Finite element modelling of transportation tunnels

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FINITE ELEMENT MODELLING OF TRANSPORTATION TUNNELS

VOLUME II

APPENDICES

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September, 1995

VOLUME II

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APPENDIX A

PROGRAM OPERATIONAL PROCEDURE

A.1 Program Operational Procedure

A.1.1 List of commands

BEGIN

[hp-pa] 1% `cd $HOME/BEAM`

[hp-pa] 2% `mkdir /tmp/des3hb`

[hp-pa] 3% `mv * /tmp/des3hb`

[hp-pa] 4% `cd /tmp/des3hb`

[hp-pa] 5% `pafec.init`

[hp-pa] 6% `uniras.init`

THEN compile FORTRAN programs

Pre and post-processing of data and construction of finite element mesh

[hp-pa] 7% `make` (Compile all FORTRAN programs)

A.1.1.1 List of Gravity Difference Method Commands

A.1.1.1.1 Pre-Processing of Data

[hp-pa] 1% `setenv file nodes1` (Variable file name which tab looks at to determine where put the data)

EDIT *tub1.in* (Input unexcavated ground and tunnel parameters)

[hp-pa] 2% `tub < tub1.in` (Run program, this creates *nodes1.DAT*)

After that RUN PAFEC-FE

[hp-pa] 3% `lj7 nodes1`

After running unexcavated ground, run excavated ground

[hp-pa] 4% `setenv file nodes2` (Variable file name which tab looks at to determine where put the data)

EDIT *tub2.in* (Input excavated ground and tunnel parameters)

[hp-pa] 5% `tub < tub2.in` (Run program, this creates *nodes2.DAT*)

After that RUN PAFEC-FE

[hp-pa] 6% `lj7 nodes2`

Then the gravity difference can be obtained by the following

[hp-pa] 7% `gravdif nodes1 nodes2 nodes3` (This processes and plots UNIRAS graph for three files (*nodes1, nodes2, nodes3*) and gets differences between two displacement and stress results. *nodes3.DAT* which will contain the gravity difference information, mainly displacements and Von Mises stresses.

A.1.1.1.2 Post-Processing of Results

EDIT files *nodes1.ras, nodes2.ras and nodes3.ras* respectively (Enter UNIRAS graph required input parameters)

Finally RUN UNIRAS

[hp-pa] 8% `plot nodes1` (Process and plot UNIRAS graphs)

[hp-pa] 9% `plot nodes2` (Process and plot UNIRAS graphs)

[hp-pa] 10% `plot nodes3` (Process and plot UNIRAS graphs)

A.1.1.2 List of Reverse Stress Technique Commands

A.1.1.2.1 Pre-Processing of Data

[hp-pa] 1% `setenv file nodes1` (Variable file name which tab looks at to determine where put the data)

EDIT *tub1.in* (Input unexcavated ground and tunnel parameters)

[hp-pa] 2% `tub < tub1.in` (Run program, this creates *nodes1.DAT*)

After that RUN PAFEC-FE

[hp-pa] 3% `lj7 nodes1`

After running unexcavated ground the reverse forces can be obtained by the following;

hp-pa] 4% `setenv unex nodes1` (This tells revforce2.f that *nodes1* is the file to be processed) [hp-pa] 5% `revforce2`

This creates the files *nodes1*.REVNUM containing number of entries in revforce2.f and *nodes1*.REVFOR containing reverse forces.

[hp-pa] 6% `setenv file nodes2` (Variable file name which tab looks at to determine where put the data)

EDIT *tub2.in* (Input excavated ground and tunnel parameters)

[hp-pa] 7% `tub < tub2.in` (Run program, this creates *nodes2.DAT*)

CUT OUT *GRAVITY* module and PASTE IN the contents of *nodes1*.REVFOR to the *nodes2.DAT* input file and save results some where else for example; *nodes4.DAT*

After that RUN PAFEC-FE

[hp-pa] 8% `lj7 nodes4`

A.1.1.2.2 Post-Processing of Results

EDIT file *nodes4.ras* (Enter UNIRAS graph required input parameters)

Finally RUN UNIRAS

[hp-pa] 9% `plot nodes4` (Processes and plot UNIRAS graphs)

APPENDIX B

EXAMPLE OF PAFEC-FE INPUT AND OUTPUT FILES

B.1 Example of a Two-Dimensional Model

B.1.1 A Two-Dimensional Model Pre-Processing Input File

```
KISIKLI NORTH TUBE HETEROGENEOUS WITHOUT SHOTCRETE LINING  (EXCAVATED GROUND)
Km 1+400
7.9         [INPUT CLEAR HEIGHT OF TUNNEL IN METRES]
13.0        [INPUT HEIGHT OF OVERBURDEN IN METRES]
4.5         [INPUT HEIGHT UNDER TUNNEL  IN METRES(Hover+Hover/2do)]
1           [INPUT NUMBER OF ROCK LAYERS]
22.0
3
2           [INPUT MATERIAL PROPERTY OF REST OF GROUND]
0.005       [MINOR (1/2) WIDTH OF STEEL ARCH = ? (SAMIN)]
0.08        [MAJOR (1/2) WIDTH OF STEEL ARCH ALONG THE Z AXIS = ? (SAMAJ)]
0.105       [MAJOR (1/2) WIDTH OF STEEL ARCH ALONG THE Y AXIS = ? (SAMAJ2)]
0           [IS A STEEL ARCH PRESENT ?  0) NO, 1) YES]
8           [WHAT IS THE MATERIAL PROPERTY OF THE STEEL ARCH USED]
6.0 0.5     [HEIGHT OF  ANCHORAGES 1 AND 2= ?]
4.0  4.0    [LENGTH OF  ANCHORAGES 1 AND 2= ?]
0.014       [RADIUS OF ANCHORAGES = ?]
25 -10      [ANGLE OF ANCHORAGES 1 AND 2= ?]
0           [ARE ANCHORAGES PRESENT ?  0) NO, 1) YES']
8           [WHAT IS THE MATERIAL PROPERTY OF THE ANCHORAGES USED ?]
0.35        [LENGTH OF (1/2) PERIOD = ?]
1           [INPUT WHAT ROCK TYPE OF EXCAVATION ?, 0)A,B OR 1)C]
0 0         [REGION: 1    C FOR EACH REGION INDICATE 0) IF EXCAVATED OR 1) IF NOT']
0 0         [REGION: 2A   C AND]
0 0         [REGION: 2B   C IS THERE AN OUTER (SHOTCRETE) LINING? 0) NO, 1) YES']
0 0         [REGION: 3A]
0 0         [REGION: 3B]
0 0         [REGION: 4]
0 0         [REGION: 5a]
0 0         [REGION: 5b]
0 0         [REGION: 6]
6           [WHAT IS THE MATERIAL PROPERTY OF THE SHOTCRETE USED ?]
0.25        [THICKNESS OF SHOTCRETE]
0           [IS THERE AN INNER LINING ?  0) NO, 1) YES]
7           [WHAT IS THE MATERIAL PROPERTY OF THE INNER LINING USED ?]
.5          [THICKNESS OF INNER LINING]
1           [RESOLUTION  (increase resolution number to achieve fine mesh)]
0           [IS THIS EXAMPLE A SYMMETRICAL MODEL ? MSYM.EQ 0) NO or 1) YES]
2           [NUMBER OF DIMENSIONS]
```

B.1.2 Generated a Two-Dimensional Model PAFEC-FE Input File

```
TITLE 2D-KISIKLI NORTH TUBE CO-ORDINATES AND FE-MESH DESIGN
 C Km (1+400)
 C
 C           APPLIED MECHANICS GROUP
 C            SCHOOL OF ENGINEERING
 C            UNIVERSITY OF DURHAM
 C
 C
 C TUNNEL NAME = KISIKLI
 C KM          = 1+400
 C CLEAR HEIGHT OF TUNNEL IN METERS =  7.9
 C HEIGHT OF OVERBURDEN IN METERS = 13.0
 C INPUT HEIGHT UNDER TUNNEL IN METERS = 4.5
 C INPUT NUMBER OF ROCK LAYERS = 1
 C HEIGHT OF LAYERS FROM GROUND SURFACE IN METERS = 22.0
 C MATERIAL PROPERTIES OF LAYER ,= 3
 C MATERIAL PROPERTY OF REST OF GROUND = 2
 C NUMBER OF SHELLS = 3
 C HEIGHT OF CIRCULAR SHELL NUMBER 1IN METRES =  .5
 C HEIGHT OF CIRCULAR SHELL NUMBER 2IN METRES =  .25
 C HEIGHT OF FLATTENED SHELL NUMBER   3IN METRES = 1.40
 C WHAT ROCK TYPE OF EXCAVATION ?, 0)A,B OR 1)C = 1
 C  C ROCK TYPE OF EXCAVATION
 C 1, 2A, 2B, 3A, 3B, 4, 5A, 5B, 6
 C REGIONS EXCAVATED:  1  2A 2B 3A 3B 4  5A 5B 6
 C MAJOR (1/2) WIDTH OF STEEL ARCH (Z)=  .080
 C 2nd MAJOR (1/2) WIDTH OF STEEL ARCH (Y) = .105
 C HEIGHT OF  ANCHORAGES 1 AND 2 =  6.0 .5
 C LENGTH OF ANCHORAGES 1 AND 2 =  4.0 4.0
 C RADIUS OF ANCHORAGES =  .014
 C ANGLE OF ANCHORAGES 1 AND 2= 25.0 -10.0
 C THE MATERIAL PRO.OF THE SHOTCRETE USED = 6
 C THICKNESS OF SHOTCRETE = .25
 C IS THERE AN INNER LINING ? = 0
 C 0) NO or 1) YES
 C THE MATERIAL PRO.OF THE INNER LINING = 7
 C THE THICKNESS OF THE INNER LINING .5
 C RESOLUTION = 1
 C IS THIS EXAMPLE A SYMMETRICAL MODEL ? =  0
 C 0) NO or 1) YES
 C NUMBER OF DIMENSIONS ? (2 OR 3) = 2
 C
 C THE CO-ORDINATES OF THE NODES CORRESPONDING TO
 C THE STRUCTURE ARE GIVEN BELOW EXPRESSED IN METERS.
 C
 C THERE IS ONLY NEED TO SPECIFY THE CORNER NODES
 C OF THE ELEMENTS, SINCE PAFEC WILL CALCULATE
 C AUTOMATICALLY THE CO-ORDINATES OF THE MID-SIDE NODES.
 C
 NODES
 NODES.NUMBER        X          Y          Z
    1              .00000    7.40000    .00000
    2              .60000    7.37564    .00000
    3             1.20000    7.30205    .00000
==========================================================================
   MAJORITY OF NODE CO-ORDINATES LIST OMITTED
==========================================================================
  440              .00000     .00000    .00000
  441              .00000   -1.44653    .00000
  442            -1.20000   -1.44653    .00000
  443             1.20000   -1.44653    .00000
  444            -3.20000   -1.44653    .00000
  445             3.20000   -1.44653    .00000
  446            -5.00000   -1.44653    .00000
  447             5.00000   -1.44653    .00000
  448            -5.89550   -1.44653    .00000
  449             5.89550   -1.44653    .00000
```

```
  450            -6.15922  -1.38538    .00000
  451             6.15922  -1.38538    .00000
  452              .00000    .00000    .00000
  905              .00000    .00000    .00000
  906             1.20363   1.59727    .00000
  907             -.68596   1.39867    .00000
  908             5.79084   -.83147    .00000
  909              .00000  28.95983    .00000
  910              .00000    .00000    .00000
  911            -1.20363   1.59727    .00000
  912              .68596   1.39867    .00000
  913            -5.79084   -.83147    .00000
  914              .00000  28.95983    .00000
C
C
PAFBLOCKS
BLOCK.NUMBER TYPE ELEMENT.TYPE PROPERTIES N1 N2 N5 TOPOLOGY
       1     1 36210     9     1     1     0   1   3  69  71   2   0   0  70
       2     1 36210     9     1     1     0   3   5  71  73   4   0   0  72
       3     1 36210     9     1     1     0   5   7  73  75   6   0   0  74
=============================================================================
              MAJORITY OF PAFBLOCK TOPOLOGY LIST OMITTED
=============================================================================
     238     1 36210     9     1     1     0 435 437 447 449   0   0   0   0
     239     1 36210     9     1     1     0 437 439 449 451   0   0   0   0
     240     1 36210     9     1     1     0 430 429 442 441   0   0   0   0
     241     1 36210     9     1     1     0 432 430 444 442   0   0   0   0
     242     1 36210     9     1     1     0 434 432 446 444   0   0   0   0
     243     1 36210     9     1     1     0 436 434 448 446   0   0   0   0
     244     1 36210     9     1     1     0 438 436 450 448   0   0   0   0
C
C Define local axis and directions
C
AXES
RELAXISNO = 1
TYPE = 1
AXISNO   NODE   ANG1
4 905 .0
5 905 -4.22191376007178
6 905 -8.466971581149
7 905 -15.6606162210402
8 905 -23.1187456601791
9 905 -25.7116177044377
10 905 -28.173097145412
=============================================================================
MAJORITY OF LOCAL AXIS LIST OMITTED
=============================================================================
65 910 30.51675355503308
66 910 28.17309714541204
67 910 25.71161770443768
68 910 23.11874566017914
69 910 15.66061622104018
70 910 8.466971581149
71 910 4.22191376007178
C
C
LOCAL.DIRECTIONS
NODE.NUMBER  LOCAL.AXIS
137 4
138 5
139 6
140 7
141 8
142 9
143 10

=============================================================================
MAJORITY OF LOCAL DIRECTION LIST OMITTED
=============================================================================
201 68
202 69
203 70
204 71
```

```
C
C Elements which form the Excavated Surface
EXTERNAL.FORCE
AXIS.SET = 1
LIST
69
70
71
================================================================================
MAJORITY OF EXTERNAL FORCE LIST OMITTED
================================================================================
99
100
101
102
C
C The PLATES.AND.SHELLS module is used to
C link the PROPERTIES
C specified in the ELEMENTS module with
C the MATERIAL.NUMBER
C used in the MATERIAL module.
C
PLATES.AND.SHELLS
PLATE.NUMBER   MATERIAL.NUMBER
1                 11
2                 12
3                 13
4                 14
5                 15
6                 16
7                 17
8                 18
9                 19
C
C In the MATERIAL module the Young's modulus (E),
C the Poisson's ratio
C (NU) and the density (RO),are specified for
C Neogene cover (MATERIAL.NUMBER 11),
C the micaceous sandstone,
C siltstone and claystone (MATERIAL.NUMBER 12),
C the quartzite
C (MATERIAL.NUMBER 13), the arkose,
C conglomeratic arkose (MATERIAL.NUMBER 14),
C the volcanic dyke rock (MATERIAL.NUMBER 15),
C Shotcrete (MATERIAL.NUMBER 16),
C Inner (final) lining (MATERIAL.NUMBER 17).
C Mild steel for anchorages and steel arch
C beam element (MATERIAL.NUMBER 18).
C
C The unit used for Young's modulus is Pa (N/m2)
C and the density is expressed
C in (kg/m3).
C
MATERIAL
MATERIAL.NUMBER        E         NU         RO
    11               90E+6     0.35        2060
    12               0.7E+9    0.27        2200
    13               68E+9     0.16        2600
    14               15E+9     0.26        2600
    15               1.9E+9    0.28        2300
    16               15E+9     0.20        2000
    17               30E+9     0.20        2400
    18               209E+9    0.30        7800
    19               0E-9     0.499        0.0
C
C In the GRAVITY module the sign in the YGVALUE
C is negative,
C indicating that gravity acts in the vertical
C downwards direction.
C
GRAVITY
XGVALUE    YGVALUE
  0          -1
```

```
C
C To ensure that the nodes lying on the boundary
C are restricted from
C moving in the horizontal direction, all nodes
C lying on the plane that
C passes through boundary and is normal to
C the x-axis (PLANE 1),are
C prevented from moving along the x-direction
C (DIRECTION 1).
C Similarly, the right side boundary is also
C prevented from moving along the
C horizontal direction.
C In this way the horizontal geostatic stresses
C are allowed to develop as a
C function of Poisson's ratio of the ground.
C
C Furthermore there is a need to restrict the
C lower boundary of the mesh
C from moving in the vertical directions a restraint
C is introduced to
C prevent any node lying on the plane and is normal
C to y-axis (PLANE 2),
C and is normal to y-axis (PLANE 2), to move
C (DIRECTION 2).
C
C
RESTRAINTS
NODE.NUMBER  PLANE    AXIS.NUMBER      DIRECTION
  343          1           1               1
  343          2           1               2
  345          1           1               1
C
C The CONTROL facility is used to specify
C plane strain analysis and to
C indicate that stress averaging across
C different material types is to be
C performed.
C
CONTROL
PLANE.STRAIN
USE.R70632MOD
C
C Since PAFEC-FE does not perform stress averaging
C across different
C material types, the supplied source must be modified
C Inspection of the
C stressing routines indicated that a small number of
C changes to PAFEC-FE
C subroutine R70632 was necessary. A section of the
C subroutine with the
C modification is shown in Figure
C The modified source is incorporated
C into the PAFEC-FE system for this analysis
C using the USE.option.
C
STRESS
CONTROL.END
C
PROCESSING.FOR.PRINTED.OUTPUT
ORDER  FORMAT.TYPE LOCAL.AXIS  WINDOW
  1           1           1          0
  2           1           1          0
C
ORDER.FOR.PRINTED.OUTPUT
ORDER    LIST.OF.TYPES
 1       101  103   102   4   8  9   10 11 12 13
 2       101        102   4   8  9   10 11 12 13
END.OF.DATA
```

B.1.2.1 A Two-Dimensional Nodal Co-ordinates and Element Topology Output File (*file$.O02*)

```
1
PAFEC PAGE          41

                                                 PPPPP  AAAAA FFFFF EEEEE CCCCC
  SYSTEM LEVEL 7.400 A                           P   P  A   A FF    E     C  CC
  JUNE 1992                                      P   P  A   A FF    E     C
                                                 PPPPP  AAAAA FFF   EEE   C
                                                 PP     AA   A F    EE    C
  PHASE NO.  2                                   PP     AA   A F    EE    C
  STARTS HERE                                    PP     AA   A F    EE    C
                                                 PP     AA   A F    EEEEE CCCCC

  TITLE 2D-TUNNEL COORDINATES AND FE-MESH DESIGN
                                         ----------------------------------------------------
                                               THE TOLERANCE USED IN THIS PHASE IS 1E -4
                                         ----------------------------------------------------

 GLOBAL COORDINATES
 ------------------

 --------------------------------                    ----------------------------------------
NODE      X          Y          Z                          NODE      X          Y          Z
 --------------------------                       -----------------------------------------
1       .0000     7.4000     .0000                          2       .6020     7.3755     .0000
3      1.2000     7.3021     .0000                          4      2.2224     7.0584     .0000
5      3.2000     6.6723     .0000                          6      3.4190     6.5628     .0000
7      3.6343     6.4461     .0000                          8      3.8457     6.3223     .0000
9      4.0528     6.1915     .0000                          10     4.2554     6.0540     .0000
==============================================================================================
                                   MAJORITY OF NODE CO-ORDINATES LIST OMITTED
==============================================================================================
1630      5.7444    -.8204      .0000                        1631     5.4109    -1.1408     .0000
1632      6.0092    -1.1408     .0000                        1633    -1.2000    -.8204      .0000
1634      -.6000    -1.1408     .0000                        1635    -3.2000    -.8204      .0000
1636     -2.2000    -1.1408     .0000                        1637    -4.6800    -.8204      .0000
1638     -4.1000    -1.1408     .0000                        1639    -5.7444    -.8204      .0000
1640     -5.4109    -1.1408     .0000                        1641    -6.0092    -1.1408     .0000
1642       .0000    -1.2936     .0000                        1643     1.2000    -1.2936     .0000
1644      3.2000    -1.2936     .0000                        1645     5.0000    -1.2936     .0000
1646      5.8586    -1.2936     .0000                        1647    -1.2000    -1.2936     .0000
1648     -3.2000    -1.2936     .0000                        1649    -5.0000    -1.2936     .0000
1650     -5.8586    -1.2936     .0000
 ----------------------------------------                    ------------------------------------

   * COMMENT *  COORDINATES OF NON-STRUCTURAL NODES ARE NOT INCLUDED IN THE ABOVE TABLE

                NUMBER OF STRUCTURAL NODES IN THIS PHASE =        1131
                HIGHEST NUMBERED NODE IN THIS PHASE IS   =        1650

  ELEMENTS
  --------

----------------------------------------------------------------------------------------------
  ELEMENT  GROUP ELEM.TYPE PROPERTY INE    TOPOLOGY
----------------------------------------------------------------------------------------------
1     1    36210      9      8      1      3      69     71     2     915     916     70
2     1    36210      9      8      3      5      71     73     4     916     917     72
3     1    36210      9      8      5      7      73     75     6     917     918     74
4     1    36210      9      8      7      9      75     77     8     918     919     76
5     1    36210      9      8      9     11      77     79    10     919     920     78
==============================================================================================
                                   MAJORITY PF ELEMENT TOPOLOGY LIST OMITTED
==============================================================================================
```

350	1	36210	9	8	435	437	447	449	1631	1645	1646	1488
351	1	36210	9	8	437	439	449	451	1632	1646	1484	1486
352	1	36210	9	8	430	429	442	441	1634	1647	1642	1496
353	1	36210	9	8	432	430	444	442	1636	1648	1647	1498
354	1	36210	9	8	434	432	446	444	1638	1649	1648	1500
355	1	36210	9	8	436	434	448	446	1640	1650	1649	1502
356	1	36210	9	8	438	436	450	448	1641	1506	1650	1504

```
1
PAFEC PAGE          64

 ---------------------------------------------------------------------------------------------------
   ELEMENT  GROUP ELEM.TYPE PROPERTY INE    TOPOLOGY
 ---------------------------------------------------------------------------------------------------
 ---------------------------------------------------------------------------------------------------

    END OF PAFBLOCKS GENERATION

 **********************************
 *                                *
 *    NO ERRORS IN GEOMETRY CHECK *
 *                                *
 *  60 WARNINGS IN GEOMETRY CHECK *
 *                                *
 **********************************


 END OF PAFBLOCKS DATA GENERATION

 E S T I M A T E   O F   B A S E   A N D   F I L E   S I Z E   R E Q U I R E M E N T S   ( B )
 ===================================================================================================

 NOTE - (1) AN ASTERISK * DENOTES AN OVERESTIMATE

 ------------------------------------------------
 PHASE    BASE/FILE    SINGLE PRECISION NUMBERS.
 ------------------------------------------------
     3       BASE                 17017
     4       BASE                 52145*
 ------------------------------------------------
1
PAFEC PAGE          68

 C O N T E N T S
 ===============

 ---------------------------------------------
 HEADING                                  PAGE
 ---------------------------------------------
 PHASE  2                                   41

 ESTIMATE OF BASE AND FILE SIZE
 REQUIREMENTS (B)                           67

 ---------------------------------------------

 **********************************
 *                                *
 *    0 ERRORS IN THIS PHASE      *
 *                                *
 *   56 WARNINGS IN THIS PHASE    *
 *                                *
 **********************************

 **** MAXIMUM SIZE OF BASE IN THIS PHASE WAS    21489 WORDS ****

 +++ END OF PHASE  2 +++
```

B.1.2.2 A Two-Dimensional Model Displacement Output File (*file$.O07*)

```
1
PAFEC PAGE        112


                                          PPPPP  AAAAA FFFFF EEEEE CCCCC
 SYSTEM LEVEL 7.400 A                     P   P  A   A FF    E     C   CC
 JUNE 1992                                P   P  A   A FF    E     C
                                          PPPPP  AAAAA FFF   EEE   C
                                          PP     AA  A F     EE    C
 PHASE NO.  7                             PP     AA  A F     EE    C
 STARTS HERE                              PP     AA  A F     EE    C
                                          PP     AA  A F     EEEEE CCCCC

 TITLE 2D-TUNNEL COORDINATES AND FE-MESH DESIGN
                                    ****************************************
                                    *                                      *
                                    * STATICS  SOLUTION BY BLOCK FRONT     *
                                    *         IN DOUBLE PRECISION          *
                                    *  THE PLANE.STRAIN OPTION IS PRESENT  *
                                    *                                      *
                                    *   STRUCTURE CONTAINS  2175 FREEDOMS  *
                                    *                        356 ELEMENTS  *
                                    *     AND THE FRONT SIZE IS   107      *
                                    *                                      *
                                    ****************************************

0                    *** A BLOCKED FRONT SOLUTION HAS BEEN REQUESTED ***
0                                THE BLOCK SIZE IS     11556
1
PAFEC PAGE        129
 D I S P L A C E M E N T S   F O R   L O A D   C A S E     1
 ============================================================


 NOTE - (1) THE  LETTER  L  FOLLOWING A NODE NUMBER INDICATES
            THAT THE DISPLACEMENTS  AT THAT NODE ARE GIVEN IN
            THE LOCAL DIRECTIONS DEFINED AT THE NODE


OSAMPLE OF LARGEST DISPLACEMENTS
 --------------------------------


 -------------------     -------------------     -------------------
  NODE        UX          NODE        UY          NODE     RESULTANT
 -------------------     -------------------     -------------------
   153L    0.0042841      1249    -0.0044235      1249      0.0044235
   189L   -0.0042836      1246    -0.0044231      1246      0.0044231
   188L   -0.0042822      1247    -0.0044229      1247      0.0044229
   154L    0.0042822      1410    -0.0044229      1410      0.0044229
   187L   -0.0042299      1250    -0.0044228      1250      0.0044228
   155L    0.0042299      1407    -0.0044228      1407      0.0044228
   186L   -0.0041791       305    -0.0044228       305      0.0044228
   156L    0.0041791      1251    -0.0044227      1251      0.0044227
   185L   -0.0041137      1411    -0.0044227      1411      0.0044227
   157L    0.0041137      1406    -0.0044224      1406      0.0044224
 -------------------     -------------------     -------------------

 DISPLACEMENTS AT NODES
 ----------------------
```

NOTE - (2) THE HISTOGRAM INDICATES THE MAGNITUDE OF THE RESULTANT TRANSLATION AT EACH NODE. EACH STAR * REPRESENTS .4422E-03 UNITS

(3) A STAR * IN A DISPLACEMENT COLUMN INDICATES THAT A CONSTRAINT HAS BEEN APPLIED.

(4) ONLY STRUCTURAL NODES ARE GIVEN IN THE TABLE BELOW

1

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CASE 1 NODE NUMBER	TRANSLATIONS MULTIPLIED BY 1E 3 UX	UY	RESULTANT TRANSLATION MULTIPLIED BY 1E 3 U	HISTOGRAM	SCALED COORDINATES MULTIPLIED BY 1E 0 X	Y	Z
1	0.0000	0.0000	0.0000		0.00	7.40	
2	0.0000	0.0000	0.0000		0.60	7.38	
3	0.0000	0.0000	0.0000		1.20	7.30	
4	0.0000	0.0000	0.0000		2.22	7.06	
5	0.0000	0.0000	0.0000		3.20	6.67	
MAJORITY OF DISPLACEMENTS OMITTED							
135	0.0000	0.0000	0.0000		-1.20	7.81	
136	0.0000	0.0000	0.0000		-0.60	7.88	
137L	0.0000	-4.4215	4.4215	**********	0.00	8.15	
138L	0.3268	-4.4090	4.4211	**********	0.60	8.13	
139L	0.6535	-4.3713	4.4199	**********	1.20	8.06	
140L	1.1968	-4.2505	4.4158	**********	2.22	7.84	
141L	1.7376	-4.0523	4.4092	**********	3.20	7.50	
142L	1.9185	-3.9667	4.4063	**********	3.53	7.35	
143L	2.0860	-3.8776	4.4031	**********	3.85	7.18	
144L	2.2416	-3.7862	4.4000	**********	4.13	7.02	
145L	2.3865	-3.6926	4.3966	**********	4.41	6.85	
146L	2.5220	-3.5973	4.3933	**********	4.66	6.69	
147L	2.6493	-3.5002	4.3897	**********	4.90	6.51	
148L	2.8188	-3.3603	4.3860	**********	5.15	6.32	
149L	2.9807	-3.2120	4.3820	**********	5.38	6.11	
150L	3.2816	-2.8941	4.3755	**********	5.72	5.76	
151L	3.4448	-2.6857	4.3680	**********	6.05	5.39	
152L	4.0536	-1.5470	4.3388	**********	6.91	3.89	
153L	4.2841	-0.4273	4.3053	**********	7.32	2.21	
154L	4.2822	0.0349	4.2823	**********	7.36	1.33	
155L	4.2299	0.4899	4.2582	**********	7.31	0.46	
156L	4.1791	0.7319	4.2427	**********	7.24	-0.02	
157L	4.1137	0.9693	4.2264	**********	7.14	-0.50	
158L	4.0614	1.1220	4.2135	**********	7.05	-0.82	
159L	4.0033	1.2705	4.2001	*********	6.95	-1.14	
160L	2.9213	1.7750	3.4182	********	6.81	-1.47	
161L	1.8993	1.6324	2.5044	******	6.58	-1.74	
162L	1.2013	1.5049	1.9256	****	6.32	-1.91	

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CASE 1 NODE NUMBER	TRANSLATIONS MULTIPLIED BY 1E 3 UX	UY	RESULTANT TRANSLATION MULTIPLIED BY 1E 3 U	HISTOGRAM	SCALED COORDINATES MULTIPLIED BY 1E 0 X	Y	Z
163L	0.6601	1.2818	1.4418	***	6.02	-2.01	
164L	0.5659	0.7447	0.9353	**	5.51	-2.10	
165L	0.5437	0.4052	0.6781	**	5.00	-2.18	
166L	0.5218	0.0349	0.5230	*	4.10	-2.31	
167L	0.4992	-0.1263	0.5149	*	3.20	-2.42	
168L	0.3872	-0.1899	0.4312	*	2.20	-2.50	
169L	0.2307	-0.2032	0.3074	*	1.20	-2.56	
170L	0.1177	-0.2011	0.2330	*	0.60	-2.57	
171L	-0.0000	-0.2005	0.2005		0.00	-2.58	
172L	-0.1177	-0.2011	0.2330	*	-0.60	-2.57	
173L	-0.2307	-0.2032	0.3074	*	-1.20	-2.56	
174L	-0.3872	-0.1899	0.4312	*	-2.20	-2.50	
175L	-0.4992	-0.1263	0.5149	*	-3.20	-2.42	
176L	-0.5218	0.0349	0.5230	*	-4.10	-2.31	

177L	-0.5437	0.4052	0.6781	**	-5.00	-2.18
178L	-0.5659	0.7447	0.9353	**	-5.51	-2.10
179L	-0.6601	1.2818	1.4418	***	-6.02	-2.01
180L	-1.2013	1.5049	1.9256	****	-6.32	-1.91
181L	-1.8993	1.6324	2.5044	******	-6.58	-1.74
182L	-2.9213	1.7750	3.4182	********	-6.81	-1.47
183L	-4.0732	1.0248	4.2001	*********	-6.95	-1.14
184L	-4.0614	1.1220	4.2135	**********	-7.05	-0.82
185L	-4.1137	0.9693	4.2264	**********	-7.14	-0.50
186L	-4.1791	0.7319	4.2427	**********	-7.24	-0.02
187L	-4.2299	0.4899	4.2582	**********	-7.31	0.46
188L	-4.2822	0.0349	4.2823	**********	-7.36	1.33
189L	-4.2836	-0.4317	4.3053	**********	-7.32	2.21
190L	-4.0536	-1.5470	4.3388	**********	-6.91	3.89
191L	-3.4448	-2.6857	4.3680	**********	-6.05	5.39
192L	-3.2816	-2.8941	4.3755	**********	-5.72	5.76
193L	-2.9807	-3.2120	4.3820	**********	-5.38	6.11
194L	-2.8188	-3.3603	4.3860	**********	-5.15	6.32
195L	-2.6493	-3.5002	4.3897	**********	-4.90	6.51
196L	-2.5220	-3.5973	4.3933	**********	-4.66	6.69
197L	-2.3865	-3.6926	4.3966	**********	-4.41	6.85
198L	-2.2416	-3.7862	4.4000	**********	-4.13	7.02
199L	-2.0860	-3.8776	4.4031	**********	-3.85	7.18
200L	-1.9185	-3.9667	4.4063	**********	-3.53	7.35
201L	-1.7376	-4.0523	4.4092	**********	-3.20	7.50
202L	-1.1968	-4.2505	4.4158	**********	-2.22	7.84
203L	-0.6535	-4.3713	4.4199	**********	-1.20	8.06
204L	-0.3268	-4.4090	4.4211	**********	-0.60	8.13
205	-0.0000	-4.4215	4.4215	**********	0.00	9.55
206	-0.0002	-4.4211	4.4211	**********	0.60	9.55

MAJORITY OF DISPLACEMENTS OMITTED

1646	0.0000	0.0000	0.0000		5.86	-1.29
1647	0.0000	0.0000	0.0000		-1.20	-1.29
1648	0.0000	0.0000	0.0000		-3.20	-1.29
1649	0.0000	0.0000	0.0000		-5.00	-1.29
1650	0.0000	0.0000	0.0000		-5.86	-1.29

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F O R C E S O N E L E M E N T S

NOTE - (1) AN E IN THE AXIS SET COLUMN INDICATES THAT THE FORCES ON EACH ELEMENT ARE GIVEN IN LOCAL ELEMENT AXES. THE LOCAL ELEMENT AXIS SET IS FORMED BY AN X-AXIS POSITIVE FROM THE FIRST NODE IN THE TOPOLOGY TO THE SECOND. THE Y-AXIS PASSES THROUGH THE FIRST NODE NORMAL TO THE X-AXIS IN THE PLANE OF THE FIRST THREE NODES AND IS POSITIVE TOWARDS THE THIRD.

(2) FORCES AT NODES WHICH HAVE LOCAL.DIRECTIONS ARE ONLY GIVEN IN THOSE LOCAL DIRECTIONS IF THE AXIS SET REQUESTED IS THE GLOBAL SET. IN SUCH A CASE THE NODE NUMBER IN THE TABLE IS FOLLOWED BY AN L.

ELEM NUMB	ELEM TYPE	GROUP NUMB	LOAD CASE	NODE NUMB	AXIS SET	FORCES F-X	F-Y	F-Z
69	36210	1	1	137L	4	-34942.558	3672.729	
69	36210	1	1	139L	6	28287.779	6056.435	
69	36210	1	1	205	1	5895.122	7083.367	
69	36210	1	1	207	1	1393.747	16926.392	
69	36210	1	1	138L	5	1098.619	-14528.963	
69	36210	1	1	983	1	-50979.718	-14424.025	
69	36210	1	1	984	1	34064.605	4658.478	

```
     69 36210       1      1    206     1      15671.570   -5171.875
===============================================================================================
            MAJORITY OF FORCES ON ELEMENTS OMITTED
===============================================================================================
    102 36210       1      1    203L   70    -28300.384    6043.812
    102 36210       1      1    137L    4     34935.066    3661.636
    102 36210       1      1    271     1     -1395.653   16927.546
    102 36210       1      1    205     1     -5910.344    7069.922
    102 36210       1      1    204L   71     -1061.499  -14527.283
    102 36210       1      1   1032     1    -34060.820    4670.281
    102 36210       1      1    983     1     50971.359  -14439.428
    102 36210       1      1    272     1    -15668.653   -5134.962
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 C O N T E N T S
 ===============

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 HEADING                                 PAGE
 --------------------------------------------
 PHASE  7                                 112

 DISPLACEMENTS                            129

 FORCES ON ELEMENTS                       151

 --------------------------------------------


 **********************************
 *                                *
 *     0 ERRORS IN THIS PHASE     *
 *                                *
 *   966 WARNINGS IN THIS PHASE   *
 *                                *
 **********************************


 **** MAXIMUM SIZE OF BASE IN THIS PHASE WAS     29840 WORDS ****

 +++ END OF PHASE  7 +++
```

B.1.2.3 A Two-Dimensional Stress Output File (*file$.O09*)

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                                       PPPPP  AAAAA FFFFF EEEEE CCCCC
  SYSTEM LEVEL 7.400 A                 P   P  A   A FF    E     C  CC
  JUNE 1992                            P   P  A   A FF    E     C
                                       PPPPP  AAAAA FFF   EEE   C
                                       PP     AA    A F   EE    C
  PHASE NO.  9                         PP     AA    A F   EE    C
  STARTS HERE                          PP     AA    A F   EE    C
                                       PP     AA    A F   EEEEE CCCCC

  TITLE 2D-TUNNEL COORDINATES AND FE-MESH DESIGN

 DEFAULT STRESS.ELEMENTS MODULE CREATED.
1
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    ELEMENT TYPE 36210  8-NODE ISOPARAMETRIC QUADRILATERAL( PLANE STRAIN ) ISOTROPIC
    ---------------------------------------------------------------------------------

    PRINCIPAL STRESSES  -  SIGMA-1 IS THE MAXIMUM VALUE OF STRESS IN THE PLANE OF THE ELEMENT
                           SIGMA-2 IS THE MINIMUM VALUE OF STRESS IN THE PLANE OF THE ELEMENT

                           SIGMA-3 IS THE PRINCIPAL STRESS NORMAL TO THE PLANE OF THE ELEMENT

    ANGLES OF SIGMA-1   -  LOCAL  ANGLE IS MEASURED  POSITIVE  FROM THE  ELEMENT  X-AXIS IN A
                           POSITIVE SENSE ABOUT THE ELEMENT Z-AXIS
                           GLOBAL ANGLE IS PRINTED IF THE ELEMENT LIES WITHIN  TOLERANCE OF A
                           GLOBAL PLANE. FOR ELEMENTS IN THE  XY PLANE THE ANGLE IS  MEASURED
                           FROM THE X-AXIS IN A POSITIVE  SENSE ABOUT THE Z-AXIS OR BY CYCLIC
                           PERMUTATION FOR OTHER PLANES

    ELEMENT STRESSES    -  STRESS COMPONENTS REFERRED TO ELEMENT AXES
```

ELEM NO	LOAD CASE	NODE NO	PRINCIPAL.STRESSES SIGMA-1	SIGMA-2	SIGMA-3	MAX.SHEAR STRESS	ANG.OF.SIG-1 LOCAL	GLOBAL	ELEMENT.STRESSES..... SIGMA-X	SIGMA-Y	SIGMA-XY
1	1	1	.00E+00	.00E+00	.00E+00	.00E+00	.0	-4.7	.00D+00	.00D+00	.00D+00
1	1	2	.00E+00	.00E+00	.00E+00	.00E+00	.0	-4.7	.00D+00	.00D+00	.00D+00
1	1	3	.00E+00	.00E+00	.00E+00	.00E+00	.0	-4.7	.00D+00	.00D+00	.00D+00
1	1	915	.00E+00	.00E+00	.00E+00	.00E+00	.0	-4.7	.00D+00	.00D+00	.00D+00
1	1	*	.00E+00	.00E+00	.00E+00	.00E+00	.0	-4.7	.00D+00	.00D+00	.00D+00
1	1	916	.00E+00	.00E+00	.00E+00	.00E+00	.0	-4.7	.00D+00	.00D+00	.00D+00
1	1	69	.00E+00	.00E+00	.00E+00	.00E+00	.0	-4.7	.00D+00	.00D+00	.00D+00
1	1	70	.00E+00	.00E+00	.00E+00	.00E+00	.0	-4.7	.00D+00	.00D+00	.00D+00
1	1	71	.00E+00	.00E+00	.00E+00	.00E+00	.0	-4.7	.00D+00	.00D+00	.00D+00
2	1	3	.00E+00	.00E+00	.00E+00	.00E+00	.0	-17.5	.00D+00	.00D+00	.00D+00
2	1	4	.00E+00	.00E+00	.00E+00	.00E+00	.0	-17.5	.00D+00	.00D+00	.00D+00
2	1	5	.00E+00	.00E+00	.00E+00	.00E+00	.0	-17.5	.00D+00	.00D+00	.00D+00
2	1	916	.00E+00	.00E+00	.00E+00	.00E+00	.0	-17.5	.00D+00	.00D+00	.00D+00
2	1	*	.00E+00	.00E+00	.00E+00	.00E+00	.0	-17.5	.00D+00	.00D+00	.00D+00
2	1	917	.00E+00	.00E+00	.00E+00	.00E+00	.0	-17.5	.00D+00	.00D+00	.00D+00
2	1	71	.00E+00	.00E+00	.00E+00	.00E+00	.0	-17.5	.00D+00	.00D+00	.00D+00
2	1	72	.00E+00	.00E+00	.00E+00	.00E+00	.0	-17.5	.00D+00	.00D+00	.00D+00
2	1	73	.00E+00	.00E+00	.00E+00	.00E+00	.0	-17.5	.00D+00	.00D+00	.00D+00
MAJORITY OF STRESESS OMITTED											
69	1	137	1.61E+05	9.21E+03	2.73E+04	7.61E+04	4.0	-.2	1.61D+05	9.95D+03	1.06D+04
69	1	138	1.51E+05	9.05E+03	2.56E+04	7.10E+04	1.2	-3.1	1.51D+05	9.11D+03	2.88D+03
69	1	139	1.24E+05	2.78E+03	2.02E+04	6.05E+04	-.4	-4.7	1.24D+05	2.79D+03	-9.04D+02
69	1	983	4.99E+04	1.27E+04	1.00E+04	1.99E+04	4.9	.7	4.96D+04	1.29D+04	3.18D+03
69	1	*	4.64E+04	8.37E+03	8.77E+03	1.90E+04	18.6	14.4	4.25D+04	1.23D+04	1.15D+04
69	1	984	4.35E+04	-6.91E+03	5.86E+03	2.52E+04	32.3	28.1	2.91D+04	7.53D+03	2.28D+04
69	1	205	2.53E+04	-1.33E+04	1.93E+03	1.93E+04	-86.0	89.8	-1.31D+04	2.51D+04	-2.71D+03
69	1	206	3.25E+04	-2.82E+04	6.89E+02	3.03E+04	68.2	63.9	-1.98D+04	2.41D+04	2.09D+04
69	1	207	4.78E+04	-5.59E+04	-1.31E+03	5.19E+04	58.4	54.2	-2.74D+04	1.93D+04	4.63D+04

70	1	139	1.29E+05	3.16E+03	2.12E+04	6.32E+04	9.7	-6.1	1.26D+05	6.78D+03	2.11D+04
70	1	140	4.45E+04	3.84E+03	7.73E+03	2.03E+04	17.2	1.4	4.09D+04	7.41D+03	1.15D+04
70	1	141	-5.88E+02	-9.76E+04	-1.57E+04	4.85E+04	68.8	53.0	-8.49D+04	-1.33D+04	3.27D+04
70	1	984	4.26E+04	-1.27E+04	4.80E+03	2.76E+04	48.2	32.4	1.19D+04	1.81D+04	2.75D+04
70	1	*	3.76E+04	-6.25E+04	-3.99E+03	5.00E+04	58.5	42.8	-3.53D+04	1.03D+04	4.45D+04
70	1	985	3.67E+04	-1.52E+05	-1.85E+04	9.46E+04	59.1	43.3	-1.03D+05	-1.32D+04	8.33D+04
70	1	207	4.65E+04	-6.76E+04	-3.39E+03	5.70E+04	71.4	55.6	-5.61D+04	3.49D+04	3.44D+04
70	1	208	5.38E+04	-1.28E+05	-1.19E+04	9.09E+04	62.1	46.3	-8.82D+04	1.40D+04	7.52D+04
70	1	209	6.63E+04	-2.14E+05	-2.37E+04	1.40E+05	56.8	41.0	-1.30D+05	-1.78D+04	1.29D+05

MAJORITY OF STRESSES OMITTED

252	1	239	-2.16E+04	-1.83E+05	-5.53E+04	8.07E+04	-89.8	-89.8	-1.83D+05	-2.16D+04	-4.52D+02
252	1	1010	-2.17E+04	-1.83E+05	-5.52E+04	8.06E+04	-88.1	-88.1	-1.83D+05	-2.18D+04	-5.31D+03
252	1	241	-2.28E+04	-1.84E+05	-5.57E+04	8.05E+04	-86.3	-86.3	-1.83D+05	-2.34D+04	-1.03D+04
252	1	1413	-4.43E+04	-2.18E+05	-7.08E+04	8.67E+04	-89.9	-89.9	-2.18D+05	-4.43D+04	-2.38D+02
252	1	*	-4.49E+04	-2.19E+05	-7.12E+04	8.69E+04	-89.0	-89.0	-2.19D+05	-4.49D+04	-2.92D+03
252	1	1458	-4.67E+04	-2.20E+05	-7.21E+04	8.68E+04	-88.1	-88.1	-2.20D+05	-4.69D+04	-5.79D+03
252	1	331	-6.01E+04	-2.34E+05	-7.94E+04	8.69E+04	90.0	90.0	-2.34D+05	-6.01D+04	-6.00D-03
252	1	1460	-6.11E+04	-2.36E+05	-8.02E+04	8.74E+04	-89.8	-89.8	-2.36D+05	-6.11D+04	-5.09D+02
252	1	355	-6.35E+04	-2.38E+05	-8.15E+04	8.75E+04	-89.6	-89.6	-2.38D+05	-6.35D+04	-1.20D+03
253	1	357	.00E+00	.00E+00	.00E+00	.00E+00	.0	.0	.00D+00	.00D+00	.00D+00
253	1	1461	.00E+00	.00E+00	.00E+00	.00E+00	.0	.0	.00D+00	.00D+00	.00D+00
253	1	359	.00E+00	.00E+00	.00E+00	.00E+00	.0	.0	.00D+00	.00D+00	.00D+00
253	1	1462	.00E+00	.00E+00	.00E+00	.00E+00	.0	.0	.00D+00	.00D+00	.00D+00
253	1	*	.00E+00	.00E+00	.00E+00	.00E+00	.0	.0	.00D+00	.00D+00	.00D+00
253	1	1463	.00E+00	.00E+00	.00E+00	.00E+00	.0	.0	.00D+00	.00D+00	.00D+00
253	1	69	.00E+00	.00E+00	.00E+00	.00E+00	.0	.0	.00D+00	.00D+00	.00D+00
253	1	70	.00E+00	.00E+00	.00E+00	.00E+00	.0	.0	.00D+00	.00D+00	.00D+00
253	1	71	.00E+00	.00E+00	.00E+00	.00E+00	.0	.0	.00D+00	.00D+00	.00D+00

MAJORITY OF STRESSES OMITTED

356	1	438	.00E+00	.00E+00	.00E+00	.00E+00	.0	.0	.00D+00	.00D+00	.00D+00
356	1	1641	.00E+00	.00E+00	.00E+00	.00E+00	.0	.0	.00D+00	.00D+00	.00D+00
356	1	436	.00E+00	.00E+00	.00E+00	.00E+00	.0	.0	.00D+00	.00D+00	.00D+00
356	1	1506	.00E+00	.00E+00	.00E+00	.00E+00	.0	.0	.00D+00	.00D+00	.00D+00
356	1	*	.00E+00	.00E+00	.00E+00	.00E+00	.0	.0	.00D+00	.00D+00	.00D+00
356	1	1650	.00E+00	.00E+00	.00E+00	.00E+00	.0	.0	.00D+00	.00D+00	.00D+00
356	1	450	.00E+00	.00E+00	.00E+00	.00E+00	.0	.0	.00D+00	.00D+00	.00D+00
356	1	1504	.00E+00	.00E+00	.00E+00	.00E+00	.0	.0	.00D+00	.00D+00	.00D+00
356	1	448	.00E+00	.00E+00	.00E+00	.00E+00	.0	.0	.00D+00	.00D+00	.00D+00

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C O N T E N T S


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***********************************
*                                 *
*     0 ERRORS IN THIS PHASE      *
*                                 *
*    92 WARNINGS IN THIS PHASE    *
*                                 *
***********************************
```

**** MAXIMUM SIZE OF BASE IN THIS PHASE WAS 232111 WORDS ****

+++ END OF PHASE 9 +++

B.1.2.4 A Two-Dimensional Averaged and Unaveraged Stress Output File (*file$.SP*)

```
1
PAFEC PAGE       228
                              PPPPPPP      AA     FFFFFFFF  EEEEEEEE    CCCC
                              PP    PP    AAAA    FFF       EE         CC  CC
                              PP    PP   AA  AA   FFF       EE        CC    CC
                              PP    PP   AA  AA   FFF       EE        CC
                              PP    PP  AA    AA  FFF       EE        CC
                              PPPPPPP   AA    AA  FFFFFF    EEEEEE    CC
                              PP        AAAAAAAA  FF        EEE       CC
                              PP        AA    AA  FF        EEE       CC
                              PP        AA    AA  FF        EEE       CC    CC
                              PP        AA    AA  FF        EEE        CC  CC
                              PP        AA    AA  FF        EEEEEEEE    CCCC

                                   PPPPPPP    OOOO     SSSS    TTTTTTTT
                                   PP    PP  OOOOOO   SS  SS      TT
                                   PP    PP OOO  OOO SS    SS     TT
                                   PP    PP OO    OO SS           TT
                                   PP    PP OO    OO  SS          TT
                                   PPPPPPP  OO    OO  SSSS        TT
                                   PP       OO    OO     SS       TT
                                   PP       OO    OO      SS      TT
                                   PP       OOO  OOO SS    SS     TT
                                   PP        OOOOOO   SS  SS      TT
                                   PP         OOOO     SSSS       TT

          PPPPPPP   RRRRRRR    OOOO      CCCC    EEEEEEEE    SSSS      SSSS      OOOO     RRRRRRR
          PP    PP  RR    RR  OOOOOO    CC  CC   EE         SS  SS    SS  SS    OOOOOO    RR    RR
          PP    PP  RR    RR OOO  OOO  CC    CC  EE        SS    SS  SS    SS  OOO  OOO   RR    RR
          PP    PP  RR    RR OO    OO  CC        EE        SS        SS        OO    OO   RR    RR
          PP    PP  RR    RR OO    OO  CC        EE         SS        SS       OO    OO   RR    RR
          PPPPPPP   RRRRRRR  OO    OO  CC        EEEEEE     SSSS      SSSS     OO    OO   RRRRRRR
          PP        RRRRR    OO    OO  CC        EEE           SS        SS    OO    OO   RRRRR
          PP        RR  RR   OO    OO  CC        EEE            SS        SS   OO    OO   RR  RR
          PP        RR   RR  OOO  OOO  CC    CC  EEE       SS    SS  SS    SS  OOO  OOO   RR   RR
          PP        RR    RR  OOOOOO    CC  CC   EEE        SS  SS    SS  SS    OOOOOO    RR    RR
          PP        RR    RR   OOOO      CCCC    EEEEEEEE    SSSS      SSSS      OOOO     RR    RR
1
PAFEC PAGE       229


   OOOO     RRRRRRR    DDDDDD     EEEEEEEE   RRRRRRR           11
  OOOOOO    RR    RR   DDDDDDD    EE         RR    RR         1111
 OOO  OOO   RR    RR   DD   DDD   EE         RR    RR        11111
 OO    OO   RR    RR   DD    DD   EE         RR    RR           11
 OO    OO   RR    RR   DD    DD   EE         RR    RR           11
 OO    OO   RRRRRRR    DD    DD   EEEEEE     RRRRRRR            11
 OO    OO   RRRRR      DD    DD   EEE        RRRRR              11
 OO    OO   RR  RR     DD    DD   EEE        RR  RR             11
 OOO  OOO   RR   RR    DD   DDD   EEE        RR   RR            11
  OOOOOO    RR    RR   DDDDDDD    EEE        RR    RR           11
   OOOO     RR    RR   DDDDDD     EEEEEEEE   RR    RR        11111111



     THERE IS  1  TABLE UNDER THIS ORDER

     THE VALUES OUTPUT IN THE TABLES UNDER THIS ORDER
     ARE SCALED BY    1.00000     AND ARE OFFSET BY    .000000E+00
     CONTINUITY VALUES ARE NOT SCALED OR OFFSET

     ANY DIRECTIONAL VALUES ARE GIVEN WITH RESPECT TO THE GLOBAL AXIS SET

     ANY DIRECTIONAL VALUES ARE GIVEN WITH RESPECT TO A LOCAL AXIS SET
```

IN PREFERENCE TO OTHERS. THE LETTER L IS PRINTED AFTER EACH LINE OF OUTPUT WHERE THE DIRECTIONAL STRESSES ARE WITH RESPECT TO A LOCAL AXIS SET.

THERE IS NO SORTING UNDER THIS ORDER

ALL DIRECTIONAL STRAINS UNDER THIS ORDER ARE ENGINEERING STRAINS .

1

PAFEC PAGE 230

```
********************
*                  *
*  TABLE 1  OF 1   *
*                  *
********************
```

LOAD CASE 1

ELEMENT NUMBER	NODE NO.	SIG MISES	SIG XX	SIG YY	SIG ZZ	TAU XY	TAU YZ	TAU ZX
1	1	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
1	2	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
1	3	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
1	915	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
1	916	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
1	69	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
1	70	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
1	71	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
2	3	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
2	4	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
2	5	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
2	916	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
2	917	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
2	71	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
2	72	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
2	73	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
				MAJORITY OF STRESSES OMITTED				
68	135	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
68	136	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
68	69	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
68	982	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
68	949	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
68	203	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00L
68	204	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00L
68	137	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00L
69	137	1.4408E+05	1.6149E+05	9.2160E+03	2.7313E+04	-6.1837E+02	0.0000E+00	0.0000E+00L
69	138	1.3444E+05	1.5095E+05	9.1052E+03	2.5608E+04	2.8560E+03	0.0000E+00	0.0000E+00L
69	139	1.1319E+05	1.2315E+05	3.3111E+03	2.0233E+04	8.0058E+03	0.0000E+00	0.0000E+00L
69	983	3.8644E+04	4.9905E+04	1.2663E+04	1.0011E+04	4.4302E+02	0.0000E+00	0.0000E+00
69	984	4.5411E+04	3.2321E+04	4.2912E+03	5.8580E+03	2.0960E+04	0.0000E+00	0.0000E+00
69	205	3.3679E+04	-1.3267E+04	2.5331E+04	1.9302E+03	1.3782E+02	0.0000E+00	0.0000E+00
69	206	5.2512E+04	-1.6445E+04	2.0751E+04	6.8898E+02	2.3928E+04	0.0000E+00	0.0000E+00
69	207	8.9868E+04	-2.0376E+04	1.2217E+04	-1.3054E+03	4.9233E+04	0.0000E+00	0.0000E+00
				MAJORITY OF STRESSES OMITTED				
251	241	1.4725E+05	-1.8134E+05	-2.2790E+04	-5.5114E+04	-1.4440E+04	0.0000E+00	0.0000E+00
251	1012	1.4808E+05	-1.8358E+05	-2.3733E+04	-5.5975E+04	-1.2785E+04	0.0000E+00	0.0000E+00
251	243	1.4103E+05	-1.9310E+05	-4.4349E+04	-6.4113E+04	-1.0158E+04	0.0000E+00	0.0000E+00
251	1458	1.6439E+05	-2.2322E+05	-4.8053E+04	-7.3243E+04	-6.3253E+03	0.0000E+00	0.0000E+00
251	1456	1.4956E+05	-2.3376E+05	-8.3153E+04	-8.5567E+04	-3.7633E+03	0.0000E+00	0.0000E+00
251	355	1.6852E+05	-2.4134E+05	-6.4527E+04	-8.2583E+04	-1.2001E+03	0.0000E+00	0.0000E+00
251	1459	1.5962E+05	-2.4236E+05	-7.9009E+04	-8.6769E+04	-1.2650E+03	0.0000E+00	0.0000E+00
251	353	1.4553E+05	-2.5065E+05	-1.1317E+05	-9.8231E+04	-3.5786E+02	0.0000E+00	0.0000E+00
252	239	1.4749E+05	-1.8302E+05	-2.1619E+04	-5.5252E+04	-4.5211E+02	0.0000E+00	0.0000E+00
252	1010	1.4740E+05	-1.8278E+05	-2.1838E+04	-5.5248E+04	-5.3080E+03	0.0000E+00	0.0000E+00
252	241	1.4727E+05	-1.8305E+05	-2.3425E+04	-5.5749E+04	-1.0346E+04	0.0000E+00	0.0000E+00

252	1413	1.6190E+05	-2.1782E+05	-4.4331E+04	-7.0782E+04	-2.3792E+02	0.0000E+00	0.0000E+00
252	1458	1.6238E+05	-2.2009E+05	-4.6896E+04	-7.2086E+04	-5.7851E+03	0.0000E+00	0.0000E+00
252	331	1.6503E+05	-2.3396E+05	-6.0138E+04	-7.9407E+04	-5.9951E-03	0.0000E+00	0.0000E+00
252	1460	1.6612E+05	-2.3596E+05	-6.1115E+04	-8.0209E+04	-5.0882E+02	0.0000E+00	0.0000E+00
252	355	1.6671E+05	-2.3846E+05	-6.3461E+04	-8.1518E+04	-1.2001E+03	0.0000E+00	0.0000E+00
253	357	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
253	1461	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
253	359	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
253	1462	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
253	1463	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
253	69	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

1

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LOAD CASE 1

==============

ELEMENT NUMBER	NODE NO.	SIG MISES	SIG XX	SIG YY	SIG ZZ	TAU XY	TAU YZ	TAU ZX
253	70	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
253	71	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
356	438	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
356	1641	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
356	436	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
356	1506	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
356	1650	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
356	450	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
356	1504	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
356	448	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

1

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```
  OOOO      RRRRRRR    DDDDDD     EEEEEEEE   RRRRRRR          2222
 OOOOOO     RR    RR   DDDDDDD    EE         RR    RR        222222
OOO  OOO    RR    RR   DD   DDD   EE         RR    RR       22    22
OO    OO    RR    RR   DD    DD   EE         RR    RR             22
OO    OO    RR    RR   DD    DD   EE         RR    RR             22
OO    OO    RRRRRRR    DD    DD   EEEEEE     RRRRRRR           22
OO    OO    RRRRR      DD    DD   EEE        RRRRR           222
OO    OO    RR  RR     DD    DD   EEE        RR  RR         222
OOO  OOO    RR   RR    DD   DDD   EEE        RR   RR        22
 OOOOOO     RR    RR   DDDDDDD    EEE        RR    RR       22
  OOOO      RR    RR   DDDDDD     EEEEEEEE   RR    RR       22222222
```

THERE IS 1 TABLE UNDER THIS ORDER

THE VALUES OUTPUT IN THE TABLES UNDER THIS ORDER
ARE SCALED BY 1.00000 AND ARE OFFSET BY .000000E+00
CONTINUITY VALUES ARE NOT SCALED OR OFFSET

ANY DIRECTIONAL VALUES ARE GIVEN WITH RESPECT TO THE GLOBAL AXIS SET

ANY DIRECTIONAL VALUES ARE GIVEN WITH RESPECT TO A LOCAL AXIS SET
IN PREFERENCE TO OTHERS. THE LETTER L IS PRINTED AFTER EACH LINE OF
OUTPUT WHERE THE DIRECTIONAL STRESSES ARE WITH RESPECT TO
A LOCAL AXIS SET.

THERE IS NO SORTING UNDER THIS ORDER

ALL DIRECTIONAL STRAINS UNDER THIS ORDER ARE ENGINEERING STRAINS .

1

PAFEC PAGE 286

```
********************
*                  *
*  TABLE 1  OF 1   *
*                  *
********************
```

LOAD CASE 1
==============

NODE NO.	SIG MISES	SIG XX	SIG YY	SIG ZZ	TAU XY	TAU YZ	TAU ZX	
1	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	
2	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	
3	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	
4	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	
5	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	
6	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	
7	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	
8	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	
9	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	
MAJORITY OF STRESSES OMITTED								
133	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	
134	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	
135	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	
136	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	
137	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	L
137	1.4406E+05	1.6147E+05	9.2116E+03	2.7308E+04	-1.7014E+01	-1.4171E-01	1.0496E+00	L
138	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	L
138	1.3444E+05	1.5095E+05	9.1053E+03	2.5608E+04	2.8573E+03	-1.0979E-01	9.8353E-01	L
139	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	L
139	1.1573E+05	1.2621E+05	3.3496E+03	2.0729E+04	6.6613E+03	-9.3891E-02	8.3438E-01	L
140	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	L
140	3.8827E+04	4.0947E+04	7.3547E+03	7.7283E+03	1.1423E+04	1.1365E-01	2.6575E-01	L
141	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	L
141	8.7674E+04	-8.8970E+04	-6.3048E+03	-1.5244E+04	2.2451E+04	2.6407E-01	-5.7412E-01	L
142	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	L
142	1.4657E+05	-1.5496E+05	-7.6303E+03	-2.6015E+04	2.6751E+04	3.5914E-01	-9.9859E-01	L
143	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	L
143	2.0585E+05	-2.2208E+05	-1.5584E+04	-3.8026E+04	3.5891E+04	4.6756E-01	-1.4296E+00	L

1
PAFEC PAGE 293
LOAD CASE 1
==============

NODE NO.	SIG MISES	SIG XX	SIG YY	SIG ZZ	TAU XY	TAU YZ	TAU ZX
311	1.7930E+05	-1.9522E+05	-3.9352E+03	-3.1865E+04	6.3605E+03	2.6254E-01	-1.2717E+00
313	1.4343E+05	-1.5504E+05	-1.9431E+03	-2.5118E+04	6.8901E+03	2.2927E-01	-1.0097E+00
315	1.0362E+05	-1.0923E+05	1.6637E+03	-1.7211E+04	7.6521E+03	2.0104E-01	-7.1199E-01
317	1.2541E+05	1.3568E+05	1.2102E+03	2.1903E+04	-1.4575E+01	-1.6200E-01	8.9021E-01
319	1.2544E+05	1.3567E+05	1.1558E+03	2.1892E+04	1.3576E+01	1.6233E-01	8.9018E-01
321	1.0360E+05	-1.0925E+05	1.5921E+03	-1.7225E+04	-7.7389E+03	-2.0127E-01	-7.1195E-01
323	1.4338E+05	-1.5510E+05	-2.0663E+03	-2.5147E+04	-6.7761E+03	-2.2774E-01	-1.0101E+00
325	1.7940E+05	-1.9525E+05	-3.8301E+03	-3.1853E+04	-6.3605E+03	-2.6325E-01	-1.2721E+00
327	2.1070E+05	-2.3091E+05	-6.4218E+03	-3.7973E+04	-5.3484E+03	-2.8374E-01	-1.5042E+00
329	2.3975E+05	-2.6371E+05	-8.3396E+03	-4.3527E+04	-2.3578E+03	-2.9138E-01	-1.7203E+00
331	1.6503E+05	-2.3396E+05	-6.0138E+04	-7.9407E+04	-1.3600E+00	-1.5077E-01	-1.2092E+00
333	1.6762E+05	-2.3990E+05	-6.3994E+04	-8.2050E+04	1.1977E+03	1.4974E-01	-1.2341E+00
335	1.5051E+05	-2.5859E+05	-1.1610E+05	-1.0117E+05	3.5489E+02	-1.1378E-01	-1.2320E+00
337	1.2110E+05	-2.2912E+05	-2.7162E+05	-1.3520E+05	-3.9073E+03	-9.9933E-01	-8.2617E-01
339	2.6606E+05	-1.6222E+05	-4.2664E+05	-1.5899E+05	-1.5261E+03	-2.0940E+00	-3.7288E-02
341	5.0094E+05	-1.1222E+05	-6.5369E+05	-2.0680E+05	-2.4112E+03	-3.4999E+00	7.2445E-01
343	4.9130E+05	-2.7818E+05	-7.7216E+05	-2.8359E+05	-8.2180E+00	-3.8227E+00	4.2299E-02
345	4.9130E+05	-2.7818E+05	-7.7216E+05	-2.8359E+05	-8.2180E+00	-3.8227E+00	4.2298E-02
347	5.0094E+05	-1.1222E+05	-6.5369E+05	-2.0680E+05	2.4094E+03	3.4999E+00	7.2448E-01
349	2.6606E+05	-1.6222E+05	-4.2664E+05	-1.5899E+05	1.5235E+03	2.0940E+00	-3.7266E-02
351	1.2110E+05	-2.2912E+05	-2.7162E+05	-1.3520E+05	3.9037E+03	9.9930E-01	-8.2615E-01
353	1.5051E+05	-2.5859E+05	-1.1610E+05	-1.0117E+05	-3.5897E+02	1.1375E-01	-1.2320E+00
355	1.6762E+05	-2.3990E+05	-6.3994E+04	-8.2050E+04	-1.2015E+03	-1.4977E-01	-1.2341E+00
357	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

358	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
359	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

MAJORITY OF STRESSES OMITTED

1641	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
1642	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
1643	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
1644	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
1645	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
1646	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
1647	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
1648	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
1649	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
1650	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

1
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```
                                      EEEEEEEE  N      NN  DDDDDD
                                      EE        NN     NN  DDDDDDD
                                      EE        NNN    NN  DD    DDD
                                      EE        NNNN   NN  DD     DD
                                      EE        NNNNN  NN  DD     DD
                                      EEEEEE    NNNNNNNNN  DD     DD
                                      EEE       NN  NNNNN  DD     DD
                                      EEE       NN   NNNN  DD     DD
                                      EEE       NN    NNN  DD    DDD
                                      EEE       NN     NN  DDDDDDD
                                      EEEEEEEE  NN      N  DDDDDD


                                             OOOO     FFFFFFFF
                                            OOOOOO    FFF
                                           OOO  OOO   FFF
                                           OO    OO   FFF
                                           OO    OO   FFF
                                           OO    OO   FFFFFF
                                           OO    OO   FF
                                           OO    OO   FF
                                           OOO  OOO   FF
                                            OOOOOO    FF
                                             OOOO     FF


PPPPPPP   RRRRRRR     OOOO      CCCC    EEEEEEEE    SSSS      SSSS    IIIIIIII  N      NN     GGGG
PP    PP  RR    RR   OOOOOO    CC  CC   EE         SS  SS    SS  SS      II     NN     NN   GG    GG
PP    PP  RR    RR  OOO  OOO  CC    CC  EE        SS    SS  SS    SS     II     NNN    NN  GG     GG
PP    PP  RR    RR  OO    OO  CC        EE        SS        SS           II     NNNN   NN  GG
PP    PP  RR    RR  OO    OO  CC        EE         SS        SS          II     NNNNN  NN  GG
PPPPPPP   RRRRRRR   OO    OO  CC        EEEEEE      SSSS      SSSS       II     NNNNNNNNN  GG
PP        RRRRR     OO    OO  CC        EEE            SS        SS      II     NN  NNNNN  GG   GGG
PP        RR  RR    OO    OO  CC        EEE             SS        SS     II     NN   NNNN  GG    GG
PP        RR   RR   OOO  OOO  CC    CC  EEE       SS    SS  SS    SS     II     NN    NNN  GG    GG
PP        RR    RR   OOOOOO    CC  CC   EEE        SS  SS    SS  SS      II     NN     NN   GG  GG
PP        RR    RR    OOOO      CCCC    EEEEEEEE    SSSS      SSSS    IIIIIIII  NN      N    GGGG
```

