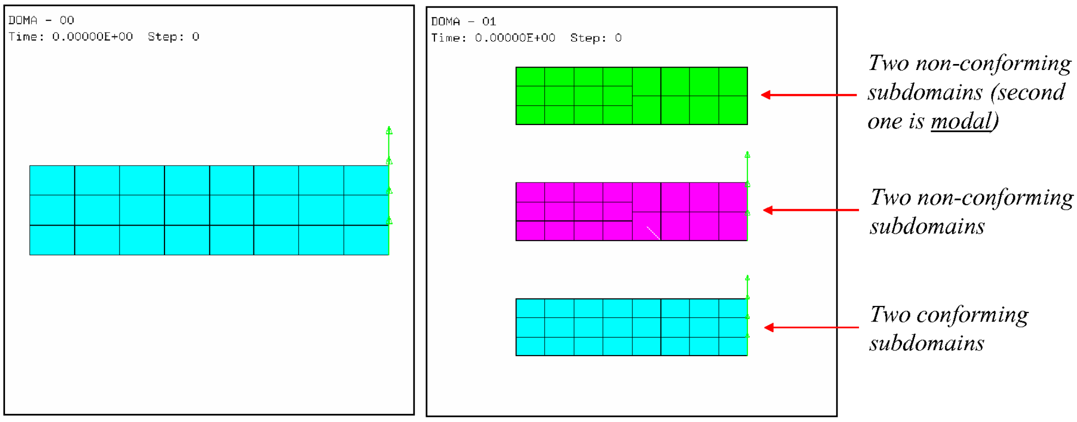
Example 13 – Domains in 2D

- Thick plane strain beam under bending:



Reference Case (no decomposition)

Case with various decompositions

104

<u>Problem description:</u>
This example represents the bending of a thick beam in 2D plane strain conditions. The beam is clamped at the left end and loaded by concentrated forces at the right end. The material is linear elastic.
Two solutions are obtained. The first one without domain decomposition is used as a reference, while the second uses various alternative domain decompositions, one of which is modal.
<u>Numerical Solutions</u>
DOMA00
This calculation uses no domain decomposition and is used to obtain a reference solution. It uses a regular mesh of 24 elements of type CAR4.
The mesh generation file is:

```
*%siz 50
*
OPTI ECHO 1 DIME 2 ELEM QUA4;
opti titr 'DOMA - 00';
opti trac psc ftra 'doma00_mesh.ps';
*
P11=0. 0.;
P12=0. 1.;
P13=2. 0.;
P14=2. 1.;
*
VEC1=2. 0.;
*
P1=P11;
R1=P13;
S1=P13 PLUS VEC1;
*
N2=3;
N3=4;
*
P11_P12=P11 D N2 P12;
P11_P12P=P11_P12 PLUS VEC1;
P13_P14=P13 D N2 P14;
P13_P14P=P13_P14 PLUS VEC1;
*
DOM11=P11_P12 REGL N3 P11_P12P;
DOM12=P13_P14 REGL N3 P13_P14P;
*
TRAC (DOM11 ET DOM12);
*
ELIM 0.001 (DOM11 ET DOM12 ET P1 ET R1 ET S1);
*
TOUT=DOM11 ET DOM12;
*
OPTI SAUV FORMAT 'doma00.msh';
SAUV FORMAT TOUT;
*
FIN;
```

