

APPENDIX

ANSYS APDL

PROGRAMMING

APPENDIX

3.4.1 Preliminary Simulations

3.4.2 Simulation of a superelastic case

3.4.2.1 Preliminary simulation for 2D uniaxial tension load

```
/COM, USING 2D 4-NODE PLANE182 STRUCTURAL SOLID ELEMENTS
/PREP7
ET,1,182          !* 2D 4-NODE STRUCTURAL SOLID ELEMENT
KEYOPT,1,3,1     !* AXISYMMETRIC OPTION
MP, EX, 1, 60.0E3    !* MPA
MP,NUXY, 1, 0.3
TB,SMA,1
TBDATA,1,520,600,300,200,0.07,0 !* SHAPE MEMORY ALLOY
N,101, 0.00, 0.00
N,102,10.00, 0.00
N,103,10.00,10.00
N,104, 0.00,10.00
TYPE,1
MAT,1
E,101,102,103,104
NSEL,S,LOC,X
D,ALL,UX
NSEL,S,LOC,Y
D,ALL,UY
NSEL,ALL
FINISH
/SOLU
NLGEOM,ON
NSUBST,100,100,100
OUTRES,ALL,1
```

```

NSEL,S,LOC,Y,10
SF,ALL,PRES,-600    !* 1ST LOAD STEP -- LOAD THE MODEL
NSEL,ALL
/OUT,SCRATCH
SOLVE
NSEL,S,LOC,Y,10
SF,ALL,PRES,0      !* 2ND LOAD STEP -- UNLOAD THE MODEL
NSEL,ALL
SOLVE
FINISH
/POST26
ESOL,2,1,103,S,EQV    !* EQUIVALENT STRESS AT NODE 103
ESOL,3,1,103,EPEL,EQV !* ELASTIC STRAIN AT NODE 103
ESOL,4,1,103,EPPL,EQV !* PLASTIC STRAIN AT NODE 103
ADD,5,3,4           !* TOTAL STRAIN AT NODE 103
PROD,6,5,, ,STRAIN,, ,100 !* PERCENT TOTAL STRAIN
XVAR,6
/AXLAB,X,Strain[%]
/AXLAB,Y,Stress [MPa]
/YRANGE,0,700      !* SET Y-RANGE
/XRANGE,0,8        !* SET X-RANGE
/GROPT,DIVY,7
PLVAR,2            !* PLOT TOTAL STRAIN VS EQV STRESS
/OUT,
PRVAR,2,5
FINISH

```

Preliminary simulation for 3D uniaxial tension load

```

/PREP7
ET,1,185           !* 3D 8-NODE STRUCTURAL SOLID ELEMENT
MP, EX, 1, 60.0E3  !* MPA
MP,NUXY, 1, 0.3

```

```
TB,SMA,1
TBDATA,1,520,600,300,200,0.07,0 !* SHAPE MEMORY ALLOY
N,101, 0.00, 0.00
N,102, 10.00, 0.00
N,103, 10.00, 10.00
N,104, 0.00, 10.00
N,105, 0.00, 0.00,10.00
N,106, 10.00, 0.00,10.00
N,107, 10.00, 10.00,10.00
N,108, 0.00, 10.00,10.00
TYPE,1
MAT,1
E,101,102,103,104,105,106,107,108
TYPE,1
NSEL,S,LOC,X
D,ALL,UX
NSEL,S,LOC,Y
D,ALL,UY
NSEL,S,LOC,Z
D,ALL,UZ
NSEL,ALL
FINISH
/SOLU
NLGEOM,ON
NSUBST,100,100,100
OUTRES,ALL,1
NSEL,S,LOC,Y,10.0
SF,ALL,PRES,-600    !* 1ST LOAD STEP -- LOAD THE MODEL
NSEL,ALL
/OUT,SCRATCH
SOLVE
```

```

NSEL,S,LOC,Y,10.0

SF,ALL,PRES,0      !* 2ND LOAD STEP -- UNLOAD THE MODEL

NSEL,ALL

SOLVE

FINISH

/POST26

ESOL,2,1,103,S,EQV      !* EQUIVALENT STRESS AT NODE 103

ESOL,3,1,103,EPEL,EQV  !* ELASTIC STRAIN AT NODE 103

ESOL,4,1,103,EPPL,EQV  !* PLASTIC STRAIN AT NODE 103

ADD,5,3,4           !* TOTAL STRAIN AT NODE 103

PROD,6,5,, ,STRAIN, , ,100 !* PERCENT TOTAL STRAIN

XVAR,6

/axlab,x,Strain[%]

/axlab,y,Stress [MPa]

/YRANGE,0,700       !* SET Y-RANGE

/XRANGE,0,8         !* SET X-RANGE

/GROPT,DIVY,7

PLVAR,2            !* PLOT TOTAL STRAIN VS EQV STRESS

/OUT,

PRVAR,2,5

FINISH

/POST1

SET, , , , ,0.87

*get,SIG_SAS,node,103,s,eqv

*get,EPTO_SAS,node,103,epto,eqv

SET, , , , ,1

*get,SIG_FAS,node,103,s,eqv

*get,EPTO_FAS,node,103,epto,eqv

SET, , , , ,1.5

*get,SIG_SSA,node,103,s,eqv

*get,EPTO_SSA,node,103,epto,eqv

```

```

SET, , , , 1.67

*get,SIG_FSA,node,103,s,eqv

*get,EPTO_FSA,node,103,epto,eqv

R1 = SIG_SAS/520

R2 = EPTO_SAS/0.01

R3 = SIG_FAS/600

R4 = EPTO_FAS/0.08

R5 = SIG_SSA/300

R6 = EPTO_SSA/0.074

R7 = SIG_FSA/200

R8 = EPTO_FSA/0.32E-02

*DIM,LABEL,CHAR,8,2

*DIM,VALUE,,8,3

LABEL(1,1) = 'Sig','EPTO','Sig','EPTO','Sig','EPTO','Sig','EPTO'

LABEL(1,2) = '-SAS','-SAS','-FAS','-FAS','-SSA','-SSA','-FSA','-FSA'

*VFILL,VALUE(1,1),DATA,520,0.01,600,0.08,300,0.074,200,0.32E-02

*VFILL,VALUE(1,2),DATA,SIG_SAS,EPTO_SAS,SIG_FAS,EPTO_FAS,SIG_SSA,EPTO_SSA,SIG_FSA,EPTO_F
SA

*VFILL,VALUE(1,3),DATA,R1,R2,R3,R4,R5,R6,R7,R8

SAVE,TABLE_3

RESUME,TABLE_1

/COM

/OUT,vm251,vrt

/COM,----- VM251 RESULTS COMPARISON -----

/COM,

/COM,      | TARGET | Mechanical APDL | RATIO

/COM,

/COM,RESULTS USING PLANE182 ELEMENT

*VWRITE,LABEL(1,1),LABEL(1,2),VALUE(1,1),VALUE(1,2),VALUE(1,3)

(1X,A4,A8,' ',F10.3,' ',1F14.3,' ',1F15.3)

/NOPR

```

```

RESUME, TABLE_2

/GOPR

/COM,

/COM, RESULTS USING PLANE183 ELEMENT

*VWRITE, LABEL(1,1), LABEL(1,2), VALUE(1,1), VALUE(1,2), VALUE(1,3)
(1X, A4, A8, ' ', F10.3, ' ', F14.3, ' ', F15.3)

/NOPR

RESUME, TABLE_3

/GOPR

/COM,

/COM, RESULTS USING SOLID185 ELEMENT

*VWRITE, LABEL(1,1), LABEL(1,2), VALUE(1,1), VALUE(1,2), VALUE(1,3)
(1X, A4, A8, ' ', F10.3, ' ', F14.3, ' ', F15.3)

/COM, -----

/OUT

FINISH

*LIST, vm251, vrt

```

3.4.3 Simulation of a shape memory case

Preliminary output of simulation of shape memory behavior of Nitinol at temperature 285.15 K

```

/PREP7

ET, 1, SOLID185          !* 3D 8-NODE STRUCTURAL SOLID ELEMENT

/COM, DEFINING SMA MATERIAL PROPERTIES

MP, EX, 1, 70E3         !MPA, [AUSTENITE MODULUS]

MP, PRXY, 1, 0.33

C1=500                  !MPA [HARDENING PARAMETER]

C2=253.15              !K [REF TEMP]

C3=45                   !MPA [ELASTIC LIMIT]

C4=7.5                  !MPA [TEMPERATURE SCALING PARAMETER]

C5=0.03                 ![MAX TRANSFORMATION STRAIN]

```

```
C6=70E3          !MPA, [MARTENSITE MODULUS]
C7=0            ! M = 0, SYMMETRICAL BEHAVIOR
TB,SMA,1,,7,MEFF
TBDATA,1,C1,C2,C3,C4,C5,C6,C7
BLOCK,0.00,10.00,0.00,10.00,0.00,10.00
ESIZE,10
TYPE,1
MAT,1
VMESH,1
NSEL,S,LOC,X
D,ALL,UX
NSEL,S,LOC,Y
D,ALL,UY
NSEL,S,LOC,Z
D,ALL,UZ
NSEL,ALL
BFUNIF,TEMP,285.15
FINISH
/SOLU
NROPT,UNSYM
OUTRES,ALL,ALL
NSUBST,50,50,50
TIME,1
NSEL,S,LOC,Y,10
D,ALL,UY,0.35      ! TENSION LOADING
ALLSEL
/OUT,SCRATCH
SOLVE
TIME,2
NSEL,S,LOC,Y,10
D,ALL,UY,0.00      ! UNLOADING
```

```

ALLSEL
SOLVE
TIME,3
NSEL,S,LOC,Y,10
D,ALL,UY,-0.35      ! COMPRESSION LOADING
ALLSEL
SOLVE
TIME,4
NSEL,S,LOC,Y,10
D,ALL,UY,0.00      ! UNLOADING
ALLSEL
SOLVE
FINISH
/POST26
ESOL,2,1,NODE(10,10,0),S,Y      !* Y STRESS AT NODE(10,10,0)
ESOL,3,1,NODE(10,10,0),EPEL,Y      !* ELASTIC STRAIN AT NODE(10,10,0)
ESOL,4,1,NODE(10,10,0),EPPL,Y      !* PLASTIC STRAIN AT NODE(10,10,0)
ADD,5,3,4      !* TOTAL STRAIN AT NODE(10,10,0)
PROD,6,5,, ,STRAIN, , ,100 !* PERCENT TOTAL STRAIN
XVAR,6
/AXLAB,X,Strain[%]
/AXLAB,Y,Stress [MPa]
/YRANGE,-800,800      !* SET Y-RANGE
/XRANGE,-4,4      !* SET X-RANGE
PLVAR,2      !* PLOT TOTAL STRAIN VS Y STRESS
PRVAR,3,4,2
FINISH

```

Preliminary output of simulation of shape memory behavior of Nitinol at temperature 253.15 K

```

/COM, CASE TWO: WITH BODY TEMPERATURE T=253.15K

```

```
/PREP7
ET,1,SOLID185          !* 3D 8-NODE STRUCTURAL SOLID ELEMENT
/COM, DEFINING SMA MATERIAL PROPERTIES
MP,EX,1,70E3  !MPA, [AUSTENITE MODULUS]
MP,PRXY,1,0.33
C1=500              !MPA [HARDENING PARAMETER]
C2=253.15          !K [REF TEMP]
C3=45              !MPA [ELASTIC LIMIT]
C4=7.5             !MPA
C5=0.03            ! [MAX TRANSFORMATION STRAIN]
C6=70E3            !MPA, [MARTENSITE MODULUS]
C7=0              ! M = 0
TB,SMA,1,,7,MEFF
TBDATA,1,C1,C2,C3,C4,C5,C6,C7
BLOCK,0.00,10.00,0.00,10.00,0.00,10.00
ESIZE,10
TYPE,1
MAT,1
VMESH,1
NSEL,S,LOC,X
D,ALL,UX
NSEL,S,LOC,Y
D,ALL,UY
NSEL,S,LOC,Z
D,ALL,UZ
NSEL,ALL
BFUNIF,TEMP,253.15
FINISH
/SOLU
NROPT,UNSYM
OUTRES,ALL,ALL
```

```
NSUBST,50,50,50

TIME,1

NSEL,S,LOC,Y,10

D,ALL,UY,0.35      ! TENSION LOADING

ALLSEL

/OUT,SCRATCH

SOLVE

TIME,2

NSEL,S,LOC,Y,10

D,ALL,UY,0.00      ! UNLOADING

ALLSEL

SOLVE

TIME,3

NSEL,S,LOC,Y,10

D,ALL,UY,-0.35     ! COMPRESSION LOADING

ALLSEL

SOLVE

TIME,4

NSEL,S,LOC,Y,10

D,ALL,UY,0.00      ! UNLOADING

ALLSEL

SOLVE

FINISH

/POST26

ESOL,2,1,NODE(10,10,0),S,Y      !* Y STRESS AT NODE(10,10,0)

ESOL,3,1,NODE(10,10,0),EPEL,Y    !* ELASTIC STRAIN AT NODE(10,10,0)

ESOL,4,1,NODE(10,10,0),EPPL,Y    !* PLASTIC STRAIN AT NODE(10,10,0)

ADD,5,3,4                !* TOTAL STRAIN AT NODE(10,10,0)

PROD,6,5,, ,STRAIN, , ,100      !* PERCENT TOTAL STRAIN

XVAR,6
```

/AXLAB,X,Strain[%]

/AXLAB,Y,Stress [MPa]

/YRANGE,-800,800 !* SET Y-RANGE

/XRANGE,-4,4 !* SET X-RANGE

PLVAR,2 !* PLOT TOTAL STRAIN VS YSTRESS

PRVAR,3,4,2

FINISH