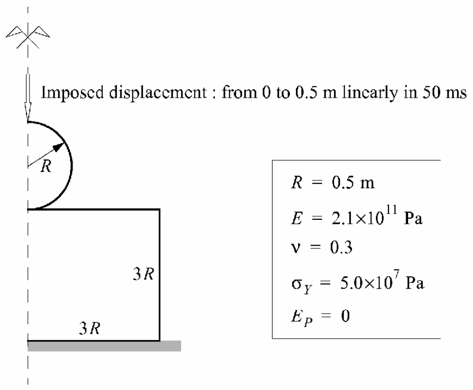
Example 7b – Indentation

- A rigid spherical indenter is pushed at constant speed of 10 m/s into a ductile block of material



- Compute the indentation force as a function of displacement
  - 2D axisymmetric solution
  - 3D solution(s)

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TITLE:
Indentation problem.
PROBLEM:
This problem was suggested by EDF as a check of the code capability to model a classical contact problem by the contact models available, in particular by the pinballs method. The ideal problem is a static one. A rigid spherical indenter is forced to penetrate into an elastic perfectly plastic half space. The computed result is the resultant of the contact forces in the indentation direction as a function of time.
An approximated analytical solution exists, due to Johnson.
MESH:
The 2D model is axisymmetric and uses 1694 elements Q42L for the piece (half space represented by a square region of side equal to 3 times the indenter radius), and one PMAT element for the indenter.
MATERIALS:
The VM23 material is assigned to the piece, with zero plastic hardening. The MASS element is assigned to the indenter.
BOUNDARY CONDITIONS:
All nodes on the axis of symmetry are blocked in the radial direction. The base of the piece is blocked in all directions. Contact is represented by the pinball model. A single pinball with radius equivalent to that of the indenter is associated with the PMAT element. The region of the piece likely to come in contact is filled by parent pinballs with a hierarchy level of 4 to get accurate contact resolution.
LOADING:
The indenter is pushed into the piece at constant imposed speed (linear displacement in time), until it reaches an indentation depth equal to the radius of the indenter.
INITIAL CONDITIONS
The indenter has an initial velocity equal to the imposed indentation velocity (to avoid an initial error in the energy balance).
CALCULATION:
The calculation is performed up to 50 ms. At the final time, the indenter has reached a depth equal to its radius.
RESULTS:
The computed resultant contact force is in good agreement with the approximate analytical solution up to an indentation depth equal to approximately 1/2 of the indenter radius. For larger indentations, the analytical (linear) solution is no longer valid.

POST-TREATMENT

Several animations of the computed results from this calculation are available on the EUROPLEXUS Consortium Web site.

REFERENCES:

The indentation problem is detailed in the following EDF document:

N. Tardieu, B. Serre: "Indentation elasto-plastique d'un bloc par un indenteur spherique elastique", Code_Aster, Manuel de Validation, Report V6.04.506, December 2002.

This calculation is detailed in:

F. Casadei: "Validation of the EUROPLEXUS Pinball Impact-Contact Model on an Indentation Problem", Technical Note in press, July 2007. (available on the EUROPLEXUS Consortium Web site).

Numerical Solutions

INDE10

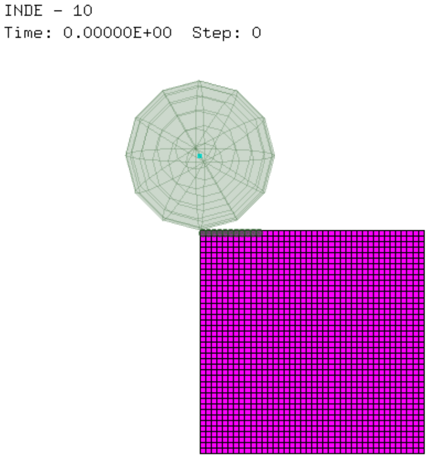
2D axisymmetric solution. The mesh generation file is:

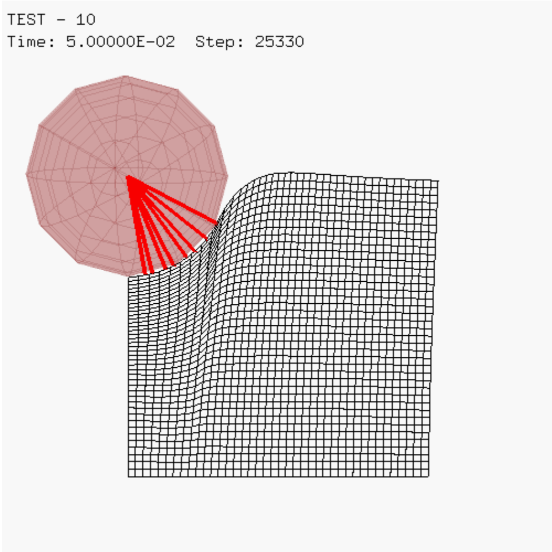
```
*%siz 50
opti echo 1;
opti dime 2 elem qua4;
p0 = 0 0;
p1 = 0 -1.5;
p2 = 1.5 -1.5;
p3 = 1.5 0;
pc = 0 0.5;
p13 = 0.375 0;
tol = 1.e-5;
piece = dall (p0 d 40 p1) (p1 d 40 p2) (p2 d 40 p3) (p3 d 40 p0) plan;
sphere = manu poi1 pc;
opti trac psc ftra 'vl_jrc_inde10_msh.ps';
trac qual (piece et sphere);
tout = piece et sphere;
axe = tout poin droi p1 pc tol;
base = piece poin droi p1 p2 tol;
cp = p0 d 10 p13;
elim tol (piece et cp);
c_p = piece elem appu larg cp;
mesh = tout et axe et base et c_p;
tass mesh;
opti sauv form 'vl_jrc_inde10.msh';
sauv form mesh;
list (nbno mesh);
list (nbel mesh);
fin;
```

The input file is:

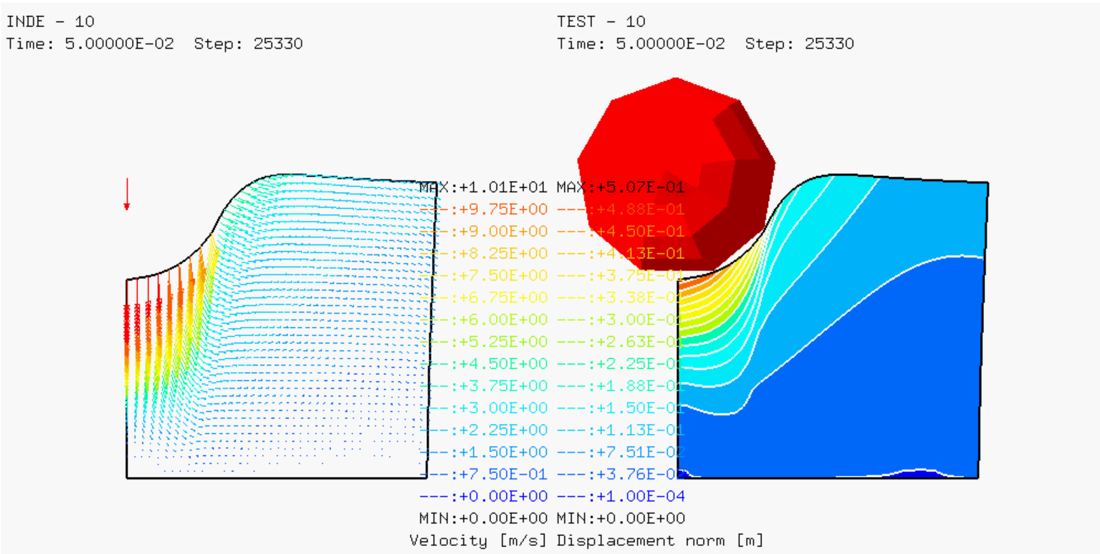
```
INDE - 10
ECHO
!CONV WIN
NONL AXIS
CAST mesh
DIME
  PT2L 1682
  Q42L 1694
  PMAT 1
  ZONE 2
TERM
GEOM
  Q42L piece PMAT sphere
TERM
COMP EPAI 1.0 LECT piece sphere TERM
     COUL rose LECT piece TERM
          turq LECT sphere TERM
MATE MASS 650.D0
          LECT sphere TERM
     VM23 RO 7800 YOUN 2.1E11 NU 0.3 ELAS 5.E7
          TRAC 2 5.E7 2.38095E-4 5.E7 1.0
          LECT piece TERM
OPTI PINS CNOR NCOL RCEL
LINK COUP
     BLOQ 1 LECT axe base TERM
          2 LECT base TERM
     DEPL 2 -1.D0 FONC 1 LECT sphere TERM
     PINB BODY DIAM 1.D0 LECT sphere TERM
          BODY MLEV 4    LECT c_p TERM
FONC 1 TABL 2 0. 0. 2. 20.
INIT VITE 2 -10. LECT sphere TERM
REGI 'r_piece' RESU LECT c_p  TERM
     'r_base'  RESU POIN LECT base TERM
ECRI DEPL VITE FEXT TFRE 0.005
     FICH ALIC TFRE 25.E-5
OPTI CSTA 0.5 LOG 1
CALCUL TINI 0. TFIN 50.E-3
FIN
```

The initial configuration (with parent pinballs shown) and the final configuration (with contacts shown) are:

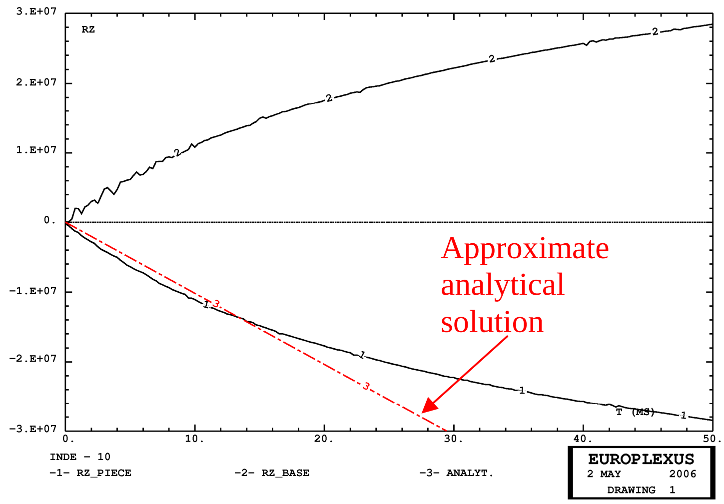




The final velocities and displacement norm:



The reaction force is:



INDE13

3D solution using only hexahedra. The model is not perfectly axisymmetric. The mesh generation file is:

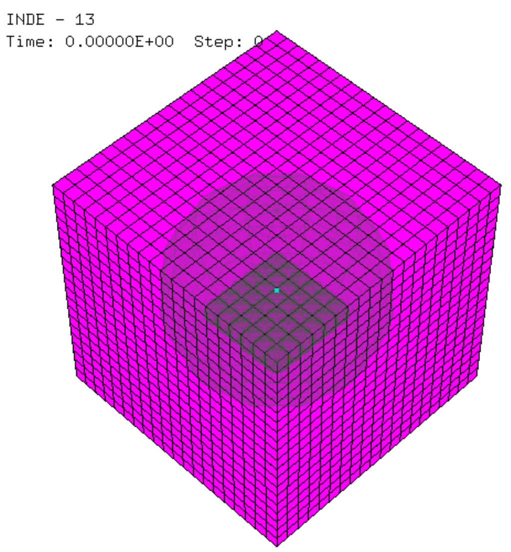
```
*%siz 50
opti echo 1;
opti dime 3 elem cub8;
p0 = 0 0 0;
p1 = 0 0 -1.5;
p2 = 1.5 0 -1.5;
p3 = 1.5 0 0;
pc = 0 0 0.5;
p13 = 0.375 0 0;
vy = 0 1.5 0;
py = 0 0.375 0;
tol = 1.e-5;
piece2 = dall (p0 d 20 p1) (p1 d 20 p2) (p2 d 20 p3) (p3 d 20 p0) plan;
piece = piece2 volu tran 20 vy;
sphere = manu poi1 pc;
opti trac psc ftra 'vl_jrc_inde13_msh.ps';
trac cach qual (piece et sphere);
tout = piece et sphere;
blox = tout poin plan p1 p0 (p1 plus vy) tol;
bloy = tout poin plan p1 p0 p2 tol;
base = piece poin plan p1 p2 (p1 plus vy) tol;
p13y = p13 plus py;
cp = dall (p0 d 5 p13) (p13 d 5 p13y)
          (p13y d 5 py) (py d 5 p0) plan;
elim tol (piece et cp);
c_p = piece elem appu larg cp;
mesh = tout et blox et bloy et base et c_p;
tass mesh;
opti sauv form 'vl_jrc_inde13.msh';
sauv form mesh;
list (nbno mesh);
list (nbel mesh);
fin;
```

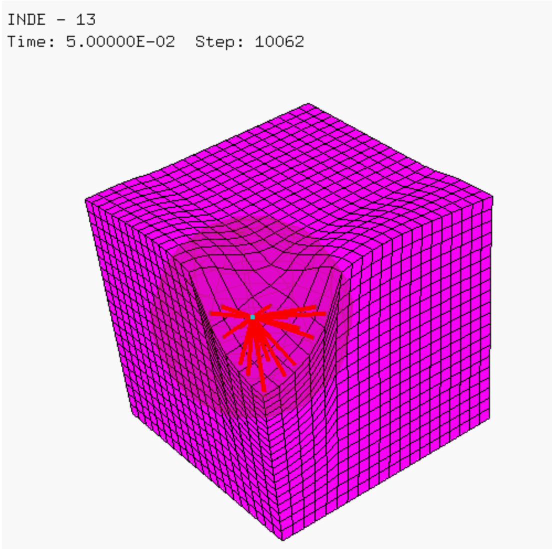
The input file is:

```
INDE - 13
```

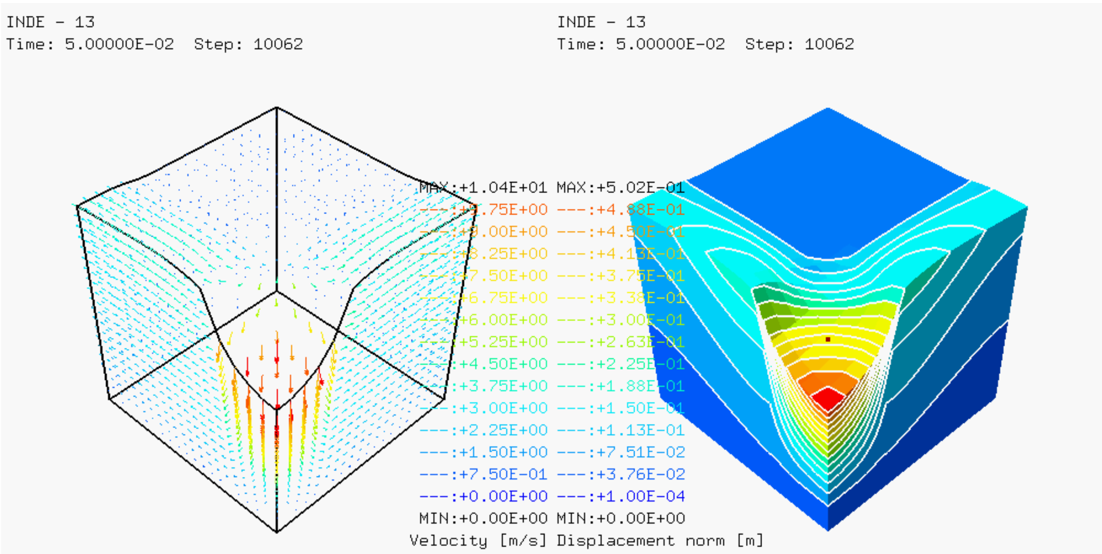
```
ECHO
!CONV WIN
NONL TRID
CAST mesh
DIME
  PT3L 9262
  CUB8 9361
  PMAT 1
  ZONE 2
TERM
GEOM
  CUB8 piece PMAT sphere
TERM
COMP COUL rose LECT piece TERM
          turq LECT sphere TERM
MATE MASS 1021.02D0
          LECT sphere TERM
     VMIS PARF RO 7800 YOUN 2.1E11 NU 0.3 ELAS 5.E7
          LECT piece TERM
OPTI PINS CNOR NCOL RCEL
LINK COUP
     BLOQ 1 LECT blox base TERM
          2 LECT bloy base TERM
          3 LECT base TERM
     DEPL 3 -1.D0 FONC 1 LECT sphere TERM
     PINB BODY DIAM 1.D0 LECT sphere TERM
          BODY MLEV 4    LECT c_p TERM
FONC 1 TABL 2 0. 0. 2. 20.
INIT VITE 3 -10. LECT sphere TERM
REGI 'r_piece' RESU LECT c_p  TERM
     'r_base'  RESU POIN LECT base TERM
ECRI DEPL VITE FEXT TFRE 0.005
     FICH ALIC TFRE 25.E-5
OPTI CSTA 0.5 LOG 1
CALCUL TINI 0. TFIN 50.E-3
FIN
```

The initial configuration (with parent pinballs shown) and the final configuration) are:

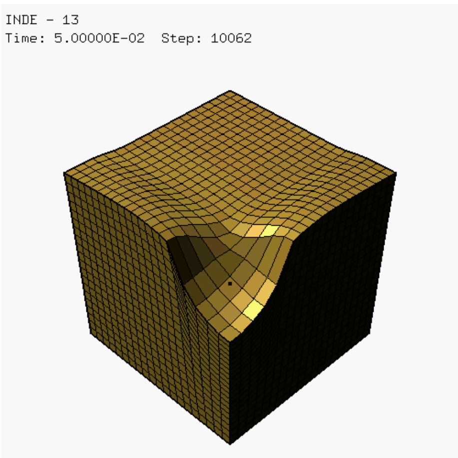


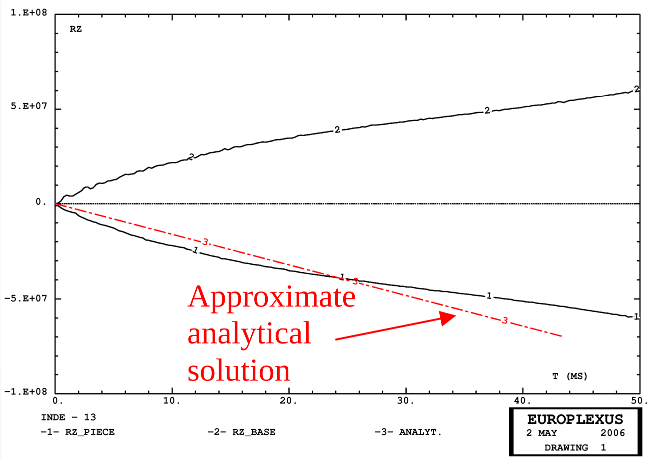


The final velocities and displacement norm:



The final deformed shape and the reaction force are:





TEST14

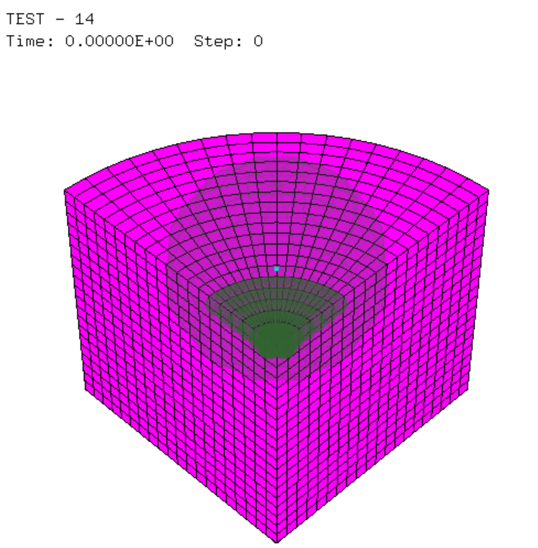
3D solution using an axisymmetric mes (hexahedra and prisms). The model is perfectly axisymmetric. The mesh generation file is:

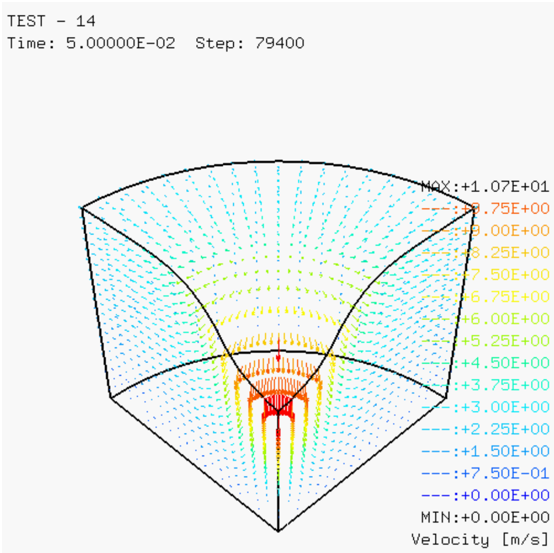
```
*%siz 50
opti echo 0;
opti donn 'D:\Users\Folco\Plexis3c\Proc\pxordpoi.proc';
opti donn 'D:\Users\Folco\Plexis3c\Proc\pxrota3d.proc';
opti echo 1;
opti dime 3 elem cub8;
p0 = 0 0 0;
p1 = 0 0 -1.5;
p2 = 1.5 0 -1.5;
p3 = 1.5 0 0;
pc = 0 0 0.5;
p13 = 0.375 0 0;
vy = 0 1.5 0;
py = 0 0.375 0;
tol = 1.e-5;
c1 = p1 d 20 p2;
ax = p1 d 20 p0;
base ier = pxrota3d c1 18 90.0 ax tol;
oubl ax;
piece = base volu tran 20 (0 0 1.5);
p_cube = piece elem cub8;
p_pris = piece elem pri6;
sphere = manu poi1 pc;
opti trac psc ftra 'test14_msh.ps';
trac cach qual (piece et sphere);
tout = piece et sphere;
blox = tout poin plan p1 p0 (p1 plus vy) tol;
bloy = tout poin plan p1 p0 p2 tol;
c2 = p0 d 5 p13;
ax2 = p0 d 1 pc;
cp ier = pxrota3d c2 18 90.0 ax2 tol;
oubl ax2;
elim tol (piece et cp);
c_p = piece elem appu larg cp;
mesh = tout et blox et bloy et base et c_p;
tass mesh;
opti sauv form 'test14.msh';
sauv form mesh;
list (nbno mesh);
list (nbel mesh);
list (nbel p_pris);
list (nbel p_cube);
fin;
```

The input file is:

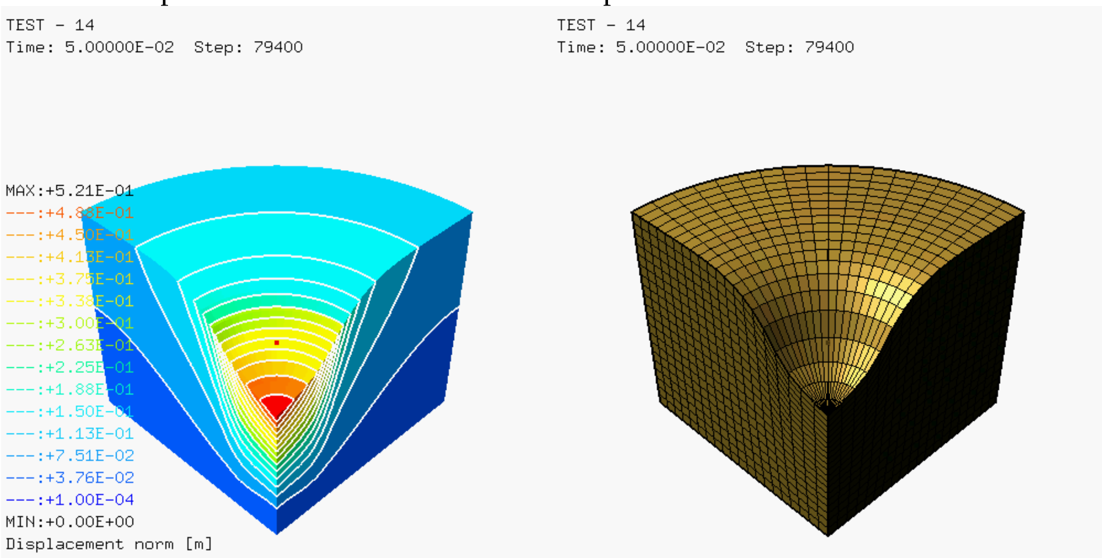
```
TEST - 14
ECHO
!CONV WIN
NONL TRID
CAST mesh
DIME
  PT3L 8002
  PR6  360
  CUB8 8192
  PMAT 1
  ZONE 3
TERM
GEOM
  PR6 p_pris CUB8 p_cube PMAT sphere
TERM
COMP COUL rose LECT piece TERM
          turq LECT sphere TERM
MATE MASS 1021.02D0
          LECT sphere TERM
     VMIS PARF RO 7800 YOUN 2.1E11 NU 0.3 ELAS 5.E7
          LECT piece TERM
OPTI PINS CNOR NCOL RCEL
LINK COUP
     BLOQ 1 LECT blox base TERM
          2 LECT bloy base TERM
          3 LECT base TERM
     DEPL 3 -1.D0 FONC 1 LECT sphere TERM
     PINB BODY DIAM 1.D0 LECT sphere TERM
          BODY MLEV 4    LECT c_p TERM
FONC 1 TABL 2 0. 0. 2. 20.
INIT VITE 3 -10. LECT sphere TERM
REGI 'r_piece' RESU LECT c_p  TERM
     'r_base'  RESU POIN LECT base TERM
ECRI DEPL VITE FEXT TFRE 0.005
     FICH ALIC TFRE 25.E-5
OPTI CSTA 0.5 LOG 1
CALCUL TINI 0. TFIN 50.E-3
FIN
```

The initial configuration (with parent pinballs shown) and the final velocities are:

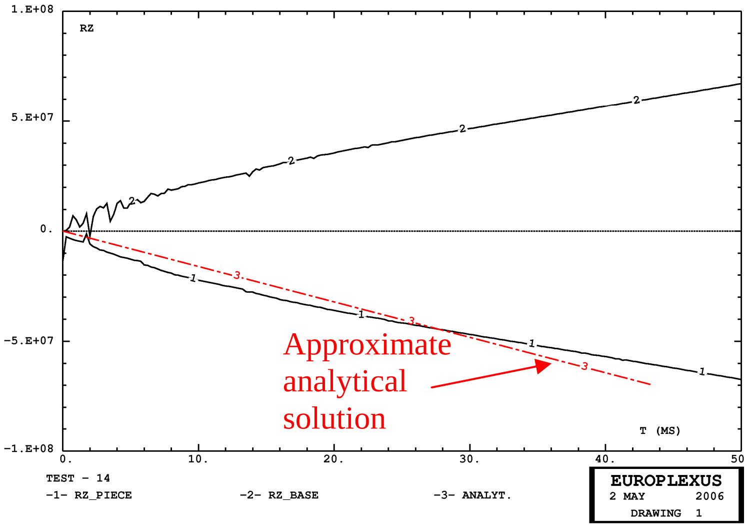




The final displacement norm and deformed shape:



The reaction force is:



Comparison of all solutions: