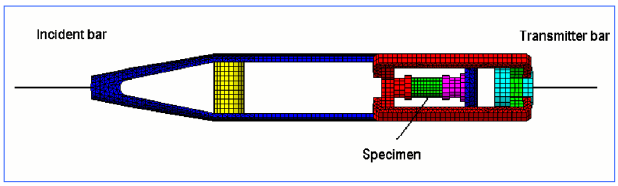
Exercise 4 – Hopkinson Bar

JRC Large Dynamic Test Facility (HopLab)



Fast Compression Test on Ductile Metallic Specimen

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TITLE:
Hopbar: simulation of an experiment on JRC's Hopkinson Bar.

PROBLEM:
At JRC a large Hopkinson bar is used to assess the dynamic behaviour of materials and small structural components at high rates of strain. The scope is to simulate an experiment of fast compressive loading of a ductile metallic specimen.

REFERENCES:
This calculation is detailed in:
1) C. Giry, G. Solomos, F. Casadei. "Numerical Analysis of the JRC Large Hopkinson Bar". Technical Note, PUBSY N. JRC46866, September 2008.
(all documents are available on the EUROPLEXUS Consortium Web site).

Numerical Solution

HOPKBARUR

The mesh generation file (K2000):

```
************************************************************************
*            Mesh Hopkinson test machine
*           ----------------------------
*
*                    (Units : m )
*
************************************************************************


*-----------------------------------------------------------------
* This file generates the mesh of the Large Hopkinson bar of the
* HopLab at the European Laboratory for Structural Assessement (ELSA)
* J.R.C. Ispra
*-----------------------------------------------------------------

*-----------------------------------------------------------------
* Choice of the type of test
*
* UNCONFME: Tests on unconfined metallic specimen. Two caps placed
* over the steel anvils in order to increase the surface of loading
* in contact with the specimen and to accomodate the lateral
* expansion of the specimen.
*     - Type of contact for Europlexus:
*           RIGI: Simple restrain on the displacement on x for
* the surfaces in contact (specimen - bars)  (CRIGI = VRAI)
*           GLIS: More complex condition using the Lagrange
* multiplier (nothing to write in this file)
*
* UNCONF: Tests on unconfined specimen made of other type of
* material (ex: concrete). The two caps are not used.
*     - Type of contact for Europlexus:
*           RIGI: Simple restrain on the displacement on x for
* the surfaces in contact (specimen - bars)  (CRIGI = VRAI)
*           GLIS: More complex condition using the Lagrange
* multiplier (nothing to write in this file)
*
*
* CONFIN: Tests on confined specimen (passive confinement with steel
* jacket).

UNCONFME= VRAI;
UNCONF= FAUX;
CONFIN= FAUX;

CRIGI= VRAI;


*-----------------------------------------------------------------

opti echo 1;
```

```
*---------------------------------------------------------------------
* Dimension, elements
* ...................
* The tetrahedrons are used for the operator VOLU. For the specimen,
* and the simple part of the inversion cages, cubes and prisms are
* used.
*---------------------------------------------------------------------

opti dime 3 elem TET4;


*---------------------------------------------------------------------
* Mesh size
* .........
* Inversion cages: 1.5 cm (dens1)
* Specimen: 0.5 cm (dens2)
* Bar elements far from the specimen: 20 cm (dens3)
* edens1 = dens1/100 (to erase double node)
*---------------------------------------------------------------------

dens1=0.015; edens1=dens1/100;
dens2=0.005; edens2=dens2/100;
dens3=0.2;


*---------------------------------------------------------------------
* Specimen size
* .............
* "widthsp" corresponds to the height of the specimen
* "diametsp": corresponds to the diameter of the specimen
* "widthja": corresponds to the width of the jacket (half the
* external diameter minus the internal diameter
*---------------------------------------------------------------------

widthsp = 0.1;

SI UNCONF;
diametsp = 0.06;
FINSI;
SI UNCONFME;
diametsp = 0.06;
FINSI;
SI CONFIN;
diametsp = 0.062;
FINSI;

widthja = 0.014;


**********************************************************************
*            Definition of the geometry of the machine
*           -------------------------------------------
**********************************************************************

* The mesh is composed of differents parts:
* -----------------------------------------
* --- The pulse generation device (bars) + the input bar (bars) + the
* inversion cages of the input bar (tetrahedrons, prisms and cubes) +
* the tube to avoid bending (prisms)
* --- The specimen (cubes and prisms)
* --- The output bar (bars) + the inversion cages of the output bar
*(tetrahedrons, prisms and cubes)
* --- The jacket for the confined tests (prisms and cubes)


dens dens1;

*---------------------------------------------------------------------
*  Pulse Generation device - Input bar - Inversion cage of the input
*  ................................................................
*---------------------------------------------------------------------

* Pulse generation system + Input bar
* ----------------------------------


len21 = -0.1429 ;
len20 = -1.42 + len21 ;
len19 = -8.48 + len20 ;
len18 = -0.75 + len19  ;
len17 = -0.6571 + len18 ;
len16 = -0.08 + len17 ;
len15 = -1.164 + len16 ;
len14 = -0.15 + len15 ;
len13 = -0.102 + len14 ;
len12 = -0.875 + len13 ;
len11 = -0.05 + len12 ;
len10 = -0.09 + len11 ;
len9 = -0.02 + len10 ;
len8 = -0.1 + len9 ;
len7 = -0.015 + len8 ;
len6 = -0.04 + len7 ;
len5 = -0.09 + len6 ;
len4 = -0.017 + len5 ;
len3 = -0.02 + len4 ;
len2 = -0.085 + len3 ;
len1 = -0.04 + len2 ;
lenca = -90. + len1;

*.....................................................................
* Evolutive size of the mesh in order to reduce the number of
* elements

dens dens3;
PLCA = (0.47442+lenca) 0. 0.;
* .....................................................................

dens dens1;
PL1 = (0.47442+len1) 0. 0.;
PL2 = (0.47442+len2) 0. 0.;
PL3 = (0.47442+len3) 0. 0.;
PL4 = (0.47442+len4) 0. 0.;
PL5 = (0.47442+len5) 0. 0.;
PL6 = (0.47442+len6) 0. 0.;
PL7 = (0.47442+len7) 0. 0.;
PL8 = (0.47442+len8) 0. 0.;
PL9 = (0.47442+len9) 0. 0.;
PL10 = (0.47442+len10) 0. 0.;
PL11 = (0.47442+len11) 0. 0.;
PL12 = (0.47442+len12) 0. 0.;
PL13 = (0.47442+len13) 0. 0.;
PL14 = (0.47442+len14) 0. 0.;
PL15 = (0.47442+len15) 0. 0.;
PL16 = (0.47442+len16) 0. 0.;
PL17 = (0.47442+len17) 0. 0.;
PL18 = (0.47442+len18) 0. 0.;
PL19 = (0.47442+len19) 0. 0.;
PL20 = (0.47442+len20) 0. 0.;
PL21 = (0.47442+len21) 0. 0.;
PL22 = (0.47442) 0. 0.;
PL23 = 0.53152 0. 0.;



LLOACA = PLCA D PL1 ;
LLOA1 = PL1 D PL2 ;
LLOA2 = PL2 D PL3 ;
LLOA3 = PL3 D PL4 ;
LLOA4 = PL4 D PL5 ;
LLOA5 = PL5 D PL6 ;
LLOA6 = PL6 D PL7 ;
LLOA7 = PL7 D PL8 ;
LLOA8 = PL8 D PL9 ;
LLOA9 = PL9 D PL10 ;
LLOA10 = PL10 D PL11 ;
LLOA11 = PL11 D PL12 ;
LLOA12 = PL12 D PL13 ;
LLOA13 = PL13 D PL14 ;
LLOA14 = PL14 D PL15 ;
LLOA15 = PL15 D PL16 ;
LLOA16 = PL16 D PL17 ;
LLOA17 = PL17 D PL18 ;
LLOA18 = PL18 D PL19 ;
LLOA19 = PL19 D PL20 ;
LLOA20 = PL20 D PL21 ;
LLOA21 = PL21 D PL22 ;
LLOA22 = PL22 D PL23 ;

linp = LLOACA et LLOA1 et LLOA2 et LLOA3 et LLOA4 et LLOA5 et LLOA6 et
LLOA7 et LLOA8 et LLOA9 et LLOA10 et LLOA11 et LLOA12 et LLOA13 et
LLOA14 et LLOA15 et LLOA16 et LLOA17 et LLOA18 et LLOA19 et LLOA20 et
 LLOA21 et LLOA22;


*.....................................................................
* SLOAD41 corresponds to the surface limit at right of the inversion cage
* of the input bar. This sruface will be linked to the input bar in
* Europlexus.

PLOA41 = 0.53152 0. -0.036;
PLOA42 = 0.53152 -0.036 0.;
PLOA43 = 0.53152 0. 0.036;
PLOA44 = 0.53152 0.036 0.;
l1LOA4 = PLOA41 CER3 PLOA42 PLOA43;
l2LOA4 = PLOA43 CER3 PLOA44 PLOA41;
ctloa4 = l1LOA4 et l2LOA4;
SLOAD41 = ctloa4 SURF 'PLAN';
elim SLOAD41 edens1;
*.....................................................................


* Inversion cage of the input bar
* -------------------------------


* ..............................Volume 2.....................................
*.....................................................................
width3 = 0.1 ;
nbd3 = nbel l1LOA4;

* For the operator DALL, we need to have the same number of elements for
* facing lines. The density nbd3 is taken from a line and apply to the
* the corresponding one in front.

