CHAPTER EIGHT

Material Nonlinearity

Example 8.3 (p. 427): Four-bar truss

Consider a four bar pin-jointed truss shown in Figure 8.14. Assume $E = 200\,\text{GPa}$, $\sigma_Y = 150\,\text{MPa}$, and $H = 10\,\text{GPa}$. For elements 1 and 2 assume kinematic hardening material with area of cross section $A = 0.0004\,m^2$. For the rest use an isotropic hardening model with area of cross section $A = 0.0002\,m^2$. The load $P = 40\,\text{kN}$ and acts at an angle $\alpha = 60\,°$ at node 2. Determine permanent deflection after the load is removed. The dimensions in meters are shown in the figure. We use N and mm units in calculations. The displacements will be in mm and the stress in MPa.

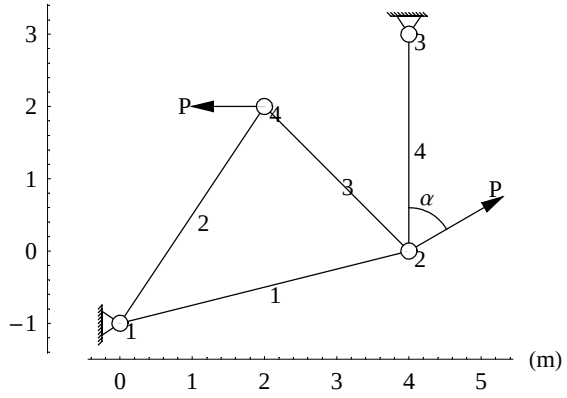


Figure 8.14. Four-bar Truss

AnsysFiles\\Chap08\\FourBarTruss.txt

```
!* Model creation
/PREP7
!* Element type
ET,1,LINK1
!* Real constants
R,1,400, ,
R,2,200,,
!* Material property
!*
*set,e,200000
*set,h,10000
*set,et,e*h/(e+h)
*set, sy, 150
MPTEMP,,,,,,,,
MPTEMP,1,0
MPDATA,EX,1,,e
MPTEMP,,,,,,,,
MPTEMP,1,0
MPDATA,EX,2,,e
TB,BKIN,1,1,2,1
```

```
TB,BKIN,1,1,2,1
TBTEMP,0
TBDATA,,sy,et,,,,
TB,BISO,2,1,2,
TBTEMP,0
TBDATA,,sy,et,,,,
!* Create nodes
N,1,0,-1000,,,,,
N,2,4000,0,,,,,
N,3,4000, 3000,,,,,
N,4,2000, 2000,,,,,
!* Create elements
!* with appropriate attributes
MAT,1
REAL,1
E,1,2
E,1,4
MAT,2
REAL,2
e,2,4
e,2,3
!*
!* Specify displacement boundary conditions
D,1, ,0, , , ,UX,UY, , , ,
D,3, ,0, , , ,UX,UY, , , ,
!* Solution module
/SOLU
ARCLEN,1,1,0.0001
AUTOTS,-1.0
NCNV,2,0,0,0,0
RESCONTRL,DEFINE,ALL,1,1
OUTRES,ERASE
OUTRES,ALL,-1
AUTOTS,-1.0
!* First load step - no applied load
!* Used for initialization of the arc-length controls
LSWRITE,1,
!* Specify applied forces
F,2,FY,20000
F,2,FX,34641
```

```
F,2,FX,34041
F,4,FX,-40000
LSWRITE,2,
!* Remove applied forces
F,2,FY,0
F,2,FX,0
F,4,FX,0
LSWRITE,3,
LSSOLVE,1,3,1
FINISH
!* Postprocessing
/POST1
SET,LAST
ETABLE,SIGMA,LS, 1
ETABLE,EPSPLAS,LEPPL, 1
PRETAB,SIGMA,EPSPLAS
```

Converged results after full application of given loads

```
 PRINT U    NODAL SOLUTION PER NODE

  ***** POST1 NODAL DEGREE OF FREEDOM LISTING *****

  LOAD STEP=     2  SUBSTEP=     9
   TIME=    2.0000      LOAD CASE=   0

  THE FOLLOWING DEGREE OF FREEDOM RESULTS ARE IN GLOBAL COORDINATES

    NODE      UY
       1   0.0000
       2   20.117
       3   0.0000
       4   13.401

 MAXIMUM ABSOLUTE VALUES
 NODE          2
 VALUE    20.117

 PRINT ELEMENT TABLE ITEMS PER ELEMENT

  ***** POST1 ELEMENT TABLE LISTING *****

    STAT    PREVIOUS    PREVIOUS
    ELEM    SIGMA       EPSPLAS
       1  0.14655E-17  0.0000
       2 -0.38538E-17  0.0000
       3   0.0000     0.19723E-02
```

```
      4   0.0000    -0.56719E-02

MINIMUM VALUES
ELEM          2           4
VALUE  -0.38538E-17-0.56719E-02

MAXIMUM VALUES
ELEM          1           3
VALUE   0.14655E-17 0.19723E-02
```

Converged results after the loads are removed

```
PRINT U    NODAL SOLUTION PER NODE

 ***** POST1 NODAL DEGREE OF FREEDOM LISTING *****

 LOAD STEP=     3  SUBSTEP=    12
  TIME=    3.0000      LOAD CASE=   0

 THE FOLLOWING DEGREE OF FREEDOM RESULTS ARE IN GLOBAL COORDINATES

   NODE      UY
      1   0.0000
      2   17.016
      3   0.0000
      4   11.664

MAXIMUM ABSOLUTE VALUES
NODE          2
VALUE    17.016

PRINT ELEMENT TABLE ITEMS PER ELEMENT

 ***** POST1 ELEMENT TABLE LISTING *****

   STAT    CURRENT     CURRENT
   ELEM    SIGMA       EPSPLAS
      1  0.14655E-17  0.0000
      2 -0.38538E-17  0.0000
      3   0.0000     0.19723E-02
      4   0.0000    -0.56719E-02

MINIMUM VALUES
ELEM          2           4
VALUE  -0.38538E-17-0.56719E-02

MAXIMUM VALUES
ELEM          1           3
VALUE   0.14655E-17 0.19723E-02
```

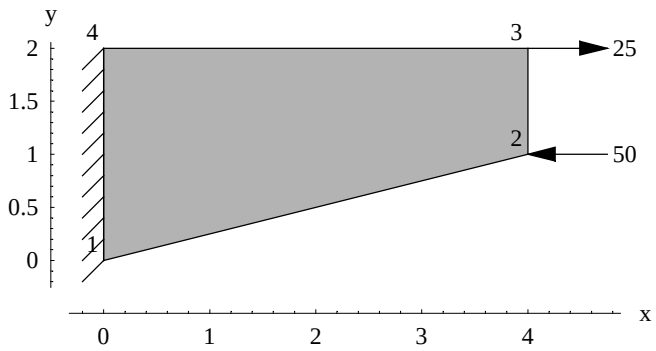
Tension Plate Example

This example is not included in the printed book.

Small displacement analysis of a tension plate with nonlinear material properties.

$E = 100000$, $\nu = 0.25$, $h = 0.1$

$\sigma_Y = 380$, $H = 260$



■ One element solution with kinematic hardening

AnsysFiles\\Chap08\\TensionPlateKin1.txt

```
!* Tension plate
!* Small displacement analysis
!* von Mises plasticity
!* with kinematic hardening
/PREP7
!* Element type
ET,1,PLANE42
```

```
!*
!*
KEYOPT,1,1,0
KEYOPT,1,2,1
KEYOPT,1,3,3
KEYOPT,1,5,0
KEYOPT,1,6,0
!*
R,1,0.1
!* Material property
!*
*set,e,100000
*set,h,260
*set,et,e*h/(e+h)
*set, sy,380
MPTEMP,,,,,,,,
MPTEMP,1,0
MPDATA,EX,1,,e
MPDATA,PRXY,1,,0.25
TB,BKIN,1,1,2,1
TBTEMP,0
TBDATA,,sy,et,,,,
!*
K,1,0,0
K,2,4,1
K,3,4,2
K,4,0,2
A,1,2,3,4
ESIZE,10
AMESH,1
DL,4, ,ALL
/SOLU
ARCLEN,1,1,0.0001
AUTOTS,-1.0
NCNV,2,0,0,0,0
RESCONTRL,DEFINE,ALL,1,1
ERESX,NO
OUTRES,ERASE
OUTRES,ALL,-1
```

```
AUTOTS,-1.0
!* First load step - no applied load
!* Used for initialization of the arc-length controls
LSWRITE,1,
!* Specify applied forces
FK,2,FX,-50
FK,3,FX,25
LSWRITE,2,
!* Remove applied forces
FK,2,FX,0
FK,3,FX,0
LSWRITE,3,
!* Reverse forces
FK,2,FX,50
FK,3,FX,-25
LSWRITE,4,
!* Remove applied forces
FK,2,FX,0
FK,3,FX,0
LSWRITE,5,
!* Specify applied forces
FK,2,FX,-50
FK,3,FX,25
LSWRITE,6,
!* Remove applied forces
FK,2,FX,0
FK,3,FX,0
LSWRITE,7,
LSSOLVE,1,7,1
FINISH
!* Postprocessing
/POST1
SET,LAST
PRNSOL,UX
```

Results after three full load cycles (load step 6)

```
 PRINT U    NODAL SOLUTION PER NODE

  ***** POST1 NODAL DEGREE OF FREEDOM LISTING *****
```

```
  LOAD STEP=     6  SUBSTEP=     6
   TIME=    6.0000      LOAD CASE=   0

  THE FOLLOWING DEGREE OF FREEDOM RESULTS ARE IN GLOBAL COORDINATES

    NODE      UX
       1   0.0000
       2 -0.24793E-01
       3  0.79347E-02
       4   0.0000

 MAXIMUM ABSOLUTE VALUES
 NODE          2
 VALUE  -0.24793E-01

 PRINT S    ELEMENT SOLUTION PER ELEMENT

 ***** POST1 ELEMENT NODAL STRESS LISTING *****

  LOAD STEP=     6  SUBSTEP=     6
   TIME=    6.0000      LOAD CASE=   0

  THE FOLLOWING X,Y,Z VALUES ARE IN GLOBAL COORDINATES


  ELEMENT=       1        PLANE42
    NODE    SX          SY          SZ          SXY         SYZ
SXZ
       1  -378.10     -102.04      0.0000     -100.01      0.0000
0.0000
       2  -301.68     -58.105      0.0000      151.77      0.0000
0.0000
       3   9.9876      107.82      0.0000      211.93      0.0000
0.0000
       4   16.510      45.894      0.0000     -146.29      0.0000
0.0000

 PRINT EPPL ELEMENT SOLUTION PER ELEMENT

 ***** POST1 ELEMENT NODAL PLASTIC STRAIN LISTING *****

  LOAD STEP=     6  SUBSTEP=     6
   TIME=    6.0000      LOAD CASE=   0

  THE FOLLOWING X,Y,Z VALUES ARE IN GLOBAL COORDINATES


  ELEMENT=       1        PLANE42
    NODE    EPPLX       EPPLY       EPPLZ       EPPLXY      EPPLYZ
EPPLXZ
```

```
       1 -0.17056E-02 0.49277E-03 0.12128E-02-0.17275E-02  0.0000
0.0000
       2 -0.57990E-02 0.21285E-02 0.36705E-02 0.90483E-02  0.0000
0.0000
       3 -0.70142E-03 0.12484E-02-0.54700E-03 0.83867E-02  0.0000
0.0000
       4   0.0000      0.0000      0.0000      0.0000      0.0000
0.0000
```

Results after load is removed (load step 7)

```
 PRINT U    NODAL SOLUTION PER NODE

  ***** POST1 NODAL DEGREE OF FREEDOM LISTING *****

  LOAD STEP=     7  SUBSTEP=    46
   TIME=    7.0000      LOAD CASE=   0

  THE FOLLOWING DEGREE OF FREEDOM RESULTS ARE IN GLOBAL COORDINATES

    NODE      UX
       1   0.0000
       2 -0.13312E-01
       3  0.49024E-02
       4   0.0000

 MAXIMUM ABSOLUTE VALUES
 NODE          2
 VALUE  -0.13312E-01
```

■ One element solution with isotropic hardening

AnsysFiles\\Chap08\\TensionPlateIso1.txt

```
!* Tension plate
!* Small displacement analysis
!* von Mises plasticity
!* with isotropic hardening
/PREP7
!* Element type
ET,1,PLANE42
!*
!*
```

```
KEYOPT,1,1,0
KEYOPT,1,2,1
KEYOPT,1,3,3
KEYOPT,1,5,0
KEYOPT,1,6,0
!*
R,1,0.1
!* Material property
!*
*set,e,100000
*set,h,260
*set,et,e*h/(e+h)
*set, sy,380
MPTEMP,,,,,,,,
MPTEMP,1,0
MPDATA,EX,1,,e
MPDATA,PRXY,1,,0.25
TB,BISO,1,1,2,
TBTEMP,0
TBDATA,,sy,et,,,,
!*
K,1,0,0
K,2,4,1
K,3,4,2
K,4,0,2
A,1,2,3,4
ESIZE,10
AMESH,1
DL,4, ,ALL
/SOLU
ARCLEN,1,1,0.0001
AUTOTS,-1.0
NCNV,2,0,0,0,0
RESCONTRL,DEFINE,ALL,1,1
ERESX,NO
OUTRES,ERASE
OUTRES,ALL,-1
AUTOTS,-1.0
!* First load step - no applied load
```

```
!* Used for initialization of the arc-length controls
LSWRITE,1,
!* Specify applied forces
FK,2,FX,-50
FK,3,FX,25
LSWRITE,2,
!* Remove applied forces
FK,2,FX,0
FK,3,FX,0
LSWRITE,3,
!* Reverse forces
FK,2,FX,50
FK,3,FX,-25
LSWRITE,4,
!* Remove applied forces
FK,2,FX,0
FK,3,FX,0
LSWRITE,5,
!* Specify applied forces
FK,2,FX,-50
FK,3,FX,25
LSWRITE,6,
!* Remove applied forces
FK,2,FX,0
FK,3,FX,0
LSWRITE,7,
LSSOLVE,1,7,1
FINISH
!* Postprocessing
/POST1
SET,LAST
PRNSOL,UX
```

Results after three full load cycles (load step 6)

```
 PRINT U    NODAL SOLUTION PER NODE

  ***** POST1 NODAL DEGREE OF FREEDOM LISTING *****

  LOAD STEP=     6  SUBSTEP=     5
```

```
   TIME=    6.0000      LOAD CASE=   0

  THE FOLLOWING DEGREE OF FREEDOM RESULTS ARE IN GLOBAL COORDINATES

    NODE      UX
       1   0.0000
       2 -0.21067E-01
       3  0.65911E-02
       4   0.0000

 MAXIMUM ABSOLUTE VALUES
 NODE          2
 VALUE  -0.21067E-01

 PRINT S    ELEMENT SOLUTION PER ELEMENT

 ***** POST1 ELEMENT NODAL STRESS LISTING *****

  LOAD STEP=     6  SUBSTEP=     5
   TIME=    6.0000      LOAD CASE=   0

  THE FOLLOWING X,Y,Z VALUES ARE IN GLOBAL COORDINATES


  ELEMENT=       1        PLANE42
    NODE    SX          SY          SZ          SXY         SYZ
SXZ
       1  -360.49     -84.457      0.0000     -114.35      0.0000
0.0000
       2  -308.16     -56.531      0.0000      152.97      0.0000
0.0000
       3 -0.73189      99.387      0.0000      214.79      0.0000
0.0000
       4   10.549      36.619      0.0000     -134.70      0.0000
0.0000


 PRINT EPPL ELEMENT SOLUTION PER ELEMENT

 ***** POST1 ELEMENT NODAL PLASTIC STRAIN LISTING *****

  LOAD STEP=     6  SUBSTEP=     5
   TIME=    6.0000      LOAD CASE=   0

  THE FOLLOWING X,Y,Z VALUES ARE IN GLOBAL COORDINATES


  ELEMENT=       1        PLANE42
    NODE    EPPLX       EPPLY       EPPLZ       EPPLXY      EPPLYZ
EPPLXZ
       1 -0.10561E-02 0.28317E-03 0.77291E-03-0.97283E-03  0.0000
```

```
0.0000
       2 -0.44158E-02 0.16676E-02 0.27482E-02 0.67819E-02  0.0000
0.0000
       3 -0.50900E-03 0.87697E-03-0.36797E-03 0.59218E-02  0.0000
0.0000
       4   0.0000      0.0000      0.0000      0.0000      0.0000
0.0000
```

Results after load is removed (load step 7)

```
 PRINT U    NODAL SOLUTION PER NODE

  ***** POST1 NODAL DEGREE OF FREEDOM LISTING *****

  LOAD STEP=     7  SUBSTEP=    23
   TIME=    7.0000      LOAD CASE=   0

  THE FOLLOWING DEGREE OF FREEDOM RESULTS ARE IN GLOBAL COORDINATES

    NODE      UX
       1   0.0000
       2 -0.95864E-02
       3  0.35588E-02
       4   0.0000

 MAXIMUM ABSOLUTE VALUES
 NODE          2
 VALUE  -0.95864E-02
```