WTNV113 – Gravitating flow in a Summarized saturated porous environment

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This test consists in studying the influence of a gravitating flow on the distribution of the pressure of the fluid of the saturated medium. It is about an evolutionary problem. The hydraulic behavior of a porous environment saturated by only one fluid is studied

Ten modelizations are carried out: four modelizations two-dimensional (modelizations A, b: elements `HM_DPQ8`, modelizations E, F: elements `THM_DPQ8`) and six three-dimensional modelizations (modelizations C and D: elements `HM_HEXA20`, modelizations G and H: elements `THM_HEXA20`, I: `THM_HEXA20D` and J: `THM_HEXA20S`).

The distinction between the modelizations A and B (respectively C and D, E and F, G and H) lies in the constitutive law of the fluid.
The modelizations I and J are alternatives in modelization selective and lumped of G, they have results which differ from the suggested analytical solution (integration is different), and are thus of non regression.

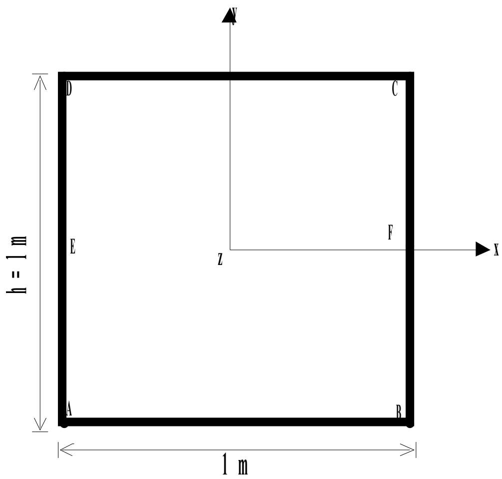
The reference solution is unidimensional because it depends only on the vertical coordinate.

1 Problem of reference

1.1 Presentation

One studies in this case test the hydraulic behavior of a porous environment saturated by only one fluid: water in its liquid phase. It acts in *Code_Aster* of a modelization HM or THM by blocking the temperature. The associated constitutive law of the fluid is according to the modelizations either of type LIQU_SATU (modelizations A, C, E, G, I, J) or of type LIQU_GAZ_ATM (modelizations B, D, F, H).

1.2 Geometry



Coordinated of the points (m) :

Points	X	Y
A	$-0,5$	$-0,5$
B	$0,5$	$-0,5$
C	$0,5$	$0,5$
D	$-0,5$	$0,5$

1.3 Properties of the solid

material	Density $(kg.m^{-3})$ Young Modulus drained $E(Pa)$ Fluid	$2.\times 10^3$ $225.\times 10^6$ $0.$
Poisson's ratio (liquid water)	Density $(kg.m^{-3})$ Compressibility of the fluid (Pa) Dynamic viscosity of the liquid water $(Pa.s)$ Derived from the viscosity of the fluid compared to the temperature	10^3 2.65×10^8 10^{-3} $0.$
Coefficients of homogenization	Coefficient of $Biot$ Porosity	$1.$ 0.4
homogenized Coefficients	Density homogenized $(kg.m^{-3})$ Saturation Derived from saturation compared to the pressure Gravity according to X Gravity according to Y Gravity according to Z intrinsic Permeability (m^2) Permeability relating to the fluid (m^2)	1.6×10^3 $1.$ $0.$ $0.$ -10 in $2D$, 0 in $3D$ -10 of $3D$, 0 in $2D$ 10^{-18} $1.$

1.4 Boundary conditions and loadings

- •complete Element:
- •Displacements $u_x=0.0\,m\,, u_y=0.0\,m\,, u_z=0.0\,m$.
- •For the modelizations THM $T=0°$.

1.5 Initial conditions

the fields of displacement, of capillary pressure are initially null, the air pressure dryness is equal to the atmospheric pressure and the reference temperature is worth $T_0=273\,°K$

2 Reference solution

2.1 Method of calculating used for the reference solution

the conservation equation of the fluid mass is given by the following statement:

$$\frac{dm_i}{dt}+Div\,\boldsymbol{M}_i=0 \qquad i \text{ varying } 1 \text{ with the number of components} \tag{1}$$

In our example, the model consists of a fluid: liquid water. The equation (1) thus applies to this component:

$$\frac{dm_e}{dt}+Div\,\boldsymbol{M}_e=0 \tag{2}$$

the fluid flux has as a statement:

$$M_e=\rho_e\lambda_e(-\nabla p_e+\rho_e g) \tag{3}$$

But the mass fluid contribution is defined by the equation (4) where terms N_{ee} and N_{ea} (equation (5)) depend on the degree on saturation S , porosity ϕ , coefficient of Biot b , permeability of the fluid K_e and elasticity of the solid matrix K_s .

$$\frac{dm_e}{dt}=\rho_e N_{ee}\frac{dp_e}{dt}+\rho_e N_{ea}\frac{dp_a}{dt} \tag{4}$$

$$\begin{cases} N_{ee}=-\varphi\dfrac{\partial S}{\partial p_c}+S\left(\dfrac{\varphi}{K_e}+\dfrac{b-\varphi}{K_s}S\right) \\ N_{ea}=N_{ae}=\varphi\dfrac{\partial S}{\partial p_c}+(1-S)\left(\dfrac{b-\varphi}{K_s}S\right) \end{cases} \tag{5}$$

the material is saturated, $S=1$ and $\frac{\partial S}{\partial P_c}=0$. $\Rightarrow N_{ee}=S\left(\frac{\varphi}{K_e}+\frac{b-\varphi}{K_s}S\right)$ and $N_{ea}=0$.

The variational formulation of the equation (2), by taking account of (3) and (4) is:
$\forall P_e^*$ checking the boundary conditions in pressure:

$$\int_\Omega N_{ee}\frac{dp_e}{dt}p_e^*+\int_\Omega \lambda_e\nabla p_e.\nabla p_e^*=\int_\Omega \lambda_e\rho_e g.\nabla p_e^*-\int_{\partial\Omega}\frac{M_e^{ext}}{\rho_e}p_e^* \tag{6}$$

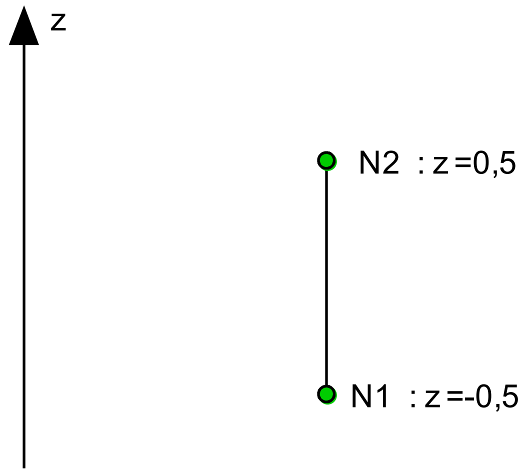
Discretization

For the computation of the analytical solution, one is placed in a unidimensional case and one considers a discretization with only one element of degree 2 (HEXA20, DPQ8). It is specified that any modelization HM being of type $P2P1$, even if the mesh is quadratic, the hydraulic modelization is as for it linear.

One supposes in both cases that gravity is directed according to z the negative ones.

It is supposed in addition that non-linearities are low and that the coefficients N, λ, ρ are constant. It is necessary thus that the variations of pressure are sufficiently weak so that N and ρ can be presumedly constant.

Linear discretization:



One will write:

$$p(z,t)=\sum_{i=1}^{2} p^i(t)\lambda_i(z) \quad (7)$$

With:

$$\begin{cases}\lambda_1=\dfrac{1}{2}-z\\ \lambda_2=\dfrac{1}{2}+z\end{cases} \quad (8)$$

By introducing the matrixes and vectors then:

(9)

$$[A]=[A_{ij}] \quad ; \quad A_{ij}=\int_{-1/2}^{1/2}\lambda_i\lambda_j dz$$

$$[B]=[B_{ij}] \quad ; \quad B_{ij}=\int_{-1/2}^{1/2}\frac{d\lambda_i}{dz}\frac{d\lambda_j}{dz}dz$$

$$\{F_g\}=\{F_{gi}\} \quad ; \quad F_{gi}=\int_{-1/2}^{1/2}\frac{d\lambda_i}{dz}dz$$

And while noting:

$$\{p_e\}=\begin{Bmatrix}P_e^1\\ p_e^2\end{Bmatrix} \quad (10)$$

$$\{M_e^{ext}\}=\begin{Bmatrix}M_{e\ 1}^{ext}\\ M_{e\ 2}^{ext}\end{Bmatrix} \quad (11)$$

the equation (6) becomes:

$$\frac{N_{ee}}{\lambda_e}[A]\left\{\frac{dp_e}{dt}\right\}+[B]\{p_e\}=\rho_e\{F_g\}-\frac{1}{\lambda_e\rho_e}\{M_e^{ext}\} \quad (12)$$

The computation of the matrixes $[A]$ and $[B]$ the vector $\{f_g\}$ gives:

$$[A]=\frac{1}{3}\begin{bmatrix}1 & 1/2\\ 1/2 & 1\end{bmatrix} \quad ; \quad [B]=\begin{bmatrix}1 & -1\\ -1 & 1\end{bmatrix} \quad ; \quad \{F\}=\begin{Bmatrix}-1\\ 1\end{Bmatrix}$$

(13)

One defines the eigenvectors then $[A]^{-1}[B]$ of : $\{v_1\},\{v_2\}$ who have the following properties of orthogonality:

$$\{v_i\}^T[A]\{v_j\}=\{v_i\}^T[B]\{v_j\}=0 \quad si \quad i\neq j \quad (14)$$

And one poses:

$$a_i=\{v_i\}^T[A]\{v_i\} \ , \ b_i=\{v_i\}^T[B]\{v_i\} \ , \ f_i=\{v_i\}^T\{F_g\} \ et \ M^i=\{v_i\}^T\{M^{ext}\} \quad (15)$$

One finds:

$$\{v_1\}=\{\begin{matrix}1\\1\end{matrix}\} \quad ; \quad \{v_2\}=\{\begin{matrix}-1\\1\end{matrix}\} \quad (16)$$

$$\begin{cases} a_1=1 \quad ; \quad b_1=0 \quad ; \quad f_1=0\\ a_2=\dfrac{1}{3} \quad ; \quad b_2=4 \quad ; \quad f_2=-2\text{g}\end{cases} \quad (17)$$

One breaks up then $\{p_e\}$ on the basis of $\{v_i\}$:

$$\{p_e\}=\sum_{i=1}^{2}\alpha_e^i\{v_i\} \quad (18)$$

Taking into account the properties of orthogonality (14), the equation (12) is written:

$$\frac{N_{ee}}{\lambda_e}a_i\frac{d\alpha_e^i}{dt}+b_i\alpha_e^i=\rho_e f_i-\frac{1}{\lambda_e\rho_e}M_e^i \quad (19)$$

Initial conditions

It is supposed that:

$p_e(x,t=0)=p_a^0-p_c^0$ uniforms in space;

Taking into account the values of the vectors $\{v_1\},\{v_2\}$ (equations (16)), it is seen easily that:

$$\begin{cases}\alpha_e^1(t=0)=P_a^0-p_c^0\\ \alpha_e^2(t=0)=0\end{cases} \quad (20)$$

One places oneself in a case where the fluid flux is null ($\{M_e^{ext}\}=0$).

Taking into account (20), of $f_1=0$ (equations (17)), the solution of the system of equations (19) is:

$$\begin{cases}\alpha_e^1=P_a^0-p_c^0\\ \alpha_e^2=\dfrac{f_2}{b_2}\rho_e\left(1-\exp\left(-\dfrac{b_2}{a_2}\dfrac{\lambda_e}{N_{ee}}t\right)\right)\end{cases} \quad (21)$$

One finds while returning to the nodal variables:

$$\begin{Bmatrix}P_1\\ p_2\end{Bmatrix}=\begin{Bmatrix}\alpha_1-\alpha_2\\ \alpha_1+\alpha_2\end{Bmatrix}$$

$$\begin{Bmatrix}P_1\\ p_2\end{Bmatrix}_{eau}=\begin{Bmatrix}P_a^0-p_c^0+\dfrac{\rho_e g}{2}\left(1-\exp(-12\dfrac{\lambda_e}{N_{ee}}t)\right)\\ P_a^0-p_c^0-\dfrac{\rho_e g}{2}\left(1-\exp(-12\dfrac{\lambda_e}{N_{ee}}t)\right)\end{Bmatrix} \quad (22)$$

2.2 reference Variable

1) Evolution of the capillary pressure according to time to the points:
   $C, D \quad (z=h)$
   $A, B \quad (z=0)$
1) For the quadratic discretization: Checking of the constant value of the pressure to the nodes $E, F\,(z=\dfrac{h}{2})$.

2.3 Uncertainties

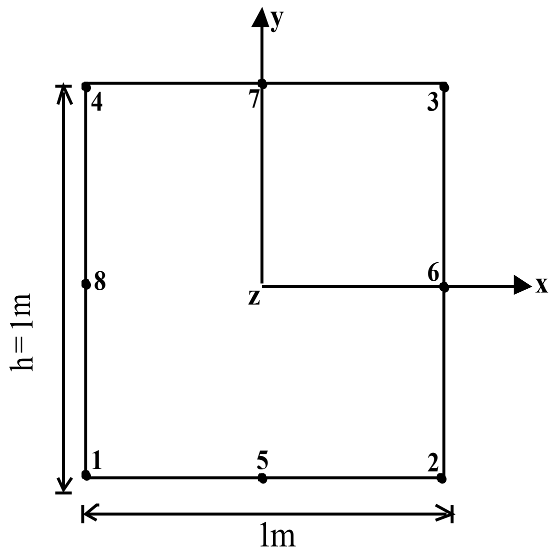
analytical Solution on the equation of hydraulics, uncertainties are thus negligible.

3 Modelization A

Behavior of the fluid: `THMC = LIQU_SATU`

3.1 Characteristic of the modelization A

plane Modelization `D_PLAN_HM`



1 net `DPQ8` of modelization `D_PLAN_HM` : `HM_ DPQ8`

3.2 Quantities tested and Discretization

results in time: Several time step (16) to study the evolution of the pressure during the transitional stage until stabilizing itself. The time scheme is implicit $(\vartheta=1)$.

List times of computation in seconds:
$1,5,10,50,100,500,10^3, 5.10^3, 10^4, 5.10^4, 10^5, 5.10^5, 10^6, 5.10^6, 10^7, 10^{10}$.

The nodal unknowns, fluid pressures evaluated in `Code_Aster`, are variations compared to the initial pressures of reference defined under key word `THM_INIT`, this is why this table present of the variations of pressure in our comparison between computation `Code_Aster` and the reference solution.

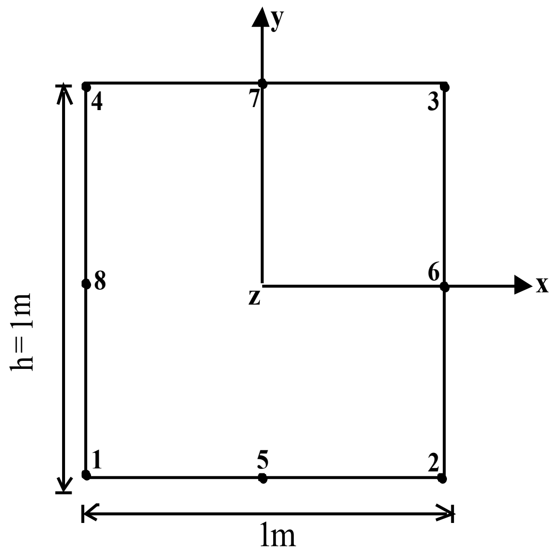
Node/not	urgent Sequence number/ (s)	Value	Reference (Pa)	Tolerance $(\%)$
$N1/A$	$1(t=1\,s)$	$PRE1$	3,98.10 -2.1.0	
	$2(t=5\,s)$	$PRE1$	1,99.10 -1.1.0	
	$3(t=10\,s)$	$PRE1$	3,98.10 -1.1.0	
	$4(t=50\,s)$	$PRE1$	1,99	1.0
	$8(t=5.10^3\,s)$	$PRE1$	1,95.10 +2	1.0
	$16(t=10^{10}\,s)$	$PRE1$	5.10 +3	1.0
$N3/C$	$1(t=1\,s)$	$PRE1$	-3,98.10 -2.1.0	
	$2(t=5\,s)$	$PRE1$	-1,99.10 -1.5.0	
	$3(t=10\,s)$	$PRE1$	-3,98.10 -1.2.0	
	$4(t=50\,s)$	$PRE1$	-1,99	2.0
	$8(t=5.10^3\,s)$	$PRE1$	-1,95.10 +2	1.0
	$16(t=10^{10}\,s)$	$PRE1$	-5.10 +3	1.0

4 Modelization B

Behavior of the fluid: `THMC = LIQU_GAZ_ATM` with a constant saturation $S=1$

4.1 Characteristics of the modelization B

plane Modelization: `D_PLAN_HM`



1 nets `DPQ8` of modelization `D_PLAN_HM` : `HM_ DPQ8`

4.2 Quantities tested and Discretization

results in time: Several time step (16) to study the evolution of the pressure during the transitional stage until stabilizing itself. The time scheme is implicit $(\vartheta=1)$.

List times of computation in seconds:
$1,5,10,50,100,500,10^3, 5.10^3, 10^4, 5.10^4, 10^5, 5.10^5, 10^6, 5.10^6, 10^7, 10^{10}$

The nodal unknowns of fluid pressure evaluated in `Code_Aster` are variations compared to the initial pressures of reference defined under key word `THM_INIT`, this is why this table present of the variations of pressure in our comparison between computation `Code_Aster` and the reference solution.

Node/not	Sequence number	Pressure	Reference (Pa)	Tolerance $(\%)$
$N1/A$	1 (t=1 S)	$PRE1$	-3,98.10 -2.1.0	
	2 (t=5 S)	$PRE1$	-1,99.10 -1.1.0	
	3 (t=10 S)	$PRE1$	-3,98.10 -1.1.0	
	4 (t=50 S)	$PRE1$	-1,99	1.0
	8 (t=5.10 3 S)	$PRE1$	-1,95.10 +2	1.0
	16 (t=10 10 S)	$PRE1$	-5.10 +3	1.0
$N3/C$	1 (t=1 S)	$PRE1$	3,98.10 -2.1.0	
	2 (t=5 S)	$PRE1$	1,99.10 -1.1.0	
	3 (t=10 S)	$PRE1$	3,98.10 -1.2.0	
	4 (t=50 S)	$PRE1$	1,99	2.0
	8 (t=5.10 3 S)	$PRE1$	1,95.10 +2	1.0
	16 (t=10 10 S)	$PRE1$	5.10 +3	1.0

4.3 Remarks

One notices that the pressures calculated for the two preceding behaviors (THMC=LIQU_SATU (models A) and THMC=LIQU_GAZ_ATM (models B)) are equal in absolute values. The difference of signs is due to the fact that:

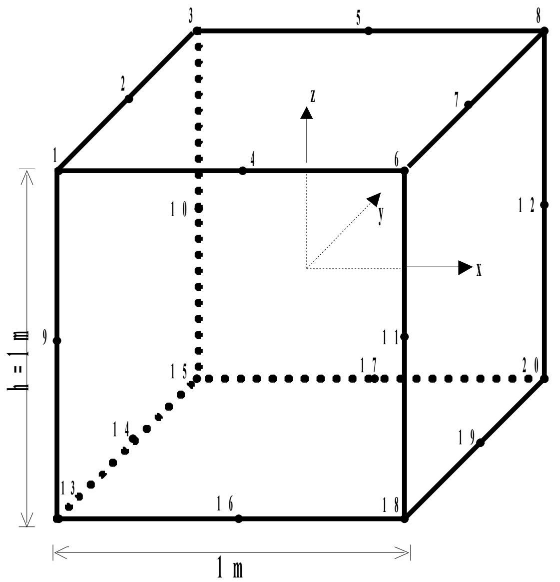
- the pressure $PRE1$ evaluated in the code is the pressure of water for behavior THMC=LIQU_SATU,
- $PRE1$ is equal to the capillary pressure for behavior THMC=LIQU_GAZ. The capillary pressure is equal to the difference between the gas pressure and the liquid pressure. In the typical case where the air pressure dryness is the atmospheric pressure (THMC=LIQU_GAZ_ATM), the capillary pressure has as a value the opposite of the liquid pressure.

5 Modelization C

Behavior of the fluid: THMC = LIQU_SATU

5.1 Characteristic of the voluminal modelization

- C Modelization: 3D_HM
- 1 mesh HEXA20 of the modelization 3D_HM : HM_HEXA20



5.2 Quantities tested and Discretization

results in time: Several time step (16) to study the evolution of the pressure during the transitional stage until stabilizing itself. The time scheme is implicit $(\vartheta=1)$.

List times of computation in seconds:
$1,5,10,50,100,500,10^3, 5.10^3, 10^4, 5.10^4, 10^5, 5.10^5, 10^6, 5.10^6, 10^7, 10^{10}$

The nodal unknowns of fluid pressure evaluated in Code_Aster are variations compared to the initial pressures of reference defined under key word THM_INIT, this is why this table present of the variations of pressure in our comparison between computation Code_Aster and the reference solution.

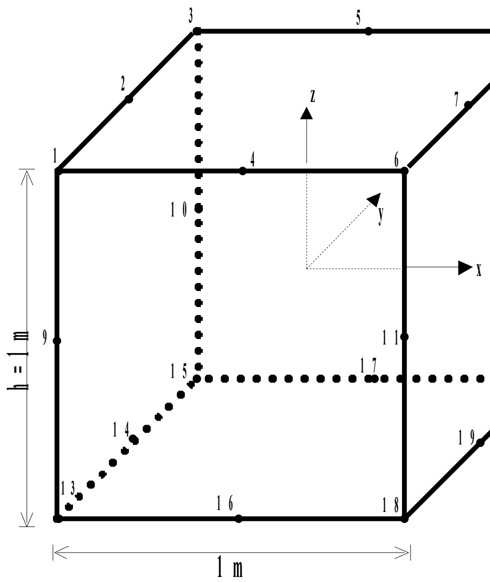
Node	Sequence number	Pressure	Reference (Pa)	Tolerance $(\%)$
$NO20$	1 (t=1 S)	$PRE1$	3,98.10 -2.1.0	
	2 (t=5 S)	$PRE1$	1,99.10 -1.1.0	
	3 (t=10 S)	$PRE1$	3,98.10 -1.1.0	
	4 (t=50 S)	$PRE1$	1,99	1.0
	8 (t=5.10 3 S)	$PRE1$	1,95.10 +2	1.0
	16 (t=10 10 S)	$PRE1$	5.10 +3	1.0
$NO1$	1 (t=1 S)	$PRE1$	-3,98.10 -2.1.0	
	2 (t=5 S)	$PRE1$	-1,99.10 -1.1.0	
	3 (t=10 S)	$PRE1$	-3,98.10 -1.2.0	
	4 (t=50 S)	$PRE1$	-1,99	2.0
	8 (t=5.10 3 S)	$PRE1$	-1,95.10 +2	1.0
	16 (t=10 10 S)	$PRE1$	-5.10 +3	1.0

6 Modelization D

Behavior of the fluid: THMC = LIQU_GAZ_ATM with a constant saturation $S=1$

6.1 Characteristics of the voluminal modelization

- •D Modelization: 3D_HM
- •1 mesh HEXA20 of the modelization 3D_HM : HM_HEXA20



6.2 Quantities tested and Discretization

results in time: Several time step (16) to study the evolution of the pressure during the transitional stage until stabilizing itself. The time scheme is implicit ($\vartheta=1$).

List times of computation in seconds:
$1, 5, 10, 50, 100, 500, 10^3, 5.10^3, 10^4, 5.10^4, 10^5, 5.10^5, 10^6, 5.10^6, 10^7, 10^{10}$

The nodal unknowns of fluid pressure evaluated in Code_Aster are variations compared to the initial pressures of reference defined under key word THM_INIT, this is why this table present of the variations of pressure in our comparison between computation Code_Aster and the reference solution.

Node	Sequence number	Pressure	Reference (Pa)	Tolerance $(\%)$
$NO20$	1 (t=1 S)	$PRE1$	-3,98.10 -2.1.0	
	2 (t=5 S)	$PRE1$	-1,99.10 -1.1.0	
	3 (t=10 S)	$PRE1$	-3,98.10 -1.1.0	
	4 (t=50 S)	$PRE1$	-1,99	1.0
	8 (t=5.10 ^{3} S)	$PRE1$	-1,95.10 $^{+2}$	1.0
	16 (t=10 ^{10} S)	$PRE1$	-5.10 $^{+3}$	1.0
$NO1$	1 (t=1 S)	$PRE1$	3,98.10 -2.1.0	
	2 (t=5 S)	$PRE1$	1,99.10 -1.1.0	
	3 (t=10 S)	$PRE1$	3,98.10 -1.2.0	
	4 (t=50 S)	$PRE1$	1,99	2.0
	8 (t=5.10 ^{3} S)	$PRE1$	1,95.10 $^{+2}$	1.0
	16 (t=10 ^{10} S)	$PRE1$	5.10 $^{+3}$	1.0

6.3 Remarks

Just as for the two-dimensional modelization, one notices that the pressures calculated for the two preceding behaviors (THMC=LIQU_SATU (models C) and THMC=LIQU_GAZ_ATM (models D)) are equal in absolute values. The difference of signs is due to the fact that:

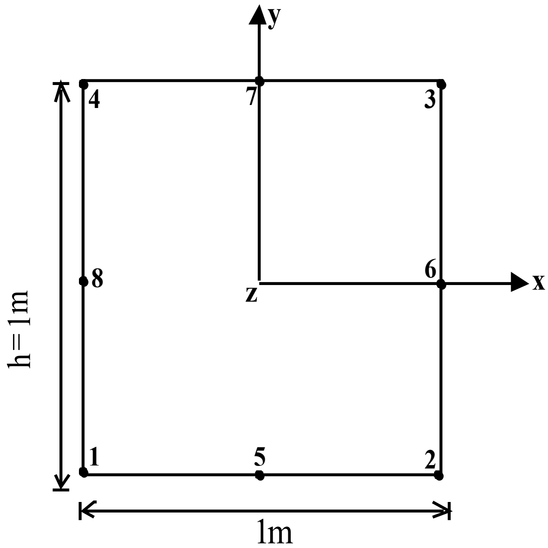
•for the behavior THMC=LIQU_SATU, the pressure $PRE1$ evaluated in the code is the pressure of water,
•and for behavior THMC=LIQU_GAZ, $PRE1$ is equal to the capillary pressure. The capillary pressure is equal to the difference between the gas pressure and the liquid pressure. In the typical case where the air pressure dryness is the atmospheric pressure (THMC=LIQU_GAZ_ATM), the capillary pressure has as a value the opposite of the liquid pressure.

7 Modelization E

Behavior of the fluid: THMC = LIQU_SATU

7.1 Characteristic of the modelization E

- Modelization plane
- 1 mesh DPQ8 of modelization D_PLAN_THM: THM_ DPQ8



7.2 Quantities tested and Discretization

results in time: Several time step (16) to study the evolution of the pressure during the transitional stage until stabilizing itself. The time scheme is implicit ($\vartheta=1$).

List times of computation in seconds:
$1,5,10,50,100,500,10^3, 5.10^3, 10^4, 5.10^4, 10^5, 5.10^5, 10^6, 5.10^6, 10^7, 10^{10}$

The nodal unknowns, fluid pressures evaluated in Code_Aster, are variations compared to the initial pressures of reference defined under key word THM_INIT, this is why this table present of the variations of pressure in our comparison between computation Code_Aster and the reference solution.

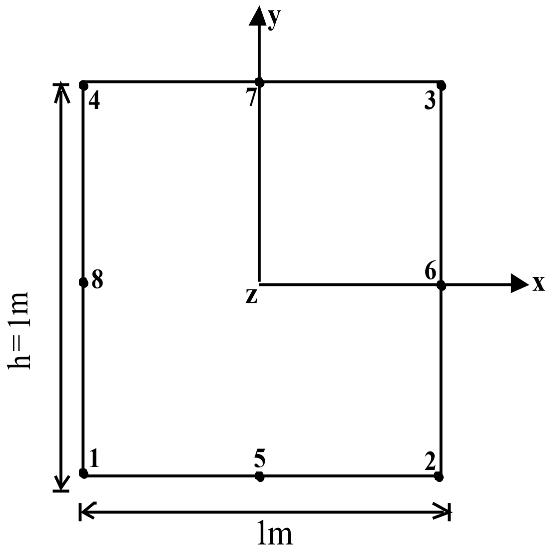
Node/not	Sequence number	Pressure	Reference (Pa)	Tolerance $(\%)$
$N1/A$	1 (t=1 S)	$PRE1$	3,98.10 $^{-2.1.0}$	
	2 (t=5 S)	$PRE1$	1,99.10 $^{-1.1.0}$	
	3 (t=10 S)	$PRE1$	3,98.10 $^{-1.1.0}$	
	4 (t=50 S)	$PRE1$	1,99	1.0
	8 (t=5.10 ^{3} S)	$PRE1$	1,95.10 $^{+2}$	1.0
	16 (t=10 ^{10} S)	$PRE1$	5.10 $^{+3}$	1.0
$N3/B$	1 (t=1 S)	$PRE1$	-3,98.10 $^{-2.1.0}$	
	2 (t=5 S)	$PRE1$	-1,99.10 $^{-1.1.0}$	
	3 (t=10 S)	$PRE1$	-3,98.10 $^{-1.2.0}$	
	4 (t=50 S)	$PRE1$	-1,99	2.0
	8 (t=5.10 ^{3} S)	$PRE1$	-1,95.10 $^{+2}$	1.0
	16 (t=10 ^{10} S)	$PRE1$	-5.10 $^{+3}$	1.0

8 Modelization F

Behavior of the fluid: THMC = LIQU_GAZ_ATM with a constant saturation $S=1$

8.1 Characteristics of the modelization F

- Modelization planes
- 1 mesh DPQ8 of modelization D_PLAN_THM: THM_ DPQ8



8.2 Quantities tested and Discretization

results in time: Several time step (16) to study the evolution of the pressure during the transitional stage until stabilizing itself. The time scheme is implicit ($\theta=1$).

List times of computation in seconds:
$1, 5, 10, 50, 100, 500, 10^3, 5.10^3, 10^4, 5.10^4, 10^5, 5.10^5, 10^6, 5.10^6, 10^7, 10^{10}$

The nodal unknowns of fluid pressure evaluated in Code_Aster are variations compared to the initial pressures of reference defined under key word THM_INIT, this is why this table present of the variations of pressure in our comparison between computation Code_Aster and the reference solution.

Node/not	Sequence number	Pressure	Reference (Pa)	Tolerance $(\%)$
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	2 (t=5 S)	$PRE1$	-1,99.10 -1.1.0	
	3 (t=10 S)	$PRE1$	-3,98.10 -1.1.0	
	4 (t=50 S)	$PRE1$	-1,99	1.0
	8 (t=5.10 ^{3} S)	$PRE1$	-1,95.10 $^{+2}$	1.0
	16 (t=10 ^{10} S)	$PRE1$	-5.10 $^{+3}$	1.0
$N3/B$	1 (t=1 S)	$PRE1$	3,98.10 -2.1.0	
	2 (t=5 S)	$PRE1$	1,99.10 -1.1.0	
	3 (t=10 S)	$PRE1$	3,98.10 -1.2.0	
	4 (t=50 S)	$PRE1$	1,99	2.0
	8 (t=5.10 ^{3} S)	$PRE1$	1,95.10 $^{+2}$	1.0
	16 (t=10 ^{10} S)	$PRE1$	5.10 $^{+3}$	1.0

8.3 Remarks

One notices that the pressures calculated for the two preceding behaviors (`THMC=LIQU_SATU` (models E) and `THMC=LIQU_GAZ_ATM` (models F)) are equal in absolute values. The difference of signs is due to the fact that:

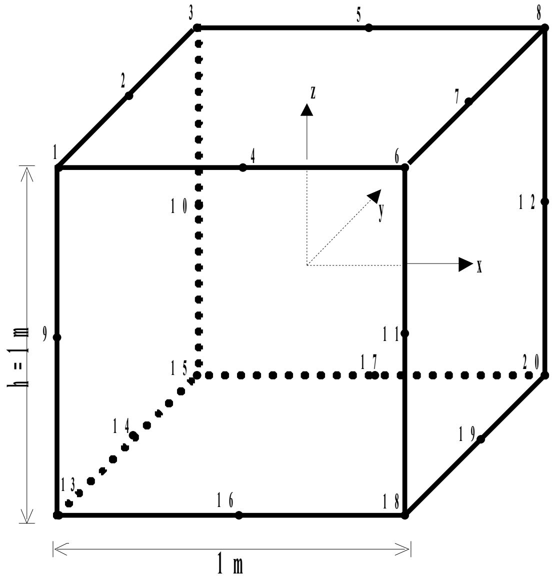
- the pressure $PRE1$ evaluated in the code is the pressure of water for behavior `THMC=LIQU_SATU`,
- $PRE1$ is equal to the capillary pressure for behavior `THMC=LIQU_GAZ`. The capillary pressure is equal to the difference between the gas pressure and the liquid pressure. In the typical case where the air pressure dryness is the atmospheric pressure (`THMC=LIQU_GAZ_ATM`), the capillary pressure has as a value the opposite of the liquid pressure.

9 Modelization G

Behavior of the fluid: THMC = LIQU_SATU

9.1 Characteristic of the voluminal modelization

- •G Modelization
- •1 mesh HEXA20 of modelization 3D_THM: THM_HEXA20



9.2 Quantities tested and Discretization

results in time: Several time step (16) to study the evolution of the pressure during the transitional stage until stabilizing itself. The time scheme is implicit $(\vartheta=1)$.

List times of computation in seconds:
$1, 5, 10, 50, 100, 500, 10^3, 5.10^3, 10^4, 5.10^4, 10^5, 5.10^5, 10^6, 5.10^6, 10^7, 10^{10}$

The nodal unknowns of fluid pressure evaluated in Code_Aster are variations compared to the initial pressures of reference defined under key word THM_INIT, this is why this table present of the variations of pressure in our comparison between computation Code_Aster and the reference solution.

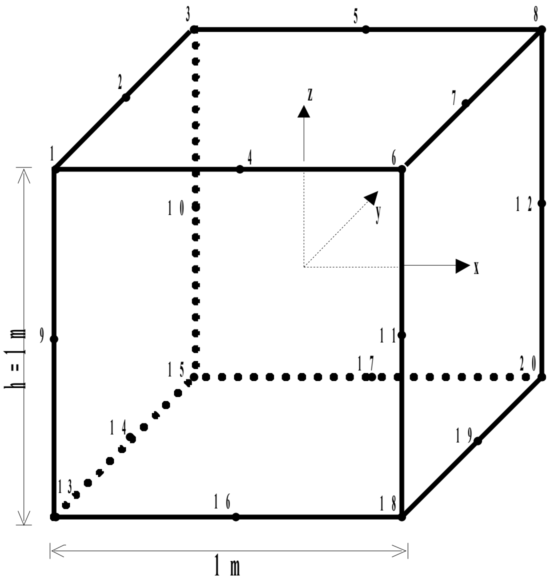
Node	Sequence number	Pressure	Reference (Pa)	Tolerance $(\%)$
NO20	1 (t=1 S)	*PRE1*	3,98.10 -2.1.0	
	2 (t=5 S)	*PRE1*	1,99.10 -1.1.0	
	3 (t=10 S)	*PRE1*	3,98.10 -1.1.0	
	4 (t=50 S)	*PRE1*	1,99	1.0
	8 (t=5.10 ^{3} S)	*PRE1*	1,95.10 $^{+2}$	1.0
	16 (t=10 ^{10} S)	*PRE1*	5.10 $^{+3}$	1.0
NO1	1 (t=1 S)	*PRE1*	-3,98.10 -2.1.0	
	2 (t=5 S)	*PRE1*	-1,99.10 -1.1.0	
	3 (t=10 S)	*PRE1*	-3,98.10 -1.2.0	
	4 (t=50 S)	*PRE1*	-1,99	2.0
	8 (t=5.10 ^{3} S)	*PRE1*	-1,95.10 $^{+2}$	1.0
	16 (t=10 ^{10} S)	*PRE1*	-5.10 $^{+3}$	1.0

10 Modelization H

Behavior of the fluid: THMC = LIQU_GAZ_ATM with a constant saturation $S=1$

10.1 Characteristics of the voluminal modelization

•H Modelization: 3D_THM



1 nets HEXA20 of modelization 3D_THM: THM_HEXA20

10.2 Quantities tested and Discretization

results in time: Several time step (16) to study the evolution of the pressure during the transitional stage until stabilizing itself. The time scheme is implicit $(\vartheta=1)$.

List times of computation in seconds:
$1,5,10,50,100,500,10^3, 5.10^3, 10^4, 5.10^4, 10^5, 5.10^5, 10^6, 5.10^6, 10^7, 10^{10}$

The nodal unknowns of fluid pressure evaluated in Code_Aster are variations compared to the initial pressures of reference defined under key word THM_INIT , this is why this table present of the variations of pressure in our comparison between computation Code_Aster and the reference solution.

Node	Sequence number	Pressure	Reference (Pa)	Tolerance $(\%)$
$NO20$	1 (t=1 S)	$PRE1$	-3,98.10 -2.1.0	
	2 (t=5 S)	$PRE1$	-1,99.10 -1.1.0	
	3 (t=10 S)	$PRE1$	-3,98.10 -1.1.0	
	4 (t=50 S)	$PRE1$	-1,99	1.0
	8 (t=5.10 3 S)	$PRE1$	-1,95.10 +2	1.0
	16 (t=10 10 S)	$PRE1$	-5.10 +3	1.0
$NO1$	1 (t=1 S)	$PRE1$	3,98.10 -2.1.0	
	2 (t=5 S)	$PRE1$	1,99.10 -1.1.0	
	3 (t=10 S)	$PRE1$	3,98.10 -1.2.0	
	4 (t=50 S)	$PRE1$	1,99	2.0
	8 (t=5.10 3 S)	$PRE1$	1,95.10 +2	1.0
	16 (t=10 10 S)	$PRE1$	5.10 +3	1.0

10.3 Remarks

Just as for the two-dimensional modelization, one notices that the pressures calculated for the two preceding behaviors (THMC=LIQU_SATU (models G) and THMC=LIQU_GAZ_ATM (models H)) are equal in absolute values. The difference of signs is due to the fact that:

- for the behavior THMC=LIQU_SATU, the pressure $PRE1$ evaluated in the code is the pressure of water,
- and for behavior THMC=LIQU_GAZ, $PRE1$ is equal to the capillary pressure. The capillary pressure is equal to the difference between the gas pressure and the liquid pressure. In the typical case where the air pressure dryness is the atmospheric pressure (THMC=LIQU_GAZ_ATM), the capillary pressure has as a value the opposite of the liquid pressure.

11 Modelization I

Behavior of the fluid: `THMC = LIQU_SATU`

11.1 Characteristic of the voluminal modelization

- •I Modelization
- •1 mesh `HEXA20` of modelization `3D_THMD: THM_HEXA20D`

They "acts of the same modelization as G but into lumped (integration at the tops). The results will be thus appreciably different from the case of reference. It is thus here about a case of non regression.

11.2 Quantities tested and results

This test being of non regression, one is satisfied with a simple validation over 2 times.

Discretization in time: Several time step (16) to study L" evolution of the pressure during the transitional stage until stabilizing itself. The time scheme is implicit $(\vartheta=1)$.

List times of computation in seconds: $5.10^{3}, 10^{10}$

Node	Sequence number	Pressure	Reference (Pa)	Tolerance $(\%)$
$NO20$	8 (t=5.10 ^{3} S)	$PRE1$	65	
	16 (t=10 ^{10} S)	$PRE1$	5.10 $^{+3}$	1.0
$NO1$	8 (t=5.10 ^{3} S)	$PRE1$	-65	
	16 (t=10 ^{10} S)	$PRE1$	-5.10 $^{+3}$	1.0

12 Modelization J

Behavior of the fluid: THMC = LIQU_SATU

12.1 Characteristic of the voluminal modelization

- •J Modelization
- •1 mesh HEXA20 of modelization 3D_THMS: THM_HEXA20S

They "acts of the same modelization as G but into selective (integration at the tops for the evolutionary terms and Gauss points for the others). The results will be thus appreciably different from the case of reference. It is thus here about a case of non regression.

12.2 Quantities tested and results

This test being of non regression, one is satisfied with a simple validation according to 2 times.

Discretization in time: Several time step (16) to study L" evolution of the pressure during the transitional stage until stabilizing itself. The time scheme is implicit $(\vartheta=1)$.

List times of computation in seconds: $5.10^{3}, 10^{10}$

Node	Sequence number	Pressure	Reference (Pa)	Tolerance $(\%)$
$NO20$	8 (t=5.10 ^{3} S)	$PRE1$	65	
	16 (t=10 ^{10} S)	$PRE1$	5.10 $^{+3}$	1.0
$NO1$	8 (t=5.10 ^{3} S)	$PRE1$	-65	
	16 (t=10 ^{10} S)	$PRE1$	-5.10 $^{+3}$	1.0

This test is also used as validation of keyword OBSERVATION , on mesh HEXA20 :

Observation	FIELD	CMP	EVAL_ELGA	EVAL_CHAM
1	SIEF_ELGA	SIP	VALE - POINT =1	MIN
2	SIEF_ELGA	SIYY	MIN	MIN
3	SIEF_ELGA	SIZZ	MIN	MIN
3	SIEF_ELGA	SIP	MIN	MIN

With the following results (NON_REGRESSION):

Observation	Sequence number	Reference (Pa)	Tolerance $(\%)$
1	16 (t=10 ^{10} S)	2886.7983561532	1.00E-006
2	16 (t=10 ^{10} S)	-4999.9526983562	1.00E-006
3	16 (t=10 ^{10} S)	-9.74094E-18	1,00E-012 (absolute)
4	16 (t=10 ^{10} S)	-6.21766E-17	1,00E-012 (absolute)
5 - MINI_ABS	16 (t=10 ^{10} S)	4999.9526983751	1.00E-006
6 - MAXI_ABS	16 (t=10 ^{10} S)	5000.0469320954	1.00E-006

13 Summary of the results

the values of *the Code_Aster* are in very good agreement with the values of reference.