ORNL/SUB-4269/15

DOCUMENTATION OF THE HEAT CONDUCTION CODE TRANCO

Memorandum Report RSI-0037

Gary D. Callahan

August 8, 1975

MASTER

This report was prepared by RE/SPEC, Inc. under Subcontract 4269 with Union Carbide Corporation, Nuclear Division. The subcontract was administered by Oak Ridge National Laboratory

UNION CARBIDE

OFFICE OF WASTE ISOLATION

OAK RIDGE, TENNESSEE

prepared for the **U.S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION**
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DOCUMENTATION OF THE HEAT CONDUCTION CODE TRANCO

Submitted To

Holifield National Laboratory
Oak Ridge, Tennessee

operated by

Union Carbide Corporation
Nuclear Division
for the
Energy Research and Development Administration

by

Gary D. Callahan

MASTER

RE/SPEC INC.
P. O. BOX 725 - RAPID CITY, S. D. 57701 - 605/343-7868

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950 3780

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FOREWORD

The contents of this report have been reviewed by Mr. Joe L. Ratigan and Dr. Paul F. Gnirk.

(RSI-0037)

RE/SPEC INC.

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August 8, 1975

MEMORANDUM REPORT RSI-0037

TO: Dr. William C. McClain
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P. O. Box Y
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FROM: Gary D. Callahan
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SUBJECT: Documentation of the Heat Conduction Code TRANCO (Union Carbide Corporation, Nuclear Division Subcontract No. 4269, RSI/001000/FY76).

1. INTRODUCTORY REMARKS AND OBJECTIVES

The major objective of this report is to provide documentation of the transient heat conduction code utilized by RE/SPEC Inc. for thermal, thermoelastic, thermoelastic/plastic, and thermo/viscoelastic analyses. The theory and formulation of heat conduction problems by the finite element method have been the topic of numerous books and papers (for example see references 1, 2, and 3) and will not be covered herewith. Rather, a basic description is provided with comments directed toward the Fortran listing included in Appendix A.

2. CODE DESCRIPTION AND COMMENTS

The transient heat conduction code, designated as TRANCO, has the capability to solve two dimensional X-Y and axially-symmetric R-θ-Z thermal problems involving the following conditions:

(1) Boundary Conditions

a. Constant Temperature

b. Constant Flux

c. Convective

d. Adiabatic

(2) Time Dependent or Constant Internal Heat Generation

(3) Anisotropic Thermal Conductivities

In addition, an initial spatially-dependent temperature field may be specified; otherwise, zero initial temperatures are assumed throughout the body under consideration.

A basic flow chart of the code is presented in Figure 2.1. The direct solution technique consists of a step-by-step integration procedure through time. The technique is quite efficient, since with constant material properties, the global conductivity matrix is psuedo-inverted or upper triangularized (in the usual Gauss-Doolittle fashion) during the first time step and used throughout the total specified time interval with updates on the flux and temperature.

An example problem utilizing quadrilateral and triangular constant flux elements is given in Appendix B.

Presently, quadratic temperature distributions are under consideration for incorporation into the code in the form of isoparametric quadrilateral and linear flux triangular elements.

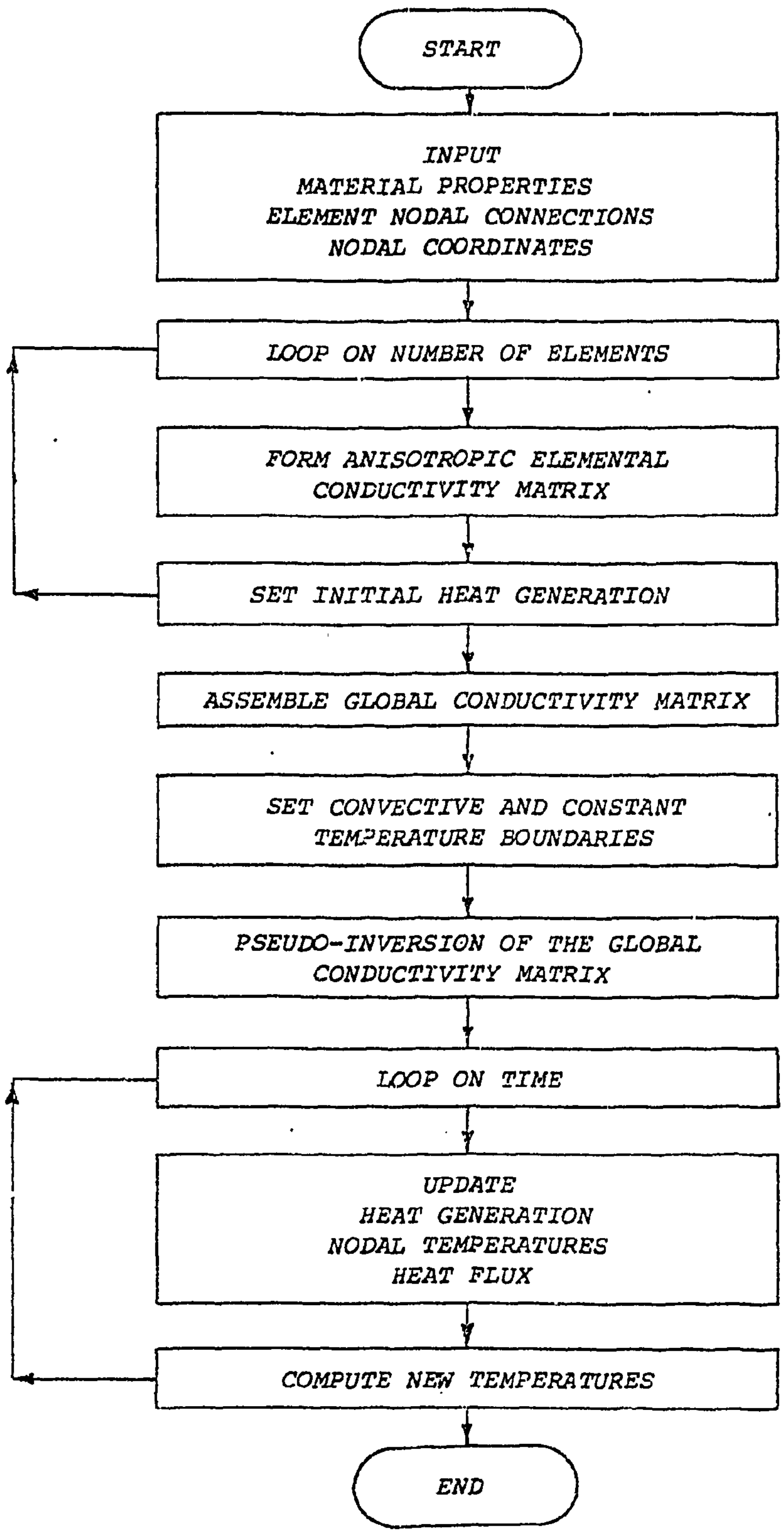

Figure 2.1. Basic flow chart of the computer code TRANCO as applied to the solution of transient heat conduction problems.

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1. Zienkiewicz, O. C.: The Finite Element Method in Engineering Science, McGraw-Hill, London, (1971).

2. Desai, C. S., and Abel, J. F.: Introduction to the Finite Element Method, Van Nostrand Reinhold Company, New York, (1972).

3. Wilson, E. L. and Nickell, R. E.: "Application of the Finite Element Method to Heat Conduction", Nuclear Eng. and Design, Vol 4, 1966, pp. 276-286.

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APPENDIX A

FORTRAN LISTING OF COMPUTER CODE TRANCO

PROGRAM TRANCO

```
C
C ........... TRANCO SOLVES TRANSIENT OR STEADY STATE HEAT .........
C ........... CONDUCTION PROBLEMS WITH FIXED TEMPERATURE BOUNDARIES OR .
C ........... CONVECTIVE BOUNDARIES WHERE HEAT TRANSFER MAY BE .........
C ........... DEFINED BY NEWTONS LAW OF COOLING ........................
C
C                  SYMBOL            IDENTIFICATION
C
C
C                  IDENT             0 FOR TWO DIMENSIONAL OR
C                                    1 FOR AXISYMMETRICAL PROBLEMS
C                  IJ                1 FOR CONVECTIVE BOUNDARIES,
C                                    AND 0 WITHOUT
C                  IPRN              1 TO PRINT INPUT DATA
C                  ITYPN             1 FOR SPECIFIED TEMPERATURE,
C                                    AND 0 FOR EXTERNAL HEAT FLOW SP.
C                                    -1 FOR INITIAL TEMPERATURE SPECIFIED
C                  IWRIT             -1 TO WRITE NODAL TEMPERATURES
C                                    0 TO WRITE ELEMENTAL TEMPS.
C                                    2 TO WRITE NODAL TEMP AND PUNCH ELEM
C                                    1 TO WRITE BOTH
C                  JSKP              1 SKIPS WRITING ON TAPE UNIT
C                                    0 SAVES TEMPS FOR VE-3 CALC.
C                  NCB               NUMBER OF CONVECTIVE BOUNDARIES
C                                    ONE BOUNDARY CONSISTS OF TWO NODE
C                  NELEM             NUMBER OF ELEMENTS
C                  NELMAT            NUMBER OF MATERIALS
C                  NNODES            NUMBER OF NODES
C
C
      COMMON/TVE/ NELEM,NELMAT,NNODES,JSKP,IQUIT
      COMMON/TVES/ CORDS(317,2),NELCON(542,5),IELMAT(542)
      COMMON/DELCOM/ DELT,TM,JT,TITLE(16),JTMAX,IPR
      COMMON/PROP/ COND(10,2,2),CP(10),DEN(10),JHGEN(10),IDENT,ANG(542)
      COMMON/TBOUN/ NCB,NCBN(20,2),CFC(20),TCONV(20),TCONS(542)
     $, ITYPN(317)
      COMMON/MXARG/ A(5),B(5),ELCON(5,5)
      COMMON/SOLT/ HKD(542),HKB(542),HGPN(2,317),SHGPN(317)
      COMMON BEQMTX(317,30),HEAT(317),MBAND
      COMMON/LUNITS/ LU10
C
    1 IQUIT=0
      READ(60,500) NPROB,JTMAX,IJ,MBAND,IWRIT,JSKP
      IF(EOF,60)2,32
   32 READ(60,510) DELT,IPR
       LU10=10
       REWIND LU10
C
C
      CALL INPUT
C
      CALL BEKMTX
C
      CALL BYCON(TJ)
C
```

```
      DO 10 JT=1,JTMAX
C
      TM=JT*DELT
C
      CALL SOLCON(IWRIT)
C
   10 CONTINUE
   20 CONTINUE
      END FILE 1
      IF(NPROB .GT. 1) GO TO 1
C
  500 FORMAT(9I5)
  510 FORMAT(F15.6,I5)
      END FILE LUTO
      REWIND LUTO
    2 CALL EXIT
      END
```

```
      SUBROUTINE INPUT
C
C ........... INPUT CONTROLS DATA INPUT.  INCLUDED ARE THE MATERIAL ....
C ........... PROPERTIES, THE NODAL COORDINATES, THE ELEMENT NODAL .....
C ........... CONNECTIONS, AND THE CONVECTIVE BOUNDARY CONDITIONS, .....
C ........... IF ANY. IN ADDITION,IF IPR=1, THE DATA IS PRINTED OUT ....
C
C
C ........... WHEN NODAL POINT CARDS ARE OMITTED, THE NODES AND ........
C ........... COORDINATES ARE GENERATED AT EQUAL INTERVALS TO THE ......
C ........... NEXT SPECIFIED POINT.  FOR GENERATED POINTS, EXTERNAL ....
C ........... HEAT FLOW IS SET EQUAL TO ZERO.
C
C ........... WHEN ELEMENT NODAL CONNECTIONS ARE OMITTED, THE NEXT .....
C ........... CONNECTION IS GENERATED BY INCREMENTING THE PREVIOUS .....
C ........... ELEMENT ARRAY AND THE MATERIAL IS ASSUMED THE SAME.  .....
C
C
      COMMON/TVF/ NELEM,NELMAT,NNODES
      COMMON/TVES/ CORDS(317,2),NELCON(542,5),IELMAT(542)
      COMMON/PROP/ COND(10,2,2),CP(10),DEN(10),JHGEN(10),IDENT,ANG(542)
      COMMON/IBOUN/ NCB,NCBN(20,2),CFC(20),TCONV(20),TCONS(542)
     $, ITYPN(317)
      COMMON/DELCOM/ DELT,TM,JT,TITLE(16),JTMAX
      COMMON/HAI / GENRA
C
      READ(60,500) TITLE
      WRITE(61,510) TITLE
C
      READ(60,520) NNODES,NELEM,NCB,NELMAT,IDENT,IPRN
      WRITE(61,530) NNODES,NELEM,NCB,NELMAT,IDENT
C
C ...........  READ MATERIAL PROPERTIES .................................
C
      WRITE(61,550)
      READ(60,540) (L,((COND(N,I,J),I=1,2),J=1,2),CP(N),DEN(N),JHGEN(N),
     $ N=1,NELMAT)
      WRITE(61,551) (N,((COND(N,I,J),I=1,2),J=1,2),CP(N),DEN(N),
     $JHGEN(N),N=1,NELMAT)
      KK=0
      DO 23 IK=1,NELMAT
      IF(JHGEN(IK).GT.0) KK=1
   23 CONTINUE
      IF(KK) 26,26,24
   24 READ(60,555) GENRA
  555 FORMAT(E10.3)
      WRITE(61,556) GENRA
  556 FORMAT(/,* THE HEAT GENERATION RATE IS *,E10.3,* BTU/YR-FT-CU*,/)
C
C ........... READ AND/OR GENERATE NODAL COORDINATES ...................
C
   26 IGC=0
      KC=1
   60 READ(60,560) N,JIG,ITYPN(N),(CORDS(N,J),J=1,2),TCONS(N)
      IGC=IGC+1
      IF(IGC .LE. N) GO TO 61
```

```
      WRITE(61,650) IGC
  650 FORMAT(1H ,/# DATA OUT OF ORDER AT NODE#,I5,/)
      JTMAX=1
   61 DNOD=N+1-KC
      IF(N-KC) 90,80,70
C
   70 MC=KC-1
      DX=(CORDS(N,1)-CORDS(MC,1))/DNOD
      DY=(CORDS(N,2)-CORDS(MC,2))/DNOD
C
   75 ITYPN(KC)=0
      IF(JIG .GT. 0) ITYPN(KC)=ITYPN(MC)
      IGC=IGC+1
      MC=KC-1
      CORDS(KC,1)=CORDS(MC,1)+DX
      CORDS(KC,2)=CORDS(MC,2)+DY
      TCONS(KC)=0.0
      IF(JIG .GT. 0) TCONS(KC)=TCONS(MC)
C
   80 KC=KC+1
      IF(N-KC) 90,80,75
   90 IF(NNODES+1-KC) 100,100,60
  100 CONTINUE
C
C ............ READ AND/OR GENERATE NODAL CONNECTION ARRAY ..............
C
      LEN=0
      IHH=0
      NEL=0
      DO 175 N=1,NELEM
      ISTD=4
      IHH=IHH+1
      IF(NEL-N) 120,170,150
  120 READ(60,558) NEL,(NELCON(N,J),J=1,4),IELMAT(N),ANG(N)
      IF(IHH .LE. NEL) GO TO 119
      WRITE(61,660) IHH
  660 FORMAT(1H ,/,+ DATA OUT OF ORDER AT ELEMENT#,I5,/)
      IHH=NEL
      WRITE(61,620) NEL,(NELCON(N,J),J=1,4),IELMAT(N)
      JTMAX=1
  119 IF(NEL-1-N) 170,130,130
C
  130 IF(LEN .EQ. NEL) GO TO 150
      DO 135 I=1,4
  135 NELCON(NEL,I)=NELCON(N,I)
      IELMAT(NEL)=IELMAT(N)
      ANG(NEL)=ANG(N)
      LEN=NEL
C
  150 M=N-1
C
      IF(NELCON(M,4) .GT. 0) GO TO 159
      NELCON(N,4)=0
      ISTD=3
  159 DO 160 I=1,ISTD
  160 NELCON(N,I)=NELCON(M,I)+1
```

```
      IELMAT(N)=IELMAT(M)
      ANG(N)=ANG(M)
      IF(NELEM-N-1) 180,180,170
  170 IF(IELMAT(N) .LE. 0) IELMAT(N)=IELMAT(N-1)
  175 CONTINUE
  180 CONTINUE
C
C
C ........... READ CONVECTIVE BOUNDARY DATA ...........................
C
      IF(NCB) 200,200,190
  190 DO 192 N=1,NCB
      READ(60,590) (NCBN(N,K),K=1,2),CFC(N),TCONV(N)
      IF(CFC(N) .LE. 0.0) CFC(N)=CFC(N-1)
      IF( TCONV(N) .LE. 0.0) TCONV(N)=TCONV(N-1)
  192 CONTINUE
C
C ........... PRINT INPUT DATA IF DESIRED ..........................
C
  200 IF(IPRN .NE. 1) GO TO 220
C
      WRITE(61,590)
      WRITE(61,600) (I,ITYPN(I),(CORDS(I,J),J=1,2),TCONS(I),I=1,NNODES)
      WRITE(61,610)
      WRITE(61,620) (I,(NELCON(I,J),J=1,4),IELMAT(I),ANG(I),I=1,NELEM)
      IF(NCB) 220,220,210
  210 WRITE(61,630)
      WRITE(61,640) ((NCBN(I,J),J=1,2),CFC(I),TCONV(I),I=1,NCB)
C
C ........... FORMAT STATEMENTS ....................................
C
  500 FORMAT(16A5)
  510 FORMAT(1H1,25X,16A5)
  520 FORMAT(6I5)
  528 FORMAT(6I5,F10.3)
  530 FORMAT(1H0,≠NNODES=≠,I4,/,≠ NELEM=≠,I5,/,≠ NCB=≠,I7,/,≠ NELMAT=≠,I
     $4,/,≠ IDENT=≠,I5,/)
  540 FORMAT(I5,6E10.2,I5)
  550 FORMAT(1H ,2X,≠MAT≠,30X,≠CONDUCT≠,28X,≠SP HEAT≠, 8X,≠DENSITY≠,6X,
     $≠HEAT GEN≠,//)
  551 FORMAT(1H,I5,6E15.4,I10)
  560 FORMAT(I10,I2,I3,3F10.2)
  580 FORMAT(2I5,2E15.6)
  590 FORMAT(//,3X,≠NODES≠,5X,≠ITYPN≠,11X,        ≠COORDINATES≠,
     $6X,≠TEMPERATURE≠,/)
  600 FORMAT(I6,I10,6X,2F10.3,E15.4)
  610 FORMAT(//≠ ELEMENTS≠,6X,≠NODAL CONNECTIONS≠,2X,≠IELMAT≠2X,≠ANGLE≠
     $,/)
  620 FORMAT(I5,7X,5I5,F10.3)
  630 FORMAT(//,4X,≠NODES≠,10X,≠FILM COEFF≠,2X,≠AMBIENT TEMP.≠,//)
  640 FORMAT(2I7,2E15.4)
C
  220 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE BEKMTX
C
C ............ BEKMTX CALLS CONMTX TO FORM ELEMENTAL CONDUCTIVITY .......
C ............ THEN FORM THE GLOBAL CONDUCTIVITY MATRIX  ................
C
      COMMON/TVF/ NELEM,NELMAT,NNODES
      COMMON/TVFS/ CORDS(317,2),NELCON(542,5),IELMAT(542)
      COMMON/MXARG/ A(5),B(5),ELCON(5,5)
      COMMON/SOLT/ HKD(542),HKB(542),HGPN(2,317),SHGPN(317)
      COMMON/PROP/ COND(10,2,2),CP(10),DEN(10),JHGEN(10),IDENT,ANG(542)
      COMMON BEQMTX(317,30),HEAT(317),MBAND
C
      MAXDIF=0
      DO 5 I=1,NELEM
      LIM=4
      IF(NELCON(I,4).EQ.0) LIM=3
      DO 5 J=1,LIM
      DO 5 K=1,LIM
      LL= IABS(NELCON(I,J) - NELCON(I,K))
      IF(LL .GT. MAXDIF) MAXDIF=LL
    5 CONTINUE
      MBAND=MAXDIF + 1
C
      DO 10 I=1,NNODES
      HKD(I)=0.0
      HKB(I)=0.0
      DO 10 J=1,MBAND
   10 BEQMTX(I,J)=0.0
C
C ............ CONTRUCT CONDUCTIVITY MATRIX FOR EACH ELEMENT FROM .......
C ............ CONMTX AND RETURN ELCON .................................
C
      DO 180 N=1,NELEM
C
      CALL CONMTX(N)
      LIM=4
      IF(NELCON(N,4) .EQ. 0) LIM=3
C
      MNUM=IELMAT(N)
      DO 176 I=1,LIM
      ISAV=NELCON(N,I)
      HKD(ISAV)=HKD(ISAV)+A(I)
      HKB(ISAV)=HKB(ISAV)+B(I)
      IF(JHGEN(MNUM) .EQ. 0) GO TO 157
      HGPN(2,ISAV) = HKB(ISAV)
      SHGPN(ISAV)=HKB(ISAV)
C
  157 DO 175 J=1,LIM
      JJSA=NELCON(N,J)
      JSAV=JJSA-ISAV+1
C
  165 IF(JSAV) 175,175,170
  170 BEQMTX(ISAV,JSAV)=BEQMTX(ISAV,JSAV) + ELCON(I,J)
C
  175 CONTINUE
  176 CONTINUE
```

N 1.4 DATE 08/07/75 AT 100435 PAGE NO. 2

```
100 CONTINUE
    RETURN
    END
```

```
      SUBROUTINE CONMTX(N)
C
C ........... CONMTX CREATES ELEMENTAL CONDUCTIVITY MATRICES ...........
C
      COMMON/TVF/ NELEM,NELMAT,NNODES,JSKP,IQUIT
      COMMON/TVFS/ CORDS(317,2),NELCON(542,5),IELMAT(542)
      COMMON/PROP/ COND(10,2,2),CP(10),DEN(10),JHGEN(10),IDENT,ANG(542)
      COMMON/TBOUN/ NCB,NCBN(20,2),CFC(20),TCONV(20),TCONS(542)
     $, ITYPN(317)
      COMMON/SOLT/ HKD(542),HKB(542),HDEC(2)
      COMMON/DELCOM/ DELT,TM,JT,TITLE(16)
      COMMON/MXARG/ A(5),B(5),ELCON(5,5)
      COMMON BEQMTX(317,30),HEAT(317),MBAND
      COMMON/HAL/ GENRA
      REAL KMAT(2,2)
      DIMENSION D(3,3),IHLD(3)
      DIMENSION DNT(3,2),PM(2,2),TM1(2,2),DN(2,3),DNTK(3,2)
C
C
      DO 10 I=1,5
      A(I)=0.0
      B(I)=0.0
      DO 10 J=1,5
   10 ELCON(I,J)=0.0
C
      NOD1=NELCON(N,1)
      NOD2=NELCON(N,2)
      NOD3=NELCON(N,3)
      NOD4=NELCON(N,4)
      NELCON(N,5)=NOD1
      MNUM=IELMAT(N)
C
      IF(NOD4 .LE. 0) GO TO 11
C
   15 DISX=(CORDS(NOD1,1)+CORDS(NOD2,1)+CORDS(NOD3,1)+ CORDS(NOD4,1))/4.
      DISY=(CORDS(NOD1,2)+CORDS(NOD2,2)+CORDS(NOD3,2)+ CORDS(NOD4,2))/4.
      ISIDES=4
      GO TO 16
   11 DISX=CORDS(NOD3,1)
      DISY=CORDS(NOD3,2)
      ISIDES=1
C
   16 DO 80 I=1,ISIDES
C
      L=NELCON(N,I)
      J=I+1
      M=NELCON(N,J)
      IF(L-M) 20,80,20
C
   20 XJ=CORDS(M,1)-CORDS(L,1)
      XK=DISX-CORDS(L,1)
      YJ=CORDS(M,2)-CORDS(L,2)
      YK=DISY-CORDS(L,2)
      YY=YJ-YK
      XX=XK-XJ
C
```

```
      X=1.0
      IF(IDENT) 30,40,30
   30 X=X*(CORDS(L,1)+CORDS(M,1)+DISX)/3.0
C
   40 AR=XJ*YK-YK*YJ
      IF(AR .GT. 0.0) GO TO 33
      WRITE(61,500)N
      IQUIT=1
  500 FORMAT(≠ ELEMENT NO. ≠,I5,≠ ZERO OR NEGATIVE AREA≠)
   33 RATIO=X/(2.*AR)
      IF(N .EQ. NELEM .AND. IQUIT .EQ. 1) CALL EXIT
      IF(JHGEN(MNUM) .EQ. 0) GO TO 41
      GP=X*AR*GENRA/6.0
      GO TO 42
   41 GP=0.0
   42 DRES=AR*X*CP(MNUM)*DEN(MNUM)/6.0
C
C----- FORM COORDINATE MATRIX TRANSPOSED
      DNT(1,1)=YY
      DNT(2,1)=YK
      DNT(3,1)=-YJ
      DNT(1,2)=XX
      DNT(2,2)=-XK
      DNT(3,2)=XJ
C
      KMAT(1,1)=COND(MNUM,1,1)
      KMAT(2,1)=COND(MNUM,2,1)
      KMAT(1,2)=COND(MNUM,1,2)
      KMAT(2,2)=COND(MNUM,2,2)
C
      IF(ANG(N))71,72,71
C
C----- DETERMINE SINE AND COSINE OF ELEMENT ANGLE FOR TRANSFORMATION MATRIX
   71 CS=COS(ANG(N)*.017453)
      SS=SIN(ANG(N)*.017453)
C
C------- FORM TRANSFORMATION MATRIX FOR GLOBAL AXES
C
      PM(1,1)=CS
      PM(2,1)=SS
      PM(1,2)=-SS
      PM(2,2)=CS
C
C
      DO 115 J=1,2
      DO 115 M=1,2
      TM1(M,J)=0.
      DO 115 K=1,2
  115 TM1(M,J)=TM1(M,J)+KMAT(M,K)*PM(J,K)
C
      DO 116 J=1,2
      DO 116 M=1,2
      KMAT(M,J)=0.
      DO 116 K=1,2
  116 KMAT(M,J)=KMAT(M,J)+PM(M,K)*TM1(K,J)
C
```

```
   72 DN(1,1)=YY
      DN(2,1)=XY
      DN(1,2)=YK
      DN(2,2)=-YK
      DN(1,3)=-YJ
      DN(2,3)=XJ
C
      DO 117 J=1,2
      DO 117 M=1,3
      DNTK(M,J)=0.
      DO 117 K=1,2
C
C
  117 DNTK(M,J)=DNTK(M,J)+DNT(M,K)*KMAT(J,K)
      DO 118 J=1,3
      DO 118 M=1,3
      D(M,J)=0.
      DO 118 K=1,2
C
C
  118 D(M,J)=D(M,J)+DNTK(M,K)*DN(K,J)
C
      IF(ISIDES .EQ. 1) GO TO 91
C
      IHLD(1)=I
      IHLD(2)=I+1
      IF(I-4) 60,50,60
   50 IHLD(2)=1
   60 IHLD(3)=5
C
      DO 70 J=1,3
      JJ=IHLD(J)
      B(JJ)=B(JJ)+QP
      A(JJ)=A(JJ)+QPES
C
      DO 70 IK=1,3
      IKK=IHLD(IK)
   70 ELCON(JJ,IKK)=ELCON(JJ,IKK)+D(J,IK)*RATIO
   80 CONTINUE
      DO 89 I=1,4
      A(I)=A(I)-A(5)/ELCON(5,5)*ELCON(I,5)
   89 B(I)=B(I)-B(5)/ELCON(5,5)*ELCON(I,5)
C
C
      DO 90 I=1,4
      DO 90 J=1,4
   90 ELCON(I,J)=ELCON(I,J)-ELCON(I,5)*ELCON(J,5)/ELCON(5,5)
C
      GO TO 99
   91 DO 92 J=1,3
      B(J)=B(J)+QP
      A(J)=A(J)+QRES
      DO 92 I=1,3
   92 ELCON(J,I)=ELCON(J,I) + D(J,I)*RATIO
   99 CONTINUE
C
```

RETURN
END

```
      SUBROUTINE BYCON(JE)
C
C ........... BYCON ANALYZES THE CONVECTIVE AND TEMPERATURE BOUNDARY ...
C ........... CONDITIONS AND INCLUDES THEM IN THE CONDUCTIVITY ........
C ........... MATRIX (GLOBAL) ........................................
C
C
      COMMON    / NELEM,NELMAT,NNODES
      COMMON    / CORDS(317,2),NELCON(542,5),IELMAT(542)
      COMMON/PROP/ COND(10,2,2),CP(10),DEN(10),JHGEN(10),IDENT,ANG(542)
      COMMON/TBOUN/ NCB,NCBN(20,2),CFC(20),TCONV(20),TCONS(542)
     $, ITYPN(317)
      COMMON/SOLT/ HKD(542),HKB(542),HDEC(2)
      COMMON/MXARG/ A(5),B(5),ELCON(5,5)
      COMMON BEQMTX(317,30),HEAT(317),MBAND
C
C
      IF(JE) 70,70,10
C
C ........... CONVECTIVE BOUNDARIES .....................................
C
   10 DO 60 N=1,NCB
C
      NOD1=NCBN(N,1)
      NOD2=NCBN(N,2)
      HYP=SQRT((CORDS(NOD2,1)-CORDS(NOD1,1))**2+(CORDS(NOD2,2)-CORDS(NOD
     $1,2))**2)
C
      IF(IDENT) 20,30,20
   20 HYP=HYP*(CORDS(NOD1,1)+CORDS(NOD2,1))/2.0
   30 TCONV(N)=CFC(N)*HYP*TCONV(N)/2.
      CFC(N)=CFC(N)*HYP
C
      HKB(NOD1)=HKB(NOD1)+TCONV(N)
      HKB(NOD2)=HKB(NOD2)+TCONV(N)
C
      BEQMTX(NOD1,1)=BEQMTX(NOD1,1)+CFC(N)/3.0
      BEQMTX(NOD2,1)=BEQMTX(NOD2,1)+CFC(N)/3.0
C
      LL=NOD2-NOD1+1
      IF(LL) 50,50,40
   40 BEQMTX(NOD1,LL)=BEQMTX(NOD1,LL)+CFC(N)/6.0
      GO TO 60
   50 LL=NOD1-NOD2+1
      BEQMTX(NOD2,LL)=BEQMTX(NOD2,LL)+CFC(N)/6.0
   60 CONTINUE
   70 CONTINUE
C
C ........... TEMPERATURE BOUNDARIES ....................................
C
      DO 140 N=1,NNODES
C
      IF(ITYPN(N) .LT. 0) GO TO 140
      HKB(N)=HKB(N)+TCONS(N)
      IF(ITYPN(N))140,140,80
C
```

```
   80 DO 130 M=2,MBAND
      L=N-M+1
      IF(L) 100,100,90
   90 HKR(L)=HKR(L)-BEQMTX(L,M)*TCONS(N)
      BEQMTX(L,M)=0.0
  100 LL=N+M-1
      IF(NNODES-LL) 120,110,110
  110 HKR(LL)=HKR(LL)-BEQMTX(N,M)*TCONS(N)
  120 BEQMTX(N,M)=0.0
  130 CONTINUE
C
      BEQMTX(N,1)=1.0
      HKR(N)=TCONS(N)
  140 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE SOLCON (IWRIT)
C
C ........... SOLCON CONTROLS THE SOLUTION TO PROCEDURE TO THE .........
C ........... CONDUCTIVITY MATRIX. IF THE TIME STEP (DELT) IS ZERO .....
C ........... OR NEGATIVE THE STEADY-STATE NODAL POINT TEMPERATURES ....
C ........... ARE CALCULATED USING SUBROUTINE SOLVE. SPECIFYING DELT ...
C ........... RESULTS IN TRANSIENT TEMPERATURE SOLUTIONS OVER THE ......
C ........... NUMBER OF TIME STEPS INITIATED IN TRANCO. ...............
C
C
      COMMON/TVE/ NELEM,NELMAT,NNODES,JSKP
      COMMON/LUNITS/ LU10
      COMMON/TVES/ CORDS(317,2),NELCON(542,5),IELMAT(542)
      COMMON/DELCOM/ DELT,IM,JT,TITLE(16),JIMAX,IPR
      COMMON/TBOUN/ NCB,NCBN(20,2),CFC(20),ICONV(20),TCONS(542)
     $, ITYPN(317)
      COMMON/SOLT/ HKD(542),HKB(542),HGPN(2,317),SHGPN(317)
      COMMON/PROP/ COND(10,2,2),CP(10),DEN(10),JHGEN(10),IDENT,ANG(542)
      COMMON BEQMTX(317,30),HEAT(317),MBAND
      DIMENSION ELTEMP(542),TDUM(542)
      DIMENSION HDIF(3)
C
C ........... STEADY STATE OR TRANSIENT SOLUTION .....................
C
      IF(DELT) 100,100,10
   10 IF(JT.GT.1) 45,15
   15 TLED=1./DELT
      XNDT=1.0/DELT
      REWIND 1
      IAMT=INT(XNDT)
      IF(IPR.LE.0) IPR=1
      JTROL=0
      JCNT=0
C
      DO 40 I=1,NNODES
      IF(ITYPN(I) .LT. 0) GO TO 16
      TCONS(I)=0.0
C
   16 IF(ITYPN(I)) 20,20,40
   20 IF(HKD(I)) 30,40,30
   30 HKD(I)=TLED*HKD(I)
      BEQMTX(I,1)=BEQMTX(I,1)+HKD(I)
   40 CONTINUE
C
      CALL SOLVE(1,NNODES)
C
C ........... FIND NODAL TEMPERATURES BY CONSTRUCTING EFFECTIVE LOAD ...
C ........... MATRIX AND CALLING SOLVE ................................
C
C ........... CALCULATE DECLINE IN HEAT GENERATION ....................
C
C ---------------- UPDATE HEAT DECLINE TO THE LAST TIME STEP ----------
C
C
   45 JTROL=JTROL+1
      JCNT=JCNT+1
```

```
      DO 220 N=1,NELEM
C
      NNUM=IELMAT(N)
      IF(JHGEN(NNUM) .EQ. 0) GO TO 220
C
      DO 219 I=1,3
C
      NOD=NELCON(N,I)
      HGPN(1,NOD)=HGPN(2,NOD)
      HGPN(2,NOD)=SHGPN(NOD)*EXP(-.023105*TM)
C
      HKB(NOD)=HKB(NOD) + HDIF(I)
  219 CONTINUE
  220 CONTINUE
C
      DO 60 J=1,NNODES
      HEAT(J)=HKB(J)
      IF(ITYPN(J)) 50,50,60
   50 HEAT(J)=HKB(J)+HKD(J)*TCONS(J)
   60 CONTINUE
C
C ............CALCULATE TEMPERATURES ....................................
C
      CALL SOLVE(2,NNODES)
   32 DO 95 M=1,NNODES
   95 TCONS(M)=HEAT(M)
C
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      IF(TM .LE. 5.0) GO TO 85
      IF(JTROL .NE. IAMT) GO TO 120
   85 IF(JCNT.NE.IPR) GO TO 120
      DO 70 K=1,NELEM
      JTROL=0
C
      NOD1=NELCON(K,1)
      NOD2=NELCON(K,2)
      NOD3=NELCON(K,3)
      NOD4=NELCON(K,4)
C
      IF(NOD4 .LE. 0) GO TO 942
C
      ELTEMP(K)=(HEAT(NOD1)+HEAT(NOD2)+HEAT(NOD3)+HEAT(NOD4))/4.0
      GO TO 70
  942 ELTEMP(K)=(HEAT(NOD1) + HEAT(NOD2) + HEAT(NOD3))/3.0
C
   70 CONTINUE
C
      WRITE(61,500) TM
      IF(IWRIT) 71,78,71
   71 INCR=NNODES
      DO 72 I=1,INCR
   72 TDUM(I)=TCONS(I)
      GO TO 75
   78 IF(IWRIT .NE. 2) WRITE(61,520)
   73 INCR=NELEM
```

```
      DO 74 I=1,INCR
   74 TDUM(I)=ELTEMP(I)
      IF(JSKP .EQ. 1) GO TO 181
      WRITE(LUTO) TM,(ELTEMP(I),I=1,INCR)
  181 CONTINUE
      IF(IWRIT .NE. 2) GO TO 777
      IF(JT.EQ. 7.OR.JT.EQ.400) GO TO 666
      IF(JT.EQ.20.OR.JT.EQ.100.OR.JT.EQ.200.OR.JT.EQ.300) GO TO 666
      GO TO 777
  666 WRITE(62,888)(N,TDUM(N),N=1,INCR)
  888 FORMAT(5(I5,F10.3))
  777 CONTINUE
      IF(IWRIT .EQ. 2) GO TO 76
   75 WRITE(61,510) (N,TDUM(N),N=1,INCR)
      JCNT=0
      IF(IWRIT) 76,76,77
   77 IF(INCR .EQ. NELEM) 76,78
   76 CONTINUE
C
      GO TO 120
C
C ........... STEADY STATE ...............................................
C
  100 DO 110 L=1,NNODES
  110 HEAT(L)=HKB(L)
      CALL SOLVE(1,NNODES)
      CALL SOLVE(2,NNODES)
      GO TO 32
C
  500 FORMAT(1H0,30X,≠TIME=≠,E12.5,//)
  510 FORMAT (6(I6,F14.6))
  520 FORMAT(//,40X,≠ELEMENTAL TEMPERATURES≠,/)
C
  120 CONTINUE
 7761 FORMAT(5(I5,F10.2))
      RETURN
      END
```

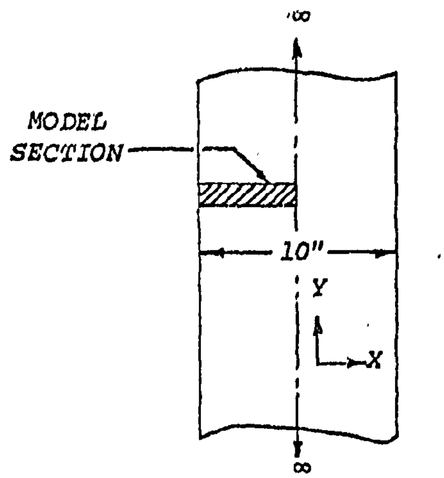
```
      SUBROUTINE SOLVE(IP,NUMEQ)
C
C ........... SOLVE SOLVES THE CONDUCTIVITY MATRIX FOR THE NODAL TEMP...
C
      COMMON EQNS(317,30),FUNC(317),IBAND
C
C ........... SELECT SOLUTION TYPE DESIRED ..............................
C
      IF(IP .EQ. 2) GO TO 50
C
C ........... REDUCE BEQMTX (CONDUCTIVITY MATRIX) .......................
C
      DO 40 I=1,NUMEQ
      DO 30 J=2,IBAND
C
      HLD=EQNS(I,J)/EQNS(I,1)
      I1=I+J-1
      IF(NUMEQ - I1) 30,10,10
   10 J1=0
C
      DO 20 K=J,IBAND
      J1=J1+1
   20 EQNS(I1,J1)=EQNS(I1,J1)-HLD*EQNS(I,K)
   30 EQNS(I,J)=HLD
   40 CONTINUE
      GO TO 120
C
C ........... MODIFY VECTORS FOR EACH EQUATION .........................
C
   50 DO 70 I=1,NUMEQ
      DO 60 J=2,IBAND
      I1=I+J-1
      IF(NUMEQ-I1) 70,60,60
   60 FUNC(I1)=FUNC(I1)-EQNS(I,J)*FUNC(I)
   70 FUNC(I)=FUNC(I)/EQNS(I,1)
C
C ........... BACK SUBSTITUTION ........................................
C
      NB=NUMEQ
   80 NB=NB-1
      IF(NB) 90,120,90
   90 DO 110 II=2,IBAND
      JJ=NB+II-1
      IF(NUMEQ-JJ) 110,100,100
  100 FUNC(NB)=FUNC(NB)-EQNS(NB,II)*FUNC(JJ)
  110 CONTINUE
      GO TO 80
C
  120 RETURN
      END
```

APPENDIX B

AN EXAMPLE HEAT CONDUCTION PROBLEM

B.1 Problem Description

To illustrate the finite element heat conduction code TRANCO, consider one dimensional heat conduction in an infinite plane slab, ten inches thick, as depicted in Figure B.1 (after Chapman (4)).



$C_p = 0.2$ Btu/lb_m - ^oF

$\rho = 144$ lb_m/ft^3

$k = 1.0$ Btu/hr-ft-^oF

Figure B.1. Plane slab heat conduction example problem.

Initially the slab is at a uniform temperature of 100 ^oF. The temperature at both surfaces is suddenly raised to 500 ^oF and maintained at that value.

The finite element discretization is shown in Figure B.2. Both quadrilateral and triangular elements are used for illustrative purposes only.

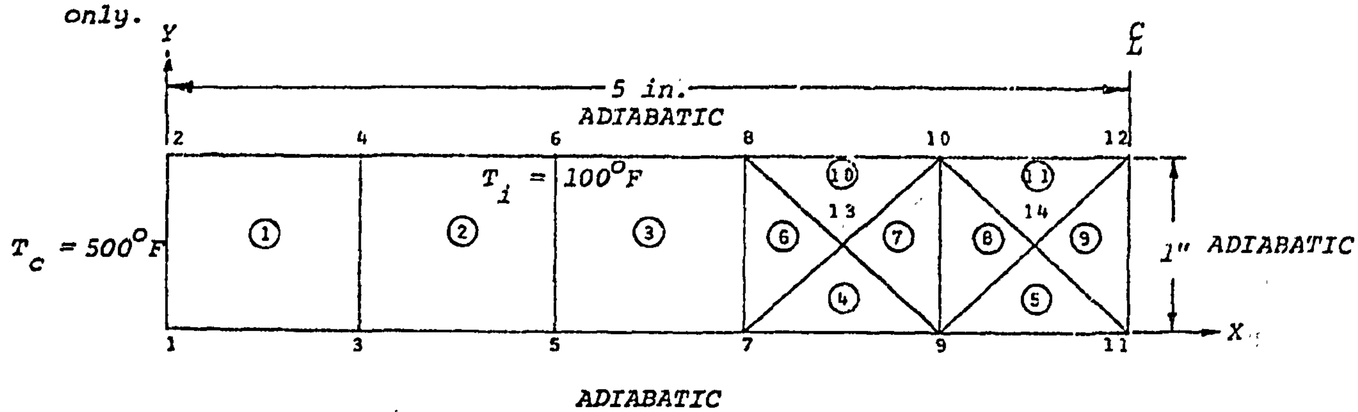


Figure B.2. Finite element discretization of the plane slab conduction problem (element numbers are circled).

B.2 Results

A listing of the computed results follow and illustrate the temperature field for each 0.05 hour (time step utilized) up to a total time of 1.0 hour. These results are also compared with the analytical solution (4) in Figure B.3.

EXAMPLE HEAT CONDUCTION PROBLEM

NNODES= 14
NELEM= 11
NCB= 0
NELMAT= 1
IDENT= 0

(RSI-0037)

MAT	CONDUCT				SP HEAT	DENSITY	HEAT GEN
1	1.0000+000	0.0000+000	0.0000+000	1.0000+000	2.0000-001	1.4400+002	0

NODES	ITYPN	COORDINATES		TEMPERATURE
1	1	0.000	0.000	5.0000+002
2	1	0.000	0.083	5.0000+002
3	-1	0.083	0.000	1.0000+002
4	-1	0.083	0.083	1.0000+002
5	-1	0.167	0.000	1.0000+002
6	-1	0.167	0.083	1.0000+002
7	-1	0.250	0.000	1.0000+002
8	-1	0.250	0.083	1.0000+002
9	-1	0.333	0.000	1.0000+002
10	-1	0.333	0.083	1.0000+002
11	-1	0.417	0.000	1.0000+002
12	-1	0.417	0.083	1.0000+002
13	-1	0.292	0.042	1.0000+002
14	-1	0.375	0.042	1.0000+002

ELEMENTS	NODAL CONNECTIONS				IELMAT	ANGLE
1	1	3	4	2	1	-0.000
2	3	5	6	4	1	-0.000
3	5	7	8	6	1	-0.000
4	7	9	13	-0	1	-0.000
5	9	11	14	-0	1	-0.000
6	7	13	8	-0	1	-0.000
7	9	10	13	-0	1	-0.000
8	10	14	10	-0	1	-0.000
9	11	12	14	-0	1	-0.000
10	13	10	8	-0	1	-0.000
11	14	12	10	-0	1	-0.000

TIME= 5.00000-002

1	5.000000+002	2	5.000000+002	3	1.686334+002	4	1.686334+002	5	1.117984+002	6	1.117984+002
7	1.021570+002	8	1.021570+002	9	1.003269+002	10	1.003269+002	11	1.000949+002	12	1.000949+002
13	1.009315+002	14	1.001582+002								

TIME= 1.00000-001

1	5.000000+002	2	5.000000+002	3	2.1-1731+002	4	2.171731+002	5	1.285032+002	6	1.285032+002
7	1.066517+002	8	1.066517+002	9	1.013064+002	10	1.013064+002	11	1.004589+002	12	1.004589+002
13	1.032171+002	14	1.007015+002								

TIME= 1.50000-001

1	5.000000+002	2	5.000000+002	3	2.525480+002	4	2.525480+002	5	1.465979+002	6	1.465979+002
7	1.130256+002	8	1.130256+002	9	1.031303+002	10	1.031303+002	11	1.012814+002	12	1.012814+002
13	1.068627+002	14	1.018298+002								

TIME= 2.00000-001

1	5.000000+002	2	5.000000+002	3	2.790934+002	4	2.790934+002	5	1.643652+002	6	1.643652+002
7	1.207058+002	8	1.207058+002	9	1.058568+002	10	1.058568+002	11	1.027159+002	12	1.027159+002
13	1.116766+002	14	1.036722+002								

TIME= 2.50000-001

1	5.000000+002	2	5.000000+002	3	2.995685+002	4	2.995685+002	5	1.810368+002	6	1.810368+002
7	1.291907+002	8	1.291907+002	9	1.094505+002	10	1.094505+002	11	1.048562+002	12	1.048562+002
13	1.174096+002	14	1.062831+002								

TIME= 3.00000-001

1	5.000000+002	2	5.000000+002	3	3.157684+002	4	3.157684+002	5	1.963356+002	6	1.963356+002
7	1.380973+002	8	1.380973+002	9	1.138238+002	10	1.138238+002	11	1.077359+002	12	1.077359+002
13	1.238228+002	14	1.096556+002								

TIME= 3.50000-001

1	5.000000+002	2	5.000000+002	3	3.288840+002	4	3.288840+002	5	2.102304+002	6	2.102304+002
7	1.471549+002	8	1.471549+002	9	1.188657+002	10	1.188657+002	11	1.113387+002	12	1.113387+002
13	1.307134+002	14	1.137406+002								

TIME= 4.00000-001

1	5.000000+002	2	5.000000+002	3	3.397236+002	4	3.397236+002	5	2.228049+002	6	2.228049+002
7	1.561832+002	8	1.561832+002	9	1.244613+002	10	1.244613+002	11	1.156134+002	12	1.156134+002
13	1.379200+002	14	1.184631+002								

TIME= 4.50000-001

1	5.000000+002	2	5.000000+002	3	3.488473+002	4	3.488473+002	5	2.341895+002	6	2.341895+002
7	1.650690+002	8	1.650690+002	9	1.305011+002	10	1.305011+002	11	1.204872+002	12	1.204872+002
13	1.453188+002	14	1.237364+002								

TIME= 5.00000-001

1	5.000000+002	2	5.000000+002	3	3.566526+002	4	3.566526+002	5	2.445262+002	6	2.445262+002
7	1.737456+002	8	1.737456+002	9	1.368867+002	10	1.368867+002	11	1.258773+002	12	1.258773+002
13	1.528158+002	14	1.294705+002								

TIME= 5.50000-001

1	5.000000+002	2	5.000000+002	3	3.634271+002	4	3.634271+002	5	2.539518+002	6	2.539518+002
7	1.821780+002	8	1.821780+002	9	1.435321+002	10	1.435321+002	11	1.316984+002	12	1.316984+002

(RSI-0037).

13	1.603454+002	14	1.355790+002

TIME= 6.00000-001

1	5.000000+002	2	5.000000+002	3	3.693832+002	4	3.693832+002	5	2.625904+002	6	2.625904+002
7	1.903514+002	8	1.903513+002	9	1.503638+002	10	1.503638+002	11	1.378685+002	12	1.378685+002
13	1.678545+002	14	1.419818+002								

TIME= 6.50000-001 (RST-0037)

1	5.000000+002	2	5.000000+002	3	3.746807+002	4	3.746807+002	5	2.705512+002	6	2.705512+002
7	1.982637+002	8	1.982636+002	9	1.573200+002	10	1.573200+002	11	1.443119+002	12	1.443119+002
13	1.753075+002	14	1.486074+002								

TIME= 7.00000-001

1	5.000000+002	2	5.000000+002	3	3.794418+002	4	3.794418+002	5	2.779279+002	6	2.779279+002
7	2.059203+002	8	2.059203+002	9	1.643494+002	10	1.643494+002	11	1.509607+002	12	1.509607+002
13	1.826780+002	14	1.553931+002								

TIME= 7.50000-001

1	5.000000+002	2	5.000000+002	3	3.837613+002	4	3.837613+002	5	2.848008+002	6	2.848008+002
7	2.133308+002	8	2.133308+002	9	1.714095+002	10	1.714094+002	11	1.577554+002	12	1.577554+002
13	1.899470+002	14	1.622850+002								

TIME= 8.00000-001

1	5.000000+002	2	5.000000+002	3	3.877138+002	4	3.877138+002	5	2.912374+002	6	2.912374+002
7	2.205066+002	8	2.205066+002	9	1.784655+002	10	1.784655+002	11	1.646447+002	12	1.646448+002
13	1.971012+002	14	1.692375+002								

TIME= 8.50000-001

1	5.000000+002	2	5.000000+002	3	3.913584+002	4	3.913584+002	5	2.972968+002	6	2.972968+002
7	2.274598+002	8	2.274597+002	9	1.854893+002	10	1.854893+002	11	1.715854+002	12	1.715854+002
13	2.041312+002	14	1.762123+002								

TIME= 9.00000-001

1	5.000000+002	2	5.000000+002	3	3.947424+002	4	3.947424+002	5	3.030207+002	6	3.030207+002
7	2.342021+002	8	2.342021+002	9	1.924582+002	10	1.924582+002	11	1.785408+002	12	1.785408+002
13	2.110304+002	14	1.831777+002								

TIME= 9.50000-001

1	5.000000+002	2	5.000000+002	3	3.979042+002	4	3.979042+002	5	3.084555+002	6	3.084555+002
7	2.407449+002	8	2.407449+002	9	1.993540+002	10	1.993540+002	11	1.854809+002	12	1.854809+002
13	2.1779[illegible]6+002	14	1.901074+002								

TIME= 1.00000+000

```
 1  5.000000+002    2  5.000000+002    3  4.008749+002    4  4.008749+002    5  3.136327+002    6  3.136327+002
 7  2.470986+002    8  2.470986+002    9  2.061622+002   10  2.061622+002   11  1.923809+002   12  1.923807+002
13  2.244214+002   14  1.909804+002

END  ,UDC001, 130253 08/08/75,   250381 0003.11   777   962   U 5
```

(RST-0037)

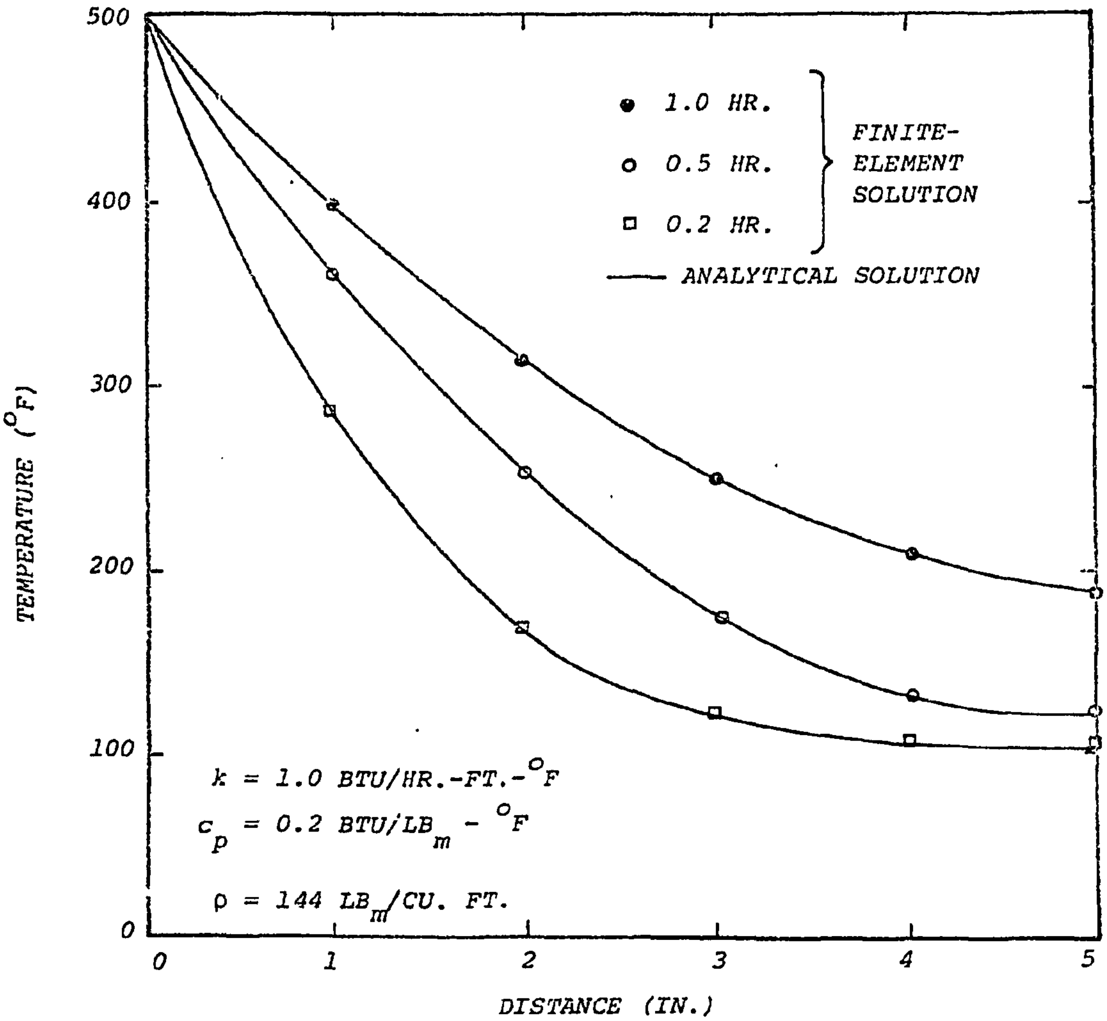


Figure B.3. *Comparison of analytical and finite-element results for the transient temperature distribution in an infinite slab with an initial uniform temperature and prescribed surface temperatures (Analytical solution after Bird, et. al. (5))*