B.2 Example of a Three-Dimensional Model

B.2.1 A Three-Dimensional Model Pre-Processing Input File

```
KISIKLI NORTH TUBE HETEROGENEOUS WITHOUT SHOTCRETE LINING  (EXCAVATED GROUND)
1+400
7.9         [INPUT CLEAR HEIGHT OF TUNNEL IN METERS]
13.0        [INPUT HEIGHT OF OVERBURDEN IN METERS]
4.5         [INPUT HEIGTH UNDER TUNNEL  IN METER=(Hover+Hover/2do)]
1           [INPUT NUMBER OF ROCK LAYERS]
22.0
3
2           [INPUT MATERIAL PROPERTY OF REST OF GROUND]
0.005       [MINOR (1/2) WIDTH OF STEEL ARCH = ? (SAMIN)]
0.08        [MAJOR (1/2) WIDTH OF STEEL ARCH ALONG THE Z AXIS = ? (SAMAJ)]
0.105       [MAJOR (1/2) WIDTH OF STEEL ARCH ALONG THE Y AXIS = ? (SAMAJ2)]
0           [IS A STEEL ARCH PRESENT ?  0) NO, 1) YES]
8           [WHAT IS THE MATERIAL PROPERTY OF THE STEEL ARCH USED]
6.0 0.5     [HEIGHT OF  ANCHORAGES 1 AND 2= ?]
4.0  4.0    [LENGTH OF  ANCHORAGES 1 AND 2= ?]
0.014       [RADIUS OF ANCHORAGES = ?]
25 -10      [ANGLE OF ANCHORAGES 1 AND 2= ?]
0           [ARE ANCHORAGES PRESENT ?  0) NO, 1) YES']
8           [WHAT IS THE MATERIAL PROPERTY OF THE ANCHORAGES USED ?]
0.35        [LENGTH OF (1/2) PERIOD = ?]
1           [INPUT WHAT ROCK TYPE OF EXCAVATION ?, 0)A,B OR 1)C]
0 0         [REGION: 1    C FOR EACH REGION INDICATE 0) IF EXCAVATED OR 1) IF NOT']
0 0         [REGION: 2A   C AND]
0 0         [REGION: 2B   C IS THERE AN OUTER (SHOTCRETE) LINING? 0) NO, 1) YES']
0 0         [REGION: 3A]
0 0         [REGION: 3B]
0 0         [REGION: 4]
0 0         [REGION: 5a]
0 0         [REGION: 5b]
0 0         [REGION: 6]
6           [WHAT IS THE MATERIAL PROPERTY OF THE SHOTCRETE USED ?]
0.25        [THICKNESS OF SHOTCRETE]
0           [IS THERE AN INNER LINING ?  0) NO, 1) YES]
7           [WHAT IS THE MATERIAL PROPETY OF THE INNER LINING USED ?]
.5          [THICKNESS OF INNER LINNING]
1           [RESOLUTION  (increase resolution number to achieve fine mesh)]
0           [IS THIS EXAMPLE A SYMMETRICAL MODEL ? MSYM.EQ 0) NO or 1) YES]
3           [NUMBER OF DIMENSIONS]
```

B.2.2 Generated A Three-Dimensional Model PAFEC-FE Input File

```
TITLE 3D-KISIKLI NORTH TUBE CO-ORDINATES AND FE-MESH DESIGN
 C Km (1+400)
 C          APPLIED MECHANICS GROUP
 C           SCHOOL OF ENGINEERING
 C           UNIVERSITY OF DURHAM
 C
 C
 C TUNNEL NAME = KISIKLI
 C KM          = 1+400
 C CLEAR HEIGHT OF TUNNEL IN METRES =  7.9
 C HEIGHT OF OVERBURDEN IN METERS = 13.0
 C INPUT HEIGHT UNDER TUNNEL IN METRES = 4.5
 C INPUT NUMBER OF ROCK LAYERS = 1
 C HEIGHT OF LAYERS FROM GROUND SURFACE IN METERS = 22.0
 C MATERIAL PROPERTIES OF LAYER ,= 3
 C MATERIAL PROPERTY OF REST OF GROUND = 2
 C NUMBER OF SHELLS = 3
 C HEIGTH OF CIRCULAR SHELL NUMBER 1IN METRES =  .5
 C HEIGTH OF CIRCULAR SHELL NUMBER 2IN METRES =  .25
 C HEIGTH OF FLATTENED SHELL NUMBER   3IN METRES = 1.40
 C WHAT ROCK TYPE OF EXCAVATION ?, 0)A,B OR 1)C = 1
 C  C ROCK TYPE OF EXCAVATION
 C 1, 2A, 2B, 3A, 3B, 4, 5A, 5B, 6
 C REGIONS EXCAVATED:  1  2A 2B 3A 3B 4  5A 5B 6
 C MAJOR (1/2) WIDTH OF STEEL ARCH (Z)=  .080
 C 2nd MAJOR (1/2) WIDTH OF STEEL ARCH (Y) = .105
 C HEIGHT OF  ANCHORAGES 1 AND 2 =  6.0 .5
 C LENGTH OF ANCHORAGES 1 AND 2 =  4.0 4.0
 C RADIUS OF ANCHORAGES =  .014
 C ANGLE OF ANCHORAGES 1 AND 2= 25.0 -10.0
 C THE MATERIAL PRO.OF THE SHOTCRETE USED = 6
 C THICKNESS OF SHOTCRETE = .25
 C IS THERE AN INNER LINING ? = 0
 C 0) NO or 1) YES
 C THE MATERIAL PRO.OF THE INNER LINING = 7
 C THE THICKNESS OF THE INNER LINING .5
 C RESOLUTION = 1
 C IS THIS EXAMPLE A SYMMETRICAL MODEL ? =  0
 C 0) NO or 1) YES
 C NUMBER OF DIMENSIONS ? (2 OR 3) = 3
 C
 C THE CO-ORDINATES OF THE NODES CORRESPONDING TO
 C THE STRUCTURE ARE GIVEN BELOW EXPRESSED IN METERS.
 C
 C THERE IS ONLY NEED TO SPECIFY THE CORNER NODES
 C OF THE ELEMENTS, SINCE PAFEC WILL CALCULATE
 C AUTOMATICALLY THE CO-ORDINATES OF THE MID-SIDE NODES.
 C
 NODES
 NODES.NUMBER        X          Y          Z
    1              .00000    7.40000     .00000
    2              .60000    7.37564     .00000
    3             1.20000    7.30205     .00000
=============================================================================================
    MAJORITY OF NODE CO-ORDINATES LIST OMITTED
=============================================================================================
  900            -5.89550   -1.44653     .35000
  901             5.89550   -1.44653     .35000
  902            -6.15922   -1.38538     .35000
  903             6.15922   -1.38538     .35000
  904              .00000     .00000     .35000
  905              .00000     .00000     .00000
  906             1.20363    1.59727     .00000
  907             -.68596    1.39867     .00000
  908             5.79084    -.83147     .00000
  909              .00000   28.95983     .00000
  910              .00000     .00000     .00000
  911            -1.20363    1.59727     .00000
```

```
 912              .68596   1.39867    .00000
 913            -5.79084   -.83147    .00000
 914              .00000  28.95983    .00000
 915              .00000    .00000    .35000
 916             1.20363   1.59727    .35000
 917             -.68596   1.39867    .35000
 918             5.79084   -.83147    .35000
 919              .00000  28.95983    .35000
 920              .00000    .00000    .35000
 921            -1.20363   1.59727    .35000
 922              .68596   1.39867    .35000
 923            -5.79084   -.83147    .35000
 924              .00000  28.95983    .35000
C
C
PAFBLOCKS
BLOCK.NUMBER TYPE ELEMENT.TYPE PROPERTIES N1 N2 N5 TOPOLOGY
    1     1 37110     19     1     1     1
*     1    3   69    71  453  455  521  523
*     2    0    0    70    0    0    0    0  454    0    0  522
    2     1 37110     19     1     1     1
*     3    5   71    73  455  457  523  525
*     4    0    0    72    0    0    0    0  456    0    0  524
    3     1 37110     19     1     1     1
*     5    7   73    75  457  459  525  527
*     6    0    0    74    0    0    0    0  458    0    0  526
==========================================================================================
       MAJORITY OF PAFBLOCK TOPOLOGY LIST OMITTED
==========================================================================================
  238     1 37110     19     1     1     1
*   435  437  447  449  887  889  899  901
*     0    0    0    0    0    0    0    0    0    0    0    0
  239     1 37110     19     1     1     1
*   437  439  449  451  889  891  901  903
*     0    0    0    0    0    0    0    0    0    0    0    0
  240     1 37110     19     1     1     1
*   430  429  442  441  882  881  894  893
*     0    0    0    0    0    0    0    0    0    0    0    0
  241     1 37110     19     1     1     1
*   432  430  444  442  884  882  896  894
*     0    0    0    0    0    0    0    0    0    0    0    0
  242     1 37110     19     1     1     1
*   434  432  446  444  886  884  898  896
*     0    0    0    0    0    0    0    0    0    0    0    0
  243     1 37110     19     1     1     1
*   436  434  448  446  888  886  900  898
*     0    0    0    0    0    0    0    0    0    0    0    0
  244     1 37110     19     1     1     1
*   438  436  450  448  890  888  902  900
*     0    0    0    0    0    0    0    0    0    0    0    0
C
C Define local axis and directions
C
AXES
RELAXISNO = 1
TYPE = 1
AXISNO   NODE   ANG1
4 905 .0
5 905 -4.22191376007178
6 905 -8.466971581149
7 905 -15.6606162210402
8 905 -23.1187456601791
9 905 -25.7116177044377
10 905 -28.173097145412
==========================================================================================
  MAJORITY OF LOCAL AXIS LIST OMITTED
==========================================================================================
117 923 123.9999999999999
118 923 104.9028605902197
119 922 106.0012480610754
120 922 103.6422778569183
121 922 100.1629576156789
122 922 96.72116306809526
```

```
123 922 90.45136174359382
124 922 84.1869782034804
125 921 68.99381750222022
126 921 51.92750511869923
127 921 48.46285905946267
128 921 42.73322386227446
129 921 39.86661193113721
130 921 37.00000000000001
131 920 34.91493064058877
132 920 32.75869816121942
133 920 30.51675355503308
134 920 28.17309714541204
135 920 25.71161770443768
136 920 23.11874566017914
137 920 15.66061622104018
138 920 8.466971581149
139 920 4.22191376007178
C
C
LOCAL.DIRECTIONS
NODE.NUMBER  LOCAL.AXIS
137 4
138 5
139 6
140 7
141 8
142 9
==========================================================================================
 MAJORITY OF LOCAL DIRECTION LIST OMITTED
==========================================================================================
645 128
646 129
647 130
648 131
649 132
650 133
651 134
652 135
653 136
654 137
655 138
656 139
C
C
C Elements which form the Excavated Surface
C
C
EXTERNAL.FORCE
AXIS.SET = 1
LIST
69
70
71
72
73
74
==========================================================================================
 MAJORITY OF EXTERNAL FORCE LIST OMITTED
==========================================================================================
95
96
97
98
99
100
101
102
C
C
C In the MATERIAL module the Young's modulus (E),
C the Poisson's ratio
C (NU) and the density (RO),are specified for
C Neogene cover (MATERIAL.NUMBER 11),
```

```
C the micaceous sandstone,
C siltstone and claystone (MATERIAL.NUMBER 12),
C the quartzite
C (MATERIAL.NUMBER 13), the arkose,
C conglomeratic arkose (MATERIAL.NUMBER 14),
C the volcanic dyke rock (MATERIAL.NUMBER 15),
C Shotcrete (MATERIAL.NUMBER 16),
C Inner (final) lining (MATERIAL.NUMBER 17).
C Mild steel for anchorages and steel arch
C beam element (MATERIAL.NUMBER 18).
C
C The unit used for Young's modulus is Pa (N/m2)
C and the density is expressed
C in (kg/m3).
C
MATERIAL
MATERIAL.NUMBER        E         NU        RO
    11               90E+6     0.35      2060
    12               0.7E+9    0.27      2200
    13               68E+9     0.16      2600
    14               15E+9     0.26      2600
    15               1.9E+9    0.28      2300
    16               15E+9     0.200     2000
    17               30E+9     0.200     2400
    18               209E+9    0.300     7800
    19                 0E-9    0.499      0.0
C In the GRAVITY module the sign in the
C YGVALUE is negative, indicating that
C gravity acts in the vertical downwards
C direction.
C
GRAVITY
XGVALUE    YGVALUE    ZGVALUE
   0          -1         0
C
C
RESTRAINTS
NODE.NUMBER     PLANE    AXIS.NUMBER     DIRECTION
  343             1          1              1
  343             2          1              2
  345             1          1              1
  331             3          1              3
  819             3          1              3
C
C
CONTROL
USE.R70632MOD
C
C Since PAFEC-FE does not perform stress averaging
C across different
C material types, the supplied source must be modified
C Inspection of the
C stressing routines indicated that a small number of
C changes to PAFEC-FE
C subroutine R70632 was necessary. A section of the
C subroutine with the
C modification is shown in Figure
C The modified source is incorporated
C into the PAFEC-FE system for this analysis
C using the USE.option.
C
STRESS
CONTROL.END
C
PROCESSING.FOR.PRINTED.OUTPUT
ORDER  FORMAT.TYPE LOCAL.AXIS  WINDOW
  1       2           1          0
C
ORDER.FOR.PRINTED.OUTPUT
ORDER    LIST.OF.TYPES
 1       101  102  4  8  9  10 11 12 13
END.OF.DATA
```

B.2.2.1 A Three-Dimensional Model Nodal Co-ordinates and Element Topology Output File (*file$.O02*)

```
1
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                                  PPPPP  AAAAA FFFFF EEEEE CCCCC
 SYSTEM LEVEL 7.400 A             P   P  A   A FF    E     C  CC
 JUNE 1992                        P   P  A   A FF    E     C
                                  PPPPP  AAAAA FFF   EEE   C
                                  PP     AA  A F     EE    C
 PHASE NO.  2                     PP     AA  A F     EE    C
 STARTS HERE                      PP     AA  A F     EE    C
                                  PP     AA  A F     EEEEE CCCCC


 TITLE 3D-TUNNEL COORDINATES AND FE-MESH DESIGN
                         --------------------------------------------------------
                               THE TOLERANCE USED IN THIS PHASE IS 1E -4
                         --------------------------------------------------------


 GLOBAL COORDINATES
 ------------------
```

NODE	X	Y	Z	NODE	X	Y	Z
1	.0000	7.4000	.0000	2	.6020	7.3755	.0000
3	1.2000	7.3021	.0000	4	2.2224	7.0584	.0000
5	3.2000	6.6723	.0000	6	3.4190	6.5628	.0000
7	3.6343	6.4461	.0000	8	3.8457	6.3223	.0000
9	4.0528	6.1915	.0000	10	4.2554	6.0540	.0000

MAJORITY OF NODE CO-ORDINATES LIST OMITTED

2739	5.7444	-.8204	.3500	2740	5.4109	-1.1408	.0000
2741	5.8217	-1.1408	.1750	2742	5.4109	-1.1408	.3500
2743	6.0092	-1.1408	.0000	2744	6.0092	-1.1408	.3500
2745	-1.2000	-.8204	.0000	2746	-1.2000	-.8204	.3500
2747	-.6000	-1.1408	.0000	2748	-1.2000	-1.1408	.1750
2749	-.6000	-1.1408	.3500	2750	-3.2000	-.8204	.0000
2751	-3.2000	-.8204	.3500	2752	-2.2000	-1.1408	.0000
2753	-3.2000	-1.1408	.1750	2754	-2.2000	-1.1408	.3500
2755	-4.6800	-.8204	.0000	2756	-4.6800	-.8204	.3500
2757	-4.1000	-1.1408	.0000	2758	-5.0000	-1.1408	.1750
2759	-4.1000	-1.1408	.3500	2760	-5.7444	-.8204	.0000
2761	-5.7444	-.8204	.3500	2762	-5.4109	-1.1408	.0000
2763	-5.8217	-1.1408	.1750	2764	-5.4109	-1.1408	.3500
2765	-6.0092	-1.1408	.0000	2766	-6.0092	-1.1408	.3500
2767	.0000	-1.2936	.0000	2768	1.2000	-1.2936	.0000
2769	.0000	-1.2936	.3500	2770	1.2000	-1.2936	.3500
2771	3.2000	-1.2936	.0000	2772	3.2000	-1.2936	.3500
2773	5.0000	-1.2936	.0000	2774	5.0000	-1.2936	.3500
2775	5.8586	-1.2936	.0000	2776	5.8586	-1.2936	.3500
2777	-1.2000	-1.2936	.0000	2778	-1.2000	-1.2936	.3500

```
1
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NODE	X	Y	Z	NODE	X	Y	Z
2779	-3.2000	-1.2936	.0000	2780	-3.2000	-1.2936	.3500
2781	-5.0000	-1.2936	.0000	2782	-5.0000	-1.2936	.3500
2783	-5.8586	-1.2936	.0000	2784	-5.8586	-1.2936	.3500

* COMMENT * COORDINATES OF NON-STRUCTURAL NODES ARE NOT INCLUDED IN THE ABOVE TABLE

NUMBER OF STRUCTURAL NODES IN THIS PHASE = 2650
HIGHEST NUMBERED NODE IN THIS PHASE IS = 2784

ELEMENTS

ELEMENT	GROUP	ELEM.TYPE	PROPERTY	INE	TOPOLOGY								
1	1	37110	19	20	1	3	453	455	69	71	521	523	2
					925	926	454	927	928	929	930	70	931
					932	522							
2	1	37110	19	20	3	5	455	457	71	73	523	525	4
					926	933	456	928	934	930	935	72	932
					936	524							
3	1	37110	19	20	5	7	457	459	73	75	525	527	6
					933	937	458	934	938	935	939	74	936
					940	526							
4	1	37110	19	20	7	9	459	461	75	77	527	529	8
					937	941	460	938	942	939	943	76	940
					944	528							
5	1	37110	19	20	9	11	461	463	77	79	529	531	10
					941	945	462	942	946	943	947	78	944
					948	530							

MAJORITY OF ELEMENT LIST OMITTED

350	1	37110	19	20	435	437	887	889	447	449	899	901	2740
					2736	2741	2742	2773	2775	2774	2776	2385	2386
					2381	2387							

1
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ELEMENT	GROUP	ELEM.TYPE	PROPERTY	INE	TOPOLOGY								
351	1	37110	19	20	437	439	889	891	449	451	901	903	2743
					2741	2371	2744	2775	2375	2776	2377	2380	2381
					2376	2382							
352	1	37110	19	20	430	429	882	881	442	441	894	893	2747
					2748	2725	2749	2777	2767	2778	2769	2405	2406
					2401	2407							
353	1	37110	19	20	432	430	884	882	444	442	896	894	2752
					2753	2748	2754	2779	2777	2780	2778	2410	2411
					2406	2412							
354	1	37110	19	20	434	432	886	884	446	444	898	896	2757
					2758	2753	2759	2781	2779	2782	2780	2415	2416
					2411	2417							
355	1	37110	19	20	436	434	888	886	448	446	900	898	2762
					2763	2758	2764	2783	2781	2784	2782	2420	2421
					2416	2422							
356	1	37110	19	20	438	436	890	888	450	448	902	900	2765
					2431	2763	2766	2430	2783	2432	2784	2425	2426
					2421	2427							

END OF PAFBLOCKS GENERATION

```
***********************************
*                                 *
*    NO ERRORS IN GEOMETRY CHECK  *
*                                 *
* 822 WARNINGS IN GEOMETRY CHECK  *
*                                 *
***********************************
```

END OF PAFBLOCKS DATA GENERATION

```
E S T I M A T E   O F   B A S E   A N D   F I L E   S I Z E   R E Q U I R E M E N T S   ( B )
==============================================================================================


NOTE - (1) AN ASTERISK * DENOTES AN OVERESTIMATE


-----------------------------------------------
PHASE    BASE/FILE    SINGLE PRECISION NUMBERS.
-----------------------------------------------
    3       BASE                29390
    4       BASE               104100*
-----------------------------------------------
1
PAFEC PAGE         158

 C O N T E N T S
 ===============

 --------------------------------------------
 HEADING                                 PAGE
 --------------------------------------------
 PHASE  2                                  71

 ESTIMATE OF BASE AND FILE SIZE
 REQUIREMENTS (B)                         157

 --------------------------------------------


 **********************************
 *                                *
 *     0 ERRORS IN THIS PHASE     *
 *                                *
 *    56 WARNINGS IN THIS PHASE   *
 *                                *
 **********************************


 **** MAXIMUM SIZE OF BASE IN THIS PHASE WAS    32561 WORDS ****


 +++ END OF PHASE  2 +++
```

B.2.2.2 A Three-Dimensional Model Displacement Output File (*file$.007*)

```
1
PAFEC PAGE        245


                                        PPPPP  AAAAA FFFFF EEEEE CCCCC
 SYSTEM LEVEL 7.400 A                   P   P  A   A FF    E     C  CC
 JUNE 1992                              P   P  A   A FF    E     C
                                        PPPPP  AAAAA FFF   EEE   C
                                        PP    AA   A F     EE    C
 PHASE NO.  7                           PP    AA   A F     EE    C
 STARTS HERE                            PP    AA   A F     EE    C
                                        PP    AA   A F     EEEEE CCCCC

 TITLE 3D-TUNNEL COORDINATES AND FE-MESH DESIGN

                                  ****************************************
                                  *                                      *
                                  * STATICS  SOLUTION BY BLOCK FRONT     *
                                  *         IN DOUBLE PRECISION          *
                                  *                                      *
                                  *   STRUCTURE CONTAINS  5469 FREEDOMS  *
                                  *                        356 ELEMENTS  *
                                  *     AND THE FRONT SIZE IS   283      *
                                  *                                      *
                                  ****************************************

0                    *** A BLOCKED FRONT SOLUTION HAS BEEN REQUESTED ***
0                               THE BLOCK SIZE IS     80372
1
PAFEC PAGE        286
 D I S P L A C E M E N T S   F O R   L O A D   C A S E     1
 ============================================================


 NOTE - (1) THE  LETTER  L  FOLLOWING A NODE NUMBER INDICATES
            THAT THE DISPLACEMENTS  AT THAT NODE ARE GIVEN IN
            THE LOCAL DIRECTIONS DEFINED AT THE NODE


OSAMPLE OF LARGEST DISPLACEMENTS
 -------------------------------

0
```

NODE	UX	NODE	UY	NODE	UZ	NODE	RESULTANT
153L	0.0042841	1813	-0.0044235	1603	0.1288747E-09	1813	0.0044235
605L	0.0042841	1815	-0.0044235	1473	0.7882761E-10	1815	0.0044235
641L	-0.0042836	1810	-0.0044231	1509	0.7433343E-10	1808	0.0044231
189L	-0.0042836	1808	-0.0044231	1629	-0.6741540E-10	1805	0.0044231
606L	0.0042822	1805	-0.0044231	1551	-0.6427569E-10	1810	0.0044231
154L	0.0042822	2194	-0.0044229	1268	-0.6140333E-10	2194	0.0044229
640L	-0.0042821	1806	-0.0044229	1093	0.5367440E-10	1806	0.0044229
188L	-0.0042821	2195	-0.0044229	1421	0.2984990E-10	2195	0.0044229
607L	0.0042299	1811	-0.0044229	1624	0.2960210E-10	1811	0.0044229
155L	0.0042299	1816	-0.0044228	1459	-0.2889067E-10	1816	0.0044228

```
 DISPLACEMENTS AT NODES
 ----------------------
```

NOTE - (2) THE HISTOGRAM INDICATES THE MAGNITUDE OF THE RESULTANT TRANSLATION AT EACH NODE. EACH STAR * REPRESENTS .4423E-03 UNITS
(3) A STAR * IN A DISPLACEMENT COLUMN INDICATES THAT A CONSTRAINT HAS BEEN APPLIED.
(4) ONLY STRUCTURAL NODES ARE GIVEN IN THE TABLE BELOW

1
PAFEC PAGE 287

CASE 1 NODE NUMBER	TRANSLATIONS MULTIPLIED BY 1E 3 UX	UY	UZ	RESULTANT TRANSLATION MULTIPLIED BY 1E 3 U	HISTOGRAM	SCALED COORDINATES MULTIPLIED BY 1E 0 X	Y	Z
1	0.0000	0.0000	*	0.0000		0.00	7.40	0.00
2	0.0000	0.0000	*	0.0000		0.60	7.38	0.00
3	0.0000	0.0000	*	0.0000		1.20	7.30	0.00
4	0.0000	0.0000	*	0.0000		2.22	7.06	0.00
5	0.0000	0.0000	*	0.0000		3.20	6.67	0.00

MAJORITY OF DISPLACEMENTS OMITTED

135	0.0000	0.0000	*	0.0000		-1.20	7.81	0.00
136	0.0000	0.0000	*	0.0000		-0.60	7.88	0.00
137L	-0.0000	-4.4215	*	4.4215	**********	0.00	8.15	0.00
138L	0.3268	-4.4090	*	4.4211	**********	0.60	8.13	0.00
139L	0.6535	-4.3713	*	4.4199	**********	1.20	8.06	0.00
140L	1.1968	-4.2505	*	4.4158	**********	2.22	7.84	0.00
141L	1.7376	-4.0523	*	4.4092	**********	3.20	7.50	0.00
142L	1.9185	-3.9667	*	4.4063	**********	3.53	7.35	0.00
143L	2.0860	-3.8776	*	4.4031	**********	3.85	7.18	0.00
144L	2.2416	-3.7862	*	4.4000	**********	4.13	7.02	0.00
145L	2.3865	-3.6926	*	4.3966	**********	4.41	6.85	0.00
146L	2.5220	-3.5973	*	4.3933	**********	4.66	6.69	0.00
147L	2.6493	-3.5002	*	4.3897	**********	4.90	6.51	0.00
148L	2.8188	-3.3603	*	4.3860	**********	5.15	6.32	0.00
149L	2.9807	-3.2120	*	4.3820	**********	5.38	6.11	0.00
150L	3.2816	-2.8941	*	4.3755	**********	5.72	5.76	0.00
151L	3.4448	-2.6857	*	4.3680	**********	6.05	5.39	0.00
152L	4.0536	-1.5470	*	4.3388	**********	6.91	3.89	0.00
153L	4.2841	-0.4273	*	4.3053	**********	7.32	2.21	0.00
154L	4.2822	0.0349	*	4.2823	**********	7.36	1.33	0.00
155L	4.2299	0.4899	*	4.2582	**********	7.31	0.46	0.00
156L	4.1791	0.7319	*	4.2427	**********	7.24	-0.02	0.00
157L	4.1137	0.9693	*	4.2264	**********	7.14	-0.50	0.00
158L	4.0614	1.1220	*	4.2135	**********	7.05	-0.82	0.00
159L	4.0033	1.2705	*	4.2001	*********	6.95	-1.14	0.00
160L	2.9213	1.7750	*	3.4182	********	6.81	-1.47	0.00
161L	1.8993	1.6324	*	2.5044	******	6.58	-1.74	0.00
162L	1.2013	1.5049	*	1.9256	****	6.32	-1.91	0.00

1
PAFEC PAGE 290

CASE 1 NODE NUMBER	TRANSLATIONS MULTIPLIED BY 1E 3 UX	UY	UZ	RESULTANT TRANSLATION MULTIPLIED BY 1E 3 U	HISTOGRAM	SCALED COORDINATES MULTIPLIED BY 1E 0 X	Y	Z
163L	0.6601	1.2818	*	1.4418	***	6.02	-2.01	0.00
164L	0.5659	0.7447	*	0.9353	**	5.51	-2.10	0.00
165L	0.5437	0.4052	*	0.6781	**	5.00	-2.18	0.00
166L	0.5218	0.0349	*	0.5230	*	4.10	-2.31	0.00
167L	0.4992	-0.1263	*	0.5149	*	3.20	-2.42	0.00
168L	0.3872	-0.1899	*	0.4312	*	2.20	-2.50	0.00
169L	0.2307	-0.2032	*	0.3074	*	1.20	-2.56	0.00
170L	0.1177	-0.2011	*	0.2330	*	0.60	-2.57	0.00
171L	0.0000	-0.2005	*	0.2005		0.00	-2.58	0.00
172L	-0.1177	-0.2011	*	0.2330	*	-0.60	-2.57	0.00
173L	-0.2307	-0.2032	*	0.3074	*	-1.20	-2.56	0.00
174L	-0.3872	-0.1899	*	0.4312	*	-2.20	-2.50	0.00
175L	-0.4992	-0.1263	*	0.5149	*	-3.20	-2.42	0.00
176L	-0.5218	0.0349	*	0.5230	*	-4.10	-2.31	0.00

```
  177L    -0.5437   0.4052       *           0.6781  **                -5.00  -2.18   0.00
  178L    -0.5659   0.7447       *           0.9353  **                -5.51  -2.10   0.00
  179L    -0.6601   1.2818       *           1.4418  ***               -6.02  -2.01   0.00
  180L    -1.2013   1.5049       *           1.9256  ****              -6.32  -1.91   0.00
  181L    -1.8993   1.6324       *           2.5044  ******            -6.58  -1.74   0.00
  182L    -2.9213   1.7750       *           3.4182  ********          -6.81  -1.47   0.00
  183L    -4.0732   1.0248       *           4.2001  *********         -6.95  -1.14   0.00
  184L    -4.0614   1.1220       *           4.2135  **********        -7.05  -0.82   0.00
  185L    -4.1137   0.9693       *           4.2264  **********        -7.14  -0.50   0.00
  186L    -4.1791   0.7319       *           4.2427  **********        -7.24  -0.02   0.00
  187L    -4.2299   0.4899       *           4.2582  **********        -7.31   0.46   0.00
  188L    -4.2821   0.0349       *           4.2823  **********        -7.36   1.33   0.00
  189L    -4.2836  -0.4317       *           4.3053  **********        -7.32   2.21   0.00
  190L    -4.0536  -1.5470       *           4.3388  **********        -6.91   3.89   0.00
  191L    -3.4448  -2.6857       *           4.3680  **********        -6.05   5.39   0.00
  192L    -3.2816  -2.8941       *           4.3755  **********        -5.72   5.76   0.00
  193L    -2.9807  -3.2120       *           4.3820  **********        -5.38   6.11   0.00
  194L    -2.8188  -3.3603       *           4.3860  **********        -5.15   6.32   0.00
  195L    -2.6493  -3.5002       *           4.3897  **********        -4.90   6.51   0.00
  196L    -2.5220  -3.5973       *           4.3933  **********        -4.66   6.69   0.00
  197L    -2.3865  -3.6925       *           4.3966  **********        -4.41   6.85   0.00
  198L    -2.2416  -3.7862       *           4.4000  **********        -4.13   7.02   0.00
  199L    -2.0860  -3.8776       *           4.4031  **********        -3.85   7.18   0.00
  200L    -1.9185  -3.9667       *           4.4063  **********        -3.53   7.35   0.00
  201L    -1.7376  -4.0523       *           4.4092  **********        -3.20   7.50   0.00
  202L    -1.1968  -4.2505       *           4.4158  **********        -2.22   7.84   0.00
  203L    -0.6535  -4.3713       *           4.4199  **********        -1.20   8.06   0.00
  204L    -0.3268  -4.4090       *           4.4211  **********        -0.60   8.13   0.00
  205      0.0000  -4.4215       *           4.4215  **********         0.00   9.55   0.00
  206     -0.0002  -4.4211       *           4.4211  **********         0.60   9.55   0.00
=============================================================================================
                                   MAJORITY OF DISPLACEMENTS OMITTED
=============================================================================================
  585      0.0000   0.0000       *           0.0000                    -3.20   7.22   0.35
  586      0.0000   0.0000       *           0.0000                    -2.22   7.58   0.35
  587      0.0000   0.0000       *           0.0000                    -1.20   7.81   0.35
  588      0.0000   0.0000       *           0.0000                    -0.60   7.88   0.35
  589L    -0.0000  -4.4215       *           4.4215  **********         0.00   8.15   0.35
  590L     0.3268  -4.4090       *           4.4211  **********         0.60   8.13   0.35
  591L     0.6535  -4.3713       *           4.4199  **********         1.20   8.06   0.35
  592L     1.1968  -4.2505       *           4.4158  **********         2.22   7.84   0.35
  593L     1.7376  -4.0523       *           4.4092  **********         3.20   7.50   0.35
  594L     1.9185  -3.9667       *           4.4063  **********         3.53   7.35   0.35
  595L     2.0860  -3.8776       *           4.4031  **********         3.85   7.18   0.35
  596L     2.2416  -3.7862       *           4.4000  **********         4.13   7.02   0.35
  597L     2.3865  -3.6926       *           4.3966  **********         4.41   6.85   0.35
1
PAFEC PAGE          297
-------------------------------------------------------------------------------------------
 CASE  1            TRANSLATIONS                RESULTANT TRANSLATION        SCALED COORDINATES
 NODE             MULTIPLIED BY 1E 3             MULTIPLIED BY 1E 3          MULTIPLIED BY 1E 0
 NUMBER         UX           UY          UZ           U     HISTOGRAM          X        Y       Z
-------------------------------------------------------------------------------------------

  598L     2.5220  -3.5973       *           4.3933  **********         4.66   6.69   0.35
  599L     2.6493  -3.5002       *           4.3897  **********         4.90   6.51   0.35
  600L     2.8188  -3.3603       *           4.3860  **********         5.15   6.32   0.35
  601L     2.9807  -3.2120       *           4.3820  **********         5.38   6.11   0.35
  602L     3.2816  -2.8941       *           4.3755  **********         5.72   5.76   0.35
  603L     3.4448  -2.6857       *           4.3680  **********         6.05   5.39   0.35
  604L     4.0536  -1.5470       *           4.3388  **********         6.91   3.89   0.35
  605L     4.2841  -0.4273       *           4.3053  **********         7.32   2.21   0.35
  606L     4.2822   0.0349       *           4.2823  **********         7.36   1.33   0.35
  607L     4.2299   0.4899       *           4.2582  **********         7.31   0.46   0.35
  608L     4.1791   0.7319       *           4.2427  **********         7.24  -0.02   0.35
  609L     4.1137   0.9693       *           4.2264  **********         7.14  -0.50   0.35
  610L     4.0614   1.1220       *           4.2135  **********         7.05  -0.82   0.35
  611L     4.0033   1.2705       *           4.2001  *********          6.95  -1.14   0.35
  612L     2.9213   1.7750       *           3.4182  ********           6.81  -1.47   0.35
  613L     1.8993   1.6324       *           2.5044  ******             6.58  -1.74   0.35
  614L     1.2013   1.5049       *           1.9256  ****               6.32  -1.91   0.35
  615L     0.6601   1.2818       *           1.4418  ***                6.02  -2.01   0.35
  616L     0.5659   0.7447       *           0.9353  **                 5.51  -2.10   0.35
```

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  617L    0.5437   0.4052        *             0.6781  **             5.00  -2.18   0.35
  618L    0.5218   0.0349        *             0.5230  *              4.10  -2.31   0.35
  619L    0.4992  -0.1263        *             0.5149  *              3.20  -2.42   0.35
  620L    0.3872  -0.1899        *             0.4312  *              2.20  -2.50   0.35
  621L    0.2307  -0.2032        *             0.3074  *              1.20  -2.56   0.35
  622L    0.1177  -0.2011        *             0.2330  *              0.60  -2.57   0.35
  623L    0.0000  -0.2005        *             0.2005                 0.00  -2.58   0.35
  624L   -0.1177  -0.2011        *             0.2330  *             -0.60  -2.57   0.35
  625L   -0.2307  -0.2032        *             0.3074  *             -1.20  -2.56   0.35
  626L   -0.3872  -0.1899        *             0.4312  *             -2.20  -2.50   0.35
  627L   -0.4992  -0.1263        *             0.5149  *             -3.20  -2.42   0.35
  628L   -0.5218   0.0349        *             0.5230  *             -4.10  -2.31   0.35
  629L   -0.5437   0.4052        *             0.6781  **            -5.00  -2.18   0.35
  630L   -0.5659   0.7447        *             0.9353  **            -5.51  -2.10   0.35
  631L   -0.6601   1.2818        *             1.4418  ***           -6.02  -2.01   0.35
  632L   -1.2013   1.5049        *             1.9256  ****          -6.32  -1.91   0.35
  633L   -1.8993   1.6324        *             2.5044  ******        -6.58  -1.74   0.35
  634L   -2.9213   1.7750        *             3.4182  ********      -6.81  -1.47   0.35
  635L   -4.0732   1.0248        *             4.2001  *********     -6.95  -1.14   0.35
  636L   -4.0614   1.1220        *             4.2135  **********    -7.05  -0.82   0.35
  637L   -4.1137   0.9693        *             4.2264  **********    -7.14  -0.50   0.35
  638L   -4.1791   0.7319        *             4.2427  **********    -7.24  -0.02   0.35
  639L   -4.2299   0.4899        *             4.2582  **********    -7.31   0.46   0.35
  640L   -4.2821   0.0349        *             4.2823  **********    -7.36   1.33   0.35
  641L   -4.2836  -0.4317        *             4.3053  **********    -7.32   2.21   0.35
  642L   -4.0536  -1.5470        *             4.3388  **********    -6.91   3.89   0.35
  643L   -3.4448  -2.6857        *             4.3680  **********    -6.05   5.39   0.35
  644L   -3.2816  -2.8941        *             4.3755  **********    -5.72   5.76   0.35
  645L   -2.9807  -3.2120        *             4.3820  **********    -5.38   6.11   0.35
  646L   -2.8188  -3.3603        *             4.3860  **********    -5.15   6.32   0.35
  647L   -2.6493  -3.5002        *             4.3897  **********    -4.90   6.51   0.35
  648L   -2.5220  -3.5973        *             4.3933  **********    -4.66   6.69   0.35
  649L   -2.3865  -3.6925        *             4.3966  **********    -4.41   6.85   0.35
  650L   -2.2416  -3.7862        *             4.4000  **********    -4.13   7.02   0.35
  651L   -2.0860  -3.8776        *             4.4031  **********    -3.85   7.18   0.35
1
PAFEC PAGE        298
 ------------------------------------------------------------------------------------------
 CASE  1          TRANSLATIONS                RESULTANT TRANSLATION      SCALED COORDINATES
  NODE         MULTIPLIED BY 1E 3              MULTIPLIED BY 1E 3        MULTIPLIED BY 1E 0
 NUMBER        UX         UY         UZ             U     HISTOGRAM           X      Y      Z
 ------------------------------------------------------------------------------------------

  652L   -1.9185  -3.9667        *             4.4063  **********    -3.53   7.35   0.35
  653L   -1.7376  -4.0523        *             4.4092  **********    -3.20   7.50   0.35
  654L   -1.1968  -4.2505        *             4.4158  **********    -2.22   7.84   0.35
  655L   -0.6535  -4.3713        *             4.4199  **********    -1.20   8.06   0.35
  656L   -0.3268  -4.4090        *             4.4211  **********    -0.60   8.13   0.35
  657     0.0000  -4.4215        *             4.4215  **********     0.00   9.55   0.35
  658    -0.0002  -4.4211        *             4.4211  **********     0.60   9.55   0.35
  659    -0.0004  -4.4199        *             4.4199  **********     1.20   9.55   0.35
============================================================================================
                                   MAJORITY OF DISPLACEMENTS OMITTED
============================================================================================
  2775    0.0000   0.0000        *             0.0000                 5.86  -1.29   0.00
  2776    0.0000   0.0000        *             0.0000                 5.86  -1.29   0.35
  2777    0.0000   0.0000        *             0.0000                -1.20  -1.29   0.00
  2778    0.0000   0.0000        *             0.0000                -1.20  -1.29   0.35
  2779    0.0000   0.0000        *             0.0000                -3.20  -1.29   0.00
  2780    0.0000   0.0000        *             0.0000                -3.20  -1.29   0.35
1
PAFEC PAGE        336
 ------------------------------------------------------------------------------------------
 CASE  1          TRANSLATIONS                RESULTANT TRANSLATION      SCALED COORDINATES
  NODE         MULTIPLIED BY 1E 3              MULTIPLIED BY 1E 3        MULTIPLIED BY 1E 0
 NUMBER        UX         UY         UZ             U     HISTOGRAM           X      Y      Z
 ------------------------------------------------------------------------------------------

  2781    0.0000   0.0000        *             0.0000                -5.00  -1.29   0.00
  2782    0.0000   0.0000        *             0.0000                -5.00  -1.29   0.35
  2783    0.0000   0.0000        *             0.0000                -5.86  -1.29   0.00
  2784    0.0000   0.0000        *             0.0000                -5.86  -1.29   0.35
 ------------------------------------------------------------------------------------------
```

1
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F O R C E S   O N   E L E M E N T S

NOTE - (1) AN E IN THE AXIS SET COLUMN INDICATES THAT THE FORCES ON EACH ELEMENT ARE GIVEN IN LOCAL ELEMENT AXES. THE LOCAL ELEMENT AXIS SET IS FORMED BY AN X-AXIS POSITIVE FROM THE FIRST NODE IN THE TOPOLOGY TO THE SECOND. THE Y-AXIS PASSES THROUGH THE FIRST NODE NORMAL TO THE X-AXIS IN THE PLANE OF THE FIRST THREE NODES AND IS POSITIVE TOWARDS THE THIRD.

(2) FORCES AT NODES WHICH HAVE LOCAL.DIRECTIONS ARE ONLY GIVEN IN THOSE LOCAL DIRECTIONS IF THE AXIS SET REQUESTED IS THE GLOBAL SET. IN SUCH A CASE THE NODE NUMBER IN THE TABLE IS FOLLOWED BY AN L.

ELEM NUMB	ELEM TYPE	GROUP NUMB	LOAD CASE	NODE NUMB	AXIS SET	FORCES F-X	F-Y	F-Z
69	37110	1	1	137L	4	932.748	1814.541	559.006
69	37110	1	1	139L	6	-389.879	542.971	824.022
69	37110	1	1	589L	72	935.890	1846.083	-574.827
69	37110	1	1	591L	74	-396.474	588.077	-841.798
69	37110	1	1	205	1	2403.818	1527.199	1782.529
69	37110	1	1	207	1	-2820.189	1005.593	1917.416
69	37110	1	1	657	1	2404.302	1544.865	-1787.111
69	37110	1	1	659	1	-2819.572	1024.194	-1922.105
69	37110	1	1	138L	5	188.685	-2503.046	-8059.968
69	37110	1	1	1065	1	-14100.015	-2378.708	11.278
69	37110	1	1	1066	1	10725.830	-604.481	9.608
69	37110	1	1	590L	73	193.312	-2546.461	8072.166
69	37110	1	1	1163	1	-8917.961	-2489.587	-5679.436
69	37110	1	1	1164	1	5956.978	842.060	-4934.660
69	37110	1	1	1165	1	-8921.297	-2550.003	5692.867
69	37110	1	1	1166	1	5955.733	785.990	4952.232
69	37110	1	1	206	1	2741.947	-878.722	-3374.972
69	37110	1	1	1167	1	-2745.795	-598.452	-3.838
69	37110	1	1	1168	1	6129.624	3892.603	-4.503
69	37110	1	1	658	1	2739.988	-953.750	3362.093
70	37110	1	1	139L	6	-450.174	4876.055	-3696.057
70	37110	1	1	141L	8	3807.931	-1294.758	-356.954

MAJORITY OF FORCES ON ELEMENTS OMITTED

101	37110	1	1	1293	1	-9693.075	8369.864	5.300
101	37110	1	1	1296	1	-14331.855	-14946.582	15.834
101	37110	1	1	722	1	-18793.144	-12886.642	-8551.681
102	37110	1	1	203L	70	400.275	601.287	840.387
102	37110	1	1	137L	4	-929.055	1844.343	565.914
102	37110	1	1	655L	138	401.227	612.484	-841.144
102	37110	1	1	589L	72	-931.848	1863.169	-574.336
102	37110	1	1	271	1	2823.593	989.273	1927.984
102	37110	1	1	205	1	-2398.792	1526.958	1786.439
102	37110	1	1	723	1	2820.782	1010.006	-1921.744
102	37110	1	1	657	1	-2400.619	1527.444	-1790.826
102	37110	1	1	204L	71	-190.825	-2528.104	-8064.780
102	37110	1	1	1162	1	-10718.736	-670.353	1.682
102	37110	1	1	1065	1	14086.911	-2420.823	6.243
102	37110	1	1	656L	139	-188.477	-2556.960	8068.741
102	37110	1	1	1294	1	-5962.153	812.405	-4961.097
102	37110	1	1	1163	1	8917.723	-2516.414	-5693.266

1
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```
 -----------------------------------------------------------------------
   ELEM  ELEM  GROUP  LOAD  NODE  AXIS                FORCES
   NUMB  TYPE  NUMB   CASE  NUMB  SET       F-X         F-Y         F-Z
 -----------------------------------------------------------------------
    102 37110     1      1  1295    1    -5959.834    802.313    4955.031
    102 37110     1      1  1165    1     8922.499  -2530.783    5699.359
    102 37110     1      1   272    1    -2743.840   -896.648   -3378.118
    102 37110     1      1  1296    1    -6133.081   3933.154      -1.698
    102 37110     1      1  1167    1     2736.914   -577.378       1.830
    102 37110     1      1   724    1    -2740.602   -916.031    3373.400
 -----------------------------------------------------------------------
1
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 C O N T E N T S
 ===============

 ---------------------------------------------
 HEADING                                  PAGE
 ---------------------------------------------
 PHASE  7                                  245

 DISPLACEMENTS                             286

 FORCES ON ELEMENTS                        337

 ---------------------------------------------


 **********************************
 *                                *
 *    0 ERRORS IN THIS PHASE      *
 *                                *
 * 2400 WARNINGS IN THIS PHASE    *
 *                                *
 **********************************


 **** MAXIMUM SIZE OF BASE IN THIS PHASE WAS   132302 WORDS ****


 +++ END OF PHASE  7 +++
```

B.2.2.3 A Three-Dimensional Model Stress Output File (*file$.O09*)

```
1
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                                         PPPPP  AAAAA FFFFF EEEEE CCCCC
  SYSTEM LEVEL 7.400 A                   P   P  A   A FF    E     C  CC
  JUNE 1992                              P   P  A   A FF    E     C
                                         PPPPP  AAAAA FFF   EEE   C
                                         PP     AA   A F    EE    C
  PHASE NO.  9                           PP     AA   A F    EE    C
  STARTS HERE                            PP     AA   A F    EE    C
                                         PP     AA   A F    EEEEE CCCCC


  TITLE 3D-TUNNEL COORDINATES AND FE-MESH DESIGN


 DEFAULT STRESS.ELEMENTS MODULE CREATED.
1
PAFEC PAGE        353
     37110 20-NODE ISOPARAMETRIC BRICK ELEMENT
     -------------------------------------


     GLOBAL STRESSES     -   SIGMA-X, SIGMA-Y AND SIGMA-Z ARE THE STRESSES IN THE GLOBAL AXES


     PRINCIPAL STRESSES  -   SIGMA-1 IS THE MOST POSITIVE PRINCIPAL STRESS
                             SIGMA-3 IS THE MOST NEGATIVE PRINCIPAL STRESS


     ANGLES OF PRINCIPAL -   AX, AY AND AZ ARE THE ANGLES OF SIGMA-1 TO THE GLOBAL AXES
      STRESSES               BX, BY AND BZ ARE THE ANGLES OF SIGMA-2 TO THE GLOBAL AXES
                             SIGMA-2 IS PERPENDICULAR TO SIGMA-1 AND SIGMA-3
```

LOAD CASE	NODE NO	.GLOBAL.STRESSES.. SIGMA-X	SIGMA-Y	SIGMA-Z	.PRINCIPAL.STRESSES... SIGMA-1	SIGMA-2	SIGMA-3	VON.MISES STRESS	ANGS.OF.PRINCIPAL.DIRECTIONS AX	AY	AZ	BX	BY	BZ
ELEMENT NO. 1														
1	1	. 00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	927	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	69	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	925	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	0	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	931	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	453	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	929	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	521	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	2	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	0	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	70	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	0	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	0	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	0	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	454	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	0	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	522	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	3	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	928	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	71	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	926	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	0	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	932	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90

```
1 455 .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    0 90 90 90 0 90
1 930 .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    0 90 90 90 0 90
1 523 .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    0 90 90 90 0 90
=====================================================================================================
                                   MAJORITY OF STRESSES OMITTED
=====================================================================================================
ELEMENT NO.    68

1 135  .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    0 90 90 90 0 90
1 1160 .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    0 90 90 90 0 90
1 203  .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    0 90 90 90 0 90
1 1060 .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    0 90 90 90 0 90
1 0    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    0 90 90 90 0 90
1 1162 .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    0 90 90 90 0 90
1 587  .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    0 90 90 90 0 90
1 1161 .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    0 90 90 90 0 90
1 655  .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    0 90 90 90 0 90
1 136  .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    0 90 90 90 0 90
1 0    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    0 90 90 90 0 90
1 204  .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    0 90 90 90 0 90
1 0    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    0 90 90 90 0 90
1 0    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    0 90 90 90 0 90
1 0    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    0 90 90 90 0 90
1 588  .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    0 90 90 90 0 90
1 0    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    0 90 90 90 0 90
1 656  .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    0 90 90 90 0 90
1 69   .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    0 90 90 90 0 90
1 1061 .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    0 90 90 90 0 90
1 137  .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    0 90 90 90 0 90
1 931  .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    0 90 90 90 0 90
1 0    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    0 90 90 90 0 90
1 1065 .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    0 90 90 90 0 90
1 521  .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    0 90 90 90 0 90
1 1063 .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    0 90 90 90 0 90
1 589  .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    .00D+00    0 90 90 90 0 90

 ELEMENT NO.    69

1 137 1.62D+05   9.34D+03   2.73D+04   1.62D+05   2.74D+04   9.32D+03   1.44D+05  0 90 90 89 88 1
1 1163 4.99D+04  1.27D+04   1.00D+04   4.99D+04   1.28D+04   1.00D+04  3.86D+04  0 89 90 89 175 94
1 205 -1.32D+04  2.54D+04   1.94D+03   2.54D+04   1.94D+03  -1.32D+04  3.37D+04  89 0 90 89 90 179
1
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 ----------------------------------------------------------------------------------------------------
LOAD NODE .GLOBAL.STRESSES....    PRINCIPAL.STRESSES.     VON.MISES  ANGS.OF.PRINCIPAL.DIRECTIONS
CASE NO    SIGMA-X SIGMA-Y SIGMA-Z  SIGMA-1 SIGMA-2 SIGMA-3 STRESS      AX    AY    AZ    BX    BY    BZ
 ----------------------------------------------------------------------------------------------------
1 1065   1.62D+05  9.24D+03   2.73D+04   1.62D+05   2.73D+04  9.24D+03  1.44D+05  0 90 89 89 90 179
1 0      4.99D+04  1.26D+04   1.00D+04   4.99D+04   1.26D+04  1.00D+04  3.87D+04  0 89 90 89 178 90
1 1167  -1.33D+04  2.52D+04   1.91D+03   2.52D+04   1.91D+03 -1.33D+04  3.36D+04  89 0 90 89 89   0
1 589    1.61D+05  9.26D+03   2.73D+04   1.61D+05   2.73D+04  9.25D+03  1.44D+05  0 90 89 89 89 179
1 1165   4.99D+04  1.26D+04   1.00D+04   4.99D+04   1.26D+04  9.99D+03  3.87D+04  0 89 89 89 176 86
1 657   -1.33D+04  2.52D+04   1.91D+03   2.52D+04   1.91D+03 -1.33D+04  3.35D+04  89 0 90 89 89  0
1 138    1.51D+05  9.53D+03   2.56D+04   1.51D+05   2.56D+04  9.11D+03  1.34D+05  3 93 90 89 88  1
1  0     4.41D+04  1.07D+04   8.76D+03   4.64D+04   8.77D+03  8.34D+03  3.79D+04 14 75 89 88 97 172
1 206   -1.65D+04  2.06D+04   6.68D+02   3.24D+04   6.67D+02  -2.82D+04  5.25D+04  63 26 90 89 89 0
1  0     1.51D+05  9.39D+03   2.56D+04   1.51D+05   2.56D+04   8.98D+03  1.35D+05 3 93 89 89 89 179
1  0     4.41D+04  1.06D+04   8.75D+03   4.64D+04   8.76D+03   8.26D+03  3.79D+04  14 75 90 88 97 7
1   0   -1.65D+04  2.06D+04   6.61D+02   3.23D+04   6.61D+02  -2.82D+04  5.24D+04  63 26 90 89 89 0
1 590    1.51D+05  9.39D+03   2.56D+04   1.51D+05   2.56D+04   8.97D+03  1.34D+05 3 93 89 89 881 78
1  0     4.41D+04  1.07D+04   8.76D+03   4.64D+04   8.83D+03   8.26D+03  3.79D+04 14 75 90 84 109 20
1 658   -1.64D+04  2.07D+04  6.82D+02   3.25D+04   6.82D+02  -2.82D+04  5.25D+04  63 26 89 89 89 179
1 139    1.23D+05  3.88D+03  2.03D+04   1.24D+05   2.03D+04   3.02D+03  1.13D+05  4 94 89 89 87  2
1 1164   3.24D+04  4.45D+03  5.88D+03   4.35D+04   5.88D+03  -6.71D+03  4.53D+04  28 61 89 89 90 179
1 207   -2.04D+04  1.22D+04 -1.30D+03   4.79D+04  -1.30D+03  -5.60D+04  9.00D+04  54  35 90 89 89 0
1 1066   1.23D+05  3.58D+03  2.02D+04   1.24D+05   2.02D+04   2.76D+03  1.13D+05  4 94 89 89 89  0
1  0     3.23D+04  4.28D+03  5.86D+03   4.35D+04   5.86D+03  -6.87D+03  4.53D+04  28 61 90 89 90 179
1 1168  -2.04D+04  1.22D+04   -1.31D+03   4.78D+04  -1.31D+03   -5.60D+04  8.99D+04  54 35 90 89 89  0
1 591    1.23D+05  3.44D+03   2.02D+04   1.24D+05   2.02D+04   2.64D+03  1.13D+05  4 94 90 89 89 179
1 1166   3.23D+04  4.28D+03   5.86D+03   4.35D+04   5.86D+03  -6.92D+03  4.54D+04  28 61 90 89 90  0
1 659   -2.04D+04  1.23D+04   -1.29D+03   4.79D+04  -1.29D+03  -5.60D+04  9.00D+04 54 35 89 89 89 179
```

MAJORITY OF STRESSES OMITTED

ELEMENT NO. 252

1	239	-1.83D+05	-2.16D+04	-5.53D+04	-2.16D+04	-5.53D+04	-1.83D+05	1.47D+05	89	179	89	89	90	179
1	2199	-2.18D+05	-4.43D+04	-7.08D+04	-4.43D+04	-7.08D+04	-2.18D+05	1.62D+05	89	179	89	89	90	179
1	331	-2.34D+05	-6.01D+04	-7.94D+04	-6.01D+04	-7.94D+04	-2.34D+05	1.65D+05	89	179	89	89	89	0
1	1231	-1.83D+05	-2.16D+04	-5.53D+04	-2.16D+04	-5.53D+04	-1.83D+05	1.47D+05	89	179	90	89	89	179
1	0	-2.18D+05	-4.43D+04	-7.08D+04	-4.43D+04	-7.08D+04	-2.18D+05	1.62D+05	89	179	89	89	89	0
1	2204	-2.34D+05	-6.01D+04	-7.94D+04	-6.01D+04	-7.94D+04	-2.34D+05	1.65D+05	89	179	90	89	89	179
1	691	-1.83D+05	-2.16D+04	-5.53D+04	-2.16D+04	-5.53D+04	-1.83D+05	1.47D+05	89	179	90	89	90	0
1	2201	-2.18D+05	-4.43D+04	-7.08D+04	-4.43D+04	-7.08D+04	-2.18D+05	1.62D+05	89	179	90	89	90	0
1	783	-2.34D+05	-6.01D+04	-7.94D+04	-6.01D+04	-7.94D+04	-2.34D+05	1.65D+05	89	0	90	89	90	179
1	1235	-1.83D+05	-2.18D+04	-5.52D+04	-2.17D+04	-5.52D+04	-1.83D+05	1.47D+05	88	178	90	89	89	179
1	0	-2.19D+05	-4.49D+04	-7.12D+04	-4.49D+04	-7.12D+04	-2.19D+05	1.62D+05	89	179	89	89	90	179
1	2315	-2.36D+05	-6.11D+04	-8.02D+04	-6.11D+04	-8.02D+04	-2.36D+05	1.66D+05	89	179	90	89	89	179
1	0	-1.83D+05	-2.18D+04	-5.52D+04	-2.17D+04	-5.52D+04	-1.83D+05	1.47D+05	88	178	90	89	89	179
1	0	-2.19D+05	-4.49D+04	-7.12D+04	-4.49D+04	-7.12D+04	-2.19D+05	1.62D+05	89	179	89	89	89	0
1	0	-2.36D+05	-6.11D+04	-8.02D+04	-6.11D+04	-8.02D+04	-2.36D+05	1.66D+05	89	179	90	89	89	179
1	1237	-1.83D+05	-2.18D+04	-5.52D+04	-2.17D+04	-5.52D+04	-1.83D+05	1.47D+05	88	178	90	89	90	0
1	0	-2.19D+05	-4.49D+04	-7.12D+04	-4.49D+04	-7.12D+04	-2.19D+05	1.62D+05	89	179	89	89	89	0
1	2316	-2.36D+05	-6.11D+04	-8.02D+04	-6.11D+04	-8.02D+04	-2.36D+05	1.66D+05	89	179	90	89	89	179
1	241	-1.83D+05	-2.34D+04	-5.57D+04	-2.28D+04	-5.57D+04	-1.84D+05	1.47D+05	86	176	90	89	89	179
1	2310	-2.20D+05	-4.69D+04	-7.21D+04	-4.67D+04	-7.21D+04	-2.20D+05	1.62D+05	88	178	89	89	90	179
1	355	-2.38D+05	-6.35D+04	-8.15D+04	-6.35D+04	-8.15D+04	-2.38D+05	1.67D+05	89	179	90	89	89	179
1	1236	-1.83D+05	-2.34D+04	-5.57D+04	-2.28D+04	-5.57D+04	-1.84D+05	1.47D+05	86	176	90	89	89	179
1	0	-2.20D+05	-4.69D+04	-7.21D+04	-4.67D+04	-7.21D+04	-2.20D+05	1.62D+05	88	178	89	89	90	179
1	2313	-2.38D+05	-6.35D+04	-8.15D+04	-6.35D+04	-8.15D+04	-2.38D+05	1.67D+05	89	179	90	89	89	179
1	693	-1.83D+05	-2.34D+04	-5.57D+04	-2.28D+04	-5.57D+04	-1.84D+05	1.47D+05	86	176	90	89	90	0
1	2311	-2.20D+05	-4.69D+04	-7.21D+04	-4.67D+04	-7.21D+04	-2.20D+05	1.62D+05	88	178	89	89	89	0
1	807	-2.38D+05	-6.35D+04	-8.15D+04	-6.35D+04	-8.15D+04	-2.38D+05	1.67D+05	89	179	90	89	89	179

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ELEMENT NO. 253

LOAD CASE	NODE NO	.GLOBAL.STRESSES.... SIGMA-X	SIGMA-Y	SIGMA-Z	.PRINCIPAL.STRESSES.... SIGMA-1	SIGMA-2	SIGMA-3	VON.MISES STRESS	ANGS.OF.PRINCIPAL.DIRECTIONS AX	AY	AZ	BX	BY	BZ
1	357	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	2321	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	69	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	2318	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	0	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	931	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	809	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	2323	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	521	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	2317	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	0	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	70	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	0	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	0	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	0	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	2320	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	0	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	522	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	359	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	2322	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	71	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	2319	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	0	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	932	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	811	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	2324	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	523	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90

MAJORITY OF STRESSES OMITTED

ELEMENT NO. 356

1	438	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	2430	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	450	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	2431	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	0	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	2426	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	890	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	2432	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	902	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	2765	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	0	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	2425	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	0	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	0	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	0	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	2766	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	0	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	2427	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	436	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	2783	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	448	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	2763	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	0	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	2421	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	888	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	2784	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90
1	900	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90

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1
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 AVERAGED STRESSES FOR NODES WRITTEN TO BLOCKS    97 TO   143
 OF THE STRESS FILE
1
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 C O N T E N T S
 ===============

 ---------------------------------------------
 HEADING                                  PAGE
 ---------------------------------------------
 PHASE  9                                  352

 STRESSES FOR ELEMENT TYPE 37110           353

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1
PAFEC PAGE        615


 **********************************
 *                                *
 *   0 ERRORS IN THIS PHASE       *
 *                                *
 *  230 WARNINGS IN THIS PHASE    *
 *                                *
 **********************************


 **** MAXIMUM SIZE OF BASE IN THIS PHASE WAS   562257 WORDS ****
```

B.2.2.4 A Three-Dimensional Model Averaged and Unaveraged Stress Output File (*file$.SP*)

```
1
PAFEC PAGE          557
                              PPPPPPP       AA       FFFFFFFF  EEEEEEEE     CCCC
                              PP     PP    AAAA      FFF       EE         CC   CC
                              PP     PP   AA  AA     FFF       EE        CC      CC
                              PP     PP   AA  AA     FFF       EE        CC
                              PP     PP  AA    AA    FFF       EE        CC
                              PPPPPPP    AA    AA    FFFFFF    EEEEEE    CC
                              PP         AAAAAAAA    FF        EEE       CC
                              PP         AA    AA    FF        EEE       CC
                              PP         AA    AA    FF        EEE       CC      CC
                              PP         AA    AA    FF        EEE        CC   CC
                              PP         AA    AA    FF        EEEEEEEE     CCCC

                                   PPPPPPP      OOOO       SSSS      TTTTTTTT
                                   PP     PP   OOOOOO     SS   SS       TT
                                   PP     PP  OOO  OOO   SS      SS     TT
                                   PP     PP  OO    OO   SS             TT
                                   PP     PP  OO    OO    SS            TT
                                   PPPPPPP    OO    OO     SSSS         TT
                                   PP         OO    OO        SS        TT
                                   PP         OO    OO         SS       TT
                                   PP         OOO  OOO   SS      SS     TT
                                   PP          OOOOOO     SS   SS       TT
                                   PP           OOOO       SSSS         TT

          PPPPPPP    RRRRRRR     OOOO       CCCC      EEEEEEEE    SSSS       SSSS       OOOO      RRRRRRR
          PP     PP  RR     RR  OOOOOO    CC   CC    EE          SS   SS    SS   SS    OOOOOO     RR     RR
          PP     PP  RR     RR OOO  OOO  CC      CC  EE         SS      SS SS      SS OOO  OOO    RR     RR
          PP     PP  RR     RR OO    OO  CC          EE         SS         SS         OO    OO    RR     RR
          PP     PP  RR     RR OO    OO  CC          EE          SS         SS        OO    OO    RR     RR
          PPPPPPP    RRRRRRR   OO    OO  CC          EEEEEE       SSSS       SSSS     OO    OO    RRRRRRR
          PP         RRRRR     OO    OO  CC          EEE             SS         SS    OO    OO    RRRRR
          PP         RR  RR    OO    OO  CC          EEE              SS         SS   OO    OO    RR  RR
          PP         RR   RR   OOO  OOO  CC      CC  EEE        SS      SS SS      SS OOO  OOO    RR   RR
          PP         RR     RR  OOOOOO    CC   CC    EEE         SS   SS    SS   SS    OOOOOO     RR     RR
          PP         RR     RR   OOOO       CCCC     EEEEEEEE     SSSS       SSSS       OOOO      RR     RR
1
PAFEC PAGE          558


   OOOO      RRRRRRR     DDDDDD     EEEEEEEE    RRRRRRR              11
  OOOOOO     RR     RR   DDDDDDD    EE          RR     RR          1111
 OOO  OOO    RR     RR   DD    DDD  EE          RR     RR         11111
 OO    OO    RR     RR   DD     DD  EE          RR     RR            11
 OO    OO    RR     RR   DD     DD  EE          RR     RR            11
 OO    OO    RRRRRRR     DD     DD  EEEEEE      RRRRRRR              11
 OO    OO    RRRRR       DD     DD  EEE         RRRRR                11
 OO    OO    RR  RR      DD     DD  EEE         RR  RR               11
 OOO  OOO    RR   RR     DD    DDD  EEE         RR   RR              11
  OOOOOO     RR     RR   DDDDDDD    EEE         RR     RR            11
   OOOO      RR     RR   DDDDDD     EEEEEEEE    RR     RR         11111111
```

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THERE IS  1  TABLE UNDER THIS ORDER

THE VALUES OUTPUT IN THE TABLES UNDER THIS ORDER
ARE SCALED BY     1.00000     AND ARE OFFSET BY     .000000E+00
CONTINUITY VALUES ARE NOT SCALED OR OFFSET

