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# **FINITE ELEMENT MODELLING OF TRANSPORTATION TUNNELS**

## **VOLUME II**

## **APPENDICES**

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**This thesis is submitted to the University of Durham  
for the Degree of Doctor of Philosophy**

**School of Engineering  
University of Durham  
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**30 OCT 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% l j7 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% l j7 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% l j7 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/m<sup>2</sup>)  
 C and the density is expressed  
 C in (kg/m<sup>3</sup>).

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
RERAINTS
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\$.002)**

1  
PAFEC PAGE 41

```

SYSTEM LEVEL 7.400 A
JUNE 1992

PHASE NO. 2
STARTS HERE

PPPPP AAAAA FFFFF EEEEE CCCCC
P P A A FF E C CC
P P A A FF E C
PPPPP AAAAA FFF EEE C
PP AA A F EE C
PP AA A F EE C
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 OF 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

ESTIMATE OF BASE AND FILE SIZE REQUIREMENTS (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\$.007)**

1  
PAFEC PAGE 112

SYSTEM LEVEL 7.400 A  
JUNE 1992

PHASE NO. 7  
STARTS HERE

```

PPPPP AAAAA FFFFF EEEEE CCCCC
P P A A FF E C CC
P P A A FF E C
PPPPP AAAAA FFF EEE C
PP AA A F EE C
PP AA A F EE C
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  
DISPLACEMENTS FOR LOAD CASE 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

PAFEC PAGE 130

CASE 1 NODE NUMBER	TRANSLATIONS MULTIPLIED BY 1E 3		RESULTANT TRANSLATION MULTIPLIED BY 1E 3		SCALED COORDINATES MULTIPLIED BY 1E 0		
	UX	UY	U	HISTOGRAM	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	

1

PAFEC PAGE 133

CASE 1 NODE NUMBER	TRANSLATIONS MULTIPLIED BY 1E 3		RESULTANT TRANSLATION MULTIPLIED BY 1E 3		SCALED COORDINATES MULTIPLIED BY 1E 0		
	UX	UY	U	HISTOGRAM	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

1  
PAFEC PAGE 151  
FORCES ON ELEMENTS  
=====

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	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

1  
PAFEC PAGE 157

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

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\$.009)

1  
PAFEC PAGE 158

```

SYSTEM LEVEL 7.400 A
JUNE 1992

PPPPP AAAAA FFFFF EEEEE CCCCC
P P A A FF E C CC
P P A A FF E C
PPPPP AAAAA FFF EEE C
PP AA A F EE C
PP AA A F EE C
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  
PAFEC PAGE 159  
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		LOAD	NODE	PRINCIPAL STRESSES			MAX. SHEAR	ANG. OF SIG-1		ELEMENT STRESSES.....		
NO	CASE	NO	SIGMA-1	SIGMA-2	SIGMA-3	STRESS	LOCAL	GLOBAL	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 STRESSES 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

1  
PAFEC PAGE 311

C O N T E N T S

HEADING	PAGE
PHASE 9	158
STRESSES FOR ELEMENT TYPE 36210	159

\*\*\*\*\*  
\*  
\* 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

```

PPPPPP AA FFFFFFFF EEEEEEE CCCC
PP PP AAAA FFF EE CC CC
PP PP AA AA FFF EE CC CC
PP PP AA AA FFF EE CC
PPPPPP AA AA FFFFF EEEEE CC
PP AAAAAA 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 EEEEE CCCC
    
```

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PPPPPP OOOO SSSS TTTTTT
PP PP OOOOO SS SS TT
PP PP OOO OOO SS SS TT
PP PP OO OO SS TT
PP PP OO OO SS TT
PPPPPP OO OO SSSS TT
PP OO OO SS TT
PP OO OO SS TT
PP OOO OOO SS SS TT
PP OOOOO SS SS TT
PP OOOO SSSS TT
    
```

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PPPPPP RRRRRR OOOO CCCC EEEEEEE SSSS SSSS OOOO RRRRRR
PP PP RR RR OOOOO CC CC EE SS SS SS SS OOOOO RR RR
PP PP RR RR OOO OOO CC CC EE SS SS OOO OOO RR RR
PP PP RR RR OO OO CC EE SS SS OO OO RR RR
PPPPPP RRRRRR OO OO CC EEEEE SSSS SSSS OO OO RRRRRR
PP RRRRR OO OO CC EEE SS SS OO OO RRRRR
PP RR RR OO OO CC EEE SS SS SS SS OO OO RR RR
PP RR RR OOO OOO CC CC EEE SS SS SS SS OOOOO RR RR
PP RR RR OOOOO CC CC EEE SS SS SS SS OOOOO RR RR
PP RR RR OOOO CCCC EEEEEEE SSSS SSSS OOOO RR RR
    
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1  
PAFEC PAGE 229

```

OOOO RRRRRR DDDDDD EEEEEEE RRRRRR 11
OOOOO RR RR DDDDDD EE RR RR 1111
OOO OOO RR RR DD DDD EE RR RR 1111
OO OO RR RR DD DD EE RR RR 11
OO OO RR RR DD DD EE RR RR 11
OO OO RRRRRR DD DD EEEEE RRRRRR 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
OOOOO RR RR DDDDDD EEE RR RR 11
OOOO RR RR DDDDDD EEEEEEE RR RR 1111111
    
```

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

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\*  
\* TABLE 1 OF 1 \*  
\*  
\*\*\*\*\*

LOAD CASE 1  
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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

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PAFEC PAGE 269  
LOAD CASE 1  
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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

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PAFEC PAGE 285

0000	RRRRRR	DDDDD	EEEEEEE	RRRRRR	2222
000000	RR RR	DDDDDD	EE RR RR	222222	
000 000	RR RR	DD DD	EE RR RR	22 22	
00 00	RR RR	DD DD	EE RR RR	22	
00 00	RR RR	DD DD	EE RR RR	22	
00 00	RRRRRR	DD DD	EEEEEE	RRRRRR	22
00 00	RRRRR	DD DD	EEE	RRRRR	222
00 00	RR RR	DD DD	EEE	RR RR	222
000 000	RR RR	DD DD	EEE	RR RR	22
000000	RR RR	DDDDDD	EEE	RR RR	22
0000	RR RR	DDDDD	EEEEEEE	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

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\* \*  
\* TABLE 1 OF 1 \*  
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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  
PAFEC PAGE 310

```

EEEEEEEE N NN DDDDD
EE NN NN DDDDDD
EE NNN NN DD DDD
EE NNNN NN DD DD
EE NNNNN NN DD DD
EEEEEE NNNNNNN DD DD
EEE NN NNNN DD DD
EEE NN NNNN DD DD
EEE NN NNN DD DDD
EEE NN NN DDDDDD
EEEEEEEE NN N DDDDD
    
```

```

OOO FFFFFFFF
OOOOO FFF
OOO OOO FFF
OO OO FFF
OO OO FFF
OO OO FFFFFFFF
OO OO FF
OO OO FF
OOO OOO FF
OOOOO FF
OOOO FF
    
```

```

PPPPPP RRRRRR OOOO CCCC EEEEEEE SSSS SSSS IIIIIII N NN GGGG
PP PP RR RR OOOOOO CC CC EE SS SS SS SS II NN NN GG GG
PP PP RR RR OO OO CC CC EE SS SS II NNN NN GG GG
PP PP RR RR OO OO CC CC EE SS SS II NNNN NN GG
PPPPPP RRRRRR OO OO CC EEEEE SSSS SSSS II NNNNNN GG
PP RRRRR OO OO CC EEE SS SS II NN NNNN GG GG
PP RR RR OO OO 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 EEEEEEE SSSS SSSS IIIIIII 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 HEIGHT 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 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]
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 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) = 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	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	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	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
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
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
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
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
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
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

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	123.99999999999999
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 30.5167535503308  
 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),



**B.2.2.1 A Three-Dimensional Model Nodal Co-ordinates and Element Topology Output File (file\$.002)**

1  
PAFEC PAGE 71

SYSTEM LEVEL 7.400 A	PPPPP	AAAAA	FFFFF	EEEE E	CCCCC
JUNE 1992	P P	A A	FF	E C	CC
	P P	A A	FF	E C	
PHASE NO. 2	PPPPP	AAAAA	FFF	EEE	C
STARTS HERE	PP	AA	A F	EE	C
	PP	AA	A F	EE	C
	PP	AA	A F	EE	C
	PP	AA	A F	EEEE	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  
PAFEC PAGE 102

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  
PAFEC PAGE 121

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

ESTIMATE OF BASE AND FILE SIZE REQUIREMENTS (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

```

SYSTEM LEVEL 7.400 A
JUNE 1992

PHASE NO. 7
STARTS HERE

PPPPP AAAAA FFFFF EEEEE CCCCC
P P A A FF E C CC
P P A A FF E C
PPPPP AAAAA FFF EEE C
PP AA A F EE C
PP AA A F EE C
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  
 DISPLACEMENTS FOR LOAD CASE 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	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			RESULTANT TRANSLATION MULTIPLIED BY 1E 3		SCALED COORDINATES MULTIPLIED BY 1E 0		
	UX	UY	UZ	U	HISTOGRAM	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

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CASE 1 NODE NUMBER	TRANSLATIONS MULTIPLIED BY 1E 3			RESULTANT TRANSLATION MULTIPLIED BY 1E 3		SCALED COORDINATES MULTIPLIED BY 1E 0		
	UX	UY	UZ	U	HISTOGRAM	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

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CASE 1 NODE NUMBER	TRANSLATIONS MULTIPLIED BY 1E 3			RESULTANT TRANSLATION MULTIPLIED BY 1E 3	HISTOGRAM	SCALED COORDINATES MULTIPLIED BY 1E 0		
	UX	UY	UZ			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

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

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CASE 1 NODE NUMBER	TRANSLATIONS MULTIPLIED BY 1E 3			RESULTANT TRANSLATION MULTIPLIED BY 1E 3		SCALED COORDINATES MULTIPLIED BY 1E 0		
	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

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CASE 1 NODE NUMBER	TRANSLATIONS MULTIPLIED BY 1E 3			RESULTANT TRANSLATION MULTIPLIED BY 1E 3		SCALED COORDINATES MULTIPLIED BY 1E 0		
	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

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FORCES ON ELEMENTS  
=====

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	ELEM	GROUP	LOAD	NODE	AXIS	FORCES		
NUMB	TYPE	NUMB	CASE	NUMB	SET	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

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ELEM NUMB	ELEM TYPE	GROUP NUMB	LOAD CASE	NODE NUMB	AXIS SET	F-X	FORCES 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

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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\$.009)**

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SYSTEM LEVEL 7.400 A	PPPPP	AAAA	FFFF	EEEE	CCCC
JUNE 1992	P P A A	FF	E	C	CC
	P P A A	FF	E	C	
PHASE NO. 9	PPPPP	AAAA	FFF	EEE	C
STARTS HERE	PP	AA	A F	EE	C
	PP	AA	A F	EE	C
	PP	AA	A F	EE	C
	PP	AA	A F	EEEE	CCCC

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 STRESSES - AX, AY AND AZ ARE THE ANGLES OF SIGMA-1 TO THE GLOBAL AXES  
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 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  
-----

ELEMENT NO.	1																			
1 1	.00D+00	.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	.00D+00	0	90	90	90	0	90						
1 69	.00D+00	.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	.00D+00	0	90	90	90	0	90						
1 0	.00D+00	.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	.00D+00	0	90	90	90	0	90						
1 453	.00D+00	.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	.00D+00	0	90	90	90	0	90						
1 521	.00D+00	.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	.00D+00	0	90	90	90	0	90						
1 0	.00D+00	.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	.00D+00	0	90	90	90	0	90						
1 0	.00D+00	.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	.00D+00	0	90	90	90	0	90						
1 0	.00D+00	.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	.00D+00	0	90	90	90	0	90						
1 0	.00D+00	.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	.00D+00	0	90	90	90	0	90						
1 3	.00D+00	.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	.00D+00	0	90	90	90	0	90						
1 71	.00D+00	.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	.00D+00	0	90	90	90	0	90						
1 0	.00D+00	.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	.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