P1S21 = 0.59152 (-0.015) -0.03816;
P2S21 = 0.59152 (0.015) -0.03816;
P3S21 = 0.59152 (-0.015) 0.03816;
P4S21 = 0.59152 (0.015) 0.03816;

P1S22 = 0.6472 (-0.03) -0.04017;
P2S22 = 0.6472 (-0.03) 0.04017;
P3S22 = 0.6472 0.03 -0.04017;
P4S22 = 0.6472 0.03 0.04017;
P5S22 = 0.6472 0.025 -0.04017;
P6S22 = 0.6472 0.025 0.04017;
P7S22 = 0.6472 (-0.025) -0.04017;
P8S22 = 0.6472 (-0.025) 0.04017;

P1S23 = 0.6222 0. -0.03927;
P2S23 = 0.6222 0. 0.03927;

P1S24 = 0.92 (-0.08) ((-1)*(width3/2));
P2S24 = 0.92 (-0.08) (width3/2);
P3S24 = 0.92 (-0.09176) ((-1)*(width3/2));
P4S24 = 0.92 (-0.09176) (width3/2);
P5S24 = 0.92 -0.1045 0.;

P1S31 = 0.92 0.08 ((-1)*(width3/2));
P2S31 = 0.92 0.08 (width3/2);
P3S31 = 0.92 0.09176 (width3/2);
P4S31 = 0.92 0.1045 0.;
P5S31 = 0.92 0.09176 ((-1)*(width3/2));

P1sym = 0. 0. 0. ;
P2sym = 0. 0. 1.;
P3sym = 1. 0. (-1.);
P4sym = 0. 1. 0.;
P5sym = 1. 0. 0.;

l1S21 = P1S22 CER3 P1S21 PLOA41;
l1S22 = PLOA41 CER3 P2S21 P3S22;
l1s2 = l1s21 et l1s22;
l2S2 = P3S22 d P5S31;
l4S2 = P1S31 d P5S22;
l5S2 = P5S22 CER3 P1S23 P7S22;
l51S2 = P8S22 CER3 P2S23 P6S22;
l6S2 = P7S22 d P1S24;
l7S2 = P1S24 d P3S24;
l8S2 = P3S24 d P1S22;
l9S2 = P8S22 d P7S22;
l10S2 = P5S22 d P6S22;
l11S2 = P1S24 d P2S24;
l13S2 = P2S24 d P8S22;
l14S2 = P6S22 d P2S31;
l16S2 = P2S22 d P4S24;
l17S2 = P4S24 CER3 nbd3 P5S24 P3S24;
l18S21 = P4S22 CER3 P4S21 PLOA43;
l18S22 = PLOA43 CER3 P3S21 P2S22;
l18S2 = l18S21 et l18S22;
L19S2 = l8s2 et l1s21;
L20S2 = l18s22 et l16s2;

l1S31 = P1S31 d P2S31;
l2S31 = P2S31 d P3S31;
l3S31 = P3S31 CER3 nbd3 P4S31 P5S31;
l4S31 = P5S31 d P1S31;


ct1S2 = l1S2 et l2S2 et l4S31 et l4S2 et l5S2 et l6S2 et l7S2 et l8S2;

S31 = (l1S31 et l2S31 et l3S31 et l4S31) surf PLAN;
S21 = ct1S2 SURF PLAN;
S22 = S21 syme 'PLAN' P1sym P5sym P4sym ;
S24 = S31 syme 'PLAN' P1sym P2sym P3sym ;
S25 = (l6S2 et l11S2 et l13S2 et l9S2) surf PLAN;
S26 = S25 syme 'PLAN' P1sym P2sym P3sym;
S27 = L19S2 l17s2 L20S2 (l1LOA4) dall 'QUELCONQUE';
S28 = S27 syme 'PLAN' P1sym P2sym P3sym;
S29 = L5S2 (INVE L9S2) L51S2 (INVE L10S2) dall 'QUELCONQUE';


S2 = S21 ET S22 ET SLOAD41 ET S24 ET S25 ET S26
ET S27 ET S28 ET S29 ET S31;
elim (S2) edens1;


vol2 = S2 VOLU;
elim vol2 edens1;
vol2 = (vol2 rege) couleur bleu;


* ..............................Volume 3.....................................
*.....................................................................

diamet3 = 0.209 ;
length3 = 0.8 ;
vl3 = length3 0. 0. ;
vecc3 = -0.34 0. 0.;


P1S32 = 1.05 0.08 ((-1)*(width3/2));
P2S32 = 1.05 0.08 (width3/2);
P3S32 = 1.05 0.09176 (width3/2);
P4S32 = 1.05 0.1045 0.;
P5S32 = 1.05 0.09176 ((-1)*(width3/2));

P1S34 = 1.72 0.08 ((-1)*(width3/2));
P2S34 = 1.72 0.08 (width3/2);
P3S34 = 1.72 0.09176 (width3/2);
P4S34 = 1.72 0.1045 0.;
P5S34 = 1.72 0.09176 ((-1)*(width3/2));


l1S32 = P1S32 d P2S32;
l2S32 = P2S32 d P3S32;
l3S32 = P3S32 CER3 nbd3 P4S32 P5S32;
l4S32 = P5S32 d P1S32;
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l1S34 = P1S34 d P2S34;
l2S34 = P2S34 d P3S34;
l3S34 = P3S34 CER3 nbd3 P4S34 P5S34;
l4S34 = P5S34 d P1S34;


l1s3l = P2S31 d P2S32;
l2s3l = P1S32 d P1S31;
l3s3l = P5S31 d P5S32;
l4s3l = P3S32 d P3S31;

*.....................................................................
* Definition of the surface of the tube to obtain the  continuity
* with the volume 3
*
vecrig = 0. -0.16 0.;
diamrig1 = 0.095 ;
diamrig2 = 0.0865 ;
thickrig = ((diamrig1 - diamrig2)/2);

Prig11 = (0.9225 + (diamrig1/2)) 0.08 ((-1)*(diamrig1/2));
Prig12 = 0.9225 0.08 0.;
Prig13 = (0.9225 + (diamrig1/2)) 0.08 (diamrig1/2);
Prig14 = (0.9225 + diamrig1) 0.08 0.;

Prig21 = (0.9225 + (diamrig1/2)) 0.08 (((-1)*(diamrig1/2)+thickrig));
Prig22 = (0.9225+thickrig) 0.08 0.;
Prig23 = (0.9225 + (diamrig1/2)) 0.08 ((diamrig1/2)-thickrig);
Prig24 = (0.9225+thickrig+diamrig2) 0.08 0.;

lrig11 = Prig11 CER3 Prig12 Prig13;
lrig12 = Prig13 CER3 Prig14 Prig11;
lrig21 = Prig21 CER3 Prig22 Prig23;
lrig22 = Prig23 CER3 Prig24 Prig21;
*.....................................................................



S32 = (l1S32 et l2S32 et l3S32 et l4S32) surf PLAN;
S33 = S32 MOIN vecc3;
S34 = (l1S34 et l2S34 et l3S34 et l4S34) surf PLAN;

S311 = (l2S3l et (INVE l4S31) et l3S3l et l4S32) SURF 'PLAN';
S312 = (l1S3l et  l2S32 et l4S3l et (INVE l2S31)) SURF 'PLAN';
S313 = ((l1S32 et (INVE l1S31) et (INVE l1S31) et (INVE l2S3l)) et
(lrig11 et lrig12)) SURF 'PLAN';
S314 =  (((INVE lrig21) et (INVE lrig22)) et (lrig11 et lrig12))
SURF 'PLAN';
S315 = ((INVE lrig21) et (INVE lrig22)) SURF 'PLAN';
S316 = (INVE L3S32) L4S3l L3S31 L3S3l DALL 'QUELCONQUE';
S3 = S311 ET S312 ET S313 ET S314 ET S315 ET S316 ET S31 ET S32;
elim S3 edens1;


vol311 = S3 volu ;
vol312 = S32 volu S33;
vol313 = S33 volu S34;
vol31 = vol311 et vol312 et vol313;
vol32 = (vol31) syme 'PLAN' P1sym P2sym P3sym ;
elim vol31 edens1;
elim vol32 edens1;
vol3 = (vol31 et vol32) couleur bleu;
elim vol3 edens1;
elim (vol2 et vol3) edens1;

* .............................Aluminium tube.............................
*.....................................................................

Volrig = (S314 VOLU TRAN vecrig) couleur jaune ;
ELIM (volrig et vol32) edens1;



* .............................Volume 4...................................
*.....................................................................

length4 = 0.04;
diamet4 = 0.045;
width4 = 0.06172;
diamet41 = 0.09;
diamet42 = 0.062;
diamet43 = 0.078;
vecc4 = 0.01 0. 0.;

P1S41 = 1.72 0. -0.1045;
P2S41 = 1.72 0. ((-1)*(diamet4/2));
P3S41 = 1.72 (diamet4/2) 0. ;
P4S41 = 1.72 0. (diamet4/2);
P5S41 = 1.72 0. 0.1045;
P6S41 = 1.72 0. ((-1)*(diamet41/2));
P7S41 = 1.72 (diamet41/2) 0.;
P8S41 = 1.72 0. (diamet41/2);
P9S41 = 1.72 0. ((-1)*(diamet42/2));
P10S41 = 1.72 (diamet42/2) 0.;
P11S41 = 1.72 0. (diamet42/2);
PCE1S41 = 1.72 0. 0.;
PCE2S41 = 1.72 0.05664 0.03086;
PCE3S41 = 1.72 0.05664 -0.03086;
PCE4S41 = 1.72 0. -0.0645;
PCE5S41 = 1.72 0. 0.0645;

P1S42 = 1.76 0. (diamet4/2);
P2S42 = 1.76 0. 0.0645;
P3S42 = 1.76 0.0567 (width4/2);
P31S42 = 1.76 0.0645 0.;
P4S42 = 1.76 0.0567 ((-1)*(width4/2));
P5S42 = 1.76 0. -0.0645;
P6S42 = 1.76 0. ((-1)*(diamet4/2));
P7S42 = 1.76 (diamet4/2) 0. ;
PCES42 = 1.76 0. 0.;


PI1S412 = 1.73 0. ((-1)*(diamet4/2));
PI2S412 = 1.73 0. (diamet4/2);
PI3S412 = 1.73 (diamet4/2) 0.;

L1S41 = P3S34 CERC PCE1S41 P5S41;
l2S41 = P5S41 d P8S41;
l3S41 = P2S41 CER3 P3S41 P4S41;
l4S41 = P6S41 d P1S41;
L5S41 = P1S41 CERC PCE1S41 P5S34;
l6S41 = P8S41 CER3 P7S41 P6S41;
l7S41 = P4S41 d P2S41;
l8S41 = P6S41 d P9S41;
l9S41 = P11S41 d P8S41;
l10S41 = P9S41 CER3 P10S41 P11S41;
l11S41 = P11S41 d P4S41;
l12S41 = P2S41 d P9S41;

ds4n1= nbel l2S41;
ds4n2= nbel l1S41;
ds4n3= nbel l3S34;
ds4n4= nbel l5S41;
ds4n5= nbel l4S41;
* For the operator DALL, we need to have the same number of elements for
* facing lines. The density ds4ni is taken from a line and is applied to
* the corresponding one in front.

l1S42 = P1S42 d ds4n1 P2S42;
l2S42 = P2S42 CERC ds4n2 PCES42 P3S42;
l3S42 = P3S42 CER3 ds4n3 P31S42 P4S42;
l4S42 = P4S42 CERC ds4n4 PCES42 P5S42;
L5S42 = P5S42 d ds4n5 P6S42;
l6S42 = P6S42 CER3 P7S42 P1S42;

l1S43 = P3S34 CERC PCE2S41 P3S42;
l2S43 = P4S42 CERC PCE3S41 P5S34;
l3S43 = P1S41 CERC PCE4S41 P5S42;
l4S43 = P6S42 d PI1S412;
l5S43 = P2S42 CERC PCE5S41 P5S41;
l6S43 = PI2S412 d P1S42;
l7S43 = PI1S412 d PI2S412;
l8S43 = PI2S412 CER3 PI3S412 PI1S412;

S4121 = (l1S34 et l2S34 et l1S41 et l2S41 et l6S41 et l4S41 et l5S41 et
l4S34) surf PLAN;
S4122 = S4121 syme 'PLAN' P1sym P2sym P3sym;
S412 = S4121 et S4122;

S41311 = (l8S41 et l10S41 et l9S41 et l6S41) surf PLAN;
S41312 = S41311 syme 'PLAN' P1sym P2sym P3sym;
S4131 = S41311 et S41312;

S41321 = (l10S41 et l11S41 et (INVE l3S41) et l12S41) surf PLAN;
S41322 = S41321 syme 'PLAN' P1sym P2sym P3sym;
S4132 = S41321 et S41322;

S413 = S4131 et S4132;

S4141 = (l3S41 et l7S41) surf PLAN;
S4142 = S4141 syme 'PLAN' P1sym P2sym P3sym;
S414 = S4141 et S4142;

S341 = S34 syme 'PLAN' P1sym P2sym P3sym;
S41 = S34 ET S341 ET S412 ET S413 ET S414;
elim (S41 et S414) edens1;


S421 = (l1S42 et l2S42 et l3S42 et l4S42 et l5S42 et l6S42) surf PLAN;
S422 = S421 syme 'PLAN' P1sym P2sym P3sym;
S42 = S421 et S422;


S431 = l1S43 l3s42 l2s43 (INVE l3S34) dall 'QUELCONQUE';
S432 = S431 syme 'PLAN' P1sym P2sym P3sym;
S43 = S431 et S432;


S441 = l2S43 (INVE L5S41) l3S43 (INVE l4S42) dall 'QUELCONQUE';
S442 = l5S43 l1s41 l1s43 l2S42 dall 'QUELCONQUE';
S443 = S441 ET S442;
S444 = S443 syme 'PLAN' P1sym P2sym P3sym;
S44 = S444 et S443;
elim S44 edens1;

S451 = l8S43 l6S43 l6S42 l4S43 dall 'QUELCONQUE';
S452 = S451 syme 'PLAN' P1sym P2sym P3sym;
S45 = S451 et S452;


S461 = (l8S43 et l7S43) surf PLAN;
S462 = S461 syme 'PLAN' P1sym P2sym P3sym;
S46 = S461 et S462;

S4 = S41 ET S42 ET S43 ET S44 ET S45 ET S46;
elim S4 edens1;

vol41 = S4 volu ;
elim vol41 edens1;
vol41 = vol41 rege;



* ..............................Right punch................................
*.....................................................................

veccrp1 = 0.016 0. 0.;
veccrp2 = 0.026 0. 0.;
veccrp3 = 0.061 0. 0.;

SRP4111 = S4131 MOIN veccrp1;
SRP4112 = S4132 MOIN veccrp1;
SRP4113 = S414  MOIN veccrp1;

SRP4211 = S4131 MOIN veccrp2;
SRP4212 = S4132 MOIN veccrp2;
SRP4213 = S414  MOIN veccrp2;

SRP4311 = S4131 MOIN veccrp3;
SRP4312 = S4132 MOIN veccrp3;
SRP4313 = S414  MOIN veccrp3;

elim (SRP4111 et SRP4112 et SRP4113) edens1;
elim (SRP4211 et SRP4212 et SRP4213) edens1;
elim (SRP4311 et SRP4312 et SRP4313) edens1;


vol4311 = (S4131 VOLU SRP4111) couleur bleu;
vol4312 = (S4132 VOLU SRP4112) couleur bleu;
vol4313 = (S414 VOLU SRP4113) couleur bleu;
vol431 = vol4311 et vol4312 et vol4313;
vol4321 = (SRP4112 VOLU SRP4212) couleur bleu;
vol4322 = (SRP4113 VOLU SRP4213) couleur bleu;
vol432 = vol4321 et vol4322;
vol433 = vol431 et vol432;

vol4341 = (SRP4212 VOLU SRP4312) couleur bleu;
vol4342 = (SRP4213 VOLU SRP4313) couleur bleu;


SI CONFIN;
VGLIMR = (vol4341 et vol4342) couleur rose;
elim VGLIMR edens1;
Volrp = (VOL433 ET VGLIMR) couleur rose;
elim volrp edens1;
volrp = volrp rege;
elim (volrp et vol41) edens1;
SI CRIGI;
elim (volrp et vol41) edens1;
NSRP = CHAN 'POI1' (SRP4312 et SRP4313);
FINSI;
FINSI;


SI UNCONF;
VGLIMR = (vol4341 et vol4342) couleur rose;
elim VGLIMR edens1;
Volrp = (VOL433 ET VGLIMR) couleur rose;
elim volrp edens1;
volrp = volrp rege;
SI CRIGI;
elim (volrp et vol41) edens1;
NSRP = CHAN 'POI1' (SRP4312 et SRP4313);
FINSI;
FINSI;


SI UNCONFME;
vmeccrp2 = 0.051 0. 0.;
vmeccrp3 = 0.02 0. 0.;

Pm6S41 = 1.669 0. ((-1)*(diamet43/2));
Pm7S41 = 1.669 (diamet43/2) 0.;
Pm8S41 = 1.669 0. (diamet43/2);
Pm9S41 = 1.669 0. ((-1)*(diamet42/2));
Pm10S41 = 1.669 (diamet42/2) 0.;
Pm11S41 = 1.669 0. (diamet42/2);

lm6S41 = Pm8S41 CER3 Pm7S41 Pm6S41;
lm8S41 = Pm6S41 d Pm9S41;
lm9S41 = Pm11S41 d Pm8S41;
lm10S41 = Pm9S41 CER3 Pm10S41 Pm11S41;

Sm41311 = (lm8S41 et lm10S41 et lm9S41 et lm6S41) surf PLAN;
Sm41312 = Sm41311 syme 'PLAN' P1sym P2sym P3sym;
SmRP4211 = Sm41311 et Sm41312;

SmRP4212 = S4132 MOIN vmeccrp2;
SmRP4213 = S414  MOIN vmeccrp2;

SmRP4311 = SmRP4211 MOIN vmeccrp3;
SmRP4312 = SmRP4212 MOIN vmeccrp3;
SmRP4313 = SmRP4213 MOIN vmeccrp3;

elim (SmRP4211 et SmRP4212 et SmRP4213) edens1;
elim (SmRP4311 et SmRP4312 et SmRP4313) edens1;
```

```
vmol4321 = (SRP4112 VOLU SmRP4212) couleur bleu;
vmol4322 = (SRP4113 VOLU SmRP4213) couleur bleu;
vmol432 = vmol4321 et vmol4322;
vmol433 = vol431 et vmol432;

vmol4341 = (SmRP4212 VOLU SmRP4312) couleur bleu;
vmol4342 = (SmRP4213 VOLU SmRP4313) couleur bleu;
vmol4345 = (SmRP4211 VOLU SmRP4311) couleur bleu;

VGLIMR = (vmol4341 et vmol4342 et vmol4345)
couleur rose;
elim VGLIMR edens1;
Volrp = (VmOL433 ET VGLIMR) couleur rose;
elim volrp edens1;
volrp = volrp rege;
elim (volrp et vol41) edens1;

SI CRIGI;
NSRP = CHAN 'POI1' (SmRP4312 et SmRP4313 et SmRP4311);
FINSI;

FINSI;

* .............Volume of the inversion cage of the input bar.............
*.....................................................................

volinp =vol2 et vol41 et vol3;


elim volinp edens1;
volinp = (volinp rege) couleur bleu;

*---------------------------------------------------------------------
*               Output bar - Inversion cage of the output
*  ...................................................................
*---------------------------------------------------------------------


* ..............................Left cross.................................
*.....................................................................

posrp = 1.659;

SI UNCONF;
posrp = 1.659;
FINSI;
SI CONFIN;
posrp = 1.659;
FINSI;
SI UNCONFME;
posrp = 1.649;
FINSI;

diametcl = 0.062;
diametc2 = 0.078;
widthcl = 0.04;
gdiamecl = 0.12;

SI UNCONF;
posxcl = posrp - widthsp - widthcl - 0.045;
FINSI;
SI CONFIN;
posxcl = posrp - widthsp - widthcl - 0.045;
FINSI;
SI UNCONFME;
posxcl = posrp - widthsp - widthcl - 0.055;
FINSI;

veccl = widthcl 0. 0.;
veccl1 = ((-1)*widthcl) 0. 0.;
veccl2 = -0.01 0. 0.;
veccl3 = -0.035 0. 0.;
veccl4 = -0.02 0. 0.;

P1cl = posxcl (diametcl/2) 0.;
P11cl = posxcl 0.065 0.;
P2cl = posxcl 0.105 0.;
P3cl = posxcl 0.065 0.02;
P4cl = posxcl 0.0566 0.02;
P5cl = posxcl 0.0424 0.0424;
P6cl = posxcl 0.02 0.0566;
P61cl = posxcl 0.02 0.065;
P7cl = posxcl 0. 0.065;
P8cl = posxcl 0. 0.105;
P9cl = posxcl 0. (diametcl/2);
Pce1cl = posxcl 0. 0.;
Psymcl = posxcl 1. 0.;

l1cl = P1cl d P11cl;
l2cl = P3cl d P4cl;
l4cl = P4cl CER3 P5cl P6cl;
l5cl = P6cl d P61cl;
l6cl = P7cl d P61cl;
l7cl = P7cl d P9cl;
l8cl = P9cl CERC Pce1cl P1cl;
l9cl = P1cl d Pce1cl;
l10cl = Pce1cl d P9cl;
l11cl = P3cl d P11cl;


ctcl1 = l1cl et (INVE l11cl) ET l2cl ET L4CL ET L5CL ET (INVE l6cl)
ET l7cl ET L8CL;
ctclc = l8cl et l9cl et l10cl;

scl1 = ctcl1 SURF 'PLAN';
elim scl1 edens1;
scl2 = scl1 SYME DROIT P1cl P2cl;
scl3 = scl1 SYME DROIT P8cl P9cl;
scl4 = scl3 SYME DROIT Pce1cl Psymcl ;
SCL = SCL1 ET SCL2 ET SCL3 ET SCL4;

scllc11 = ctclc SURF 'PLAN';
scllc12 = scllc11 SYME PLAN P1sym P2SYM P3SYM;
scllc13 = (scllc11 et scllc12) SYME PLAN P1sym P4SYM P5SYM;
SCL1C1 = SCL1C11 ET SCL1C12 ET SCL1C13 ;
SCL1C2 = SCL1C1 MOINS veccl1;
SCL1C3 = SCL1C2 MOINS veccl2;
SCL1C4 = SCL1C3 MOINS veccl3;

elim scl edens1;

vcl1 = (scl VOLU TRAN veccl) couleur bleu;
vclc = (SCL1C1 VOLU SCL1C2) couleur bleu;

SI UNCONF;
vclc1 = (SCL1C2 VOLU SCL1C3) couleur bleu;
vclc2 = (SCL1C3 VOLU SCL1C4) couleur bleu;
vclc11 = vclc et vclc1;
elim vclc11 edens1;

VGLIML = vclc2 couleur rouge;
ELIM VGLIML edens1;
vollc = (vcl1 et vclc11 et VGLIML) couleur rouge;
ELIM vollc edens1;
SI CRIGI;
NSLC = CHAN 'POI1' SCL1C4;
FINSI;
FINSI;

SI CONFIN;
vclc1 = (SCL1C2 VOLU SCL1C3) couleur bleu;
vclc2 = (SCL1C3 VOLU SCL1C4) couleur bleu;
vclc11 = vclc et vclc1;
elim vclc11 edens1;

VGLIML = vclc2 couleur rouge;
ELIM VGLIML edens1;
vollc = (vcl1 et vclc11 et VGLIML) couleur rouge;
ELIM vollc edens1;
SI CRIGI;
NSLC = CHAN 'POI1' SCL1C4;
FINSI;
FINSI;

SI UNCONFME;
Pm1cl11 = (posxcl+widthcl+0.035) 0. (diametcl/2.);
Pm2cl11 = (posxcl+widthcl+0.035) (diametcl/2.) 0.;
Pm3cl11 = (posxcl+widthcl+0.035) 0. (diametc2/2.);
Pm4cl11 = (posxcl+widthcl+0.035) (diametc2/2.) 0.;
Pmce2cl1 = (posxcl+widthcl+0.035) 0. 0.;

Pm1cl12 = (posxcl + widthcl + 0.055) 0. (diametcl/2);
Pm2cl12 = (posxcl + widthcl + 0.055) (diametcl/2) 0.;
Pm3cl12 = (posxcl + widthcl + 0.055) 0. (diametc2/2);
Pm4cl12 = (posxcl + widthcl + 0.055) (diametc2/2) 0.;
Pmce2cl2 = (posxcl + widthcl + 0.055) 0. 0.;

lm1cl11 = CERC Pm1cl11 Pmce2cl1 Pm2cl11;
lm2cl11 = Pm2cl11 d Pmce2cl1;
lm3cl11 = Pmce2cl1 d Pm1cl11;
lm4cl11 = Pm2cl11 d Pm4cl11;
lm5cl11 = CERC Pm4cl11 Pmce2cl1 Pm3cl11;
lm6cl11 = Pm3cl11 d Pm1cl11;

lm1cl12 = Pm1cl12 CERC Pmce2cl2 Pm2cl12;
lm2cl12 = Pm2cl12 d Pmce2cl2;
lm3cl12 = Pmce2cl2 d Pm1cl12;
lm4cl12 = Pm2cl12 d Pm4cl12;
lm5cl12 = Pm4cl12 CERC Pmce2cl2 Pm3cl12;
lm6cl12 = Pm3cl12 d Pm1cl12;

cmtclc11 = lm1cl11 et lm2cl11 et lm3cl11 ;
cmtclc12 = lm1cl11 et lm4cl11 et lm5cl11 et lm6cl11;
cmtclc21 = lm1cl12 et lm2cl12 et lm3cl12 ;
cmtclc22 = lm1cl12 et lm4cl12 et lm5cl12 et lm6cl12;


smcllc11 = cmtclc11 SURF 'PLAN';
smcllc12 = smcllc11 SYME PLAN P1sym P2SYM P3SYM;
smcllc13 = (smcllc11 et smcllc12) SYME PLAN P1sym P4SYM P5SYM;
smcllc1 = smcllc11 et smcllc12 et smcllc13;

smcllc21 = cmtclc12 SURF 'PLAN';
smcllc22 = smcllc21 SYME PLAN P1sym P2SYM P3SYM;
smcllc23 = (smcllc21 et smcllc22) SYME PLAN P1sym P4SYM P5SYM;
smcllc2 = smcllc21 et smcllc22 et smcllc23;

smcllc31 = smcllc1 MOIN veccl4;
smcllc32 = smcllc2 MOIN veccl4;

vmclc1 = (SCL1C2 VOLU SmCL1C1) couleur bleu;
vmclc2 = (SmCL1C1 VOLU SmCL1C31) couleur bleu;
vmclc3 = (SmCL1C2 VOLU SmCL1C32) couleur bleu;
vmclc11 = vclc et vmclc1;
elim vmclc11 edens1;


VGLIML = (vmclc2 et vmclc3) couleur rouge;
ELIM VGLIML edens1;
vollc = (vcl1 et vmclc11 et VGLIML)
couleur rouge;
ELIM vollc edens1;
SI CRIGI;
NSLC = CHAN 'POI1' (SmCL1C32 et SmCL1C31);
FINSI;

FINSI;


* ............Right cross + Left nut + Right nut.........................
*.....................................................................


diametcr = 0.072;
diamecy1 = 0.055;
diamecy2 = 0.03;
diametcy = 0.0425;
widthcr = 0.04;
widthln = -0.05;
widthba = 0.025;
widthrn = 0.03;
gdiamecr = 0.129;
posxcr = (posxcl+0.41);
lengcr1 = 0.025+widthcr;
lengcr2 = 0.38+lengcr1;
lengcr3 = 0.5+lengcr2;
lengcr4 = 0.1+lengcr3;
lengcr51 = 0.001 + lengcr4;
lengcr5 = 1.+lengcr4;
lengcr6 = 100.+lengcr5;
veccr1 = -0.05 0. 0.;
veccr2 = 0.025 0. 0.;
veccr3 = ((-1)*widthba) 0. 0.;


P1cri = posxcr (diametcr/2) 0.;
P1crii = (posxcr+widthcr) (diametcr/2) 0.;
P1cyi = posxcr (diametcy/2) 0.;
P1cyii = (posxcr+widthcr) (diametcy/2) 0.;
P2cr = posxcr 0.105 0.;
P2bcr = (posxcr+widthcr) 0.105 0.;
P3cr = posxcr 0.0608 0.02;
P3bcr = (posxcr+widthcr) 0.0608 0.02;
P4cr = posxcr 0.02 0.0608;
P4bcr = (posxcr+widthcr) 0.02 0.0608;
P5cr = posxcr 0. 0.105;
P5bcr = (posxcr+widthcr) 0. 0.105;
P6cr = posxcr 0.02 0.065;
P6bcr = (posxcr+widthcr) 0.02 0.065;
P7cr = posxcr 0.065 0.02 ;
P7bcr = (posxcr+widthcr) 0.065 0.02 ;
P8cr = posxcr 0. 0.065;
P8bcr = (posxcr+widthcr) 0. 0.065;
P9cri = posxcr 0. (diametcr/2);
P9crii = (posxcr+widthcr) 0. (diametcr/2);
P9cyi = posxcr 0. (diametcy/2);
P9cyii = (posxcr+widthcr) 0. (diametcy/2);
P10cr = posxcr 0.065 0. ;
P10bcr = (posxcr+widthcr) 0.065 0. ;
Pccr = (posxcr+widthln) 0. 0.;
Pccri = posxcr 0. 0.;
Pccrii = (posxcr+widthcr) 0. 0.;

Psymcr = posxcr 1. 0.;
Psymbcr = (posxcr+widthcr) 1. 0.;


l1cr = P1CRi D P10cr;
l1bcr = P1CRii D P10bcr;
l2cr = P3CR CERC PCCRi P4cr;
l2bcr = P3bCR CERC PCCRii P4bcr;
l3cr = P8cr D P9CRi;
l3bcr = P8bcr D P9CRii;
l4cr = P3CR D P7cr;
l4bcr = P3bCR D P7bcr;
l5cr = P6cr D P4cr;
l5bcr = P6bcr D P4bcr;
l6cr = P7cr D P10cr;
l6bcr = P7bcr D P10bcr;
l7cr = P8cr D P6cr;
l7bcr = P8bcr D P6bcr;
L1CRi = P1CYi D P1CRi;
L2CRi = P1CRi CERC PCCRi P9CRi;
L3CRi = P9CRi D P9CYi;
L1CYi = P9CYi CERC PCCRi P1CYi;
L1CRii = P1CYii D P1CRii;
L2CRii = P1CRii CERC PCCRii P9CRii;
L3CRii = P9CRii D P9CYii;
L1CYii = P9CYii CERC PCCRii P1CYii;
L2CYii = P1CYii D PCCRii;
L3CYii = PCCRii D P9CYii;


ctcli = L1CRi et L2CRi et L3CRi et L1CYi;
ctcliii = L1CRii et L2CRii et L3CRii et L1CYii;
ctc2ii = L1CYii et L2CYii et L3CYii;
ctcr1 = l1cr ET (INVE l6cr) ET (INVE l4cr) ET l2cr ET (INVE l5cr) ET
(INVE l7cr) ET l3cr ET (INVE L2CRi);
```

```
ctcr2 = l1bcr ET (INVE l6bcr) ET (INVE l4bcr) ET l2bcr ET
(INVE l5bcr) ET (INVE l7bcr) ET l3bcr ET (INVE L2CRii);


s1oi = ctc1i SURF 'PLAN';
s2oi = s1oi SYME PLAN P1sym P2SYM P3SYM;
s3oi = (s1oi et s2oi) SYME PLAN P1sym P4SYM P5SYM;
s1oui = s1oi et s2oi et s3oi;
elim s1oui edens1;

s1oii = ctc1ii SURF 'PLAN';
s2oii = s1oii SYME PLAN P1sym P2SYM P3SYM;
s3oii = (s1oii et s2oii) SYME PLAN P1sym P4SYM P5SYM;
s4oii = ctc2ii SURF 'PLAN';
s5oii = s4oii SYME PLAN P1sym P2SYM P3SYM;
s6oii = (s4oii et s5oii) SYME PLAN P1sym P4SYM P5SYM;
s2ouii = s1oii et s2oii et s3oii;
s3ouii = s4oii et s5oii et s6oii;
s1ouii = s2ouii et s3ouii;
elim s1ouii edens1;

s1ouiii = s1ouii MOIN veccr3;
elim s1ouiii edens1;

scr11 = ctcr1 SURF 'PLAN';
scr12 = scr11 SYME DROIT P1cri P2cr;
scr13 = scr11 SYME DROIT P5cr P9cri;
scr14 = scr13 SYME DROIT Pccri Psymcr ;
scr21 = ctcr2 SURF 'PLAN';
scr22 = scr21 SYME DROIT P1crii P2bcr;
scr23 = scr21 SYME DROIT P5bcr P9crii;
scr24 = scr23 SYME DROIT Pccrii Psymbcr ;
scr1 = scr11 ET scr12 ET scr13 ET scr14;
scr2 = scr21 ET scr22 ET scr23 ET scr24;
elim scr2 edens1;


v1out = (s1oui volu s2ouii) couleur rouge;
v2out = (s1ouii volu s1ouiii) couleur rouge;
volout = v1out et v2out;
elim volout edens1;
volln = ((scr1 et s1oui) VOLU TRAN veccR1) couleur turquoise ;
elim volln edens1;
volln = volln rege;
Volrn = (scr2 VOLU TRAN veccr2) couleur turquoise ;
elim volrn edens1;
volrn = volrn rege;
volrc = (scr1 VOLU scr2) couleur verte;
elim volrc edens1;
elim (volrc et volrn et volln et volout) edens1;


* ............Bars of the inversion cage of the output bar..............
*.....................................................................................

dis1b = 0.025;
posxb = posxcl-dis1b;
dis2b = 0.45;

VECB1 = 0. 0.02 0.;

P1bar = posxb 0. 0.065;
P3bar = (posxb + dis1b + widthcr) 0. 0.065;
P31bar = (posxb + dis1b + widthcr) 0. 0.105;
P4bar = (posxb + dis1b + dis2b) 0. 0.105;
P5bar = (posxb + dis1b + dis2b) 0. 0.065;
P6bar = (posxb + dis1b + dis2b + dis1b) 0. 0.065;
P7bar = (posxb + dis1b + dis2b + dis1b) 0. 0.115;
P8bar = (posxb + dis1b + dis2b + dis1b - 0.015) 0. 0.13;
P9bar = (posxb + 0.015) 0. 0.13;
P10bar = (posxb ) 0. 0.115;

PSYB1 = 1. 0. 0.;
PSYB2 = 0. 1. 1.;
PSYB3 = 1. 0. 0.;
L1B = P1BAR D P7cl;
L2B = P7cl D P3BAR;
L3B = P3BAR D P31BAR;
L31B = P31BAR D P5cr;
L32B = P5cr D P8cr;
L4B = P8cr D P8bcr;
L5B = P8bcr D P6BAR;
L6B = P6BAR D P7BAR;
L7B = P7BAR D P8BAR;
L8B = P8BAR D P9BAR;
L9B = P9BAR D P10BAR;
L10B = P10BAR D P1BAR;
CT1 = L1B ET L2B ET L3B ET L31B ET L32B ET L4B ET L5B ET L6B ET L7B ET
L8B ET L9B ET L10B;

SB1 = CT1 SURF PLAN;
VB11 = SB1 VOLU TRAN VECB1;
VB12 = VB11 SYME PLAN P1sym P2sym P3sym;
VB1 = VB11 et VB12;
elim VB1 edens1;
VB2 = VB1 SYME PLAN P1sym P5sym P4sym;
VBB1 = VB1 ET VB2;
VBB2 = VBB1 SYME PLAN P1sym PSYB1 PSYB2;
Volba = (VBB1 ET VBB2) COULEUR ROUGE;
elim Volba edens1;
Volba = volba rege;
elim (Volba et volrc) edens1;
elim (Volba et vollc) edens1;
elim (volrc et volrn et volout et volln) edens1;


* .............................Output bar ..................................
*.....................................................................................


opti dime 3 elem SEG2;

Pout10 = (posxcr+lengcr1) 0. 0.;
Pout11 = (posxcr+lengcr2) 0. 0.;
Pout12 = (posxcr+lengcr3) 0. 0.;
Pout1 = (posxcr+lengcr4) 0. 0.;
Pout2 = (posxcr+lengcr5) 0. 0.;

lout10 = Pout10 d Pout11;
lout11 = Pout11 d Pout12;
lout12 = Pout12 d Pout1;
lout1 = Pout1 d Pout2;

dens dens3;
Pout3 = (posxcr+lengcr6) 0. 0.;
lout2 = Pout2 d Pout3;
lout = lout10 et lout11 et lout12 et lout1 et lout2;

DEPL (Volout et volba et vollc et VGLIML et volrc et volln et
volrn et lout)
TOUR 45 p1sym PSYB3;




opti dime 3 elem CUB8;
dens dens2;
*----------------------------------------------------------------------
*                              Specimen
*  ..................................................................