ANY DIRECTIONAL VALUES ARE GIVEN WITH RESPECT TO THE GLOBAL AXIS SET
```

ANY DIRECTIONAL VALUES ARE GIVEN WITH RESPECT TO A LOCAL AXIS SET
IN PREFERENCE TO OTHERS. THE LETTER L IS PRINTED AFTER EACH LINE OF
OUTPUT WHERE THE DIRECTIONAL STRESSES ARE WITH RESPECT TO
A LOCAL AXIS SET.

THERE IS NO SORTING UNDER THIS ORDER

ALL DIRECTIONAL STRAINS UNDER THIS ORDER ARE ENGINEERING STRAINS .

1

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********************
*                  *
*  TABLE 1   OF 1  *
*                  *
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LOAD CASE	NODE NO.	SIG MISES	SIG XX	SIG YY	SIG ZZ	TAU XY	TAU YZ	TAU ZX	
1	1	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	
1	2	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	
1	3	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	
1	4	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	
1	5	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	
1	6	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	
1	7	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	
1	8	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	
1	9	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	
					MAJORITY OF STRESSES OMITTED				
1	133	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	
1	134	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	
1	135	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	
1	136	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	
1	137	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	L
1	137	1.4400E+05	1.6149E+05	9.3334E+03	2.7340E+04	3.1394E+01	5.0709E+02	-2.1380E+01	L
1	138	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	L
1	138	1.3442E+05	1.5097E+05	9.1706E+03	2.5619E+04	2.8204E+03	3.7094E+02	-7.7773E+00	L
1	139	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	L
1	139	1.1566E+05	1.2635E+05	3.6441E+03	2.0785E+04	6.5752E+03	6.2820E+02	-1.9385E+01	L
1	140	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	L
1	140	3.8793E+04	4.0960E+04	7.5117E+03	7.7571E+03	1.1459E+04	3.4882E+02	-3.0521E+01	L
1	141	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	L
1	141	8.7817E+04	-8.8981E+04	-6.1880E+03	-1.5209E+04	2.2529E+04	2.3500E+02	6.5763E+01	L
1	142	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	L
1	142	1.4675E+05	-1.5510E+05	-7.5469E+03	-2.6016E+04	2.6753E+04	1.0838E-01	1.4479E+02	L
1	143	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	L
1	143	2.0599E+05	-2.2212E+05	-1.5494E+04	-3.8021E+04	3.5991E+04	1.1335E+01	3.4105E+02	L
1	311	1.7932E+05	-1.9524E+05	-3.9398E+03	-3.1869E+04	6.4096E+03	-3.9322E+01	7.4676E-01	
1	313	1.4352E+05	-1.5507E+05	-1.8291E+03	-2.5107E+04	6.7896E+03	-3.1223E+02	-2.2571E+00	
1	315	1.0374E+05	-1.0928E+05	1.7486E+03	-1.7206E+04	7.7482E+03	2.7318E+02	-9.5834E-01	
1	317	1.2547E+05	1.3566E+05	1.1032E+03	2.1883E+04	-3.9656E+01	2.3414E+02	1.2368E+00	
1	319	1.2542E+05	1.3566E+05	1.1715E+03	2.1893E+04	1.9826E+01	-3.8835E+01	1.2402E+00	
1	321	1.0369E+05	-1.0926E+05	1.6929E+03	-1.7211E+04	-7.7657E+03	-3.5091E+02	-4.8750E+00	
1	323	1.4334E+05	-1.5508E+05	-2.0867E+03	-2.5146E+04	-6.7704E+03	1.5586E+02	-1.2292E+00	
1	325	1.7941E+05	-1.9524E+05	-3.8104E+03	-3.1848E+04	-6.3964E+03	1.9481E+02	2.5987E-01	
1	327	2.1064E+05	-2.3092E+05	-6.5260E+03	-3.7990E+04	-5.3730E+03	3.8796E+01	5.0595E+00	
1	329	2.3967E+05	-2.6369E+05	-8.4492E+03	-4.3544E+04	-2.3394E+03	-1.1660E+02	3.3774E+00	
1	331	1.6503E+05	-2.3396E+05	-6.0138E+04	-7.9407E+04	-1.3807E+00	-1.5075E-01	1.2277E+00	
1	333	1.6762E+05	-2.3990E+05	-6.3994E+04	-8.2050E+04	1.2015E+03	1.5369E-01	-1.3951E+00	
1	335	1.5051E+05	-2.5859E+05	-1.1610E+05	-1.0117E+05	3.5889E+02	-1.1090E-01	-1.8669E+00	
1	337	1.2110E+05	-2.2912E+05	-2.7162E+05	-1.3520E+05	-3.9031E+03	-1.0841E+00	-1.7654E+00	

1

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LOAD CASE	NODE NO.	SIG MISES	SIG XX	SIG YY	SIG ZZ	TAU XY	TAU YZ	TAU ZX
1	339	2.6606E+05	-1.6222E+05	-4.2664E+05	-1.5899E+05	-1.5192E+03	2.1162E+00	-1.8503E-01
1	341	5.0094E+05	-1.1222E+05	-6.5369E+05	-2.0680E+05	-2.4009E+03	-3.5316E+00	1.3599E+00
1	343	4.9130E+05	-2.7818E+05	-7.7216E+05	-2.8359E+05	3.8649E+00	3.8226E+00	-4.3954E+00
1	345	4.9130E+05	-2.7818E+05	-7.7216E+05	-2.8359E+05	3.8649E+00	3.8226E+00	-4.3954E+00
1	347	5.0094E+05	-1.1222E+05	-6.5369E+05	-2.0680E+05	2.4093E+03	3.4718E+00	-4.5236E+00
1	349	2.6606E+05	-1.6222E+05	-4.2664E+05	-1.5899E+05	1.5235E+03	2.0627E+00	-1.9827E+00
1	351	1.2110E+05	-2.2912E+05	-2.7162E+05	-1.3520E+05	3.9036E+03	-1.0309E+00	-1.9292E+00
1	353	1.5051E+05	-2.5859E+05	-1.1610E+05	-1.0117E+05	-3.5912E+02	1.6945E+00	-1.7457E+00
1	355	1.6762E+05	-2.3990E+05	-6.3994E+04	-8.2050E+04	-1.2015E+03	1.1295E+00	-1.2700E+00
1	357	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
1	358	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
1	359	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

MAJORITY OF STRESSES OMITTED

1	580	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
1	581	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
1	582	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
1	583	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
1	584	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
1	585	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
1	586	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
1	587	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
1	588	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
1	589	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00L
1	589	1.4404E+05	1.6147E+05	9.2570E+03	2.7308E+04	1.9521E+01	-2.7312E+02	3.7388E+01L
1	590	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00L
1	590	1.3449E+05	1.5095E+05	9.0388E+03	2.5602E+04	2.8567E+03	-3.7090E+02	3.4513E+01L
1	591	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00L
1	591	1.1583E+05	1.2622E+05	3.2140E+03	2.0724E+04	6.6650E+03	-8.2146E+01	1.8720E+00L
1	592	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00L
1	592	3.8912E+04	4.0938E+04	7.2131E+03	7.7024E+03	1.1445E+04	-1.9264E+02	-2.7313E+01L
1	593	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00L
1	593	8.7753E+04	-8.9090E+04	-6.3502E+03	-1.5288E+04	2.2467E+04	-1.5702E+02	1.2240E+01L
1	594	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00L
1	594	1.4672E+05	-1.5509E+05	-7.6622E+03	-2.6047E+04	2.6874E+04	7.7834E+01	-1.4477E+02L
1	595	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00L
1	595	2.0576E+05	-2.2209E+05	-1.5774E+04	-3.8055E+04	3.5914E+04	5.3537E+02	-2.2445E+02L

MAJORITY OF STRESSES OMITTED

1	2310	1.6339E+05	-2.2165E+05	-4.7475E+04	-7.2665E+04	-6.0565E+03	8.6914E-01	-1.3086E+00
1	2311	1.6339E+05	-2.2165E+05	-4.7475E+04	-7.2665E+04	-6.0566E+03	-1.5961E-01	1.2889E+00
1	2312	1.5962E+05	-2.4236E+05	-7.9009E+04	-8.6769E+04	-1.2663E+03	1.2815E+00	-1.3668E+00
1	2313	1.6762E+05	-2.3990E+05	-6.3994E+04	-8.2050E+04	-1.2015E+03	1.1295E+00	-1.2700E+00
1	2314	1.5962E+05	-2.4236E+05	-7.9009E+04	-8.6769E+04	-1.2661E+03	1.2819E+00	-1.2553E+00
1	2315	1.6612E+05	-2.3596E+05	-6.1115E+04	-8.0209E+04	-5.1025E+02	1.1002E+00	-1.2439E+00
1	2316	1.6612E+05	-2.3596E+05	-6.1115E+04	-8.0209E+04	-5.1018E+02	1.1001E+00	-1.2811E+00
1	2317	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
1	2318	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
1	2319	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
1	2320	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
1	2321	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
1	2322	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
1	2775	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
1	2776	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
1	2777	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
1	2778	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
1	2779	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
1	2780	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
1	2781	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
1	2782	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
1	2783	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
1	2784	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

1
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```
EEEEEEEE  N     NN  DDDDDD
EE        NN    NN  DDDDDDD
EE        NNN   NN  DD   DDD
EE        NNNN  NN  DD    DD
EE        NNNNN NN  DD    DD
EEEEEE    NNNNNNNN  DD    DD
EEE       NN NNNNN  DD    DD
EEE       NN  NNNN  DD    DD
EEE       NN   NNN  DD   DDD
EEE       NN    NN  DDDDDDD
EEEEEEEE  NN     N  DDDDDD
```

```
  OOOO    FFFFFFFF
 OOOOOO   FFF
OOO  OOO  FFF
OO    OO  FFF
OO    OO  FFF
OO    OO  FFFFFF
OO    OO  FF
OO    OO  FF
OOO  OOO  FF
 OOOOOO   FF
  OOOO    FF
```

```
PPPPPPP   RRRRRRR     OOOO      CCCC    EEEEEEEE    SSSS      SSSS    IIIIIIII  N     NN    GGGG
PP    PP  RR    RR   OOOOOO   CC   CC   EE         SS  SS    SS  SS      II      NN    NN   GG  GG
PP    PP  RR    RR  OOO  OOO CC     CC  EE        SS    SS  SS    SS     II      NNN   NN  GG     GG
PP    PP  RR    RR  OO     OO CC         EE        SS        SS          II      NNNN  NN  GG
PP    PP  RR    RR  OO     OO CC         EE         SS        SS         II      NNNNN NN  GG
PPPPPPP   RRRRRRR   OO     OO CC         EEEEEE      SSSS      SSSS     II      NNNNNNNN  GG
PP        RRRRR     OO     OO CC         EEE            SS        SS       II      NN NNNNN  GG    GGG
PP        RR  RR    OO     OO CC         EEE             SS        SS      II      NN  NNNN  GG     GG
PP        RR   RR   OOO  OOO CC     CC  EEE       SS    SS  SS    SS     II      NN   NNN  GG     GG
PP        RR    RR   OOOOOO   CC   CC   EEE        SS  SS    SS  SS      II      NN    NN   GG  GG
PP        RR    RR    OOOO      CCCC    EEEEEEEE    SSSS      SSSS    IIIIIIII  NN     N    GGGG
```

APPENDIX C

STRUCTURE OF PRE-PROCESSING PROGRAM

C.1 Compilation Script (makefile)

```
# compiles tunnel program
#
CFLAGS= -O
.KEEP_STATE:

all: tub getin dispget avstrget unstrget stressget finddim indistress gddisp gdstress revforce2

tub:            tsub2d1.o preprob.o nodecob2.o toplgyb.o subdiv.o wrtout3.o supports.o
        f77 -o tub tsub2d1.o preprob.o nodecob2.o toplgyb.o subdiv.o wrtout3.o supports.o

lightgen:       lightgen.o
  unilink  lightgen.o

indistress:     indistress.o
  unilink  indistress.o

clean:
  rm *.o
```

C.2 Input File

The input file completely defines the problem to be solved in simple and short form as shown in Table 5.1. All distances are given in metres.

C.3 Structure of Pre-Processing Program

The following section provides some details of the FORTRAN programs written to pre-process data for the simulations. The filename and a brief description of each are given. These are programs, written for a PAFEC-FE input data file and stored it in a suitable format. The first program *'tsub2d1'* contains the main subroutines, namely ***DATAIN, NODECO, TOPLGY, SUBDIV, SUPPORTS, WRTOUT. DATAIN*** concerns tunnel data, tunnel supports data, excavation data, symmetry data, dimension of model (two or three) and the number of subdivisions (NZ) determined by the element resolution number. The last five concern pre-processing the tunnel data, calculation of the nodel co-ordinates for the tunnel geometry, pafblock topology, pafblock subdivision for maximum element size and aspect ratio, support systems and finally the written output for two- and three-dimensional models. The following programs and their subroutines use the input to the model in order to generate the tunnel model referred to and pictured throughout this report.

C.4 Tunnel Data In-Main Routine

```
C************************************************************************
C   PROGRAM TO FIND NEW COORDINATES OF TUNNEL AND FE-PAFBLOCK DESIGN
C   FILENAME=tsub2d1.f
C************************************************************************

C ======================================================================
C MAIN ROUTINES FOR CREATING FE-PAFBLOCK DESIGN
C ======================================================================

      CALL DATAIN
      CALL PREPRO
      CALL NODECO
      CALL TOPLGY
      CALL SUBDIV
      CALL WRTOUT

      STOP
      END

C ======================================================================
C SUBROUTINE DATAIN
C ======================================================================

        SUBROUTINE DATAIN

        CALL TUNNAK
        CALL TUNNIN
        CALL ROCKIN
        CALL SUPPIN
        CALL EXCVIN
        CALL RESNIN

        RETURN
        END

C ======================================================================
C SUBROUTINE TUNNAK FOR READING THE TUNNEL NAME AND KM IN
C ======================================================================

        SUBROUTINE TUNNAK

        IMPLICIT DOUBLE PRECISION  (A-H,O-Z)
        CHARACTER*10 TNAME,TKM

        COMMON / CTUNNA / TNAME, TKM

        WRITE(6,*)'INPUT TUNNEL NAME = ',TNAME
        READ*,TNAME

        WRITE(6,*)'INPUT KM          =',TKM
        READ'(A5)',TKM

        RETURN
        END

C ======================================================================
C SUBROUTINE TUNNIN  FOR READING THE TUNNEL DATA IN
C ======================================================================

        SUBROUTINE TUNNIN

        IMPLICIT DOUBLE PRECISION  (A-H,O-Z)
        COMMON / CTUNIN / H, HOVER, HUNDER

        WRITE(6,*)'INPUT CLEAR HEIGHT OF TUNNEL IN METRES, HCLEAR='
        READ*,H

        WRITE(6,*)'INPUT HEIGHT OF OVERBURDEN IN METRES,HOVER='
```

```
      READ*,HOVER

      WRITE(6,*)'INPUT HEIGHT UNDER TUNNEL IN METERS, HUNDER='
      READ*,HUNDER

      RETURN
      END

C =====================================================================
C SUBROUTINE ROCKIN FOR READING THE ROCK STARA DATA IN
C ====================================================================

      SUBROUTINE ROCKIN

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)
      COMMON / CTUNIN / H, HOVER, HUNDER
      COMMON / CROKIN / NLAY, HINLAY(20), MLAY(20), HLAY(20)

C INPUT NUMBER OF ROCK LAYER (STRATA), NLAY

      WRITE(6,*)'INPUT NUMBER OF ROCK LAYERS, NLAY='
      READ*,NLAY

      DO 10 ILAY=1,NLAY

C INPUT HEIGHT OF LAYERS FROM GROUND SURFACE IN METRES

      WRITE(6,*)
     &'INPUT HEIGHT OF LAYERS FROM GROUND SURFACE IN METRES, HINLAY='

      READ*,HINLAY(ILAY)

C INPUT MATERIAL PROPERTIES OF EACH LAYER

      WRITE(6,*)'INPUT MATERIAL PROPERTIES OF LAYER, MLAY='
      READ*,MLAY(ILAY)

C ARRAY OF LAYERS HEIGTHS RELATIVE TO TUNNEL ORIGIN

      HLAY(ILAY)=H+HOVER-HINLAY(ILAY)

  10  CONTINUE

      WRITE(6,*)'INPUT MATERIAL PROPERTY OF REST OF GROUND'
      READ*,MLAY(NLAY+1)

      RETURN
      END

C =====================================================================
C SUBROUTINE SUPPIN FOR READING TUNNEL SUPPORT DATA IN
C ====================================================================

      SUBROUTINE SUPPIN

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)
      COMMON / CSUPIN / SAMIN, SAMAJ, HANCH(2), DANCH(2),
     &                  RANCH,AANCH(2),PERIOD, SANCH, SAMAJ2,
     &                  MARCH,MPARCH,MANCH,MPANCH

C INPUT STEEL ARCH MINOR AND MAJOR WIDTH
       WRITE(6,*)'MINOR (1/2) WIDTH OF STEEL ARCH = ?'
       READ*,SAMIN

       WRITE(6,*)'MAJOR (1/2) WIDTH OF STEEL ARCH = ?'
       READ*,SAMAJ

       WRITE(6,*)'2nd MAJOR (1/2) WIDTH OF STEEL ARCH = ?'
       READ*,SAMAJ2

C IS A STEEL ARCH PRESENT ?
      WRITE(6,*)'IS A STEEL ARCH PRESENT ?  0) NO, 1) YES'
      READ*,MARCH
```

```
C WHAT IS THE MATERIAL PROPERTY OF THE STEEL ARCH USED ?
      WRITE(6,*)'WHAT IS THE MATERIAL PROPERTY OF THE STEEL ARCH USED ?'
      READ*,MPARCH

C INPUT HEIGHT,LENGHT,RADIUS AND ANGLE OF ANCHORAGES
         WRITE(6,*)'HEIGHT OF  ANCHORAGES 1 AND 2= ?'
         READ*,HANCH

         WRITE(6,*)'LENGHT OF ANCHORAGES 1 AND 2= ?'
         READ*,DANCH

         WRITE(6,*)'RADIUS OF ANCHORAGES = ?'
         READ*,RANCH

C SQUARE APPROXIMATION OF CIRCULAR CROSS SECTION ANCHORAGE WITH
C SAME CROSS SECTIONAL AREA
C LENGTH OF (1/2) RANDOM SQUARE (SANCH)

         SANCH=SQRT(2D0*DACOS(0D0))*RANCH/2D0

         WRITE(6,*)'ANGLE OF ANCHORAGES 1 AND 2= ?'
         READ*,AANCH

C ARE ANCHORAGES PRESENT  ?
        WRITE(6,*)'ARE ANCHORAGES PRESENT  ?  0) NO, 1) YES'
        READ*,MANCH

C WHAT IS THE MATERIAL PROPERTY OF THE ANCHORAGES USED ?
      WRITE(6,*)'WHAT IS THE MATERIAL PROPERTY OF THE ANGHORAGES USED ?'
      READ*,MPANCH

C ASSING LENGHT OF (1/2) PERIOD ;

         WRITE(6,*)'LENGTH OF (1/2) PERIOD = ?'
         READ*,PERIOD

         RETURN
         END

C ====================================================================
C SUBROUTINE EXCVIN FOR READING TUNNEL EXCAVATION DATA IN
C ===================================================================

         SUBROUTINE EXCVIN

        IMPLICIT DOUBLE PRECISION  (A-H,O-Z)
        COMMON / CEXCIN / NEXCVT,MEXCVT(0:9),MSHOT(0:9),KSHOT,HSHOT,
     &                   MINNER,KINNER,HINNER
        CHARACTER*2 ZEXCVT(9)

        DATA ZEXCVT/'1 ','2A','2B','3A','3B','4 ','5A','5B','6 '/

C TYPE OF EXCAVATIONS FOR ROCK TYPES A,B AND C

C WHICH REGIONS HAVE BEEN EXCAVATED, REGIONS NUMBER ?
C REGION NUMBERS FOR ROCK TYPES A AND B
C 1, 2a, 2b, 3a, 3b, 4
C REGION NUMBERS FOR ROCK TYPE C
C 1, 2a, 2b, 3a, 3b, 4, 5a, 5b, 6

        WRITE(6,*)'INPUT WHAT ROCK TYPE OF EXCAVATION ?, 0)A,B OR 1)C'
        READ*,NEXCVT

        IF(NEXCVT.EQ.1) THEN
           JEXCVT=9
        ELSE
           JEXCVT=6
        ENDIF

C MEXCVT(0)=1  FOR PAFBLOCKS OUTSIDE THE EXCAVATION REGIONS

        MEXCVT(0)=1
```

```
       MSHOT(0) =1

C FOR EACH REGION MEXCVT(0) INDICATES IF EXCAVATED  MEXCVT(1) IF NOT
      WRITE(6,*)'FOR EACH REGION INDICATE 0) IF EXCAVATED OR 1) IF NOT'
       WRITE(6,*)'AND'
       WRITE(6,*)'IS THERE AN OUTER (SHOTCRETE) LINING? 0) NO, 1) YES'

           DO 45 IEXCVT=1,JEXCVT
             WRITE(6,*)'REGION: ', ZEXCVT(IEXCVT)
               READ*,MEXCVT(IEXCVT),MSHOT(IEXCVT)
 45        CONTINUE

C IS THERE AN OUTER (SHOTCRETE) LINING ?

      WRITE(6,*)'WHAT IS THE MATERIAL PROPERTY OF THE SHOTCRETE USED ?'
      READ*,KSHOT

      WRITE(6,*)'WHAT IS THE THICKNESS OF THE SHOTCRETE USED ?'
      READ*,HSHOT

C IS THERE AN INNER LINING ?

      WRITE(6,*)'IS THERE AN INNER LINING ?  0) NO, 1) YES'
      READ*,MINNER

      WRITE(6,*)'WHAT IS THE MATERIAL PROPETY OF THE INNER LINING ?'
      READ*,KINNER

      WRITE(6,*)'WHAT IS THE THICKNESS OF THE INNER LINNING ?'
      READ*,HINNER

      RETURN
      END

C ====================================================================
C SUBROUTINE RESNIN FOR READING  RESOLUTION OF THE MESH
C ====================================================================

       SUBROUTINE RESNIN

       IMPLICIT DOUBLE PRECISION  (A-H,O-Z)

       COMMON / CRESNI / NZ, ZSIZE, RATIO
       COMMON / CFLAG  / MSYM, MDIM

       RATIO=14.9D0

C  NZ  IS NUMBER OF SUBDIVISION MADE OF THE MINIMUM PAFBLOCK

       WRITE(6,*)'INPUT RESOLUTION =  , NZ ? '
       READ*,NZ

C SYMMETRIC MODEL

       WRITE(6,*)'SYMMETRICAL MODEL ? 0) NO or 1) YES'
       READ*,MSYM

C NUMBER OF DIMENSIONS

       WRITE(6,*)'NUMBER OF DIMENSIONS ? (2 OR 3)'
       READ*,MDIM

       RETURN
       END
```

C.4.1 Pre-Processing the Tunnel Data-Subroutine *PREPRO*

```
C*************************************************************************
C   PROGRAM TO FIND NEW COORDINATES OF 2D-TUNNEL AND FE-PAFBLOCK DESIGN
C   FILENAME=prepro.f
C*************************************************************************

C ======================================================================
C SUBROUTINE PREPRO FOR PRE-PROCESSING THE TUNNEL DATA
C ======================================================================

      SUBROUTINE PREPRO

      CALL ARBPR3
      CALL ANGPRE
      CALL CENPRE
      CALL HFXPRE
      CALL ANCPRE
      CALL ROKPRE
      CALL SHLPRB
      CALL ZSZPRB
      CALL KEYPRE
      CALL INXPRE

      RETURN
      END

C ==========================================================================
C SUBROUTINE ARBPRE3 SET ARBITARY SMALL DISTANCE FOR BOUNDARIES
C ==========================================================================

        SUBROUTINE ARBPR3

        IMPLICIT DOUBLE PRECISION  (A-H,O-Z)

        COMMON / CARB / ARB2
        COMMON / CEXCIN / NEXCVT,MEXCVT(0:9),MSHOT(0:9),KSHOT,HSHOT,
     &                    MINNER,KINNER,HINNER

        ARB2 = HSHOT

        RETURN
        END

C ==========================================================================
C SUBROUTINE ANGPRE FOR SETTING ANGLES OF TUNNEL GEOMETRY
C ==========================================================================

        SUBROUTINE ANGPRE

        IMPLICIT DOUBLE PRECISION  (A-H,O-Z)
        COMMON / CANGLE / DRAD, BETA(22)

        DRAD=DACOS(0D0)/90D0

        BETA(1)=(37D0/4D0)*DRAD
        BETA(2)=(37D0/2D0)*DRAD
        BETA(3)=(37D0*(3D0/4D0))*DRAD
        BETA(4)=37D0*DRAD
        BETA(5)=37D0*DRAD+(13D0/2D0)*DRAD
        BETA(6)=37D0*DRAD+13D0*DRAD
        BETA(7)=(50D0+(47D0-13D0)/2D0)*DRAD
        BETA(8)=37D0*DRAD+47D0*DRAD
        BETA(9)=37D0*DRAD+47D0*DRAD+(25D0/2D0)*DRAD
        BETA(10)=37D0*DRAD+47D0*DRAD+25D0*DRAD
        BETA(11)=37D0*DRAD+47D0*DRAD+25D0*DRAD+(60D0/4D0)*DRAD
        BETA(12)=37D0*DRAD+47D0*DRAD+25D0*DRAD+(60D0/2D0)*DRAD
        BETA(13)=37D0*DRAD+47D0*DRAD+25D0*DRAD+(60D0*(3D0/4D0))*DRAD
        BETA(14)=37D0*DRAD+47D0*DRAD+25D0*DRAD+60D0*DRAD
```

```
      BETA(15)=37D0*DRAD+47D0*DRAD+25D0*DRAD+60D0*DRAD+(11D0/2D0)*DRAD
      BETA(16)=180D0*DRAD
      BETA(20)=90D0*DRAD-37D0*DRAD
      BETA(21)=41D0*DRAD
      BETA(22)=11D0*DRAD

      RETURN
      END

C ======================================================================
C SUBROUTINE CENPRE FOR PRE-PROCESSING AND SETTING CENTRES OF TUNNEL GEOMETRY
C ======================================================================

     SUBROUTINE CENPRE

     IMPLICIT DOUBLE PRECISION  (A-H,O-Z)
     COMMON / CTUNIN / H, HOVER, HUNDER
     COMMON / CCENPR / XC(10), YC(10)
     COMMON / CANGLE / DRAD, BETA(22)

     XC(1)=0D0
     YC(1)=0D0

     XC(2)=XC(1)+(H*(2D0/7.9D0))*DSIN(BETA(4))
     YC(2)=YC(1)+(H*(2D0/7.9D0))*DCOS(BETA(4))

     XC(3)=XC(2)-(H*(1.9D0/7.9D0))*DSIN(BETA(8))
     YC(3)=YC(2)-(H*(1.9D0/7.9D0))*DCOS(BETA(8))

     XC(4)=XC(3)+(H*(6.85D0/7.9D0))*DSIN(BETA(10))
     YC(4)=YC(3)+(H*(6.85D0/7.9D0))*DCOS(BETA(10))

     XC(5)=XC(4)-(H*((31.2989D0-0.95D0)/7.9D0))*DSIN(BETA(14))
     YC(5)=YC(4)-(H*((31.2989D0-0.95D0)/7.9D0))*DCOS(BETA(14))
     DO 10 I=1,5
        XC(5+I) = - XC(I)
        YC(5+I) =   YC(I)
  10 CONTINUE

     RETURN
     END

C ====================================================================
C SUBROUTINE HFXPRE FOR PRE-PROCESSING AND SETTING FIXED HEIGHTS OF
C REGIONS (PAFBLOCK BOUNDARIES).
C ====================================================================

      SUBROUTINE HFXPRE

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)
      COMMON / CTUNIN / H, HOVER, HUNDER
      COMMON / CCENPR / XC(10), YC(10)
      COMMON / CHFXPR / HFX(17)
      COMMON / CANGLE / DRAD, BETA(22)

C HFX(7),HFX(8),HFX(13),HFX(14) AND HFX(15) ARE FIXED HEIGTHS OF TUNNEL

C HFX(7) IS EQUAL HEIGTH OF NODE NUMBER 17, Y(17)
      HFX(7)=YC(2)+H*(5.9D0/7.9D0)*DCOS(BETA(6))

C HFX(8) IS EQUAL HEIGTH OF NODE NUMBER 19, Y(19+2*NMIDA)
      HFX(8)=YC(2)+H*(5.9D0/7.9D0)*DCOS(BETA(8))

C HFX(13) IS EQUAL HEIGTH OF NODE NUMBER 21, Y(21+NMIDA+NMIDC)
      HFX(13)=-0.5D0

C HFX(15) IS EQUAL HEIGTH OF NODE NUMBER 23, Y(23+NMIDA+NMIDC)
      HFX(15)=YC(4)+H*(0.95D0/7.9D0)*DCOS(BETA(10))

C HFX(14) IS EQUAL HEIGTH BETWEEN HFX(13) AND HFX(15)
      HFX(14)=(HFX(13)+HFX(15))/2D0

      RETURN
```

```
      END
C =========================================================================
C SUBROUTINE ANCPRE FOR PRE-PROCESSING AND SETTING FLEAXIABLE HEIGHTS OF REGIONS
C (PAFBLOCK BOUNDARIES) AND LAST FLATTENED SHELL HEIGHT FROM ANCHOARAGES POSITION
C =========================================================================

      SUBROUTINE ANCPRE

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)
      COMMON / CTUNIN / H, HOVER, HUNDER
      COMMON / CHFXPR / HFX(17)
      COMMON / CCENPR / XC(10), YC(10)
      COMMON / CSUPIN / SAMIN, SAMAJ, HANCH(2), DANCH(2),
     &                  RANCH,AANCH(2),PERIOD, SANCH, SAMAJ2,
     &                  MARCH,MPARCH,MANCH,MPANCH
      COMMON / CANGLE / DRAD, BETA(22)
      COMMON / CANCPR / XA(9),YA(9)
      COMMON / EXAM / HL(17)

C FIND BEGINNING AND END POINTS OF THE ANCHORAGES USING PYTHAGOROUS THEOREM

      AANCH(1)=AANCH(1)*DRAD
      AANCH(2)=AANCH(2)*DRAD

      YA(1)=HANCH(1)
      XA(1)=XC(2)+SQRT((H*(5.9D0/7.9D0))**2-(YA(1)-YC(2))**2)

      XA(2)=XA(1)+DANCH(1)*DCOS(AANCH(1))
      YA(2)=YA(1)+DANCH(1)*DSIN(AANCH(1))

      YA(3)=HANCH(2)
      XA(3)=XC(3)+SQRT((H*(7.8D0/7.9D0))**2-(YC(3)-YA(3))**2)

      XA(4)=XA(3)+DANCH(2)*DCOS(AANCH(2))
      YA(4)=YA(3)+DANCH(2)*DSIN(AANCH(2))

C ASSIGN FLEAXIBLE HEIGHT OF PAFBLOCK  BOUNDARIES
C FROM THE END POINTS THE HEIGHTS FOR THE ANCHORAGES BOUNDARIES

C      HFX(3)=YA(2)+SANCH*DCOS(AANCH(1))
      HFX(3)=YA(2)
      HFX(4)=YA(2)
      HFX(5)=YA(2)
C      HFX(5)=YA(2)-SANCH*DCOS(AANCH(1))

C      HFX(9)=YA(4)+SANCH*DCOS(AANCH(2))
      HFX(9) =YA(3)
      HFX(10)=YA(3)
      HFX(11)=YA(3)
C      HFX(11)=YA(4)-SANCH*DCOS(AANCH(2))
C
C HEIGHT OF THE FLATTENED SHELL YA(5) ON THE TOP OF TUNNEL
C FROM INTERSECTION OF TWO STRAIGHT LINES

      ANG1=90D0*DRAD-BETA(4)

      XA(7)=XA(2)+(YA(2)-HFX(7))/DTAN(50D0*DRAD)
      YA(7)=HFX(7)

      XA(5)=-((XA(7)*YA(2)-YA(7)*XA(2))/(XA(7)-XA(2)))/
     &    (((YA(7)-YA(2))/(XA(7)-XA(2)))-DTAN(ANG1))

      YA(5)=DTAN(ANG1)*XA(5)

C HEIGHT OF THE FLATTENED SHELL YA(6) ON THE BOTTOM  OF THE TUNNEL
C TOP REGION FLATTENED SHELL HEIGHT IS USED BECAUSE OF SYMMETRY
C YA(8) BOTTOM COORDITANE OF TUNNEL

      YA(8)=YC(5)-H*(31.2989D0/7.9D0)

      ANG2=49*DRAD
      YA(6)=YA(8)-(YA(5)-H)
      XA(6)=XC(4)+(YC(4)-YA(6))/DTAN(ANG2)
```

```
C SIGNIFICANT FLEXIBLE HEIGHT OF REGIONS ARE HFX(1-6,9-12,16-17)
C HEIGTH OF FIXED REGIONS ARE HFX(7,8, 13-15)
C AND REGION BOUNDRIES RELATIVE TO THE TUNNEL ORIGIN(C1(CX1,CY1))
C 0.005 M EXTENDED REGION TO INCLUDE ANY LAYERS FALLING TOO CLOSE
C TO A FIXED PAFBLOCK BOUNDARY. IN ORDER TO ENSURE NARROW
C PAFBLOCKS ARE NOT CREATED.


C HFX(1) IS EQUAL LAST FLATTENED SHELL HEIGHT
       HFX(1)=YA(5)

C HFX(2) IS EQUAL HEIGHT BETWEEN HFX(1) AND HFX(2)
       HFX(2)=(HFX(1)+HFX(3))/2D0

C HFX(3) IS ASSIGNED ABOVE

C HFX(5) IS ASSIGNED ABOVE

C HFX(4) IS ASSIGNED ABOVE

C HFX(7) IS FIXED HEIGHT OF PAFBLOCK BOUNDARY CALCULATED IN SUBROUTINE HFXPRE

C HFX(6) IS EQUAL HEIGHT BETWEEN HFX(5) AND HFX(7)
       HFX(6)=(HFX(5)+HFX(7))/2D0

C HFX(8) IS FIXED HEIGHT OF PAFBLOCK BOUNDARY CALCULATED IN SUBROUTINE HFXPRE

C HFX(9) IS ASSIGNED ABOVE

C HFX(10) IS ASSIGNED ABOVE

C HFX(11) IS ASSIGNED ABOVE

C HFX(13) IS FIXED HEIGHT OF PAFBLOCK BOUNDARY CALCULATED IN SUBROUTINE HFXPRE

C HFX(12) IS EQUAL HEIGHT BETWEEN HFX(11) AND HFX(13)
       HFX(12)=(HFX(11)+HFX(13))/2D0

C HFX(14) IS FIXED HEIGHT OF PAFBLOCK BOUNDARY CALCULATED IN SUBROUTINE HFXPRE

C HFX(15) IS FIXED HEIGHT OF PAFBLOCK BOUNDARY CALCULATED IN SUBROUTINE HFXPRE

C H17 IS HEIGHT OF LAST FLATTENED SHELL BELOW THE TUNNEL
      HFX(17)=YA(6)

C HFX(16) IS EQUAL HEIGHT BETWEEN HFX(15) AND HFX(17)
       HFX(16)=(HFX(15)+HFX(17))/2D0

c         DO  100 I=1,17

c           HL(I)=H+HOVER-HFX(I)
c 100          WRITE(6,*)I,HL(I),HL(I)

c            WRITE(6,*)DATAN((YA(5)-YA(2))/(XA(2)-XA(5)))/DRAD
c            WRITE(6,*)DATAN((YA(6)-HFX(15))/(XA(4)-XA(6)))/DRAD

      RETURN
      END

C =============================================================================
C SUBROUTINE ROKPRE FOR PRE-PROCESSING AND SETTING PAFBLOCK BOUNDARIES AND EXTRA-LAYERS
C =============================================================================

       SUBROUTINE ROKPRE

       IMPLICIT DOUBLE PRECISION  (A-H,O-Z)
       COMMON / CTUNIN / H, HOVER, HUNDER
       COMMON / CHFXPR / HFX(17)
       COMMON / CSUPIN / SAMIN, SAMAJ, HANCH(2), DANCH(2),
    &                    RANCH,AANCH(2),PERIOD, SANCH, SAMAJ2,
    &                    MARCH,MPARCH,MANCH,MPANCH
       COMMON / CROKIN / NLAY, HINLAY(20), MLAY(20), HLAY(20)
```

```
        COMMON / CROKPR / MATPRO(20), HTOP(4), HMIDA(4), HMIDC(4),
     &                  HBOT(4),NMIDA,NMIDC,NTOP,NBOT
        COMMON / CARB / ARB2

C INITIALISING BEGINNING ROW OF LAYER
       MROW=1

C COUNTERS FOR THE NUMBER OF EXTRA LAYERS REQUIRED

C OVER THE TUNNEL NTOP
       NTOP=0
C TUNNEL LEVEL REGION A
       NMIDA=0
C TUNNEL LEVEL REGION C
       NMIDC=0
C BELOW THE TUNNEL
       NBOT=0

       DO 50 ILAY=1, NLAY

          IF (HLAY(ILAY).GT.HFX(1)+ARB2) THEN

C REGION (I)
             NTOP=NTOP+1
             HTOP(NTOP)=HLAY(ILAY)
             NROW=NTOP

         ELSE IF(HLAY(ILAY).GT.HFX(2)) THEN
C REGION (II)
             HLAY(ILAY)=HFX(1)
             NROW=1+NTOP

         ELSE IF(HLAY(ILAY).GT.HFX(4)) THEN
C REGION(III)
            HLAY(ILAY)=HFX(3)
             NROW=2+NTOP

         ELSE IF(HLAY(ILAY).GT.HFX(6)) THEN
C REGION(IV)
            HLAY(ILAY)=HFX(5)
             NROW=2+NTOP

         ELSE IF(HLAY(ILAY).GT.HFX(7)-ARB2) THEN
C REGION (V)
            HLAY(ILAY)=HFX(17)
             NROW=3+NTOP

         ELSE IF(HLAY(ILAY).GT.HFX(8)+ARB2) THEN
C REGION (VIA)
              NMIDA=NMIDA+1
              HMIDA(NMIDA)=HLAY(ILAY)
               NROW=3+NTOP+NMIDA

         ELSE IF(HLAY(ILAY).GT.HFX(8)-ARB2) THEN
C REGION (VIB)
              HLAY(ILAY)=HFX(8)
               NROW=4+NTOP+NMIDA

         ELSE IF(HLAY(ILAY).GT.HFX(9)+ARB2) THEN
C REGION (VIC)
              NMIDC=NMIDC+1
              HMIDC(NMIDC)=HLAY(ILAY)
               NROW=4+NTOP+NMIDA+NMIDC

         ELSE IF(HLAY(ILAY).GT.HFX(10)) THEN
C REGION (VII)
              HLAY(ILAY)=HFX(9)
               NROW=5+NTOP+NMIDA+NMIDC

         ELSE IF(HLAY(ILAY).GT.HFX(12)) THEN

C REGION (VIII)
              HLAY(ILAY)=HFX(11)
```

```
                NROW=5+NTOP+NMIDA+NMIDC

          ELSE IF(HLAY(ILAY).GT.HFX(14)) THEN

C REGION (IX)
               HLAY(ILAY)=HFX(13)
                NROW=6+NTOP+NMIDA+NMIDC

          ELSE IF(HLAY(ILAY).GT.HFX(16)) THEN
C REGION (X)
               HLAY(ILAY)=HFX(15)
                NROW=7+NTOP+NMIDA+NMIDC

          ELSE IF(HLAY(ILAY).GT.HFX(17)-ARB2) THEN
C REGION (XI)
               HLAY(ILAY)=HFX(17)
               NROW=8+NTOP+NMIDA+NMIDC

          ELSE
C REGION (XII)
               NBOT=NBOT+1
               HBOT(NBOT)=HLAY(ILAY)
                NROW=8+NTOP+NMIDA+NMIDC+NBOT

          ENDIF

          DO 60 IROW=MROW,NROW
c              write(6,*)'matpro(',irow,'):',mlay(ilay)
 60            MATPRO(IROW)=MLAY(ILAY)

C MROW = NEW LAYER BEGINS THE ROW AFTER THE PREVIOUS LAYER FINISHES(NROW)

         MROW=NROW+1
  50     CONTINUE

         NROW=9+NBOT+NTOP+NMIDA+NMIDC

         DO 70 IROW=MROW,NROW
c             write(6,*)'matpro(',irow,'):',mlay(nlay+1)
  70         MATPRO(IROW)=MLAY(NLAY+1)

          WRITE(6,*)'Extra Layers in Top, Middle A, C and Bottom Regions'
          WRITE(6,*) NTOP,NMIDA,NMIDC,NBOT

         RETURN
         END

C ========================================================================
C SUBROUTINE SHLPRB FOR SHELL THICKNESS CALCULATIONS
C BEAM ELEMENT IS USED TO MODEL STEEL ARCH AND ANCHORAGES
C ========================================================================

       SUBROUTINE SHLPRB

       IMPLICIT DOUBLE PRECISION  (A-H,O-Z)
       COMMON / CTUNIN / H, HOVER, HUNDER
       COMMON / CHFXPR / HFX(17)
       COMMON / CEXCIN / NEXCVT,MEXCVT(0:9),MSHOT(0:9),KSHOT,HSHOT,
      &                   MINNER,KINNER,HINNER
       COMMON / CSHLPR / NSHELL, HIN(5), SUMR

       NSHELL=
       HIN(1)=HINNER
       HIN(2)=HSHOT
       HIN(3)=HFX(1)-H-HSHOT
       SUMR=HFX(1)-H

       RETURN
       END
```

```
C ====================================================================
C SUBROUTINE ZSZPRB CALCULATES THE MAXIMUM SIZE OF THE ELEMENTS
C BEAM ELEMENT IS USED TO MODEL STEEL ARCH AND ANCHORAGES
C ====================================================================

        SUBROUTINE ZSZPRB

        IMPLICIT DOUBLE PRECISION  (A-H,O-Z)

        COMMON / CRESNI / NZ, ZSIZE, RATIO
        COMMON / CSUPIN / SAMIN, SAMAJ, HANCH(2), DANCH(2),
     &                    RANCH,AANCH(2),PERIOD, SANCH, SAMAJ2,
     &                    MARCH,MPARCH,MANCH,MPANCH

C ZSIZE IS THE MAXSIZE OF THE ELEMENTS

          ZSIZE=RATIO*PERIOD/NZ
c          write(6,*)zsize
          RETURN
          END

C ========================================================================
C SUBROUTINE KEYPRE FOR  KEY(K) CALCULATIONS
C THE NUMBER OF PAFBLOCKS IN DISTINCT REGIONS OF SHELL CALCULATION
C ========================================================================

      SUBROUTINE KEYPRE

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)
      COMMON / CROKPR / MATPRO(20), HTOP(4), HMIDA(4), HMIDC(4),
     &                  HBOT(4),NMIDA,NMIDC,NTOP,NBOT
      COMMON / CSHLPR / NSHELL, HIN(5),SUMR
      COMMON / CKEYPR /K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF
      COMMON / COUNT  / KPSH(8), NPSIDE, NCOL, NROW

C THE NUMBER OF PAFBLOCKS IN DISTINCT REGIONS OF SHELL CALCULATION
      KPSH(1) = 2
      KPSH(2) = KPSH(1) + 3
      KPSH(3) = KPSH(2) + 2
      KPSH(4) = KPSH(3) + 1 + NMIDA
      KPSH(5) = KPSH(4) + 1 + NMIDC
      KPSH(6) = KPSH(5) + 2
      KPSH(7) = KPSH(6) + 2
      KPSH(8) = KPSH(7) + 4

C NUMBER OF PAFBLOCKS BESIDES THE TUNNEL
      NPSIDE = KPSH(7) - KPSH(2) - 1

C NUMBER OF COLUMNS
      NCOL   = 6

C NUMBER OF ROWS
      NROW   = NPSIDE + NTOP + NBOT + 2

C NNS=NUMBER OF NODES IN EACH SHELL
C NBS=NUMBER OF PAFBLOCKS IN EACH SHELL
C NPOT=NUMBER OF PAFBLOCK OUTSIDE THE TUNNEL
C NPLR IS NUMBER OF PAFBLOCKS FROM LAST RING INSIDE THE TUNNEL
      NNS=4*KPSH(8)
      NBS=2*KPSH(8)
      NPOT=2*NPSIDE+NBS*NSHELL
     &      +2*NCOL*(NTOP+1+NBOT+1)
      NPLR=NPOT+NBS

C NUMBER OF EXTRA LAYERS IN TUNNEL AND MULTIPLES
      K(0)=NMIDA+NMIDC
      K(1)=2*K(0)
      K(2)=4*K(0)
C NUMBER OF NODES DESCRIBING SHELLS
      K(3)=NNS*(NSHELL+1)
C NUMBER OF NODES DESCRIBING SHELLS + SIDES OF TUNNEL
      K(4)=K(3)+4*(NPSIDE+1)
```

```
C NUMBER OF NODES DESCRIBING SHELLS + SIDES + TOP OF TUNNEL
      K(5)=4*(NPSIDE+1)+K(3)+(4*NCOL+2)*(NTOP+1)
C NUMBER OF NODES DESCRIBING SHELLS + SIDES + TOP + BOTTOM OF TUNNEL
C IE. ALL THE NODES OUTSIDE THE TUNNEL
      K(6)=K(5)+(4*NCOL+2)*(NBOT+1)
      K(7)=0
      K(8)=K(6)+12*K(0)

C NNODE TOTAL NUMBER OF NODES FROM 2D PLANE
      NNODE=(2*NCOL)*(NPSIDE+1)+K(6)
C NODE TOTAL NUMBER OF PAFBLOCKS FROM 2D PLANE
      NPAF=NPLR+2*(NCOL-1)*NPSIDE

      RETURN
      END

C ============================================================================
C SUBROUTINE INXPRE SET SHELL TO ROW INDEX CONVERSION
C ============================================================================

      SUBROUTINE INXPRE

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)
      COMMON / CROKPR / MATPRO(20), HTOP(4), HMIDA(4), HMIDC(4),
     &                    HBOT(4),NMIDA,NMIDC,NTOP,NBOT
      COMMON / CKEYPR /K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF
      COMMON / CSHLPR / NSHELL, HIN(5),SUMR
      COMMON / COUNT  / KPSH(8), NPSIDE, NCOL, NROW
      COMMON / CINDEX / INXSUB(100), INXMAT(100)

      DO 10 I=1,NBS

C SUBDIVISION INDEX

         IF (I.LE.NCOL-1) THEN
            INXSUB(I) = NSHELL + I
         ELSE IF (I.LE.NBS/2-(NCOL-1)) THEN
            INXSUB(I) = NSHELL + I + NTOP + 2
         ELSE IF (I.LE.NBS/2) THEN
            INXSUB(I) = NSHELL + NBS/2 + 1 - I
         ELSE IF (I.LE.NBS/2+(NCOL-1)) THEN
            INXSUB(I) = NSHELL + I -NBS/2
         ELSE IF (I.LE.NBS-(NCOL-1)) THEN
            INXSUB(I) = NSHELL + NTOP + 3 + NBS - I
         ELSE
            INXSUB(I) = NSHELL + NBS + 1 - I
         ENDIF

C MATERIAL PROPERTY INDEX

         IF (I.LE.NCOL) THEN
            INXMAT(I) = 2 + NTOP
         ELSE IF (I.LE.NBS/2-NCOL) THEN
            INXMAT(I) = I - NCOL+ NTOP + 2
         ELSE IF (I.LE.NBS/2+NCOL) THEN
            INXMAT(I) = NPSIDE + NTOP + 1
         ELSE IF (I.LE.NBS-(NCOL-1)) THEN
            INXMAT(I) = NTOP + 3 + NBS - NCOL - I
         ELSE
            INXMAT(I) = 2 + NTOP
         ENDIF

 10   CONTINUE

      RETURN
      END
```

