WTNV133 – Triaxial not drained with the law of Hujeux

Summary

This test makes it possible to validate the monotonous mechanism déviatoires installation of and the cyclic mechanism of consolidation of the law of Hujeux. It is about a triaxial compression test carried out in not drained condition. The hydraulic coupling is taken into account, the sample is completely saturated, the skeleton and the fluid is supposed to be incompressible.

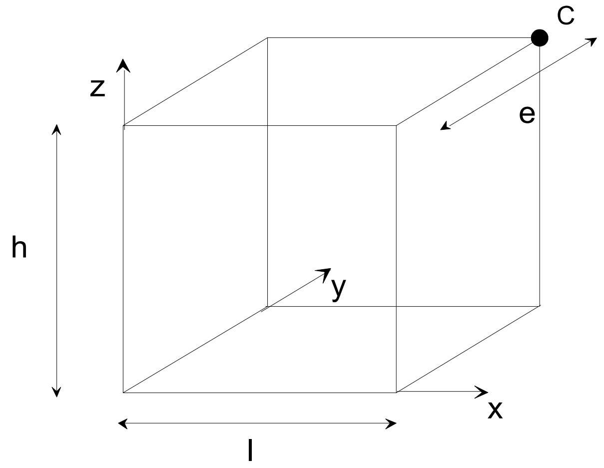
The levels of containment applied are of $50\,kPa$ and $200\,kPa$.

The results got with the law of Hujeux are compared with results resulting from the code finite elements GEFDYN of the Central School Paris.

1 Problem of reference

1.1 Geometry

It is about a cubic sample of form of representation $1/8$ using an element $\mathrm{HEXA20}$.



hauteur : h = 1 m
largeur : l = 1 m
épaisseur : e = 1 m

1.2 Material properties

The elastic properties are:

- isotropic module of compressibility: $K=516200\,kPa$;
- modulus of rigidity: $\mu=238200\,kPa$;
- density [1] : $\rho_s=2500\,kg/m^3$.

The unelastic properties of the cyclic law of Hujeux are:

- 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: $P_{c0}=-1\,MPa$;
- pressure of reference: $P_{ref}=-1\,MPa$;
- elastic ray of the isotropic mechanisms: $r^s_{éla}=0{,}001$;
- elastic ray of the mechanisms déviatoires: $r^d_{éla}=0{,}005$;
- $a_{mon}=0{,}008$;
- $a_{cyc}=0{,}0001$;
- $c_{mon}=0{,}2$;
- $c_{cyc}=0{,}1$;
- $r_{hys}=0{,}05$;
- $r_{mob}=0{,}9$;
- $x_m=1$;
- $dila=1$;

The hydraulic properties are:

1 In the absence of gravity, the densities of the ground and water do not intervene in the problem.

- coefficient of Biot: $B=1$;
- density of water: $\rho_e=1000\,kg/m^3$;
- viscosity: $\nu=0{,}001$;
- the intrinsic permeability: $K^{\text{int}}=1\,E^{-8}\,m^3/kg/s$;
- the module of compressibility of water: $K_e=1\,E^{+12}\,Pa$ (coefficient of compressibility $1/K_e=1\,E^{-12}\,Pa^{-1}$)

1.3 Boundary conditions and loadings

1.3.1 Boundary conditions

They is the conditions of symmetry on the element, which represents $1/8$ sample. Displacements are blocked on the front faces ($u_y=0$), side left ($u_x=0$) and lower ($u_z=0$).

1.3.2 Loading

Phase 1: consolidation of the sample until the confining pressure p_0
One brings the sample in a homogeneous state of stress *effective* isostatic $\sigma_{xx}^0=\sigma_{yy}^0=\sigma_{zz}^0=\sigma_0$, by imposing the pressure σ_0 on the faces postpones, side right-hand side and higher of the element, and by maintaining water pressures everywhere $PRE1$ worthless.

Phase 2: triaxial loading not drained
To obtain the not drained conditions, one forces on all the faces of worthless hydraulic flows.

While maintaining on the faces back and side right-hand side a pressure equalizes with σ_0 , one applies a loading in displacement of amplitude Δu equalize with $0{,}02\,m$ on the higher face, in order to obtain a homogeneous deformation of the sample of $2\,\%$.

1.4 Results

The solutions post-are treated with the point C , in terms of equivalent constraint of Von Mises Q ($=\sqrt{\frac{1}{2}\left(\sigma^d:\sigma^d\right)}$), of effective isotropic pressure P ($=\frac{trace\left(\sigma'\right)}{3}$), of plastic voluminal deformation ε_v^p and of isotropic coefficients of work hardening $\left(r_{iso}^m+r_{ela}^{iso,m}\right)$ and $\left(r_{iso}^c+r_{ela}^{iso,c}\right)$ and déviatoire $\left(r_d^m+r_{ela}^{d,m}\right)$.
The validation is carried out by comparison with solutions GEFDYN provided by the Central School Paris.

2 Modeling A

2.1 Characteristics of modeling

Modeling is $3\mathrm{D}$ with a hydro-mechanical coupling into quasi-static non-linear.
In the phase 1 of loading, one brings the sample to the pressure of consolidation $\sigma_{xx}^0=\sigma_{yy}^0=\sigma_{zz}^0=\sigma_0=-50\,kPa$. This state of containment allows to regard the sample as sand *dense* .

One uses the law of Hujeux *cyclic*.

2.2 Characteristics of the grid

Many nodes: 20

Number of meshs and type: 1 $HEXA20$ and 6 $QUAD8$.

2.3 Sizes tested and results

The solutions are calculated at the point C and compared with references GEFDYN. They are given in terms of isotropic pressure, of plastic voluminal deformation ε_v^p and of factors of mobilization, and recapitulated in the following tables :

$$Q=\sqrt{\frac{1}{2}\sigma_{ij}^d:\sigma_{ij}^d}(kPa)$$

ε_{zz}	Type of reference	GEFDYN (kPa)	tolerance (%)
-1.E-3	SOURCE_EXTERNE	3.154E+1	3.0
-2.E-3	SOURCE_EXTERNE	4.013E+1	2.0
-5.E-3	SOURCE_EXTERNE	5.194E+1	1.0
-1.E-2	SOURCE_EXTERNE	6.829E+1	1.0
-2.E-2	SOURCE_EXTERNE	1.032E+2	1.0

$$3\ .\ P'=\sigma_{ij}\cdot\delta_{ij}(kPa)$$

ε_{zz}	Type of reference	GEFDYN (kPa)	tolerance (%)
-1.E-3	SOURCE_EXTERNE	-1.389E+2	1.0
-2.E-3	SOURCE_EXTERNE	-1.338E+2	1.0
-5.E-3	SOURCE_EXTERNE	-1.250E+2	1.0
-1.E-2	SOURCE_EXTERNE	-1.368E+2	1.0
-2.E-2	SOURCE_EXTERNE	-1.860E+2	1.0

$$\varepsilon_v^p=trace(\varepsilon^p)$$

ε_{zz}	Type of reference	GEFDYN	tolerance (%)
-1.E-3	SOURCE_EXTERNE	-2.42E-5	6.0
-2.E-3	SOURCE_EXTERNE	-3.55E-5	4.0
-5.E-3	SOURCE_EXTERNE	-5.56E-5	3.0
-1.E-2	SOURCE_EXTERNE	-2.88E-5	5.0
-2.E-2	SOURCE_EXTERNE	7.437E-5	5.0

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

ε_{zz}	Type of reference	GEFDYN	tolerance (%)
-1.E-3	SOURCE_EXTERNE	0.02	1.0
-2.E-2	SOURCE_EXTERNE	0.0248	1.0

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

ε_{zz}	Type of reference	GEFDYN	tolerance (%)
-1.E-3	SOURCE_EXTERNE	1.49E-3	2.0
-2.E-3	SOURCE_EXTERNE	2.18E-3	2.0
-5.E-3	SOURCE_EXTERNE	3.36E-3	2.0
-1.E-2	SOURCE_EXTERNE	1.68E-3	3.0

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

ε_{zz}	Type of reference	GEFDYN	tolerance (%)
-1.E-3	SOURCE_EXTERNE	0,353	3.0
-2.E-3	SOURCE_EXTERNE	0,451	2.0
-5.E-3	SOURCE_EXTERNE	0,593	1.0
-1.E-2	SOURCE_EXTERNE	0,699	1.0
-2.E-2	SOURCE_EXTERNE	0,794	1.0

2.4 Remarks

The comparison enters the solutions *Code_Aster* and GEFDYN is relatively good, with generally less 1% of error. Relative errors higher than 1% appear for levels of values tested relatively low and close to the digital precision applied during calculation.

3 Modeling B

3.1 Characteristics of modeling

Modeling is 3D with a hydro-mechanical coupling into quasi-static non-linear.
In the phase 1 of loading, one brings the sample to the pressure of consolidation $\sigma_{xx}^0=\sigma_{yy}^0=\sigma_{zz}^0=\sigma_0=-200\,kPa$. This state of containment allows to regard the sample as sand *fairly dense*.
One uses the law of Hujeux *cyclic*.

3.2 Characteristics of the grid

Many nodes: 20
Number of meshs and type: 1 HEXA20 and 6 QUAD8.

3.3 Sizes tested and results

The solutions are calculated at the point C and compared with references GEFDYN. They are given in terms of isotropic pressure, of plastic voluminal deformation ε_v^p and of factors of mobilization, and recapitulated in the following tables:

$$Q=\sqrt{\frac{1}{2}\sigma_{ij}^d:\sigma_{ij}^d}(kPa)$$

ε_{zz}	Type of reference	GEFDYN (kPa)	tolerance (%)
-1.E-3	SOURCE_EXTERNE	1.015E+2	3.0
-2.E-3	SOURCE_EXTERNE	1.343E+2	2.0
-5.E-3	SOURCE_EXTERNE	1.808E+2	1.0
-1.E-2	SOURCE_EXTERNE	2.139E+2	1.0
-2.E-2	SOURCE_EXTERNE	2.495E+2	1.0

$$3\ .\ P'=\sigma_{ij}\cdot\delta_{ij}(kPa)$$

ε_{zz}	Type of reference	GEFDYN (kPa)	tolerance (%)
-1.E-3	SOURCE_EXTERNE	-5.889E+2	1.0
-2.E-3	SOURCE_EXTERNE	-5.823E+2	1.0
-5.E-3	SOURCE_EXTERNE	-5.638E+2	1.0
-1.E-2	SOURCE_EXTERNE	-5.439E+2	1.0
-2.E-2	SOURCE_EXTERNE	-5.442E+2	1.0

$$\varepsilon_v^p=trace(\varepsilon^p)$$

ε_{zz}	Type of reference	GEFDYN	tolerance (%)
-1.E-3	SOURCE_EXTERNE	-1.37E-5	8.0
-2.E-3	SOURCE_EXTERNE	-2.19E-5	6.0
-5.E-3	SOURCE_EXTERNE	-4.51E-5	3.0
-1.E-2	SOURCE_EXTERNE	-7.03E-5	2.0
-2.E-2	SOURCE_EXTERNE	-7.00E-5	2.0

$$(r_{iso}^c+r_{ela}^{s,c})$$

ε_{zz}	Type of reference	GEFDYN	tolerance (%)

-1.E-3	SOURCE_EXTERNE	1.51E-3	1.0
-2.E-3	SOURCE_EXTERNE	2.40E-3	1.0
-5.E-3	SOURCE_EXTERNE	4.91E-3	1.0
-1.E-2	SOURCE_EXTERNE	7.60E-3	1.0
-2.E-2	SOURCE_EXTERNE	1.16E-3	2.0

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

ε_{zz}	Type of reference	GEFDYN	tolerance (%)
-1.E-3	SOURCE_EXTERNE	0,334	3.0
-2.E-3	SOURCE_EXTERNE	0,436	2.0
-5.E-3	SOURCE_EXTERNE	0,583	1.0
-1.E-2	SOURCE_EXTERNE	0,693	1.0
-2.E-2	SOURCE_EXTERNE	0,790	1.0

3.4 Remarks

The comparison enters the solutions *Code_Aster* and GEFDYN is relatively good, with generally less 1% of error. Relative errors higher than 1% appear for levels of values tested relatively low and close to the digital precision applied during calculation.

4 Modeling C

4.1 Characteristics of modeling

Modeling is $3D$ under-integrated (3D_HM_SI) with a hydro-mechanical coupling into quasi-static non-linear.
In the phase 1 of loading, one brings the sample to the pressure of consolidation $\sigma_{xx}^0=\sigma_{yy}^0=\sigma_{zz}^0=\sigma_0=-50\,kPa$. This state of containment allows to regard the sample as sand *dense* .

One uses the law of Hujeux *cyclic*.

4.2 Characteristics of the grid

Many nodes: 20

Number of meshs and type: 1 $HEXA20$ and 6 $QUAD8$.

4.3 Sizes tested and results

The solutions are calculated at the point C and compared with references GEFDYN. They are given in terms of isotropic pressure, of plastic voluminal deformation ε_v^p and of factors of mobilization, and recapitulated in the following tables :

$$Q=\sqrt{\frac{1}{2}\sigma_{ij}^d:\sigma_{ij}^d}(kPa)$$

ε_{zz}	Type of reference	GEFDYN (kPa)	tolerance (%)
-1.E-3	SOURCE_EXTERNE	3.154E+1	3.0
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$$3\ .\ P'=\sigma_{ij}\cdot\delta_{ij}(kPa)$$

ε_{zz}	Type of reference	GEFDYN (kPa)	tolerance (%)
-1.E-3	SOURCE_EXTERNE	-1.389E+2	1.0
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-2.E-2	SOURCE_EXTERNE	-1.860E+2	1.0

$$\varepsilon_v^p=trace(\varepsilon^p)$$

ε_{zz}	Type of reference	GEFDYN	tolerance (%)
-1.E-3	SOURCE_EXTERNE	-2.42E-5	6.0
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$\left(r_{iso}^{m}+r_{ela}^{s,m}\right)$

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4.4 Remarks

The comparison enters the solutions *Code_Aster* and GEFDYN is relatively good, with generally less 1% of error. Relative errors higher than 1% appear for levels of values tested relatively low and close to the digital precision applied during calculation.

5 Summary of the results

One represents in the following curves the various comparisons enters *Code_Aster* and Lawyer (calculation programme of law of behavior, not finite elements), in terms of isotropic pressure (Figure 5-a), of plastic voluminal deformation (Figure 5-b) and of coefficients of monotonous and cyclic isotropic work hardening (figures 5-c and 5-d).

The differences noted between two modelings for the values of the cyclic factors of mobilization are due to a management different in time from variable kinematics. Their values are only different when the cyclic mechanisms are not active.

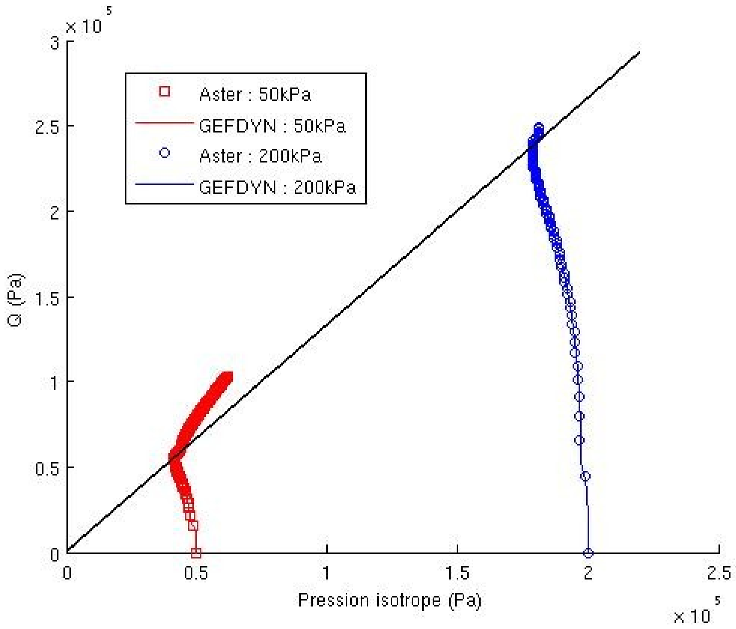

Figure 5-a : ***Cyclic triaxial compression test not drained (Plan $P-Q$): comparison enters the solutions Code_Aster and Lawyer for the pressures of consolidation of $50\,kPa$ and $200\,kPa$.***

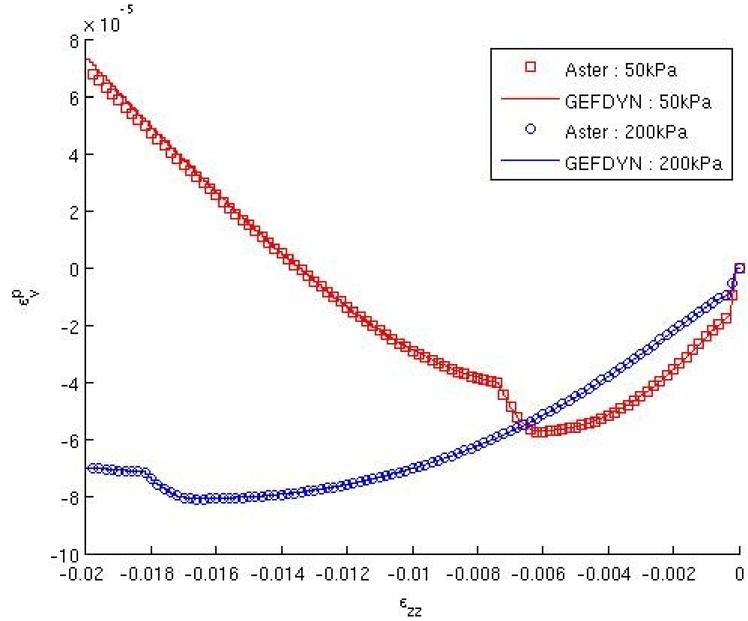

Figure 5-b : Plastic voluminal deformation according to the vertical deformations for the two levels of compression with $50\,kPa$ and $200\,kPa$: comparison enters the solutions Code_Aster and Lawyer .

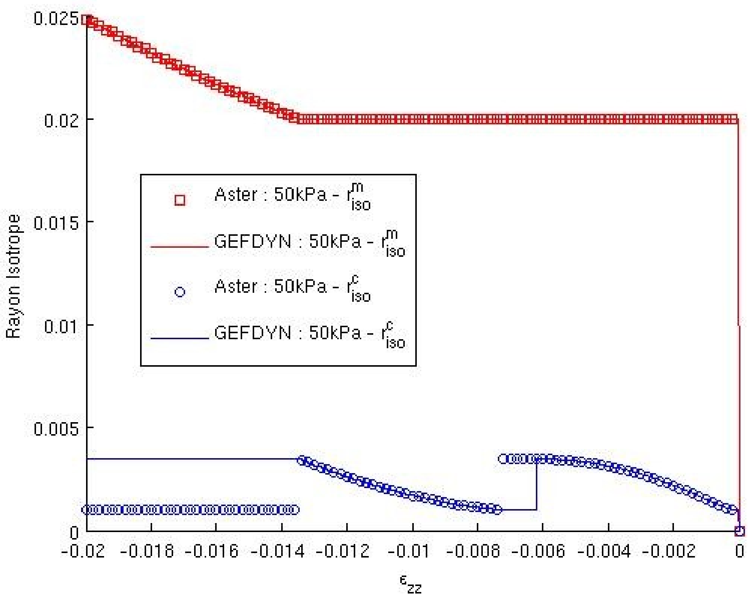

Figure 5-c : isotropic rays monotonous and cyclic according to the vertical deformations for the level of consolidation of $50\,kPa$: comparison enters the results Code_Aster and Lawyer.

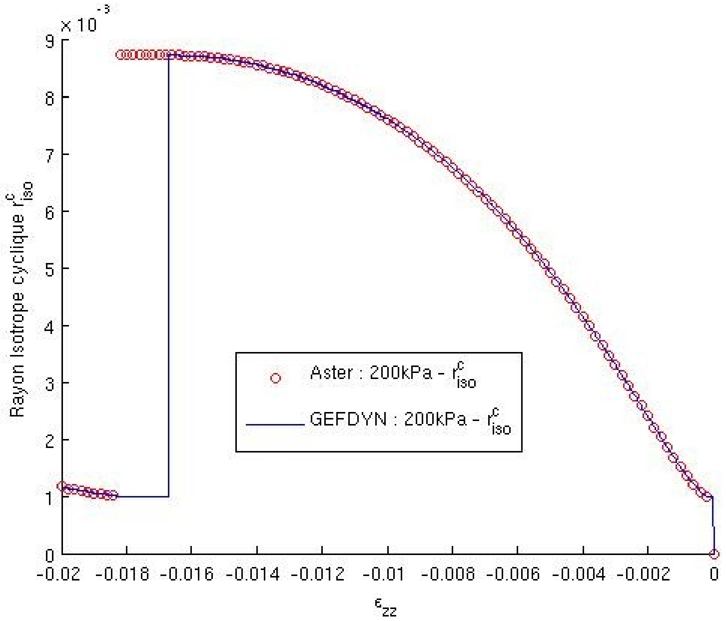

Figure 5-d : cyclic isotropic ray according to the vertical deformations for the level of consolidation of $200\,kPa$ ***: comparison enters the results Code_Aster and Lawyer.***