*----------------------------------------------------------------------

veccsp1 = ((-1)*(widthsp/2)) 0. 0.;
veccsp2 = ((-1)*widthsp) 0. 0.;

P1sp = (posrp + ((-1)*widthsp)) (diametsp/2) 0.;
P2sp = (posrp + ((-1)*widthsp)) 0. (diametsp/2);
Pcesp = (posrp + ((-1)*widthsp)) 0. 0.;

l1sp = P1sp CERC Pcesp P2sp;
l2sp = P2sp D Pcesp;
l3sp = Pcesp D P1sp;

ctsp1 = l1sp et l2sp et l3sp;


ssp1 = ctsp1 surf 'PLAN';
ssp2 =  ssp1 SYME PLAN P1sym P2SYM P3SYM ;
ssp3 = (ssp1 et ssp2) SYME PLAN P1sym P4SYM P5SYM;
ssp = ssp1 et ssp2 et ssp3;
ELIM ssp edens2;
ssp21 = ssp MOIN veccsp1;
ELIM ssp21 edens2;
ssp2 = ssp MOIN veccsp2;
ELIM ssp2 edens2;

volsp1 = (ssp VOLU ssp21) couleur verte;
ELIM volsp1 edens2;
volsp2 = (ssp21 VOLU ssp2) couleur verte;
ELIM volsp2 edens2;
volsp = volsp1 et volsp2;
ELIM volsp edens2;
volsp = (volsp rege) couleur verte;

VGLIL = VOLSP ELEM APPU LARG SSP;
VGLIR = VOLSP ELEM APPU LARG SSP2;
NSLSP = CHAN 'POI1' SSP;
NLOADSL = BARY SSP;
PSL = MANU POI1 NLOADSL;
NSRSP = CHAN 'POI1' SSP2;
NLOADSR = BARY SSP2;
PSR = MANU POI1 NLOADSR;

*----------------------------------------------------------------------
*                              Jacket
*  ..................................................................
*----------------------------------------------------------------------
diamjai = diametsp;
diamjae = diamjai + ((2)*(widthja));

P1ja = (posrp + 0.025) (diamjai/2) 0.;
P2ja = (posrp + 0.025) 0. (diamjai/2);
P3ja = (posrp + 0.025) ((diamjae/2)) 0.;
P4ja = (posrp + 0.025) 0. ((diamjae/2));
P5ja = (posrp + 0.025) ((-1)*(diamjai/2)) 0.;
P6ja = (posrp + 0.025) 0. ((-1)*(diamjai/2));
P7ja = (posrp + 0.025) ((-1)*(diamjae/2)) 0.;
P8ja = (posrp + 0.025) 0. ((-1)*(diamjae/2));
Pceja = (posrp + 0.025) 0. 0.;


P1ja1 = (posrp + 0.0075 + ((-1)*(0.5*widthsp))) (diamjai/2) 0.;
P2ja1 = (posrp + 0.0075 + ((-1)*(0.5*widthsp))) 0. (diamjai/2);
P3ja1 = (posrp + 0.0075 + ((-1)*(0.5*widthsp))) (diamjae/2) 0.;
P4ja1 = (posrp + 0.0075 + ((-1)*(0.5*widthsp))) 0. (diamjae/2);
P5ja1 = (posrp + 0.0075 + ((-1)*(0.5*widthsp))) ((-1)*(diamjai/2)) 0.;
P6ja1 = (posrp + 0.0075 + ((-1)*(0.5*widthsp))) 0. ((-1)*(diamjai/2));
P7ja1 = (posrp + 0.0075 + ((-1)*(0.5*widthsp))) ((-1)*(diamjae/2)) 0.;
P8ja1 = (posrp + 0.0075 + ((-1)*(0.5*widthsp))) 0. ((-1)*(diamjae/2));
Pceja1 = (posrp + 0.0075 + ((-1)*(0.5*widthsp))) 0. 0.;

P1ja2 = (posrp + 0.0025 + ((-1)*(0.5*widthsp))) (diamjai/2) 0.;
P2ja2 = (posrp + 0.0025 + ((-1)*(0.5*widthsp))) 0. (diamjai/2);
P3ja2 = (posrp + 0.0025 + ((-1)*(0.5*widthsp))) (diamjae/2) 0.;
P4ja2 = (posrp + 0.0025 + ((-1)*(0.5*widthsp))) 0. (diamjae/2);
P5ja2 = (posrp + 0.0025 + ((-1)*(0.5*widthsp))) ((-1)*(diamjai/2)) 0.;
P6ja2 = (posrp + 0.0025 + ((-1)*(0.5*widthsp))) 0. ((-1)*(diamjai/2));
P7ja2 = (posrp + 0.0025 + ((-1)*(0.5*widthsp))) ((-1)*(diamjae/2)) 0.;
P8ja2 = (posrp + 0.0025 + ((-1)*(0.5*widthsp))) 0. ((-1)*(diamjae/2));
Pceja2 = (posrp + 0.0025 + ((-1)*(0.5*widthsp))) 0. 0.;

P1ja3 = (posrp + ((-1)*(0.0025 + (0.5*widthsp)))) (diamjai/2) 0.;
P2ja3 = (posrp + ((-1)*(0.0025 + (0.5*widthsp)))) 0. (diamjai/2);
P3ja3 = (posrp + ((-1)*(0.0025 + (0.5*widthsp)))) (diamjae/2) 0.;
P4ja3 = (posrp + ((-1)*(0.0025 + (0.5*widthsp)))) 0. (diamjae/2);
P5ja3 = (posrp + ((-1)*(0.0025 + (0.5*widthsp)))) ((-1)*(diamjai/2)) 0.;
P6ja3 = (posrp + ((-1)*(0.0025 + (0.5*widthsp)))) 0. ((-1)*(diamjai/2));
P7ja3 = (posrp + ((-1)*(0.0025 + (0.5*widthsp)))) ((-1)*(diamjae/2)) 0.;
P8ja3 = (posrp + ((-1)*(0.0025 + (0.5*widthsp)))) 0. ((-1)*(diamjae/2));
Pceja3 = (posrp + ((-1)*(0.0025 + (0.5*widthsp)))) 0. 0.;

P1ja4 = (posrp + ((-1)*(0.0075 + (0.5*widthsp)))) (diamjai/2) 0.;
P2ja4 = (posrp + ((-1)*(0.0075 + (0.5*widthsp)))) 0. (diamjai/2);
P3ja4 = (posrp + ((-1)*(0.0075 + (0.5*widthsp)))) (diamjae/2) 0.;
P4ja4 = (posrp + ((-1)*(0.0075 + (0.5*widthsp)))) 0. (diamjae/2);
P5ja4 = (posrp + ((-1)*(0.0075 + (0.5*widthsp)))) ((-1)*(diamjai/2)) 0.;
P6ja4 = (posrp + ((-1)*(0.0075 + (0.5*widthsp)))) 0. ((-1)*(diamjai/2));
P7ja4 = (posrp + ((-1)*(0.0075 + (0.5*widthsp)))) ((-1)*(diamjae/2)) 0.;
P8ja4 = (posrp + ((-1)*(0.0075 + (0.5*widthsp)))) 0. ((-1)*(diamjae/2));
Pceja4 = (posrp + ((-1)*(0.0075 + (0.5*widthsp)))) 0. 0.;

P1ja5 = (posrp + ((-1)*(0.025 + widthsp))) (diamjai/2) 0.;
P2ja5 = (posrp + ((-1)*(0.025 + widthsp))) 0. (diamjai/2);
P3ja5 = (posrp + ((-1)*(0.025 + widthsp))) (diamjae/2) 0.;
P4ja5 = (posrp + ((-1)*(0.025 + widthsp))) 0. (diamjae/2);
P5ja5 = (posrp + ((-1)*(0.025 + widthsp))) ((-1)*(diamjai/2)) 0.;
P6ja5 = (posrp + ((-1)*(0.025 + widthsp))) 0. ((-1)*(diamjai/2));
P7ja5 = (posrp + ((-1)*(0.025 + widthsp))) ((-1)*(diamjae/2)) 0.;
P8ja5 = (posrp + ((-1)*(0.025 + widthsp))) 0. ((-1)*(diamjae/2));
Pceja5 = (posrp + ((-1)*(0.025 + widthsp))) 0. 0.;

l1ja = P1ja CERC Pceja P2ja;
nmja = nbel l1ja;
l2ja = P2ja CERC Pceja P5ja;
l3ja = P5ja CERC Pceja P6ja;
l4ja = P6ja CERC Pceja P1ja;
l5ja = P8ja CERC nmja Pceja P7ja;
l6ja = P7ja CERC nmja Pceja P4ja;
l7ja = P4ja CERC nmja Pceja P3ja;
l8ja = P3ja CERC nmja Pceja P8ja;


l1ja1 = P1ja1 CERC Pceja1 P2ja1;
l2ja1 = P2ja1 CERC Pceja1 P5ja1;
l3ja1 = P5ja1 CERC Pceja1 P6ja1;
l4ja1 = P6ja1 CERC Pceja1 P1ja1;
l5ja1 = P8ja1 CERC nmja Pceja1 P7ja1;
l6ja1 = P7ja1 CERC nmja Pceja1 P4ja1;
l7ja1 = P4ja1 CERC nmja Pceja1 P3ja1;