C.4.2 Node Co-ordinates - Subroutine *NODECO*

```
C***************************************************************************
C  PROGRAM TO FIND NEW COORDINATES OF 2D-TUNNEL AND FE-PAFBLOCK(O)DESIGN
C  FILENAME=nodeco.f
C***************************************************************************

C ======================================================================
C SUBROUTINE NODECO FOR NODE COORDINATES CALCULATION OF TUNNEL GEOMERTY
C ======================================================================

      SUBROUTINE NODECO

      CALL ZNODB
      CALL SHNOD
      CALL RLNOD
      CALL TPNOD
      CALL BTNOD
      CALL ITNOD

      RETURN
      END

C ===========================================================================
C SUBROUTINE ZNODB TO PRODUCE PLANES OF NODES VARING Z FOR MODIFIED PROJECT DATA
C BEAM ELEMENT IS USED TO MODEL STEEL ARCH AND ANCHORAGES
C ===========================================================================

      SUBROUTINE ZNODB

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)

      COMMON / CSUPIN / SAMIN, SAMAJ, HANCH(2), DANCH(2),
     &                    RANCH,AANCH(2),PERIOD, SANCH, SAMAJ2,
     &                    MARCH,MPARCH,MANCH,MPANCH
      COMMON / CZNOD / Z(5), NDEPTH

      NDEPTH = 1
      Z(1)=0
      Z(2)=PERIOD

      RETURN
      END

C ========================================================================
C SUBROUTINE SHNOD FOR SHELL NODE COORDINATES CALCULATIONS
C ========================================================================

      SUBROUTINE SHNOD

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)

      COMMON / CSHLPR / NSHELL, HIN(5),SUMR
      COMMON / CSHPAR / R,DLAMDA(8),PHI(20),PSI(20)

      DO 100 ISHELL=0,NSHELL

C SET ACCUMULATIVE DISTANCE OF SHELL FROM FIRST SHELL

         IF (ISHELL.EQ.0) THEN
            R=-HIN(1)
         ELSE
            R=R+HIN(ISHELL)
         ENDIF

         CALL SC1NOD (ISHELL)
         CALL SC2NOD (ISHELL)
         CALL SC3NOD (ISHELL)
         CALL SC4NOD (ISHELL)
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```
         CALL SC5NOD (ISHELL)
         CALL SYMNOD (ISHELL)

  100 CONTINUE

      RETURN
      END

C
C ======================================================================
C SUBROUTINE SC1NOD FOR SHELL NODE COORDINATES CALCULATIONS FOR CENTRE 1
C ======================================================================

      SUBROUTINE SC1NOD (ISHELL)

C REGION A: VERTICAL BOUNDARIES
      CALL SC1AND (ISHELL)
C REGION B: TRANSITION BETWEEN VERTICAL BOUNDARY AND RADIAL BOUNDARY
      CALL SC1BND (ISHELL)

      RETURN
      END

C ======================================================================
C SUBROUTINE SC1AND FOR SHELL NODE COORDINATES CALCULATIONS FOR CENTRE 1
C ZONE 1A: IPSH=1  VERTICAL BOUNDARIES
C ======================================================================

      SUBROUTINE SC1AND (ISHELL)

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)

      PARAMETER(NNODES=5000)
      COMMON / CNODES / X(NNODES), Y(NNODES)
      COMMON / CSHPAR / R,DLAMDA(8),PHI(20),PSI(20)
      COMMON / CTUNIN / H, HOVER, HUNDER
      COMMON / CKEYPR /K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF
      COMMON / CSHLPR / NSHELL, HIN(5),SUMR
      COMMON / COUNT  / KPSH(8), NPSIDE, NCOL, NROW

C CORNER NODES DEFINED BY EXCAVATION BOUNDARIES
      X(1+NNS*ISHELL)=0D0
      X(3+NNS*ISHELL)=(1.2D0/7.9D0)*H
      X(5+NNS*ISHELL)=(3.2D0/7.9D0)*H

C MID-SIDE NODES MID-WAY BETWEEN CORNER NODES IN X-DIRECTION
      DO 10 I=1,KPSH(1)
   10    X(I*2+NNS*ISHELL) = (X(I*2-1)+X(I*2+1))/2D0

C Y-VALUES FOUND USING PYTHAGORAS, SAVE LAST SHELL WHICH IS AT CONSTANT HEIGHT
      DO 20 I=1,2*KPSH(1)+1
         IF (ISHELL.EQ.NSHELL) THEN
            Y(I+NNS*ISHELL)=H+R
         ELSE
            Y(I+NNS*ISHELL)=SQRT((H+R)**2-(X(I))**2)
         ENDIF
   20 CONTINUE
c
      RETURN
      END

C ======================================================================
C SUBROUTINE SC1BND FOR SHELL NODE COORDINATES CALCULATIONS FOR CENTRE 1
C ZONE 1B: IPSH=2 TRANSITION BETWEEN VERTICAL BOUNDARY AND RADIAL BOUNDARY
C ======================================================================

      SUBROUTINE SC1BND (ISHELL)

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)

      PARAMETER(NNODES=5000)
      COMMON / CNODES / X(NNODES), Y(NNODES)
      COMMON / CSHPAR / R,DLAMDA(8),PHI(20),PSI(20)
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      COMMON / CANGLE / DRAD, BETA(22)
      COMMON / CTUNIN / H, HOVER, HUNDER
      COMMON / CKEYPR /K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF
      COMMON / CHFXPR / HFX(17)
      COMMON / CSHLPR / NSHELL, HIN(5),SUMR
      COMMON / COUNT  / KPSH(8), NPSIDE, NCOL, NROW

C CALCULATE POSITION OF RADIAL BOUNDARY FOR ALL BUT LAST SHELL

      IF (ISHELL.LE.(NSHELL-1)) THEN
         X(2*KPSH(2)+1+NNS*ISHELL)=(H+R)*DSIN(BETA(4))
         Y(2*KPSH(2)+1+NNS*ISHELL)=(H+R)*DCOS(BETA(4))
      ENDIF

C FIRST SHELL (ISHELL=0) BOUNDARY COORDINATES

      IF (ISHELL.EQ.0) THEN

C FIRST SHELL (ISHELL=0) CORDINATES
C CALCULATE POSITION OF RADIAL BOUNDARY
          X(2*KPSH(2)+1)=(H+R)*DSIN(BETA(4))
          Y(2*KPSH(2)+1)=(H+R)*DCOS(BETA(4))
          B=(H+SUMR)/DSIN(BETA(20))
          X(2*KPSH(2)+1+NNS*NSHELL)=B*DSIN(BETA(4))
          Y(2*KPSH(2)+1+NNS*NSHELL)=B*DCOS(BETA(4))

C CALCULATE X-POSITION OF VERTICAL BOUNDARY
C FOR LAST FLATTENED SHELL
          X(2*KPSH(1)+1+NNS*NSHELL)=(3.2D0/7.9D0)*H

       ENDIF

C CALCULATION OF NODES BETWEEN BOUNDARIES

       DO 120 I=2*KPSH(1)+2,2*KPSH(2)

           IF (ISHELL.EQ.0) THEN
C FOR FIRST SHELL:
C   THE NODES LIE EQUALLY SPACED ON THE ARC
C   FROM NODE 2*KPSH(1)+1 TO NODE 2*KPSH(2)+1.
C   HENCE THE ARC ANGLE PSI (ANGLE FROM THE VERTICAL) OF THESE NODES
C   IS IN EQUAL STEPS.
             OMEGA=DASIN(X(2*KPSH(1)+1)/(H+R))

             PSI(I-(2*KPSH(1)+1))=
     &            OMEGA+(BETA(4)-OMEGA)*(I-(2*KPSH(1)+1))
     &            /(2D0*(KPSH(2)-KPSH(1)))

C CALCULATE THE POSITION OF THE NODES ALONG THIS ARC
             X(I)=(H+R)*DSIN(PSI(I-(2*KPSH(1)+1)))
             Y(I)=(H+R)*DCOS(PSI(I-(2*KPSH(1)+1)))

C LAST FLATTENED SHELL COORDINATES ARE EQUALLY SPACED ALONG THE HORIZONTAL
C BOUNDARY OF THE FLATTENED SHELL
             Y(I+NNS*NSHELL)=HFX(1)
             X(I+NNS*NSHELL)=X(2*KPSH(1)+1+NNS*NSHELL)+
     &        (X(2*KPSH(2)+1+NNS*NSHELL)-X(2*KPSH(1)+1+NNS*NSHELL))
     &        *(I-(2*KPSH(1)+1))/(2D0*(KPSH(2)-KPSH(1)))

C PHI IS AN ANGLE BETWEEN STRAIGHT LINES WHICH PASSES THROUGH NODES
C 2*KPSH(1)+2 TO 2*KPSH(2) AND HORIZONTAL

             PHI(I-(2*KPSH(1)+1))=DATAN((Y(I+NNS*NSHELL)-Y(I))/
     &        (X(I+NNS*NSHELL)-X(I)))

           ELSE IF(ISHELL.LE.(NSHELL-1)) THEN

C Q IS LENGTH OF STRAIGHT LINE FROM THE NODE ON THE FIRST SHELL
C TO THE NODE ON THE ISHELL+1 SHELL.
C THIS IS FOUND FROM THE GEOMETRY OF A STRAIGHT LINE CUTTING TWO ARCS.
C THE FIRST ARC IS RADIUS H AND THE LINE INTERSECTS AT A KNOWN POSITION
C ARC ANGLE PSI ( IE. THE POSITION OF THE NODE ),
C THE DISTANCE ( Q )TO THE SECOND INTERSECT OF THE SECOND ARC ( RADIUS H+R )
```

```
C IS THEN CALCULATED.

            A=1
            B=  2D0*(X(I)*DCOS(PHI(I-(2*KPSH(1)+1)))
     &              + Y(I)*DSIN(PHI(I-(2*KPSH(1)+1))))
            C= -(H+R)*(H+R)+(H-HIN(1))*(H-HIN(1))

            Q= (-B + SQRT(B*B-4*A*C) )/(2D0*A)

            X(I+NNS*ISHELL)=X(I)+Q*DCOS(PHI(I-(2*KPSH(1)+1)))
            Y(I+NNS*ISHELL)=Y(I)+Q*DSIN(PHI(I-(2*KPSH(1)+1)))

         ENDIF
 120  CONTINUE

      RETURN
      END

C ======================================================================
C SUBROUTINE SC2NOD FOR SHELL NODE COORDINATES CALCULATIONS FOR CENTRE 2
C ======================================================================

      SUBROUTINE SC2NOD (ISHELL)

C REGION A: BOUNDARY FOR ANCHORAGE 1
      CALL SC2AND (ISHELL)
C REGION B: HORIZONTAL BOUNDARIES FOR REGION MIDA OF TUNNEL
      CALL SC2BND (ISHELL)

      RETURN
      END

C ======================================================================
C SUBROUTINE SC2AND FOR SHELL NODE COORDINATES CALCULATIONS FOR CENTRE 2
C ZONE 2A: BOUNDARY FOR ANCHORAGE 1 AND SURROUNDING NODES
C ======================================================================

      SUBROUTINE SC2AND (ISHELL)

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)

      PARAMETER(NNODES=5000)
      COMMON / CNODES / X(NNODES), Y(NNODES)
      COMMON / CCENPR / XC(10), YC(10)
      COMMON / CSHPAR / R,DLAMDA(8),PHI(20),PSI(20)
      COMMON / CANGLE / DRAD, BETA(22)
      COMMON / CTUNIN / H, HOVER, HUNDER
      COMMON / CKEYPR /K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF
      COMMON / COUNT  / KPSH(8), NPSIDE, NCOL, NROW
      COMMON / CSUPIN / SAMIN, SAMAJ, HANCH(2), DANCH(2),
     &                  RANCH,AANCH(2),PERIOD, SANCH, SAMAJ2,
     &                  MARCH,MPARCH,MANCH,MPANCH
      COMMON / CHFXPR / HFX(17)
      COMMON / CSHLPR / NSHELL, HIN(5),SUMR
      COMMON / CANCPR / XA(9),YA(9)

C Find Node that terminates region

      IF (ISHELL.EQ.0) THEN

C Inner Lining forms radial boundary

         Y(2*KPSH(3)+1)=YC(2)+(HFX(7)-YC(2))*
     &        (H*(5.9D0/7.9D0)+R)/(H*(5.9D0/7.9D0))
      ELSE

C REST FORMS HORIZONTAL BOUNDARY AT HFX(7)

         Y(2*KPSH(3)+1+NNS*ISHELL)=HFX(7)

      ENDIF

      IF (ISHELL.LE.(NSHELL-1)) THEN
```

```
C THE POSITION OF THE NODE CAN BE FOUND WHERE THE HORIZONTAL BOUNDARY CUTS
C THE ARC OF THE SHELL, USING PYTHAGORAS.

         YF1=Y(2*KPSH(3)+1+NNS*ISHELL)-YC(2)
         XF1=SQRT(((H*(5.9D0/7.9D0)+R)**2)-(YF1)**2)
         X(2*KPSH(3)+1+NNS*ISHELL)=XC(2)+XF1

      ELSE

C THE FLATTENED SHELL BOUNDARY IS A VERTICAL LINE AT XA(4)

         X(2*KPSH(3)+1+NNS*NSHELL)=XA(4)

      ENDIF

C FIND POSITION OF THE ANCHORAGE BOUNDARY

      NANCH = KPSH(2)+KPSH(3)+1

      IF (ISHELL.LE.(NSHELL-1)) THEN

C NODES ALONG ANCHORAGE
C The equation of an arc is;
C     (xb-x0)^2 + (yb-y0)^2 = Radius^2    (1)
C A straight line passing through A at angle alpha is;
C      xb = xa + q cos(alpha)             (2a)
C      yb = ya + q sin(alpha)             (2b)
C Substituting (2) into (1) produceses a quadratic in q
C Noting that A also lies on an arc of Radius0, the quadratic
C can be simply solved to find the length of q and hence the position
C of B, using the standard quadratic formula.

         A=1
         B=  2D0*( (XA(1)-XC(2)) * DCOS(AANCH(1))
     &            +(YA(1)-YC(2)) * DSIN(AANCH(1)) )
         C= -2D0*H*(5.9D0/7.9D0)*R - R*R

         Q= (-B + SQRT(B*B-4*A*C) )/(2D0*A)

         X(NANCH+NNS*ISHELL)=XA(1)+Q*DCOS(AANCH(1))
         Y(NANCH+NNS*ISHELL)=YA(1)+Q*DSIN(AANCH(1))

      ELSE

C END OF ANCHORAGE

         X(NANCH+NNS*NSHELL)=XA(2)
         Y(NANCH+NNS*NSHELL)=YA(2)

      ENDIF

C CENTRALIZING MIDSIDE NODES FOR CIRCULAR SHELLS ONLY

      IF (ISHELL.LE.(NSHELL-1)) THEN

C CENTRALISING MIDSIDE NODE NANCH-1+NNS*ISHELL

C THETA1=THE ANGLE BETWEEN NODE NANCH+NNS*ISHELL AND HORIZONTAL
C THETA2=THE ANGLE BETWEEN NODE NANCH-2+NNS*ISHELL AND NODE NANCH+NNS*ISHELL
C THETA3=THE ANGLE BETWEEN NODE NANCH-1+NNS*ISHELL AND VERTICAL

         THETA1=DASIN((Y(NANCH+NNS*ISHELL)-YC(2))/(H*(5.9D0/7.9D0)+R))
         THETA2=90D0*DRAD-BETA(4)-THETA1
         THETA3=BETA(4)+THETA2/2D0

         X(NANCH-1+NNS*ISHELL)=XC(2)+(H*(5.9D0/7.9D0)+R)*DSIN(THETA3)
         Y(NANCH-1+NNS*ISHELL)=YC(2)+(H*(5.9D0/7.9D0)+R)*DCOS(THETA3)

C CENTRALISING MIDSIDE NODE NANCH+1

C THETA4=THE ANGLE BETWEEN NODE NANCH+2+NNS*ISHELL AND HORIZONTAL
C THETA5=THE ANGLE BETWEEN NODE NANCH+NNS*ISHELL AND NODE NANCH+2+NNS*ISHELL
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C THETA6=THE ANGLE BETWEEN NODE NANCH+2+NNS*ISHELL AND VERTICAL

         ANG15=(X(NANCH)/(H*(5.9D0/7.9D0)))
         THETA4=DASIN((Y(NANCH+2+NNS*ISHELL)-YC(2))/(H*(5.9D0/7.9D0)+R))
         THETA5=90D0*DRAD-ANG15-THETA4
         THETA6=ANG15+THETA5/2D0

         X(NANCH+1+NNS*ISHELL)=XC(2)+(H*(5.9D0/7.9D0)+R)*DSIN(THETA6)
         Y(NANCH+1+NNS*ISHELL)=YC(2)+(H*(5.9D0/7.9D0)+R)*DCOS(THETA6)

      ELSE

C FLATTENED SHELL DOESN'T REQUIRE MID-SIDE NODES

         X(NANCH-1+NNS*ISHELL) = 0D0
         Y(NANCH-1+NNS*ISHELL) = 0D0
         X(NANCH+1+NNS*ISHELL) = 0D0
         Y(NANCH+1+NNS*ISHELL) = 0D0

      ENDIF

      RETURN
      END

C ==========================================================================
C SUBROUTINE SC2BND FOR SHELL NODE COORDINATES CALCULATIONS FOR CENTRE 2
C ZONE 2B: HORIZONTAL BOUNDARIES FOR REGION MIDA OF TUNNEL
C ==========================================================================

      SUBROUTINE SC2BND (ISHELL)

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)

      PARAMETER(NNODES=5000)
      COMMON / CNODES / X(NNODES), Y(NNODES)
      COMMON / CCENPR / XC(10), YC(10)
      COMMON / CSHPAR / R,DLAMDA(8),PHI(20),PSI(20)
      COMMON / CTUNIN / H, HOVER, HUNDER
      COMMON / CKEYPR /K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF
      COMMON / CSHLPR / NSHELL, HIN(5),SUMR
      COMMON / COUNT  / KPSH(8), NPSIDE, NCOL, NROW
      COMMON / CHFXPR / HFX(17)
      COMMON / CROKPR / MATPRO(20), HTOP(4), HMIDA(4), HMIDC(4),
     &                  HBOT(4),NMIDA,NMIDC,NTOP,NBOT
      COMMON / CANCPR / XA(9),YA(9)

C ITERATIVE LAYER'S NODES COORDINATES CALCULATIONS IN REGION A

       DO 130 IMIDA=1,NMIDA

C INCLUDE EXTRA LAYERS AT ROCK BOUNDARY

          Y(2*KPSH(3)+1+2*IMIDA+NNS*ISHELL)=HMIDA(IMIDA)

C PLACE MID-SIDE NODE AT HALF VERTICAL DISTANCE BETWEEN SURROUNDING NODES

          Y(2*KPSH(3)+2*IMIDA+NNS*ISHELL)=
     &              (Y(2*KPSH(3)+1+2*IMIDA+NNS*ISHELL)+
     &               Y(2*KPSH(3)+1+2*(IMIDA-1)+NNS*ISHELL))/2D0

          IF (ISHELL.LE.(NSHELL-1)) THEN

C CALCULATE X-POSITIONS TO LIE ON ARC
C   CORNER NODE

             X(2*KPSH(3)+1+2*IMIDA+NNS*ISHELL)=
     &            XC(2)+SQRT((H*(5.9D0/7.9D0)+R)**2-
     &                       (HMIDA(IMIDA)-YC(2))**2)

C   MID-SIDE NODE

             X(2*KPSH(3)+2*IMIDA+NNS*ISHELL)=
     &              XC(2)+SQRT((H*(5.9D0/7.9D0)+R)**2-
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     &                 (Y(2*KPSH(3)+2*IMIDA+NNS*ISHELL)-YC(2))**2)

          ELSE

C LAST SHELL IS VERTICAL AT XA(4)
C   CORNER NODE

             X(2*KPSH(3)+1+2*IMIDA+NNS*ISHELL)=XA(4)

C   MID-SIDE NODE

             X(2*KPSH(3)+2*IMIDA+NNS*ISHELL)=XA(4)

         ENDIF

  130 CONTINUE

C CALCULATE HORIZONTAL BOUNDARY BETWEEN MIDA AND MIDC REGIONS AT HFX(8)

      Y(2*KPSH(4)+1+NNS*ISHELL)=HFX(8)

      IF (ISHELL.LE.(NSHELL-1)) THEN

C ENSURE NODE IS ON THE ARC

          YF2=HFX(8)-YC(2)
          XF2=SQRT(((H*(5.9D0/7.9D0)+R)**2)-(YF2)**2)

          X(2*KPSH(4)+1+NNS*ISHELL)=XC(2)+XF2

       ELSE

C AGAIN FLATTENED SHELL HAS A VERTICAL BOUNDARY AT XA(4)

          X(2*KPSH(4)+1+NNS*ISHELL)=XA(4)

       ENDIF

C CENTRALIZING MIDSIDE NODE 2*KPSH(4)+NNS*ISHELL IN Y-DIRECTION

      Y(2*KPSH(4)+NNS*ISHELL)=
     &     (Y(2*KPSH(4)+1+NNS*ISHELL)+Y(2*KPSH(4)-1+NNS*ISHELL))/2D0

      IF (ISHELL.LE.(NSHELL-1)) THEN

C ENSURE NODE IS ON THE ARC

          X(2*KPSH(4)+NNS*ISHELL)=XC(2)+SQRT(((H*5.9D0/7.9D0)+R)**2-
     &        (Y(2*KPSH(4)+NNS*ISHELL)-YC(2))**2)
      ELSE

C AGAIN FLATTENED SHELL HAS A VERTICAL BOUNDARY AT XA(4)

         X(2*KPSH(4)+NNS*ISHELL)=XA(4)

      ENDIF

      RETURN
      END

C =======================================================================
C SUBROUTINE SC3NOD FOR SHELL NODE COORDINATES CALCULATIONS FOR CENTRE 3
C =======================================================================

      SUBROUTINE SC3NOD (ISHELL)

C MIDC REGION EXTRA LAYERS
      CALL SC3AND (ISHELL)
C ANCHORAGE 2 AND FIXED HORIZONTAL BOUNDARIES
      CALL SC3BND (ISHELL)

      RETURN
      END
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C =====================================================================
C SUBROUTINE SC3AND FOR SHELL NODE COORDINATES CALCULATIONS FOR CENTRE 3
C ZONE 3A: HORIZONTAL BOUNDARIES FOR REGION MIDC OF TUNNEL
C =====================================================================

      SUBROUTINE SC3AND (ISHELL)

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)

      PARAMETER(NNODES=5000)
      COMMON / CNODES / X(NNODES), Y(NNODES)
      COMMON / CCENPR / XC(10), YC(10)
      COMMON / CSHPAR / R,DLAMDA(8),PHI(20),PSI(20)
      COMMON / CTUNIN / H, HOVER, HUNDER
      COMMON / CKEYPR /K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF
      COMMON / COUNT  / KPSH(8), NPSIDE, NCOL, NROW
      COMMON / CHFXPR / HFX(17)
      COMMON / CROKPR / MATPRO(20), HTOP(4), HMIDA(4), HMIDC(4),
     &                  HBOT(4),NMIDA,NMIDC,NTOP,NBOT
      COMMON / CSHLPR / NSHELL, HIN(5),SUMR
      COMMON / CANCPR / XA(9),YA(9)

C ITERATIVE LAYER'S NODES CORDINATES CALCULATIONS IN REGION C

      DO 140 IMIDC=1,NMIDC

C INCLUDE EXTRA LAYERS AT ROCK BOUNDARY

         Y(2*KPSH(4)+1+2*IMIDC+NNS*ISHELL)=HMIDC(IMIDC)

C PLACE MID-SIDE NODE AT HALF VERTICAL DISTANCE BETWEEN SURROUNDING NODES

         Y(2*KPSH(4)+2*IMIDC+NNS*ISHELL)=
     &        (Y(2*KPSH(4)+1+2*IMIDC+NNS*ISHELL)+
     &         Y(2*KPSH(4)+1+2*(IMIDC-1)+NNS*ISHELL))/2D0

         IF (ISHELL.LE.(NSHELL-1)) THEN

C CALCULATE X-POSITIONS TO LIE ON ARC
C   CORNER NODE

            X(2*KPSH(4)+1+2*IMIDC+NNS*ISHELL)=XC(3)+
     &      SQRT((H*(7.8D0/7.9D0)+R)**2-(YC(3)-HMIDC(IMIDC))**2 )

C   MID-SIDE NODE

            X(2*KPSH(4)+2*IMIDC+NNS*ISHELL)=XC(3)+
     &           SQRT((H*(7.8D0/7.9D0)+R)**2-
     &           (YC(3)-Y(2*KPSH(4)+2*IMIDC+NNS*ISHELL))**2 )

         ELSE

C LAST SHELL IS VERTICAL AT XA(4)
C   CORNER NODE

            X(2*KPSH(4)+1+2*IMIDC+NNS*ISHELL)=XA(4)

C   MID-SIDE NODE

            X(2*KPSH(4)+2*IMIDC+NNS*ISHELL)=XA(4)
        ENDIF

 140  CONTINUE

      RETURN
      END

C =====================================================================
C SUBROUTINE SC3BND FOR SHELL NODE COORDINATES CALCULATIONS FOR CENTRE 3
C ZONE 3B: ANCHORAGE 2 AND FIXED HORIZONTAL BOUNDARIES
C =====================================================================
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      SUBROUTINE SC3BND (ISHELL)

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)

      PARAMETER(NNODES=5000)
      COMMON / CNODES / X(NNODES), Y(NNODES)
      COMMON / CCENPR / XC(10), YC(10)
      COMMON / CSHPAR / R,DLAMDA(8),PHI(20),PSI(20)
      COMMON / CTUNIN / H, HOVER, HUNDER
      COMMON / CKEYPR /K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF
      COMMON / COUNT  / KPSH(8), NPSIDE, NCOL, NROW
      COMMON / CHFXPR / HFX(17)
      COMMON / CROKPR / MATPRO(20), HTOP(4), HMIDA(4), HMIDC(4),
     &                    HBOT(4),NMIDA,NMIDC,NTOP,NBOT
      COMMON / CSUPIN / SAMIN, SAMAJ, HANCH(2), DANCH(2),
     &                    RANCH,AANCH(2),PERIOD, SANCH, SAMAJ2,
     &                    MARCH,MPARCH,MANCH,MPANCH
      COMMON / CSHLPR / NSHELL, HIN(5),SUMR
      COMMON / CANCPR / XA(9),YA(9)
      COMMON / CANGLE / DRAD, BETA(22)

C ANCHOR 2 NODE COORDINATES CALCULATIONS

C FIND POSITION OF THE ANCHORAGE BOUNDARY

      NANCH = 2*KPSH(5)+1

      IF (ISHELL.LE.(NSHELL-1)) THEN

C NODES ALONG ANCHORAGE
C The equation of an arc is;
C     (xb-x0)^2 + (yb-y0)^2 = Radius^2    (1)
C A straight line passing through A at angle alpha is;
C      xb = xa + q cos(alpha)             (2a)
C      yb = ya + q sin(alpha)             (2b)
C Substituting (2) into (1) produceses a quadratic in q
C Noting that A also lies on an arc of Radius0, the quadratic
C can be simply solved to find the length of q and hence the position
C of B, using the standard quadratic formula.

         A=1
         B=  2D0*( (XA(3)-XC(3))*DCOS(AANCH(2))
     &            +(YA(3)-YC(3))*DSIN(AANCH(2)) )
         C= -2D0*H*(7.8D0/7.9D0)*R - R*R

         Q=(-B+SQRT(B*B-4*A*C))/(2D0*A)

         X(NANCH+NNS*ISHELL)=XA(3)+Q*DCOS(AANCH(2))
         Y(NANCH+NNS*ISHELL)=YA(3)+Q*DSIN(AANCH(2))

      ELSE

C END OF ANCHORAGE

         X(NANCH+NNS*NSHELL)=XA(4)
         Y(NANCH+NNS*NSHELL)=YA(4)

      ENDIF

C CENTRALISING MIDSIDE NODE NANCH-1+NNS*ISHELL

      Y(NANCH-1+NNS*ISHELL)=( Y(NANCH+NNS*ISHELL)
     &                       +Y(NANCH-2+NNS*ISHELL))/2D0

      IF (ISHELL.LE.(NSHELL-1)) THEN
         X(NANCH-1+NNS*ISHELL)=XC(3)+SQRT((H*(7.8D0/7.9D0)+R)**2-
     &                          (YC(3)-Y(NANCH-1+NNS*ISHELL))**2)
      ELSE
         X(NANCH-1+NNS*ISHELL)=XA(4)
      ENDIF

C SET HORIZONTAL BOUNDARIES AT HFX(13) AND HFX(15)
```

```
      DO 10 I=1,2

         Y(2*KPSH(5)+1+2*I+NNS*ISHELL)=HFX(11+2*I)

         IF (ISHELL.LT.NSHELL) THEN
            YF3=YC(3)-HFX(11+2*I)
            XF3=SQRT((H*(7.8D0/7.9D0)+R)**2-(YF3)**2)
            X(2*KPSH(5)+1+2*I+NNS*ISHELL)=XC(3)+XF3
         ELSE
            X(2*KPSH(5)+1+2*I+NNS*ISHELL)=XA(4)
         ENDIF

C MAKE BOUNDARY FOR INNER LINNING RADIAL

         IF ((ISHELL.EQ.0).AND.(I.EQ.2)) THEN
            X(2*KPSH(5)+1+2*I+NNS*ISHELL)=XC(3)
     &         +(H*(7.8D0/7.9D0)+R)*DSIN(BETA(10))
            Y(2*KPSH(5)+1+2*I+NNS*ISHELL)=YC(3)
     &         +(H*(7.8D0/7.9D0)+R)*DCOS(BETA(10))
         ENDIF

C CENTRALISING MIDSIDE NODES 2*KPSH(5)+2, 2*KPSH(5)+4

         Y(2*KPSH(5)+2*I+NNS*ISHELL)=(Y(2*KPSH(5)+1+2*I+NNS*ISHELL)
     &      +Y(2*KPSH(5)-1+2*I+NNS*ISHELL))/2D0

         IF (ISHELL.LE.(NSHELL-1)) THEN
            X(2*KPSH(5)+2*I+NNS*ISHELL)=XC(3)+SQRT((H*(7.8D0/7.9D0)+
     &       R)**2-(YC(3)-Y(2*KPSH(5)+2*I+NNS*ISHELL))**2)
         ELSE
             X(2*KPSH(5)+2*I+NNS*ISHELL)=XA(4)
         ENDIF
  10  CONTINUE

       RETURN
       END

C ======================================================================
C SUBROUTINE SC4NOD FOR SHELL NODE COORDINATES CALCULATIONS FOR CENTRE 4
C TRANSITION BETWEEN HORIZONTAL AND VERTICAL BOUNDARIES
C ======================================================================

      SUBROUTINE SC4NOD (ISHELL)

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)

      PARAMETER(NNODES=5000)
      COMMON / CNODES / X(NNODES), Y(NNODES)
      COMMON / CCENPR / XC(10), YC(10)
      COMMON / CANGLE / DRAD, BETA(22)
      COMMON / CSHPAR / R,DLAMDA(8),PHI(20),PSI(20)
      COMMON / CTUNIN / H, HOVER, HUNDER
      COMMON / CKEYPR /K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF
      COMMON / CSHLPR / NSHELL, HIN(5),SUMR
      COMMON / COUNT  / KPSH(8), NPSIDE, NCOL, NROW
      COMMON / CHFXPR / HFX(17)
      COMMON / CANCPR / XA(9),YA(9)

      IF (ISHELL.EQ.NSHELL) THEN

C LAST SHELL CORNER NODES LIE ON HORIZONTAL BOUNDARY AT YA(6)

         X(2*KPSH(7)-1+NNS*ISHELL)=XA(6)
         Y(2*KPSH(7)-1+NNS*ISHELL)=YA(6)

         Y(2*KPSH(7)+1+NNS*ISHELL)=YA(6)
         X(2*KPSH(7)+1+NNS*ISHELL)=XC(4)+
     &      (YA(6)-YC(4))*DTAN(BETA(14))

      ELSE

C CORNER NODES FORM RADIAL BOUNDARIES BETWEEN ARCS
```

```
          X(2*KPSH(7)-1+NNS*ISHELL)=XC(4)+
     &          (H*(0.95D0/7.9D0)+R)*DSIN(BETA(12))
          Y(2*KPSH(7)-1+NNS*ISHELL)=YC(4)+
     &         (H*(0.95D0/7.9D0)+R)*DCOS(BETA(12))

              X(2*KPSH(7)+1+NNS*ISHELL)=XC(4)+
     &          (H*(0.95D0/7.9D0)+R)*DSIN(BETA(14))
              Y(2*KPSH(7)+1+NNS*ISHELL)=YC(4)+
     &          (H*(0.95D0/7.9D0)+R)*DCOS(BETA(14))

          ENDIF

C BETA(11)=37D0*DRAD+47D0*DRAD+25D0*DRAD+(60D0/4D0)*DRAD

C CENTRALISING MIDSIDE NODE 2*KPSH(7)-2+NNS*ISHELL FOR CIRCULAR SHELLS ONLY

          IF (ISHELL.LT.NSHELL) THEN

C THETA9=THE ANGLE BETWEEN NODE 2*KPSH(7)-2+NNS*ISHELL AND VERTICAL
C THETA7=THE ANGLE BETWEEN NODE 2*KPSH(7)-1+NNS*ISHELL AND HORIZSIZEONTAL
C THETA8=THE ANGLE BETWEEN NODE 2*KPSH(6)+1+NNS*ISHELL AND NODE 2*KPSH(7)-1+NNS*ISHELL

             THETA7=DASIN((Y(2*KPSH(7)-1+NNS*ISHELL)-YC(4))/
     &             (H*(0.95D0/7.9D0)+R))
             THETA8=90D0*DRAD-BETA(10)-THETA7
             THETA9=BETA(10)+(THETA8/2D0)

             X(2*KPSH(7)-2+NNS*ISHELL)=XC(4)+
     &          (H*(0.95D0/7.9D0)+R)*DSIN(THETA9)
             Y(2*KPSH(7)-2+NNS*ISHELL)=YC(4)+
     &          (H*(0.95D0/7.9D0)+R)*DCOS(THETA9)

             X(2*KPSH(7)+NNS*ISHELL)=XC(4)+
     &          (H*(0.95D0/7.9D0)+R)*DSIN(BETA(13))
             Y(2*KPSH(7)+NNS*ISHELL)=YC(4)+
     &          (H*(0.95D0/7.9D0)+R)*DCOS(BETA(13))

          ELSE

C NO MID-SIDE NODES REQUIRED FOR FLATTENED SHELL

             X(2*KPSH(7)-2+NNS*ISHELL) = 0D0
             Y(2*KPSH(7)-2+NNS*ISHELL) = 0D0
             X(2*KPSH(7)  +NNS*ISHELL) = 0D0
             Y(2*KPSH(7)  +NNS*ISHELL) = 0D0

          ENDIF

       RETURN
       END

C ===========================================================================
C SUBROUTINE SC5NOD FOR SHELL NODE COORDINATES CALCULATIONS FOR CENTRE 5
C ===========================================================================

       SUBROUTINE SC5NOD (ISHELL)

       IMPLICIT DOUBLE PRECISION  (A-H,O-Z)

       PARAMETER(NNODES=5000)
       COMMON / CNODES / X(NNODES), Y(NNODES)
       COMMON / CCENPR / XC(10), YC(10)
       COMMON / CSHPAR / R,DLAMDA(8),PHI(20),PSI(20)
       COMMON / CTUNIN / H, HOVER, HUNDER
       COMMON / CKEYPR /K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF
       COMMON / COUNT  / KPSH(8), NPSIDE, NCOL, NROW
       COMMON / CSHLPR / NSHELL, HIN(5),SUMR
       COMMON / CANCPR / XA(9),YA(9)

C IN FIRST LAYER X-POSITIONS OF CORNER NODES SET BY EXACAVATION BOUNDARIES
C   AND FORM VERTICAL BOUNDARIES

       IF (ISHELL.EQ.0) THEN
```

```
          X(2*KPSH(7)+3) = (5D0/7.9D0)*H
          X(2*KPSH(7)+5) = (3.2D0/7.9D0)*H
          X(2*KPSH(7)+7) = (1.2D0/7.9D0)*H
          X(2*KPSH(7)+9) = 0D0

       ELSE

C FOR EACH PAFBLOCK

          DO 10 IPSH=KPSH(7)+1,KPSH(8)
  10         X(2*IPSH+1+NNS*ISHELL) = X(2*IPSH+1)

       ENDIF

C FOR EACH PAFBLOCK

       DO 20 IPSH=KPSH(7)+1,KPSH(8)

C SET THE Y-POSITIONS TO LIE ON ARC BOUNDARIES OR VERTICAL BOUNDARY FOR FLATTENED SHELL

          IF (ISHELL.EQ.NSHELL) THEN

C LAST SHELL NODE LIE ON HORIZONTAL BOUNDARY AT YA(6)

              Y(2*IPSH+1+NNS*ISHELL)=YA(6)

          ELSE

C ENSURE NODE LIES ON ARC FOR CIRCULAR SHELLS
             Y(2*IPSH+1+NNS*ISHELL)=YC(5)-SQRT((H*(31.29D0/7.9D0)+R)**2-
     &                                  X(2*IPSH+1+NNS*ISHELL)**2)

          ENDIF

          IF (ISHELL.LT.NSHELL) THEN

C PLACE MID-SIDE NODE IN AVERAGE X-POSITION THEN ENSURE THEY LIE ON THE ARC

             X(2*IPSH+NNS*ISHELL)=
     &         (X(2*IPSH-1+NNS*ISHELL)+X(2*IPSH+1+NNS*ISHELL))/2D0
             Y(2*IPSH+NNS*ISHELL)=YC(5)-SQRT((H*(31.29D0/7.9D0)+R)**2
     &                                   -(X(2*IPSH+NNS*ISHELL))**2)

          ELSE

C NO MID-SIDE NODE REQUIRED FOR LAST SHELL

             X(2*IPSH+NNS*ISHELL)= 0D0
             Y(2*IPSH+NNS*ISHELL)= 0D0

          ENDIF

  20   CONTINUE

       RETURN
       END

C ============================================================================
C SUBROUTINE SYMNOD FOR SHELL SYMMETRIC NODES COORDINATES
C ============================================================================

       SUBROUTINE SYMNOD (ISHELL)

       IMPLICIT DOUBLE PRECISION  (A-H,O-Z)

       PARAMETER(NNODES=5000)
       COMMON / CNODES / X(NNODES), Y(NNODES)
       COMMON / CKEYPR /K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF

C  SHELL SYMMETRIC NODES COORDINATES

       DO 10 I=2,NNS/2
```

```
         X(NNS-(I-2)+NNS*ISHELL) = -X(I+NNS*ISHELL)
         Y(NNS-(I-2)+NNS*ISHELL) =  Y(I+NNS*ISHELL)
   10  CONTINUE

        RETURN
        END

C =========================================================================
C SUBROUTINE RLNOD FOR RIGTH AND LEFT HAND SIDES OF
C TUNNEL NODE COORDINATES CALCULATIONS
C =========================================================================

      SUBROUTINE RLNOD

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)

      PARAMETER(NNODES=5000)
      COMMON / CNODES / X(NNODES), Y(NNODES)
      COMMON / CSHLPR / NSHELL, HIN(5),SUMR
      COMMON / CKEYPR /K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF
      COMMON / COUNT  / KPSH(8), NPSIDE, NCOL, NROW

C NODES ON EITHER SIDE OF TUNNEL SHELLS

        DO  170 I=1,2*NPSIDE+1

C CALCULATION OF RIGTH HAND SIDE NODES OF TUNNEL SHELL

            X(I+K(3))=29D0
            Y(I+K(3))=Y(2*KPSH(2)+I+NNS*NSHELL)

C  CALCULATION OF LEFT HAND SIDE NODES OF TUNNEL SHELL

            X(I+2*NPSIDE+2+K(3))=-29D0
            Y(I+2*NPSIDE+2+K(3))=Y(2*KPSH(7)-I+NNS*NSHELL)

  170   CONTINUE

       RETURN
       END

C =========================================================================
C SUBROUTINE TPNOD FOR TOP REGION NODE COORDINATES CALCULATIONS
C =========================================================================

      SUBROUTINE TPNOD

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)

      PARAMETER(NNODES=5000)
      COMMON / CNODES / X(NNODES), Y(NNODES)
      COMMON / CTUNIN / H, HOVER, HUNDER
      COMMON / CROKPR / MATPRO(20), HTOP(4), HMIDA(4), HMIDC(4),
     &                    HBOT(4),NMIDA,NMIDC,NTOP,NBOT
      COMMON / CKEYPR /K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF
      COMMON / CSHLPR / NSHELL, HIN(5),SUMR
      COMMON / COUNT  / KPSH(8), NPSIDE, NCOL, NROW

C  CALCULATION OF NODES ON THE TOP REGION

      DO 180 I=1,2*NCOL-1,2
         X(I+4*(NPSIDE+1)+K(3))=X(I+NNS*NSHELL)
         Y(I+4*(NPSIDE+1)+K(3))=H+HOVER
   180 CONTINUE
         X(2*NCOL+1+4*(NPSIDE+1)+K(3))=X(1+K(3))
         Y(2*NCOL+1+4*(NPSIDE+1)+K(3))=H+HOVER
      DO 190 I=3,2*NCOL+1,2
         X(4*(NCOL+1)+4*(NPSIDE+1)-I+K(3))=-X(I+4*(NPSIDE+1)+K(3))
         Y(4*(NCOL+1)+4*(NPSIDE+1)-I+K(3))=H+HOVER
  190  CONTINUE

C CALCULATION OF EXTRA LAYERS NODES ON THE TOP REGION
```

```
      DO 210 ITOP=1,NTOP
         DO 200 I=1,4*NCOL+1,2
           X(I+4*(NPSIDE+1)+(4*NCOL+2)*ITOP+K(3))=X(I+4*(NPSIDE+1)+K(3))
           Y(I+4*(NPSIDE+1)+(4*NCOL+2)*ITOP+K(3))=HTOP(ITOP)
  200    CONTINUE
  210 CONTINUE

      RETURN
      END

C ==========================================================================
C SUBROUTINE BTNOD FOR BOTTOM  REGION NODE COORDINATES CALCULATIONS
C ==========================================================================

      SUBROUTINE BTNOD

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)

      PARAMETER(NNODES=5000)
      COMMON / CNODES / X(NNODES), Y(NNODES)
      COMMON / CTUNIN / H, HOVER, HUNDER
      COMMON / CROKPR / MATPRO(20), HTOP(4), HMIDA(4), HMIDC(4),
     &                  HBOT(4),NMIDA,NMIDC,NTOP,NBOT
      COMMON / CKEYPR /K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF
      COMMON / CSHLPR / NSHELL, HIN(5),SUMR
      COMMON / COUNT  / KPSH(8), NPSIDE, NCOL, NROW

C CALCULATION OF NODES ON THE BOTTOM REGION

      DO 180 I=1,2*NCOL-1,2
         X(I+K(5))=X(2*KPSH(8)+2-I+NNS*NSHELL)
         Y(I+K(5))=Y(2*KPSH(8)+1)-HUNDER
  180 CONTINUE
         X(2*NCOL+1+K(5))=X(2*NPSIDE+1+K(3))
         Y(2*NCOL+1+K(5))=Y(2*KPSH(8)+1)-HUNDER
      DO 190 I=3,2*NCOL+1,2
         X(4*(NCOL+1)-I+K(5))=-X(I+K(5))
         Y(4*(NCOL+1)-I+K(5))=Y(2*KPSH(8)+1)-HUNDER
 190  CONTINUE

C CALCULATION OF EXTRA LAYERS NODE ON THE BOTTOM REGION

      DO 330 IBOT=1,NBOT
         DO 200 I=1,4*NCOL+1,2
           X(I+26*IBOT+K(5))=X(I+K(5))
           Y(I+26*IBOT+K(5))=HBOT(1+NBOT-IBOT)
  200    CONTINUE
  330 CONTINUE

      RETURN
      END

C ===================================================================
C SUBROUTINE ITNOD FOR NODE COORDINATES CALCULATIONS INPSIDE THE TUNNEL
C ===================================================================

      SUBROUTINE ITNOD

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)

      PARAMETER(NNODES=5000)
      COMMON / CNODES / X(NNODES), Y(NNODES)
      COMMON / COUNT  / KPSH(8), NPSIDE, NCOL, NROW
      COMMON / CTUNIN / H, HOVER, HUNDER
      COMMON / CANGLE / DRAD, BETA(22)
      COMMON / CSUPIN / SAMIN, SAMAJ, HANCH(2), DANCH(2),
     &                  RANCH,AANCH(2),PERIOD, SANCH, SAMAJ2,
     &                  MARCH,MPARCH,MANCH,MPANCH
      COMMON / CROKPR / MATPRO(20), HTOP(4), HMIDA(4), HMIDC(4),
     &                  HBOT(4),NMIDA,NMIDC,NTOP,NBOT
      COMMON / CKEYPR /K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF
      COMMON / CSHLPR / NSHELL, HIN(5),SUMR
      COMMON / CANCPR / XA(9),YA(9)
```

```
      DOUBLE PRECISION DLAMDA(3)

C NODES COORINATES INPSIDE THE TUNNEL

C SET CO-ORDINATES OF FIRST LAYER DETERMINED BY VARIOUS GEOMETRICAL FACTORS

C HORIZONTAL LAYER MIDWAY BETWEEN HEIGHTS OF NODES 2*KPSH(2)+1 AND 2*KPSH(3)+1

      Y(1+K(6))= (Y(2*KPSH(2)+1+NNS)+Y(2*KPSH(3)+1+NNS))/2D0
      DO 10 I=2,NCOL
   10    Y(2*I-1+K(6)) = Y(1+K(6))

C ANGLE BETWEEN NODE 2*(KPSH(1)+1)+1+NNS ON SHELL AND EXCAVATION POINT

      DLAMDA(1)=-DATAN((Y(2*(KPSH(1)+1)+1+NNS)+(0.5D0/7.9D0)*H)/
     &        (X(2*(KPSH(1)+1)+1+NNS)-(4.36D0/7.9D0)*H) )

C  Assign the x-values of the top line of nodes

      X(1+K(6))=0D0
      X(3+K(6))=X(3+NNS)
      X(5+K(6))=X(5+NNS)
      X(7+K(6))=X(7+NNS)+(Y(7+NNS)-Y(1+K(6)))/DTAN(DLAMDA(1))
      X(11+K(6))=Y(1+K(6))*DTAN(BETA(4))
      X(9+K(6))=X(7+K(6))+(X(11+K(6))-X(7+K(6)))/2D0

C Find angles of the excavation lines

      DLAMDA(2)=-DATAN((Y(9+K(6))-Y(2*KPSH(7)+1+NNS))/
     &       (X(9+K(6))-X(2*KPSH(7)+1+NNS)))

C LAST NODE IN 2ND TO LAST LAYER

      X(2*NCOL*NPSIDE-1+K(6))=(6.19672D0/7.9D0)*H
      Y(2*NCOL*NPSIDE-1+K(6))=Y(2*KPSH(6)+1+NNS)

C ANGLE BETWEEN THE LAST NODE IN THE 1ST LAYER AND THE LAST NODE IN THE
C    2ND TO LAST LAYER

      DLAMDA(3)=-DATAN((Y(2*NCOL-1+K(6))-Y(2*NCOL*NPSIDE-1+K(6)))/
     &   (X(2*NCOL-1+K(6))-X(2*NCOL*NPSIDE-1+K(6))))

C SET HEIGHT OF BOUNDARY ASSOCIATED WITH ANCHORAGE SO THAT THE
C  YDIMS OF THE SURROUNDING LAYERS HAVE THE SAME RATIO AS OUTSIDE THE TUNNEL

C INITIALIZING THE HEIGHT OF THE CENTRAL COLUMN OF NODES

C ALIGN WITH HORIZONTAL LAYER
      Y(4*NCOL+1+K(6))=Y(2*KPSH(3)+1+NNS)

C SET HEIGHT OF BOUNDARY ASSOCIATED WITH ANCHORAGE SO THAT THE
C  YDIMS OF THE SURROUNDING LAYERS HAVE THE SAME RATIO AS OUTSIDE THE TUNNEL

      Y(2*NCOL+1+K(6))=Y(4*NCOL+1+K(6)) + (Y(1+K(6))-Y(4*NCOL+1+K(6)))
     & * (Y(5+K(3))-Y(3+K(3))) / (Y(5+K(3))-Y(1+K(3)))

      DO 20 IMIDA=1,NMIDA
   20    Y(4*NCOL+1+K(6)+2*NCOL*IMIDA)=HMIDA(IMIDA)
      Y(2*NCOL*(3+NMIDA)+1+K(6))=Y(2*KPSH(4)+1+NNS)
      DO 30 IMIDC=1,NMIDC
   30    Y(2*NCOL*(3+NMIDA)+1+K(6)+12*IMIDC)=HMIDC(IMIDC)
      Y(8*NCOL+1+K(8))  =Y(2*KPSH(5)+1+NNS)
      Y(10*NCOL+1+K(8)) =Y(2*KPSH(5)+3+NNS)
      Y(12*NCOL+1+K(8)) =Y(2*KPSH(5)+5+NNS)
      Y((NPSIDE+1)*2*NCOL-3+K(6))=Y(2*KPSH(5)+7+NNS)-
     &           0.25*(Y(2*KPSH(5)+7+NNS)-Y(2*KPSH(5)+5+NNS))
      Y(14*NCOL+1+K(8))=Y((NPSIDE+1)*2*NCOL-3+K(6))

C LAST NODE OF EACH ROW INPSIDE THE TUNNEL IS OMITTED

      DO 1010 J=1,NPSIDE+1

         DO 1020 I=1,NCOL
```

```
          IF (I.LE.3) THEN
             X(2*I-1+(J-1)*2*NCOL+K(6))=X(2*I-1+NNS)
             Y(2*I-1+(J-1)*2*NCOL+K(6))=Y(1+K(6)+(J-1)*2*NCOL)
          ELSE
             Y(2*I-1+(J-1)*2*NCOL+K(6))=Y(1+K(6)+(J-1)*2*NCOL)
             X(2*I-1+(J-1)*2*NCOL+K(6))=X(2*I-1+K(6))+(Y(2*I-1+K(6))
     &             -Y(2*I-1+(J-1)*2*NCOL+K(6)))/DTAN(DLAMDA(I-3))
          ENDIF
 1020    CONTINUE
 1010 CONTINUE

      N95 = (NPSIDE+1)*2*NCOL-1
      N93 = (NPSIDE+1)*2*NCOL-3
      N91 = (NPSIDE+1)*2*NCOL-5
      N83 = (NPSIDE)*2*NCOL-1
      N81 = (NPSIDE)*2*NCOL-3
      N79 = (NPSIDE)*2*NCOL-5
      N67 = (NPSIDE-1)*2*NCOL-5

      X(N79+K(6))=X(N67+K(6))+(0.64D0/7.9D0)*H

      X(N91+K(6))=X(N79+K(6))

      X(N95+K(6))=X(N83+K(6))-0.1*(X(N83+K(6))-X(N81+K(6)))
      Y(N95+K(6))=Y(N95+K(6))-0.2*(Y(N95+K(6))-Y(N83+K(6)))

C SYMMETRIC NODE VALUES INPSIDE THE TUNNEL
C ASSIGMENT OF SYMMETRIC NODE VALUES INPSIDE THE TUNNEL

      DO 1140 J=1,NPSIDE+1
         DO 1150 I=1,NCOL-1

            X(2*I+(J-1)*2*NCOL+K(6))=-X(2*I+1+(J-1)*2*NCOL+K(6))
            Y(2*I+(J-1)*2*NCOL+K(6))= Y(2*I+1+(J-1)*2*NCOL+K(6))

 1150    CONTINUE
 1140 CONTINUE

      RETURN
      END
```

C.4.3 Pafblock Topology - Subroutine *TOPLGY*

```
C***************************************************************************
C     PROGRAM TO FIND NEW COORDINATES OF 2D-TUNNEL ANDFE-PAFBLOCK DESIGN
C     FILENAME=toplgy.f
C***************************************************************************

C =====================================================================
C SUBROUTINE TOPLGY FOR PAFBLOCK TOPOLOGY - NODELE
C =====================================================================

         SUBROUTINE TOPLGY

         CALL SHTOP
         CALL RLTOP
         CALL TPTOP
         CALL BTTOP
         CALL LRTOP
         CALL ITTOP

         RETURN
         END

C =========================================================================
C SUBROUTINE SHTOP FOR SHELL PAFBLOCK TOPOLOGY - NODELE
C =========================================================================
```

```
      SUBROUTINE SHTOP

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)
      PARAMETER(NNODES=5000)
      COMMON / CNODES / X(NNODES), Y(NNODES)
      COMMON / CSHLPR / NSHELL, HIN(5),SUMR
      COMMON / CKEYPR /K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF
      COMMON / CSHTOP / NODELE(5000,8)

C NODELE NODELE NODELE NODELE NODELE NODELE NODELE NODELE NODELE
C SHELL PAFBLOCKS TOPOLOGY

        DO 500 ISHELL=0,(NSHELL-1)

           DO 550 J=1,NBS

             IPAF=J+NBS*ISHELL

             NODELE(IPAF,1)=(2*J-1)+(NNS*ISHELL)
             NODELE(IPAF,3)=(2*J-1)+(NNS*(ISHELL+1))

              IF(J.EQ.NBS) THEN
                   NODELE(IPAF,2)=1+NNS*ISHELL
                   NODELE(IPAF,4)=1+NNS*(ISHELL+1)
              ELSE
                   NODELE(IPAF,2)=(2*J+1)+(NNS*ISHELL)
                   NODELE(IPAF,4)=(2*J+1)+(NNS*(ISHELL+1))
               ENDIF
            NODELE(IPAF,5)=(2*J)+(NNS*ISHELL)
            NODELE(IPAF,6)=0
            NODELE(IPAF,7)=0
            IF(ISHELL.EQ.(NSHELL-1)) THEN
              NODELE(IPAF,8)=0
             ELSE
              NODELE(IPAF,8)=(2*J)+(NNS*(ISHELL+1))
             ENDIF
  550      CONTINUE
  500   CONTINUE

        RETURN
        END

C =======================================================================
C SUBROUTINE RLTOP FOR RIGTH AND LEFT HAND SIDES OF
C PAFBLOCK TOPOLOGY - NODELE
C =======================================================================

      SUBROUTINE RLTOP

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)
      PARAMETER(NNODES=5000)
      COMMON / CNODES / X(NNODES), Y(NNODES)
      COMMON / CSHLPR / NSHELL, HIN(5),SUMR
      COMMON / CKEYPR /K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF
      COMMON / CSHTOP /NODELE(5000,8)
      COMMON / COUNT  / KPSH(8), NPSIDE, NCOL, NROW

C OUTER PAFBLOCKS TOPOLOGY RIGHT HAND SIDE OF THE SHELL

      DO 570 J=1,NPSIDE

           IPAF=J+NBS*NSHELL

           NODELE(IPAF,1)=2*J+2*KPSH(2)-1+NNS*NSHELL
           NODELE(IPAF,2)=2*J+2*KPSH(2)+1+NNS*NSHELL
           NODELE(IPAF,3)=2*J-1+K(3)
           NODELE(IPAF,4)=2*J+1+K(3)
           NODELE(IPAF,5)=0
           NODELE(IPAF,6)=0
           NODELE(IPAF,7)=0
           NODELE(IPAF,8)=0
 570  CONTINUE
```

```
C OUTER PAFBLOCKS TOPOLOGY LEFT HAND SIDE OF SHELL

        DO 600 L=1,NPSIDE

           IPAF=L+NPSIDE+NBS*NSHELL

           NODELE(IPAF,1)=2*L+2*(NBS-KPSH(6)-1)-1+NNS*NSHELL
           NODELE(IPAF,2)=2*L+2*(NBS-KPSH(6)-1)+1+NNS*NSHELL
           NODELE(IPAF,3)=2*L+2*NPSIDE+1+K(3)
           NODELE(IPAF,4)=2*L+2*NPSIDE+3+K(3)
           NODELE(IPAF,5)=0
           NODELE(IPAF,6)=0
           NODELE(IPAF,7)=0
           NODELE(IPAF,8)=0

 600   CONTINUE

       RETURN
       END

C ======================================================================
C SUBROUTINE TPTOP FOR TOP REGION PAFBLOCK TOPOLOGY - NODELE
C ======================================================================

      SUBROUTINE TPTOP

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)
      PARAMETER(NNODES=5000)
      COMMON / CNODES / X(NNODES), Y(NNODES)
      COMMON / CSHLPR / NSHELL, HIN(5),SUMR
      COMMON / CKEYPR /K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF
      COMMON / CROKPR / MATPRO(20), HTOP(4), HMIDA(4), HMIDC(4),
     &                    HBOT(4),NMIDA,NMIDC,NTOP,NBOT
      COMMON / CSHTOP / NODELE(5000,8)
      COMMON / COUNT  / KPSH(8), NPSIDE, NCOL, NROW

      DO 650 L=1,2*NCOL

         IPAF=L+2*NPSIDE+NBS*NSHELL

C PAFBLOCK TOPOLOGY OF TOP REGION FOR FIXED PAFBLOCKS

         NODELE(IPAF,5)=0
         NODELE(IPAF,6)=0
         NODELE(IPAF,7)=0
         NODELE(IPAF,8)=0

         IF (L.LE.NCOL) THEN
            NODELE(IPAF,1)=2*L-1+NNS*NSHELL
         ELSE IF (L.EQ.NCOL+1) THEN
            NODELE(IPAF,1)=K(4)-1
         ELSE
            NODELE(IPAF,1)=K(3)-1+2*(L-2*NCOL)
         ENDIF

         IF (L.LT.NCOL) THEN
            NODELE(IPAF,2)=2*L+1+NNS*NSHELL
         ELSE IF (L.EQ.NCOL) THEN
            NODELE(IPAF,2)=1+K(3)
         ELSE IF (L.LT.2*NCOL) THEN
            NODELE(IPAF,2)=K(3)+1+2*(L-2*NCOL)
         ELSE
            NODELE(IPAF,2)=1+NNS*NSHELL
         ENDIF

         NODELE(IPAF,3)=2*L-1+4*(NPSIDE+1)+K(3)+(4*NCOL+2)*NTOP
         IF (L.GT.NCOL) NODELE(IPAF,3)=NODELE(IPAF,3)+2

         NODELE(IPAF,4)=2*L+1+4*(NPSIDE+1)+K(3)+(4*NCOL+2)*NTOP
         IF (L.GT.NCOL) NODELE(IPAF,4)=NODELE(IPAF,4)+2
         IF (L.EQ.2*NCOL)
     &      NODELE(IPAF,4)=1+4*(NPSIDE+1)+K(3)+(4*NCOL+2)*NTOP
```

```
 650   CONTINUE

C PAFBLOCK TOPOLOGY OF TOP REGION FOR EXTRA PAFBLOCKS

       DO 700 ITOP=1,NTOP
          DO 800 L=1,2*NCOL

             IPAF=L+2*NPSIDE+NBS*NSHELL+2*NCOL*ITOP

C PAFBLOCK TOPOLOGY OF TOP REGION FOR FIXED PAFBLOCKS

             NODELE(IPAF,5)=0
             NODELE(IPAF,6)=0
             NODELE(IPAF,7)=0
             NODELE(IPAF,8)=0

             NODELE(IPAF,1)=2*L+(4*NCOL+2)*ITOP-1+K(4)
             NODELE(IPAF,2)=2*L+(4*NCOL+2)*ITOP+1+K(4)
             NODELE(IPAF,3)=2*L+(4*NCOL+2)*(ITOP-1)-1+K(4)
             NODELE(IPAF,4)=2*L+(4*NCOL+2)*(ITOP-1)+1+K(4)

             IF (L.GT.NCOL) THEN
                NODELE(IPAF,1)=NODELE(IPAF,1)+2
                NODELE(IPAF,2)=NODELE(IPAF,2)+2
                NODELE(IPAF,3)=NODELE(IPAF,3)+2
                NODELE(IPAF,4)=NODELE(IPAF,4)+2
             ENDIF

             IF (L.EQ.2*NCOL) THEN
                NODELE(IPAF,2)=(4*NCOL+2)*ITOP+1+K(4)
                NODELE(IPAF,4)=(4*NCOL+2)*(ITOP-1)+1+K(4)
             ENDIF

 800      CONTINUE
 700   CONTINUE

       RETURN
       END

C ============================================================================
C SUBROUTINE BTTOP FOR BOTTOM REGION PAFBLOCK TOPOLOGY - NODELE
C ============================================================================

      SUBROUTINE BTTOP

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)
      PARAMETER(NNODES=5000)
      COMMON / CNODES / X(NNODES), Y(NNODES)
      COMMON / CSHLPR / NSHELL, HIN(5),SUMR
      COMMON / CKEYPR /K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF
      COMMON / CROKPR / MATPRO(20), HTOP(4), HMIDA(4), HMIDC(4),
     &                  HBOT(4),NMIDA,NMIDC,NTOP,NBOT
      COMMON / CSHTOP / NODELE(5000,8)
      COMMON / COUNT  / KPSH(8), NPSIDE, NCOL, NROW

      DO 850 L=1,2*NCOL

         IPAF=L+2*NPSIDE+NBS*NSHELL+2*NCOL*(NTOP+1)

C PAFBLOCK TOPOLOGY OF BOTTOM REGION FOR FIXED PAFBLOCKS

         NODELE(IPAF,5)=0
         NODELE(IPAF,6)=0
         NODELE(IPAF,7)=0
         NODELE(IPAF,8)=0

         IF (L.LT.NCOL) THEN
            NODELE(IPAF,1)=NNS/2+1-2*L+NNS*NSHELL
         ELSE IF (L.EQ.NCOL) THEN
            NODELE(IPAF,1)=2*NPSIDE+1+K(3)
         ELSE IF (L.LT.2*NCOL) THEN
            NODELE(IPAF,1)=K(3)-NNS/2+1-2*(L-2*NCOL)
         ELSE
```

```
            NODELE(IPAF,1)=K(3)-NNS/2+1
         ENDIF

         IF (L.LE.NCOL) THEN
            NODELE(IPAF,2)=NNS/2+3-2*L+NNS*NSHELL
         ELSE IF (L.EQ.NCOL+1) THEN
            NODELE(IPAF,2)=2*(NPSIDE+1)+1+K(3)
         ELSE
            NODELE(IPAF,2)=K(3)-NNS/2+3-2*(L-2*NCOL)
         ENDIF

         NODELE(IPAF,3)=2*L+1+K(5)+(4*NCOL+2)*NBOT
         IF (L.GT.NCOL)   NODELE(IPAF,3)=NODELE(IPAF,3)+2
         IF (L.EQ.2*NCOL) NODELE(IPAF,3)=1+K(5)+(4*NCOL+2)*NBOT

         NODELE(IPAF,4)=2*L-1+K(5)+(4*NCOL+2)*NBOT
         IF (L.GT.NCOL) NODELE(IPAF,4)=NODELE(IPAF,4)+2

  850 CONTINUE

C PAFBLOCK TOPOLOGY OF BOTTOM REGION FOR EXTRA PAFBLOCKS

      DO 900 IBOT=1,NBOT
         DO 950 L=1,2*NCOL

            IPAF=L+2*NPSIDE+NBS*NSHELL+
     &              2*NCOL*(NTOP+1)+2*NCOL*(IBOT)

C PAFBLOCK TOPOLOGY OF BOTTOM REGION FOR FIXED PAFBLOCKS

             NODELE(IPAF,5)=0
             NODELE(IPAF,6)=0
             NODELE(IPAF,7)=0
             NODELE(IPAF,8)=0

             NODELE(IPAF,1)=-1+2*L+(4*NCOL+2)*IBOT+K(5)
             NODELE(IPAF,2)=1+2*L+(4*NCOL+2)*IBOT+K(5)
             NODELE(IPAF,3)=-1+2*L+(4*NCOL+2)*(IBOT-1)+K(5)
             NODELE(IPAF,4)=1+2*L+(4*NCOL+2)*(IBOT-1)+K(5)

             IF (L.GT.NCOL) THEN
                NODELE(IPAF,1)=NODELE(IPAF,1)+2
                NODELE(IPAF,2)=NODELE(IPAF,2)+2
                NODELE(IPAF,3)=NODELE(IPAF,3)+2
                NODELE(IPAF,4)=NODELE(IPAF,4)+2
             ENDIF

             IF (L.EQ.2*NCOL) THEN
                NODELE(IPAF,2)=1+(4*NCOL+2)*IBOT+K(5)
                NODELE(IPAF,4)=1+(4*NCOL+2)*(IBOT-1)+K(5)
             ENDIF

 950        CONTINUE
 900     CONTINUE

         RETURN
         END

C =========================================================================
C SUBROUTINE LRTOP FOR LAST RING PAFBLOCK TOPOLOGY - NODELE INSIDE THE TUNNEL
C =========================================================================

      SUBROUTINE LRTOP

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)
      PARAMETER(NNODES=5000)
      COMMON / CNODES / X(NNODES), Y(NNODES)
      COMMON / CSHLPR / NSHELL, HIN(5),SUMR
      COMMON / CKEYPR /K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF
      COMMON / CROKPR / MATPRO(20), HTOP(4), HMIDA(4), HMIDC(4),
     &                  HBOT(4),NMIDA,NMIDC,NTOP,NBOT
      COMMON / CSHTOP / NODELE(5000,8)
      COMMON / COUNT  / KPSH(8), NPSIDE, NCOL, NROW
```

```
C LAST RING PAFBLOCK TOPOLOGY

C LAST RING PAFBLOCK TOPOLOGY FROM 1+NPOT TO 8+NPOT

      DO 2000 L=1,NBS

         IPAF=L+NPOT

         NODELE(IPAF,3)=2*L-1+NNS
         NODELE(IPAF,4)=2*L+1+NNS
         NODELE(IPAF,8)=2*L+NNS
         NODELE(IPAF,5)=0D0
         NODELE(IPAF,6)=0D0
         NODELE(IPAF,7)=0D0

         IF (L.LE.NCOL-1) THEN
C RIGHT TOP
            NODELE(IPAF,1)=2*L-1+K(6)
            NODELE(IPAF,2)=2*L+1+K(6)
         ELSE  IF (L.LE.NCOL-1+NPSIDE) THEN
C RIGHT SIDE
            NODELE(IPAF,1)=2*NCOL*(L-(NCOL-1))  -1+K(6)
            NODELE(IPAF,2)=2*NCOL*(L-(NCOL-1)+1)-1+K(6)
         ELSE IF (L.LE.NBS/2) THEN
C RIGHT BOTTOM
            NODELE(IPAF,1)=2*NCOL*NPSIDE+3-2*(L-NBS/2)+K(6)
            NODELE(IPAF,2)=2*NCOL*NPSIDE+1-2*(L-NBS/2)+K(6)
         ELSE IF (L.EQ.NBS/2+1) THEN
C LEFT OF CENTRE BOTTOM
            NODELE(IPAF,1)=2*NCOL*NPSIDE+1+K(6)
            NODELE(IPAF,2)=2*NCOL*NPSIDE+2+K(6)
         ELSE IF (L.LE.NCOL-1+NBS/2) THEN
C LEFT BOTTOM
            NODELE(IPAF,1)=2*(L-NBS/2)+2*NCOL*NPSIDE-2+K(6)
            NODELE(IPAF,2)=2*(L-NBS/2)+2*NCOL*NPSIDE  +K(6)
         ELSE IF (L.LE.NBS-NCOL+1) THEN
C LEFT SIDE
            NODELE(IPAF,1)=2*NCOL*(NBS-NCOL+1-L+2)-2+K(6)
            NODELE(IPAF,2)=2*NCOL*(NBS-NCOL+1-L+1)-2+K(6)
         ELSE IF (L.LT.NBS) THEN
C LEFT TOP
            NODELE(IPAF,1)=2*(NBS-L+1)+K(6)
            NODELE(IPAF,2)=2*(NBS-L  )+K(6)
         ELSE
C LEFT OF CENTRE TOP
            NODELE(IPAF,1)=2+K(6)
            NODELE(IPAF,2)=1+K(6)
            NODELE(IPAF,4)=1+NNS
         ENDIF

 2000 CONTINUE

      RETURN
      END

C ===================================================================
C SUBROUTINE ITTOP FOR PAFBLOCK TOPOLOGY -NODELE INSIDE THE TUNNEL
C ===================================================================

      SUBROUTINE ITTOP

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)

      PARAMETER(NNODES=5000)
      COMMON / CNODES / X(NNODES), Y(NNODES)
      COMMON / CSHLPR / NSHELL, HIN(5),SUMR
      COMMON / CKEYPR /K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF
      COMMON / CROKPR / MATPRO(20), HTOP(4), HMIDA(4), HMIDC(4),
     &                   HBOT(4),NMIDA,NMIDC,NTOP,NBOT
      COMMON / CSHTOP / NODELE(5000,8)
      COMMON / COUNT  / KPSH(8), NPSIDE, NCOL, NROW
```

```
C CENTRAL PAFBLOCK TOPOLOGY INSIDE THE TUNNEL
C CENTRAL PAFBLOCK TOPOLOGY INSIDE THE TUNNEL


C CENTRAL PAFBLOCK TOPOLOGY FROM 1+NPLR TO 50+NPLR

      DO 3000 J=1,NPSIDE
         DO 3100 L=1,2*(NCOL-1)

            IPAF=L+2*(NCOL-1)*(J-1)+NPLR

            NODELE(IPAF,5)=0
            NODELE(IPAF,6)=0
            NODELE(IPAF,7)=0
            NODELE(IPAF,8)=0

            IF(L.LE.NCOL-1) THEN
               NODELE(IPAF,1)=2*L-1+2*NCOL*(J-1)+K(6)
               NODELE(IPAF,2)=2*L+1+2*NCOL*(J-1)+K(6)
            ELSE
               NODELE(IPAF,1)=2*(L-(NCOL-1))+2*NCOL*(J-1)+K(6)
               NODELE(IPAF,2)=2*(L-NCOL)+2*NCOL*(J-1)+K(6)
            ENDIF

            IF(L.EQ.NCOL) NODELE(IPAF,2)=1+2*NCOL*(J-1)+K(6)

            NODELE(IPAF,3)=NODELE(IPAF,1)+2*NCOL
            NODELE(IPAF,4)=NODELE(IPAF,2)+2*NCOL

 3100    CONTINUE
 3000 CONTINUE

      RETURN
      END
```

C.4.4 Pafblock Subdivisions - Subroutine *SUBDIV*

```
C*****************************************************************************
C     PROGRAM TO FIND NEW COORDINATES OF 2D-TUNNEL AND FE-PAFBLOCK DESIGN
C     FILENAME=subdiv.f
C****************************************************************************

C ======================================================================
C SUBROUTINE SUBDIV FOR PAFBLOCK SUBDIVISION FOR MAX ELEMENT SIZE
C AND ASPECT RATIO.
C ======================================================================

      SUBROUTINE SUBDIV

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)

      COMMON / CSUBDV / NSUB(0:50),MASPCT
      COMMON / CDIM   / DIM(4), DMIN, DMAX, IPMAX, IPMIN

C SUBDIVIDE Z DIRECTION

      ipmax = 0
      ipmin = 0

      CALL ZSUBB

      IT=0

C SET MAXIMUM SIZE OF ELEMENTS

   10       CALL MAXSI
            CALL WRTMAX

C CLEAR FLAG, MASPCT, WHICH IS SET WHEN THE SUBDIVISIONS CHANGE
```

```
  20          MASPCT = 0

C ITERATION COUNTER

              IT=IT+1
              WRITE(6,*)'ITERATION = ',IT

C STOP IF REPEATED MORE THAN 10 TIMES

              IF (IT .GT. 10) WRITE(6,*)'Conflict in Geometry !!'
              IF (IT .GT. 10) STOP

C INITIALIZE GLOBAL MINIMUM AND MAXIMUM ELEMENT SIZE WITH DUMMY VALUES

              DMIN = 1D2
              DMAX = 0D0

C ASPECT RATIO CHECK
              CALL SHASP
              CALL RLASP
              CALL TPASP
              CALL BTASP
              CALL LRASP
              CALL ITASP

C REPEAT ASPECT RATIO CHECK UNTIL THERE ARE NO MORE CHANGES TO THE
C SUBDIVISIONS
          IF ( MASPCT .NE. 0 ) GO TO 20

C CLEAR FLAG, MASPCT, WHICH IS SET WHEN THE SUBDIVISIONS CHANGE

          MASPCT = 0

C CHECK THAT RESULTING SUBDIVISION IS COMPATABLE WITH Z SUBDIVISION

          CALL ZASP

C REPEAT SUBDIVISION UNTIL Z SUBDIVISION IS SATISFIED
      IF ( MASPCT .NE. 0 ) GO TO 10

      RETURN
      END

C ====================================================================
C SUBROUTINE ZSUB2 FOR DIVISION OF LENGTH OF PAFBLOCK IN Z-DIRECTION
C BY THE MINIMUM Z-DIMENSION AND ROUNDED BY NEAREST WHOLE NUMBER
C FOR MODIFIED PROJECT DATA
C ====================================================================

      SUBROUTINE ZSUBB

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)

      COMMON / CSUBDV / NSUB(0:50),MASPCT
      COMMON / CZNOD  / Z(5), NDEPTH
      COMMON / CSHLPR / NSHELL, HIN(5),SUMR
      COMMON / COUNT  / KPSH(8), NPSIDE, NCOL, NROW
      COMMON / CRESNI / NZ, ZSIZE, RATIO
      COMMON / CSUPIN / SAMIN, SAMAJ, HANCH(2), DANCH(2),
     &                    RANCH,AANCH(2),PERIOD, SANCH, SAMAJ2,
     &                    MARCH,MPARCH,MANCH,MPANCH

      DO 10 I=1,NDEPTH
         NSUB(NSHELL+NCOL+NROW+I)=0.5+NZ*(Z(I+1)-Z(I))/PERIOD
  10  CONTINUE

      RETURN
      END

C ====================================================================
C SUBROUTINE SUBDIVIDE PAFBLOCKS USING MAXIMUM PAFBLOCK SIZE
C ====================================================================
```

```
      SUBROUTINE MAXSI

C THERE ARE THREE GROUP OF SUBDIVISIONS
C 3. NSHELL = NSUB(I)
C    1.1. NSUB(ISHELL)  ISHELL=1, NSHELL
C    1.2. NSUB(0)  LAST RING
C 2. NCOLUMN = NSUB(NSHELL+I)
C 1. NROW = NSUB(NSHELL+NCOL+I)

      CALL MAXSSH
      CALL MAXSCO
      CALL MAXSRO

      RETURN
      END

C =====================================================================
C SUBROUTINE MAXIMUM PAFBLOCK SUBDIVISION FOR SHELL
C =====================================================================

      SUBROUTINE MAXSSH

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)
      PARAMETER(NNODES=5000)
      COMMON / CNODES / X(NNODES), Y(NNODES)
      COMMON / CSHLPR / NSHELL, HIN(5),SUMR
      COMMON / CKEYPR /K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF
      COMMON / CSUBDV / NSUB(0:50),MASPCT
      COMMON / CRESNI / NZ, ZSIZE, RATIO
      COMMON / CROKPR / MATPRO(20), HTOP(4), HMIDA(4), HMIDC(4),
     &                   HBOT(4),NMIDA,NMIDC,NTOP,NBOT
      COMMON / COUNT  / KPSH(8), NPSIDE, NCOL, NROW

C LARGEST HEIGTH OF SHELLS IS USED THE CALCULATION OF DIVIDING THE SHELLS
C THE HEIGTH BETWEEN LAST SHELL AND ONE BEFORE IS THE LARGEST HEIGTH (RE)

      DO 1190 ISHELL=1,NSHELL
 1190    NSUB(ISHELL)=1+( X(2*KPSH(4)+1+NNS*ISHELL)-
     &                    X(2*KPSH(4)+1+NNS*(ISHELL-1)) )/ZSIZE

C LAST RING PAFBLOCK TOPOLOGY SUBDIVISION N1=NSUBSH(0)
C LARGEST DIMENSION OF LAST RING IS USED THE CALCULATION OF DIVIDING THE LAST RING
C LARGEST DIMENSION OF LAST RING IS BORDER BETWEEN REGION A AND C

      NSUB(0)=1+( X(2*KPSH(4)+1+NNS)
     &           -X(2*NCOL*(4+NMIDA)+K(6)-1) )/ZSIZE

      RETURN
      END

C =====================================================================
C SUBROUTINE MAXIMUM PAFBLOCK SUBDIVISION FOR COLUMN
C =====================================================================

      SUBROUTINE MAXSCO

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)
      PARAMETER(NNODES=5000)
      COMMON / CNODES / X(NNODES), Y(NNODES)
      COMMON / CKEYPR /K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF
      COMMON / CSUBDV / NSUB(0:50),MASPCT
      COMMON / CRESNI / NZ, ZSIZE, RATIO
      COMMON / COUNT  / KPSH(8), NPSIDE, NCOL, NROW
      COMMON / CSHLPR / NSHELL, HIN(5),SUMR

C LARGEST DIMENSION OF EACH COLUMNS IS USED THE CALCULATION OF DIVIDING
C THE COLUMNS

      DO 10 I=1,NCOL
         XDIM=X(2*I+1+K(5))-X(2*I-1+K(5))
 10      NSUB(NSHELL+I)=1+(XDIM/ZSIZE)

      RETURN
```

```
      END
C ====================================================================
C SUBROUTINE MAXIMUM PAFBLOCK SUBDIVISION FOR ROW
C ====================================================================

      SUBROUTINE MAXSRO

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)
      PARAMETER(NNODES=5000)

      COMMON / CNODES / X(NNODES), Y(NNODES)
      COMMON / CSHLPR / NSHELL, HIN(5),SUMR
      COMMON / CKEYPR /K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF
      COMMON / CSHTOP / NODELE(5000,8)
      COMMON / CROKPR / MATPRO(20), HTOP(4), HMIDA(4), HMIDC(4),
     &                    HBOT(4),NMIDA,NMIDC,NTOP,NBOT
      COMMON / CSUBDV / NSUB(0:50),MASPCT
      COMMON / CRESNI / NZ, ZSIZE, RATIO
      COMMON / CSUPIN / SAMIN, SAMAJ, HANCH(2), DANCH(2),
     &                    RANCH,AANCH(2),PERIOD, SANCH, SAMAJ2,
     &                    MARCH,MPARCH,MANCH,MPANCH
      COMMON / COUNT  / KPSH(8), NPSIDE, NCOL, NROW

C MAXIMUM PAFBLOCK SUBDIVISION FOR ROW

      DO 10 J=1,NROW
         IF (J.LE.NTOP) THEN
C EXTRA LAYERS IN TOP REGION
            YDIM = Y(1+4*(NPSIDE+1)+K(3)+(4*NCOL+2)*(J-1))
     &           - Y(1+4*(NPSIDE+1)+K(3)+(4*NCOL+2)*J)
         ELSE IF (J.EQ.NTOP+1) THEN
C TOP REGION
            YDIM = Y(1+4*(NPSIDE+1)+K(3)+(4*NCOL+2)*NTOP)
     &           - Y(1+K(3))
         ELSE IF (J.LE.1+NTOP+NPSIDE) THEN
C RIGHT SIDE OF TUNNEL
            YDIM = SQRT( ( X(2*NCOL-1+2*(J-(2+NTOP))+NNS*NSHELL)
     &                   -X(2*NCOL+1+2*(J-(2+NTOP))+NNS*NSHELL) )**2
     &                  +( Y(2*NCOL-1+2*(J-(2+NTOP))+NNS*NSHELL)
     &                   -Y(2*NCOL+1+2*(J-(2+NTOP))+NNS*NSHELL) )**2 )
C PAFBLOCKS BELOW 2ND ANCHORAGE ARE LARGER IN TUNNEL
            IF (J.EQ.NTOP+NPSIDE-1) YDIM=Y(2*KPSH(5)+1)-Y(2*KPSH(5)+3)
         ELSE IF (J.EQ.NTOP+2+NPSIDE) THEN
            YDIM = Y(2*NPSIDE+1+K(3))
     &           - Y(1+K(5)+(4*NCOL+2)*NBOT)
         ELSE
            YDIM = Y(1+K(5)+(4*NCOL+2)*(11+NTOP+K(0)+NBOT+1-J))
     &           - Y(1+K(5)+(4*NCOL+2)*(11+NTOP+K(0)+NBOT  -J))
         ENDIF
         NSUB(NSHELL+NCOL+J)=1+(YDIM/ZSIZE)
 10   CONTINUE

      RETURN
      END

C ====================================================================
C SUBROUTINE PRINT OUT MAXIMUM PAFBLOCK SUBDIVISIONS
C ====================================================================

      SUBROUTINE WRTMAX

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)
      PARAMETER(NNODES=5000)
      COMMON / CHFXPR / HFX(17)
      COMMON / CSHLPR / NSHELL, HIN(5),SUMR
      COMMON / CROKPR / MATPRO(20), HTOP(4), HMIDA(4), HMIDC(4),
     &                    HBOT(4),NMIDA,NMIDC,NTOP,NBOT
      COMMON / CSUBDV / NSUB(0:50),MASPCT
      COMMON / COUNT  / KPSH(8), NPSIDE, NCOL, NROW
      COMMON / CZNOD  / Z(5), NDEPTH

      DO 10 L=0,NSHELL
```

```
   10    WRITE(6,*)'NSUBSH(',L,')= ',NSUB(L)
      DO 20 L=1,NCOL
   20    WRITE(6,*)'NSUBCO(',L,')= ',NSUB(NSHELL+L)
      DO 30 L=1,NROW
   30    WRITE(6,*)'NSUBRO(',L,')= ',NSUB(NSHELL+NCOL+L)
      DO 40 L=1,NDEPTH
   40    WRITE(6,*)'NSUBZ (',L,')= ',NSUB(NSHELL+NCOL+NROW+L)

      RETURN
      END

C ====================================================================
C SUBROUTINE ASPECT RATIO CHECK
C ====================================================================

      SUBROUTINE ASPCHK (IPAF,N1,N2)

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)

      COMMON / CDIM   / DIM(4), DMIN, DMAX, IPMAX, IPMIN
      COMMON / CRESNI / NZ, ZSIZE, RATIO
      COMMON / CSUBDV / NSUB(0:50),MASPCT

c      WRITE(6,*)'DIMENSIONS OF PAFBLOCK ',IPAF
c      WRITE(6,*)DIM(1)
c      WRITE(6,*)DIM(2)
c      WRITE(6,*)DIM(3)
c      WRITE(6,*)DIM(4)

C FIND THE MAXIMUM AND MINIMUM DIMENSION FOR EACH PAIR OF DIMENSIONS
C AND ASSIGN D1MAX,D1MIN,D2MAX,D2MIN ACCORDINGLY

      IF (DIM(1).GT.DIM(2)) THEN
         D1MAX=DIM(1)
         D1MIN=DIM(2)
      ELSE
         D1MAX=DIM(2)
         D1MIN=DIM(1)
      ENDIF

      IF (DIM(3).GT.DIM(4)) THEN
         D2MAX=DIM(3)
         D2MIN=DIM(4)
      ELSE
         D2MAX=DIM(4)
         D2MIN=DIM(3)
      ENDIF

C CHECK EXTREME ASPECT RATIOS OF PAFBLOCK ELEMENT SUBDIVISION DIMENSIONS
C   AND CORRECT IF BEYOND THE REQUIRED RATIO

c      WRITE(6,*)'PREVIOUS SUBDIVISIONS'
c      WRITE(6,*)N1,N2

      IF ((D1MAX/N1)/(D2MIN/N2).GT.RATIO) THEN
c         write(6,*)Ipaf
c         WRITE(6,*)'Old N1 VALUE = ',N1
         N1=1+N2*D1MAX/(RATIO*D2MIN)
         MASPCT = 1
c         WRITE(6,*)'NEW N1 VALUE = ',N1
      ENDIF

      IF ((D2MAX/N2)/(D1MIN/N1).GT.RATIO) THEN
c        write(6,*)Ipaf
c        WRITE(6,*)'OLD N2 VALUE = ',N2
         N2=1+N1*D2MAX/(RATIO*D1MIN)
         MASPCT = 1
c        WRITE(6,*)'NEW N2 VALUE = ',N2
      ENDIF

C Check Maximum Element size against ZSIZE

      IF (D1MAX/N1.GT.ZSIZE) THEN
```

```
c         write(6,*)Ipaf
c         WRITE(6,*)'Old N1 VALUE = ',N1
         N1=1+D1MAX/ZSIZE
         MASPCT = 1
c         WRITE(6,*)'NEW N1 VALUE = ',N1
      ENDIF

      IF (D2MAX/N2.GT.ZSIZE) THEN
c        write(6,*)Ipaf
c        WRITE(6,*)'OLD N2 VALUE = ',N2
         N2=1+D2MAX/ZSIZE
         MASPCT = 1
c        WRITE(6,*)'NEW N2 VALUE = ',N2
      ENDIF

c      WRITE(6,*)'NEW SUBDIVISIONS'
c      WRITE(6,*)N1,N2

C FIND MAXIMUM AND MINIMUM ELEMENT SIZES OF XY-PLANE

      IF (D1MAX/N1.GT.DMAX) IPMAX=10000+IPAF
      IF (D2MAX/N2.GT.DMAX) IPMAX=20000+IPAF
      IF (D1MAX/N1.GT.DMAX) DMAX=D1MAX/N1
      IF (D2MAX/N2.GT.DMAX) DMAX=D2MAX/N2
      IF (D1MIN/N1.LT.DMIN) IPMIN=10000+IPAF
      IF (D2MIN/N2.LT.DMIN) IPMIN=20000+IPAF
      IF (D1MIN/N1.LT.DMIN) DMIN=D1MIN/N1
      IF (D2MIN/N2.LT.DMIN) DMIN=D2MIN/N2

      RETURN
      END

C =====================================================================
C SUBROUTINE SHASP FOR SHELL PAFBLOCK SUBDIVISION AND ASPECT RATIO
C =====================================================================

      SUBROUTINE SHASP

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)

      PARAMETER(NNODES=5000)
      COMMON / CNODES / X(NNODES), Y(NNODES)
      COMMON / CTUNIN / H, HOVER, HUNDER
      COMMON / CSHLPR / NSHELL, HIN(5),SUMR
      COMMON / CKEYPR /K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF
      COMMON / CSHTOP / NODELE(5000,8)
      COMMON / CSUBDV / NSUB(0:50),MASPCT
      COMMON / COUNT  / KPSH(8), NPSIDE, NCOL, NROW
      COMMON / CINDEX / INXSUB(100), INXMAT(100)
      COMMON / CDIM   / DIM(4), DMIN, DMAX, IPMAX, IPMIN

      DO 5500 ISHELL=0,(NSHELL-1)

         DO 5550 I=1,NBS/2

C SHELL PAFBLOCKS SUBDIVISIONS

            IPAF=I+NBS*ISHELL

C SHELL PAFBLOCKS DIMENSIONS DIM(1), DIM(2), DIM(3), DIM(4)
C DIM(1) AND DIM(2) ARE ALWAYS ARCS

            IF (ISHELL.EQ.0) THEN
               R1=-HIN(1)
               R2=0D0
            ELSE
               R1=R1+HIN(ISHELL+1)
               R2=R2+HIN(ISHELL+2)
            ENDIF

            IF (I.LE.KPSH(2)) THEN
               Q1=H+R1
               Q2=H+R2
```

```
          ELSE IF (I.LE.KPSH(4)) THEN
             Q1=H*(5.9D0/7.9D0)+R1
             Q2=H*(5.9D0/7.9D0)+R2
          ELSE IF (I.LE.KPSH(6)) THEN
             Q1=H*(7.8D0/7.9D0)+R1
             Q2=H*(7.8D0/7.9D0)+R2
          ELSE IF (I.LE.KPSH(7)) THEN
             Q1=H*(0.95D0/7.9D0)+R1
             Q2=H*(0.95D0/7.9D0)+R2
          ELSE
             Q1=H*(31.2989D0/7.9D0)+R1
             Q2=H*(31.2989D0/7.9D0)+R2
          ENDIF

          CORD1=SQRT((X(NODELE(IPAF,1))-X(NODELE(IPAF,2)))**2
     &    +(Y(NODELE(IPAF,1))-Y(NODELE(IPAF,2)))**2)

          CORD2=SQRT((X(NODELE(IPAF,3))-X(NODELE(IPAF,4)))**2
     &    +(Y(NODELE(IPAF,3))-Y(NODELE(IPAF,4)))**2)

          ANGLE1= 2D0*DASIN(CORD1/(2D0*Q1))
          ANGLE2= 2D0*DASIN(CORD2/(2D0*Q2))

          DIM(1)=Q1*ANGLE1
          IF (ISHELL.GT.(NSHELL-2)) THEN
            DIM(2)=SQRT((X(NODELE(IPAF,4))-X(NODELE(IPAF,3)))**2
     &      +(Y(NODELE(IPAF,4))-Y(NODELE(IPAF,3)))**2)
          ELSE
            DIM(2)=Q2*ANGLE2
          ENDIF

C DIM(3) AND DIM(4) ARE STRAIGHT LINES

          DIM(3)=SQRT((X(NODELE(IPAF,1))-X(NODELE(IPAF,3)))**2
     &    +(Y(NODELE(IPAF,1))-Y(NODELE(IPAF,3)))**2)

          DIM(4)=SQRT((X(NODELE(IPAF,2))-X(NODELE(IPAF,4)))**2
     &    +(Y(NODELE(IPAF,2))-Y(NODELE(IPAF,4)))**2)

C MAXIMUM SUBDIVISION VALUES OF N1 AND N2 FOR PAFBLOCKS

          N1 = NSUB(INXSUB(I))
          N2 = NSUB(ISHELL+1)

C CHECK ASPECT RATIOS

          CALL ASPCHK(IPAF,N1,N2)

C ASSIGNING THE NEW SUBDIVISION VALUE OF N1 AND N1 TO THE APPROPRIATE
C VARIABLE NSUBRO(-),NSUBCO(-),NSUB (-) DEPENDING ON THE PAFBLOCK

          NSUB(INXSUB(I)) = N1
          NSUB(ISHELL+1)  = N2

 5550    CONTINUE
 5500 CONTINUE

      RETURN
      END

C =====================================================================
C SUBROUTINE RLASP FOR OUTER PAFBLOCKS DIMENSIONS AND ASPECT RATIO
C RIGHT AND LEFT HAND SIDES OF THE SHELL
C =====================================================================

      SUBROUTINE RLASP

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)

      PARAMETER(NNODES=5000)
      COMMON / CNODES / X(NNODES), Y(NNODES)
      COMMON / CSHLPR / NSHELL, HIN(5),SUMR
      COMMON / CKEYPR /K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF
```

```
      COMMON / CSHTOP / NODELE(5000,8)
      COMMON / CROKPR / MATPRO(20), HTOP(4), HMIDA(4), HMIDC(4),
     &                   HBOT(4),NMIDA,NMIDC,NTOP,NBOT
      COMMON / CSUBDV / NSUB(0:50),MASPCT
      COMMON / COUNT  / KPSH(8), NPSIDE, NCOL, NROW
      COMMON / CDIM   / DIM(4), DMIN, DMAX, IPMAX, IPMIN

      DO 5570 I=1,NPSIDE

         IPAF=I+NBS*NSHELL

C PAFBLOCKS DIMENSIONS DIM(1), DIM(2), DIM(3), DIM(4)
C DIM(1), DIM(2), DIM(3), DIM(4) ARE STRAGTH LINES

         DIM(1)=SQRT((X(NODELE(IPAF,1))-X(NODELE(IPAF,2)))**2
     &      +(Y(NODELE(IPAF,1))-Y(NODELE(IPAF,2)))**2)
         DIM(2)=ABS(Y(NODELE(IPAF,3))-Y(NODELE(IPAF,4)))
         DIM(3)=ABS(X(NODELE(IPAF,3))-X(NODELE(IPAF,1)))
         DIM(4)=ABS(X(NODELE(IPAF,4))-X(NODELE(IPAF,2)))

C MAXIMUM SUBDIVISION VALUES OF N1 AND N2 FOR PAFBLOCKS

         N1=NSUB(NSHELL+NCOL+I+1+NTOP)
         N2=NSUB(NSHELL+ NCOL)

C CHECK ASPECT RATIOS
         CALL ASPCHK(IPAF,N1,N2)

C ASSIGNING  THE NEW SUBDIVISION VALUE  OF N1 AND N1 TO THE APPROPRIATE
C VARIABLE NSUBRO(-),NSUBCO(-),NSUBSH(-) DEPENDING ON THE PAFBLOCK

         NSUB(NSHELL+NCOL+I+1+NTOP)=N1
         NSUB(NSHELL+NCOL)=N2

 5570 CONTINUE

      RETURN
      END

C ======================================================================
C SUBROUTINE TPASP FOR TOP REGION PAFBLOCKS DIMENSIONS AND ASPECT RATIO
C ======================================================================

      SUBROUTINE TPASP

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)

      PARAMETER(NNODES=5000)
      COMMON / CNODES / X(NNODES), Y(NNODES)
      COMMON / CSHLPR / NSHELL, HIN(5),SUMR
      COMMON / CKEYPR /K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF
      COMMON / CSHTOP / NODELE(5000,8)
      COMMON / CROKPR / MATPRO(20), HTOP(4), HMIDA(4), HMIDC(4),
     &                   HBOT(4),NMIDA,NMIDC,NTOP,NBOT
      COMMON / CSUBDV / NSUB(0:50),MASPCT
      COMMON / COUNT  / KPSH(8), NPSIDE, NCOL, NROW
      COMMON / CDIM   / DIM(4), DMIN, DMAX, IPMAX, IPMIN

      DO 5700 ITOP=0,NTOP
         DO 5800 I=1,NCOL

            IPAF=I+2*NPSIDE+NBS*NSHELL+2*NCOL*ITOP

C PAFBLOCKS DIMENSIONS DIM(1), DIM(2), DIM(3), DIM(4)
C DIM(1), DIM(2), DIM(3) AND DIM(4) ARE STRAIGHT LINES

            DIM(1)=ABS(X(NODELE(IPAF,2))-X(NODELE(IPAF,1)))
            DIM(2)=ABS(X(NODELE(IPAF,4))-X(NODELE(IPAF,3)))
            DIM(3)=ABS(Y(NODELE(IPAF,3))-Y(NODELE(IPAF,1)))
            DIM(4)=ABS(Y(NODELE(IPAF,4))-Y(NODELE(IPAF,2)))

C MAXIMUM SUBDIVISION VALUES OF N1 AND N2 FOR PAFBLOCKS
```

```
            N1 = NSUB(NSHELL+I)
            N2 = NSUB(NSHELL+NCOL+ITOP+1)

C CHECK ASPECT RATIOS

            CALL ASPCHK(IPAF,N1,N2)

C ASSIGNING  THE NEW SUBDIVISION VALUE  OF N1 AND N1 TO THE APPROPRIATE
C VARIABLE NSUBRO(-),NSUBCO(-),NSUBSH(-) DEPENDING ON THE PAFBLOCK

            NSUB(NSHELL+I) = N1
            NSUB(NSHELL+NCOL+ITOP+1) = N2

 5800    CONTINUE
 5700 CONTINUE

      RETURN
      END

C =====================================================================
C SUBROUTINE BTASP FOR BOTTOM REGION PAFBLOCKS DIMENSIONS AND ASPECT RATIO
C =====================================================================

      SUBROUTINE BTASP

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)

      PARAMETER(NNODES=5000)
      COMMON / CNODES / X(NNODES), Y(NNODES)
      COMMON / CSHLPR / NSHELL, HIN(5),SUMR
      COMMON / CKEYPR /K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF
      COMMON / CSHTOP / NODELE(5000,8)
      COMMON / CROKPR / MATPRO(20), HTOP(4), HMIDA(4), HMIDC(4),
     &                    HBOT(4),NMIDA,NMIDC,NTOP,NBOT
      COMMON / CSUBDV / NSUB(0:50),MASPCT
      COMMON / COUNT  / KPSH(8), NPSIDE, NCOL, NROW
      COMMON / CDIM   / DIM(4), DMIN, DMAX, IPMAX, IPMIN

      DO 5900 IBOT=0,NBOT
         DO 5950 I=1,NCOL

            IPAF=I+2*NPSIDE+NBS*NSHELL+
     &              2*NCOL*(NTOP+1+IBOT)

C PAFBLOCKS DIMENSIONS DIM(1), DIM(2), DIM(3), DIM(4)
C DIM(1), DIM(2), DIM(3) ARE STRAIGHT LINES

            DIM(1)=ABS(X(NODELE(IPAF,1))-X(NODELE(IPAF,2)))
            DIM(2)=ABS(X(NODELE(IPAF,3))-X(NODELE(IPAF,4)))
            DIM(3)=ABS(Y(NODELE(IPAF,1))-Y(NODELE(IPAF,3)))
            DIM(4)=ABS(Y(NODELE(IPAF,2))-Y(NODELE(IPAF,4)))

C MAXIMUM SUBDIVISION VALUES OF N1 AND N2 FOR PAFBLOCKS

            N1 = NSUB(NSHELL+I)
            N2 = NSUB(NSHELL+NCOL+NPSIDE+IBOT+NTOP+2)

C CHECK ASPECT RATIOS

            CALL ASPCHK(IPAF,N1,N2)

C ASSIGNING  THE NEW SUBDIVISION VALUE  OF N1 AND N1 TO THE APPROPRIATE
C VARIABLE NSUBRO(-),NSUBCO(-),NSUBSH(-) DEPENDING ON THE PAFBLOCK

            NSUB(NSHELL+I) = N1
            NSUB(NSHELL+NCOL+NPSIDE+IBOT+NTOP+2)=N2

 5950    CONTINUE
 5900 CONTINUE

      RETURN
      END
```

```
C ====================================================================
C SUBROUTINE LRASP FOR LAST RING PAFBLOCKS DIMENSIONS AND ASPECT RATIO
C ====================================================================

      SUBROUTINE LRASP

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)

      PARAMETER(NNODES=5000)
      COMMON / CNODES / X(NNODES), Y(NNODES)
      COMMON / CTUNIN / H, HOVER, HUNDER
      COMMON / CSHLPR / NSHELL, HIN(5),SUMR
      COMMON / CKEYPR /K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF
      COMMON / CSHTOP / NODELE(5000,8)
      COMMON / CSUBDV / NSUB(0:50),MASPCT
      COMMON / COUNT  / KPSH(8), NPSIDE, NCOL, NROW
      COMMON / CINDEX / INXSUB(100), INXMAT(100)
      COMMON / CDIM   / DIM(4), DMIN, DMAX, IPMAX, IPMIN

      DO 6000 I=1,NBS/2

         IPAF=I+NPOT

C DIM(1) IS ALWAYS A STRAIGHT LINE

         DIM(1)=SQRT((X(NODELE(IPAF,1))-X(NODELE(IPAF,2)))**2
     &     +(Y(NODELE(IPAF,1))-Y(NODELE(IPAF,2)))**2)

C DIM(2) IS ALWAYS AN ARC

         IF (I.LE.KPSH(2)) THEN
            Q1=H
         ELSE IF (I.LE.KPSH(4)) THEN
            Q1=H*(5.9D0/7.9D0)
         ELSE IF (I.LE.KPSH(6)) THEN
            Q1=H*(7.8D0/7.9D0)
         ELSE IF (I.LE.KPSH(7)) THEN
            Q1=H*(0.95D0/7.9D0)
         ELSE
            Q1=H*(31.2989D0/7.9D0)
         ENDIF

         CORD1=SQRT((X(NODELE(IPAF,3))-X(NODELE(IPAF,4)))**2
     &     +(Y(NODELE(IPAF,3))-Y(NODELE(IPAF,4)))**2)

         ANGLE1= 2D0*DASIN(CORD1/(2D0*Q1))

         DIM(2)=Q1*ANGLE1

C DIM(3) AND DIM(4) ARE ALWAYS STRAIGHT LINES

         DIM(3)=SQRT((X(NODELE(IPAF,1))-X(NODELE(IPAF,3)))**2
     &     +(Y(NODELE(IPAF,1))-Y(NODELE(IPAF,3)))**2)

         DIM(4)=SQRT((X(NODELE(IPAF,2))-X(NODELE(IPAF,4)))**2
     &     +(Y(NODELE(IPAF,2))-Y(NODELE(IPAF,4)))**2)

C MAXIMUM SUBDIVISION VALUES OF N1 AND N2 FOR PAFBLOCKS

         N1 = NSUB(INXSUB(I))
         N2 = NSUB(0)


C CHECK ASPECT RATIOS

         CALL ASPCHK(IPAF,N1,N2)

C ASSIGNING  THE NEW SUBDIVISION VALUE  OF N1 AND N1 TO THE APPROPRIATE
C VARIABLE NSUBRO(-),NSUBCO(-),NSUBSH(-) DEPENDING ON THE PAFBLOCK

         NSUB(INXSUB(I)) = N1
         NSUB(0)=N2
```

```
 6000 CONTINUE

      RETURN
      END

C =====================================================================
C SUBROUTINE ITASP FOR CENTRAL PAFBLOCKS DIMENSIONS AND
C ASPECT RATIO INSIDE THE TUNNEL
C =====================================================================

      SUBROUTINE ITASP

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)

      PARAMETER(NNODES=5000)
      COMMON / CNODES / X(NNODES), Y(NNODES)
      COMMON / CSHLPR / NSHELL, HIN(5),SUMR
      COMMON / CKEYPR /K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF
      COMMON / CSHTOP / NODELE(5000,8)
      COMMON / CSUBDV / NSUB(0:50),MASPCT
      COMMON / CRESNI / NZ, ZSIZE, RATIO
      COMMON / CDIM   / DIM(4), DMIN, DMAX, IPMAX, IPMIN
      COMMON / COUNT  / KPSH(8), NPSIDE, NCOL, NROW
      COMMON / CROKPR / MATPRO(20), HTOP(4), HMIDA(4), HMIDC(4),
     &                    HBOT(4),NMIDA,NMIDC,NTOP,NBOT

      DO 6200 J=1,NPSIDE

         DO 6210 I=1,NCOL-1

            IPAF=I+NPLR+(J-1)*2*(NCOL-1)

C DIM(1), DIM(2), DIM(3), DIM(4) ARE ALWAYS STRAIGHT LINES

            DIM(1)=SQRT((X(NODELE(IPAF,1))-X(NODELE(IPAF,2)))**2
     &      +(Y(NODELE(IPAF,1))-Y(NODELE(IPAF,2)))**2)

            DIM(2)=SQRT((X(NODELE(IPAF,3))-X(NODELE(IPAF,4)))**2
     &      +(Y(NODELE(IPAF,3))-Y(NODELE(IPAF,4)))**2)

            DIM(3)=SQRT((X(NODELE(IPAF,1))-X(NODELE(IPAF,3)))**2
     &      +(Y(NODELE(IPAF,1))-Y(NODELE(IPAF,3)))**2)

            DIM(4)=SQRT((X(NODELE(IPAF,2))-X(NODELE(IPAF,4)))**2
     &      +(Y(NODELE(IPAF,2))-Y(NODELE(IPAF,4)))**2)

C MAXIMUM SUBDIVISION VALUES OF N1 AND N2 FOR PAFBLOCKS

            N1=NSUB(NSHELL+I)
            N2=NSUB(NSHELL+NCOL+J+1+NTOP)

C CHECK ASPECT RATIOS

            CALL ASPCHK(IPAF,N1,N2)

C ASSIGNING  THE NEW SUBDIVISION VALUE  OF N1 AND N1 TO THE APPROPRIATE
C VARIABLE NSUBRO(-),NSUBCO(-),NSUBSH(-) DEPENDING ON THE PAFBLOCK

            NSUB(NSHELL+I)=N1
            NSUB(NSHELL+NCOL+J+1+NTOP)=N2

 6210    CONTINUE
 6200 CONTINUE

      RETURN
      END

C =====================================================================
C SUBROUTINE ZASP FOR Z-DIRECTION SUBDIVISION AND
C ASPECT RATIO
C =====================================================================
```

```
      SUBROUTINE ZASP

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)

      COMMON / CDIM   / DIM(4), DMIN, DMAX, IPMAX, IPMIN
      COMMON / CRESNI / NZ, ZSIZE, RATIO
      COMMON / CSUBDV / NSUB(0:50),MASPCT
      COMMON / CZNOD  / Z(5), NDEPTH
      COMMON / CSHLPR / NSHELL, HIN(5),SUMR
      COMMON / COUNT  / KPSH(8), NPSIDE, NCOL, NROW
      COMMON / CSUPIN / SAMIN, SAMAJ, HANCH(2), DANCH(2),
     &                  RANCH,AANCH(2),PERIOD, SANCH, SAMAJ2,
     &                  MARCH,MPARCH,MANCH,MPANCH

C CHECK IF A Z-SUBDIVISION WHICH PROVIDES THE REQUIRED ASPECT RATIO
C FOR THE EXTREME ELEMENT DIMENSIONS IN THE XY-PLANE IS POSSIBLE.
C IF IMPOSSIBLE STOP PROGRAM.

c       write(6,*)(nsub(i),I=0,NSHELL+NCOL+NROW+NDEPTH)
c       write(6,*)ipmax,dmax,ipmin,dmin,(period/nz)
c            write(6,*)zsize
c       write(6,*)dmax/(period/nz),(period/nz)/dmin
      IF (DMAX/DMIN.GE.RATIO*RATIO)
     &   WRITE(6,*)'Geometry Conflict in Z-Subdivision'
      IF (DMAX/DMIN.GE.RATIO*RATIO) STOP

C FOR EACH PLANE OF PAFBLOCKS

      DO 10 I=1,NDEPTH

         J=I+NSHELL+NCOL+NROW
         ZDIM = DABS (Z(I+1) - Z(I))

C ENSURE THAT Z-SUBDIVISION IS COMPATABLE WITH MINIMUM XY-ELEMENT SIZE

c            write(6,*)ipmin,DMIN*RATIO,ZDIM/NSUB(J)
         IF (DMIN*RATIO.LT.ZDIM/NSUB(J)) THEN
c            write(6,*)DMIN*RATIO,ZDIM/NSUB(J)
           NSUB(J) = 1+ ZDIM / (RATIO * DMIN)
         ENDIF

C CHECK THAT Z-SUBDIVISION IS COMPATABLE WITH MAXIMUM XY-ELEMENT SIZE
C IF NOT REDO SUBDIVISION FROM START WITH NEW MAXIMUM ELEMENT SIZE

         IF (DMAX/RATIO.GT.ZDIM/NSUB(J)) THEN
c            write(6,*)DMAX/RATIO,ZDIM/NSUB(J),zsize
c            WRITE(6,*)IPMAX
           MASPCT = 1
           ZSIZE = RATIO*ZDIM/NSUB(J)
c            write(6,*)zsize
         ENDIF

   10 CONTINUE
c     write(6,*)(nsub(i),I=0,NSHELL+NCOL+NROW+NDEPTH)
c
      RETURN
      END
```

C.4.5 Support Systems - Program *supports.f*

```
C***********************************************************************
C   PROGRAM ADD SUPPORTS (ANCHORAGES AND STEEL ARCHES)TO THE TUNNEL
C   FILENAME=supports.f
C***********************************************************************

C ====================================================================
C SUBROUTINE WRITE OUT NODES FOR CENTRES OF STEEL ARCHES
C ====================================================================
```

```
      SUBROUTINE NODARC

      IMPLICIT DOUBLE PRECISION (A-H,O-Z)

      COMMON / CCENPR / XC(10), YC(10)
      COMMON / CZNOD / Z(5), NDEPTH
      COMMON / CKEYPR /K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF
      COMMON / CFLAG / MSYM, MDIM

      DO 30 L=1,mdim-1
       DO 20 J=0,1-MSYM
        DO 10 ICEN=1,5
         NCEN = NNODE*(NDEPTH+1)+ICEN+J*5 + (L-1)*10
         WRITE(8,9)NCEN,(-1)**J*XC(ICEN),YC(ICEN),Z(L)
 10     CONTINUE
 20    CONTINUE
 30   CONTINUE

 9    FORMAT (I5,10X,3F10.5)

      RETURN
      END
C ======================================================================
C SUBROUTINE ELEMENTS HEADER
C ======================================================================

       SUBROUTINE ELEHED

       WRITE(8,*)'ELEMENTS'
       WRITE(8,*)' NUMBER ELEMENT.TYPE PROPERTIES TOPOLOGY'

       RETURN
       END

C ======================================================================
C SUBROUTINE ADD ANCHORAGE BEAM PAFBLOCKS TO THE TUNNEL
C ======================================================================

       SUBROUTINE ANCHPB

       IMPLICIT DOUBLE PRECISION (A-H,O-Z)

       COMMON / CZNOD / Z(5), NDEPTH
       COMMON / CSUPIN / SAMIN, SAMAJ, HANCH(2),DANCH(2),
     &                 RANCH,AANCH(2),PERIOD, SANCH, SAMAJ2,
     &                 MARCH,MPARCH,MANCH,MPANCH
       COMMON / CSHLPR / NSHELL, HIN(5),SUMR
       COMMON / COUNT /KPSH(8), NPSIDE, NCOL,NROW
       COMMON / CKEYPR / K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF
       COMMON / CSUBDV / NSUB(0:50),MASPCT
       COMMON / CBEAM / KANCH, KARCH
       COMMON / CFLAG / MSYM, MDIM

       KTP=6
       KET=34000
       KANCH=20

       DO 30 J=0,1-MSYM
          DO 20 I=1,2
             DO 10 ISHELL=2,NSHELL

                IPAF = NPAF+(ISHELL-1)+((I-1)+2*J)*(NSHELL-1)

                N1 = 2 * NSUB(ISHELL)
          N2 = 0
          N5 = 0

                IF (I.EQ.1) NANCH = KPSH(2)+KPSH(3)+1
                IF (I.EQ.2) NANCH = 2*KPSH(5)+1
```

```
             NANCH = J*(NNS+2) + (-1)**J *NANCH

             NANCH1 = NANCH + NNS*(ISHELL-1) + NNODE
             NANCH2 = NANCH + NNS* ISHELL    + NNODE

             WRITE(8,9)IPAF,KTP,KET,KANCH,N1,N2,N5,NANCH1,NANCH2

 10          CONTINUE
 20       CONTINUE
 30    CONTINUE

 9     FORMAT(9I6)

       RETURN
       END

C ==================================================================
C SUBROUTINE ADD ANCHORAGE BEAM PAFBLOCKS TO THE TUNNEL
C ==================================================================

      SUBROUTINE ANCHPBold

      IMPLICIT DOUBLE PRECISION (A-H,O-Z)

      COMMON / CZNOD / Z(5), NDEPTH
      COMMON / CSUPIN / SAMIN, SAMAJ, HANCH(2),DANCH(2),
     &                 RANCH,AANCH(2),PERIOD, SANCH, SAMAJ2,
     &                 MARCH,MPARCH,MANCH,MPANCH
      COMMON / CSHLPR / NSHELL, HIN(5),SUMR
      COMMON / COUNT /KPSH(8), NPSIDE, NCOL,NROW
      COMMON / CKEYPR / K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF
      COMMON / CSUBDV / NSUB(0:50),MASPCT
      COMMON / CBEAM / KANCH, KARCH
      COMMON / CFLAG / MSYM, MDIM

      KTP=6
      KET=34000
      KANCH=20

      DO 30 J=0,1-MSYM
         DO 20 I=1,2
c           DO 10 ISHELL=2,NSHELL

             IPAF = NPAF+((I-1)+2*J)*(NSHELL-1)

c             N1 = NSUB(ISHELL)
             N1 = 1
             N2 = 0
             N5 = 0

             IF (I.EQ.1) NANCH = KPSH(2)+KPSH(3)+1
             IF (I.EQ.2) NANCH = 2*KPSH(5)+1

             NANCH = J*(NNS+2) + (-1)**J *NANCH

             NANCH1 = NANCH + NNS          + NNODE
             NANCH2 = NANCH + NNS* NSHELL + NNODE

             WRITE(8,9)IPAF,KTP,KET,KANCH,N1,N2,N5,NANCH1,NANCH2

c 10          CONTINUE
 20       CONTINUE
 30    CONTINUE

 9    FORMAT(9I6)

      RETURN
      END

C ==================================================================
C SUBROUTINE ADD ANCHORAGE AS RIGID LINKS
C ==================================================================
```

```
      SUBROUTINE ANCHRL

      IMPLICIT DOUBLE PRECISION (A-H,O-Z)

      COMMON / CZNOD / Z(5), NDEPTH
      COMMON / CSUPIN / SAMIN, SAMAJ, HANCH(2),DANCH(2),
     &                 RANCH,AANCH(2),PERIOD, SANCH, SAMAJ2,
     &                 MARCH,MPARCH,MANCH,MPANCH
      COMMON / CSHLPR / NSHELL, HIN(5),SUMR
      COMMON / COUNT /KPSH(8), NPSIDE, NCOL,NROW
      COMMON / CKEYPR / K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF
      COMMON / CSUBDV / NSUB(0:50),MASPCT
      COMMON / CBEAM / KANCH, KARCH
      COMMON / CFLAG / MSYM, MDIM

      INTEGER NANCH(2)

      WRITE(8,*)'C'
      WRITE(8,*)'C'
      WRITE(8,*)'RIGID.LINKS'
      WRITE(8,*)' N1       N2'

      DO 30 J=0,1-MSYM
         DO 20 I=1,2

            IF (I.EQ.1) NANCHO = KPSH(2)+KPSH(3)+1
            IF (I.EQ.2) NANCHO = 2*KPSH(5)+1

            NANCHO = J*(NNS+2) + (-1)**J *NANCHO

c            DO 10 ISHELL = 2,NSHELL
c               NANCH(1)    = NANCHO + NNS*(ISHELL-1) + NNODE
c               DO 5 JSHELL = ISHELL,NSHELL
c                  NANCH(2) = NANCHO + NNS*(JSHELL) + NNODE
c                  WRITE(8,9) NANCH(2),  NANCH(1)
c 5             CONTINUE
c 10         CONTINUE

             NANCH(1) = NANCHO + NNS        + NNODE
             NANCH(2) = NANCHO + NNS* NSHELL + NNODE

             WRITE(8,9) NANCH(1),  NANCH(2)

 20      CONTINUE
 30   CONTINUE
      WRITE(8,*)'C'
      WRITE(8,*)'C'

 9    FORMAT(2I6)

      RETURN
      END

C ===================================================================
C SUBROUTINE ADD STEEL ARCH PAFBLOCKS TO THE TUNNEL
C ===================================================================

      SUBROUTINE ARCHPB

      IMPLICIT DOUBLE PRECISION (A-H,O-Z)

      COMMON / CSUPIN / SAMIN, SAMAJ, HANCH(2), DANCH(2),
     &                 RANCH,AANCH(2),PERIOD, SANCH, SAMAJ2,
     &                 MARCH,MPARCH,MANCH,MPANCH
      COMMON / COUNT / KPSH(8), NPSIDE, NCOL, NROW
      COMMON / CKEYPR /K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF
      COMMON / CFLAG / MSYM, MDIM
      COMMON / CBEAM / KANCH, KARCH
      COMMON / CINDEX / INXSUB(100), INXMAT(100)
      COMMON / CSUBDV / NSUB(0:50),MASPCT
      COMMON / CSHTOP / NODELE(5000,8)
      COMMON / CSHLPR / NSHELL, HIN(5),SUMR
```

```
      KET=34000
      KTP=6

      DO 50 I=1,NBS

         N1 = 2*NSUB(INXSUB(I))
         N2 = 0
         N5 = 0
         KARCH=21
         IPAF = I + NPAF + (NSHELL-1)*4

C Next commented out if blok is used for continuation of still arc until pafblock KPSH(6)

c         IF ((I.LE.KPSH(6)).OR.(I.GT.NBS-KPSH(6)))THEN
            IF ( (MSYM.EQ.0) .OR.  (I.LE.NBS/2) ) THEN
               WRITE(8,9)IPAF,KTP,KET,KARCH,N1,N2,N5,
     &                NODELE(I,3),NODELE(I,4),NODELE(I,8)
            ENDIF
c         ENDIF

 50   CONTINUE

 9    FORMAT(10I6)

      RETURN
      END

C ====================================================================
C SUBROUTINE ADD STEEL ARCH BEAM ELEMENTS TO THE TUNNEL
C ====================================================================

      SUBROUTINE ARCHEL

      IMPLICIT DOUBLE PRECISION (A-H,O-Z)

      COMMON / CSUPIN / SAMIN, SAMAJ, HANCH(2), DANCH(2),
     &                  RANCH,AANCH(2),PERIOD, SANCH, SAMAJ2,
     &                  MARCH,MPARCH,MANCH,MPANCH
      COMMON / COUNT / KPSH(8), NPSIDE, NCOL, NROW
      COMMON / CKEYPR /K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF
      COMMON / CFLAG / MSYM, MDIM
      COMMON / CBEAM / KANCH, KARCH

      KET=34300
      DO 20 J=0,1-MSYM
         NARCH2 = 1 + NNS
            DO 10 I=1,7
               NARCH1 = NARCH2
               IF (I.EQ.1) NARCH2 = 2*KPSH(2) + 1
               IF (I.EQ.2) NARCH2 = 2*KPSH(3) + 1
               IF (I.EQ.3) NARCH2 = 2*KPSH(4) + 1
               IF (I.EQ.4) NARCH2 = 2*KPSH(6) + 1
               IF (I.EQ.5) NARCH2 = 2*KPSH(7) - 1
               IF (I.EQ.6) NARCH2 = 2*KPSH(7) + 1
               IF (I.EQ.7) NARCH2 = 2*KPSH(8) + 1
               NARCH2 = (J+1)*NNS +(-1)**J *NARCH2

               IF (I.EQ.1) NODCEN = 1
               IF (I.EQ.2) NODCEN = 2
               IF (I.EQ.3) NODCEN = 2
               IF (I.EQ.4) NODCEN = 3
               IF (I.EQ.5) NODCEN = 4
               IF (I.EQ.6) NODCEN = 4
               IF (I.EQ.7) NODCEN = 5

               WRITE(8,9) 4+I+2*J, KET, KANCH+NODCEN, NARCH1, NARCH2

 10         CONTINUE
 20   CONTINUE

 9    FORMAT(5I10)

      RETURN
```

```
      END
C ====================================================================
C SUBROUTINE BEAM DESCRIPTION HEADER
C ====================================================================

      SUBROUTINE BEMHED

      WRITE(8,*)'C'
      WRITE(8,*)'C'
      WRITE(8,*)'BEAMS'
      WRITE(8,*)
     &'SECTION MATERIAL AREA   IYY   IZZ    ZY    ZZ'

      RETURN
      END

C ====================================================================
C SUBROUTINE ADD ANCHORAGE BEAM DESCRIPTION TO THE TUNNEL
C ====================================================================

      SUBROUTINE ANCHBM

      IMPLICIT DOUBLE PRECISION (A-H,O-Z)

      COMMON / CZNOD / Z(5), NDEPTH
      COMMON / CSUPIN / SAMIN, SAMAJ, HANCH(2), DANCH(2),
     &                  RANCH,AANCH(2),PERIOD, SANCH, SAMAJ2,
     &                  MARCH,MPARCH,MANCH,MPANCH
      COMMON / CBEAM / KANCH, KARCH

      PI=2D0*DACOS(0D0)
      AYY = PI*(RANCH)**4/8
      AZZ = PI*(RANCH)**4/8

      ZY  = PI*(RANCH)**3/4
      ZZ  = PI*(RANCH)**3/8

      WRITE(8,9) KANCH, MPANCH, 5D-1*PI*SANCH*SANCH,
     & AYY, AZZ, ZY, ZZ

 9    FORMAT(2I5,5E10.3)

      RETURN
      END

C ====================================================================
C SUBROUTINE ADD STEEL ARCH BEAM DESCRIPTION TO THE TUNNEL
C ====================================================================

      SUBROUTINE ARCHBM

      IMPLICIT DOUBLE PRECISION (A-H,O-Z)

      COMMON / CZNOD / Z(5), NDEPTH
      COMMON / CSUPIN / SAMIN, SAMAJ, HANCH(2),DANCH(2),
     &                  RANCH,AANCH(2),PERIOD, SANCH, SAMAJ2,
     &                  MARCH,MPARCH,MANCH,MPANCH
      COMMON / CBEAM / KANCH, KARCH
      COMMON / CKEYPR / K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF

      KARCH =21
      AREA = 2D0*SAMAJ2*SAMAJ - 2*(SAMAJ2-SAMIN)*(SAMAJ-SAMIN)

      AYY = (2/3)*((SAMAJ)**3)*(2*SAMIN)+((1/3)*(2*(SAMAJ2)*(SAMAJ)**3)*(15E6/206E9)
      AZZ = (((2*SAMAJ)**2)*(2*SAMIN)*(2*SAMAJ)/4 + (2*SAMAJ2)/6 +
     &      ((1/12)*(SAMAJ)*(2*SAMAJ2)**3)*(15E6/206E9)
      ZY  = AYY / SAMAJ/2
      ZZ  = AZZ / (2*SAMAJ2)/2
      WRITE(8,9)KARCH,MPARCH,AREA, AYY, AZZ, ZY, ZZ

 9    FORMAT(2I5,5E10.3)

      RETURN
```

```
      END
C ====================================================================
C SUBROUTINE ADD STEEL ARCH BEAM DESCRIPTION TO THE TUNNEL
C ====================================================================

      SUBROUTINE ARCHBMold

      IMPLICIT DOUBLE PRECISION (A-H,O-Z)

      COMMON / CZNOD / Z(5), NDEPTH
      COMMON / CSUPIN / SAMIN, SAMAJ, HANCH(2), DANCH(2),
     &                  RANCH,AANCH(2),PERIOD, SANCH, SAMAJ2,
     &                  MARCH,MPARCH,MANCH,MPANCH
      COMMON / CBEAM / KANCH, KARCH
      COMMON / CKEYPR / K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF

      AREA = 2D0*SAMAJ2*SAMAJ - 2*(SAMAJ2-SAMIN)*(SAMAJ-SAMIN)

      AYY = 4*SAMIN*SAMAJ**3 + SAMIN**3*(2*SAMAJ2-4*SAMIN)
      AZZ = 4*SAMAJ2**2*SAMIN + 8*SAMIN*(SAMAJ-SAMIN)
      ZY  = AYY / SAMAJ
      ZZ  = AZZ / (2*SAMAJ2)

      DO 10 ICEN=1,10

 10      WRITE(8,9)KANCH+ICEN,MPARCH,AREA, AYY, AZZ, ZY, ZZ

 9    FORMAT(2I10,5E10.3,I5)

      RETURN
      END
```

C.4.6 Write Out of Two- and Three-Dimensional Models-Subroutine *WRTOUT*

```
C***************************************************************************
C        PROGRAM TO FIND NEW COORDINATES OF TUNNEL ANDFE-PAFBLOCK DESIGN
C        FILENAME=wrtout.f
C***************************************************************************

C ====================================================================
C SUBROUTINE WRTOUT2 FOR WRITE OUT OF 3-D MODEL
C ====================================================================

      SUBROUTINE WRTOUT

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)

      COMMON / CFLAG  / MSYM, MDIM
      COMMON / CZNOD / Z(5), NDEPTH
      COMMON / CSUPIN / SAMIN, SAMAJ, HANCH(2), DANCH(2),
     &                    RANCH,AANCH(2),PERIOD, SANCH, SAMAJ2,
     &                    MARCH,MPARCH,MANCH,MPANCH

      CALL HEDWRT
c      CALL ONESUB
      CALL WRTMAX
      CALL NODWRT
      CALL NODARC
      CALL PAFWRT
      CALL PAFSET
      DO 10 IDEPTH=1,NDEPTH
         CALL SHWRT(IDEPTH)
         CALL RLWRT(IDEPTH)
         CALL TPWRT(IDEPTH)
         CALL BTWRT(IDEPTH)
         write(6,*)'Last Ring'
         CALL LRWRT(IDEPTH)
         write(6,*)'Inside Tunnel'
         CALL ITWRT(IDEPTH)
```

```
   10  CONTINUE
       IF (MDIM.EQ.3) THEN
          IF ((MANCH.EQ.1).OR.(MARCH.EQ.1)) THEN
             IF (MANCH.EQ.1) CALL ANCHPB
             IF (MARCH.EQ.1) CALL ARCHPB
             CALL BEMHED
             IF (MANCH.EQ.1) CALL ANCHBM
             IF (MARCH.EQ.1) CALL ARCHBM
          ENDIF
       ENDIF
       CALL EXCLOC
       IF (MDIM.EQ.2) CALL F2DWRT
       IF (MDIM.EQ.3) CALL F3DWRT

       RETURN
       END

C =========================================================================
C SUBROUTINE HEDWRT: OPEN FILE AND WRITE OUT HEADER
C =========================================================================

       SUBROUTINE HEDWRT

       IMPLICIT DOUBLE PRECISION  (A-H,O-Z)

       CHARACTER*10 TNAME,TKM
       CHARACTER*3 ZEXCVT(9), FILE*6

       DATA ZEXCVT/' 1 ',' 2A',' 2B',' 3A',' 3B',' 4 ',' 5A',' 5B',' 6 '/

       COMMON / CSHLPR / NSHELL, HIN(5),SUMR
       COMMON / CROKPR / MATPRO(20), HTOP(4), HMIDA(4), HMIDC(4),
      &                  HBOT(4),NMIDA,NMIDC,NTOP,NBOT
       COMMON / CKEYPR /K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF
       COMMON / CSUPIN / SAMIN, SAMAJ, HANCH(2), DANCH(2),
      &                  RANCH,AANCH(2),PERIOD, SANCH, SAMAJ2,
      &                  MARCH,MPARCH,MANCH,MPANCH
       COMMON / CEXCIN / NEXCVT,MEXCVT(0:9),MSHOT(0:9),KSHOT,HSHOT,
      &                  MINNER,KINNER,HINNER
       COMMON / CROKIN / NLAY, HINLAY(20), MLAY(20), HLAY(20)
       COMMON / CTUNIN / H, HOVER, HUNDER
       COMMON / CTUNNA / TNAME, TKM
       COMMON / CZNOD / Z(5), NDEPTH
       COMMON / CRESNI / NZ, ZSIZE, RATIO
       COMMON / CFLAG  / MSYM, MDIM
       COMMON / CANGLE / DRAD,BETA(22)
C PRINTOUT NODES

C Find files name

       CALL GETENV ("file",FILE)

       OPEN(8,FILE=FILE//'.DAT')

       WRITE(8,*)'TITLE', MDIM,'D-TUNNEL COORDINATES AND FE-MESH DESIGN'
       WRITE(8,*)'C'
       WRITE(8,*)'C           APPLIED MECHANICS GROUP'
       WRITE(8,*)'C            SCHOOL OF ENGINEERING'
       WRITE(8,*)'C            UNIVERSITY OF DURHAM'
       WRITE(8,*)'C'
       WRITE(8,*)'C'
       WRITE(8,*)'C TUNNEL NAME = ',TNAME
       WRITE(8,*)'C KM          = ',TKM
       WRITE(8,*)'C CLEAR HEIGTH OF TUNNEL IN METERS = ',H
       WRITE(8,*)'C HEIGTH OF OVERBURDEN IN METERS =',HOVER
       WRITE(8,*)'C INPUT HEIGHT UNDER TUNNEL IN METERS =',HUNDER
       WRITE(8,*)'C INPUT NUMBER OF ROCK LAYERS =', NLAY

       DO 10 ILAY=1,NLAY

          WRITE(8,*)
      &'C HEIGHT OF LAYERS FROM GROUND SURFACE IN METERS =',HINLAY(ILAY)
```

```
         WRITE(8,*)'C MATERIAL PROPERTIES OF LAYER,=',MLAY(ILAY)

10    CONTINUE

      WRITE(8,*)'C MATERIAL PROPERTY OF REST OF GROUND =',MLAY(NLAY+1)

      WRITE(8,*)'C NUMBER OF SHELLS =',NSHELL

      DO 400 ISHELL=1,NSHELL

         IF (ISHELL.GT.(NSHELL-1)) THEN
            WRITE(8,39)'C HEIGTH OF FLATTENED SHELL NUMBER',
     &                     ISHELL,'IN METERS = ',HIN(ISHELL)
         ELSE
                WRITE(8,*)'C HEIGTH OF CIRCULAR SHELL NUMBER',
     &                    ISHELL,'IN METERS = ',HIN(ISHELL)
         ENDIF
400   CONTINUE

 39   FORMAT(1X,A34,I4,A12,F4.2)

      WRITE(8,*)
     &'C WHAT ROCK TYPE OF EXCAVATION ?, 0)A,B OR 1)C =',NEXCVT

      IF (NEXCVT.EQ.1) THEN
         JEXCVT=9
         WRITE(8,*)'C  C ROCK TYPE OF EXCAVATION'
         WRITE(8,*)'C 1, 2A, 2B, 3A, 3B, 4, 5A, 5B, 6 '
      ELSE
         JEXCVT=6
         WRITE(8,*)'C A,B ROCK TYPE OF EXCAVATION'
         WRITE(8,*) 'C 1 ,2A, 2B, 3A, 3B, 4 '
      ENDIF

      KEXCVT=JEXCVT
      IEXCVT=0
 20      IEXCVT = IEXCVT + 1
         IF (MEXCVT(IEXCVT).EQ.1) KEXCVT=IEXCVT-1
         IF ((MEXCVT(IEXCVT).EQ.0) .AND. (IEXCVT.LT.KEXCVT)) GO TO 20
      IF (KEXCVT.EQ.0) THEN
         WRITE(8,*)'C NO EXCAVATION'
      ELSE
         WRITE(8,*)'C REGIONS EXCAVATED: ',
     & (ZEXCVT(IEXCVT),IEXCVT=1,KEXCVT)
      ENDIF

      WRITE(8,29)'C MAJOR (1/2) WIDTH OF STEEL ARCH (Z)= ',SAMAJ
      WRITE(8,*)'C 2nd MAJOR (1/2) WIDTH OF STEEL ARCH (Y) =',SAMAJ2
      WRITE(8,*)'C HEIGHT OF  ANCHORAGES 1 AND 2 = ',HANCH
      WRITE(8,*)'C LENGHT OF ANCHORAGES 1 AND 2 = ', DANCH
      WRITE(8,19)'C RADIUS OF ANCHORAGES = ',RANCH
      WRITE(8,*)'C ANGLE OF ANCHORAGES 1 AND 2=',AANCH/DRAD
      WRITE(8,*)'C THE MATERIAL PRO.OF THE SHOTCRETE USED =',KSHOT
      WRITE(8,*)'C THICKNESS OF SHOTCRETE =',HSHOT
      WRITE(8,*)'C IS THERE AN INNER LINING ? =',MINNER
      WRITE(8,*)'C 0) NO or 1) YES'
      WRITE(8,*)'C THE MATERIAL PRO.OF THE INNER LINING =',KINNER
      WRITE(8,*)'C THE THICKNESS OF THE INNER LINNING=',HINNER
      WRITE(8,*)'C RESOLUTION =', NZ
      WRITE(8,*)'C IS THIS EXAMPLE A SYMMETRICAL MODEL ? = ', MSYM
      WRITE(8,*)'C 0) NO or 1) YES '
      WRITE(8,*)'C NUMBER OF DIMENSIONS ? (2 OR 3) =',MDIM
      WRITE(8,*)'C'
      WRITE(8,*)'C THE COORDINATES OF THE NODES CORRESPONDING TO'
      WRITE(8,*)'C THE STRUCTURE ARE GIVEN BELOW EXPRESSED IN METERS.'
      WRITE(8,*)'C'
      WRITE(8,*)'C THERE IS ONLY NEED TO SPECIFY THE CORNER NODES'
      WRITE(8,*)'C OF THE ELEMENTS, SINCE PAFEC WILL CALCULATE '
      WRITE(8,*)'C AUTOMATICALLY THE COORDINATES OF THE MID-SIDE NODES.'

29    FORMAT(1X,A39,F5.3)
19    FORMAT(1X,A25,F5.3)
```

```
      RETURN
      END

C ========================================================================
C SUBROUTINE ONESUB: SET ALL SUBDIVISIONS TO ONE
C ========================================================================

      SUBROUTINE ONESUB

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)

      COMMON / CSUBDV / NSUB(0:50),MASPCT
      COMMON / CSHLPR / NSHELL, HIN(5),SUMR
      COMMON / COUNT  / KPSH(8), NPSIDE, NCOL, NROW
      COMMON / CZNOD / Z(5), NDEPTH

      DO 10 I=0,NSHELL+NCOL+NROW+NDEPTH
   10    NSUB(I)=1

      RETURN
      END

C ======================================================================
C SUBROUTINE PROVIDE DUMMY VARIABLES FOR SUBDIVISIONS
C ======================================================================

      SUBROUTINE DUMSUB

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)
      PARAMETER(NNODES=5000)
      COMMON / CHFXPR / HFX(17)
      COMMON / CSHLPR / NSHELL, HIN(5),SUMR
      COMMON / CROKPR / MATPRO(20), HTOP(4), HMIDA(4), HMIDC(4),
     &                  HBOT(4),NMIDA,NMIDC,NTOP,NBOT
      COMMON / CSUBDV / NSUB(0:50),MASPCT
      COMMON / COUNT  / KPSH(8), NPSIDE, NCOL, NROW
      COMMON / CZNOD  / Z(5), NDEPTH

      DO 10 L=0,NSHELL
   10    NSUB(L) = 100
      DO 20 L=1,NCOL
   20    NSUB(NSHELL+L) = 100
      DO 30 L=1,NROW
   30    NSUB(NSHELL+NCOL+L) = L
      DO 40 L=1,NDEPTH
   40    NSUB(NSHELL+NCOL+NROW+L) = 100

      RETURN
      END

C ========================================================================
C SUBROUTINE NODWRT FOR NODE CORRDINATES WRITE OUT
C ========================================================================

      SUBROUTINE NODWRT

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)

      PARAMETER(NNODES=5000)
      COMMON / CNODES / X(NNODES), Y(NNODES)
      COMMON / CKEYPR /K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF
      COMMON / CZNOD / Z(5), NDEPTH
      COMMON / CFLAG  / MSYM, MDIM

C PRINTOUT NODES

      WRITE(8,*)'C'
      WRITE(8,*)'NODES'
      WRITE(8,*)'NODES.NUMBER       X          Y          Z'

      DO 410 IDEPTH=1,MDIM-1
        DO 420 INODE=1,NNODE
  420     WRITE(8,9)INODE+NNODE*(IDEPTH-1),X(INODE),Y(INODE),Z(IDEPTH)
```

```
 410 CONTINUE

 9    FORMAT (I5,10X,3F10.5)

      RETURN
      END

C ============================================================================
C SUBROUTINE PAFWRT WRITE OUT HEADER FOR PAFBLOCKS
C ============================================================================

      SUBROUTINE PAFWRT

      COMMON / CFLAG  / MSYM, MDIM

      WRITE(8,*)'C'
      WRITE(8,*)'C'
      WRITE(8,*)'PAFBLOCKS'
      IF (MDIM.EQ.2) WRITE(8,*)
     &    'BLOCK.NUMBER TYPE ELEMENT.TYPE PROPERTIES N1 N2 N3 TOPOLOGY'
      IF (MDIM.EQ.3) WRITE(8,*)
     &    'BLOCK.NUMBER TYPE ELEMENT.TYPE PROPERTIES N1 N2 N5 TOPOLOGY'

      RETURN
      END

C ============================================================================
C SUBROUTINE PAFSET SET TYPE OF PAFBLOCKS FOR SYSTEM
C ============================================================================

      SUBROUTINE PAFSET

      COMMON / CFLAG  / MSYM, MDIM
      COMMON / CPAFBL / KTY, KET

C ELEMENT.TYPE=KET

C EIGHT NODED ISOPARAMETRIC CURVILINEAR QUADRILATERAL ELEMENT
C FOR PLANE.STAIN, PLANE.STRESS AND AXISYMMETRIC PROBLEMS 36210
C EIGHT NODED QUADRATIC ELEMENTS

      IF (MDIM.EQ.2) KET=36210

C 20 NODED ISOPARAMETRIC CURVILINEAR QUADRILATERAL ELEMENT
C FOR 3-D PROBLEMS 37110
C 20 NODED QUADRATIC ELEMENTS

      IF (MDIM.EQ.3) KET=37110

C PAFBLOCK.TYPE=KTY
C KTY=1 QUADRALATERAL BASED ELEMENTS

      KTY=1

      RETURN
      END

C ============================================================================
C SUBROUTINE SET EXCAVATION INDEX FOR SHELLS
C ============================================================================

      SUBROUTINE EXCTSH (I,IEXCVT)

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)

      COMMON / CEXCIN / NEXCVT,MEXCVT(0:9),MSHOT(0:9),KSHOT,HSHOT,
     &                  MINNER,KINNER,HINNER
      COMMON / COUNT  / KPSH(8), NPSIDE, NCOL, NROW
      COMMON / CKEYPR /K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF

C WHICH REGION EXCAVATED ? FOR ROCK TYPE A,B OR C
C IF NEXCVT.EQ.0 THEN EXCAVATION FOR ROCK TYPE A,B ELSE
C IF NEXCVT.EQ.1 THEN EXCAVATION FOR ROCK TYPE C
```

```
      IF (NEXCVT.EQ.0) THEN

C EXCAVATION FOR ROCK TYPE A AND B
                 IF(I.LE.2) THEN
                    IEXCVT=1
                 ELSE IF(I.LE.KPSH(4)) THEN
                    IEXCVT=2
                 ELSE IF(I.LE.NBS/2-2) THEN
                    IEXCVT=5
                 ELSE IF(I.LE.NBS/2+2) THEN
                    IEXCVT=6
                 ELSE IF(I.LE.NBS-KPSH(4)) THEN
                    IEXCVT=4
                 ELSE IF(I.LE.NBS-2) THEN
                    IEXCVT=3
                 ELSE
                    IEXCVT=1
                 ENDIF

             ELSE

C EXCAVATION FOR ROCK TYPE C
                 IF(I.LE.1) THEN
                    IEXCVT=1
                 ELSE IF(I.LE.KPSH(3)) THEN
                    IEXCVT=3
                 ELSE IF(I.LE.KPSH(4)) THEN
                    IEXCVT=5
                 ELSE IF(I.LE.NBS/2-2) THEN
                    IEXCVT=8
                 ELSE IF(I.LE.NBS/2+2) THEN
                    IEXCVT=9
                 ELSE IF(I.LE.NBS-KPSH(4)) THEN
                     IEXCVT=7
                 ELSE IF(I.LE.NBS-KPSH(3)) THEN
                    IEXCVT=4
                 ELSE IF(I.LE.NBS-1) THEN
                    IEXCVT=2
                 ELSE
                    IEXCVT=1
                 ENDIF
            ENDIF

      RETURN
      END

C ========================================================================
C SUBROUTINE SET EXCAVATION INDEX FOR INSIDE TUNNEL
C ========================================================================

      SUBROUTINE EXCTIT (I,J,IEXCVT)

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)

      COMMON / CEXCIN / NEXCVT,MEXCVT(0:9),MSHOT(0:9),KSHOT,HSHOT,
     &                  MINNER,KINNER,HINNER
      COMMON / CROKPR / MATPRO(20), HTOP(4), HMIDA(4), HMIDC(4),
     &                  HBOT(4),NMIDA,NMIDC,NTOP,NBOT
      COMMON / COUNT  / KPSH(8), NPSIDE, NCOL, NROW
      COMMON / CKEYPR /K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF

C WHICH REGION EXCAVATED ? FOR ROCK TYPE A,B OR C
C IF NEXCVT.EQ.0 THEN EXCAVATION FOR ROCK TYPE A,B ELSE
C IF NEXCVT.EQ.1 THEN EXCAVATION FOR ROCK TYPE C

      IF (NEXCVT.EQ.0) THEN
C EXCAVATION FOR ROCK TYPE A AND B
         IF (J.LE.3+NMIDA) THEN
            IF (I.LE.2) THEN
               IEXCVT=1
            ELSE IF (I.LE.NCOL-1) THEN
               IEXCVT=2
```

```
            ELSE IF (I.LE.NCOL+1) THEN
               IEXCVT=1
            ELSE
               IEXCVT=3
            ENDIF
         ELSE
            IF (I.LE.2) THEN
               IEXCVT=6
            ELSE IF (I.LE.NCOL-1) THEN
               IEXCVT=5
            ELSE IF (I.LE.NCOL+1) THEN
               IEXCVT=6
            ELSE
               IEXCVT=4
            ENDIF
         ENDIF
C EXCAVATION FOR ROCK TYPE C
      ELSE
         IF (J.LE.2) THEN
            IF (I.LE.1) THEN
               IEXCVT=1
            ELSE IF (I.LE.NCOL-1) THEN
               IEXCVT=3
            ELSE IF (I.LE.NCOL) THEN
               IEXCVT=1
            ELSE
               IEXCVT=2
            ENDIF
         ELSE IF (J.LE.3+NMIDA) THEN
            IF (I.LE.2) THEN
               IEXCVT=6
            ELSE IF (I.LE.NCOL-1) THEN
               IEXCVT=5
            ELSE IF (I.LE.NCOL+1) THEN
               IEXCVT=6
            ELSE
               IEXCVT=4
            ENDIF
         ELSE
            IF (I.LE.2) THEN
               IEXCVT=9
            ELSE IF (I.LE.NCOL-1) THEN
               IEXCVT=8
            ELSE IF(I.LE.NCOL+1) THEN
               IEXCVT=9
            ELSE
               IEXCVT=7
            ENDIF
         ENDIF
      ENDIF

      RETURN
      END

C ======================================================================
C SUBROUTINE WRITE OUT PAFBLOCK TOPOLOGY
C ======================================================================

      SUBROUTINE WRITES(IDEPTH,IPAF,KPR,N1,N2,N5)

      COMMON / CPAFBL / KTY, KET
      COMMON / CFLAG  / MSYM, MDIM
      COMMON / CSHTOP / NODELE(5000,8)
      COMMON / CKEYPR /K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF
      INTEGER N3DELE(20)

      IF (MDIM.EQ.2) THEN

C WRITE OUT 2-D FORM

         N3 = 0
         WRITE(8,9)IPAF,KTY,KET,KPR,N1,N2,N3,(NODELE(IPAF,L),L=1,8)
```

```
      ELSE

C CONVERSION FROM 2D TO 3D TOPOLOGY

         DO 10 L=1,4
            N3DELE(L)=NODELE(IPAF,L)+NNODE *(IDEPTH-1)
            N3DELE(4+L)=NODELE(IPAF,L)+NNODE *IDEPTH
            N3DELE(12+L)=0
            IF (NODELE(IPAF,4+L).NE.0) THEN
               N3DELE(8+L)=NODELE(IPAF,4+L)+NNODE *(IDEPTH-1)
               N3DELE(16+L)=NODELE(IPAF,4+L)+NNODE *IDEPTH
            ELSE
               N3DELE(8+L)=0
               N3DELE(16+L)=0
            ENDIF
 10      CONTINUE

C WRITE OUT 3-D FORM

         WRITE(8,19)IPAF+NPAF*(IDEPTH-1),KTY,KET,KPR,N1,N5,N2
         WRITE(8,29)'* ',(N3DELE(L),L=1,8)
         WRITE(8,39)'* ',(N3DELE(L),L=9,20)

      ENDIF

  9   FORMAT(2X,7I6,8I4)
 19   FORMAT(7I6)
 29   FORMAT(A2,8I5)
 39   FORMAT(A2,12I5)

      RETURN
      END

C =========================================================================
C SUBROUTINE SHWRT WRITES OUT SHELL PAFBLOCK TOPOLOY
C =========================================================================

      SUBROUTINE SHWRT (IDEPTH)

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)
      COMMON / CSHLPR / NSHELL, HIN(5),SUMR
      COMMON / CKEYPR /K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF
      COMMON / CSUBDV / NSUB(0:50),MASPCT
      COMMON / CROKPR / MATPRO(20), HTOP(4), HMIDA(4), HMIDC(4),
     &                    HBOT(4),NMIDA,NMIDC,NTOP,NBOT
      COMMON / CEXCIN / NEXCVT,MEXCVT(0:9),MSHOT(0:9),KSHOT,HSHOT,
     &                    MINNER,KINNER,HINNER
      COMMON / CFLAG  / MSYM, MDIM
      COMMON / CINDEX / INXSUB(100), INXMAT(100)
      COMMON / COUNT  / KPSH(8), NPSIDE, NCOL, NROW

C SHELLS PAFBLOCKS TOPOLOGY (FROM (1+NBS*ISHELL) TO (30+NBS*ISHELL))

      DO 6500 ISHELL=0,(NSHELL-1)

         DO 6550 I=1,NBS

C KTY=PAFBLOCKS.TYPE, KET=ELEMENT.TYPE, KPR=MATERIAL.PROPERTIES, N1,5=PAFBLOCK
C DIVISION NUMBER ALONG THE X,Y AND ZSIZE AXIS.


C SHELL PAFBLOCK TOPOLOGY SUBDIVISIONS

            IPAF=I+NBS*ISHELL

C SUBDIVISION VALUES OF N1 AND N2 FOR PAFBLOCKS

            N1 = NSUB(INXSUB(I))
            N2 = NSUB(ISHELL+1)
            N5 = NSUB(NSHELL+NCOL+NROW+IDEPTH)

C MATERIAL PROPERTIES KPR
```

```
          KPR=MATPRO(INXMAT(I))

C SET EXCAVATION INDEX

          IF (ISHELL.LE.1) THEN
             CALL EXCTSH (I,IEXCVT)
          ELSE
             IEXCVT = 0
          ENDIF

C CONCRETE LINNINGS

          IF (MEXCVT(IEXCVT).EQ.0) THEN
             IF (ISHELL.EQ.0) THEN
                IF (MINNER.EQ.1) THEN
                   KPR=KINNER
                   IEXCVT = 0
                ENDIF
             ELSE IF (ISHELL.EQ.1) THEN
                IF (MSHOT(IEXCVT).EQ.1) THEN
                   IEXCVT = 0
                   KPR = KSHOT
                   IEXCVT = 0
                ENDIF
             ENDIF
          ELSE
             IF (ISHELL.EQ.0) THEN
                KPR = 9
             ENDIF
          ENDIF

C If excavated set material property to AIR

          IF (MEXCVT(IEXCVT).EQ.0) THEN
             KPR = 9
          ENDIF

C CONVERT TO 3-D MATERIAL DESCRIPTIONS

          IF (MDIM.EQ.3) KPR = 10 + KPR

          IF ( (MSYM.EQ.0) .OR. (I.LE.NBS/2) ) THEN
             CALL WRITES(IDEPTH,IPAF,KPR,N1,N2,N5)
          ENDIF

 6550    CONTINUE
 6500 CONTINUE

      RETURN
      END

C ===============================================================================
C SUBROUTINE RLWRT WRITES OUT RIGTH AND LEFT HAND SIDES OF TUNNEL PAFBLOCK TOPOLOGY
C ===============================================================================

      SUBROUTINE RLWRT (IDEPTH)

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)
      COMMON / COUNT  / KPSH(8), NPSIDE, NCOL, NROW
      COMMON / CSHLPR / NSHELL, HIN(5),SUMR
      COMMON / CKEYPR /K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF
      COMMON / CROKPR / MATPRO(20), HTOP(4), HMIDA(4), HMIDC(4),
     &                  HBOT(4),NMIDA,NMIDC,NTOP,NBOT
      COMMON / CSUBDV / NSUB(0:50),MASPCT
      COMMON / CFLAG  / MSYM, MDIM

C OUTER PAFBLOCKS TOPOLOGY RIGHT HAND SIDE OF THE SHELL

      DO 6570 I=1,NPSIDE

         IPAF=I+NBS*NSHELL

C SUBDIVISION VALUES OF N1 AND N2 FOR PAFBLOCKS
```

```
         N1=NSUB(NSHELL+NCOL+I+1+NTOP)
         N2=NSUB(NSHELL+NCOL)
         N5=NSUB(NSHELL+NCOL+NROW+IDEPTH)

C MATERIAL PROPERTIES KPR

         KPR=MATPRO(I+1+NTOP)
C CONVERT TO 3-D MATERIAL DESCRIPTIONS

         IF (MDIM.EQ.3) KPR = 10 + KPR

         CALL WRITES(IDEPTH,IPAF,KPR,N1,N2,N5)

 6570 CONTINUE

C OUTER PAFBLOCKS TOPOLOGY LEFT HAND SIDE OF SHELL

      DO 6600 I=1,NPSIDE

         IPAF=I+NPSIDE+NBS*NSHELL

C SUBDIVISION VALUES OF N1 AND N2 FOR PAFBLOCKS

         N1=NSUB(NSHELL+NCOL+NPSIDE+NTOP+2-I)
         N2=NSUB(NSHELL+NCOL)
         N5=NSUB(NSHELL+NCOL+NROW+IDEPTH)

C MATERIAL PROPERTIES KPR

         KPR=MATPRO(NPSIDE+NTOP+2-I)

C CONVERT TO 3-D MATERIAL DESCRIPTIONS

         IF (MDIM.EQ.3) KPR = 10 + KPR

         IF (MSYM.EQ.0) THEN
            CALL WRITES(IDEPTH,IPAF,KPR,N1,N2,N5)
         ENDIF

 6600 CONTINUE

      RETURN
      END
C ========================================================================
C SUBROUTINE TPWRT WRITES OUT TOP REGION PAFBLOCK TOPOLOGY
C ========================================================================

      SUBROUTINE TPWRT (IDEPTH)

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)
      COMMON / CSHLPR / NSHELL, HIN(5),SUMR
      COMMON / COUNT  / KPSH(8), NPSIDE, NCOL, NROW
      COMMON / CKEYPR /K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF
      COMMON / CSHTOP / NODELE(5000,8)
      COMMON / CROKPR / MATPRO(20), HTOP(4), HMIDA(4), HMIDC(4),
     &                    HBOT(4),NMIDA,NMIDC,NTOP,NBOT
      COMMON / CSUBDV / NSUB(0:50),MASPCT
      COMMON / CFLAG  / MSYM, MDIM

      DO 6700 ITOP=0,NTOP
         DO 6800 I=1,2*NCOL

            IPAF=I+2*NPSIDE+NBS*NSHELL+2*NCOL*ITOP

C SUBDIVISION VALUES OF N1 AND N2 FOR PAFBLOCKS

            IF (I.LE.NCOL) THEN
               N1=NSUB(NSHELL+I)
            ELSE
               N1=NSUB(NSHELL+2*NCOL+1-I)
            ENDIF
```

```
          N2=NSUB(NSHELL+NCOL+ITOP+1)
          N5=NSUB(NSHELL+NCOL+NROW+IDEPTH)

C MATERIAL PROPERTIES KPR
          IF (ITOP.EQ.0) THEN
C PERMINENT ROW
             KPR=MATPRO(NTOP+1)
          ELSE
C EXTRA LAYERS
             KPR=MATPRO(ITOP)
          ENDIF

C CONVERT TO 3-D MATERIAL DESCRIPTIONS

          IF (MDIM.EQ.3) KPR = 10 + KPR

          IF ( (MSYM.EQ.0) .OR. (I.LE.NCOL) ) THEN
             CALL WRITES(IDEPTH,IPAF,KPR,N1,N2,N5)
          ENDIF

 6800    CONTINUE
 6700 CONTINUE

      RETURN
      END

C ===========================================================================
C SUBROUTINE BTWRT WRITES OUT BOTTOM REGION PAFBLOCK TOPOLOGY
C ===========================================================================

      SUBROUTINE BTWRT (IDEPTH)

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)
      COMMON / CSHLPR / NSHELL, HIN(5),SUMR
      COMMON / COUNT  / KPSH(8), NPSIDE, NCOL, NROW
      COMMON / CKEYPR /K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF
      COMMON / CROKPR / MATPRO(20), HTOP(4), HMIDA(4), HMIDC(4),
     &                  HBOT(4),NMIDA,NMIDC,NTOP,NBOT
      COMMON / CSUBDV / NSUB(0:50),MASPCT
      COMMON / CFLAG  / MSYM, MDIM


      DO 6900 IBOT=0,NBOT
         DO 6950 I=1,2*NCOL

          IPAF=I+2*NPSIDE+NBS*NSHELL+2*NCOL*(NTOP+1+IBOT)

C SUBDIVISION VALUES OF N1 AND N2 FOR PAFBLOCKS

          IF (I.LE.NCOL) THEN
             N1=NSUB(NSHELL+I)
          ELSE
             N1=NSUB(NSHELL+2*NCOL+1-I)
          ENDIF

          N2=NSUB(NSHELL+NCOL+NPSIDE+IBOT+NTOP+2)
          N5=NSUB(NSHELL+NCOL+NROW+IDEPTH)

C MATERIAL PROPERTIES KPR
          KPR=MATPRO(NPSIDE+IBOT+NTOP+2)

C CONVERT TO 3-D MATERIAL DESCRIPTIONS

          IF (MDIM.EQ.3) KPR = 10 + KPR

          IF ( (MSYM.EQ.0) .OR. (I.LE.NCOL) ) THEN
             CALL WRITES(IDEPTH,IPAF,KPR,N1,N2,N5)
          ENDIF

 6950    CONTINUE
 6900 CONTINUE
```

```
      RETURN
      END

C =====================================================================
C SUBROUTINE LRWRT WRITES OUT LAST RING PAFBLOCK TOPOLOGY INSIDE THE TUNNEL
C =====================================================================

      SUBROUTINE LRWRT (IDEPTH)

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)
      COMMON / CSHLPR / NSHELL, HIN(5),SUMR
      COMMON / CKEYPR /K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF
      COMMON / CROKPR / MATPRO(20), HTOP(4), HMIDA(4), HMIDC(4),
     &                    HBOT(4),NMIDA,NMIDC,NTOP,NBOT
      COMMON / CSUBDV / NSUB(0:50),MASPCT
      COMMON / CEXCIN / NEXCVT,MEXCVT(0:9),MSHOT(0:9),KSHOT,HSHOT,
     &                    MINNER,KINNER,HINNER
      COMMON / COUNT  / KPSH(8), NPSIDE, NCOL, NROW
      COMMON / CINDEX / INXSUB(100), INXMAT(100)
      COMMON / CFLAG  / MSYM, MDIM

      DO 7000 I=1,NBS

         IPAF=I+NPOT

C SUBDIVISION VALUES OF N1 AND N2 FOR PAFBLOCKS

         N1 = NSUB(INXSUB(I))
         N2 = NSUB(0)
         N5 = NSUB(NSHELL+NCOL+NROW+IDEPTH)

C MATERIAL PROPERTIES KPR

         KPR=MATPRO(INXMAT(I))

C SET EXCAVATION INDEX

         CALL EXCTSH (I,IEXCVT)

C Give Air Material Properties to PAFBLOCK instead of Removing it

         IF (MEXCVT(IEXCVT).EQ.0) THEN
            KPR = 9
         ENDIF

C CONVERT TO 3-D MATERIAL DESCRIPTIONS

         IF (MDIM.EQ.3) KPR = 10 + KPR

         IF ( (MSYM.EQ.0) .OR. (I.LE.NBS/2) ) THEN
              CALL WRITES(IDEPTH,IPAF,KPR,N1,N2,N5)
         ENDIF

 7000 CONTINUE

      RETURN
      END

C ===================================================================
C SUBROUTINE ITWRT WRITES OUT CENTRAL PAFBLOCK TOPOLOGY INSIDE THE TUNNEL
C ===================================================================

      SUBROUTINE ITWRT(IDEPTH)

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)
      COMMON / CSHLPR / NSHELL, HIN(5),SUMR
      COMMON / CKEYPR /K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF
      COMMON / CROKPR / MATPRO(20), HTOP(4), HMIDA(4), HMIDC(4),
     &                     HBOT(4),NMIDA,NMIDC,NTOP,NBOT
      COMMON / CEXCIN / NEXCVT,MEXCVT(0:9),MSHOT(0:9),KSHOT,HSHOT,
     &                    MINNER,KINNER,HINNER
      COMMON / CSUBDV / NSUB(0:50),MASPCT
      COMMON / COUNT  / KPSH(8), NPSIDE, NCOL, NROW
```

```
      COMMON / CFLAG  / MSYM, MDIM

      DO 20 J=1,NPSIDE

         DO 10 I=1,2*(NCOL-1)

            IPAF=I+NPLR+(J-1)*2*(NCOL-1)

C SUBDIVISION VALUES OF N1 AND N2 FOR PAFBLOCKS
            IF (I.LE.NCOL-1) THEN
               N1=NSUB(NSHELL+I)
            ELSE
               N1=NSUB(NSHELL+I-(NCOL-1))
            ENDIF
            N2=NSUB(NSHELL+NCOL+J+1+NTOP)
            N5=NSUB(NSHELL+NCOL+NROW+IDEPTH)

C MATERIAL PROPERTIES KPR
            KPR=MATPRO(J+1+NTOP)

C SET EXCAVATION INDEX

            CALL EXCTIT (I,J,IEXCVT)

C Give Air Material Properties to PAFBLOCK instead of Removing it

         IF (MEXCVT(IEXCVT).EQ.0) THEN
            KPR = 9
         ENDIF

C CONVERT TO 3-D MATERIAL DESCRIPTIONS

         IF (MDIM.EQ.3) KPR = 10 + KPR

            IF ( (MSYM.EQ.0) .OR. (I.LE.5) ) THEN
                 CALL WRITES(IDEPTH,IPAF,KPR,N1,N2,N5)
            ENDIF

 10      CONTINUE
 20   CONTINUE

      RETURN
      END

C ==================================================================
C SUBROUTINE F3DWRT WRITES THE FOOT OF THE FILE AND CLOSES IT FOR 3D
C ==================================================================

      SUBROUTINE F3DWRT
      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)

      COMMON / CKEYPR /K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF
      COMMON / CFLAG  / MSYM, MDIM
      COMMON / CSUPIN / SAMIN, SAMAJ, HANCH(2), DANCH(2),
     &                    RANCH,AANCH(2),PERIOD, SANCH, SAMAJ2,
     &                    MARCH,MPARCH,MANCH,MPANCH
      COMMON / CSHLPR / NSHELL, HIN(5),SUMR

      WRITE(8,*)'C In the MATERIAL module the Young's modulus (E),'
      WRITE(8,*)'C the Poisson's ratio'
      WRITE(8,*)'C (NU) and the density (RO),are specified for'
      WRITE(8,*)'C Neogene cover (MATERIAL.NUMBER 11),'
      WRITE(8,*)'C the micaceous sandstone,'
      WRITE(8,*)'C siltstone and claystone (MATERIAL.NUMBER 12),'
      WRITE(8,*)'C the quartzite'
      WRITE(8,*)'C (MATERIAL.NUMBER 13), the arkose,'
      WRITE(8,*)'C conglomeratic arkose (MATERIAL.NUMBER 14),'
      WRITE(8,*)'C the volcanic dyke rock (MATERIAL.NUMBER 15),'
      WRITE(8,*)'C Shotcrete (MATERIAL.NUMBER 16),'
      WRITE(8,*)'C Inner (final) lining (MATERIAL.NUMBER 17).'
      WRITE(8,*)'C Mild steel for anchorages and steel arch'
      WRITE(8,*)'C beam element (MATERIAL.NUMBER 18).'
      WRITE(8,*)'C'
```

```
      WRITE(8,*)'C The unit used for youngs modulus is Pa (N/m2)'
      WRITE(8,*)'C and the density is expressed'
      WRITE(8,*)'C in (kg/m3).'
      WRITE(8,*)'C'
      WRITE(8,*)'MATERIAL'
      WRITE(8,*)'MATERIAL.NUMBER        E         NU        RO'
      WRITE(8,*)'     11               90E+6     0.35      2060'
      WRITE(8,*)'     12               0.7E+9    0.27      2200'
      WRITE(8,*)'     13               68E+9     0.16      2600'
      WRITE(8,*)'     14               15E+9     0.26      2600'
      WRITE(8,*)'     15               1.9E+9    0.28      2300'
      WRITE(8,*)'     16               15E+9     0.200     2000'
      WRITE(8,*)'     17               30E+9     0.200     2400'
      WRITE(8,*)'     18               209E+9    0.300     7800'
C Give Air Material Properties to PAFBLOCK instead of Removing it
      WRITE(8,*)'     19               0E-9      0.499      0.0'
      WRITE(8,*)'C In the GRAVITY module the sign in the'
      WRITE(8,*)'C YGVALUE is negative,indicating that'
      WRITE(8,*)'C gravity acts in the vertical downwards'
      WRITE(8,*)'C direction.'
      WRITE(8,*)'C'
      WRITE(8,*)'GRAVITY'
      WRITE(8,*)'XGVALUE    YGVALUE    ZGVALUE  '
      WRITE(8,*)'  0          -1         0'
      WRITE(8,*)'C'
      WRITE(8,*)'C'
      WRITE(8,*)'RESTRAINTS'
      WRITE(8,*)'NODE.NUMBER     PLANE    AXIS.NUMBER     DIRECTION'
      WRITE(8,20)13+K(5),      1,           1,              1
      WRITE(8,20)13+K(5),      2,           1,              2
      IF (MSYM.EQ.1) THEN
        WRITE(8,20)1+K(5),       1,           1,              1
      ELSE
        WRITE(8,20)15+K(5),      1,           1,              1
      ENDIF
      WRITE(8,20)1+K(5),      3,           1,              3
      WRITE(8,20)1+K(5)+2*NPAF,    3,          1,              3
      IF ((MARCH.EQ.1).OR.(SANCH.EQ.1)) THEN
         WRITE(8,20) 1, 3, 1, 456
         WRITE(8,20) NNODE+1, 3, 1, 456
      ENDIF
      WRITE(8,*)'C'
c      WRITE(8,*)'DISPLACEMENT.PRESCRIBED'
c      WRITE(8,*)'NODE.NUMBER    DIRECTION   DISPLACEMENT.VALUE'
c      WRITE(8,*)'13              1                 0'
c      WRITE(8,*)13+NNS*NSHELL,   '       1 ' , '      0'
c      WRITE(8,*)19+K(1),         '       1'  , '      0'
c      WRITE(8,*)19+K(1)+NNS*NSHELL, '    1'  , '      0'
      WRITE(8,*)'C'
      WRITE(8,*)'C'
      WRITE(8,*)'C'
      WRITE(8,*)'CONTROL'
      WRITE(8,*)'USE.R70632MOD'
      WRITE(8,*)'C'
      WRITE(8,*)'C Since PAFEC-FE does not perform stress averaging'
      WRITE(8,*)'C across different'
      WRITE(8,*)'C material types, the supplied source must be modified'
      WRITE(8,*)'C Inspection of the'
      WRITE(8,*)'C stressing routines indicated that a small number of'
      WRITE(8,*)'C changes to PAFEC-FE'
      WRITE(8,*)'C subroutine R70632 was necessary. A section of the'
      WRITE(8,*)'C subroutine with the'
      WRITE(8,*)'C modification is shown in Figure'
      WRITE(8,*)'C The modified source is incorporated'
      WRITE(8,*)'C into the PAFEC-FE system for this analysis'
      WRITE(8,*)'C using the USE.option.'
      WRITE(8,*)'C'
      WRITE(8,*)'C'
      WRITE(8,*)'STRESS'
      WRITE(8,*)'CONTROL.END'
      WRITE(8,*)'C'
      WRITE(8,*)'C'
      WRITE(8,*)'PROCESSING.FOR.PRINTED.OUTPUT'
```

```
      WRITE(8,*)'ORDER  FORMAT.TYPE LOCAL.AXIS  WINDOW'
      WRITE(8,*)'  1       2           1          0 '
      WRITE(8,*)'C'
      WRITE(8,*)'C'
      WRITE(8,*)'ORDER.FOR.PRINTED.OUTPUT'
      WRITE(8,*)'ORDER   LIST.OF.TYPES'
      WRITE(8,*)' 1       101  102  4  8  9  10 11 12 13'
      WRITE(8,*)'END.OF.DATA'

20    FORMAT(2X,I4,12X,I2,8X,I2,2X,2I)

C CLOSE  OPEN FILE OPEN(8,FILE='nodes.DAT')

      CLOSE(8)

      RETURN
      END


C ====================================================================
C SUBROUTINE F2DWRT WRITES THE FOOT OF THE FILE AND CLOSES IT FOR 2D
C ====================================================================

      SUBROUTINE F2DWRT

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)

      COMMON / CKEYPR /K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF
      COMMON / CFLAG  / MSYM, MDIM


      WRITE(8,*)'C'
      WRITE(8,*)'C The PLATES.AND.SHELLS module is used to'
      WRITE(8,*)'C link the PROPERTIES'
      WRITE(8,*)'C specified in the ELEMENTS module with'
      WRITE(8,*)'C the MATERIAL.NUMBER'
      WRITE(8,*)'C used in the MATERIAL module.'
      WRITE(8,*)'C'
      WRITE(8,*)'PLATES.AND.SHELLS'
      WRITE(8,*)'PLATE.NUMBER   MATERIAL.NUMBER     '
      WRITE(8,*)'1                  11              '
      WRITE(8,*)'2                  12              '
      WRITE(8,*)'3                  13              '
      WRITE(8,*)'4                  14              '
      WRITE(8,*)'5                  15              '
      WRITE(8,*)'6                  16              '
      WRITE(8,*)'7                  17              '
      WRITE(8,*)'8                  18              '
      WRITE(8,*)'9                  19              '
      WRITE(8,*)'C'
      WRITE(8,*)'C In the MATERIAL module the Young's modulus (E),'
      WRITE(8,*)'C the Poisson's ratio'
      WRITE(8,*)'C (NU) and the density (RO),are specified for'
      WRITE(8,*)'C Neogene cover (MATERIAL.NUMBER 11),'
      WRITE(8,*)'C the micaceous sandstone,'
      WRITE(8,*)'C siltstone and claystone (MATERIAL.NUMBER 12),'
      WRITE(8,*)'C the quartzite'
      WRITE(8,*)'C (MATERIAL.NUMBER 13), the arkose,'
      WRITE(8,*)'C conglomeratic arkose (MATERIAL.NUMBER 14),'
      WRITE(8,*)'C the volcanic dyke rock (MATERIAL.NUMBER 15),'
      WRITE(8,*)'C Shotcrete (MATERIAL.NUMBER 16),'
      WRITE(8,*)'C Inner (final) lining (MATERIAL.NUMBER 17).'
      WRITE(8,*)'C Mild steel for anchorages and steel arch'
      WRITE(8,*)'C beam element (MATERIAL.NUMBER 18).'
      WRITE(8,*)'C'
      WRITE(8,*)'C The unit used for youngs modulus is Pa (N/m2)'
      WRITE(8,*)'C and the density is expressed'
      WRITE(8,*)'C in (kg/m3).'
      WRITE(8,*)'C'
      WRITE(8,*)'MATERIAL'
      WRITE(8,*)'MATERIAL.NUMBER        E        NU        RO'
      WRITE(8,*)'     11              90E+6     0.35      2060'
      WRITE(8,*)'     12              0.7E+9    0.27      2200'
```

```
      WRITE(8,*)'    13               68E+9    0.16       2600'
      WRITE(8,*)'    14               15E+9    0.26       2600'
      WRITE(8,*)'    15               1.9E+9   0.28       2300'
      WRITE(8,*)'    16               15E+9    0.20       2000'
      WRITE(8,*)'    17               30E+9    0.20       2400'
      WRITE(8,*)'    18               209E+9   0.30       7800'
C Give Air Material Properties to PAFBLOCK instead of Removing it
      WRITE(8,*)'    19               0E-9    0.499       0.0'
      WRITE(8,*)'C'
      WRITE(8,*)'C In the GRAVITY module the sign in the YGVALUE'
      WRITE(8,*)'C is negative,'
      WRITE(8,*)'C indicating that gravity acts in the vertical'
      WRITE(8,*)'C downwards direction.'
      WRITE(8,*)'C'
      WRITE(8,*)'GRAVITY'
      WRITE(8,*)'XGVALUE    YGVALUE'
      WRITE(8,*)'  0          -1'
      WRITE(8,*)'C'
      WRITE(8,*)'C To ensure that the nodes lying on the boundary'
      WRITE(8,*)'C are restricted from'
      WRITE(8,*)'C moving in the horizontal direction, all nodes'
      WRITE(8,*)'C lying on the plane that'
      WRITE(8,*)'C passes through boundary and is normal to'
      WRITE(8,*)'C the x-axis (PLANE 1),are'
      WRITE(8,*)'C prevented from moving along the x-direction'
      WRITE(8,*)'C (DIRECTION 1).'
      WRITE(8,*)'C Similarly, the right side boundary is also'
      WRITE(8,*)'C prevented from moving along the'
      WRITE(8,*)'C horizontal direction.'
      WRITE(8,*)'C In this way the horizontal geostatic stresses'
      WRITE(8,*)'C are allowed to develop as a'
      WRITE(8,*)'C function of Poissns ratio of the ground.'
      WRITE(8,*)'C'
      WRITE(8,*)'C Furthermore there is a need to restrict the'
      WRITE(8,*)'C lower boundary of the mesh'
      WRITE(8,*)'C from moving in the vertical direction,so a restraint'
      WRITE(8,*)'C is introduced to'
      WRITE(8,*)'C prevent any node lying on the plane and is normal'
      WRITE(8,*)'C to y-axis (PLANE 2),'
      WRITE(8,*)'C and is normal to y-axis (PLANE 2), to move'
      WRITE(8,*)'C (DIRECTION 2).'
      WRITE(8,*)'C'
      WRITE(8,*)'C'
      WRITE(8,*)'RESTRAINTS'
      WRITE(8,*)'NODE.NUMBER  PLANE    AXIS.NUMBER    DIRECTION'
      WRITE(8,20)13+K(5),      1,           1,            1
      WRITE(8,20)13+K(5),      2,           1,            2
      IF (MSYM.EQ.1) THEN
        WRITE(8,20)1+K(5),       1,           1,            1
      ELSE
        WRITE(8,20)15+K(5),      1,           1,            1
      ENDIF
      WRITE(8,*)'C'
      WRITE(8,*)'C'
      WRITE(8,*)'C The CONTROL facility is used to specify'
      WRITE(8,*)'C plane strain analysis and to'
      WRITE(8,*)'C indicate that stress averaging across'
      WRITE(8,*)'C different material types is to be'
      WRITE(8,*)'C performed.'
      WRITE(8,*)'C'
      WRITE(8,*)'CONTROL'
      WRITE(8,*)'PLANE.STRAIN'
      WRITE(8,*)'USE.R70632MOD'
      WRITE(8,*)'C'
      WRITE(8,*)'C Since PAFEC-FE does not perform stress averaging'
      WRITE(8,*)'C across different'
      WRITE(8,*)'C material types, the supplied source must be modified'
      WRITE(8,*)'C Inspection of the'
      WRITE(8,*)'C stressing routines indicated that a small number of'
      WRITE(8,*)'C changes to PAFEC-FE'
      WRITE(8,*)'C subroutine R70632 was necessary. A section of the'
      WRITE(8,*)'C subroutine with the'
      WRITE(8,*)'C modification is shown in Figure'
```

```
      WRITE(8,*)'C The modified source is incorporated'
      WRITE(8,*)'C into the PAFEC-FE system for this analysis'
      WRITE(8,*)'C using the USE.option.'
      WRITE(8,*)'C'
      WRITE(8,*)'C'
      WRITE(8,*)'STRESS'
      WRITE(8,*)'CONTROL.END'
      WRITE(8,*)'C'
      WRITE(8,*)'C'
      WRITE(8,*)'PROCESSING.FOR.PRINTED.OUTPUT'
      WRITE(8,*)'ORDER  FORMAT.TYPE LOCAL.AXIS  WINDOW'
      WRITE(8,*)'  1            1            1          0 '
      WRITE(8,*)'  2            1            1          0 '
      WRITE(8,*)'C'
      WRITE(8,*)'C'
      WRITE(8,*)'ORDER.FOR.PRINTED.OUTPUT'
      WRITE(8,*)'ORDER   LIST.OF.TYPES'
      WRITE(8,*)' 1      101  103   102   4   8  9  10 11 12 13'
      WRITE(8,*)' 2      101        102   4   8  9  10 11 12 13'
      WRITE(8,*)'END.OF.DATA'

20    FORMAT(2X,I4,9X,I2,9X,I2,13X,I2)

C CLOSE  OPEN FILE OPEN(8,FILE='nodes.DAT')
      CLOSE(8)

      RETURN
      END

C ==================================================================
C SUBROUTINE EXCLOC WRITES LOCAL DIRECTIONS FOR EXCAVATION SURFACE
C ==================================================================

      SUBROUTINE EXCLOC

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)

      PARAMETER(NNODES=5000)
      COMMON / CNODES / X(NNODES), Y(NNODES)
      COMMON / CFLAG  / MSYM, MDIM
      COMMON / CKEYPR /K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF
      COMMON / COUNT / KPSH(8), NPSIDE, NCOL, NROW
      COMMON / CCENPR / XC(10), YC(10)
      COMMON / CZNOD / Z(5), NDEPTH

      DRAD=DACOS(0D0)/90D0

      WRITE(8,*)'C'
      WRITE(8,*)'C Define local axis and directions'
      WRITE(8,*)'C'
      WRITE(8,*)'AXES'
      WRITE(8,*)'RELAXISNO = 1'
      WRITE(8,*)'TYPE = 1'
      WRITE(8,*)'AXISNO   NODE   ANG1'
      IF (MSYM.EQ.0) N = NNS
      IF (MSYM.EQ.1) N = (NNS/2)+1
      DO 15 L=1,mdim-1
         DO 10 I=1,N
            IF (I .LE.(2*KPSH(2) + 1)) THEN
               ICEN=1
            ELSE IF (I .LE.(2*KPSH(4) + 1)) THEN
               ICEN=2
            ELSE IF (I .LE.(2*KPSH(6) + 1 )) THEN
               ICEN=3
            ELSE IF (I .LE.(2*KPSH(7) +1 )) THEN
               ICEN=4
            ELSE IF (I .LE.(NNS/2 + 1)) THEN
               ICEN=5
            ELSE IF (I .LE.(NNS - 2*KPSH(7) )) THEN
               ICEN=10
            ELSE IF (I .LE.(NNS - 2*KPSH(6) + 1)) THEN
               ICEN=9
            ELSE IF (I .LE.(NNS - 2*KPSH(4) + 1)) THEN
```

```
               ICEN=8
            ELSE IF (I .LE.(NNS - 2*KPSH(2) + 1)) THEN
               ICEN=7
            ELSE
               ICEN=6
            ENDIF

            IO = NNODE*(NDEPTH+1)+ICEN
            IP = I + 2*NNS

            ANG = DATAN2(X(IP)-XC(ICEN),Y(IP)-YC(ICEN)) / DRAD
            IF(I.EQ.((NNS/2)+1)) ANG=180.0
            WRITE(8,*) 3+I+(L-1)*NNS, IO + (L-1)*10,  -ANG
10       CONTINUE
15    CONTINUE

      WRITE(8,*)'C'
      WRITE(8,*)'C'
      WRITE(8,*)'LOCAL.DIRECTIONS'
      WRITE(8,*)'NODE.NUMBER  LOCAL.AXIS '
      DO 25 L=1,mdim-1
         DO 20 I=1,N
            INODE = I+2*NNS+(L-1)*NNODE
            IAX   = 3+I+(L-1)*NNS
            WRITE(8,*) INODE,  IAX
20       CONTINUE
25    CONTINUE
      WRITE(8,*)'C'
      WRITE(8,*)'C'
      WRITE(8,*)'C Elements which form the Excavated Surface'
      WRITE(8,*)'C'
      WRITE(8,*)'C'
      WRITE(8,*)'EXTERNAL.FORCE'
      WRITE(8,*)'AXIS.SET = 1'
      WRITE(8,*)'LIST'
      DO  5 I=0,(N/2)-1
5        WRITE(8,*)I+N
      WRITE(8,*)'C'
      WRITE(8,*)'C'
      WRITE(8,*)'C'
      WRITE(8,*)'C'
      WRITE(8,*)'C'

      RETURN
      END
```

APPENDIX D

STRUCTURE OF POST-PROCESSING PROGRAMS

D.1 Gravity Difference Method Script (gravdif)

```
#!/Bin/csh

echo $1 $2 $3
setenv unex $1
setenv exct $2
setenv gdif $3

# Process and Plot
#  Unexcavated & Excavated Ground

plot $unex
plot $exct

# Copy Data, Graphic and Number
#  files for Difference file

setenv file $gdif

cp $exct.GDAT $file.GDAT
cp $exct.DAT  $file.DAT
cp $exct.NUM  $file.NUM

# Find Gravity Difference
#  for Displacement and Stress

gddisp
gdstress
# Plot Result
indistress < $file.ras
```

D.2 Colour Outputs Script (plot) for UNIRAS software

```
#!/bin/csh
setenv file $1
getin
dispget
stressget
indistress < $file.ras
```

D.3 List of Programs

D.3.1 Post Processing of Nodal Co-ordinates and Element Topology

```
*****************************************************************************
*     PROGRAM TO OBTAIN NODAL CO-ORDINATES AND ELEMENTS FROM                *
*     PAFEC OUTPUT FILES from .002 files    File name: getin.f               *
*****************************************************************************

      CHARACTER*4 TEST,CHAR*2, FILE*6
      INTEGERN(2),NEL(30)
      IFLG=0

C Find files name

      CALL GETENV ("file",FILE)
```

```
      OPEN(7,FILE=FILE//'.002')
      OPEN(9,FILE=FILE//'.GDAT')
      OPEN(10,FILE=FILE//'.NUM')
*
10    IF (IFLG.GT.1) GOTO 200
      READ(7,901)TEST
      IF (TEST.EQ.' GLO')THEN
*
*     ***  NODE RECOGNITION ROUTINE  ***
*
        IFLG=IFLG+1
        NONOS=0
        READ(7,901)TEST
        READ(7,901)TEST
55      READ(7,901)TEST
        READ(7,901)TEST
        READ(7,901)TEST
60      READ(7,902,ERR=10)CHAR,N(1),A,B,C,N(2),X,Y,Z
        IF (CHAR.EQ.'1 ')GOTO 55
        WRITE(9,903)N(1),A,B,C
        NONOS=NONOS+1
        IF (N(2).EQ.0) GOTO 10
c        WRITE(8,903)N(2),X,Y,Z
        WRITE(9,903)N(2),X,Y,Z
        NONOS=NONOS+1
        GOTO 60
      ENDIF
*
      IF (TEST.EQ.'  EL')THEN
*
*     ***  ELEMENT RECOGNITION ROUTINE  ***
*
        NOELS=0
        IFLG=IFLG+1
        READ(7,901)TEST
70      READ(7,901)TEST
        READ(7,901)TEST
        READ(7,901)TEST
        READ(7,901)TEST
*
80      READ(7,910,ERR=82)CHAR,(NEL(M),M=1,5),(NEL(M),M=6,14)
82      IF (CHAR.EQ.' -')GOTO 10
        IF (CHAR.EQ.'1 ')GOTO 70
        NA=NEL(5)/9
*
        IF (NEL(5).EQ.8) THEN
          MJ=4
        ELSE IF (NEL(5).EQ.20) THEN
          MJ=8
        ELSE IF (NEL(5).EQ.6) THEN
          MJ=3
        ELSE
          MJ=2
        ENDIF
        IF (NEL(5).EQ.8) THEN
           NDIM = 2
        ELSE
           NDIM = 3
        ENDIF
        WRITE(9,914)NEL(1),MJ,(NEL(M),M=6,5+MJ),NEL(4)
        NOELS=NOELS+1
*
90      IF (NA.LT.1) THEN
          GOTO 80
        ELSE
          NA=NA-1
          READ(7,910,ERR=91)CHAR
91        IF (CHAR.EQ.' -')GOTO 10
          IF (CHAR.EQ.'1')THEN
            READ(7,901)TEST
            READ(7,901)TEST
            READ(7,901)TEST
            READ(7,901)TEST
```

```
            READ(7,901)TEST
          ENDIF
        ENDIF
        GOTO 90
*
      ENDIF
      GOTO 10
*
200   WRITE(6,*)'GetIn: Successful Completion',NONOS,NOELS
      WRITE(9,916)'*'
      WRITE(9,*)NONOS,NOELS
      WRITE(10,*)NONOS,NOELS,NDIM
      CLOSE(7,STATUS='KEEP')
      CLOSE(9,STATUS='KEEP')
      CLOSE(10,STATUS='KEEP')
      STOP
*
901   FORMAT(A4)
902   FORMAT(A2,I6,3X,F9.4,2X,F9.4,2X,F9.4,20X,I6,3X,F9.4,2X,F9.4,2
     &X,F9.4)
903   FORMAT(3X,I6,2X,3(F9.4,2X))
910   FORMAT(A2,I6,4X,I3,3X,I6,5X,I3,4X,I3,9(2X,I6))
911   FORMAT(2X,I6,2X,I3,2X,I6,2X,I3,9(2X,I6))
912   FORMAT(A2,39X,9(2X,I6))
913   FORMAT('*',25X,9(2X,I6))
914   FORMAT(11(2X,I6))
915   FORMAT(7(2X,I6))
916   FORMAT(A3,I6,2X,I6)
917   FORMAT(I4)
*
      END
```

D.3.2 Post-Processing of Results for Gravity Difference Method

D.3.2.1 Stresses

```
*****************************************************************************
*     PROGRAM TO OBTAIN Unaveraged & Averaged Stresses from                *
*     PAFEC OUTPUT FILES from .SP files   File name: gdstress.f            *
*****************************************************************************

      PARAMETER (MXNOS1 = 80 000)
      PARAMETER (MXELS  = 25 00)
      PARAMETER (MXEN   = 20*MXELS )

      CHARACTER*6 UNEX, EXCT, GDIF, TEST
      CHARACTER*1 CHRU, CHAR1, ELNO*12
      INTEGER IEL(MXEN,2), NN(MXEN,2), NONO(3), NS(MXEN,2)
      REAL  VUSTR(MXEN,2)
      REAL  USTR(6,3)
      REAL  ASTR(MXEN,6,3,2), VASTR(MXEN,3,2), DSTR(6)

C Find files name

      CALL GETENV ("unex",UNEX)
      CALL GETENV ("exct",EXCT)
      CALL GETENV ("gdif",GDIF)

      OPEN(7,FILE=UNEX//'.SP')
      OPEN(8,FILE=EXCT//'.SP')

      OPEN(10,FILE=UNEX//'.NUM')
      READ(10,*)NONOS,NOELS,NDIM
      CLOSE(10,STATUS='KEEP')

C For 2-D Problems only

      IF (NDIM.EQ.2) THEN
*
```

```
      OPEN(7,FILE=UNEX//'.SP')
      OPEN(8,FILE=EXCT//'.SP')
      OPEN(9,FILE=GDIF//'.USTRDAT')
      OPEN(10,FILE=GDIF//'.USTRNUM')
C
C========================================================
C Read in Directional Stresses for each node in each element
C========================================================
C
C Find Beginning of Tables

      NU = 1

      DO 20 K=1,2
 10         READ(6+K,101)TEST
            IF (TEST.NE.'  ELEM') GO TO 10
         READ(6+K,101)TEST
         READ(6+K,101)TEST
 20   CONTINUE

C Read in Stress Entry

 30      DO 60 K=1,2
 40         READ(6+K,103,ERR=50)
     *       CHRU,IEL(NU,K),NN(NU,K),VUSTR(NU,K),(USTR(I,K),I=1,6)
 50         CONTINUE

            IF (CHRU.EQ.'1') THEN
               DO 55 I=1,7
 55              READ(6+K,101)CHAR1
            ENDIF
            IF (CHRU.EQ.'1') GO TO 40
            IF (IEL(NU,K).EQ.0)    GO TO 100
 60      CONTINUE

         IF (NN(NU,K) .NE. 0) THEN
            DO 70 I=1,6
 70            USTR(I,3) = USTR(I,2) - USTR(I,1)
            ESTR = SQRT ( ( (USTR(1,3)-USTR(2,3))**2 +
     *                      (USTR(2,3)-USTR(3,3))**2 +
     *                      (USTR(3,3)-USTR(1,3))**2 +
     *      6.0 * (USTR(4,3)**2+USTR(5,3)**2+USTR(6,3)**2) )
     *                                          / 2.0 )
            WRITE(9,104)IEL(NU,1),NN(NU,1),ESTR
            NU = NU+1
         ENDIF
      GO TO 30

 100  NU=NU-1

      WRITE(6,*)'Unaverage Stresses: ',NU
      WRITE(9,*)'*'
      WRITE(10,*)NU

      CLOSE(9,STATUS='KEEP')
      CLOSE(10,STATUS='KEEP')

 101  FORMAT(A6)
 103  FORMAT(A1,2I7,E14.4,6E13.4)
 104  FORMAT(3X,2I7,E14.5)
C
C========================================================
C Read in Directional Stresses for each node
C========================================================
C
C Since there are unaveraged stress values for nodes
C  on material boundaries, three stress values may exist.
C This program converts from a list of node numbers
C  and stress, with repeated nodes for multiple
C  stress values to a triple column format,
C  which contains either a duplicated stress value
C  or the three seperate values.
C
```

```
C Find Beginning of Tables
C For Each File

        DO 180 K=1,2

 120          READ(6+K,201)TEST
              IF (TEST.NE.'  NODE') GO TO 120
           NONO(K)=0
           READ(6+K,201)TEST
           READ(6+K,201)TEST

C Read in Stress entry

 130          READ (6+K,203,ERR=140)
     *             CHAR,N,VSTR,(DSTR(I),I=1,6)
 140          CONTINUE
C Allow for page turning

              IF (CHAR.EQ.'1') THEN
                 DO 150 I=1,7
 150                READ(6+K,201)CHAR1
              ENDIF
              IF (CHAR.EQ.'1') GO TO 130

C If last value to be read is a Null value finish

              IF ( N .EQ. 0 ) GO TO 170

              NS(N,K)=NS(N,K)+1
              VASTR(N,NS(N,K),K)=VSTR
              DO 160 I=1,6
                 ASTR(N,I,NS(N,K),K)= DSTR(I)
 160          CONTINUE

Count nodes read in

              NONO(K)=NONO(K) +1

              GO TO 130

 170       CLOSE(6+K,STATUS='KEEP')

 180    CONTINUE

 201    FORMAT(A6)
 203    FORMAT(A1,I6,7E13.4)

        OPEN(9,FILE=GDIF//'.ASTRDAT')
        OPEN(10,FILE=GDIF//'.ASTRNUM')

        DO 280 I=1,NU

C Loop over all elements

           DO 250 K=1,2

C Assign average stress value which is closest to the
C  unaveraged stress value of that element

C Using Unaveraged Stress at that Node for comparison

              US = VUSTR(I,K)

C Calclulate the differences between Values

              A1 =  ABS(US-VASTR(NN(I,K),1,K))
              A2 =  ABS(US-VASTR(NN(I,K),2,K))
              A3 =  ABS(US-VASTR(NN(I,K),3,K))

C Choose closest value

              IF ((A1.LE.A2).AND.(A1.LE.A3)) THEN
                 DO 210 J=1,6
```

```
 210                 USTR(J,K) = ASTR(NN(I,K),J,1,K)
              ELSE IF (A2.LE.A3) THEN
                 DO 220 J=1,6
 220                 USTR(J,K) = ASTR(NN(I,K),J,2,K)
              ELSE
                 DO 230 J=1,6
 230                 USTR(J,K) = ASTR(NN(I,K),J,3,K)
              ENDIF

 250       CONTINUE

           DO 260 J=1,6
 260          USTR(J,3) = USTR(J,2) - USTR(J,1)

           IF (USTR(1,2).EQ.0.0) THEN
              DO 270 J=1,6
 270             USTR(J,3) = USTR(J,2)
           ENDIF

           ESTR = SQRT ( ( (USTR(1,3)-USTR(2,3))**2 +
     *                     (USTR(2,3)-USTR(3,3))**2 +
     *                     (USTR(3,3)-USTR(1,3))**2 +
     *     6.0 * (USTR(4,3)**2+USTR(5,3)**2+USTR(6,3)**2) )
     *                                              / 2.0 )

           WRITE(9,104)IEL(I,1),NN(I,1),ESTR

 280    CONTINUE

        WRITE(6,*)'Average Stresses: ',NU
        WRITE(9,*)'*'
        WRITE(10,*)NU

        CLOSE(9,STATUS='KEEP')
        CLOSE(10,STATUS='KEEP')

      ELSE

C 3-D Problems Only.

C The complete Directional Unaveraged Stress Tensor is not
C  available for the 3-D results so only the Average stresses
C  will be calculated.

C The unaveraged Von Mises stresses will be used to correctly
C  pick the appropriate averaged stresses for each element
C  at material boundaries.

C========================================================
C Read in Unaveraged Von Mises Stress of 3-D problems
C  for each node in each element
C========================================================
C
C Set number of nodes in each element
        IF (NDIM .EQ. 3) N=27

        OPEN(7,FILE=UNEX//'.009')
        OPEN(8,FILE=EXCT//'.009')

        DO 390 K=1,2

           NU = 1
C Find Beginning of Tables

 310       READ(6+K,301)TEST
           IF (TEST.NE.'  CASE') GO TO 310

           READ(6+K,301)TEST
           READ(6+K,301)TEST

           DO 380 I=1,NOELS
C Find Element Number
```

```
               READ(6+K,302,ERR=400)ELNO,IEL(NU,K)
               nnoels=i

C Finish if no more elements

               IF (IEL(NU,K) .EQ. 0 ) GO TO 400

               READ(6+K,301)TEST
*
*     ***  NODE RECOGNITION ROUTINE  ***
*
               DO 360 INODE=1,N

C Read in Line of Data

  330              READ(6+K,303,ERR=400)
     *             CHAR,L,NN(NU,K),(USTR(J,K),J=1,6),VUSTR(NU,K)

C Allow for Page Turning

                  IF (CHAR.EQ.'1') THEN
                     DO 340 J=1,4
 340                    READ(6+K,301)CHAR1
                  ENDIF
                  IF (CHAR.EQ.'1') GO TO 330

                  IF (NN(NU,K).NE.0) NU=NU+1
                   IEL(NU,K)=IEL(NU-1,K)

 360           CONTINUE

C Allow for Page Turning

               READ(6+K,301)TEST
               IF (TEST.EQ.'1') THEN
                  DO 370 J=1,5
  370                READ(6+K,301)CHAR1
               ENDIF

  380       CONTINUE
*
  390    CONTINUE
*
  400    NU=NU-1

         CLOSE(7,STATUS='KEEP')
         CLOSE(8,STATUS='KEEP')
*
301      FORMAT(A6)
 302      FORMAT(A12,I6)
c302      FORMAT(A16,I8)
303      FORMAT(A1,I5,I7,7E11.2)
304      FORMAT(3X,2I7,E11.4)
316      FORMAT(A3,I6,2X,I6)
*
C==========================================================
C Read in Directional Stresses for each node
C==========================================================
C
C Since there are unaveraged stress values for nodes
C  on material boundaries, three stress values may exist.
C
         OPEN(7,FILE=UNEX//'.SP')
         OPEN(8,FILE=EXCT//'.SP')

         DO 480 K=1,2

 420           READ(6+K,401)TEST
               IF (TEST.NE.'  CASE') GO TO 420
            NONO(K)=0
            READ(6+K,401)TEST

C Read in Stress entry
```

```
 430          READ (6+K,403,ERR=440)
    *              CHAR,l,N,VSTR,(DSTR(I),I=1,6)
 440          CONTINUE
C Allow for page turning

              IF (CHAR.EQ.'1') THEN
                 DO 450 I=1,5
 450                READ(6+K,401)CHAR1
              ENDIF
              IF (CHAR.EQ.'1') GO TO 430

C If last value to be read is a Null value finish

              IF ( N .EQ. 0 ) GO TO 470

              NS(N,K)=NS(N,K)+1
              VASTR(N,NS(N,K),K)=VSTR
              DO 460 I=1,6
                 ASTR(N,I,NS(N,K),K)= DSTR(I)
 460          CONTINUE

Count nodes read in

              NONO(K)=NONO(K) +1

              GO TO 430

 470       CLOSE(6+K,STATUS='KEEP')

 480    CONTINUE

 401    FORMAT(A6)
 403    FORMAT(A1,I4,I8,7E13.4)

        OPEN(7,FILE=GDIF//'.ASTRDAT')
        OPEN(8,FILE=GDIF//'.ASTRNUM')
        OPEN(9,FILE=GDIF//'.USTRDAT')
        OPEN(10,FILE=GDIF//'.USTRNUM')

        DO 580 I=1,NU

C Loop over all elements

           DO 550 K=1,2

C Assign average stress value which is closest to the
C  unaveraged stress value of that element

C Using Unaveraged Stress at that Node for comparison

              US = VUSTR(I,K)

C Calclulate the differences between Values

              A1 =  ABS(US-VASTR(NN(I,K),1,K))
              A2 =  ABS(US-VASTR(NN(I,K),2,K))
              A3 =  ABS(US-VASTR(NN(I,K),3,K))

C Choose closest value

              IF ((A1.LE.A2).AND.(A1.LE.A3)) THEN
                 DO 510 J=1,6
  510               USTR(J,K) = ASTR(NN(I,K),J,1,K)
              ELSE IF (A2.LE.A3) THEN
                 DO 520 J=1,6
  520               USTR(J,K) = ASTR(NN(I,K),J,2,K)
              ELSE
                 DO 530 J=1,6
  530               USTR(J,K) = ASTR(NN(I,K),J,3,K)
              ENDIF

  550      CONTINUE
           DO 560 J=1,6
```

```
 560          USTR(J,3) = USTR(J,2) - USTR(J,1)

           IF (USTR(1,2).EQ.0.0) THEN
              DO 570 J=1,6
 570             USTR(J,3) = USTR(J,2)
           ENDIF

           ESTR = SQRT ( ( (USTR(1,3)-USTR(2,3))**2 +
     *                     (USTR(2,3)-USTR(3,3))**2 +
     *                     (USTR(3,3)-USTR(1,3))**2 +
     *     6.0 * (USTR(4,3)**2+USTR(5,3)**2+USTR(6,3)**2) )
     *                                           / 2.0 )

           WRITE(9,304)IEL(I,1),NN(I,1),ESTR
           WRITE(7,304)IEL(I,1),NN(I,1),ESTR

 580    CONTINUE

        WRITE(6,*)'Unaverage Stresses: ',NU
        WRITE(6,*)'Average Stresses: ',NU
        WRITE(9,*)'*'
        WRITE(8,*)NU
        WRITE(10,*)NU

        CLOSE(7,STATUS='KEEP')
        CLOSE(8,STATUS='KEEP')
        CLOSE(9,STATUS='KEEP')
        CLOSE(10,STATUS='KEEP')
      ENDIF

      STOP
      END
```

D.3.2.2 Displacements

```
************************************************************************
*     PROGRAM TO OBTAIN DISPLACEMENTS FROM
*                PAFEC OUTPUT FILES from .007 files  File name: gddisp.f
************************************************************************

      CHARACTER*6 UNEX, EXCT, GDIF

C Find files name

      CALL GETENV ("unex",UNEX)
      CALL GETENV ("exct",EXCT)
      CALL GETENV ("gdif",GDIF)

      OPEN(10,FILE=UNEX//'.NUM')
      READ(10,*)NONOS,NOELS,NDIM
      CLOSE(10,STATUS='KEEP')
*
      OPEN(7,FILE=UNEX//'.DISP')
      OPEN(8,FILE=EXCT//'.DISP')
      OPEN(9,FILE=GDIF//'.DISP')
*
      DO 200 I=1,NONOS
         READ(7,*)NU,XU,YU,ZU
         READ(8,*)NE,XE,YE,ZE
         WRITE(9,*)NE,XE-XU,YE-YU,ZE-ZU
 200  CONTINUE

      WRITE(6,*)'Gravity Difference Displacemants ',NONOS
      CLOSE(7,STATUS='KEEP')
      CLOSE(8,STATUS='KEEP')
      CLOSE(9,STATUS='KEEP')

      STOP
      END
```

D.3.3 Post-Processing of Results for Stress Reversal Technique

D.3.3.1 Stresses

```
*******************************************************************************
*     PROGRAM TO OBTAIN Unaveraged & Averaged Stresses from                    *
*     PAFEC OUTPUT FILES from .SP & .009 files  File name: stressget.f         *
*******************************************************************************

      COMMON / NUMBRS / NONOS, NOELS, NDIM

C Find general file name

      CALL FILEIN

C Read in Numerical Parameters of the System
      CALL NUMBIN

C Find the unaveraged stresses
C Read in and write out the unaveraged stresses

      IF (NDIM.EQ.2) CALL UNST2D
      IF (NDIM.EQ.3) CALL UNST3D

C Find the averaged stresses
C Read in and write out the averaged stresses

      IF (NDIM.EQ.2) CALL AVST2D
      IF (NDIM.EQ.3) CALL AVST3D

C Rearrange Average Stress Values by Element and Node
C  Using Unaveraged Stresses to determine Values on
C  either side of material boundaries

      CALL REAVST

      STOP
      END
C
C=========================================================
C Find General File Name
C=========================================================
C
      SUBROUTINE FILEIN

      CHARACTER FILE*6
      COMMON / FILNAM / FILE

      CALL GETENV ("file",FILE)

      RETURN
      END
C
C=========================================================
C Read in Numerical Parameters of the System
C=========================================================
C
      SUBROUTINE NUMBIN

      PARAMETER (MXNOS1 = 80 000)
      PARAMETER (MXELS  = 25 000)

      CHARACTER FILE*6
      COMMON / FILNAM / FILE
      COMMON / NUMBRS / NONOS, NOELS, NDIM

      OPEN(10,FILE=FILE//'.NUM')
      READ(10,*)NONOS,NOELS,NDIM
      CLOSE(10,STATUS='KEEP')
```

```
      IF (NONOS.GT.MXNOS1) THEN
         WRITE(6,*)'Number of nodes    NONOS  = ',NONOS
         WRITE(6,*)'exceeds max. limit MXNOS1 = ',MXNOS1
         WRITE(6,*)'Recompile with increased MXNOS1 value.'
         STOP
      ENDIF

      IF (NOELS.GT.MXELS) THEN
         WRITE(6,*)'Number of elements NOELS  = ',NOELS
         WRITE(6,*)'exceeds max. limit MXELS  = ',MXELS
         WRITE(6,*)'Recompile with increased MXNOS1 value.'
         STOP
      ENDIF

      RETURN
      END
C
C==========================================================
C Read in Unaveraged Von Mises Stress of 2-D problems
C  for each node in each element & write out
C==========================================================
C
      SUBROUTINE UNST2D

      PARAMETER (MXNOS1 = 80 000)
      PARAMETER (MXELS  = 25 000)
      PARAMETER (MXEN   = 20*MXELS )

      CHARACTER FILE*6
      COMMON / FILNAM / FILE
      COMMON / CUNSTR / NU,IEL(MXEN),NN(MXEN),USTR(MXEN)
      CHARACTER*6 TEST,CHAR*1,CHAR1*1

      OPEN(8,FILE=FILE//'.SP')
      OPEN(9,FILE=FILE//'.USTRDAT')
      OPEN(10,FILE=FILE//'.USTRNUM')

C Find Beginning of Tables

      NU = 1
   10 READ(8,101)TEST
      IF (TEST.NE.'  ELEM') GO TO 10

      READ(8,101)TEST
      READ(8,101)TEST

C Read in line of Date

   30    READ(8,103,ERR=100)CHAR,IEL(NU),NN(NU),USTR(NU)

C Allow for page turning

         IF (CHAR.EQ.'1') THEN
            DO 40 J=1,7
   40          READ(8,101)CHAR1
         ENDIF
         IF (CHAR.EQ.'1') GO TO 30

C Count out Data

         IF (NN(NU) .NE. 0) WRITE(9,104)IEL(NU),NN(NU),USTR(NU)
         IF (NN(NU) .NE. 0) NU = NU+1

      GO TO 30

  100 NU=NU-1
      WRITE(6,*)'Unaverage Stresses: ',NU
      WRITE(9,*)'*'
      WRITE(10,*)NU

      CLOSE(9,STATUS='KEEP')
      CLOSE(10,STATUS='KEEP')
```

```
 101  FORMAT(A6)
 103  FORMAT(A1,2I7,7E14.4)
 104  FORMAT(3X,2I7,E14.5)

      RETURN
      END
C
C=========================================================
C Read in Unaveraged Von Mises Stress of 3-D problems
C  for each node in each element & write out
C=========================================================
C
      SUBROUTINE UNST3D

      PARAMETER (MXNOS1 = 80 000)
      PARAMETER (MXELS  = 25 000)
      PARAMETER (MXEN   = 20*MXELS )

      CHARACTER FILE*6
      COMMON / FILNAM / FILE
      COMMON / CUNSTR / NU,IEL(MXEN),NN(MXEN),USTR(MXEN)
      COMMON / NUMBRS / NONOS, NOELS, NDIM

      CHARACTER*6 TEST,CHAR*1,CHAR1*1, ELNO*12
      REAL STR(7)

      NU = 1
C Set number of nodes in each element
      IF (NDIM .EQ. 3) N=27

      OPEN(8,FILE=FILE//'.009')
      OPEN(9,FILE=FILE//'.USTRDAT')
      OPEN(10,FILE=FILE//'.USTRNUM')

C Find Beginning of Tables

  10  READ(8,901)TEST
      IF (TEST.NE.'  CASE') GO TO 10

      READ(8,901)TEST
      READ(8,901)TEST

      DO 100 I=1,NOELS

C Find Element Number

         READ(8,902,ERR=200)ELNO,IEL(NU)
         nnoels=i

C Finish if no more elements

         IF (IEL(NU) .EQ. 0 ) GO TO 200

         READ(8,901)TEST
*
*     ***  NODE RECOGNITION ROUTINE  ***
*
         DO 60 INODE=1,N

C Read in Line of Data

  30        READ(8,903,ERR=200)CHAR,L,NN(NU),(STR(J),J=1,6),USTR(NU)

C Allow for Page Turning

            IF (CHAR.EQ.'1') THEN
               DO 40 J=1,4
  40              READ(8,901)CHAR1
            ENDIF
            IF (CHAR.EQ.'1') GO TO 30

C Write out Data
```

```
           IF (NN(NU) .NE. 0) WRITE(9,904)IEL(NU),NN(NU),USTR(NU)
           IF (NN(NU) .NE. 0) NU = NU+1
           IEL(NU)=IEL(NU-1)

  60    CONTINUE

C Allow for Page Turning

        READ(8,901)TEST
        IF (TEST.EQ.'1') THEN
           DO 70 J=1,5
  70          READ(8,901)CHAR1
        ENDIF

 100  CONTINUE
*
200   WRITE(6,*)'UnStrGet: Successful Completion',nNOELS * 20
      WRITE(9,916)'*'
      WRITE(10,*)nNOELS  * 20

      CLOSE(8,STATUS='KEEP')
      CLOSE(9,STATUS='KEEP')
      CLOSE(10,STATUS='KEEP')

901   FORMAT(A6)
 902   FORMAT(A12,I6)
c902   FORMAT(A16,I8)
903   FORMAT(A1,I5,I7,7E11.2)
904   FORMAT(3X,2I7,E11.4)
916   FORMAT(A3,I6,2X,I6)
*
      RETURN
      END
C
C==========================================================
C Read in Averaged Von Mises Stress for each node (2-D)
C==========================================================
C
      SUBROUTINE AVST2D

      PARAMETER (MXNOS1 = 80 000)
      PARAMETER (MXELS  = 25 000)

      CHARACTER FILE*6
      COMMON / FILNAM / FILE
      COMMON / CAVSTR / NS(MXNOS1), ASTR(MXNOS1,3)
      COMMON / NUMBRS / NONOS, NOELS, NDIM
      CHARACTER*6 TEST,CHAR*1,CHAR1*1

C Initailize Number of Stress Enteries file

      DO 10 I=1,NONOS
  10     NS(I) = 0

C Find Beginning of Tables

 110  READ(8,201)TEST

      IF (TEST.NE.'  NODE') GO TO 110

      NONOS=0
      READ(8,201)TEST
      READ(8,201)TEST
*
*     ***  NODE RECOGNITION ROUTINE  ***
*
 140     READ(8,203,ERR=200)CHAR,I,STR

C Allow for page turning

        IF (CHAR.EQ.'1') THEN
           DO 150 J=1,7
```

```
 150          READ(8,201)CHAR1
        ENDIF
        IF (CHAR.EQ.'1') GO TO 140

C If last read was a Null value finish

        IF (I.EQ.0) GO TO 200

C Count in Stress Value for node

        NS(I)=NS(I)+1
        ASTR(I,NS(I))=STR

     GO TO 140
*
200  CONTINUE

     CLOSE(8,STATUS='KEEP')
*
201  FORMAT(A6)
203  FORMAT(A1,I5,E14.4)
204  FORMAT(3X,I7,3E14.5)
*
     RETURN
     END
C
C==========================================================
C Read in Averaged Von Mises Stress for each node (3-D)
C==========================================================
C
     SUBROUTINE AVST3D

     PARAMETER (MXNOS1 = 80 000)
     PARAMETER (MXELS  = 25 000)

     CHARACTER FILE*6
     COMMON / FILNAM / FILE
     COMMON / CAVSTR / NS(MXNOS1), ASTR(MXNOS1,3)
     COMMON / NUMBRS / NONOS, NOELS, NDIM
     CHARACTER*6 TEST,CHAR*1,CHAR1*1

     OPEN(8,FILE=FILE//'.SP')

C Initailize Number of Stress Enteries file

     DO 10 I=1,NONOS
  10    NS(I) = 0

C Find Beginning of Tables

 110 READ(8,201)TEST

     IF (TEST.NE.'  CASE') GO TO 110

     NONOS=0
     READ(8,201)TEST
*
*    ***  NODE RECOGNITION ROUTINE  ***
*
 140    READ(8,203,ERR=200)CHAR,L,I,STR

C Allow for page turning

        IF (CHAR.EQ.'1') THEN
           DO 150 J=1,5
  150         READ(8,201)CHAR1
        ENDIF
        IF (CHAR.EQ.'1') GO TO 140

C If last read was a Null value finish
        IF (I.EQ.0) GO TO 200

C Count in Stress Value for node
```

```
         NS(I)=NS(I)+1
         ASTR(I,NS(I))=STR

      GO TO 140
*
200   CONTINUE

      CLOSE(8,STATUS='KEEP')
*
201   FORMAT(A6)
203   FORMAT(A1,I4,I8,E14.4)
204   FORMAT(3X,I7,3E14.5)
*
      RETURN
      END
C
C==========================================================
C Rearrange Average Stresses to Element and Node Order
C==========================================================
C
      SUBROUTINE REAVST

      PARAMETER (MXNOS1 = 80 000)
      PARAMETER (MXELS  = 25 000)
      PARAMETER (MXEN   = 20*MXELS )

      CHARACTER FILE*6
      COMMON / FILNAM / FILE
      COMMON / NUMBRS / NONOS, NOELS, NDIM
      COMMON / CUNSTR / NU,IEL(MXEN),NN(MXEN),USTR(MXEN)
      COMMON / CAVSTR / NS(MXNOS1), ASTR(MXNOS1,3)

      OPEN(9,FILE=FILE//'.ASTRDAT')
      OPEN(10,FILE=FILE//'.ASTRNUM')

C Loop over all elements

      DO 50 I=1,NU

C Ensure no Zero Values are picked up erroneously

         DO 10 J=1,3
  10        IF (ASTR(NN(I),J).EQ.0.0) ASTR(NN(I),J) = -9E29

C Assign average stress value which is closest to the
C  unaveraged stress value of that element

C Using Unaveraged Stress at that Node for comparison

         US = USTR(I)

C Calclulate the differences between Values

         A1 =  ABS(US-ASTR(NN(I),1))
         A2 =  ABS(US-ASTR(NN(I),2))
         A3 =  ABS(US-ASTR(NN(I),3))

C Write out closest value

         IF ((A1.LE.A2).AND.(A1.LE.A3)) THEN
            RSTR = ASTR(NN(I),1)
         ELSE IF (A2.LE.A3) THEN
            RSTR = ASTR(NN(I),2)
         ELSE
            RSTR = ASTR(NN(I),3)
         ENDIF

         WRITE(9,904)IEL(I),NN(I),RSTR

  50  CONTINUE

      WRITE(6,*)'Average Stresses: ',NU
```

```
      WRITE(9,*)'*'
      WRITE(10,*)NU

904   FORMAT(3X,2I7,E11.4)
      CLOSE(9,STATUS='KEEP')
      CLOSE(10,STATUS='KEEP')

      RETURN
      END
```

D.3.3.2 Displacements

```
*****************************************************************************
*     PROGRAM TO OBTAIN DISPLACEMENTS FROM                                  *
*     PAFEC OUTPUT FILES from .007 files    File name: dispget.f            *
*****************************************************************************

      CHARACTER*4 TEST,CHAR*1,A*9,B*9,C*9, FILE*6
      INTEGERN(2)

C Find files name

      CALL GETENV ("file",FILE)
*
      OPEN(8,FILE=FILE//'.007')
      OPEN(9,FILE=FILE//'.DISP')
      OPEN(10,FILE=FILE//'.NUM')
      READ(10,*)NONOS,NOELS,NDIM
      CLOSE(10,STATUS='KEEP')
*
      DO 200 I=1,1
10    READ(8,901)TEST
      IF (TEST.EQ.' DIS')THEN
*
*     ***  NODE RECOGNITION ROUTINE  ***
*
        NONOS = 0
        IFLG=IFLG+1
50        READ(8,902)CHAR
        IF (CHAR.NE.'1') GO TO 50
55      READ(8,901)TEST
        READ(8,901)TEST
        READ(8,901)TEST
        READ(8,901)TEST
        READ(8,901)TEST
        READ(8,901)TEST
        READ(8,901)TEST
60      IF (NDIM.EQ.3) THEN
           READ(8,902,ERR=60)CHAR,N(1),A,B,C
        ELSE
           READ(8,904,ERR=60)CHAR,N(1),A,B
           C='   0.0000'
        ENDIF
70      IF (CHAR.EQ.'1')GOTO 55
        IF (N(1).EQ.0.00)GOTO 200
        IF (A.EQ.'      *  ')THEN
          A='   0.0000'
        ENDIF
        IF (B.EQ.'      *  ')THEN
          B='   0.0000'
        ENDIF
        IF (C.EQ.'      *  ')THEN
          C='   0.0000'
        ENDIF
        WRITE(9,903)N(1),A,B,C
        NONOS=NONOS+1
        GOTO 60
      ENDIF
*
      GOTO 10
```

```
*
200   CONTINUE
      WRITE(6,*)'DispGet: Successful Completion',I-1,NONOS/(I-1)
      CLOSE(8,STATUS='KEEP')
      CLOSE(9,STATUS='KEEP')
      STOP
*
901   FORMAT(A4)
902   FORMAT(A1,I5,3X,3(A9))
903   FORMAT(6X,I5,3X,3(A9))
904   FORMAT(A1,I5,6X,2(A9))
910   FORMAT(A2,I6,4X,I3,3X,I6,5X,I3,4X,I3,9(2X,I6))
911   FORMAT(2X,I6,2X,I3,2X,I6,2X,I3,9(2X,I6))
912   FORMAT(A2,39X,9(2X,I6))
913   FORMAT('*',25X,9(2X,I6))
914   FORMAT(9(2X,I6))
915   FORMAT(7(2X,I6))
916   FORMAT(A3,I6,2X,I6)
917   FORMAT(I4)
*
      END
```

D.3.4 Production of Tunnel Colour Output Using UNIRAS Software

```
***************************************************************
*       PROGRAM FOR PRODUCTION OF TUNNEL COLOUR OUTPUT        *
*       USING UNIRAS SOFTWARE                                 *
***************************************************************

      COMMON / PLOTYP / MRTE, MFLAG, DISPLC

C Read in Data

      CALL DATAIN

C Convert Data to form appropriate for plotting

      CALL CONDAT

C Open Graphics Page

      CALL OPNGRP

C Set Up Colour Scheme for plotting
C    for material property or stress

      IF ( MFLAG.LE.1 ) CALL MATCOL
      IF ( MFLAG.GE.2 ) CALL STRCOL

C Plot out Tunnel

      CALL PLOTUN

C Draw Template for tunnel output

      CALL TEMPLATE

C Close Graphics Page

      CALL RCLOSE

      STOP
      END
C
C=========================================================
C Read in Data
C=========================================================
C
      SUBROUTINE DATAIN
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```
      COMMON / PLOTYP / MRTE, MFLAG, DISPLC

C Find general file name

      CALL FILEIN

C Read in user information

      CALL USERIN

C Read in Numerical Parameters of the System

      CALL NUMBIN

C Read in Nodal Co-ordinates and Element Description

      CALL NDELIN

C Read in Displacement Values if required

       CALL DISPIN

C Read in local co-ords

      IF (2*(MFLAG/2).NE.MFLAG) CALL LOCCIN

C Convert Displacements from Local to Global

      IF (2*(MFLAG/2).NE.MFLAG) CALL DISCON

C Read in Unaveraged Stress Results if required

      IF ((MFLAG.GE.2).AND.(MFLAG.LE.3)) CALL USTRIN

C Read in Averaged Stress Results if required

      IF (MFLAG.GE.4) CALL ASTRIN

      RETURN
      END
C
C==========================================================
C Find General File Name
C==========================================================
C
      SUBROUTINE FILEIN

      CHARACTER FILE*6
      COMMON / FILNAM / FILE

      CALL GETENV ("file",FILE)

      RETURN
      END
C

C==========================================================
C Read in user information
C==========================================================
C
      SUBROUTINE USERIN

      IMPLICIT CHARACTER*50 (A)

      COMMON / TITLES / ATITLE, ASUB, ADATE, ATIME
      COMMON / PLOTYP / MRTE, MFLAG, DISPLC
      COMMON / VEWFOC / V(3), F(3)
      COMMON / LIMITS / ZCL(2)

      WRITE(6,*)'G-Route: 0) Window, 1) B/W, 2) Colour'
      READ (5,*) MRTE
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```
      WRITE(6,*)'Main Title'
      READ (5,*) ATITLE

      WRITE(6,*)'SUB Title'
      READ (5,*) ASUB

      WRITE(6,*)'Date'
      READ (5,*) ADATE

      WRITE(6,*)'Time'
      READ (5,*) ATIME

      WRITE(6,*)'Type of Plot ?'
      WRITE(6,*)'   0) Material Properties'
      WRITE(6,*)'   1) Material Properties & Displacement'
      WRITE(6,*)'   2) Unaveraged Stress Contours'
      WRITE(6,*)'   3) Unaveraged Stress Contours & Displacement'
      WRITE(6,*)'   4) Averaged Stress Contours'
      WRITE(6,*)'   5) Averaged Stress Contours & Displacement'
      READ (5,*) MFLAG

      IF (2*(MFLAG/2).NE.MFLAG) THEN
         WRITE(6,*)' Scaling Factor for Displacement ?'
         READ (5,*) DISPLC
      ELSE
         WRITE(6,*)' Scaling Factor for Displacement ?'
         READ (5,*) DISPLC
         DISPLC = 0.0
      ENDIF

      WRITE(6,*)'Position of View and Focus'
      READ (5,*) V, F

      WRITE(6,*)'Stress Limits'
      READ (5,*) ZCL

      RETURN
      END
C
C=========================================================
C Read in Numerical Parameters of the System
C=========================================================
C
      SUBROUTINE NUMBIN

      PARAMETER (MXNOS1 = 80 000)
      PARAMETER (MXELS  = 25 000)

      CHARACTER FILE*6
      COMMON / FILNAM / FILE
      COMMON / NUMBRS / NONOS, NOELS, NDIM

      OPEN(10,FILE=FILE//'.NUM')
      READ(10,*)NONOS,NOELS,NDIM
      CLOSE(10,STATUS='KEEP')

      IF (NONOS.GT.MXNOS1) THEN
         WRITE(6,*)'Number of nodes    NONOS  = ',NONOS
         WRITE(6,*)'exceeds max. limit MXNOS1 = ',MXNOS1
         WRITE(6,*)'Recompile with increased MXNOS1 value.'
         STOP
      ENDIF

      IF (NOELS.GT.MXELS) THEN
         WRITE(6,*)'Number of elements NOELS  = ',NOELS
         WRITE(6,*)'exceeds max. limit MXELS  = ',MXELS
         WRITE(6,*)'Recompile with increased MXNOS1 value.'
         STOP
      ENDIF

      RETURN
      END
C
```

```
C========================================================
C Read in Nodal Co-ordinates and Element Description
C========================================================
C
      SUBROUTINE NDELIN

      PARAMETER (MXNOS1 = 80 000)
      PARAMETER (MXELS  = 25 000)

      CHARACTER FILE*6
      COMMON / FILNAM / FILE
      COMMON / NUMBRS / NONOS, NOELS, NDIM
      COMMON / ELENOD / X(MXNOS1), Y(MXNOS1), Z(MXNOS1)
      COMMON / ELEDES / NTOPY(MXELS), E(MXELS,8), MAT(MXELS), IE(MXELS)

      OPEN(7,FILE=FILE//'.GDAT',FORM='FORMATTED')

C Read in nodal Co-ordinates

      DO 10 I=1,NONOS
        READ(7,*)N,X(N),Y(N),Z(N)
10    CONTINUE

C Read in Element description
C  and convert material property to a number 1-8

      DO 20 NM=1,NOELS
         READ(7,*)IE(NM),NTOPY(IE(NM)),
     &           (E(IE(NM),J),J=1,NTOPY(IE(NM))),MAT(IE(NM))
         IF (MAT(IE(NM)).GE.10) MAT(IE(NM)) = MAT(IE(NM)) - 10
         IF (MAT(IE(NM)).GE.10) MAT(IE(NM)) = 8
C If Triangular element repeat node number in forth position
C  for quadralateral drawing
         IF (NTOPY(IE(NM)).EQ.3) E(IE(NM),4) = E(IE(NM),2)
20    CONTINUE

      CLOSE(7, STATUS='KEEP')

      RETURN
      END
C
C========================================================
C Read in Displacement Values
C========================================================
C
      SUBROUTINE DISPIN

      PARAMETER (MXNOS1 = 80 000)

      CHARACTER FILE*6
      COMMON / FILNAM / FILE
      COMMON / NUMBRS / NONOS, NOELS, NDIM
      COMMON / DISPMT / DX(MXNOS1), DY(MXNOS1), DZ(MXNOS1)
      COMMON / PLOTYP / MRTE, MFLAG, DISPLC

      IF (2*(MFLAG/2).NE.MFLAG) THEN
         OPEN(8,FILE=FILE//'.DISP',FORM='FORMATTED')
         DO 10 I=1,NONOS
            READ(8,*)N,DX(N),DY(N),DZ(N)
   10    CONTINUE
         CLOSE(8)
      ELSE
         DO 20 I=1,NONOS
            DX(I)=0.0
            DY(I)=0.0
            DZ(I)=0.0
   20    CONTINUE
      ENDIF

      RETURN
      END
C
C========================================================
```

```
C Read in Local Co-ordinate Data
C=========================================================
C
      SUBROUTINE LOCCIN

      PARAMETER (MXNOS1 = 80 000)

C In order to produce a generalized conversion of
C  local to global co-ordinates an array of axis will
C  be produced for each node, initailized to 1.
C The axis set 1 will be set to angle zero, hence
C  represent the global co-ords.

      CHARACTER FILE*6
      COMMON / FILNAM / FILE
      COMMON / LOCORD / ANG(1000), IAXS(MXNOS1)
      CHARACTER TEST*5

      DO 10 I=1,MXNOS1
   10    IAXS(I)=1
      ANG(1)=0.0

      OPEN(8,FILE=FILE//'.DAT',FORM='FORMATTED')
   20 READ(8,901,ERR=60)TEST
      IF (TEST.EQ.' END.') GO TO 60
      IF (TEST.EQ.'END.0') GO TO 60
      IF (TEST.NE.' AXES') GO TO 20
      READ(8,901)TEST
      READ(8,901)TEST
      READ(8,901)TEST
   30    READ(8,*,ERR=40)IAX,IO,ANG(IAX)
      GO TO 30
   40 READ(8,901)TEST
      IF (TEST.NE.' LOCA') GO TO 40
      READ(8,901)TEST
   50    READ (8,*,ERR=60)INODE,IAXS(INODE)
      GO TO 50

   60 CLOSE(8)

  901 FORMAT(A5)

      RETURN
      END
C
C=========================================================
C Read in Convert Displacements from Local to Global
C=========================================================
C
      SUBROUTINE DISCON

      PARAMETER (MXNOS1 = 80 000)

C In order to produce a generalized conversion of
C  local to global co-ordinates an array of axis will
C  be produced for each node, initailized to 1.
C The axis set 1 will be set to angle zero, hence
C  represent the global co-ords.

      COMMON / NUMBRS / NONOS, NOELS, NDIM
      COMMON / DISPMT / DX(MXNOS1), DY(MXNOS1), DZ(MXNOS1)
      COMMON / PLOTYP / MRTE, MFLAG, DISPLC
      COMMON / LOCORD / ANG(1000), IAXS(MXNOS1)

      RAD=ACOS(0.0)/90.0
        NONOS=1555
      DO 10 I=1,NONOS
         ANGLE = ANG(IAXS(I))*RAD
         DXT = DX(I)*COS(ANGLE) - DY(I)*SIN(ANGLE)
         DYT = DX(I)*SIN(ANGLE) + DY(I)*COS(ANGLE)
         DX(I) = DXT
         DY(I) = DYT
         if (IAXS(I).EQ.4) write(6,*)ANGLE/RAD,DX(I),DY(I)
```

```
          write(6,*)I
 10   CONTINUE

      RETURN
      END
C
C======================================================
C Read in Unaveraged Stress Results
C======================================================
C
      SUBROUTINE USTRIN

      PARAMETER (MXNOS1 = 80 000)
      PARAMETER (MXELS  = 25 000)

      CHARACTER FILE*6
      COMMON / FILNAM / FILE
      COMMON / STRESS / USTR(MXELS,8), ASTR(MXELS,8)
      COMMON / NUMBRS / NONOS, NOELS, NDIM
      COMMON / ELEDES / NTOPY(MXELS), E(MXELS,8), MAT(MXELS), IE(MXELS)
      REAL STRNOD(MXNOS1)

      IF (NDIM.EQ.3) NN = 20
      IF (NDIM.EQ.2) NN =  8

C Read in Stress Values
      OPEN(10,FILE=FILE//'.USTRNUM',FORM='FORMATTED')
      READ(10,*) NSTRSEL
      CLOSE(10)

      OPEN(9,FILE=FILE//'.USTRDAT',FORM='FORMATTED')
      write (6,*)NSTRSEL/NN
      DO 20 I=1,NSTRSEL/NN
         DO 5 L=1,NN
            READ(9,*)IEL,NOD,STRNOD(NOD)
  5         STRNOD(NOD) = STRNOD(NOD) / 1E5
         DO 10 J=1,NTOPY(IEL)
            USTR(IEL,J)=STRNOD(E(IEL,J))
 10      CONTINUE
 20   CONTINUE
      CLOSE(9)

      RETURN
      END
C
C======================================================
C Read in Averaged Stress Results
C======================================================
C
      SUBROUTINE ASTRIN

      PARAMETER (MXNOS1 = 80 000)
      PARAMETER (MXELS  = 25 000)

      CHARACTER FILE*6
      COMMON / FILNAM / FILE
      COMMON / STRESS / USTR(MXELS,8), ASTR(MXELS,8)
      COMMON / NUMBRS / NONOS, NOELS, NDIM
      COMMON / ELEDES / NTOPY(MXELS), E(MXELS,8), MAT(MXELS), IE(MXELS)
      REAL STRNOD(MXNOS1)

      IF (NDIM.EQ.3) NN = 20
      IF (NDIM.EQ.2) NN =  8

C Read in Stress Values
      OPEN(10,FILE=FILE//'.ASTRNUM',FORM='FORMATTED')
      READ(10,*) NSTRSNO
      CLOSE(10)

      OPEN(9,FILE=FILE//'.ASTRDAT',FORM='FORMATTED')
      DO 20 I=1,NSTRSNO/NN
         DO 5 L=1,NN
            READ(9,*)IEL,NOD,STRNOD(NOD)
```

```
   5         STRNOD(NOD) = STRNOD(NOD) / 1E5
          DO 10 J=1,NTOPY(IEL)
             ASTR(IEL,J)=STRNOD(E(IEL,J))
             IF (ASTR(IEL,J).EQ.0.0)ASTR(IEL,J)=-9E29
  10      CONTINUE
  20  CONTINUE
      CLOSE(9)

      RETURN
      END
C
C==========================================================
C Convert Data to form appropriate for plotting
C==========================================================
C
      SUBROUTINE CONDAT

      PARAMETER (MXNOS1 = 80 000)
      PARAMETER (MXELS  = 25 000)
      PARAMETER (MXNOS2 = 24 * MXELS)

      COMMON / NUMBRS / NONOS, NOELS, NDIM
      COMMON / ELENOD / X(MXNOS1), Y(MXNOS1), Z(MXNOS1)
      COMMON / DISPMT / DX(MXNOS1), DY(MXNOS1), DZ(MXNOS1)
      COMMON / STRESS / USTR(MXELS,8), ASTR(MXELS,8)
      COMMON / ELEDES / NTOPY(MXELS), E(MXELS,8), MAT(MXELS), IE(MXELS)
      COMMON / FACNOD / R(MXNOS2), S(MXNOS2), T(MXNOS2)
      COMMON / COLNUM / CLR(MXNOS2), NP
      COMMON / PLOTYP / MRTE, MFLAG, DISPLC

C Data for the conversion from Element to Face Topology

      INTEGER L (24)

      DATA L   / 1,2,4,3, 5,6,8,7,
     &           1,2,6,5, 3,4,8,7,
     &           2,4,8,6, 1,3,7,5 /

C Arbitary 1/2 thickness of beam element

      BEAM = 0.1

C Zero node list counter

      NP = 0

C Loop over all elements

      DO 50 KE=1,NOELS

         K=IE(KE)

C Set number of faces required to describe element;
C  if 2-D System or Beam element, one face,
C  else six faces.

         IF ((NDIM.EQ.2).OR.(NTOPY(K).EQ.2)) THEN
            MFACE = 1
         ELSE
            MFACE = 6
         ENDIF

C Exclude AIR elements from plot

         IF (MAT(K).EQ.9) MFACE = 0

C If Beam element represent as flat tile shifted out
C   from rock.

         IF (MAT(K).NE.9) THEN

         IF (NTOPY(K).EQ.2) THEN
```

```
C Find Angle of Anchorage to the vertical

            PHI=ATAN( ( X(E(K,2))-X(E(K,1)) ) /
     &                ( Y(E(K,2))-Y(E(K,1)) )   )

C Assign nodal values shifted either side of each end
C  of beam and shifted out from rock face.

            DO 20 M=1,2
               DO 10 I=0,1
                  J = I+2*M-1+NP
                  R(J)=X(E(K,L(M)))+(-1)**(I+M)*BEAM*COS(-PHI)
     &                 +DISPLC*DX(E(K,L(M)))
                  S(J)=Y(E(K,L(M)))+(-1)**(I+M)*BEAM*SIN(-PHI)
     &                 +DISPLC*DY(E(K,L(M)))
                  IF ( Z(E(K,L(M))).LE.0.0 ) THEN
                     T(J)=Z(E(K,L(M)))-1*BEAM
     &                 +DISPLC*DZ(E(K,L(M)))
                  ELSE
                     T(J)=Z(E(K,L(M)))+1*BEAM
     &                 +DISPLC*DZ(E(K,L(M)))
                  ENDIF

 10            CONTINUE
 20         CONTINUE

         ELSE

C Else assign corner nodes of face(s)

            DO 30 M=1,4*MFACE
               R(M+NP)=X(E(K,L(M)))+DISPLC*DX(E(K,L(M)))
               S(M+NP)=Y(E(K,L(M)))+DISPLC*DY(E(K,L(M)))
               T(M+NP)=Z(E(K,L(M)))+DISPLC*DZ(E(K,L(M)))
 30         CONTINUE

         ENDIF

C Assign Mat. Prop. of Stress value to Colour array

         DO 40 M=1,4*MFACE
            IF (MFLAG.LE.1) THEN
C Assign Material Property of Element
               CLR(M+NP) = FLOAT(MAT(K))
            ELSE IF (MFLAG.LE.3) THEN
C Assign Unaveraged Stress of node in element
               CLR(M+NP) = USTR(K,L(M))
               IF (NTOPY(K).EQ.2) CLR(M+NP) = 0.0
            ELSE
C Assign Averaged Stress of node in element
               CLR(M+NP) = ASTR(K,L(M))
               IF (NTOPY(K).EQ.2) CLR(M+NP) = 0.0
            ENDIF
 40      CONTINUE
         ENDIF

C Count number of nodes added to list

         NP = NP + 4*MFACE

 50   CONTINUE

      RETURN
      END
C
C=========================================================
C Set Up Graphics Page
C=========================================================
C
      SUBROUTINE OPNGRP

      COMMON / PPRSIZ / XSIZ, YSIZ, SF
      COMMON / PLOTYP / MRTE, MFLAG, DISPLC
```

```
      COMMON / VEWFOC / V(3), F(3)

C Select windows or postscript Driver

      IF (MRTE.EQ.0) CALL GROUTE('select mx11; exit')
      IF (MRTE.EQ.1) CALL GROUTE('select mpost; exit')
      IF (MRTE.EQ.2) CALL GROUTE('select hcposta4; exit')

C Open Page

      CALL ROPEN

C Orientation Landscape

      CALL RORIEN(1)

C Find size of paper, open port within that

      CALL GRPSIZ(XSIZ,YSIZ)
      IF (XSIZ.LT.(1.25*YSIZ))THEN
        YSIZ=0.8*XSIZ
        SF=XSIZ/250
      ELSE
        XSIZ=1.25*YSIZ
        SF=YSIZ/200
      ENDIF

      CALL GVPORT(2.0*SF,2.0*SF,0.78*XSIZ,0.88*YSIZ)
      CALL GCLIP

C Set axis, x-horizontal, y-vertical, z-perpendicular

      CALL GVPROJ(1)

C Scale size of port

      CALL GLIMIT(-150.0,150.0,-150.0,150.0,-150.0,150.0)

C Set position of veiwer and focus

      CALL GEYE(V(1),V(2),V(3))
      CALL GSCALE
      CALL GFOCUS(F(1),F(2),F(3))
      CALL GDIST(1.0)

      RETURN
      END
C
C============================================================
C Set Up Colour Scheme for plotting Material Properties
C============================================================
C
      SUBROUTINE MATCOL

C Material Colour Table

      REAL COL(4,16), ZCL(7)

C Brown, Purple, Yellow, Red, Green, Lt. Grey, Dk. Grey, Blue

      DATA COL /  1.0,      180., 50., 100.,
     &            1.0e-6,   180., 50., 100.,
     &            1.0,      120., 50.,  25.,
     &            1.0e-6,   120., 50.,  25.,
     &            1.0,      120., 50., 100.,
     &            1.0e-6,   120., 50., 100.,
     &            1.0,       50., 50., 100.,
     &            1.0e-6,    50., 50., 100.,
     &            1.0,      240., 50., 100.,
     &            1.0e-6,   240., 50., 100.,
     &            1.0,        0., 66.,   0.,
     &            1.0e-6,     0., 66.,   0.,
     &            1.0,        0., 33.,   0.,
```

```
     &           1.0e-6,     0., 33.,   0.,
     &           1.0,        0., 50., 100.,
     &           1.0e-6,     0., 50., 100.  /

C Define User Pallette number 7 with 16 fixed points

      CALL RCSDEF (7, COL, 16, 1, 100.0)

C Load Palette

      CALL RSHADE (7,0)

C Define Contours at 7 positions  1.5 to 7.5 step 1

      DO 20 I=1,7
         ZCL(I) = 0.5 + float(I)
   20 CONTINUE

      CALL RCLASS (ZCL,7,0)

      RETURN
      END
C
C============================================================
C Set Up Colour Scheme for plotting Von Mises Stress
C============================================================
C
      SUBROUTINE STRCOL

      COMMON / LIMITS / ZCL(2)

C Material Colour Table

      REAL COL(4,6)

C Define a spectrum of colours

      DATA COL /  20.0,   0.0,   0.0,  100.0,
     &            25.0,   0.0, 100.0,  100.0,
     &            10.0,   0.0, 100.0,    0.0,
     &            15.0,  75.0, 100.0,    0.0,
     &            30.0, 100.0, 100.0,    0.0,
     &             0.0, 100.0,   0.0,    0.0   /

C Define User Pallette number 7 with 6 fixed points

      CALL RCSDEF (7, COL, 6, 2, 100.0)

C Load Palette

      CALL RSHADE (7,0)

C Set 16 levels of equal divisions

      CALL RCLASS (ZCL,16,3)

      RETURN
      END
C
C============================================================
C Plot Tunnel
C============================================================
C
      SUBROUTINE PLOTUN

      PARAMETER (MXNOS1 = 80 000)
      PARAMETER (MXELS = 25 000)
      PARAMETER (MXNOS2 = 24 * MXELS)

      COMMON / FACNOD / R(MXNOS2), S(MXNOS2), T(MXNOS2)
      COMMON / COLNUM / CLR(MXNOS2), NP

C Create Segment
```

```
      CALL GSEGCR(1)

C Draw anti-background frame about faces

      CALL GSURFR(1)

C Draw Faces

      CALL CSRF4S(R,S,T,CLR,-NP,1)

C Close Segment

      CALL GSEGCL(1)

      RETURN
      END
C
C============================================================
C Plot Tunnel 2 (Using Z-Buffer)
C============================================================
C
      SUBROUTINE PLOTU2

      PARAMETER (MXNOS1 = 80 000)
      PARAMETER (MXELS = 25 000)
      PARAMETER (MXNOS2 = 24 * MXELS)

      COMMON / FACNOD / R(MXNOS2), S(MXNOS2), T(MXNOS2)
      COMMON / COLNUM / CLR(MXNOS2), NP

C Create Segment

      CALL GSEGCR(1)

C Draw anti-background frame about faces

      CALL GSURFR(1)

C Open Z-Buffer

      CALL CZBUF('OPEN')

C Draw Faces

      DO 10 I=1,NP-3,4
10      CALL CSURF(R(I),S(I),T(I),CLR(I),-NP)

C Close Z-Buffer

      CALL CZBUF('CLOSE')

C Close Segment
      CALL GSEGCL(1)

      RETURN
      END
C
C========================================================
C SUBROUTINE FOR CREATING TEMPLATE FOR PAFEC/UNIRAS OUTPUT
C========================================================
C
      SUBROUTINE TEMPLATE

      IMPLICIT CHARACTER*50 (A)
      COMMON / TITLES / ATITLE, ASUB, ADATE, ATIME
      COMMON / PPRSIZ / XSIZ, YSIZ, SF
      COMMON / PLOTYP / MRTE, MFLAG, DISPLC
      COMMON / VEWFOC / V(3), F(3)

      INTEGER NCHAR(3)
      CHARACTER*5 CSTXT(3)
      CHARACTER*25 AMAT(8)
```

```
      REAL XBOX(5),YBOX(5),X(4),Y(4),Z(4)
      REAL XB(12),YB(12),ZB(12),BZINT(24)
      DATA XBOX/0.0,1250.0,1250.0,0.0,0.0/
      DATA YBOX/0.0,0.0,1000.0,1000.0,0.0/
      DATA X/0.0,2.0,0.0,0.0/
      DATA Y/0.0,0.0,2.0,0.0/
      DATA Z/0.0,0.0,0.0,2.0/
c      DATAXB/0,1,1,0,0,1,1,0,1,1,1,1,0,0,0,0,0,1,1,0,0,1,1,0/
c      DATAYB/1,1,1,1,0,0,0,0,0,1,1,0,0,1,1,0,0,0,1,1,0,0,1,1/
c      DATAZB/0,0,1,1,0,0,1,1,0,0,1,1,0,0,1,1,1,1,1,1,0,0,0,0/
      DATAXB/0,1,1,0,0,0,0,0,0,1,1,0/
      DATAYB/0,0,0,0,0,1,1,0,0,0,1,1/
      DATAZB/0,0,1,1,0,0,1,1,0,0,0,0/
      DATA NCHAR/5,5,5/
      DATA AMAT / 'Neogene Cover',
     &            'Sand/Silt/Clay-stone',
     &            'Quartzite',
     &            'Arkose',
     &            'Volcanic Dyke Rock',
     &            'Outer Shotcrete Lining',
     &            'Inner Shotcrete Lining',
     &            'Mild Steel Supports'     /

      CSTXT(1)='BELOW'
      CSTXT(2)='ABOVE'
      CSTXT(3)='UNDEF'
      CALL RTXESC(1,'\')
      CALL RTXESC(2,'~')

      VX=(V(1)-F(1))*6
      VY=(V(2)-F(2))*6
      VZ=(V(3)-F(3))*6
      FX=0.0
      FY=0.0
      FZ=0.0

      CALL GSEGCR(50)

      CALL GVPORT(.0,.0,XSIZ,YSIZ)
      CALL GVPROJ(1)
*
      CALL GLIMIT(0.0,1250.0,0.0,1000.0,0.0,0.0)
      CALL GSCALE
*
      CALL GWICOL(1.0*SF,1)
      CALL GVECT(XBOX,YBOX,5)
      CALL GWICOL(0.5*SF,1)
      CALL GVECT(1000.0,0.0,0)
      CALL GVECT(1000.0,1000.0,1)
      CALL GVECT(0.0,900.0,0)
      CALL GVECT(1000.0,900.0,1)
      CALL GVECT(1000.0,875.0,0)
      CALL GVECT(1250.0,875.0,1)
      CALL GVECT(1000.0,330.0,0)
      CALL GVECT(1250.0,330.0,1)
      CALL GVECT(1000.0,150.0,0)
      CALL GVECT(1250.0,150.0,1)
      CALL GVECT(350.0,900.0,0)
      CALL GVECT(350.0,1000.0,1)
*
      CALL RTXFON(SIMP,1)
      CALL RTXHEI(3.0*SF)
      CALL RTXBOL(0.15)
*
      CALL RTX(-1,'     PAFEC-FE     ',20.0,940.0)
      CALL RTX(-1,ATITLE,360.0,960.0)
      CALL RTX(-1,ASUB,360.0,920.0)
      CALL RTXHEI(3.0*SF)
      CALL RTX(-1,'PLOT TYPE:',1025.0,970.0)
      CALL RTXHEI(2.0*SF)
      IF (MFLAG.LE.1) A1='Material Properties'
      IF (MFLAG.GE.2) A1='3D Von Mises Stress'
      IF (MFLAG.LE.1) A2='                   '
```

```
      IF (MFLAG.GE.2) A2='(unaveraged)'
      IF (MFLAG.GE.4) A2='(averaged)'
      CALL RTXJUS(1,1)
      CALL RTX(-2,A1,1125.0,935.0)
      CALL RTX(-2,A2,1125.0,920.0)
      CALL RTX(-1,'Displacement Factor: ',1100.0,895.0)
      CALL RTXNC(DISPLC,3)
      CALL RTXJUS(0,1)
*
      CALL RTXHEI(3.5*SF)
      CALL RTXBOL(0.15)
      CALL RTX(-1,'View:',1010.0,300.0)
      CALL RTXHEI(1.5*SF)
      CALL RTXBOL(0.2)
      CALL RTX(-1,'X: ',1005.0,160.0)
      CALL RTXNC(V(1),3)
      CALL RTXC(-1,'  Y: ')
      CALL RTXNC(V(2),3)
      CALL RTXC(-1,'  Z: ')
      CALL RTXNC(V(3),3)
*
      CALL RTXHEI(3.0*SF)
      CALL RTXJUS(1,1)
      CALL RTX(-1,'Produced by:',1125.0,125.0)

      CALL RTXHEI(3.25*SF)
      CALL RTXBOL(0.25)
      CALL RTX(-1,'DES3HB ',1125.0,90.0)
      CALL RTXBOL(0.2)
      CALL RTX(-2,ADATE,1125.0,50.0)
      CALL RTX(-2,ATIME,1125.0,20.0)
      CALL RTXHEI(1.5*SF)
      CALL RTX(-1,'LJP',1235.0,20.0)
      CALL RTX(-1,'STB',1235.0,10.0)
*
*     COLOUR LEGEND DEFINITION
*
C Material Properties Legend

      IF (MFLAG.LE.1) THEN

       CALL RTXHEI(3.0*SF)
       CALL RTXBOL(0.15)
       CALL RTX(-1,'Material Properties:',1125.0,835.0)
       CALL RTXCOL(0,0)
       CALL GCLOPT(NCHAR,CSTXT,5*SF,0,0.0,-1)
       CALL GCOSCL(1015.0,540.0)
       CALL RTXCOL(1,1)
       CALL RTXJUS(0,0)
       CALL RTXHEI(2.0*SF)
       DO 10 I=1,8
   10  CALL RTX(-2,AMAT(9-I),1070.0,540.0+6.25*(I-1)*5*SF)
*
      ELSE

C Von Mises Stress

       CALL RTXHEI(3.0*SF)
       CALL RTXBOL(0.15)
       CALL RTX(-1,'Legend',1060.0,845.0)
       CALL RTXPAT(0)
       CALL RTXHEI(2.5*SF)
       CALL RTXANG(90.0)
       CALL RTX(-1,'    Stress - Von Mises x10~5 Nm~-~2 ',1100.0,575.0)
       CALL RTXANG(0)
       CALL RTXPAT(0)
*      CALL RTX(-1,'~oC',1100.0,465.0)
       CALL GCLOPT(NCHAR,CSTXT,4.5*SF,1,0.0,1)
       CALL GCOSCL(1015.0,350.0)

      ENDIF
*
C Draw Progection Box
```

```
      CALL RTXHEI(3.0*SF)
      CALL RTXBOL(0.2)

      CALL GVPORT(0.846*XSIZ,0.165*YSIZ,0.108*XSIZ,0.135*YSIZ)
      CALL GVPROJ(1)
      CALL GLIMIT(-2.0,2.0,-2.0,2.0,-2.0,2.0)
      CALL GCLIP
      VMR=(((VX**2)+(VY**2)+(VZ**2))**0.5)*0.65
      CALL GEYE(VX/VMR,VY/VMR,VZ/VMR)
      CALL GFOCUS(FX,FY,FZ)
      CALL GSCAMM
c      CALL GDIST(VMR)
      CALL GTRANS(X,Y,Z,4)
      CALL RTXBOL(0.25)
      CALL RTXHEI(2.1*SF)
      C=X(1)+((X(2)-X(1))*1.2)
      B=Y(1)+((Y(2)-Y(1))*1.2)
      CALL RTX(-1,'X',C,B)
      C=X(1)+((X(3)-X(1))*1.2)
      B=Y(1)+((Y(3)-Y(1))*1.2)
      CALL RTX(-1,'Y',C,B)
      C=X(1)+((X(4)-X(1))*1.2)
      B=Y(1)+((Y(4)-Y(1))*1.2)
      CALL RTX(-1,'Z',C,B)
      CALL GSURFR(2)
      CALL CCONST(0,24,BZINT)
      CALL GAROPT(3.0,3.0)
      CALL CSRF4S(XB,YB,ZB,BZINT,-12)
      CALL GARROW(X(2),Y(2),1,X(1),Y(1),0,2,2,0.1*SF)
      CALL GARROW(X(3),Y(3),1,X(1),Y(1),0,2,2,0.1*SF)
      CALL GARROW(X(4),Y(4),1,X(1),Y(1),0,2,2,0.1*SF)
      CALL CSRF4S(XB,YB,ZB,BZINT,-12)
*
      CALL GSEGCL(50)

      RETURN
      END
```

APPENDIX E

SHELL NODE CO-ORDINATE CALCULATIONS

E.1 Introduction

The tunnel height determine the tunnel geometry according to five centres. Centre one (C1) radius is equal to the tunnel height as shown in Fig. E.1. The other four centres are calculated in terms of tunnel height as follows.

$$C_1 \rightarrow \beta_4 = 37^\circ \quad r_1 = h = 7.90m \tag{5.1a}$$

$$C_2 \rightarrow \beta_8 = 47^\circ \quad r_2 = h \; x \, \frac{r_2 = 5.90}{7.90} \tag{5.1b}$$

$$C_3 \rightarrow \beta_{10} = 25^\circ \quad r_3 = h \; x \, \frac{r_3 = 7.80}{7.90} \tag{5.1c}$$

$$C_4 \rightarrow \beta_{14} = 60^\circ \quad r_4 = h \; x \, \frac{r_4 = 0.95}{7.90} \tag{5.1d}$$

$$C_5 \rightarrow \beta_{22} = 11^\circ \quad r_5 = h \; x \, \frac{r_5 = 34.12}{7.90} \tag{5.1e}$$

IPSH (Shell pafblock counter)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
KPSH (Number of pafblock in each zone)	**2**	**3**	**2**	**1+NMIDA**	**2+NMIDC**	**1+NMIDC**	**2**	**4**
Cumulative number of pafblock	**2**	**5**	**7**	**8+NMIDA**	**9+NMIDA +NMIDC**	**11+K(0)**	**13+K(0)**	**17+K(0)**
Zones	**1A**	**1B**	**2A**	**2B**	**3A**	**3B**	**4**	**5**

Node number
KPSH(1) = 2
KPSH(2) = KPSH(1)+3
KPSH(3) = KPSH(2)+2
KPSH(4) = KPSH(3)+1+NMIDA
KPSH(5) = KPSH(4)+1+NMIDC
KPSH(6) = KPSH(5)+2
KPSH(7) = KPSH(6)+2
KPSH(8) = KPSH(7)+4

Table E.1 Shell pafblock counters and number of the pafblock in each region

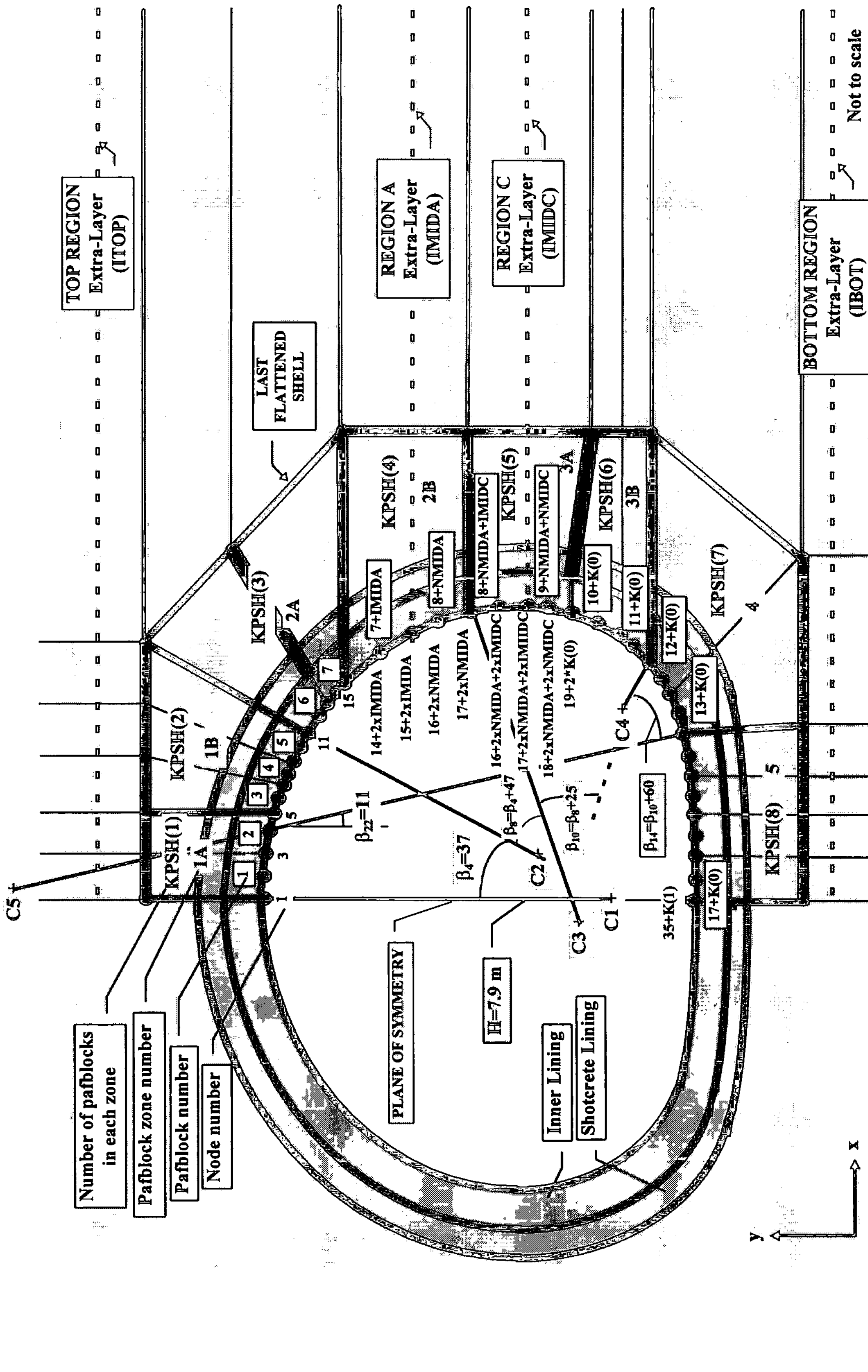

Fig. E.1 Angles of the tunnel geometry, node numbers and the number of pafblocks in distinct zones of the tunnel

E.2 Shell Node Co-ordinate Calculations for Zone 1A

Vertical boundaries of corner nodes 1, 3 and 5 are defined by excavation boundaries in zone '1A' for shell node co-ordinates calculations of centre 1. Midside nodes are midway between corner nodes in x-direction. Y-values are found using Pythagoras' theorem for each node in zone '1A'. The accumulative distance from first shell is set according to thickness of inner and shotcrete linings. Codes for zone 1A are as shown in Fig. E.2

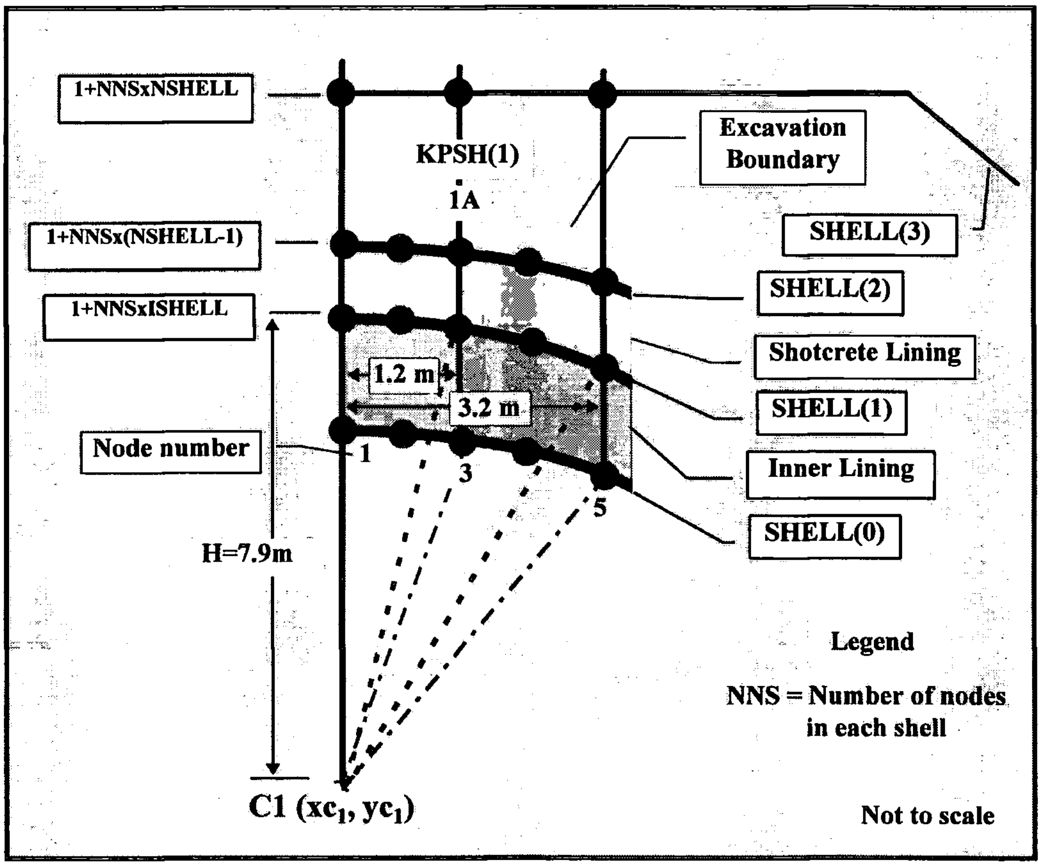

Fig. E.2 Shell node co-ordinates for zone 1A

```
C ==================================================================
C SUBROUTINE SC1AND FOR SHELL NODE COORDINATES CALCULATIONS
C FOR CENTRE 1
C ZONE 1A : IPSH=1  VERTICAL BOUNDARIES
C ==================================================================

  SUBROUTINE SC1AND (ISHELL)

  IMPLICIT DOUBLE PRECISION  (A-H,O-Z)

  PARAMETER(NNODES=5000)
  COMMON / CNODES / X(NNODES), Y(NNODES)
  COMMON / CSHPAR / R,DLAMDA(8),PHI(20),PSI(20)
  COMMON / CTUNIN / H, HOVER, HUNDER
  COMMON / CKEYPR /K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF
  COMMON / CSHLPR / NSHELL, HIN(5),SUMR
  COMMON / COUNT  / KPSH(8), NPSIDE, NCOL, NROW

C CORNER NODES DEFINED BY EXCAVATION BOUNDARIES
  X(1+NNS*ISHELL)=0D0
  X(3+NNS*ISHELL)=(1.2D0/7.9D0)*H
  X(5+NNS*ISHELL)=(3.2D0/7.9D0)*H

C MID-SIDE NODES MID-WAY BETWEEN CORNER NODES IN X-DIRECTION
  DO 10 I=1,KPSH(1)
10   X(I*2+NNS*ISHELL) = (X(I*2-1)+X(I*2+1))/2D0

C Y-VALUES FOUND USING PYTHAGORUS, SAVE LAST SHELL WHICH IS AT
C CONSTANT HEIGHT
  DO 20 I=1,2*KPSH(1)+1
    IF (ISHELL.EQ.NSHELL) THEN
      Y(I+NNS*ISHELL)=H+R
    ELSE
      Y(I+NNS*ISHELL)=SQRT((H+R)**2-(X(I))**2)
    ENDIF
20 CONTINUE

  RETURN
  END
```

Fig. E.3 Shell node co-ordinate calculations for zone 1A

E.3 Shell Node Co-ordinate Calculations for Zone 1B

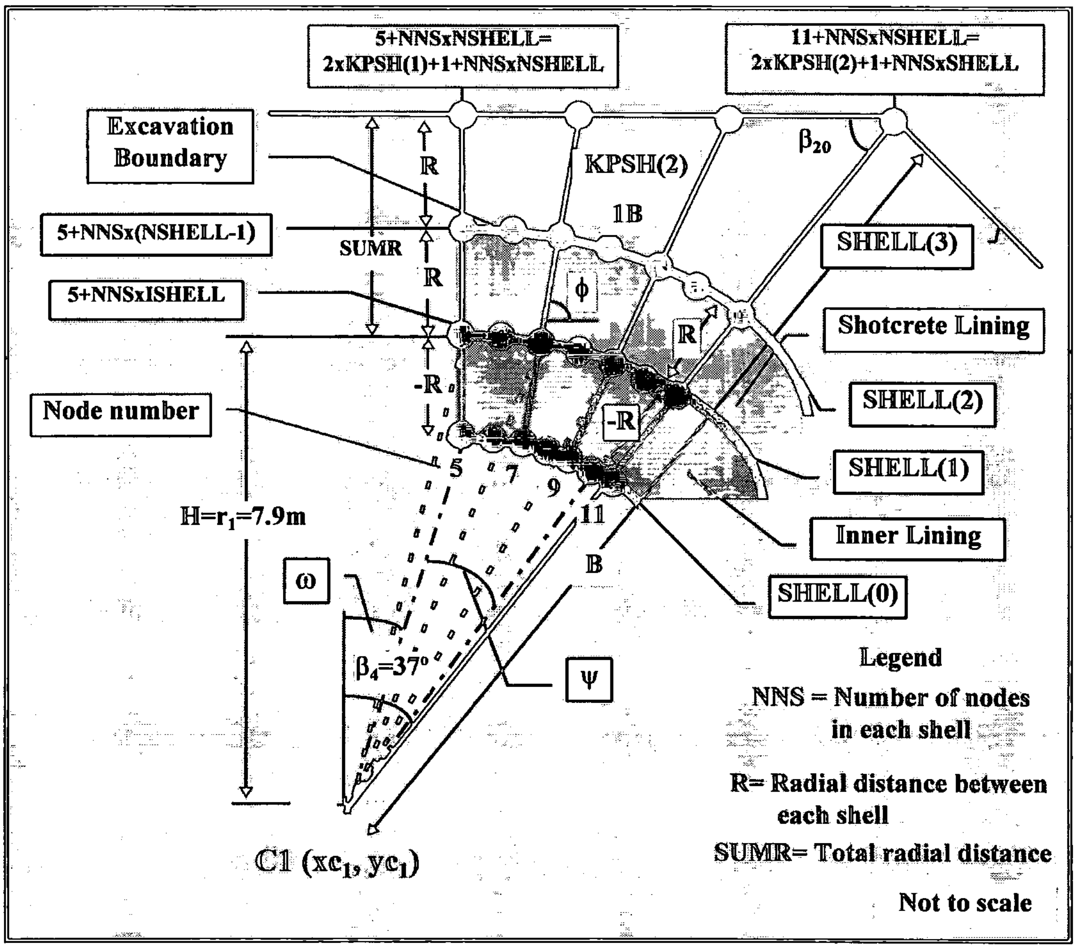

Fig. E.4 Shell node co-ordinates for zone 1B

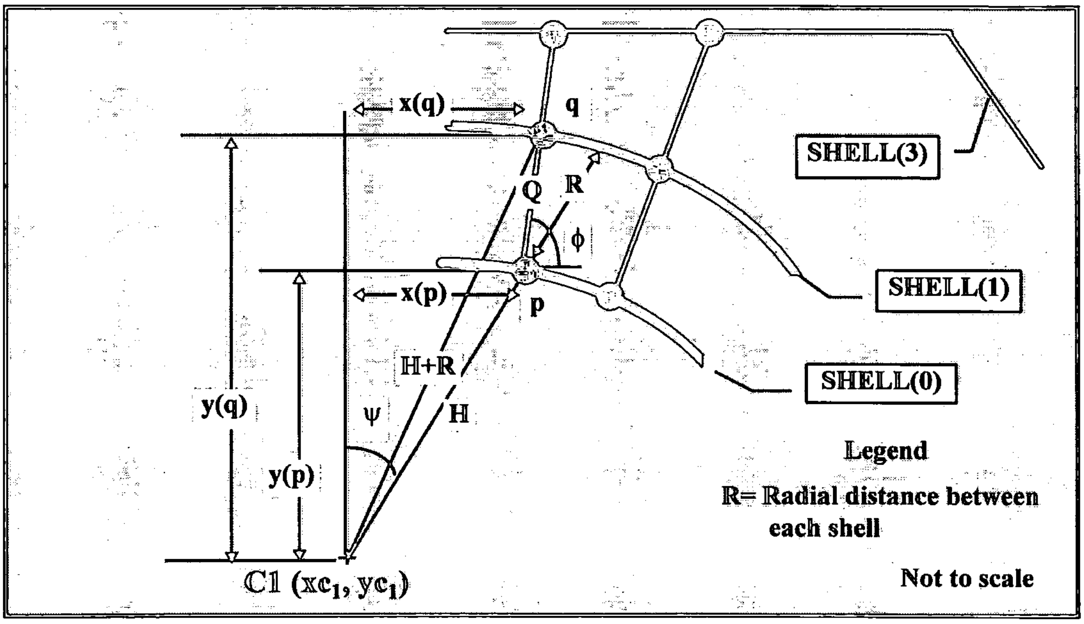

Fig. E.5 Shell node co-ordinate calculations using first and last flattened shells

Node p co-ordinates, x(p) and y(p), are known. Node q has two properties

i) It lies on an arc with centre and radius is 'H+R.'

$$x^2(q) + y^2(q) = (H+R)^2 \quad (1)$$

$$x^2(p) + y^2(p) = H^2 \quad (2)$$

ii) It lies on a straight line which passes through node p and is at an angle ϕ to the horizontal.

$$x(q) = x(p) + Q\,Cos\phi \quad (3)$$

$$y(q) = y(p) + Q\,Sin\phi \quad (4)$$

From equation (1)

$$\left(x(p) + Q\,Cos\phi\right)^2 + \left(y(p) + Q\,Sin\phi\right)^2 = (H+R)^2 \quad (5a)$$

$$x^2(p) + Q^2Cos^2\phi + 2x(p)QCos\phi + y^2(p) + Q^2Sin^2\phi + 2y(p)QSin\phi = (H+R) \quad (5b)$$

$$Q^2\left(Cos\phi^2 + Sin\phi^2\right) + 2Q\left(x(p)Cos\phi + y(p)Sin\phi\right) + x^2(p) + y^2(p) - (H+R) = 0 \quad (5c)$$

$$Q^2 + 2Q\left(x(p)\,Cos\phi + y(p)\,Sin\phi\right) + H^2 - (H+R)^2 = 0 \quad (5d)$$

$$Q^2 + 2Q\left(x(p)\,Cos\phi + y(p)\,Sin\phi\right) + H^2 - (H^2 + R^2 + H + R) = 0 \quad (5e)$$

$$Q^2 + 2Q\left(x(p)\,Cos\phi + y(p)\,Sin\phi\right) - (2HR + R^2) = 0 \quad (5f)$$

$$aQ^2 + bQ^2 + c = 0 \quad (5g)$$

$$a = 1 \quad (5h)$$

$$b = 2\left(x(p)\,Cos\phi + y(q)\,Sin\phi\right) \quad (5k)$$

$$c = -(2HR + R^2) \quad (5m)$$

Equation (5g) is a quadratic equation which contains the square of the unknown 'Q' quantity and constants a, b and c. It can be solved using the formula for the general quadratic equation. Q is calculated in terms of R which is cumulative shell thickness so Q is also calculated cumulatively. Node q co-ordinates then calculated using equations (3) and (4).

```
C ==========================================================================
C SUBROUTINE SC1BND FOR SHELL NODE COORDINATES CALCULATIONS
C FOR CENTRE 1
C ZONE 1B: IPSH=2 TRANSITION BETWEEN VERTICAL BOUNDARY AND
C RADIAL BOUNDARY
C ==========================================================================

   SUBROUTINE SC1BND (ISHELL)

   IMPLICIT DOUBLE PRECISION  (A-H,O-Z)

   PARAMETER(NNODES=5000)
   COMMON / CNODES / X(NNODES), Y(NNODES)
   COMMON / CSHPAR / R,DLAMDA(8),PHI(20),PSI(20)
   COMMON / CANGLE / DRAD, BETA(22)
   COMMON / CTUNIN / H, HOVER, HUNDER
   COMMON / CKEYPR /K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF
   COMMON / CHFXPR / HFX(17)
   COMMON / CSHLPR / NSHELL, HIN(5),SUMR
   COMMON / COUNT  / KPSH(8), NPSIDE, NCOL, NROW

C CALCULATE POSITION OF RADIAL BOUNDARY FOR ALL BUT LAST SHELL

   IF (ISHELL.LE.(NSHELL-1)) THEN
    X(2*KPSH(2)+1+NNS*ISHELL)=(H+R)*DSIN(BETA(4))
    Y(2*KPSH(2)+1+NNS*ISHELL)=(H+R)*DCOS(BETA(4))
   ENDIF

C FIRST SHELL (ISHELL=0) BOUNDARY COORDINATES

   IF (ISHELL.EQ.0) THEN

C FIRST SHELL (ISHELL=0) CORDINATES
C CALCULATE POSITION OF RADIAL BOUNDARY
     X(2*KPSH(2)+1)=(H+R)*DSIN(BETA(4))
     Y(2*KPSH(2)+1)=(H+R)*DCOS(BETA(4))
     B=(H+SUMR)/DSIN(BETA(20))
     X(2*KPSH(2)+1+NNS*NSHELL)=B*DSIN(BETA(4))
     Y(2*KPSH(2)+1+NNS*NSHELL)=B*DCOS(BETA(4))

C CALCULATE X-POSITION OF VERTICAL BOUNDARY
C FOR LAST FLATTENED SHELL
     X(2*KPSH(1)+1+NNS*NSHELL)=(3.2D0/7.9D0)*H

    ENDIF
```

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```
C CALCULATION OF NODES BETWEEN BOUNDARIES
      DO 120 I=2*KPSH(1)+2,2*KPSH(2)
          IF (ISHELL.EQ.0) THEN
C FOR FIRST SHELL:
C  THE NODES LIE EQUALLY SPACED ON THE ARC
C  FROM NODE 2*KPSH(1)+1 TO NODE 2*KPSH(2)+1.
C  HENCE THE ARC ANGLE PSI (ANGLE FROM THE VERTICAL) OF THESE
C NODES IS IN EQUAL STEPS.
      OMEGA=DASIN(X(2*KPSH(1)+1)/(H+R))
      PSI(I-(2*KPSH(1)+1))=
   &      OMEGA+(BETA(4)-OMEGA)*(I-(2*KPSH(1)+1))
   &      /(2D0*(KPSH(2)-KPSH(1)))

C CALCULATE THE POSITION OF THE NODES ALONG THIS ARC
      X(I)=(H+R)*DSIN(PSI(I-(2*KPSH(1)+1)))
      Y(I)=(H+R)*DCOS(PSI(I-(2*KPSH(1)+1)))
C LAST FLATTENED SHELL COORDINATES ARE EQUALLY SPACED ALONG
C THE HORIZONTAL
C BOUNDARY OF THE FLATTENED SHELL
      Y(I+NNS*NSHELL)=HFX(1)
      X(I+NNS*NSHELL)=X(2*KPSH(1)+1+NNS*NSHELL)+
   &    (X(2*KPSH(2)+1+NNS*NSHELL)-X(2*KPSH(1)+1+NNS*NSHELL))
   &    *(I-(2*KPSH(1)+1))/(2D0*(KPSH(2)-KPSH(1)))
C PHI IS AN ANGLE BETWEEN STRAIGHT LINES WHICH PASSES
C THROUGH NODES
C 2*KPSH(1)+2 TO 2*KPSH(2) AND HORIZSIZEONTAL
      PHI(I-(2*KPSH(1)+1))=DATAN((Y(I+NNS*NSHELL)-Y(I))/
   &    (X(I+NNS*NSHELL)-X(I)))

     ELSE IF(ISHELL.LE.(NSHELL-1)) THEN
C Q IS LENGTH OF STRAIGHT LINE FROM THE NODE ON THE FIRST SHELL
C TO THE NODE ON THE ISHELL+1 SHELL.
C THIS IS FOUND FROM THE GEOMETRY OF A STRAIGHT LINE CUTTING
C TWO ARCS.
C THE FIRST ARC IS RADIUS H AND THE LINE INTERSECTS AT A KNOWN
C POSITION
C ARC ANGLE PSI ( IE. THE POSITION OF THE NODE ),
C THE DISTANCE (Q)TO THE SECOND INTERSECT OF THE SECOND ARC
C (RADIUS H+R) IS THEN CALCULATED.
      A=1
      B= 2D0*(X(I)*DCOS(PHI(I-(2*KPSH(1)+1)))
   &       + Y(I)*DSIN(PHI(I-(2*KPSH(1)+1))))
      C= -(H+R)*(H+R)+(H-HIN(1))*(H-HIN(1))
      Q= (-B + SQRT(B*B-4*A*C) )/(2D0*A)
      X(I+NNS*ISHELL)=X(I)+Q*DCOS(PHI(I-(2*KPSH(1)+1)))
      Y(I+NNS*ISHELL)=Y(I)+Q*DSIN(PHI(I-(2*KPSH(1)+1)))

     ENDIF
120 CONTINUE
    RETURN
    END
```

Fig. E.6 Shell node co-ordinate calculations for zone 1B

E.4 Shell Node Co-ordinate Calculations for Zone 2A

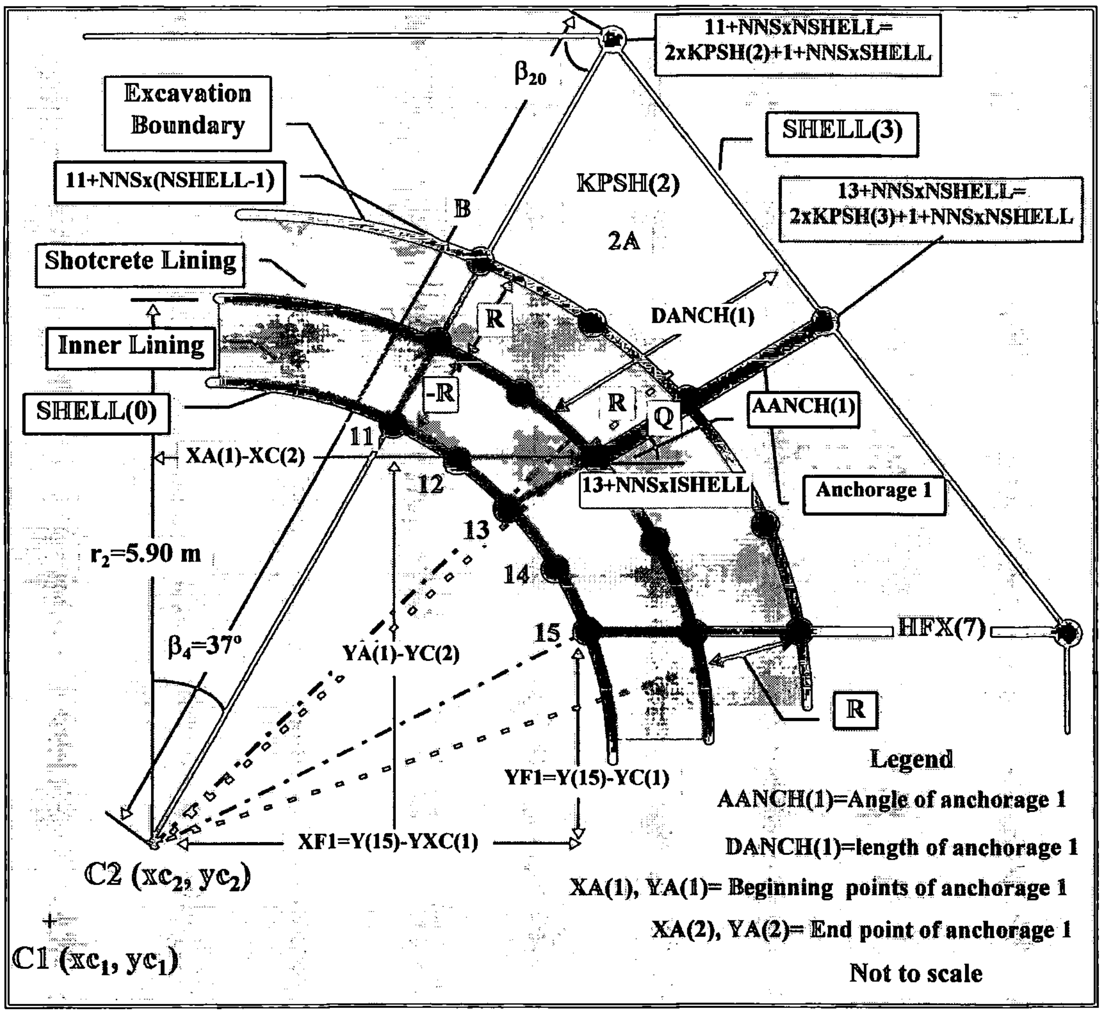

Fig. E.7 Shell node co-ordinates for zone 2A

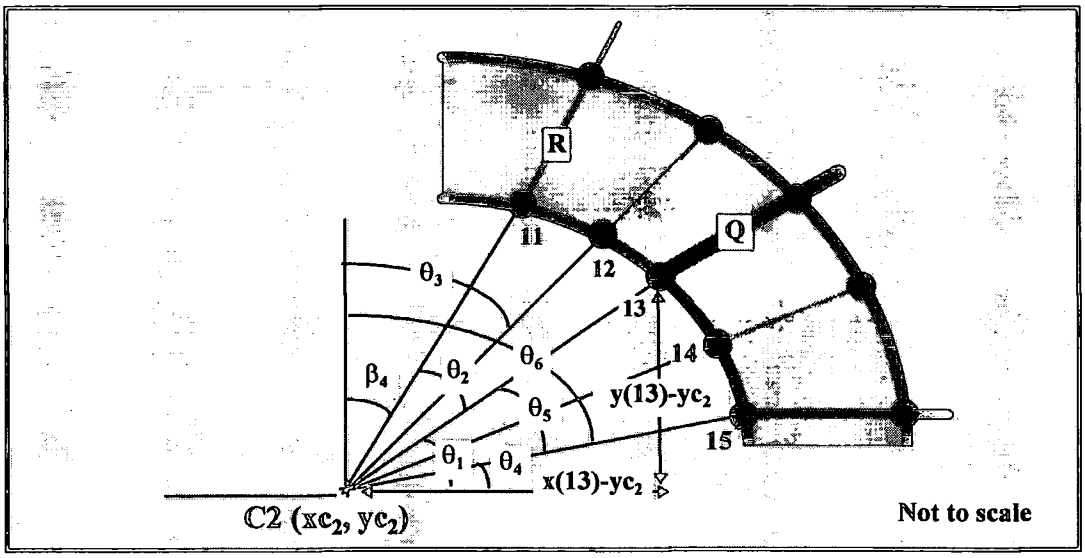

Fig. E.8 Centralising the midside nodes for 2A

```
C ================================================================
C SUBROUTINE SC2AND FOR SHELL NODE COORDINATES CALCULATIONS
C FOR CENTRE 2
C ZONE 2A: BOUNDARY FOR ANCHORAGE 1 AND SURROUNDING NODES
C ================================================================

      SUBROUTINE SC2AND (ISHELL)

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)

      PARAMETER(NNODES=5000)
      COMMON / CNODES / X(NNODES), Y(NNODES)
      COMMON / CCENPR / XC(10), YC(10)
      COMMON / CSHPAR / R,DLAMDA(8),PHI(20),PSI(20)
      COMMON / CANGLE / DRAD, BETA(22)
      COMMON / CTUNIN / H, HOVER, HUNDER
      COMMON / CKEYPR /K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF
      COMMON / COUNT  / KPSH(8), NPSIDE, NCOL, NROW
      COMMON / CSUPIN / SAMIN, SAMAJ, HANCH(2), DANCH(2),
     &                 RANCH,AANCH(2),PERIOD, SANCH, SAMAJ2,
     &                 MARCH,MPARCH,MANCH,MPANCH
      COMMON / CHFXPR / HFX(17)
      COMMON / CSHLPR / NSHELL, HIN(5),SUMR
      COMMON / CANCPR / XA(9),YA(9)

C FIND NODE THAT TERMINATES REGION

      IF (ISHELL.EQ.0) THEN

C INNER LINING FORMS RADIAL BOUNDARY

        Y(2*KPSH(3)+1)=YC(2)+(HFX(7)-YC(2))*
     &       (H*(5.9D0/7.9D0)+R)/(H*(5.9D0/7.9D0))
      ELSE

C REST FORMS HORIZONTAL BOUNDARY AT HFX(7)

        Y(2*KPSH(3)+1+NNS*ISHELL)=HFX(7)

      ENDIF

      IF (ISHELL.LE.(NSHELL-1)) THEN

C THE POSITION OF THE NODE CAN BE FOUND WHERE THE HORIZONTAL
C BOUNDARY CUTS
C THE ARC OF THE SHELL, USING PYTHAGORUS.

        YF1=Y(2*KPSH(3)+1+NNS*ISHELL)-YC(2)
        XF1=SQRT(((H*(5.9D0/7.9D0)+R)**2)-(YF1)**2)
        X(2*KPSH(3)+1+NNS*ISHELL)=XC(2)+XF1

      ELSE
```

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```
C THE FLATTENED SHELL BOUNDARY IS A VERTICAL LINE AT XA(4)

      X(2*KPSH(3)+1+NNS*NSHELL)=XA(4)

    ENDIF

C FIND POSITION OF THE ANCHORAGE BOUNDARY

    NANCH = KPSH(2)+KPSH(3)+1

    IF (ISHELL.LE.(NSHELL-1)) THEN

C NODES ALONG ANCHORAGE
C The equation of an arc is;
C     (xb-x0)^2 + (yb-y0)^2 = Radius^2    (1)
C A straight line passing through A at angle alpha is;
C     xb = xa + q cos(aplpha)         (2a)
C     yb = ya + q sin(aplpha)         (2b)
C Substituting (2) into (1) produceses a quadratic in q
C Noting that A also lies on an arc of Radius 0, the quadratic
C can be simply solved to find the length of q and hence the position
C of B, using the standard quadratic formula.

      A=1
      B= 2D0*( (XA(1)-XC(2)) * DCOS(AANCH(1))
   &         +(YA(1)-YC(2)) * DSIN(AANCH(1)) )
      C= -2D0*H*(5.9D0/7.9D0)*R - R*R

      Q= (-B + SQRT(B*B-4*A*C) )/(2D0*A)

      X(NANCH+NNS*ISHELL)=XA(1)+Q*DCOS(AANCH(1))
      Y(NANCH+NNS*ISHELL)=YA(1)+Q*DSIN(AANCH(1))

    ELSE

C END OF ANCHORAGE

      X(NANCH+NNS*NSHELL)=XA(2)
      Y(NANCH+NNS*NSHELL)=YA(2)

    ENDIF
```

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```
C CENTRALIZING MIDSIDE NODES FOR CIRCULAR SHELLS ONLY

   IF (ISHELL.LE.(NSHELL-1)) THEN

C CENTRALIZING MIDSIDE NODE NANCH-1+NNS*ISHELL

C THETA1=THE ANGLE BETWEEN NODE NANCH+NNS*ISHELL AND
C HORIZONTAL
C THETA2=THE ANGLE BETWEEN NODE NANCH-2+NNS*ISHELL AND
C NODE NANCH+NNS*ISHELL
C THETA3=THE ANGLE BETWEEN NODE NANCH-1+NNS*ISHELL AND
C VERTICAL

     THETA1=DASIN((Y(NANCH+NNS*ISHELL)-YC(2))/(H*(5.9D0/7.9D0)+R))
     THETA2=90D0*DRAD-BETA(4)-THETA1
     THETA3=BETA(4)+THETA2/2D0

     X(NANCH-1+NNS*ISHELL)=XC(2)+(H*(5.9D0/7.9D0)+R)*DSIN(THETA3)
     Y(NANCH-1+NNS*ISHELL)=YC(2)+(H*(5.9D0/7.9D0)+R)*DCOS(THETA3)

C CENTRALIZING MIDSIDE NODE NANCH+1

C THETA4=THE ANGLE BETWEEN NODE NANCH+2+NNS*ISHELL AND
C HORIZONTAL
C THETA5=THE ANGLE BETWEEN NODE NANCH+NNS*ISHELL AND
C NODE NANCH+2+NNS*ISHELL
C THETA6=THE ANGLE BETWEEN NODE NANCH+2+NNS*ISHELL AND
C VERTICAL

     ANG15=(X(NANCH)/(H*(5.9D0/7.9D0)))
     THETA4=DASIN((Y(NANCH+2+NNS*ISHELL)-YC(2))/(H*(5.9D0/7.9D0)+R))
     THETA5=90D0*DRAD-ANG15-THETA4
     THETA6=ANG15+THETA5/2D0

     X(NANCH+1+NNS*ISHELL)=XC(2)+(H*(5.9D0/7.9D0)+R)*DSIN(THETA6)
     Y(NANCH+1+NNS*ISHELL)=YC(2)+(H*(5.9D0/7.9D0)+R)*DCOS(THETA6)

   ELSE

C FLATTENED SHELL DOESN'T REQUIRE MID-SIDE NODES

     X(NANCH-1+NNS*ISHELL) = 0D0
     Y(NANCH-1+NNS*ISHELL) = 0D0
     X(NANCH+1+NNS*ISHELL) = 0D0
     Y(NANCH+1+NNS*ISHELL) = 0D0

   ENDIF

   RETURN
   END
```

Fig. E.9 Shell node co-ordinate calculations for zone 2A

E.5 Shell Node Co-ordinate Calculations for Zone 2B

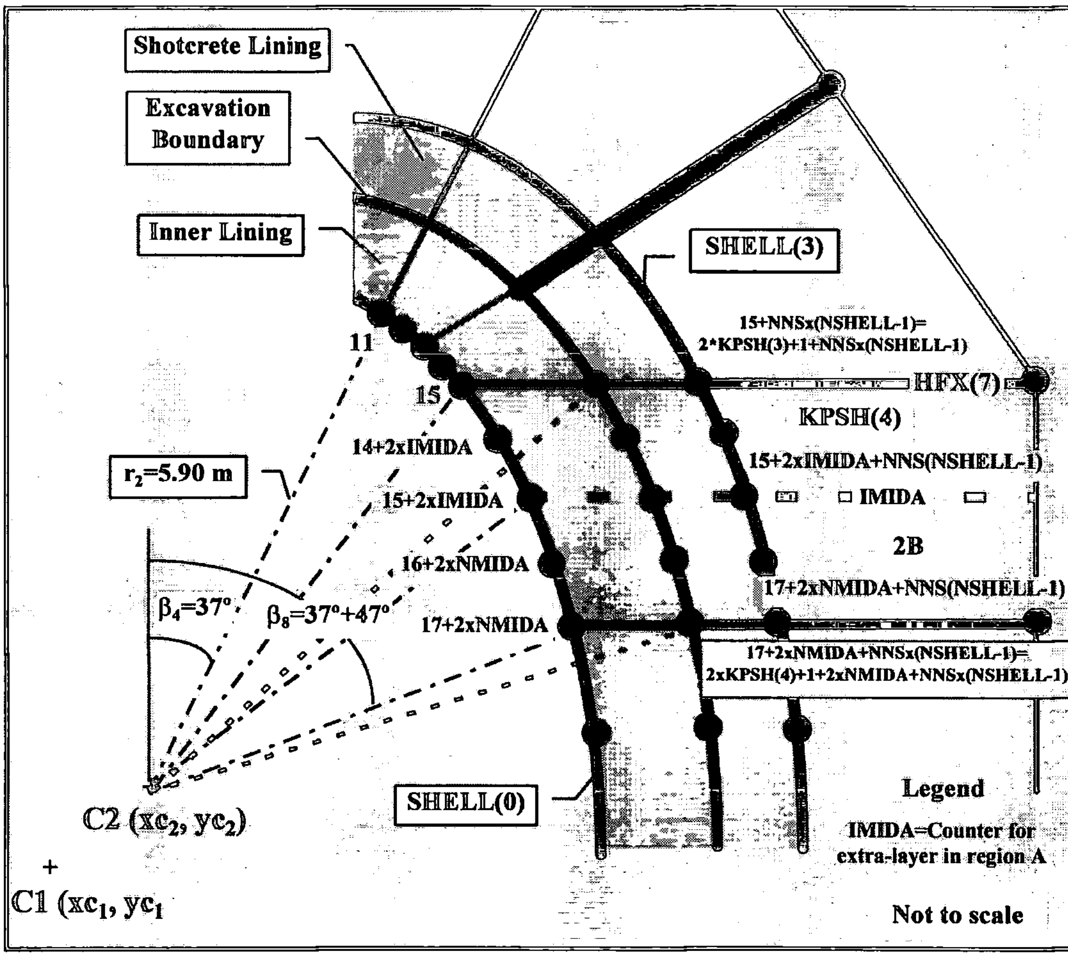

Fig. E.10 Shell node co-ordinates for zone 2B

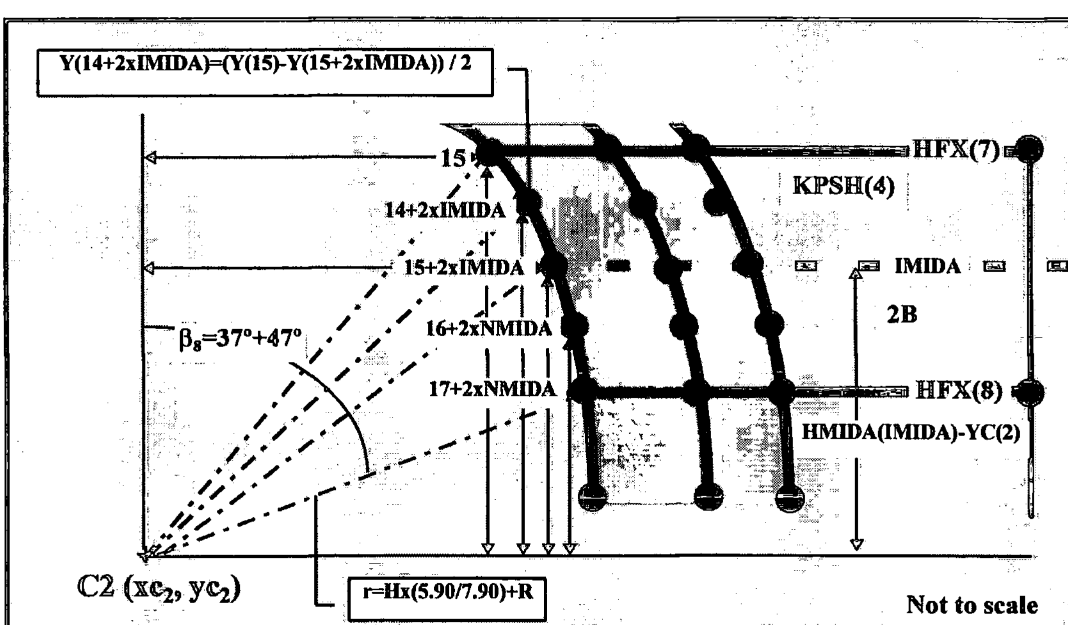

Fig. E.11 Centralising the midside nodes for zone 2B

```
C ==========================================================================
C SUBROUTINE SC2BND FOR SHELL NODE COORDINATES CALCULATIONS
C FOR CENTRE 2
C ZONE 2B: HORIZONTAL BOUNDARIES FOR REGION MIDA OF TUNNEL
C ==========================================================================

      SUBROUTINE SC2BND (ISHELL)

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)

      PARAMETER(NNODES=5000)
      COMMON / CNODES / X(NNODES), Y(NNODES)
      COMMON / CCENPR / XC(10), YC(10)
      COMMON / CSHPAR / R,DLAMDA(8),PHI(20),PSI(20)
      COMMON / CTUNIN / H, HOVER, HUNDER
      COMMON / CKEYPR /K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF
      COMMON / CSHLPR / NSHELL, HIN(5),SUMR
      COMMON / COUNT  / KPSH(8), NPSIDE, NCOL, NROW
      COMMON / CHFXPR / HFX(17)
      COMMON / CROKPR / MATPRO(20), HTOP(4), HMIDA(4), HMIDC(4),
     &              HBOT(4),NMIDA,NMIDC,NTOP,NBOT
      COMMON / CANCPR / XA(9),YA(9)

C ITERATIVE LAYER'S NODES COORDINATES CALCULATIONS IN REGION A

      DO 130 IMIDA=1,NMIDA

C INCLUDE EXTRA LAYERS AT ROCK BOUNDARY
        Y(2*KPSH(3)+1+2*IMIDA+NNS*ISHELL)=HMIDA(IMIDA)

C PLACE MID-SIDE NODE AT HALF VERTICAL DISTANCE BETWEEN
C SURROUNDING NODES
        Y(2*KPSH(3)+2*IMIDA+NNS*ISHELL)=
     &       (Y(2*KPSH(3)+1+2*IMIDA+NNS*ISHELL)+
     &        Y(2*KPSH(3)+1+2*(IMIDA-1)+NNS*ISHELL))/2D0

        IF (ISHELL.LE.(NSHELL-1)) THEN

C CALCULATE X-POSITIONS TO LIE ON ARC
C   CORNER NODE
          X(2*KPSH(3)+1+2*IMIDA+NNS*ISHELL)=
     &       XC(2)+SQRT((H*(5.9D0/7.9D0)+R)**2-
     &              (HMIDA(IMIDA)-YC(2))**2)

C   MID-SIDE NODE

          X(2*KPSH(3)+2*IMIDA+NNS*ISHELL)=
     &        XC(2)+SQRT((H*(5.9D0/7.9D0)+R)**2-
     &        (Y(2*KPSH(3)+2*IMIDA+NNS*ISHELL)-YC(2))**2)

        ELSE
```

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```
C LAST SHELL IS VERTICAL AT XA(4)
C   CORNER NODE
        X(2*KPSH(3)+1+2*IMIDA+NNS*ISHELL)=XA(4)

C   MID-SIDE NODE
        X(2*KPSH(3)+2*IMIDA+NNS*ISHELL)=XA(4)

      ENDIF
 130 CONTINUE

C CALCULATE HORIZONTAL BOUNDARY BETWEEN MIDA AND MIDC
C REGIONS AT HFX(8)

    Y(2*KPSH(4)+1+NNS*ISHELL)=HFX(8)

    IF (ISHELL.LE.(NSHELL-1)) THEN

C ENSURE NODE IS ON THE ARC

      YF2=HFX(8)-YC(2)
      XF2=SQRT(((H*(5.9D0/7.9D0)+R)**2)-(YF2)**2)
      X(2*KPSH(4)+1+NNS*ISHELL)=XC(2)+XF2

     ELSE

C AGAIN FLATTENED SHELL HAS A VERTICAL BOUNDARY AT XA(4)

      X(2*KPSH(4)+1+NNS*ISHELL)=XA(4)
     ENDIF

C CENTRALIZING MIDSIDE NODE 2*KPSH(4)+NNS*ISHELL IN Y-DIRECTION

    Y(2*KPSH(4)+NNS*ISHELL)=
    &    (Y(2*KPSH(4)+1+NNS*ISHELL)+Y(2*KPSH(4)-1+NNS*ISHELL))/2D0

    IF (ISHELL.LE.(NSHELL-1)) THEN

C ENSURE NODE IS ON THE ARC

      X(2*KPSH(4)+NNS*ISHELL)=XC(2)+SQRT(((H*5.9D0/7.9D0)+R)**2-
    &      (Y(2*KPSH(4)+NNS*ISHELL)-YC(2))**2)
    ELSE

C AGAIN FLATTENED SHELL HAS A VERTICAL BOUNDARY AT XA(4)
      X(2*KPSH(4)+NNS*ISHELL)=XA(4)

    ENDIF

    RETURN
    END
```

Fig. E.12 Shell node co-ordinate calculations for zone 2B

E.6 Shell Node Co-ordinate Calculations for Zone 3A

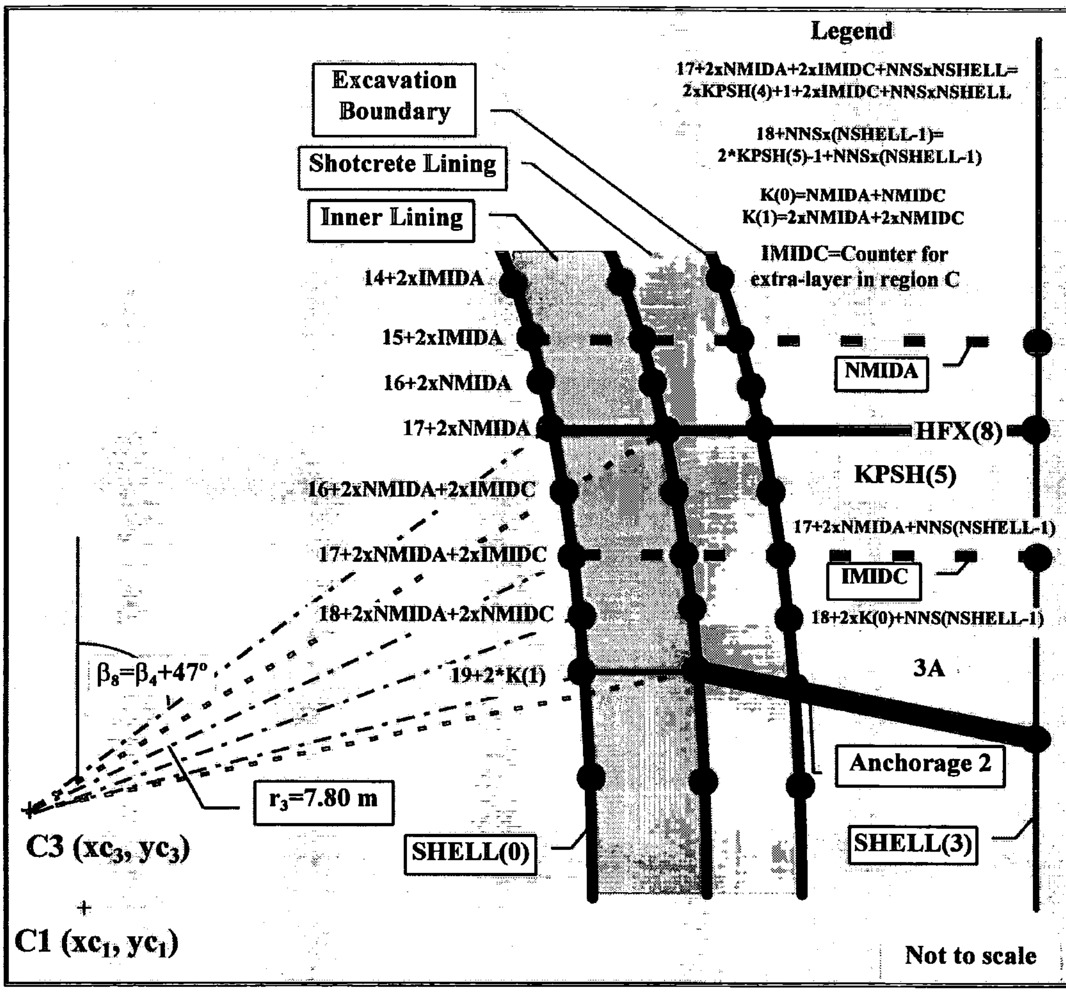

Fig. E.13 Shell node co-ordinates for zone 3A

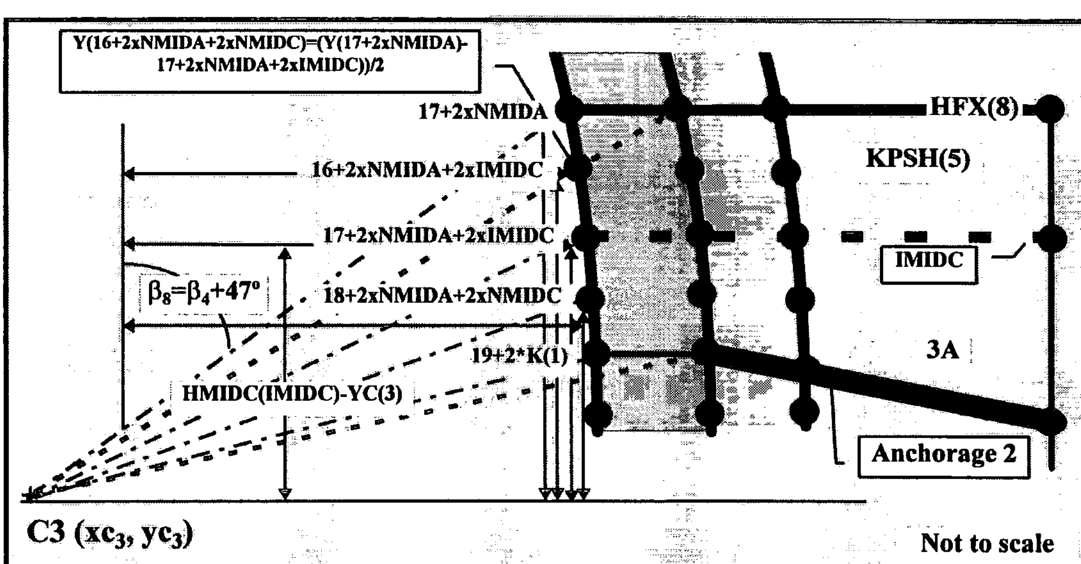

Fig. E.14 Centralising midside nodes for zone 3A

```
C ====================================================================
C SUBROUTINE SC3AND FOR SHELL NODE COORDINATES CALCULATIONS
C FOR CENTRE 3
C ZONE 3A: HORIZONTAL BOUNDARIES FOR REGION MIDC OF TUNNEL
C ====================================================================

      SUBROUTINE SC3AND (ISHELL)

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)

      PARAMETER(NNODES=5000)
      COMMON / CNODES / X(NNODES), Y(NNODES)
      COMMON / CCENPR / XC(10), YC(10)
      COMMON / CSHPAR / R,DLAMDA(8),PHI(20),PSI(20)
      COMMON / CTUNIN / H, HOVER, HUNDER
      COMMON / CKEYPR /K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF
      COMMON / COUNT  / KPSH(8), NPSIDE, NCOL, NROW
      COMMON / CHFXPR / HFX(17)
      COMMON / CROKPR / MATPRO(20), HTOP(4), HMIDA(4), HMIDC(4),
     &             HBOT(4),NMIDA,NMIDC,NTOP,NBOT
      COMMON / CSHLPR / NSHELL, HIN(5),SUMR
      COMMON / CANCPR / XA(9),YA(9)

C ITERATIVE LAYER'S NODES CORDINATES CALCULATIONS IN REGION C
      DO 140 IMIDC=1,NMIDC

C INCLUDE EXTRA LAYERS AT ROCK BOUNDARY
        Y(2*KPSH(4)+1+2*IMIDC+NNS*ISHELL)=HMIDC(IMIDC)
C PLACE MID-SIDE NODE AT HALF VERTICAL DISTANCE BETWEEN
C SURROUNDING NODES
        Y(2*KPSH(4)+2*IMIDC+NNS*ISHELL)=
     &      (Y(2*KPSH(4)+1+2*IMIDC+NNS*ISHELL)+
     &       Y(2*KPSH(4)+1+2*(IMIDC-1)+NNS*ISHELL))/2D0

        IF (ISHELL.LE.(NSHELL-1)) THEN

C CALCULATE X-POSITIONS TO LIE ON ARC
C CORNER NODE
          X(2*KPSH(4)+1+2*IMIDC+NNS*ISHELL)=XC(3)+
     &    SQRT((H*(7.8D0/7.9D0)+R)**2-(YC(3)-HMIDC(IMIDC))**2 )
C MID-SIDE NODE
          X(2*KPSH(4)+2*IMIDC+NNS*ISHELL)=XC(3)+
     &        SQRT((H*(7.8D0/7.9D0)+R)**2-
     &        (YC(3)-Y(2*KPSH(4)+2*IMIDC+NNS*ISHELL))**2 )
        ELSE
C LAST SHELL IS VERTICAL AT XA(4)
C CORNER NODE
          X(2*KPSH(4)+1+2*IMIDC+NNS*ISHELL)=XA(4)
C  MID-SIDE NODE
          X(2*KPSH(4)+2*IMIDC+NNS*ISHELL)=XA(4)
        ENDIF
 140  CONTINUE
      RETURN
      END
```

Fig. E.15 Shell node co-ordinate calculations for zone 3A

E.7 Shell Node Co-ordinate Calculations for Zone 3B

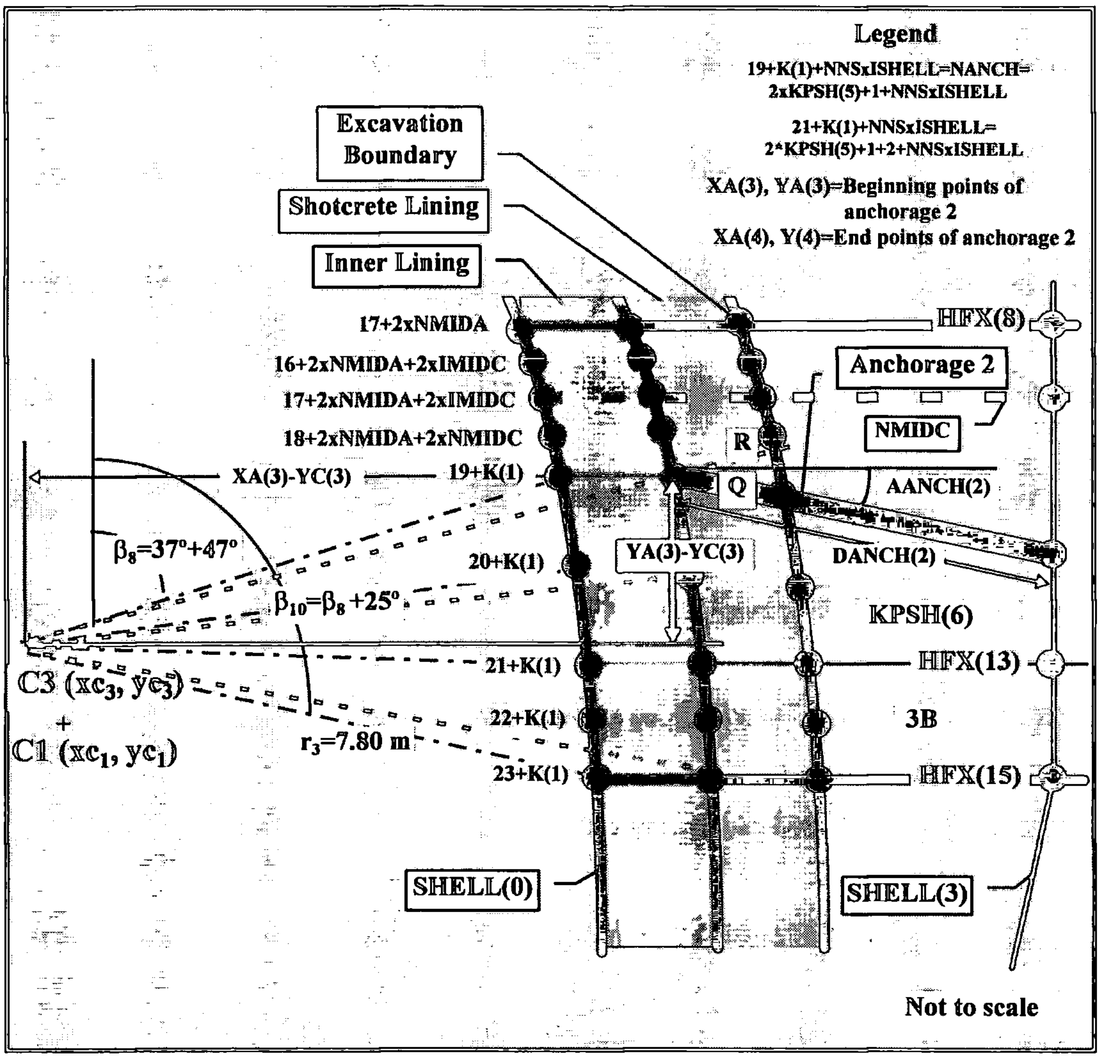

Fig. E.16 Shell node co-ordinates for zone 3B

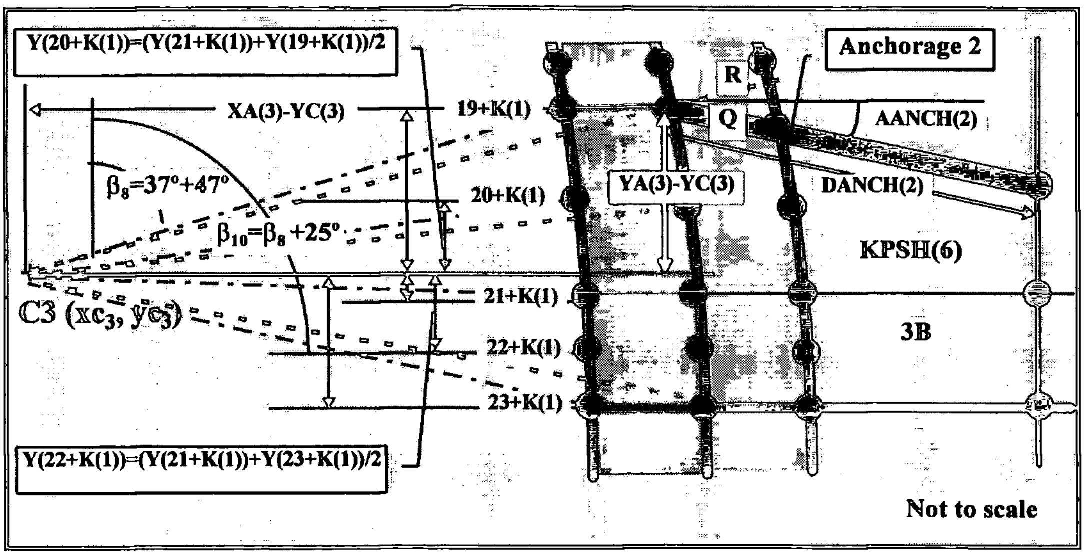

Fig. E.17 Centralising midside nodes for zone 3B

```
C=====================================================================
C SUBROUTINE SC3BND FOR SHELL NODE COORDINATES CALCULATIONS
C FOR CENTRE 3
C ZONE 3B: ANCHORAGE 2 AND FIXED HORIZONTAL BOUNDARIES
C=====================================================================

  SUBROUTINE SC3BND (ISHELL)

  IMPLICIT DOUBLE PRECISION  (A-H,O-Z)

  PARAMETER(NNODES=5000)
  COMMON / CNODES / X(NNODES), Y(NNODES)
  COMMON / CCENPR / XC(10), YC(10)
  COMMON / CSHPAR / R,DLAMDA(8),PHI(20),PSI(20)
  COMMON / CTUNIN / H, HOVER, HUNDER
  COMMON / CKEYPR /K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF
  COMMON / COUNT  / KPSH(8), NPSIDE, NCOL, NROW
  COMMON / CHFXPR / HFX(17)
  COMMON / CROKPR / MATPRO(20), HTOP(4), HMIDA(4), HMIDC(4),
 &              HBOT(4),NMIDA,NMIDC,NTOP,NBOT
  COMMON / CSUPIN / SAMIN, SAMAJ, HANCH(2), DANCH(2),
 &              RANCH,AANCH(2),PERIOD, SANCH, SAMAJ2,
 &              MARCH,MPARCH,MANCH,MPANCH
  COMMON / CSHLPR / NSHELL, HIN(5),SUMR
  COMMON / CANCPR / XA(9),YA(9)
  COMMON / CANGLE / DRAD, BETA(22)

C ANCHOR 2 NODE COORDINATES CALCULATIONS
C FIND POSITION OF THE ANCHORAGE BOUNDARY
  NANCH = 2*KPSH(5)+1
  IF (ISHELL.LE.(NSHELL-1)) THEN
C NODES ALONG ANCHORAGE
C The equation of an arc is;
C   (xb-x0)^2 + (yb-y0)^2 = Radius^2   (1)
C A straight line passing through A at angle alpha is;
C    xb = xa + q cos(aplpha)        (2a)
C    yb = ya + q sin(aplpha)        (2b)
C Substituting (2) into (1) produces a quadratic in q
C Noting that A also lies on an arc of Radius 0, the quadratic
C can be simply solved to find the length of q and hence the position
C of B, using the standard quadratic formula.
    A=1
    B= 2D0*( (XA(3)-XC(3))*DCOS(AANCH(2))
 &       +(YA(3)-YC(3))*DSIN(AANCH(2)) )
    C= -2D0*H*(7.8D0/7.9D0)*R - R*R
    Q=(-B+SQRT(B*B-4*A*C))/(2D0*A)
    X(NANCH+NNS*ISHELL)=XA(3)+Q*DCOS(AANCH(2))
    Y(NANCH+NNS*ISHELL)=YA(3)+Q*DSIN(AANCH(2))
  ELSE
C END OF ANCHORAGE
    X(NANCH+NNS*NSHELL)=XA(4)
    Y(NANCH+NNS*NSHELL)=YA(4)

  ENDIF
```

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```
C CENTRALIZING MIDSIDE NODE NANCH-1+NNS*ISHELL

   Y(NANCH-1+NNS*ISHELL)=( Y(NANCH+NNS*ISHELL)
  &             +Y(NANCH-2+NNS*ISHELL))/2D0

   IF (ISHELL.LE.(NSHELL-1)) THEN
     X(NANCH-1+NNS*ISHELL)=XC(3)+SQRT((H*(7.8D0/7.9D0)+R)**2-
  &                (YC(3)-Y(NANCH-1+NNS*ISHELL))**2)
   ELSE
     X(NANCH-1+NNS*ISHELL)=XA(4)
   ENDIF

C SET HORIZONTAL BOUNDARIES AT HFX(13) AND HFX(15)
   DO 10 I=1,2

     Y(2*KPSH(5)+1+2*I+NNS*ISHELL)=HFX(11+2*I)

     IF (ISHELL.LT.NSHELL) THEN
       YF3=YC(3)-HFX(11+2*I)
       XF3=SQRT((H*(7.8D0/7.9D0)+R)**2-(YF3)**2)
       X(2*KPSH(5)+1+2*I+NNS*ISHELL)=XC(3)+XF3
     ELSE
       X(2*KPSH(5)+1+2*I+NNS*ISHELL)=XA(4)
     ENDIF

C MAKE BOUNDARY FOR INNER LINING RADIAL

     IF ((ISHELL.EQ.0).AND.(I.EQ.2)) THEN
       X(2*KPSH(5)+1+2*I+NNS*ISHELL)=XC(3)
  &       +(H*(7.8D0/7.9D0)+R)*DSIN(BETA(10))
       Y(2*KPSH(5)+1+2*I+NNS*ISHELL)=YC(3)
  &       +(H*(7.8D0/7.9D0)+R)*DCOS(BETA(10))
     ENDIF

C CENTRALISING MIDSIDE NODES 2*KPSH(5)+2, 2*KPSH(5)+4

     Y(2*KPSH(5)+2*I+NNS*ISHELL)=(Y(2*KPSH(5)+1+2*I+NNS*ISHELL)
  &    +Y(2*KPSH(5)-1+2*I+NNS*ISHELL))/2D0

     IF (ISHELL.LE.(NSHELL-1)) THEN
       X(2*KPSH(5)+2*I+NNS*ISHELL)=XC(3)+SQRT((H*(7.8D0/7.9D0)+
  &     R)**2-(YC(3)-Y(2*KPSH(5)+2*I+NNS*ISHELL))**2)
     ELSE
       X(2*KPSH(5)+2*I+NNS*ISHELL)=XA(4)
     ENDIF
 10 CONTINUE

    RETURN
    END
```

Fig. E.18 Shell node co-ordinate calculations for zone 3B

E.8 Shell Node Co-ordinate Calculations for Zone 4

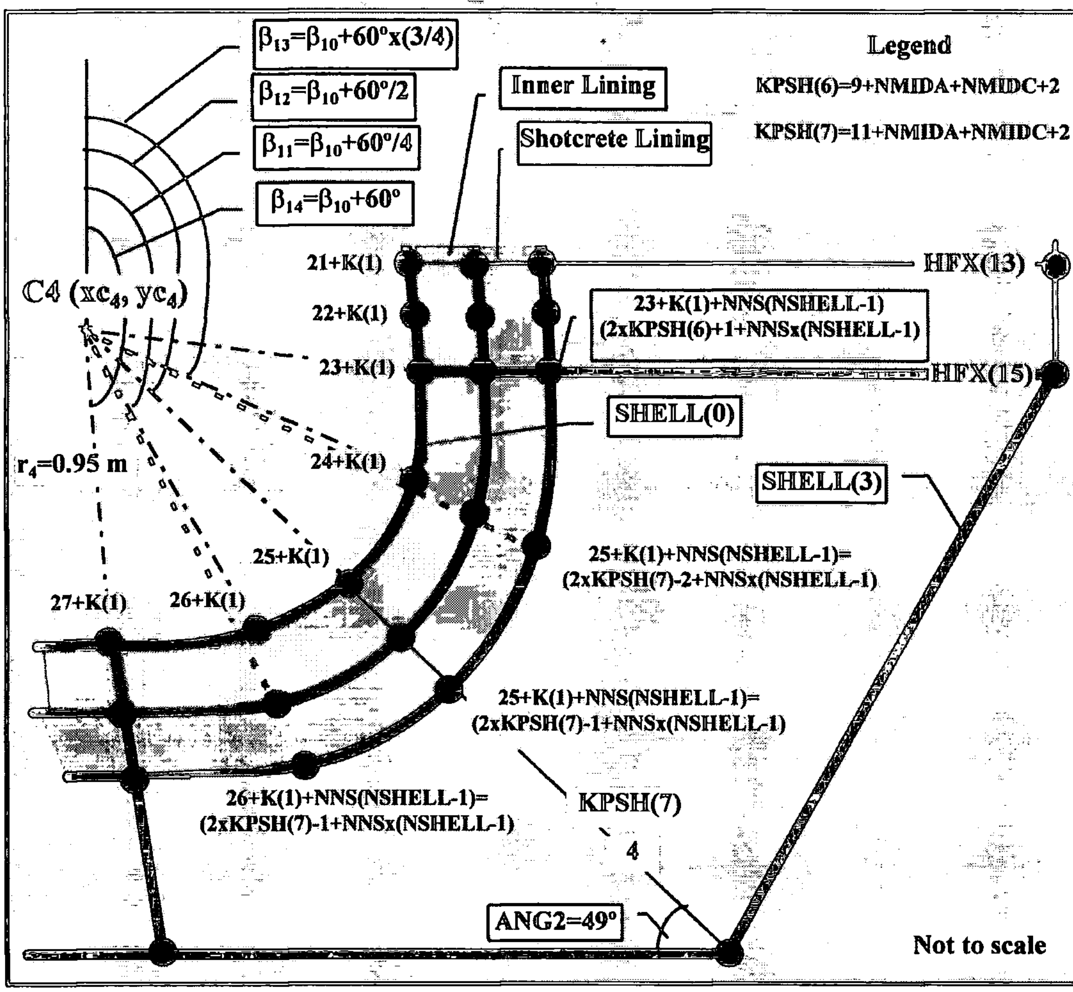

Fig. E.19 Shell node co-ordinates for zone 4

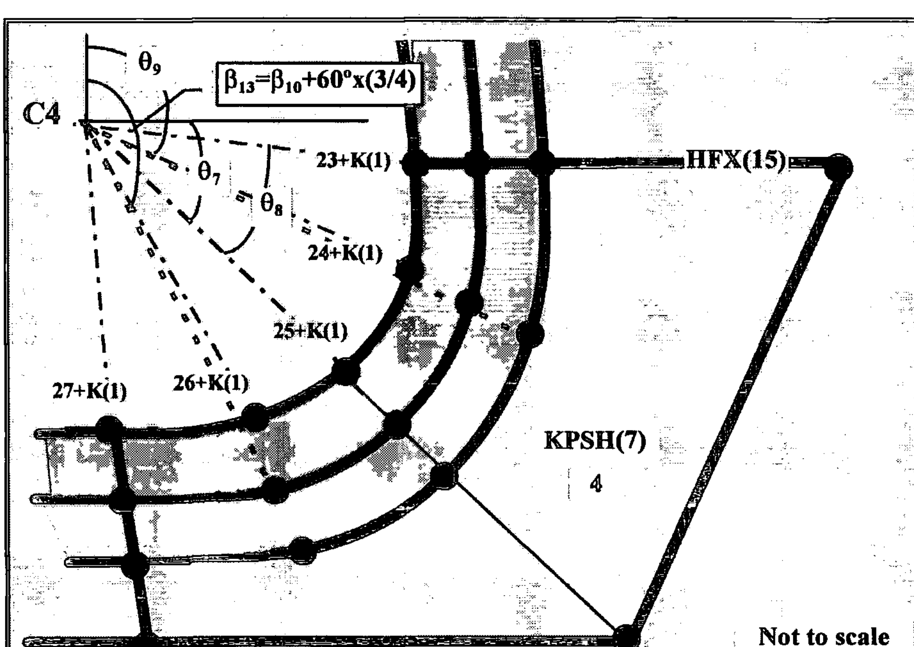

Fig. E.20 Centralising midside nodes for zone 4

```
C===========================================================================
C SUBROUTINE SC4NOD FOR SHELL NODE COORDINATES CALCULATIONS
C FOR CENTRE 4
C TRANSITION BETWEEN HORIZONTAL AND VERTICAL BOUNDARIES
C ==========================================================================

      SUBROUTINE SC4NOD (ISHELL)

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)

      PARAMETER(NNODES=5000)
      COMMON / CNODES / X(NNODES), Y(NNODES)
      COMMON / CCENPR / XC(10), YC(10)
      COMMON / CANGLE / DRAD, BETA(22)
      COMMON / CSHPAR / R,DLAMDA(8),PHI(20),PSI(20)
      COMMON / CTUNIN / H, HOVER, HUNDER
      COMMON / CKEYPR /K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF
      COMMON / CSHLPR / NSHELL, HIN(5),SUMR
      COMMON / COUNT  / KPSH(8), NPSIDE, NCOL, NROW
      COMMON / CHFXPR / HFX(17)
      COMMON / CANCPR / XA(9),YA(9)

      IF (ISHELL.EQ.NSHELL) THEN

C LAST SHELL CORNER NODES LIE ON HORIZONTAL BOUNDARY AT YA(6)

        X(2*KPSH(7)-1+NNS*ISHELL)=XA(6)
        Y(2*KPSH(7)-1+NNS*ISHELL)=YA(6)

        Y(2*KPSH(7)+1+NNS*ISHELL)=YA(6)
        X(2*KPSH(7)+1+NNS*ISHELL)=XC(4)+
     &      (YA(6)-YC(4))*DTAN(BETA(14))

      ELSE

C CORNER NODES FORM RADIAL BOUNDARIES BETWEEN ARCS

        X(2*KPSH(7)-1+NNS*ISHELL)=XC(4)+
     &        (H*(0.95D0/7.9D0)+R)*DSIN(BETA(12))
        Y(2*KPSH(7)-1+NNS*ISHELL)=YC(4)+
     &        (H*(0.95D0/7.9D0)+R)*DCOS(BETA(12))

          X(2*KPSH(7)+1+NNS*ISHELL)=XC(4)+
     &        (H*(0.95D0/7.9D0)+R)*DSIN(BETA(14))
          Y(2*KPSH(7)+1+NNS*ISHELL)=YC(4)+
     &        (H*(0.95D0/7.9D0)+R)*DCOS(BETA(14))

        ENDIF
```

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```
C BETA(11)=37D0*DRAD+47D0*DRAD+25D0*DRAD+(60D0/4D0)*DRAD

C CENTRALIZSIZEING MIDSIDE NODE 2*KPSH(7)-2+NNS*ISHELL FOR
C CIRCULAR
C SHELLS ONLY

   IF (ISHELL.LT.NSHELL) THEN

C THETA9=THE ANGLE BETWEEN NODE 2*KPSH(7)-2+NNS*ISHELL AND
C VERTICAL
C THETA7=THE ANGLE BETWEEN NODE 2*KPSH(7)-1+NNS*ISHELL AND
C HORIZSIZEONTAL
C THETA8=THE ANGLE BETWEEN NODE 2*KPSH(6)+1+NNS*ISHELL AND
C NODE 2*KPSH(7)-1+NNS*ISHELL

     THETA7=DASIN((Y(2*KPSH(7)-1+NNS*ISHELL)-YC(4))/
  &        (H*(0.95D0/7.9D0)+R))
     THETA8=90D0*DRAD-BETA(10)-THETA7
     THETA9=BETA(10)+(THETA8/2D0)

     X(2*KPSH(7)-2+NNS*ISHELL)=XC(4)+
  &      (H*(0.95D0/7.9D0)+R)*DSIN(THETA9)
     Y(2*KPSH(7)-2+NNS*ISHELL)=YC(4)+
  &      (H*(0.95D0/7.9D0)+R)*DCOS(THETA9)

     X(2*KPSH(7)+NNS*ISHELL)=XC(4)+
  &      (H*(0.95D0/7.9D0)+R)*DSIN(BETA(13))
     Y(2*KPSH(7)+NNS*ISHELL)=YC(4)+
  &      (H*(0.95D0/7.9D0)+R)*DCOS(BETA(13))

   ELSE

C NO MID-SIDE NODES REQUIRED FOR FLATTENED SHELL

     X(2*KPSH(7)-2+NNS*ISHELL) = 0D0
     Y(2*KPSH(7)-2+NNS*ISHELL) = 0D0
     X(2*KPSH(7) +NNS*ISHELL) = 0D0
     Y(2*KPSH(7) +NNS*ISHELL) = 0D0

   ENDIF

  RETURN
  END
```

Fig. E.21 Shell node co-ordinates calculations for zone 4

E.9 Shell Node Co-ordinate Calculations for Zone 5

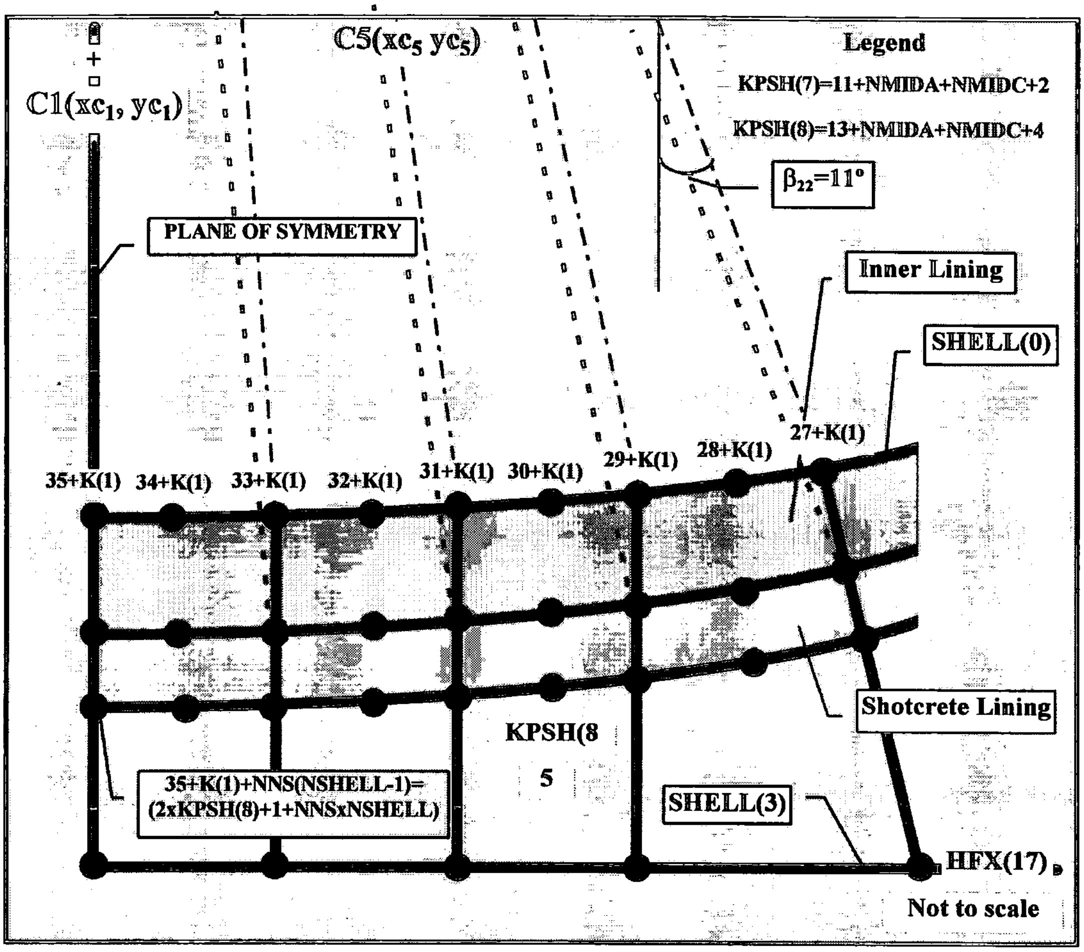

Fig. E.22 Shell node co-ordinates for zone 5

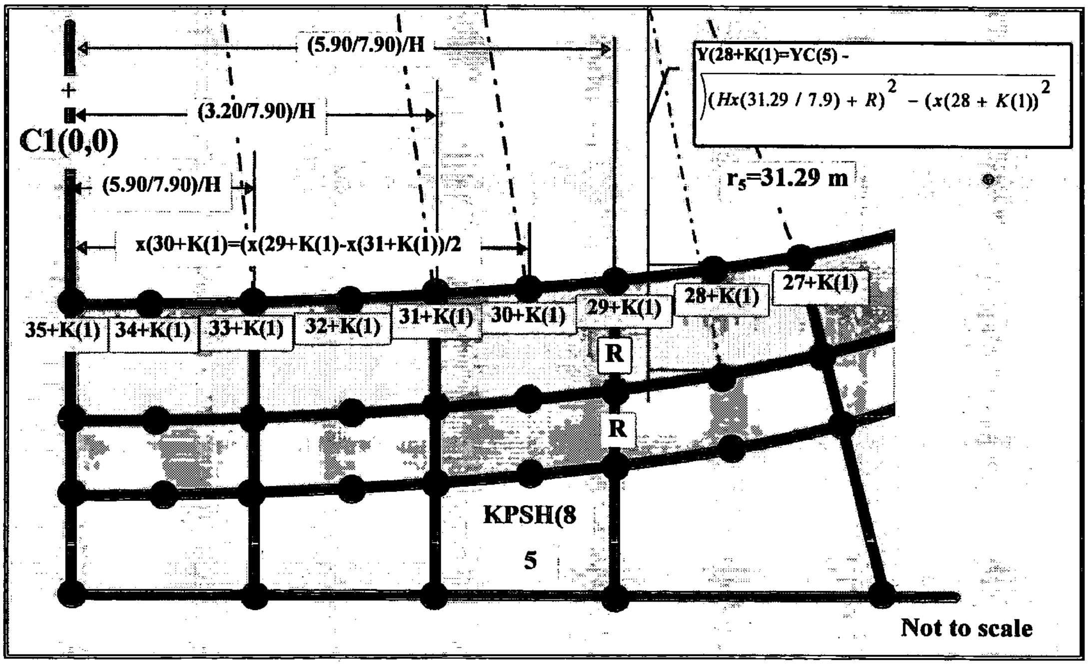

Fig. E.23 Centralising midside nodes for zone 5

```
C ==========================================================================
C SUBROUTINE SC5NOD FOR SHELL NODE COORDINATES CALCULATIONS
C FOR CENTRE 5
C ==========================================================================

      SUBROUTINE SC5NOD (ISHELL)

      IMPLICIT DOUBLE PRECISION  (A-H,O-Z)

      PARAMETER(NNODES=5000)
      COMMON / CNODES / X(NNODES), Y(NNODES)
      COMMON / CCENPR / XC(10), YC(10)
      COMMON / CSHPAR / R,DLAMDA(8),PHI(20),PSI(20)
      COMMON / CTUNIN / H, HOVER, HUNDER
      COMMON / CKEYPR /K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF
      COMMON / COUNT  / KPSH(8), NPSIDE, NCOL, NROW
      COMMON / CSHLPR / NSHELL, HIN(5),SUMR
      COMMON / CANCPR / XA(9),YA(9)

C IN FIRST LAYER X-POSITIONS OF CORNER NODES SET BY EXACAVATION
C BOUNDARIES
C AND FORM VERTICAL BOUNDARIES

      IF (ISHELL.EQ.0) THEN
        X(2*KPSH(7)+3) = (5D0/7.9D0)*H
        X(2*KPSH(7)+5) = (3.2D0/7.9D0)*H
        X(2*KPSH(7)+7) = (1.2D0/7.9D0)*H
        X(2*KPSH(7)+9) = 0D0
      ELSE

C FOR EACH PAFBLOCK

        DO 10 IPSH=KPSH(7)+1,KPSH(8)
 10        X(2*IPSH+1+NNS*ISHELL) = X(2*IPSH+1)

      ENDIF

C FOR EACH PAFBLOCK
      DO 20 IPSH=KPSH(7)+1,KPSH(8)

C SET THE Y-POSITIONS TO LIE ON ARC BOUNDARIES OR VERTICAL
C BOUNDARY FOR FLATTENED SHELL

        IF (ISHELL.EQ.NSHELL) THEN

C LAST SHELL NODE LIE ON HORIZONTAL BOUNDARY AT YA(6)
          Y(2*IPSH+1+NNS*ISHELL)=YA(6)

        ELSE
C ENSURE NODE LIES ON ARC FOR CIRCULAR SHELLS
          Y(2*IPSH+1+NNS*ISHELL)=YC(5)-SQRT((H*(31.29D0/7.9D0)+R)**2-
     &                      X(2*IPSH+1+NNS*ISHELL)**2)

        ENDIF
```

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```
      IF (ISHELL.LT.NSHELL) THEN

C PLACE MID-SIDE NODE IN AVERAGE X-POSITION THEN ENSURE THEY
C LIE ON THE ARC

        X(2*IPSH+NNS*ISHELL)=
     &    (X(2*IPSH-1+NNS*ISHELL)+X(2*IPSH+1+NNS*ISHELL))/2D0
        Y(2*IPSH+NNS*ISHELL)=YC(5)-SQRT((H*(31.29D0/7.9D0)+R)**2
     &                      -(X(2*IPSH+NNS*ISHELL))**2)

      ELSE

C NO MID-SIDE NODE REQUIRED FOR LAST SHELL

        X(2*IPSH+NNS*ISHELL)= 0D0
        Y(2*IPSH+NNS*ISHELL)= 0D0

      ENDIF

 20 CONTINUE

    RETURN
    END
```

Fig. E.24 Shell node co-ordinate calculations for zone 5

```
C ================================================================
C SUBROUTINE SYMNOD FOR SHELL SYMMETRIC NODES COORDINATES
C ================================================================

    SUBROUTINE SYMNOD (ISHELL)

    IMPLICIT DOUBLE PRECISION  (A-H,O-Z)

    PARAMETER(NNODES=5000)
    COMMON / CNODES / X(NNODES), Y(NNODES)
    COMMON / CKEYPR /K(0:8),NNS,NBS,NPOT,NPLR,NNODE,NPAF

C  SHELL SYMMETRIC NODES COORDINATES

    DO 10 I=2,NNS/2
      X(NNS-(I-2)+NNS*ISHELL) = -X(I+NNS*ISHELL)
      Y(NNS-(I-2)+NNS*ISHELL) =  Y(I+NNS*ISHELL)
 10 CONTINUE

    RETURN
    END
```

Fig. E.25 Symmetric node co-ordinate calculations for shells

APPENDIX F

BEAM ELEMENTS FOR ANCHORAGE AND STEEL ARCH

F.1 Introduction

The simple beam element 34000 was used as anchorages which end in the first and last flattened shells as shown in Fig. 5.4. The simple beam elements (the two-noded PAFEC type 34000) were used to model the steel arch. Implementation of the anchorages and steel arch in the pre-processing program is given in the subroutine 'support' in Appendix C. A more detailed explanation of these support systems is given in Chapter 2 and Chapter 5. The derivation of the equivalent section properties for the anchorage and steel arch beam elements is given below. Because of plane of symmetry bending about axes YY in plane of symmetry cannot occur, so I_{yy} for 'I' section and circular section are irrelevant as shown in Figs. F1 and F2.

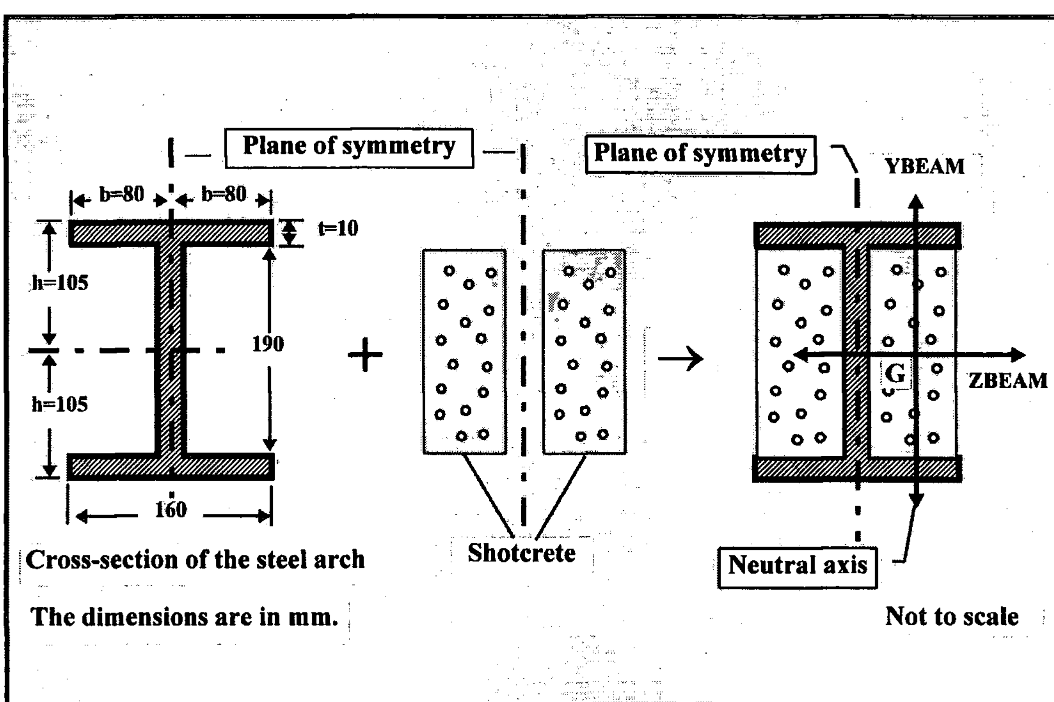

Fig. F.1 Cross-section of the steel arch

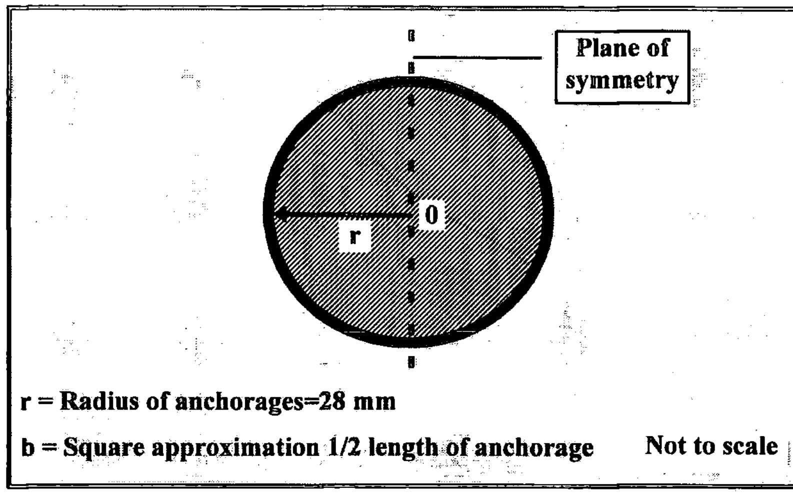

Fig. F2. Cross-section of an anchorage

F.2 Anchorage

I_{zz} for the half circular section are calculated as follows. 'G' lies on ZZ for the half section as shown in Fig. F.3.

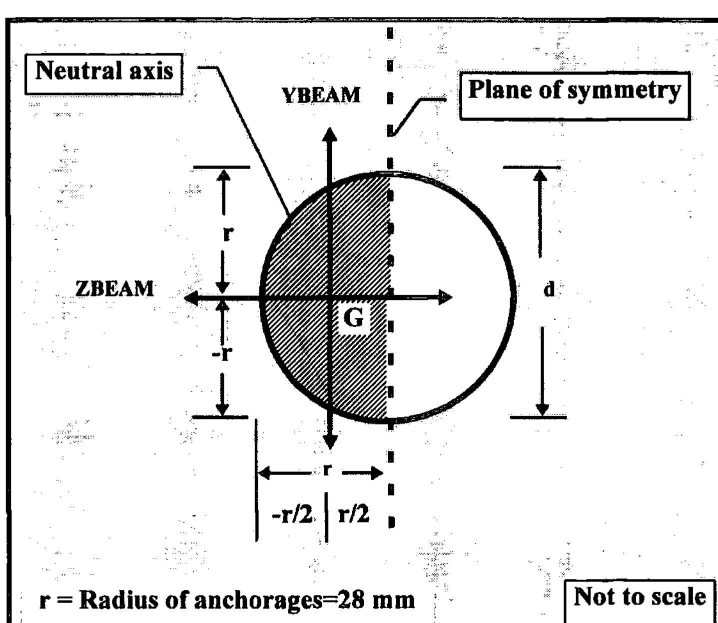

Fig. F.3 Cross-sectional moment area of the anchorage

Second moment areas of half section anchorages are as follows.

$$I_{ZG} = I_{ZZ(1/2)} = \frac{1}{2} I_{ZZ} \quad \text{and} \quad I_{YG} = I_{YY(1/2)} = \frac{1}{2} I_{YY} \tag{F.1a}$$

$$I_{ZZ}\,(\textit{for circular section}) = \frac{\pi r^4}{4} = \frac{\pi d^4}{64} \tag{F.1b}$$

where r and d are radius and diameter respectively. Hence $\frac{1}{2} I_{ZZ}$

$$\frac{1}{2} I_{ZZ} = \frac{1}{2}\,\frac{\pi r^4}{4} = \frac{\pi r^4}{8} = \frac{\pi\,(RANCH)^4}{8} \tag{F.1c}$$

$$\frac{1}{2} I_{YY} = \frac{1}{2}\,\frac{\pi r^4}{4} = \frac{\pi r^4}{8} = \frac{\pi\,(RANCH)^4}{8} \tag{F.1d}$$

$$ZY = \frac{I_{YY}}{z_{\max}} = \frac{\frac{\pi r^4}{8}}{\frac{r}{2}} = \frac{\pi r^3}{4} = \frac{\pi\,(RANCH)^3}{4} \tag{F.2a}$$

$$ZZ = \frac{I_{ZZ}}{y_{\max}} = \frac{\frac{\pi r^4}{8}}{r} = \frac{\pi r^3}{8} = \frac{\pi\,(RANCH)^3}{8} \tag{F.2b}$$

F.3 Steel Arch

'G' lies on ZZ (neutral axis) for the half 'I' section as shown in Fig. F.4. Second moment areas of the steel arch are as follows.

$$I_{ZG} = I_{ZZ(1/2)} = \frac{1}{2} I_{ZZ} \quad \text{and} \quad I_{YG} = I_{YY(1/2)} = \frac{1}{2} I_{YY} \tag{F.3a}$$

$$I_{ZZ\,STEEL} = 2\,I_{FZZ\,FLANGE} + I_{WZZ\,WEB} \tag{F.3b}$$

$$I_{FZZ\,FLANGE} = I_F + A_F\left(\frac{D}{2} - \frac{t}{2}\right)^2 \tag{F.4a}$$

$$I_{FZZ\,FLANGE} = \frac{B t_f^{\,3}}{12} + \frac{B t_f}{4}\,(D - t_f)^2 \tag{F.4b}$$

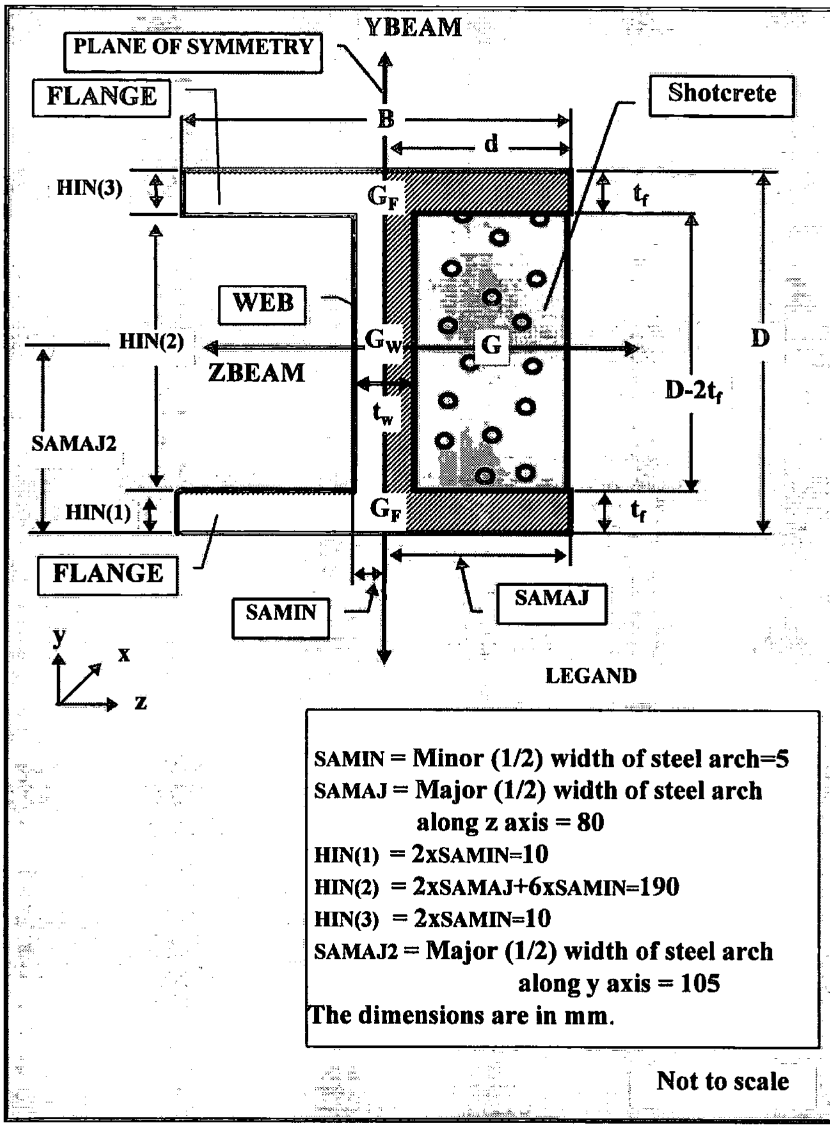

Fig. F.4 Cross-sectional moment area of the steel arch

$$I_{FZZ\,FLANGE} = \frac{Bt_f}{4}\left[\frac{t_f^{\,2}}{3} + (D-t_f)^2\right] \tag{F.4c}$$

$$I_{FZZ\,FLANGE} = \frac{Bt_f}{4}\left[\frac{t_f^{\,2}}{3} + D^2 - 2Dt_f + t_f^{\,2}\right] \tag{F.4d}$$

$$\text{If } t \ll D,\ I_{FZZ\,FLANGE} = \frac{Bt_f}{4}\left[\,D^2\right] \tag{F.4e}$$

$$I_{WZZ\,WEB} = \frac{1}{12}\,t_w\,(D-2t_f)^3 \tag{F.5a}$$

$$\text{If t} \ll \text{D}, \; I_{WZZ\,WEB} = \frac{1}{12} t_w \, D^3 \qquad \text{(F.5b)}$$

$$\text{Hence } I_{ZZ\,STEEL} = 2\left(\frac{B t_f}{2} D^2\right) + \frac{t_w D^3}{12} \qquad \text{(F.6a)}$$

$$I_{ZZ\,STEEL} = D^2 \left(\frac{B t_f}{2} + \frac{t_w D}{12}\right) \qquad \text{(F.6b)}$$

$$I_{ZZ\,STEEL} = \frac{D^2}{2} \left(B t_f + \frac{t_w D}{6}\right) \qquad \text{(F.6c)}$$

$$\text{Hence } I_{ZZ\,STEEL\,1/2} = \frac{D^2}{4} \left(B t_f + \frac{t_w D}{6}\right) \qquad \text{(F.6d)}$$

$$t_f = t_w \qquad \text{(F.6e)}$$

$$I_{ZZ\,STEEL\,1/2} = \frac{D^2}{4} \left[2 d t + \frac{t D}{6}\right] \qquad \text{(F.6f)}$$

$$I_{ZZ\,STEEL\,1/2} = \frac{D^2}{4} \left(2 d t + \frac{t D}{6}\right) \qquad \text{(F.6g)}$$

$$I_{ZZ\,STEEL\,1/2} = \frac{D^2 t}{4} \left(2 d + \frac{D}{6}\right) \qquad \text{(F.6h)}$$

Second moment areas of shotcrete are as follows

$$I_{ZZ\,Shotcrete} = \frac{1}{12} (d-(t/2))\,(D-2t)^3 \qquad \text{(F.7a)}$$

$$I_{ZZ\,Shotcrete} = \frac{1}{12} (d-(t/2))\,(D^3 - 3D^2 2t + 3D(2t)^2 - (2t)^3) \qquad \text{(F.7b)}$$

$$\text{If t} \ll \text{D, t} \ll \text{d} \quad I_{ZZ\,Shotcrete} = \frac{1}{12} d D^3 \qquad \text{(F.7c)}$$

The equivalent steel section I_{zz} is

$$I_{ZZ} = I_{ZZ\,STEEL} + I_{ZZ\,Shotcrete} \frac{E_{Shotcrete}}{E_{STEEL}} \qquad \text{(F.8a)}$$

$$I_{ZZ} = \frac{D^2 t}{4} \left(2d + \frac{D}{6}\right) + \frac{1}{12} d D^3 \frac{E_{Shotcrete}}{E_{STEEL}} \qquad \text{(F.8b)}$$

The variables used in program are as shown in Fig. F.4

$$t = 2\,SAMIN, \; D = 2\,SAMAJ2, \; d = SAMAJ \qquad \text{(F.9a)}$$

$$I_{ZZ} = \left(\frac{(2\,SAMAJ)^2\,(2\,SAMIN)}{4}\,2\,SAMAJ + \frac{2\,SAMAJ2}{6}\right) + \frac{1}{12}\,(SAMAJ)(2\,SAMAJ2)^3\,\frac{E_{Shotcrete}}{E_{STEEL}} \tag{F.9b}$$

$$ZZ = \frac{I_{ZZ}}{y_{\max}} = \frac{\frac{D^2\,t}{4}\,(2d+\frac{D}{6}) + \frac{1}{12}\,d\,D^3\,\frac{E_{Shotcrete}}{E_{STEEL}}}{\frac{D}{2}} \tag{F.10a}$$

$$ZZ = \frac{I_{ZZ}}{y_{\max}} = \frac{\left(\frac{(2\,SAMAJ)^2\,(2\,SAMIN)}{4}\,2\,SAMAJ + \frac{2\,SAMAJ2}{6}\right)}{\frac{2\,SAMAJ2}{2}} + \frac{\frac{1}{12}\,(SAMAJ)(2\,SAMAJ2)^3\,\frac{E_{Shotcrete}}{E_{STEEL}}}{\frac{2\,SAMAJ2}{2}} \tag{F.10b}$$

Second moment area of I_{yy} for half section

$$I_{YY} = I_{YY\,STEEL} + I_{YY\,Shotcrete}\,\frac{E_{Shotcrete}}{E_{STEEL}} \tag{F.11a}$$

$$I_{YY\,STEEL} = 2\,I_{FYY\,FLANGE} + I_{WYY\,WEB} \tag{F.11b}$$

$$I_{YY\,STEEL} = 2\,\frac{1}{3}\,d^3\,t_f + \frac{1}{3}2(\frac{D}{2}-t_f)(\frac{t_w}{2})^3 \tag{F.12a}$$

$$t_f = t_w \tag{F.12b}$$

$$I_{YY\,STEEL} = 2\,\frac{1}{3}\,d^3\,t + \frac{1}{3}2(\frac{D}{2}-t)(\frac{t}{2})^3 \tag{F.12c}$$

If $t \ll D$ and $t \ll d$ $\quad I_{YY\,STEEL} = \frac{2}{3}\,d^3\,t$ (F.12d)

$$I_{YY\,Shotcrete} = I_{YY\,Shotcrete} + A_{Shotcrete}\left[d - \left(\frac{d-(t/2)}{2}\right)\right]^2 \tag{F.13a}$$

$$I_{YY\,Shotcrete} = \frac{1}{12}\,2(\frac{D}{2}-t)(d-(t/2))^3 + 2(\frac{D}{2}-t)(d-(t/2))\left[d - \left(\frac{d-(t/2)}{2}\right)\right]^2 \tag{F.13b}$$

$$I_{YY\,Shotcrete} = \frac{1}{6}\left(\frac{D}{2}-t\right)(d-(t/2))^3 + 2\left(\frac{D}{2}-t\right)(d-(t/2))\left[d-\left(\frac{d-(t/2)}{2}\right)\right]^2 \tag{F.13c}$$

$$I_{YY\,Shotcrete} = \left(\frac{D}{2}-t\right)\left[\frac{(d-(t/2))^3}{6} + \frac{1}{2}\,(d^2-(t^2/4)(d+\frac{t}{2})\right] \tag{F.13d}$$

$$\text{If } t \ll D \text{ and } t \ll d \quad I_{YY\,Shotcrete} = \left(\frac{1}{6}+\frac{1}{2}\right)\frac{D}{2}d^3 = \frac{1}{3}\,Dd^3 \tag{F.13e}$$

The equivalent steel section second moment of area

$$I_{YY} = I_{YY\,STEEL} + I_{YY\,Shotcrete}\,\frac{E_{Shotcrete}}{E_{STEEL}} \tag{F.14a}$$

$$I_{YY} = \frac{2}{3}\,d^3\,t + \frac{1}{3}\,Dd^3\,\frac{E_{Shotcrete}}{E_{STEEL}} \tag{F.14b}$$

The variables used in program are as shown in Fig. F.4

$$t = 2\,SAMIN,\; D = 2\,SAMAJ2,\; d = SAMAJ \tag{F.14c}$$

$$I_{YY} = \frac{2}{3}\,(SAMAJ)^3\,(2\,SAMIN) + \frac{1}{3}\,(2\,SAMAJ2)\,(SAMAJ)^3\,\frac{E_{Shotcrete}}{E_{STEEL}} \tag{F.14d}$$

$$ZY = \frac{I_{YY}}{z_{\max}} = \frac{I_{YY} = \frac{2}{3}\,d^3\,t + \frac{1}{3}\,Dd^3\,\frac{E_{Shotcrete}}{E_{STEEL}}}{\frac{d}{2}} \tag{F.15a}$$

$$ZY = \frac{I_{YY}}{z_{\max}} = \frac{I_{YY} = \frac{2}{3}\,(SAMAJ)^3\,(2\,SAMIN) +}{\frac{SAMAJ}{2}} \quad \frac{\frac{1}{3}\,(2\,SAMAJ2)\,(SAMAJ)^3\,\frac{E_{Shotcrete}}{E_{STEEL}}}{\frac{SAMAJ}{2}} \tag{F.15b}$$