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LOAD CASE NO	GLOBAL STRESSES	PRINCIPAL STRESSES			VON MISES STRESS	ANGS. OF PRINCIPAL DIRECTIONS						
	SIGMA-X	SIGMA-Y	SIGMA-Z	SIGMA-1	SIGMA-2	SIGMA-3	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 89 179				
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 89 179				
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				

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MAJORITY OF STRESSES OMITTED

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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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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

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ELEMENT NO. 253

1 357	.00D+00	.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	.00D+00	0	90	90	90	0	90
1 69	.00D+00	.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	.00D+00	0	90	90	90	0	90
1 0	.00D+00	.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	.00D+00	0	90	90	90	0	90
1 809	.00D+00	.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	.00D+00	0	90	90	90	0	90
1 521	.00D+00	.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	.00D+00	0	90	90	90	0	90
1 0	.00D+00	.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	.00D+00	0	90	90	90	0	90
1 0	.00D+00	.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	.00D+00	0	90	90	90	0	90
1 0	.00D+00	.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	.00D+00	0	90	90	90	0	90
1 0	.00D+00	.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	.00D+00	0	90	90	90	0	90
1 359	.00D+00	.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	.00D+00	0	90	90	90	0	90
1 71	.00D+00	.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	.00D+00	0	90	90	90	0	90
1 0	.00D+00	.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	.00D+00	0	90	90	90	0	90
1 811	.00D+00	.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	.00D+00	0	90	90	90	0	90
1 523	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	.00D+00	0	90	90	90	0	90

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MAJORITY OF STRESSES OMITTED

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ELEMENT NO. 356

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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
1
PAFEC PAGE 545
    
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AVERAGED STRESSES FOR NODES WRITTEN TO BLOCKS 97 TO 143 OF THE STRESS FILE

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1
PAFEC PAGE 614
    
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C O N T E N T S  
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HEADING PAGE
-----
PHASE 9 352
STRESSES FOR ELEMENT TYPE 37110 353
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1
PAFEC PAGE 615
    
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*****
* 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 EEEEE      CC
PP      AAAAAAA      FF      EEE      CC
PP      AA  AA      FF      EEE      CC
PP      AA  AA      FF      EEE      CC  CC
PP      AA  AA      FF      EEEEEEE      CCCC
    
```

```

PPPPPPP      OOOO      SSSS      TTTTTTTT
PP  PP      OOOOO      SS  SS      TT
PP  PP      OO  OO      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      OOOOO      SS  SS      TT
PP      OOOO      SSSS      TT
    
```

```

PPPPPPP  RRRRRR  OOOO  CCCC  EEEEEEEE  SSSS  SSSS  OOOO  RRRRRR
PP  PP  RR  RR  OOOOO  CC  CC  EE  SS  SS  SS  SS  OOOOO  RR  RR
PP  PP  RR  RR  OO  OO  CC  CC  EE  SS  SS  SS  OO  OO  RR  RR
PP  PP  RR  RR  OO  OO  CC  CC  EE  SS  SS  SS  OO  OO  RR  RR
PPPPPPP  RRRRRR  OO  OO  CC  EEEEE  SSSS  SSSS  OO  OO  RRRRRR
PP      RRRR  OO  OO  CC  EEE  SS  SS  OO  OO  RRRR
PP      RR  RR  OO  OO  CC  CC  EEE  SS  SS  SS  SS  OO  OO  RR  RR
PP      RR  RR  OOOOO  CC  CC  EEE  SS  SS  SS  SS  OOOOO  RR  RR
PP      RR  RR  OOOO  CCCC  EEEEEEE  SSSS  SSSS  OOOO  RR  RR
    
```

1  
PAFEC PAGE 558

```

OOOO  RRRRRR  DDDDD  EEEEEEE  RRRRRR  11
OOOOO  RR  RR  DDDDD  EE  RR  RR  1111
OOO  OO  RR  RR  DD  DD  EE  RR  RR  1111
OO  OO  RR  RR  DD  DD  EE  RR  RR  11
OO  OO  RRRRRR  DD  DD  EEEEE  RRRRRR  11
OO  OO  RRRR  DD  DD  EEE  RRRR  11
OO  OO  RR  RR  DD  DD  EEE  RR  RR  11
OOO  OO  RR  RR  DD  DD  EEE  RR  RR  11
OOOOO  RR  RR  DDDDD  EEE  RR  RR  11
OOOO  RR  RR  DDDDD  EEEEEEE  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 559

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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+01	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

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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

```

EEEEEEEE N   NN DDDDD
EE       NN  NN DDDDDD
EE       NNN  NN DD  DDD
EE       NNNN NN DD  DD
EE       NNNN NN DD  DD
EEEEEE   NNNNNN DD  DD
EEE      NN NNNN DD  DD
EEE      NN NNNN DD  DD
EEE      NN  NNN DD  DDD
EEE      NN   NN DDDDDD
EEEEEEEE NN   N  DDDDD
    
```

```

      0000 FFFFFFFF
    000000 FFF
  000 000 FFF
00  00 FFF
00  00 FFF
00  00 FFFFFF
00  00 FF
00  00 FF
000 000 FF
000000 FF
      0000 FF
    
```

```

PPPPPPP RRRRRR   0000   CCCC EEEEEEE SSSS   SSSS  I1111111 N   NN   GGGG
PP  PP  RR  RR  000000  CC  CC  EE      SS  SS  SS  SS  II   NN  NN  GG  GG
PP  PP  RR  RR  000 000  CC  CC  EE      SS  SS  SS  SS  II   NNN  NN  GG  GG
PP  PP  RR  RR  00  00  CC      EE      SS      SS      II   NNNN  NN  GG
PPPPPPP RRRRRR  00  00  CC      EEEEEE  SSSS   SSSS  II   NNNNNNN  GG
PP      RRRRR  00  00  CC      EEE      SS      SS      II   NN  NNNN  GG  GGG
PP      RR  RR  00  00  CC      EEE      SS  SS  SS  SS  II   NN  NNN  GG  GG
PP      RR  RR  000000  CC  CC  EEE      SS  SS  SS  SS  II   NN  NN  GG  GG
PP      RR  RR  0000   CCCC EEEEEEE SSSS   SSSS  I1111111 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 HEIGHTS 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(DD0))*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 PROPEY OF THE INNER LINING ?'
READ*,KINNER

WRITE(6,*)'WHAT IS THE THICKNESS OF THE INNER LINING ?'
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 ANGPRES
      CALL CENPRE
      CALL HFXPRE
      CALL ANCPRE
      CALL ROKPRE
      CALL SHLPRB
      CALL ZSZPRB
      CALL KEYPRE
      CALL INXPRES

      RETURN
      END

C =====
C SUBROUTINE ARBPRE3 SET ARBITRARY 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 ANGPRES FOR SETTING ANGLES OF TUNNEL GEOMETRY
C =====

      SUBROUTINE ANGPRES

      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 HEIGHTS OF TUNNEL

```

```

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

```

```

C HFX(8) IS EQUAL HEIGHT 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 HEIGHT OF NODE NUMBER 21, Y(21+NMIDA+NMIDC)
  HFX(13)=-0.5D0

```

```

C HFX(15) IS EQUAL HEIGHT 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 HEIGHT 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 / CHFEXPR / 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 / CANCEPR / 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 HEIGHT 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)

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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 INXPRES SET SHELL TO ROW INDEX CONVERSION
C =====

  SUBROUTINE INXPRES

  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 / CINDE / 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) = 1 - 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(0)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 VARIING 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)

```

```

        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, HUNDR
COMMON / CKEYPR / K(0:8), NNS, NBS, NPOT, NPLR, NNODE, NPAF
COMMON / CHFXP / 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) COORDINATES
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 / CHFXP / HFX(17)
      COMMON / CSHLPR / NSHELL, HIN(5),SUMR
      COMMON / CANCEPR / 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

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, HUNDR
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 / CHFXP / HFX(17)
COMMON / CROKPR / MATPRO(20), HTOP(4), HMIDA(4), HMIDC(4),
& HBOT(4),NMIDA,NMIDC,NTOP,NBOT
COMMON / CANCEPR / 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-

```

```

&          (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

```

```

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 / CANCEPR / 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 =====

```

```

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 / CHFXP / 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 / CANCEPR / 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  $(x_b-x_0)^2 + (y_b-y_0)^2 = \text{Radius}^2$  (1)
C A straight line passing through A at angle alpha is;
C  $x_b = x_a + q \cos(\alpha)$  (2a)
C  $y_b = y_a + q \sin(\alpha)$  (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 / CANCEPR / 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 HORIZONTAL
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 / CANCEPR / XA(9),YA(9)

C IN FIRST LAYER X-POSITIONS OF CORNER NODES SET BY EXCAVATION 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(1+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 INSIDE 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 / CANCEPR / 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 LRTO
        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+1)
C 1. NROW = NSUB(NSHELL+NCOL+1)

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 / CNOES / 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 HEIGHT OF SHELLS IS USED THE CALCULATION OF DIVIDING THE SHELLS
C THE HEIGHT BETWEEN LAST SHELL AND ONE BEFORE IS THE LARGEST HEIGHT (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 / CNOES / 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,*)Ipadf
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,*)Ipadf
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, HUNDR
      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 (1.LE.KPSH(4)) THEN
  Q1=H*(5.9D0/7.9D0)+R1
  Q2=H*(5.9D0/7.9D0)+R2
ELSE IF (1.LE.KPSH(6)) THEN
  Q1=H*(7.8D0/7.9D0)+R1
  Q2=H*(7.8D0/7.9D0)+R2
ELSE IF (1.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(1))
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(1)) = 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+1)
      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+1) = 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+1)
          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+1) = 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, HUNDR
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+1)  
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+1)=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 (15,10X,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 (1.EQ.1) NANCH = KPSH(2)+KPSH(3)+1  
 IF (1.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*NNSUB(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 ((1.LE.KPSH(6)).OR.(1.GT.NBS-KPSH(6)))THEN
          IF ( (MSYM.EQ.0) .OR. (1.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 = 2DO*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(2I10,5E10.3,15)

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 HEIGHT OF TUNNEL IN METERS = ',H
  WRITE(8,*)'C HEIGHT 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 HEIGHT OF FLATTENED SHELL NUMBER',
& ISHELL,'IN METERS = ',HIN(ISHELL)
    ELSE
        WRITE(8,*)'C HEIGHT 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 LENGTH 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 LINING=',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 QUADRILATERAL 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
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
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 LININGS

      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(IDEPH,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 (IDEPH)

      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+I-1)
          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).'
```

