APPENDIX A8 – ANSYS APDL plastic work macro

```
!PIPE BRANCH MODEL (Chapter 6)
/prep7
!
model='pipe branch'
*cfopen,pipe_branch_res,txt,,append          !result file
*vwrite,
 ("********************** ",30a)
*vwrite,model
 ("MODEL: ",40a)
*vwrite,
 ("********************** ",30a)
!
!properties beam element!
et,1,4
r,1,100,10000/12,10000/12,10,10
mp,ex,1,211428.5714
mp,nuxy,1,0.3
!element SOLID45!
et,2,95,,,,,,,,,1
!mat. properties pipe and branch!
tb,mkin,2,1
tbtemp,,strain
tbdata,1,0.0014,0.0166,0.042,0.078,0.15      !strains
tbtemp,0
tbdata,1,296,296,380,475,560         !stresses
mp,ex,2,211428.5714
/xrange,0,0.15
tbplot,mkin,2
sm=296 !YIELD STRESS
!
!Some geometry parameters
d1mean=70.67    !run pipe mean diameter
d2mean=35.335   !branch pipe mean diameter
t1=d1mean/20    !run pipe thickness
t2=t1           !branch pipe thickness
ldratio=1
!
!Creating the half model!
local,11,1,,,,-90
ri1=(d1mean-t1)/2 !inner radius run pipe!
ro1=ri1+t1                  !outer radius run pipe!
z1=1*d1mean                 !0.5 * length of run pipe
ri2=(d2mean-t2)/2           !inner radius branch pipe
ro2=ri2+t2                  !outer radius branch pipe
str=1 !inside fillet!
z2=(ldratio*d2mean)+ro1  !length of branch pipe+run pipe
r=2.05 !weld fillet!
!
!Applied moment
cmy=120000
cmf=400000

csys,1
k,1,ro1,20,z1
k,2,ro1,20
kgen,2,1,2,1,,70
a,1,2,4,3
csys,11
```

```
k,5,ro2,-90
k,6,ro2
kgen,2,5,6,,,,z2
a,5,6,8,7
/view,,1,1,1
/pnum,area,1
/pnum,kpoi,1
/pnum,line,1
aplot
aovlap,1,2
aplot
adele,3,4,1,1
afillt,5,6,r
csys,1
k,22,ri1,20,z1
k,23,ri1,20
kgen,2,22,23,1,,70
a,22,23,5,4
csys,11
k,24,ri2,-90
k,25,ri2
kgen,2,24,25,,,,z2
a,24,25,9,6
aovlap,4,5
adele,6,7,1,1
afillt,8,9,str
csys,0
lgen,2,25,,,-ri2,-z2/2
a,20,21,10,5
asba,6,7
k,100,,ro1+r
a,16,19,100
asba,4,6
a,5,16,21,12,30,25
a,20,11,29,28,10,19
a,19,10,5,16
a,21,12,11,20
va,4,8,5,10,11,2,12,6
a,5,16,7,6
a,6,7,8,9
a,8,9,10,19
va,11,13,7,15,1,14
a,1,3,4,22
a,1,2,23,22
a,11,20,2,23
a,12,21,3,4
va,9,12,18,17,16,19,3
/pnum,volu,1
vplot

esize,,4 !number of element divisions along lines, if not specified otherwise!
!Concatenate areas and lines for meshed mapping
flst,2,3,5,orde,3
fitem,2,5
fitem,2,8
fitem,2,10
accat,p51x
flst,2,3,4,orde,3
fitem,2,8
fitem,2,16
```

```
fitem,2,28
lccat,p51x
flst,2,3,4,orde,3
fitem,2,6
fitem,2,15
fitem,2,29
lccat,p51x
accat,16,17
lccat,5,9
lccat,1,4
csys,1
lgen,2,1,5,4,,-110
l,1,13
l,22,15
l,2,14
l,23,17
v,1,22,15,13,2,23,17,14
vplot

!element division on specified lines!
a=10
lesi,24,,,a
lesi,20,,,a
lesi,31,,,a
lesi,36,,,a
lesi,25,,,a
lesi,17,,,a
lesi,15,,,5
lesi,16,,,5
lesi,28,,,5
lesi,29,,,5
lesi,6,,,1
lesi,8,,,1
lesi,13,,,12,.33
lesi,14,,,12,3
lesi,19,,,12,.33
lesi,23,,,12,.33
lesi,1,,,5
lesi,5,,,5
lesi,4,,,5
lesi,27,,,10,.33
lesi,44,,,16
lesi,45,,,16
lesi,46,,,16
lesi,47,,,16

!use mapped meshing!
mshkey,1
!meshing!
vsel,s,,,2
type,2
mat,2
vmesh,all
eplot
allsel
vsel,u,,,2
vplot
type,2
mat,2
vmesh,all
```

```
allsel
csys,0
!generate the other half of the model by reflection!
vsymm,x,all
nummrg,all
eplot
!
!/eof
!
*get,nodeult,node,0,num,max
node11=nodeult+1
node22=nodeult+2
!create beam element!
k,100,0,z2,0
k,101,0,z2+10,0
nkpt,,100 !node No. 17251!
nkpt,,101 !node No. 17252!
type,1
real,1
mat,1
!e,17251,17252    !
e,node11,node22
eplot
!symmetry b.c.!
nsel,s,loc,z,0
dsym,symm,z
allsel
!b.c. for dummy end of beam!
!d,17252,uz,0
d,node22,uz,0      !
!
!b.c. at the ends of the shell!
nsel,s,loc,z,z1
d,all,all
allsel
!
!create rigid region!
csys,0
nsel,s,loc,y,z2
!cerig,17251,all,uy            !
cerig,node11,all,uy
allsel
save
!
/solu
!
!Apply steady moment load!
NLGEOM,on
pred,on
autots,on
outres,all,all
!apply load up to first yield
!f,17251,mz,cmy !
f,node11,mz,cmy
sbctra
time,cmy
!eresx,no
lswrite,1
!
!apply rest of load
```

```
NLGEOM,on
pred,on
autots,on
outres,all,all
!f,17251,mz,cmf  !
f,node11,mz,cmf
sbctra
neqit,100
time,cmf
nsubst,20,20,20
!eresx,no
lswrite,2
!
lssolve,1,2,1
fini
!
!!!! Plastic work macro !!!!
/post26
nsol,2,node11,rot,z
/grid,1
xvar,2
plvar,1
*get,nosubs,vari,,nsets
finish
!
!Calculate and store work values
/post1
!avprin,,0.3
*get,emax,elem,,num,max
*dim,load,table,nosubs
*dim,ework,table,nosubs
*dim,plwork,table,nosubs
*dim,totalwk,table,nosubs
*dim,tostener,table,nosubs
*dim,diftowk,table,nosubs
*dim,ratio,table,nosubs
*dim,displa1,table,nosubs
*dim,displa2,table,nosubs
*dim,alpha,table,nosubs
*dim,maxttstr,table,nosubs
*dim,elemno,table,nosubs
*dim,etot,table,2
*dim,plwork2,table,nosubs !!

*do,i,1,nosubs,1   !nloads
 *if,i,eq,1,then
  set,first
 *else
  set,next
 *endif

 etable,tsigmaeqv,s,eqv     !equivalent stress
 etable,tvolum,volu                 !volume
 etable,teldeqv,epel,eqv    !elastic equivalent strain
 etable,tpldeqv,nl,epeq             !equivalent plastic strain
 etable,tsten,sene          !strain energy
etable,te1,epto,1           !total principal strain 1
etable,te3,epto,3           !total principal strain 3
etable,tplaswrk,nl,plwk            !plastic work directly from Ansys 5.7  !!
 j=i-1
```

```
 elw=0
 plwk=0
 tosten=0
  mstrain=0
 maxtem=0
pwf=0 !!

 *do,enum,1,emax,1
  *get,sigmaeqv,tsigmaeqv,enum
  *get,volum,tvolum,enum
  *get,eldeqv,teldeqv,enum
  *get,pldeqv,tpldeqv,enum
  *get,sten,tsten,enum
*get,plaswrk,tplaswrk,enum  !!
*get,e1,te1,enum
*get,e3,te3,enum
 etot(1)=e1
 etot(2)=e3
*vabs,1,1,1,1
*vscfun,mstrain,max,etot(1)
!
mstrain=mstrain*100
*if,mstrain,gt,maxtem,then
 maxttstr(i)=mstrain
 maxtem=mstrain
 elemno(i)=enum
*endif

  helw=0.5*volum*eldeqv*sigmaeqv
  elw=elw+helw
  hplwk=0.5*volum*pldeqv*(sigmaeqv+sm)
  plwk=plwk+hplwk
  tosten=tosten+sten
            plaswrk=plaswrk*volum
            pwf=pwf+plaswrk !!
 *enddo
 *get,tosub,active,,set,time
 load(i)=tosub
 ework(i)=elw
 plwork(i)=plwk
 plwork2(i)=pwf !!
 totalwk(i)=(elw+plwk)
 tostener(i)=tosten
diftowk(i)=((elw+plwk)-tosten)
ratio(i)=((elw+plwk)/tosten)
alpha(i)= plwk/elw

!Rotation at the nozzle
*get,disp1,node,node11,rot,z
displa1(i)=disp1

*enddo

*vwrite,
("Load",a30)
*vwrite,
("------------",a30)
*vwrite,Load(1)
(f20.3)
!
```

```
*vwrite,
("Elastic Work",a30)
*vwrite,
("------------",a30)
*vwrite,ework(1)
(f20.3)

*vwrite,
("Plastic Work",a30)
*vwrite,
("------------",a30)
*vwrite,plwork(1)
(f20.3)
!
*vwrite,
("Plastic Work 2 - direct from Ansys5.7",a40)
*vwrite,
("------------",a30)
*vwrite,plwork2(1)
(f20.3)
!
*vwrite,
("Alpha",a30)
*vwrite,
("------------",a30)
*vwrite,alpha(1)
(f20.3)
!
*vwrite,
("Total work            Total Energy (Ansys)    Difference            Ratio",a85)
*vwrite,
("--------------------------------------------------------------------------------",a85)
*vwrite,totalwk(1),tostener(1),diftowk(1),ratio(1)
(4f20.3)
!
!
*vwrite,
("Rotation at nozzle",a30)
*vwrite,
("----------------------",a30)
*vwrite,displa1(1)
(f20.5)
!
*vwrite,
("Displacement at knuckle",a30)
*vwrite,
("-----------------------",a30)
*vwrite,displa2(1)
(f20.5)
!
!
*vwrite,
("% Max total principal strain   Element number",a30)
*vwrite,
("---------------------------------------------",a30)
*vwrite,maxttstr(1),elemno(1)
(2f20.9)
!
*cfclose
```

APPENDIX A9 – ANSYS APDL elastic shakedown macros

'shdown1' – Shakedown loads (proportional loading) - axisymmetric models

```
/config,nproc,2
/config/nlcontrol,0
/prep7
/nerr,0,10000  !Suppress err messages after 1st loss of equil. is met bisection used
!Enter name of model here
/dscale,1,off
!****************** INPUT MODEL NAME HERE *****
/input,2nz10l,txt
!************************************************
refine=0
!
tstart=0.02
tmax=0.1
tmin=0.02
!
!Solution options
/solve
nropt,auto
neqit,100
nlgeom,off  !For limit load analysis
deltim,tstart,tmin,tmax
time,1
outres,all,all
eqslv,frontal
autots,on
eresx,no !Copy integration pt. results to nodes
solv
!
!Postprocessing
/post1
!
*get,subs,active,0,solu,ncmss          !Get cumulative no. of substeps
subs=subs-1                            !Last converged subset
!
!Define arrays for 1st calculation
!You can use these arrays as a rough calculation for shakedown load
*dim,tim,,subs
!*dim,shakemax,,subs
*dim,residmax,,subs
!
set,1,1
lcwrite,99,eresu   !Write first elastic result to loadcase file
!
*do,nn,1,subs                  !substep no. (nn)
 set,1,nn
 *get,tim(nn),active,0,set,time
 lcdef,nn,1,nn
 f=(tim(nn))/(tim(1))
 lcase,nn              !define loaded results as loadcase(nn)
!
! eltim=tim(1)
!Record shakedown and residual fields on contour plots
 /show,colors,f33
 /window,1,-0.8,0.8,-0.8,0.8
 /title,Shakedown stress field
```

```
 plnsol,s,eqv
! *get,shakemax(nn),plnsol,,max
 lcfile,99,eresu     !read in first elastic result
 lcfact,99,-f
 lcoper,add,99                !Add elastic result * -ve factor to shakedown stress field
 /window,1,-0.8,0.8,-0.8,0.8
 /title,Residual stress field
 plnsol,s,eqv
 *get,residmax(nn),plnsol,,max !get averaged stress
!
*enddo
!
finish !exit post1
!
!Write results file
*cfopen,model,txt
*vwrite,model
("Model name : ",10a)
!
*vwrite,tim(nn)
("Limit load multiplier= ",f16.4)
!
!Improve on 1st calculation of shakedown load
*do,jjj,1,subs
 *if,residmax(jjj),gt,sm,then
  !Refine substeps near shakedown load and solve
  nn=jjj
  parsav,all
  /clear
  /input,shdown2,txt
  *exit    !exit DO loop
 *endif
*enddo

*if,refine,eq,0,then
 *vwrite
  ("FAILS BY REACHING LIMIT LOAD ")
*else
  *do,nn,1,subs
   *if,resmax(nn),gt,sm,then
     mela=(tim2(nn-1))/abs(p2)
     *vwrite,mela
     ("SHAKEDOWN LIMIT LOAD MULTIPLIER = ",f16.4)
     *CFCLOSE,model,txt
     /exit
   *endif
  *enddo
*endif
```

'shdown2' – Shakedown loads (proportional loading) - axisymmetric models

```
/config,nproc,2
/config/nlcontrol,0
/prep7
parres,new          !Restore parameters frpm shakey80
!Enter name of model here
/input,2nz10l,txt
!
```

```
refine=1
na=nn-1
tstart=0.2*tim(na)
tmax=tmax/10
!
!Define loadstep 1 (load1)and loadstep 2 (load2) size
!Time is controlled by 'P2' here
p2load1=p2*tim(na)*0.9
p2load2=p2*(tim(nn))
pnload1=pn*tim(na)*0.9
pnload2=pn*(tim(nn))
!....... Continue entering load segments here
loadt1=abs(p2load1)
loadt2=abs(p2load2)
!
/solve
!
!Apply loadstep 1
time,loadt1

lsel,s,line,,5,11,3
lsel,a,line,,7
sfl,all,pres,p2load1
lsel,all
sfl,3,pres,-pnload1
sbctra
!....... Continue entering rest of loads here
!
nsubst,50,50,10
outres,all,all
eqslv,frontal
autots,on
neqit,100
eresx,no
lswrit
!
!Apply loadstep 2
time,loadt2

lsel,s,line,,5,11,3
lsel,a,line,,7
sfl,all,pres,p2load2
lsel,all
sfl,3,pres,-pnload2
sbctra
!....... Continue entering rest of loads here
!
nsubst,10,20,10
outres,all,all
eqslv,frontal
eresx,no
lswrit
!
lssolve,1,2
save
!
!Postprocessing
/post1
!
*get,ecemax,elem,,num,max !get max element number as ecemax
```

```
!
*dim,elxe,,ecemax,4
*dim,elye,,ecemax,4
*dim,elxye,,ecemax,4
*dim,elze,,ecemax,4
!
!Calculate elastic stress fields
set,1,1
*get,eltim,active,0,set,time                    !Time of first substep of 1st loadstep
  *do,ii,1,ecemax                   !Element no.
   esel,s,elem,,ii                  !To store unaveraged results
   *do,nn,1,4                               !No. of corner nodes in element
    *get,nnum,elem,ii,node,nn               !Get node no. (nn) of element
    *get,elxe(ii,nn),node,nnum,s,x
    *get,elye(ii,nn),node,nnum,s,y
    *get,elze(ii,nn),node,nnum,s,z
    *get,elxye(ii,nn),node,nnum,s,xy
   *enddo
  *enddo
!
set,2
*get,subs,active,0,solu,ncmss
!
!Define arrays
*dim,tim2,,subs
*dim,shmax,,subs
*dim,resmax,,subs
!
*dim,shx,,ecemax,subs,4   !(no. of substeps, no.of elem, no. of nodes per elem)
*dim,shy,,ecemax,subs,4
*dim,shz,,ecemax,subs,4
*dim,shxy,,ecemax,subs,4
!*dim,shmis,,ecemax,subs,4          !Von Mises
!
!
*dim,elx,,ecemax,subs,4
*dim,ely,,ecemax,subs,4
*dim,elz,,ecemax,subs,4
*dim,elxy,,ecemax,subs,4
!
!Fill in shakedown arrays (shake(i) - i=x,y,xy)
*do,jj,1,subs                               !Substep no.
 set,2,jj                           !Read results from loadstep 2, substep (jj)
 *do,ii,1,ecemax                    !Element no. (ii)
  esel,s,elem,,ii                   !Store unaveraged results
  *do,nn,1,4                                !No. of corner nodes in element
   *get,nnum,elem,ii,node,nn        !get node no. (nn) of element
   *get,shx(ii,jj,nn),node,nnum,s,x
   *get,shy(ii,jj,nn),node,nnum,s,y
   *get,shz(ii,jj,nn),node,nnum,s,z
   *get,shxy(ii,jj,nn),node,nnum,s,xy
  *enddo
 *enddo
 esel,all
!
!Calc. corresponding elastic field
 *get,tim2(jj),active,0,set,time
   *do,ii,1,ecemax          !elem. no.
    *do,nn,1,4              !no. of corner nodes in element
     elx(ii,jj,nn)=(elxe(ii,nn))*(tim2(jj)/eltim)
```

```
      ely(ii,jj,nn)=(elye(ii,nn))*(tim2(jj)/eltim)
      elz(ii,jj,nn)=(elze(ii,nn))*(tim2(jj)/eltim)
      elxy(ii,jj,nn)=(elxye(ii,nn))*(tim2(jj)/eltim)
     *enddo
   *enddo
*enddo
!
*dim,resx,,ecemax,subs,4
*dim,resy,,ecemax,subs,4
*dim,resz,,ecemax,subs,4
*dim,resxy,,ecemax,subs,4
*dim,remis,,ecemax,subs,4            !Von Mises
!
!Calculate residual stress fields
*do,jj,1,subs
  *do,nn,1,4                  !no. of corner node in element
    *voper,resx(1,jj,nn),shx(1,jj,nn),sub,elx(1,jj,nn)
    *voper,resy(1,jj,nn),shy(1,jj,nn),sub,ely(1,jj,nn)
    *voper,resz(1,jj,nn),shz(1,jj,nn),sub,elz(1,jj,nn)
    *voper,resxy(1,jj,nn),shxy(1,jj,nn),sub,elxy(1,jj,nn)
  *enddo
*enddo
!
!Find maximum residual
*do,jj,1,subs
 *do,ii,1,ecemax  !elem. no.
  *do,nn,1,4                  !no. of corner node in element
    x=resx(ii,jj,nn)
    y=resy(ii,jj,nn)
    z=resz(ii,jj,nn)
    mar1=x-y
    mar2=y-z
    mar3=z-x
    xy=resxy(ii,jj,nn)
    remis(ii,jj,nn)=(sqrt((mar1*mar1)+(mar2*mar2)+(mar3*mar3)+(6*xy*xy)))/sqrt(2)
    temp=abs(remis(ii,jj,nn))
    *if,resmax(jj),lt,temp,then
     resmax(jj)=temp
    *endif
  *enddo
 *enddo
*enddo
```

Axisymmetric nozzle sphere intersection model file

```
/prep7
/title,Nozzle/Sphere junction
/nopr
MODEL='2nz10l'
kan,0
!Define element type
et,1,plane82,,,1

!Enter material properties for elas-perfectly plastic mat. here
*SET,sm,300  !Yield stress
mp,ex,1,200e3   !Young's Modulus
mp,nuxy,1,0.3     !Poisson's ratio
```

```
tb,bkin,1,1
tbdata,1,sm,0

!Define parameters
!*****************************
T=20
rn=282.8  !varied from 14.14 to 282.8
!*****************************
t=T
flt=t/3
R=1000
h=1250
RINT=R-T/2
ROUT=R+T/2
ri=rn-t/2
ro=rn+t/2

!Set value of loadings here
!'P2' is the controlling load
!All loads will be increased monotonically in the incremental soln.
p2=8
pn=(p2*ri*ri)/(2*rn*t)
!..... Enter more loads as necessary here

csys,1
k,1,RINT,0
k,2,ROUT,0
k,3,RINT,90
k,4,ROUT,90
l,1,3
l,1,2
l,2,4
csys,0
k,5,ri,h
k,6,ro,h
k,7,ri,0
k,8,ro,0
l,5,7
l,6,8
lcsl,1,4
lcsl,5,3
ldele,4
ldele,7,11,2
lfillt,1,10,flt,100
*get,ypos,kp,12,loc,y
k,,0,ypos
l,12,13
lcsl,4,8
ldele,11
k,,0,0
l,11,15
lcsl,4,6
ldele,13
l,9,100
lcsl,4,3
ldele,15
l,5,6
al,7,9,14,6
al,6,11,12,13
al,2,1,12,8
```

```
al,9,10,3,5

lesize,6,,,10
lesize,7,,,8
lesize,11,,,8
lesize,13,,,8
lesize,14,,,8

lesize,9,,,10
lesize,3,,,10
lesize,10,,,20,0.1
lesize,5,,,20,0.1

lesize,12,,,10
lesize,2,,,10
lesize,1,,,50,0.05
lesize,8,,,50,0.05
amap,3,16,11,2,1
amap,1,14,12,17,9
amap,2,17,11,16,9
amap,4,14,12,5,6

!Boundary conditions
nsel,s,loc,y,0
d,all,uy,0
nsel,all

!Apply all loading here
!'P2' is the controlling load
*if,refine,ne,1,then
lsel,s,line,,5,11,3
lsel,a,line,,7
sfl,all,pres,p2
lsel,all
sfl,3,pres,-pn
sbctra
!..... Continue entering load application here
*endif
save
fini
```

‘ shtrue’– Finds exact elastic shakedown loads (proportional loading) - axisymmetric

```
/config,nlcontrol,0
/config,nproc,2
/prep7
/nerr,0,10000  !Suppress err messages after 1st loss of equil. is met bisection used
!Enter name of model here
/dscale,1,off
!Bisection method is being used
!****************** INPUT LOAD RANGE HERE *****
sp2=3.5   ! LOWER BOUND ***************
ep2=3.8   ! UPPER BOUND ***************
!*************************************************
!
tol=0.5
*do,drabi,1,10     !set no. of iterations here
!****************** INPUT MODEL NAME HERE *****
```

```
/input,1nz10k,txt
!*********************************************
!
tstart=0.02
tmax=0.1
tmin=0.02
resmax=0
!
!Solution options
/solve
nropt,auto
neqit,100
nlgeom,off  !For limit load analysis
deltim,tstart,tmin,tmax
time,P2
outres,all,all
eqslv,frontal
autots,on
eresx,no !Copy integration pt. results to nodes
solv
!
!Postprocessing
/post1
!
*get,ecemax,elem,,num,max !get max element number as ecemax
!
*if,drabi,eq,1,then
!Define shakedown arrays
*dim,shx,,ecemax,4          !(no.of elem, no. of nodes per elem)
*dim,shy,,ecemax,4
*dim,shz,,ecemax,4
*dim,shxy,,ecemax,4
!
!Define 1st elastic arrays
*dim,elxe,,ecemax,4
*dim,elye,,ecemax,4
*dim,elxye,,ecemax,4
*dim,elze,,ecemax,4
!
!Define scaled-up elastic arrays
*dim,elx,,ecemax,4
*dim,ely,,ecemax,4
*dim,elz,,ecemax,4
*dim,elxy,,ecemax,4
!
!Define residual stress arrays
*dim,resx,,ecemax,4
*dim,resy,,ecemax,4
*dim,resz,,ecemax,4
*dim,resxy,,ecemax,4
*dim,remis,,ecemax,4       !Von Mises
*endif
!
!Calculate elastic stress fields
set,1,1
*get,eltim,active,0,set,time                    !Time of first substep
  *do,ii,1,ecemax                   !Element no.
   esel,s,elem,,ii                  !To store unaveraged results
    *do,nn,1,4                              !No. of corner nodes in element
     *get,nnum,elem,ii,node,nn              !Get node no. (nn) of element
```

```
    *get,elxe(ii,nn),node,nnum,s,x
    *get,elye(ii,nn),node,nnum,s,y
    *get,elze(ii,nn),node,nnum,s,z
    *get,elxye(ii,nn),node,nnum,s,xy
   *enddo
  *enddo
!
set,1,last
!
!Fill in shakedown array (shake(i) - i=x,y,xy)
!
 *do,ii,1,ecemax                    !Element no. (ii)
  esel,s,elem,,ii                   !Store unaveraged results
  *do,nn,1,4                                !No. of corner nodes in element
   *get,nnum,elem,ii,node,nn        !get node no. (nn) of element
   *get,shx(ii,nn),node,nnum,s,x
   *get,shy(ii,nn),node,nnum,s,y
   *get,shz(ii,nn),node,nnum,s,z
   *get,shxy(ii,nn),node,nnum,s,xy
  *enddo
 *enddo
 esel,all
!
!Calc. corresponding elastic field
 *get,tim2,active,0,set,time
   *do,ii,1,ecemax          !elem. no.
    *do,nn,1,4              !no. of corner nodes in element
     elx(ii,nn)=(elxe(ii,nn))*(tim2/eltim)
     ely(ii,nn)=(elye(ii,nn))*(tim2/eltim)
     elz(ii,nn)=(elze(ii,nn))*(tim2/eltim)
     elxy(ii,nn)=(elxye(ii,nn))*(tim2/eltim)
    *enddo
   *enddo
!
!Calculate residual stress fields
!
  *do,nn,1,4                !no. of corner node in element
   *voper,resx(1,nn),shx(1,nn),sub,elx(1,nn)
   *voper,resy(1,nn),shy(1,nn),sub,ely(1,nn)
   *voper,resz(1,nn),shz(1,nn),sub,elz(1,nn)
   *voper,resxy(1,nn),shxy(1,nn),sub,elxy(1,nn)
  *enddo
!
!Find maximum residual
 *do,ii,1,ecemax  !elem. no.
  *do,nn,1,4                !no. of corner node in element
   x=resx(ii,nn)
   y=resy(ii,nn)
   z=resz(ii,nn)
   mar1=x-y
   mar2=y-z
   mar3=z-x
   xy=resxy(ii,nn)
   remis(ii,nn)=(sqrt((mar1*mar1)+(mar2*mar2)+(mar3*mar3)+(6*xy*xy)))/sqrt(2)
   temp=abs(remis(ii,nn))
   *if,resmax,lt,temp,then
    resmax=temp
   *endif
  *enddo
 *enddo
```

```
!Check for residual stress higher than yield stress
toler=abs(sm-resmax)

! Write results file
*cfopen,modlat,txt,,append              !result file
*if,drabi,eq,1,then
 *vwrite,model
 ("Model name : ",10a)
*endif
*vwrite,resmax
("Maximum residual stress= ",f16.4)
*if,toler,lt,tol,then
 *if,resmax,lt,sm,then
 *vwrite,p2
 ("Elastic shakedown load = ",e20.8)
 *endif
*endif
*if,resmax,ge,sm,then
 ep2=p2
 *else
 sp2=p2
*endif
*if,resmax,lt,sm,then
 *if,toler,lt,tol,exit
 *endif
*endif
!
parsav,all
finish
/clear,start
/input,start56,ans,d:\ansys56\docu\,,,,,,,,,,,,,,,1
/prep7
parres,new
!
*enddo                !Repeat iteration with narrower load range

*if,drabi,eq,10,then
 *vwrite,P2
 ("Best Lower Bound in given range = ",e20.8)
*endif
/eof
```

Axisymmetric nozzle sphere intersection model file

```
/prep7
/title,Nozzle/Sphere junction
/nopr
MODEL='1nz10k'
kan,0
!Define element type
et,1,plane82,,,1

!Enter material properties for elas-perfectly plastic mat. here
*SET,sm,300  !Yield stress
mp,ex,1,200e3   !Young's Modulus
mp,nuxy,1,0.3     !Poisson's ratio
tb,bkin,1,1
```

```
tbdata,1,sm,0

!Define parameters
!*****************************
T=10
rn=150  !varied from 10 to 200
!*****************************
t=T
flt=t/3
R=1000
h=1250
RINT=R-T/2
ROUT=R+T/2
ri=rn-t/2
ro=rn+t/2

!Set value of loadings here
!'P2' is the controlling load
!All loads will be increased monotonically in the incremental soln.
p2=(sp2+ep2)/2
pn=(p2*ri*ri)/(2*rn*t)
!..... Enter more loads as necessary here

csys,1
k,1,RINT,0
k,2,ROUT,0
k,3,RINT,90
k,4,ROUT,90
l,1,3
l,1,2
l,2,4
csys,0
k,5,ri,h
k,6,ro,h
k,7,ri,0
k,8,ro,0
l,5,7
l,6,8
lcsl,1,4
lcsl,5,3
ldele,4
ldele,7,11,2
lfillt,1,10,flt,100
*get,ypos,kp,12,loc,y
k,,0,ypos
l,12,13
lcsl,4,8
ldele,11
k,,0,0
l,11,15
lcsl,4,6
ldele,13
l,9,100
lcsl,4,3
ldele,15
l,5,6
al,7,9,14,6
al,6,11,12,13
al,2,1,12,8
al,9,10,3,5
```

```
lesize,6,,,10
lesize,7,,,8
lesize,11,,,8
lesize,13,,,8
lesize,14,,,8

lesize,9,,,10
lesize,3,,,10
lesize,10,,,20,0.1
lesize,5,,,20,0.1

lesize,12,,,10
lesize,2,,,10
lesize,1,,,50,0.05
lesize,8,,,50,0.05
amap,3,16,11,2,1
amap,1,14,12,17,9
amap,2,17,11,16,9
amap,4,14,12,5,6

!Boundary conditions
nsel,s,loc,y,0
d,all,uy,0
nsel,all

!Apply all loading here
!'P2' is the controlling load
*if,refine,ne,1,then
lsel,s,line,,5,11,3
lsel,a,line,,7
sfl,all,pres,p2
lsel,all
sfl,3,pres,-pn
sbctra
!..... Continue entering load application here
*endif
save
fini
/eof
```

‘ shtrue’– Finds exact elastic shakedown loads (proportional loading) – 2D Solid

```
/config,nlcontrol,0
/config,nproc,2
/prep7
/nerr,0,10000  !Suppress err messages after 1st loss of equil. is met bisection used
!Enter name of model here
/dscale,1,off
!Bisection method is being used
!****************** INPUT LOAD RANGE HERE *****
sp2=150  ! LOWER BOUND ***************
ep2=170  ! UPPER BOUND ***************
!*************************************************
!
tol=0.5
*do,drabi,1,10     !set no. of iterations here
!****************** INPUT MODEL NAME HERE *****
```

```
/input,shplate,txt
!*********************************************
!
tstart=0.02
tmax=0.1
tmin=0.02
resmax=0
!
!Solution options
/solve
nropt,auto
neqit,100
nlgeom,off  !For limit load analysis
deltim,tstart,tmin,tmax
time,1
outres,all,all
eqslv,frontal
autots,on
eresx,no !Copy integration pt. results to nodes
solv
!
!Postprocessing
/post1
!
*get,ecemax,elem,,num,max !get max element number as ecemax
!
*if,drabi,eq,1,then
!Define shakedown arrays
*dim,shx,,ecemax,4          !(no.of elem, no. of nodes per elem)
*dim,shy,,ecemax,4
*dim,shz,,ecemax,4
*dim,shxy,,ecemax,4
!
!Define 1st elastic arrays
*dim,elxe,,ecemax,4
*dim,elye,,ecemax,4
*dim,elxye,,ecemax,4
*dim,elze,,ecemax,4
!
!Define scaled-up elastic arrays
*dim,elx,,ecemax,4
*dim,ely,,ecemax,4
*dim,elz,,ecemax,4
*dim,elxy,,ecemax,4
!
!Define residual stress arrays
*dim,resx,,ecemax,4
*dim,resy,,ecemax,4
*dim,resz,,ecemax,4
*dim,resxy,,ecemax,4
*dim,remis,,ecemax,4       !Von Mises
*endif
!
!Calculate elastic stress fields
set,1,1
*get,eltim,active,0,set,time                    !Time of first substep
  *do,ii,1,ecemax                   !Element no.
   esel,s,elem,,ii                  !To store unaveraged results
    *do,nn,1,4                              !No. of corner nodes in element
     *get,nnum,elem,ii,node,nn              !Get node no. (nn) of element
```

```
     *get,elxe(ii,nn),node,nnum,s,x
     *get,elye(ii,nn),node,nnum,s,y
     *get,elze(ii,nn),node,nnum,s,z
     *get,elxye(ii,nn),node,nnum,s,xy
    *enddo
   *enddo
!
set,1,last
!
!Fill in shakedown array (shake(i) - i=x,y,xy)
!
 *do,ii,1,ecemax                    !Element no. (ii)
   esel,s,elem,,ii                  !Store unaveraged results
   *do,nn,1,4                               !No. of corner nodes in element
    *get,nnum,elem,ii,node,nn       !get node no. (nn) of element
    *get,shx(ii,nn),node,nnum,s,x
    *get,shy(ii,nn),node,nnum,s,y
    *get,shz(ii,nn),node,nnum,s,z
    *get,shxy(ii,nn),node,nnum,s,xy
   *enddo
 *enddo
 esel,all
!
!Calc. corresponding elastic field
 *get,tim2,active,0,set,time
    *do,ii,1,ecemax             !elem. no.
      *do,nn,1,4                !no. of corner nodes in element
       elx(ii,nn)=(elxe(ii,nn))*(tim2/eltim)
       ely(ii,nn)=(elye(ii,nn))*(tim2/eltim)
       elz(ii,nn)=(elze(ii,nn))*(tim2/eltim)
       elxy(ii,nn)=(elxye(ii,nn))*(tim2/eltim)
      *enddo
    *enddo
!
!Calculate residual stress fields
!
  *do,nn,1,4                    !no. of corner node in element
    *voper,resx(1,nn),shx(1,nn),sub,elx(1,nn)
    *voper,resy(1,nn),shy(1,nn),sub,ely(1,nn)
    *voper,resz(1,nn),shz(1,nn),sub,elz(1,nn)
    *voper,resxy(1,nn),shxy(1,nn),sub,elxy(1,nn)
  *enddo
!
!Find maximum residual
 *do,ii,1,ecemax  !elem. no.
  *do,nn,1,4                    !no. of corner node in element
    x=resx(ii,nn)
    y=resy(ii,nn)
    z=resz(ii,nn)
    mar1=x-y
    mar2=y-z
    mar3=z-x
    xy=resxy(ii,nn)
    remis(ii,nn)=(sqrt((mar1*mar1)+(mar2*mar2)+(mar3*mar3)+(6*xy*xy)))/sqrt(2)
    temp=abs(remis(ii,nn))
    *if,resmax,lt,temp,then
     resmax=temp
    *endif
  *enddo
 *enddo
```

```
!Check for residual stress higher than yield stress
toler=abs(sm-resmax)

! Write results file
*cfopen,pwhres,txt,,append              !result file
*if,drabi,eq,1,then
 *vwrite,model
 ("Model name : ",10a)
*endif
*vwrite,resmax
("Maximum residual stress= ",f16.4)
*if,toler,lt,tol,then
 *if,resmax,lt,sm,then
 *vwrite,p2
 ("Elastic shakedown load = ",e20.8)
 *endif
*endif
*if,resmax,ge,sm,then
 ep2=p2
 *else
 sp2=p2
*endif
*if,resmax,lt,sm,then
 *if,toler,lt,tol,exit
 *endif
*endif
!
parsav,all
finish
/clear,start
/input,start56,ans,c:\ansys56\,,,,,,,,,,,,,,,1
/prep7
parres,new
!
*enddo                !Repeat iteration with narrower load range

*if,drabi,eq,10,then
 *vwrite,P2
 ("Best Lower Bound in given range = ",e20.8)
*endif
/eof
```

! * * Model sample * *

```
!Enter geometry and loading only
/prep7
/nopr
/title,Circular Hole - elasto-plastic analysis
kan,0
et,1,82

!Enter material properties for elas-perfectly plastic mat. here
*SET,sm,300  !Yield stress
mp,ex,1,207e3   !Young's Modulus
tb,bkin,1,1
tbdata,1,sm,0

*SET,rat,0.2
```

```
*SET,l,100
*SET,d,rat*l
*SET,model,'hplate'

!Set value of loadings here
!'P2' is the controlling load
!All loads will be increased monotonically in the incremental soln.
p2=(sp2+ep2)/2
p1=-0.5*p2
!....... Enter more loads as necessary here

divs=15
k,1,0,0
k,2,d/2,0
k,3,l/2,0
k,4,l/2,l/2
k,5,0,l/2
k,6,0,d/2
l,2,3,divs,4
l,3,4,divs
l,4,5,divs
l,6,5,divs,4
larc,2,6,1,d/2,divs*2
ldiv,5
l,7,4,divs,6
ldvs,6,,divs
ldvs,5,,divs
a,2,3,4,7
a,7,4,5,6
amesh,1,2,1
nrsel,x,0
d,all,ux,0
nall
nrsel,y,0
d,all,uy,0
nall

!Apply all loading here
!'P2' is the controlling load
*if,refine,ne,1,then
sfl,3,pres,p2
sbctra
sfl,2,pres,p1
sbctra
!......... Continue entering load application here
*endif
save
fini
```

‘ shk3dnew’– Finds exact elastic shakedown loads (proportional loading) – 3D Solid

```
/prep7
/nerr,0,10000  !Suppress err messages after 1st loss of equil. is met bisection used
!Enter name of model here
/dscale,1,off
!****************** INPUT MODEL NAME HERE *****
/input,3dcylnew,txt           !Model must include also solution stage
!************************************************
```

```
!
!Postprocessing
/post1
*get,ecemax,elem,,num,max !get max element number as ecemax
!

!
!Define arrays
!!
!Define arrays
*dim,elasx,,ecemax,8,2
*dim,elasy,,ecemax,8,2
*dim,elasz,,ecemax,8,2
*dim,elasxy,,ecemax,8,2
*dim,elasyz,,ecemax,8,2
*dim,elasxz,,ecemax,8,2

*dim,indepx,,ecemax,8      !(no.of elem, no. of nodes per elem)
*dim,indepy,,ecemax,8
*dim,indepz,,ecemax,8
*dim,indepxy,,ecemax,8
*dim,indepyz,,ecemax,8
*dim,indepxz,,ecemax,8
*dim,indepmis,,ecemax,8

*dim,postx,,ecemax,8
*dim,posty,,ecemax,8
*dim,postz,,ecemax,8
*dim,postxy,,ecemax,8
*dim,postyz,,ecemax,8
*dim,postxz,,ecemax,8
*dim,postmis,,ecemax,8    !Von Mises

*dim,postmis2,,ecemax,8  !Von Mises material shell+weld
*dim,postmis3,,ecemax,8  !Von Mises material nozzle

!!
!*dim,tim,,subs
!*dim,shakemax,,subs
!*dim,residmax,,subs

!
!To be used for the scaled up elastic loading of P1
set,1,last
*get,tme,active,0,set,time
!
!Get elastic stress field
 *do,ii,1,ecemax  !elem. no.
  esel,s,elem,,ii                !To store unaveraged results
     *do,nn,1,8                  !no. of corner nodes in element
      *get,nnum,elem,ii,node,nn       !get node no. (nn) of element
      *get,elasx(ii,nn,1),node,nnum,s,x
      *get,elasy(ii,nn,1),node,nnum,s,y
      *get,elasz(ii,nn,1),node,nnum,s,z
      *get,elasxy(ii,nn,1),node,nnum,s,xy
      *get,elasyz(ii,nn,1),node,nnum,s,yz
      *get,elasxz(ii,nn,1),node,nnum,s,xz
     *enddo
 *enddo
esel,all
```

```
!
!last save

!Get shakedown and residual stress fields for each substep
!
set,2
*get,subs,active,0,solu,ncmss          !Get cumulative no. of substeps
!subs=subs-1                           !Last converged subset
!
*dim,tim,,subs
*dim,shakemax,,subs
*dim,residmax,,subs
!
*do,subi,1,subs                        !substep no. (nn)
 set,2,subi
!
 *get,tim(subi),active,0,set,time
! lcdef,nn,2,nn
 f=(tim(subi))/(tme)
!
!Calculate scaled up elastic stress field for p1
  *do,ii,1,ecemax  !elem. no.
     *do,nn,1,8                  !no. of corner nodes in element
      elasx(ii,nn,2)=(elasx(ii,nn,1))*f
      elasy(ii,nn,2)=(elasy(ii,nn,1))*f
      elasz(ii,nn,2)=(elasz(ii,nn,1))*f
      elasxy(ii,nn,2)=(elasxy(ii,nn,1))*f
      elasyz(ii,nn,2)=(elasyz(ii,nn,1))*f
      elasxz(ii,nn,2)=(elasxz(ii,nn,1))*f
     *enddo  !loop trough nodes
   *enddo  !loop through elements
!
!Read in shakedown stress field for substep subi
  *do,ii,1,ecemax  !elem. no.
      esel,s,elem,,ii             !To store unaveraged results
     *do,nn,1,8                   !no. of corner nodes in element
    *get,nnum,elem,ii,node,nn          !get node no. (nn) of element
       *get,indepx(ii,nn),node,nnum,s,x
       *get,indepy(ii,nn),node,nnum,s,y
       *get,indepz(ii,nn),node,nnum,s,z
       *get,indepxy(ii,nn),node,nnum,s,xy
       *get,indepyz(ii,nn),node,nnum,s,yz
       *get,indepxz(ii,nn),node,nnum,s,xz
    *enddo   !loop trough nodes
  *enddo  !loop through elements
esel,all
!
!Create residual stress field   RENAME POST ARRAYS AS RESID & INDEP ARRAYS AS SHAKE
  *do,ii,1,ecemax  !elem. no.
     *do,nn,1,8                   !no. of corner nodes in element
    *voper,postx(1,nn),indepx(1,nn),sub,elasx(1,nn,2)
    *voper,posty(1,nn),indepy(1,nn),sub,elasy(1,nn,2)
    *voper,postz(1,nn),indepz(1,nn),sub,elasz(1,nn,2)
    *voper,postxy(1,nn),indepxy(1,nn),sub,elasxy(1,nn,2)
    *voper,postyz(1,nn),indepyz(1,nn),sub,elasyz(1,nn,2)
    *voper,postxz(1,nn),indepxz(1,nn),sub,elasxz(1,nn,2)
     *enddo   !loop trough nodes
  *enddo  !loop through elements

!Find Von Mises residual stress field
```

```
 *do,ii,1,ecemax  !elem. no.
  *do,nn,1,8                  !no. of corner node in element
    sxx=postx(ii,nn)
    syy=posty(ii,nn)
    szz=postz(ii,nn)
    sxy=postxy(ii,nn)
    syz=postyz(ii,nn)
    sxz=postxz(ii,nn)
    d11=sxx-syy
    d22=syy-szz
    d33=szz-sxx
    d44=(sxy*sxy)+(syz*syz)+(sxz*sxz)
    postmis(ii,nn)=(sqrt((d11*d11)+(d22*d22)+(d33*d33)+(6*d44)))/sqrt(2)
  *enddo
 *enddo
!
!Find maximum Von Mises stresses
postmax=0
temp=0
 *do,ii,1,ecemax  !elem. no.
  *do,nn,1,8                  !no. of corner node in element
    temp=postmis(ii,nn)
    *if,postmax,lt,temp,then
      postmax=temp
    *endif
  *enddo
 *enddo
residmax(subi)=postmax

!
 *enddo  !end looping through substeps
!
!Print out results
!
*cfopen,rescrbores,txt   !result file
*vscfun,resmaxx,max,residmax(1)
!*****************************************************************************************
!*****************************************************************************************
!*vwrite,pint
!("Pint = ",f15.3)
*vwrite,
("-----------------------------------------------------------------",a80)
*vwrite,
("       Load                        Residual stress",a80)
*vwrite,
("-----------------------------------------------------------------",a80)
*vwrite,tim(1),residmax(1)
(f15.5,f15.5)
*vwrite,resmaxx,
("max residual stress= ",f15.5)

!*****************************************************************************************
!
*cfclose
*cfclose
/eof
```

3D - Model file

```
!Enter geometry and loading only
/prep7
/nerr,0,10000  !Suppress err messages after 1st loss of equil. is met bisection used
/nopr
/title,Circular Hole - elasto-plastic analysis
kan,0
et,1,solid45

!Enter material properties for elas-perfectly plastic mat. here
*SET,sm,300  !Yield stress
mp,ex,1,207e3   !Young's Modulus
tb,bkin,1,1
tbdata,1,sm,0

*SET,model,'cylinder'
nd1=48
nd2=16
nd3=3
!
!!
!!!!!!! Set value of applied pressure here  !!!!!!!!!!!!!!!!!!!!!
!All loads will be increased monotonically in the incremental soln.
pyint=160
pfint=480
!!
!
inrad=10
outrad=40
length=2
clocal,11,cylin
k,1,inrad,0
k,2,outrad,0
k,3,inrad,30
k,4,outrad,30
l,1,2,nd1
l,2,4,nd2
l,4,3,nd1
l,3,1,nd2
al,1,2,3,4
vext,1,,,,,-length
lsel,s,line,,9,12,1
lesize,all,,,nd3
lsel,all
vmesh,all
!Boundary conditions
asel,s,area,,3,5,2
da,all,symm
asel,all
nsel,s,loc,z,0
nsel,a,loc,z,-length
d,all,uz,0
nsel,all

/solu

!Apply all loading here
!
asel,s,area,,6
```

```
sfa,all,,pres,pyint
asel,all
autots,on
nlgeom,off  !For limit load analysis
time,pyint
outres,all,all
eresx,no !Copy integration pt. results to nodes
lswrit
!
asel,s,area,,6
sfa,all,,pres,pfint
asel,all
sstart=20
smax=50
smin=5
nropt,auto
neqit,50
nlgeom,off  !For limit load analysis
nsubst,sstart,smax,smin
time,pfint
outres,all,all
eqslv,frontal
eresx,no !Copy integration pt. results to nodes
lswrit
!
lssolve,1,2
```

File for plate with a hole – non proportional loading

```
/config,nlcontrol,0
/config,nproc,1
/prep7
/com,-ve sign on pressure gives tension
model='Plate with hole'
!
*cfopen,r100,txt,,append    !result file
*vwrite,model
 ("* ",30a)
!
/prep7

/prep7
subs=0
/nopr
/title,Circular Hole - elasto-plastic analysis
/nerr,0,10000  !Suppress err messages after 1st loss of equil. is met bisection used
kan,0
et,1,82
mp,ex,1,207e3
rat=0.2
l=100
d=rat*l
sm=300
indepmax=0        !Reset values
postmax=0         !Reset values
tb,bkin,1,1
tbdata,1,300,0
```

```
tol=0.5
tol2=0.00*sm


p2=186.366
p1=1*p2
!p1=p2
pnull=0
p1e=30              !To be used for the elastic response of p1
f=p1/p1e

divs=15
k,1,0,0
k,2,d/2,0
k,3,l/2,0
k,4,l/2,l/2
k,5,0,l/2
k,6,0,d/2
l,2,3,divs,4
l,3,4,divs
l,4,5,divs
l,6,5,divs,4
larc,2,6,1,d/2,divs*2
ldiv,5
l,7,4,divs,6
ldvs,6,,divs
ldvs,5,,divs
a,2,3,4,7
a,7,4,5,6
amesh,1,2,1
nrsel,x,0
d,all,ux,0
nall
nrsel,y,0
d,all,uy,0
nall

!Apply loadsteps here
/solve
nropt,auto
neqit,100
nlgeom,off  !for limit load analysis
!
!!Apply loadstep 1 (to be used for elastic load/unload of P2)
time,1
sfl,2,pres,-p1e
sbctra
nsubst,50,50,10
neqit,100
outres,all,all
eqslv,frontal
autots,on
eresx,no
lswrit
!
!!Apply loadstep 2 (remove load applied in loadstep 1)
time,1
sfl,2,pres,pnull
sbctra
nsubst,50,50,10
```

```
neqit,100
outres,all,all
eqslv,frontal
autots,on
eresx,no
lswrit
!

!!Apply loadstep 3 (P2 - vertical)
time,1
sfl,3,pres,-p2
sfl,2,pres,-p1
sbctra
nsubst,50,50,10
neqit,100
outres,all,all
eqslv,frontal
autots,on
eresx,no
lswrit
!
!!Apply loadstep 4 unload P1 - keeping P2 applied
time,1
sfl,3,pres,-p2
sfl,2,pres,pnull
sbctra
nsubst,50,50,10
neqit,100
outres,all,all
eqslv,frontal
autots,on
eresx,no
lswrit
!
!!Apply loadstep 5 load P1 - keeping P2 applied
time,1
sfl,3,pres,-p2
sfl,2,pres,-p1
sbctra
nsubst,50,50,10
neqit,100
outres,all,all
eqslv,frontal
autots,on
eresx,no
lswrit
!
!!Apply loadstep 6 unload P1 - keeping P2 applied
!That is obtain time independent stress field 's'
time,1
sfl,3,pres,-p2
sfl,2,pres,pnull
sbctra
nsubst,50,50,10
neqit,100
outres,all,all
eqslv,frontal
autots,on
eresx,no
lswrit
```

```
lssolve,1,6
save

/post1
!Check if limit load was exceeded on the 1st loading of 'P2'
set,4                   !Loadstep when P2 was applied
*get,subs,active,0,solu,ncmss          !Get cumulative no. of substeps for loadstep 3
!Output msg that limit load was exceeded with the 1st loading of p2 & P1
 *if,subs,gt,50,then
*vwrite
 ("L.load exceeded on 1st app. of P2, REDUCE P2 ",70a)
  *msg,note
  Limit load exceeded on 1st application of P2, REDUCE P2 hence P1, (P1=fact*P2)
  /eof
 *endif
 *if,subs,gt,50,exit
 *endif

/post1

*get,ecemax,elem,,num,max !get max element number as ecemax

!Define arrays
*dim,elasx,,ecemax,2,4
*dim,elasy,,ecemax,2,4
*dim,elasxy,,ecemax,2,4

*dim,indepx,,ecemax,4      !(no.of elem, no. of nodes per elem)
*dim,indepy,,ecemax,4
*dim,indepxy,,ecemax,4
*dim,indepmis,,ecemax,4

*dim,postx,,ecemax,4
*dim,posty,,ecemax,4
*dim,postxy,,ecemax,4
*dim,postmis,,ecemax,4    !Von Mises


!Calculate 1st elastic stress field for P1 acting alone
!To be used for the scaled up elastic loading of P1
set,1,last
 *do,ii,1,ecemax  !elem. no.
  esel,s,elem,,ii                !To store unaveraged results
     *do,nn,1,4                  !no. of corner nodes in element
      *get,nnum,elem,ii,node,nn       !get node no. (nn) of element
      *get,elasx(ii,1,nn),node,nnum,s,x
      *get,elasy(ii,1,nn),node,nnum,s,y
      *get,elasxy(ii,1,nn),node,nnum,s,xy
     *enddo
 *enddo
esel,all


!Calculate scaled up elastic stress field for p1
  *do,ii,1,ecemax  !elem. no.
     *do,nn,1,4                  !no. of corner nodes in element
      elasx(ii,2,nn)=(elasx(ii,1,nn))*f
      elasy(ii,2,nn)=(elasy(ii,1,nn))*f
      elasxy(ii,2,nn)=(elasxy(ii,1,nn))*f
```

```
     *enddo
  *enddo

!Time independent stress field 's'- P2 in equilibrium with residual stress field
set,6
 *do,ii,1,ecemax   !elem. no. (jj)
   esel,s,elem,,ii                !To store unaveraged results
   *do,nn,1,4                     !no. of corner nodes in element
    *get,nnum,elem,ii,node,nn          !get node no. (nn) of element
    *get,indepx(ii,nn),node,nnum,s,x
    *get,indepy(ii,nn),node,nnum,s,y
    *get,indepxy(ii,nn),node,nnum,s,xy
    x=indepx(ii,nn)
    y=indepy(ii,nn)
    xy=indepxy(ii,nn)
    indepmis(ii,nn)=sqrt((x*x)+(y*y)-(x*y)+(3*xy*xy))
    temp=abs(indepmis(ii,nn))
    *if,indepmax,lt,temp,then
     indepmax=temp
    *endif
   *enddo
 *enddo
 esel,all

!Calculate stress field after reloading scaled up elastic field of P1
  *do,nn,1,4                     !no. of corner node in element
    *voper,postx(1,nn),indepx(1,nn),add,elasx(1,2,nn)
    *voper,posty(1,nn),indepy(1,nn),add,elasy(1,2,nn)
    *voper,postxy(1,nn),indepxy(1,nn),add,elasxy(1,2,nn)
  *enddo
!Find maximum Von Mises post transient stress field
 *do,ii,1,ecemax   !elem. no.
  *do,nn,1,4                     !no. of corner node in element
    x=postx(ii,nn)
    y=posty(ii,nn)
    xy=postxy(ii,nn)
    postmis(ii,nn)=sqrt((x*x)+(y*y)-(x*y)+(3*xy*xy))
    temp=abs(postmis(ii,nn))
    *if,postmax,lt,temp,then
     postmax=temp
    *endif
  *enddo
 *enddo

!Check for post transient stress higher than yield stress
toler=abs(sm-postmax)

! Write results file

*vwrite,postmax,P1,P2
("Maximum final stress= ",f16.4,"      P1=",e20.8,"      P2=",e20.8)

*cfclos
```

File for nozzle cylinder intersection – non proportional loading

```
/config,nlcontrol,0
/config,nproc,2
```

```
/prep7

*cfopen,rult1765,txt,,append   !result file

!properties beam element!
et,1,4
r,1,100,10000/12,10000/12,10,10
mp,ex,1,210125
mp,nuxy,1,0.3
!element SOLID45!
et,2,45
!mat. properties shell!
tb,bkin,2
tbdat,1,234,0
mp,ex,2,210125
!mat. properties nozzle!
tb,bkin,3
tbdat,1,343,0
mp,ex,3,210125
pie=2.6
pi=17.65!*****INPUT VALUE OF PRESSURE HERE*****
cm=355550
f=pi/pie
postmax2=0
postmax3=0
temp2=0
temp3=0

!Creating the half model!
local,11,1,,,,-90
ri1=142.5 !inner radius shell!
t1=15 !thickness shell!
ro1=ri1+t1
z1=100 !0.5 * length of shell!
ri2=10 !inner radius nozzle!
t2=7.5 !thickness nozzle!
str=1 !inside fillet!
ro2=ri2+t2
z2=ri1+t1+100
r=6.5 !weld fillet!
csys,1
k,1,ro1,65,z1
k,2,ro1,65
kgen,2,1,2,1,,25
a,1,2,4,3
csys,11
k,5,ro2,-90
k,6,ro2
kgen,2,5,6,,,,z2
a,5,6,8,7
/view,,1,1,1
/pnum,area,1
/pnum,kpoi,1
/pnum,line,1
aplot
aovlap,1,2
aplot
adele,3,4,1,1
afillt,5,6,r
```

```
csys,1
k,22,ri1,65,z1
k,23,ri1,65
kgen,2,22,23,1,,25
a,22,23,5,4
csys,11
k,24,ri2,-90
k,25,ri2
kgen,2,24,25,,,,z2
a,24,25,9,6
aovlap,4,5
adele,6,7,1,1
afillt,8,9,str
csys,0
lgen,2,25,,,-ri2,-z2/2
a,20,21,10,5
asba,6,7
k,100,,ro1+r
a,16,19,100
asba,4,6
a,5,16,21,12,30,25
a,20,11,29,28,10,19
a,19,10,5,16
a,21,12,11,20
va,4,8,5,10,11,2,12,6
a,5,16,7,6
a,6,7,8,9
a,8,9,10,19
va,11,13,7,15,1,14
a,1,3,4,22
a,1,2,23,22
a,11,20,2,23
a,12,21,3,4
va,9,12,18,17,16,19,3
/pnum,volu,1
vplot
esize,,4 !number of element divisions along lines, if not specified otherwise!
flst,2,3,5,orde,3
fitem,2,5
fitem,2,8
fitem,2,10
accat,p51x
flst,2,3,4,orde,3
fitem,2,8
fitem,2,16
fitem,2,28
lccat,p51x
flst,2,3,4,orde,3
fitem,2,6
fitem,2,15
fitem,2,29
lccat,p51x
accat,16,17
lccat,5,9
lccat,1,4
csys,1
lgen,2,1,5,4,,-155
l,1,13
l,22,15
l,2,14
```

```
l,23,17
v,1,22,15,13,2,23,17,14
vplot

!element division on specified lines!
a=10
lesi,24,,,a
lesi,20,,,a
lesi,31,,,a
lesi,36,,,a
lesi,25,,,a
lesi,17,,,a
lesi,15,,,5
lesi,16,,,5
lesi,28,,,5
lesi,29,,,5
lesi,6,,,1
lesi,8,,,1
lesi,13,,,12,.33
lesi,14,,,12,3
lesi,19,,,12,.33
lesi,23,,,12,.33
lesi,1,,,5
lesi,5,,,5
lesi,4,,,5
lesi,27,,,10,.33
lesi,44,,,16
lesi,45,,,16
lesi,46,,,16
lesi,47,,,16

!use mapped meshing!
mshkey,1
!meshing!
vsel,s,,,2
type,2
mat,3
vmesh,all
eplot
allsel
vsel,u,,,2
vplot
type,2
mat,2
vmesh,all
allsel
csys,0

!generate the other half of the model by reflection!
vsymm,z,all
nummrg,all
eplot

!create beam element!
k,100,0,z2,0
k,101,0,z2+10,0
nkpt,,100 !node No. 4701!
nkpt,,101 !node No. 4702!
type,1
real,1
```

```
mat,1
e,4701,4702
eplot
!symmetry b.c.!
nsel,s,loc,x,0
dsym,symm,x
allsel

!b.c. for dummy end of beam!
d,4702,uz,0

!b.c. at the ends of the shell!
csys,1
nsel,s,loc,z,100
nsel,u,loc,y,90
nsel,u,loc,y,-90
nrotat,all !rotate the nodal CS!
d,all,uy,0 !hoop displacements constraint!
nsel,r,loc,y,16.563
nsel,r,loc,x,ro1
d,all,uz,0 !longitudinal displacement constraint!
allsel
nsel,s,loc,z,-100
nsel,u,loc,y,90
nsel,u,loc,y,-90
nrotat,all !rotate the nodal CS!
d,all,uy,0 !hoop displacement constraint!
allsel

!create rigid region!
csys,0
nsel,s,loc,y,z2
cerig,4701,all,uy
allsel
save

/solu

!Apply internal pressure for elastic calculation!
asel,s,,,7
asel,a,,,9
asel,a,,,10
asel,a,,,23
asel,a,,,30
asel,a,,,36
asel,a,,,40
asel,a,,,47
asel,a,,,28
asel,a,,,29
asel,a,,,5
asel,a,,,8
sfa,all,,pres,pie
allsel
!longitudinal stress in nozzle!
asel,s,,,14
asel,a,,,39
sfa,all,,pres,-0.4848*pie
allsel
!longitudinal stress shell!
asel,s,,,16
```

```
asel,a,,,22
asel,a,,,42
asel,a,,,46
sfa,all,,pres,-4.5125*pie
allsel
solcon,on
nropt,auto
autots,on
nsubst,5,25,5
neqit,50
outres,all,all
eresx,no
time,1
lswrit

!Unload internal pressure for elastic calculation!
asel,s,,,7
asel,a,,,9
asel,a,,,10
asel,a,,,23
asel,a,,,30
asel,a,,,36
asel,a,,,40
asel,a,,,47
asel,a,,,28
asel,a,,,29
asel,a,,,5
asel,a,,,8
sfa,all,,pres,0
allsel
!longitudinal stress in nozzle!
asel,s,,,14
asel,a,,,39
sfa,all,,pres,-0.4848*0
allsel
!longitudinal stress shell!
asel,s,,,16
asel,a,,,22
asel,a,,,42
asel,a,,,46
sfa,all,,pres,-4.5125*0
allsel
solcon,on
nropt,auto
autots,on
nsubst,5,25,5
neqit,50
outres,all,all
eresx,no
time,1
lswrit

!Apply steady moment load!
f,4701,mx,cm
solcon,on
nropt,auto
autots,on
nsubst,2,10,2
neqit,50
outres,all,all
```

```
eresx,no
time,1
lswrit

!Apply cyclic internal pressure!
f,4701,mx,cm
asel,s,,,7
asel,a,,,9
asel,a,,,10
asel,a,,,23
asel,a,,,30
asel,a,,,36
asel,a,,,40
asel,a,,,47
asel,a,,,28
asel,a,,,29
asel,a,,,5
asel,a,,,8
sfa,all,,pres,pi
allsel
!longitudinal stress in nozzle!
asel,s,,,14
asel,a,,,39
sfa,all,,pres,-0.4848*pi
allsel
!longitudinal stress shell!
asel,s,,,16
asel,a,,,22
asel,a,,,42
asel,a,,,46
sfa,all,,pres,-4.5125*pi
allsel
solcon,on
nropt,auto
autots,on
nsubst,5,25,5
neqit,50
outres,all,all
eresx,no
time,1
lswrit

!Unload internal cyclic pressure!
f,4701,mx,cm
asel,s,,,7
asel,a,,,9
asel,a,,,10
asel,a,,,23
asel,a,,,30
asel,a,,,36
asel,a,,,40
asel,a,,,47
asel,a,,,28
asel,a,,,29
asel,a,,,5
asel,a,,,8
sfa,all,,pres,0
allsel
!longitudinal stress in nozzle!
asel,s,,,14
```

```
asel,a,,,39
sfa,all,,pres,-0.4848*0
allsel
!longitudinal stress shell!
asel,s,,,16
asel,a,,,22
asel,a,,,42
asel,a,,,46
sfa,all,,pres,-4.5125*0
allsel
solcon,on
nropt,auto
autots,on
nsubst,5,25,5
neqit,50
outres,all,all
eresx,no
time,1
lswrit

!Apply cyclic internal pressure!
f,4701,mx,cm
asel,s,,,7
asel,a,,,9
asel,a,,,10
asel,a,,,23
asel,a,,,30
asel,a,,,36
asel,a,,,40
asel,a,,,47
asel,a,,,28
asel,a,,,29
asel,a,,,5
asel,a,,,8
sfa,all,,pres,pi
allsel
!longitudinal stress in nozzle!
asel,s,,,14
asel,a,,,39
sfa,all,,pres,-0.4848*pi
allsel
!longitudinal stress shell!
asel,s,,,16
asel,a,,,22
asel,a,,,42
asel,a,,,46
sfa,all,,pres,-4.5125*pi
allsel
solcon,on
nropt,auto
autots,on
nsubst,5,25,5
neqit,50
outres,all,all
eresx,no
time,1
lswrit

!Unload internal cyclic pressure!
f,4701,mx,cm
```

```
asel,s,,,7
asel,a,,,9
asel,a,,,10
asel,a,,,23
asel,a,,,30
asel,a,,,36
asel,a,,,40
asel,a,,,47
asel,a,,,28
asel,a,,,29
asel,a,,,5
asel,a,,,8
sfa,all,,pres,0
allsel
!longitudinal stress in nozzle!
asel,s,,,14
asel,a,,,39
sfa,all,,pres,-0.4848*0
allsel
!longitudinal stress shell!
asel,s,,,16
asel,a,,,22
asel,a,,,42
asel,a,,,46
sfa,all,,pres,-4.5125*0
allsel
solcon,on
nropt,auto
autots,on
nsubst,5,25,5
neqit,50
outres,all,all
eresx,no
time,1
lswrit

!Apply cyclic internal pressure!
f,4701,mx,cm
asel,s,,,7
asel,a,,,9
asel,a,,,10
asel,a,,,23
asel,a,,,30
asel,a,,,36
asel,a,,,40
asel,a,,,47
asel,a,,,28
asel,a,,,29
asel,a,,,5
asel,a,,,8
sfa,all,,pres,pi
allsel
!longitudinal stress in nozzle!
asel,s,,,14
asel,a,,,39
sfa,all,,pres,-0.4848*pi
allsel
!longitudinal stress shell!
asel,s,,,16
asel,a,,,22
```

```
asel,a,,,42
asel,a,,,46
sfa,all,,pres,-4.5125*pi
allsel
solcon,on
nropt,auto
autots,on
nsubst,5,25,5
neqit,50
outres,all,all
eresx,no
time,1
lswrit

!Unload internal cyclic pressure!
f,4701,mx,cm
asel,s,,,7
asel,a,,,9
asel,a,,,10
asel,a,,,23
asel,a,,,30
asel,a,,,36
asel,a,,,40
asel,a,,,47
asel,a,,,28
asel,a,,,29
asel,a,,,5
asel,a,,,8
sfa,all,,pres,0
allsel
!longitudinal stress in nozzle!
asel,s,,,14
asel,a,,,39
sfa,all,,pres,-0.4848*0
allsel
!longitudinal stress shell!
asel,s,,,16
asel,a,,,22
asel,a,,,42
asel,a,,,46
sfa,all,,pres,-4.5125*0
allsel
solcon,on
nropt,auto
autots,on
nsubst,5,25,5
neqit,50
outres,all,all
eresx,no
time,1
lswrit

!Apply cyclic internal pressure!
f,4701,mx,cm
asel,s,,,7
asel,a,,,9
asel,a,,,10
asel,a,,,23
asel,a,,,30
asel,a,,,36
```

```
asel,a,,,40
asel,a,,,47
asel,a,,,28
asel,a,,,29
asel,a,,,5
asel,a,,,8
sfa,all,,pres,pi
allsel
!longitudinal stress in nozzle!
asel,s,,,14
asel,a,,,39
sfa,all,,pres,-0.4848*pi
allsel
!longitudinal stress shell!
asel,s,,,16
asel,a,,,22
asel,a,,,42
asel,a,,,46
sfa,all,,pres,-4.5125*pi
allsel
solcon,on
nropt,auto
autots,on
nsubst,5,25,5
neqit,50
outres,all,all
eresx,no
time,1
lswrit

!Unload internal cyclic pressure!
f,4701,mx,cm
asel,s,,,7
asel,a,,,9
asel,a,,,10
asel,a,,,23
asel,a,,,30
asel,a,,,36
asel,a,,,40
asel,a,,,47
asel,a,,,28
asel,a,,,29
asel,a,,,5
asel,a,,,8
sfa,all,,pres,0
allsel
!longitudinal stress in nozzle!
asel,s,,,14
asel,a,,,39
sfa,all,,pres,-0.4848*0
allsel
!longitudinal stress shell!
asel,s,,,16
asel,a,,,22
asel,a,,,42
asel,a,,,46
sfa,all,,pres,-4.5125*0
allsel
solcon,on
nropt,auto
```

```
autots,on
nsubst,5,25,5
neqit,50
outres,all,all
eresx,no
time,1
lswrit

!Apply cyclic internal pressure!
f,4701,mx,cm
asel,s,,,7
asel,a,,,9
asel,a,,,10
asel,a,,,23
asel,a,,,30
asel,a,,,36
asel,a,,,40
asel,a,,,47
asel,a,,,28
asel,a,,,29
asel,a,,,5
asel,a,,,8
sfa,all,,pres,pi
allsel
!longitudinal stress in nozzle!
asel,s,,,14
asel,a,,,39
sfa,all,,pres,-0.4848*pi
allsel
!longitudinal stress shell!
asel,s,,,16
asel,a,,,22
asel,a,,,42
asel,a,,,46
sfa,all,,pres,-4.5125*pi
allsel
solcon,on
nropt,auto
autots,on
nsubst,5,25,5
neqit,50
outres,all,all
eresx,no
time,1
lswrit

!Unload internal cyclic pressure!
f,4701,mx,cm
asel,s,,,7
asel,a,,,9
asel,a,,,10
asel,a,,,23
asel,a,,,30
asel,a,,,36
asel,a,,,40
asel,a,,,47
asel,a,,,28
asel,a,,,29
asel,a,,,5
asel,a,,,8
```

```
sfa,all,,pres,0
allsel
!longitudinal stress in nozzle!
asel,s,,,14
asel,a,,,39
sfa,all,,pres,-0.4848*0
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asel,a,,,40
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outres,all,all
eresx,no
time,1
```

```
lswrit

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f,4701,mx,cm
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asel,a,,,9
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f,4701,mx,cm
asel,s,,,7
asel,a,,,9
```

```
asel,a,,,10
asel,a,,,23
asel,a,,,30
asel,a,,,36
asel,a,,,40
asel,a,,,47
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```

```
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solcon,on
nropt,auto
autots,on
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asel,s,,,7
asel,a,,,9
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asel,a,,,23
asel,a,,,30
asel,a,,,36
asel,a,,,40
asel,a,,,47
```

```
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asel,a,,,29
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asel,a,,,8
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```

```
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sfa,all,,pres,pi
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neqit,50
outres,all,all
eresx,no
time,1
lswrit
```

```
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asel,a,,,10
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```

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asel,s,,,16
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asel,s,,,7
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```

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asel,a,,,30
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asel,a,,,47
asel,a,,,28
asel,a,,,29
```

```
asel,a,,,5
asel,a,,,8
sfa,all,,pres,pi
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sfa,all,,pres,-4.5125*0
allsel
solcon,on
nropt,auto
autots,on
nsubst,5,25,5
neqit,50
outres,all,all
```

```
eresx,no
time,1
lswrit



lssolve,1,33

save

/post1
*get,ecemax,elem,,num,max !get max element number as ecemax

!Define arrays
*dim,elasx,,ecemax,8,2
*dim,elasy,,ecemax,8,2
*dim,elasz,,ecemax,8,2
*dim,elasxy,,ecemax,8,2
*dim,elasyz,,ecemax,8,2
*dim,elasxz,,ecemax,8,2

*dim,indepx,,ecemax,8      !(no.of elem, no. of nodes per elem)
*dim,indepy,,ecemax,8
*dim,indepz,,ecemax,8
*dim,indepxy,,ecemax,8
*dim,indepyz,,ecemax,8
*dim,indepxz,,ecemax,8
*dim,indepmis,,ecemax,8

*dim,postx,,ecemax,8
*dim,posty,,ecemax,8
*dim,postz,,ecemax,8
*dim,postxy,,ecemax,8
*dim,postyz,,ecemax,8
*dim,postxz,,ecemax,8
*dim,postmis,,ecemax,8    !Von Mises

*dim,postmis2,,ecemax,8  !Von Mises material shell+weld
*dim,postmis3,,ecemax,8  !Von Mises material nozzle


!Calculate 1st elastic stress field for P1 acting alone
!To be used for the scaled up elastic loading of P1
set,1,last
 *do,ii,1,ecemax  !elem. no.
  esel,s,elem,,ii                !To store unaveraged results
     *do,nn,1,8                  !no. of corner nodes in element
      *get,nnum,elem,ii,node,nn       !get node no. (nn) of element
      *get,elasx(ii,nn,1),node,nnum,s,x
      *get,elasy(ii,nn,1),node,nnum,s,y
      *get,elasz(ii,nn,1),node,nnum,s,z
      *get,elasxy(ii,nn,1),node,nnum,s,xy
      *get,elasyz(ii,nn,1),node,nnum,s,yz
      *get,elasxz(ii,nn,1),node,nnum,s,xz
     *enddo
 *enddo
esel,all

!Calculate scaled up elastic stress field for p1
  *do,ii,1,ecemax !elem. no.
```

```
      *do,nn,1,8                !no. of corner nodes in element
       elasx(ii,nn,2)=(elasx(ii,nn,1))*f
       elasy(ii,nn,2)=(elasy(ii,nn,1))*f
       elasz(ii,nn,2)=(elasz(ii,nn,1))*f
       elasxy(ii,nn,2)=(elasxy(ii,nn,1))*f
       elasyz(ii,nn,2)=(elasyz(ii,nn,1))*f
       elasxz(ii,nn,2)=(elasxz(ii,nn,1))*f
      *enddo
  *enddo

!Time independent stress field 's'- P2 in equilibrium with residual stress field
set,33                !**CHANGE HERE FOR A BETTER TIME INDEP. STRESS FIELD
 *do,ii,1,ecemax  !elem. no. (jj)
   esel,s,elem,,ii             !To store unaveraged results
   *do,nn,1,8                  !no. of corner nodes in element
    *get,nnum,elem,ii,node,nn          !get node no. (nn) of element
    *get,indepx(ii,nn),node,nnum,s,x
    *get,indepy(ii,nn),node,nnum,s,y
    *get,indepz(ii,nn),node,nnum,s,z
    *get,indepxy(ii,nn),node,nnum,s,xy
    *get,indepyz(ii,nn),node,nnum,s,yz
    *get,indepxz(ii,nn),node,nnum,s,xz
    sxx=indepx(ii,nn)
    syy=indepy(ii,nn)
    szz=indepz(ii,nn)
    sxy=indepxy(ii,nn)
    syz=indepyz(ii,nn)
    sxz=indepxz(ii,nn)
    d11=sxx-syy
    d22=syy-szz
    d33=szz-sxx
    d44=(sxy*sxy)+(syz*syz)+(sxz*sxz)
    indepmis(ii,nn)=(sqrt((d11*d11)+(d22*d22)+(d33*d33)+(6*d44)))/sqrt(2)
    temp=abs(indepmis(ii,nn))
    *if,indepmax,lt,temp,then
     indepmax=temp
    *endif
   *enddo
 *enddo
 esel,all

!Calculate stress field after reloading scaled up elastic field of P1
  *do,nn,1,8                  !no. of corner node in element
    *voper,postx(1,nn),indepx(1,nn),add,elasx(1,nn,2)
    *voper,posty(1,nn),indepy(1,nn),add,elasy(1,nn,2)
    *voper,postz(1,nn),indepz(1,nn),add,elasz(1,nn,2)
    *voper,postxy(1,nn),indepxy(1,nn),add,elasxy(1,nn,2)
    *voper,postyz(1,nn),indepyz(1,nn),add,elasyz(1,nn,2)
    *voper,postxz(1,nn),indepxz(1,nn),add,elasxz(1,nn,2)
  *enddo

!Find Von Mises post transient stress field
 *do,ii,1,ecemax  !elem. no.
  *do,nn,1,8                  !no. of corner node in element
    sxx=postx(ii,nn)
    syy=posty(ii,nn)
    szz=postz(ii,nn)
    sxy=postxy(ii,nn)
    syz=postyz(ii,nn)
    sxz=postxz(ii,nn)
```

```
   d11=sxx-syy
   d22=syy-szz
   d33=szz-sxx
   d44=(sxy*sxy)+(syz*syz)+(sxz*sxz)
   postmis(ii,nn)=(sqrt((d11*d11)+(d22*d22)+(d33*d33)+(6*d44)))/sqrt(2)
  *enddo
 *enddo

!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!Separate into different material types
 *do,ii,1,ecemax   !elem. no.
  *get,poli,elem,ii,attr,mat
   *do,nn,1,8                    !no. of corner node in element
    *if,poli,eq,2,then
     postmis2(ii,nn)=postmis(ii,nn)
    *endif
    *if,poli,eq,3,then
     postmis3(ii,nn)=postmis(ii,nn)
    *endif
   *enddo !nn
 *enddo !ii

!Find maximum Von Mises stresses
postmax2=0
postmax3=0
temp2=0
temp3=0
 *do,ii,1,ecemax   !elem. no.
  *do,nn,1,8                    !no. of corner node in element
    temp2=postmis2(ii,nn)
    *if,postmax2,lt,temp2,then
     postmax2=temp2
     la2=ii
     mel2=nn
    *endif
    temp3=postmis3(ii,nn)
    *if,postmax3,lt,temp3,then
     postmax3=temp3
     la3=ii
     mel3=nn
    *endif
  *enddo
 *enddo

!!!!!!!!!!!!!!!!!!!
! Write results file

betind=15.0
*vwrite,betind
("load/unload cycle = ",e20.8)

*vwrite,postmax2,la2,mel2
("postmax2 = ",f16.4,"      la2=",e20.8,"      mel2=",e20.8)

*vwrite,postmax3,la3,mel3
("postmax3 = ",f16.4,"      la3=",e20.8,"      mel3=",e20.8)
!
```

APPENDIX A10 – List of papers published on the PhD research

M.Muscat, R.Hamilton, J.T.Boyle – Shakedown Analysis For Complex Loading Using Superposition (accepted for publication) *Journal for Strain Analysis*, April 2002

M.Muscat, D.Mackenzie, R.Hamilton – Evaluating Shakedown by Non-linear Static Analysis (under review) *Computers and Structures*, July 2001

M.Muscat, D.Mackenzie – Elastic Shakedown Analysis of Axi-symmetric Nozzles, PVP-Vol.430, Pressure Vessel and Piping Design and Analysis – 2001, ASME 2001 (also under review to be published in *Journal of Pressure Vessel Technology* – Transactions of the ASME)

M.Muscat, R.Hamilton – Elastic Shakedown in Pressure Vessel Components Under Non-Proportional Loading (accepted for presentation in ASME PVP conference in Vancouver 2002)

M.Muscat, D.Mackenzie, R.Hamilton – A Work Criterion for Plastic Collapse (under review) *Journal of Pressure Vessels and Piping*, February 2002