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Yucca Mountain Site Characterization Project

HEFF—A User's Manual and Guide for the HEFF Code for Thermal-Mechanical Analysis Using the Boundary-Element Method

Version 4.1

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**HEFF-A USER'S MANUAL AND GUIDE FOR THE HEFF CODE
FOR THERMAL-MECHANICAL ANALYSIS
USING THE BOUNDARY-ELEMENT METHOD**

VERSION 4.1

by

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formerly with
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Grand Junction, CO 81506

for

Sandia National Laboratories
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ABSTRACT

The HEFF Code combines a simple boundary-element method of stress analysis with the closed form solutions for constant or exponentially decaying heat sources in an infinite elastic body to obtain an approximate method for analysis of underground excavations in a rock mass with heat generation. This manual describes the theoretical basis for the code, the code structure, model preparation, and steps taken to assure that the code correctly performs its intended functions. The material contained within the report addresses the Software Quality Assurance Requirements for the Yucca Mountain Site Characterization Project.

MASTER

This work was performed under WBS 1.2.4.2.3.1.

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1. INTRODUCTION

1.1 Description and Use

The computer program HEFF (HEAT with Fictitious Force) is a FORTRAN code based on an indirect formulation of the boundary-element method for plane strain elastic analysis. The initial conditions for such analysis are prescribed boundary tractions or displacements and self-equilibrated initial stress. Through use of a thermoelastic solution to the problem of a line heat source in an infinite elastic, isotropic medium, thermal loading can be treated as additional initial displacements and initial stresses. That allows approximate solution to thermal-mechanical problems in which the heat transfer process is transient, but the process of deformation is considered to be pseudostatic.

It is intended that the HEFF code be used for analysis of relatively simple geometric configurations in circumstances where it may be assumed that the medium is homogeneous, isotropic, linearly elastic, and with material properties that are independent of temperature. Typical applications include scoping analyses of alternative emplacement configurations for a potential nuclear waste repository. This and other applications are illustrated in Figure 1.

By virtue of its boundary-element formulation, the code is particularly well suited to solving problems involving long holes in an infinite media. Semi-infinite problems can also be treated if the appropriate boundary conditions are defined at the free surface through the use of boundary elements and image heat sources.

For the Yucca Mountain Site Characterization Project (YMP), the primary application of the HEFF code has been for performing simple scoping analyses investigating the behavior associated with different waste emplacement options, thermal loading densities, excavation shapes, and panel layout of a potential nuclear waste repository. It is anticipated that it will continue to be used for such purposes due to the simplicity of data preparation and its suitability for use on microcomputers. It is with this use in mind that this documentation, which is intended to meet the Software Quality Assurance Requirements of YMP, has been prepared. However, because HEFF is based on a boundary-element formulation

and incorporates a closed-form solution for heat sources, it represents a significant departure from other thermal and thermal-mechanical modeling capabilities utilized by the YMP. Accordingly, the HEFF may be well suited for use in the verification studies necessary in qualifying the more comprehensive computer models that will be used in the YMP project.

1.2 Background

The program HEFF was developed at the University of Minnesota during studies on numerical modeling of rock stresses within a basaltic nuclear waste repository by Hocking and St. John (1979). The program was constructed by combining the subroutine HEAT with a boundary-element stress analysis code written at the University of Minnesota and subsequently described by Crouch and Starfield (1983). HEAT was developed by Roger Hart at the University of Minnesota and was documented later by Hart (1981) and by Lindner et al. (1984). A user's manual for HEFF was prepared by Brady (1980) as part of the University of Minnesota's subcontract with Rockwell International for the Basalt Waste Isolation Project (BWIP). The present version of the code differs both numerically and cosmetically from the earlier version documented by Brady (1980). Specifically, the HEAT routine has been reprogrammed and tolerances changed significantly, a sign error in the calculation of thermal stresses was corrected, the calculation of out-of-plane stresses has been added, and thermally induced displacements have been accounted for when treating boundary elements with prescribed displacements. The cosmetic changes are intended to improve clarity of both the coding and the output.

The HEFF code has been used in both the BWIP and YMP. One example of the use of HEFF is in SAND86-7005, "Reference Thermal and Thermal/Mechanical Analysis on Drifts for Vertical and Horizontal Emplacement of Nuclear Waste in a Repository in Tuff, St. John (1987)".

1.3 Availability

The version of HEFF documented in this report is available in the public domain by virtue of this publication. An earlier public domain version was documented by Brady (1980). Participants in the YMP project can obtain copies of the code on floppy discs from SNL.

2. DESCRIPTION OF MODELS

This section of the report comprises a general description of the purpose and mathematical basis of the HEFF code. First, the overall solution strategy for thermal-mechanical analysis is described. Subsequently, the boundary-element model and the embedded heat transfer model are described in more detail.

2.1 Nature and Purpose of Analysis

The HEFF code is intended for calculating temperatures, displacements and stresses in a linear, elastic, homogeneous medium. Although finite bodies can be defined by the boundary elements, the primary purpose of the code is to solve problems involving infinite bodies with internal holes or excavations. For the purposes of analysis, such excavations are assumed to be long relative to their other dimensions, which allows a two-dimensional plane strain approximation to be made. For such problems, the initial conditions are usually the initial stress and temperature. The purpose of the analysis is to investigate the excavation-induced and thermally-induced deformation, as well as the total state of stress.

The effect of emplacement of high level nuclear waste in a potential geologic repository is to add a thermal stress to the preexisting initial stress. HEFF was developed with the intention of providing an approximate solution for the temperature, displacements, and stresses in the vicinity of the underground excavations of such a repository. The nature and consequence of the approximations, which derive from the use of a thermal model that is based on the closed-form solution for a line heat source in an infinite medium, are discussed in Sections 2.4.2 and 2.4.3 below.

2.2 Solution Strategy

The HEFF code is based on a boundary-element method that has been referred to as the fictitious stress method (Crouch and Starfield, 1983). The basic characteristics of that method can be illustrated simply by considering the analysis of an underground excavation. The cross section of such an excavation in a stressed medium is illustrated in Figure 2a. The excavation surface S may be subject to imposed tractions t_x , t_y after excavation, or may undergo excavation induced displacements u_x , u_y at any point on the surface. Also shown in Figure 2a is an infinite line heat source of intensity Q embedded in the

isotropic, elastic medium. The effect of the embedded source can be considered as additional initial stresses, and consequently, there will be corresponding induced displacements. Shown in Figure 2b is the surface S' geometrically identical to S , inscribed in a continuum that is stress-free at infinity. S' is subject to tractions, t'_x , t'_y and displacements, u'_x , u'_y . These quantities represent tractions and displacements that must be induced in an unstressed medium, subject to known thermal loading, to simulate excavation of the opening. If the solution to the problem represented by Figure 2b can be obtained, then the solution to the problem represented by Figure 2a can be obtained directly by addition of the initial stress state.

The solution to the problem represented by Figure 2b is obtained by dividing S' into a number of discrete elements, as shown in Figure 2c. For a representative element i , tractions $t_{x,i}$, $t_{y,i}$ and displacements $u_{x,i}$, $u_{y,i}$ are assumed constant over the range of the elements. For a properly posed problem, either tractions or displacements are specified on every element i . The requirement is then to use the known boundary conditions (i.e., surface values) to calculate the unknown values.

The general flow of computation within the HEFF code is illustrated schematically in Figure 3. The subroutine INCO2 is called when it is necessary to compute the influence of a boundary force on the stresses and displacements at other locations. It is within the INCO2 routine that the influence coefficients for the boundary-element procedure are developed.

The flowchart also indicates that the TEMCAL subroutine is called when the effect of embedded heat sources is to be determined. This occurs first when computing the boundary tractions equivalent to the thermal loading. Solution of the boundary-element problem leads to computation of a set of displacements and stresses that are induced by those tractions. The total deformation is equal to the sum of the displacements associated with the thermal loads plus the excavation induced displacement (the initial stresses are self-equilibrating). In contrast, the total stress is equal to the sum of the initial, thermal and induced values. Calls to TEMCAL occur whenever the displacements and stresses associated with the heat sources are required.

The assumption made in the formulation of the HEFF solution procedure is that the thermal properties of the material contained within S in Figure 2a are identical to those of the material contained within S' in Figure 2b. This also requires that no heat be extracted from within S' , so that the temperature distribution around S is identical to that around S' . The consequence of this assumption is to avoid implicit satisfaction of the thermal boundary conditions on S and to simplify considerably the numerical problem to be solved. However, it also means that it is impossible to simulate heat lost to a ventilating air stream, unless the loss can be approximated by placing a heat sink (negative source) somewhere within the excavation.

Whether or not the thermal boundary conditions on S are satisfied directly, the solution of the coupled thermal-mechanical problem is simplified considerably by noting that the thermal and mechanical processes are, in fact, only semi-coupled. That is, while heat sources generate temperature, strain, displacement, and stress fields, the imposed boundary tractions or displacements generate stress and displacement fields in the medium, but no temperature change. This condition allows the temperature distribution in the medium to be obtained directly from the heat-conduction equations.

2.3 Overall Performance

The HEFF code is based on the use of a fictitious stress method that utilizes straight line elements over which the prescribed tractions or displacements are assumed to be constant. The numerical accuracy of such a procedure is discussed in detail by Crouch and Starfield (1983), who demonstrated that the solutions obtained using constant-strength elements converge to the exact solution as the number of elements is increased. It should be noted that use of constant-strength elements necessarily introduces discontinuities in traction and displacement between adjacent elements.

The numerical solution that is employed in HEFF is generally unreliable at points within a circle of radius equal to one element length, centered at the midpoint of a boundary element. However, the solution on the boundary is accurate at the center of the element and can usually be relied upon for points along the outward normal from the center of the element, providing the other points are no closer to the element than one-half the element length.

The accuracy of thermal calculation is discussed in detail in subsequent sections. The user should be aware of the numerical limitations and approximations of those calculations, but should be more concerned by the physical approximations usually involved. These are first, that any heat source must be idealized as one or more infinite line sources, and second, that the thermo-elastic solution for each source is based on the assumption that the body is infinite. The practical implications of these approximations are that the simulated heat source is usually more concentrated than in reality and that the effect of any excavations are completely ignored when computing the temperature and thermally induced stress and displacements.

In view of the inherent physical approximations of the thermal model within the HEFF code, it is generally recommended that the code be used with circumspection when heat sources are emplaced very close to excavations. If an attempt is made to model conditions very soon after emplacement, the results are likely to be in error because the presence of the excavation may significantly perturb heat transfer in the short-term. In the longer term, when temperature gradients in the vicinity of the drift are low, acceptable results are obtained for unventilated excavations even when the sources are close to the excavation boundary. (See comparisons of HEFF and finite-element analyses reported in Section 4.)

2.4 Mechanical Submodel

The mechanical submodel, an indirect form of the boundary-element method, has been referred to as the "fictitious stress method" because it involves development of a set of boundary tractions lacking direct physical significance. The mathematical basis and a numerical implementation of the method are described in detail by Crouch and Starfield (1983). In view of the detailed nature of their presentation and the close similarities between their code TWOFS and HEFF, the description in this section is abbreviated.

2.4.1 Purpose and Scope

The purpose and scope of the mechanical submodel, the heart of the HEFF code, is to solve mixed boundary value problems involving either infinite (unbounded) or finite (bounded) elastic domains. The model is suitable for

solving problems involving creation of a cavity in an initially stressed material.

2.4.2 Mathematical Form

The boundary-element methods are based on the use of elementary solutions to problems in elastostatics. In the case of HEFF, the elementary solution is for a strip segment, in an infinite elastic solid, subjected to uniform tractions. The uniform tractions are designated $t_s = P_s$ and $t_n = P_n$, with s and n corresponding to a local coordinate-scheme with origin at the center of the element. HEFF analyzes only plane sections, so that the strip segment appears as a line and the local coordinates are as illustrated in Figure 4a. Crouch and Starfield (1983, p. 48, 49) give the displacements and stresses due to these tractions as

$$u_s = \frac{P_s}{2G} \left[(3-4\nu)f + nf_{,n} \right] + \frac{P_n}{2G} \left[-nf_{,s} \right] \quad (1)$$

$$u_n = \frac{P_s}{2G} \left[-nf_{,s} \right] + \frac{P_n}{2G} \left[(3-4\nu)f - nf_{,n} \right] \quad (2)$$

$$\sigma_{ss} = P_s \left[(3-2\nu)f_{,s} + nf_{,sn} \right] + P_n \left[2\nu f_{,n} + nf_{,nn} \right] \quad (3)$$

$$\sigma_{nn} = P_s \left[-(1-2\nu)f_{,s} - nf_{,sn} \right] + P_n \left[2(1-\nu)f_{,n} - nf_{,nn} \right] \quad (4)$$

$$\sigma_{sn} = P_s \left[2(1-\nu)f_{,n} + nf_{,nn} \right] + P_n \left[(1-2\nu)f_{,s} - nf_{,sn} \right] \quad (5)$$

in which G and ν are the elastic properties, shear modulus and Poisson's ratio, and the derivatives, $f_{,s}$, $f_{,n}$, $f_{,sn}$, etc., are defined from the following function:

$$f(s,n) = -\frac{1}{4\pi(1-\nu)} \left[n \left(\arctan \frac{n}{s-a} - \arctan \frac{n}{s+a} \right) \right] \\ - (s-a) \ln / \left[(s-a)^2 + n^2 \right] + (s+a) \ln / \left[(s+a)^2 + n^2 \right] \quad (6)$$

Further, because plane strain conditions are assumed

$$u_z = 0 \quad (7)$$

$$\sigma_{zz} = \nu(\sigma_{ss} + \sigma_{nn}) \quad (8)$$

in which z designates the out-of-plane direction.

These equations define the displacements and stresses at any point within the body due to shear and normal tractions applied on the finite segment. Since the body is assumed to be linearly elastic, the effect of applying tractions to several such segments can be obtained by superimposing individual contributions. However, the superimposition requires that the individual contributions first be expressed with reference to an appropriate coordinate system. For points in the interior of a body, that system will usually be the global Cartesian coordinate system, while for points on a specific surface it is convenient to use the local coordinate system defined earlier.

A stress boundary value problem for a cavity in an infinite medium is depicted in Figure 4b. Following the nomenclature introduced earlier, the boundary of the cavity is designated S and the local coordinates s and n are respectively tangent and normal to S . To solve this problem numerically, the boundary S is approximated by N straight line segments (Figure 4c), each of which has a length $2a_i$. If it is assumed that there are prescribed shear and normal stresses σ_{s_i} and σ_{n_i} at each segment, the problem is fully defined. In the case illustrated in Figure 4b, the cavity is subjected to an internal pressure p . This is equivalent to prescribing shear and normal tractions that are respectively zero and p .

The sole condition for solution of the static elastic problem is that all the boundary conditions are satisfied. Hence, the real problem of a cavity, or a bounded body, can be replaced by an alternative problem of an imaginary surface subjected to identical boundary conditions. This substitute problem can be solved using the relationship defined above by developing a set of tractions P_{s_i} and P_{n_i} that satisfy the stress boundary conditions σ_{s_i} and σ_{n_i} along the surface. This process can be expressed mathematically for each segment i as

$$\sigma_s^i = \sum_{j=1}^N A_{ss}^{ij} P_s^j + \sum_{j=1}^N A_{sn}^{ij} P_n^j \quad (9)$$

$$\sigma_n^i = \sum_{j=1}^N A_{ns}^{ij} P_s^j + \sum_{j=1}^N A_{nn}^{ij} P_n^j \quad (10)$$

Here, A_{ss} , A_{sn} , A_{ns} , and A_{nn} are the boundary stress influence coefficients that can be derived directly from Equations 3 through 6. Similar relationships can also be derived for the displacements

$$u_s^i = \sum_{j=1}^N B_{ss}^{ij} P_s^j + \sum_{j=1}^N B_{sn}^{ij} P_n^j \quad (11)$$

$$u_n^i = \sum_{j=1}^N B_{ns}^{ij} P_s^j + \sum_{j=1}^N B_{nn}^{ij} P_n^j \quad (12)$$

in which B_{ss} , etc. are the boundary displacement influence coefficients derivable from equations 1, 2 and 6.

In any well-posed problem for which either boundary stresses or displacements are defined for all elements, the only unknowns are the tractions P_s^i and P_n^i on the imaginary surface. The problem is reduced to developing a set of simultaneous equations in which P_s^i and P_n^i are the unknown parameters. Once these parameters are determined, equations similar to 9 through 12 can be used to compute the displacements and stresses at any sample point within the body.

2.4.3 Numerical Methods

The boundary-element method relies on development and solution of a set of influence equations. The coefficients of these influence equations are derived directly from the equations given above, with the appropriate derivatives obtained analytically by differentiation of the function $f(s,n)$. (The influence equations are detailed in Crouch and Starfield, 1983.) The influence equations are fully populated and not symmetric. In the HEFF code, the influence functions are assembled as four sets of equations or submatrices; their solution is obtained using Gaussian elimination.

2.5 Temperature and Thermal Stress Submodel

A complete closed-form solution for temperature, stress, and displacement around a continuous line heat source is presented. Both constant and exponentially decaying heat sources are considered. In the latter case, the solution is given in the form of an infinite series, but a good approximation can be obtained by using a limited number of terms. Calculations of the temperature, stresses, and displacement using the line heat source solution as it is performed within the code are also presented.

2.5.1 Purpose and Scope

The purpose and scope of the thermal and thermal stress submodel is to compute the temperatures, displacements, and stresses developed as a result of embedment of a line heat source in an infinite medium. The computed thermal stresses, displacements, or stress and displacements are additional boundary conditions for the mechanical submodel. The computed temperature, displacement, and stress are superimposed on the results of the boundary-element analysis to obtain the total thermal-mechanical response.

2.5.2 Mathematical Formulation for a Continuous Line Heat Source

A continuous line heat source, as described by Carslaw and Jaeger (1959), corresponds to the generation of heat at a prescribed rate per unit time per unit length of line. The consequent temperature changes can be derived by integrating the solution for an instantaneous line heat source. A similar procedure can be used to derive the thermal and thermal-mechanical effects of a line heat source by integrating the following solution for an instantaneous line heat pulse in an infinite medium (Nowacki, 1962)

$$T = Qe^{-r^2/4\kappa t}/(4\pi\kappa t) \quad (13)$$

$$\sigma_{rr} = GmQ(1-e^{-r^2/4\kappa t})/(\pi r^2) \quad (14)$$

$$\sigma_{\theta\theta} = GmQ \left[(1+2r^2/4\kappa t)e^{-r^2/4\kappa t} - 1 \right] / (\pi r^2) \quad (15)$$

$$u_r = mQ(1-e^{-r^2/4\kappa t})/(2\pi r) \quad (16)$$

Compressive stresses are considered to be positive in these equations, in which:

T = temperature change

Q = heat strength, or heat generation divided by the heat capacity of the medium

κ = diffusivity

t = time

r = radial distance

G = shear modulus

$m = \left(\frac{1+\nu}{1-\nu}\right)\alpha$

α = thermal expansion coefficient

ν = Poisson's ratio

As for the mechanical submodel, the out-of-plane displacement and stress are derived directly from the plane strain condition, i.e.

$$u_z = 0 \quad (17)$$

$$\sigma_{zz} = \nu(\sigma_{rr} + \sigma_{\theta\theta}) + E\alpha T \quad (18)$$

Upon integration with respect to time, these equations become

$$T = \frac{1}{4\pi\kappa} \int_0^t \phi(\tau) e^{-r^2/4\kappa(t-\tau)} / (t-\tau) d\tau \quad (19)$$

$$\sigma_{rr} = \frac{Gm}{\pi r^2} \int_0^t \phi(\tau) \left[1 - e^{-r^2/4\kappa(t-\tau)} \right] d\tau \quad (20)$$

$$\sigma_{\theta\theta} = \frac{Gm}{\pi r^2} \int_0^t \phi(\tau) \left[\left(1 + \frac{2r^2}{4\kappa(t-\tau)} \right) e^{-r^2/4\kappa(t-\tau)} - 1 \right] d\tau \quad (21)$$

$$u_r = \frac{m}{2\pi r} \int_0^t \phi(\tau) \left[1 - e^{-r^2/4\kappa(t-\tau)} \right] d\tau$$

in which $\phi(\tau)$ describes the time dependency of the heat generation.

To solve these equations, for either a constant or time-varying heat source, three integrals must be evaluated

$$I_1 = \int_0^t \phi(\tau) d\tau \quad (22)$$

$$I_2 = \int_0^t \phi(\tau) \frac{e^{-r^2/4\kappa(t-\tau)}}{t-\tau} d\tau \quad (23)$$

$$I_3 = \int_0^t \phi(\tau) e^{-r^2/4\kappa(t-\tau)} d\tau \quad (24)$$

Evaluation of these integrals for a constant strength heat source is straightforward. If the heat is generated at a constant rate, $\phi(\tau)$ is constant and equal to Q_0 . Note that Q_0 is the heat power per unit length divided by the heat capacity. The integral I_1 is then

$$I_1 = Q_0 t \quad (25)$$

Integral I_2 , upon making the substitution $u = r^2/4\kappa(t-\tau)$, becomes

$$I_2 = Q_0 \int_{\frac{r^2}{4\kappa t}}^{\infty} \frac{e^{-u}}{u} du \quad (26)$$

I_2 is now in the form of the exponential integral ($Ei(u)$) and can be written

$$I_2 = -Q_0 Ei\left(\frac{-r^2}{4\kappa t}\right) \quad (27)$$

The basic properties of the exponential integral are described by Gautschi and Cahill (1980). Its evaluation within HEFF is described in Section 2.5.4.

The integral I_3 can be obtained in a manner similar to that for I_2 . Again substituting $u = r^2/4\kappa(t-\tau)$, I_3 becomes

$$I_3 = \frac{Q_0 r^2}{4\kappa} \int_{\frac{r^2}{4\kappa t}}^{\infty} \frac{e^{-u}}{u^2} du \quad (28)$$

Integrating by parts and using the solution to I_2

$$I_3 = \frac{Q_o r^2}{4\kappa} \left[\frac{e^{-r^2/4\kappa t}}{r^2/4\kappa t} + \text{Ei}\left(\frac{-r^2}{4\kappa t}\right) \right] \quad (29)$$

Equations 25, 27, and 29 can now be used to give the solutions for temperature, stress, and displacement induced by a constant line heat source.

$$T = \frac{-Q_o}{4\pi\kappa} \text{Ei}\left(\frac{-r^2}{4\kappa t}\right) \quad (30)$$

$$\sigma_{rr} = \frac{Q_o G_m}{\pi r^2} \left\{ t - \frac{r^2}{4\kappa} \left[\frac{e^{-r^2/4\kappa t}}{r^2/4\kappa t} + \text{Ei}\left(\frac{-r^2}{4\kappa t}\right) \right] \right\} \quad (31)$$

$$\sigma_{\theta\theta} = \frac{Q_o G_m}{\pi r^2} \left\{ t e^{-r^2/4\kappa t} - \frac{r^2}{4\kappa} \text{Ei}\left(\frac{-r^2}{4\kappa t}\right) - t \right\} \quad (32)$$

$$u_r = \frac{mQ_o}{2\pi r} \left\{ t - \frac{r^2}{4\kappa} \left[\frac{e^{-r^2/4\kappa t}}{r^2/4\kappa t} + \text{Ei}\left(\frac{-r^2}{4\kappa t}\right) \right] \right\} \quad (33)$$

2.5.3 Mathematical Formulation for an Exponentially Decaying Heat Source

Within HEFF, the case of a time-varying heat source is defined as the sum of several components, which may be either constant or exponentially decaying. This composition can be expressed by

$$\phi(\tau) = Q_{o_c} + Q_{o_d} \sum_{j=1}^n q_j e^{-\lambda_j \tau} \quad (34)$$

in which Q_{o_c} is the strength of the constant part, Q_{o_d} is the initial strength of the decaying part (at time $\tau = 0$), and q_j and λ_j are respectively the proportion and decay rate of each of the n decaying components used to describe the time variation. Clearly

$$\sum_{j=1}^n q_j = 1 \quad (35)$$

if Q_{o_d} is the initial strength of the combined decaying components.

In this section, the temperature, displacements, and stresses induced by a single decaying component characterized by an initial strength Q_0 and decay rate λ are defined. Note that the rate of decay can be alternatively characterized by the half-life of the source. For example, a decay rate of 0.03466/year corresponds to a half-life of 20 years. The number of half-lives a heat source has decayed at a given time t is equal to $\lambda t / \ln 2$.

As for the constant source, derivation of the necessary equations to define the induced temperature, displacement, and stress involves evaluation of the three integrals I_1 , I_2 , and I_3 . As before, the integral I_1 can be evaluated directly. Its solution is:

$$I_1 = Q_0 \left(\frac{1 - e^{-\lambda t}}{\lambda} \right) \quad (36)$$

The evaluation of integrals I_2 and I_3 is somewhat more involved, but they can be treated as functions of the exponential integral.

Integral I_2 can be written

$$I_2 = Q_0 \int_0^t \frac{e^{-\lambda \tau - r^2/4\kappa(t-\tau)}}{t - \tau} d\tau \quad (37)$$

Substituting $u = r^2/4\kappa(t-\tau)$, yields

$$I_2 = Q_0 e^{-\lambda t} \int_{\frac{r^2}{4\kappa t}}^{\infty} \frac{e^{-u}}{u} e^{\lambda r^2/4\kappa u} du \quad (38)$$

By making a Taylor's Series expansion of the exponential term containing $\frac{\lambda r^2}{4\kappa u}$, I_2 becomes

$$I_2 = Q_0 e^{-\lambda t} \int_{\frac{r^2}{4\kappa t}}^{\infty} \frac{e^{-u}}{u} \left[1 + \frac{\lambda r^2}{4\kappa} \frac{1}{u} + \lambda^2 \left(\frac{r^2}{4\kappa} \right)^2 \left(\frac{1}{u^2} \right) + \lambda^3 \left(\frac{r^2}{4\kappa} \right)^3 \left(\frac{1}{u^3} \right) + \dots \right] du \quad (39)$$

or

$$I_2 = Q_0 e^{-\lambda t} \left[\int_{\frac{r^2}{4\kappa t}}^{\infty} \frac{e^{-u}}{u} du + \sum_{n=2}^{\infty} \frac{\lambda^{n-1} \left(\frac{r^2}{4\kappa}\right)^{n-1}}{(n-1)!} \int_{\frac{r^2}{4\kappa t}}^{\infty} \frac{e^{-u}}{u^n} du \right] \quad (40)$$

Integration by parts can be performed on each integral in the summation. Gradshteyn and Ryzhik (1980) give a solution to integrals of this form as

$$\int \frac{e^{ax}}{x^n} dx = -e^{ax} \sum_{k=1}^{n-1} \frac{a^{k-1}}{(n-1)(n-2)\cdots(n-k)} + \frac{a^{n-1}}{(n-1)!} \text{Ei}(ax) \quad (41)$$

Letting $a = -1$ and solving between the limits of integration $r^2/4\kappa t$ and ∞ , I_2 becomes

$$I_2 = Q_0 e^{-\lambda t} \left\{ -\text{Ei}\left(\frac{r^2}{4\kappa t}\right) + \sum_{n=2}^{\infty} A \left[e^{-r^2/4\kappa t} \sum_{k=1}^{n-1} B - \frac{(-1)^{n-1}}{(n-1)!} \text{Ei}\left(\frac{-r^2}{4\kappa t}\right) \right] \right\} \quad (42)$$

where

$$A = \frac{\lambda^{n-1} \left(\frac{r^2}{4\kappa}\right)^{n-1}}{(n-1)!} \quad \text{and} \quad B = \frac{(-1)^{k-1}}{(n-1)(n-2)\cdots(n-k) \left(\frac{r^2}{4\kappa t}\right)^{n-k}}$$

The evaluation of integral I_3 for an exponentially decaying function is solved in the same way as that for integral I_2 . Making the same substitution and using a Taylor's Series expansion, as before, I_3 becomes

$$I_3 = Q_0 e^{-\lambda t} \sum_{n=2}^{\infty} \frac{\lambda^{n-2} \left(\frac{r^2}{4\kappa}\right)^{n-1}}{(n-2)!} \int_{\frac{r^2}{4\kappa t}}^{\infty} \frac{e^{-u}}{u^n} du \quad (43)$$

I_3 is now in the same form as I_2

$$I_3 = Q_0 e^{-\lambda t} \sum_{n=2}^{\infty} C \left[e^{-r^2/4\kappa t} \sum_{k=1}^{n-1} B - \frac{(-1)^{n-1}}{(n-1)!} \text{Ei}\left(\frac{-r^2}{4\kappa t}\right) \right] \quad (44)$$

where

$$C = \frac{\lambda^{n-2} \left(\frac{r^2}{4\kappa}\right)^{n-1}}{(n-2)!}$$

Equations 36, 42, and 44 can now be used to give the solutions for temperature, stress, and displacement induced by a exponentially decaying line heat source.

$$T = \frac{Q_0 e^{-\lambda t}}{4\pi\kappa} \left\{ -\text{Ei}\left(\frac{r^2}{4\kappa t}\right) + \sum_{n=2}^{\infty} A \left[e^{-r^2/4\kappa t} \sum_{k=1}^{n-1} B - \frac{(-1)^{n-1}}{(n-1)!} \text{Ei}\left(\frac{-r^2}{4\kappa t}\right) \right] \right\} \quad (45)$$

$$\sigma_{rr} = \frac{Q_0 G_m}{\pi r^2} \left\{ \frac{1-e^{-\lambda t}}{\lambda} - e^{-\lambda t} \sum_{n=2}^{\infty} C \left[e^{-r^2/4\kappa t} \sum_{k=1}^{n-1} B - \frac{(-1)^{n-1}}{(n-1)!} \text{Ei}\left(\frac{-r^2}{4\kappa t}\right) \right] \right\} \quad (46)$$

$$\sigma_{\theta\theta} = \frac{Q_0 G_m}{\pi r^2} \left\{ -\frac{1-e^{-\lambda t}}{\lambda} - e^{-\lambda t} \frac{2r^2}{4\kappa} \text{Ei}\left(\frac{-r^2}{4\kappa t}\right) + e^{-\lambda t} \sum_{n=2}^{\infty} \left(C + 2 \frac{r^2}{4\kappa} A \right) \left[e^{-r^2/4\kappa t} \sum_{k=1}^{n-1} B - \frac{(-1)^{n-1}}{(n-1)!} \text{Ei}\left(\frac{-r^2}{4\kappa t}\right) \right] \right\} \quad (47)$$

$$u_r = \frac{Q_0 m}{2\pi r} \left\{ \frac{1-e^{-\lambda t}}{\lambda} - e^{-\lambda t} \sum_{n=2}^{\infty} C \left[e^{-r^2/4\kappa t} \sum_{k=1}^{n-1} B - \frac{(-1)^{n-1}}{(n-1)!} \text{Ei}\left(\frac{-r^2}{4\kappa t}\right) \right] \right\} \quad (48)$$

The out-of-plane displacement and stress were given by Equations 17 and 18.

2.5.4 Numerical Methods

The solution for both constant and exponentially decaying heat sources involves the exponential integral. This may be approximated by an infinite series expansion given by Gautschi and Cahill (1980)

$$-\text{Ei}(-x) = \gamma + \ln(x) + \sum_{n=1}^{\infty} \frac{(-1)^n x^n}{n \cdot n!} \quad (49)$$

in which γ = Euler's constant (0.5772).

This function is shown graphically in Figure 5, where $XB = r^2/4\kappa t$ is the variable of the exponential integral function $\text{Ei}(-XB)$. $\text{Ei}(-XB)$ decreases monotonically from the value $\text{Ei}(0) = \infty$ to the value $\text{Ei}(-\infty) = 0$. Series expansions for $\text{Ei}(-XB)$ are also plotted on the figure for 5, 7, and 11 terms in the expansion. For 7 terms in the expansion, for example, the function decreases correctly until $XB = 2$, but then begins to diverge from the correct value. Additional terms are required to provide an acceptable approximation as the argument is increased.

Alternatively, for larger values of x , the following inequality (Gautschi and Cahill, 1980) can be used

$$\frac{1}{2} \ln(1+\frac{2}{x}) < -e^x \text{Ei}(-x) < \ln(1+\frac{1}{x})$$

For large x , the inequality approaches

$$-\text{Ei}(-x) = \frac{e^{-x}}{x} \quad (50)$$

With a correction factor, the approximation to $\text{Ei}(-x)$ is

$$-\text{Ei}(-x) = \frac{e^{-x}}{x} \left(1 - \frac{3}{4x} + \frac{5}{6x^2} - \frac{9}{8x^3} + \frac{17}{10x^4} \right) \quad (51)$$

Values of the function were calculated using Equations 49 and 51 for a given range of the argument and several values of n , the number of terms in the infinite series expansion. Those tests revealed that an acceptable approximation was achieved if Equation 49, with 15 terms, is used in the range $0 < x \leq 4$ and Equation 51 for $x > 4$. Comparison between this numerical approximation and values tabulated in Gautschi and Cahill (1980) is provided in Table 1.

2.5.5 Implementation

A computer subroutine is used to calculate the temperature, stresses, and displacements using the closed-form solutions developed for both the constant and exponentially decaying line heat sources. A flowchart outlining the coding is provided in Figure 6.

The program first checks for excessively large values of the dimensionless parameters $r^2/4\kappa t$. If this exceeds 50, then it is assumed that the induced temperature and stress at the sample point of concern are insignificant. This dimensionless number has been selected based on experience and has been acceptable for most cases. In problems involving many heat sources, their accumulated contribution at a significant distance may be significant, requiring the numerical limit of 50 be increased. There is no known algorithm to test for significance in this case. The exponential integral is evaluated next, using the procedure discussed in Section 2.5.4. Thereafter, either the exponentially decaying heat source solution or the constant heat source solution is selected.

Choice of a zero decay rate will automatically result in use of a constant source. In principal, the same result could be obtained using the exponential solution with a very small value for the decay rate. However, experience has indicated that numerical instabilities can develop in the exponentially decaying heat source solution for values of λt less than 10^{-10} . To avoid such difficulties, the constant source solution is used for λt less than 10^{-10} and appears to provide acceptable results.

For the exponentially decaying heat source solution, individual terms of the series expansion are calculated and then the convergence of the series is checked. A study of the temperature, radial, and tangential stress displacement showed that the radial stress converges slowly and in a more predictable manner than the tangential stress. Therefore, the number of terms used in the series is determined by a tolerance set for the radial stress. For the implementation used in HEFF, a tolerance of $1 * 10^{-6}$ of the initial radial stress terms has been used and appears to provide good accuracy. To eliminate unnecessary calculation and avoid numerical underflow, a check is made to establish when to skip calculations because the influence of the heat source is insignificant. This check is made on the basis of the first term of the temperature calculation. When this falls below a limiting temperature value of 10^{-10}°C , the remainder of the calculations for a decaying heat source are skipped.

The various checks built into the implementation of the line heat source solution limit the range of distances and times over which values of the induced temperatures, stress, and displacement will be computed. Consider the case of a single heat source with strength $1000 \text{ m}^3\text{C/yr/m}$ and decay constant 0.1 in an infinite elastic medium with the properties

$$\begin{aligned}\text{Thermal Diffusivity } (\kappa) &= 25 \text{ m}^2/\text{yr} \\ \text{Elastic Modulus } (E) &= 10000 \text{ MPa} \\ \text{Poisson's Ratio } (\nu) &= 0.2 \\ \text{Thermal Expansion } (\alpha) &= 10*10^{-6} \text{ }^{\circ}\text{C}^{-1}\end{aligned}$$

The results of a series of calculations of the radial stress at different locations and times are listed in Table 2. Note both the obvious limit to the range over which thermally induced stress will be experienced at any time and that the thermally induced stress eventually becomes insignificantly small. Note also that numerical instabilities have been encountered in some circumstances; most

noticeably after long time periods and at close ranges. Every reasonable step has been taken to avoid the numerical problems that cause these instabilities. To prevent them entirely would unnecessarily limit the calculation in most cases of practical significance. Hence, the user should both exercise discretion in selection of sample points when simulating long periods of emplacement and be prepared to make minor changes if instabilities are encountered.

3. USER'S MANUAL

This section comprises documentation for the user of HEFF boundary-element code. First, modeling options offered by the code are described briefly. Second, the input and output files are described and illustrated by a sample problem. Third, the software and hardware resources required for use of the code are defined.

3.1 Function and Invocation of Options

The code offers the user a number of options. In several cases, the use of a particular option has implications of which the user should be aware. Those cases are discussed below. In addition, several features are illustrated schematically in Figure 7.

Geometrical Symmetry - The problem may be geometrically symmetrical about the y axis (i.e., about $x = 0$). Since this symmetry applies to heat sources, the user should take care to halve the strength of any heat source located on the y axis if this option is used.

Image Heat Sources - Image heat sources (of the same magnitude but opposite sign) are used to enforce an isothermal boundary condition on the plane $y = 0$. The image heat source also removes any thermally induced normal tractions on that surface, but not the thermally induced shear tractions on the surface. Hence, boundary elements must be placed along the free surface of all half-space problems. The extent of the surface to be defined for any particular application can be determined by simple experimentation.

Heat Source Characteristics - Heat source strength is described by one or more components that can be either constant or exponentially decaying or both. Each component is ascribed some proportion of a separately specified strength and a time at which the component is activated. All sources have identical time-varying characteristics. However, their location, strength at emplacement, and time of emplacement are specified individually. This allows phased emplacement of sources of varied strength.

Heat Sinks - The user is free to specify negative strength heat sources if desired. These might be used to simulate heat loss due to ventilation of an underground excavation, for example. They can also be used to terminate previously activated components of the source. For example, a constant component of strength 1 activated at time zero when combined with a second component of strength -1 activated after one year would be equivalent to emplacing a source of strength 1 for one year and removing it thereafter. To achieve the same effect with decaying components, it is important to note that the magnitude of the negative component (sink) must be equal to the magnitude of the source after decay over the specified period, i.e.

$$Q_0^- = -Q_0^+ e^{-\lambda t}$$

in which Q_0^+ and Q_0^- are the magnitudes of the strengths of the source and sink, respectively, λ is the decay constant describing both source and sink, and t is the time between emplacement and removal.

Mechanical or Thermal-Mechanical Analyses - If the number of heat sources specified in the control data is zero, then all data relating to the thermal and thermal-mechanical properties for the problem are eliminated (including specification of time). In these circumstances, the thermal submodel is never invoked.

Generation of Sample Points - The code allows sample points to be generated either automatically along lines perpendicular to the boundary elements or along independently specified sample lines. In the former case, the user has the option of requesting that sample points are generated for less than the full number of boundary elements. In those circumstances, the user must order the boundary-element segments so that the elements with associated sample lines are generated first. Ordering of the sample lines is particularly important if it is intended that the plot files be postprocessed.

Postprocessing - A postprocessor, POSTHEF, has been developed to display and plot output from the HEFF analysis. If POSTHEF is to be used to contour variables, exterior sample points perpendicular to the boundary elements must be specified (see input type M2). POSTHEF is described in Appendix C.

3.2 Input and Output Information

3.2.1 Input Data

This summary details the input file for the HEFF code. User specifies names of input and output files during program execution. Except for the first three data lines, free format is used. This means that some value, even if zero, must be entered for every variable to be read. Data items are separated by blanks or commas. Note that an input data set applies for one time only. Hence, output for successive time intervals is obtained by completing a series of independent analyses.

Input A Plot File Name (10 Characters)

Cols. 1-8 Name of file on which output is to be stored for plotting using POSTHEF (see Appendix C).

Input B QA Number - A QA number is embedded within the code. Execution is terminated if that number does not correspond with the value specified in the data set, i.e., you are not using the version you think you are?

Input C Title Input (72 Characters)

Cols. 1-72 Alphanumeric description of job

Input D Job Execution Data (Free Format)

NUMBS	Number of boundary segments
NUMOS	Number of stress lines (see Input L)
NSORC	Number of components used to describe heat sources
NCOMP	Number of time components defining the heat sources
KSYM	Geometric symmetry identifier
IMAG	Heat source image specifier

Note: (a) The geometric symmetry identifier (KSYM) takes a value of 0 or 1, designating either no symmetry or symmetry about $y = 0$. Remember

that specification of KSYM = 1 (symmetry invoked) will also generate symmetrically located heat sources.

- (b) The heat source image specifier (IMAG) takes a value of 0 or 1, designating, respectively, no image sources or the generation of image sources to activate isothermal conditions at $y = 0$. Remember, selection of an isothermal boundary condition does not result in development of a stress free surface.

Input E Rock Mass Elastic Constants (Free Format)

PR Poisson's Ratio
E Young's Modulus

Input F Constants to Define Initial State of Stress (Free Format)

AXX
Ayy Ground surface, pre-mining stresses are:
AXY
BXX $\sigma_{yy} = AYY * Y + BYY$
BYY $\sigma_{xx} = AXX * Y + BXX + (CXX + DXX/Y) * \sigma_{yy}$
BXY $\sigma_{xy} = AXY * Y + BXY$
CXX
DXX $CXX + DXX/Y < RMAX$
RMAX
XZRAT $\sigma_{zz} = XZRAT * \sigma_{xx}$

Note: The sign convention for stresses is illustrated in Figure 8. Note that compressive stresses are assumed to be positive. This means that the value of the coefficients that describe a dependency on y are usually negative (since y becomes more negative with depth). It is particularly important to conform to this convention if performing thermal-mechanical analyses, since the thermal stress calculations are carried out on that basis.

Input G TIM Time at which output is desired (Free Format)

- Note: (a) Skip this input and inputs H through K if there are no heat sources (NSORC = 0).
- (b) The units of time must be consistent with other units used to define the problem. Any consistent unit can be used, but it is usually convenient to use years for the time unit.

Input H Constants to Determine Initial Rock Temperature VRT (Free Format)

TSURF Temperature at depth $Y = 0$
TGRAD Temperature gradient

where $VRT = TGRAD * Y + TSURF$.

Note: For the initial rock temperature (VRT) to increase with depth, TGRAD should be negative. (See Note on Input F above.)

Input I Rock Mass Thermal Properties (Free Format)

DIFF Thermal diffusivity
ALPHA Coefficient of thermal expansion

Note: The units of diffusivity must be consistent with the time units assumed for Input G. For example, if time is denoted in years, then the units of diffusivity might be m^2/yr .

Input J Definition of Heat Source Components (Free Format), NCOMP records should be input (see Input D)

TOG(I) Switch-on time for component
PROP(I) Proportion of strength specified in Input K below (can be negative)
QEXP(I) Decay constant for component (0 for constant component or a positive value for a decaying component)

Note: (a) All heat sources are assumed to have the same decay characteristics. Only the strength and switch-on time are specified in Input K below.

- (b) Time here is the time relative to the switch-on time specified in Input K below.
- (c) See Section 2.5.2 for additional discussion.

Input K Specification of Heat Sources (Free Format), NSORC records should be input (Input D)

XS(I)	x coordinate of source
YS(I)	y coordinate of source
QS(I)	Initial strength of source
TOS(I)	Switch-on time for source

Note: (a) Strength of heat source is the power per unit length of the out-of-plane line heat source (e.g., watts/m) divided by the heat capacity ($J/m^3^{\circ}C$) of the medium. Typical units are $m^3^{\circ}C/yr$ per meter. Take care that a consistent set of units, including those of time, are used.

- (b) Switch-on time can be alternatively considered as emplacement time.

Input L All boundaries are defined as a series of segments. Each segment is then subdivided automatically into the specified number of equal length straight elements. Two alternative means of specification are provided. These allow for straight and curved segments and are illustrated in Figure 9a and b. Both types may be used in any combination.

Type L1 Specification of a Straight Line Segment (Free Format)

NUM	Number of boundary elements to be generated from segment
KODE	Code describing boundary conditions, as defined below
XBEG	x coordinate of start of segment
YBEG	y coordinate of start of segment
XEND	x coordinate of end of segment
YEND	y coordinate of end of segment
RADIUS	Zero for straight line segment
RATIO	Zero for straight line segment

PSI	Zero for straight line segment
BVS}	Transverse (BVS) and normal (BVN) components of imposed surface traction or displacement (depends on KODE)
BVN}	

Note: See Figure 9a.

Type L2 Specification of a Circular or Elliptical Segment (Free Format)

NUM	Number of boundary elements to be generated from segment
KODE	Code describing boundary conditions, as defined below
XC/YC	Coordinates of center of circular or elliptical segment
THET1}	Angles defining angular range of segment measured counterclockwise from the x-axis (see Figure 9b)
THET2}	
RADIUS	Radius of circular segment or length of one semi-axis (a) of an ellipse
RATIO	Ratio b/a, where (a) and (b) are the lengths of the semi-axes of the ellipse, 0 for a circular segment
PSI	Polar angle of semi-axis (a) measured counterclockwise from the x-axis, 0 for a circular segment
BVS}	Transverse (BVS) and normal (BVN) components of imposed surface traction or displacement (depends on KODE)
BVN}	

Note: See Figure 9b.

General Notes:

- (a) When specifying boundary elements, the solid is assumed to be on the right-hand side when moving from the start of the segment to the end.
- (b) Apart from as noted in (d) below, the ordering of elements is arbitrary.
- (c) If KODE = 1, surface tractions are specified.
 = 2, surface displacements are specified.
 = 3, normal component of traction, transverse component of displacement are specified.

= 4, normal component of displacement and transverse component of traction are specified.

- (d) If the POSTHEF postprocessor is to be used, then the boundary segments must be specified in which the elements will be plotted, with the first element to be plotted first in the sequence.

Input M

Specification of Interior Points

Two alternative means of specification are provided. One or the other, but not both, can be used. If POSTHEF is to be used, the second alternative should be used.

Type M1

Specification of Points Along Sample Lines

XB(I)}	x,y coordinates of start of line I
YB(I)}	
XE(I)}	x,y coordinates of end of line I
YE(I)}	
NUMPB(I)	Total number of points along line I, including endpoints

- Note: (a) NUMOS records should be input (Input D).
(b) See Figure 9d.

Type M2

Specification for Generation of Interior Points in Medium (Free Format)

DELN	Distance to first stress point from centroid of each boundary element
RATTY	Multiplier to expand or contract spacing
NUMPT	Number of points generated along each line
NBE	Number of boundary elements where generation is needed (There will be generation normal to the first NBE elements.)

- Note: (a) This type is invoked when NUMOS = 0 (Input D).
(b) See Figure 9e.

- (c) The variable RATTY defines the spacing between successive sample points along a line normal to each boundary element.
- (d) Only one record is required in this case since the sample points are automatically generated for the first NBE elements. This option must be used to generate data for POSTHEF. It is recommended that DELN is not less than 50 percent of the length of the boundary element from which it is generated.

3.2.2 Output Data

Output comprises

- o Title, date of creation, and timing information.
- o A record of all input information, including generated data for the boundary elements and internal sample points.
- o Preexisting stresses at the center of each element, prior to creation of the surfaces defined by the elements. If there are heat sources in the model, then the associated temperature change and thermal stresses are included in this list.
- o Computed displacements, stresses, and temperature at each boundary element. Both displacements and stresses are expressed in Cartesian and local (tangential and normal to each element) coordinate frames.
- o Computed displacements, stresses, and temperature at each internal sample point. The displacements and stresses are given in Cartesian coordinate frame. In addition, the principal in-plane stresses and their orientations are defined.
- o A plot file that can be postprocessed by POSTHEF to obtain graphical output.

The nomenclature used in the output file is defined in Table 3. The complete output for a sample problem is contained within Section 3.2.3.

3.2.3 Sample Problem

The sample problem concerns analysis of a long drift for emplacement of nuclear waste within vertical boreholes drilled along its centerline. For the sake of simplicity, the case of an isolated drift is investigated. The more typical case of a representative drift within a large repository is discussed in Section 4.2.

Geomechanical data required for this problem are

Drift Width	16.0 ft (4.88 m)
Drift Height	22.0 ft (6.71 m)
Radius of Roof Arch	9.0 ft (2.74 m)
Borehole Depth	25.0 ft (7.62 m)
Container Length	18.0 ft (5.49 m)
Depth Below Surface	985.0 ft (300 m)

The material properties and initial conditions required for the analysis are

Specific Gravity	2.34 g/cc
Young's Modulus	15.1 GPa
Poisson's Ratio	0.2
Thermal Conductivity	2.07 W/m°C
Thermal Capacity	2.25 J/cm ³ °C
Thermal Expansion	10.7x10 ⁻⁶ °C ⁻¹
Horizontal/Vertical In-Situ Stress	0.55
Ground Surface Temperature	16.0°C
Temperature Gradient	0.0239°C/m

The waste containers are presumed to be spaced along the drift to achieve an initial thermal loading density of 590.5 W/m, which is assumed to decay in accordance with the following normalized power decay function

$$P(t) = 0.15602\exp(-0.0013539t) + 0.59787\exp(-0.019142t) \\ + 0.15227\exp(-0.005188t) + 0.09384\exp(-0.43768t)$$

in which t is the time in years since emplacement.

To solve this problem, a total of 27 boundary elements were used to define one half of the drift perimeter, the other half being generated automatically by prescribing a vertical plane of symmetry along the centerline. The arrangement of elements is illustrated in Figure 10, on which the location of sample points and heat sources are also marked.

The data set for this problem is reproduced in Figure 11. The following annotation is intended to be read in conjunction with the input data list defined in Section 3.2.1.

Line 1:	Name of plot file for subsequent postprocessing.
Line 2:	QA number (HEFF 4.1 in this case).
Line 3:	Title for problem.
Line 4:	Control Information <ul style="list-style-type: none">o Boundary segments define the problemo Sample point generation usedo Three heat sources usedo Four decay components for the heat sourceso Symmetry about $x = 0$o No image heat sources
Line 5:	Specification of rock mass elastic constants.
Line 6:	Definition of the in-situ stress state. Here a stress gradient of -0.023 MPa/m is defined. The entry is negative, so the calculated in-situ stress is +6.95 MPa (compressive) at an elevation of -300 m below the ground surface. Note that the horizontal stresses are both equal to 0.55 of the vertical stress.
Line 7:	Time for which the analysis is to be performed.
Line 8:	Definition of initial temperature. Note again that the gradient is negative and that the initial temperature will be positive at some depth below the surface ($y < 0.0$), where the initial temperature is 16 °C.
Line 9:	Definition of thermal diffusivity and coefficient of linear thermal expansion. Note that units of thermal diffusivity are m^2/yr . The units of time must be the same as used when

defining the analysis time and the decay characteristics of the waste form.

Lines 10-13: Definition of the four components used to describe the heat generation of the waste form. In this case, the datum for each component is zero years. Here the components have been normalized so that the total strength at 0 years is 1.0.

Lines 14-16: Definition of the location, strength, and timing of the heat sources. In this case, three heat sources are located beneath the center of the drift (i.e., on the line of symmetry, $x = 0$). These heat sources are intended to simulate the heat generation of a line of containers placed within holes in the floor of the emplacement drift. They are located at the mid-height of the container (-307.335 m) and one-sixth of the container length from each end, with the intention of approximating uniform heat-generation with the volume of the container. Note that the strength of each source is equivalent to one-sixth of the initial thermal output of the containers because the three heat sources are placed on the line of symmetry.

Lines 17-20: Definition of the boundary elements. Note that four boundary segments are used. These define first the floor, then the bottom right-hand corner, the right wall, and a circular roof with radius 2.74 meters. The corner segment, which comprises a single element, is included solely for the purposes of generation of internal sample points.

Line 21: Definition of the generation of sample points. In this case, the first point is 0.3 m from each element. Six points are generated along lines normal to all 27 elements. The ratio of the spacing between adjacent pairs of sample points on a line is 1.5.

Output for the sample problem is shown in Figure 12. The user specifies the output file name during execution. Postprocessing of the output file identified in Line 1 of the input file can be done interactively to produce contours of temperature, stress, and safety factors, as well as the deformed shape of the cavity and tangential stresses around the excavation. Details of the postprocessor POSTHEF are presented in Appendix C.

3.3 Software and Computer System Requirements

The Fortran computer code and executable code has been developed using the Microsoft Fortran 77 compiler and associated linker for IBM-PCs and compatible microcomputers. With the exception of the timing and date routines, which are marked clearly in the code, there are no system-dependent features.

Users wishing to implement the code using an alternative compiler may expect to modify the OPEN statements for units 1 (input), 2 (output), and 3 (plot file) and either remove calls to the date and time functions or replace them with equivalent subroutines.

It is assumed that unit 0 is the monitor and the keyboard, and it is via those devices that the user is prompted for, and responds to requests for, the names of the input and output fields. Under MS-DOS, the user can circumvent these interactions by creating a small batch file in which the names of the input and output files are piped at execution time. However, progress messages will still be sent to unit 0 during execution of the code. Different arrangements may be necessary on other computers or operating systems.

The maximum size of problem that can be analyzed using the HEFF code is determined by the parameter LIMIT in the main program. This is currently set at a value of 100, which is the maximum number of elements, heat sources, or sample lines that can be used in any one problem. There may be as many points as desired on each sample line, although the number of points along lines generated normal to boundary elements should be restricted to 10 if the postprocessor is to be used. The minimum recommended configuration for an IBM-PC or compatible microcomputer is

512K RAM
360K Floppy Disk Drive
8087/80287 Math Coprocessor

The executable version of the code used for the sample and verification problems described in this report was developed using Version 4.1 of the Microsoft Fortran 77 optimizing compiler and run under Version 3.2 of MS-DOS. Execution times given in output reproduced in this report are typical of an IBM PC-AT operating at 8 MHz.

4. VERIFICATION

4.1 Introduction

This section of the documentation describes measures taken to verify the computer software. That is, the measures taken to assure that the mathematical formulation has been correctly translated into computer code are described. Those measures include detailed comparison with four independent analytical solutions for identical or similar problems and also with independent analyses using alternative numerical procedures.

4.2 Code Verification

The purpose of this section is to demonstrate that the mathematical formulations described in Section 2 have been correctly translated into computer code. First, the adequacy of the mechanical model is demonstrated by comparison with the results of closed-form solutions for a thick circular cylinder subjected to external pressure and for a circular hole in an infinite medium with biaxial initial stress. Second, the adequacy of the thermal and thermal-mechanical submodel is demonstrated through detailed comparison with the results of three-dimensional analyses using a computer code based on the closed-form solution for point heat sources. Third, integration of the mechanical and thermal models is demonstrated by comparison with the closed-form solution for a heated thick-walled cylinder and a heat-generating layer within a semi-infinite medium. Finally, the results of analysis of an emplacement drift within a potential nuclear waste repository are compared with those obtained for the same problem using a finite-element model.

4.2.1 Analysis of a Thick-Walled Cylinder Subject to External Pressure

Objective

To verify the mechanical submodel within the HEFF code.

Code Capabilities Exercised

- o Analysis of a finite body defined by two surfaces
- o Definition of plane of symmetry at $x = 0$
- o Application of boundary traction (pressure)
- o Calculation of displacements and stresses at the boundary and internal sample points

Physical Problem

An initially unstressed thick-walled cylinder is subjected to an external pressure. The cylinder is assumed to be long so plane strain conditions apply. The geometry and material properties for the problem are

Inner Radius (a)	= 4. m
Outer Radius (b)	= 6. m
External Pressure (P)	= 6 MPa
Elastic Modulus (E)	= 60 GPa
Poisson's Ratio (ν)	= 0.25

The physical problem is illustrated in Figure 13a.

Assumptions

The material of the cylinder is homogeneous and isotropic and the strains are small.

Analytical Solution

The solution for the radial (σ_r) and hoop stress (σ_θ) for this problem is provided by Timoshenko and Goodier (1970)

$$\sigma_r = \frac{pa^2b^2}{(b^2-a^2)r^2} - \frac{pb^2}{(b^2-a^2)}$$
$$\sigma_\theta = -\frac{pa^2b^2}{(b^2-a^2)r^2} - \frac{pb^2}{(b^2-a^2)}$$

in which r is the radial coordinate and both σ_r and σ_θ are independent of θ .

The out-of-plane stress can be calculated using the condition that the out-of-plane strain is zero. Specifically

$$\sigma_z = \nu(\sigma_r + \sigma_\theta).$$

The radial displacement, (u_r) can be calculated from the relationship

$$u_r = r\epsilon_\theta$$

in which ϵ_θ is the hoop strain, which can be calculated from the stress state using

$$\begin{aligned}\epsilon_\theta &= [\sigma_\theta - \nu(\sigma_r + \sigma_z)]/E \\ &= [\sigma_\theta(1 - \nu^2) - \nu\sigma_r(1 + \nu)]/E\end{aligned}$$

Computer Model

The boundary-element model is represented schematically in Figure 13b and input to the HEFF code is reproduced in Figure 14. The model is defined by two semicircular segments, each subdivided into 23 equal length elements. All boundary elements have prescribed shear and normal stresses, i.e., are assigned boundary code $KODE = 1$. Note that the interior boundary is defined in a counterclockwise sense, while the exterior boundary is defined in a clockwise sense. The solid always lies to the right as the boundary elements are generated.

Results

Complete output for this problem is reproduced in Appendix B. A comparison of computed and "exact" displacements and stresses is provided by Table 4. As indicated by Table 4, agreement between two solutions is generally on the order of 1 to 2 percent for the hoop stress and radial displacement. The radial stresses appear to be relatively inaccurate toward the inner boundary. This is attributed to two factors. First, the stress gradient is relatively high close to the inner surface. Second, the boundary-element mesh generator generates linear segments with center points along an arc of a specified radius. Thus, the average inner radius of the boundary-element model of the cylinder is slightly

greater than assumed in the analytical solution. An improved solution was obtained when additional elements were used to define boundaries.

4.2.2 Analysis of Creation of a Cylindrical Hole in an Initially Stressed Elastic Medium

Objective

To verify the mechanical submodel within the HEFF code.

Code Capabilities Exercised

- o Analysis of a hole in an unbounded medium
- o Relaxation of an initial stress state
- o Definition of a plane of symmetry at $x = 0$
- o Calculation of displacements and stresses at the boundary and internal sample points

Physical Problem

An infinitely long cylindrical hole is created in an elastic medium with uniform biaxial initial stress. The hole is created in one step and induced displacements and total stresses are calculated. Because the hole is infinitely long, plane strain conditions are assumed. The geometry, initial conditions, and material properties for the problem are

Radius of Hole (a)	= 5 m
Initial Horizontal Stress (σ_{xx}^o)	= 30 MPa
Initial Vertical Stress (σ_{yy}^o)	= 15 MPa
Initial Out-of-Plane Stress (σ_{zz}^o)	= 0 MPa
Elastic Modulus (E)	= 60 GPa
Poisson's Ratio (ν)	= 0.25

The physical problem is illustrated in Figure 15a.

Assumptions

The material in which the hole is created is homogeneous and isotropic and the strains are small.

Analytical Solution

The analytical solution for the total radial (σ_r) and hoop (σ_θ) stresses after excavation is given by Jaeger and Cook (1976)

$$\sigma_r = \frac{\sigma_x^0 + \sigma_y^0}{2} \left(1 - \frac{a^2}{r^2} \right) + \frac{\sigma_x^0 - \sigma_y^0}{2} \left(1 - \frac{4a^2}{r^2} + \frac{3a^4}{r^4} \right) \cos 2\theta$$
$$\sigma_\theta = \frac{\sigma_x^0 + \sigma_y^0}{2} \left(1 + \frac{a^2}{r^2} \right) - \frac{\sigma_x^0 - \sigma_y^0}{2} \left(1 + \frac{3a^4}{r^4} \right) \cos 2\theta$$

in which both σ_r and σ_θ are functions of the radial distance r from the center of the hole and the angle θ , which is measured counterclockwise relative to the positive x -axis. The out-of-plane stress can be calculated, given the condition that the induced out-of-plane strain is zero

$$\sigma_z = \sigma_z^0 - 2\nu \frac{a^2}{r^2} (\sigma_x^0 - \sigma_y^0) \cos 2\theta$$

The radial displacement that accompanies relaxation of the initial stress state once the hole is created is given by

$$u_r = \frac{(1 + \nu)a^2}{2Er} \left[(\sigma_x^0 + \sigma_y^0) + (\sigma_x^0 - \sigma_y^0) \left(4 - 4\nu - \frac{a^2}{r^2} \right) \cos 2\theta \right]$$

Computer Model

The boundary-element model is illustrated schematically in Figure 15b, and input for the HEFF code is reproduced in Figure 16. The model is defined by a single semicircular segment, divided into 49 straight line elements of equal length.

Results

Complete output for this problem is reproduced in Appendix B and a comparison of the computed and "exact" displacements and stresses is provided by Table 5. The distribution of stress is illustrated in Figure 17. As indicated, the agreement between the closed-form and boundary-element solutions is good, except for the radial stresses close to the boundary of the hole. As in the case of the thick-walled cylinder, the lack of agreement between the predictions of the radial stress is attributed to the stress gradient and the approximation of a circular profile used in the boundary-element model.

4.2.3 Verification of Temperature and Thermal Stress Calculations

Objective

To verify the thermal submodel within the HEFF Code.

Code Capabilities Exercised

- o Analysis of a single constant strength source
- o Analysis of single decaying source
- o Analysis of general time-varying sources

Physical Problem

A single line source is located within an infinite, linear elastic medium. The physical properties of the medium are

Elastic Modulus (E)	= 15,100 MPa
Poisson's Ratio (ν)	= 0.2
Thermal Expansion Coefficient (α)	= $10.7 \times 10^{-6} \text{ }^{\circ}\text{C}^{-1}$
Thermal Diffusivity (κ)	= $29.03 \text{ m}^2/\text{yr}$

The following alternatives for the time-varying characteristics of the sources are considered.

Case A: Constant source, strength $4140 \text{ m}^3\text{ }^{\circ}\text{C}/\text{yr}/\text{m}$

Case B: Exponentially decaying source

Initial strength (Q_0) = 4140 m³°C/yr/m

Decay constant (λ) = 0.025 (half life = 27.7 years)

Case C: Exponentially decaying source

Initial strength (Q_0) = 4140 m³°C/yr/m

Decay constant (λ) = 0.25 (half life = 2.77 years)

Case D: Arbitrary time varying source

Initial strength (Q_0) = 4140 m³°C/yr/m

Decay characteristics and proportional contributions

$$\begin{aligned} Q(t) = Q_0 & (0.15602 \exp(-0.0013539t) \\ & + 0.59787 \exp(-0.019142t) \\ & + 0.15227 \exp(-0.051888t) \\ & + 0.093840 \exp(-0.43768t)) \end{aligned}$$

Physically, the problem appears as a point source in a cross section normal to the line source.

Assumptions

The material in which the source is embedded is linearly elastic, homogeneous, isotropic, and of infinite extent. The strains are small.

Analytical Solution

The thermal submodel within HEFF is itself a closed-form solution, even though evaluation of the equation does involve numerical approximation. Hence comparison, in the sense used in the previous verification problems, is not possible. Instead, an approximate three-dimensional solution for the infinite line source is constructed by defining, in three dimensions, a large number of point heat sources that lie along the line represented in the two-dimensional model.

The solutions for constant and decaying heat sources in an infinite elastic body is given by Crouch and McClain (1977). Briefly, these are

$$T = \frac{V_3}{\pi^{3/2}}$$

$$\sigma_{rr} = \frac{mG}{\pi r^2} \left\{ \frac{V_1}{r} - \frac{2V_2}{\sqrt{\pi}} \right\}$$

$$u_r = - \frac{m}{4\pi r^2} \left\{ \frac{V_1}{r} - \frac{2V_2}{\sqrt{\pi}} \right\}$$

in which $m = \alpha(1+\nu)/(1+\nu)$, G is the shear modulus, ν is Poisson's ratio, α the expansion coefficient, and r the radial distance from the source to the sample point. The three functions V_1 , V_2 , and V_3 differ depending on whether the source is constant or time-varying.

For a constant strength source, the functions are defined by

$$V_1(r, t) = Q_c \left\{ t \cdot \operatorname{erf} \frac{r}{\sqrt{4\kappa t}} - \frac{r^2}{2\kappa} \cdot \operatorname{erfc} \frac{r}{\sqrt{4\kappa t}} + \sqrt{\frac{t}{\pi\kappa}} \cdot r \cdot \exp \left(\frac{-r^2}{4\kappa t} \right) \right\}$$

$$V_2(r, t) = Q_c \left\{ \sqrt{\frac{t}{\kappa}} \cdot \exp \left(\frac{-r^2}{4\kappa t} \right) - \frac{\sqrt{\pi}}{2\kappa} \cdot r \cdot \operatorname{erfc} \left(\frac{r}{\sqrt{4\kappa t}} \right) \right\}$$

$$V_3(r, t) = Q_c \frac{\sqrt{\pi}}{4\kappa} \cdot \frac{1}{r} \cdot \operatorname{erfc} \left(\frac{r}{\sqrt{4\kappa t}} \right)$$

where $\operatorname{erfc}(z) = 1 - \operatorname{erf}(z)$ is the complementary error function.

For a source described by the relationship $Q(t) = Q_0 \exp(-\lambda t)$, the functions are defined by

$$V_1(r, t) = Q_0 \left\{ -\frac{1}{\lambda} \cdot \exp(-\lambda t) + \frac{1}{\lambda} \left[\operatorname{erf} \left(\frac{r}{\sqrt{4\kappa t}} \right) + \exp \left(\frac{-r^2}{4\kappa t} \right) \cdot \operatorname{Re} \left\{ \omega \left(\sqrt{\lambda t} + i \frac{r}{\sqrt{4\kappa t}} \right) \right\} \right] \right\}$$

$$V_2(r, t) = Q_0 \cdot \frac{\sqrt{\pi}}{\sqrt{4\kappa\lambda}} \cdot \exp \left(\frac{-r^2}{4\kappa t} \right) \cdot \operatorname{Im} \left\{ \omega \left(\sqrt{\lambda t} + i \frac{r}{\sqrt{4\kappa t}} \right) \right\}$$

$$V_3(r, t) = Q_0 \cdot \frac{\sqrt{\pi}}{4\kappa r} \cdot \exp \left(\frac{-r^2}{4\kappa t} \right) \cdot \operatorname{Re} \left\{ \omega \left(\sqrt{\lambda t} + i \frac{r}{\sqrt{4\kappa t}} \right) \right\}$$

where $\omega(z) = \frac{2iz}{\pi} \int_0^\infty \frac{e^{-t^2}}{z^2 - t^2} dt$ (with $\operatorname{Im}(z) > 0$) is the complex error function, and Re and Im designate real and imaginary parts.

These equations have been incorporated within a computer program, named STRES3D (see Asgarian et al., 1991 for Version 4.0), that allows point sources to be distributed according to a user-defined pattern within planes in an infinite elastic body.

Computer Model

For HEFF, the model comprises a single source located anywhere in the medium. This arrangement is approximated using STRES3D by locating 500 heat sources at intervals of 2 m along a line 1000 m in length. The strength of each source at the time of emplacement is $8280 \text{ m}^3\text{°C/yr}$ (equal to the product of the strength per unit length and the spacing).

Results

Comparison of the temperatures, displacements, and stress computed using the HEFF and STRES3D computer codes is provided in Tables 6 through 9. Generally, correspondence between the two solutions is excellent. Minor differences observed very close to the source are attributed to the finite spacing of the point sources in the three-dimensional model.

Additional details of verification of the thermal and thermal-mechanical submodel in HEFF is provided by Lindner et al. (1984). In particular, several tests on the convergence of the infinite series needed to obtain the solution of exponentially decaying sources are described.

4.2.4 Thermoelastic Response of a Hollow Cylinder

Objective

To verify the thermal-mechanical model within the HEFF code.

Code Capabilities Exercised

- o Analysis of a solid body defined by two surfaces
- o Definition of a plane of symmetry at $x = 0$

- o Application of thermal stress by means of an out-of-plane line heat source
- o Coupling of mechanical submodel to thermal submodel

Physical Problem

An initially unstressed thick-walled cylinder is heated by placing line heat source at its center. The cylinder is assumed to be infinitely long so plane strain conditions apply. The geometry and material properties are

Inner Radius (a)	= 4.0 m
Outer Radius (b)	= 6.0 m
Elastic Modulus (E)	= 6×10^4 MPa
Poisson's Ratio (ν)	= 0.25
Coefficient of Linear Thermal Expansion (α)	= $6 \times 10^{-6} \text{ } ^\circ\text{C}^{-1}$
Thermal Conductivity (K)	= 1.0 W/m $^\circ\text{C}$
	= $3.156 \times 10^7 \text{ J/yr m}^\circ\text{C}$
Specific Heat (c)	= 850 J/kg $^\circ\text{C}$
Density (ρ)	= 2950 kg/m 3
Heat Capacity (ρc)	= $2.51 \times 10^7 \text{ J/m}^3 \text{ } ^\circ\text{C}$
Thermal Diffusivity (κ)	= $4.0 \times 10^{-7} \text{ m}^2/\text{s}$
	= 12.623 m $^2/\text{yr}$
Heat Source Intensity (Q_o)	= 250 W/m
Heat Source Strength	= $\frac{Q_o}{\text{Heat Capacity}}$
	= 3143.0 m $^3 \text{ } ^\circ\text{C}/\text{yr}/\text{m}$

The physical problem is the same as that illustrated in Figure 13, except a line heat source is located at the axis of the cylinder. Clearly, the problem is not entirely realistic since the heat source is actually placed outside the material of the cylinder. However, the purpose of the arrangement is to develop a simple boundary value problem with a prescribed temperature distribution.

Assumptions

The material of the cylinder is homogeneous and isotropic and the strains are small.

Analytical Solution

The solution for the radial (σ_r) and hoop (σ_θ) stresses within a thick cylinder with known temperature distribution is given in Timoshenko and Goodier (1970).

$$\sigma_r = \frac{\alpha E}{(1-\nu)r^2} \left[\frac{r^2 - a^2}{b^2 - a^2} \int_a^b T r dr - \int_a^r T r dr \right]$$
$$\sigma_\theta = \frac{\alpha E}{(1-\nu)r^2} \left[\frac{r^2 + a^2}{b^2 - a^2} \int_a^b T r dr + \int_a^r T r dr - T r^2 \right]$$
$$\sigma_z = \nu(\sigma_r + \sigma_\theta) - E\alpha T$$

where r is the radial coordinate and T is the temperature change from the base temperature and compressive stresses are negative.

Similar to the first verification problem, the radial displacement (u_r) can be calculated from the relationship

$$u_r = r\epsilon_\theta$$

in which ϵ_θ is the hoop strain that can be calculated from the stress state using

$$\epsilon_\theta = (\sigma_\theta - \nu(\sigma_r + \sigma_z))/E + \alpha T$$

Computer Model

The boundary-element model for this problem is the same as for an unheated cylinder, illustrated by Figure 13b; the input file is reproduced in Figure 18. The model is defined by two semicircular segments, each subdivided into 29 equal

length elements. Shear and normal stresses are prescribed for the boundary elements (i.e., $KODE = 1$).

Results

To derive the closed-form solution, a second order fit to the temperatures computed using the HEFF code was obtained. For the particular sample time (five years) this was

$$T(r) = 95.10 - 16.25r + 0.89r^2$$

The closed-form solution was then evaluated by performing the necessary integrations. The results are listed in Table 10, together with the corresponding values obtained using the HEFF code.

When assessing the measure of agreement between the two solutions, it is important to recall the physical approximations assumed in the HEFF analysis. Since the heat source is treated as though it is located within an infinite elastic domain, the thermally induced displacements and stresses are being computed for a problem that is very different from the one we seek to solve. However, the mechanical model within HEFF does ensure that all the mechanical boundary conditions are satisfied.

Despite the approximations of the HEFF model, the agreement between the closed-form and boundary-element solutions is generally satisfactory. Qualitatively, the distributions of displacement and stress (Figure 19) are correct. Thus, the mechanical and thermal models are correctly coupled and the thermally induced displacements and stresses can be computed as though for an infinite elastic domain, even in the extreme circumstances investigated here.

4.2.5 Analysis of Heat Generation Within a Layer in a Semi-Infinite Body

Objective

To verify the coupling between the mechanical and thermal-mechanical submodel.

Code Capabilities Exercised

- o Definition of a constant temperature horizontal surface
- o Definition of a plane of symmetry about $x = 0$ for both thermal and mechanical models
- o Definition of mixed boundary conditions
- o Definition of a free surface by boundary elements
- o Calculation of temperatures, displacements, and stresses at boundary and interior points

Physical Problem

Heat is generated at a constant rate within a thin layer of infinite lateral extent that lies parallel to the surface of a half-space. The geometry, material properties, and heat generation for the problem are

Depth of Layer Below Surface (d)	100 m
Thickness of Layer (2L)	5 m
Thermal Diffusivity of Medium (κ)	12.62 m ² /yr
Thermal Expansion Coefficient (α)	6*10 ⁻⁶ /°C
Elastic Modulus (E)	60 GPa
Poisson's Ratio (ν)	0.25
Heat Generation Per Unit Volume	10 W/m ³

The physical problem is illustrated in Figure 20a. It is assumed that the material properties of half-space are uniform, so the layer differs from the rest of the medium only in that heat is generated uniformly within it.

Assumption

The material of the half-space is homogeneous and isotropic and the strains are small.

Analytical Solution

The temperature distribution within an infinite region due to heat generation within a layer of thickness 2L is given by Carslaw and Jaeger (1959) as

$$T = \frac{2\kappa Q_0}{K} \left\{ i^2 \operatorname{erfc} \frac{y-L}{2\sqrt{\kappa t}} - i^2 \operatorname{erfc} \frac{y+L}{2\sqrt{\kappa t}} \right\} \quad \text{for } y > L$$

In this equation, the function $i^2 \operatorname{erfc}(x)$ is the second repeated integral of the error function and can be evaluated from

$$i^2 \operatorname{erfc}(x) = \frac{1}{4} \left[(1+2x^2) \operatorname{erf}(x) - \frac{2}{\sqrt{\pi}} x \exp(-x^2) \right]$$

in which $\operatorname{erfc}(x)$ is the complementary error function and is defined as $[1-\operatorname{erf}(x)]$.

The solution for the case of a semi-infinite body with the layer located at depth d below an isothermal surface at $y = 0$ can be obtained using the method of images.

$$T = \frac{2\kappa Q_0 t}{K} \left\{ i^2 \operatorname{erfc} \frac{d+y-L}{2\sqrt{\kappa t}} - i^2 \operatorname{erfc} \frac{d+y+L}{2\sqrt{\kappa t}} - i^2 \operatorname{erfc} \frac{d-y-L}{2\sqrt{\kappa t}} + i^2 \operatorname{erfc} \frac{d-y+L}{2\sqrt{\kappa t}} \right\}$$

Since the layer is infinite and parallel to the free surface, both the thermal and thermal-mechanical problems are one-dimensional. As there is no restriction on the vertical movement of the surface, the vertical stress must remain zero at all times.

$$\sigma_y = 0$$

The corresponding horizontal stresses can be obtained from the condition that there can be no horizontal strain.

$$\sigma_x = \sigma_z = \frac{E\alpha T}{(1-\nu)}$$

Since the distribution of T was defined as a function of depth y and time t , the corresponding distributions of the horizontal stresses can be calculated. The vertical expansion of the column of material between the heat-generating layer and the surface can be shown to be

$$\delta_v = \frac{(1+\nu)\alpha}{(1-\nu)} \int_{-d}^0 T dy$$

The integral can be evaluated numerically.

Computer Model

Several approximations are required before this problem can be analyzed using the HEFF code. First, generation of heat within a layer must be replaced by equivalent line heat sources. In the present instance, these sources were assumed to be located on the midplane of the heat-generating layer, spaced at intervals of 5 meters. The strength of each heat source was 250 W/m, or 3.156×10^8 J/yr/m. Second, HEFF cannot represent the infinite extent of either the heat-generating layer or the surface of the half-space. In one model, the heat-generating layer was extended to 300 m either side of the centerline and to 2000 m at the surface. Analysis performed using that model revealed a very distinct curvature of the free surface. This was assumed to be a result of the finite extent of the heat-generating layer. As an alternative to attempting a model with greater lateral extent, a vertical boundary 160 m from the model centerline was added. This is analogous to a plane of symmetry, and provides a better approximation to a heated layer of infinite extent. Boundary conditions prescribed for that boundary are zero normal displacement and zero shear stress (i.e., $KODE = 4$). The revised model, which is illustrated schematically in Figure 20b, provided a better approximation to the exact solution, as well as data for that model which is reproduced in the following section. The heat sources extend beyond the vertical boundary to ensure the temperature, displacements, and stresses due to the heat sources are adequately approximated within the central region of the model. There is no provision within HEFF to prescribe adiabatic vertical boundary for the thermal submodel. Figure 21 shows the HEFF input for this problem.

Results

A comparison of the temperatures and stresses predicted by the two models, after 100 years of heat generation, is provided by Table 11. The displacements could have been listed for either the midplane of the layer or the free surface. Instead, the total expansion of the material between the surface and the layer was calculated. The closed-form solution given above predicts 0.309 m, while a value of 0.308 m was obtained using HEFF.

The data presented in Table 11 indicates that the HEFF solution satisfies both temperature and stress boundary conditions at the free surface and provides an excellent approximation to the temperature field throughout. There are minor

differences in the computed temperature near the heat source, but this can be attributed to real differences in the nature of the heat source. It is reasonable that the temperatures should be slightly lower in the boundary-element solution because all heat is generated in a plane 100 m below the surface. For the closed-form solution, the heat is distributed over a five meter thick layer.

Agreement between the stresses computed from the closed-form solution and by the boundary-element model, as illustrated in Figure 22, is generally considered excellent, particularly near the heat sources. The analytical solution predicts that the horizontal stresses should be equal, whereas there are minor differences between the in-plane and out-of-plane stresses in the results of the HEFF analysis (because the line heat sources used in the HEFF code are infinitely long out of the plane of the section, but only a finite number are defined in the plane of the section). The vertical stresses remain essentially zero, as predicted by the analytical solution.

4.2.6 Near-Field Analysis of an Emplacement Drift

Problem Statement

This problem consists of transient thermal simulation of the near-field single-room region of a hypothetical repository in a tuff rock mass and static stress analysis at specified times. A complete description of the problem and additional results are presented in the report SAND86-7005, entitled "Reference Thermal and Thermal/Mechanical Analysis of Drifts for Vertical and Horizontal Emplacement of Nuclear Waste in a Repository in Tuff (St. John, 1987)". In the interest of brevity, only the results of analysis of the vertical emplacement drift are presented here.

Objectives

The objective of this test problem is to demonstrate that the code provides an acceptable means of modeling heat transfer and the state of stress induced by both the in-situ stress and the thermal loading. The particular case under consideration is that of emplacement of waste containers within vertical holes in the floor of an unventilated drift. Comparison of the results of analysis using the HEFF code with those obtained using a finite-element code

verifies the modeling strategy used and provides a basis for assessing the consequences of the approximate thermal analysis model used by the boundary-element code.

Physical Description

Geometrical data for the emplacement drift and the emplacement boreholes are given in Table 12; thermal and thermal-mechanical data are given in Table 13. The geometrical configuration is also illustrated schematically in Figure 23.

The nuclear waste is assumed to comprise a mix of PWR and BWR spent fuel that has been stored for an average of 8.55 years since removal from the reactors. Its power generation, as a function of time, is defined by the following normalized decay function

$$P(t) = 0.15601\exp(-0.00135t) + 0.59787\exp(-0.01914t) \\ + 0.15227\exp(-0.05188t) + 0.09384\exp(-0.43708t)$$

in which t is time in years since emplacement. For each drift, the thermal loading at the time of emplacement is equivalent to 590.5 W/m.

Assumptions

The problem is solved as one of two-dimensional plane strain. In the case of the finite-element model, the room and pillar centerlines are treated as vertical planes of symmetry, thereby simulating an infinite array of such drifts. In the case of the boundary-element model, the potential repository is assumed to comprise 37 parallel drifts 300 m below the ground surface. A plane of symmetry through the middle of the central drift is imposed, thereby requiring that the location of only 19 drifts be explicitly represented in the model (see Figure 23).

The boundary-element approximation to the real problem is shown in Figure 24. In Figure 24a, the repository scale illustrating the surface and edge boundary elements and the heat source locations is shown. In Figure 24b, the detailed representation of the central room is shown. Boundary elements were used to represent the next adjacent room (illustrated in Figure 23). Drifts further from

the centerline are assumed to have no influence on the state of stress and deformation around the central drift and therefore are not modeled. However, the effect of the emplaced, heat-generating waste at each drift location is considered. The edge boundary elements with the condition of no lateral deformation were imposed, simulating the far-field effect of the free surface as in Example 5. This approach gave superior results to modeling the surface with stress-free boundary elements out to 1000 meters.

The ground surface is assumed to be isothermal; heat equivalent to 590.5 W/m is input at each drift location. For the finite-element model, this input is distributed uniformly over the container as it appears in the cross section of the drift. For the boundary-element model, the emplaced containers are approximated by line heat sources. In the case of the central drift, around which temperature, displacements, and stresses are calculated, the heat generated by the container is approximated by three line heat sources approximately 3.8 m, 5.3 m, and 6.9 m below the centerline of the floor of the drift. The strength of each of those sources is given by

$$\text{Strength} = \frac{1}{3} \frac{Q_0}{\rho c} = \frac{590.5}{3 \cdot 2.25} \frac{\text{W/m}}{\text{J/cm}^3 \cdot ^\circ\text{C}} = 2760.7 \text{ m}^3 \cdot ^\circ\text{C/yr/m}$$

in which Q_0 is the initial thermal loading of the drift and ρ and c are respectively the density and specific heat capacity. At all other locations the emplaced containers are approximated by a single line heat source at midheight.

Since the thermal model in the HEFF code is based on the solution for a line heat source in an infinite medium, the thermal and thermal stress analyses are performed as though the drift is not present. This situation corresponds reasonably closely with that of an unventilated drift. That condition was simulated in the finite-element model by ascribing to the air in the drift an effective thermal conductivity of 80 W/m $^\circ$ C, and density and specific heat capacity of 1.0 kg/m 3 and 1 KJ/kg $^\circ$ C, respectively. The rationale for selection of the value of effective thermal conductivity is discussed by St. John (1987).

Input Specifications

Details of the boundary-element idealization of the model are provided in Figure 24. The second drift, which is located approximately 34 m from the model

centerline, was modeled using 16 elements to define its circumference. The internal sample points marked on Figure 24b are points at which data is generated for postprocessing. The vertical edge was modeled using 20 boundary elements located at $x = 324$ m and extending from $y = 0$ to $y = -600$ meters. The image heat source option has been used to enforce an isothermal boundary at the ground surface. The strengths of the heat sources beneath the central drift have been halved because they lie upon the imposed plane of symmetry ($x = 0$). A complete listing of input for analysis of conditions 10 years after waste emplacement is reproduced in Figure 25. Data for other sample times is identical, with the exception of the value for the time.

Output

A complete file for the the sample data set is reproduced in Appendix B. A comparison of the results of the boundary-element and finite-element analyses is provided in Table 14. The results of postprocessing output data from both boundary-element and finite-element analyses, using the rock mass strength data listed in Table 13 and a Mohr-Coulomb strength model, are reproduced in Figure 26.

Discussion

In general, the agreement between the results of the two numerical simulations is excellent. Some differences between the predicted temperatures around the drift may be observed. There is almost no temperature gradient across the drift in the case of the finite-element model because the air in the drift was assumed to have a high thermal conductivity and low heat capacity, in contrast to the boundary-element model in which, in effect, the air is assumed to have the same thermal properties as the rock mass. Despite this difference, the predicted temperatures at the midheight of the drift compare very favorably with one another. The stresses and displacements also agree favorably. Postprocessing to determine contours of the ratio of the rock mass strength to the computed stress state provides nearly identical results, even given differences in the location and density of sample points used to develop the plots.

4.2.7 Conclusion From Verification Studies

The verification studies described in this section provide definitive evidence of the accuracy of the HEFF code when performing mechanical stress analyses. These findings are consistent with reports of other investigators, including Crouch and Starfield (1983). It is concluded that HEFF is appropriate for mechanical stress analyses, providing the assumptions of linear elasticity, homogeneity, and elastic isotropy are justifiable. In addition to assuring that these assumptions are justifiable, the user should assure that an adequate number of elements are used to define the boundary of the structure analyzed, by performing sample analyses using different element densities.

The verification studies also serve to clarify the numerical and physical approximations inherent in the thermal and thermal-mechanical models. Despite these approximations, the computed values for temperature, displacement, and stress appear to be in good agreement with both closed-form solutions and an independent finite-element analysis. Accordingly, the code is recommended for simple thermal-mechanical analyses. However, any such analysis should be primarily of a scoping nature and the user should carefully evaluate the possible consequences of the physical approximations imposed by the code.

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TABLE 1

**COMPARISON OF TABULATED AND COMPUTED VALUES
OF THE EXPONENTIAL INTEGRAL**

x	-E ₁ (-x)	Equation (51)	Equation (49) Terms in Series		
			11	13	15
0.01	4.03793 ¹	0.1672*10 ¹¹	4.03793	4.03793	4.03793
0.10	1.82292 ¹	0.1443*10 ⁶	1.82292	1.82292	1.82292
0.30	0.90568 ¹	0.4345*10 ³	0.90568	0.90568	0.90568
0.50	0.55977 ²	0.2551*10 ²	0.55977	0.55977	0.55977
0.80	0.31059 ²	0.1863*10 ¹	0.31060	0.31060	0.31060
1.00	0.21938 ²	0.61077	0.21938	0.21938	0.21938
2.00	0.04890 ²	0.05064	0.04890	0.04890	0.04890
3.00	0.01305 ³	0.01364	0.01312	0.01305	0.01305
3.20	0.01013 ³	0.01056	0.01030	0.01014	0.01013
3.40	0.00789 ³	0.00820	0.00822	0.00791	0.00789
3.60	0.00616 ³	0.00639	0.00682	0.00620	0.00616
3.80	0.00482 ³	0.00499	0.00658	0.00491	0.00482
4.00	0.00378 ³	0.00391	0.00604	0.00396	0.00379
5.00	0.00115 ³	0.00118	0.03234	0.00495	0.00150
9.00	0.00001 ²	0.00001	29.65	11.92	3.67

Notes: 1: Derived from tabulated values of $x^{-1}[E_1(x) + \ln x + \gamma]$

2: Tabulated as $E_1(x)$

3: Derived from tabulated values of $xe^x E_1(x)$

Reference: Gautschi and Cahill, 1980

TABLE 2

COMPUTED VALUES OF THE RADIAL STRESS (MPa)
FOR VARIOUS SAMPLE POINTS AND AT VARIOUS TIMES

Time (yrs)	Sample Point		Distance (m) From Source		
	0.1	1.0	10.0	100.0	500.0
1	1.753	0.924	0.16	---	---
10	0.970	0.633	0.288	0.013	---
50	0.069	0.063	0.056	0.018	---
100	0.024	0.023	0.022	0.013	0.0008
200	0.014	0.011	0.010	0.008	0.0008
300	o.f.	0.007	0.006	0.006	---
400	o.f.	o.f.	0.005	0.005	---
500	---	---	---	---	---

Note: o.f. indicates numerical overflow

TABLE 3

OUTPUT FILE NOMENCLATURE

Name	Meaning
UX/UY	x/y displacements for element center or sample point
US/UN	Shear/normal displacements of element center
SIGXX/YY	Normal stress in xx/yy direction
SIGXY	Shear stress acting on the plane normal to the x-axis
SIGZZ	Out-of-plane normal stress
SIGMA-S	Shear traction on boundary element
SIGMA-N	Normal traction on boundary element
SIGMA-T	Tangential stress, parallel to element surface
SIG1	More compressive, in-plane principal stress
SIG2	Less compressive, in-plane principal stress
ALPHA	Angle of SIG1, measured counterclockwise from x

Note: See Figure 4 for a definition of global and local coordinate frames. Displacements, stress, and tractions are treated as positive if acting against the positive coordinate direction. These sign conventions are illustrated in Figure 8.

TABLE 4
COMPARISON OF ANALYTIC AND HEFF ANALYSES FOR DISPLACEMENTS AND STRESSES IN A THICK-WALLED CYLINDER
SUBJECT TO EXTERNAL PRESSURE

Radial Distance (m)	Analytical Solution					HEFF				
	Radial Displacement (mm)	Radial Stress (MPa)	Hoop Stress (MPa)	Out-of-Plane Stress (MPa)	Radial Displacement (mm)	E*	Radial Stress (MPa)	Hoop Stress (MPa)	Out-of-Plane Stress (MPa)	E
4.0	1.350	0.00	21.60	5.40	1.370	+1.16	0.00	21.58	-0.09	5.40
4.4	1.313	1.87	19.73	5.40	1.334	+1.16	1.64	19.94	+1.06	5.40
4.8	1.290	3.30	18.30	5.40	1.309	+1.5	3.09	18.49	+1.04	5.40
5.2	1.277	4.41	17.19	5.40	1.295	+1.4	4.23	17.35	+0.93	5.40
5.6	1.273	5.29	16.31	5.40	1.289	+1.3	5.15	16.43	+0.74	5.40
6.0	1.275	6.00	15.60	5.40	1.287	+1.2	6.00**	15.58	-0.13	5.40

* E = Percent Difference Between Solutions

** Results for Element 74, See Appendix B, Point (6.0) is Outside HEFF Model

TABLE 5

COMPARISON OF ANALYTIC AND HEFF ANALYSIS FOR DISPLACEMENTS AND STRESSES AROUND A CIRCULAR HOLE IN AN ELASTIC PLATE WITH BIAXIAL INITIAL STRESS STATE

Radial Distance (m)	Analytical Solution*					HEFF*				
	Radial Dis- place- ment (m)	Radial Stress (MPa)	Hoop Stress (MPa)	Out-of-Plane Stress (MPa)	Radial Displacement (m)	E** (MPa)	Radial Stress (MPa)	Hoop Stress (MPa)	Out-of-Plane Stress (MPa)	E
5.00	-3.506	0.00	15.00	-7.50	-3.960	+1.41	0.00	15.00	-7.50	0.0
5.40	-3.720	1.53	17.75	-6.43	-3.774	+1.45	1.19	17.69	-6.53	+1.56
5.80	-3.540	3.41	19.29	-5.58	-3.592	+1.47	3.07	19.28	-5.66	+1.43
6.20	-3.370	5.37	20.12	-4.88	-3.420	+1.48	5.05	20.14	-4.95	+1.43
6.60	-3.211	7.28	20.50	-4.31	-3.259	+1.49	6.97	20.54	-4.37	+1.39
7.00	-3.064	9.07	20.62	-3.83	-3.109	+1.47	8.78	20.67	-3.89	+1.57
7.40	-2.926	10.72	20.58	-3.43	-2.970	+1.5	10.45	20.64	-3.48	+1.46

* Data is Presented for a Radial Line Parallel to the Maximum Principal Initial Stress

** E = Percent Difference Between Solutions

TABLE 6

COMPARISON OF STRES3D AND HEFF ANALYSIS FOR TEMPERATURE, STRESS, AND DISPLACEMENTS FOR SINGLE LINE HEAT SOURCE IN AN INFINITE MEDIUM - CASE A, CONSTANT STRENGTH SOURCE

STRES3D

Radial Distance (m)	Temperature (°C)		Radial Stress (MPa)		Radial Displacement (mm)	
	1	10	1	10	1	10
1	92.41	144.50	10.69	15.97	21.29	-13.41
11	4.65	40.53	1.89	6.28	11.49	-54.76
21	0.11	16.74	0.60	3.60	8.56	-60.00
51	0.00	0.80	0.10	1.00	4.70	-40.13
101	0.00	0.00	0.03	0.27	2.19	-20.55
151	0.00	0.00	0.01	0.12	1.17	-13.41
201	0.00	0.00	0.01	0.07	0.69	-9.76
						-17.57
						-99.55
						-141.10
						-186.10
						-168.00
						-128.60
						-96.99

HEFF

Radial Distance (m)	Temperature (°C)		Radial Stress (MPa)		Radial Displacement (mm)	
	1	10	1	10	1	10
1	95.01	147.10	11.88	17.15	22.42	-13.63
11	4.64	40.53	1.89	6.27	11.44	-54.81
21	0.11	16.74	0.60	3.60	8.51	-60.00
51	0.00	0.80	0.10	1.00	4.65	-40.33
101	0.00	0.00	0.00	0.26	2.14	-20.94
151	0.00	0.00	0.00	0.12	1.12	-14.01
201	0.00	0.00	0.00	0.07	0.65	-10.52
						-17.82
						-100.00
						-142.00
						-188.30
						-172.10
						-134.60
						-104.60

TABLE 8

COMPARISON OF STRES3D AND HEFF ANALYSIS FOR TEMPERATURE, STRESS, AND DISPLACEMENTS FOR SINGLE LINE HEAT SOURCE IN AN INFINITE MEDIUM - CASE C, DECAYING SOURCE, $\lambda = 0.25$

STRES3D

Radial Distance (m)	Temperature (°C)		Radial Stress (MPa)		Radial Displacement (mm)	
	1	10	1	10	1	10
1	76.48	22.22	0.95	2.36	-0.76	-0.19
11	4.29	11.51	0.94	1.44	-1.45	-1.26
21	0.11	6.49	0.91	1.03	-0.89	-1.71
51	0.00	0.50	0.75	0.36	-0.36	-1.44
101	0.00	0.00	0.38	0.09	-0.18	-0.75
151	0.00	0.00	0.12	0.04	-0.12	-0.49
201	0.00	0.00	0.03	0.03	-0.09	-0.36
						-0.01
						-0.08
						-0.15
						-0.34
						-0.49
						-0.46
						-0.38

HEFF

Radial Distance (m)	Temperature (°C)		Radial Stress (MPa)		Radial Displacement (mm)	
	1	10	1	10	1	10
1	78.50	22.40	0.00	2.45	-0.77	-0.20
11	4.29	11.50	0.00	1.44	-1.45	-1.26
21	0.11	6.49	0.00	1.02	-0.88	-1.71
51	0.00	0.49	0.00	0.36	-0.37	-1.45
101	0.00	0.00	0.00	0.10	0.00	-0.77
151	0.00	0.00	0.00	0.04	0.00	-0.51
201	0.00	0.00	0.00	0.02	0.00	-0.39
						0.00
						0.00
						0.00
						0.00
						0.00
						0.00
						0.00

TABLE 9

COMPARISON OF STRES3D AND HEFF ANALYSIS FOR TEMPERATURE, STRESS, AND DISPLACEMENTS FOR SINGLE LINE HEAT SOURCE IN AN INFINITE MEDIUM - CASE D, 4 COMPONENT, DECAYING SOURCE

STRES3D

Radial Distance (m)	Temperature (°C)		Radial Stress (MPa)			Radial Displacement (mm)			
	1	10	100	1	10	100	1	10	100
1	88.61	110.93	52.45	10.23	12.22	5.62	-0.88	-1.02	-0.46
11	4.56	33.03	28.30	1.84	4.99	3.41	-1.60	-4.36	-2.94
21	0.11	14.18	21.28	0.58	2.93	2.72	-0.97	-4.88	-4.46
51	0.00	0.72	10.85	0.10	0.84	1.71	-0.40	-3.36	-6.74
101	0.00	0.00	3.26	0.03	0.22	0.90	-0.20	-1.72	-6.91
151	0.00	0.00	0.72	0.02	0.10	0.51	-0.13	-1.12	-5.58
201	0.00	0.00	0.11	0.01	0.06	0.31	-0.09	-0.82	-4.28

HEFF

Radial Distance (m)	Temperature (°C)			Radial Stress (MPa)			Radial Displacement (mm)		
	1	10	100	1	10	100	1	10	100
1	91.08	112.90	53.02	11.36	13.10	5.87	-0.90	-1.04	-0.47
11	4.56	33.04	28.27	1.84	4.99	3.38	-1.61	-4.36	-2.96
21	0.11	14.19	21.24	0.58	2.93	2.69	-0.97	-4.89	-4.49
51	0.00	0.73	10.82	0.10	0.83	1.68	-0.40	-3.96	-6.82
101	0.00	0.00	3.24	0.00	0.22	0.88	0.00	-1.76	-7.07
151	0.00	0.00	0.71	0.00	0.10	0.48	0.00	-1.17	-5.83
201	0.00	0.00	0.11	0.00	0.06	0.28	0.00	-0.88	-4.60

TABLE 10
COMPARISON OF ANALYTIC AND HEFF ANALYSIS OF DISPLACEMENTS AND STRESSES THROUGH A HEATED THICK CYLINDER

Radial Distance	Analytical Solution				HEFF			
	Radial Displacement (mm)	Radial Stress (MPa)	Hoop Stress (MPa)	Radial Displacement (mm)	E*	Radial Stress (MPa)	E	Hoop Stress (MPa)
4.0	-1.08	0.00	4.05	-1.031	-4.54	0.00	0.00	4.63
4.33	-1.19	0.24	2.40	-1.147	-3.61	0.15	-37.50	3.05
4.67	-1.29	0.34	0.96	-1.251	-3.02	0.00	-11.76	1.60
5.0	-1.38	0.35	-0.25	-1.345	-2.54	0.34	0.00	0.35
5.33	-1.47	0.28	-1.30	-1.431	-2.65	0.31	+10.71	-0.72
5.67	-1.54	0.15	-2.23	-1.510	-1.95	0.22	+46.67	-1.65
6.0	-1.61	0.00	-3.01	-1.581	-1.80	0.00	0.00	-2.36**
								-21.59

* E = Percent Difference Between Solutions

** Result for Element 74, See Appendix B, Point (6.0,0) is Outside HEFF Model

TABLE 11

COMPARISON OF ANALYTIC AND HEFF TEMPERATURES AND STRESSES IN A SEMI-INFINITE REGION WITH HEATED LAYER

Depth Below Surface (m)	Analytic Solution			HEFF Analysis						
	Temp. (°C)	Horiz. Stress (MPa)	Vert. Stress (MPa)	Temp. (°C)	E*	In-Plane Horiz. Stress	E	Out-of-Plane Horiz. Stress	E	Vert. Stress
0	0.00	0.0	0.0	0.0	0.00	0.70	---	0.21	---	0.0
10	24.05	11.54	0.0	23.91	-0.58	11.91	-3.2	11.68	0.34	0.04
20	52.48	25.19	0.0	52.18	-0.57	25.37	0.71	25.28	-0.27	-0.03
30	89.84	43.12	0.0	89.31	-0.59	43.11	0.02	43.12	-0.49	-0.08
40	140.8	67.60	0.0	140.10	-0.50	67.38	-0.33	67.43	-0.54	-0.14
50	210.5	101.05	0.0	209.4	-0.52	100.6	-0.45	100.7	-0.54	-0.19
60	303.9	145.85	0.0	302.4	-0.49	145.1	-0.51	145.3	-0.61	-0.22
70	425.9	204.41	0.0	423.8	-0.49	203.3	-0.54	203.5	-0.54	-0.25
80	580.9	278.86	0.0	578.2	-0.46	277.2	-0.59	277.6	-0.52	-0.25
90	772.2	370.64	0.0	768.9	-0.42	368.5	-0.58	369.0	-0.47	-0.24
95	882.7	423.72	0.0	878.6	-0.46	421.9	-0.61	421.7	-0.52	0.34

* E = Percent Difference Between Solutions

TABLE 12

GEOMETRICAL DATA FOR ANALYSIS OF A
VERTICAL EMPLACEMENT DRIFT

	Feet	
Drift Dimensions		
Width	6.0	(4.88 m)
Height	22.0	(6.71 m)
Radius of Roof Arch	9.0	(2.74 m)
Emplacement Drift Spacing	112.0	(34.14 m)
Depth Below Ground Surface	984.3	(300.0 m)
Container Borehole Dimensions		
Depth	25.00	(7.62 m)
Diameter	2.42	(0.74 m)

TABLE 13

THERMAL AND THERMAL-MECHANICAL DATA FOR ANALYSIS
OF A VERTICAL EMPLACEMENT DRIFT

Rock Mass

Specific Gravity	2.34 g/cc
Young's Modulus	15.1 GPa
Poisson's Ratio	0.2
Thermal Conductivity	
(25 to 100°C temp. range)	2.07 W/m°K
Thermal Capacitance	2.25 J/cm ³ K
Thermal Expansion(*10 ⁶)	
(25 to 200°C temp. range)	10.7 * 10 ⁻⁶ C ⁻¹
Horiz./Vert. In-Situ Stress	0.55
Ground Surface Temperature	16.0°C
Temperature Gradient	0.0239°C/m

Rock Matrix (for postprocessing only)

Unconfined Compressive Rock Strength	75.4 MPa
Tensile Strength	-9.0 MPa
Angle of Internal Friction	29.2°

TABLE 14

COMPARISON OF RESULTS OF BOUNDARY-ELEMENT AND FINITE-ELEMENT
ANALYSES OF A VERTICAL EMPLACEMENT DRIFT

Model Types and Time	Boundary Element (HEFF)				Finite Element (VISCOT)			
	t=0 yr	10 yr	35 yr	100 yr	t=0 yr	10 yr	35 yr	100 yr
<u>Temperature °C</u>								
Crown (27)	NC	61.65	93.17	104.9	23.0	73.4	101.8	108.5
Midfloor (1)	NC	90.34	114.0	115.3	23.0	75.9	103.6	109.3
Midwall (14)	NC	73.75	102.5	109.7	23.0	74.7	102.8	109.0
<u>Uy Displacement (cm)</u>								
Crown (27)	-0.2967	-1.721	-2.003	+0.743	+0.191	-2.330	-5.826	-10.382
Midfloor (1)	-0.7253	-1.843	-1.602	+1.473	-0.235	-2.341	-5.299	-9.332
Closure	+0.4286	+0.122	-0.401	-0.730	+0.426	+0.011	-0.527	-1.050
<u>Ux Displacement (cm)</u>								
Midwall	0.1161	0.3687	0.7381	0.833	+0.113	+0.399	+0.687	+0.791
Closure	0.2322	0.7374	1.476	1.666	0.226	0.800	1.374	1.582
<u>σT Stress (MPa)</u>								
Crown (27)	5.724	27.08	44.38	55.92	5.75	28.48	47.78	54.28
Midfloor (1)	0.7264	10.50	22.72	29.51	0.80	10.38	23.13	28.30
Midwall (14)	8.437	6.572	0.9031	-3.538	8.16	4.99	-1.24	-3.84

The following supplemental information is provided to clarify the meaning of various response measures.

Displacements are considered positive if in the negative coordinate direction.

Closure is negative if the dimension increases.

Compressive stresses are positive.

Note that in the case of finite-element analyses, the stresses are extrapolated to the nodal points using computed values at the element Gauss points and assuming a linear variation of stress within the element.

a) Single excavation;
infinite domain

b) Multiple excavation;
semi-infinite domain

c) Thick-walled, elastic
cylinder

d) Foundation problem

Figure 1. Classes of Problems That Can Be Analyzed Using The HEFF Boundary-Element Code

a) Excavation Surface S Subject to Imposed Surface Traction t_x, t_y and N Displacements u_x, u_y

b) Traction and Displacements Induced on Surface (S) in a Medium Stress-Free at Infinity

c) Discretization of Surface into Boundary Elements

Figure 2. Schematic Interpretation of Boundary-Element Idealization

Figure 3. Flowchart for the HEFF Code

a) Cross Section Through an Infinite Body

b) Physical Problem

c) Numerical Model

Figure 4. The Boundary-Element Method for a Cavity Problem

Figure 5. Exponential Integral Function (Hart, 1981)

Figure 6. Evaluation of Temperature, Displacement, and Stress by the Thermal and Thermal-Mechanical Submodel

Figure 7. Drawing Showing Reference Coordinates and Illustrating Symmetry and Image Options

a) Displacements and Stresses in the Interior: Normal stresses are positive if compressive. The sign convention for displacements corresponds (i.e., displacements are positive if directed toward the origin).

(b)

b) Boundary Stresses: Normal stresses are positive if compressive, while shear stresses are positive if to the left with respect to the outward normal.

(c)

c) Principal Stresses: The major principal stress calculated for interior points is the most compressive stress and is oriented at an angle measured counter-clockwise from the positive direction.

Figure 8. Sign Conventions for the HEFF Code

Figure 9. Designation of Variables Defining Segments, Elements, and Internal Sample Points

Figure 10. Boundary-Element Model for Analysis of Vertical Emplacement

```

VERT10S
HEFF 4 1
VERTICAL EMPLACEMENT - OUTPUT AT T=10 YRS.
4 0 3 4 1 1
0.2 15100.
0 -0.023 0 0 0 0 0.55 0 0.55 1
10.
-0.0239 16.9
29.03 10.7E-6
0 .15602 .0013539
0 .59787 .019142
0 .15227 .051888
0 .09384 .43768
0 0 -305.812 1380.328 0.0
0 0 -307.335 1380.328 0.0
0 0 -308.858 1380.328 0.0
6 1 0 -302. 2.34 -302. 0. 0. 0. 0. 0.
1 1 2.34 -302. 2.44 -301.9 0. 0. 0. 0. 0.
12 1 2.44 -301.9 2.44 -296.78 0. 0. 0. 0. 0.
8 1 0 -298.03 27.13 90.0 2.74 0. 0. 0. 0.
.3 1.50 6 27

```

Figure 11. Input to the HEFF Code for the Sample Problem

(Please find attached output data)

Figure 12. Output From Sample Problem

VERTICAL EMPLACEMENT - OUTPUT AT T=10 YRS. OUTPUT CREATED ON 12/ 7/1987

17	.2440E+01	-.2078E+03	.7576E-03	-.4341E-02	-.4341E-02	-.7576E-03	.1629E+02	.6103E+02
	-.1788E-05	.1629E+02	-.2617E-06	.1088E+02	.2617E-06	-.1788E-05		
18	.2440E+01	-.2074E+03	.6093E-03	-.4250E-02	-.4250E-02	-.6093E-03	.1836E+02	.5067E+02
	-.1252E-05	.1836E+02	-.2941E-06	.1108E+02	.2941E-06	-.1252E-05		
19	.2440E+01	-.2070E+03	.3898E-03	-.4059E-02	-.4059E-02	-.3898E-03	.2492E+02	.5038E+02
	-.8047E-06	.2492E+02	.4197E-06	.1218E+02	-.4197E-06	-.8047E-06		
20	.2342E+01	-.2066E+03	.1771E-03	-.3560E-02	-.3141E-02	.1685E-02	.2011E+02	.5735E+02
	.7483E+01	.2063E+02	-.1242E+02	.1285E+02	.1891E-05	-.5083E-06		
21	.2127E+01	-.2063E+03	.1211E-03	-.3207E-02	-.2571E-02	.1921E-02	.2177E+02	.5660E+02
	.8590E+01	.1318E+02	-.1084E+02	.1126E+02	-.2124E-05	-.2891E-05		
22	.1872E+01	-.2060E+03	.8837E-04	-.2927E-02	-.2089E-02	.2073E-02	.1814E+02	.5588E+02
	.9835E+01	.8510E+01	-.8055E+01	.1043E+02	.1227E-05	.2023E-05		
23	.1582E+01	-.2058E+03	.8418E-04	-.2698E-02	-.1614E-02	.2183E-02	.1520E+02	.5543E+02
	.1011E+02	.5092E+01	-.7174E+01	.9757E+01	-.8147E-03	.6695E-05		
24	.1262E+01	-.2056E+03	.4520E-04	-.2514E-02	-.1201E-02	.2208E-02	.1272E+02	.5501E+02
	.1801E+02	.2714E+01	-.5212E+01	.9193E+01	.2464E-06	.3901E-05		
25	.9191E+00	-.2055E+03	.2994E-04	-.2375E-02	-.8266E-03	.2227E-02	.1076E+02	.5470E+02
	.9541E+01	.1216E+01	-.3408E+01	.8748E+01	-.2993E-05	.1138E-05		
26	.5584E+00	-.2054E+03	.1703E-04	-.2282E-02	-.4820E-03	.2230E-02	.9368E+01	.5440E+02
	.8999E+01	.5919E+00	-.1878E+01	.8440E+01	.5208E-06	-.4372E-06		
27	.1873E+00	-.2053E+03	.5521E-05	-.2235E-02	-.1586E-03	.2230E-02	.8683E+01	.5438E+02
	.8642E+01	.4075E-01	-.5934E+00	.8282E+01	-.3157E-06	-.3395E-05		

TIME REQUIRED TO COMPUTE BOUNDARY STRESSES AND DISPLACEMENTS= 9.77 SECONDS.

INTERIOR STRESSES AND DISPLACEMENTS AT TIME = .100E+02

POINT	X-COORD SIGXX	Y-COORD SIGYY	UX SIGXY	UY SIGZZ	SIG1	SIG2	ALPHA	TEMP
1	.1950E+00	-.3023E+03	-.1488E-03	-.8540E-02	.2309E+01	.3318E+00	.5681E+01	.6387E+02
	.2290E+01	.3512E+00	.1948E+00	.1185E+02				
2	.1950E+00	-.3028E+03	-.1039E-03	-.8009E-02	.6845E+01	.1145E+01	.5313E+01	.8724E+02
	.8796E+01	.1194E+01	.5255E+00	.1346E+02				
3	.1950E+00	-.3034E+03	-.7753E-04	-.7184E-02	.1079E+02	.3568E+01	.6669E+01	.9309E+02
	.1070E+02	.3666E+01	.8334E+00	.1569E+02				
4	.1950E+00	-.3044E+03	-.9197E-04	-.6016E-02	.1320E+02	.8065E+01	.9863E+01	.1049E+03
	.1305E+02	.8218E+01	.8752E+00	.1897E+02				
5	.1950E+00	-.3060E+03	-.1604E-03	-.4302E-02	.1653E+02	.1431E+02	.4747E+00	.1373E+03
	.1653E+02	.1431E+02	.1841E-01	.2614E+02				
6	.1950E+00	-.3082E+03	-.1720E-03	-.1885E-02	.1698E+02	.1463E+02	.8687E+02	.1329E+03
	.1464E+02	.1697E+02	.1280E+00	.2558E+02				
7	.5850E+00	-.3023E+03	-.4382E-03	-.8426E-02	.3026E+01	.2398E+00	.1316E+02	.8363E+02
	.2882E+01	.3841E+00	.6177E+00	.1184E+02				
8	.5850E+00	-.3028E+03	-.3048E-03	-.7886E-02	.7751E+01	.9419E+00	.1451E+02	.8693E+02
	.7323E+01	.1369E+01	.1851E+01	.1356E+02				
9	.5850E+00	-.3034E+03	-.2304E-03	-.7073E-02	.1169E+02	.3204E+01	.1821E+02	.9264E+02
	.1086E+02	.4032E+01	.2510E+01	.1572E+02				
10	.5850E+00	-.3044E+03	-.2739E-03	-.5933E-02	.1411E+02	.7253E+01	.2365E+02	.1030E+03
	.1300E+02	.8356E+01	.2518E+01	.1881E+02				
11	.5850E+00	-.3060E+03	-.4306E-03	-.4269E-02	.1632E+02	.1236E+02	.2080E+02	.1261E+03
	.1502E+02	.1287E+02	.1310E+01	.2389E+02				
12	.5850E+00	-.3082E+03	-.4932E-03	-.1876E-02	.1570E+02	.1483E+02	.7928E+02	.1279E+03
	.1486E+02	.1576E+02	.1751E+00	.2458E+02				
13	.9750E+00	-.3023E+03	-.7031E-03	-.8173E-02	.4532E+01	.1413E+00	.1617E+02	.8316E+02
	.4181E+01	.4818E+00	.1175E+01	.1214E+02				
14	.9750E+00	-.3028E+03	-.4860E-03	-.7635E-02	.9571E+01	.8624E+00	.2149E+02	.8635E+02
	.8376E+01	.1858E+01	.3037E+01	.1377E+02				
15	.9750E+00	-.3034E+03	-.3788E-03	-.6853E-02	.1323E+02	.2743E+01	.2694E+02	.9178E+02
	.1108E+02	.4886E+01	.4237E+01	.1580E+02				
16	.9750E+00	-.3044E+03	-.4522E-03	-.5776E-02	.1519E+02	.6391E+01	.3122E+02	.1019E+03
	.1283E+02	.8756E+01	.3901E+01	.1855E+02				
17	.9750E+00	-.3060E+03	-.6675E-03	-.4191E-02	.1639E+02	.1103E+02	.2811E+02	.1189E+03
	.1520E+02	.1222E+02	.2228E+01	.2247E+02				
18	.9750E+00	-.3082E+03	-.7749E-03	-.1863E-02	.1491E+02	.1449E+02	.3032E+02	.1216E+03
	.1480E+02	.1460E+02	.1817E+00	.2331E+02				
19	.1365E+01	-.3023E+03	-.9215E-03	-.7774E-02	.7267E+01	.7480E-01	.1818E+02	.8249E+02
	.6567E+01	.7750E+00	.2132E+01	.1257E+02				
20	.1365E+01	-.3028E+03	-.6367E-03	-.7247E-02	.1246E+02	.4628E+00	.2783E+02	.8552E+02
	.9847E+01	.3077E+01	.4953E+01	.1417E+02				
21	.1365E+01	-.3034E+03	-.5251E-03	-.6532E-02	.1516E+02	.2464E+01	.3424E+02	.9059E+02
	.1114E+02	.6484E+01	.5905E+01	.1593E+02				
22	.1365E+01	-.3044E+03	-.6301E-03	-.5558E-02	.1614E+02	.5819E+01	.3666E+02	.9953E+02
	.1246E+02	.8497E+01	.4843E+01	.1825E+02				
23	.1365E+01	-.3060E+03	-.8841E-03	-.4080E-02	.1642E+02	.1010E+02	.3229E+02	.1131E+03
	.1462E+02	.1191E+02	.2856E+01	.2136E+02				
24	.1365E+01	-.3082E+03	-.1024E-02	-.1846E-02				

	.1452E+02	.1374E+02	.2587E+00	.2213E+02	.1460E+02	.1366E+02	.1667E+02	.1157E+03
25	.1755E+01 .1076E+02	-.3023E+03 .1062E+01	-.1060E-02 .4420E+01	-.7188E-02 .1351E+02	.1260E+02	.1206E+00	.2259E+02	.8164E+02
26	.1755E+01 .1113E+02	-.3028E+03 .6080E+01	-.7587E-03 .7550E+01	-.6713E-02 .1406E+02	.1657E+02	.6368E+00	.3577E+02	.8449E+02
27	.1755E+01 .1079E+02	-.3034E+03 .8945E+01	-.6808E-03 .7205E+01	-.6129E-02 .1812E+02	.1713E+02	.2603E+01	.4130E+02	.8916E+02
28	.1755E+01 .1192E+02	-.3044E+03 .1052E+02	-.6127E-03 .5579E+01	-.5298E-02 .1794E+02	.1685E+02	.5600E+01	.4143E+02	.8703E+02
29	.1755E+01 .1403E+02	-.3060E+03 .1182E+02	-.1087E-02 .3254E+01	-.3945E-02 .2042E+02	.1636E+02	.9488E+01	.3563E+02	.1061E+03
30	.1755E+01 .1416E+02	-.3082E+03 .1512E+02	-.1248E-02 .3710E+00	-.1022E-02 .2107E+02	.1427E+02	.1300E+02	.1775E+02	.1104E+03
31	.2145E+01 .1571E+02	-.3023E+03 .9286E+01	-.1089E-02 .1070E+02	-.6337E-02 .1580E+02	.2387E+02	.1332E+01	.3664E+02	.8004E+02
32	.2145E+01 .1077E+02	-.3028E+03 .1213E+02	-.8888E-03 .8469E+01	-.6065E-02 .1581E+02	.2094E+02	.1854E+01	.4708E+02	.8330E+02
33	.2145E+01 .1002E+02	-.3034E+03 .1195E+02	-.8805E-03 .7592E+01	-.5688E-02 .1631E+02	.1864E+02	.3329E+01	.4862E+02	.8757E+02
34	.2145E+01 .1130E+02	-.3044E+03 .1166E+02	-.1004E-02 .5768E+01	-.5016E-02 .1763E+02	.1725E+02	.5711E+01	.4588E+02	.9447E+02
35	.2145E+01 .1344E+02	-.3080E+03 .1188E+02	-.1282E-02 .3455E+01	-.3796E-02 .1960E+02	.1620E+02	.9114E+01	.3864E+02	.1037E+03
36	.2145E+01 .1375E+02	-.3082E+03 .1266E+02	-.1454E-02 .4061E+00	-.1703E-02 .2012E+02	.1394E+02	.1247E+02	.2083E+02	.1056E+03
37	.2602E+01 .1624E+02	-.3022E+03 .2603E+02	-.1227E-02 .7025E+01	-.5313E-02 .1863E+02	.2970E+02	.1257E+02	.6244E+02	.7862E+02
38	.2920E+01 .1131E+02	-.3025E+03 .1875E+02	-.1311E-02 .4545E+01	-.5050E-02 .1678E+02	.2173E+02	.9324E+01	.6645E+02	.7026E+02
39	.3398E+01 .9772E+01	-.3030E+03 .1054E+02	-.1535E-02 .3835E+01	-.4679E-02 .1503E+02	.1827E+02	.8040E+01	.6570E+02	.7983E+02
40	.4114E+01 .9608E+01	-.3037E+03 .1434E+02	-.1832E-02 .3289E+01	-.4128E-02 .1545E+02	.1603E+02	.7923E+01	.6287E+02	.7974E+02
41	.5188E+01 .9952E+01	-.3047E+03 .1251E+02	-.2499E-02 .2463E+01	-.3323E-02 .1402E+02	.1400E+02	.8455E+01	.5871E+02	.7771E+02
42	.6789E+01 .9972E+01	-.3064E+03 .1092E+02	-.3157E-02 .1250E+01	-.2233E-02 .1360E+02	.1178E+02	.9109E+01	.5535E+02	.7208E+02
43	.2740E+01 .8419E+01	-.3017E+03 .2738E+02	-.8492E-03 .9338E+01	-.5031E-02 .1719E+02	.3121E+02	.4594E+01	.6772E+02	.7587E+02
44	.3190E+01 .9779E+01	-.3017E+03 .1968E+02	-.1093E-02 .7151E+01	-.4824E-02 .1573E+02	.2344E+02	.6034E+01	.6236E+02	.7469E+02
45	.3865E+01 .8882E+01	-.3017E+03 .1636E+02	-.1402E-02 .5203E+01	-.4705E-02 .1458E+02	.1902E+02	.6212E+01	.6284E+02	.7280E+02
46	.4878E+01 .8134E+01	-.3017E+03 .1437E+02	-.1852E-02 .3835E+01	-.4403E-02 .1355E+02	.1619E+02	.6309E+01	.6455E+02	.6981E+02
47	.6396E+01 .7803E+01	-.3017E+03 .1286E+02	-.2459E-02 .2772E+01	-.4028E-02 .1241E+02	.1392E+02	.6547E+01	.6562E+02	.6531E+02
48	.8674E+01 .7658E+01	-.3017E+03 .1093E+02	-.3178E-02 .1670E+01	-.3605E-02 .1102E+02	.1186E+02	.6734E+01	.6486E+02	.5901E+02
49	.2740E+01 .1727E+01	-.3013E+03 .2348E+02	-.3135E-03 .3741E+01	-.4787E-02 .1474E+02	.2410E+02	.1101E+01	.8051E+02	.7386E+02
50	.3190E+01 .4893E+01	-.3013E+03 .2056E+02	-.7184E-03 .5927E+01	-.4856E-02 .1463E+02	.2255E+02	.2904E+01	.7144E+02	.7282E+02
51	.3865E+01 .6639E+01	-.3013E+03 .1714E+02	-.1166E-02 .5213E+01	-.4720E-02 .1402E+02	.1029E+02	.4481E+01	.6761E+02	.7113E+02
52	.4878E+01 .7105E+01	-.3013E+03 .1479E+02	-.1701E-02 .3881E+01	-.4468E-02 .1320E+02	.1642E+02	.5479E+01	.6733E+02	.6841E+02
53	.6396E+01 .7299E+01	-.3013E+03 .1287E+02	-.2361E-02 .2774E+01	-.4119E-02 .1216E+02	.1402E+02	.6154E+01	.6757E+02	.6424E+02
54	.8674E+01 .7402E+01	-.3013E+03 .1102E+02	-.3111E-02 .1984E+01	-.3710E-02 .1087E+02	.1190E+02	.6528E+01	.6620E+02	.5829E+02
55	.2740E+01 .6585E+00	-.3008E+03 .1984E+02	-.4906E-04 .1731E+01	-.4650E-02 .1349E+02	.1999E+02	.5035E+00	.8408E+02	.7195E+02
56	.3190E+01 .2348E+01	-.3008E+03 .1968E+02	-.3859E-03 .3863E+01	-.4755E-02 .1365E+02	.2051E+02	.1526E+01	.7799E+02	.7102E+02
57	.3865E+01 .4570E+01	-.3008E+03 .1755E+02	-.8219E-03 .4444E+01	-.4709E-02 .1342E+02	.1892E+02	.3194E+01	.7280E+02	.6950E+02
58	.4878E+01 .5999E+01	-.3008E+03 .1519E+02	-.1544E-02 .3688E+01	-.4506E-02 .1284E+02	.1647E+02	.4713E+01	.7069E+02	.6703E+02
59	.6396E+01 .6769E+01	-.3008E+03 .1398E+02	-.2281E-02 .2680E+01	-.4194E-02 .1194E+02	.1407E+02	.5778E+01	.6977E+02	.6317E+02
60	.8674E+01 .7139E+01	-.3008E+03 .1111E+02	-.3042E-02 .1972E+01	-.3807E-02 .1072E+02	.1192E+02	.6326E+01	.6760E+02	.5756E+02
61	.2740E+01 .3718E+00	-.3004E+03 .1776E+02	-.2976E-03 .8413E+00	-.4564E-02 .1272E+02	.1781E+02	.3210E+00	.8691E+02	.7012E+02
62	.3190E+01 .1292E+01	-.3004E+03 .1846E+02	-.1338E-03 .2411E+01	-.4664E-02 .1291E+02	.1880E+02	.9577E+00	.8213E+02	.6929E+02

63	.3885E+01	-.3004E+03	-.7071E-03	-.4883E-02	.1026E+02	.2375E+01	.7734E+02	.6703E+02
64	.4878E+01	-.3004E+03	-.1302E-02	-.4221E-02	.1637E+02	.4094E+01	.7423E+02	.6588E+02
65	.6398E+01	-.3004E+03	-.2181E-02	-.4254E-02	.1408E+02	.5442E+01	.7213E+02	.6210E+02
66	.6674E+01	-.3004E+03	-.2973E-02	-.3893E-02	.1192E+02	.6138E+01	.6903E+02	.5881E+02
67	.2740E+01	-.3000E+03	.4688E-03	-.4511E-02	.1658E+02	.2419E+00	.8813E+02	.6837E+02
68	.3190E+01	-.3000E+03	.4581E-04	-.4588E-02	.1761E+02	.7042E+00	.8408E+02	.6763E+02
69	.3885E+01	-.3000E+03	-.5388E-03	-.4010E-02	.1759E+02	.1904E+01	.8114E+02	.6840E+02
70	.4878E+01	-.3000E+03	-.1259E-02	-.4518E-02	.1615E+02	.3847E+01	.7770E+02	.6435E+02
71	.6398E+01	-.3000E+03	-.2088E-02	-.4300E-02	.1399E+02	.5163E+01	.7455E+02	.6104E+02
72	.6674E+01	-.3000E+03	-.2804E-02	-.3875E-02	.1180E+02	.5988E+01	.7047E+02	.5605E+02
73	.2740E+01	-.2898E+03	.5741E-03	-.4474E-02	.1585E+02	.2030E+00	.8902E+02	.6671E+02
74	.3190E+01	-.2898E+03	.1641E-03	-.4525E-02	.1684E+02	.5919E+00	.8713E+02	.6604E+02
75	.3885E+01	-.2898E+03	-.4145E-03	-.4550E-02	.1702E+02	.1664E+01	.8438E+02	.6493E+02
76	.4878E+01	-.2898E+03	-.1150E-02	-.4499E-02	.1586E+02	.3389E+01	.8098E+02	.6305E+02
77	.6398E+01	-.2898E+03	-.1980E-02	-.4336E-02	.1387E+02	.4951E+01	.7694E+02	.5998E+02
78	.6674E+01	-.2898E+03	-.2836E-02	-.4048E-02	.1186E+02	.5810E+01	.7189E+02	.5528E+02
79	.2740E+01	-.2891E+03	.6283E-03	-.4440E-02	.1552E+02	.1878E+00	.8980E+02	.6512E+02
80	.3190E+01	-.2891E+03	.2290E-03	-.4466E-02	.1642E+02	.5629E+00	.8904E+02	.6452E+02
81	.3885E+01	-.2891E+03	-.3383E-03	-.4489E-02	.1659E+02	.1592E+01	.8731E+02	.6350E+02
82	.4878E+01	-.2891E+03	-.1069E-02	-.4473E-02	.1555E+02	.3247E+01	.8409E+02	.6178E+02
83	.6398E+01	-.2891E+03	-.1904E-02	-.4363E-02	.1370E+02	.4808E+01	.7924E+02	.5894E+02
84	.6674E+01	-.2891E+03	-.2770E-02	-.4115E-02	.1180E+02	.5673E+01	.7326E+02	.5452E+02
85	.2740E+01	-.2887E+03	.6343E-03	-.4403E-02	.1551E+02	.1924E+00	.8938E+02	.6360E+02
86	.3190E+01	-.2887E+03	.2448E-03	-.4406E-02	.1628E+02	.6065E+00	.8905E+02	.6306E+02
87	.3885E+01	-.2887E+03	-.3056E-03	-.4428E-02	.1629E+02	.1667E+01	.8984E+02	.6213E+02
88	.4878E+01	-.2887E+03	-.1016E-02	-.4445E-02	.1522E+02	.3265E+01	.8700E+02	.6055E+02
89	.6398E+01	-.2887E+03	-.1840E-02	-.4384E-02	.1350E+02	.4730E+01	.8138E+02	.5791E+02
90	.6674E+01	-.2887E+03	-.2706E-02	-.4176E-02	.1172E+02	.5553E+01	.7455E+02	.5375E+02
91	.2740E+01	-.2883E+03	.5931E-03	-.4353E-02	.1586E+02	.2254E+00	.8836E+02	.6215E+02
92	.3190E+01	-.2883E+03	.2135E-03	-.4339E-02	.1641E+02	.7483E+00	.8682E+02	.6165E+02
93	.3885E+01	-.2883E+03	-.3132E-03	-.4368E-02	.1607E+02	.1903E+01	.8692E+02	.6081E+02
94	.4878E+01	-.2883E+03	-.9887E-03	-.4417E-02	.1487E+02	.3408E+01	.8970E+02	.5935E+02
95	.6398E+01	-.2883E+03	-.1786E-02	-.4401E-02	.1326E+02	.4707E+01	.8331E+02	.5690E+02
96	.6674E+01	-.2883E+03	-.2646E-02	-.4232E-02	.1162E+02	.5450E+01	.7575E+02	.5298E+02
97	.2740E+01	-.2878E+03	.5023E-03	-.4281E-02	.1671E+02	.3205E+00	.8581E+02	.6076E+02
98	.3190E+01	-.2878E+03	.1353E-03	-.4261E-02	.1678E+02	.1072E+01	.8392E+02	.6031E+02
99	.3885E+01	-.2878E+03	-.3558E-03	-.4310E-02	.1586E+02	.2332E+01	.8383E+02	.5953E+02
100	.4878E+01	-.2878E+03	-.9825E-03	-.4394E-02	.1449E+02	.3658E+01	.8787E+02	.5819E+02
101	.6398E+01	-.2878E+03	-.1743E-02	-.4418E-02	.1300E+02	.4726E+01	.8498E+02	.5591E+02

102	.8074E+01	-.2070E+03	-.2500E-02	-.4203E-02	.1151E+02	.5361E+01	.7003E+02	.5222E+02
	.5600E+01	.1110E+02	.1384E+01	.0375E+01				
103	.2740E+01	-.2074E+03	.3543E-03	-.4172E-02	.1834E+02	.8332E+00	-.8303E+02	.5043E+02
	.8375E+00	.1814E+02	-.1801E+01	.1118E+02				
104	.3190E+01	-.2074E+03	.1251E-04	-.4173E-02	.1722E+02	.1770E+01	-.7903E+02	.5001E+02
	.2231E+01	.1875E+02	-.2850E+01	.1110E+02				
105	.3085E+01	-.2074E+03	-.4241E-03	-.4201E-02	.1555E+02	.2075E+01	-.8077E+02	.5030E+02
	.3280E+01	.1523E+02	-.1882E+01	.1088E+02				
106	.4070E+01	-.2074E+03	-.0908E-03	-.4078E-02	.1407E+02	.3075E+01	-.8585E+02	.5708E+02
	.4020E+01	.1402E+02	-.7205E+00	.1059E+02				
107	.8398E+01	-.2074E+03	-.1707E-02	-.4435E-02	.1273E+02	.4770E+01	.0835E+02	.5404E+02
	.4803E+01	.1270E+02	-.5038E+00	.1014E+02				
108	.8074E+01	-.2074E+03	-.2533E-02	-.4331E-02	.1139E+02	.5282E+01	.7770E+02	.5140E+02
	.5555E+01	.1112E+02	.1283E+01	.0412E+01				
109	.2740E+01	-.2070E+03	.1423E-03	-.4017E-02	.2004E+02	.1081E+01	-.7720E+02	.5815E+02
	.2868E+01	.1074E+02	-.4014E+01	.1180E+02				
110	.3190E+01	-.2070E+03	-.1365E-03	-.4094E-02	.1718E+02	.3071E+01	-.7541E+02	.5777E+02
	.3066E+01	.1628E+02	-.3440E+01	.1115E+02				
111	.3065E+01	-.2070E+03	-.5017E-03	-.4226E-02	.1505E+02	.3730E+01	-.7833E+02	.5711E+02
	.4201E+01	.1450E+02	-.2240E+01	.1075E+02				
112	.4078E+01	-.2070E+03	-.1008E-02	-.4370E-02	.1363E+02	.4301E+01	-.8442E+02	.5597E+02
	.4390E+01	.1354E+02	-.8030E+00	.1039E+02				
113	.6396E+01	-.2070E+03	-.1677E-02	-.4453E-02	.1246E+02	.4022E+01	.8740E+02	.5390E+02
	.4838E+01	.1244E+02	.3455E+00	.0942E+01				
114	.8674E+01	-.2070E+03	-.2490E-02	-.4376E-02	.1127E+02	.5210E+01	.7863E+02	.5072E+02
	.5445E+01	.1103E+02	.1170E+01	.0252E+01				
115	.2599E+01	-.2065E+03	-.1180E-04	-.3759E-02	.2094E+02	.3010E+01	-.6768E+02	.5874E+02
	.5504E+01	.1036E+02	-.8208E+01	.1172E+02				
116	.2084E+01	-.2062E+03	-.2354E-03	-.3931E-02	.1630E+02	.4185E+01	-.7095E+02	.5583E+02
	.5484E+01	.1508E+02	-.3763E+01	.1089E+02				
117	.3562E+01	-.2059E+03	-.5120E-03	-.4127E-02	.1380E+02	.4585E+01	-.7508E+02	.5447E+02
	.5201E+01	.1327E+02	-.2314E+01	.1026E+02				
118	.4430E+01	-.2054E+03	-.8704E-03	-.4342E-02	.1236E+02	.4742E+01	-.8083E+02	.5240E+02
	.4935E+01	.1218E+02	-.1198E+01	.0859E+01				
119	.5731E+01	-.2046E+03	-.1320E-02	-.4547E-02	.1129E+02	.4764E+01	-.8768E+02	.4985E+02
	.4774E+01	.1128E+02	-.2637E+00	.8990E+01				
120	.7682E+01	-.2034E+03	-.1845E-02	-.4694E-02	.1040E+02	.4644E+01	.8528E+02	.4576E+02
	.4683E+01	.1036E+02	.4722E+00	.8159E+01				
121	.2380E+01	-.2061E+03	.4188E-05	-.3491E-02	.1901E+02	.1855E+01	-.5838E+02	.5504E+02
	.8576E+01	.1428E+02	-.7680E+01	.1097E+02				
122	.2710E+01	-.2058E+03	-.1747E-03	-.3761E-02	.1582E+02	.3424E+01	-.6535E+02	.5497E+02
	.5580E+01	.1366E+02	-.4698E+01	.1049E+02				
123	.3236E+01	-.2054E+03	-.4140E-03	-.4024E-02	.1350E+02	.4220E+01	-.7144E+02	.5354E+02
	.5160E+01	.1250E+02	-.2801E+01	.9955E+01				
124	.4023E+01	-.2040E+03	-.7287E-03	-.4289E-02	.1190E+02	.4565E+01	-.7780E+02	.5140E+02
	.4893E+01	.1166E+02	-.1524E+01	.8380E+01				
125	.5205E+01	-.2038E+03	-.1123E-02	-.4544E-02	.1096E+02	.4647E+01	-.8504E+02	.4860E+02
	.4694E+01	.1091E+02	-.5435E+00	.8730E+01				
126	.6977E+01	-.2024E+03	-.1583E-02	-.4749E-02	.1015E+02	.4509E+01	.8777E+02	.4471E+02
	.4517E+01	.1015E+02	.2180E+00	.7911E+01				
127	.2078E+01	-.2058E+03	.2473E-04	-.3235E-02	.1655E+02	.1395E+01	-.4998E+02	.5527E+02
	.7663E+01	.1028E+02	-.7464E+01	.1028E+02				
128	.2386E+01	-.2055E+03	-.1031E-03	-.3581E-02	.1460E+02	.7816E+01	-.5797E+02	.5425E+02
	.6130E+01	.1128E+02	-.5286E+01	.1001E+02				
129	.2848E+01	-.2050E+03	-.3025E-03	-.3887E-02	.1283E+02	.3823E+01	-.6560E+02	.5276E+02
	.5351E+01	.1130E+02	-.3380E+01	.8614E+01				
130	.3541E+01	-.2043E+03	-.5752E-03	-.4209E-02	.1149E+02	.4394E+01	-.7349E+02	.5065E+02
	.4968E+01	.1092E+02	-.1935E+01	.9118E+01				
131	.4581E+01	-.2032E+03	-.9102E-03	-.4517E-02	.1056E+02	.4577E+01	-.8177E+02	.4772E+02
	.4699E+01	.1044E+02	-.8485E+00	.8484E+01				
132	.6142E+01	-.2015E+03	-.1317E-02	-.4778E-02	.9873E+01	.4431E+01	-.8966E+02	.4384E+02
	.4431E+01	.9872E+01	-.3259E-01	.7698E+01				
133	.1756E+01	-.2056E+03	.4022E-04	-.3008E-02	.1431E+02	.1137E+01	-.4200E+02	.5471E+02
	.8412E+01	.7036E+01	-.6551E+01	.9688E+01				
134	.2016E+01	-.2052E+03	-.4283E-04	-.3359E-02	.1314E+02	.2464E+01	-.5005E+02	.5365E+02
	.6866E+01	.8738E+01	-.5256E+01	.8548E+01				
135	.2407E+01	-.2046E+03	-.1983E-03	-.3731E-02	.1190E+02	.3600E+01	-.5855E+02	.5212E+02
	.5859E+01	.9639E+01	-.3693E+01	.9278E+01				
136	.2093E+01	-.2038E+03	-.4268E-03	-.4107E-02	.1082E+02	.4357E+01	-.6792E+02	.4996E+02
	.5270E+01	.9807E+01	-.2251E+01	.8864E+01				
137	.3872E+01	-.2026E+03	-.7186E-03	-.4469E-02	.1006E+02	.4614E+01	-.7810E+02	.4701E+02
	.4845E+01	.9832E+01	-.1099E+01	.8285E+01				
138	.5190E+01	-.2007E+03	-.1054E-02	-.4784E-02	.9546E+01	.4429E+01	-.8722E+02	.4314E+02
	.4441E+01	.9534E+01	-.2478E+00	.7517E+01				
139	.1401E+01	-.2053E+03	.4693E-04	-.2813E-02	.1237E+02	.9643E+00	-.3382E+02	.5426E+02
	.6836E+01	.4499E+01	-.5275E+01	.8194E+01				
140	.1609E+01	-.2049E+03	-.1386E-05	-.3174E-02				

	.7501E+01	.0410E+01	-.4675E+01	.0151E+01	.1172E+02	.2202E+01	-.4142E+02	.5317E+02
141	.1021E+01	-.2043E+03	-.1154E-03	-.3577E-02	.1003E+02	.3585E+01	-.5020E+02	.5161E+02
	.6555E+01	.7664E+01	-.3565E+01	.0000E+01				
142	.2300E+01	-.2034E+03	-.2050E-03	-.3090E-02	.0901E+01	.4510E+01	-.6142E+02	.4042E+02
	.5764E+01	.0737E+01	-.2302E+01	.8641E+01				
143	.3090E+01	-.2021E+03	-.5308E-03	-.4410E-02	.0465E+01	.4790E+01	-.7454E+02	.4644E+02
	.5122E+01	.0132E+01	-.1201E+01	.8109E+01				
144	.4142E+01	-.2001E+03	-.7990E-03	-.4773E-02	.0104E+01	.4507E+01	-.8532E+02	.4250E+02
	.4538E+01	.0153E+01	-.3805E+00	.7370E+01				
145	.1020E+01	-.2052E+03	.4338E-04	-.2660E-02	.1080E+02	.8561E+00	-.2508E+02	.5393E+02
	.0016E+01	.2644E+01	-.3810E+01	.0804E+01				
146	.1171E+01	-.2047E+03	.1863E-04	-.3021E-02	.1047E+02	.2256E+01	-.3161E+02	.5202E+02
	.8211E+01	.4512E+01	-.3865E+01	.8837E+01				
147	.1398E+01	-.2041E+03	-.5805E-04	-.3443E-02	.0773E+01	.3754E+01	-.4014E+02	.5123E+02
	.7271E+01	.8255E+01	-.2067E+01	.8740E+01				
148	.1739E+01	-.2032E+03	-.1881E-03	-.3898E-02	.0088E+01	.4866E+01	-.5384E+02	.4002E+02
	.6320E+01	.7605E+01	-.2002E+01	.8462E+01				
149	.2248E+01	-.2017E+03	-.3807E-03	.4350E-02	.0708E+01	.5105E+01	-.7100E+02	.4803E+02
	.5481E+01	.8442E+01	-.1091E+01	.7071E+01				
150	.3015E+01	-.2096E+03	-.5502E-03	-.4755E-02	.0817E+01	.4644E+01	-.8449E+02	.4218E+02
	.4883E+01	.8778E+01	-.3886E+00	.7257E+01				
151	.0197E+00	-.2051E+03	.3042E-04	.2554E-02	.0602E+01	.8004E+00	-.1556E+02	.5371E+02
	.0052E+01	.1440E+01	-.2298E+01	.8535E+01				
152	.7117E+00	-.2046E+03	.1081E-04	-.2011E-02	.0519E+01	.2304E+01	-.2015E+02	.5250E+02
	.8663E+01	.3160E+01	-.2334E+01	.8619E+01				
153	.0496E+00	-.2040E+03	-.2403E-04	.3343E-02	.0861E+01	.4033E+01	-.2721E+02	.5098E+02
	.7852E+01	.5042E+01	-.1864E+01	.8573E+01				
154	.1056E+01	-.2030E+03	-.1024E-03	-.3822E-02	.0127E+01	.5309E+01	-.4393E+02	.4875E+02
	.8014E+01	.8712E+01	-.1363E+01	.8338E+01				
155	.1367E+01	-.2015E+03	-.2080E-03	.4303E-02	.0132E+01	.5510E+01	-.7215E+02	.4576E+02
	.5765E+01	.7887E+01	-.7625E+00	.7876E+01				
156	.1832E+01	-.2093E+03	-.3288E-03	-.4737E-02	.0502E+01	.4790E+01	-.8536E+02	.4192E+02
	.4823E+01	.8477E+01	-.2086E+00	.7182E+01				
157	.2070E+00	-.2050E+03	.1092E-04	.2499E-02	.0113E+01	.7796E+00	-.5202E+01	.5360E+02
	.0042E+01	.8504E+00	-.7652E+00	.8397E+01				
158	.2387E+00	-.2046E+03	.0127E-05	-.2854E-02	.0909E+01	.2361E+01	-.6902E+01	.5247E+02
	.8901E+01	.2459E+01	-.8009E+00	.8507E+01				
159	.2849E+00	-.2039E+03	-.6099E-05	.3291E-02	.0296E+01	.4270E+01	-.9972E+01	.5086E+02
	.8176E+01	.4380E+01	-.6867E+00	.8467E+01				
160	.3543E+00	-.2029E+03	-.3225E-04	-.3780E-02	.7308E+01	.6006E+01	-.2397E+02	.4862E+02
	.7093E+01	.6221E+01	-.4833E+00	.8274E+01				
161	.4584E+00	-.2014E+03	-.6782E-04	-.4277E-02	.7622E+01	.5898E+01	-.8074E+02	.4562E+02
	.5943E+01	.7577E+01	-.2738E+00	.7828E+01				
162	.6144E+00	-.2801E+03	-.1085E-03	-.7265E-02	.0313E+01	.4906E+01	-.8814E+02	.4178E+02
	.4909E+01	.8309E+01	-.1104E+00	.7143E+01				

TIME REQUIRED TO COMPUTE STRESSES AND DISPLACEMENTS AT STRESS POINTS= 277.38 SECONDS.

JOB COMPLETED AT 8: 8 HOURS

DATA FOR PLOTTING WILL BE STORED IN FILE NAMED VERT105

a) Infinite Thick-Walled Cylinder With External Pressure

b) Idealization for Plane Strain Model

Figure 13. Verification Problem 1: Thick-Walled Cylinder

```

VERIF1
HEFF 4 1
THICK WALLED CYLINDER SUBJECTED TO EXTERNAL PRESSURE
2 1 0 0 1 0
0.25 60000.0
0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
23 1 0. 0. -90. -90. 4. 0. 0. 0. 0.
23 1 0. 0. 90. -90. 5. 0. 0. 0. 6.
4.0 0.0 6.0 0. 6

```

Figure 14. Input to the HEFF Code for Analysis of a Thick-Walled Cylinder Subject to External Pressure

a) Infinite Length Cylindrical Hole in Initially Stressed Medium

b) Idealization for Plane Strain Model

Figure 15. Verification Problem 2: Hole in Biaxially Stressed Plate

```

VERIF2
HEFF 4.1
EXCAVATION OF A CIRCULAR HOLE IN A BI-AXIALLY STRESSED PLATE
1 1 0 0 1 0
0.25 60000.0
0. 0. 0. 30. 15. 0. 0. 0. 0. 0.
49 1 0. 0. -90. 90. 5.005 0. 0. 0. 0.
5. 0. 10.2 0. 14

```

Figure 16. Input to the HEFF Code for Analysis of a Circular Hole in a Material with Biaxial Initial Stress State

Figure 17. Distribution of Radial and Tangential Stress Along a Line $\theta = 0$, for a Cylindrical Hole in an Elastic Plate, With Biaxial Initial Stress State


```

VERIF3
HEFF 4.1
THERMO-ELASTIC RESPONSE OF A HOLLOW CYLINDER
2 1 1 1 1 0
0.25 60000.
0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
5.
0.
12.62 6.0E-06
0. 1.0 0.
0. 0. 1573.16 0.
29 1 0. 0. -90. -90. 4. 0. 0. 0. 0.
29 1 0. 0. 90. -90. 6. 0. 0. 0. 0.
4.0 0. 6.0 0. 7

```

Figure 18. Input to the HEFF Code for Analysis of a Heated Thick-Walled Cylinder

Figure 19. Comparison of Results of HEFF and "Exact" Analyses of a Heated Thick-Walled Cylinder

a) Heat-Generating Horizontal Layer in a Half-Space

b) Idealization for Plane Strain Model

Figure 20. Illustration of the Boundary-Element Model Used for Analysis of a Heat-Generating Layer in an Elastic Half-Space

```

VERIF4
HEFF 4.1
UNIFORM HEAT GENERATION IN SEMI-INFINITE MEDIUM
2 1 60 1 1 1
0.25 60000
0.0 0.0 0.0 0.0 0.0 0.0 0.0
100.0
0.0
12.623 6.0E-06
0.1 0
0.5 -100. 3143. 0.
0.5 -100. 3143. 0.
12.5 -100. 3143. 0.
17.5 -100. 3143. 0.
22.5 -100. 3143. 0.
27.5 -100. 3143. 0.
32.5 -100. 3143. 0.
37.5 -100. 3143. 0.
42.5 -100. 3143. 0.
47.5 -100. 3143. 0.
52.5 -100. 3143. 0.
57.5 -100. 3143. 0.
62.5 -100. 3143. 0.
67.5 -100. 3143. 0.
72.5 -100. 3143. 0.
77.5 -100. 3143. 0.
82.5 -100. 3143. 0.
87.5 -100. 3143. 0.
92.5 -100. 3143. 0.
97.5 -100. 3143. 0.
102.5 -100. 3143. 0.
107.5 -100. 3143. 0.
112.5 -100. 3143. 0.
117.5 -100. 3143. 0.
122.5 -100. 3143. 0.
127.5 -100. 3143. 0.
132.5 -100. 3143. 0.
137.5 -100. 3143. 0.
142.5 -100. 3143. 0.
147.5 -100. 3143. 0.
152.5 -100. 3143. 0.
157.5 -100. 3143. 0.
162.5 -100. 3143. 0.
167.5 -100. 3143. 0.
172.5 -100. 3143. 0.
177.5 -100. 3143. 0.
182.5 -100. 3143. 0.
187.5 -100. 3143. 0.
192.5 -100. 3143. 0.
197.5 -100. 3143. 0.
202.5 -100. 3143. 0.
207.5 -100. 3143. 0.
212.5 -100. 3143. 0.
217.5 -100. 3143. 0.
222.5 -100. 3143. 0.
227.5 -100. 3143. 0.
232.5 -100. 3143. 0.
237.5 -100. 3143. 0.
242.5 -100. 3143. 0.
247.5 -100. 3143. 0.
252.5 -100. 3143. 0.
257.5 -100. 3143. 0.
262.5 -100. 3143. 0.
267.5 -100. 3143. 0.
272.5 -100. 3143. 0.
277.5 -100. 3143. 0.
282.5 -100. 3143. 0.
287.5 -100. 3143. 0.
292.5 -100. 3143. 0.
297.5 -100. 3143. 0.
20 1 0.0 0.0 160.0 0.0 0.0 0.0 0.0 0.0
15 4 160.0 0.0 160.0 -150.0 0.0 0.0 0.0 0.0
5.0 0.0 5.0 -100.0 21

```

Figure 21. Input to the HEFF Code for Analysis of a Heat-Generating Layer

Figure 22. Comparison of Closed Form and HEFF Analyses for Heat-Generating Layer

Figure 23. Idealized Cross Section of a Repository with Parallel Drifts for Vertical Emplacement of Waste (Note That Only Drifts A, B and C were Modeled Using Boundary Elements)

a) Repository Model

b) Drift Detail and Sample Points

Figure 24. Details of Boundary-Element Model for Analysis of Vertical Emplacement

```

VERT10
HEFF 4 1
VERTICAL EMPLACEMENT - OUTPUT AT T=10 YRS.
10 0 22 4 1 1
0.2 0 15100. 0 0 0 0.55 0 0.55 1
0 -0.023 0 0 0 0 0.55 0 0.55 1
10.
-0.0239 16.9
29.03 10.7E-6
0 .15602 .0013539
0 .59787 .019142
0 .15227 .051888
0 .09384 .43768
0 0 -305.812 1380.328 0.0
0 0 -307.335 1380.328 0.0
0 0 -308.858 1380.328 0.0
34.138 -307.335 8281.97 0.0
68.276 -307.335 8281.97 0.0
102.414 -307.335 8281.97 0.0
136.552 -307.335 8281.97 0.0
170.690 -307.335 8281.97 0.0
204.828 -307.335 8281.97 0.0
238.966 -307.335 8281.97 0.0
273.104 -307.335 8281.97 0.0
307.242 -307.335 8281.97 0.0
341.380 -307.335 8281.97 0.0
375.518 -307.335 8281.97 0.0
409.656 -307.335 8281.97 0.0
443.794 -307.335 8281.97 0.0
477.932 -307.335 8281.97 0.0
512.070 -307.335 8281.97 0.0
546.208 -307.335 8281.97 0.0
580.346 -307.335 8281.97 0.0
614.484 -307.335 8281.97 0.0
648.622 -307.335 8281.97 0.0
6 1 0 -302. 2.34 -302. 0. 0. 0. 0. 0.
1 1 2.34 -302. 2.44 -301.9 0. 0. 0. 0. 0.
12 1 2.44 -301.9 2.44 -296.78 0. 0. 0. 0. 0.
8 1 0 -298.03 27.13 -80.0 2.74 0. 0. 0. 0.
4 1 31.698 -302. 36.578 -302. 0. 0. 0. 0. 0.
4 1 36.578 -302. 36.578 -296.78 0. 0. 0. 0. 0.
4 1 34.138 -298.03 27.13 -152.87 2.74 0. 0. 0. 0.
4 1 31.698 -286.78 31.698 -302.0 0. 0. 0. 0. 0.
10 1 0 0. 324.3 -600. 0. 0. 0. 0. 0.
20 4 324.3 0.0 324.3 -600. 0. 0. 0. 0. 0.
.3 1.50 6 27

```

Figure 25. Input to the HEFF Code for the Near-Field Analysis of the Emplacement Drift

Figure 26. Comparison of HEFF and Finite Element Predictions of Ratio Between Matrix Strength and Stress Around Vertical Emplacement Drift at Times Up to 100 Years After Waste Emplacement

APPENDIX A
Listing of HEFF Version 4.1

SLARGE

PROGRAM HEFF
- IMPLEMENTED UNDER MS FORTRAN 77 VERSION 4.01 - DECEMBER 6 1987
VERSION 4.1 - DECEMBER 6 1987

HEF 1

THIS VERSION DIFFERS FROM EARLIER VERSIONS ONLY IN THE HEAT
ROUTINE, WHERE MINOR CHANGES HAVE BEEN MADE TO IMPROVE
ACCURACY AND AVOID MATHEMATICAL DIFFICULTIES

HEFF IS AN INDIRECT FORMULATION OF THE BOUNDARY ELEMENT
METHOD. IT IS A COMBINATION OF PROGRAM "BEP2D" WHICH USES
STRIP LOAD SINGULARITIES, AND A ROUTINE MODELLING
EXPONENTIALLY DECAYING HEAT SOURCES
ORIGINAL CODING OF HEFF WAS BY B.H.G. BRADY USING THE MECHANICAL
MODEL OF S.L. CROUCH AND THERMAL MODEL OF R.D. HART

THIS VERSION CLEANED-UP BY : CHRIS ST. JOHN (DEC. 9, 1987)
J.F.T. AGAPITO AND ASSOCIATES
(303) 242-4220

CONTROL VARIABLES

NUMBS : NUMBER OF LINE SEGMENTS DEFINING EXCAVATIONS
NUMOS : NUMBER OF LINE SEGMENTS DEFINING STRESS POINTS
NSORC : NUMBER OF EXPONENTIALLY DECAYING HEAT SOURCES
NCOMP : NUMBER OF EXPONENTIALLY DECAYING COMPONENTS
KSYM : CODE DEFINING SYMMETRY CONDITIONS
= 1 NO SYMMETRY
= 2 XS=X=0 IS A LINE OF SYMMETRY
IMAG : CODE DEFINING USE OF IMAGE HEAT SOURCES
= 0 NO IMAGE HEAT SOURCES
= 1 IMAGE HEAT SOURCES

LOGICAL UNIT DEFINITIONS

UNIT 0 : MONITOR AND KEYBOARD
UNIT 1 : INPUT FILE NAMED BY THE USER
UNIT 2 : OUTPUT FILE NAMED BY THE USER
UNIT 3 : FILE CONTAINING DATA FOR PLOTTING

DIMENSIONS OF ARRAYS

ARRAY SIZES ARE SPECIFIED BY THE PARAMETER 'LIMIT'

NUMBER OF ELEMENTS : NUMBE --- CSS, CSN, CNS, CNM, RS, RN, PS, PN, XM, YM,
A, COSBET, SINBET, KOD, SS, SN, BS, BN
NUMBER OF STRESS LINES : NUMOS --- XS, YS, XE, YE, NUMPB
NUMBER OF EXP. DECAYING COMPONENTS : NCOMP --- TOC, PROP, QEXP
NUMBER OF HEAT SOURCES : NSORC --- XS, YS, QS, TOS

VARIABLE DEFINITIONS

PR : POISSONS RATIO
E : YOUNGS MODULUS
G : SHEAR MODULUS
DIFF : THERMAL DIFFUSIVITY
ALPHA : THERMAL EXPANSION COEFFICIENT
TGRAD : TEMPERATURE GRADIENT
TSURF : INITIAL SURFACE TEMPERATURE

AXX, AYY : CONSTANTS DEFINING IN SITU STRESSES
AXY, BYX : CONSTANTS DEFINING IN SITU STRESSES
BYX, BXY : CONSTANTS DEFINING IN SITU STRESSES
CX, DX, RMAX : CONSTANTS DEFINING VERTICAL STRESS
XZRAI : CONSTANT DEFINING OUT OF PLANE STRESS

TOC(I) : TIME ON FOR COMPONENT I
PROP(I) : PROPORTION OF COMPONENT I
QEXP(I) : DECAY CONSTANT FOR COMPONENT I

XS(J) : X-COORDINATE OF SOURCE J
YS(J) : Y-COORDINATE OF SOURCE J
QS(J) : INITIAL STRENGTH OF SOURCE J
TOS(J) : TIME ON FOR SOURCE J

XB(K) : BEGINNING X-COORDINATE OF STRESS LINE K
YB(K) : BEGINNING Y-COORDINATE OF STRESS LINE K
XE(K) : ENDING X-COORDINATE OF STRESS LINE K
YE(K) : ENDING Y-COORDINATE OF STRESS LINE K
NUMPB(K) : NUMBER OF STRESS POINTS ALONG STRESS LINE K

USER NOTES

SURFACE BOUNDARY CONDITIONS
AS CURRENTLY CODED, THE PROGRAM DOES NOT PLACE IMAGE BOUNDARY
ELEMENTS ABOVE THE SURFACE. IF THE EXCAVATIONS ARE SUFFICIENTLY
FAR FROM THE SURFACE TO HAVE NO EFFECT THESE IMAGE BOUNDARY
ELEMENTS ARE NOT NECESSARY. IMAGE HEAT SOURCES CAN BE USED TO
YIELD A ZERO NORMAL STRESS, ZERO HEAT FLOW BOUNDARY CONDITION AT
THE SURFACE. THE PROGRAM DOES NOT REMOVE THE SURFACE SHEARS.

PARAMETER (LIMIT =100)

HEF 2

REAL CSS(LIMIT,LIMIT), CSN(LIMIT,LIMIT), CNS(LIMIT,LIMIT)
REAL CNM(LIMIT,LIMIT), RS(LIMIT,LIMIT), RN(LIMIT,LIMIT), PS(LIMIT,LIMIT), PN(LIMIT,LIMIT)
REAL XS(LIMIT), YS(LIMIT), QS(LIMIT), TOS(LIMIT), TOC(5), PROP(5)
REAL AA(6), XM(LIMIT), YM(LIMIT), A(LIMIT), COSBET(LIMIT)
REAL SINBET(LIMIT), STORE(7,LIMIT), BN(LIMIT), BS(LIMIT)
REAL XB(LIMIT), YB(LIMIT), XE(LIMIT), YE(LIMIT), QEXP(5), TIM, SS, SN
INTEGER NUMPB(LIMIT), KOD(LIMIT)
CHARACTER*2 TITLE
CHARACTER*10 NAME, QACIN, QANUM, QANUM1

HEF 3

HEF 4

HEF 5

HEF 6

HEF 7

HEF 8

HEF 9

HEF 10

HEF 11

DATA QANUM, /'HEFF 4.1' /
DATA QANUM1, /'heff 4.1' /

HEF 12

HEF 13

DEFINE ARRAY SIZE

NIFL = LIMIT

HEF 14

OPEN INPUT AND OUTPUT FILES

```

C-----
C POSSIBLE SYSTEM DEPENDENCE BELOW IN OPENING FILES AND CALLS TO
C GETTIM,GETDAT
C
C WRITE(0, '(A)') ' Enter name of input file '
C READ(0, '(A)') NAME
C OPEN(1, FILE=NAME, FORM='FORMATTED', STATUS='OLD')
C WRITE(0, '(A)') ' Enter name of output file '
C READ(0, '(A)') NAME
C OPEN(2, FILE=NAME, FORM='FORMATTED', STATUS='UNKNOWN')
C
C READ NAME OF PLOT FILE
C READ(1, '(A10)') NAME
C
C OPEN(3, FILE=NAME, FORM='FORMATTED', STATUS='UNKNOWN',
C 1 ACCESS='SEQUENTIAL')
C
C CHECK QA NUMBER
C-----
C READ(1, '(A10)') QACIN
C IF (QACIN.NE.QANUM1.AND.QACIN.NE.QANUM1) THEN
C   WRITE(0, '(50A)') 'WRONG QA NUMBER'
C   WRITE(2, '(50A)') 'WRONG QA NUMBER. JOB ABORTED'
C   STOP
C ENDIF
C
C COMPLETE FILE OPENING
C-----
C READ(1, '(A72)') ITITLE
C WRITE(2, 1000)
C
C FIRST SCREEN MESSAGE : READ INPUT
C-----
C WRITE(0, 2000)
C
C CALL BUILT-IN ROUTINE FOR DATE TO RECORD ON OUTPUT
C-----
C (MS FORTRAN 4.0 ONLY)
C-----
C CALL GETDAT(IY, IM, ID)
C WRITE(2, 1010) ITITLE, IM, ID, IY
C
C READ(1, *) NUMBS, NUMOS, NSORC, NCOMP, KSYM, IMAG
C READ(1, *) PR, E
C READ(1, *) AXX, AYY, AXY, BXX, BYY, BXY, CXX, DXX, RMAX, XZRAT
C WRITE(2, 1030) NUMBS, NUMOS, NSORC, NCOMP
C IF (KSYM.EQ.0) WRITE(2, 1040)
C IF (KSYM.EQ.1) WRITE(2, 1050)
C IF (IMAG.EQ.0) WRITE(2, 1060)
C IF (IMAG.NE.0) WRITE(2, 1070)
C
C G=E/(2.0*(1.0+PR))
C WRITE(2, 10 0) PR, E, G
C WRITE(2, 1090) AXX, BXX, CXX, DXX, AYY, BYY, AXY, BXY, RMAX, XZRAT
C
C PI=4.*ATAN(1.)
C CON=1./((4.*PI*(1.-PR))
C CPAC=PI/180.0
C
C ALFAE=0.0
C IF (NSORC.NE.0) THEN
C   READ(1, *) TIM
C   WRITE(2, 1110) TIM
C   READ(1, *) TORAD, TSURF
C   WRITE(2, 1100) TORAD, TSURF
C   READ(1, *) DIFF, ALPHA
C   VE=(1.0+PR)*ALPHA*G/(1.0-PR)
C   ALFAE=ALPHA*E
C   WRITE(2, 1120) DIFF, ALPHA, VE
C   WRITE(2, 1130)
C
C   DO 10 J=1, NCOMP
C     READ(1, *) TOC(I), PROP(I), QEXP(I)
C     WRITE(2, 1140) TOC(I), PROP(I), QEXP(I)
C     CONTINUE
C   WRITE(2, 1150)
C
C   DO 20 I=1, NSORC
C     READ(1, *) XS(I), YS(I), QS(I), TOS(I)
C     WRITE(2, 1160) XS(I), YS(I), QS(I), TOS(I)
C     CONTINUE
C   ENDIF
C
C DEFINE LOCATIONS, SIZES, ORIENTATIONS AND BOUNDARY CONDITIONS OF
C BOUNDARY ELEMENTS.
C-----
C WRITE(2, 1170)
C WRITE(2, 1180)
C NUMBE=0
C
C DO 80 N=1, NUMBS
C   READ(1, *) NUM, KODE, XBEG, YBEG, XEND, YEND, RADIUS, RATIO, PSI, BVS,
C   1 BVN
C   IF (RADIUS.LE.0.0) THEN
C     XD=(XEND-XBEG)/NUM
C     YD=(YEND-YBEG)/NUM
C     SW=SQRT(XD*XD+YD*YD)
C
C     DO 30 JA=1, NUM
C       NUMBE=NUMBE+1
C       M=NUMBE
C       XM(M)=XBEG+0.5*(2.*JA-1.)*XD
C       YM(M)=YBEG+0.5*(2.*JA-1.)*YD
C       A(M)=0.5*SW
C       SINBET(M)=YD/SW

```

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HEF 15
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HEF 17
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HEF 84
HEF 85
HEF 86

```

```

30      COSBET(M)=XD/SW
      KOD(M)=KODE
      BS(M)=BVS
      BN(M)=BVN
      CONTINUE
ELSE
      NELG=0
      RELG=NELG
      RELR=NUM
      IF(RATIO.EQ.0.0) RATIO=1.0
      SINPSI=SIN(PSI*PI/180.)
      COSPSI=COS(PSI*PI/180.)
      GD=-1E-10
      GA=RATIO*COS((XEND-PSI)*PI/180.0)
      IF (ABS(GA).LT.GD) GA=GD
      GB=RATIO*COS((YEND-PSI)*PI/180.0)
      IF (ABS(GB).LT.GD) GB=GD
      CHI1=ATAN2(SIN((XEND-PSI)*PI/180.0),GA)
      CHI2=ATAN2(SIN((YEND-PSI)*PI/180.0),GB)
      DCHI=(CHI2-CHI1)/RELR
      IF (ABS(DCHI).GE.GD) THEN
        GC=DCHI/ABS(DCHI)
      ELSE
        GC=-1.0
      ENDIF
      DCHI=DCHI+((YEND-XEND)/ABS(YEND-XEND)-GC)*PI/RELR
70      NUMBE=NUMBE+1
      M=NUMBE
      CHI=CHI1+RELG*DCHI
      EV1=RADIUS*(COS(CHI)*SINPSI+SIN(CHI)*COSPSI*RATIO)+YBEG
      EX1=RADIUS*(COS(CHI)*COSPSI-SIN(CHI)*SINPSI*RATIO)+XBEG
      CHI=CHI1+DCHI
      EV2=RADIUS*(COS(CHI)*SINPSI+SIN(CHI)*COSPSI*RATIO)+YBEG
      EX2=RADIUS*(COS(CHI)*COSPSI-SIN(CHI)*SINPSI*RATIO)+XBEG
      DX=EX2-EX1
      DY=EY2-EY1
      IF (ABS(DX).LT.(1E-13)*RADIUS) DX=0.0
      IF (ABS(DY).LT.(1E-13)*RADIUS) DY=0.0
      SW=SQRT(DX*DX+DY*DY)
      XM(M)=0.5*(EX1+EX2)
      YM(M)=0.5*(EY1+EY2)
      COSBET(M)=DX/SW
      SINBET(M)=DY/SW
      A(M)=0.5*SW
      KOD(M)=KODE
      BS(M)=BVS
      BN(M)=BVN
      NELG=NELG+1
      RELG=NELG
      IF (NELG.LT.NUM) GO TO 70
ENDIF
80      CONTINUE
      WRITE (2,1190) (M,KOD(M),XM(M),YM(M),A(M),SINBET(M),COSBET(M),BS(M)
1) ,BN(M),M=1,NUMBE)
      WRITE (2,1200)
      IF (NUMOS.NE.0) THEN
        DO 90 I=1,NUMOS
          READ (1,*) XB(I),YB(I),XE(I),YE(I),NUMPB(I)
          WRITE (2,1210) XB(I),YB(I),XE(I),YE(I),NUMPB(I)
90      CONTINUE
      ELSE
100     READ (1,*) DELN,RATTY,NUMPT,NBE
        SET UP LENGTH OF LINES TO BE GENERATED NORMAL TO BOUNDARY
        -----
        DELS=DELN
        RLINE=0.0
        IF (NUMPT.LT.2) NUMPT=2
        NUMP=NUMPT-1
        DO 110 I=1,NUMP
          DELS=DELS+RATTY
          RLINE=RLINE+DELS
110     CONTINUE
          DO 120 M=1,NBE
            SB=COSBET(M)
            CB=SINBET(M)
            XC=XM(M)
            YC=YM(M)
            XB(M)=XC+CB*DELN
            YB(M)=YC+SB*DELN
            XE(M)=XB(M)+CB*RLINE
            YE(M)=YB(M)+SB*RLINE
            NUMPB(M)=0
120     CONTINUE
          WRITE (2,1210) (XB(I),YB(I),XE(I),YE(I),NUMPB(I),I=1,NBE)
          NUMOS=NBE
        ENDIF
        START RECORD ON PLOT FILE
        WRITE (3,3000) NAME,NUMBE,NUMPT,IY,IM,ID,IH,IM
        COMPUTE INFLUENCE COEFFICIENTS AND SET UP SYSTEM OF ALGEBRAIC
        EQUATIONS.
        -----
        CALL SECOND (TIMO)
        SECOND SCREEN MESSAGE : COMPUTE INFLUENCE COEFFICIENTS
        -----
        WRITE (0,2100)
        DO 200 I=1,NUMBE
          X1=XM(I)
          Y1=YM(I)
          COSB1=COSBET(I)
          SINB1=SINBET(I)
          KODE=KOD(I)

```

```

HEF 87
HEF 88
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DO 190 J=1,NUMBE
CALL INITL(SXXS,SXXN,SYYS,SYYN,SKYS,SKYN,DKS,DXN,DYS,DYN)
XJ=XM(J)
YJ=YM(J)
COSBJ=COSBET(J)
SINBJ=SINBET(J)
AJ=A(J)
CALL INCO2 (XI,YI,XJ,YJ,AJ,COSBJ,SINBJ,+1,PR,E,CON,PI,
SXXS,SXXN,SYYS,SYYN,SKYS,SKYN,DKS,DXN,DYS,DYN)
IF (KSYM.NE.0) THEN
XJ=-XM(J)
CALL INCO2 (XI,YI,XJ,YJ,AJ,COSBJ,-SINBJ,-1,PR,E,CON,PI,
SXXS,SXXN,SYYS,SYYN,SKYS,SKYN,DKS,DXN,DYS,DYN)
ENDIF
GO TO (150,160,170,180), KODE

150 CSN(I,J)=(SYYN-SXXN)*SINBI*COSBI+SKYN*(COSBI*COSBI-SINBI*SINBI)
CSS(I,J)=(SYYS-SXXS)*SINBI*COSBI+SKYS*(COSBI*COSBI-SINBI*SINBI)
CHS(I,J)=SXXS*SINBI*SINBI-2.*SKYS*SINBI*COSBI+SYYS*COSBI*COSBI
CHN(I,J)=SXXN*SINBI*SINBI-2.*SKYN*SINBI*COSBI+SYYN*COSBI*COSBI
GO TO 190

160 CSN(I,J)= DXN*COSBI+DYN*SINBI
CSS(I,J)= DKS*COSBI+DYS*SINBI
CHS(I,J)= -DKS*SINBI+DYS*COSBI
CHN(I,J)= -DXN*SINBI+DYN*COSBI
GO TO 190

170 CSN(I,J)=DXN*COSBI+DYN*SINBI
CSS(I,J)=DKS*COSBI+DYS*SINBI
CHS(I,J)=SXXS*SINBI*SINBI-2.*SKYS*SINBI*COSBI+SYYS*COSBI*COSBI
CHN(I,J)=SXXN*SINBI*SINBI-2.*SKYN*SINBI*COSBI+SYYN*COSBI*COSBI
GO TO 190

180 CSN(I,J)=(SYYN-SXXN)*SINBI*COSBI+SKYN*(COSBI*COSBI-SINBI*SINBI)
CSS(I,J)=(SYYS-SXXS)*SINBI*COSBI+SKYS*(COSBI*COSBI-SINBI*SINBI)
CHS(I,J)=DKS*SINBI+DYS*COSBI
CHN(I,J)=DXN*SINBI+DYN*COSBI

190 CONTINUE
200 CONTINUE

CALL SECOND (TIME)
TIME=TIME-TIMO
TIMO=TIMO+TIME
WRITE (2,1220) TIME
-----
COMPUTE OUTPUT AT DESIRED TIME
-----
WRITE (2,1230)
WRITE (2,1240) TIM
-----
COMPUTE PRE-EXISTING STRESSES AND SET BOUNDARY CONDITIONS
-----
THIRD SCREEN MESSAGE: COMPUTE PRE-EXISTING STRESSES
-----
WRITE (0,2200) TIM

DO 260 N=1,NUMBE
YT=YM(N)
PY=AYY*YT+BYY
RK=CKX
IF (YT.NE.0.) RK=CKX+DKX/YT
IF (RK.GT.RMAX) RK=RMAX
PXX=AXX*YT+BXX+RK*PY
PXY=AXY*YT+BXY
PZZ=XZ*AT*PXX
TP=0.0
IF (NSORC.NE.0) THEN
TP=TGRAD*YT+TSURF
CALL TEMCAL (XM(N),YM(N),TIM,DIFF,G,VE,
1 TOC,PROP,QEXP,NCOMP,XS,YS,QS,TOS,KSVM,NSORC,IMAG,AA)
TP=TP+AA(1)
PXX=PXX+AA(2)
PXY=PXY+AA(3)
PYY=PY+AA(4)
PZZ=PZZ+PR*(AA(2)+AA(3))+ALFAE*AA(1)
ENDIF
COSB=COSBET(N)
SINB=SINBET(N)

THERMALLY INDUCED INITIAL STRESSES

SS=(PYY-PXX)*SINB*COSB+PXY*(COSB*COSB-SINB*SINB)
SN=PXX*SINB*SINB-2.0*PXY*SINB*COSB+PYY*COSB*COSB

THERMALLY INDUCED DISPLACEMENTS

UX=AA(5)
UY=AA(6)
DS=UX*COSB + UY*SINB
DN=-UX*SINB + UY*COSB

STORE OUTPUT FROM THERMAL SOLUTION FOR EACH BOUNDARY ELEMENT
-----
STORE(1,N)=TP
STORE(2,N)=PXX
STORE(3,N)=PYY
STORE(4,N)=PXY
STORE(5,N)=PZZ
STORE(6,N)=UX

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C      STORE(7,N)=UY                                HEF261
C      WRITE (2,1250) N,TP,PXX,PYY,PXY,PZZ,SN,SS,DN,DS HEF262
C      KODE=KOD(N)                                    HEF263
C      GO TO (220,230,240,250), KODE                 HEF264
220    RN(N)=BN(N)-SN                                HEF265
C      RS(N)=BS(N)-SS                                HEF266
C      GO TO 260                                       HEF267
230    RN(N)=BN(N)-DN                                HEF268
C      RS(N)=BS(N)-DS                                HEF269
C      GO TO 260                                       HEF270
240    RN(N)=BN(N)-SN                                HEF271
C      RS(N)=BS(N)-DS                                HEF272
C      GO TO 260                                       HEF273
250    RN(N)=BS(N)-SS                                HEF274
C      RS(N)=BN(N)-DN                                HEF275
260    CONTINUE                                       HEF276
C      CALL SECOND (TIME)                             HEF277
C      TIME=TIME-TIMO                                HEF278
C      TIME=TIME+TIME                                HEF279
C      WRITE (2,1260) TIME                            HEF280
C      -----
C      SOLVE SYSTEM OF ALGEBRAIC EQUATIONS.
C      -----
C      CALL SOLVE3 (NUMBE,CSS,CSN,CNS,CNN,RS,RN,PS,PN,NIFL) HEF281
C      CALL SECOND (TIME)                             HEF282
C      TIME=TIME-TIMO                                HEF283
C      TIME=TIME+TIME                                HEF284
C      WRITE (2,1270) TIME                            HEF285
C      -----
C      COMPUTE BOUNDARY STRESSES AND DISPLACEMENTS.
C      -----
C      FOURTH SCREEN MESSAGE : COMPUTE BOUNDARY STRESSES AND DISPLACEMENTS
C      -----
C      WRITE (0,2300)                                  HEF286
C      WRITE (2,1280)                                  HEF287
C      WRITE (2,1290) TIM                             HEF288
C      DO 300 I=1,NUMBE                                HEF289
C      X1=XM(I)                                         HEF290
C      Y1=YM(I)                                         HEF291
C      COSBI=COSBET(I)                                HEF292
C      SINBI=SINBET(I)                                HEF293
C      -----
C      SET INITIAL CONDITIONS, INCLUDING THERMAL EFFECT
C      -----
C      TP=STORE(1,I)                                  HEF294
C      SIGXX=STORE(2,I)                                HEF295
C      SIGYY=STORE(3,I)                                HEF296
C      SIGXY=STORE(4,I)                                HEF297
C      SIGZZ=STORE(5,I)                                HEF298
C      UX=STORE(6,I)                                  HEF299
C      UY=STORE(7,I)                                  HEF300
C      DO 280 J=1,NUMBE                                HEF301
C      CALL INITL(SXXS,SXXN,SYYS,SYYN,SKXS,SKYN,DXS,DXN,DYS,DYN) HEF302
C      XJ=XM(J)                                         HEF303
C      YJ=YM(J)                                         HEF304
C      AJ=A(J)                                           HEF305
C      COSBJ=COSBET(J)                                HEF306
C      SINBJ=SINBET(J)                                HEF307
C      CALL INCO2 (X1,Y1,XJ,YJ,AJ,COSBJ,SINBJ,+1,PR,E,CON,PI, HEF308
1      SXXS,SXXN,SYYS,SYYN,SKXS,SKYN,DXS,DXN,DYS,DYN) HEF309
C      IF (KSYM,NE,0) THEN                             HEF310
C      XJ=-XM(J)                                       HEF311
C      CALL INCO2 (X1,Y1,XJ,YJ,AJ,COSBJ,-SINBJ,-1,PR,E,CON,PI, HEF312
1      SXXS,SXXN,SYYS,SYYN,SKXS,SKYN,DXS,DXN,DYS,DYN) HEF313
C      ENDIF                                           HEF314
C      DIGXX=SXXS*PS(J)+SXXN*PN(J)                   HEF315
C      DIGYY=SYYS*PS(J)+SYYN*PN(J)                   HEF316
C      SIGXX=SIGXX+DIGXX                               HEF317
C      SIGYY=SIGYY+DIGYY                               HEF318
C      SIGXY=SIGXY+DIGXY                               HEF319
C      SIGZZ=SIGZZ+PR*(DIGXX+DIGYY)                   HEF320
C      UX=UX+DXS*PS(J)+DXN*PN(J)                     HEF321
C      UY=UY+DYS*PS(J)+DYN*PN(J)                     HEF322
280    CONTINUE                                       HEF323
C      -----
C      US=UX*COSBI+UY*SINBI                           HEF324
C      UN=-UX*SINBI+UY*COSBI                           HEF325
C      SIGS=(SIGYY-SIGXX)*SINBI*COSBI+SIGXY*(COSBI*COSBI-SINBI*SINBI) HEF326
C      SIGN=SIGXX*SINBI*SINBI-2.*SIGXY*SINBI*COSBI+SIGYY*COSBI*COSBI HEF327
C      SIGT=SIGXX*COSBI*COSBI+2.*SIGXY*SINBI*COSBI+SIGYY*SINBI*SINBI HEF328
C      WRITE (2,1300) I,XM(I),YM(I),UX,UY,US,UN,SIGXX,SIGYY,SIGXY,SIGZZ HEF329
1      SIGS,SIGN,SIGT,TP                               HEF330
1      WRITE (3,3001) I,XM(I),YM(I),UX,UY,A(I),SINBI,COSBI,SIGS,SIGN, HEF331
1      SIGT,SIGZZ,TP                                   HEF332
C      CONTINUE                                       HEF333
C      CALL SECOND (TIME)                             HEF334
C      TIME=TIME-TIMO                                HEF335
C      TIME=TIME+TIME                                HEF336
C      WRITE (2,1310) TIME                            HEF337
C      -----
C      COMPUTE STRESSES AND DISPLACEMENTS AT SPECIFIED POINTS IN BODY.
C      -----
C      FIFTH SCREEN MESSAGE : COMPUTE INTERIOR POINT VALUES
C      -----
C      WRITE (0,2400)                                  HEF338
C      IF (NUMOS,LE,0) GO TO 400                      HEF339
C      WRITE (2,1280)                                  HEF340
C      WRITE (2,1320) TIM                             HEF341
C      NPOINT=0                                         HEF342
C      DO 370 N=1,NUMOS                                HEF343
C      NUMP=NUMPB(N)-1                                HEF344

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IF (NUMP.NE.-1).THEN
  DELX=(XE(N)-XB(N))/NUMP
  DELY=(YE(N)-YB(N))/NUMP
  NUMPT=NUMP+1
  RATTY=1.0
ELSE
  DELX=DELN*(XE(N)-XB(N))/RLINE
  DELY=DELN*(YE(N)-YB(N))/RLINE
ENDIF
XP=XB(N)-DELX
YP=YB(N)-DELY

DO 360 NI=1,NUMPT
  NPOINT=NPOINT+1
  X=X+DELX
  Y=Y+DELY
  DELX=DELX*RATTY
  DELY=DELY*RATTY
  TP=IGRAD*Y+TSURF
  SIGYY=AYY*Y+BYI
  RK=CXX
  IF (YF.NE.0.) RK=CXX+DXX/YF
  IF (RK.GT.RMAX) RK=RMAX
  SIGXX=AXX*Y+BXI+RK*SIGYY
  SIGXY=AXY*Y+BXY
  SIGZZ=XZRAT*SIGXX
  UX=0.
  UY=0.

DO 340 J=1,NUMBE
  CALL INITL(SXXS,SXXN,SYYS,SYYN,SKYS,SKYN,DXS,DXN,DYS,DYN)
  XJ=XM(J)
  YJ=YM(J)
  AJ=A(J)
  COSBJ=COSBET(J)
  SINBJ=SINBET(J)
  CALL INCO2 (XP,YP,XJ,YJ,AJ,COSBJ,SINBJ,+1,PR,E,CON,PI,
    SXXS,SXXN,SYYS,SYYN,SKYS,SKYN,DXS,DXN,DYS,DYN)

  IF (KSYM.NE.0) THEN
    CALL INCO2 (XP,YP,XJ,YJ,AJ,COSBJ,SINBJ,-1,PR,E,CON,PI,
      SXXS,SXXN,SYYS,SYYN,SKYS,SKYN,DXS,DXN,DYS,DYN)

  ENDIF

  DIGXX=SXXS*PS(J)+SXXN*PN(J)
  DIGYY=SYYS*PS(J)+SYYN*PN(J)
  SIGXX=SIGX+DIGXX
  SIGYY=SIGY+DIGYY
  SIGXY=SIGXY+SKYS*PS(J)+SKYN*PN(J)
  SIGZZ=SIGZZ+PR*(DIGXX+DIGYY)
  UX=UX+DXS*PS(J)+DXN*PN(J)
  UY=UY+DYS*PS(J)+DYN*PN(J)

CONTINUE
IF (NSORC.NE.0) THEN
  ADD THERMAL EFFECT
  CALL TEMCAL (XP,YP,TIM,DIFF,G,VE,
    TOC,PROP,QEXP,NCOMP,XS,YS,QS,TOS,KSYM,NSORC,IMAG,AA)
  TP=TP+AA(1)
  SIGXX=SIGXX+AA(2)
  SIGYY=SIGYY+AA(3)
  SIGXY=SIGXY+AA(4)
  SIGZZ=SIGZZ+PR*(AA(2)+AA(3))+ALFAE*AA(1)
  UX=UX+AA(5)
  UY=UY+AA(6)

ENDIF

CENT=(SIGXX+SIGYY)/2.0
DIFF1=SIGX-CENT
TAUM=SQRT(SIGXY*SIGXY+DIFF1*DIFF1)
SIG1=CENT+TAUM
SIG3=CENT-TAUM
IF (SIGXY.EQ.0.0) SIGXY=0.0001
ALPHA2=ATAN2(SIGXY,DIFF1)
ALPHA=0.5*ALPHA2/C/AC

OUTPUT RESULTS FOR PLOTTING
WRITE (3,3002) NPOINT,XP,YP,UX,UY,SIG1,SIG3,ALPHA,SIGZZ,TP
WRITE (2,1330) NPOINT,XP,YP,UX,UY,SIGXX,SIGYY,SIGXY,SIGZZ,SIG1,
  SIG3,ALPHA,TP

CONTINUE
CONTINUE

CALL SECOND (TIME)
TIME=TIME-TIMO
TIMO=TIMO+TIME
WRITE (2,1340) TIME

CALL BUILT-IN ROUTINE FOR TIME (MS FORTRAN 4.0 ONLY)

CALL GETTIM(IH,IMIN,ISEC,IHUN)
WRITE(2,1350)IH,IMIN

CONTINUE

CLOSE ALL FILES
CLOSE(3)
WRITE(*,*)
WRITE(*,*)
WRITE(0,1360)NAME
WRITE(2,1360)NAME

FORMAT STATEMENTS - FOR OUTPUT FILE
FORMAT (//,2X,100(' '),/2X,'*',98X,'*',/2X,'*',98X,'*',/
  12X,'*',44X,'H E F F 44X,'*',/2X,'*',98X,'*',/
  22X,'*',28X,'A BOUNDARY ELEMENT CODE',28X,'*',/
  32X,'*',28X,'FOR TWO-DIMENSIONAL THERMOELASTIC ANALYSIS',28X,'*',/
  42X,'*',28X,'OF A ROCK MASS',28X,'*',/
  52X,'*',28X,'SUBJECT TO CONSTANT OR DECAYING',28X,'*',/
  1000
  12X,'*',44X,'H E F F 44X,'*',/2X,'*',98X,'*',/
  22X,'*',28X,'A BOUNDARY ELEMENT CODE',28X,'*',/
  32X,'*',28X,'FOR TWO-DIMENSIONAL THERMOELASTIC ANALYSIS',28X,'*',/
  42X,'*',28X,'OF A ROCK MASS',28X,'*',/
  52X,'*',28X,'SUBJECT TO CONSTANT OR DECAYING',28X,'*',/

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62X 28X THERMAL LOADING
72X 28X VERSION DATED: DEC. 6 1987 (MS-FORTRAN 77)
72X 28X
72X 28X VERSION 4.1
82X 98X
1010 FORMAT (2X,A63,' OUTPUT CREATED ON: ',I10,' ',I2,' ',I4,' ')
1030 FORMAT (
1 // NUMBER OF BOUNDARY SEGMENTS = ,I3
2 // NUMBER OF STRESS LINES = ,I3
3 // NUMBER OF HEAT SOURCES = ,I3
4 // NUMBER OF EXP. DECAYING COMPONENTS = ,I3,/)
1040 FORMAT (
1 // NO SYMMETRY CONDITIONS IMPOSED
2 // THE LINE X=0.0 IS A LINE OF SYMMETRY
3 // IMAGE BOUNDARY ELEMENTS AND HEAT SOURCES WILL BE
4 // GENERATED WITH RESPECT TO THIS LINE
1060 FORMAT (
1 // EFFECT OF IMAGE HEAT SOURCES NOT COMPUTED
1070 FORMAT (
1 // CONSTANT TEMPERATURE H.C. IMPOSED AT SURFACE
1080 FORMAT (
1 // POISSONS RATIO OF BODY = ,F6.2
2 // MODULUS OF ELASTICITY OF BODY = ,E12.4
3 // SHEAR MODULUS OF BODY = ,E12.4
1090 FORMAT (
1 // XX-COMPONENT OF FIELD STRESS = ,E10.4, 'Y +',E10.4, '
2 // (E10.4, 'Y -',E10.4, 'Y) * SIGYY
3 // YY-COMPONENT OF FIELD STRESS = ,E10.4, 'Y +',E10.4, '
4 // XY-COMPONENT OF FIELD STRESS = ,E10.4, 'Y -',E10.4, '
5 // MAXIMUM VALUE FOR CXX + DXX / Y = ,E10.4, '
1100 FORMAT (
1 // RATIO OF ZZ STRESS TO XX STRESS = ,E10.4
1110 FORMAT (
1 // TEMPERATURE VARIATION WITH DEPTH = ,F10.4, 'Y +',F10.4
1120 FORMAT (
1 // TIME FOR OUTPUT = (5(E10.3))
2 // THERMAL DIFFUSIVITY = ,E12.4
3 // THERMAL EXPANSION COEFFICIENT = ,E12.4
1130 FORMAT (
1 // STRESS COEFFICIENT VE = ,E12.4
2 // PROPERTIES OF HEAT SOURCES - 'CONSTANT OR DECAYING'
1140 FORMAT (F10.2,E15.5)
1150 FORMAT (
1 // SOURCE DATA
2 // X-COORD Y-COORD STRENGTH TIME ON
1160 FORMAT (8F10.3)
1170 FORMAT (
1 // IN THE LIST BELOW, THE VALUE ASSIGNED TO KODE,
2 // DENOTES BOUNDARY CONDITIONS AS FOLLOWS
3 // KODE = 1 NORMAL AND SHEAR STRESSES PRESCRIBED
4 // KODE = 2 NORMAL AND SHEAR DISPL. PRESCRIBED
5 // KODE = 3 NORMAL STRESS AND SHEAR DISPL. PRESCRIBED
6 // KODE = 4 NORMAL DISPL. AND SHEAR STRESS PRESCRIBED
1180 FORMAT (
1 // ELEMENT KODE X(CENTER) Y(CENTER) HALF
2 // B-WIDTH SIN BETA COS BETA B-VALUE (S)
1190 FORMAT (2I6,5F12.4,X,2E13.4)
1200 FORMAT (
1 // LINES DEFINING STRESS POINTS, //,12X
2 // XBEG YBEG XEND YEND NUNPB
1210 FORMAT (4X,4F12.4,4X,I4)
1220 FORMAT (
1 // TIME REQUIRED TO COMPUTE INFLUENCE COEFFICIENTS =
2 // F7.2, ' SECONDS.')
1230 FORMAT (
1 // 65, ' ')
1240 FORMAT (
1 // OUTPUT FOR TIME = ,E12.4, '
2 // PRE-EXISTING STRESS AT EACH ELEMENT //,
3 // ELEMENT TEMP SIGMAXX SIGMAXY
4 // SIGMAZZ NORM-STR SHEAR-STR, 5X, ' NORM-DIS
1250 FORMAT (4X, 'SHEAR-DIS')
1260 FORMAT (15,9E12.4)
1270 FORMAT (
1 // TIME REQUIRED TO COMPUTE PRE-EXISTING STRESSES = ,
2 // F7.2, ' SECONDS.')
1280 FORMAT (
1 // TIME REQUIRED TO SOLVE EQUATIONS = , F7.2, ' SECONDS.')
1290 FORMAT (
1 // BOUNDARY STRESSES AND DISPLACEMENTS AT TIME = ,E12.3,
2 // ELM X-COORD Y-COORD UX UY,
3 // US UN SIGZZ SIGXX SIGYY
4 // SIGXY SIGMA-T SIGMA-S SIGMA-N,
1300 FORMAT (
1 // 13,2E12.4,4E12.4/5X,8E12.4)
1310 FORMAT (
1 // TIME REQUIRED TO COMPUTE BOUNDARY STRESSES
2 // AND DISPLACEMENTS = , F7.2, ' SECONDS.')
1320 FORMAT (
1 // INTERIOR STRESSES AND DISPLACEMENTS AT TIME = ,E10.3,
2 // POINT X-COORD Y-COORD UX UY,
3 // SIGXX SIGY SIGY ALPHA SIGZZ SIG1
4 // SIG2 SIGY TEMP
1330 FORMAT (
1 // 13,2E12.4,2E12.4/5X,8E12.4)
1340 FORMAT (
1 // TIME REQUIRED TO COMPUTE STRESSES AND DISPLACEMENTS
2 // AT STRESS POINTS = , F7.2, ' SECONDS.')
1350 FORMAT (
1 // JOB COMPLETED AT ,I2, ' I2, ' HOURS')
1360 FORMAT (
1 // DATA FOR PLOTTING WILL BE STORED IN FILE NAMED ,A8
1 // )

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SCREEN MESSAGE FORMATS

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2000 FORMAT (////,
18X,
1 // H E F F
28X,
38X, A BOUNDARY ELEMENT CODE
48X, FOR TWO-DIMENSIONAL THERMOELASTIC ANALYSIS
58X, OF A ROCK MASS
68X, SUBJECT TO CONSTANT OR DECAYING
78X, THERMAL LOADING
78X, DEC. 6 1987 (MS-FORTRAN 77)
78X,
78X, VERSION 4.1
2100 FORMAT (
1 // READ INPUT DATA
2200 FORMAT (
1 // COMPUTE INFLUENCE COEFFICIENTS
2300 FORMAT (
1 // COMPUTE PRE-EXISTING STRESSES AT TIME = ,E10.3
2400 FORMAT (
1 // COMPUTE BOUNDARY STRESSES AND DISPLACEMENTS
2 // COMPUTE INTERIOR STRESSES AND DISPLACEMENTS

```

HEF517
HEF518
HEF519
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HEF521
HEF522
HEF523
HEF524
HEF525
HEF526
HEF527
HEF528
HEF529
HEF530
HEF531
HEF532
HEF533

PLOT FILE FORMATS

```

3000 FORMAT(A8,2I5,5I5)
3001 FORMAT(15,2E14.8,10E12.4)
3002 FORMAT(15,2E14.8,7E12.4)
STOP
END

```

HEF533
HEF534
HEF535
HEF536
HEF537


```

1100 DO 1100 I=J,N
1110 CNM(JJ,I)=CNM(JJ,I)-XM*CNM(J,I)
      RN(JJ)=RN(JJ)-XM*RN(J)
C FOR MICROSOFT
      IF (CNM(N,N).EQ.0.) CNM(N,N)=1.E-20
      PH(N)=RN(N)/CNM(N,N)
      DO 1130 J=1,NB
      JJ=N-J
      L=JJ+1
      SUM=0
      DO 1120 I=L,N
      SUM=SUM+CNM(JJ,I)*PH(I)
      PN(JJ)=(RN(JJ)-SUM)/CNM(JJ,JJ)
1120 SUM=0
1130 DO 1140 I=1,N
      SUM=SUM+CSN(N,I)*PN(I)
      PS(N)=(RS(N)-SUM)/CSS(N,N)
      DO 1170 J=1,NB
      JJ=N-J
      L=JJ+1
      SUM=0
      DO 1150 I=L,N
      SUM=SUM+CSN(JJ,I)*PN(I)
      DO 1160 I=L,N
      SUM=SUM+CSS(JJ,I)*PS(I)
      PS(JJ)=(RS(JJ)-SUM)/CSS(JJ,JJ)
1150 SUM=0
1160 PS(JJ)=(RS(JJ)-SUM)/CSS(JJ,JJ)
1170
C RETURN
END
C
C SUBROUTINE INCO2 (Y,Y,CX,CY,A,COSB,SINB,MSYM,PR,E,CON,PI,
1 SXXS,SXXN,SYY,SYYN,SXYS,SXYN,DXS,DXN,DYS,DYN)
C -----
C INFLUENCE COEFFICIENTS
C -----
      COND=(1.+PR)/E
      PR1=1.-2.*PR
      PR2=2.*(1.-PR)
      PR3=3.-4.*PR
      COS2B=COSB*COSB-SINB*SINB
      SIN2B=2.*SINB*COSB
      XB=(X-CX)*COSB+(Y-CY)*SINB
      YB=-(X-CX)*SINB+(Y-CY)*COSB
      COMPUTE FUNCTION F(XB,YB) AND ITS REQUIRED DERIVATIVES.
      -----
      R1S=(XB-A)*(XB-A)+YB*YB
      R2S=(XB+A)*(XB+A)+YB*YB
      FL1=0.5*ALOG(R1S)
      FL2=0.5*ALOG(R2S)
      FB2=CON*(FL1-FL2)
      IF (YB.NE.0.) GO TO 1010
      FB3=0
      IF (ABS(XB).GT.A) GO TO 1020
      FB3=CON*PI
      GO TO 1020
1010 FB3=-CON*(ATAN((XB+A)/YB)-ATAN((XB-A)/YB))
1020 FB1=YB*FB3*CON*(XB-A)*FL1-(XB-A)*FL2
      FB4=CON*(YB/R1S-YB/R2S)
      FB5=CON*((XB-A)/R1S-(XB+A)/R2S)
      COMPUTE COEFFICIENTS FOR DISPLACEMENTS.
      -----
      DXPS=COND*( PR3*COSB*FB1+YB*(COSB*FB3+SINB*FB2))
      DYN=COND*(-PR3*SINB*FB1+YB*(SINB*FB3-COSB*FB2))
      DYPS=COND*( PR3*SINB*FB1+YB*(SINB*FB3-COSB*FB2))
      DYFN=COND*( PR3*COSB*FB1-YB*(COSB*FB3+SINB*FB2))
      COMPUTE COEFFICIENTS FOR STRESSES.
      -----
      SXSPS=FB2*PR2*(COS2B*FB2-SIN2B*FB3)+YB*(SIN2B*FB5+COS2B*FB4)
      SXXPN=FB3*PR1*(COS2B*FB3+SIN2B*FB2)+YB*(SIN2B*FB4-COS2B*FB5)
      SYSPS=FB2*PR2*(COS2B*FB2-SIN2B*FB3)-YB*(SIN2B*FB5+COS2B*FB4)
      SYYPN=FB3*PR1*(COS2B*FB3+SIN2B*FB2)-YB*(SIN2B*FB4-COS2B*FB5)
      SXSPS= PR2*(SIN2B*FB2+COS2B*FB3)+YB*(SIN2B*FB4-COS2B*FB5)
      SXXPN= PR1*(COS2B*FB2-SIN2B*FB3)-YB*(COS2B*FB4+SIN2B*FB5)
      DXS=DXS+MSYM*DXPS
      DXN=DXN+XPN
      DYS=DYS+MSYM*DYPS
      DYN=DYN+DYPN
      SXXS=SXXS+MSYM*SXXPS
      SXXN=SXXN+SXXPN
      SYYN=SYYN+MSYM*SYYPS
      SYYPN=SYYPN+SYYPN
      SXYS=SXYS+MSYM*SXSPS
      SXYN=SXYN+SXYPN
      RETURN
      END
C
C SUBROUTINE INITL(SXXS,SXXN,SYY,SYYN,SXYS,SXYN,DXS,DXN,DYS,DYN)
C -----
C THIS SUBROUTINE INITIALIZES VARIABLES
      SXXS=0.
      SXXN=0.
      SYYN=0.
      SYYPN=0.
      SXYS=0.
      SXYN=0.
      DXS=0.
      DXN=0.
      DYS=0.
      DYN=0.

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SOL 35
SOL 36
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SOL 61
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INC 44
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INC 46
INI 1
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INI 3
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INI 5
INI 6
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INI 8
INI 9
INI 10
INI 11

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```

      RETURN
      END
      *****
      SUBROUTINE TEMCAL (XP,YP,TIM,DIFF,G,VE
1 TOC,PROP,QEXP,NCOMP,XS,YS,QS,TOS,KSVM,NSORC,IMAG,AA)
      -----
      COMPUTE THERMAL EFFECT AT (XP,YP) FOR TIME = TIM
      -----
      DIMENSION DD(6),AA(1),TOC(1),PROP(1),QEXP(1),XS(1),YS(1),QS(1),
1 TOS(1)
      VECTORS DD AND AA CONTAIN TEMP, STRESS, AND DISPLACEMENT DATA
      DD(1) / AA(1) :- INDUCED TEMPERATURE (EACH SOURCE/TOTAL)
      DD(2) / AA(2) :- INDUCED XX STRESS
      DD(3) / AA(3) :- INDUCED YY STRESS
      DD(4) / AA(4) :- INDUCED XY STRESS
      DD(5) / AA(5) :- INDUCED X DISPLACEMENT
      DD(6) / AA(6) :- INDUCED Y DISPLACEMENT
      DO 1010 I=1,6
      AA(I)=0.0
1010 CONTINUE
      IMSIGN=-1
1020 IMSIGN=-IMSIGN
      SNCH=-1.0
1030 SNCH=-SNCH
      DO 1070 I=1,NSORC
      IF (TIM,LT,TOS(I)) GO TO 1070
      X=XP-XS(I)*SNCH
      Y=YP-YS(I)*IMSIGN
      DO 1060 J=1,NCOMP
      TIME=TIM-TOS(I)-TOC(J)
      IF (TIME,LE,0.0) GO TO 1060
      IF (TIME*QEXP(J)/0.7,GT,20.0) GO TO 1060
      OC=QS(I)*PROP(J)*IMSIGN
      DO 1040 II=1,6
      DD(II)=0.0
1040 CALL HEAT (OC,QEXP(J),TIME,X,Y,DD(1),DD(2),DD(3),DD(4),DD(5),
1 DD(6),DIFF,G,VE)
      DO 1050 K=1,6
      AA(K)=AA(K)+DD(K)
1050 CONTINUE
1060 CONTINUE
1070 CONTINUE
      IF (KSVM.EQ,1.AND,SNCH,GT,0) GO TO 1030
      IF (IMAG.NE,0.AND,IMSIGN,GT,0) GO TO 1020
      RETURN
      END
      SUBROUTINE HEAT (A1,A2,A3,A4,A5,A6,A7,A8,A9,A10,A11,
1 DIFF,G,VE)
      -----
      THIS SUBROUTINE WAS ORIGINALLY CODED BY R.D.HART (UNIVERSITY
      OF MINNESOTA). IMPROVEMENTS AND DOUBLE PRECISION MODIFICATIONS
      BY S.KEY (RE/SPEC).
      -----
      LOGICAL B
      DOUBLE PRECISION OC,QEXP,TM,Y,Z,R,XA,XP,XC,XAEXP,XBEXP,CON1,CON2,
1 E1,FRL,SUM,RS,TS,TOL,FAC,Y,TSUM,XN,TEMP1,
2 TEMP2,EXFCT,TP,FCT,SNEW,SOLD,S1,S2,TEST,
3 SINTH,COSTH,UP,UX,UZ,S,C,TX,TZ,TXZ,XB1,DPI,
4 XBR,XCN,QP2,QP1,SG1,XBN,XBNK,CEUL,CON3
      DATA CEUL /0.57721566490153D0/
      DATA DPI /3.14159265358979D0/
      DATA CON3 /0.83333333333333D0/
      OC=DBLE(A1)
      QEXP=DBLE(A2)
      TM=DBLE(A3)
      X=DBLE(A4)
      Z=DBLE(A5)
      HEAT SOURCE - CLOSED FORM SOLUTION
      TP = 0.0D0
      TX = 0.0D0
      TZ = 0.0D0
      TXZ = 0.0D0
      UX = 0.0D0
      UZ = 0.0D0
      IFLAG=0
      R=DSQRT(X*X+Z*Z)
      AVOID CALCULATIONS TOO CLOSE TO SOURCE
      IF(R,LT,1.0D-2) THEN
      R = 1.0D-2
      K = 1.0D-2
      Z = 0.0D0
      ENDIF
      XA = -QEXP*TM
      XB = R*R/(4.0D0*DBLE(DIFF)*TM)
      AVOID VERY SMALL NUMBERS - EXPONENTIAL INTEGRAL
      IS STABLE WITHIN THIS LIMIT
      IF (XB,GT,50.0D0) GO TO 1110
      XC = XB*TM
      XBI = 1.0D0/XB
      XAEXP = DEXP(XA)
      XBEXP = DEXP(-XB)

```

INI 12
INI 13

TEM 1
TEM 2

TEM 3
TEM 4

TEM 5
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HEA 1
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HEA 35
HEA 36

```

CON1 = CC/(4.0D0*DPI*DBLE(DIFF))
CON2 = CC*DBLE(VE)/(DPI*R*K)
EXPONENTIAL INTEGRAL
IF (XB.GT.4.0D0) THEN
  EI = XEXP*XB1
1  (1.0D0 - XB1*(0.75D0 - XB1*(CON3-XB1*(1.125D0-XB1*1.7D0))))
ELSE
  XBK = 1.0D0
  SUM = 0.0D0
  FRL = 1.0D0
  DO 1030 K=1,15
    XBK = XBK*(-XB)
    FRL = DBLE(FLOAT(K))*FRL
    SUM = SUM+XBK/(DBLE(FLOAT(K))*FRL)
1030 CONTINUE
EI = CEUL + DLOG(XB) + SUM
ENDIF

SET LIMIT ON DECAY CONSTANT - USE CONSTANT SOURCE
FOR SMALLER VALUES
1040 IF (DABS(XA).LT.1.0D-10) GO TO 1090
DECAYING SOURCE
TP = -XEXP*EI
IF (DABS(TP).LT.1.0D-20) GO TO 1110
RS = (1.0D0-XEXP)/QEXP
TS = ((XEXP-1.0D0)/QEXP-2.0D0*XEXP*XC*EI)
TOL = (1.0D-6)*DABS(RS)
S1 = 0.0D0
SNEW = 0.0D0
FAC = 1.0D0
QPI = 1.0D0
XCN = 1.0D0
XBN = XB
SG1 = 1.0D0
B = .FALSE.
DO 1080 N=2,80
  N1 = N-1
  FAC = DBLE(FLOAT(N1))*FAC
  QP2 = QPI
  QPI = QPI*QEXP
  XCN = XCN*XC
  SG1 = -SG1
EXPONENTIAL FUNCTION
Y = -1.0D0
XBH = XBN*XB
XBN = XBN
TSUM = 0.0D0
DO 1050 K=1,N1
  XN = 1.0D0
  DO 1050 L=1,K
    XN = XN*DBLE(FLOAT(N-L))
1050 CONTINUE
Y = -Y
XBNK = XBN*XB1
TSUM = TSUM+Y/(XN*XBNK)
1060 CONTINUE
TEMP1 = XEXP*TSUM
TEMP2 = SG1/FAC*EI
EXFCT = TEMP1-TEMP2
TEMPERATURE
TP = TP*XEXP*QPI*XCN/FAC*EXFCT
STRESSES
FCT = FAC/(DBLE(FLOAT(N1)))
SOLD = SNEW
S1 = XEXP*QP2*XCN/FCT*EXFCT
SNEW = S1
S2 = 2.0D0*XEXP*QPI*XCN*XC/FAC*EXFCT
RS = RS-SNEW
TS = TS*(S1+S2)
TEST = DABS(SOLD)-DABS(SNEW)
IF (TEST.GE.0.0D0.AND.TEST.LT.TOL) THEN
  IF (B) GO TO 1100
  B = .TRUE.
ENDIF
1080 CONTINUE
WRITE (6,1120)
GO TO 1100
CONSTANT SOURCE :
TEMPERATURE
1090 TP=-EI
STRESSES
RS = (TM-XC*(XEXP/XB+EI))
TS = (XEXP*(TM-XC*EI-TM))
1100 SINTH = X/R
COSTH = Z/R
TP = TP * CON1
RS = RS * CON2
TS = TS * CON2
UR = RS*R/(DBLE(G)*DBLE(G))
UX = -UR*SINTH
UZ = -UR*COSTH
S = SINTH*SINTH
C = COSTH*COSTH
TX = RS*S+TS*C
TZ = RS*C+TS*S
TXZ = (RS-TS)*SINTH*COSTH
1110 CONTINUE

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HEA117
HEA118
HEA119
HEA120
HEA121

HEA122

	A6 = SNGL(TP)	HEA123
	A7 = SNGL(TX)	HEA124
	A8 = SNGL(TZ)	HEA125
	A9 = SNGL(TXZ)	HEA126
	A10 = SNGL(UX)	HEA127
	A11 = SNGL(UZ)	HEA128
C	RETURN	HEA129
C	1120 FORMAT (48H RADIAL STRESS DOES NOT CONVERGE WITHIN 80 TERMS)	HEA130
	END	HEA131

APPENDIX B

Output for Verification Analyses

```

*****
*                                     H E F F
*                                     A BOUNDARY ELEMENT CODE
* FOR TWO-DIMENSIONAL THERMOELASTIC ANALYSIS
*                                     OF A ROCK MASS
* SUBJECT TO CONSTANT OR DECAYING
* THERMAL LOADING
* VERSION DATED: DEC. 6 1987 (MS-FORTRAN 77)
*                                     VERSION 4.1
*****

```

THICK WALLED CYLINDER SUBJECTED TO EXTERNAL PRESSURE OUTPUT CREATED ON 12/ 6/1987

NUMBER OF BOUNDARY SEGMENTS = 2
 NUMBER OF STRESS LINES = 1
 NUMBER OF HEAT SOURCES = 0
 NUMBER OF EXP. DECAYING COMPONENTS = 0

THE LINE X=0.0 IS A LINE OF SYMMETRY.
 IMAGE BOUNDARY ELEMENTS AND HEAT SOURCES WILL BE GENERATED WITH RESPECT TO THIS LINE.

EFFECT OF IMAGE HEAT SOURCES NOT COMPUTED

POISSONS RATIO OF BODY = .25
 MODULUS OF ELASTICITY OF BODY = .6000E+05
 SHEAR MODULUS OF BODY = .2400E+05

XX-COMPONENT OF FIELD STRESS = .0000E+00Y + .0000E+00 + (.0000E+00 + .0000E+00 / Y) * SIGYY
 YY-COMPONENT OF FIELD STRESS = .0000E+00Y + .0000E+00
 XY-COMPONENT OF FIELD STRESS = .0000E+00Y + .0000E+00
 MAXIMUM VALUE FOR CX + DX / Y = .0000E+00
 RATIO OF ZZ STRESS TO XX STRESS = .0000E+00

IN THE LIST BELOW, THE VALUE ASSIGNED TO KODE DENOTES BOUNDARY CONDITIONS AS FOLLOWS.

KODE= 1 NORMAL AND SHEAR STRESSES PRESCRIBED
 KODE= 2 NORMAL AND SHEAR DISPL. PRESCRIBED
 KODE= 3 NORMAL STRESS AND SHEAR DISPL. PRESCRIBED
 KODE= 4 NORMAL DISPL. AND SHEAR STRESS PRESCRIBED

ELEMENT KODE	X(CENTER)	Y(CENTER)	HALF-WIDTH	SIN BETA	COS BETA	B-VALUE (S)	B-VALUE (N)
1	1.281	-3.9959	.1282	.0321	.9995	.0000E+00	.0000E+00
2	.3839	-3.9795	.1282	.0960	.9954	.0000E+00	.0000E+00
3	.6381	-3.9467	.1282	.1596	.9872	.0000E+00	.0000E+00
4	.8896	-3.8977	.1282	.2225	.9749	.0000E+00	.0000E+00
5	1.1375	-3.8327	.1282	.2845	.9587	.0000E+00	.0000E+00
6	1.3808	-3.7519	.1282	.3454	.9385	.0000E+00	.0000E+00
7	1.6183	-3.6558	.1282	.4048	.9144	.0000E+00	.0000E+00
8	1.8492	-3.5446	.1282	.4625	.8866	.0000E+00	.0000E+00
9	2.0725	-3.4188	.1282	.5184	.8551	.0000E+00	.0000E+00
10	2.2873	-3.2790	.1282	.5721	.8202	.0000E+00	.0000E+00
11	2.4927	-3.1257	.1282	.6235	.7818	.0000E+00	.0000E+00
12	2.6878	-2.9596	.1282	.6723	.7403	.0000E+00	.0000E+00
13	2.8719	-2.7813	.1282	.7183	.6957	.0000E+00	.0000E+00
14	3.0442	-2.5916	.1282	.7614	.6482	.0000E+00	.0000E+00
15	3.2040	-2.3912	.1282	.8014	.5981	.0000E+00	.0000E+00
16	3.3506	-2.1810	.1282	.8381	.5455	.0000E+00	.0000E+00
17	3.4835	-1.9619	.1282	.8713	.4907	.0000E+00	.0000E+00
18	3.6020	-1.7346	.1282	.9010	.4339	.0000E+00	.0000E+00
19	3.7058	-1.5003	.1282	.9269	.3753	.0000E+00	.0000E+00
20	3.7943	-1.2598	.1282	.9491	.3151	.0000E+00	.0000E+00
21	3.8672	-1.0141	.1282	.9673	.2537	.0000E+00	.0000E+00
22	3.9242	-.7642	.1282	.9816	.1912	.0000E+00	.0000E+00
23	3.9651	-.5112	.1282	.9918	.1279	.0000E+00	.0000E+00
24	3.9897	-.2561	.1282	.9979	.0641	.0000E+00	.0000E+00
25	3.9979	.0000	.1282	1.0000	.0000	.0000E+00	.0000E+00
26	3.9897	.2561	.1282	.9979	-.0641	.0000E+00	.0000E+00
27	3.9651	.5112	.1282	.9918	-.1279	.0000E+00	.0000E+00
28	3.9242	.7642	.1282	.9816	-.1912	.0000E+00	.0000E+00
29	3.8672	1.0141	.1282	.9673	-.2537	.0000E+00	.0000E+00
30	3.7943	1.2598	.1282	.9491	-.3151	.0000E+00	.0000E+00
31	3.7058	1.5003	.1282	.9269	-.3753	.0000E+00	.0000E+00
32	3.6020	1.7346	.1282	.9010	-.4339	.0000E+00	.0000E+00
33	3.4835	1.9619	.1282	.8713	-.4907	.0000E+00	.0000E+00
34	3.3506	2.1810	.1282	.8381	-.5455	.0000E+00	.0000E+00
35	3.2040	2.3912	.1282	.8014	-.5981	.0000E+00	.0000E+00
36	3.0442	2.5916	.1282	.7614	-.6482	.0000E+00	.0000E+00
37	2.8719	2.7813	.1282	.7183	-.6957	.0000E+00	.0000E+00
38	2.6878	2.9596	.1282	.6723	-.7403	.0000E+00	.0000E+00
39	2.4927	3.1257	.1282	.6235	-.7818	.0000E+00	.0000E+00
40	2.2873	3.2790	.1282	.5721	-.8202	.0000E+00	.0000E+00
41	2.0725	3.4188	.1282	.5184	-.8551	.0000E+00	.0000E+00
42	1.8492	3.5446	.1282	.4625	-.8866	.0000E+00	.0000E+00
43	1.6183	3.6558	.1282	.4048	-.9144	.0000E+00	.0000E+00
44	1.3808	3.7519	.1282	.3454	-.9385	.0000E+00	.0000E+00
45	1.1375	3.8327	.1282	.2845	-.9587	.0000E+00	.0000E+00
46	.8896	3.8977	.1282	.2225	-.9749	.0000E+00	.0000E+00
47	.6381	3.9467	.1282	.1596	-.9872	.0000E+00	.0000E+00
48	.3839	3.9795	.1282	.0960	-.9954	.0000E+00	.0000E+00
49	.1281	3.9959	.1282	.0321	-.9995	.0000E+00	.0000E+00
50	.1922	3.9938	.1923	-.0321	.9995	.0000E+00	.6000E+01
51	.5718	3.9692	.1923	-.0960	.9954	.0000E+00	.6000E+01
52	.6571	3.9200	.1923	-.1596	.9872	.0000E+00	.6000E+01
53	1.3344	3.8466	.1923	-.2225	.9749	.0000E+00	.6000E+01
54	1.7063	3.7401	.1923	-.2845	.9587	.0000E+00	.6000E+01
55	2.0711	3.6279	.1923	-.3454	.9385	.0000E+00	.6000E+01
56	2.4275	3.4837	.1923	-.4048	.9144	.0000E+00	.6000E+01
57	2.7738	3.3169	.1923	-.4625	.8866	.0000E+00	.6000E+01
58	3.1028	3.1282	.1923	-.5184	.8551	.0000E+00	.6000E+01
59	3.4309	2.9185	.1923	-.5721	.8202	.0000E+00	.6000E+01
60	3.7390	2.6886	.1923	-.6235	.7818	.0000E+00	.6000E+01
61	4.0317	2.4394	.1923	-.6723	.7403	.0000E+00	.6000E+01
62	4.3079	2.1720	.1923	-.7183	.6957	.0000E+00	.6000E+01
63	4.5663	1.8874	.1923	-.7614	.6482	.0000E+00	.6000E+01
64	4.8060	1.5868	.1923	-.8014	.5981	.0000E+00	.6000E+01

65	1	5.0259	3.2715	.1923	- .8381	.5455	.0000E+00	.6000E+01
66	1	5.2252	2.9428	.1923	- .8713	.4907	.0000E+00	.6000E+01
67	1	5.4030	2.6020	.1923	- .9010	.4339	.0000E+00	.6000E+01
68	1	5.5806	2.2504	.1923	- .9269	.3753	.0000E+00	.6000E+01
69	1	5.7614	1.8897	.1923	- .9491	.3153	.0000E+00	.6000E+01
70	1	5.9408	1.5211	.1923	- .9673	.2537	.0000E+00	.6000E+01
71	1	5.8663	1.1464	.1923	- .9816	.1912	.0000E+00	.6000E+01
72	1	5.9477	.7669	.1923	- .9918	.1279	.0000E+00	.6000E+01
73	1	5.9846	.3842	.1923	- .9979	.0641	.0000E+00	.6000E+01
74	1	5.9699	.0000	.1923	- 1.0000	.0000	.0000E+00	.6000E+01
75	1	5.9408	-.3842	.1923	- .9979	-.0641	.0000E+00	.6000E+01
76	1	5.9477	-.7669	.1923	- .9918	-.1279	.0000E+00	.6000E+01
77	1	5.8663	-1.1464	.1923	- .9816	-.1912	.0000E+00	.6000E+01
78	1	5.8008	-1.5211	.1923	- .9673	-.2537	.0000E+00	.6000E+01
79	1	5.6914	-1.8897	.1923	- .9491	-.3153	.0000E+00	.6000E+01
80	1	5.5806	-2.2504	.1923	- .9269	-.3753	.0000E+00	.6000E+01
81	1	5.4030	-2.6020	.1923	- .9010	-.4339	.0000E+00	.6000E+01
82	1	5.2252	-2.9428	.1923	- .8713	-.4907	.0000E+00	.6000E+01
83	1	5.0259	-3.2715	.1923	- .8381	-.5455	.0000E+00	.6000E+01
84	1	4.8060	-3.5868	.1923	- .8014	-.5981	.0000E+00	.6000E+01
85	1	4.5663	-3.8874	.1923	- .7614	-.6482	.0000E+00	.6000E+01
86	1	4.3079	-4.1720	.1923	- .7183	-.6957	.0000E+00	.6000E+01
87	1	4.0317	-4.4394	.1923	- .6723	-.7403	.0000E+00	.6000E+01
88	1	3.7390	-4.6886	.1923	- .6235	-.7818	.0000E+00	.6000E+01
89	1	3.4309	-4.9185	.1923	- .5721	-.8202	.0000E+00	.6000E+01
90	1	3.1068	-5.1282	.1923	- .5184	-.8551	.0000E+00	.6000E+01
91	1	2.7738	-5.3169	.1923	- .4625	-.8866	.0000E+00	.6000E+01
92	1	2.4275	-5.4837	.1923	- .4048	-.9144	.0000E+00	.6000E+01
93	1	2.0711	-5.6299	.1923	- .3454	-.9385	.0000E+00	.6000E+01
94	1	1.7063	-5.7491	.1923	- .2845	-.9587	.0000E+00	.6000E+01
95	1	1.3344	-5.8466	.1923	- .2225	-.9749	.0000E+00	.6000E+01
96	1	.9571	-5.9200	.1923	- .1596	-.9872	.0000E+00	.6000E+01
97	1	.5758	-5.9692	.1923	- .0960	-.9954	.0000E+00	.6000E+01
98	1	.1922	-5.9938	.1923	- .0321	-.9995	.0000E+00	.6000E+01

LINES DEFINING STRESS POINTS
 XLEG YLEG XEND YEND NUMFB
 4.0000 .0000 6.0000 .0000 6
 TIME REQUIRED TO COMPUTE INFLUENCE COEFFICIENTS= 133.42 SECONDS.

OUTPUT FOR TIME= .0000E+00

PRE-EXISTING STRESS AT EACH ELEMENT

ELEMENT	TEMP	SIGMAXX	SIGMAYY	SIGMAXY	SIGMAZZ	NORM-STR	SHEAR-STR	NORM-DIS	SHEAR-DIS
1	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
2	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
3	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
4	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
5	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
6	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
7	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
8	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
9	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
10	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
11	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
12	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
13	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
14	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
15	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
16	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
17	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
18	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
19	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
20	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
21	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
22	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
23	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
24	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
25	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
26	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
27	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
28	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
29	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
30	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
31	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
32	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
33	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
34	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
35	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
36	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
37	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
38	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
39	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
40	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
41	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
42	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
43	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
44	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
45	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
46	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
47	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
48	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
49	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
50	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
51	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
52	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
53	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
54	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
55	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
56	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
57	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
58	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
59	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
60	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
61	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
62	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
63	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
64	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
65	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
66	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
67	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00

68	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
69	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
70	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
71	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
72	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
73	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
74	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
75	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
76	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
77	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
78	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
79	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
80	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
81	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
82	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
83	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
84	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
85	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
86	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
87	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
88	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
89	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
90	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
91	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
92	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
93	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
94	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
95	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
96	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
97	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
98	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00

TIME REQUIRED TO COMPUTE PRE-EXISTING STRESSES = 1.15 SECONDS.

TIME REQUIRED TO SOLVE EQUATIONS= 239.53 SECONDS.

BOUNDARY STRESSES AND DISPLACEMENTS AT TIME = .000E+00

ELM	X-COORD SIGXX	Y-COORD SIGYY	UX SIGXY	UY SIGZZ	US SIGMA-S	UN SIGMA-N	SIGMA-T	TEMP
1	.1281E+00 .2156E+02	-.3996E+01 .2216E-01	.4362E-04 .6913E+00	-.1360E-02 .5395E+01	.4045E-08 -.3938E-06	-.1361E-02 -.5399E-05	.2158E+02	.0000E+00
2	.3639E+00 .2138E+02	-.3979E+01 .1990E+00	.1307E-03 .2063E+01	-.1355E-02 .5395E+01	.1092E-07 .1055E-05	-.1361E-02 -.4827E-06	.2158E+02	.0000E+00
3	.6381E+00 .2103E+02	-.3947E+01 .5497E+00	.2172E-03 .3400E+01	-.1343E-02 .5395E+01	.1934E-07 -.7192E-06	-.1361E-02 -.5451E-06	.2158E+02	.0000E+00
4	.8896E+00 .2051E+02	-.3898E+01 .1069E+01	.3028E-03 .4681E+01	-.1327E-02 .5395E+01	.2627E-07 .5409E-06	-.1361E-02 -.3977E-05	.2158E+02	.0000E+00
5	.1138E+01 .1963E+02	-.3833E+01 .1747E+01	.3872E-03 .5866E+01	-.1305E-02 .5395E+01	.3422E-07 .4062E-06	-.1361E-02 -.1133E-05	.2158E+02	.0000E+00
6	.1361E+01 .1901E+02	-.3752E+01 .2574E+01	.4700E-03 .6994E+01	-.1277E-02 .5395E+01	.4176E-07 -.2692E-05	-.1361E-02 -.3260E-05	.2158E+02	.0000E+00
7	.1618E+01 .1854E+02	-.3656E+01 .3536E+01	.5509E-03 .7987E+01	-.1244E-02 .5395E+01	.4852E-07 .1829E-05	-.1361E-02 -.4318E-06	.2158E+02	.0000E+00
8	.1849E+01 .1696E+02	-.3545E+01 .4617E+01	.6295E-03 .8847E+01	-.1206E-02 .5395E+01	.5421E-07 -.1042E-05	-.1361E-02 -.3304E-06	.2158E+02	.0000E+00
9	.2073E+01 .1578E+02	-.3419E+01 .5799E+01	.7055E-03 .9566E+01	-.1164E-02 .5395E+01	.6011E-07 .2394E-05	-.1361E-02 -.3865E-05	.2158E+02	.0000E+00
10	.2287E+01 .1452E+02	-.3279E+01 .7063E+01	.7786E-03 .1013E+02	-.1116E-02 .5395E+01	.6670E-07 -.3487E-05	-.1361E-02 -.2673E-05	.2158E+02	.0000E+00
11	.2493E+01 .1319E+02	-.3126E+01 .8389E+01	.8485E-03 .1052E+02	-.1064E-02 .5395E+01	.7160E-07 .1380E-05	-.1361E-02 -.4638E-05	.2158E+02	.0000E+00
12	.2688E+01 .1183E+02	-.2960E+01 .9754E+01	.9149E-03 .1074E+02	-.1007E-02 .5395E+01	.7626E-07 .1804E-06	-.1361E-02 -.3931E-05	.2158E+02	.0000E+00
13	.2872E+01 .1044E+02	-.2781E+01 .1114E+02	.9776E-03 .1078E+02	-.9467E-03 .5395E+01	.8182E-07 -.3823E-06	-.1361E-02 -.2441E-05	.2158E+02	.0000E+00
14	.3044E+01 .9066E+01	-.2592E+01 .1251E+02	.1036E-02 .1065E+02	-.8821E-03 .5395E+01	.8574E-07 .2073E-05	-.1361E-02 .3424E-05	.2158E+02	.0000E+00
15	.3204E+01 .7720E+01	-.2391E+01 .1386E+02	.1091E-02 .1034E+02	-.8139E-03 .5395E+01	.8882E-07 -.9586E-06	-.1361E-02 -.2213E-05	.2158E+02	.0000E+00
16	.3351E+01 .6422E+01	-.2181E+01 .1516E+02	.1141E-02 .9866E+01	-.7423E-03 .5395E+01	.9222E-07 -.1772E-05	-.1361E-02 -.1109E-04	.2158E+02	.0000E+00
17	.3483E+01 .5196E+01	-.1962E+01 .1638E+02	.1186E-02 .9227E+01	-.6677E-03 .5395E+01	.9507E-07 -.2932E-05	-.1361E-02 -.4083E-05	.2158E+02	.0000E+00
18	.3602E+01 .4062E+01	-.1735E+01 .1752E+02	.1226E-02 .8436E+01	-.5904E-03 .5395E+01	.9612E-07 -.1222E-05	-.1361E-02 .3762E-05	.2158E+02	.0000E+00
19	.3706E+01 .3039E+01	-.1500E+01 .1854E+02	.1261E-02 .7506E+01	-.5106E-03 .5395E+01	.9799E-07 -.1301E-05	-.1361E-02 -.5132E-05	.2158E+02	.0000E+00
20	.3794E+01 .2143E+01	-.1260E+01 .1944E+02	.1292E-02 .6453E+01	-.4287E-03 .5395E+01	.9929E-07 -.4149E-07	-.1361E-02 .4596E-05	.2158E+02	.0000E+00
21	.3867E+01 .1388E+01	-.1014E+01 .2019E+02	.1316E-02 .5295E+01	-.3451E-03 .5395E+01	.9980E-07 .8139E-06	-.1361E-02 .1930E-05	.2158E+02	.0000E+00
22	.3924E+01 .7885E+00	-.7642E+00 .2079E+02	.1336E-02 .4049E+01	-.2600E-03 .5395E+01	.1010E-06 -.3055E-06	-.1361E-02 .4155E-05	.2158E+02	.0000E+00
23	.3965E+01 .3529E+00	-.5112E+00 .2123E+02	.1350E-02 .2737E+01	-.1739E-03 .5395E+01	.1014E-06 -.2231E-06	-.1361E-02 .2564E-05	.2158E+02	.0000E+00
24	.3990E+01	-.2561E+00	.1358E-02	-.8709E-04	.1005E-06	-.1361E-02		

	.8859E-01	.2149E+02	.1380E+01	.5395E+01	.1600E-05	.7023E-05	.2158E+02	.0000E+00
25	.3998E+01 .1954E-05	.8941E-07 .2158E+02	.1361E-02 .3184E-05	.9878E-07 .5395E+01	.9894E-07 -.6658E-06	-.1361E-02 .1954E-05	.2158E+02	.0000E+00
26	.3990E+01 .8858E-01	.2561E+00 .2149E+02	.1358E-02 -.1380E+01	.8729E-04 .5395E+01	.9792E-07 .5838E-06	-.1361E-02 .1683E-05	.2158E+02	.0000E+00
27	.3965E+01 .3529E+00	.5112E+00 .2123E+02	.1350E-02 -.2737E+01	.1741E-03 .5395E+01	.9570E-07 .1670E-05	-.1361E-02 -.4467E-05	.2158E+02	.0000E+00
28	.3924E+01 .7885E+00	.7642E+00 .2079E+02	.1336E-02 -.4049E+01	.2602E-03 .5395E+01	.9406E-07 .5601E-06	-.1361E-02 .4963E-06	.2158E+02	.0000E+00
29	.3867E+01 .1388E+01	.1014E+01 .2019E+02	.1316E-02 -.5295E+01	.3453E-03 .5395E+01	.9034E-07 .1279E-05	-.1361E-02 .4211E-05	.2158E+02	.0000E+00
30	.3794E+01 .2143E+01	.1260E+01 .1944E+02	.1292E-02 -.8453E+01	.4289E-03 .5395E+01	.8906E-07 .3770E-06	-.1361E-02 -.8469E-06	.2158E+02	.0000E+00
31	.3706E+01 .3039E+01	.1500E+01 .1854E+02	.1261E-02 -.7506E+01	.5108E-03 .5395E+01	.8604E-07 -.3795E-06	-.1361E-02 .3384E-05	.2158E+02	.0000E+00
32	.3602E+01 .4062E+01	.1735E+01 .1752E+02	.1226E-02 -.8436E+01	.5906E-03 .5395E+01	.8230E-07 -.1170E-05	-.1361E-02 -.7792E-05	.2158E+02	.0000E+00
33	.3483E+01 .5196E+01	.1962E+01 .1638E+02	.1186E-02 -.9227E+01	.6679E-03 .5395E+01	.7750E-07 .4203E-06	-.1361E-02 -.1690E-05	.2158E+02	.0000E+00
34	.3351E+01 .6422E+01	.2181E+01 .1516E+02	.1141E-02 -.9866E+01	.7425E-03 .5395E+01	.7400E-07 .5220E-06	-.1361E-02 -.2762E-05	.2158E+02	.0000E+00
35	.3204E+01 .7720E+01	.2391E+01 .1366E+02	.1091E-02 -.1034E+02	.8141E-03 .5395E+01	.7022E-07 -.1791E-05	-.1361E-02 .4207E-06	.2158E+02	.0000E+00
36	.3044E+01 .9068E+01	.2592E+01 .1251E+02	.1036E-02 -.1065E+02	.8823E-03 .5395E+01	.6604E-07 .3357E-05	-.1361E-02 -.4806E-05	.2158E+02	.0000E+00
37	.2872E+01 .1044E+02	.2781E+01 .1114E+02	.9776E-03 -.1078E+02	.9469E-03 .5395E+01	.6169E-07 -.1303E-05	-.1361E-02 -.3750E-06	.2158E+02	.0000E+00
38	.2688E+01 .1183E+02	.2960E+01 .9754E+01	.9149E-03 -.1074E+02	.1008E-02 .5395E+01	.5649E-07 -.1426E-05	-.1361E-02 -.5213E-05	.2158E+02	.0000E+00
39	.2493E+01 .1319E+02	.3126E+01 .8389E+01	.8485E-03 -.1052E+02	.1064E-02 .5395E+01	.5335E-07 .1616E-05	-.1361E-02 -.4970E-05	.2158E+02	.0000E+00
40	.2287E+01 .1452E+02	.3279E+01 .7063E+01	.7786E-03 -.1013E+02	.1116E-02 .5395E+01	.4750E-07 -.1460E-06	-.1361E-02 -.3824E-06	.2158E+02	.0000E+00
41	.2073E+01 .1578E+02	.3419E+01 .5799E+01	.7055E-03 -.9566E+01	.1164E-02 .5395E+01	.4228E-07 -.2318E-05	-.1361E-02 -.5973E-05	.2158E+02	.0000E+00
42	.1849E+01 .1696E+02	.3545E+01 .4617E+01	.6295E-03 -.8849E+01	.1207E-02 .5395E+01	.3809E-07 -.6861E-07	-.1361E-02 -.2773E-05	.2158E+02	.0000E+00
43	.1618E+01 .1804E+02	.3656E+01 .3536E+01	.5509E-03 -.7987E+01	.1245E-02 .5395E+01	.3275E-07 -.3778E-05	-.1361E-02 .4467E-05	.2158E+02	.0000E+00
44	.1381E+01 .1901E+02	.3752E+01 .2574E+01	.4700E-03 -.6994E+01	.1277E-02 .5395E+01	.2777E-07 -.2390E-05	-.1361E-02 -.4655E-05	.2158E+02	.0000E+00
45	.1138E+01 .1983E+02	.3833E+01 .1747E+01	.3872E-03 -.5886E+01	.1305E-02 .5395E+01	.2258E-07 .9763E-07	-.1361E-02 -.4208E-05	.2158E+02	.0000E+00
46	.8896E+00 .2051E+02	.3898E+01 .1069E+01	.3028E-03 -.4681E+01	.1327E-02 .5395E+01	.1852E-07 -.1921E-06	-.1361E-02 -.3381E-05	.2158E+02	.0000E+00
47	.6381E+00 .21031E+02	.3947E+01 .5497E+00	.2172E-03 -.3400E+01	.1344E-02 .5395E+01	.1365E-07 -.7893E-06	-.1361E-02 .7344E-05	.2158E+02	.0000E+00
48	.3839E+00 .2138E+02	.3979E+01 .1990E+00	.1307E-03 -.2063E+01	.1355E-02 .5395E+01	.8707E-08 -.3832E-06	-.1361E-02 -.3996E-06	.2158E+02	.0000E+00
49	.1281E+00 .2156E+02	.3996E+01 .2217E-01	.4362E-04 -.6913E+00	.1360E-02 .5395E+01	.2778E-08 -.1473E-06	-.1361E-02 .2964E-05	.2158E+02	.0000E+00
50	.1922E+00 .1557E+02	.5994E+01 .6010E+01	.4109E-04 -.3069E+00	.1281E-02 .5395E+01	.3818E-08 .2182E-06	.1282E-02 .6000E+01	.1558E+02	.0000E+00
51	.5758E+00 .1549E+02	.5969E+01 .6088E+01	.1231E-03 -.9156E+00	.1276E-02 .5395E+01	-.7946E-08 .2582E-06	.1282E-02 .6000E+01	.1558E+02	.0000E+00
52	.9571E+00 .1534E+02	.5920E+01 .6244E+01	.2046E-03 -.1509E+01	.1266E-02 .5395E+01	-.1371E-07 .1873E-06	.1282E-02 .6000E+01	.1558E+02	.0000E+00
53	.1334E+01 .1510E+02	.5847E+01 .6474E+01	.2853E-03 -.2078E+01	.1250E-02 .5395E+01	-.2204E-07 -.8316E-06	.1282E-02 .6000E+01	.1558E+02	.0000E+00
54	.1708E+01 .1480E+02	.5749E+01 .6775E+01	.3647E-03 -.2613E+01	.1229E-02 .5395E+01	-.2734E-07 -.2767E-06	.1282E-02 .6000E+01	.1558E+02	.0000E+00
55	.2071E+01 .1444E+02	.5628E+01 .7143E+01	.4427E-03 -.3105E+01	.1203E-02 .5395E+01	-.3279E-07 -.2627E-08	.1282E-02 .6000E+01	.1558E+02	.0000E+00
56	.2427E+01 .1401E+02	.5484E+01 .7570E+01	.5189E-03 -.3546E+01	.1172E-02 .5395E+01	-.3722E-07 .2514E-05	.1282E-02 .6000E+01	.1558E+02	.0000E+00
57	.2774E+01 .1353E+02	.5317E+01 .8049E+01	.5929E-03 -.3928E+01	.1137E-02 .5395E+01	-.4298E-07 -.9862E-06	.1282E-02 .6000E+01	.1558E+02	.0000E+00
58	.3109E+01 .1300E+02	.5128E+01 .8574E+01	.6645E-03 -.4246E+01	.1096E-02 .5395E+01	-.4841E-07 .1830E-05	.1282E-02 .6000E+01	.1558E+02	.0000E+00
59	.3431E+01 .1244E+02	.4919E+01 .9135E+01	.7334E-03 -.4495E+01	.1052E-02 .5395E+01	-.5423E-07 -.5482E-06	.1282E-02 .6000E+01	.1558E+02	.0000E+00
60	.3739E+01 .1186E+02	.4689E+01 .9724E+01	.7993E-03 .4670E+01	.1002E-02 .5395E+01	-.6029E-07 -.8289E-06	.1282E-02 .6000E+01	.1558E+02	.0000E+00
61	.4032E+01 .1125E+02	.4439E+01 .1033E+02	.8618E-03 -.4767E+01	.9491E-03 .5395E+01	-.6399E-07 .1387E-05	.1282E-02 .6000E+01	.1558E+02	.0000E+00
62	.4308E+01 .1064E+02	.4172E+01 .1084E+02	.9209E-03 -.4787E+01	.8919E-03 .5395E+01	-.6875E-07 -.9121E-06	.1282E-02 .6000E+01	.1558E+02	.0000E+00

63	.4566E+01	.3887E+01	.9761E-03	.8311E-03	-.7235E-07	.1282E-02	.1558E+02	.0000E+00
	.1003E+02	.1155E+02	-.4728E+01	.5395E+01	.3096E-07	.6000E+01		
64	.4806E+01	.3587E+01	.1027E-02	.7668E-03	-.7598E-07	.1282E-02	.1558E+02	.0000E+00
	.9427E+01	.1215E+02	-.4592E+01	.5395E+01	.1526E-05	.6000E+01		
65	.5026E+01	.3272E+01	.1074E-02	.6994E-03	-.7946E-07	.1282E-02	.1558E+02	.0000E+00
	.8851E+01	.1273E+02	-.4380E+01	.5395E+01	.1082E-05	.6000E+01		
66	.5225E+01	.2943E+01	.1117E-02	.6292E-03	-.8322E-07	.1282E-02	.1558E+02	.0000E+00
	.8307E+01	.1327E+02	-.4096E+01	.5395E+01	-.1280E-07	.6000E+01		
67	.5403E+01	.2602E+01	.1155E-02	.5563E-03	-.8581E-07	.1282E-02	.1558E+02	.0000E+00
	.7803E+01	.1378E+02	-.3745E+01	.5395E+01	-.1422E-05	.6000E+01		
68	.5559E+01	.2250E+01	.1188E-02	.4812E-03	-.8933E-07	.1282E-02	.1558E+02	.0000E+00
	.7349E+01	.1423E+02	-.3332E+01	.5395E+01	.1020E-05	.6000E+01		
69	.5691E+01	.1890E+01	.1217E-02	.4040E-03	-.9337E-07	.1282E-02	.1558E+02	.0000E+00
	.6951E+01	.1463E+02	-.2865E+01	.5395E+01	.3781E-06	.6000E+01		
70	.5801E+01	.1521E+01	.1240E-02	.3253E-03	-.9336E-07	.1282E-02	.1558E+02	.0000E+00
	.6616E+01	.1496E+02	-.2350E+01	.5395E+01	.2192E-06	.6000E+01		
71	.5886E+01	.1146E+01	.1258E-02	.2452E-03	-.9811E-07	.1282E-02	.1558E+02	.0000E+00
	.6350E+01	.1523E+02	-.1797E+01	.5395E+01	-.5502E-06	.6000E+01		
72	.5948E+01	.7669E+00	.1271E-02	.1340E-03	-.9807E-07	.1282E-02	.1558E+02	.0000E+00
	.6157E+01	.1542E+02	-.1215E+01	.5395E+01	-.1239E-05	.6000E+01		
73	.5985E+01	.3842E+00	.1279E-02	.8224E-04	-.1006E-06	.1282E-02	.1558E+02	.0000E+00
	.6039E+01	.1554E+02	-.6125E+00	.5395E+01	-.9456E-06	.6000E+01		
74	.5997E+01	-.1341E-06	.1282E-02	.1009E-06	-.1007E-06	.1282E-02	.1558E+02	.0000E+00
	.6000E+01	.1558E+02	-.1401E-05	.5395E+01	.2832E-06	.6000E+01		
75	.5985E+01	-.3842E+00	.1279E-02	-.8203E-04	-.9995E-07	.1282E-02	.1558E+02	.0000E+00
	.6039E+01	.1554E+02	-.6125E+00	.5395E+01	-.1359E-05	.6000E+01		
76	.5948E+01	-.7669E+00	.1271E-02	-.1638E-03	-.1003E-06	.1282E-02	.1558E+02	.0000E+00
	.6157E+01	.1542E+02	-.1215E+01	.5395E+01	-.1163E-05	.6000E+01		
77	.5866E+01	-.1146E+01	.1258E-02	-.2450E-03	-.9817E-07	.1282E-02	.1558E+02	.0000E+00
	.6350E+01	.1523E+02	-.1797E+01	.5395E+01	-.7123E-06	.6000E+01		
78	.5801E+01	-.1521E+01	.1240E-02	-.3251E-03	-.9812E-07	.1282E-02	.1558E+02	.0000E+00
	.6616E+01	.1496E+02	-.2350E+01	.5395E+01	-.4138E-06	.6000E+01		
79	.5691E+01	-.1890E+01	.1217E-02	-.4039E-03	-.9629E-07	.1282E-02	.1558E+02	.0000E+00
	.6951E+01	.1463E+02	-.2865E+01	.5395E+01	-.6795E-06	.6000E+01		
80	.5559E+01	-.2250E+01	.1188E-02	-.4810E-03	-.9142E-07	.1282E-02	.1558E+02	.0000E+00
	.7349E+01	.1423E+02	-.3332E+01	.5395E+01	-.1276E-05	.6000E+01		
81	.5403E+01	-.2602E+01	.1155E-02	-.5561E-03	-.9161E-07	.1282E-02	.1558E+02	.0000E+00
	.7803E+01	.1378E+02	-.3745E+01	.5395E+01	.2016E-05	.6000E+01		
82	.5225E+01	-.2943E+01	.1117E-02	-.6290E-03	-.9064E-07	.1282E-02	.1558E+02	.0000E+00
	.8307E+01	.1327E+02	-.4096E+01	.5395E+01	-.9246E-06	.6000E+01		
83	.5026E+01	-.3272E+01	.1074E-02	-.6992E-03	-.8692E-07	.1282E-02	.1558E+02	.0000E+00
	.8851E+01	.1273E+02	-.4380E+01	.5395E+01	.2767E-05	.6000E+01		
84	.4806E+01	-.3587E+01	.1027E-02	-.7666E-03	-.8474E-07	.1282E-02	.1558E+02	.0000E+00
	.9427E+01	.1215E+02	-.4592E+01	.5395E+01	.2271E-05	.6000E+01		
85	.4566E+01	-.3887E+01	.9761E-03	-.8309E-03	-.7760E-07	.1282E-02	.1558E+02	.0000E+00
	.1003E+02	.1155E+02	.4728E+01	.5395E+01	.1467E-05	.6000E+01		
86	.4308E+01	-.4172E+01	.9209E-03	-.8917E-03	-.7369E-07	.1282E-02	.1558E+02	.0000E+00
	.1064E+02	.1094E+02	.4787E+01	.5395E+01	.7298E-06	.6000E+01		
87	.4032E+01	-.4439E+01	.8618E-03	-.9489E-03	-.6950E-07	.1282E-02	.1558E+02	.0000E+00
	.1125E+02	.1035E+02	.4767E+01	.5395E+01	-.2625E-07	.6000E+01		
88	.3739E+01	-.4689E+01	.7993E-03	-.1002E-02	-.6488E-07	.1282E-02	.1558E+02	.0000E+00
	.1166E+02	.9724E+01	.4670E+01	.5395E+01	-.7113E-06	.6000E+01		
89	.3431E+01	-.4919E+01	.7334E-03	-.1051E-02	-.6041E-07	.1282E-02	.1558E+02	.0000E+00
	.1244E+02	.9135E+01	.4495E+01	.5395E+01	.5365E-06	.6000E+01		
90	.3109E+01	-.5128E+01	.6645E-03	-.1096E-02	-.5287E-07	.1282E-02	.1558E+02	.0000E+00
	.1300E+02	.8574E+01	.4246E+01	.5395E+01	.6397E-06	.6000E+01		
91	.2774E+01	-.5317E+01	.5929E-03	-.1136E-02	-.4769E-07	.1282E-02	.1558E+02	.0000E+00
	.1353E+02	.8079E+01	.3928E+01	.5395E+01	-.7350E-07	.6000E+01		
92	.2427E+01	-.5484E+01	.5189E-03	-.1172E-02	-.4263E-07	.1282E-02	.1558E+02	.0000E+00
	.1401E+02	.7570E+01	.3546E+01	.5395E+01	-.3423E-06	.6000E+01		
93	.2071E+01	-.5628E+01	.4427E-03	-.1203E-02	-.3628E-07	.1282E-02	.1558E+02	.0000E+00
	.1444E+02	.7143E+01	.3105E+01	.5395E+01	-.1425E-06	.6000E+01		
94	.1706E+01	-.5749E+01	.3647E-03	-.1229E-02	-.3018E-07	.1282E-02	.1558E+02	.0000E+00
	.1488E+02	.6775E+01	.2613E+01	.5395E+01	-.1269E-05	.6000E+01		
95	.1334E+01	-.5847E+01	.2853E-03	-.1250E-02	-.2267E-07	.1282E-02	.1558E+02	.0000E+00
	.1510E+02	.6474E+01	.2078E+01	.5395E+01	-.2430E-06	.6000E+01		
96	.9571E+00	-.5920E+01	.2046E-03	-.1265E-02	-.1807E-07	.1282E-02	.1558E+02	.0000E+00
	.1534E+02	.6244E+01	.1509E+01	.5395E+01	-.5956E-06	.6000E+01		
97	.5758E+00	-.5969E+01	.1231E-03	-.1276E-02	-.1107E-07	.1282E-02	.1558E+02	.0000E+00
	.1549E+02	.6088E+01	.9156E+00	.5395E+01	-.1050E-06	.6000E+01		
98	.1922E+00	-.5994E+01	.4109E-04	-.1281E-02	-.2894E-08	.1282E-02	.1558E+02	.0000E+00
	.1557E+02	.6010E+01	.3069E+00	.5395E+01	-.1201E-06	.6000E+01		

TIME REQUIRED TO COMPUTE BOUNDARY STRESSES AND DISPLACEMENTS= 136.65 SECONDS.

INTERIOR STRESSES AND DISPLACEMENTS AT TIME = .000E+00

POINT	X-COORD SIGXX	Y-COORD SIGYY	UX SIGXY	UY SIGZZ	SIG1	SIG2	ALPHA	TEMP
1	.4000E+01 .5549E-02	.0000E+00 .2157E+02	.1361E-02 .1257E-05	.9767E-07 .5395E+01	.2157E+02	.5550E-02	.9000E+02	.0000E+00
2	.4400E+01 .1752E+01	.0000E+00 .1983E+02	.1323E-02 .2277E-05	.9887E-07 .5395E+01	.1983E+02	.1752E+01	.9000E+02	.0000E+00
3	.4800E+01 .3196E+01	.0000E+00 .1838E+02	.1299E-02 .6381E-06	.9953E-07 .5395E+01	.1838E+02	.3196E+01	.9000E+02	.0000E+00
4	.5200E+01 .4319E+01	.0000E+00 .1726E+02	.1285E-02 .1074E-05	.9981E-07 .5395E+01	.1726E+02	.4318E+01	.9000E+02	.0000E+00
5	.5600E+01 .5211E+01	.0000E+00 .1637E+02	.1280E-02 .3311E-05	.9852E-07 .5395E+01	.1637E+02	.5211E+01	.9000E+02	.0000E+00
6	.6000E+01 -.1018E+02	.0000E+00 .1018E+02	.1281E-02 .2007E-03	.1003E-06 -.2807E-04	.1018E+02	-.1018E+02	.9000E+02	.0000E+00

TIME REQUIRED TO COMPUTE STRESSES AND DISPLACEMENTS AT STRESS POINTS= 8.41 SECONDS.

JOB COMPLETED AT 16:10 HOURS

DATA FOR PLOTTING WILL BE STORED IN FILE NAMED VERIF1

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*****
*                                     *
*               H E F F               *
*               A BOUNDARY ELEMENT CODE *
*               FOR TWO-DIMENSIONAL THERMOELASTIC ANALYSIS *
*               OF A ROCK MASS          *
*               SUBJECT TO CONSTANT OR DECAYING *
*               THERMAL LOADING          *
*               VERSION DATED: DEC. 6 1987 (MS-FORTRAN 77) *
*               VERSION 4.1              *
*****

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EXCAVATION OF A CIRCULAR HOLE IN A BI-AXIALLY STRESSED PLATE OUTPUT CREATED ON 12/ 6/1987

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NUMBER OF BOUNDARY SEGMENTS . . . . . = 1
NUMBER OF STRESS LINES . . . . . = 1
NUMBER OF HEAT SOURCES . . . . . = 0
NUMBER OF EXP. DECAYING COMPONENTS . . . = 0

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THE LINE X=0.0 IS A LINE OF SYMMETRY.
IMAGE BOUNDARY ELEMENTS AND HEAT SOURCES WILL BE GENERATED WITH RESPECT TO THIS LINE.

EFFECT OF IMAGE HEAT SOURCES NOT COMPUTED

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POISSONS RATIO OF BODY . . . . . = .25
MODULUS OF ELASTICITY OF BODY . . . . . = .6000E+05
SHEAR MODULUS OF BODY . . . . . = .2400E+05

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XX-COMPONENT OF FIELD STRESS = .0000E+00 + .3000E+02 + ( .0000E+00 + .0000E+00 / Y ) * SIGYY
YY-COMPONENT OF FIELD STRESS = .0000E+00 + .1500E+02
XY-COMPONENT OF FIELD STRESS = .0000E+00 + .0000E+00
MAXIMUM VALUE FOR CXX + DXX / Y = .0000E+00
RATIO OF ZZ STRESS TO XX STRESS = .0000E+00

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IN THE LIST BELOW THE VALUE ASSIGNED TO KODE DENOTES BOUNDARY CONDITIONS AS FOLLOWS.

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KODE= 1 NORMAL AND SHEAR STRESSES PRESCRIBED
KODE= 2 NORMAL AND SHEAR DISPL. PRESCRIBED
KODE= 3 NORMAL STRESS AND SHEAR DISPL. PRESCRIBED
KODE= 4 NORMAL DISPL. AND SHEAR STRESS PRESCRIBED

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ELEMENT	KODE	X(CENTER)	Y(CENTER)	HALF-WIDTH	SIN BETA	COS BETA	B-VALUE (S)	B-VALUE (N)
1	1	.1603	-4.9999	.1604	.0321	.9995	.0000E+00	.0000E+00
2	1	.4803	-4.9793	.1604	.0960	.9954	.0000E+00	.0000E+00
3	1	.7984	-4.9383	.1604	.1586	.9872	.0000E+00	.0000E+00
4	1	1.1131	-4.8770	.1604	.2225	.9749	.0000E+00	.0000E+00
5	1	1.4233	-4.7957	.1604	.2845	.9587	.0000E+00	.0000E+00
6	1	1.7277	-4.6946	.1604	.3454	.9385	.0000E+00	.0000E+00
7	1	2.0249	-4.5743	.1604	.4048	.9144	.0000E+00	.0000E+00
8	1	2.3138	-4.4352	.1604	.4625	.8866	.0000E+00	.0000E+00
9	1	2.5932	-4.2778	.1604	.5184	.8551	.0000E+00	.0000E+00
10	1	2.8620	-4.1029	.1604	.5721	.8202	.0000E+00	.0000E+00
11	1	3.1190	-3.9111	.1604	.6235	.7818	.0000E+00	.0000E+00
12	1	3.3631	-3.7032	.1604	.6723	.7403	.0000E+00	.0000E+00
13	1	3.5935	-3.4801	.1604	.7183	.6957	.0000E+00	.0000E+00
14	1	3.8091	-3.2427	.1604	.7614	.6482	.0000E+00	.0000E+00
15	1	4.0090	-2.9920	.1604	.8014	.5981	.0000E+00	.0000E+00
16	1	4.1925	-2.7290	.1604	.8381	.5455	.0000E+00	.0000E+00
17	1	4.3587	-2.4548	.1604	.8713	.4907	.0000E+00	.0000E+00
18	1	4.5070	-2.1705	.1604	.9010	.4339	.0000E+00	.0000E+00
19	1	4.6368	-1.8772	.1604	.9269	.3753	.0000E+00	.0000E+00
20	1	4.7476	-1.5763	.1604	.9491	.3151	.0000E+00	.0000E+00
21	1	4.8388	-1.2689	.1604	.9673	.2537	.0000E+00	.0000E+00
22	1	4.9102	-.9563	.1604	.9816	.1912	.0000E+00	.0000E+00
23	1	4.9614	-.6397	.1604	.9918	.1270	.0000E+00	.0000E+00
24	1	4.9922	-.3205	.1604	.9979	.0641	.0000E+00	.0000E+00
25	1	5.0024	.0000	.1604	1.0000	.0000	.0000E+00	.0000E+00
26	1	4.9922	.3205	.1604	.9979	-.0641	.0000E+00	.0000E+00
27	1	4.9614	.6397	.1604	.9918	-.1270	.0000E+00	.0000E+00
28	1	4.9102	.9563	.1604	.9816	-.1912	.0000E+00	.0000E+00
29	1	4.8388	1.2689	.1604	.9673	-.2537	.0000E+00	.0000E+00
30	1	4.7476	1.5763	.1604	.9491	-.3151	.0000E+00	.0000E+00
31	1	4.6368	1.8772	.1604	.9269	-.3753	.0000E+00	.0000E+00
32	1	4.5070	2.1705	.1604	.9010	-.4339	.0000E+00	.0000E+00
33	1	4.3587	2.4548	.1604	.8713	-.4907	.0000E+00	.0000E+00
34	1	4.1925	2.7290	.1604	.8381	-.5455	.0000E+00	.0000E+00
35	1	4.0090	2.9920	.1604	.8014	-.5981	.0000E+00	.0000E+00
36	1	3.8091	3.2427	.1604	.7614	-.6482	.0000E+00	.0000E+00
37	1	3.5935	3.4801	.1604	.7183	-.6957	.0000E+00	.0000E+00
38	1	3.3631	3.7032	.1604	.6723	-.7403	.0000E+00	.0000E+00
39	1	3.1190	3.9111	.1604	.6235	-.7818	.0000E+00	.0000E+00
40	1	2.8620	4.1029	.1604	.5721	-.8202	.0000E+00	.0000E+00
41	1	2.5932	4.2778	.1604	.5184	-.8551	.0000E+00	.0000E+00
42	1	2.3138	4.4352	.1604	.4625	-.8866	.0000E+00	.0000E+00
43	1	2.0249	4.5743	.1604	.4048	-.9144	.0000E+00	.0000E+00
44	1	1.7277	4.6946	.1604	.3454	-.9385	.0000E+00	.0000E+00
45	1	1.4233	4.7957	.1604	.2845	-.9587	.0000E+00	.0000E+00
46	1	1.1131	4.8770	.1604	.2225	-.9749	.0000E+00	.0000E+00
47	1	.7984	4.9383	.1604	.1586	-.9872	.0000E+00	.0000E+00
48	1	.4803	4.9793	.1604	.0960	-.9954	.0000E+00	.0000E+00
49	1	.1603	4.9999	.1604	.0321	-.9995	.0000E+00	.0000E+00

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LINES DEFINING STRESS POINTS
XBEG YBEG XEND YEND NUMPB
5.0000 .0000 10.2000 .0000 14

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TIME REQUIRED TO COMPUTE INFLUENCE COEFFICIENTS= 33.40 SECONDS.

OUTPUT FOR TIME= .0000E+00

PRE-EXISTING STRESS AT EACH ELEMENT

ELEMENT	TEMP	SIGMAXX	SIGMAYY	SIGMAXY	SIGMAZZ	NORM-STR	SHEAR-STR	NORM-DIS	SHEAR-DIS
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1	.0000E+00	.3000E+02	.1500E+02	.0000E+00	.0000E+00	.1502E+02	-.4805E+00	.0000E+00	.0000E+00
2	.0000E+00	.3000E+02	.1500E+02	.0000E+00	.0000E+00	.1514E+02	-.1434E+01	.0000E+00	.0000E+00
3	.0000E+00	.3000E+02	.1500E+02	.0000E+00	.0000E+00	.1530E+02	-.2363E+01	.0000E+00	.0000E+00
4	.0000E+00	.3000E+02	.1500E+02	.0000E+00	.0000E+00	.1574E+02	-.3254E+01	.0000E+00	.0000E+00
5	.0000E+00	.3000E+02	.1500E+02	.0000E+00	.0000E+00	.1621E+02	-.4092E+01	.0000E+00	.0000E+00
6	.0000E+00	.3000E+02	.1500E+02	.0000E+00	.0000E+00	.1679E+02	-.4862E+01	.0000E+00	.0000E+00
7	.0000E+00	.3000E+02	.1500E+02	.0000E+00	.0000E+00	.1746E+02	-.5552E+01	.0000E+00	.0000E+00
8	.0000E+00	.3000E+02	.1500E+02	.0000E+00	.0000E+00	.1821E+02	-.6151E+01	.0000E+00	.0000E+00
9	.0000E+00	.3000E+02	.1500E+02	.0000E+00	.0000E+00	.1903E+02	-.6649E+01	.0000E+00	.0000E+00
10	.0000E+00	.3000E+02	.1500E+02	.0000E+00	.0000E+00	.1991E+02	-.7039E+01	.0000E+00	.0000E+00
11	.0000E+00	.3000E+02	.1500E+02	.0000E+00	.0000E+00	.2083E+02	-.7312E+01	.0000E+00	.0000E+00
12	.0000E+00	.3000E+02	.1500E+02	.0000E+00	.0000E+00	.2178E+02	-.7485E+01	.0000E+00	.0000E+00
13	.0000E+00	.3000E+02	.1500E+02	.0000E+00	.0000E+00	.2274E+02	-.7496E+01	.0000E+00	.0000E+00
14	.0000E+00	.3000E+02	.1500E+02	.0000E+00	.0000E+00	.2370E+02	-.7404E+01	.0000E+00	.0000E+00
15	.0000E+00	.3000E+02	.1500E+02	.0000E+00	.0000E+00	.2463E+02	-.7190E+01	.0000E+00	.0000E+00
16	.0000E+00	.3000E+02	.1500E+02	.0000E+00	.0000E+00	.2554E+02	-.6858E+01	.0000E+00	.0000E+00
17	.0000E+00	.3000E+02	.1500E+02	.0000E+00	.0000E+00	.2639E+02	-.6414E+01	.0000E+00	.0000E+00
18	.0000E+00	.3000E+02	.1500E+02	.0000E+00	.0000E+00	.2718E+02	-.5864E+01	.0000E+00	.0000E+00
19	.0000E+00	.3000E+02	.1500E+02	.0000E+00	.0000E+00	.2789E+02	-.5218E+01	.0000E+00	.0000E+00
20	.0000E+00	.3000E+02	.1500E+02	.0000E+00	.0000E+00	.2851E+02	-.4486E+01	.0000E+00	.0000E+00
21	.0000E+00	.3000E+02	.1500E+02	.0000E+00	.0000E+00	.2903E+02	-.3680E+01	.0000E+00	.0000E+00
22	.0000E+00	.3000E+02	.1500E+02	.0000E+00	.0000E+00	.2945E+02	-.2815E+01	.0000E+00	.0000E+00
23	.0000E+00	.3000E+02	.1500E+02	.0000E+00	.0000E+00	.2975E+02	-.1902E+01	.0000E+00	.0000E+00
24	.0000E+00	.3000E+02	.1500E+02	.0000E+00	.0000E+00	.2994E+02	-.9591E+00	.0000E+00	.0000E+00
25	.0000E+00	.3000E+02	.1500E+02	.0000E+00	.0000E+00	.3000E+02	-.4253E-05	.0000E+00	.0000E+00
26	.0000E+00	.3000E+02	.1500E+02	.0000E+00	.0000E+00	.2994E+02	.8591E+00	.0000E+00	.0000E+00
27	.0000E+00	.3000E+02	.1500E+02	.0000E+00	.0000E+00	.2975E+02	.1902E+01	.0000E+00	.0000E+00
28	.0000E+00	.3000E+02	.1500E+02	.0000E+00	.0000E+00	.2945E+02	.2815E+01	.0000E+00	.0000E+00
29	.0000E+00	.3000E+02	.1500E+02	.0000E+00	.0000E+00	.2903E+02	.3680E+01	.0000E+00	.0000E+00
30	.0000E+00	.3000E+02	.1500E+02	.0000E+00	.0000E+00	.2851E+02	.4486E+01	.0000E+00	.0000E+00
31	.0000E+00	.3000E+02	.1500E+02	.0000E+00	.0000E+00	.2789E+02	.5218E+01	.0000E+00	.0000E+00
32	.0000E+00	.3000E+02	.1500E+02	.0000E+00	.0000E+00	.2718E+02	.5864E+01	.0000E+00	.0000E+00
33	.0000E+00	.3000E+02	.1500E+02	.0000E+00	.0000E+00	.2639E+02	.6414E+01	.0000E+00	.0000E+00
34	.0000E+00	.3000E+02	.1500E+02	.0000E+00	.0000E+00	.2554E+02	.6858E+01	.0000E+00	.0000E+00
35	.0000E+00	.3000E+02	.1500E+02	.0000E+00	.0000E+00	.2463E+02	.7190E+01	.0000E+00	.0000E+00
36	.0000E+00	.3000E+02	.1500E+02	.0000E+00	.0000E+00	.2370E+02	.7404E+01	.0000E+00	.0000E+00
37	.0000E+00	.3000E+02	.1500E+02	.0000E+00	.0000E+00	.2274E+02	.7496E+01	.0000E+00	.0000E+00
38	.0000E+00	.3000E+02	.1500E+02	.0000E+00	.0000E+00	.2178E+02	.7485E+01	.0000E+00	.0000E+00
39	.0000E+00	.3000E+02	.1500E+02	.0000E+00	.0000E+00	.2083E+02	.7312E+01	.0000E+00	.0000E+00
40	.0000E+00	.3000E+02	.1500E+02	.0000E+00	.0000E+00	.1991E+02	.7039E+01	.0000E+00	.0000E+00
41	.0000E+00	.3000E+02	.1500E+02	.0000E+00	.0000E+00	.1903E+02	.6649E+01	.0000E+00	.0000E+00
42	.0000E+00	.3000E+02	.1500E+02	.0000E+00	.0000E+00	.1821E+02	.6151E+01	.0000E+00	.0000E+00
43	.0000E+00	.3000E+02	.1500E+02	.0000E+00	.0000E+00	.1746E+02	.5552E+01	.0000E+00	.0000E+00
44	.0000E+00	.3000E+02	.1500E+02	.0000E+00	.0000E+00	.1679E+02	.4862E+01	.0000E+00	.0000E+00
45	.0000E+00	.3000E+02	.1500E+02	.0000E+00	.0000E+00	.1621E+02	.4092E+01	.0000E+00	.0000E+00
46	.0000E+00	.3000E+02	.1500E+02	.0000E+00	.0000E+00	.1574E+02	.3254E+01	.0000E+00	.0000E+00
47	.0000E+00	.3000E+02	.1500E+02	.0000E+00	.0000E+00	.1530E+02	.2363E+01	.0000E+00	.0000E+00
48	.0000E+00	.3000E+02	.1500E+02	.0000E+00	.0000E+00	.1514E+02	.1434E+01	.0000E+00	.0000E+00
49	.0000E+00	.3000E+02	.1500E+02	.0000E+00	.0000E+00	.1502E+02	.4805E+00	.0000E+00	.0000E+00

TIME REQUIRED TO COMPUTE PRE-EXISTING STRESSES = .82 SECONDS.

TIME REQUIRED TO SOLVE EQUATIONS= 31.03 SECONDS.

BOUNDARY STRESSES AND DISPLACEMENTS AT TIME = .000E+00

ELM	X-COORD SIGXX	Y-COORD SIGYY	UX SIGXY	UY SIGZY	US SIGMA-S	UH SIGMA-N	SIGMA-T	TEMP
1	.1603E+00	-.5000E+01	.1274E-03	-.7961E-03	.1018E-03	-.7998E-03	.7494E+02	.0000E+00
2	.7486E+02	.7698E-01	.2401E+01	.7485E+01	.5866E-06	-.2849E-05	.7445E+02	.0000E+00
3	.4803E+00	-.4979E+01	.3818E-03	-.7927E-03	.3039E-03	-.8257E-03	.7445E+02	.0000E+00
4	.7376E+02	.6864E+00	.7116E+01	.7362E+01	-.2832E-06	.3028E-06	.7445E+02	.0000E+00
5	.7984E+00	-.4938E+01	.6345E-03	-.7859E-03	.5009E-03	-.8771E-03	.7347E+02	.0000E+00
6	.7100E+02	.1871E+01	.1158E+02	.7118E+01	-.3797E-05	-.3408E-05	.7347E+02	.0000E+00
7	.1113E+01	-.4877E+01	.8645E-03	-.7758E-03	.6897E-03	-.9532E-03	.7203E+02	.0000E+00
8	.6846E+02	.3567E+01	.1563E+02	.6757E+01	.2328E-05	-.7224E-05	.7203E+02	.0000E+00
9	.1423E+01	-.4796E+01	.1131E-02	-.7624E-03	.8672E-03	-.1053E-02	.7014E+02	.0000E+00
10	.6446E+02	.5678E+01	.1013E+02	.6286E+01	-.4072E-05	-.3928E-05	.7014E+02	.0000E+00
11	.1728E+01	-.4695E+01	.1372E-02	-.7458E-03	.1030E-02	-.1174E-02	.6784E+02	.0000E+00
12	.5975E+02	.8092E+01	.2199E+02	.5711E+01	.1274E-06	-.2210E-05	.6784E+02	.0000E+00
13	.2025E+01	-.4574E+01	.1608E-02	-.7260E-03	.1177E-02	-.1315E-02	.6517E+02	.0000E+00
14	.5449E+02	.1068E+02	.2412E+02	.5042E+01	.4256E-05	-.3095E-05	.6517E+02	.0000E+00
15	.2314E+01	-.4435E+01	.1837E-02	-.7033E-03	.1304E-02	-.1473E-02	.6216E+02	.0000E+00
16	.4886E+02	.1330E+02	.2549E+02	.4291E+01	.3920E-05	.6074E-05	.6216E+02	.0000E+00
17	.2593E+01	-.4278E+01	.2059E-02	-.6776E-03	.1409E-02	-.1647E-02	.5888E+02	.0000E+00
18	.4305E+02	.1582E+02	.2610E+02	.3469E+01	-.6523E-06	-.2692E-05	.5888E+02	.0000E+00
19	.2862E+01	-.4103E+01	.2272E-02	-.6492E-03	.1492E-02	-.1832E-02	.5536E+02	.0000E+00
20	.3724E+02	.1812E+02	.2598E+02	.2590E+01	.1344E-06	.7695E-05	.5536E+02	.0000E+00
21	.3119E+01	-.3811E+01	.2475E-02	-.6181E-03	.1550E-02	-.2026E-02	.5168E+02	.0000E+00
22	.3159E+02	.2009E+02	.2519E+02	.1666E+01	.1585E-05	.7232E-05	.5168E+02	.0000E+00
23	.3363E+01	-.3703E+01	.2668E-02	-.5845E-03	.1582E-02	-.2227E-02	.4788E+02	.0000E+00
24	.2624E+02	.2164E+02	.2383E+02	.7202E+00	-.1084E-05	.3297E-05	.4788E+02	.0000E+00
25	.3593E+01	-.3480E+01	.2850E-02	-.5486E-03	.1589E-02	-.2429E-02	.4404E+02	.0000E+00
26	.2131E+02	.2272E+02	.2201E+02	-.2404E+00	-.2048E-05	-.1179E-04	.4404E+02	.0000E+00
27	.3809E+01	-.3243E+01	.3021E-02	-.5106E-03	.1569E-02	-.2631E-02	.4021E+02	.0000E+00
28	.1690E+02	.2331E+02	.1885E+02	-.1197E+01	-.1105E-05	.5381E-05	.4021E+02	.0000E+00
29	.4009E+01	-.2992E+01	.3178E-02	-.4705E-03	.1524E-02	-.2829E-02	.3646E+02	.0000E+00
30	.1304E+02	.2342E+02	.1748E+02	-.2134E+01	-.4460E-05	.5260E-05	.3646E+02	.0000E+00
31	.4192E+01	-.2729E+01	.3323E-02	-.4287E-03	.1454E-02	-.3019E-02	.3286E+02	.0000E+00
32	.9778E+01	.2308E+02	.1502E+02	-.3036E+01	.8245E-06	-.2589E-05	.3286E+02	.0000E+00
33	.4359E+01	-.2455E+01	.3454E-02	-.3852E-03	.1359E-02	-.3199E-02	.2945E+02	.0000E+00
34	.7091E+01	.2236E+02	.1259E+02	-.3888E+01	.4876E-07	-.6891E-06	.2945E+02	.0000E+00
35	.4507E+01	-.2170E+01	.3571E-02	-.3402E-03	.1243E-02	-.3365E-02		

	.4950E+01	.2135E+02	.1028E+02	-.4676E+01	.1019E-05	.4974E-05	.2630E+02	.0000E+00
19	.4637E+01	-.1877E+01	.3673E-02	-.2940E-03	.1106E-02	-.3515E-02	.2345E+02	.0000E+00
	.3302E+01	.2015E+02	.8157E+01	-.5388E+01	-.1950E-05	-.6316E-05		
20	.4748E+01	-.1578E+01	.3760E-02	-.2467E-03	.9508E-03	-.3646E-02	.2096E+02	.0000E+00
	.2081E+01	.1888E+02	.6268E+01	-.6011E+01	.4888E-05	-.2530E-05		
21	.4838E+01	-.1269E+01	.3832E-02	-.1984E-03	.7801E-03	-.3757E-02	.1886E+02	.0000E+00
	.1214E+01	.1765E+02	.4628E+01	-.6535E+01	-.1407E-05	-.5805E-05		
22	.4810E+01	-.9563E+00	.3888E-02	-.1494E-03	.5965E-03	-.3845E-02	.1719E+02	.0000E+00
	.6262E+00	.1656E+02	.3226E+01	-.6952E+01	.3383E-06	-.8016E-05		
23	.4961E+01	-.6397E+00	.3928E-02	-.9993E-04	.4032E-03	-.3909E-02	.1598E+02	.0000E+00
	.2613E+00	.1572E+02	.2027E+01	-.7255E+01	-.1214E-05	-.4959E-05		
24	.4992E+01	-.3205E+00	.3952E-02	-.5006E-04	.2033E-03	-.3948E-02	.1525E+02	.0000E+00
	.6260E-01	.1518E+02	.9748E+00	-.7438E+01	.3140E-07	.1756E-04		
25	.5002E+01	.1118E-06	.3961E-02	.2084E-09	.1332E-08	-.3961E-02	.1500E+02	.0000E+00
	.7033E-05	.1500E+02	.4784E-05	-.7500E+01	-.5282E-06	.7033E-05		
26	.4992E+01	-.3205E+00	.3952E-02	-.5006E-04	-.2033E-03	-.3948E-02	.1525E+02	.0000E+00
	.6260E-01	.1518E+02	-.9748E+00	-.7438E+01	.7252E-06	.1806E-04		
27	.4961E+01	.6397E+00	.3928E-02	.9993E-04	-.4032E-03	-.3909E-02	.1598E+02	.0000E+00
	.2613E+00	.1572E+02	-.2027E+01	-.7255E+01	.1063E-05	.7925E-05		
28	.4910E+01	.9563E+00	.3888E-02	.1494E-03	.5965E-03	-.3845E-02	.1719E+02	.0000E+00
	.6262E+00	.1656E+02	-.3226E+01	-.6952E+01	-.1985E-05	-.1373E-04		
29	.4839E+01	-.1269E+01	.3832E-02	-.1984E-03	.7801E-03	-.3757E-02	.1886E+02	.0000E+00
	.1213E+01	.1765E+02	-.4628E+01	-.6535E+01	.6539E-06	-.1556E-04		
30	.4748E+01	-.1578E+01	.3760E-02	-.2467E-03	.9508E-03	-.3646E-02	.2096E+02	.0000E+00
	.2081E+01	.1888E+02	-.6268E+01	-.6011E+01	-.1520E-05	-.8682E-05		
31	.4637E+01	.1877E+01	.3673E-02	.2940E-03	.1106E-02	-.3515E-02	.2345E+02	.0000E+00
	.3302E+01	.2015E+02	-.8157E+01	-.5388E+01	.1345E-05	.1323E-05		
32	.4507E+01	.2170E+01	.3571E-02	.3402E-03	-.1243E-02	-.3365E-02	.2630E+02	.0000E+00
	.4950E+01	.2135E+02	-.1028E+02	-.4676E+01	.5232E-09	-.4593E-05		
33	.4359E+01	.2455E+01	.3454E-02	.3852E-03	-.1359E-02	-.3199E-02	.2945E+02	.0000E+00
	.7091E+01	.2236E+02	-.1259E+02	-.3888E+01	.9292E-06	-.8269E-06		
34	.4192E+01	.2729E+01	.3323E-02	.4287E-03	-.1454E-02	-.3019E-02	.3286E+02	.0000E+00
	.9778E+01	.2308E+02	-.1502E+02	-.3036E+01	.4157E-05	.6445E-06		
35	.4009E+01	.2992E+01	.3178E-02	.4705E-03	-.1524E-02	-.2829E-02	.3646E+02	.0000E+00
	.1304E+02	.2342E+02	-.1748E+02	-.2134E+01	.3316E-05	.1218E-04		
36	.3809E+01	.3243E+01	.3021E-02	.5106E-03	-.1569E-02	-.2631E-02	.4021E+02	.0000E+00
	.1690E+02	.2331E+02	-.1965E+02	-.1197E+01	.1821E-05	-.9424E-05		
37	.3593E+01	.3480E+01	.2850E-02	.5486E-03	-.1589E-02	-.2429E-02	.4404E+02	.0000E+00
	.2131E+02	.2272E+02	-.2201E+02	-.2404E+00	.8533E-06	-.3422E-05		
38	.3363E+01	.3703E+01	.2668E-02	.5845E-03	-.1562E-02	-.2227E-02	.4788E+02	.0000E+00
	.2624E+02	.2164E+02	-.2383E+02	.7202E+00	.1364E-05	.9271E-06		
39	.3119E+01	.3911E+01	.2475E-02	.6181E-03	-.1550E-02	-.2026E-02	.5168E+02	.0000E+00
	.3159E+02	.2009E+02	-.2519E+02	.1668E+01	.1703E-05	.6356E-06		
40	.2862E+01	.4103E+01	.2272E-02	.6492E-03	-.1492E-02	-.1832E-02	.5536E+02	.0000E+00
	.3724E+02	.1812E+02	-.2598E+02	.2590E+01	.2621E-05	.9513E-05		
41	.2593E+01	.4278E+01	.2059E-02	.6776E-03	-.1409E-02	-.1647E-02	.5888E+02	.0000E+00
	.4305E+02	.1582E+02	-.2610E+02	.3469E+01	.1429E-05	.6065E-06		
42	.2314E+01	.4435E+01	.1837E-02	.7033E-03	-.1304E-02	-.1473E-02	.6216E+02	.0000E+00
	.4886E+02	.1330E+02	-.2549E+02	.4291E+01	-.6989E-05	.2869E-05		
43	.2025E+01	.4574E+01	.1608E-02	.7260E-03	-.1177E-02	-.1315E-02	.6517E+02	.0000E+00
	.5449E+02	.1068E+02	-.2412E+02	.5042E+01	-.5315E-05	.6927E-05		
44	.1728E+01	.4695E+01	.1372E-02	.7458E-03	-.1030E-02	-.1174E-02	.6784E+02	.0000E+00
	.5975E+02	.8092E+01	-.2159E+02	.5711E+01	.5589E-05	.1199E-04		
45	.1423E+01	.4796E+01	.1131E-02	.7624E-03	-.8672E-03	-.1053E-02	.7014E+02	.0000E+00
	.6446E+02	.5678E+01	-.1913E+02	.6286E+01	.2955E-05	.1422E-04		
46	.1113E+01	.4877E+01	.8845E-03	.7758E-03	-.6897E-03	-.9532E-03	.7203E+02	.0000E+00
	.6846E+02	.3567E+01	-.1563E+02	.6757E+01	.1132E-05	-.1185E-04		
47	.7984E+00	.4938E+01	.6345E-03	.7859E-03	-.5009E-03	-.8771E-03	.7347E+02	.0000E+00
	.7160E+02	.1871E+01	-.1158E+02	.7118E+01	-.2721E-06	-.3421E-06		
48	.4803E+00	.4979E+01	.3818E-03	.7927E-03	-.3039E-03	-.8257E-03	.7445E+02	.0000E+00
	.7376E+02	.6864E+00	-.7116E+01	.7362E+01	.7724E-06	-.1036E-05		
49	.1603E+00	.5000E+01	.1274E-03	.7961E-03	-.1018E-03	-.7998E-03	.7494E+02	.0000E+00
	.7486E+02	.7700E-01	-.2401E+01	.7485E+01	-.2504E-06	.9098E-05		

TIME REQUIRED TO COMPUTE BOUNDARY STRESSES AND DISPLACEMENTS= 35.38 SECONDS.

INTERIOR STRESSES AND DISPLACEMENTS AT TIME = .000E+00

POINT	X-COORD SIGXX	Y-COORD SIGYY	UX SIGXY	UY SIGZZ	SIG1	SIG2	ALPHA	TEMP
1	.5000E+01 .9112E+02	.0000E+00 .4536E+02	.3859E-02 -.6745E-05	-.2168E-09 .2267E+02	.9112E+02	.4536E+02	-.8447E-05	.0000E+00
2	.5400E+01 .1187E+01	.0000E+00 .1769E+02	.3774E-02 -.8931E-06	.1326E-08 -.6530E+01	.1769E+02	.1187E+01	-.9000E+02	.0000E+00
3	.5800E+01 .3072E+01	.0000E+00 .1928E+02	.3592E-02 -.2354E-06	-.5127E-09 -.5661E+01	.1928E+02	.3072E+01	-.9000E+02	.0000E+00

4	.6200E+01 .5047E+01	.0000E+00 .2014E+02	.3420E-02 .3010E-06	-.4790E-09 -.4954E+01	.2014E+02	.5047E+01	.9000E+02	.0000E+00
5	.6600E+01 .6972E+01	.0000E+00 .2054E+02	.3259E-02 .3629E-05	-.2686E-09 -.4372E+01	.2054E+02	.6972E+01	.9000E+02	.0000E+00
6	.7000E+01 .8781E+01	.0000E+00 .2067E+02	.3109E-02 .4692E-05	-.4656E-09 -.3886E+01	.2067E+02	.8781E+01	.9000E+02	.0000E+00
7	.7400E+01 .1045E+02	.0000E+00 .2064E+02	.2970E-02 -.6486E-06	.2190E-08 -.3477E+01	.2064E+02	.1045E+02	-.9000E+02	.0000E+00
8	.7800E+01 .1197E+02	.0000E+00 .2051E+02	.2841E-02 -.1083E-05	-.1206E-08 -.3130E+01	.2051E+02	.1197E+02	-.9000E+02	.0000E+00
9	.8200E+01 .1335E+02	.0000E+00 .2032E+02	.2722E-02 .3514E-07	.1990E-08 -.2852E+01	.2032E+02	.1335E+02	.0000E+02	.0000E+00
10	.8600E+01 .1460E+02	.0000E+00 .2010E+02	.2611E-02 -.3345E-05	.1521E-08 -.2575E+01	.2010E+02	.1460E+02	-.9000E+02	.0000E+00
11	.9000E+01 .1573E+02	.0000E+00 .1986E+02	.2508E-02 -.2777E-05	.1910E-08 -.2351E+01	.1986E+02	.1573E+02	-.9000E+02	.0000E+00
12	.9400E+01 .1675E+02	.0000E+00 .1962E+02	.2412E-02 .2331E-05	.1148E-08 -.2155E+01	.1962E+02	.1675E+02	.9000E+02	.0000E+00
13	.9800E+01 .1768E+02	.0000E+00 .1939E+02	.2323E-02 -.3057E-05	-.9433E-09 -.1983E+01	.1939E+02	.1768E+02	-.9000E+02	.0000E+00
14	.1020E+02 .1852E+02	.0000E+00 .1916E+02	.2240E-02 -.4871E-05	.2661E-08 -.1830E+01	.1916E+02	.1852E+02	-.9000E+02	.0000E+00

TIME REQUIRED TO COMPUTE STRESSES AND DISPLACEMENTS AT STRESS POINTS= 10.05 SECONDS.

JOB COMPLETED AT 16:25 HOURS

DATA FOR PLOTTING WILL BE STORED IN FILE NAMED VERIF2

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*****
*                                     H E F F
*                                     A BOUNDARY ELEMENT CODE
* FOR TWO-DIMENSIONAL THERMOELASTIC ANALYSIS
* OF A ROCK MASS
* SUBJECT TO CONSTANT OR DECAYING
* THERMAL LOADING
* VERSION DATED: DEC. 6 1987 (MS-FORTRAN 77)
*
*                                     VERSION 4.1
*
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UNIFORM HEAT GENERATION IN SEMI-INFINITE MEDIUM OUTPUT CREATED ON 12/ 7/1987

NUMBER OF BOUNDARY SEGMENTS = 2
 NUMBER OF STRESS LINES = 1
 NUMBER OF HEAT SOURCES = 60
 NUMBER OF EXP. DECAYING COMPONENTS . . . = 1

THE LINE X=0.0 IS A LINE OF SYMMETRY.
 IMAGE BOUNDARY ELEMENTS AND HEAT SOURCES WILL BE GENERATED WITH RESPECT TO THIS LINE.

CONSTANT TEMPERATURE B.C. IMPOSED AT SURFACE

POISSONS RATIO OF BODY = .25
 MODULUS OF ELASTICITY OF BODY = .6000E+05
 SHEAR MODULUS OF BODY = .2400E+05

XX-COMPONENT OF FIELD STRESS = .0000E+00Y + .0000E+00 + (.0000E+00 + .0000E+00 / Y) * SIGYY
 YY-COMPONENT OF FIELD STRESS = .0000E+00Y + .0000E+00
 XY-COMPONENT OF FIELD STRESS = .0000E+00Y + .0000E+00
 MAXIMUM VALUE FOR CXX + DXX / Y = .0000E+00
 RATIO OF ZZ STRESS TO XX STRESS = .0000E+00

TIME FOR OUTPUT
 .100E+03

TEMPERATURE VARIATION WITH DEPTH= .0000Y + .0000

THERMAL DIFFUSIVITY = .1262E+02
 THERMAL EXPANSION COEFFICIENT = .6000E-05
 STRESS COEFFICIENT VE = .2400E+00

EXPONENTIALLY DECAYING COMPONENTS
 TIME ON PROPORTION DECAY CONST.
 .00 .10000E+01 .00000E+00

SOURCE DATA			
X-COORD	Y-COORD	STRENGTH	TIME ON
2.500	-100.000	3143.000	.000
7.500	-100.000	3143.000	.000
12.500	-100.000	3143.000	.000
17.500	-100.000	3143.000	.000
22.500	-100.000	3143.000	.000
27.500	-100.000	3143.000	.000
32.500	-100.000	3143.000	.000
37.500	-100.000	3143.000	.000
42.500	-100.000	3143.000	.000
47.500	-100.000	3143.000	.000
52.500	-100.000	3143.000	.000
57.500	-100.000	3143.000	.000
62.500	-100.000	3143.000	.000
67.500	-100.000	3143.000	.000
72.500	-100.000	3143.000	.000
77.500	-100.000	3143.000	.000
82.500	-100.000	3143.000	.000
87.500	-100.000	3143.000	.000
92.500	-100.000	3143.000	.000
97.500	-100.000	3143.000	.000
102.500	-100.000	3143.000	.000
107.500	-100.000	3143.000	.000
112.500	-100.000	3143.000	.000
117.500	-100.000	3143.000	.000
122.500	-100.000	3143.000	.000
127.500	-100.000	3143.000	.000
132.500	-100.000	3143.000	.000
137.500	-100.000	3143.000	.000
142.500	-100.000	3143.000	.000
147.500	-100.000	3143.000	.000
152.500	-100.000	3143.000	.000
157.500	-100.000	3143.000	.000
162.500	-100.000	3143.000	.000
167.500	-100.000	3143.000	.000
172.500	-100.000	3143.000	.000
177.500	-100.000	3143.000	.000
182.500	-100.000	3143.000	.000
187.500	-100.000	3143.000	.000
192.500	-100.000	3143.000	.000
197.500	-100.000	3143.000	.000
202.500	-100.000	3143.000	.000
207.500	-100.000	3143.000	.000
212.500	-100.000	3143.000	.000
217.500	-100.000	3143.000	.000
222.500	-100.000	3143.000	.000
227.500	-100.000	3143.000	.000
232.500	-100.000	3143.000	.000
237.500	-100.000	3143.000	.000
242.500	-100.000	3143.000	.000
247.500	-100.000	3143.000	.000
252.500	-100.000	3143.000	.000
257.500	-100.000	3143.000	.000
262.500	-100.000	3143.000	.000
267.500	-100.000	3143.000	.000
272.500	-100.000	3143.000	.000
277.500	-100.000	3143.000	.000

282.500 -100.000 3143.000 .000
 287.500 -100.000 3143.000 .000
 292.500 -100.000 3143.000 .000
 297.500 -100.000 3143.000 .000

IN THE LIST BELOW, THE VALUE ASSIGNED TO NODE DENOTES BOUNDARY CONDITIONS AS FOLLOWS.

NODE= 1 NORMAL AND SHEAR STRESS PRESCRIBED
 NODE= 2 NORMAL AND SHEAR DISPL. PRESCRIBED
 NODE= 3 NORMAL STRESS AND SHEAR DISPL. PRESCRIBED
 NODE= 4 NORMAL DISPL. AND SHEAR STRESS PRESCRIBED

ELEMENT	NODE	X(CENTER)	Y(CENTER)	HALF-WIDTH	SIN BETA	COS BETA	B-VALUE (S)	B-VALUE (H)
1	1	4.0000	.0000	4.0000	.0000	1.0000	.0000E+00	.0000E+00
2	1	12.0000	.0000	4.0000	.0000	1.0000	.0000E+00	.0000E+00
3	1	20.0000	.0000	4.0000	.0000	1.0000	.0000E+00	.0000E+00
4	1	28.0000	.0000	4.0000	.0000	1.0000	.0000E+00	.0000E+00
5	1	36.0000	.0000	4.0000	.0000	1.0000	.0000E+00	.0000E+00
6	1	44.0000	.0000	4.0000	.0000	1.0000	.0000E+00	.0000E+00
7	1	52.0000	.0000	4.0000	.0000	1.0000	.0000E+00	.0000E+00
8	1	60.0000	.0000	4.0000	.0000	1.0000	.0000E+00	.0000E+00
9	1	68.0000	.0000	4.0000	.0000	1.0000	.0000E+00	.0000E+00
10	1	76.0000	.0000	4.0000	.0000	1.0000	.0000E+00	.0000E+00
11	1	84.0000	.0000	4.0000	.0000	1.0000	.0000E+00	.0000E+00
12	1	92.0000	.0000	4.0000	.0000	1.0000	.0000E+00	.0000E+00
13	1	100.0000	.0000	4.0000	.0000	1.0000	.0000E+00	.0000E+00
14	1	108.0000	.0000	4.0000	.0000	1.0000	.0000E+00	.0000E+00
15	1	116.0000	.0000	4.0000	.0000	1.0000	.0000E+00	.0000E+00
16	1	124.0000	.0000	4.0000	.0000	1.0000	.0000E+00	.0000E+00
17	1	132.0000	.0000	4.0000	.0000	1.0000	.0000E+00	.0000E+00
18	1	140.0000	.0000	4.0000	.0000	1.0000	.0000E+00	.0000E+00
19	1	148.0000	.0000	4.0000	.0000	1.0000	.0000E+00	.0000E+00
20	1	156.0000	.0000	4.0000	.0000	1.0000	.0000E+00	.0000E+00
21	4	160.0000	-15.0000	5.0000	-1.0000	.0000	.0000E+00	.0000E+00
22	4	160.0000	-25.0000	5.0000	-1.0000	.0000	.0000E+00	.0000E+00
23	4	160.0000	-35.0000	5.0000	-1.0000	.0000	.0000E+00	.0000E+00
24	4	160.0000	-45.0000	5.0000	-1.0000	.0000	.0000E+00	.0000E+00
25	4	160.0000	-55.0000	5.0000	-1.0000	.0000	.0000E+00	.0000E+00
26	4	160.0000	-65.0000	5.0000	-1.0000	.0000	.0000E+00	.0000E+00
27	4	160.0000	-75.0000	5.0000	-1.0000	.0000	.0000E+00	.0000E+00
28	4	160.0000	-85.0000	5.0000	-1.0000	.0000	.0000E+00	.0000E+00
29	4	160.0000	-95.0000	5.0000	-1.0000	.0000	.0000E+00	.0000E+00
30	4	160.0000	-105.0000	5.0000	-1.0000	.0000	.0000E+00	.0000E+00
31	4	160.0000	-115.0000	5.0000	-1.0000	.0000	.0000E+00	.0000E+00
32	4	160.0000	-125.0000	5.0000	-1.0000	.0000	.0000E+00	.0000E+00
33	4	160.0000	-135.0000	5.0000	-1.0000	.0000	.0000E+00	.0000E+00
34	4	160.0000	-145.0000	5.0000	-1.0000	.0000	.0000E+00	.0000E+00
35	4	160.0000	-155.0000	5.0000	-1.0000	.0000	.0000E+00	.0000E+00

LINE DEFINING STRESS POINTS
 XBEG YBEG XEND YEND NUNPB
 5.0000 .0000 5.0000 -100.0000 21

TIME REQUIRED TO COMPUTE INFLUENCE COEFFICIENTS= 15.16 SECONDS.

OUTPUT FOR TIME= .1000E+03

PRE-EXISTING STRESS AT EACH ELEMENT

ELEMENT	TEMP	SIGMAXX	SIGMAYY	SIGMAZZ	NORM-STR	SHEAR-STR	NORM-DIS	SHEAR-DIS
1	.7753E-05	-7.153E-06	.1258E-04	.4611E+00	.1258E-04	.4611E+00	-4.922E+00	-1.746E-08
2	.1264E-05	-.9939E-05	.5171E-05	.1386E+01	.5171E-05	.1386E+01	-.4922E+00	.6752E-08
3	-.5367E-05	.4873E-05	.1445E-05	.2320E+01	-.3525E-06	.1445E-05	-.4919E+00	.5588E-08
4	.5594E-06	-.7659E-05	.8732E-05	.3267E+01	.4696E-06	.8732E-05	-.4914E+00	-.1793E-07
5	-.1777E-05	.1013E-05	-.7093E-05	.4236E+01	-.7093E-05	.4236E+01	-.4908E+00	-.3411E-07
6	-.3454E-05	-.2533E-06	.1146E-04	.5231E+01	.1146E-04	.5231E+01	-.4900E+00	.4179E-07
7	.1032E-04	.1670E-04	.7138E-05	.6259E+01	.7138E-05	.6259E+01	-.4891E+00	.7218E-08
8	-.4413E-05	.4843E-05	-.3025E-05	.7327E+01	-.3556E-05	.7327E+01	-.4886E+00	-.3056E-08
9	.4401E-06	.1253E-04	.1329E-04	.8443E+01	.6715E-05	.1329E-04	-.4866E+00	-.4342E-07
10	-.2253E-05	.1612E-04	.1043E-05	.9615E+01	.3480E-05	.1043E-05	-.4851E+00	-.1546E-07
11	-.7126E-06	-.2772E-05	.7302E-05	.1385E+02	.8750E-06	.7302E-05	-.4834E+00	-.5472E-08
12	.3707E-05	.1177E-05	-.1265E-04	.1216E+02	.4791E-05	-.1265E-04	-.4815E+00	.2506E-07
13	-.4681E-05	-.1390E-04	-.6124E-05	.1316E+02	-.6692E-05	-.6124E-05	-.4794E+00	.1618E-07
14	.6481E-05	.1490E-05	.6816E-05	.1505E+02	.4365E-05	.6816E-05	-.4770E+00	-.1607E-07
15	.6666E-05	.1410E-04	.2593E-05	.1665E+02	.4772E-05	.2593E-05	-.4745E+00	-.8149E-08
16	-.3648E-05	-.6609E-05	.2317E-05	.1838E+02	-.2386E-05	.2317E-05	-.4714E+00	.2352E-07
17	-.1352E-05	.5901E-05	.2205E-05	.2024E+02	.1540E-05	.2205E-05	-.4682E+00	.2247E-07
18	-.4754E-05	-.6020E-05	-.2086E-05	.2226E+02	-.3738E-05	-.2086E-05	-.4647E+00	-.5821E-08
19	.2072E-05	-.2354E-05	.1666E-04	.2445E+02	-.1666E-04	.2445E+02	-.4608E+00	-.1770E-07
20	.3057E-05	.8911E-05	-.2235E-05	.2683E+02	-.2235E-05	.2683E+02	-.4561E+00	-.9197E-08
21	.1167E+02	.3984E+01	.1619E+01	.2805E+02	.5602E+01	.3984E+01	-.2922E-02	.4340E+00
22	.3739E+02	.1301E+02	.4835E+01	.2770E+02	.1765E+02	.1301E+02	-.2770E+02	.4523E+00
23	.6920E+02	.2527E+02	.7986E+01	.2700E+02	.3325E+02	.2527E+02	-.2700E+02	.1444E+00
24	.1126E+03	.4302E+02	.1102E+02	.2595E+02	.5404E+02	.4302E+02	-.2595E+02	-.1997E-01
25	.1720E+03	.6864E+02	.1390E+02	.2456E+02	.8254E+02	.6864E+02	-.2456E+02	-.2524E-01
26	.2525E+03	.1046E+03	.1657E+02	.2286E+02	.1212E+03	.1046E+03	-.2286E+02	-.3018E-01
27	.3591E+03	.1534E+03	.1890E+02	.2086E+02	.1723E+03	.1534E+03	-.2086E+02	-.3474E-01
28	.4964E+03	.2173E+03	.2104E+02	.1861E+02	.2363E+03	.2173E+03	-.1861E+02	-.3886E-01
29	.6686E+03	.2982E+03	.2274E+02	.1617E+02	.2809E+03	.2982E+03	-.1617E+02	-.4242E-01
30	.8783E+03	.3977E+03	.2392E+02	.1360E+02	.4216E+03	.3977E+03	-.1360E+02	-.4559E-01
31	.8783E+03	.3968E+03	.2482E+02	.1099E+02	.4216E+03	.3968E+03	-.1099E+02	-.4815E-01
32	.6686E+03	.2956E+03	.2538E+02	.8328E+01	.3210E+03	.2956E+03	-.8328E+01	-.5106E-01
33	.4966E+03	.2129E+03	.2543E+02	.5768E+01	.2129E+03	-.5768E+01	-.5342E-01	-.7642E-02
34	.3594E+03	.1474E+03	.2515E+02	.3369E+01	.1725E+03	.1474E+03	-.3369E+01	-.5525E-01
35	.2532E+03	.9694E+02	.2458E+02	.1181E+01	.1215E+03	.9694E+02	-.1181E+01	-.5666E-01

TIME REQUIRED TO COMPUTE PRE-EXISTING STRESSES = 54.38 SECONDS.

TIME REQUIRED TO SOLVE EQUATIONS= 11.15 SECONDS.

BOUNDARY STRESSES AND DISPLACEMENTS AT TIME = .1000E+07

ELM	X-COORD	Y-COORD	UX	UY	US	SIGMA-S	SIGMA-N	SIGMA-T	TEMP
1	.4000E+01	.0000E+00	.3653E-04	-.3170E-02	.3653E-04	-.3170E-02			.7753E-05
2	.7062E+00	.3576E-06	.4989E-07	.1766E+00	.4989E-07	.3576E-06	.7062E+00		
2	.1200E+02	.0000E+00	.1085E-03	-.3187E-02	.1085E-03	-.3187E-02			

	.6897E+00	-.5364E-06	-.8851E-07	.1724E+00	-.8851E-07	-.5364E-06	.6897E+00	.1264E-05
3	.2000E+02	.0000E+00	.1772E-03	-.3226E-02	.1772E-03	-.3226E-02	.6586E+00	-.5367E-05
	.6586E+00	.3576E-06	-.5428E-07	.1642E+00	-.5428E-07	.3576E-06	.6586E+00	-.5367E-05
4	.2800E+02	.0000E+00	.2402E-03	-.3278E-02	.2402E-03	-.3278E-02	.6069E+00	.5504E-06
	.6069E+00	.5364E-06	.3284E-06	.1517E+00	.3284E-06	.5364E-06	.6069E+00	.5504E-06
5	.3600E+02	.0000E+00	.2855E-03	-.3350E-02	.2855E-03	-.3350E-02	.5404E+00	-.1777E-05
	.5404E+00	-.1669E-05	.9084E-06	.1351E+00	.9084E-06	-.1669E-05	.5404E+00	-.1777E-05
6	.4400E+02	.0000E+00	.3407E-03	-.3433E-02	.3407E-03	-.3433E-02	.4571E+00	-.3454E-05
	.4571E+00	-.2384E-06	.2181E-06	.1143E+00	.2181E-06	-.2384E-06	.4571E+00	-.3454E-05
7	.5200E+02	.0000E+00	.3734E-03	-.3526E-02	.3734E-03	-.3526E-02	.3574E+00	.1032E-04
	.3574E+00	-.2384E-06	.1063E-05	.8935E-01	.1063E-05	-.2384E-06	.3574E+00	.1032E-04
8	.6000E+02	.0000E+00	.3916E-03	-.3630E-02	.3916E-03	-.3630E-02	.2417E+00	-.4413E-05
	.2417E+00	-.4172E-06	-.5402E-07	.6043E-01	-.5402E-07	-.4172E-06	.2417E+00	-.4413E-05
9	.6800E+02	.0000E+00	.3929E-03	-.3733E-02	.3929E-03	-.3733E-02	.1112E+00	.4401E-06
	.1112E+00	-.3576E-06	-.4812E-07	.2781E-01	-.4812E-07	-.3576E-06	.1112E+00	.4401E-06
10	.7600E+02	.0000E+00	.3755E-03	-.3838E-02	.3755E-03	-.3838E-02	-.3256E-01	-.2253E-05
	-.3256E-01	-.2742E-05	.3536E-07	-.8142E-02	.3536E-07	-.2742E-05	-.3256E-01	-.2253E-05
11	.8400E+02	.0000E+00	.3376E-03	-.3933E-02	.3376E-03	-.3933E-02	-.1875E+00	-.7126E-06
	-.1875E+00	.1192E-06	-.1101E-05	-.4688E-01	-.1101E-05	.1192E-06	-.1875E+00	-.7126E-06
12	.9200E+02	.0000E+00	.2774E-03	-.4012E-02	.2774E-03	-.4012E-02	-.3511E+00	.3707E-05
	-.3511E+00	-.5960E-06	.1427E-06	-.8777E-01	.1427E-06	-.5960E-06	-.3511E+00	.3707E-05
13	.1000E+03	.0000E+00	.1938E-03	-.4071E-02	.1938E-03	-.4071E-02	-.5207E+00	-.4681E-05
	-.5207E+00	-.8345E-06	.1553E-05	-.1302E+00	.1553E-05	-.8345E-06	-.5207E+00	-.4681E-05
14	.1080E+03	.0000E+00	.8567E-04	-.4092E-02	.8567E-04	-.4092E-02	-.6947E+00	.6401E-05
	-.6947E+00	.1252E-05	-.2615E-05	-.1737E+00	.1252E-05	-.2615E-05	-.6947E+00	.6401E-05
15	.1160E+03	.0000E+00	-.4797E-04	-.4071E-02	-.4797E-04	-.4071E-02	-.8740E+00	.1666E-05
	-.8740E+00	-.4232E-05	-.3770E-05	-.2185E+00	-.3770E-05	-.4232E-05	-.8740E+00	.1666E-05
16	.1240E+03	.0000E+00	-.2089E-03	-.3982E-02	-.2089E-03	-.3982E-02	-.1067E+01	-.3648E-05
	-.1067E+01	.1311E-05	.3012E-05	-.2668E+00	.1311E-05	.3012E-05	-.1067E+01	-.3648E-05
17	.1320E+03	.0000E+00	-.4018E-03	-.3798E-02	-.4018E-03	-.3798E-02	-.1304E+01	-.1352E-05
	-.1304E+01	.4172E-05	-.1812E-05	-.3259E+00	.4172E-05	-.1812E-05	-.1304E+01	-.1352E-05
18	.1400E+03	.0000E+00	-.6401E-03	-.3468E-02	-.6401E-03	-.3468E-02	-.1684E+01	-.4754E-05
	-.1684E+01	-.7749E-06	.2662E-05	-.4210E+00	.2662E-05	-.7749E-06	-.1684E+01	-.4754E-05
19	.1480E+03	.0000E+00	-.9711E-03	-.2827E-02	-.9711E-03	-.2827E-02	-.2564E+01	.2072E-05
	-.2564E+01	-.2086E-05	.3322E-05	-.F411E+00	.3322E-05	-.2086E-05	-.2564E+01	.2072E-05
20	.1560E+03	.0000E+00	-.1489E-02	-.9656E-03	-.1489E-02	-.9656E-03	.1036E+00	.3057E-05
	.1036E+00	.6586E-05	-.1145E-05	.2591E-01	.6586E-05	-.1145E-05	.1036E+00	.3057E-05
21	.1600E+03	-.5000E+01	.4410E-08	.1954E-03	.4410E-08	.1954E-03	.2657E+02	.1167E+02
	.2657E+02	.2657E+02	.2396E-05	.1267E+02	.2396E-05	.1267E+02	.2657E+02	.1167E+02
22	.1600E+03	-.1500E+02	-.2494E-08	.5468E-03	-.2494E-08	.5468E-03	.8600E+01	.3719E+02
	.3719E+02	.8600E+01	-.1086E-05	.1967E+02	.8600E+01	-.1086E-05	.3719E+02	.8600E+01
23	.1600E+03	-.2500E+02	-.3507E-08	.4914E-02	-.3507E-08	.4914E-02	.4910E+01	.6929E+02
	.6929E+02	.4910E+01	.1816E-05	.3429E+02	.4910E+01	.1816E-05	.6929E+02	.4910E+01
24	.1600E+03	-.3500E+02	-.1722E-09	.1332E-01	-.1722E-09	.1332E-01	.3588E+01	.1126E+03
	.3588E+01	.3588E+01	-.3600E-06	.5479E+02	.3588E+01	-.3600E-06	.3588E+01	.1126E+03
25	.1600E+03	-.4500E+02	.6049E-08	.2696E-01	-.4500E+02	.6049E-08	.2979E+01	.1720E+03
	.1720E+03	.2979E+01	.1137E-05	.8317E+02	.2979E+01	.1137E-05	.2979E+01	.1720E+03
26	.1600E+03	-.5500E+02	.8130E-08	.4765E-01	-.5500E+02	.8130E-08	.2694E+01	.2525E+03
	.2694E+01	.2694E+01	.2888E-05	.1218E+03	.2694E+01	.2888E-05	.2694E+01	.2525E+03
27	.1600E+03	-.6500E+02	-.5107E-08	.7770E-01	-.6500E+02	-.5107E-08	.2568E+01	.3591E+03
	.3591E+03	.2568E+01	.1152E-04	.1729E+03	.3591E+03	.1152E-04	.2568E+01	.3591E+03
28	.1600E+03	-.7500E+02	-.1751E-07	.1199E+00	-.7500E+02	-.1751E-07	.2524E+01	.4964E+03
	.4964E+03	.2524E+01	-.3777E-05	.2389E+00	.4964E+03	-.3777E-05	.2524E+01	.4964E+03
29	.1600E+03	-.8500E+02	-.2548E-08	.1776E+00	-.8500E+02	-.2548E-08	.2504E+01	.6686E+03
	.6686E+03	.2504E+01	.2065E-05	.3216E+03	.6686E+03	.2065E-05	.2504E+01	.6686E+03
30	.1600E+03	-.9500E+02	-.2784E-08	.2544E+00	-.9500E+02	-.2784E-08	.2230E+01	.8783E+03
	.8783E+03	.2230E+01	.9937E-06	.4223E+03	.2230E+01	.9937E-06	.2230E+01	.8783E+03
31	.1600E+03	-.1050E+03	.1341E-07	.3479E+00	-.1050E+03	.1341E-07	.1737E+01	.8783E+03
	.8783E+03	.1737E+01	-.5045E-06	.4218E+03	.8783E+03	-.5045E-06	.1737E+01	.8783E+03
32	.1600E+03	-.1150E+03	-.3050E-08	.4252E+00	-.1150E+03	-.3050E-08	.3908E+01	.6686E+03
	.6686E+03	.3908E+01	-.3398E-05	.3226E+03	.6686E+03	-.3398E-05	.3908E+01	.6686E+03
33	.1600E+03	-.1250E+03	.4244E-08	.4831E+00	-.1250E+03	.4244E-08	.6041E+01	.4966E+03
	.4966E+03	.6041E+01	.2252E-05	.2413E+03	.4966E+03	.2252E-05	.6041E+01	.4966E+03
34	.1600E+03	-.1350E+03	.5037E-08	.5254E+00	-.1350E+03	.5037E-08	.1002E+02	.3594E+03
	.3594E+03	.1002E+02	.1320E-05	.1774E+03	.3594E+03	.1320E-05	.1002E+02	.3594E+03
35	.1600E+03	-.1450E+03	.1332E-07	.5550E+00	-.1450E+03	.1332E-07	.1603E+02	.2532E+03
	.2532E+03	.1603E+02	.2313E-05	.1360E+03	.2532E+03	.2313E-05	.1603E+02	.2532E+03

TIME REQUIRED TO COMPUTE BOUNDARY STRESSES AND DISPLACEMENTS= 16.86 SECONDS.

INTERIOR STRESSES AND DISPLACEMENTS AT TIME = .100E+03

POINT	X-COORD	Y-COORD	UX	UY	SIGXX	SIGYY	SIGZZ	SIG1	SIG2	ALPHA	TEMP
1	.5000E+01	.0000E+00	.4749E-04	-.3172E-02	.6950E+00	.3588E-02	.3200E+01	-.6319E-05			

2	.5000E+01	-.5000E+01	.3927E-04	-.2888E-02	.6113E+01	.1955E-01	-.1005E+00	.1168E+02
	.6113E+01	.1957E-01	-.1069E-01	.5739E+01				
3	.5000E+01	-.1000E+02	.3408E-04	-.1969E-02	.1191E+02	.4016E-02	-.6764E-01	.2391E+02
	.1191E+02	.4033E-02	-.1406E-01	.1159E+02				
4	.5000E+01	-.1500E+02	.2980E-04	-.4353E-03	.1824E+02	-.1264E-01	-.5450E-01	.3722E+02
	.1824E+02	-.1263E-01	-.1832E-01	.1786E+02				
5	.5000E+01	-.2000E+02	.2620E-04	.1799E-02	.2537E+02	-.3295E-01	-.4909E-01	.5218E+02
	.2537E+02	-.3293E-01	-.2176E-01	.2312E+02				
6	.5000E+01	-.2500E+02	.2306E-04	.4840E-02	.3357E+02	-.5622E-01	-.4128E-01	.6935E+02
	.3357E+02	-.5620E-01	-.2423E-01	.3334E+02				
7	.5000E+01	-.3000E+02	.2037E-04	.8802E-02	.4311E+02	-.8353E-01	-.3417E-01	.8931E+02
	.4311E+02	-.8351E-01	-.2575E-01	.4291E+02				
8	.5000E+01	-.3500E+02	.1788E-04	.1385E-01	.5428E+02	-.1094E+00	-.2781E-01	.1127E+03
	.5428E+02	-.1094E+00	-.2640E-01	.5411E+02				
9	.5000E+01	-.4000E+02	.1537E-04	.2016E-01	.6738E+02	-.1385E+00	-.2224E-01	.1401E+03
	.6738E+02	-.1385E+00	-.2224E-01	.6723E+02				
10	.5000E+01	-.4500E+02	.1280E-04	.2795E-01	.8271E+02	-.1654E+00	-.1741E-01	.1721E+03
	.8271E+02	-.1654E+00	-.2518E-01	.8258E+02				
11	.5000E+01	-.5000E+02	.9970E-05	.3749E-01	.1006E+03	-.1869E+00	-.1330E-01	.2094E+03
	.1006E+03	-.1869E+00	-.2339E-01	.1006E+03				
12	.5000E+01	-.5500E+02	.6782E-05	.4904E-01	.1213E+03	-.2064E+00	-.9812E-02	.2526E+03
	.1213E+03	-.2064E+00	-.2080E-01	.1212E+03				
13	.5000E+01	-.6000E+02	.3029E-05	.6291E-01	.1451E+03	-.2237E+00	-.6887E-02	.3024E+03
	.1451E+03	-.2237E+00	-.1747E-01	.1451E+03				
14	.5000E+01	-.6500E+02	-.1408E-05	.7944E-01	.1723E+03	-.2390E+00	-.4463E-02	.3592E+03
	.1723E+03	-.2390E+00	-.1344E-01	.1724E+03				
15	.5000E+01	-.7000E+02	-.6551E-05	.9900E-01	.2033E+03	-.2492E+00	-.2454E-02	.4238E+03
	.2033E+03	-.2492E+00	-.8715E-02	.2033E+03				
16	.5000E+01	-.7500E+02	-.1270E-04	.1220E+00	.2381E+03	-.2547E+00	-.7911E-03	.4967E+03
	.2381E+03	-.2547E+00	-.3292E-02	.2383E+03				
17	.5000E+01	-.8000E+02	-.1972E-04	.1488E+00	.2772E+03	-.2545E+00	.5699E-03	.5782E+03
	.2772E+03	-.2545E+00	.2759E-02	.2774E+03				
18	.5000E+01	-.8500E+02	-.2789E-04	.1800E+00	.3206E+03	-.2483E+00	.1683E-02	.6688E+03
	.3206E+03	-.2482E+00	.9423E-02	.3209E+03				
19	.5000E+01	-.9000E+02	-.3733E-04	.2159E+00	.3685E+03	-.2355E+00	.2581E-02	.7689E+03
	.3685E+03	-.2355E+00	.1661E-01	.3689E+03				
20	.5000E+01	-.9500E+02	-.4798E-04	.2570E+00	.4211E+03	-.3437E+00	.3305E-02	.8786E+03
	.4211E+03	-.3437E+00	.2431E-01	.4215E+03				
21	.5000E+01	-.1000E+03	-.5995E-04	.3039E+00	.4717E+03	-.6779E+01	.3882E-02	.9707E+03
	.4717E+03	-.6779E+01	.3242E-01	.4657E+03				

TIME REQUIRED TO COMPUTE STRESSES AND DISPLACEMENTS AT STRESS POINTS= 42.18 SECONDS.

JOB COMPLETED AT 5:41 HOURS

DATA FOR PLOTTING WILL BE STORED IN FILE NAMED VERIF4

H E F F
A BOUNDARY ELEMENT CODE
FOR TWO-DIMENSIONAL THERMOELASTIC ANALYSIS
OF A ROCK MASS
SUBJECT TO CONSTANT OR DECAYING
THERMAL LOADING
VERSION DATED: DEC. 6 1987 (MS-FORTRAN 77)
VERSION 4.1

THERMO-ELASTIC RESPONSE OF A HOLLOW CYLINDER

OUTPUT CREATED ON

12/ 6/1987

NUMBER OF BOUNDARY SEGMENTS = 2
NUMBER OF STRESS LINES = 1
NUMBER OF HEAT SOURCES = 1
NUMBER OF EXP. DECAYING COMPONENTS = 1

THE LINE X=0.0 IS A LINE OF SYMMETRY.
IMAGE BOUNDARY ELEMENTS AND HEAT SOURCES WILL BE GENERATED WITH RESPECT TO THIS LINE.
EFFECT OF IMAGE HEAT SOURCES NOT COMPUTED

POISSONS RATIO OF BODY = .25
MODULUS OF ELASTICITY OF BODY = .6000E+05
SHEAR MODULUS OF BODY = .2400E+05

XX-COMPONENT OF FIELD STRESS = .0000E+00Y + .0000E+00 + (.0000E+00 + .0000E+00 / Y) * SIGYY
YY-COMPONENT OF FIELD STRESS = .0000E+00Y + .0000E+00
XY-COMPONENT OF FIELD STRESS = .0000E+00Y + .0000E+00
MAXIMUM VALUE FOR CXX + DXX / Y = .0000E+00
RATIO OF ZZ STRESS TO XX STRESS = .0000E+00

TIME FOR OUTPUT
.500E+01

TEMPERATURE VARIATION WITH DEPTH= .0000Y + .0000

THERMAL DIFFUSIVITY = .12E2E+02
THERMAL EXPANSION COEFFICIENT = .6000E-05
STRESS COEFFICIENT VE = .2400E+00

EXPONENTIALLY DECAYING COMPONENTS
TIME ON PROPORTION DECAY CONST.
.00 .10000E+01 .00000E+00

SOURCE DATA
X-COORD Y-COORD STRENGTH TIME ON
.000 .000 1573.160 .000

IN THE LIST BELOW, THE VALUE ASSIGNED TO CODE DENOTES BOUNDARY CONDITIONS AS FOLLOWS

CODE= 1 NORMAL AND SHEAR STRESSES PRESCRIBED
CODE= 2 NORMAL AND SHEAR DISPL. PRESCRIBED
CODE= 3 NORMAL STRESS AND SHEAR DISPL. PRESCRIBED
CODE= 4 NORMAL DISPL. AND SHEAR STRESS PRESCRIBED

ELEMENT	KODE	X(CENTER)	Y(CENTER)	HALF-WIDTH	SIN BETA	COS BETA	B-VALUE (S)	B-VALUE (N)
1	1	.2162	-3.9883	.2166	.0541	.9985	.0000E+00	.0000E+00
2	1	.6462	-3.9415	.2166	.1618	.9868	.0000E+00	.0000E+00
3	1	1.0685	-3.8485	.2166	.2675	.9635	.0000E+00	.0000E+00
4	1	1.4784	-3.7105	.2166	.3701	.9290	.0000E+00	.0000E+00
5	1	1.8709	-3.5289	.2166	.4684	.8835	.0000E+00	.0000E+00
6	1	2.2415	-3.3059	.2166	.5612	.8277	.0000E+00	.0000E+00
7	1	2.5857	-3.0442	.2166	.6474	.7622	.0000E+00	.0000E+00
8	1	2.8997	-2.7468	.2166	.7260	.6877	.0000E+00	.0000E+00
9	1	3.1797	-2.4171	.2166	.7961	.6052	.0000E+00	.0000E+00
10	1	3.4224	-2.0592	.2166	.8569	.5156	.0000E+00	.0000E+00
11	1	3.6230	-1.6771	.2166	.9076	.4199	.0000E+00	.0000E+00
12	1	3.7851	-1.2753	.2166	.9477	.3193	.0000E+00	.0000E+00
13	1	3.9008	-.8586	.2166	.9766	.2150	.0000E+00	.0000E+00
14	1	3.9707	-.4318	.2166	.9941	.1081	.0000E+00	.0000E+00
15	1	3.9941	.0000	.2166	1.0000	.0000	.0000E+00	.0000E+00
16	1	3.9707	.4318	.2166	.9941	-.1081	.0000E+00	.0000E+00
17	1	3.9008	.8586	.2166	.9766	-.2150	.0000E+00	.0000E+00
18	1	3.7851	1.2753	.2166	.9477	-.3193	.0000E+00	.0000E+00
19	1	3.6230	1.6771	.2166	.9076	-.4199	.0000E+00	.0000E+00
20	1	3.4224	2.0592	.2166	.8569	-.5156	.0000E+00	.0000E+00
21	1	3.1797	2.4171	.2166	.7961	-.6052	.0000E+00	.0000E+00
22	1	2.8997	2.7468	.2166	.7260	-.6877	.0000E+00	.0000E+00
23	1	2.5857	3.0442	.2166	.6474	-.7622	.0000E+00	.0000E+00
24	1	2.2415	3.3059	.2166	.5612	-.8277	.0000E+00	.0000E+00
25	1	1.8709	3.5289	.2166	.4684	-.8835	.0000E+00	.0000E+00
26	1	1.4784	3.7105	.2166	.3701	-.9290	.0000E+00	.0000E+00
27	1	1.0685	3.8485	.2166	.2675	-.9635	.0000E+00	.0000E+00
28	1	.6462	3.9415	.2166	.1618	-.9868	.0000E+00	.0000E+00
29	1	.2162	3.9883	.2166	.0541	-.9985	.0000E+00	.0000E+00
30	1	.3244	3.9824	.3248	-.0541	.9985	.0000E+00	.0000E+00
31	1	.9693	3.9123	.3248	-.1618	.9868	.0000E+00	.0000E+00
32	1	1.6028	3.7728	.3248	-.2675	.9635	.0000E+00	.0000E+00
33	1	2.2178	3.5657	.3248	-.3701	.9290	.0000E+00	.0000E+00
34	1	2.8063	3.2933	.3248	-.4684	.8835	.0000E+00	.0000E+00
35	1	3.3622	2.9569	.3248	-.5612	.8277	.0000E+00	.0000E+00
36	1	3.8766	2.5663	.3248	-.6474	.7622	.0000E+00	.0000E+00
37	1	4.3496	2.1201	.3248	-.7260	.6877	.0000E+00	.0000E+00
38	1	4.7696	1.6237	.3248	-.7961	.6052	.0000E+00	.0000E+00
39	1	5.1368	1.0888	.3248	-.8569	.5156	.0000E+00	.0000E+00
40	1	5.4375	.5156	.3248	-.9076	.4199	.0000E+00	.0000E+00
41	1	5.6776	.19130	.3248	-.9477	.3193	.0000E+00	.0000E+00
42	1	5.8511	1.2679	.3248	-.9766	.2150	.0000E+00	.0000E+00
43	1	5.9561	.6478	.3248	-.9941	.1081	.0000E+00	.0000E+00
44	1	5.9912	.0000	.3248	-1.0000	.0000	.0000E+00	.0000E+00
45	1	5.9561	-.6478	.3248	-.9941	-.1081	.0000E+00	.0000E+00
46	1	5.8511	-1.2679	.3248	-.9766	-.2150	.0000E+00	.0000E+00
47	1	5.6776	-1.9130	.3248	-.9477	-.3193	.0000E+00	.0000E+00

7	.2586E+01	-.3044E+01	-.6673E-03	.7856E-03	-.8298E-08	.1031E-02		
	.2700E+01	.194E+01	.229E+01	.1721E+02	-.3213E-06	.6737E-06	.4648E+01	.4457E+02
8	.2900E+01	-.2747E+01	-.7484E-03	.7089E-03	-.9985E-08	.1031E-02		
	.2168E+01	.2450E+01	.2321E+01	.1721E+02	-.6850E-06	.7453E-06	.4648E+01	.4457E+02
9	.3180E+01	-.2417E+01	-.6206E-03	.6236E-03	-.1131E-07	.1031E-02		
	.1702E+01	.294E+01	.2239E+01	.1721E+02	-.1636E-05	.4034E-05	.4648E+01	.4457E+02
10	.3422E+01	-.2059E+01	-.8833E-03	.5314E-03	-.1074E-07	.1031E-02		
	.1235E+01	.3413E+01	.2053E+01	.1721E+02	-.121E-05	.1729E-05	.4648E+01	.4457E+02
11	.3625E+01	-.1677E+01	-.9355E-03	.4326E-03	-.1230E-07	.1031E-02		
	.8195E+00	.3829E+01	.1771E+01	.1721E+02	.1367E-05	.3986E-05	.4648E+01	.4457E+02
12	.3785E+01	-.1275E+01	-.9769E-03	.3291E-03	-.1284E-07	.1031E-02		
	.4739E+00	.4174E+01	.1407E+01	.1721E+02	-.1480E-05	.3233E-05	.4648E+01	.4457E+02
13	.3901E+01	-.8566E+00	-.1007E-02	.2216E-03	-.1260E-07	.1031E-02		
	.2146E+00	.4432E+01	.9759E+00	.1721E+02	-.1884E-06	.1467E-05	.4648E+01	.4457E+02
14	.3971E+01	-.4318E+00	-.1025E-02	.1114E-03	-.1229E-07	.1031E-02		
	.5434E+01	.4594E+01	.4896E+00	.1721E+02	.2927E-06	.8566E-06	.4648E+01	.4457E+02
15	.3994E+01	.1192E-06	-.1031E-02	-.1191E-07	-.1176E-07	.1031E-02		
	.2043E-05	.464E+01	.9849E-06	.1721E+02	.314E-06	.2043E-05	.4648E+01	.4457E+02
16	.3971E+01	.4318E+00	-.1025E-02	-.1115E-03	-.1110E-07	.1031E-02		
	.5434E+01	.4594E+01	.4896E+00	.1721E+02	-.3074E-06	.9252E-06	.4648E+01	.4457E+02
17	.3901E+01	.8566E+00	-.1007E-02	.2216E-03	-.1141E-07	.1031E-02		
	.2146E+00	.4432E+01	.9759E+00	.1721E+02	-.1330E-06	.2360E-05	.4648E+01	.4457E+02
18	.3785E+01	.1275E+01	-.9769E-03	.3292E-03	-.1074E-07	.1031E-02		
	.4739E+00	.4174E+01	.1407E+01	.1721E+02	-.6040E-06	.404E-05	.4648E+01	.4457E+02
19	.3625E+01	.1677E+01	-.9355E-03	.4326E-03	-.1085E-07	.1031E-02		
	.8195E+00	.3829E+01	.1771E+01	.1721E+02	-.1626E-06	.2025E-05	.4648E+01	.4457E+02
20	.3422E+01	.2059E+01	-.8833E-03	-.5315E-03	-.9610E-08	.1031E-02		
	.1235E+01	.3413E+01	.2053E+01	.1721E+02	-.1059E-05	.2132E-05	.4648E+01	.4457E+02
21	.3180E+01	.2417E+01	-.6206E-03	.6236E-03	-.9365E-08	.1031E-02		
	.1702E+01	.294E+01	.2239E+01	.1721E+02	.1637E-05	.1429E-05	.4648E+01	.4457E+02
22	.2900E+01	-.2747E+01	-.7484E-03	-.7089E-03	-.8631E-08	.1031E-02		
	.2168E+01	.2450E+01	.2321E+01	.1721E+02	.6791E-06	.9722E-05	.4648E+01	.4457E+02
23	.2586E+01	.3044E+01	-.6673E-03	-.7857E-03	-.7166E-08	.1031E-02		
	.2700E+01	.194E+01	.229E+01	.1721E+02	.8825E-06	.1537E-05	.4648E+01	.4457E+02
24	.2241E+01	.3306E+01	-.5785E-03	-.8532E-03	-.6524E-08	.1031E-02		
	.3184E+01	.1464E+01	-.2159E+01	.1721E+02	.4429E-06	.2829E-05	.4648E+01	.4457E+02
25	.1871E-01	.3529E+01	-.482E-03	-.910E-03	-.5625E-08	.1031E-02		
	.3628E+01	.1020E+01	-.1924E+01	.1721E+02	-.9652E-07	.5660E-07	.4648E+01	.4457E+02
26	.1478E+01	.3710E+01	-.3615E-03	-.9576E-03	-.3979E-08	.1031E-02		
	.4011E+01	.836E+00	.159E+01	.1721E+02	.8631E-06	.4454E-05	.4648E+01	.4457E+02
27	.1069E+01	.3849E+01	-.2758E-03	-.9933E-03	.3396E-08	.1031E-02		
	.4316E+01	.3327E+00	.119E+01	.1721E+02	.2236E-05	.732E-05	.4648E+01	.4457E+02
28	.6462E+00	.3942E+01	-.1666E-03	-.1017E-02	.2106E-08	.1031E-02		
	.4527E+01	.1217E+00	.7421E+00	.1721E+02	.6597E-06	.5026E-05	.4648E+01	.4457E+02
29	.2162E+00	.398E+01	-.5581E-04	-.102E-02	.9729E-09	.1031E-02		
	.4635E+01	.1362E+01	.2513E+00	.1721E+02	-.6016E-07	.1670E-05	.4648E+01	.4457E+02
30	.3244E+00	.5982E+01	-.8554E-04	-.1576E-02	.9110E-09	.1580E-02		
	-.2352E+01	-.6917E-02	.1275E+00	.1020E+02	.9711E-07	-.2285E-05	-.2359E+01	.2997E+02
31	.9693E+00	.5912E+01	-.2556E-03	-.1556E-02	.6167E-09	.1580E-02		
	-.2297E+01	-.6175E+01	.376E+00	.1020E+02	.1432E-06	-.6707E-06	-.2359E+01	.2997E+02
32	.1603E+01	.5773E+01	-.4227E-03	-.1522E-02	.3732E-08	.1580E-02		
	-.2190E+01	-.168E+00	.6081E+00	.1020E+02	.3612E-07	-.1104E-05	-.2359E+01	.2997E+02
33	.2218E+01	.5566E+01	-.5848E-03	-.1468E-02	.4302E-08	.1580E-02		
	-.2036E+01	-.3232E+00	.6112E+00	.1020E+02	-.4702E-06	.4367E-05	-.2359E+01	.2997E+02
34	.2806E+01	.5293E+01	-.7401E-03	-.1396E-02	.6152E-08	.1580E-02		
	-.1842E+01	-.5176E+00	.9763E+00	.1020E+02	.1137E-05	.4570E-05	-.2359E+01	.2997E+02
35	.3362E+01	.4959E+01	-.8666E-03	-.1308E-02	.6082E-08	.1580E-02		
	-.1616E+01	-.7430E+00	.109E+01	.1020E+02	.1241E-06	.1435E-05	-.2359E+01	.2997E+02
36	.3879E+01	.4566E+01	-.1023E-02	-.1204E-02	.7950E-08	.1580E-02		
	-.1370E+01	-.9867E+00	.1164E+01	.1020E+02	-.1817E-05	.9389E-05	-.2359E+01	.2997E+02
37	.4350E+01	.4120E+01	-.1147E-02	-.1087E-02	.8363E-08	.1580E-02		
	-.111E+01	-.1243E+01	.117E+01	.1020E+02	.9262E-06	.1664E-05	-.2359E+01	.2997E+02
38	.4770E+01	.362E+01	-.1256E-02	-.9561E-03	.9694E-08	.1580E-02		
	-.8640E+00	-.1495E+01	.1137E+01	.1020E+02	-.3877E-06	-.1311E-05	-.2359E+01	.2997E+02
39	.5134E+01	.3089E+01	-.1354E-02	-.814E-03	.1137E-07	.1580E-02		
	-.6270E+00	-.1732E+01	.1042E+01	.1020E+02	.1087E-05	-.4750E-05	-.2359E+01	.2997E+02
40	.5437E+01	.251E+01	-.1434E-02	-.6634E-03	.1072E-07	.1580E-02		
	-.4159E+00	-.1943E+01	.8990E+00	.1020E+02	-.3892E-06	.1194E-05	-.2359E+01	.2997E+02
41	.567E+01	.1613E+01	-.1497E-02	-.5045E-03	.104E-07	.1580E-02		
	-.2401E+00	-.211E+01	.713E+00	.1020E+02	-.9529E-06	-.1097E-05	-.2359E+01	.2997E+02
42	.5851E+01	.128E+01	-.1543E-02	-.3397E-03	.124E-07	.1580E-02		
	-.1090E+00	-.2250E+01	.4953E+00	.1020E+02	-.1002E-05	.2920E-06	-.2359E+01	.2997E+02
43	.5956E+01	.647E+00	-.1571E-02	-.170E-03	.1112E-07	.1580E-02		
	-.2756E+01	-.2332E+01	.253E+00	.1020E+02	-.334E-06	.4236E-07	-.2359E+01	.2997E+02
44	.5991E+01	-.178E-06	-.1580E-02	-.1195E-07	.1189E-07	.1580E-02		
	-.1453E-05	-.2359E+01	.34E+00	.1020E+02	-.256E-06	-.147E-05	-.2359E+01	.2997E+02
45	.5956E+01	-.647E+00	-.1571E-02	.170E-03	.122E-07	.1580E-02		

	-.2758E-01	-.2332E+01	-.2530E+00	.1020E+02	.6406E-06	-.7430E-06	-.2359E+01	.2997E+02
46	.5851E+01	-.1288E+01	-.1543E-02	.3396E-03	.1197E-07	-.1580E-02	-.2359E+01	.2997E+02
	-.1090E+00	-.2250E+01	-.4853E+00	.1020E+02	.1198E-06	.7889E-06	-.2359E+01	.2997E+02
47	.5678E+01	-.1813E+01	-.1497E-02	.5045E-03	.1174E-07	-.1580E-02	-.2359E+01	.2997E+02
	-.2405E+00	-.2118E+01	-.7138E+00	.1020E+02	.1035E-06	-.2986E-05	-.2359E+01	.2997E+02
48	.5437E+01	-.2516E+01	-.1434E-02	.6634E-03	.1087E-07	-.1580E-02	-.2359E+01	.2997E+02
	-.4159E+00	-.1943E+01	-.8990E+00	.1020E+02	-.1340E-06	.1359E-05	-.2359E+01	.2997E+02
49	.5134E+01	-.3089E+01	-.1354E-02	.8145E-03	.1076E-07	-.1580E-02	-.2359E+01	.2997E+02
	-.6271E+00	-.1732E+01	-.1042E+01	.1020E+02	.9986E-06	-.4075E-05	-.2359E+01	.2997E+02
50	.4770E+01	-.3626E+01	-.1258E-02	.9561E-03	.9889E-08	-.1580E-02	-.2359E+01	.2997E+02
	-.8640E+00	-.1495E+01	-.1137E+01	.1020E+02	-.2132E-06	.3027E-05	-.2359E+01	.2997E+02
51	.4350E+01	-.4120E+01	-.1147E-02	.1087E-02	.1029E-07	-.1580E-02	-.2359E+01	.2997E+02
	-.1116E+01	-.1243E+01	-.1176E+01	.1020E+02	.6881E-07	.1047E-05	-.2359E+01	.2997E+02
52	.3879E+01	-.4566E+01	-.1023E-02	.1204E-02	.8152E-08	-.1580E-02	-.2359E+01	.2997E+02
	-.1370E+01	-.9887E+00	-.1164E+01	.1020E+02	-.1305E-05	.7708E-06	-.2359E+01	.2997E+02
53	.3362E+01	-.4959E+01	-.6866E-03	.1308E-02	.7684E-08	-.1580E-02	-.2359E+01	.2997E+02
	-.1616E+01	-.7430E+00	-.1086E+01	.1020E+02	.6144E-06	.3507E-05	-.2359E+01	.2997E+02
54	.2806E+01	-.5293E+01	-.7401E-03	.1396E-02	.6297E-08	-.1580E-02	-.2359E+01	.2997E+02
	-.1842E+01	-.5176E+00	-.9763E+00	.1020E+02	.6426E-06	.1414E-06	-.2359E+01	.2997E+02
55	.2216E+01	-.5566E+01	-.5846E-03	.1466E-02	.4886E-08	-.1580E-02	-.2359E+01	.2997E+02
	-.2036E+01	-.3232E+00	.8112E+00	.1020E+02	.5191E-06	-.1147E-05	-.2359E+01	.2997E+02
56	.1603E+01	-.5773E+01	-.4227E-03	.1522E-02	.3385E-08	-.1580E-02	-.2359E+01	.2997E+02
	-.2190E+01	-.1688E+00	-.6081E+00	.1020E+02	.3272E-06	.2519E-06	-.2359E+01	.2997E+02
57	.9693E+00	-.5912E+01	-.2556E-03	.1559E-02	.2956E-08	-.1580E-02	-.2359E+01	.2997E+02
	-.2297E+01	-.6175E+01	-.3766E+00	.1020E+02	.1074E-07	.6200E-06	-.2359E+01	.2997E+02
58	.3244E+00	-.5982E+01	-.8554E-04	.1578E-02	.1746E-08	-.1580E-02	-.2359E+01	.2997E+02
	-.2352E+01	-.6917E+02	-.1275E+00	.1020E+02	-.6133E-07	-.1961E-05	-.2359E+01	.2997E+02

TIME REQUIRED TO COMPUTE BOUNDARY STRESSES AND DISPLACEMENTS= 48.94 SECONDS.

INTERIOR STRESSES AND DISPLACEMENTS AT TIME = .500E+01

POINT	X-COORD SIGXX	Y-COORD SIGYY	UX SIGXY	UY SIGZZ	SIG1	SIG2	ALPHA	TEMP
1	.4000E+01 -.3343E-02	.0000E+00 .4625E+01	-.1033E-02 -.5378E-06	-.1238E-07 .1716E+02	.4625E+01	-.3343E-02	-.9000E+02	.4451E+02
2	.4333E+01 -.1481E+00	.0000E+00 .3051E+01	-.1147E-02 .1295E-05	-.1209E-07 .1576E+02	.3051E+01	.1481E+00	.9000E+02	.4155E+02
3	.4667E+01 .3003E+00	.0000E+00 .1596E+01	-.1250E-02 .3153E-06	-.1213E-07 .1445E+02	.1596E+01	.3003E+00	.9000E+02	.3683E+02
4	.5000E+01 .3442E+00	.0000E+00 .3540E+00	-.1344E-02 .3448E-05	-.1234E-07 .1326E+02	.3540E+00	.3442E+00	.8996E+02	.3634E+02
5	.5333E+01 .3103E+00	.0000E+00 -.7180E+00	-.1430E-02 .3709E-06	-.1270E-07 .1215E+02	.3103E+00	-.7180E+00	.2066E-04	.3403E+02
6	.5667E+01 .2159E+00	.0000E+00 -.1646E+01	-.1509E-02 -.1717E-06	-.1268E-07 .1113E+02	.2159E+00	-.1646E+01	-.5276E-05	.3190E+02
7	.6000E+01 .1255E+02	.0000E+00 .1812E+01	-.1580E-02 -.2386E-04	-.1195E-07 .1436E+02	.1255E+02	.1812E+01	-.1274E-03	.2992E+02

TIME REQUIRED TO COMPUTE STRESSES AND DISPLACEMENTS AT STRESS POINTS= 6.15 SECONDS.

JOB COMPLETED AT 16:43 HOURS

DATA FOR PLOTTING WILL BE STORED IN FILE NAMED VERIF3

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*****
*                                     H E F F
*                                     A BOUNDARY ELEMENT CODE
*                                     FOR TWO-DIMENSIONAL THERMOELASTIC ANALYSIS
*                                     OF A ROCK MASS
*                                     SUBJECT TO CONSTANT OR DECAYING
*                                     THERMAL LOADING
*                                     VERSION DATED: DEC. 6 1967 (MS-FORTRAN 77)
*                                     VERSION 4.1
*****

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VERTICAL EMPLACEMENT - OUTPUT AT T=10 YRS.

OUTPUT CREATED ON

12/ 7/1967

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NUMBER OF BOUNDARY SEGMENTS . . . . . = 9
NUMBER OF STRESS LINES . . . . . = 0
NUMBER OF HEAT SOURCES . . . . . = 22
NUMBER OF EXP. DECAYING COMPONENTS . . . = 4

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THE LINE X=0.0 IS A LINE OF SYMMETRY.
IMAGE BOUNDARY ELEMENTS AND HEAT SOURCES WILL BE GENERATED WITH RESPECT TO THIS LINE.

CONSTANT TEMPERATURE B.C. IMPOSED AT SURFACE

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POISSON'S RATIO OF BODY . . . . . = .20
MODULUS OF ELASTICITY OF BODY . . . . . = .1510E+05
SHEAR MODULUS OF BODY . . . . . = .6292E+04

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XX-COMPONENT OF FIELD STRESS = .0000E+00Y + .0000E+00 + (.5500E+00 + .0000E+00 / Y) * SIGYY
XY-COMPONENT OF FIELD STRESS = -.2300E+01Y + .0000E+00
YY-COMPONENT OF FIELD STRESS = .0000E+00Y + .0000E+00
MAXIMUM VALUE FOR CXX + DXX / Y = .5500E+00
RATIO OF ZZ STRESS TO XX STRESS = .1000E+01

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TIME FOR OUTPUT
.100E+02

TEMPERATURE VARIATION WITH DEPTH= -.0239Y + 16.9000

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THERMAL DIFFUSIVITY . . . . . = .2903E+02
THERMAL EXPANSION COEFFICIENT . . . . . = .1070E-04
STRESS COEFFICIENT VE . . . . . = .1010E+00

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PROPERTIES OF HEAT SOURCES - CONSTANT OR DECAYING

TIME ON	PROPORTION	DECAY CONST.
.00	.15602E+00	.13539E-02
.00	.59787E+00	.19142E-01
.00	.15227E+00	.51688E-01
.00	.93640E-01	.43766E+00

SOURCE DATA

X-COORD	Y-COORD	STRENGTH	TIME ON
.000	-305.512	1360.328	.000
.000	-307.335	1360.328	.000
.000	-308.639	1360.328	.000
34.138	-307.335	6261.970	.000
68.276	-307.335	6261.970	.000
102.414	-307.335	6261.970	.000
136.552	-307.335	6261.970	.000
170.690	-307.335	6261.970	.000
204.828	-307.335	6261.970	.000
238.966	-307.335	6261.970	.000
273.104	-307.335	6261.970	.000
307.242	-307.335	6261.970	.000
341.380	-307.335	6261.970	.000
375.518	-307.335	6261.970	.000
409.656	-307.335	6261.970	.000
443.794	-307.335	6261.970	.000
477.932	-307.335	6261.970	.000
512.070	-307.335	6261.970	.000
546.208	-307.335	6261.970	.000
580.346	-307.335	6261.970	.000
614.484	-307.335	6261.970	.000
648.622	-307.335	6261.970	.000

IN THE LIST BELOW THE VALUE ASSIGNED TO KODE DENOTES BOUNDARY CONDITIONS AS FOLLOWS.

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KODE= 1 NORMAL AND SHEAR STRESSES PRESCRIBED
KODE= 2 NORMAL AND SHEAR DISPL. PRESCRIBED
KODE= 3 NORMAL STRESS AND SHEAR DISPL. PRESCRIBED
KODE= 4 NORMAL DISPL. AND SHEAR STRESS PRESCRIBED

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ELEMENT	KODE	X(CENTER)	Y(CENTER)	HALF-WIDTH	SIN BETA	COS BETA	B-VALUE (S)	B-VALUE (N)
1	1	.1950	-302.0000	.1950	.0000	1.0000	.0000E+00	.0000E+00
2	1	.0000	-302.0000	.1950	.0000	1.0000	.0000E+00	.0000E+00
3	1	.0000	-302.0000	.1950	.0000	1.0000	.0000E+00	.0000E+00
4	1	1.3650	-302.0000	.1950	.0000	1.0000	.0000E+00	.0000E+00
5	1	1.7550	-302.0000	.1950	.0000	1.0000	.0000E+00	.0000E+00
6	1	2.1450	-302.0000	.1950	.0000	1.0000	.0000E+00	.0000E+00
7	1	2.3900	-301.9500	.0757	.7071	.7071	.0000E+00	.0000E+00
8	1	2.4400	-301.6866	.2133	1.0000	.0000	.0000E+00	.0000E+00
9	1	2.4400	-301.2600	.2133	1.0000	.0000	.0000E+00	.0000E+00
10	1	2.4400	-300.8333	.2133	1.0000	.0000	.0000E+00	.0000E+00
11	1	2.4400	-300.4067	.2133	1.0000	.0000	.0000E+00	.0000E+00
12	1	2.4400	-299.9800	.2133	1.0000	.0000	.0000E+00	.0000E+00
13	1	2.4400	-299.5533	.2133	1.0000	.0000	.0000E+00	.0000E+00
14	1	2.4400	-299.1266	.2133	1.0000	.0000	.0000E+00	.0000E+00
15	1	2.4400	-298.7000	.2133	1.0000	.0000	.0000E+00	.0000E+00
16	1	2.4400	-298.2733	.2133	1.0000	.0000	.0000E+00	.0000E+00
17	1	2.4400	-297.8467	.2133	1.0000	.0000	.0000E+00	.0000E+00
18	1	2.4400	-297.4200	.2133	1.0000	.0000	.0000E+00	.0000E+00
19	1	2.4400	-296.9933	.2133	1.0000	.0000	.0000E+00	.0000E+00
20	1	2.3417	-296.6197	.1678	.8566	-.5159	.0000E+00	.0000E+00
21	1	2.1268	-296.3127	.1678	.7760	-.6262	.0000E+00	.0000E+00
22	1	1.8721	-296.0361	.1678	.6848	-.7267	.0000E+00	.0000E+00

23	1	1.5221	-295.8008	.1678	.5788	-.6155	.0000E+00	.0000E+00
24	1	1.2625	-295.6054	.1678	.4618	-.6670	.0000E+00	.0000E+00
25	1	.9191	-295.4556	.1678	.3362	-.6418	.0000E+00	.0000E+00
26	1	.5564	-295.3541	.1678	.2043	-.6789	.0000E+00	.0000E+00
27	1	.1873	-295.3028	.1678	.0685	-.6977	.0000E+00	.0000E+00
28	1	32.3060	-302.0000	.6100	.0000	1.0000	.0000E+00	.0000E+00
29	1	33.5280	-302.0000	.6100	.0000	1.0000	.0000E+00	.0000E+00
30	1	34.7460	-302.0000	.6100	.0000	1.0000	.0000E+00	.0000E+00
31	1	35.9680	-302.0000	.6100	.0000	1.0000	.0000E+00	.0000E+00
32	1	36.5760	-301.3475	.6525	1.0000	.0000	.0000E+00	.0000E+00
33	1	36.5760	-300.0425	.6525	1.0000	.0000	.0000E+00	.0000E+00
34	1	36.5780	-298.7375	.6525	1.0000	.0000	.0000E+00	.0000E+00
35	1	36.5780	-287.4325	.6525	1.0000	.0000	.0000E+00	.0000E+00
36	1	36.0718	-296.2363	.7422	.7332	-.6681	.0000E+00	.0000E+00
37	1	34.8528	-285.4911	.7422	-.2709	-.9626	.0000E+00	.0000E+00
38	1	33.4235	-285.4911	.7422	-.2709	-.9626	.0000E+00	.0000E+00
39	1	32.2042	-286.2363	.7422	-.7332	-.6681	.0000E+00	.0000E+00
40	1	31.6980	-297.4325	.6525	-1.0000	.0000	.0000E+00	.0000E+00
41	1	31.6980	-298.7375	.6525	-1.0000	.0000	.0000E+00	.0000E+00
42	1	31.6980	-300.0425	.6525	-1.0000	.0000	.0000E+00	.0000E+00
43	1	31.6980	-301.3475	.6525	-1.0000	.0000	.0000E+00	.0000E+00
44	1	50.0000	.0000	50.0000	.0000	1.0000	.0000E+00	.0000E+00
45	1	150.0000	.0000	50.0000	.0000	1.0000	.0000E+00	.0000E+00
46	1	250.0000	.0000	50.0000	.0000	1.0000	.0000E+00	.0000E+00
47	1	350.0000	.0000	50.0000	.0000	1.0000	.0000E+00	.0000E+00
48	1	450.0000	.0000	50.0000	.0000	1.0000	.0000E+00	.0000E+00
49	1	550.0000	.0000	50.0000	.0000	1.0000	.0000E+00	.0000E+00
50	1	650.0000	.0000	50.0000	.0000	1.0000	.0000E+00	.0000E+00
51	1	750.0000	.0000	50.0000	.0000	1.0000	.0000E+00	.0000E+00
52	1	850.0000	.0000	50.0000	.0000	1.0000	.0000E+00	.0000E+00
53	1	950.0000	.0000	50.0000	.0000	1.0000	.0000E+00	.0000E+00

LINES DEFINING STRESS POINTS

XBEG	YBEG	XEND	YEND	NUMPB
.1950	-302.3000	.1950	-308.2344	0
.5850	-302.3000	.5850	-308.2344	0
.9750	-302.3000	.9750	-308.2344	0
1.3650	-302.3000	1.3650	-308.2344	0
1.7550	-302.3000	1.7550	-308.2344	0
2.1450	-302.3000	2.1450	-308.2344	0
2.6021	-302.1621	6.7985	-305.3582	0
2.7400	-301.6566	8.6744	-301.2666	0
2.7400	-301.2666	8.6744	-300.8333	0
2.7400	-300.8333	8.6744	-300.4067	0
2.7400	-299.9800	8.6744	-299.5800	0
2.7400	-299.5533	8.6744	-299.1533	0
2.7400	-299.1266	8.6744	-298.7266	0
2.7400	-298.7000	8.6744	-298.3000	0
2.7400	-298.2733	8.6744	-297.8733	0
2.7400	-297.8467	8.6744	-297.4467	0
2.7400	-297.4200	8.6744	-297.0200	0
2.7400	-296.9933	8.6744	-296.5933	0
2.5666	-296.4649	7.6822	-293.4032	0
2.3602	-296.1243	6.9714	-292.3582	0
1.0776	-295.8195	6.1431	-291.4581	0
1.7557	-295.5562	4.1904	-290.7167	0
1.4010	-295.3363	4.1417	-290.0757	0
1.0169	-295.1730	3.0151	-289.5841	0
.6167	-295.0604	1.8321	-289.2512	0
.2079	-295.0026	.6144	-289.0631	0

TIME REQUIRED TO COMPUTE INFLUENCE COEFFICIENTS= 33.34 SECONDS.

OUTPUT FOR TIME= .1000E+02

PRE-EXISTING STRESS AT EACH ELEMENT

ELEMENT	TEMP	SIGMAXX	SIGMAYY	SIGMAZZ	NORM-STR	SHEAR-STR	NORM-DIS	SHEAR-D
1	.9034E+02	.1266E+02	.1126E+02	.1222E+02	.1719E+02	.1126E+02	-.524E+02	-.666E+02
2	.9014E+02	.1290E+02	.1120E+02	.1361E+02	.1715E+02	.1120E+02	-.5238E+02	-.666E+02
3	.8975E+02	.1284E+02	.1108E+02	.1584E+02	.1708E+02	.1108E+02	-.5223E+02	-.666E+02
4	.8919E+02	.1306E+02	.1091E+02	.1784E+02	.1695E+02	.1091E+02	-.5202E+02	-.666E+02
5	.8849E+02	.1306E+02	.1070E+02	.1974E+02	.1685E+02	.1070E+02	-.5175E+02	-.666E+02
6	.8765E+02	.1313E+02	.1046E+02	.2109E+02	.1665E+02	.1046E+02	-.5143E+02	-.666E+02
7	.8680E+02	.1313E+02	.1029E+02	.2266E+02	.1646E+02	.1055E+02	-.5116E+02	-.666E+02
8	.8529E+02	.1293E+02	.1018E+02	.2434E+02	.1617E+02	.1293E+02	-.5134E+02	-.666E+02
9	.8513E+02	.1261E+02	.1005E+02	.2616E+02	.1573E+02	.1261E+02	-.5106E+02	-.666E+02
10	.8106E+02	.1231E+02	.9921E+01	.2990E+02	.1531E+02	.1231E+02	-.5090E+02	-.666E+02
11	.7911E+02	.1203E+02	.9793E+01	.3373E+02	.1492E+02	.1203E+02	-.5073E+02	-.666E+02
12	.7724E+02	.1177E+02	.9668E+01	.3766E+02	.1453E+02	.1177E+02	-.5056E+02	-.666E+02
13	.7546E+02	.1151E+02	.9546E+01	.4170E+02	.1417E+02	.1151E+02	-.5039E+02	-.666E+02
14	.7375E+02	.1127E+02	.9428E+01	.4585E+02	.1382E+02	.1127E+02	-.5022E+02	-.666E+02
15	.7211E+02	.1104E+02	.9315E+01	.5010E+02	.1349E+02	.1104E+02	-.5005E+02	-.666E+02
16	.7055E+02	.1082E+02	.9205E+01	.5447E+02	.1317E+02	.1082E+02	-.4988E+02	-.666E+02
17	.6904E+02	.1061E+02	.9100E+01	.5896E+02	.1286E+02	.1061E+02	-.4971E+02	-.666E+02
18	.6756E+02	.1041E+02	.8999E+01	.6356E+02	.1256E+02	.1041E+02	-.4954E+02	-.666E+02
19	.6620E+02	.1021E+02	.8903E+01	.6828E+02	.1226E+02	.1021E+02	-.4937E+02	-.666E+02
20	.6506E+02	.1003E+02	.8840E+01	.7312E+02	.1205E+02	.1021E+02	-.4920E+02	-.666E+02
21	.6423E+02	.9884E+01	.8809E+01	.7808E+02	.1185E+02	.9884E+01	-.4903E+02	-.666E+02
22	.6350E+02	.9751E+01	.8785E+01	.8316E+02	.1173E+02	.9631E+01	-.4886E+02	-.666E+02
23	.6289E+02	.9637E+01	.8766E+01	.8836E+02	.1160E+02	.9366E+01	-.4869E+02	-.666E+02
24	.6239E+02	.9544E+01	.8756E+01	.9368E+02	.1150E+02	.9132E+01	-.4852E+02	-.666E+02
25	.6202E+02	.9473E+01	.8747E+01	.9912E+02	.1142E+02	.8945E+01	-.4835E+02	-.666E+02
26	.6177E+02	.9425E+01	.8742E+01	.1047E+02	.1137E+02	.8815E+01	-.4818E+02	-.666E+02
27	.6165E+02	.9400E+01	.8740E+01	.1103E+02	.1135E+02	.8748E+01	-.4801E+02	-.666E+02
28	.8765E+02	.1296E+02	.1064E+02	.1265E+02	.1656E+02	.1064E+02	-.5210E+02	-.666E+02
29	.8919E+02	.1280E+02	.1111E+02	.1370E+02	.1666E+02	.1111E+02	-.5225E+02	-.666E+02
30	.8919E+02	.1280E+02	.1111E+02	.1475E+02	.1666E+02	.1111E+02	-.5225E+02	-.666E+02
31	.8765E+02	.1296E+02	.1064E+02	.1580E+02	.1665E+02	.1064E+02	-.5210E+02	-.666E+02
32	.8310E+02	.1258E+02	.1008E+02	.1685E+02	.1573E+02	.1258E+02	-.5105E+02	-.666E+02
33	.7714E+02	.1174E+02	.9676E+01	.1790E+02	.1451E+02	.1174E+02	-.4970E+02	-.666E+02
34	.7195E+02	.1102E+02	.9311E+01	.1895E+02	.1346E+02	.1102E+02	-.4824E+02	-.666E+02
35	.6738E+02	.1038E+02	.8989E+01	.2000E+02	.1250E+02	.1038E+02	-.4678E+02	-.666E+02
36	.6385E+02	.9811E+01	.8805E+01	.2105E+02	.1180E+02	.9752E+01	-.4532E+02	-.666E+02
37	.6195E+02	.9458E+01	.8748E+01	.2210E+02	.1141E+02	.8872E+01	-.4386E+02	-.666E+02
38	.6195E+02	.9458E+01	.8748E+01	.2315E+02	.1141E+02	.8875E+01	-.4386E+02	-.666E+02
39	.6386E+02	.9811E+01	.8804E+01	.2420E+02	.1180E+02	.9756E+01	-.4240E+02	-.666E+02
40	.6738E+02	.1038E+02	.8988E+01	.2525E+02	.1250E+02	.1038E+02	-.4094E+02	-.666E+02
41	.7195E+02	.1102E+02	.9311E+01	.2630E+02	.1346E+02	.1102E+02	-.3948E+02	-.666E+02
42	.7714E+02	.1174E+02	.9676E+01	.2735E+02	.1451E+02	.1174E+02	-.3802E+02	-.666E+02
43	.8310E+02	.1258E+02	.1008E+02	.2840E+02	.1573E+02	.1258E+02	-.3656E+02	-.666E+02
44	.1690E+02	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00

45	.1690E+02	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
46	.1690E+02	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
47	.1690E+02	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
48	.1690E+02	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
49	.1690E+02	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
50	.1690E+02	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
51	.1690E+02	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
52	.1690E+02	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00
53	.1690E+02	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00	.0000E+00

TIME REQUIRED TO COMPUTE PRE-EXISTING STRESSES = 149.89 SECONDS.

TIME REQUIRED TO SOLVE EQUATIONS= 34.60 SECONDS.

