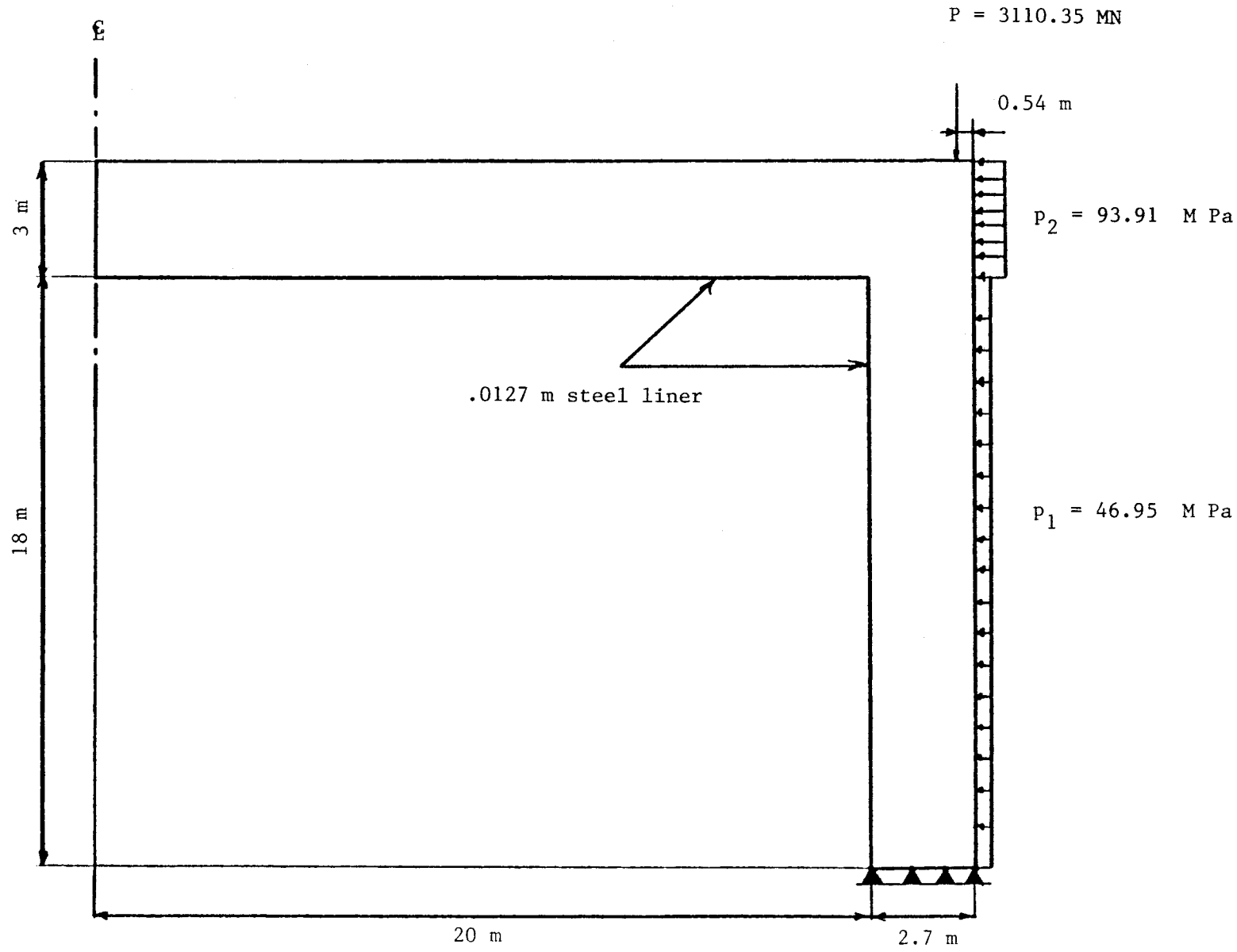

Fig 7. Cross Section of Reactor Vessel Used in the Analysis

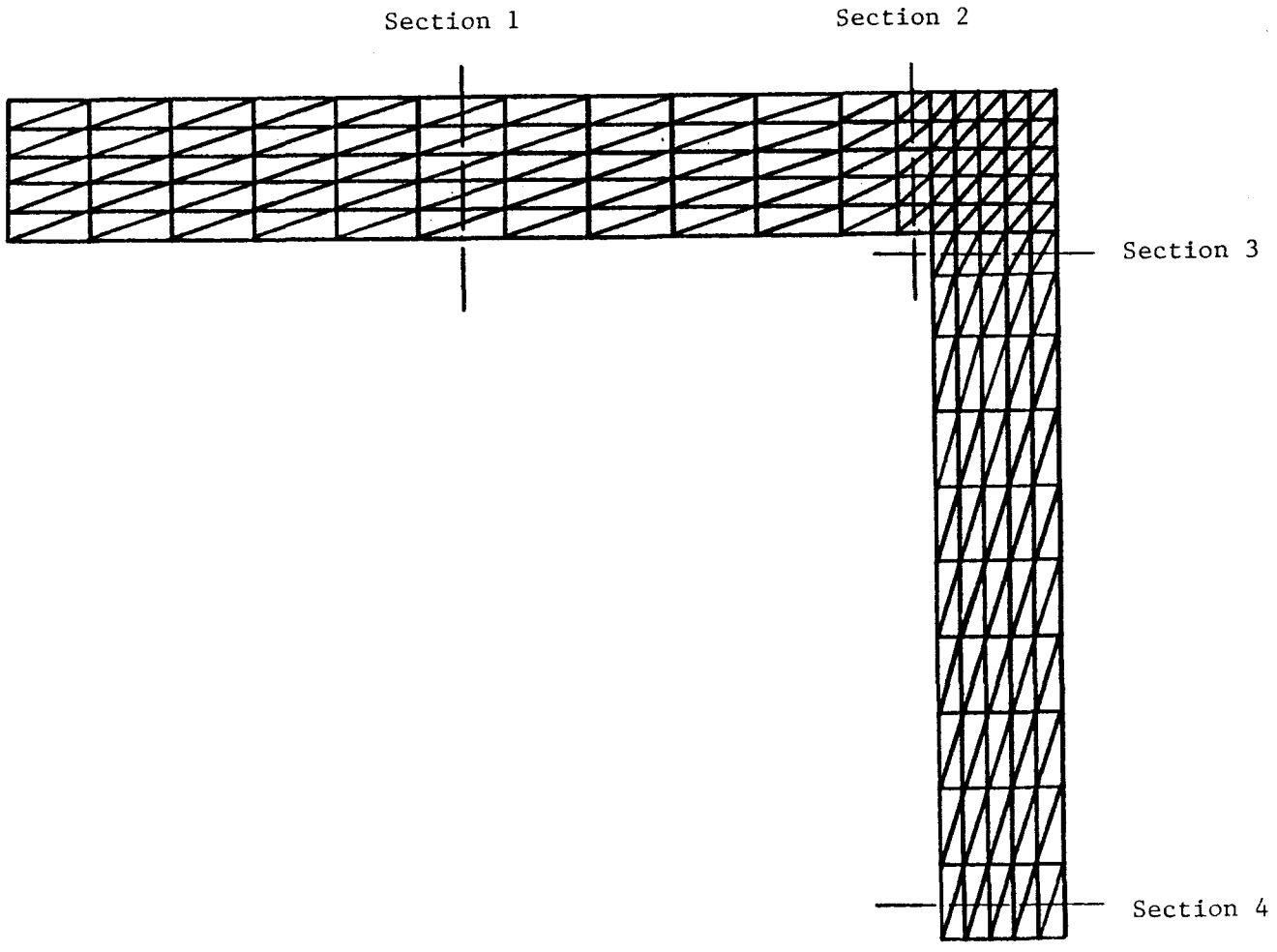

Fig. 8 Finite Element Mesh for the Reactor Vessel
(3-Node Axisymmetric Elements)

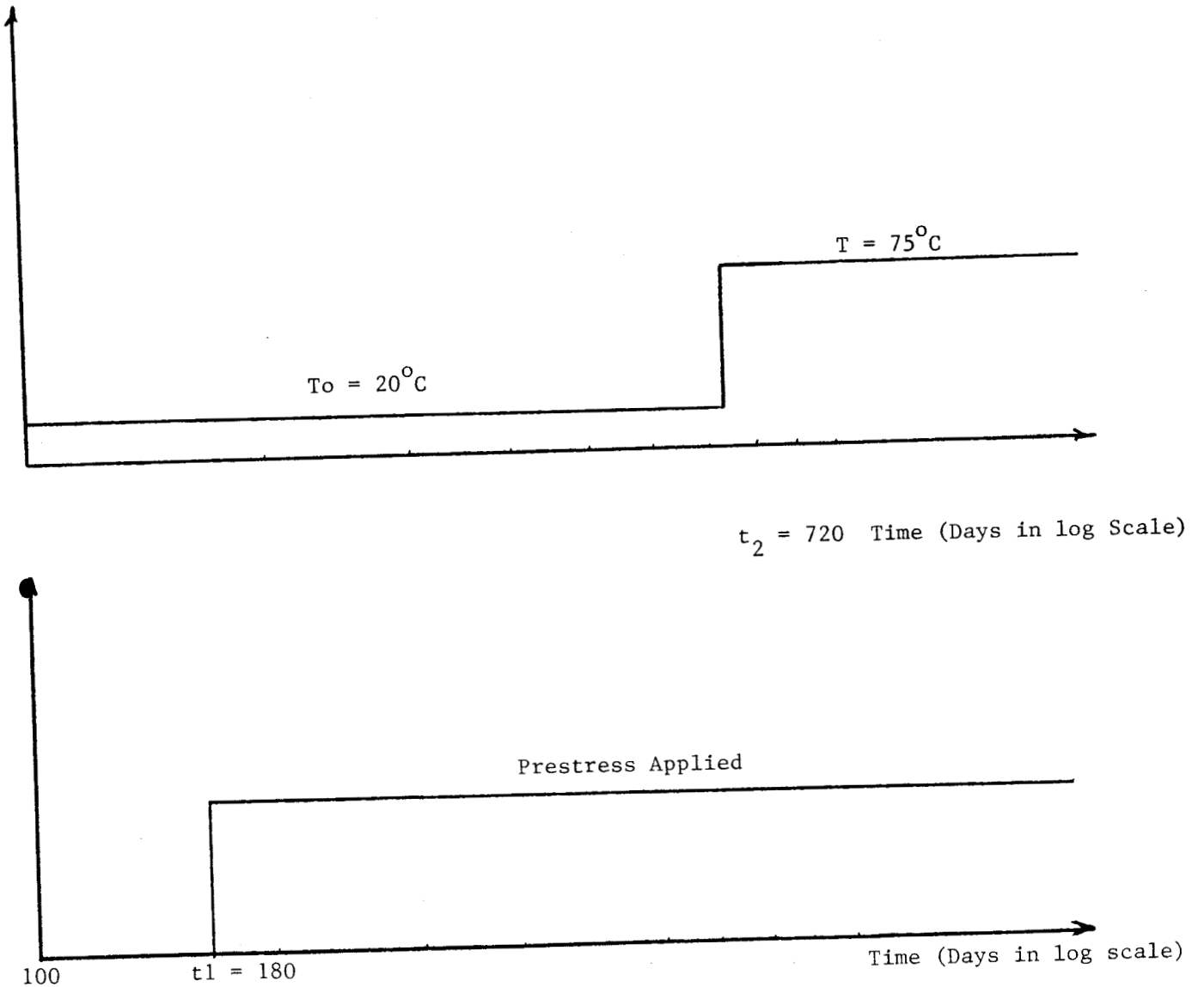

Fig. 9 Schedule of Prestressing and Heating

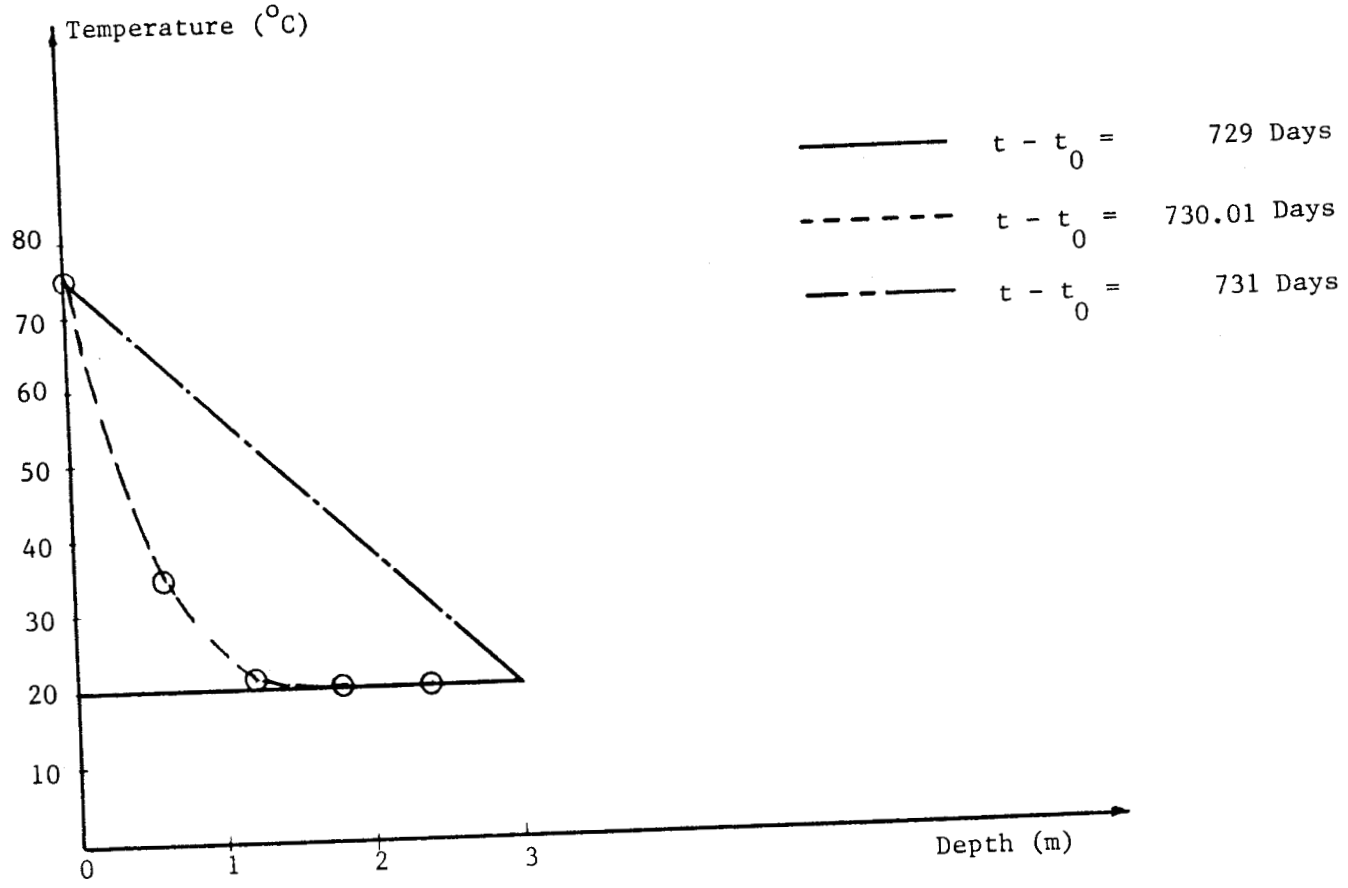

Fig. 10. Variation of Temperature Across the Depth of Concrete

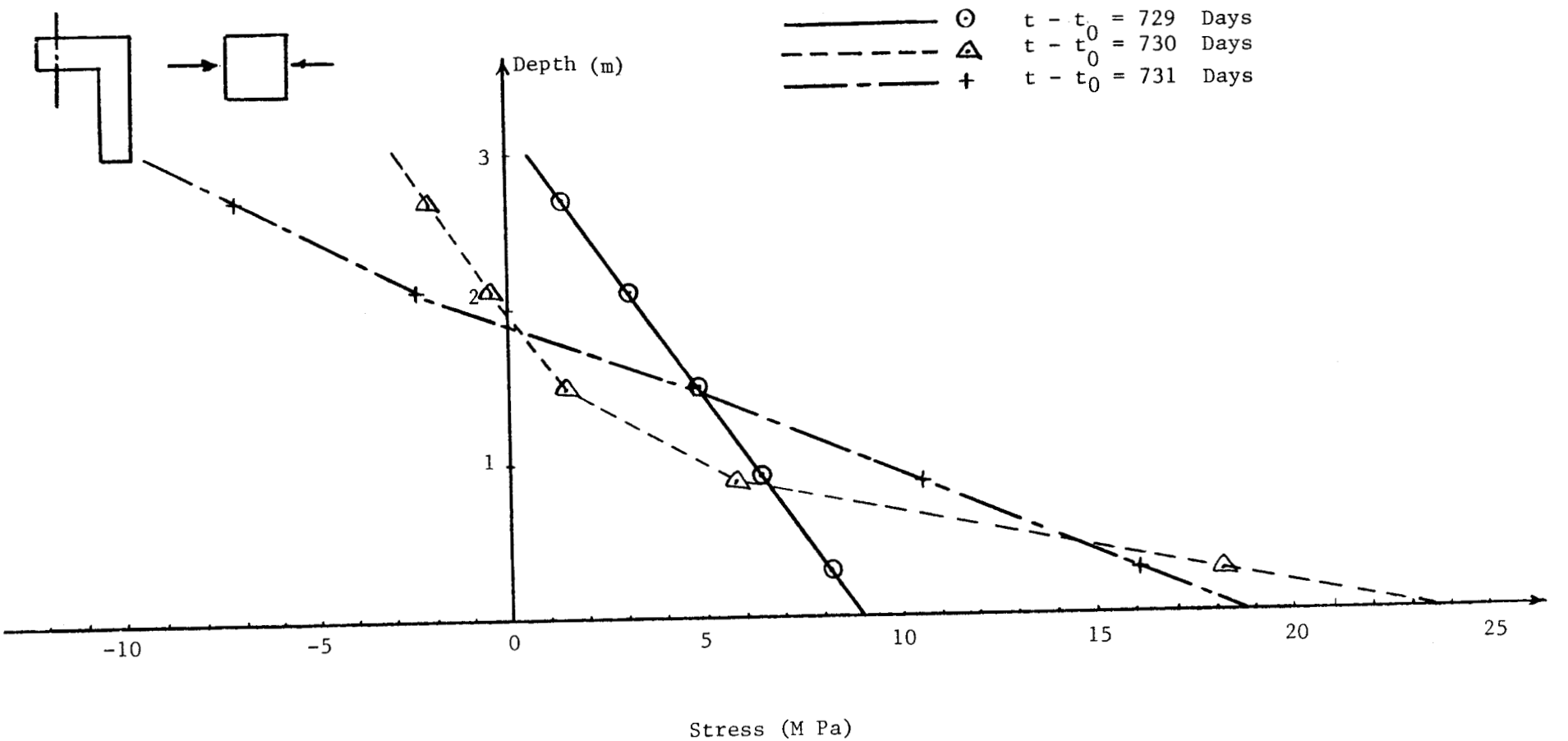

Fig. 11. Variation of Radial Stresses for Section 1

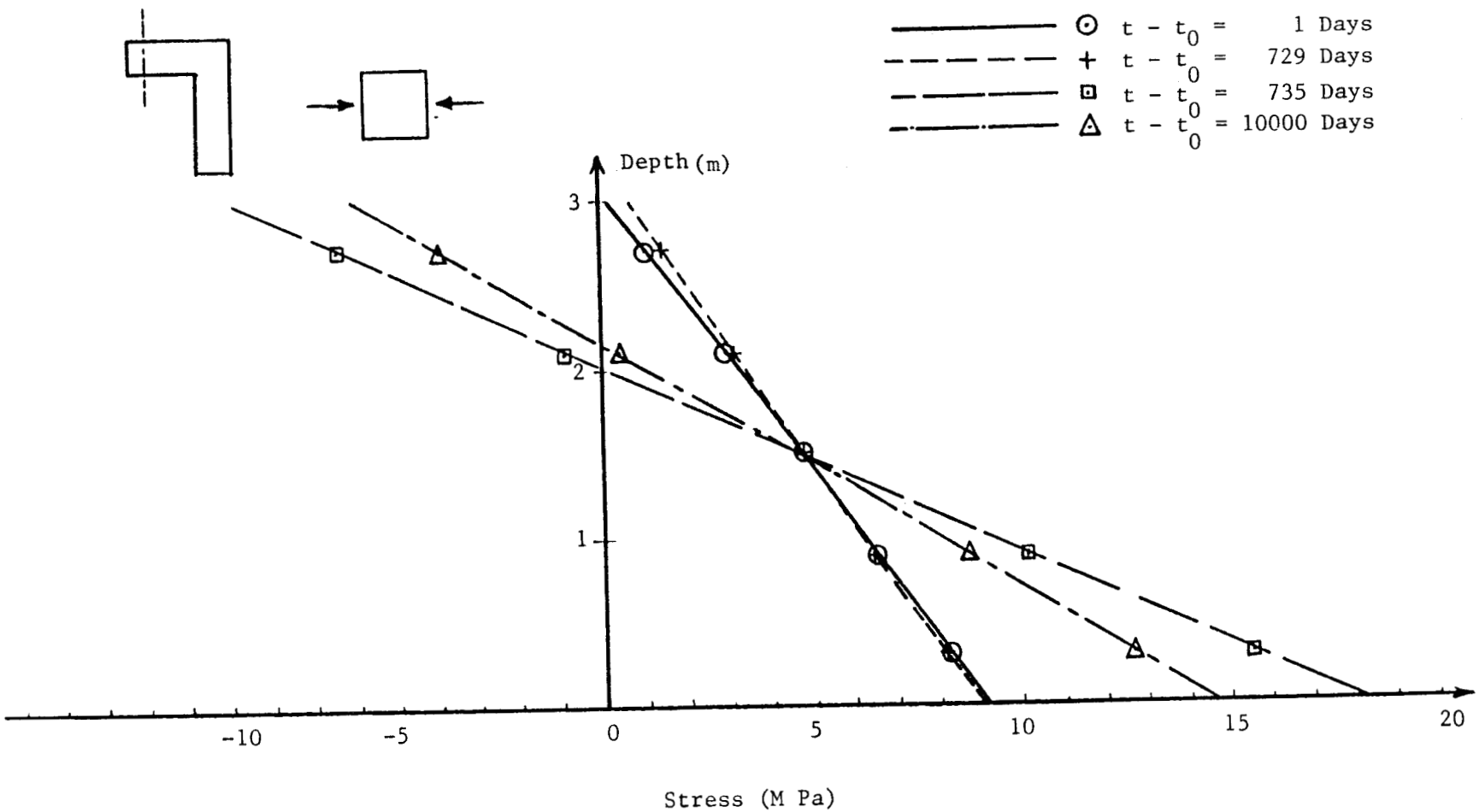

Fig. 12. Variation of Radial Stresses for Section 1

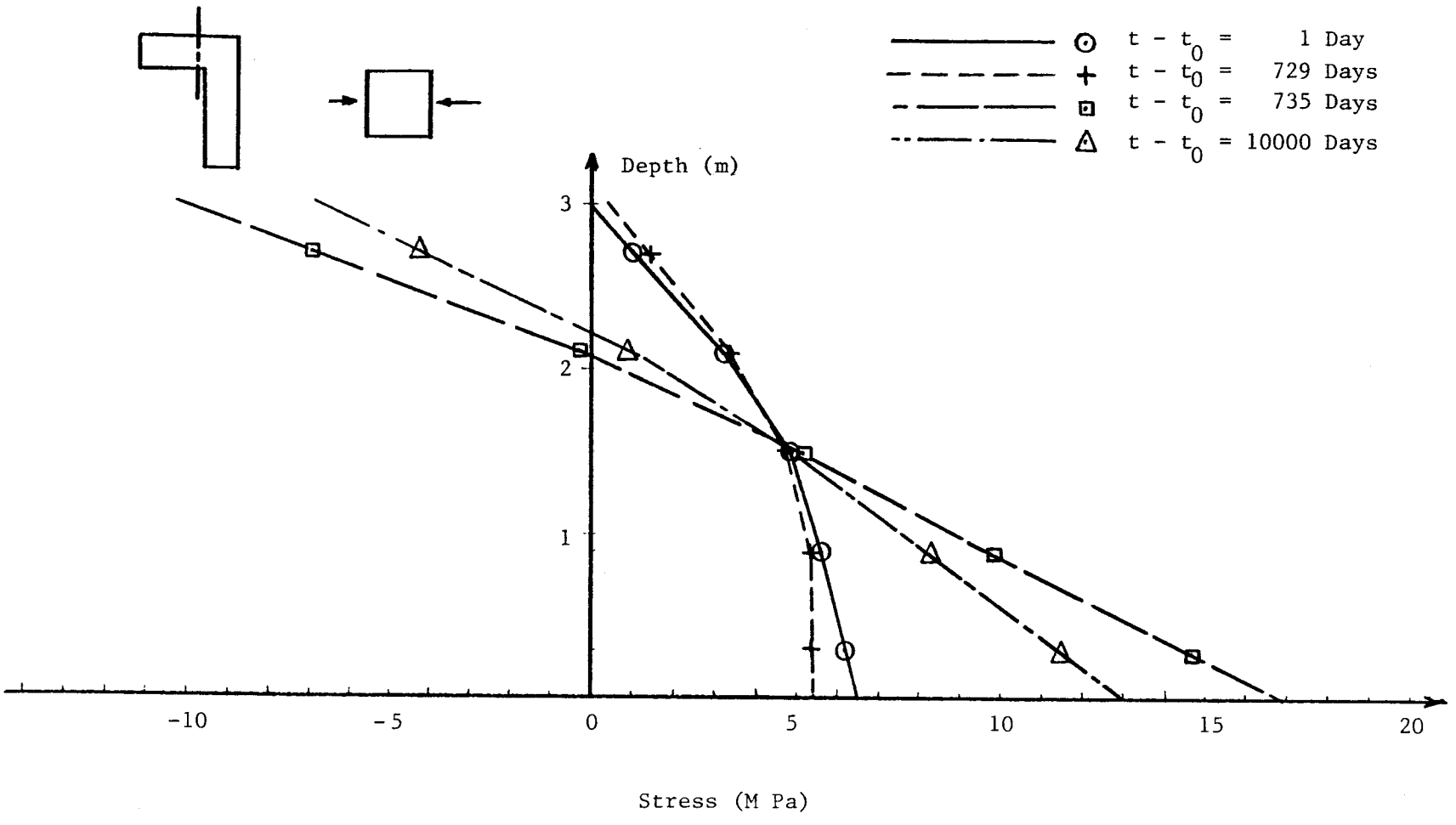

Fig. 13. Variation of Radial Stresses for Section 2

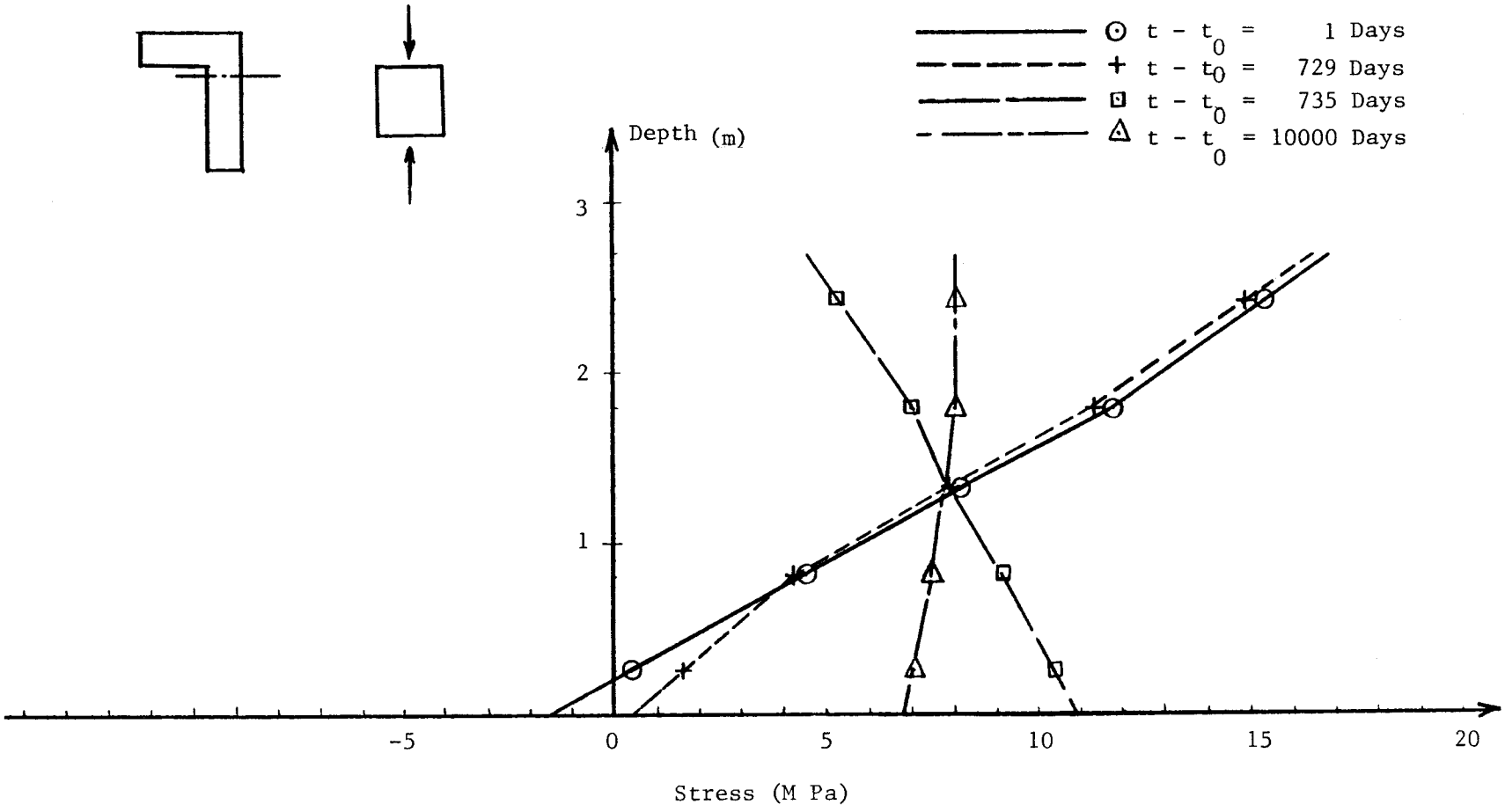

Fig. 14. Variation of Axial Stresses for Section 3

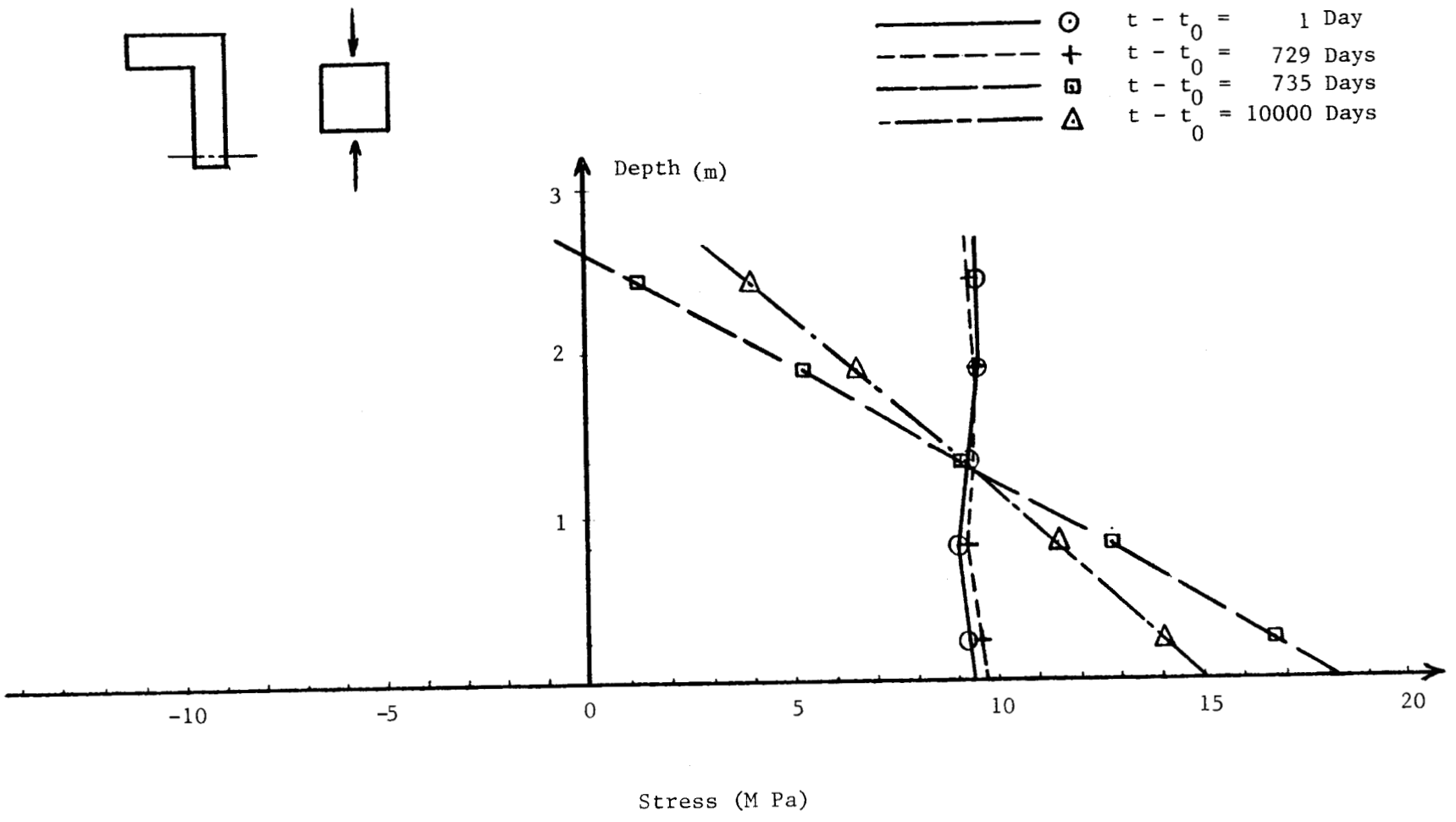

Fig. 15. Variation of Axial Stresses for Section 4

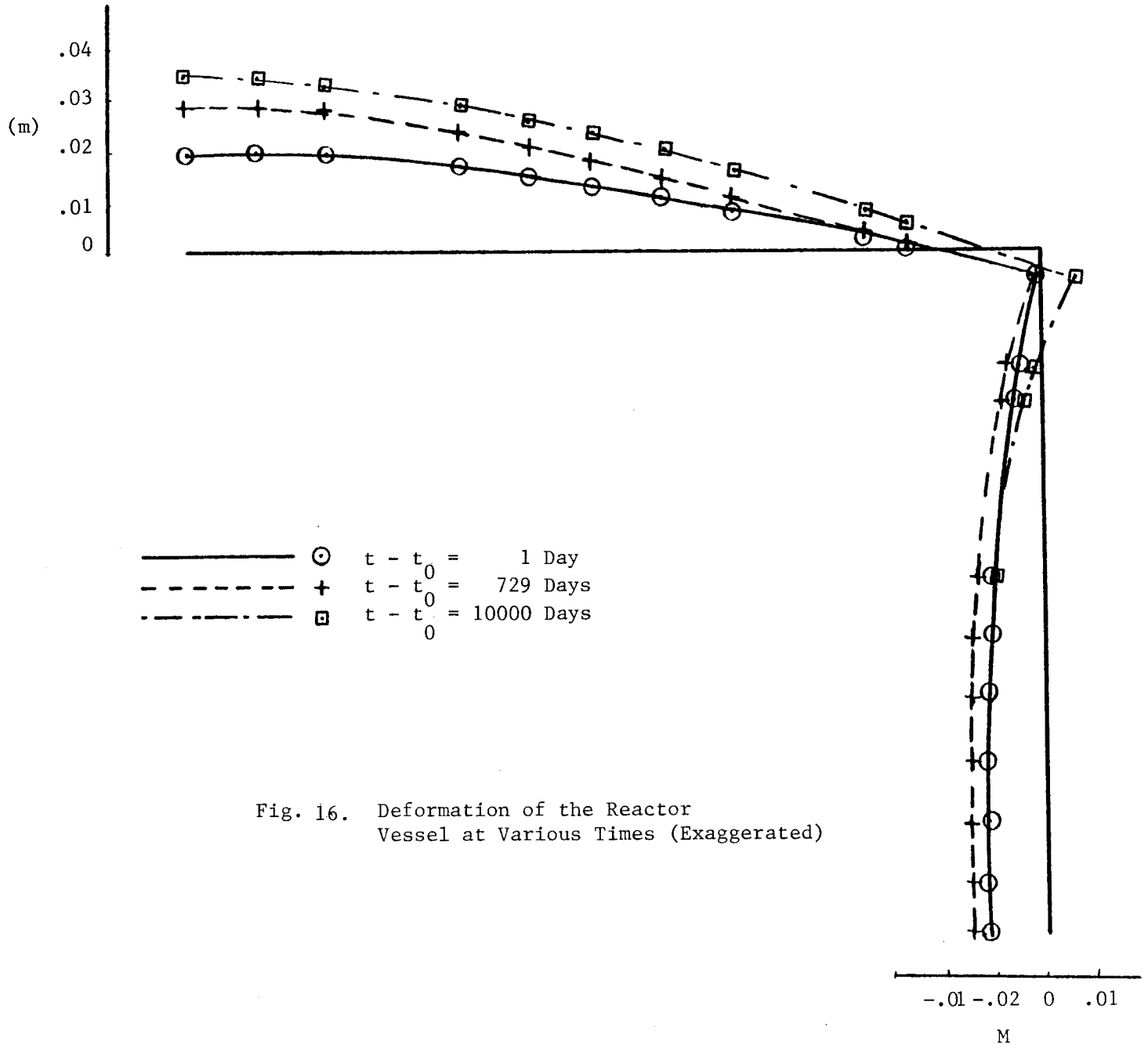

Fig. 16. Deformation of the Reactor Vessel at Various Times (Exaggerated)

MAP ØF CØMMØN FØR CREEP80 IN NØNSAP PRØGRAM

1	EMU	80
81	TPL	8
89	TP	8
97	NA	1
98	TAU	10
108	TEMPO	18
126	ICØNTR	20
146	NCØNTR	20
166	TIME	1
N101=167	IEG	3*NUMEL
N102	TEMP	2*NUMNP
N103	PØPR	NUMNP
N104	CHDAT	20
N105	ETM	NUMEL
N106	ISE	2*(NØLE + NØBE)
N107	AREA	NØLE + NØBE
N108	CØNST	20
N109	SIGMA	28*NUMEL
N110	STRAIN	4*NUMEL
N111	DTIME	NSTE
N112	RFAC	NSTE
N113	TFAC	NSTE
N114	IDIS	3*NDIS
N115	ISTR	NSTR
N116	IEPS	NEPS
N117	B	25*NUMEL
N118	RZ	6*(NUMEL + NØBE + NØLE)
N119	LM	6*(NUMEL + NØBE + NØLE)

Total Storage =
206 + 5*NUMNP +
73*NUMEL +
15*(NØLE + NØBE) +
3*(NSTE + NDIS) +
NSTR + NEPS

Total Storage $\leq$ NUMEST

Figure 17

Distribution

1. D. E. Bartine
2. J. R. Dougan
3. W. P. Eatherly
4. Uri Gat
5. A. G. Grindell
6. F. J. Homan
7-9. P. R. Kasten
10. R. E. Macpherson
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12-16. D. J. Naus
17. R. K. Nanstad
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19. P. L. Rittenhouse
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22. H. E. Trammell
23. D. B. Trauger
24. G. D. Whitman
25. R. P. Wichner
26. Laboratory Records, R. C.

External Distribution

27. G. A. Newby, Director, High-Temperature Reactor Program, Office of Nuclear Power Systems, U.S. Department of Energy, Washington, D. C. 20545

28. J. E. Fox, High-Temperature Reactor Program, Office of Nuclear Power Systems, U.S. Department of Energy, Washington, D. C. 20545

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Attention: F. E. Dearing.

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31. T. E. Northup, General Atomic Company, P. O. Box 81608, San Diego, CA 92138

32. L. E. Mears, General Manager, Gas Cooled Reactor Associates, 3344 N. Torrey Pines Court, Suite 300, La Jolla, CA 92037
Attention: H. L. Gotschall

33. G. R. Pflasterer, Energy Systems and Technology Division, General Electric Company, 310 De Guigne Drive, P. O. Box 508, Sunnyvale, CA 94086