MATERIAL	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

```

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, 1, 0
c  WRITE(8,*)19+K(1),      1, 1, 0
c  WRITE(8,*)19+K(1)+NNS*NSHELL, 1, 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,14,9X,12,9X,12,13X,12)

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

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        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(A2,16,3X,F9.4,2X,F9.4,2X,F9.4,20X,16,3X,F9.4,2X,F9.4,2
&X,F9.4)
903  FORMAT(3X,16,2X,3(F9.4,2X))
910  FORMAT(A2,16,4X,13,3X,16,5X,13,4X,13,9(2X,16))
911  FORMAT(2X,16,2X,13,2X,16,2X,13,9(2X,16))
912  FORMAT(A2,39X,9(2X,16))
913  FORMAT('* ',25X,9(2X,16))
914  FORMAT(11(2X,16))
915  FORMAT(7(2X,16))
916  FORMAT(A3,16,2X,16)
917  FORMAT(14)
*
        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,*)'Unaveraged 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 separate 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 Calculate 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
220             DO 220 J=1,6
               USTR(J,K) = ASTR(NN(I,K),J,2,K)
           ELSE
230             DO 230 J=1,6
               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
270             DO 270 J=1,6
               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,I,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
      ENDF
      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 Calculate 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
      USTR(J,K) = ASTR(NN(I,K),J,1,K)
510      ELSE IF (A2.LE.A3) THEN
      DO 520 J=1,6
      USTR(J,K) = ASTR(NN(I,K),J,2,K)
520      ELSE
      DO 530 J=1,6
      USTR(J,K) = ASTR(NN(I,K),J,3,K)
530      ENDF

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)
        ENDF

      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')
    ENDF

    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
    ENDOF
    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
90    DO 70 J=1,5
        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(A1,15,E14.4)
204  FORMAT(3X,17,3E14.5)
*
      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 Initialize Number of Stress Entries 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 Calculate 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(A1,15,3X,3(A9))
903  FORMAT(6X,15,3X,3(A9))
904  FORMAT(A1,15,6X,2(A9))
910  FORMAT(A2,16,4X,13,3X,16,5X,13,4X,13,9(2X,16))
911  FORMAT(2X,16,2X,13,2X,16,2X,13,9(2X,16))
912  FORMAT(A2,39X,9(2X,16))
913  FORMAT('!',25X,9(2X,16))
914  FORMAT(9(2X,16))
915  FORMAT(7(2X,16))
916  FORMAT(A3,16,2X,16)
917  FORMAT(14)
*
      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

```

```

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

```

```

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 / NTOPLY(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),NTOPLY(IE(NM)),
&      (E(IE(NM),J),J=1,NTOPLY(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 quadrilateral drawing
      IF (NTOPLY(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, initialized 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(I)=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, initialized 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 / NTOPI(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)
            STRNOD(NOD) = STRNOD(NOD) / 1E5
            DO 10 J=1,NTOPY(IEL)
                USTR(IEL,J)=STRNOD(E(IEL,J))
            10    CONTINUE
        5    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 / NTOPI(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(1EL)
          ASTR(1EL,J)=STRNOD(E(1EL,J))
          IF (ASTR(1EL,J).EQ.0.0)ASTR(1EL,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 Arbitrary 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 veiwier 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 Palette 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 Palette 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 CSR4S(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/0,1,1,0,0,1,1,0,1,1,1,0,0,0,0,0,1,1,0,0,1,1,0/
c   DATAYB/1,1,1,0,0,0,0,0,1,1,0,0,1,1,0,0,0,1,1,0,0,1,1,0/
c   DATAZB/0,0,1,1,0,0,1,1,0,0,1,1,0,0,1,1,0,0,1,1,1,1,0,0,0,0/
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,' °C',1100.0,465.0)
CALL GCLOPT(NCHAR,CSTXT,4.5*SF,1,0.0,1)
CALL GCOSCL(1015.0,350.0)

ENDIF
*
C Draw Projection 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.

$$C_1 \rightarrow \beta_4 = 37^\circ \quad r_1 = h = 7.90m \quad (5.1a)$$

$$C_2 \rightarrow \beta_8 = 47^\circ \quad r_2 = h \times \frac{r_2 = 5.90}{7.90} \quad (5.1b)$$

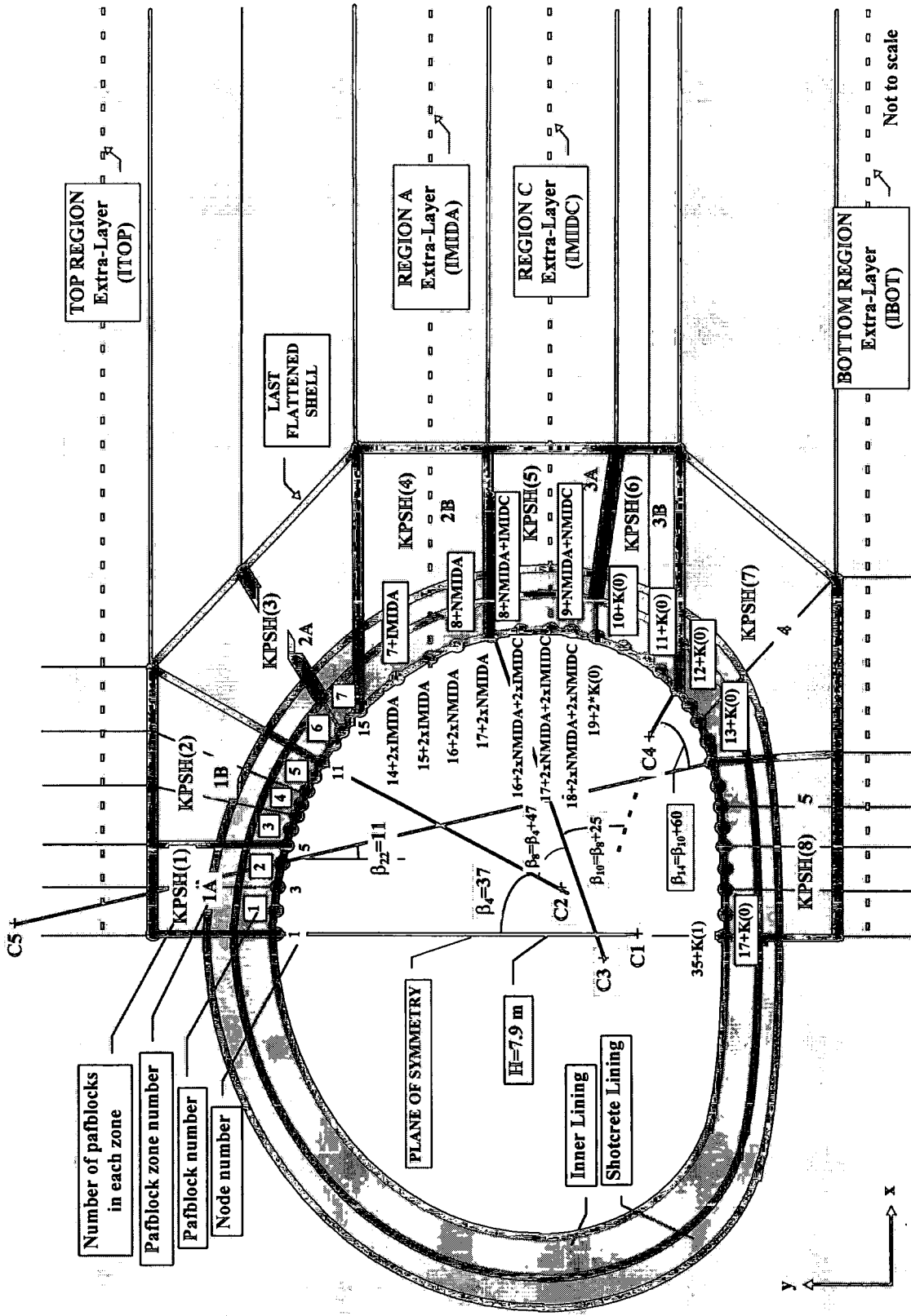
$$C_3 \rightarrow \beta_{10} = 25^\circ \quad r_3 = h \times \frac{r_3 = 7.80}{7.90} \quad (5.1c)$$

$$C_4 \rightarrow \beta_{14} = 60^\circ \quad r_4 = h \times \frac{r_4 = 0.95}{7.90} \quad (5.1d)$$

$$C_5 \rightarrow \beta_{22} = 11^\circ \quad r_5 = h \times \frac{r_5 = 34.12}{7.90} \quad (5.1e)$$

<b>IPSH (Shell pafblock counter)</b>	1	2	3	4	5	6	7	8
<b>KPSH (Number of pafblock in each zone)</b>	2	3	2	1+NMIDA	2+NMIDC	1+NMIDC	2	4
<b>Cumulative number of pafblock</b>	2	5	7	8+NMIDA	9+NMIDA +NMIDC	11+K(0)	13+K(0)	17+K(0)
<b>Zones</b>	1A	1B	2A	2B	3A	3B	4	5
<b>Node number</b>								
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**





```

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

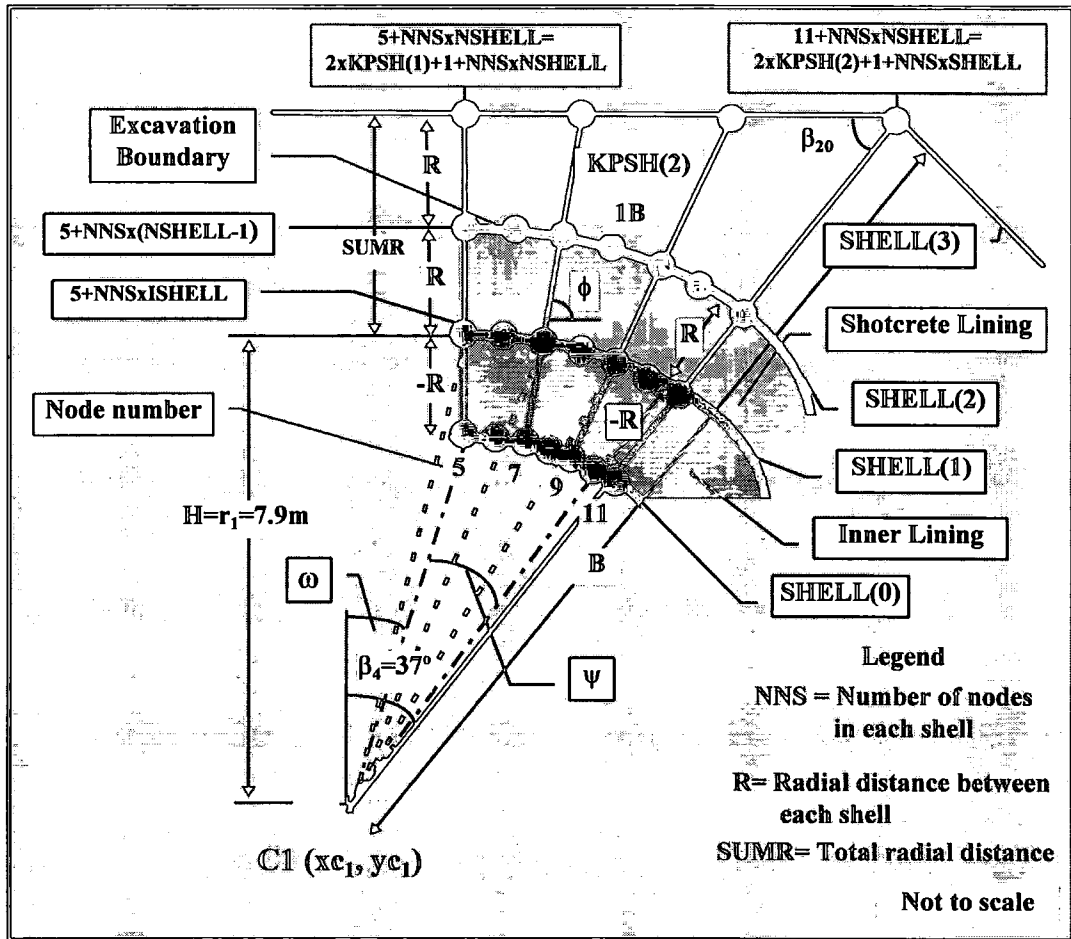


Fig. E.4 Shell node co-ordinates for zone 1B

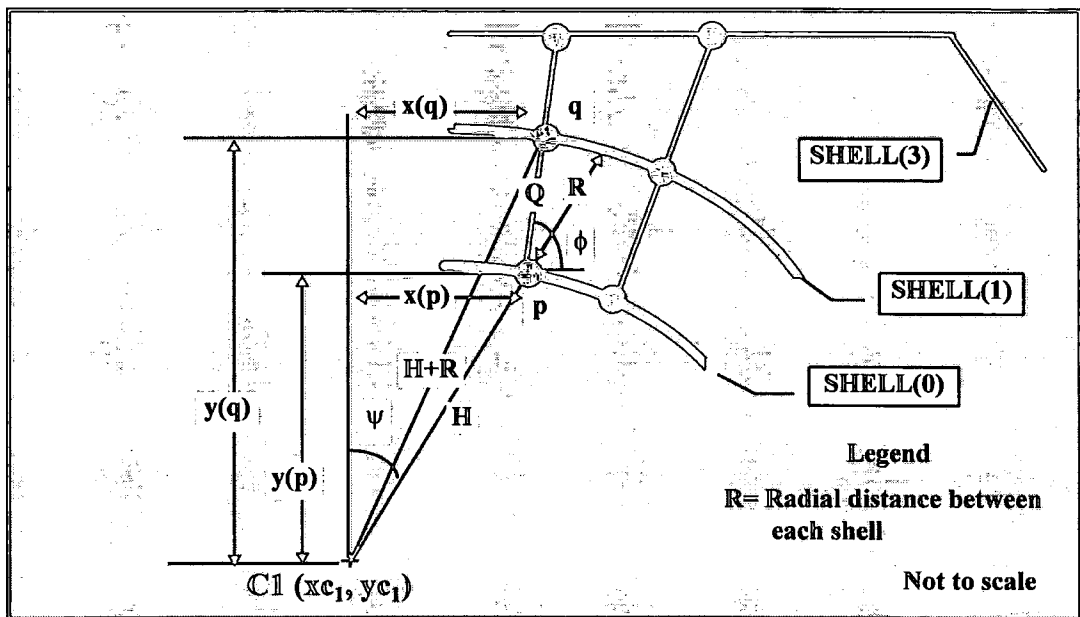


Fig. E.5 Shell node co-ordinate calculations using first and last flattened shells

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  $\phi$  to the horizontal.

$$x(q) = x(p) + Q \cos\phi \quad (3)$$

$$y(q) = y(p) + Q \sin\phi \quad (4)$$

From equation (1)

$$(x(p) + Q \cos\phi)^2 + (y(p) + Q \sin\phi)^2 = (H + R)^2 \quad (5a)$$

$$x^2(p) + Q^2 \cos^2\phi + 2x(p)Q \cos\phi + y^2(p) + Q^2 \sin^2\phi + 2y(p)Q \sin\phi = (H + R)^2 \quad (5b)$$

$$Q^2 (\cos^2\phi + \sin^2\phi) + 2Q(x(p)\cos\phi + y(p)\sin\phi) + x^2(p) + y^2(p) - (H + R)^2 = 0 \quad (5c)$$

$$Q^2 + 2Q(x(p)\cos\phi + y(p)\sin\phi) + H^2 - (H + R)^2 = 0 \quad (5d)$$

$$Q^2 + 2Q(x(p)\cos\phi + y(p)\sin\phi) + H^2 - (H^2 + R^2 + H + R) = 0 \quad (5e)$$

$$Q^2 + 2Q(x(p)\cos\phi + y(p)\sin\phi) - (2HR + R^2) = 0 \quad (5f)$$

$$aQ^2 + bQ + c = 0 \quad (5g)$$

$$a = 1 \quad (5h)$$

$$b = 2(x(p)\cos\phi + y(p)\sin\phi) \quad (5k)$$

$$c = -(2HR + R^2) \quad (5m)$$

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

```

Continued on next page

Continued from previous page

```

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

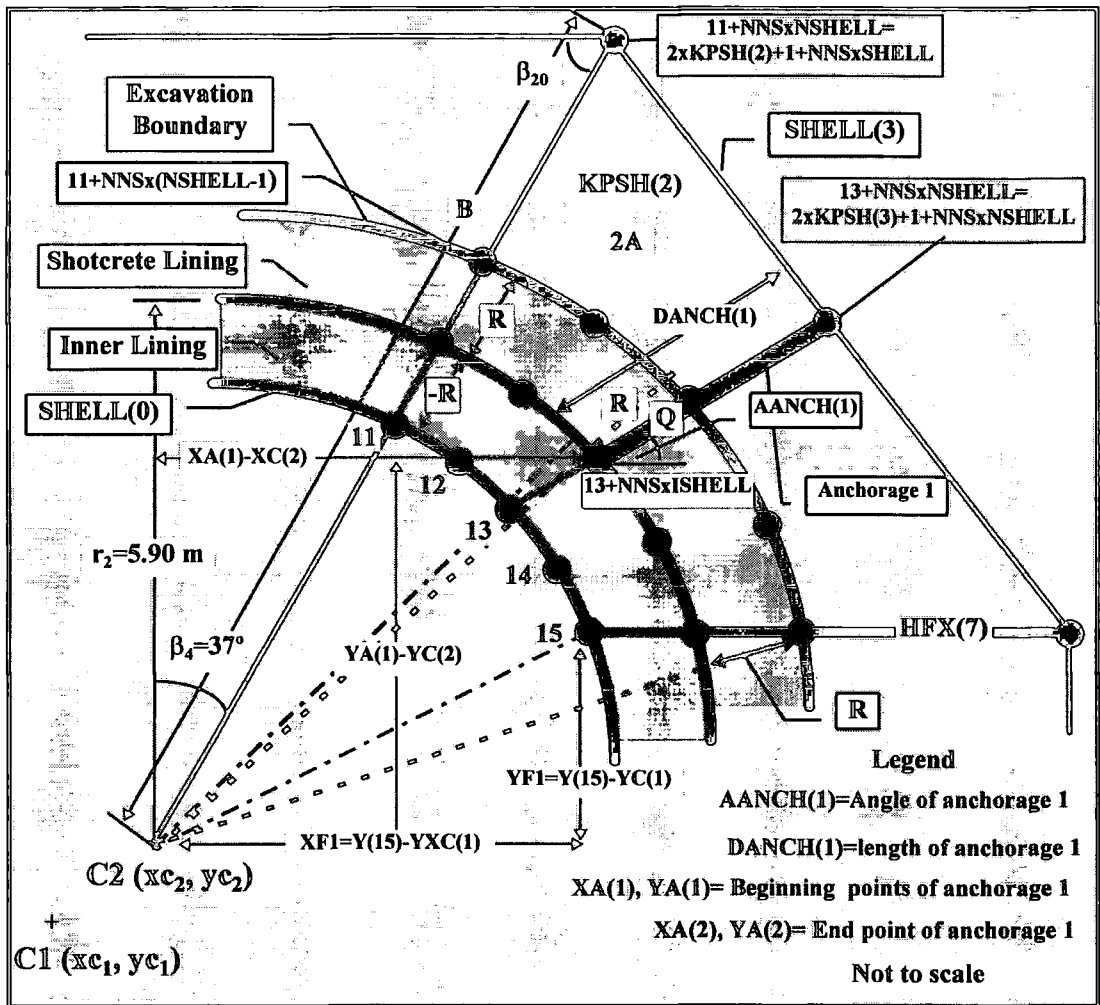


Fig. E.7 Shell node co-ordinates for zone 2A

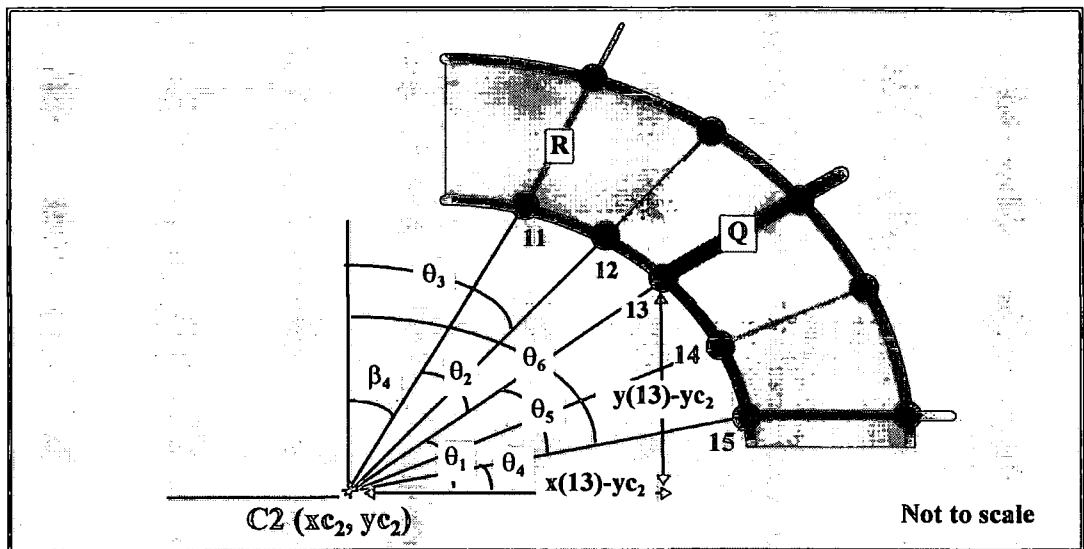


Fig. E.8 Centralising the midside nodes for 2A

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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 / CANCEPR / 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;

$$C \quad (xb-x0)^2 + (yb-y0)^2 = \text{Radius}^2 \quad (1)$$

C A straight line passing through A at angle alpha is;

$$C \quad xb = xa + q \cos(\alpha) \quad (2a)$$

$$C \quad yb = ya + q \sin(\alpha) \quad (2b)$$

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.

$$A=1$$

$$B= 2D0*((XA(1)-XC(2)) * DCOS(AANCH(1))$$

$$\& \quad +(YA(1)-YC(2)) * DSIN(AANCH(1)))$$

$$C= -2D0*H*(5.9D0/7.9D0)*R - R*R$$

$$Q= (-B + \text{SQRT}(B*B-4*A*C)) / (2D0*A)$$

$$X(NANCH+NNS*ISHELL)=XA(1)+Q*DCOS(AANCH(1))$$

$$Y(NANCH+NNS*ISHELL)=YA(1)+Q*DSIN(AANCH(1))$$

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

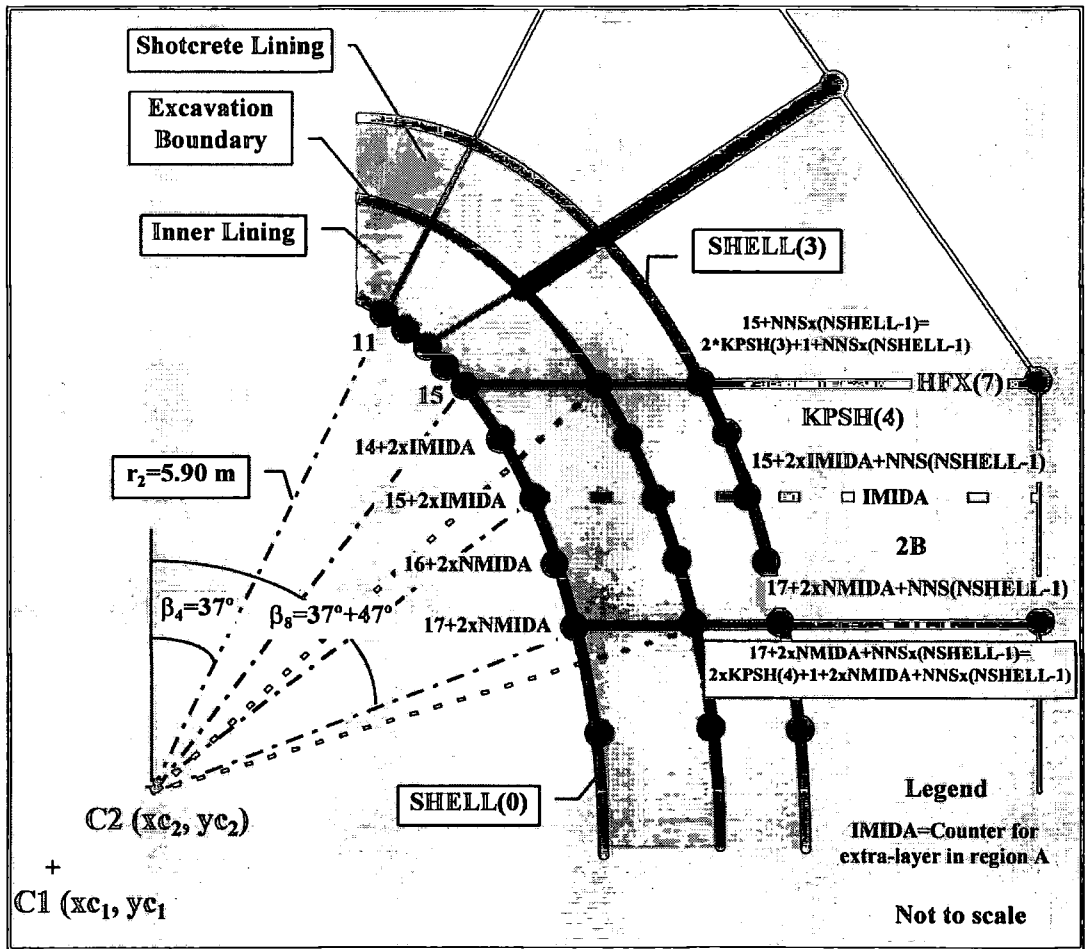


Fig. E.10 Shell node co-ordinates for zone 2B

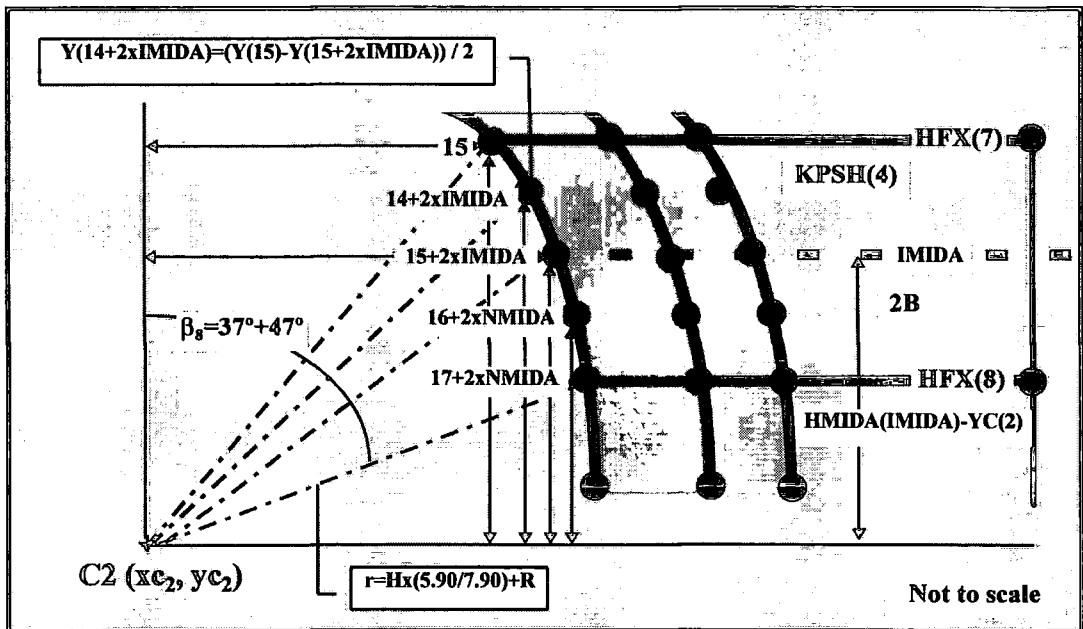


Fig. E.11 Centralising the midside nodes for zone 2B

```

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 / CANCEPR / 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

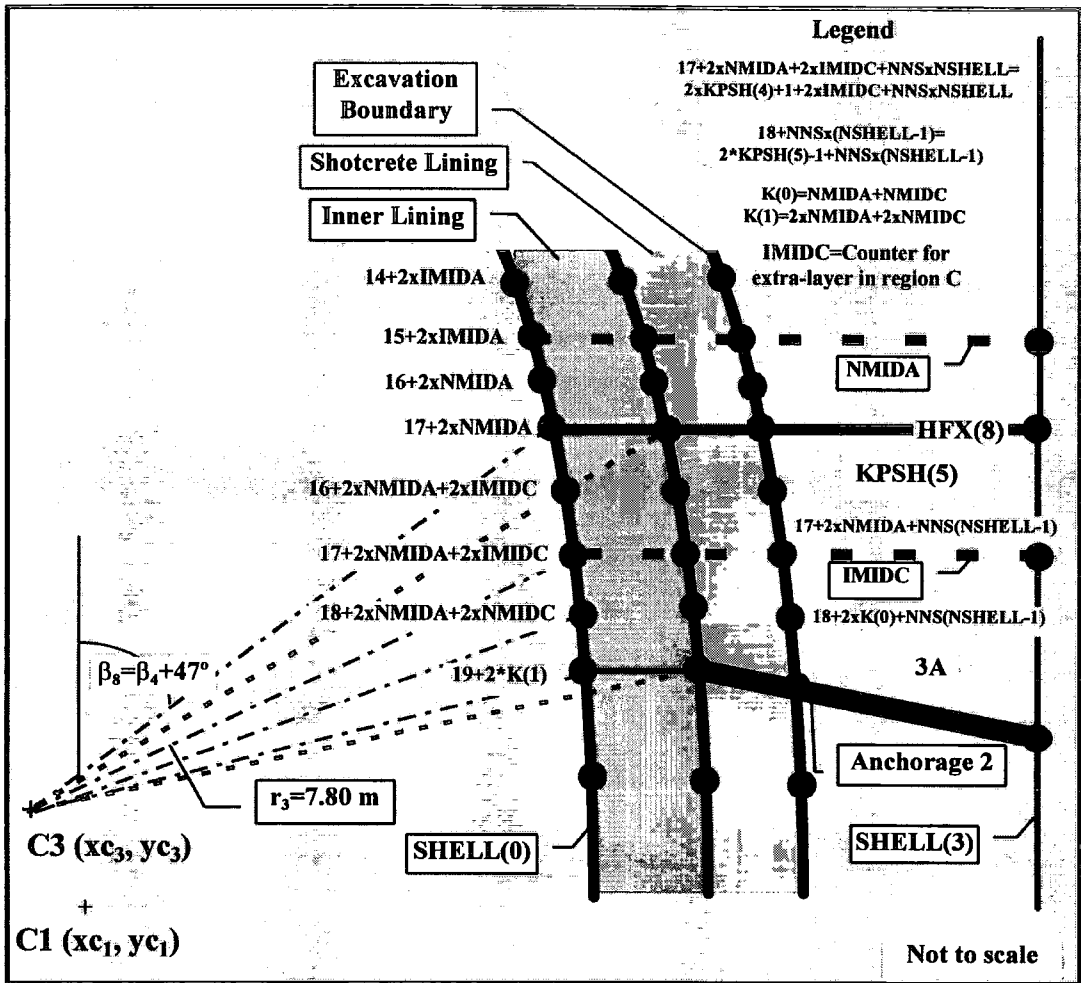


Fig. E.13 Shell node co-ordinates for zone 3A

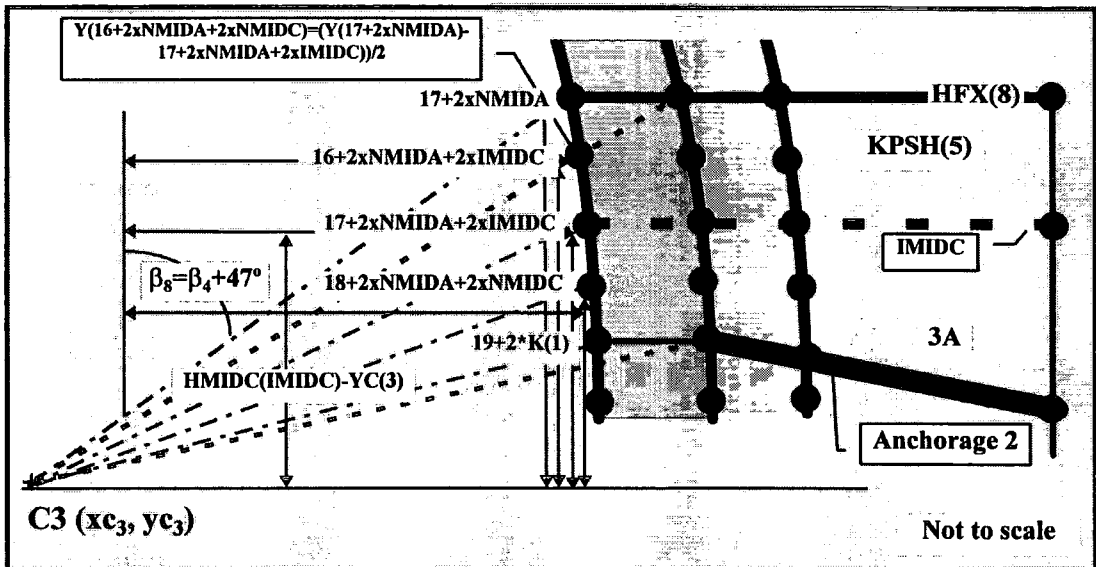


Fig. E.14 Centralising midside nodes for zone 3A

```

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 / CHFXP / 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 / CANCEPR / XA(9),YA(9)

C ITERATIVE LAYER'S NODES COORDINATES 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

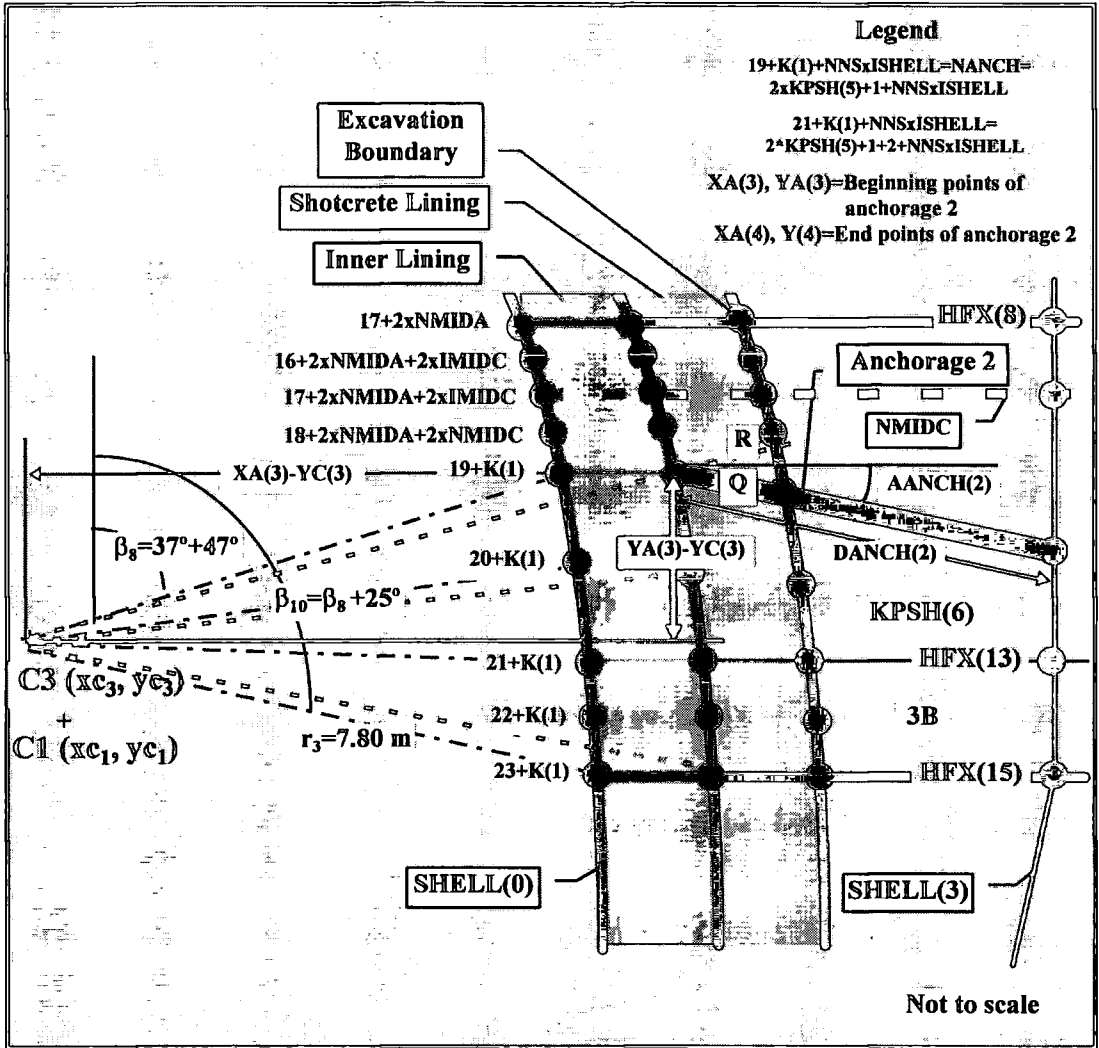


Fig. E.16 Shell node co-ordinates for zone 3B

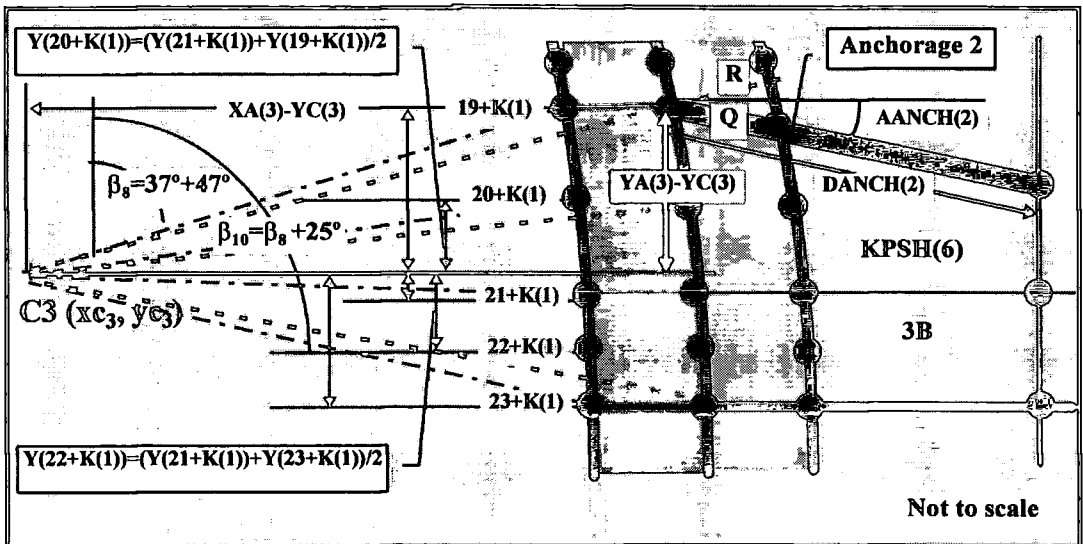


Fig. E.17 Centralising midside nodes for zone 3B

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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 / CHFXP / 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 / CANCEPR / 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  $(x_b-x_0)^2 + (y_b-y_0)^2 = \text{Radius}^2$  (1)
C A straight line passing through A at angle alpha is;
C  $x_b = x_a + q \cos(\alpha)$  (2a)
C  $y_b = y_a + q \sin(\alpha)$  (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

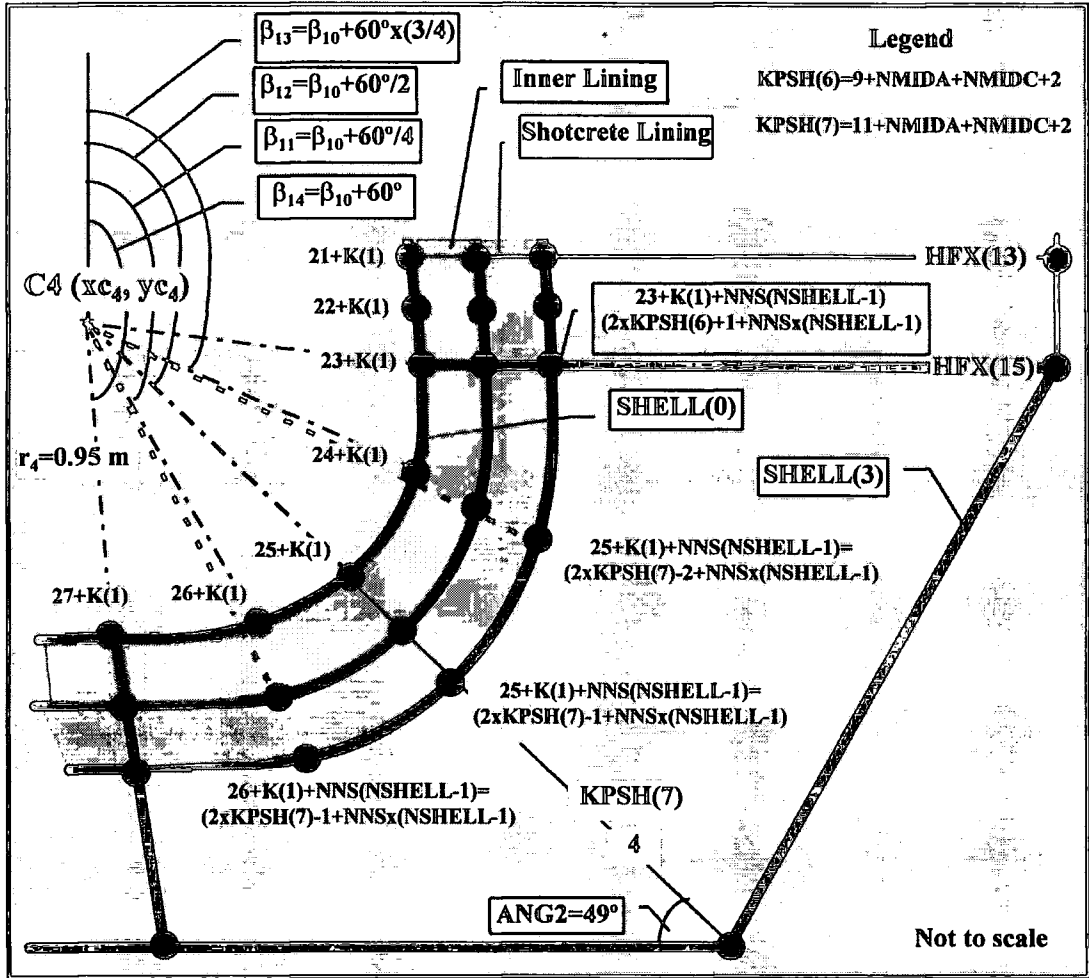


Fig. E.19 Shell node co-ordinates for zone 4

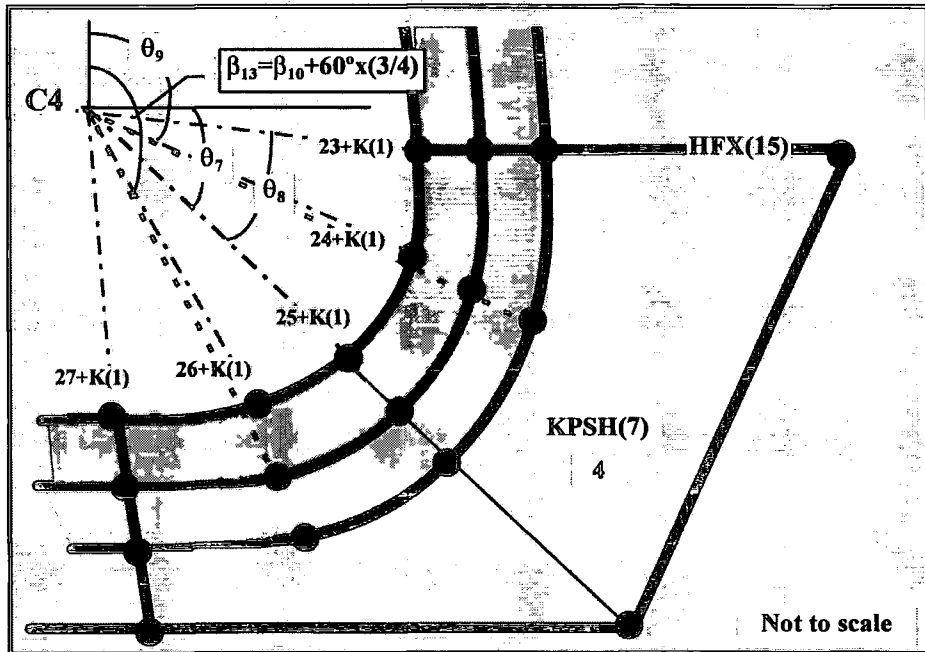


Fig. E.20 Centralising midside nodes for zone 4

```

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

  ENDF

  RETURN
  END

```

Fig. E.21 Shell node co-ordinates calculations for zone 4

E.9 Shell Node Co-ordinate Calculations for Zone 5

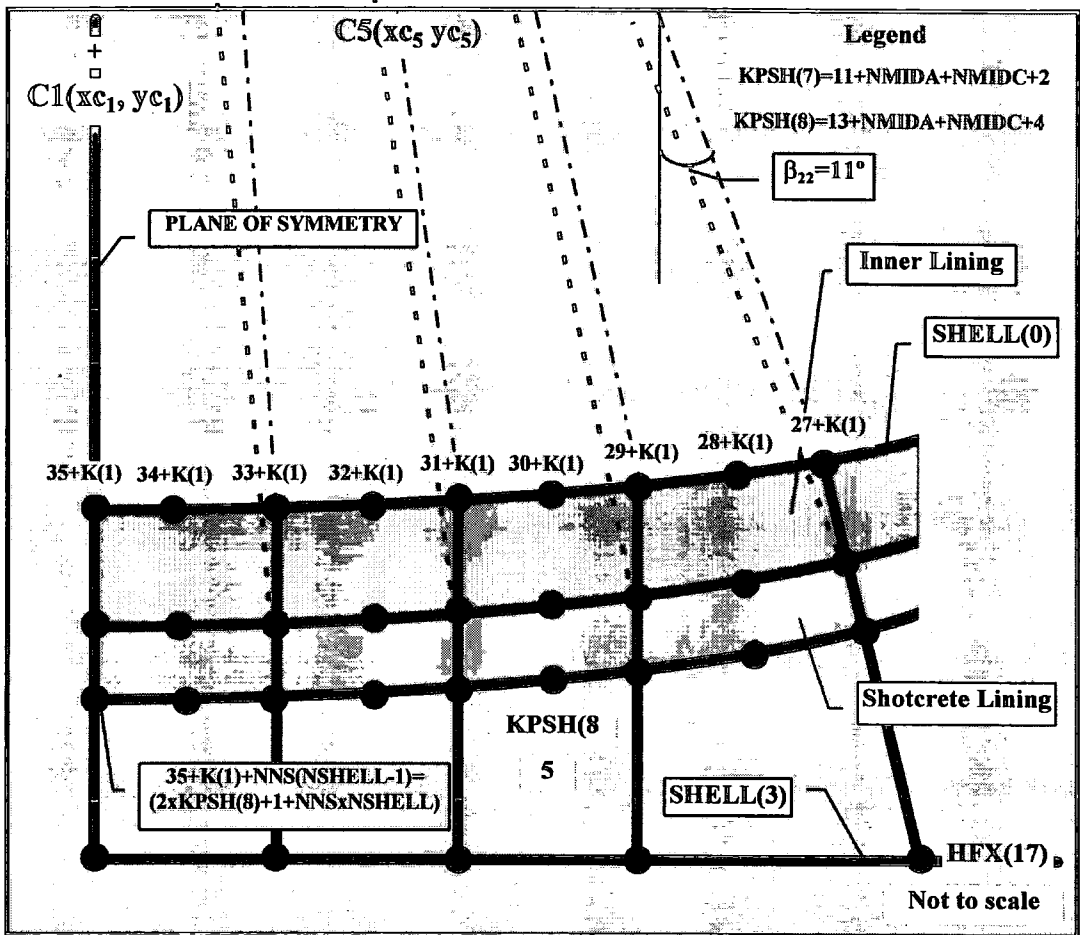


Fig. E.22 Shell node co-ordinates for zone 5

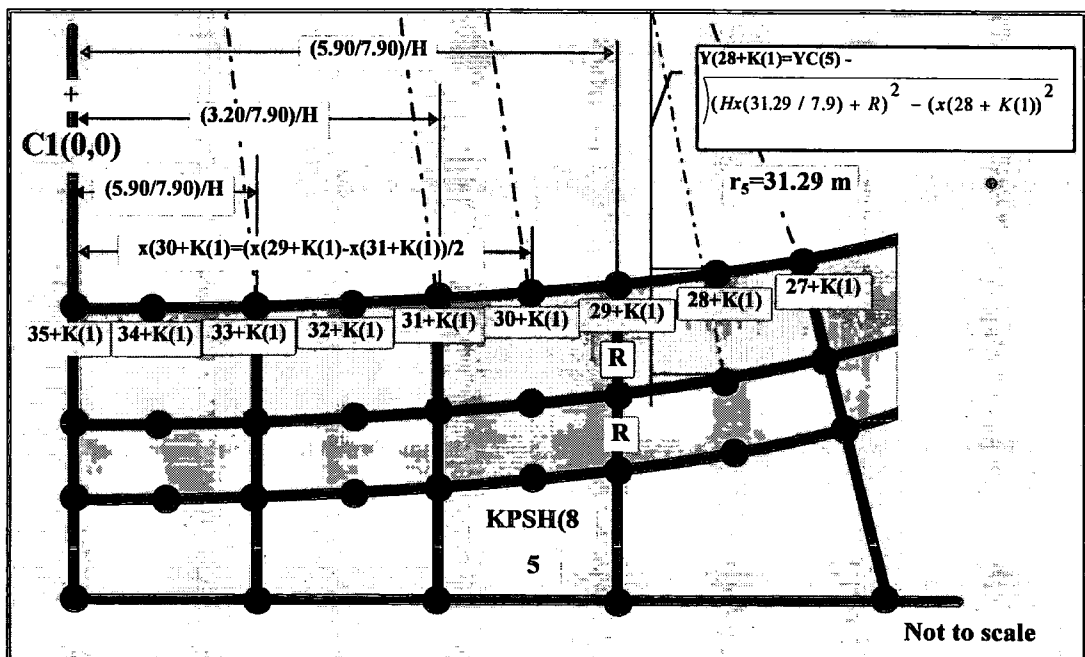


Fig. E.23 Centralising midside nodes for zone 5

```

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 / CANCEPR / XA(9),YA(9)

C IN FIRST LAYER X-POSITIONS OF CORNER NODES SET BY EXCAVATION
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.

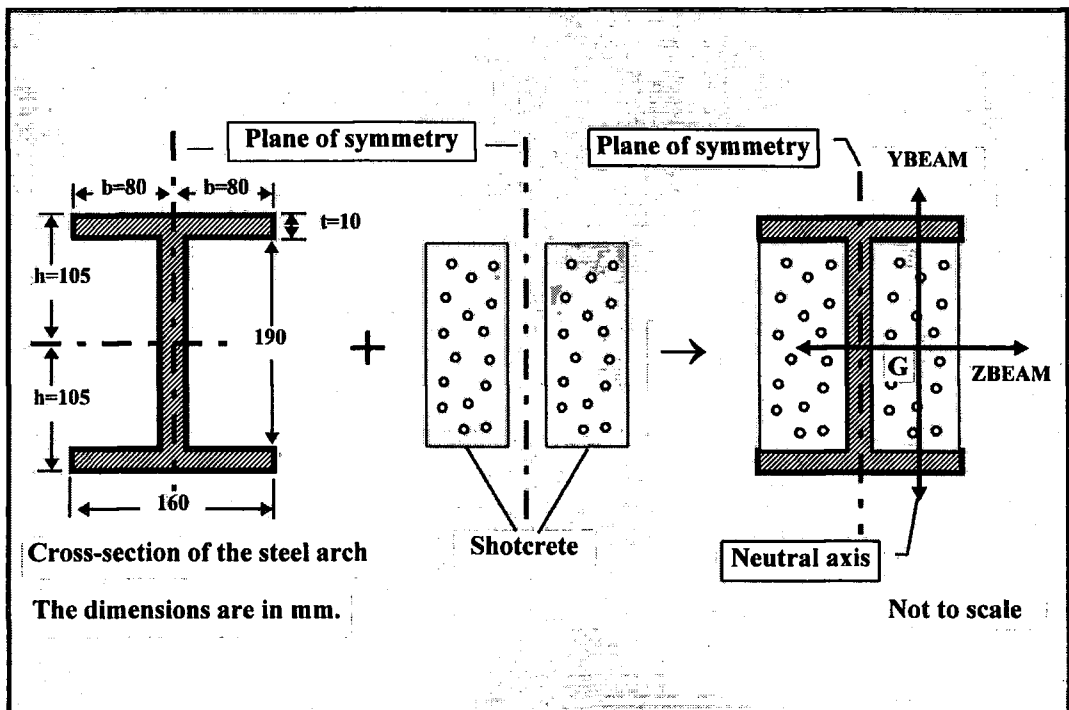


Fig. F.1 Cross-section of the steel arch

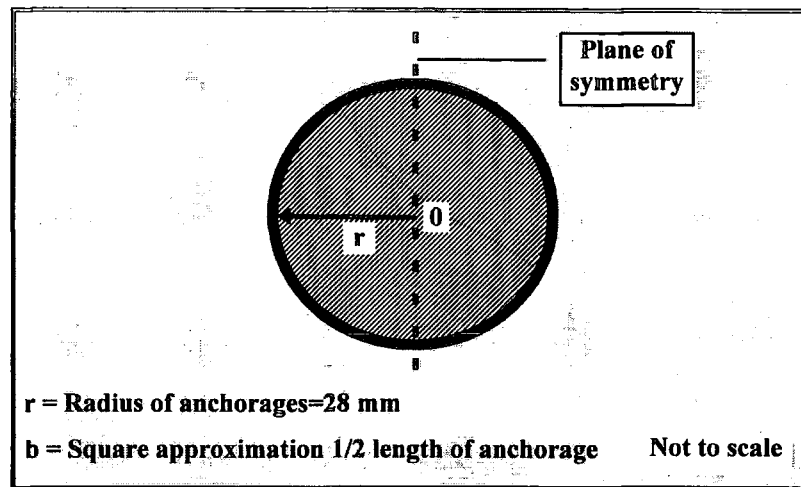


Fig. F.2. Cross-section of an anchorage

## 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.

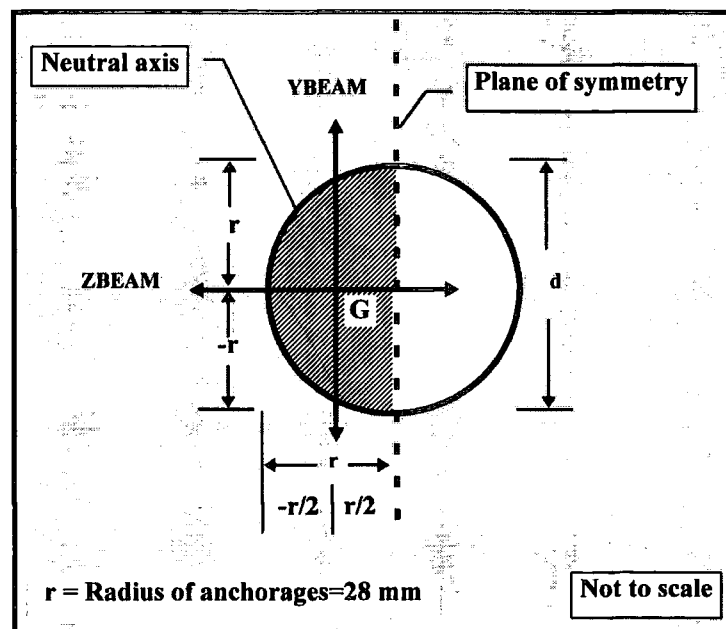


Fig. F.3 Cross-sectional moment area of the anchorage

Second moment areas of half section anchorages are as follows.

$$I_{ZG} = I_{ZZ(1/2)} = \frac{1}{2} I_{ZZ} \quad \text{and} \quad I_{YG} = I_{YY(1/2)} = \frac{1}{2} I_{YY} \quad (\text{F.1a})$$

$$I_{ZZ} \text{ (for circular section)} = \frac{\pi r^4}{4} = \frac{\pi d^4}{64} \quad (\text{F.1b})$$

where  $r$  and  $d$  are radius and diameter respectively. Hence  $\frac{1}{2} I_{ZZ}$

$$\frac{1}{2} I_{ZZ} = \frac{1}{2} \frac{\pi r^4}{4} = \frac{\pi r^4}{8} = \frac{\pi (\text{RANCH})^4}{8} \quad (\text{F.1c})$$

$$\frac{1}{2} I_{YY} = \frac{1}{2} \frac{\pi r^4}{4} = \frac{\pi r^4}{8} = \frac{\pi (\text{RANCH})^4}{8} \quad (\text{F.1d})$$

$$ZY = \frac{I_{YY}}{z_{\max}} = \frac{\frac{\pi r^4}{8}}{\frac{r}{2}} = \frac{\pi r^3}{4} = \frac{\pi (\text{RANCH})^3}{4} \quad (\text{F.2a})$$

$$ZZ = \frac{I_{ZZ}}{y_{\max}} = \frac{\frac{\pi r^4}{8}}{r} = \frac{\pi r^3}{8} = \frac{\pi (\text{RANCH})^3}{8} \quad (\text{F.2b})$$

### 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.

$$I_{ZG} = I_{ZZ(1/2)} = \frac{1}{2} I_{ZZ} \quad \text{and} \quad I_{YG} = I_{YY(1/2)} = \frac{1}{2} I_{YY} \quad (\text{F.3a})$$

$$I_{ZZ \text{ STEEL}} = 2 I_{FZZ \text{ FLANGE}} + I_{WZZ \text{ WEB}} \quad (\text{F.3b})$$

$$I_{FZZ \text{ FLANGE}} = I_F + A_F \left( \frac{D}{2} - \frac{t}{2} \right)^2 \quad (\text{F.4a})$$

$$I_{FZZ \text{ FLANGE}} = \frac{B t_f^3}{12} + \frac{B t_f}{4} (D - t_f)^2 \quad (\text{F.4b})$$

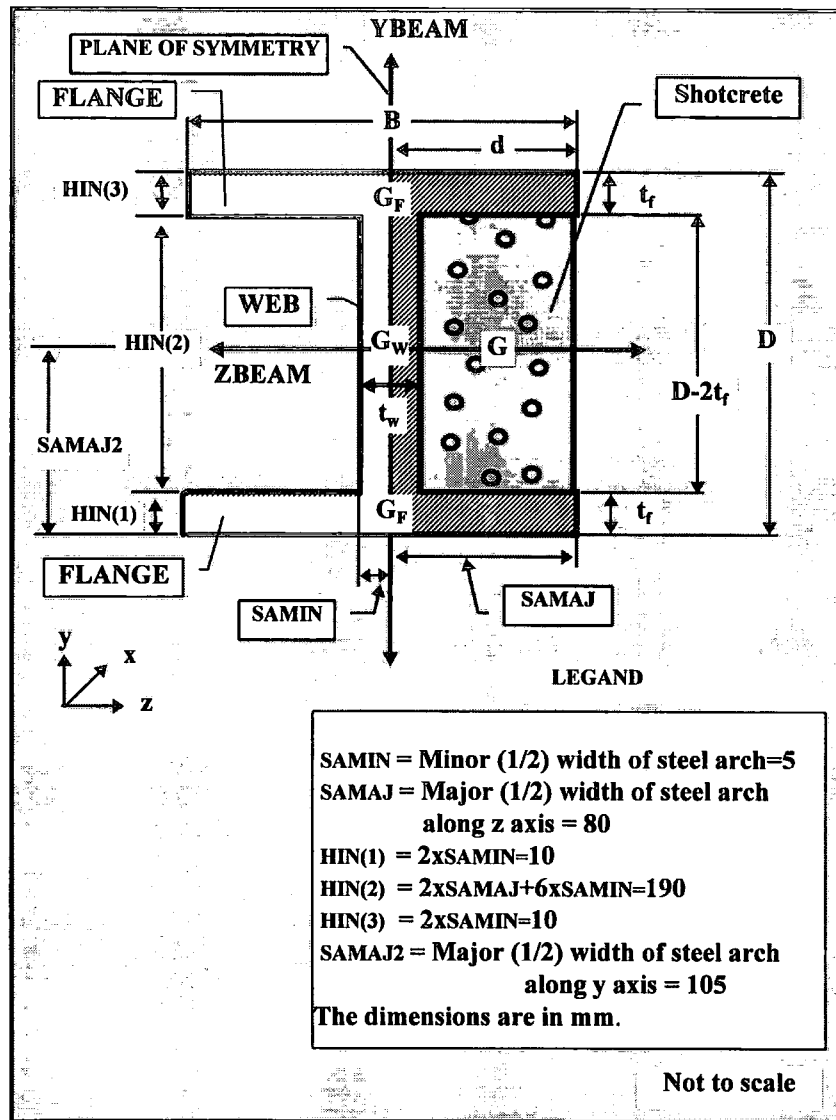


Fig. F.4 Cross-sectional moment area of the steel arch

$$I_{FZZ\ FLANGE} = \frac{Bt_f}{4} \left[ \frac{t_f^2}{3} + (D-t_f)^2 \right] \quad (F.4c)$$

$$I_{FZZ\ FLANGE} = \frac{Bt_f}{4} \left[ \frac{t_f^2}{3} + D^2 - 2Dt_f + t_f^2 \right] \quad (F.4d)$$

$$\text{If } t \ll D, I_{FZZ\ FLANGE} = \frac{Bt_f}{4} \left[ D^2 \right] \quad (F.4e)$$

$$I_{WZZ\ WEB} = \frac{1}{12} t_w (D-2t_f)^3 \quad (F.5a)$$

$$\text{If } t \ll D, I_{WZZWEB} = \frac{1}{12} t_w D^3 \quad (\text{F.5b})$$

$$\text{Hence } I_{ZZSTEEL} = 2 \left( \frac{Bt_f}{2} D^2 \right) + \frac{t_w D^3}{12} \quad (\text{F.6a})$$

$$I_{ZZSTEEL} = D^2 \left( \frac{Bt_f}{2} + \frac{t_w D}{12} \right) \quad (\text{F.6b})$$

$$I_{ZZSTEEL} = \frac{D^2}{2} \left( Bt_f + \frac{t_w D}{6} \right) \quad (\text{F.6c})$$

$$\text{Hence } I_{ZZSTEEL/2} = \frac{D^2}{4} \left( Bt_f + \frac{t_w D}{6} \right) \quad (\text{F.6d})$$

$$t_f = t_w \quad (\text{F.6e})$$

$$I_{ZZSTEEL/2} = \frac{D^2}{4} \left[ 2dt + \frac{tD}{6} \right] \quad (\text{F.6f})$$

$$I_{ZZSTEEL/2} = \frac{D^2}{4} \left( 2dt + \frac{tD}{6} \right) \quad (\text{F.6g})$$

$$I_{ZZSTEEL/2} = \frac{D^2 t}{4} \left( 2d + \frac{D}{6} \right) \quad (\text{F.6h})$$

Second moment areas of shotcrete are as follows

$$I_{ZZShotcrete} = \frac{1}{12} (d - (t/2)) (D - 2t)^3 \quad (\text{F.7a})$$

$$I_{ZZShotcrete} = \frac{1}{12} (d - (t/2)) (D^3 - 3D^2 2t + 3D(2t)^2 - (2t)^3) \quad (\text{F.7b})$$

$$\text{If } t \ll D, t \ll d \quad I_{ZZShotcrete} = \frac{1}{12} d D^3 \quad (\text{F.7c})$$

The equivalent steel section  $I_{ZZ}$  is

$$I_{ZZ} = I_{ZZSTEEL} + I_{ZZShotcrete} \frac{E_{Shotcrete}}{E_{STEEL}} \quad (\text{F.8a})$$

$$I_{ZZ} = \frac{D^2 t}{4} \left( 2d + \frac{D}{6} \right) + \frac{1}{12} d D^3 \frac{E_{Shotcrete}}{E_{STEEL}} \quad (\text{F.8b})$$

The variables used in program are as shown in Fig. F.4

$$t = 2 \text{ SAMIN}, D = 2 \text{ SAMAJ2}, d = \text{SAMAJ} \quad (\text{F.9a})$$

$$I_{ZZ} = \left( \frac{(2SAMAJ)^2 (2SAMIN)}{4} 2SAMAJ + \frac{2SAMAJ2}{6} \right) + \frac{1}{12} (SAMAJ)(2SAMAJ2)^3 \frac{E_{Shotcrete}}{E_{STEEL}} \quad (F.9b)$$

$$ZZ = \frac{I_{ZZ}}{y_{max}} = \frac{\frac{D^2 t}{4} (2d + \frac{D}{6}) + \frac{1}{12} d D^3 \frac{E_{Shotcrete}}{E_{STEEL}}}{\frac{D}{2}} \quad (F.10a)$$

$$ZZ = \frac{I_{ZZ}}{y_{max}} = \frac{\left( \frac{(2SAMAJ)^2 (2SAMIN)}{4} 2SAMAJ + \frac{2SAMAJ2}{6} \right)}{\frac{2SAMAJ2}{2}} + \frac{\frac{1}{12} (SAMAJ)(2SAMAJ2)^3 \frac{E_{Shotcrete}}{E_{STEEL}}}{\frac{2SAMAJ2}{2}} \quad (F.10b)$$

Second moment area of  $I_{yy}$  for half section

$$I_{YY} = I_{YY STEEL} + I_{YY Shotcrete} \frac{E_{Shotcrete}}{E_{STEEL}} \quad (F.11a)$$

$$I_{YY STEEL} = 2I_{FYY FLANGE} + I_{WYY WEB} \quad (F.11b)$$

$$I_{YY STEEL} = 2 \frac{1}{3} d^3 t_f + \frac{1}{3} 2 \left( \frac{D}{2} - t_f \right) \left( \frac{t_w}{2} \right)^3 \quad (F.12a)$$

$$t_f = t_w \quad (F.12b)$$

$$I_{YY STEEL} = 2 \frac{1}{3} d^3 t + \frac{1}{3} 2 \left( \frac{D}{2} - t \right) \left( \frac{t}{2} \right)^3 \quad (F.12c)$$

$$\text{If } t \ll D \text{ and } t \ll d \quad I_{YY STEEL} = \frac{2}{3} d^3 t \quad (F.12d)$$

$$I_{YY Shotcrete} = I_{YY Shotcrete} + A_{Shotcrete} \left[ d - \left( \frac{d - (t/2)}{2} \right) \right]^2 \quad (F.13a)$$

$$I_{YY Shotcrete} = \frac{1}{12} 2 \left( \frac{D}{2} - t \right) (d - (t/2))^3 + 2 \left( \frac{D}{2} - t \right) (d - (t/2)) \left[ d - \left( \frac{d - (t/2)}{2} \right) \right]^2 \quad (F.13b)$$

$$I_{YY \text{ Shotcrete}} = \frac{1}{6} \left( \frac{D}{2} - t \right) (d - (t/2))^3 + 2 \left( \frac{D}{2} - t \right) (d - (t/2)) \left[ d - \left( \frac{d - (t/2)}{2} \right) \right]^2 \quad (\text{F.13c})$$

$$I_{YY \text{ Shotcrete}} = \left( \frac{D}{2} - t \right) \left[ \frac{(d - (t/2))^3}{6} + \frac{1}{2} (d^2 - (t^2/4)(d + \frac{t}{2})) \right] \quad (\text{F.13d})$$

$$\text{If } t \ll D \text{ and } t \ll d \quad I_{YY \text{ Shotcrete}} = \left( \frac{1}{6} + \frac{1}{2} \right) \frac{D}{2} d^3 = \frac{1}{3} D d^3 \quad (\text{F.13e})$$

The equivalent steel section second moment of area

$$I_{YY} = I_{YY \text{ STEEL}} + I_{YY \text{ Shotcrete}} \frac{E_{\text{Shotcrete}}}{E_{\text{STEEL}}} \quad (\text{F.14a})$$

$$I_{YY} = \frac{2}{3} d^3 t + \frac{1}{3} D d^3 \frac{E_{\text{Shotcrete}}}{E_{\text{STEEL}}} \quad (\text{F.14b})$$

The variables used in program are as shown in Fig. F.4

$$t = 2 \text{ SAMIN}, \quad D = 2 \text{ SAMAJ2}, \quad d = \text{SAMAJ} \quad (\text{F.14c})$$

$$I_{YY} = \frac{2}{3} (\text{SAMAJ})^3 (2 \text{ SAMIN}) + \frac{1}{3} (2 \text{ SAMAJ2}) (\text{SAMAJ})^3 \frac{E_{\text{Shotcrete}}}{E_{\text{STEEL}}} \quad (\text{F.14d})$$

$$ZY = \frac{I_{YY}}{z_{\max}} = \frac{I_{YY} = \frac{2}{3} d^3 t + \frac{1}{3} D d^3 \frac{E_{\text{Shotcrete}}}{E_{\text{STEEL}}}}{\frac{d}{2}} \quad (\text{F.15a})$$

$$ZY = \frac{I_{YY}}{z_{\max}} = \frac{I_{YY} = \frac{2}{3} (\text{SAMAJ})^3 (2 \text{ SAMIN}) + \frac{1}{3} (2 \text{ SAMAJ2}) (\text{SAMAJ})^3 \frac{E_{\text{Shotcrete}}}{E_{\text{STEEL}}}}{\frac{\text{SAMAJ}}{2}} \quad (\text{F.15b})$$