BOUNDARY STRESSES AND DISPLACEMENTS AT TIME = .100E+02

ELM	X-COORD SIGXX	Y-COORD SIGYY	UX SIGXY	UY SIGZY	US SIGMA-S	UN SIGMA-N	SIGMA-T	TEMP
1	.1950E+00	-.3020E+03	-.7415E-04	-.1399E-01	-.7415E-04	-.1399E-01	.1052E+02	.9034E+02
2	.1052E+02	.3301E-05	.1914E-07	.1447E+02	.1914E-07	.3301E-05	.1111E+02	.9014E+02
3	.5850E+00	-.3020E+03	-.2162E-03	-.1389E-01	-.2162E-03	-.1389E-01	.1241E+02	.8975E+02
4	.1365E+01	-.3020E+03	-.4134E-03	-.1337E-01	-.4134E-03	-.1337E-01	.1481E+02	.8919E+02
5	.1755E+01	-.3020E+03	-.4154E-03	-.1290E-01	-.4154E-03	-.1290E-01	.1972E+02	.8648E+02
6	.2145E+01	-.3020E+03	-.2267E-03	-.1217E-01	-.2267E-03	-.1217E-01	.3624E+02	.8764E+02
7	.2390E+01	-.3020E+03	-.4949E-03	-.1135E-01	-.7665E-02	-.8364E-02	.8033E+02	.8680E+02
8	.2440E+01	-.3017E+03	.1493E-02	-.1078E-01	.1079E-01	-.1493E-02	.2983E+02	.8529E+02
9	.2440E+01	-.3013E+03	.2334E-02	-.1083E-01	.1063E-01	-.2334E-02	.1436E+02	.8313E+02
10	.2440E+01	-.3008E+03	.2866E-02	-.1103E-01	.1103E-01	-.2866E-02	.1020E+02	.8108E+02
11	.2440E+01	-.3004E+03	.3233E-02	-.1128E-01	.1128E-01	-.3233E-02	.8265E+01	.7911E+02
12	.2440E+01	-.3000E+03	.3477E-02	-.1155E-01	.1155E-01	-.3477E-02	.7273E+01	.7724E+02
13	.2440E+01	-.2996E+03	.3626E-02	-.1182E-01	.1182E-01	-.3626E-02	.6747E+01	.7546E+02
14	.2440E+01	-.2991E+03	.3692E-02	-.1209E-01	.1209E-01	-.3692E-02	.6562E+01	.7375E+02
15	.2440E+01	-.2987E+03	.3681E-02	-.1235E-01	.1235E-01	-.3681E-02	.6670E+01	.7211E+02
16	.2440E+01	-.2983E+03	.3597E-02	-.1260E-01	.1260E-01	-.3597E-02	.7110E+01	.7055E+02
17	.2440E+01	-.2978E+03	.3436E-02	-.1282E-01	.1282E-01	-.3436E-02	.8035E+01	.6904E+02
18	.2440E+01	-.2974E+03	.3189E-02	-.1299E-01	.1299E-01	-.3189E-02	.9940E+01	.6759E+02
19	.2440E+01	-.2970E+03	.2841E-02	-.1306E-01	.1306E-01	-.2841E-02	.1496E+02	.6620E+02
20	.2342E+01	-.2966E+03	.2450E-02	-.1296E-01	.1236E-01	.4566E-02	.2246E+02	.6508E+02
21	.2127E+01	-.2963E+03	.2161E-02	-.1290E-01	.1139E-01	.6422E-02	.2109E+02	.6423E+02
22	.1872E+01	-.2960E+03	.1867E-02	-.1266E-01	.1017E-01	.8096E-02	.2153E+02	.6350E+02
23	.1582E+01	-.2958E+03	.1556E-02	-.1284E-01	.8699E-02	.9569E-02	.2226E+02	.6289E+02
24	.1262E+01	-.2956E+03	.1226E-02	-.1282E-01	.7009E-02	.1080E-01	.2297E+02	.6239E+02
25	.9191E+00	-.2955E+03	.6879E-03	-.1280E-01	.5140E-02	.1176E-01	.2356E+02	.6202E+02
26	.5584E+00	-.2954E+03	.5366E-03	-.1279E-01	.3136E-02	.1241E-01	.2397E+02	.6177E+02
27	.1873E+00	-.2953E+03	.1796E-03	-.1278E-01	.1055E-02	.1274E-01	.2418E+02	.6165E+02
28	.3231E+02	-.3020E+03	.9140E-03	-.1264E-01	.9140E-03	-.1264E-01	.2710E+02	.8765E+02
29	.3353E+02	-.3020E+03	.8067E-03	-.1371E-01	.8067E-03	-.1371E-01	.1338E+02	.8918E+02
30	.3475E+02	-.3020E+03	.3869E-03	-.1371E-01	.3869E-03	-.1371E-01	.1342E+02	.8919E+02
31	.3597E+02	-.3020E+03	.2861E-03	-.1264E-01	.2861E-03	-.1264E-01	.2726E+02	.8765E+02

32	.3658E+02 .2878E-05	-.3013E+03 .2243E+02	.2747E-02 -.7951E-06	-.1078E-01 .1566E+02	-.1078E-01 .7951E-06	-.2747E-02 .2878E-05	.2243E+02	.8310E+02
33	.3658E+02 -.2106E-06	-.3000E+03 .8934E+01	.4044E-02 .3536E-05	-.1139E-01 .1202E+02	-.1139E-01 -.3536E-05	-.4044E-02 -.2106E-06	.8934E+01	.7714E+02
34	.3658E+02 .3636E-05	-.2967E+03 .7771E+01	.4324E-02 -.9592E-06	-.1219E-01 .1094E+02	-.1219E-01 .9592E-06	-.4324E-02 .3636E-05	.7771E+01	.7195E+02
35	.3658E+02 -.4770E-05	-.2974E+03 .1120E+02	.3923E-02 -.1325E-06	-.1280E-01 .1089E+02	-.1280E-01 .1325E-06	-.3923E-02 -.4770E-05	.1120E+02	.6739E+02
36	.3607E+02 .9590E+01	-.2962E+03 .1115E+02	.2870E-02 -.1034E+02	-.1276E-01 .1223E+02	-.1131E-01 -.2532E-05	.6574E-02 .3114E-05	.2074E+02	.6386E+02
37	.3485E+02 .2266E+02	-.2955E+03 .1795E+01	.1405E-02 -.6377E+01	-.1266E-01 .1266E+02	-.4782E-02 .4691E-06	.1181E-01 .1942E-05	.2446E+02	.6195E+02
38	.3342E+02 .2246E+02	-.2855E+03 .1780E+01	-.2060E-03 .6325E+01	-.1264E-01 .1223E+02	.3623E-02 -.1765E-05	.1211E-01 .2546E-05	.2426E+02	.6195E+02
39	.3220E+02 .9469E+01	-.2922E+03 .1101E+02	-.1648E-02 .1021E+02	-.1274E-01 .1217E+02	.1045E-01 -.2924E-05	.7440E-02 -.4370E-05	.2047E+02	.6386E+02
40	.3170E+02 -.6984E-05	-.2974E+03 .1130E+02	-.2679E-02 -.1306E-05	-.1276E-01 .1091E+02	.1276E-01 .1306E-05	-.2679E-02 -.6984E-05	.1130E+02	.6739E+02
41	.3170E+02 .1631E-05	-.2967E+03 .7916E+01	-.3075E-02 -.3264E-06	-.1216E-01 .1097E+02	.1216E-01 .3264E-06	-.3075E-02 .1631E-05	.7916E+01	.7195E+02
42	.3170E+02 .2890E-05	-.3000E+03 .9065E+01	-.2800E-02 .2094E-05	-.1136E-01 .1205E+02	.1136E-01 -.2094E-05	-.2800E-02 .2890E-05	.9085E+01	.7713E+02
43	.3170E+02 -.7647E-05	-.3013E+03 .2252E+02	-.1521E-02 .6910E-05	-.1076E-01 .1570E+02	.1076E-01 -.6910E-05	-.1521E-02 -.7647E-05	.2252E+02	.8310E+02
44	.5000E+02 .3466E-01	.0000E+00 -.1197E-07	.1235E-03 -.6733E-08	-.5821E-02 .6936E-02	.1235E-03 -.6733E-08	-.5821E-02 -.1197E-07	.3466E-01	.1690E+02
45	.1500E+03 .2439E-01	.0000E+00 .5036E-07	.3291E-03 .2180E-08	-.5956E-02 .4879E-02	.3291E-03 .2180E-08	-.5956E-02 .5036E-07	.2439E-01	.1690E+02
46	.2500E+03 .1202E-01	.0000E+00 -.4635E-08	.4461E-03 -.7309E-08	-.6159E-02 .2405E-02	.4461E-03 -.7309E-08	-.6159E-02 -.4635E-08	.1202E-01	.1690E+02
47	.3500E+03 .3378E-02	.0000E+00 -.1688E-08	.4893E-03 .7774E-08	-.6364E-02 .6756E-03	.4893E-03 .7774E-08	-.6364E-02 -.1688E-08	.3378E-02	.1650E+02
48	.4500E+03 -.1290E-02	.0000E+00 .3922E-08	.4900E-03 -.1842E-08	-.6543E-02 .2579E-03	.4900E-03 -.1842E-08	-.6543E-02 .3922E-08	-.1290E-02	.1690E+02
49	.5500E+03 -.3556E-02	.0000E+00 -.3056E-09	.4696E-03 .1824E-08	-.6693E-02 -.7112E-03	.4696E-03 .1824E-08	-.6693E-02 -.3056E-09	-.3556E-02	.1690E+02
50	.6500E+03 -.4644E-02	.0000E+00 .2925E-08	.4406E-03 .1023E-07	-.6819E-02 -.9266E-03	.4406E-03 .1023E-07	-.6819E-02 .2925E-08	-.4644E-02	.1690E+02
51	.7500E+03 -.5257E-02	.0000E+00 .6403E-09	.4065E-03 .1084E-08	-.6924E-02 -.1051E-02	.4065E-03 .1084E-08	-.6924E-02 .6403E-09	-.5257E-02	.1690E+02
52	.8500E+03 -.5812E-02	.0000E+00 -.1046E-08	.3696E-03 .3167E-08	-.7013E-02 -.1162E-02	.3696E-03 .3167E-08	-.7013E-02 -.1046E-08	-.5812E-02	.1690E+02
53	.9500E+03 -.6819E-02	.0000E+00 -.1879E-08	.3281E-03 .1359E-08	-.7087E-02 -.1364E-02	.3281E-03 .1359E-08	-.7087E-02 -.1879E-08	-.6819E-02	.1690E+02

TIME REQUIRED TO COMPUTE BOUNDARY STRESSES AND DISPLACEMENTS= 35.38 SECONDS.

INTERIOR STRESSES AND DISPLACEMENTS AT TIME = .100E+02

POINT	X-COORD SIGXX	Y-COORD SIGYY	UX SIGXY	UY SIGZZ	SIG1	SIG2	ALPHA	TEMP
1	.1950E+00 .1273E+02	-.3023E+03 .3971E+00	-.4072E-04 .2134E+00	-.1357E-01 .1533E+02	.1274E+02	.3935E+00	.9909E+00	.9243E+02
2	.1950E+00 .1613E+02	-.3022E+03 .1262E+01	-.9928E-05 .5390E+00	-.1291E-01 .1674E+02	.1615E+02	.1262E+01	.2076E+01	.9585E+02
3	.1950E+00 .1658E+02	-.3034E+03 .3714E+01	-.1631E-05 .7849E+00	-.1193E-01 .1867E+02	.1662E+02	.3672E+01	.3053E+01	.1016E+03
4	.1950E+00 .1955E+02	-.3044E+03 .7892E+01	-.3299E-04 .7817E+00	-.1052E-01 .2162E+02	.1960E+02	.7840E+01	.3819E+01	.1136E+03
5	.1950E+00 .2217E+02	-.3066E+03 .1524E+02	-.1101E-03 -.6932E-01	.8424E-02 .2646E+02	.2217E+02	.1324E+02	-.4450E+00	.1462E+03
6	.1950E+00 .1966E+02	-.3082E+03 .1511E+02	-.1244E-03 .7923E-01	.5335E-02 .2769E+02	.1966E+02	.1511E+02	.9556E+00	.1416E+03
7	.5850E+00 .1335E+02	-.3023E+03 .4353E+00	-.1149E-03 .6769E+00	-.1347E-01 .1542E+02	.1336E+02	.3999E+00	.2992E+01	.9220E+02
8	.5850E+00 .1661E+02	-.3022E+03 .1465E+01	-.2436E-04 .1689E+01	-.1281E-01 .1683E+02	.1680E+02	.1279E+01	.6284E+01	.9556E+02
9	.5850E+00 .1867E+02	-.3034E+03 .4055E+01	-.4239E-05 .2390E+01	-.1184E-01 .1869E+02	.1905E+02	.3674E+01	.9056E+01	.1013E+03
10	.5850E+00 .1949E+02	-.3044E+03 .7961E+01	-.9550E-04 .2234E+01	-.1046E-01 .2145E+02	.1991E+02	.7543E+01	.1059E+02	.1125E+03
11	.5850E+00 .2147E+02	-.3060E+03 .1174E+02	-.2780E-03 .1059E+01	-.8404E-02 .2623E+02	.2158E+02	.1162E+02	.6141E+01	.1350E+03
12	.5850E+00 .2010E+02	-.3082E+03 .1366E+02	-.3487E-03 .3064E-01	-.5333E-02 .2668E+02	.2010E+02	.1366E+02	.2820E+00	.1366E+03
13	.9750E+00	-.3023E+03	-.1630E-03	-.1326E-01				

	.1471E+02	.5468E+00	.1287E+01	.1565E+02	.1483E+02	.4308E+00	.5150E+01	.9171E+02
14	.9750E+00	-.3028E+03	-.2006E-04	-.1261E-01	.1815E+02	.1380E+01	.1079E+02	.9499E+02
	.1756E+02	.1968E+01	.3084E+01	.1703E+02				
15	.9750E+00	-.3034E+03	-.3666E-05	-.1166E-01	.1982E+02	.3792E+01	.1489E+02	.1005E+03
	.1876E+02	.4850E+01	.3980E+01	.1873E+02				
16	.9750E+00	-.3044E+03	-.1545E-03	-.1034E-01	.2026E+02	.7242E+01	.1585E+02	.1107E+03
	.1929E+02	.8213E+01	.3420E+01	.2115E+02				
17	.9750E+00	-.3060E+03	-.4117E-03	-.6351E-02	.2119E+02	.1066E+02	.1003E+02	.1271E+03
	.2087E+02	.1096E+02	.1806E+01	.2479E+02				
18	.9750E+00	-.3082E+03	-.5329E-03	-.5332E-02	.2006E+02	.1267E+02	-.4105E+00	.1305E+03
	.2006E+02	.1267E+02	-.5297E-01	.2542E+02				
19	.1365E+01	-.3023E+03	-.1633E-03	-.1294E-01	.1748E+02	.5486E+00	.7876E+01	.9111E+02
	.1715E+02	.6746E+00	.2326E+01	.1610E+02				
20	.1365E+01	-.3028E+03	.1058E-04	-.1228E-01	.2026E+02	.1755E+01	.1621E+02	.9420E+02
	.1882E+02	.3198E+01	.4961E+01	.1739E+02				
21	.1365E+01	-.3034E+03	-.4700E-05	-.1141E-01	.2070E+02	.4213E+01	.2069E+02	.9833E+02
	.1864E+02	.6272E+01	.5451E+01	.1881E+02				
22	.1365E+01	-.3044E+03	-.2124E-03	-.1018E-01	.2045E+02	.7163E+01	.1996E+02	.1084E+03
	.1890E+02	.8711E+01	.4263E+01	.2061E+02				
23	.1365E+01	-.3060E+03	-.5235E-03	-.8277E-02	.2084E+02	.9992E+01	.1249E+02	.1220E+03
	.2033E+02	.1050E+02	.2290E+01	.2366E+02				
24	.1365E+01	-.3082E+03	-.6837E-03	-.5333E-02	.1961E+02	.1174E+02	-.4069E+00	.1246E+03
	.1961E+02	.1174E+02	-.5735E-01	.2423E+02				
25	.1755E+01	-.3023E+03	-.8332E-04	-.1246E-01	.2245E+02	.1056E+01	.1320E+02	.9030E+02
	.2134E+02	.2172E+01	.4757E+01	.1706E+02				
26	.1755E+01	-.3026E+03	.6246E-04	-.1187E-01	.2293E+02	.2893E+01	.2365E+02	.9321E+02
	.1971E+02	.6116E+01	.7361E+01	.1800E+02				
27	.1755E+01	-.3034E+03	-.1811E-04	-.1111E-01	.2135E+02	.5136E+01	.2653E+02	.9795E+02
	.1811E+02	.8369E+01	.6477E+01	.1889E+02				
28	.1755E+01	-.3044E+03	-.2737E-03	-.9998E-02	.2039E+02	.7362E+01	.2322E+02	.1059E+03
	.1837E+02	.9356E+01	.4720E+01	.2044E+02				
29	.1755E+01	-.3060E+03	-.6197E-03	-.8190E-02	.2044E+02	.9552E+01	.1409E+02	.1171E+03
	.1979E+02	.1020E+02	.2572E+01	.2270E+02				
30	.1755E+01	-.3082E+03	-.8087E-03	-.5333E-02	.1948E+02	.1102E+02	-.9822E-01	.1193E+03
	.1948E+02	.1102E+02	-.1450E-01	.2316E+02				
31	.2145E+01	-.3023E+03	.9856E-04	-.1176E-01	.3112E+02	.4209E+01	.2699E+02	.8936E+02
	.2557E+02	.9753E+01	.1088E+02	.1927E+02				
32	.2145E+01	-.3026E+03	.9651E-04	-.1138E-01	.2467E+02	.5710E+01	.3359E+02	.9207E+02
	.1887E+02	.1152E+02	.6740E+01	.1872E+02				
33	.2145E+01	-.3034E+03	-.5641E-04	-.1080E-01	.2132E+02	.6605E+01	.3180E+02	.9641E+02
	.1724E+02	.1069E+02	.6593E+01	.1894E+02				
34	.2145E+01	-.3044E+03	-.3411E-03	-.9608E-02	.2006E+02	.7778E+01	.2556E+02	.1034E+03
	.1776E+02	.1007E+02	.4782E+01	.2005E+02				
35	.2145E+01	-.3060E+03	-.7044E-03	-.8097E-02	.1999E+02	.9280E+01	.1508E+02	.1127E+03
	.1926E+02	.1000E+02	.2690E+01	.2185E+02				
36	.2145E+01	-.3082E+03	-.9133E-03	-.5332E-02	.1912E+02	.1046E+02	.2980E+00	.1146E+03
	.1912E+02	.1046E+02	.4505E-01	.2222E+02				
37	.2602E+01	-.3022E+03	.2947E-03	-.1114E-01	.3081E+02	.1521E+02	.3846E+02	.8740E+02
	.2476E+02	.2125E+02	.7599E+01	.2110E+02				
38	.2920E+01	-.3025E+03	.1384E-03	-.1091E-01	.2210E+02	.1176E+02	.3408E+02	.8814E+02
	.1885E+02	.1501E+02	.4802E+01	.1876E+02				
39	.3396E+01	-.3030E+03	-.1046E-03	-.1049E-01	.1891E+02	.9768E+01	.2990E+02	.8867E+02
	.1664E+02	.1204E+02	.3952E+01	.1787E+02				
40	.4114E+01	-.3037E+03	-.4489E-03	-.9788E-02	.1746E+02	.8652E+01	.2440E+02	.8905E+02
	.1595E+02	.1016E+02	.3313E+01	.1738E+02				
41	.5188E+01	-.3047E+03	-.8599E-03	-.8674E-02	.1664E+02	.7911E+01	.1689E+02	.8749E+02
	.1590E+02	.8648E+01	.2427E+01	.1662E+02				
42	.6799E+01	-.3064E+03	-.1182E-02	-.7033E-02	.1565E+02	.7206E+01	.8088E+01	.8267E+02
	.1568E+02	.7377E+01	.1205E+01	.1575E+02				
43	.2740E+01	-.3017E+03	.1192E-02	-.1121E-01	.2776E+02	.3234E+01	.5987E+02	.8461E+02
	.9413E+01	.2156E+02	.1065E+02	.1764E+02				
44	.3190E+01	-.3017E+03	.9886E-03	-.1132E-01	.2244E+02	.4312E+01	.4880E+02	.8353E+02
	.1218E+02	.1458E+02	.8966E+01	.1662E+02				
45	.3865E+01	-.3017E+03	.7720E-03	-.1129E-01	.1865E+02	.4884E+01	.4469E+02	.8180E+02
	.1184E+02	.1165E+02	.6880E+01	.1569E+02				
46	.4878E+01	-.3017E+03	.4729E-03	-.1115E-01	.1597E+02	.5596E+01	.4211E+02	.7912E+02
	.1131E+02	.1026E+02	.5163E+01	.1487E+02				
47	.6396E+01	-.3017E+03	.1064E-03	-.1088E-01	.1392E+02	.6428E+01	.3729E+02	.7522E+02
	.1117E+02	.9177E+01	.3610E+01	.1399E+02				
48	.8674E+01	-.3017E+03	-.2923E-03	-.1055E-01	.1248E+02	.6896E+01	.2643E+02	.7016E+02
	.1137E+02	.8002E+01	.2225E+01	.1298E+02				
49	.2740E+01	-.3013E+03	.2014E-02	-.1120E-01	.1740E+02	.8298E+00	.7569E+02	.8454E+02
	.1843E+01	.1639E+02	.3969E+01	.1475E+02				
50	.3190E+01	-.3013E+03	.1615E-02	-.1145E-01	.1879E+02	.2039E+01	.6210E+02	.8159E+02
	.5708E+01	.1512E+02	.6926E+01	.1512E+02				
51	.3865E+01	-.3013E+03	.1201E-02	-.1151E-01	.1735E+02	.3580E+01	.5376E+02	.8006E+02
	.8399E+01	.1254E+02	.6566E+01	.1489E+02				

52	.4878E+01	-.3013E+03	.7539E-03	-.1123E-01	.1531E+02	.5040E+01	.4600E+02	.7764E+02
	.9337E+01	.1062E+02	.5600E+01	.1439E+02				
53	.6396E+01	-.3013E+03	.2793E-03	-.1114E-01	.1342E+02	.6337E+01	.4264E+02	.7401E+02
	.1024E+02	.8513E+01	.3124E+01	.1269E+02				
54	.8674E+01	-.3013E+03	.1060E-03	-.1082E-01	.1208E+02	.6092E+01	.2095E+02	.6835E+02
	.1090E+02	.8166E+01	.2156E+01	.1276E+02				
55	.2740E+01	-.3008E+03	.2560E-02	-.1130E-01	.1253E+02	.4276E+00	.8156E+02	.8050E+02
	.6674E+00	.1227E+02	.1754E+01	.1388E+02				
56	.3190E+01	-.3008E+03	.2133E-02	-.1156E-01	.1523E+02	.1170E+01	.7111E+02	.7073E+02
	.2843E+01	.1375E+02	.4302E+01	.1393E+02				
57	.3865E+01	-.3008E+03	.1604E-02	-.1167E-01	.1567E+02	.2727E+01	.6210E+02	.7637E+02
	.5561E+01	.1284E+02	.5353E+01	.1411E+02				
58	.4878E+01	-.3008E+03	.1026E-02	-.1160E-01	.1451E+02	.4610E+01	.5534E+02	.7670E+02
	.7812E+01	.1131E+02	.4630E+01	.1390E+02				
59	.6396E+01	-.3008E+03	.4544E-03	-.1134E-01	.1289E+02	.6278E+01	.4719E+02	.7293E+02
	.8331E+01	.8835E+01	.3295E+01	.1339E+02				
60	.8674E+01	-.3008E+03	.1038E-03	-.1108E-01	.1168E+02	.7101E+01	.3158E+02	.6852E+02
	.1043E+02	.8558E+01	.2045E+01	.1260E+02				
61	.2740E+01	-.3004E+03	.2945E-02	-.1147E-01	.1014E+02	.2972E+00	.8468E+02	.7866E+02
	.3818E+00	.1005E+02	.8082E+00	.1258E+02				
62	.3190E+01	-.3004E+03	.2515E-02	-.1168E-01	.1278E+02	.8309E+00	.7720E+02	.7793E+02
	.1417E+01	.1220E+02	.2581E+01	.1368E+02				
63	.3865E+01	-.3004E+03	.1838E-02	-.1161E-01	.1411E+02	.2230E+01	.6833E+02	.7672E+02
	.3710E+01	.1263E+02	.3923E+01	.1343E+02				
64	.4878E+01	-.3004E+03	.1269E-02	-.1171E-01	.1368E+02	.4282E+01	.6210E+02	.7477E+02
	.6347E+01	.1162E+02	.3881E+01	.1344E+02				
65	.6396E+01	-.3004E+03	.5877E-03	-.1160E-01	.1234E+02	.6253E+01	.5273E+02	.7174E+02
	.8466E+01	.1011E+02	.2834E+01	.1306E+02				
66	.8674E+01	-.3004E+03	.1824E-04	-.1132E-01	.1127E+02	.7224E+01	.3434E+02	.6767E+02
	.9984E+01	.8512E+01	.1885E+01	.1240E+02				
67	.2740E+01	-.3000E+03	.3200E-02	-.1166E-01	.8643E+01	.2354E+00	.8679E+02	.7685E+02
	.2623E+00	.8816E+01	.4607E+00	.1200E+02				
68	.3190E+01	-.3000E+03	.2781E-02	-.1163E-01	.1124E+02	.6798E+00	.8177E+02	.7620E+02
	.8864E+00	.1103E+02	.1487E+01	.1244E+02				
69	.3865E+01	-.3000E+03	.2183E-02	-.1194E-01	.1287E+02	.1955E+01	.7562E+02	.7512E+02
	.2628E+01	.1219E+02	.2625E+01	.1267E+02				
70	.4878E+01	-.3000E+03	.1469E-02	-.1194E-01	.1291E+02	.4084E+01	.6879E+02	.7330E+02
	.5239E+01	.1175E+02	.2975E+01	.1302E+02				
71	.6396E+01	-.3000E+03	.7300E-03	-.1178E-01	.1181E+02	.6260E+01	.5868E+02	.7063E+02
	.7760E+01	.1031E+02	.2484E+01	.1279E+02				
72	.8674E+01	-.3000E+03	.5802E-04	-.1155E-01	.1080E+02	.7356E+01	.3723E+02	.6681E+02
	.9577E+01	.8639E+01	.1666E+01	.1220E+02				
73	.2740E+01	-.2996E+03	.3357E-02	-.1168E-01	.8156E+01	.2017E+00	.8853E+02	.7511E+02
	.2070E+00	.8151E+01	.2041E+00	.1157E+02				
74	.3190E+01	-.2996E+03	.2950E-02	-.1199E-01	.1033E+02	.6096E+00	.8558E+02	.7453E+02
	.6672E+00	.1027E+02	.7461E+00	.1200E+02				
75	.3865E+01	-.2996E+03	.2364E-02	-.1207E-01	.1199E+02	.1817E+01	.8132E+02	.7356E+02
	.2049E+01	.1176E+02	.1518E+01	.1241E+02				
76	.4878E+01	-.2996E+03	.1618E-02	-.1208E-01	.1226E+02	.3970E+01	.7541E+02	.7198E+02
	.4496E+01	.1173E+02	.2020E+01	.1264E+02				
77	.6396E+01	-.2996E+03	.8373E-03	-.1198E-01	.1132E+02	.6292E+01	.6501E+02	.6946E+02
	.7166E+01	.1042E+02	.1922E+01	.1251E+02				
78	.8674E+01	-.2996E+03	.1263E-03	-.1177E-01	.1045E+02	.7500E+01	.4026E+02	.6593E+02
	.9218E+01	.8734E+01	.1456E+01	.1201E+02				
79	.2740E+01	-.2991E+03	.3430E-02	-.1211E-01	.7883E+01	.1850E+00	-.8989E+02	.7344E+02
	.1850E+00	.7883E+01	-.1429E+01	.1124E+02				
80	.3190E+01	-.2991E+03	.3033E-02	-.1215E-01	.9886E+01	.5865E+00	.8910E+02	.7292E+02
	.5866E+00	.9884E+01	.1456E+00	.1164E+02				
81	.3865E+01	-.2991E+03	.2459E-02	-.1219E-01	.1145E+02	.1776E+01	.8672E+02	.7206E+02
	.1807E+01	.1142E+02	.5521E+00	.1205E+02				
82	.4878E+01	-.2991E+03	.1713E-02	-.1221E-01	.1176E+02	.3937E+01	.8201E+02	.7063E+02
	.4086E+01	.1161E+02	.1076E+01	.1232E+02				
83	.6396E+01	-.2991E+03	.9166E-03	-.1215E-01	.1089E+02	.6342E+01	.7189E+02	.6834E+02
	.6781E+01	.1045E+02	.1342E+01	.1225E+02				
84	.8674E+01	-.2991E+03	.1822E-03	-.1198E-01	.1006E+02	.7646E+01	.4356E+02	.6505E+02
	.8913E+01	.8791E+01	.1204E+01	.1182E+02				
85	.2740E+01	-.2987E+03	.3425E-02	-.1233E-01	.7962E+01	.1818E+00	-.8826E+02	.7184E+02
	.1890E+00	.7855E+01	-.2356E+00	.1100E+02				
86	.3190E+01	-.2987E+03	.3038E-02	-.1231E-01	.9830E+01	.6043E+00	-.8730E+02	.7137E+02
	.6239E+00	.9810E+01	-.4246E+00	.1136E+02				
87	.3865E+01	-.2987E+03	.2480E-02	-.1232E-01	.1121E+02	.1819E+01	-.8790E+02	.7060E+02
	.1831E+01	.1120E+02	-.3442E+00	.1176E+02				
88	.4878E+01	-.2987E+03	.1754E-02	-.1234E-01	.1141E+02	.3970E+01	.8883E+02	.6830E+02
	.3880E+01	.1140E+02	.1776E+00	.1204E+02				
89	.6396E+01	-.2987E+03	.9666E-03	-.1211E-01	.1053E+02	.6401E+01	.7910E+02	.6721E+02
	.6547E+01	.1038E+02	.7622E+00	.1201E+02				
90	.8674E+01	-.2987E+03	.2261E-03	-.1219E-01	.9884E+01	.7793E+01	.4718E+02	.6417E+02
	.8667E+01	.8811E+01	-.8426E+00	.1163E+02				

91	.2740E+01	-.2981E+03	.3344E+02	-.1253E-01	.8419E+01	.1964E+00	-.8642E+02	.7030E+02
	.2285E+00	.8387E+01	-.9128E+00	.1065E+02				
92	.3190E+01	-.2982E+03	.2967E+02	-.1247E-01	.1014E+02	.6766E+00	-.8347E+02	.6988E+02
	.7982E+00	.1062E+02	-.1070E+01	.1122E+02				
93	.3865E+01	-.2983E+03	.2432E+02	-.1244E-01	.1122E+02	.1955E+01	-.8231E+02	.6919E+02
	.2121E+01	.1106E+02	-.1222E+01	.1136E+02				
94	.4876E+01	-.2983E+03	.1743E+02	-.1246E-01	.1119E+02	.4083E+01	-.8472E+02	.6801E+02
	.4143E+01	.1117E+02	-.6510E+00	.1181E+02				
95	.6396E+01	-.2983E+03	.9677E+03	-.1247E-01	.1025E+02	.6481E+01	.8078E+02	.6610E+02
	.6473E+01	.1023E+02	.2122E+00	.1179E+02				
96	.8674E+01	-.2983E+03	.2576E+03	-.1238E-01	.9330E+01	.7938E+01	.5145E+02	.6328E+02
	.8480E+01	.8792E+01	.6824E+00	.1144E+02				
97	.2740E+01	-.2977E+03	.3186E+02	-.1270E-01	.9390E+01	.2460E+00	-.8395E+02	.6862E+02
	.3478E+00	.9260E+01	-.9300E+00	.1081E+02				
98	.3190E+01	-.2976E+03	.2820E+02	-.1260E-01	.1085E+02	.8493E+00	-.7879E+02	.6845E+02
	.1227E+01	.1047E+02	-.1906E+01	.1116E+02				
99	.3865E+01	-.2974E+03	.2319E+02	-.1257E-01	.1144E+02	.2213E+01	-.7634E+02	.6782E+02
	.2728E+01	.1092E+02	-.2118E+01	.1145E+02				
100	.4876E+01	-.2974E+03	.1666E+02	-.1259E-01	.1109E+02	.4257E+01	-.7805E+02	.6671E+02
	.4550E+01	.1079E+02	-.1383E+01	.1162E+02				
101	.6396E+01	-.2974E+03	.9816E+03	-.1262E-01	.1004E+02	.6516E+01	-.8541E+02	.6500E+02
	.6539E+01	.1002E+02	-.2812E+00	.1156E+02				
102	.8674E+01	-.2974E+03	.2773E+03	-.1258E-01	.9020E+01	.8068E+01	.5714E+02	.6239E+02
	.8348E+01	.8740E+01	.4336E+00	.1126E+02				
103	.2740E+01	-.2974E+03	.2940E+02	-.1283E-01	.1119E+02	.4108E+00	-.7990E+02	.6739E+02
	.7384E+00	.1066E+02	-.1851E+01	.1097E+02				
104	.3190E+01	-.2974E+03	.2585E+02	-.1272E-01	.1191E+02	.1234E+01	-.7276E+02	.6706E+02
	.2173E+01	.1097E+02	-.3023E+01	.1123E+02				
105	.3865E+01	-.2974E+03	.2149E+02	-.1266E-01	.1177E+02	.2625E+01	-.6989E+02	.6649E+02
	.3706E+01	.1068E+02	-.2952E+01	.1136E+02				
106	.4876E+01	-.2974E+03	.1589E+02	-.1273E-01	.1105E+02	.4492E+01	-.7143E+02	.6552E+02
	.5157E+01	.1036E+02	-.1878E+01	.1146E+02				
107	.6396E+01	-.2974E+03	.9521E+03	-.1276E-01	.9906E+01	.8564E+01	-.7760E+02	.6392E+02
	.6717E+01	.9756E+01	-.6979E+00	.1136E+02				
108	.8674E+01	-.2974E+03	.2855E+03	-.1277E-01	.8745E+01	.8179E+01	.6678E+02	.6150E+02
	.8267E+01	.8657E+01	.2049E+00	.1106E+02				
109	.2740E+01	-.2970E+03	.2593E+02	-.1291E-01	.1414E+02	.9976E+00	-.7241E+02	.6602E+02
	.2198E+01	.1294E+02	-.3785E+01	.1146E+02				
110	.3190E+01	-.2970E+03	.2300E+02	-.1283E-01	.1305E+02	.2004E+01	-.6513E+02	.6572E+02
	.3957E+01	.1110E+02	-.4215E+01	.1136E+02				
111	.3865E+01	-.2970E+03	.1935E+02	-.1282E-01	.1208E+02	.3198E+01	-.6317E+02	.6520E+02
	.5008E+01	.1027E+02	-.3577E+01	.1135E+02				
112	.4876E+01	-.2970E+03	.1463E+02	-.1286E-01	.1104E+02	.4775E+01	-.6498E+02	.6432E+02
	.5696E+01	.9920E+01	-.2402E+01	.1132E+02				
113	.6396E+01	-.2970E+03	.9028E+03	-.1294E-01	.9825E+01	.8608E+01	-.7022E+02	.6280E+02
	.6974E+01	.9457E+01	-.1025E+01	.1120E+02				
114	.8674E+01	-.2970E+03	.2832E+03	-.1295E-01	.8550E+01	.8227E+01	.8948E+02	.6062E+02
	.8227E+01	.8550E+01	.2945E+02	.1081E+02				
115	.2599E+01	-.2965E+03	.2136E+02	-.1299E-01	.1727E+02	.2281E+01	-.5875E+02	.6447E+02
	.6315E+01	.1324E+02	-.6646E+01	.1209E+02				
116	.2984E+01	-.2962E+03	.1763E+02	-.1306E-01	.1452E+02	.3590E+01	-.5249E+02	.6356E+02
	.7642E+01	.1047E+02	-.5280E+01	.1165E+02				
117	.3562E+01	-.2958E+03	.1390E+02	-.1323E-01	.1278E+02	.4628E+01	-.4701E+02	.6223E+02
	.8419E+01	.8890E+01	-.4066E+01	.1130E+02				
118	.4430E+01	-.2954E+03	.9688E+03	-.1351E-01	.1131E+02	.5662E+01	-.4268E+02	.6031E+02
	.8715E+01	.8258E+01	-.2815E+01	.1090E+02				
119	.5731E+01	-.2946E+03	.5531E+03	-.1392E-01	.9875E+01	.6583E+01	-.3797E+02	.5761E+02
	.8690E+01	.7867E+01	-.1645E+01	.1038E+02				
120	.7682E+01	-.2934E+03	.3402E+03	-.1448E-01	.8872E+01	.7125E+01	-.2853E+02	.5403E+02
	.8474E+01	.7523E+01	-.7392E+00	.9685E+01				
121	.2360E+01	-.2961E+03	.1877E+02	-.1392E-01	.1841E+02	.1893E+01	-.5026E+02	.6356E+02
	.8644E+01	.1100E+02	-.8119E+01	.1209E+02				
122	.2710E+01	-.2958E+03	.1540E+02	-.1316E-01	.1544E+02	.3757E+01	-.4623E+02	.6257E+02
	.9346E+01	.9848E+01	-.5835E+01	.1171E+02				
123	.3236E+01	-.2954E+03	.1175E+02	-.1342E-01	.1323E+02	.4992E+01	-.4077E+02	.6113E+02
	.8715E+01	.8503E+01	-.4072E+01	.1126E+02				
124	.4023E+01	-.2948E+03	.7949E+03	-.1370E-01	.1151E+02	.5921E+01	-.3568E+02	.5906E+02
	.9600E+01	.7822E+01	-.2646E+01	.1079E+02				
125	.5205E+01	-.2936E+03	.4379E+03	-.1424E-01	.1000E+02	.6837E+01	-.3082E+02	.5819E+02
	.9173E+01	.7523E+01	-.1501E+01	.1017E+02				
126	.6977E+01	-.2924E+03	.8508E+04	-.1487E-01	.8862E+01	.7029E+01	-.2329E+02	.5240E+02
	.8576E+01	.7315E+01	-.6659E+00	.9368E+01				
127	.2078E+01	-.2958E+03	.1607E+02	-.1304E-01	.1910E+02	.3765E+01	-.4190E+02	.6278E+02
	.1137E+02	.9497E+01	-.8619E+01	.1208E+02				
128	.2386E+01	-.2955E+03	.1301E+02	-.1328E-01	.1616E+02	.3741E+01	-.3906E+02	.6171E+02
	.1124E+02	.8680E+01	-.6086E+01	.1171E+02				
129	.2848E+01	-.2950E+03	.9702E+03	-.1359E-01				

	.1093E+02	.7924E+01	-.3954E+01	.1125E+02	.1366E+02	.5197E+01	-.3458E+02	.8017E+02
130	.3541E+01	-.2943E+03	.8350E-03	-.1400E-01	.1168E+02	.6147E+01	-.2951E+02	.5799E+02
	.1034E+02	.7491E+01	-.2374E+01	.1069E+02				
131	.4581E+01	-.2932E+03	.3110E-03	-.1454E-01	.1010E+02	.6747E+01	-.2437E+02	.5497E+02
	.9531E+01	.7318E+01	-.1261E+01	.1001E+02				
132	.6142E+01	-.2915E+03	.3662E-04	-.1523E-01	.8793E+01	.7033E+01	-.1828E+02	.5099E+02
	.8820E+01	.7207E+01	-.5241E+00	.9156E+01				
133	.1756E+01	-.2956E+03	.1327E-02	-.1307E-01	.1974E+02	.1775E+01	-.3457E+02	.6212E+02
	.1412E+02	.7402E+01	-.8333E+01	.1210E+02				
134	.2016E+01	-.2952E+03	.1081E-02	-.1336E-01	.1675E+02	.3773E+01	-.3175E+02	.6100E+02
	.1315E+02	.7384E+01	-.5805E+01	.1172E+02				
135	.2407E+01	-.2946E+03	.7756E-03	-.1374E-01	.1403E+02	.5335E+01	-.2825E+02	.5938E+02
	.1208E+02	.7283E+01	-.3625E+01	.1123E+02				
136	.2993E+01	-.2938E+03	.4902E-03	-.1421E-01	.1184E+02	.6337E+01	-.2378E+02	.5709E+02
	.1094E+02	.7231E+01	-.2030E+01	.1062E+02				
137	.3872E+01	-.2922E+03	.2208E-03	-.1481E-01	.1011E+02	.6887E+01	-.1892E+02	.5395E+02
	.9768E+01	.7225E+01	-.9878E+00	.9870E+01				
138	.5180E+01	-.2907E+03	.1255E-05	-.1555E-01	.8689E+01	.7103E+01	-.1351E+02	.4981E+02
	.8803E+01	.7189E+01	-.3604E+00	.8957E+01				
139	.1401E+01	-.2953E+03	.1039E-02	-.1309E-01	.2032E+02	.1819E+01	-.2637E+02	.6159E+02
	.1667E+02	.5467E+01	-.7360E+01	.1214E+02				
140	.1609E+01	-.2949E+03	.8218E-03	-.1344E-01	.1719E+02	.3841E+01	-.2455E+02	.6042E+02
	.1469E+02	.6145E+01	-.5044E+01	.1173E+02				
141	.1921E+01	-.2943E+03	.5902E-03	-.1386E-01	.1432E+02	.5453E+01	-.2188E+02	.5874E+02
	.1309E+02	.6685E+01	-.3067E+01	.1120E+02				
142	.2388E+01	-.2934E+03	.3610E-03	-.1438E-01	.1195E+02	.6496E+01	-.1828E+02	.5637E+02
	.1142E+02	.7033E+01	-.1626E+01	.1055E+02				
143	.3090E+01	-.2921E+03	.1478E-03	-.1503E-01	.1009E+02	.7031E+01	-.1405E+02	.5313E+02
	.9909E+01	.7211E+01	-.7204E+00	.9762E+01				
144	.4142E+01	-.2901E+03	-.3915E-04	-.1582E-01	.8574E+01	.7202E+01	-.9081E+01	.4886E+02
	.8540E+01	.7236E+01	-.7138E+00	.8800E+01				
145	.1020E+01	-.2952E+03	.7465E-03	-.1311E-01	.2076E+02	.1863E+01	-.1880E+02	.6119E+02
	.1882E+02	.3827E+01	-.5770E+01	.1217E+02				
146	.1171E+01	-.2947E+03	.5851E-03	-.1349E-01	.1753E+02	.3915E+01	-.1746E+02	.5999E+02
	.1630E+02	.5141E+01	-.3897E+01	.1174E+02				
147	.1398E+01	-.2941E+03	.4144E-03	-.1396E-01	.1453E+02	.5555E+01	-.1556E+02	.5826E+02
	.1389E+02	.8201E+01	-.2321E+01	.1119E+02				
148	.1739E+01	-.2932E+03	.2459E-03	-.1452E-01	.1204E+02	.6825E+01	-.1294E+02	.5583E+02
	.1177E+02	.6896E+01	-.1181E+01	.1051E+02				
149	.2249E+01	-.2917E+03	.9156E-04	-.1520E-01	.1006E+02	.7160E+01	-.9646E+01	.5251E+02
	.9980E+01	.7241E+01	-.4794E+00	.9682E+01				
150	.3015E+01	-.2896E+03	-.4208E-04	-.1602E-01	.8465E+01	.7305E+01	-.5289E+01	.4816E+02
	.8455E+01	.7315E+01	-.1064E+00	.8684E+01				
151	.6197E+00	-.2951E+03	.4493E-03	-.1312E-01	.2110E+02	.1896E+01	-.1127E+02	.6093E+02
	.2037E+02	.2631E+01	-.3680E+01	.1220E+02				
152	.7117E+00	-.2946E+03	.3499E-03	-.1353E-01	.1775E+02	.3973E+01	-.1045E+02	.5970E+02
	.1730E+02	.4427E+01	-.2459E+01	.1175E+02				
153	.8496E+00	-.2940E+03	.2453E-03	-.1403E-01	.1467E+02	.5631E+01	-.9307E+01	.5794E+02
	.1444E+02	.5866E+01	-.1443E+01	.1116E+02				
154	.1056E+01	-.2930E+03	.1430E-03	-.1462E-01	.1209E+02	.6718E+01	-.7712E+01	.5547E+02
	.1199E+02	.6814E+01	-.7143E+00	.1048E+02				
155	.1387E+01	-.2915E+03	.4949E-04	-.1532E-01	.1004E+02	.7255E+01	-.5613E+01	.5210E+02
	.1001E+02	.7282E+01	-.2706E+00	.9629E+01				
156	.1832E+01	-.2893E+03	-.3082E-04	-.1616E-01	.8381E+01	.7389E+01	-.2436E+01	.4769E+02
	.8379E+01	.7391E+01	-.4211E-01	.8606E+01				
157	.2079E+00	-.2950E+03	.1500E-03	-.1313E-01	.2127E+02	.1816E+01	-.3754E+01	.6080E+02
	.2119E+02	.1999E+01	-.1264E+01	.1222E+02				
158	.2387E+00	-.2946E+03	.1164E-03	-.1355E-01	.1787E+02	.4005E+01	-.3481E+01	.5956E+02
	.1782E+02	.4056E+01	-.8401E+00	.1176E+02				
159	.2849E+00	-.2939E+03	.8117E-04	-.1407E-01	.1474E+02	.5672E+01	-.3097E+01	.5778E+02
	.1472E+02	.5699E+01	-.4893E+00	.1118E+02				
160	.3543E+00	-.2929E+03	.4678E-04	-.1467E-01	.1211E+02	.6766E+01	-.2561E+01	.5529E+02
	.1210E+02	.6777E+01	-.2387E+00	.1046E+02				
161	.4584E+00	-.2914E+03	.1547E-04	-.1538E-01	.1002E+02	.7307E+01	-.1839E+01	.5190E+02
	.1002E+02	.7310E+01	-.8702E-01	.9603E+01				
162	.6144E+00	-.2891E+03	-.1133E-04	-.1623E-01	.8334E+01	.7436E+01	-.6420E+00	.4745E+02
	.8334E+01	.7436E+01	-.1007E-01	.8570E+01				

TIME REQUIRED TO COMPUTE STRESSES AND DISPLACEMENTS AT STRESS POINTS= 652.35 SECONDS.

JOB COMPLETED AT 7: 7 HOURS

DATA FOR PLOTTING WILL BE STORED IN FILE NAMED VERT10

APPENDIX C

Description of the POSTHEF Code for
Postprocessing Results of HEFF Analyses

DESCRIPTION OF THE POSTHEF CODE FOR
POST-PROCESSING RESULTS OF HEFF ANALYSES

POSTHEF is a special purpose post-processor intended to plot output from a run of HEFF, during which the output has been generated for a single time step. On-screen graphics are generated using the HALO Graphics Perimitives (Media Cybernetics, 800-446-HALO), and plots are generated by performing screen dumps using the HALO instruction GPRINT. POSTHEF also uses one routine coded in PASCAL. This reads data directly from the keyboard, allowing the user to determine whether or not the graphics image generated on the screen is to be plotted.

The use of POSTHEF is almost entirely self-explanatory since the program interrogates the user. However, the following notes may be helpful.

1) Plot options offered are:

- Factors of Safety
- Temperature Contours
- Deformed Boundary
- Boundary (or Tangential) Stress
- Principal Stress Vectors
- Stress Contours
- Extensile Strain

- 2) For the factor of safety plots, the strength of the rock matrix has been defined using a Mohr-Coulomb failure criterion. Specifically, if the computed major and minor principal stresses at a point are S1 and S3, respectively, the factor of safety against matrix failure is defined as:

$$FSM = \frac{(S1+S3) \sin FM + Q (1-\sin FM)}{(S1-S3)}; \quad S3 > \text{tensile strength} \quad (1)$$

$$FSM = 0 \text{ for } S3 \leq \text{tensile strength} \quad (2)$$

in which Q and FM are, respectively, the uniaxial compressive strength and the friction angle for the matrix of the rock mass. S1 and S3 are the major

Note that the user of POSTHEF can force the code to assume that the out-of-plane stress is always intermediate. To select this option, enter "N" when requested whether out-of-plane stresses are to be considered.

The shear strength of preexisting joints is defined by a Coulomb-Navier criterion. Specifically, if SS and SN are the computed shear and normal stresses on a plane of a given orientation, the factor of safety against slip is defined as:

$$FSJ = \frac{CJ + SN \tan FJ}{SS} : SN \geq 0 \quad (3)$$

$$FSJ = 0.0 \quad SN < 0 \quad (4)$$

in which CJ and FJ are, respectively, the cohesion and friction angle of the joint. Since joints do not usually possess any strength in tension, the factor of safety is assumed to be zero if the normal stress, SN, is tensile.

The joint can be oriented in any direction relative to the plane of the analysis. Accordingly, general transformation equations are required to calculate the shear and normal stresses. If we assume that the orientation of the joint plane relative to the plane of the analysis is defined by the angles (L) and (T), then the direction cosines or mutually perpendicular axes in the joint plane and normal to it are (Jaeger and Cook, 1976):

$$\begin{array}{lll} L_1 = \cos(T)\cos(L-A) & M_1 = \cos(T)\sin(L-A) & N_1 = -\sin(T) \\ L_2 = -\sin(L-A) & M_2 = \cos(L-A) & N_2 = 0 \\ L_3 = \sin(T)\cos(L-A) & M_3 = \sin(T)\sin(L-A) & N_3 = \cos(T) \end{array}$$

L and T are defined by Figure 2.5 of Jaeger and Cook, which is reproduced as Figure 1. (L is the orientation of the trace of the

(a) Orientation of Principal Stress in the Plane of the Drift Section

(b) Definition of the Local Coordinate Axes for the Joint Planes

Figure 1

normal to the joint plane in the xy plane, relative to the x axis, and T is the orientation of the normal relative to the z axis. Hence, for a joint that is vertical and perpendicular to the plane of the section, L = 0 and T = 90 degrees.) A is the orientation of the most compressive principal stress in the plane of the analysis, measured relative to the x axis.

The normal and maximum shear stress on the joint plane are now given by (Jaeger and Cook, 1976):

$$SN = L_3^2 S1' + M_3^2 S2' + N_3^2 S3'$$

$$SS = \text{SQRT}((L_2 L_3 S1' + M_2 M_3 S2' + N_2 N_3 S3')^2 + (L_3 L_1 S1' + M_3 M_1 S2' + N_3 N_1 S3')^2)$$

in which the S1' and S2' are the in-plane principal stresses and S3' is the out-of-plane stress, SZZ.

Note that the code calculates the factor of safety using either the matrix criterion or the joint criterion or both and selects the lesser of the two on a point by point basis, for contouring.

- 3) For the extensile strain plots, the extensile strain is defined as

$$\epsilon_3 = 100 \left[S_3 - \nu (S_1 + S_2) \right] / \text{EMOD}$$

where EMOD is the Poisson ratio ν of the rock mass, S_1 , S_2 , and S_3 are the principal stresses, and the extensile strain ϵ_3 is expressed as a percentage. Both EMOD and ν are input following screen requests.

- 4) POSTHEF will only function correctly for data points generated normal to a sequence of boundary elements that define a continuous, and ordered, contour. The user may elect to plot data for fewer than the total number of elements along which output was generated using HEFF. In that case, data at the end of the records generated by HEFF is discarded. Hence, when setting up the data for the HEFF analysis, the user must take care in ordering the boundary elements, and ensure that the elements for which plotting is to be performed are defined first.

- 5) The program asks for the name of the output file. This will contain an echo of the data processed and output from the calculation of factor of safety, if performed.
- 6) Once a plot has been generated on the screen, the user has two choices; press "P," in which case the contents of the screen are redrawn and copied to the printer, or press return or space if additional plots are required. Any other keyboard entry will cause the bell to ring. Note: there is no user prompt to act as a reminder that a keyboard entry is required.
- 7) When creating an executable version of POSTHEF, it is necessary to use compatible versions of FORTRAN, PASCAL, and HALO. The current version of POSTHEF is written for Microsoft 3.3 Fortran, so the code should be linked with the Microsoft Pascal Library and the Microsoft compatible version of HALO. As of this date, the most recent version of HALO is version 2.26.

To create an executable file POSTHEF.EXE from the compiled source codes (source.OBJ), type:

```
\path\LINK @POSTHEF.LNK,,, \path\8087 \path\FORTRAN \path\PASCAL \ path\HALOF
```

where \path\ is the DOS path to the LINK program or libraries, and the file POSTHEF.LNK looks like this:

```
POSTHEF + UTILG + UTILP + UTILC + \path\HALODVXX + \path\TOOL
```

HALODVXX is the HALO graphics object file, and TOOL is the PASCAL routine for getting a character from the keyboard while in graphics mode. For example, if the program LINK.EXE and PASCAL module TOOL.OBJ are in directory c:\comp3\, along with the libraries 8087.LIB, FORTRAN.LIB and PASCAL.LIB, and if the HALO library HALOF.LIB and object file HALODVXX.OBJ are in directory c:\HALO\, then file POSTHEF.LNK would be:

```
POSTHEF + UTILG + UTILP + UTILC + \HALO\HALODVXX + \comp3\TOOL
```

and the LINK command line would be:

```
\comp3\LINK @POSTHEF,,, \comp3\8087 \comp3\FORTRAN \comp3\PASCAL \HALO\ HALOF
```

- 8) At run time, POSTHEF requires that a file called DEVICE exists in the current directory. Lines 1 and 2 of this file must contain the name of the HALO graphics card driver and printer driver file names, respectively. The path to these device drivers must also be present unless they reside in the current directory. Line 3 contains the X RANGE and Y RANGE parameters for the screen and printer being used. Line 4 contains the HALO mode number and two color numbers for plotting on an EGA monitor. The following is an example of the file DEVICE for plotting on a HERCULES monographics monitor and printing to an HP Laserjet:

```
$haloherc.dev$  
$halolasr.prn$  
8.307,6.100,7.00,3.34  
1,1,1
```

The first two numbers on line 3 are used to plot undistorted on the screen, and the second two are used for undistorted printer plots. These four numbers may need to be adjusted when using other graphics cards and printers. POSTHEF will tell the user if any syntax errors occur in file DEVICE at run time.

APPENDIX D
RIB and SEPDB Appendix

RIB AND SEPDB APPENDIX

No RIB or SEPDB data were used in this report because the results are generic in nature and, thus, are not contingent upon specific input parameters.

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