The input file is:

```
DOMA - 00
*-----------------------------------------------------------------------
ECHO
!conv win
CAST tout
*-----------------------------------------------------------Problem type
DPLA NONL
*-----------------------------------------------------------Dimensioning
DIME
  PT2L 36 CAR4 24
  TABL 1 4 ECRO 522
  FORC 10  MTPO 9
TERM
*---------------------------------------------------------------Geometry
GEOM CAR4 tout
     TERM
*--------------------------------------------------Geometric Complements
COMP GROU 1
     'prob1'  LECT dom11 dom12 TERM
     NGRO 3
     'tpln'   LECT p1 r1 s1 TERM
     'char2'  LECT p13_p14p TERM
     'bloqa'  LECT p11_p12  TERM
     COUL turq LECT prob1 TERM
*-----------------------------------------------------------Material data
MATE
   LINE RO 7800. YOUN 210.E9 NU 0.3
        LECT tout TERM
*---------------------------------------------------------Applied "loads"
CHAR 1 FACT 2
   FORC 2 0.75E7 LECT char2 TERM
   TABL 2 0.0 1.0 1.0 1.0
*-----------------------------------------------------Boundary conditions
LINK COUP BLOQ 12 LECT bloqa TERM
```

```
*-----------------------------------------------------------------Outputs
ECRI DEPL TFRE 4D-3 NOEL
          POIN LECT tpln TERM
     FICH ALIC TEMP TFREQ 0.2D-3
          POIN LECT tpln TERM
          ELEM LECT 1 TERM
     FICH ALIC TFRE 40.E-5
*-----------------------------------------------------------------Options
OPTI CSTA 0.5
  LOG 1
*---------------------------------------------------Transient calculation
CALC TINI 0. TFIN 40.E-3
*==========================================================POST-TREATMENT
SUIT
Post-treatment
```

```
ECHO
RESU ALIC TEMP GARD PSCR
SORT GRAP
AXTE 1E3 'Temps (ms)'
*-------------------------------------------------------Curve definitions
COUR  1 'noeud P1' DEPL COMP 2 NOEU LECT p1 TERM
COUR  2 'noeud R1' DEPL COMP 2 NOEU LECT r1 TERM
COUR  3 'noeud S1' DEPL COMP 2 NOEU LECT s1 TERM
*-------------------------------------------------------------------Plots
trac  3 AXES 1 'Deplacement' yzer
trac  1 2 3 AXES 1 'Deplacement' yzer
*--------------------------------------------------Results qualification
QUAL DEPL COMP 2 REFE 2.38669E-02 TOLE 1.E-2 LECT s1 TERM
*=======================================================================
FIN
```

DOMA01

This calculation uses three alternative domain decompositions (in just one run of the code):

- Two conforming domains (lower mesh) with the same grid as in the reference solution;
- Two non-conforming domains (middle mesh) of which the left one has the same element size as the reference, while the right one is coarser. The interface between these two domains is therefore non-conforming.
- Same as the previous case (upper mesh) but the right, coarse sub-domain is represented by a modal reduction.
-

The mesh generation file, including also the Cast3m command to compute the modes in the modal sub-domain, is:

```
*%siz 50
*
OPTI ECHO 1 DIME 2 ELEM QUA4;
opti titr 'DOMA - 01';
opti trac psc ftra 'doma01_mesh.ps';
*
P11=0. 0.;
P12=0. 1.;
P13=2. 0.;
P14=2. 1.;
*
P21=0. 2.;
P22=0. 3.;
P23=2. 2.;
P24=2. 3.;
*
P31=0. 4.;
P32=0. 5.;
P33=2. 4.;
P34=2. 5.;
*
VEC1=2. 0.;
*
P1=P11;
R1=P13;
S1=P13 PLUS VEC1;
*
P2=P21;
R2=P23;
S2=P23 PLUS VEC1;
*
P3=P31;
R3=P33;
S3=P33 PLUS VEC1;
*
N1=2;
N2=3;
N3=4;
*
P11_P12=P11 D N2 P12;
P11_P12P=P11_P12 PLUS VEC1;
P13_P14=P13 D N2 P14;
P13_P14P=P13_P14 PLUS VEC1;
*
DOM11=P11_P12 REGL N3 P11_P12P;
DOM12=P13_P14 REGL N3 P13_P14P;
*
P21_P22=P21 D N2 P22;
P21_P22P=P21_P22 PLUS VEC1;
P23_P24=P23 D N1 P24;
P23_P24P=P23_P24 PLUS VEC1;
*
DOM21=P21_P22 REGL N3 P21_P22P;
DOM22=P23_P24 REGL N3 P23_P24P;
*
P31_P32=P31 D N2 P32;
P31_P32P=P31_P32 PLUS VEC1;
P33_P34=P33 D N1 P34;
P33_P34P=P33_P34 PLUS VEC1;
*
DOM31=P31_P32 REGL N3 P31_P32P;
DOM32=P33_P34 REGL N3 P33_P34P;
*
TRAC (DOM11 ET DOM12 ET DOM21 ET DOM22 ET DOM31 ET DOM32);
*
ELIM 0.001 DOM11 (P1 ET R1);
ELIM 0.001 DOM12 (R1 ET S1);
ELIM 0.001 DOM21 (P2 ET R2);
ELIM 0.001 DOM22 (R2 ET S2);
ELIM 0.001 DOM31 (P3 ET R3);
ELIM 0.001 DOM32 (R3 ET S3);
*
TOUT=DOM11 ET DOM12 ET DOM21 ET DOM22 ET DOM31 ET DOM32;
*
OPTI SAUV FORMAT 'doma01.msh';
SAUV FORMAT TOUT;
*
*======================================================================
* Reduction Craig-Bampton sur le domaine 2 du cas 3
*
NMOD1=10;
*
MOD1=MODELE DOM32 MECANIQUE ELASTIQUE ISOTROPE;
MAT1=MATERIAU MOD1 YOUN 210.E9 NU 0.3 RHO 7800.;
*
CL1=BLOQ DEPL P33_P34;
*
MAS1=MASSE MOD1 MAT1;
RIG1=(RIGIDITE MOD1 MAT1) ET CL1;
*
```

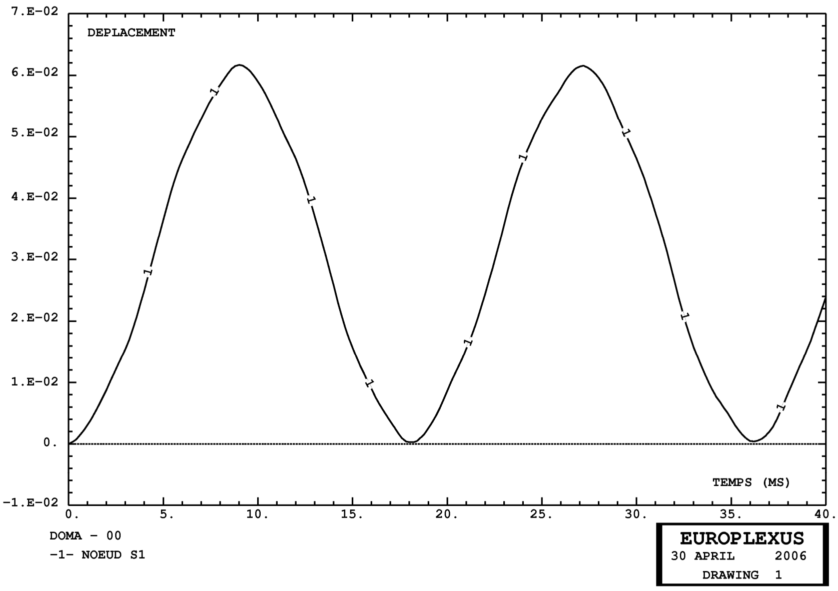
```
* Calcul des modes statiques
*
TDEPI1=TABLE;
TLREE1=TABLE;
NBN1=NBNO(P33_P34);
NSTA1=0;
*
REPETER BCL1 (NBN1);
   SI (&BCL1 EGA 1);
      LREEL1=PROG 1 * 1. (NBN1-1) * 0.;
      LREEL2=PROG NBN1 * 0.;
   SINON;
      SI (&BCL1 EGA NBN1);
         LREEL1=PROG (NBN1-1) * 0. 1 * 1.;
         LREEL2=PROG NBN1 * 0.;
      SINON;
         LREEL1=PROG (&BCL1-1) * 0. 1. (NBN1-&BCL1) * 0.;
         LREEL2=PROG NBN1 * 0.;
      FINSI;
   FINSI;
   REPETER BCL2 (2);
      REPETER BCL3 (2);
         TLREE1 . &BCL3=LREEL2;
      FIN BCL3;
      TLREE1 . &BCL2=LREEL1;
      CHIMP1=MANU CHPO P33_P34 2 UX TLREE1 . 1 UY TLREE1 . 2;
      CHIMP11=REDU DOM32 CHIMP1;
      NSTA1=NSTA1+1;
      TDEPI1 . NSTA1=CHIMP11;
   FIN BCL2;
FIN BCL1;
*
TSTAT1=TABLE;
*
REPETER BCL4 (2*NBN1);
   CHFOR1=DEPI CL1 TDEPI1 . &BCL4;
   CHSTA1=RESOUD RIG1 CHFOR1;
   TSTAT1 . &BCL4=CHSTA1;
   LIST &BCL4;
FIN BCL4;
*
* Modes propres encastres
*
TMOD1=VIBR 'SIMULTANE' 10. NMOD1 MAS1 RIG1 IMPR TBAS;
*
TDYN1=TABLE;
*
REPETER BCL5 (NMOD1);
   CHMOD1=TMOD1 . MODES . &BCL5 . DEFORMEE_MODALE;
   TDYN1 . &BCL5=CHMOD1;
FIN BCL5;
*
* Normalisation des modes dynamiques
*
REPETER BCL6 (NMOD1);
   CHPO1=TDYN1 . &BCL6;
   SCAL1=XTMX CHPO1 MAS1;
   SCAL1=SCAL1 ** 0.5;
   CHPO1=CHPO1 / SCAL1;
   CHPO1=ENLEVER CHPO1 LX;
   TDYN1 . &BCL6=CHPO1;
FIN BCL6;
*
* On retire aux modes statiques leur contribution sur les modes dynamiques
*
REPETER BCL7 (NSTA1);
   CHPO1=TSTAT1 . &BCL7;
   CHPO2=TSTAT1 . &BCL7;
   REPETER BCL8 (NMOD1);
      CHPO3=TDYN1 . &BCL8;
      SCAL1=YTMX MAS1 CHPO1 CHPO3;
      CHPO3=SCAL1 * CHPO3;
      CHPO2=CHPO2 - CHPO3;
   FIN BCL8;
   CHPO2=ENLEVER CHPO2 LX;
   TSTAT1 . &BCL7=CHPO2;
   LIST &BCL7;
FIN BCL7;
*
* Orthogonalisation de la famille des modes statiques modifies
*
TSTAT2=TABLE;
REPETER BCL9 (NSTA1);
   CHPO1=TSTAT1 . &BCL9;
   CHPO2=TSTAT1 . &BCL9;
   BOOL1=&BCL9 > 1;
   SI BOOL1;
      REPETER BCL10 (&BCL9-1);
         CHPO3=TSTAT2 . &BCL10;
         SCAL1=YTMX MAS1 CHPO1 CHPO3;
```

```
      CHPO3=SCAL1 * CHPO3;
      CHPO2=CHPO2 - CHPO3;
    FIN BCL10;
  FINSI;
  CHPO2=ENLEVER CHPO2 LX;
  SCAL1=XTMX CHPO2 MAS1;
  SCAL1=SCAL1 ** 0.5;
  CHPO2=CHPO2 / SCAL1;
  TSTAT2 . &BCL9=CHPO2;
  LIST &BCL9;
FIN BCL9;
*
* Base modale finale
*
TBAS1=TABLE 'BASE_MODALE';
TVEC1=TABLE 'MODES';
TVEC1 . MAILLAGE=TMOD1 . MODES . MAILLAGE;
REPETER BCL11 (NSTA1);
   TVEC1 . &BCL11=TABLE 'MODE';
   TVEC1 . &BCL11 . DEFORMEE_MODALE=TSTAT2 . &BCL11;
   TVEC1 . &BCL11 . POINT_REPERE=(0. 0.);
   TVEC1 . &BCL11 . FREQUENCE=0.;
   TVEC1 . &BCL11 . MASSE_GENERALISEE=1.;
FIN BCL11;
REPETER BCL12 (NMOD1);
   TVEC1 . (NSTA1 + &BCL12)=TABLE 'MODE';
   TVEC1 . (NSTA1 + &BCL12) . DEFORMEE_MODALE=TDYN1 . &BCL12;
   TVEC1 . (NSTA1 + &BCL12) . POINT_REPERE=(0. 0.);
   TVEC1 . (NSTA1 + &BCL12) . FREQUENCE=0.;
   TVEC1 . (NSTA1 + &BCL12) . MASSE_GENERALISEE=1.;
FIN BCL12;
TBAS1 . MODES=TVEC1;
*
* Projection des matrices de masse et de rigidite
*
MASP1=PJBA MAS1 TBAS1;
RIGP1=PJBA RIG1 TBAS1;
*
* Frequence max du systeme reduit
*
TSTAB1=VIBR 'INTERVALLE' 0. 50000. HAUTE 1 MASP1 RIGP1 'IMPR' 'TBAS';
*
* Sauvegarde des donnees pour PLEXUS
*
NTOT1=NSTA1 + NMOD1;
TSORT1=TABLE;
REPETER BCL13 (NTOT1);
   TSORT1 . &BCL13=TBAS1 . MODES . &BCL13 . DEFORMEE_MODALE;
FIN BCL13;
*
OPTI SAUV FORMAT 'doma01.modes';
SAUV FORMAT TOUT TSORT1;
*
TDON1=TABLE;
TDON1 . 1=NSTA1;
TDON1 . 2=NMOD1;
TDON1 . 3=TSTAB1 . MODES . 1 . FREQUENCE;
*
OPTI SAUV FORMAT 'doma01.matr';
SAUV FORMAT TDON1 MASP1 RIGP1;
*
FIN;
```

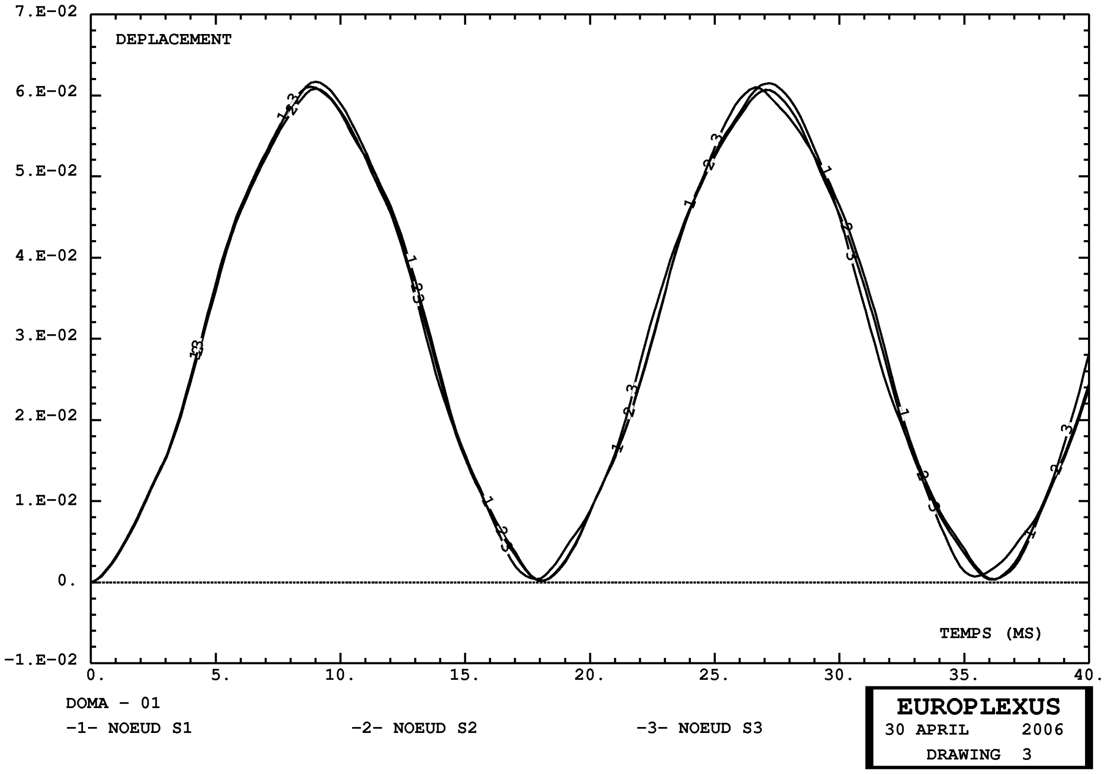
The input file is:

```
DOMA - 01
*------------------------------------------------------------------------
ECHO
!conv win
CAST tout
*------------------------------------------------------------Problem type
DPLA NONL
*------------------------------------------------------------Dimensioning
DIME
  PT2L 110 CAR4 64 CL2D 10 ZONE 2
  TABL 1 4 ECRO 522
  FORC 10  MTPO 9
TERM
*----------------------------------------------------------------Geometry
GEOM CAR4 tout
     CL2D p21_p22p p23_p24 p31_p32p p33_p34
     TERM
*---------------------------------------------------Geometric Complements
COMP GROU 4
     'interf' LECT p21_p22p p23_p24 p31_p32p p33_p34 TERM
     'prob1'  LECT dom11 dom12 TERM
     'prob2'  LECT dom21 dom22 p21_p22p p23_p24 TERM
     'prob3'  LECT dom31 dom32 p31_p32p p33_p34 TERM
     NGRO 4
     'tpln'   LECT p1 r1 s1 p2 r2 s2 p3 r3 s3 TERM
     'char1'  LECT p23_p24p p33_p34p TERM
     'char2'  LECT p13_p14p TERM
     'bloqa'  LECT p11_p12 p21_p22 p31_p32 TERM
     COUL turq LECT prob1 TERM
          rose LECT prob2 TERM
          vert LECT prob3 TERM
*-----------------------------------------------------------Material data
MATE
   LINE RO 7800. YOUN 210.E9 NU 0.3
        LECT tout TERM
   FANT 0.
        LECT interf TERM
*-------------------------------------------------------Applied "loads"
CHAR 1 FACT 2
   FORC 2 1.E7   LECT char1 TERM
   FORC 2 0.75E7 LECT char2 TERM
   TABL 2 0.0 1.0 1.0 1.0
*-------------------------------------------------Boundary conditions
LINK COUP BLOQ 12 LECT bloqa TERM
*-----------------------------------------------------------------Outputs
ECRI DEPL TFRE 4D-3 NOEL
          POIN LECT tpln TERM
     FICH ALIC TEMP TFREQ 0.2D-3
          POIN LECT tpln TERM
          ELEM LECT 1 TERM
     FICH ALIC FREQ 8
*-----------------------------------------------------------------Options
OPTI CSTA 0.5
  LOG 1
*------------------------------------------------Domain decomposition
STRU 6
   DOMA LECT dom11          TERM IDEN 91
   DOMA LECT dom12          TERM IDEN 92
   DOMA LECT dom21 p21_p22p TERM IDEN 93
   DOMA LECT dom22 p23_p24  TERM IDEN 94
   DOMA LECT dom31 p31_p32p TERM IDEN 95
   MODA LECT dom32 p33_p34  TERM IDEN 96
   FICH FORM 9 POST TOUS
$
$--- Attention : pour les BENCHs, le fichier des modes est concatené au
$                fichier maillage. D'ou la valeur 9, qui est la valeur par
$                defaut du fichier maillage, affectée au fichier  des modes.
$                Ce fait vient du fait que l'atelier logiciel ne peut gérer
$                pour l'instant que 2 fichiers input
$
$    POUR LES CALCULS STANDARDS : ces deux fichiers DOIVENT ETRE SEPARES !!!
$    Il faut donner un numero logique différent de 9 (unité logique par défaut
$    du fichier maillage)
$    Si ce numero n'est pas donné, Europlexus l'affectera le numero 50
$    et l'extension par defaut du fichier est '.mod'
$
INTE 3
   COMP TOLE 0.001
      DOMA 91 LECT p11_p12p TERM
      DOMA 92 LECT p13_p14  TERM
   OPTI
      DOMA 93 LECT p21_p22p TERM
      DOMA 94 LECT p23_p24  TERM
   MORT
      DOMA 96 LECT p33_p34  TERM
      DOMA 95 LECT p31_p32p TERM
*-------------------------------------------------Transient calculation
CALC TINI 0. TFIN 40.E-3
*=====================================================POST-TREATMENT
SUIT
Post-treatment
ECHO
RESU ALIC TEMP GARD PSCR
SORT GRAP
AXTE 1E3 'Temps (ms)'
*---------------------------------------------------Curve definitions
COUR  1 'noeud P1' DEPL COMP 2 NOEU LECT p1 TERM
COUR  2 'noeud R1' DEPL COMP 2 NOEU LECT r1 TERM
COUR  3 'noeud S1' DEPL COMP 2 NOEU LECT s1 TERM
COUR 11 'noeud P2' DEPL COMP 2 NOEU LECT p2 TERM
COUR 12 'noeud R2' DEPL COMP 2 NOEU LECT r2 TERM
COUR 13 'noeud S2' DEPL COMP 2 NOEU LECT s2 TERM
COUR 21 'noeud P3' DEPL COMP 2 NOEU LECT p3 TERM
COUR 22 'noeud R3' DEPL COMP 2 NOEU LECT r3 TERM
COUR 23 'noeud S3' DEPL COMP 2 NOEU LECT s3 TERM
*-----------------------------------------------------------------Plots
trac  1 11 21 AXES 1 'Deplacement' yzer
trac  2 12 22 AXES 1 'Deplacement' yzer
trac  3 13 23 AXES 1 'Deplacement' yzer
*-------------------------------------------------Results qualification
QUAL DEPL COMP 2 REFE 2.38669E-02 TOLE 1.E-2 LECT s1 TERM
     DEPL COMP 2 REFE 2.44172E-02 TOLE 1.E-2 LECT s2 TERM
     DEPL COMP 2 REFE 2.81579E-02 TOLE 1.E-2 LECT s3 TERM
*=================================================================
FIN
```

The tip displacement in the reference case is:



The tip displacement in the three cases with domain decomposition are:



The final displacement field in the reference case and in the three cases with domain decomposition are: