SSNV204 – Cyclic test of isotropic compression drained on sand of Hostun

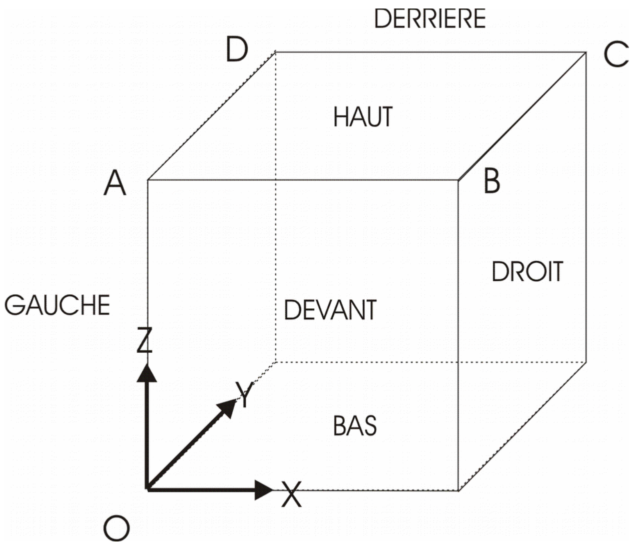
Summary

There are four following modelings:

- Modeling a: one carries out one calculation of isotropic compression cyclic in pure mechanics (equivalent under drained hydraulic conditions) with the law of Hujeux. The calculated solutions are compared with results resulting from the code finite elements GEFDYN of the Central School Paris;
- Modeling b: one carries out one calculation of isotropic compression monotonous in pure mechanics (equivalent under drained hydraulic conditions) on a material orthotropic linear rubber band. The solutions are calculated while degenerating the law of Hujeux towards an orthotropic linear elastic behavior and are compared with a true orthotropic linear elastic design;
- Modeling C: one carries out a calculation of isotropic traction cyclic in pure mechanics (equivalent under drained hydraulic conditions) with the law of Hujeux. The goal of this modeling is to test the mechanisms of traction complementary to the law of Hujeux. The calculated solutions are compared with results resulting from the code finite elements GEFDYN of the Central School Paris;
- Modeling D: one is carried out calculation of isotropic compression cyclic in pure mechanics (equivalent under drained hydraulic conditions) as for modeling A. the goal of this modeling is to test the possibility of taking into account mechanical properties which depend on the coordinates of the grid in a non-linear calculation with the law of Hujeux.

1 Problem of reference

1.1 Geometry



The 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 groups of meshs $HAUT$, BAS, $DEVANT$, $ARRIERE$, $DROIT$ and $GAUCHE$. The group of meshs SYM contains the groups of meshs in addition BAS, $DEVANT$ and $GAUCHE$; the group of meshs $COTE$ groups of meshs $ARRIERE$ and $DROIT$.

1.2 Properties of material

The elastic properties are:

- isotropic module of compressibility: $K=516200\,kPa$
- modulus of rigidity: $\mu=238200\,kPa$

The unelastic properties (Hujeux) result from the document provided by the Central School Paris [1] :

- power of the non-linear elastic law: $n_e=0.4$
- $\beta=24$
- $d=2.5$
- $b=0.2$
- angle of friction: $\varphi=33°$
- angle of dilatancy: $\psi=33°$
- critical pressure: $P_{c0}=-1000\,kPa$
- pressure of reference: $P_{ref}=-1000\,kPa$
- elastic ray of the isotropic mechanisms: $r^s_{éla}=10^{-3}$
- elastic ray of the mechanisms déviatoires: $r^d_{éla}=5.10^{-3}$
- $a_{mon}=10^{-4}$
- $a_{cyc}=0.008$
- $c_{mon}=0.2$
- $c_{cyc}=0.1$
- $r_{hys}=0.05$

- $r_{mon}=0.9$
- $x_m=1$
- $\mathrm{dila}=1$

1.3 Boundary conditions and loadings

An isotropic test of compression consists in imposing on the test-tube an equal radial force on each face of the sample.

In the model considered, the cubic element represents a eighth of the sample. The boundary 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 loading:
  - $P_n=1$ on the groups of meshs $COTE$ and $HAUT$

The loading is carried out in three phases:

1) isotropic loading of compression enters $t=-10$ and $t=0$ where pressure on the groups of meshs $COTE$ and $HAUT$ vary between $p=-100\,kPa$ and $p=-300\,kPa$.
2) isotropic loading of traction enters $t=0$ and $t=10$, where the pressure varies between $p=-300\,kPa$ and $p=-100\,kPa$.
3) isotropic loading of compression enters $t=10$ and $t=20$ where the pressure varies between $p=-100\,kPa$ and $p=-340\,kPa$.

2 Results

2.1 Method of calculating

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

2.2 Sizes and results of reference

The solutions post-are treated with the point C, in terms of isotropic pressure, plastic voluminal deformation ε_v^p and of monotonous isotropic coefficients of work hardening r_{iso}^m and cyclic r_{iso}^c.

2.3 Uncertainties on the solution

Digital solution (computer code).

2.4 Bibliographical references

[1] Reference document GEFDYN, Central School Paris. Available to the address http://www.mssmat.ecp.fr/IMG/pdf/resp_loph40.pdf

3 Modeling A

3.1 Characteristics of modeling

Modeling A is three-dimensional and non-linear statics, 3D.

One carries out initially one unelastic preconsolidation (Hujeux) of the sample until $p=-300\,kPa$ (1era phase of calculation). This preconsolidation takes place in 100 pas de time enters $t=-10$ and $t=0$. This phase requests the mechanism isotropic monotonous law of Hujeux.

The isotropic phase of traction of $p=-300\,kPa$ with $p=-100\,kPa$ (2ème phase of calculation) proceeds in 100 pas de time enters $t=0$ and $t=10$. At the time of this second phase, one activates the automatic subdivision of the step of time to manage the situations of not-convergence of local integration. This phase makes it possible to treat the passage between mechanisms isotropic monotonous and cyclic then DE to follow the mixed work hardening of the cyclic mechanism.

The new phase of isotropic compression of $p=-100\,kPa$ with $p=-340\,kPa$ (3ème phase of calculation) takes place in 100 pas de time enters the moments $t=10$ and $t=20$. The automatic subdivision of the step of time is again activated to manage the passages of mechanisms cyclic/cyclic and cyclic/monotonous. The new mechanism of consolidation cyclic created follows a mixed work hardening, then at the time of the passage to the monotonous mechanism, this one is hammer-hardened in an isotropic way.

3.2 Sizes tested and results

The solutions are calculated at the point C and compared with references GEFDYN. They are given in terms of plastic voluminal deformation ε_v^p and of coefficients of monotonous isotropic work hardening $\left(r_{ela}^{iso,m}+r_{iso}^m\right)$ and cyclic $\left(r_{ela}^{iso,c}+r_{iso}^c\right)$, and recapitulated in the following tables:

ε_v^p

p **(kPa)**	**Type of reference**	**Value of reference**	**Tolerance (%)**
-200	SOURCE_EXTERNE	-6.78E-3	1.0
-300	SOURCE_EXTERNE	-1.28E-2	1.0
-200	SOURCE_EXTERNE	-7.49E-3	1.0
-100	SOURCE_EXTERNE	-9.15E-4	4.0
-220	SOURCE_EXTERNE	-8.29E-3	1.0
-340	SOURCE_EXTERNE	-1.50E-2	1.0

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

p **(kPa)**	**Type of reference**	**Value of reference**	**Tolerance (%)**
-200	SOURCE_EXTERNE	6.8E-2	1.0
-300	SOURCE_EXTERNE	8.83E-2	1.0
-200	SOURCE_EXTERNE	8.83E-2	1.0
-100	SOURCE_EXTERNE	8.83E-2	1.0
-220	SOURCE_EXTERNE	8.83E-2	1.0
-340	SOURCE_EXTERNE	9.48E-2	1.0

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

p (kPa)	Type of reference	Value of reference	Tolerance (%)
-200	SOURCE_EXTERNE	1.E-3	1.0
-300	SOURCE_EXTERNE	1.E-3	1.0
-200	SOURCE_EXTERNE	2.14E-2	1.0
-100	SOURCE_EXTERNE	4.91E-2	1.0
-220	SOURCE_EXTERNE	3.29E-2	1.0
-340	SOURCE_EXTERNE	4.91E-2	1.0

3.3 Remarks

The difference between the two codes is very weak for the whole of the values tested.

4 Modeling B

4.1 Characteristics of modeling

Modeling B beT three-dimensional and linear statics (3D). The purpose of it is to test orthotropism of the law of Hujeux. The following mechanical properties are used:

Elastic parameters		Hujeux parameters (modified compared to the §1.2)	
E_{xx}	$62000\,MPa$	n	0
E_{yy}	$31000\,MPa$	d	100
E_{zz}	$620\,MPa$	b	0,1
$\upsilon_{xx}=\upsilon_{yy}=\upsilon_{zz}$	0,3	$r^I_{ela}=r^D_{ela}$	1
G_{xx}	$11910\,MPa$		
G_{yy}	$23820\,MPa$		
G_{zz}	$238{,}2\,MPa$		

One carries out an isotropic compression of the sample until $p_f=-300\,kPa$ in 101 pas de time enters $t=-10$ and $t=0$.

4.2 Sizes tested and results

The solutions are calculated at the point C and compared with a true orthotropic linear elastic design carried out with *Code_Aster*. They are given in terms of deflections longitudinal ϵ_{xx} and transversal ϵ_{yy} , and recapitulated in the following tables:

ϵ_{xx}

ϵ_{zz}	**Type of reference**	**Value of reference**	**Tolerance (%)**
-6,40E-5	AUTRE_ASTER	-2,580E-7	1.0
-1,28E-4	AUTRE_ASTER	-5,170E-7	1.0
-1,92E-4	AUTRE_ASTER	-7,750E-7	1.0
-2,56E-4	AUTRE_ASTER	-1,033E-6	1.0
-3,20E-4	AUTRE_ASTER	-1,291E-6	1.0

ϵ_{yy}

ϵ_{zz}	Type of reference	Value of reference	Tolerance (%)
-6,40E-5	AUTRE_ASTER	-7,10E-7	1.0
-1,28E-4	AUTRE_ASTER	-1,42E-6	1.0
-1,92E-4	AUTRE_ASTER	-2,13E-6	1.0
-2,56E-4	AUTRE_ASTER	-2,84E-6	1.0
-3,20E-4	AUTRE_ASTER	-3,55E-6	1.0

4.3 Remarks

The difference between two simulations, which model the same behavior, is very weak.

5 Modeling C

5.1 Characteristics of modeling

Modeling C beT three-dimensional and non-linear statics, (3D).

One carries out initially an elastic preconsolidation ($ELAS$) sample until $p=-100\,kPa$ (1era phase of calculation). This preconsolidation takes place in 1 pas de time enters $t=-10$ and $t=0$. This phase is purely elastic.

The isotropic phase of traction, controlled in imposed displacement, until $u_x=u_y=u_z=5\,mm$ (displacement imposed on the faces $HAUT$, $DROIT$, $ARRIERE$) is held in 100 pas de time enters $t=0$ and $t=5$. Imposed maximum displacements correspond to a deformation of 0.5% . At the time of this second phase, one activates the automatic subdivision of the step of time to manage the situations of nonconvergence of local integration. This phase makes it possible to treat the passage between the mechanisms isotropic monotonous and cyclic then to follow the mixed work hardening of the cyclic mechanism until reaching a state of stresses close to traction for material. This test makes it possible to make sure that the mechanisms parfaitemeNT plastics controlling the traction of the model of Hujeux are activated correctly.

The following phase of isotropic compression until $u_x=u_y=u_z=-5\,mm$ (3ème phase of calculation) takes place in 100 pas de time enters the moments $t=5$ and $t=10$. The automatic subdivision of the step of time is again activated to manage the passages of mechanisms traction to the mechanisms cyclic isotropic and cyclic/monotonous. The new mechanism of consolidation cyclic created follows a mixed work hardening, then at the time of the passage to the monotonous mechanism, this one is hammer-hardened in an isotropic way.

5.2 Sizes tested and results

The solutions are calculated at the point C and compared with references GEFDYN. They are given in terms of plastic voluminal deformation ε_v^p, cyclic isotropic coefficients of work hardening $\left(r_{ela}^{iso,c}+r_{iso}^{c}\right)$ and of isotropic constraint p , and recapitulated in the following tables:

ε_v^p

ε_a	Type of reference	Value of reference	Tolerance (%)
0,003	SOURCE_EXTERNE	7.43E-3	1.0
-0,005	SOURCE_EXTERNE	-2.06E-2	3.0

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

ε_a	Type of reference	Value of reference	Tolerance (%)
0,003	SOURCE_EXTERNE	4.00E-2	1.0

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

ε_a	Type of reference	Value of reference	Tolerance (%)
0,003	SOURCE_EXTERNE	1.094E-1	1.0

$p(Pa)$

ε_a	Type of reference	Value of reference	Tolerance (%)
0,003	SOURCE_EXTERNE	-2,000	1.0
-0,005	SOURCE_EXTERNE	-4.482E5	2.0

5.2.1 Comments

The difference between the two codes is very weak for the whole of the values tested.

6 Modeling D

6.1 Characteristics of modeling and values tested

The problem solved in this case is the same one as for modeling A. It makes it possible to test the possibility of taking into account the space dependence of the mechanical properties with the law of Hujeux.

6.2 Sizes tested and results

The solutions are calculated at the point C and compared with references GEFDYN. They are given in terms of plastic voluminal deformation ε_v^p and of coefficients of monotonous isotropic work hardening $\left(r_{ela}^{iso,m}+r_{iso}^m\right)$ and cyclic $\left(r_{ela}^{iso,c}+r_{iso}^c\right)$, and recapitulated in the following tables:

ε_v^p

p (kPa)	Type of reference	Value of reference	Tolerance (%)
-200	SOURCE_EXTERNE	-6.78E-3	1.0
-300	SOURCE_EXTERNE	-1.28E-2	1.0
-200	SOURCE_EXTERNE	-7.49E-3	1.0
-100	SOURCE_EXTERNE	-9.15E-4	4.0
-220	SOURCE_EXTERNE	-8.29E-3	1.0
-340	SOURCE_EXTERNE	-1.50E-2	1.0

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

p (kPa)	Type of reference	Value of reference	Tolerance (%)
-200	SOURCE_EXTERNE	6.8E-2	1.0
-300	SOURCE_EXTERNE	8.83E-2	1.0
-200	SOURCE_EXTERNE	8.83E-2	1.0
-100	SOURCE_EXTERNE	8.83E-2	1.0
-220	SOURCE_EXTERNE	8.83E-2	1.0
-340	SOURCE_EXTERNE	9.48E-2	1.0

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

p (kPa)	Type of reference	Value of reference	Tolerance (%)
-200	SOURCE_EXTERNE	1.E-3	1.0
-300	SOURCE_EXTERNE	1.E-3	1.0
-200	SOURCE_EXTERNE	2.14E-2	1.0
-100	SOURCE_EXTERNE	4.91E-2	1.0
-220	SOURCE_EXTERNE	3.29E-2	1.0
-340	SOURCE_EXTERNE	4.91E-2	1.0

6.3 Remarks

The difference between the two codes is very weak for the whole of the values tested and makes it possible to validate the taking into account of the variables of orders to represent a space dependence of the parameters of elasticity in the law of Hujeux.

7 Summary of the results

One represents in the following curves the various comparisons between Code_Aster and GEFDYN, in terms of plastic voluminal deformation (Figure **1**) and of isotropic coefficients of monotonous and cyclic work hardening (Figure **2**). These curves result from modeling A.

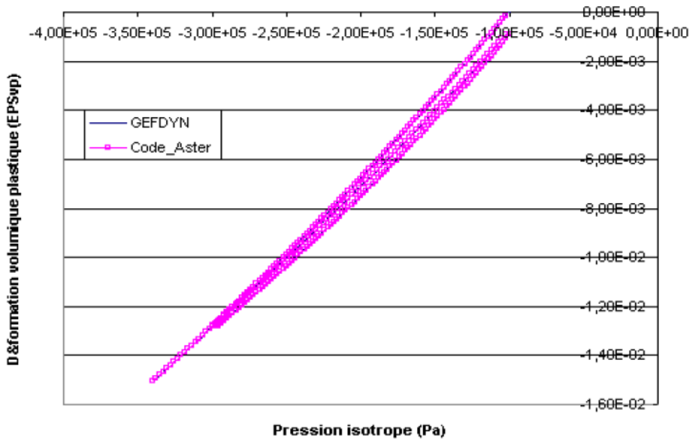


Figure **1** : Voluminal deformation plastic function of the isotropic pressure: comparison enters the solutions *Code_Aster* and GEFDYN.

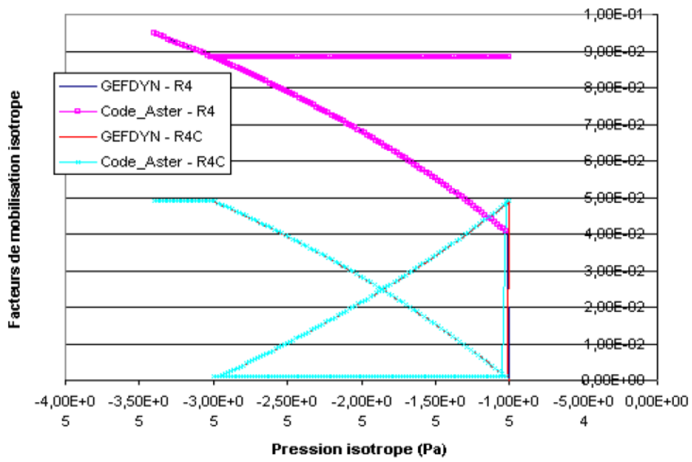


Figure **2** : Isotropic monotonous and cyclic rays according to the isotropic pressure: comparison enters the solutions *Code_Aster* and GEFDYN.