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

Hostun

One has the 3 following modelizations:

A

One carries out *a computation of isotropic compression cyclic 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;

B

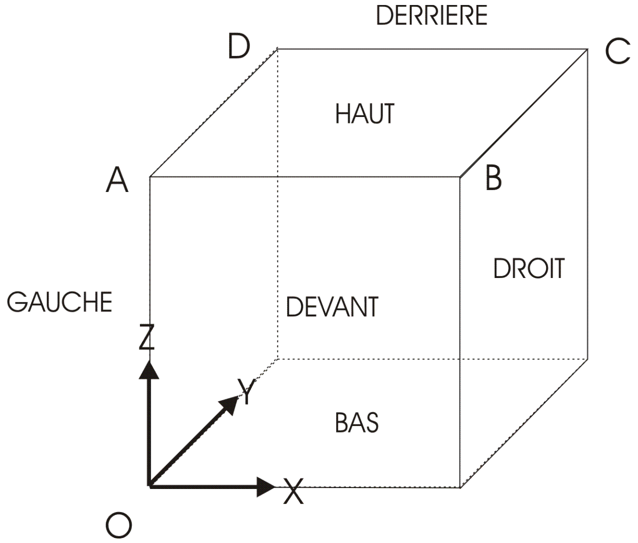
One carries out *a computation of isotropic compression monotonous in pure mechanics* (equivalent under drained hydraulic conditions) on an orthotropic *linear elastic material* . The solutions are calculated while degenerating *the model of Hujeux* towards an orthotropic linear elastic behavior and are compared with a true orthotropic linear elastic design;

C

One carries out *a computation of isotropic tension cyclic in pure mechanics* (equivalent under drained hydraulic conditions) with *the model of Hujeux*. The goal of this modelization is to test the mechanisms of tension complementary to the model of Hujeux. The calculated solutions are compared with results resulting from the code finite elements GEFDYN of the Central School Paris;

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 mesh groups $HAUT$ BAS $DEVANT$ $ARRIERE$, $DROIT$ and $GAUCHE$. Mesh group SYM contains the mesh groups in addition BAS, $DEVANT$ and $GAUCHE$; the mesh group $COTE$ mesh groups $ARRIERE$ and $DROIT$.

1.2 Properties of the sand of Hostun

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

The unelastic properties (Hujeux) result from the document provided by the School Central Paris and available to the following Internet address: http://www.mssmat.ecp.fr/IMG/pdf/resp_loph40.pdf :
- 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 mechanisms: $r_{éla}^{s}=10^{-3}$
- elastic radius of the mechanisms déviatoires: $r_{éla}^{d}=5.10^{-3}$
- $a_{mon}=10^{-4}$
- $a_{cyc}=0.008$
- $c_{mon}=0.2$
- $c_{cyc}=0.1$

- $r_{hys}=0.05$
- $r_{mon}=0.9$
- $x_m=1$
- $\mathrm{dila}=1$

The materials' properties sand of Hostun were established starting from reference document GEFDYN available on the site of the laboratory MSS-Mat of Paris Power station: http://www.mssmat.ecp.fr/IMG/pdf/resp_loph40.pdf.

1.3 Boundary conditions and loadings

an isotropic compression test 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 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 loading:
  - $P_n=1$ on the groups of mailleset $COTE$ $HAUT$

the loading is carried out in three phases:

1) isotropic loading of compression enters $t=-10$ and $t=0$ where the pressure on the groups of maillesetvarie $COTE$ $HAUT$ enters $p=-100\,kPa$ and $p=-300\,kPa$.
2) isotropic loading of tension 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 $p=-340\,kPa$.

1.4 Results

the solutions post-are treated with the point C, in terms of isotropic pressure, plastic voluminal strain ε_v^p and isotropic coefficients of monotonous and r_{iso}^m cyclic hardening r_{iso}^c.
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,* 3D.

One carries out initially *an unelastic preconsolidation* (Hujeux) of the sample until $p=-300\,kPa$ (1st phase of computation). This preconsolidation takes place in 100 time step enters $t=-10$ and $t=0$. This phase requests the monotonous *isotropic mechanism* of the model of Hujeux.

The isotropic phase of tension of $p=-300\,kPa$ with $p=-100\,kPa$ (2nd phase of computation) proceeds 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. This phase makes it possible to treat the transition between the mechanisms *isotropic monotonous* and *cyclic* then to follow the mixed hardening of the cyclic mechanism.

The new phase of isotropic compression of $p=-100\,kPa$ with $p=-340\,kPa$ (3rd phase of computation) takes place in 100 time step between times $t=10$ and $t=20$. The automatic subdivision of the time step is again activated to manage the transitions of mechanisms cyclic/cyclic and cyclic/monotonous. The new mechanism of cyclic consolidation created follows a mixed hardening, then during the transition with the monotonous mechanism, this one is hammer-hardened in an isotropic way.

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 the local integration of with increments of too large loading or increments of discharge. *This functionality is largely recommended*.

2.2 Quantities tested and results

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

ε_v^p

p (kPa)	Standard of reference	GEFDYN	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)	Standard of reference	GEFDYN	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)	Standard of reference	GEFDYN	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

2.3 Remarks

the difference between the two codes is very weak for all the values tested.

3 Modelization B

3.1 Characteristic of the modelization

The modelization B is *three-dimensional* and *static linear* (3D). The purpose of it is testing *the orthotropy* of the model 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 time step enters $t=-10$ and $t=0$.

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 the local integration of with increments of too large loading or increments of discharge. *This functionality is largely recommended*.

3.2 Quantities tested and results

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

ϵ_{xx}

ϵ_{zz}	Type of reference	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}

p (kPa)	Standard of reference	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

3.3 Remarks

the difference between two simulations is very weak, which is not abnormal taking into account the fact that two computations are a priori *identical*.

4 Modelization C

4.1 Characteristic of the modelization

The modelization C is *three-dimensional* and *static nonlinear,* (3D).

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

The isotropic phase of tension, controlled in imposed displacement, until $u_x=u_y=u_z=5\,mm$ (displacement imposed on the sides $HAUT$ $DROIT$, $ARRIERE$) proceeds in 100 time step enters $t=0$ and $t=5$. Imposed maximum displacements correspond to a strain of 0.5%. During this second phase, one activates the automatic subdivision of the time step to manage the situations of nonconvergence of local integration. This phase makes it possible to treat the transition between the mechanisms *isotropic monotonous* and *cyclic* then to follow the mixed hardening of the cyclic mechanism until reaching a stress state close to the tension for the material. This test makes it possible to make sure that the perfectly plastic mechanisms controlling the tension of the model of Hujeux correctly activate

the following phase of isotropic compression until $u_x=u_y=u_z=-5\,mm$ (3rd phase of computation) takes place in 100 time step between times $t=5$ and $t=10$. The automatic subdivision of the time step is again activated to manage the transitions of mechanisms tension to the mechanisms cyclic isotropic and cyclic/monotonous. The new mechanism of cyclic consolidation created follows a mixed hardening, then during the transition with the monotonous mechanism, this one is hammer-hardened in an isotropic way.

4.2 Quantities tested and results

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

$$\varepsilon_v^p$$

ε_a	Type of reference	GEFDYN	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	GEFDYN	Tolerance (%)
0.003	SOURCE_EXTERNE	4.00E-2	1.0

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

ε_a	Type of reference	GEFDYN	Tolerance (%)
0.003	SOURCE_EXTERNE	1.094E-1	1.0

$$p(Pa)$$

ε_a	Type of reference	GEFDYN	Tolerance (%)
0.003	SOURCE_EXTERNE	-2.000	1.0
-0.005	SOURCE_EXTERNE	-4.482E5	2.0

4.2.1 Comments

the difference between the two codes is very weak for all the values tested.

5 Summary of the results

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

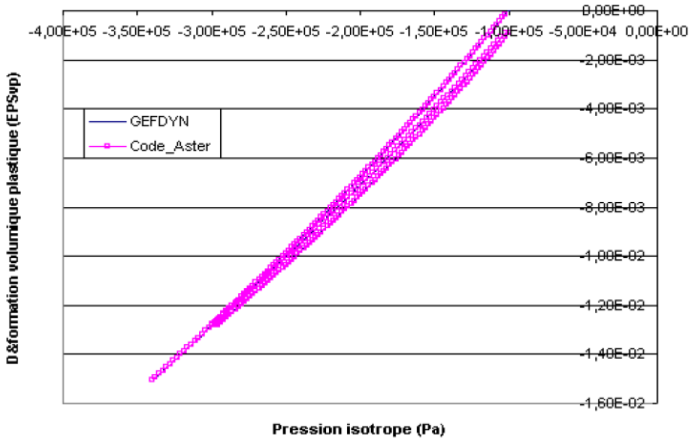


Figure **1** : *Voluminal strain plastic function of the isotropic pressure: comparison enters solutions Code_Aster and GEFDYN.*

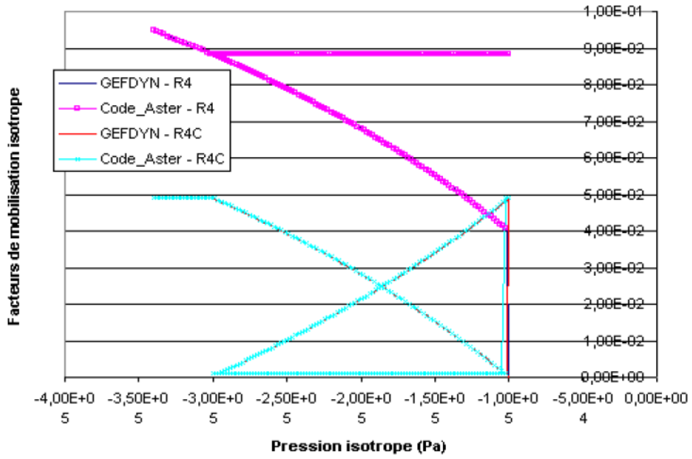


Figure **2** : *Radius isotropic monotonous and cyclic according to the isotropic pressure: comparison enters solutions Code_Aster and GEFDYN.*