SSNV197 - Triaxial drained with the model of Summarized

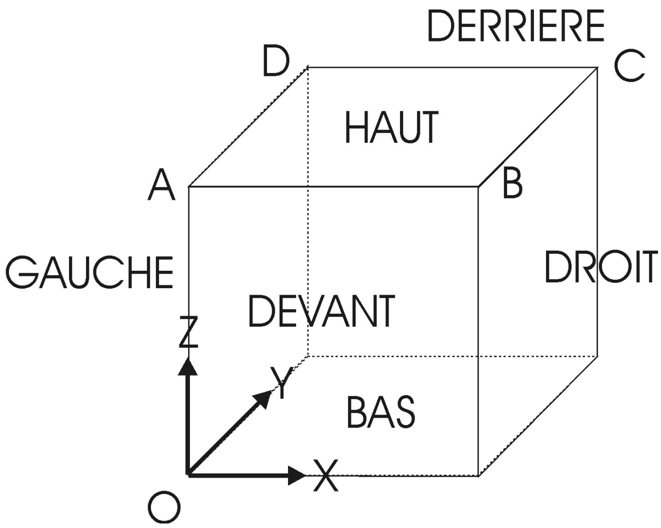
Hujeux

One carries out *a triaxial computation in pure mechanics* (equivalent under drained hydraulic conditions) with *the model of Hujeux*. The calculated solutions are compared with results resulting from the code finite elements GEFDYN of the Central School Paris. This test comprises four modelizations:

- one préconsolide the test-tube until $50\,kPa$ (surconsolidé state);
- one préconsolide the test-tube until $100\,kPa$ (fairly consolidated state);
- one préconsolide the test-tube until $200\,kPa$ (normally consolidated state) ;
- one préconsolide the test-tube until $100\,kPa$ (normally consolidated state), but one uses a sample with surfaces slip (related to the mechanisms déviatoires) tilted from $45°$ ratio with the vertical;

1 Problem of reference

1.1 Geometry



the triaxial compression test is carried out on only one isoparametric finite element of cubic form $CUB8$. The length of each edge is worth 1. The various facets of this cube are named mesh groups $HAUT$ BAS $DEVANT$ $DERRIERE$, $DROIT$ and $GAUCHE$. Mesh group *SYM* contains the mesh groups in addition BAS , $DEVANT$ and $GAUCHE$; the mesh group $COTE$ mesh groups $DERRIERE$ and $DROIT$.

1.2 Material properties

the elastic properties are:

- modulate isotropic compressibility: $K=516200\,kPa$
- shear modulus: $\mu=238200\,kPa$

The unelastic properties (Hujeux) are:

- power of the nonlinear elastic model: $n_e=0.4$
- $\beta=24$
- $d=2.5$
- $b=0.2$
- friction angle: $\varphi=33°$
- angle of dilatancy: $\psi=33°$
- critical pressure: $P_{c0}=-1000\,kPa$
- pressure of reference: $P_{ref}=-1000\,kPa$
- elastic radius of the isotropic mechanism: $r^s_{éla}=0.001$
- elastic radius of the mechanism déviatoire: $r^d_{éla}=0.005$
- $a_{mon}=0.0001$
- $a_{cyc}=0.008$
- $c_{mon}=0.2$
- $c_{cyc}=0.1$
- $r_{hys}=0.05$
- $r_{mob}=0.9$
- $x_m=1$

- $\mathrm{dila}=1$

1.3 Boundary conditions and loadings

a triaxial compression test consists in imposing on the test-tube a vertical radial force all while keeping the side pressure constant. It can be drained (the pore fluid water pressure does not vary during the test) or NON-drained (one turns off the tap: the pore fluid water pressure evolves in the sample). One is interested here in the drained case, simpler, because not utilizing the influence of the pore water pressure of the fluid and *modélisable of this fact by a pure mechanical computation*.
In the model considered, the cubic element represents a eighth of the sample. The limiting conditions are thus the following ones:

- Conditions of symmetry:
  - $u_z=0$ on the group of mesh BAS
  - $u_x=0$ on the group of mesh $GAUCHE$
  - $u_y=0$ on the group of mesh $DEVANT$
- conditions of side pressure:
  - $P_n=1$ on the group of mesh $COTE$
- conditions of loading:
  - $P_n=1$ on the group of mesh $HAUT$ (phase 1)
  - $u_z=-1$ on the group of mesh $HAUT$ (phase 2)

the loading is carried out in two phases:

- isotropic loading enters $t=-2$ and $t=0$ where the pressure on the mesh groups $COTE$ and HIGH varies between $p=0$ and $p=p_c$ (isotropic pressure of preconsolidation). In the modelizations A, B and C, the value of p_c is respectively of $50,100,200\,kPa$;
- displacement imposed on the mesh group $HAUT$ and variable enters $t=0$ and $t=10$ of $u_z=0$ and $u_z=-0.2$ (total vertical strain of $20\,\%$).

1.4 Results

the solutions post-are treated with the point C, in terms of equivalent stress Q, total voluminal strain ε_v and coefficients of isotropic hardening $\left(r_{ela}^{s,m}+r_{iso}^{m}\right)$ and déviatoire $\left(r_{ela}^{d,m}+r_{dev}^{m}\right)$.

The validation is carried out by comparison with solutions GEFDYN provided by the Central School Paris.

2 Modelization A

2.1 Characteristic of the modelization

The modelization A is *three-dimensional* and *static nonlinear*.

One carries out initially *an elastic preconsolidation* ($ELAS$) of the sample until $p_c = 50\text{kPa}$ (1st phase of computation). This preconsolidation takes place in 1 time step enters $t=-2$ and $t=0$.

The vertical displacement imposed on the higher facet varies between $0.$ and -0.2 (2nd phase of computation) in 100 time step enters $t=0$ and $t=10$. During this second phase, one activates the automatic subdivision of the time step to manage the situations of nonconvergence of local integration.
In the integration of the balance equations, one asks for a reactualization of the tangent matrix, which is provided by the routines of the model of Hujeux and accelerates convergence appreciably. One also asks for the subdivision of time step (command DEFI_LIST_INST) to treat the situations of failure of local integration due to too large increments of loading. ***This functionality is largely recommended*.**

2.2 Quantities tested and Values

2.2.1 results tested

the solutions are calculated at the point C and are compared with references GEFDYN. They are given in terms of equivalent stress Q , total voluminal strain ε_v and coefficients of hardening isotropic $\left(r_{ela}^{iso,m} + r_{iso}^{m}\right)$ and déviatoire $\left(r_{ela}^{d,m} + r_{dev}^{m}\right)$, and recapitulated in the following tables:

$$Q = \sqrt{\frac{1}{2} s : s} \quad [Pa]$$

ε_{zz}	Code_Aster	GEFDYN	relative error
-1%	115523.	117640.	-1.799%
-2%	155466.	157072.	-1.022%
-5%	199986.	200850.	-0.430%
-10%	206823.	207649.	-0.398%
-20%	184853.	185854.	-0.539%

$$\varepsilon_V = trace(\varepsilon)$$

ε_{zz}	Code_Aster	GEFDYN	relative error
-1%	-3.78E-3	-3.82E-3	-1.125%
-2%	-4.34E-003	-4.34E-3	-0.051%
-10%	1.09E-2	1.07E-2	1.917%
-20%	3.237E-2	3.191E-2	1.433%

$$\left(r_{ela}^{d,m} + r_{dev}^{m}\right)$$

ε_{zz}	Code_Aster	GEFDYN	relative error
-1%	0.673	0.679	-0.904%
-2%	0.781	0.784	-0.406%

-5%	0.887	0.888	-0.107%
-10%	0.937	0.937	0.004%
-20%	0.966	0.967	-0.054%

$\left(r_{ela}^{iso,m}+r_{iso}^{m}\right)$

ε_{zz}	Code_Aster	GEFDYN	relative error
-1%	0.0325	0.0328	-0.900%
-2%	0.0370	0.0372	-0.663%
-5%	0.0466	0.0467	-0.296%
-10%	0.0624	0.0623	0.085%
-20%	0.0979	0.0973	0.576%

2.2.2 Comments

the difference between the two codes is very weak (lower than 2%).

3 Modelization B

3.1 Characteristic of the modelization

The modelization B is *three-dimensional* and *static nonlinear*.

One carries out initially *an elastic preconsolidation* ($ELAS$) of the sample until $p_c = 100\,kPa$ (1st phase of computation). This preconsolidation takes place in 1 time step enters $t = -2$ and $t = 0$.

The vertical displacement imposed on the higher facet varies between $0.$ and -0.2 (2nd phase of computation) in 100 time step enters $t = 0$ and $t = 10$. During this second phase, one activates the automatic subdivision of the time step to manage the situations of nonconvergence of local integration. In the integration of the balance equations, one asks for a reactualization of the tangent matrix, which is provided by the routines of the model of Hujeux and accelerates convergence appreciably. One also asks for the subdivision of time step (command `DEFI_LIST_INST`) to treat the situations of failure of local integration due to too large increments of loading. ***This functionality is largely recommended.***

3.2 Quantities tested and Values

3.2.1 results tested

the solutions are calculated at the point C and are compared with references GEFDYN. They are given in terms of equivalent stress Q , total voluminal strain ε_v and coefficients of hardening isotropic $\left(r_{ela}^{iso,m} + r_{iso}^{m}\right)$ and déviatoire $\left(r_{ela}^{d,m} + r_{dev}^{m}\right)$, and recapitulated in the following tables:

$$Q = \sqrt{\frac{1}{2} s : s} \quad [Pa]$$

ε_{zz}	Code_Aster	GEFDYN	relative error
-1%	188768.	191799.	-1.580%
-2%	253219.	255501.	-0.893%
-5%	329638.	330404.	-0.232%
-10%	355436.	355895.	-0.129%
-20%	340728.	341220.	-0.144%

$$\varepsilon_V = trace(\varepsilon)$$

ε_{zz}	Code_Aster	GEFDYN	relative error
-1%	-5.47E-3	-5.53E-3	-1.086%
-2%	-7.128E-3	-7.15E-3	-0.314%
-5%	-6.684E-3	-6.64E-3	0.660%
-10%	-8.227E-4	-8.22E-4	0.083%
-20%	1.261E-2	1.25E-2	0.905%

$$\left(r_{ela}^{d,m} + r_{dev}^{m}\right)$$

ε_{zz}	Code_Aster	GEFDYN	relative error
-1%	0.659	0.665	-0.879%

-2%	0.772	0.775	-0.431%
-5%	0.882	0.883	-0.115%
-10%	0.934	0.934	0.010%
-20%	0.965	0.965	0.010%

$\left(r_{ela}^{iso,m}+r_{iso}^{m}\right)$

ε_{zz}	Code_Aster	GEFDYN	relative error
-1%	0.0575	0.0578	-0.466%
-2%	0.0627	0.0630	-0.471%
-5%	0.0723	0.0725	-0.286%
-10%	0.0867	0.0868	-0.132%
-20%	0.169	0.117	-0.054%

3.2.2 Comments

the relative error is higher when the values tested are weaker, which is not abnormal. Ultimately, the difference between the two codes is very reasonable.

4 Modelization C

4.1 Characteristic of the modelization

The modelization C is *three-dimensional* and *static nonlinear*.

One carries out initially *an elastic preconsolidation* ($ELAS$) of the sample until $p_c=200\,kPa$ (1st phase of computation). This preconsolidation takes place in 1 time step enters $t=-2$ and $t=0$.

The vertical displacement imposed on the higher facet varies between 0 and -0.2 (2nd phase of computation) in 100 time step enters $t=0$ and $t=10$. During this second phase, one activates the automatic subdivision of the time step to manage the situations of nonconvergence of local integration. In the integration of the balance equations, one asks for a reactualization of the tangent matrix, which is provided by the routines of the model of Hujeux and accelerates convergence appreciably. One also asks for the subdivision of time step (command `DEFI_LIST_INST`) to treat the situations of failure of local integration due to too large increments of loading. ***This functionality is largely recommended.***

4.2 Quantities tested and Values

4.2.1 results tested

the solutions are calculated at the point C and are compared with references GEFDYN. They are given in terms of equivalent stress Q , total voluminal strain ε_v and coefficients of hardening isotropic $\left(r_{ela}^{iso,m}+r_{iso}^{m}\right)$ and déviatoire $\left(r_{ela}^{d,m}+r_{dev}^{m}\right)$, and recapitulated in the following tables:

$$Q=\sqrt{\frac{1}{2}s:s}\;\;[Pa]$$

ε_{zz}	Code_Aster	GEFDYN	relative error
-1%	0.125 306905	. 311459	.
-1.462%	-2% 413405	. 416832	.
-0.822%	-5% 543741	. 545338	.
-0.293%	-10% 605206	. 605666	.
-0.076%	-20% 616663	. 616946	.

$$\varepsilon_V=trace(\varepsilon)$$

ε_{zz}	formula	Code_Aster	GEFDYN relative
error	-1%	-7.389E-3	-7.47E-3
-1.086%	-2%	-1.001E-2	-1.005E-2
-0.387%	-5%	-1.229E-2	-1.227E-2
0.175%	-10%	-1.096E-2	-1.092E-2
0.367%	-20%	-4.88E-3	-4.88E-3

$$\left(r_{ela}^{d,m}+r_{dev}^{m}\right)$$

ε_{zz}	formula	Code_Aster	GEFDYN relative
error	-1%	0.642	0.648

-0.939%	-2%	0.761	0.765
-0.488%	-5%	0.877	0.878
-0.130%	-10%	0.931	0.932
-0.087%	-20%	0.964	0.964

$\left(r_{ela}^{iso,m}+r_{iso}^{m}\right)$

ε_{zz}	-0.031%	Code_Aster	GEFDYN relative
error	-1%	0.102	0.102
0.112%	-2%	0.107	0.108
-0.532%	-5%	0.115	0.115
0.116%	-10%	0.126	-0.450%
-20%	0.147	0.147	-0.301%

4.2.2 Comments

the relative error is higher when the values tested are weaker. Ultimately, the difference between the two codes is very reasonable.

5 Modelization D

5.1 Characteristic of the modelization

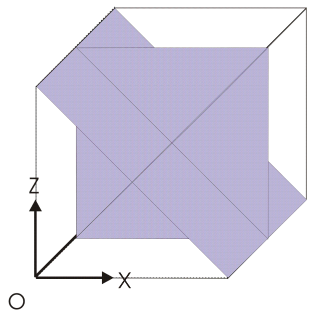
the goal of this modelization is to test the functionality of reorientation of the local coordinate system defining the three slip surfaces related to the mechanisms déviatoires of the model of Hujeux. This reorientation is carried out using operator `AFFE_CARA_ELEM` $\rightarrow$ `MASSIF`.

The modelization D is *three-dimensional* and *static nonlinear*.

One carries out initially *an elastic preconsolidation* ($ELAS$) of the sample until $p_c = 100\,kPa$ (1st phase of computation). This preconsolidation takes place in 1 time step enters $t=-2$ and $t=0$.

The vertical displacement imposed on the higher facet varies between $0.$ and -0.2 (2nd phase of computation) in 100 time step enters $t=0$ and $t=10$. During this second phase, one activates the automatic subdivision of the time step to manage the situations of nonconvergence of local integration.

One tests the reorientation of the slip surfaces defined by a rotation of the reference of $45°$ around the axis (OZ). This reorientation is defined by `AFFE_CARA_ELEM` $\rightarrow$ `MASSIF`.



One charges object `CARAEL` which lays down the direction with the local coordinate system on which the slip surfaces of the model of Hujeux will be defined. In the integration of the balance equations, one asks for a reactualization of the tangent matrix, which is provided by the routines of the model of Hujeux and accelerates convergence appreciably. One also asks for the subdivision of time step (command `DEFI_LIST_INST`) to treat the situations of failure of local integration due to too large increments of loading. ***This functionality is largely recommended*.**

5.2 Quantities tested and results of the modelization D

5.2.1 Values tested

the solutions are calculated at the point C and are compared with an identical computation carried out (with Code_Aster) on a sample turned beforehand of $45°$. They are given in terms of equivalent stress Q , total voluminal strain ε_v and coefficients of hardening isotropic $\left(r_{ela}^{iso,m} + r_{iso}^{m}\right)$ and déviatoire $\left(r_{ela}^{d,m} + r_{dev}^{m}\right)$, and recapitulated in the following tables:

$$Q = \sqrt{\frac{1}{2} s : s} \quad [Pa]$$

ε_{zz}	Code_Aster	GEFDYN	relative error
-2%	148396	148396	0.0002%
-4%	176513	176513	0.006%
-6%	185559	185554	0.002%

-8%	187683	187681	0.001%
-10%	186806	186804	0.001%

$\varepsilon_V = trace(\varepsilon)$

ε_{zz}	Code_Aster	GEFDYN	relative error
-2%	-7.40E-3	-7.40E-3	0.001%
-4%	-6.72E-3	-6.72E-3	0.016%
-6%	-4.36E-3	-4.36E-3	-0.001%
-8%	-1.45E-3	-1.45E-3	-0.013%
-10%	1.63E-3	1.63E-3	0.018%

$\left(r_{ela}^{d,m} + r_{dev}^{m}\right)$

ε_{zz}	Code_Aster	GEFDYN	relative error
-2%	0.565	0.565	-0.062%
-4%	0.630	0.630	0.008%
-6%	0.654	0.654	0.073%
-8%	0.666	0.666	-0.035%
-10%	0.671	0.671	0.054%

$\left(r_{ela}^{iso,m} + r_{iso}^{m}\right)$

ε_{zz}	Code_Aster	GEFDYN	relative error
-2%	0.067	0.067	-0.564%
-4%	0.074	0.074	0.140%
-6%	0.081	0.081	-0.499%
-8%	0.087	0.087	-0.038%
-10%	0.093	0.093	0.421%

5.2.2 Comments

the relative error is always very weak, which is normal, since it is ultimately exactly about even computation.

6 Summary of the results

One represents in the following curves the various comparisons between Code_Aster and Xloi (calculation programme of constitutive law, not finite elements, on a material point. The model of Hujeux which is implemented there is identical to that which is in GEFDYN), in terms of stress déviatoire (Figure **1**), of total voluminal strain (Figure **2** and of coefficients of hardening déviatoires (Figure **3**) and isotropic (Figure **4**).

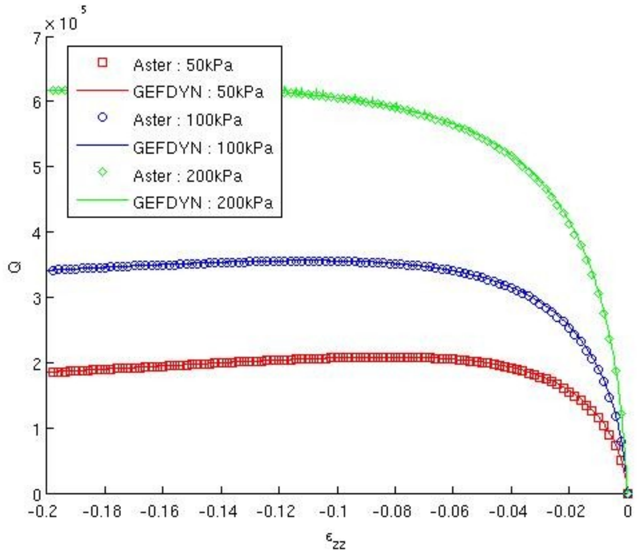


Figure 1 : ***Equivalent stress (noted " Q ") according to the axial strain: comparison enters the solutions Code_Aster and Xloi, for the pressures of consolidation of*** 50 ***,*** 100 ***and*** 200kPa ***.***

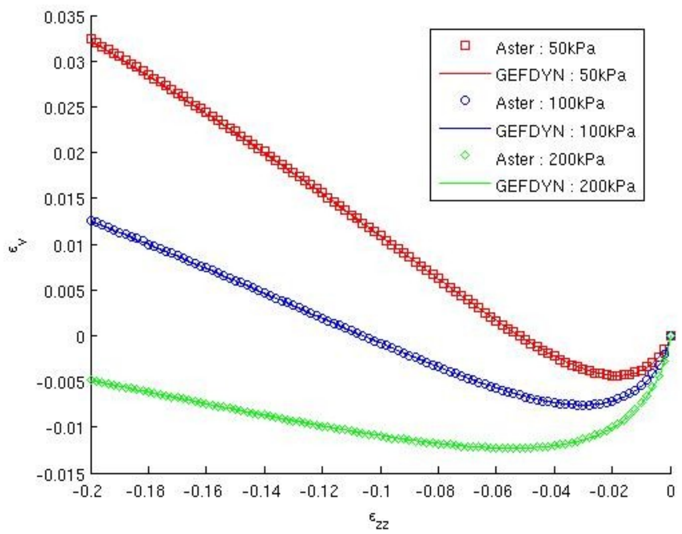


Figure 2 : ***Total voluminal strain (noted " $EPSv$ ") according to the axial strain: comparison enters the solutions Code_Aster and Xloi, for the pressures of consolidation of*** 50 ***,*** 100 ***and*** 200kPa ***.***

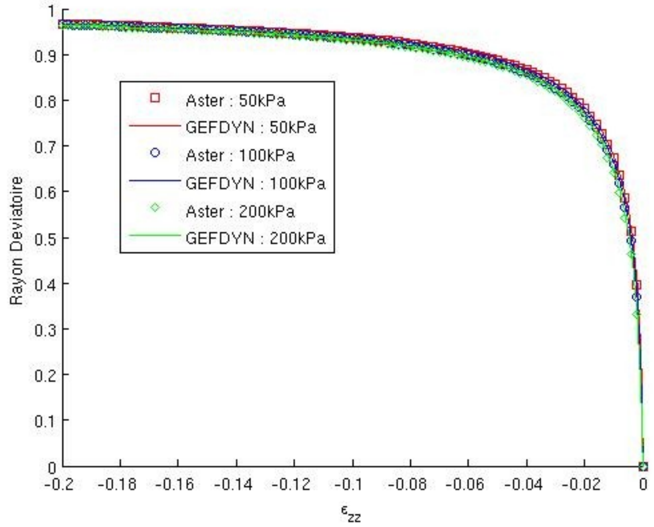


Figure 3 : ***radius déviatoire according to the axial strain: comparison enters the solutions Code_Aster and Xloi, for the pressures of consolidation of*** 50 ***,*** 100 ***and*** 200kPa ***.***

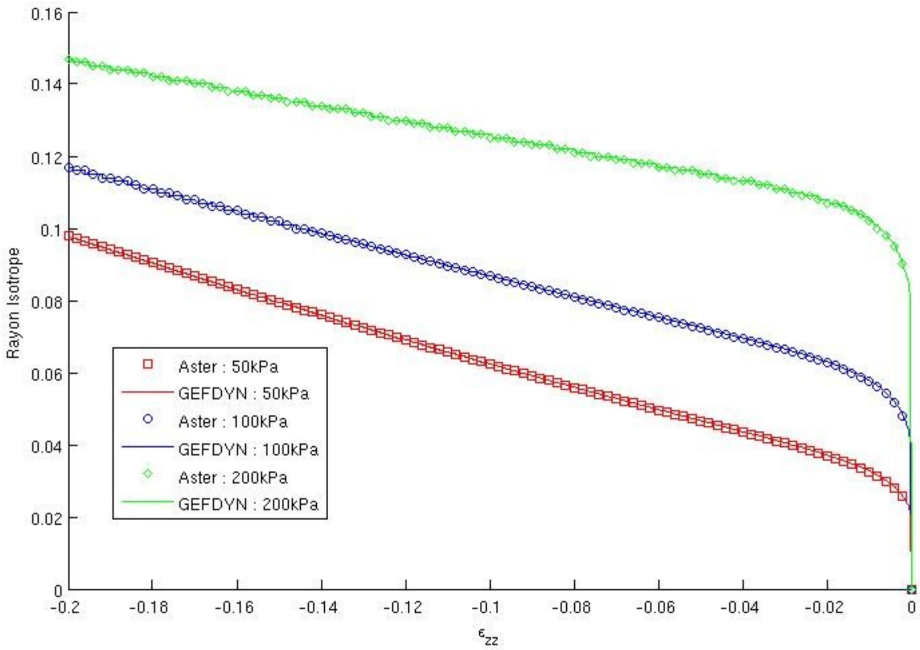


Figure 4: ***isotropic radius according to the axial strain: comparison enters the solutions Code_Aster and Xloi, for the pressures of consolidation of*** 50 ***,*** 100 ***and*** 200kPa ***.***