l8ja1 = P3ja1 CERC nmja Pceja1 P8ja1;



l1ja2 = P1ja2 CERC Pceja2 P2ja2;
l2ja2 = P2ja2 CERC Pceja2 P5ja2;
l3ja2 = P5ja2 CERC Pceja2 P6ja2;
l4ja2 = P6ja2 CERC Pceja2 P1ja2;
l5ja2 = P8ja2 CERC nmja Pceja2 P7ja2;
l6ja2 = P7ja2 CERC nmja Pceja2 P4ja2;
l7ja2 = P4ja2 CERC nmja Pceja2 P3ja2;
l8ja2 = P3ja2 CERC nmja Pceja2 P8ja2;

l1ja3 = P1ja3 CERC Pceja3 P2ja3;
l2ja3 = P2ja3 CERC Pceja3 P5ja3;
l3ja3 = P5ja3 CERC Pceja3 P6ja3;
l4ja3 = P6ja3 CERC Pceja3 P1ja3;
l5ja3 = P8ja3 CERC nmja Pceja3 P7ja3;
l6ja3 = P7ja3 CERC nmja Pceja3 P4ja3;
l7ja3 = P4ja3 CERC nmja Pceja3 P3ja3;
l8ja3 = P3ja3 CERC nmja Pceja3 P8ja3;

l1ja4 = P1ja4 CERC Pceja4 P2ja4;
l2ja4 = P2ja4 CERC Pceja4 P5ja4;
l3ja4 = P5ja4 CERC Pceja4 P6ja4;
l4ja4 = P6ja4 CERC Pceja4 P1ja4;
l5ja4 = P8ja4 CERC nmja Pceja4 P7ja4;
l6ja4 = P7ja4 CERC nmja Pceja4 P4ja4;
l7ja4 = P4ja4 CERC nmja Pceja4 P3ja4;
l8ja4 = P3ja4 CERC nmja Pceja4 P8ja4;

l1ja5 = P1ja5 CERC Pceja5 P2ja5;
l2ja5 = P2ja5 CERC Pceja5 P5ja5;
l3ja5 = P5ja5 CERC Pceja5 P6ja5;
l4ja5 = P6ja5 CERC Pceja5 P1ja5;
l5ja5 = P8ja5 CERC nmja Pceja5 P7ja5;
l6ja5 = P7ja5 CERC nmja Pceja5 P4ja5;
l7ja5 = P4ja5 CERC nmja Pceja5 P3ja5;
l8ja5 = P3ja5 CERC nmja Pceja5 P8ja5;
```

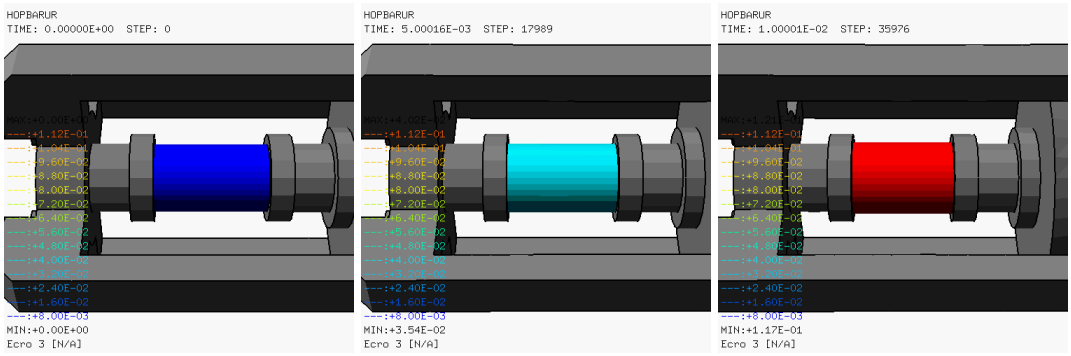
```
sja = ((l1ja et l2ja et l3ja et l4ja) et
(l5ja et l6ja et l7ja et l8ja)) surf 'PLAN';
sja1 = ((l1ja1 et l2ja1 et l3ja1 et l4ja1) et
(l5ja1 et l6ja1 et l7ja1 et l8ja1)) surf 'PLAN';
sja2 = ((l1ja2 et l2ja2 et l3ja2 et l4ja2) et
(l5ja2 et l6ja2 et l7ja2 et l8ja2)) surf 'PLAN';
sja3 = ((l1ja3 et l2ja3 et l3ja3 et l4ja3) et
(l5ja3 et l6ja3 et l7ja3 et l8ja3)) surf 'PLAN';
sja4 = ((l1ja4 et l2ja4 et l3ja4 et l4ja4) et
(l5ja4 et l6ja4 et l7ja4 et l8ja4)) surf 'PLAN';
sja5 = ((l1ja5 et l2ja5 et l3ja5 et l4ja5) et
(l5ja5 et l6ja5 et l7ja5 et l8ja5)) surf 'PLAN';

volja1 = sja volu sja1;
volja2 = sja1 volu sja2;
volja3 = sja2 volu sja3;
volja4 = sja3 volu sja4;
volja5 = sja4 volu sja5;
volja = (volja1 et volja2 et volja3 et volja4 et volja5)
couleur jaune;
elim volja edens1;

*------------------------------------------------------------------
*              Elements for the post-treatment in Europlexus
*  ................................................................
*------------------------------------------------------------------

Gauge1 = (linp ELEM APPU LARG PL18) ELEM 1;
Gauge3 = (linp ELEM APPU LARG PL19) ELEM 1;
Gauge4 = (linp ELEM APPU LARG PL20) ELEM 1;
Gauge5 = (linp ELEM APPU LARG PL21) ELEM 1;
Gauge6 = (lout ELEM APPU LARG Pout11) ELEM 1;
Gauge7 = (lout ELEM APPU LARG Pout12) ELEM 1;
VGSP = VOLSP ELEM APPU LARG ssp21;

*.....................................................................
* For the gauge 10, we take the average value of all the elements
* over the section in order to reproduce the experimental measure
* Warning! the number of elements will depend on the density
* chosen, the number should be adjuste when the value of dens1 is
* changed (the europlexus file also for the posttreatment.
*

VOL3PRI = vol3 elem pri6;
VG10 = (VOL3PRI) ELEM APPU LARG S33;
VG101 = VG10 ELEM 1 ;
VG102 = VG10 ELEM 2 ;
VG103 = VG10 ELEM 3 ;
VG104 = VG10 ELEM 4 ;
VG105 = VG10 ELEM 5 ;
VG106 = VG10 ELEM 6 ;
VG107 = VG10 ELEM 7 ;
VG108 = VG10 ELEM 8 ;
VG109 = VG10 ELEM 9 ;
VG110 = VG10 ELEM 10 ;
VG111 = VG10 ELEM 11 ;
VG112 = VG10 ELEM 12 ;
VG113 = VG10 ELEM 13 ;
VG114 = VG10 ELEM 14 ;
VG115 = VG10 ELEM 15 ;
VG116 = VG10 ELEM 16 ;
VG117 = VG10 ELEM 17 ;
VG118 = VG10 ELEM 18 ;
VG119 = VG10 ELEM 19 ;
VG120 = VG10 ELEM 20 ;
VG121 = VG10 ELEM 21 ;
VG122 = VG10 ELEM 22 ;
VG123 = VG10 ELEM 23 ;
VG124 = VG10 ELEM 24 ;
VG125 = VG10 ELEM 25 ;
VG126 = VG10 ELEM 26 ;
VG127 = VG10 ELEM 27 ;
VG128 = VG10 ELEM 28 ;
VG129 = VG10 ELEM 29 ;
VG130 = VG10 ELEM 30 ;
VG131 = VG10 ELEM 31 ;
VG132 = VG10 ELEM 32 ;
VG133 = VG10 ELEM 33 ;
VG134 = VG10 ELEM 34 ;
VG135 = VG10 ELEM 35 ;
VG136 = VG10 ELEM 36 ;
VG137 = VG10 ELEM 37 ;
VG138 = VG10 ELEM 38 ;
VG139 = VG10 ELEM 39 ;
VG140 = VG10 ELEM 40 ;
VG141 = VG10 ELEM 41 ;
VG142 = VG10 ELEM 42 ;
VG143 = VG10 ELEM 43 ;
VG144 = VG10 ELEM 44 ;
VG145 = VG10 ELEM 45 ;
VG146 = VG10 ELEM 46 ;
VG147 = VG10 ELEM 47 ;
VG148 = VG10 ELEM 48 ;
VG149 = VG10 ELEM 49 ;
VG150 = VG10 ELEM 50 ;
*.....................................................................

*------------------------------------------------------------------
*                          The whole mesh
*  ................................................................
*------------------------------------------------------------------

vinput = volinp et volrp ;
ELIM vinput edens1;
voutput = volout et vollc et volrc et volln et volrn et volba ;
ELIM voutput edens1;

SI UNCONFME;
mesh = vinput et voutput et volsp et volrig et lout et linp;
SI CRIGI;
mesh = vinput et voutput et volsp et volrig et lout et linp et PSR
et PSL;
FINSI;
FINSI;

SI UNCONF;
mesh = vinput et voutput et volsp et volrig et lout et linp;
SI CRIGI;
mesh = vinput et voutput et volsp et volrig et lout et linp et PSR
et PSL;
FINSI;
FINSI;

SI CONFIN;
mesh = vinput et voutput et volsp et volrig et lout et linp et volja;
SI CRIGI;
mesh = vinput et voutput et volsp et volrig et lout et linp et PSR
et PSL et VOLJA;
FINSI;
FINSI;

*.....................................................................
* Mesh by type of elements (used for the input file of Europlexus)
*
mesh2 = mesh elem seg2;
mesh4 = mesh elem tet4;
mesh6 = mesh elem pri6;
mesh8 = mesh elem cub8;

mess1 = 'Total number of element:';
mess2 = 'Total number of nodes:';
mess3 = 'Number of 3DOF nodes (PT3L):';
mess4 = 'Number of 6DOF nodes (PT6L):';
mess5 = 'Number of bar element (BR3D):';
mess6 = 'Number of tretraedric element (TETR):';
mess7 = 'Number of prismatic element (PRIS):';
mess8 = 'Number of cubic element (CUBE):';

nomb1 = (nbel mesh);
nomb2 = (nbno mesh);
nomb3 = ((nbno mesh) - (nbel mesh2 + 2));
nomb4 = (nbel mesh2 + 2);
nomb5 = (nbel mesh2);
nomb6 = (nbel mesh4);
nomb7 = (nbel mesh6);
nomb8 = (nbel mesh8);

*.....................................................................

*trak (vinput et voutput et volsp et volrig) 'NOSM';

tass mesh;

SI CONFIN;
  SI CRIGI;
    opti sauv form 'vl_jrc_hopbarcr.msh';
  SINON;
    opti sauv form 'vl_jrc_hopbarc.msh';
  FINSI;
FINSI;

SI UNCONF;
  SI CRIGI;
    opti sauv form 'vl_jrc_hopbarur.msh';
  SINON;
    opti sauv form 'vl_jrc_hopbaru.msh';
  FINSI;
FINSI;

SI UNCONFME;
  SI CRIGI;
    opti sauv form 'vl_jrc_hopbarur.msh';
  SINON;
    opti sauv form 'vl_jrc_hopbaru.msh';
  FINSI;
FINSI;

sauv form mesh;

SAUTER LIGNE;
mess mess1 nomb1;
mess mess2 nomb2;
mess mess3 nomb3;
mess mess4 nomb4;
mess mess5 nomb5;
mess mess6 nomb6;
mess mess7 nomb7;
mess mess8 nomb8;
SAUTER LIGNE;
```

The EUROPLEXUS input file is:

```
HOPBARUR

*-------------------------------------------------------------------------
$ The mesh generated by Cast3m is loaded in Europlexus (Hopbar.msh)
$
ECHO
!CONV win
CAST mesh
*-------------------------------------------------------------------------


*-------------------------------------------------------------Problem type
$ The problem is tridimensionnal. We use the Lagrangian coordinates.
$ The option LAGC (Lagrangian multiplier) allows us to deal with contact
$ problem (operator GLIS).
$
TRID LAGR LAGC
*-------------------------------------------------------------------------



*-----------------------------------------------------------Dimensioning
$ The characteristics of the mesh are given here (type of elements,
$ number). The corresponding values are given by Cast3m when running
$ the file Hopbar.dgibi.
$
DIME
  PT3L 10960 PT6L 3758 BR3D 3756 TETR 8319 PRIS 6914 CUBE 2240
  PMAT 2 ZONE 5
  BLOQ 1
 TERM
*-------------------------------------------------------------------------



*-------------------------------------------------------------Geometry
$ The types of element are assigned to the different parts of the mesh
$
GEOM TETR mesh4 PRIS mesh6 CUBE mesh8 BR3D mesh2 PMAT psr psl TERM
*-------------------------------------------------------------------------



*-----------------------------------------------Geometrical complements
$ For the bars, the area of the corresponding section has to be given.
$ LLOAC and the elements from LLOA1 to LLOA16 corresponds to the pulse
$ generation device of the Large Hopkinson bar. The other ones
$ corresponds to the input and output bars.

$

COMP
 SECT 3.20000E-03 LECT LLOACA TERM
 SECT 4.37435E-02 LECT LLOA1  TERM
 SECT 1.76715E-02 LECT LLOA2  TERM
 SECT 2.54469E-02 LECT LLOA3  TERM
 SECT 1.98557E-02 LECT LLOA4  TERM
 SECT 8.49487E-03 LECT LLOA5  TERM
 SECT 6.221E-03   LECT LLOA6  TERM
 SECT 6.221E-03   LECT LLOA7  TERM
 SECT 5.67450E-03 LECT LLOA8  TERM
 SECT 4.77836E-03 LECT LLOA9 LLOA10 TERM
 SECT 4.59635E-03 LECT LLOA11 TERM
 SECT 1.83854E-02 LECT LLOA13 TERM
 SECT 2.54469E-02 LECT LLOA14 TERM
 SECT 4.78708E-03 LECT LLOA15 TERM
 SECT 2.01062E-02 LECT LLOA16 TERM
 SECT 4.07150E-03 LECT LLOA12 LLOA17 LLOA18 LLOA19 LLOA20 LLOA21 LLOA22
                      LOUT   TERM
*-------------------------------------------------------------------------



*-----------------------------------------------------------Material data
$ The materials are assigned here. For the pulse generation device, the
$ input bar, the output bar and the inversion cages, the material is
$ a steel MSK. The jacket is also made of a steel MSK. The tube to avoid
$ bending is made of aluminium.
$ The material for the specimen depends on the tests modelled.
$ With the exception of the specimen, the materials behaves linearly.
$ This assumption has to be verified whan applying a high loading.
$


MATE

$ Inversion cages and input bar and output bar
$ ..............................................

LINE RO 7850. YOUN 2.E11 NU 0.3
     LECT vinput voutput lout linp TERM


$ Tube to avoid bending
$ ......................

LINE RO 2800. YOUN 7.0E10 NU 0.33
```

```
     LECT volrig TERM


$ Specimen
$ ........

VMIS DYNA RO 2704. YOUN 1.2E10 NU 0.33
     TRAC 4 6.E7 5.E-3 7.5E7 1.2E-2 1.04E8 7.E-2 1.2E8 1.5E-1
     SYMO D 6500. P 4.
     LECT volsp TERM

MASS 0.001 LECT psr psl TERM

*-------------------------------------------------------------------------


*-----------------------------------------------------Boundary conditions
$ The operator "GLIS" is used to deal with the contacts between the
$ specimen, the bars and the jacket.
$ The operator "RIGI" allows us to join the bars with the 3D mesh.
$ The condition "BLOQ" blocked the translation along x-direction of
$ the first point at left of the machine.
$


LINK COUP
      RIGI   CENT LECT psl TERM
             LIST LECT NSLSP NSLC TERM
             VECT VX 1.0
      RIGI   CENT LECT psr TERM
             LIST LECT NSRSP NSRP TERM
             VECT VX 1.0
      RIGI   CENT LECT Pout10 TERM
             LIST LECT slouiii TERM
             VECT VX 1.0
      RIGI   CENT LECT PL23 TERM
             LIST LECT SLOAD41 TERM
             VECT VX 1.0
      BLOQ 1 LECT PLCA TERM
*-------------------------------------------------------------------------


*-----------------------------------------------------Initial conditions
$ The initial conditions of the system are reproduced by applying a
$ state of stress to the pulse genration device. The stress is obtained
$ by dividing the prestressing force of the hydraulic actuator by the
$ area of the corresponding section of each elements.
$ The excel file can be used to calculate the initial condition for
$ the wanted force.
$

INIT CONT 1 2.63644E+08 LECT LLOACA TERM
 CONT 1 1.92865E+07 LECT LLOA1 TERM
 CONT 1 4.77414E+07 LECT LLOA2 TERM
 CONT 1 3.31537E+07 LECT LLOA3 LLOA14 TERM
 CONT 1 4.24897E+07 LECT LLOA4 TERM
 CONT 1 9.93141E+07 LECT LLOA5 TERM
 CONT 1 1.35612E+08 LECT LLOA6 TERM
 CONT 1 1.35612E+08 LECT LLOA7 TERM
 CONT 1 1.48676E+08 LECT LLOA8 TERM
 CONT 1 1.76558E+08 LECT LLOA9 TERM
 CONT 1 1.76558E+08 LECT LLOA10 TERM
 CONT 1 1.83550E+08 LECT LLOA11 TERM
 CONT 1 2.07211E+08 LECT LLOA12 TERM
 CONT 1 4.58875E+07 LECT LLOA13 TERM
*-------------------------------------------------------------------------


*-----------------------------------------------------------------Outputs
$ The location and the frequency of the outputs are chosen here.

ECRI DEPL VITE CONT ECRO TFRE 1.0E-2
     FICH SPLI ALIC     TFRE 1.0E-5
     FICH ALIC TEMP FREQ 50
                ELEM LECT Gauge1 Gauge3 Gauge4 Gauge5 Gauge6 Gauge7
                          VG101 VG102 VG103 VG104 VG105 VG106 VG107 VG108
                          VG109 VG110 VG111 VG112 VG113 VG114 VG115 VG116
                          VG117 VG118 VG119 VG120 VG121 VG122 VG123 VG124
                          VG125 VG126 VG127 VG128 VG129 VG130 VG131 VG132
                          VG133 VG134 VG135 VG136 VG137 VG138 VG139 VG140
                          VG141 VG142 VG143 VG144 VG145 VG146 VG147 VG148
                          VG149 VG150
                  TERM
*-------------------------------------------------------------------------


*-----------------------------------------------------------------Options
OPTI NOTE
     LOG 1

*-----------------------------------------------Transient calculation
$ The analysis is performed on 10 ms. It can be changed depending on
$ the wish of the user.
$

CALCUL TINI 0. TEND 10.E-3
*-------------------------------------------------------------------------

FIN
```

Some results: specimen progressive plastification.



Computed velocities: