A3.4 SUBROUTINE LISTING

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      SUBROUTINE EL2D14                                                 YCX00010
      IMPLICIT REAL*8 (A-H,O-Z)                                         YCX00020
      COMMON /EL/ IND,ICOUNT,NPAR(20),NUMEG,NEGL,NEGNL,IMASS,IDAMP,ISTATYCX00030
     1           ,NDOF,KLIN,IEIG,IMASSN,IDAMPN                          YCX00040
      COMMON /DIMEL/ N101,N102,N103,N104,N105,N106,N107,N108,N109,N110, YCX00050
     1              N111,N112,N113,N114,N120,N121,N122,N123,N124,N125   YCX00060
      COMMON /MATMOD/ STRESS(4),STRAIN(4),D(4,4),IPT,NEL,IPS            YCX00070
      COMMON /DPR/ ITWO                                                 YCX00080
      COMMON A(1)                                                       YCX00090
      REAL A                                                            YCX00100
      DIMENSION IA(1)                                                   YCX00110
      EQUIVALENCE (NPAR(10),NINT),(A(1),IA(1))                          YCX00120
      IDW=11*ITWO                                                       YCX00130
      NPT=NINT*NINT                                                     YCX00140
      MATP=IA(N107+NEL-1)                                               YCX00150
      NM=N109+(MATP-1)*17*ITWO                                          YCX00160
      IF (IND.NE.0) GO TO 100                                           YCX00170
C     -------------------------------------                             YCX00180
C    | INITIALIZE WORKING SPACE ARRAY WA |                              YCX00190
C     -------------------------------------                             YCX00200
      NN=N110 +(NEL-1)*NPT*IDW                                          YCX00210
      CALL EIPLA (A(NN),A(NN),A(NM),NPT,IDW)                            YCX00220
      GO TO 599                                                         YCX00230
C                                                                       YCX00240
C     -------------------------------------                             YCX00250
C    | FIND STRESS STRAIN LAW AND STRESSES |                            YCX00260
C     -------------------------------------                             YCX00270
C                                                                       YCX00280
  100 NN=N110+(NEL-1)*NPT*IDW+(IPT-1)*IDW                               YCX00290
      CALL EPLAL (A(NM),A(NN),A(NN+4*ITWO),A(NN+8*ITWO),A(NN+9*ITWO),   YCX00300
     1A(NN+10*ITWO))                                                    YCX00310
  599 CONTINUE                                                          YCX00320
      RETURN                                                            YCX00330
      END                                                               YCX00340
      SUBROUTINE EIPLA (WA,IWA,PROP,NPT,IDW)                            YCX00350
      IMPLICIT REAL*8 (A-H,O-Z)                                         YCX00360
      DIMENSION WA(11,1),IWA(IDW,1),PROP(2)                             YCX00370
      COMMON /DPR/ ITWO                                                 YCX00380
C                                                                       YCX00390
C     ------------------------------------------                        YCX00400
C    | SET INITIAL STRESSES AND STRAINS TO ZERO |                       YCX00410
C    | SET INITIAL STRESS STATE TO ELASTIC.     |                       YCX00420
C     ------------------------------------------                        YCX00430
C                                                                       YCX00440
      DO 10 J=1,NPT                                                     YCX00450
      DO 15 I=1,8                                                       YCX00460
   15 WA(I,J)=0.0                                                       YCX00470
      WA(9,J)=PROP(9)                                                   YCX00480
      WA(10,J)=PROP(10)                                                 YCX00490
      KJ=10*ITWO+1                                                      YCX00500
   10 IWA(KJ,J)=1                                                       YCX00510
      RETURN                                                            YCX00520
      END                                                               YCX00530
C                                                                       YCX00540
C                                                                       YCX00550
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      SUBROUTINE EPLAL (PROP,SIG,EPS,XK,XXALPA,IPEL)                      YCX00560
C                                                                         YCX00570
C     .............................................................       YCX00580
C     . THIS SUBROUTINE CALCULATES THE STRESSES AND STRESS STRAIN .       YCX00590
C     . LAW OF AN ISOTROPIC HARDENING MATERIAL ,SUBJECT TO THE    .       YCX00600
C     . DRUCKER-PRAGER YEID SURFACE,IN PLANE STRESS CONDITIONS    .       YCX00610
C     .                                                           .       YCX00620
C     . THE FOLLOWING VARIABLES ARE USED IN THIS SUBROUTINE       .       YCX00630
C     .                                                           .       YCX00640
C     .    IST     NUMBER OF STRESS COMPONENTS                    .       YCX00650
C     .    ISR     NUMBER OF STRAIN COMPONENTS                    .       YCX00660
C     .    SIG     STRESSES AT THE END OF THE PREVIOUS UPDATE     .       YCX00670
C     .    EPS      STRAINS AT THE END OF THE PREVIOUS UPDATE     .       YCX00680
C     .    RATIO    PART OF STRAIN INCREMENT TAKEN ELASTICALLY    .       YCX00690
C     .    DELEPS   INCREMENT IN STRAINS                          .       YCX00700
C     .    DELSIG   INCREMENT IN STRESSES                         .       YCX00710
C     .                                                           .       YCX00720
C     .    PROP(1)   MODEL TYPE (V.MISES-D.PRAGER)                .       YCX00730
C     .    PROP(2)   PLASTIC POTENTIAL (ASS.-NON ASS.)            .       YCX00740
C     .    PROP(3)   LINEAR STRAIN HARDENING GRADIENT             .       YCX00750
C     .    PROP(4)   LTMMIT R                                     .       YCX00760
C     .    PROP(5)   EXPONENTIAL CONSTANT "A"                     .       YCX00770
C     .    PROP(6)   EXPONENTIAL CONSTANT "B"                     .       YCX00780
C     .    PROP(7)   YOUNGS MODULUS                               .       YCX00790
C     .    PROP(8)   POISSONS RATIO                               .       YCX00800
C     .    PROP(9)   KAPPA -YIELD SURFACE PARAMETER               .       YCX00810
C     .    PROP(10)   ALFA  -YIELD SURFACE PARAMETER              .       YCX00820
C     .    PROP(11)   STRAIN HARDENING MODULUS                    .       YCX00830
C     .    PROP(12)   KCUTT-FAILURE SURFACE PARAMETER             .       YCX00850
C     .    PROP(13)   ALCUTT-FAILERE SURFACE PARAMETER            .       YCX00860
C     .    PROP(14)   CY  YIELD SURFACE PARAMETER C               .       YCX00870
C     .    PROP(15)  DIFFERENCE BETWEEN YIELD-FAILURE PARAMETERS  .       YCX00880
C     .                KAPPA                                      .       YCX00890
C     .    PROP(16)  DIFFERENCE BETWEEN YIELD-FAILURE PARAMETERS  .       YCX00900
C     .                                                           .       YCX00910
C     .                                                           .       YCX00920
C     .    IPEL      =1,MATERIAL ELASTIC                          .       YCX00930
C     .              =2,MATERIAL PLASTIC                          .       YCX00940
C     .              =3,FAILURE-STIFFNESS REDUCTION,PLASTIC       .       YCX00950
C     .              =4,FAILURE-STIFFNESS REDUCTION,ELASTIC       .       YCX00960
C     .                                                           .       YCX00970
C     .                                                           .       YCX00980
C     .                                                           .       YCX00990
C     .                                                           .       YCX01000
C     .............................................................       YCX01010
C                                                                         YCX01020
C
C     .............................................................
C     .   NOTE:CERTAIN STATEMENTS ARE REDUNDANT IN TERMS OF THE   .
C     .        PROGRAMS PRESENT FORM; FURTHER MODIFICATION IS RE- .
C     .        QIRED TO INCLUDE: PLANE STRAIN                     .
C     .                          AXISYMETRIC                      .
C     .                          TOTAL & UPDATED LAGRANGIAN NON-  .
C     .                          LINEAR FORMULATIONS              .
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C     .
C     ..............................................................
C
      IMPLICIT REAL*8 (A-H,O-Z)                                        YCX01030
      COMMON /EL/ IND,ICOUNT,NPAR(20),NUMEG,NEGL,NEGNL,IMASS,IDAMP,ISTATYCX01040
     1           ,NDOF,KLIN,IEIG,IMASSN,IDAMPN                          YCX01050
      COMMON /VAR/ NG,MODEX,IUPDT,KSTEP,ITEMAX,IEQREF,ITE,KPRI,IREF,   YCX01060
     1         IEQUIT,IPRI,KPLOTN,KPLOTE                               YCX01070
      COMMON /VMISES/ A1,B1,C1,D1,B2,BH,CEE,DEPS(4),TEPS(4),           YCX01080
     1             ISR,IST,ALPA,PV,ET,ST,FTR,IPELD,IPPL,RLIM,THM,PPOT  YCX01090
      COMMON /DRUCK/ UTT,YKAP,ALC,YF,XF,YC,DELP(3),YM,SHL,EXPA,EXPB,   YCX01100
     1            ALPBAR,BET
      COMMON /MATMOD/ STRESS(4),STRAIN(4),D(4,4),IPT,NEL,IPS           YCX01110
      COMMON /DISDER/ DISD(5)                                          YCX01120
      COMMON /TODIM/ BETA,THIC,DE,IEL,NND5                             YCX01130
      DIMENSION PE P(1),SIG(1),EPS(1)                                  YCX01140
      DIMENSION DE IG(4),DELEPS(4),STATE(5)                            YCX01150
      EQUIVALENCE ( PAR(3),INDNL),(NPAR(5),ITYP2D),(NPAR(15),MODEL)    YCX01160
      INTEGER PPOT,THM                                                 YCX01170
      DATA STATE /2H E,2H*P,2HFP,2HFE,2HFF/, NGLAST /1000/             YCX01180
      XKD=XK                                                           YCX01190
      XALFA=XXALFA                                                     YCX01200
      IPELD=IPEL                                                       YCX01210
      STRESS(4)=0.                                                     YCX01220
      DELSIG(4)=0.                                                     YCX01230
      DELEPS(4)=0.                                                     YCX01240
      THM=PROP(1)                                                      YCX01250
      PPOT=PROP(2)                                                     YCX01260
      SHL=PROP(3)                                                      YCX01270
      RLIM=PROP(4)                                                     YCX01280
      EXPA=PROP(5)                                                     YCX01290
      EXPB=PROP(6)                                                     YCX01300
      YM=PROP(7)                                                       YCX01310
      PV=PROP(8)                                                       YCX01320
      YKAP=PROP(9)                                                     YCX01330
      ALFA=PROP(10)                                                    YCX01340
      ET=PROP(11)                                                      YCX01350
      UTT=PROP(12)                                                     YCX01370
      ALC=PROP(13)                                                     YCX01380
      YC=PROP(14)                                                      YCX01390
      XF=PROP(15)                                                      YCX01400
      YF=PROP(16)                                                      YCX01410
      IF (ST.EQ.0.) ST=1.                                              YCX01420
      IF (UTT.EQ.0.) UTT=1000.*XK                                      YCX01430
      IST=3                                                            YCX01440
      ISR=3                                                            YCX01450
      CEE=1.-PV*PV                                                     YCX01470
      B2=(1.-PV)/2                                                     YCX01500
C     ...............                                                  YCX01510
C     . PLANE STRESS .                                                 YCX01520
C     ...............                                                  YCX01530
      A1=YM/CEE                                                        YCX01540
      B1=A1*PV                                                         YCX01550
      D1=PV/(PV-1.)                                                    YCX01560
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      BM=YM/(1-2.*PV)                                                   YCX01570
      C1=YM/(2.*(1.+PV))                                                YCX01580
C                                                                       YCX01610
C    .................................                                  YCX01620
C    . CALCULATE THE INCREMENTAL STRAINS  .                             YCX01630
C    .................................                                  YCX01640
C                                                                       YCX01650
      IF (INDNL.NE.3) GO TO 121                                         YCX01660
      DO 122 I=1,ISR                                                    YCX01670
  122 DELEPS(I)=STRAIN(I)                                               YCX01680
      GO TO 130                                                         YCX01690
  121 DO 120 I=1,ISR                                                    YCX01700
  120 DELEPS(I)=STRAIN(I)-EPS(I)                                        YCX01710
C    ...............................                                    YCX01720
C    . CALCULATE THE INCREMENTAL STRESS  .                              YCX01730
C    . ASSUMING ELASTIC BEHAVIOUR        .                              YCX01740
C    ...............................                                    YCX01750
C                                                                       YCX01760
  130 DELSIG(1)=A1*DELEPS(1)+B1*DELEPS(2)                               YCX01770
      DELSIG(2)=B1*DELEPS(1)+A1*DELEPS(2)                               YCX01780
      DELSIG(3)=C1*DELEPS(3)                                            YCX01790
C                                                                       YCX01800
C   ...........................................                         YCX01810
C   . WITH THE ASSUMPTION OF ELASTIC BEHAVIOUR,  .                      YCX01820
C   . DETERMINE WHERE THE NEW STATE OF STRESS    .                      YCX01830
C   . FALLS IN THE STRESS SPACE                  .                      YCX01840
C   ...........................................                         YCX01850
C                                                                       YCX01860
  510 DM=(DELSIG(1)+DELSIG(2)+DELSIG(4))/3.                             YCX01870
      DX=DELSIG(1)-DM                                                   YCX01880
      DY=DELSIG(2)-DM                                                   YCX01890
      DZ=DELSIG(4)-DM                                                   YCX01900
C                                                                       YCX01910
      SM=(SIG(1)+SIG(2)+SIG(4))/3.                                      YCX01920
      SX=SIG(1)-SM                                                      YCX01930
      SY=SIG(2)-SM                                                      YCX01940
      SZ=SIG(4)-SM                                                      YCX01950
      SS=SIG(3)                                                         YCX01960
C                                                                       YCX01970
      RA=.5*(DX**2+DY**2+DZ**2)+DELSIG(3)**2                            YCX01980
      RB=SX*DX+SY*DY+SZ*DZ+2.*SS*DELSIG(3)                              YCX01990
      RD=.5*((SX**2)+(SY**2)+(SZ**2))+SS**2                             YCX02000
C                                                                       YCX02010
      FTA=XALPA*3.*(DM+SM)+(DSQRT(RD+RA+RB))-XKD                        YCX02020
      IF (FTA) 170,170,300                                              YCX02030
C                                                                       YCX02040
C    .......................................................            YCX02050
C    . STATE OF STRESS WITHINN LOADING SURFACE -EASTIC BEHAVIOUR .      YCX02060
C    .......................................................            YCX02070
  170 IPELD=1                                                           YCX02080
      IF (IPEL.EQ.3) IPELD=4                                            YCX02090
      IF (IPEL.EQ.4)  IPELD=4                                           YCX02100
      DO 176 I=1,IST                                                    YCX02130
  176 STRESS(I)=SIG(I)+DELSIG(I)                                        YCX02140
      STRAIN(4)=EPS(4)+D1*(DELEPS(1)+DELEPS(2))                         YCX02150
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      GO TO 622                                                         YCX02160
C                                                                       YCX02170
C     ..................................................................YCX02180
C     . STATE OF STRESS OUTSIDE LOADING SURFACE -PLASTIC BEHAVIOUR     .YCX02190
C     . DETERMINE THE PORTION OF STRAIN TAKEN ELASTICALLY              .YCX02200
C     ..................................................................YCX02210
C                                                                       YCX02220
  300 IPELD=2                                                           YCX02230
      IF (IPEL.EQ.3) IPPL=0                                             YCX02240
      IF (IPEL.EQ.3) RATIO=0.                                           YCX02250
      IF (IPEL.EQ.3.AND.RATIO.EQ.0.) GO TO 378                          YCX02260
      IF (FTB.GT.0.) IPEL=3                                             YCX02270
      IF (IPEL.EQ.2) RATIO=0.                                           YCX02280
      IF (IPEL.EQ.2.AND.RATIO.EQ.0.) GO TO 303                          YCX02290
      IF (IPEL.EQ.3) GO TO 315                                          YCX02300
      AR=RA-(ALFA**2)*(DM**2)*9                                         YCX02310
      BR=RB+(6*XKD*ALFA*DM)-(18*ALFA*ALFA*SM*DM)                        YCX02320
      DR=RD+(6*XKD*ALFA*SM)-(XKD*XKD)-(9*ALFA*ALFA*SM*SM)               YCX02330
      GO TO 316                                                         YCX02340
  315 AR=RA-(ALC**2)*(DM**2)*9                                          YCX02350
      BR=RB+6*UTT*ALC*DM-18*ALC*ALC*SM*DM                               YCX02360
      DR=RD+6*UTT*ALC*SM-(UTT**2)-9*(ALC**2)*(SM**2)                    YCX02370
  316 R=(BR**2)-4.*AR*DR                                                YCX02380
      IF (R.LT.0.)GO TO 302                                             YCX02390
      RZ=(-BR+DSQRT(R))/(2.*AR)                                         YCX02400
      RW=(-BR-DSQRT(R))/(2.*AR)                                         YCX02410
      IF (RZ.GE.0.AND.RZ.LE.1.) RATIO=RZ                                YCX02420
      IF (RW.GE.0.AND.RW.LE.1.) GO TO 301                               YCX02430
      RATIO=RZ                                                          YCX02440
      IF (RATIO.LT.0.0) GO TO 302                                       YCX02450
      IF (RATIO.LT.1E-03) RATIO=0.                                      YCX02460
      GO TO  303                                                        YCX02470
  301 IF (RZ.LT.0.) GO TO 304                                           YCX02480
      IF (RZ.LT.RW) RATIO=RZ                                            YCX02490
      IF (RW.LT.RZ) RATIO=RW                                            YCX02500
      IF (RATIO.LE.1E-03) RATIO=0.                                      YCX02510
      GO TO 303                                                         YCX02520
  304 RATIO=RW                                                          YCX02530
      IF (RATIO.LE.1E-03) RATIO=0.                                      YCX02540
      GO TO 303                                                         YCX02550
  302 WRITE(6,2200)                                                     YCX02560
      STOP                                                              YCX02570
  303 IF (IPEL.EQ.3.AND.RATIO.GT.0.) GO TO 317                          YCX02580
      IF (IPEL.EQ.3.AND.RATIO.EQ.0.) GO TO 378                          YCX02590
      DO 320 I=1,IST                                                    YCX02600
  320 STRESS(I)=SIG(I)+RATIO*DELSIG(I)                                  YCX02610
      STRAIN(4)=EPS(4)+RATIO*D1*(DELEPS(1)+DELEPS(2))                   YCX02620
      GO TO 378                                                         YCX02630
C     ..................................                                YCX02640
C     . DETERMINE THE INCREMENT INTERVAL .                              YCX02650
C     ..................................                                YCX02660
  317 INTER=25                                                          YCX02670
      IPELD=2                                                           YCX02680
      DO 312 I=1,IST                                                    YCX02690
  312 STRESS(I)=SIG(I)                                                  YCX02700
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      STRAIN(4)=EPS(4)                                                  YCX02710
      XM=RATIO/DFLOAT(INTER)                                            YCX02720
      GO TO 318                                                         YCX02730
  378 INTER=25                                                          YCX02740
      IF (IPEL.EQ.3) IPELD=3                                            YCX02750
      IF (IPELD.NE.3) GO TO 313                                         YCX02760
      IF (RATIO.NE.0.) GO TO 313                                        YCX02770
      DO 314 I=1,IST                                                    YCX02780
  314 STRESS(I)=SIG(I)                                                  YCX02790
      STRAIN(4)=EPS(4)                                                  YCX02800
  313 XM=(1.-RATIO)/DFLOAT(INTER)                                       YCX02810
  318 DO 380 I=1,ISR                                                    YCX02820
  380 DEPS(I)=XM*DELEPS(I)                                              YCX02830
C                                                                       YCX02840
C     ......................................                            YCX02850
C     . CALCULATION OF ELASTO-PLATIC STRESSES .                         YCX02860
C     ......................................                            YCX02870
C                                                                       YCX02880
      DO 500 IN=1,INTER                                                 YCX02890
      IF(IN.GT.1) GO TO 419                                             YCX02900
      DELP(1)=A1*DEPS(1)+B1*DEPS(2)                                     YCX02910
      DELP(2)=B1*DEPS(1)+A1*DEPS(2)                                     YCX02920
      DELP(3)=C1*DEPS(3)                                                YCX02930
  419 CALL MEDIP                                                        YCX02940
      DO 420 I=1,IST                                                    YCX02950
      DELP(I)=0.                                                        YCX02960
      DO 420 J=1,ISR                                                    YCX02970
      STRESS(I)=STRESS(I)+D(I,J)*DEPS(J)                                YCX02980
  420 DELP(I)=DELP(I)+D(I,J)*DEPS(J)                                    YCX02990
      SM=(STRESS(1)+STRESS(2)+STRESS(4))/3.                             YCX03000
      SX=STRESS(1)-SM                                                   YCX03010
      SY=STRESS(2)-SM                                                   YCX03020
      SZ=STRESS(4)-SM                                                   YCX03030
C                                                                       YCX03040
  500 CONTINUE                                                          YCX03050
      FTB=3.*ALC*SM+(DSQRT(.5*(SX**2+SY**2+SZ**2)+STRESS(3)**2))        YCX03060
      FTB=FTB - UTT                                                     YCX03070
      IF (IPEL.EQ.3.AND.IPELD.EQ.3) GO TO 502                           YCX03080
      IF (IPEL.EQ.3.AND.RATIO.GT.0.) GO TO 378                          YCX03090
      IF (FTB.LE.0.) GO TO 502                                          YCX03100
      IPPL=1                                                            YCX03110
      IPELD=3                                                           YCX03120
      DO 501 I=1,IST                                                    YCX03130
  501 DELSIG(I)=STRESS(I)-SIG(I)                                        YCX03140
      GO TO 510                                                         YCX03150
  502 IPEL=IPELD                                                        YCX03160
      IF (INDNL.NE.3) GO TO 600                                         YCX03170
      OMEGA=DISD(3)-DISD(4)                                             YCX03180
      STRESS(1)=STRESS(1)+OMEGA*SIG(3)                                  YCX03190
      STRESS(2)=STRESS(2)-OMEGA*SIG(3)                                  YCX03200
      STRESS(3)=STRESS(3)+.5*OMEGA*(SIG(2)-SIG(1))                      YCX03210
C                                                                       YCX03220
C     ..................                                                YCX03230
C     . UPDATE KAPPA(XK) .                                              YCX03240
C     ..................                                                YCX03250
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600    IF (IPELD.EQ.3) GO TO 622                                         YCX03260
       IF (IPEL.EQ.3) GO TO 622                                          YCX03270
       IF (TMM.EQ.1) GO TO 601                                           YCX03280
       RD=.5*(SX**2+SY**2+SZ**2)+(STRESS(3)**2)                          YCX03290
       RT=(YF*(YKAP-DSQRT(RD))+XF*(YC-SM))                               YCX03300
       RTT=(RT**2)-4*XP*YF*(YKAP*(YC-SM)-YC*DSQRT(RD))                   YCX03310
       IF (RTT.LT.0.) RTT=0.                                             YCX03320
       IF (RTT.EQ.0.) GO TO 622                                          YCX03330
       RT=(DSQRT(RTT)-RT)/(2*XF*YP)                                      YCX03340
       IF (RT.GT.1.) GO TO 622                                           YCX03350
       XKDD=YKAP+RT*XF                                                   YCX03360
       IF (XKDD.LT.XK) GO TO 622                                         YCX03370
       XKD=XKDD                                                          YCX03380
       XALFA=(XKD/(YC+RT*YF))/3.                                         YCX03390
       GO TO 622                                                         YCX03400
601    XALFA=0.                                                          YCX03410
       XKDD=FTB+UTT                                                      YCX03420
       IF (XKDD.LT.XK) GO TO 622                                         YCX03430
       XKD=XKDD                                                          YCX03440
C                                                                        YCX03450
C                                                                        YCX03460
C                                                                        YCX03470
C     ..........................................                         YCX03480
C     . UPDATING STRESSES,STRAINS ,KAPPA,IPEL .                          YCX03490
C     ..........................................                         YCX03500
C                                                                        YCX03510
622    IF (IUPDT.NE.0) GO TO 621                                         YCX03520
       XK=XKD                                                            YCX03530
       XXALFA=XALFA                                                      YCX03540
       IPEL=IPELD                                                        YCX03550
       DO 610 I=1,IST                                                    YCX03560
       SIG(I)=STRESS(I)                                                  YCX03570
610    EPS(I)=STRAIN(I)                                                  YCX03580
       EPS(4)=STRAIN(4)                                                  YCX03590
621    IF (KPRI.EQ.0) GO TO 700                                          YCX03600
       IF (ICOUNT.EQ.3) RETURN                                           YCX03610
C                                                                        YCX03620
C     .............................................                      YCX03630
C     . FORM THE MATERIAL LAW                     .                      YCX03640
C     . IN DIVERGENCE REFORMATION (IEQREF=1),     .                      YCX03650
C     . ASSUME ELASTIC BEHAVIOUR                  .                      YCX03660
C     .............................................                      YCX03670
C                                                                        YCX03680
       IF (IEQREF.EQ.1) GO TO 623                                        YCX03690
       IF (IPELD.EQ.2) GO TO 650                                         YCX03700
       IF (IPELD.EQ.3) GO TO 650                                         YCX03710
623    DO 625 I=1,4                                                      YCX03720
       DO 625 J=1,4                                                      YCX03730
625    D(I,J)=0.                                                         YCX03740
       D(1,1)=A1                                                         YCX03750
       D(2,1)=B1                                                         YCX03760
       D(1,2)=B1                                                         YCX03770
       D(2,2)=A1                                                         YCX03780
       D(3,3)=C1                                                         YCX03790
       D(4,1)=0.                                                         YCX03800
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      D(4,2)=0.                                                          YCX03810
      D(4,3)=0.                                                          YCX03820
      D(4,4)=0.                                                          YCX03830
      IF (IPELD.EQ.1) RETURN                                             YCX03840
      RETURN                                                             YCX03880
650   CALL MEDIP                                                         YCX03890
      RETURN                                                             YCX03900
C                                                                        YCX03910
C    .......................                                             YCX03920
C    . PRINTING OF STRESSES .                                            YCX03930
C    .......................                                             YCX03940
C                                                                        YCX03950
700   DM=(STRESS(1)+STRESS(2)+STRESS(4))/3.                              YCX03960
      DX=STRESS(1)-DM                                                    YCX03970
      DY=STRESS(2)-DM                                                    YCX03980
      DZ=STRESS(4)-DM                                                    YCX03990
      DS=STRESS(3)                                                       YCX04000
      FTA=.5*(DX**2+DY**2+DZ**2)+DS**2                                   YCX04010
      FT=3*ALPA*DM+DSQRT(FTA)-YKAP                                       YCX04020
      IF (INDNL.NE.2) GO TO 800                                          YCX04030
      CALL CAUCHY                                                        YCX04040
800   IF (IPRI.NE.0) RETURN                                              YCX04050
      IF (INDNL.LE.2 .OR. ITYP2D.LT.2) GO TO 801                         YCX04060
      XBAR=THIC*DEXP(STRAIN(4))                                          YCX04070
801   IF (NG.NE.NGLAST) GO TO 802                                        YCX04080
      IF(NEL.GT.NELAST) GO TO 806                                        YCX04090
      IF (IPT-1) 809,808,809                                             YCX04100
802   NGLAST=NG                                                          YCX04110
808   IF (INDNL.EQ.3) GO TO 804                                          YCX04120
      WRITE(6,2002)                                                      YCX04130
      GO TO 806                                                          YCX04140
804   WRITE(6,2001)                                                      YCX04150
806   NELAST=NEL                                                         YCX04160
      WRITE(6,2004) NEL                                                  YCX04170
809   IF (IPELD.NE.3) GO TO 810                                          YCX04180
      WRITE(6,2221)                                                      YCX04190
810   CALL MAXMIN (STRESS,SX,SY,SM)                                      YCX04200
      IF (INDNL.EQ.3) GO TO 814                                          YCX04210
813   WRITE(6,2005) IPT,STATE(IPELD),(STRESS(I),I=1,IST),SX,SY,SM,FT     YCX04220
      GO TO 821                                                          YCX04230
814   WRITE(6,2007) IPT,STATE(IPELD),(STRESS(I),I=1,3),SX,SY,SM,FT,XBAR  YCX04240
821   WRITE(6,2006) (EPS(I),I=1,3),EPS(4)                                YCX04250
      RETURN                                                             YCX04260
2221  FORMAT(/T10,'THE MATERIAL HAS FAILED IN THIS REGION,STIFFNESS REDUYCX04270
     1CTION HAS OCCURED'//)                                              YCX04280
2001  FORMAT (90H ELEMENT  STRESS      STRESS-YY     STRESS-ZZ      STRESYCX04290
     1S-YZ          MAX STRESS     MIN STRESS,17X,10HEQUIVALENT/         YCX04300
     2           16H NUM/IPT   STATE,78X,5HANGLE,10X,6HSTRESS,5X,        YCX04310
     3           9HTHICKNESS/)                                           YCX04320
2002  FORMAT (90H ELEMENT STRESS       STRESS-YY     STRESS-ZZ      STRESYCX04330
     1S-YZ          MAX STRESS     MIN STRESS,17X,10HYELD FUNCT/         YCX04340
     2          16H NUM/IPT   STATE,78X,5HANGLE,10X,6HVALUE /)           YCX04350
2004  FORMAT(1I4/)                                                       YCX04360
2005  FORMAT(5X,I2,1X,A2,6HLASTIC,1X,3E14.6,3X,2E14.6,3X,F6.2,3X,E14.6)  YCX04370
2006  FORMAT(T10,'STRAINS',T20,'ST-YY  ',E14.7,'ST-ZZ  ',E14.7,'ST-YZ  ',YCX04380
```

```
     1E14.7,'ST-XX ',E14.7/)                                          YCX04390
2007  FORMAT(5X,I2,1X,A2,7HLASTIC ,3E14.6,3X,2E14.6,3X,F6.2,3X,2E14.6)  YCX04400
2200  FORMAT(T10,'INCORRECT VALUE FOR RATIO,STOP',3E14.7)              YCX04410
      END                                                              YCX04420
C                                                                      YCX04430
      SUBROUTINE MEDIP                                                 YCX04440
      IMPLICIT REAL*8 (A-H,O-Z)                                        YCX04450
      COMMON /EL/ IND,ICOUNT,NPAR(20),NUMEG,NEGL,NEGNL,IMASS,IDAMP,ISTATYCX04460
     1,NDOF,KLIN,IEIG,IMASSN,IDAMPN                                    YCX04470
      COMMON /VMISES/ A1,B1,C1,D1,B2,BM,CEE,DEPS(4),EPS(4),            YCX04480
     1          ISR,IST,ALFA,PV,ET,ST,FTB,IPELD,IPPL,RLIM,TMM,PPOT     YCX04490
      COMMON /DRUUK/ OTT,YKAP,ALC,YP,XP,YC,DELP(3),YM,SHL,EXPA,EXPB,   YCX04500
     1          ALFBAR,BET
      COMMON/MATMOD/ STRESS(4),STRAIN(4),D(4,4),IPT,NEL,IPS           YCX04510
      EQUIVALENCE (NPAR(5),ITYP2D)                                     YCX04520
      INTEGER PPOT,TMM                                                 YCX04530
      SM=(STRESS(1)+STRESS(2)+STRESS(4))/3.                            YCX04540
      SX=STRESS(1)-SM                                                  YCX04550
      SY=STRESS(2)-SM                                                  YCX04560
      SZ=-SM
      SS=STRESS(3)                                                     YCX04580
      SM1=SM*3./2.                                                     YCX04590
      SM2=(((STRESS(1)-STRESS(2))/2.)**2)+SS**2                        YCX04600
      PRST1=SM1+DSQRT(SM2)                                             YCX04610
      PRST2=SM1-DSQRT(SM2)                                             YCX04620
      PRS1=PRST1-SM                                                    YCX04630
      PRS2=PRST2-SM                                                    YCX04640
      DELM=(DELP(1)+DELP(2))/2.                                        YCX04650
      DELM1=(((DELP(1)-DELP(2))/2.)**2)+DELP(3)**2                     YCX04660
      DELT1=DELM+DSQRT(DELM1)                                          YCX04670
      DELT2=DELM-DSQRT(DELM1)                                          YCX04680
      BET=.5*(SX**2+SY**2+SZ**2)+SS**2                                 YCX04690
      BET=2*DSQRT(BET)                                                 YCX04700
      IF (TMM.EQ.1) ALFT=0.                                            YCX04710
      IF (TMM.EQ.1) ALC=0.                                             YCX04720
C                                                                      YCX04730
C    ...................................                               YCX04740
C    . FORM THE DP MATRIX-PLANE STRESS .                               YCX04750
C    ...................................                               YCX04760
C                                                                      YCX04770
C                                                                      YCX04780
      IF (IPELD.EQ.3) ALFT=ALC                                         YCX04790
      IF (IPELD.EQ.3) GO TO 1                                          YCX04800
      IF (TMM.EQ.1) GO TO 2                                            YCX04810
      RI=(YF*(YKAP-.5*BET)+XF*(YC-SM))                                 YCX04820
      RII=(RI**2)-4*XF*YF*(YKAP*(YC-SM)-YC*BET*0.5)                    YCX04830
      IF (RII.LT.0.) GO TO 3                                           YCX04840
      RI=(DSQRT(RII)-RI)/(2*YF*XF)                                     YCX04850
      GO TO 3                                                          YCX04860
2     RI=(.5*BET-YKAP)/XF                                              YCX04870
      GO TO 4                                                          YCX04880
3     IF (RII.LE.0.) RI=1E-03                                          YCX04890
      ALPT=(YKAP+RI*XF)/((YC+RI*YF)*3.)                                YCX04900
4     IF(RI.LT.0.) RI=1E-03                                            YCX04910
1     DG=(DELT1*(ALPT+(PRS1/BET)))+(DELT2*(ALPT+(PRS2/BET)))           YCX04920
```

```
      G=BET/(3*(PRS1*DELT1+PRS2*DELT2))                                 YCX04930
      IF(PPOT.EQ.2) GO TO  5                                            YCX04940
      G=G*2*((ALFT+(PRS1/BET))*PRST1+(ALFT+(PRS2/BET))*PRST2)           YCX04950
      G=G/BET                                                           YCX04960
C                                                                       YCX04970
5     IF (IPELD.EQ.3) BET=ET                                            YCX04980
      IF (IPELD.EQ.3) GO TO 6                                           YCX04990
      IF (RI.LE.RLIM) EET=YM+SHL*RI                                     YCX05000
      IF (RI.LE.RLIM) GO TO  6                                          YCX05010
      EET=EXPA*((2.71828183)**(EXPB*RI))                                YCX05020
6     A2=YM*EET/(YM-EET)
      G=G*DG
      IF(PPOT.EQ.1) ALFBAR=ALFT
      IF (PPOT.EQ.2) ALFBAR=0.
      ARA=ALFT+(SX/BET)                                                 YCX05040
      ARB=ALFT+(SY/BET)                                                 YCX05050
      ARC=2*SS/BET                                                      YCX05060
      ARA1=ALFBAR+(SX/BET)                                              YCX05070
      ARB1=ALFBAR+(SY/BET)                                              YCX05080
      BAT=A2*G+A1*((ARA+PV*ARB)*ARA1+(PV*ARA+ARB)*ARB1+B2*(ARC**2))     YCX05140
      RLAMBD=BAT
      BAT=A1*A1/BAT                                                     YCX05150
C                                                                       YCX05160
      WP=SX*DEPS(1)+SY*DEPS(2)+SS*DEPS(3)                               YCX05170
      IF (WP.LT.0.) BAT=0.                                              YCX05180
C                                                                       YCX05190
      D(1,1)=A1-(BAT*((ARA1+PV*ARB1)*ARA+(ARA1+PV*ARB1)*PV*ARB))        YCX05200
      D(1,2)=B1-(BAT*(PV*(ARA1+PV*ARB1)*ARA+(ARA1+PV*ARB1)*ARB))        YCX05210
      D(1,3)=-BAT*ARC*(ARA1+PV*ARB1)*B2                                 YCX05220
      D(1,4)=0.                                                         YCX05230
      D(2,1)=B1-(BAT*(ARA*(PV*ARA1+ARB1)+PV*ARB*(PV*ARA1+ARB1)))        YCX05240
      D(2,2)=A1-(BAT*(PV*ARA*(PV*ARA1+ARB1)+ARB*(PV*ARA1+ARB1)))        YCX05250
      D(2,3)=-BAT*ARC*(ARB1+PV*ARA1)*B2                                 YCX05260
      D(2,4)=0.                                                         YCX05270
      D(3,1)=-BAT*ARC*B2*(ARA+PV*ARB)                                   YCX05280
      D(3,2)=-BAT*ARC*B2*(PV*ARA+ARB)                                   YCX05290
      D(3,3)=C1-BAT*(B2*B2*ARC*ARC)                                     YCX05300
      D(3,4)=0.                                                         YCX05310
      D(4,1)=0.                                                         YCX05320
      D(4,2)=0.                                                         YCX05330
      D(4,3)=0.                                                         YCX05340
      D(4,4)=0.                                                         YCX05350
C     ...............................................                   YCX05360
C     . REDUCE THE STIFFNESS IF THE ELEMENT HAS FAILED  .               YCX05370
C     ...............................................                   YCX05380
8     DO 10 I=1,4                                                       YCX05430
      DO 10 J=1,4                                                       YCX05440
10    IF ((DABS(D(I,J))).LT.1E-13) D(I,J)=0.                            YCX05450
      IF (WP.LE.0.) GO TO 11                                            YCX05460
      IF(PPOT.EQ.1) GO TO 12                                            YCX05470
      STRAIN(4)=STRAIN(4)-(DEPS(1)+DEPS(2))                             YCX05480
      STRAIN(4)=STRAIN(4)+((DELT1+DELT2)/BM)                            YCX05490
      RETURN                                                            YCX05500
12    RLMD=((ARA+ARB*PV)*DEPS(1)+(ARA*PV+ARB)*DEPS(2))*A1+ARC*C1*DEPS(3)
      RLAMBD=RLMD/RLAMBD
```

```
      SPL4=RLAMBD*(ALFT+(SZ/BET))                                   YCX05520
      STRAIN(4)=STRAIN(4)+SPL4+(DEPS(1)+DEPS(2))*D1                 YCX05530
      RETURN                                                        YCX05540
   11 STRAIN(4)=STRAIN(4)+D1*(DEPS(1)+DEPS(2))                      YCX05550
      RETURN                                                        YCX05560
      END                                                           YCX05570
```

APPENDIX 4

PROPERTIES RELATING TO THE SHEAVE

A4.1 BEAM ELEMENT DIMENSIONS EMPLOYED IN THE PRELIMINARY ANALYSIS OF THE SHEAVE (Chapter 3)

The dimensions selected for representing the rim and spoke sections are illustrated in Fig A4.1. Owing to the naturally rectangular properties of the spoke, the dimensions represent the actual section. However the dimensions selected for the machined rim section (see Section A4.3) are based on representing the depth and second moment of area of the actual section. This approach was chosen since the significant stresses are induced by bending effects. The second moment of area and cross-sectional area of the above mentioned section is tabulated in Table A4.1.

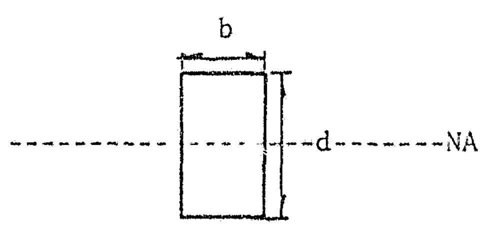


Figure 4.1 - Dimensions of the beam elements

TABLE A4.1 - DIMENSIONS OF THE BEAM ELEMENTS (RIM AND SPOKE)

	b	d	I_{NA} (mm^3)
Spoke	31	68	$812,2 \times 10^3$
Rim	37	48	340×10^3

A4.2 DIMENSIONS OF THE UNMACHINED SHEAVE

The dimensions of the unmachined sheave as used in the previous experiment conducted in 1981 are presented in Fig A4.2

A4.3 DIMENSIONS OF THE MACHINED SHEAVE

The dimensions of the machined sheave as employed in the present experiment are illustrated in Fig A4.3.

A4.4 CALCULATION OF THE SECOND MOMENT OF AREA OF THE RIM SECTION

The second moment of area, centroid and cross-sectional area were approximated by using the dimensions measured from the actual section. Owing to geometrical imperfections of the rim section introduced during the casting process, the internal and external radii of the section could not be measured accurately. This necessitated the simplification illustrated in Fig A4.4. Hence the calculation of the geometric properties was based on this section, which was divided into seven elements. These calculations are presented in Tables A4.2a and A4.2b, below Fig A4.4.

A4.5 GEOMETRIC PROPERTIES OF THE RIM SECTION EMPLOYED IN THE FINITE ELEMENT SIMULATION

As discussed in Chapter 5, the rim section was divided into eight elements, as illustrated in Fig A4.5. The dimensions of each element were selected so that the overall section would approximate the properties calculated in Section A4.4. These dimensions are illustrated in Fig A4.5. The calculation of the second moment of

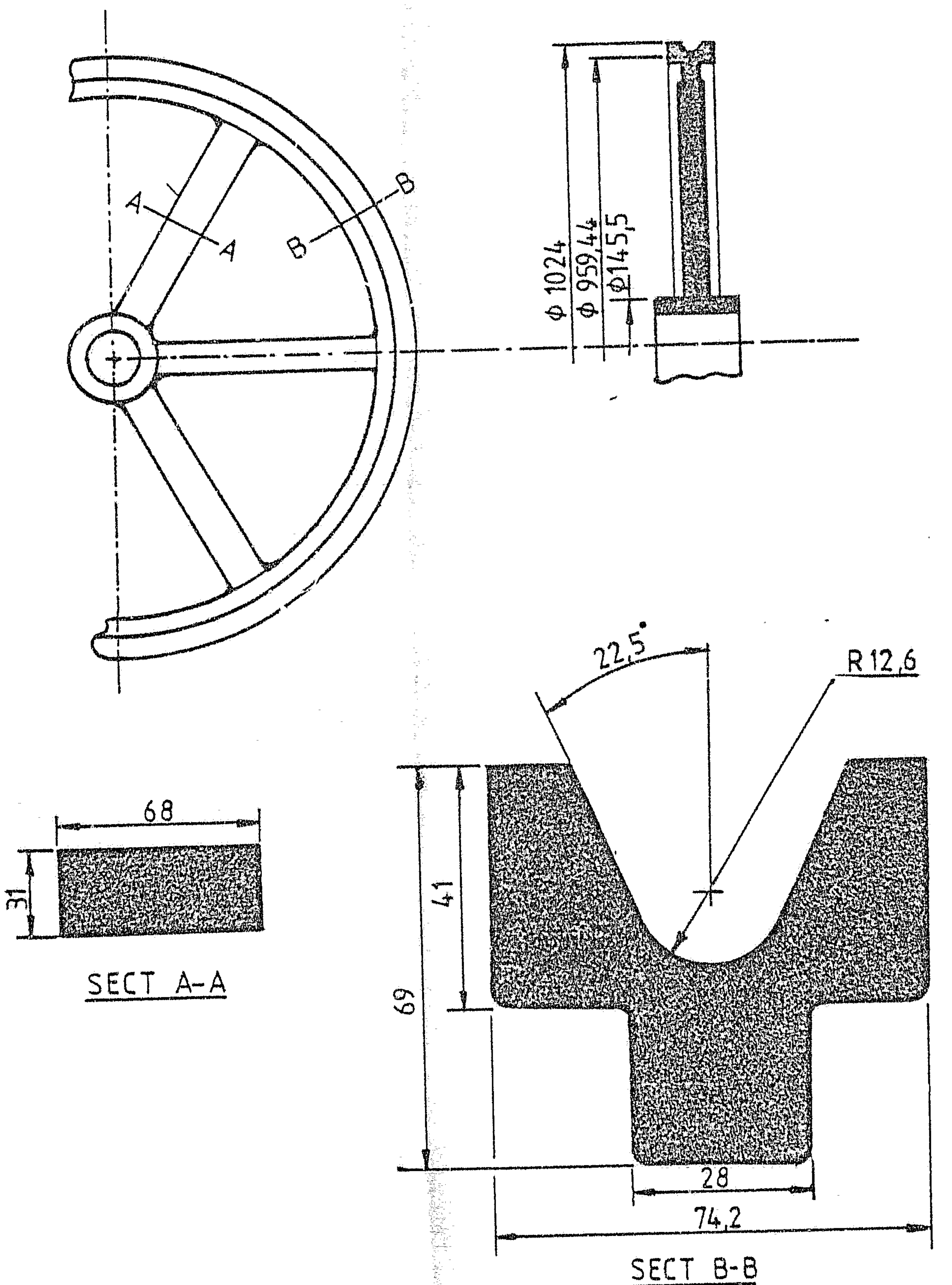


Figure A4.2 - Dimensions of the Unmachined Sheave

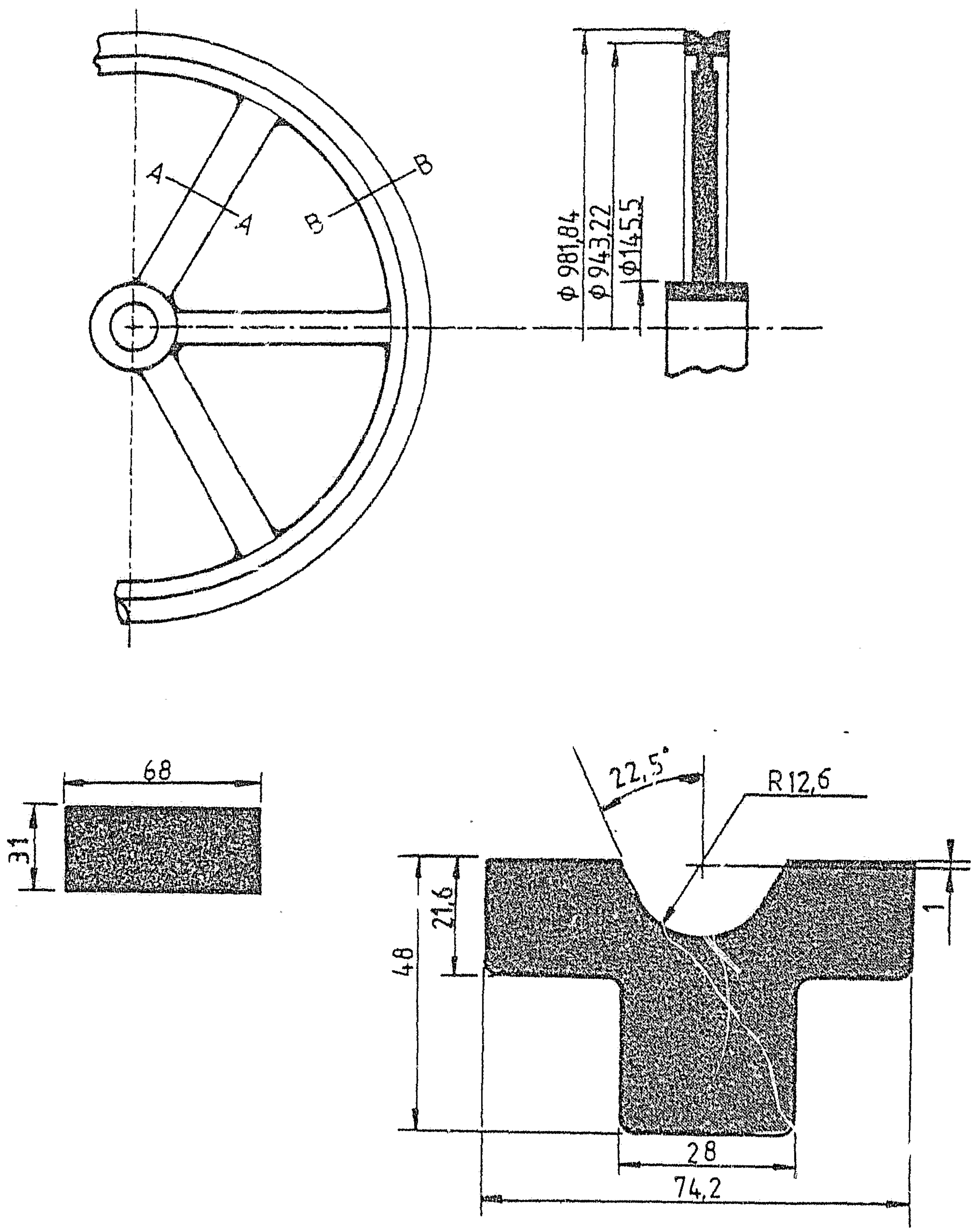


Figure A4.3 - Dimensions of the Machined Sheave

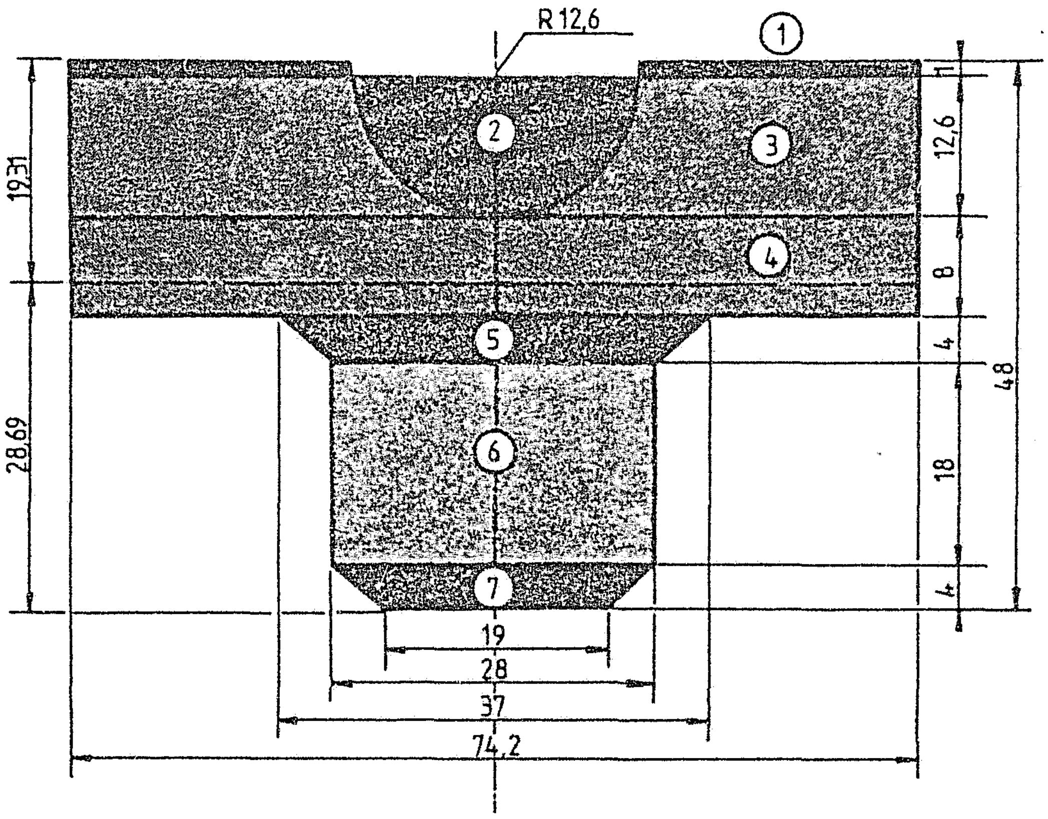


Figure A4.4 - Idealised Cross Section of the Rim

TABLE A4.2a - CALCULATION OF THE CENTROID OF THE SECTION

Element	A_e (mm^2)	$\bar{y}_e$ (mm)	$A\bar{y}_e$ ($\times 10^3$)
1	48,00	47,50	2,280
2	-249,37	41,75	-10,411
3	934,92	40,71	38,051
4	584,80	32,42	18,959
5	130,00	24,49	3,184
6	504,00	13,40	6,753
7	105,60	2,32	0,245
	2 057,45		59,060

$$\bar{y} = \frac{\Sigma A_e \bar{y}_e}{\Sigma A_e} = 28,69 \text{ mm}$$

TABLE A4.2b - CALCULATION OF THE MOMENT OF INERTIA

Element	$\bar{I}_e$ ($\times 10^3 mm^4$)	d (mm)	I_{NA} ($\times 10^3 mm^4$)
1	2 10⁻	18,801	16,968
2	-2,767	13,051	-45,241
3	12,368	12,011	147,243
4	3,118	3,721	11,215
5	0,172	- 4,208	2,473
6	13,608	-15,298	131,558
7	0,168	-26,376	73,633
			337,851

$$\bar{I}_{NA} \simeq 337,851 \times 10^3 mm^4$$

area, cross-sectional area and centroid area presented in Table A4.3, below Fig A4.5. It is evident that the second moment of area, centroid and cross-sectional area, compare well with those of the idealised section (Fig A4.5); the discrepancies are - 0,79%, 0,80% and 3,2% respectively. The larter discrepancy of modelling the cross-sectional area is not considered significant since the major effects are due to bending.

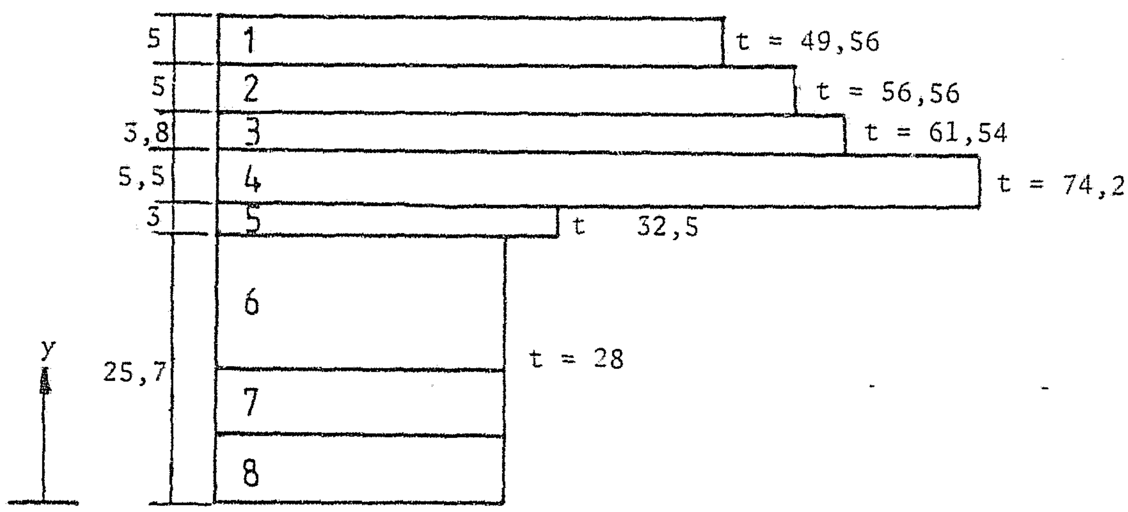


Figure A4.5 - Finite Element Simulation of the Rim Section

TABLE 4.3 - CENTROID, MOMENT OF INERTIA OF SIMULATED SECTION (FEM)

Element	A	$\bar{y}$	$A\bar{y}$	$\bar{I}$	d	I_{NA}
1	247,80	45,50	11 274,90	516,25	17,50	76 405,00
2	282,80	40,50	12 160,40	589,16	11,54	37 708,50
3	233,85	36,10	8 442,05	281,40	12,50	42 552,08
4	408,10	31,45	12 834,74	1 028,70	3,45	5 886,16
5	97,50	27,20	2 652,0	73,12	- 0,80	135,52
6,7,8	719,60	12,85	9 246,8	39 607,30	-15,15	204 771,70
	1 989,65		56 610,93			340 531,43

$\bar{y}$ = 28,452 7 mm $\bar{I}_{NA}$ = 340 531,43 mm^4

A4.6 METHOD OF CONVERTING THE FINITE ELEMENT RESULTS

As discussed in Chapter 5, the strains predicted by the finite element coordinate analysis are output in terms of the global coordinate axes. The Mohr circle of strain was employed to convert these values to their local coordinate axes for direct comparison with the experimental results.

Fig A4.6 indicates the position of the gauges relative to the integration points and their rotation from the global y-axis. Formula A4.1 was employed to convert the ε_y, ε_z, γ_{yz} strains into into a reading tangential to the surface of the sheave

$$\varepsilon = \frac{\varepsilon_y+\varepsilon_z}{2} + \frac{\varepsilon_y-\varepsilon_z}{2}\cos 2\theta + \frac{\gamma_{yz}}{2}\sin 2\theta \quad \text{(gauges 1-15)} \qquad \text{(A4.1)}$$

$$\varepsilon = \frac{\varepsilon_y+\varepsilon_z}{2} + \frac{\varepsilon_y-\varepsilon_z}{2}(\cos 2(\theta+90) + \frac{\gamma_{yz}}{2}\sin 2(\theta+90) \quad \text{(gauges 20-23)}$$

In some cases the gauge was located between two elements and the reading was taken as the average of the strains of the relevant integration points. Table A4.4 tabulates the relationship between the gauges and the integration points employed in the calculation of the finite element values.

Tables A4.5a and A4.5b tabulate the converted readings from the above mentioned integration points for associated and non associated plastic simulations. These results formed the basis of the values used in Chapter 5.

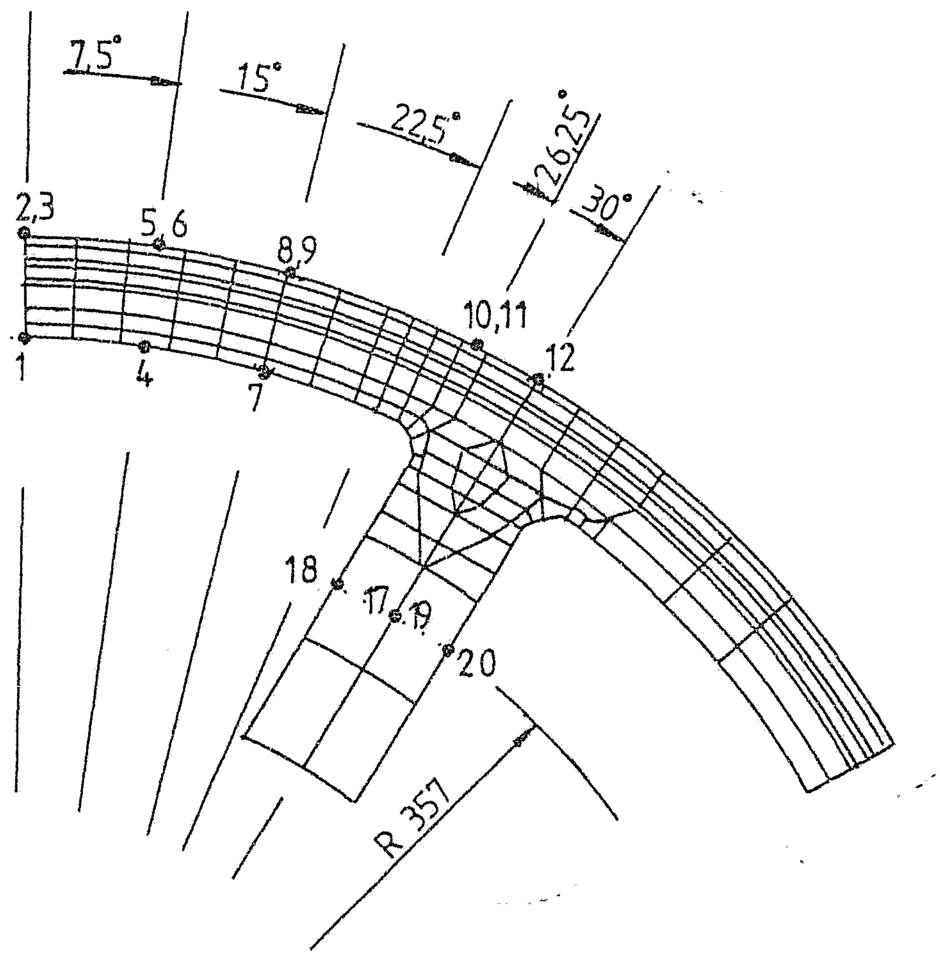


Figure A4.6 - Geometric Location of the Strain Gauges

TABLE A4.4 - ELEMENT/INTEGRATION POINT CORRESPONDING TO THE GAUGE LOCATION

Gauge	Element/Integration Point
1	104-7
2,3	16-9
4	106-4
5,6	16-6
7	109-7/108-1
8,9	11-9/12 - 3
10,11	6-6
12	4-9/5-3
18	134-7
17,19	137-8/134-2
20	137-2

TABLE A4.5a - Associated Plasticity

ROPE TENSION [KN]	ELEMENT/INTEGRATION NUMBER (DEG)							
	104.7 (0)	16.9 (0)	106.4 (7.5)	14.6 (7.5)	109.7 (15)	108.1 (15)	11.9 (15)	12.9 (15)
61.803	718.63	-578.1	551.18	-463.31	14.771	81.751	-120.8	-171.51
123.61	1515	-1178.8	1181.1	-892.98	26.375	160.41	-241.13	-342.24
185.41	2571	-1873.6	1776.4	-1420.1	20.983	220.06	-382.75	-513.94
247.21	4118.1	-2800.2	2569.5	-1995.6	22.794	283.24	-495.8	-692.44
309.02	6309.4	-4137.9	3649.8	-2704.7	-3.0849	313.23	-650.95	-887.32
370.82	9750.8	-6125	4991.3	-3610.5	-60.129	312.18	-892.2	-1085.1
492.62	19893	-8735.9	6798.2	-4817.2	-140.37	284.68	-1046.6	-1326

ROPE TENSION [KN]	ELEMENT/INTEORATION NUMBER (DEG)						
	6.6 (26.25)	4.9 (30)	5.3 (30)	137.2 (30)	137.8 (30)	134.2 (30)	134.7 (30)
61.803	479.5	300.76	341.95	-23.983	-200.47	-250.58	-378.38
123.61	988.24	604.7	689.15	-47.372	-400.12	-500.27	-755.6
185.41	1634.4	911.75	1061.3	-68.07	-586.52	-746.65	-1127.9
247.21	2553.3	1235.7	1482.3	-78.828	-780.45	-992.78	-1490.9
309.02	3828.9	1576.5	1982.5	-71.348	-992.07	-1255.5	-1870
370.82	5874.8	1825	2538.3	-42.787	-1209.8	-1546.9	-2307.8
492.62	8351.3	2260.9	3187.9	-9.5024	-1452.1	-1873.9	-2704.6

TABLE A4.5b - Non Associated Plasticity

ROPE TENSION [KN]	ELEMENT/INTEGRATION NUMBER (DEG)							
	104.7 (0)	16.9 (0)	108.4 (7.5)	14.6 (7.5)	109.7 (15)	108.1 (15)	11.9 (15)	12.3 (15)
61.803	718.84	-578.1	551.18	-463.31	14.779	81.754	-120.8	-171.52
123.61	1512.5	-1178.9	1117.6	-932.17	26.372	180.41	-241.07	-342.18
185.41	2548.5	-1867.1	1778.2	-1427.0	31.265	231.91	-363.49	-514.17
247.21	4048.9	-2785.8	2596.7	-1995.6	22.528	283.58	-493.42	-690.71
309.02	6306.9	-4131.3	3697	-2707.9	.91096	318.16	-646.6	-884.37
370.82	9518.3	-6089.9	5111.5	-3615.9	-50.401	323.45	-917.6	-1084.8
432.62	13683	-8757.2	6872.2	-4769.6	-128.4	206	-1013	-1300.8

ROPE TENSION [KN]	ELEMENT/INTEGRATION NUMBER (DEG)						
	6.6 (26.25)	4.9 (30)	5.3 (30)	197.2 (30)	197.8 (30)	194.2 (30)	194.7 (30)
61.803	479.52	300.76	341.95	-23.983	-200.47	-250.56	-378.39
123.61	986.86	604.55	689.01	-47.977	-400.14	-500.91	-755.65
185.41	1619.7	912.42	1050.7	-68.6	-596.85	-748.92	-1127.3
247.21	2493.6	1242.2	1460.5	-78.142	-792.35	-995.24	-1492.6
309.02	3795.9	1592.4	1974.9	-70.747	-995.53	-1258.8	-1874
370.82	5552.9	1952.2	2552.4	-43.802	-1215.1	-1551.9	-2281.7
432.62	7810.6	2315.2	3231.5	-3.9499	-1481	-1883	-2708.8

APPENDIX 5

ADINA/ADINAT/ADINA-PLOT PROGRAMME EXECUTION

A5.1 PROGRAMME EXECUTION ON THE IBM 370

The procedure involved in the preparation and execution of the ADINA/ADINAT/ADINA-PLOT package is illustrated in the flow chart presented in Fig A5.1 below. The VMS/CMS commands employed in this procedure are presented in Table A5.1. The function of the ENGPAC, FADINA, ADINA 81, ADINAT, ADPLOT, will be discussed in the following section.

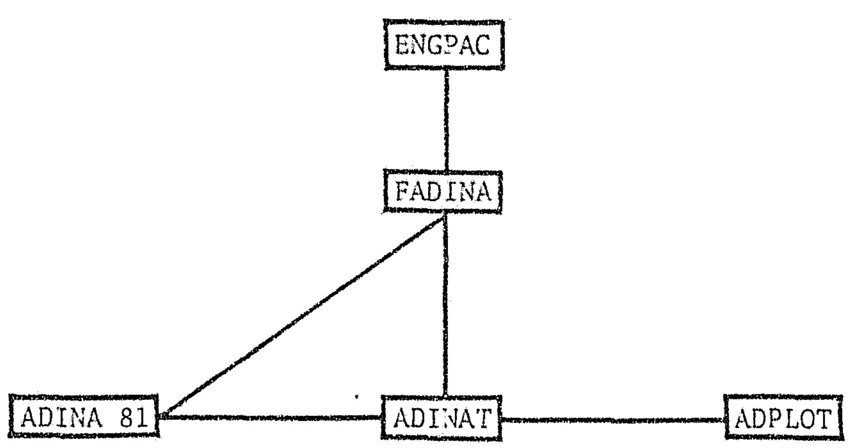


Figure A5.1 - Flow Chart Illustrating ADINA/ADINAT/ADINA-PLOT Execution Procedure

COMMAND	VMS/CMS RESPONSE
DEF STOR 2M I CMS	ENT STORAGE = 2M R = -----: ENT CMS
ENGPAC FADINA 20[+]	ENT FORMAT WILL ERASE ALL FILES ON DISK 'G(19F)'. DO YOU WISH TO CONTINUE)? (YES/NO). DMS FOR 605R ENTER DISK LABEL DMS FOR 733I FORMATTING DISK G.
ADINA PROGRAM: ADINA 81 <u>FN</u> <u>FT</u> <u>FM</u>[*] <u>FN</u> <u>FT</u> <u>FM</u>	 ENT INPUT FILE? ENT OUTPUT FILE? EXECUTION BEGINS ------
ADINAT PROGRAM: ADINAT <u>FN</u> <u>FT</u> <u>FM</u> <u>FN</u> <u>FT</u> <u>FM</u>	 ENT INPUT FILE? OUTPUT FILE? EXECUTION BEGINS -------
ADINA-PLOT PROGRAM: ADPLOT FN FT FM FN FT FM	 ENT INPUT FILE? ENT OUTPUT FILE? ENT EXECUTION BEGINS -------

+ Number of temporary storage cylinder specified by the user

* <u>FILE NAME</u> <u>FILE TYPE</u> <u>FILE MODE</u> , eg INPUT DATA A1.

A5.2 BACKUP ROUTINES

The routines ENGPAC, FADINA, ADINA 81, ADINAT, ADPLOT, were implemented by W Leong of the computer science center. The purpose of these routines is summarised briefly below:

A5.2.1 ENGPAC+

This programme links the user to the disk containing the ADINA/ADINAT/ADINA-PLOT program texts, enabling these programs to be accessed for later use.

A5.2.2 FADINA+

This program creates temporary storage space and defines the logical read write units and the formatting options as required by the program for successful execution. These units provide the slow speed storage as required during execution.

A5.2.3 ADINA81/ADINAT/ADPLOT+

These routines load the respective programs for execution. They direct the input and output listing file as specified by the user.

A5.3 DEFINING TEMPORARY STORAGE SPACE ON THE READ/WRITE DISK FOR LARGE LISTING FILES

Analyses resulting in large output listing files require the definition of extra storage space if the user's available permanent storage allocation is not to be exceeded (±4 000 lines). The VMS/CMS commands

---

+The listings of the ENGPACK, FADINA, ADINA81, ADINAT, ADPLOT programs are included at the end of the appendix.

required to define such temporary storage are listed below.

DEF □ T3350 □ 195 □ 5 ENT

FORMAT □ 195 □ D ENT

ACC □ 191 □ C ENT

ACC □ 195 □ A ENT

Copy files from C disk to temporary A disk, ie

COPY □ FN □ FT □ FM □ FN □ FT □ A ENT

eg, Copy SHG DATA C SHG DATA A

After execution is complete and the listing file has been printed and sufficient plots obtained, all updated files must be copied to the C disk before signing off.

A5.4 REMOTE JOB EXECUTION

In cases where execution may take an extended period of time an option enabling remote execution is available allowing the user to return at a later time when execution is complete.

The commands required to utilise this facility are:

#CP SET RUN ON

#CP DISC

On issuing these commands the user has effectively terminated the session on the terminal without affecting program execution. The terminal may then be utilised by another user.

On reconnecting, the following command must be issued:

B

which notifies the computer that he is once again connected as an ordinary user.

ENGPAC - listing

```
FILE: ENGPAC   EXEC     Y2                                    PAGE 001

&TRACE ERR
CP LINK ENG 196 19B RR STATS
ACCESS 19B B/A
```

FADINA - listing

```
FILE: FADINA    EXEC    B2                                                PAGE 001

&TRACE ERR
&CYL = &1
&IF .&CYL ¬= . &GOTO -BR
&TYPE TYPE IN NUMBER OF CYLINDER FOR TEMPORARY DISK
&READ VAR &CYL
-BR &CONTINUE
CP DEFINE T3350 19F &CYL
&LABEL = &CONCAT OF TMP 19F
&STACK YES
&STACK &LABEL
FORMAT 19F G
FI  1 DISK W1  SCRATCH G (RECFM VBS BLOCK 4000  XTENT 790
FI  2 DISK W2  SCRATCH G
FI  3 DISK W3  SCRATCH G
FI  4 DISK W4  SCRATCH G
FI  7 DISK W7  SCRATCH G
FI  8 DISK W8  SCRATCH G
FI  9 DISK W9  SCRATCH G
FI 10 DISK W10 SCRATCH G
FI 11 DISK W11 SCRATCH G
FI 12 DISK W12 SCRATCH G
FI 13 DISK W13 SCRATCH G
FI 14 DISK W14 SCRATCH G
FI 15 DISK W15 SCRATCH G
FI 16 DISK W16 SCRATCH G
FI 17 DISK W17 SCRATCH G
FI 18 DISK W18 SCRATCH G
FI 19 DISK W19 SCRATCH G
FI 22 DISK W22 SCRATCH G
FI 23 DISK W23 SCRATCH G
FI 56 DISK W56 SCRATCH G
FI 59 DISK W59 SCRATCH G
FI 60 DISK PLOT DATA G
FI 61 DISK W61 SCRATCH G
FI 62 DISK W62 SCRATCH G
FI 63 DISK W63 SCRATCH G
```

ADINA81 - listing

FILE: ADINA81   EXEC   B1

```
&TRACE OFF
&TYPE     ENTER DATA FILE ID:
&READ VARS &INNAME &INTYPE &INMODE
&TYPE     ENTER OUTPUT FILE ID:
&READ VARS &OUTNAME &OUTTYPE &OUTMODE
GLOBAL TXTLIB CMSLIB FORTXLIB
LOAD ADINA81
FI 5 DISK &INNAME &INTYPE &INMODE
FI 6 DISK &OUTNAME &OUTTYPE &OUTMODE
START
&EXIT
```

ADPLOT - listing

```
FILE: ADPLOT    EXEC     B1

&TRACE ERR
&TYPE     ENTER DATA FILE ID:
&READ VARS &INNAME &INTYPE &INMODE
&TYPE     ENTER OUTPUT FILE ID:
&READ VARS &OUTNAME &OUTTYPE &OUTMODE
-AGAIN &TYPE ENTER "N" OR "W" (N=NARROW PAPER(30CM), W=WIDE PAPER(83CM)):
&READ VARS &PAPER
&IF .&PAPER EQ .N &GOTO -PAPN
&IF .&PAPER EQ .W &GOTO -PAPW
&TYPE ' &PAPER ' IS AN INVALID ARGUMENT.
&GOTO -AGAIN
-PAPN &WIDTH = P
&GOTO -LIN
-PAPW &WIDTH = Q
-LIN CP LINK GRAPHICS 191 199 RR READ
AC 199 H
STACKID
&STACK &INNAME
X @ $ G (PROF @@@
GL TXTLIB
GL TXTLIB CMSLIB FORTXLIB GRAPHICS
LOAD ADPLOT
&RCC = &RC
&IF &RC NE 0 &GOTO -FAIL
FI FT01 001 CLEAR
FI FT05F001 CLEAR
FI FT06F001 CLEAR
FI FT18F001 CLEAR
FI FT19F001 CLEAR
FI FT50F001 CLEAR
FI FT60F001 CLEAR
FI 1 DISK DATA BASE G (RECFM F LRECL 2000 BLOCK 2000 DSORG DA XTENT 790
FI 5 DISK &INNAME &INTYPE &INMODE
FI 6 DISK &OUTNAME &OUTTYPE &OUTMODE
FI 18 DISK @ $ G
FI 19 DISK @ $$ G
FI 50 DISK &INNAME PLOT G (RECFM VS BLKSIZE 368
FI 60 DISK PLOT DATA G (RECFM VBS BLOCK 4000
START
&RCC = &RC
&IF &RC NE 0 &GOTO -FAIL
CP SP PU CALPLOT NOH NOC CL G CO 1 D &WIDTH
DISK DUMP &INNAME PLOT G
CP SP PU OFF CL A D OFF
-FAIL FI * CLEAR
GL TXTLIB
REL H (DET
&EXIT &RCC
```

ADPLOT - listing

```
FILE: ADPLOT    EXEC      B1

&TRACE ERR
&TYPE    ENTER DATA FILE ID:
&READ VARS &INNAME &INTYPE &INMODE
&TYPE    ENTER OUTPUT FILE ID:
&READ VARS &OUTNAME &OUTTYPE &OUTMODE
-AGAIN &TYPE ENTER "N" OR "W" (N=NARROW PAPER(30CM), W=WIDE PAPER(83CM)):
&READ VARS &PAPER
&IF .&PAPER EQ .N &GOTO -PAPN
&IF .&PAPER EQ .W &GOTO -PAPW
&TYPE ' &PAPER ' IS AN INVALID ARGUMENT.
&GOTO -AGAIN
-PAPN &WIDTH = P
&GOTO -LIN
-PAPW &WIDTH = Q
-LIN CP LINK GRAPHICS 191 199 RR READ
AC 199 H
STACKID
&STACK &INNAME
X @ $ G (PROF @@@
GL TXTLIB
GL TXTLIB CMSLIB FORTXLIB GRAPHICS
LOAD ADPLOT
&RCC = &RC
&IF &RC NE 0 &GOTO -FAIL
FI FT01F001 CLEAR
FI FT05F001 CLEAR
FI FT06F001 CLEAR
FI FT18F001 CLEAR
FI FT19F001 CLEAR
FI FT50F001 CLEAR
FI FT60F001 CLEAR
FI 1 DISK DATA BASE G (RECFM F LRECL 2000 BLOCK 2000 DSORG DA XTENT 790
FI 5 DISK &INNAME &INTYPE &INMODE
FI 6 DISK &OUTNAME &OUTTYPE &OUTMODE
FI 18 DISK @ $ G
FI 19 DISK @ $$ G
FI 50 DISK &INNAME PLOT G (RECFM VS BLKSIZE 368
FI 60 DISK PLOT DATA G (RECFM VBS BLOCK 4000
START
&RCC = &RC
&IF &RC NE 0 &GOTO -FAIL
CP SP PU CALPLOT NOH NOC CL G CO 1 D &WIDTH
DISK DUMP &INNAME PLOT G
CP SP PU OFF CL A D OFF
-FAIL FI * CLEAR
GL TXTLIB
REL H (DET
&EXIT &RCC
```

APPENDIX 6

UNDERGRADUATE PROJECTS (1982-83) RELEVANT TO THE DEVELOPMENT OF THE FINITE ELEMENT METHOD AT THE UNIVERSITY OF THE WITWATERSRAND

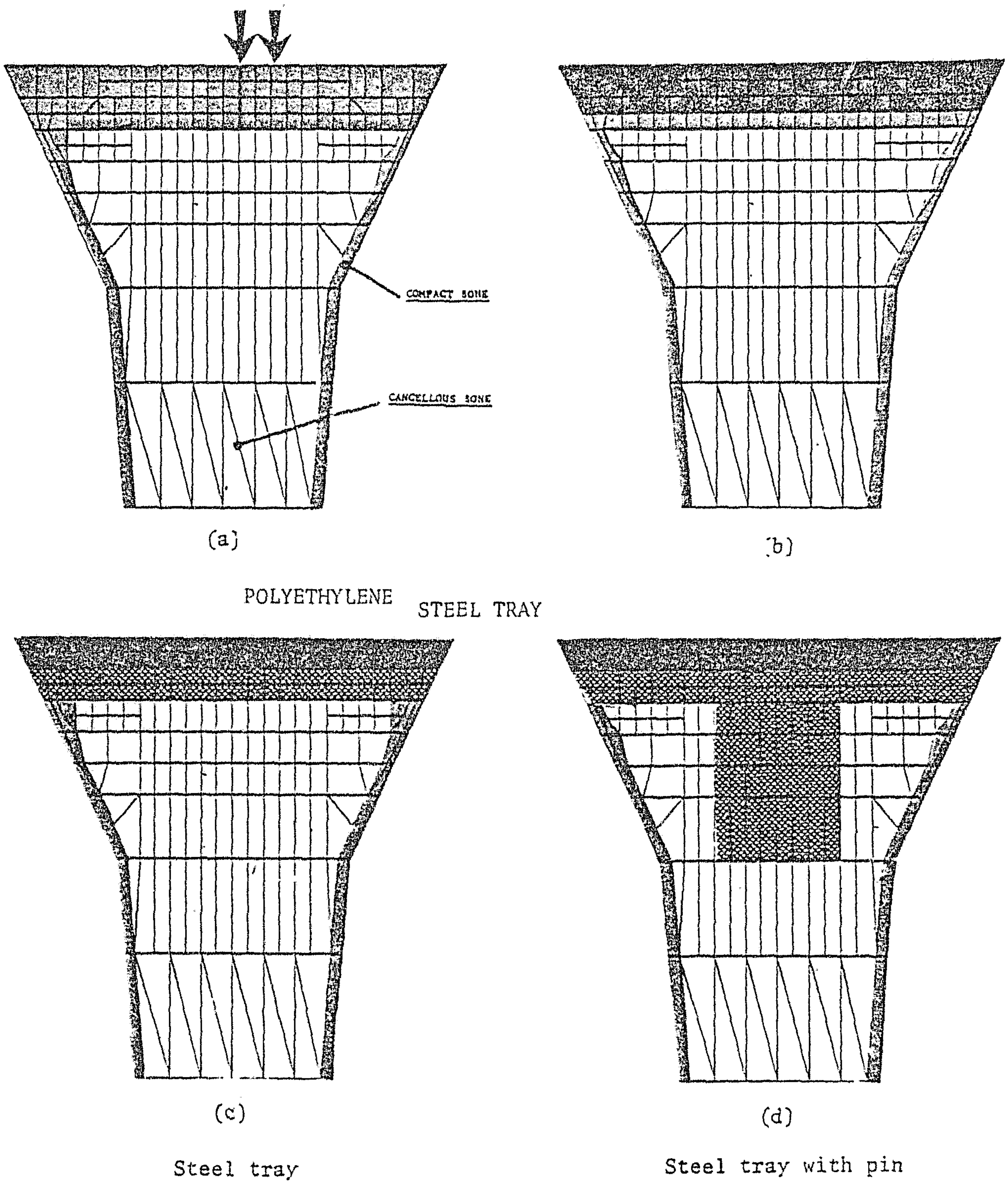
A6.1 REPLACING THE HUMAN KNEE JOINT: (G HACK, N LANE - BSc Design Report, Sept 1982. Supervisor, Dr H D Chandler)

This project consists of an overall view of knee prosthesis design with special reference to the van Reenen Knee. In order to assess the van Reenen knee prosthesis with regard to its tibial configuration a comparative study involving a finite element simulation of four different configurations (including that of the van Reenen knee) was undertaken.

The configurations examined were:

- The natural tibia.
- An all polyethylene tibial component (as used in the van Reenen knee).
- A polyethylene bearing surface supported by a metal tray.
- As above but with a pin attached to the lower surface of the metal tray.

The tibia was modelled with plain strain two-dimensional elements. The properties of the compact cancellous bone and the polyethylene/steel tray were accounted for by defining four material property sets applied to the relevant areas of the mesh indicated in Fig 6.1.



(a) Tibia modelled with compact and cancellous bone only

(b) Polyethylene tibial component

(c) Pin attached to the lower surface of the metal tray

Figure 6.1 - Analysis of a Knee Joint Prosthesis

The results of this study indicate that improved performance of the van Reenen knee can be achieved by utilising a polyethelene bearing surface supported by a steel tray. This observation is drawn from a careful examination of the stresses induced in the above configuration which closely resembles those predicted in the analysis of the natural tibia. The writer acted as advisor in the use of ADINA.

A6.2 PREPROCESSOR PROGRAM: (S PAVLOVIC - BSc Design Report, Sept 1982. Supervisors: Prof C Dimitriou & Mr C Constancon

This project involved the preparation of a preprocessor programme capable of interactively structuring an input data file in the format required by the ADINA programme. At present the programme is partially complete, facilitating data preparation up to the beginning of element data input. Further work is required to complete this facility and to extend it to include data preparation for the ADINAT programme.

A6.3 FINITE ELEMENT ANALYSIS OF A THIN SQUARE PLATE: (A BIZOS - BSc Minilab Report, July 1983. Supervisors: Prof C Dimitriou & Mr C Constancon

This project involved utilising shell/plate shell elements to approximate the central deflection of a thin square plate subjected to a uniformly distributed pressure load normal to its surface. Small deflections were considered and the material was assumed isotropic; ie a linear elastic analysis was performed.

The performance of the two element types was assessed with regard to

(i) Shell elements:
- numerical integration order
- four, eight, nine, sixteen noded elements

- mesh refinement

(ii) Plate Shell elements:
- mesh refinement[1]

The results obtained were compared with a theoretical solution for the purpose of assessing the effect of the constraints listed above on the solution accuracy. In addition a geometrically nonlinear (total langrangian) analysis of the plate provided confirmation that the deflections imposed in the analyses were within the linear region.

The main purpose of this study was to introduce the pertinent aspects of the finite element method through the preparation of input data files, execution of the analyses and the interpretation of the results. This approach illustrated in a practical manner the importance of mesh refinement, element order, numerical integration order and the correct imposition of boundary conditions.

The results of the study confirmed that

- underintegration generally results in higher accuracy
- convergence to the true solution occurs with increasing mesh refinement and higher order elements
- the choice of mesh has to draw on finite element theory and past experience.

A preliminary assessment of the accuracy achieved in approximating the natural frequencies of plates by employing the two types of elements discussed indicated that the solutions were an order of magnitude different for similar meshes. This is not documented in

---

1. Plate shell elements are 3-noded elements which for a linear elastic analysis have a fixed numerical integration order of 2 x 2.

the report since a fuller investigation is required before conclusive statements can be made. This is likely to be the topic of future study.

A P P E N D I X 7

ADINA-PLOT, PROGRAM DESCRIPTION AND INSTALLATION

A7.1 PROGRAM DESCRIPTION

The ADINA-PLOT program constitutes a post-processing facility (ie after employing the ADINA package) enabling rapid interpretation of the results obtained from a finite element simulation. A flow chart illustrating its mode of operation in conjunction with the ADINA program is shown below in Fig A7.1.

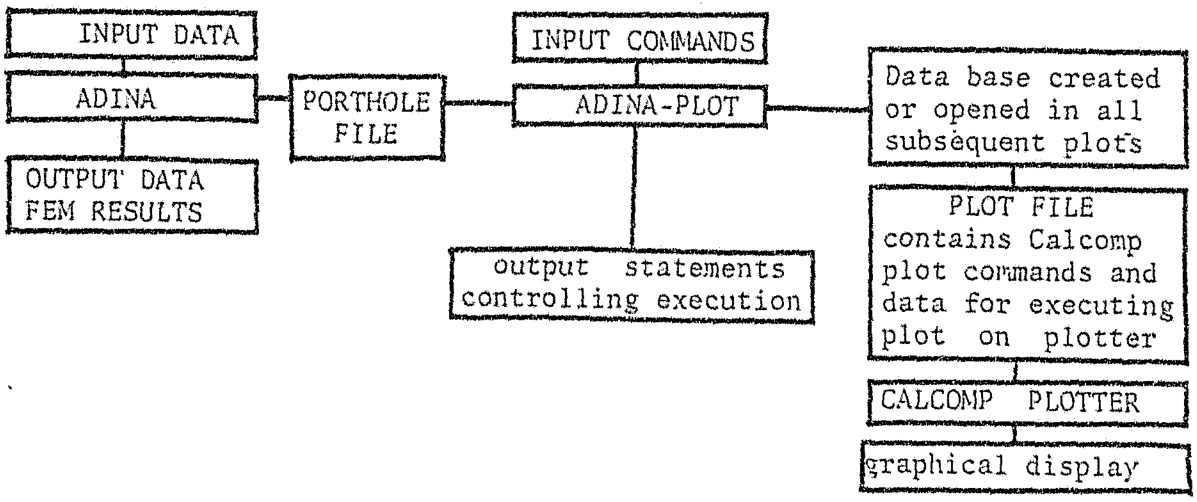


Figure A7.1 - Flow Chart Illustrating the Interaction between the ADINA/ADINA -PLOT PROGRAMS

A brief outline of the mode of operation is presented but a more detailed explanation can be found in the ADINA-PLOT user's manual [9]. The input and output data of a finite element simulation may be channelled by ADINA to a file called the porthole file. ADINA-PLOT reads this generated file in order to load a specifically designed data base which stores the data on a random access file for easy retrieval. Once the data base is loaded with data from an ADINA run it can be accessed by ADINA-PLOT any number of times, hence the porthole file becomes redundant.

The input command file contains a command language which specifies the format and type of plot required. Default options are available which ensure that a satisfactory plot will be obtained with the minimum amount of input data.

Two types of error recovery are available to decide on a solution strategy when an error is encountered during execution. Either the execution can be terminated or it can be continued at the next command in the input file.

On successful execution, a plot file containing calcomp plotting commands is submitted directly to the calcomp plotter for a graphical output. Simultaneously, the output from the ADINA-PLOT can be directed to three print files: ECHO; LOG and LIST. The ECHO file contains an echo printing of the commands and parameters as they had been defined in the input file. The LOG file contains relevant diagnostic messages generated during the execution, whilst the LIST file contains selective data listings which can be requested by the user.

A7.2 INSTALLATION

ADINA-PLOT was installed on the IBM 370 in March 1983. The installation involved writing a backup routine ADPLOT which, prior to execution, defined the logical read write units used in the source as well as the location of the input command and output listing files. Ultimately this routine links the ADINA-PLOT program to the calcomp plotting library and directs the plot file created during execution to the calcomp plotter for a graphical output.

The test analysis supplied with the ADINA/ADINA-PLOT source[1] was

1. Dynamic analysis of an eight storey building

executed in order to verify that the program was operating correctly. Satisfactory execution was not achieved since the ADINA-PLOT program did not generate the required data base. Further attempts to achieve a satisfactory execution were unsuccessful and outside help was sought [26].

Errors were apparent in both the backup routine FADINA[2] and the source. It was evident that the logical write statement defining the format of the data base file was inconsistent for a random access file. In the original FADINA routine the following statement was used with no formatting options, ie

F I 1 DISK DATA G

For a random access file this should be defined as

F I 1 DISK DATA G (RECFM VBS BLOCK 4000)

By defining this logical write statement, the porthole file was created successfully. However in early test program runs it became apparent that the first statement in the input command file was not correctly executed by the program causing premature termination. This was overcome by placing a redundant statement at the beginning of the file and selecting the error recovery option which, upon the discovery of an error, proceded to the next statement in the input file. Thus for future w :k, until this problem is rectified, the following statements should always be specified at the beginning of any input command file

```
FILE
CONTROL B = 0
.
.
.
END
```

2. A listing of the FADINA routine is presented in Appendix 5 together with a brief description.