WTNV113 – Gravitating flow in a saturated porous environment

Summary:

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 liquid is studied

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

The distinction between modelings A and B (respectively C and D, E and F, G and H) lies in the law of behavior of the fluid.
Modelings I and J are alternatives in modeling selective and lumpé of G, they have results which differ from the suggested analytical solution (integration is different), and are thus of nonregression.

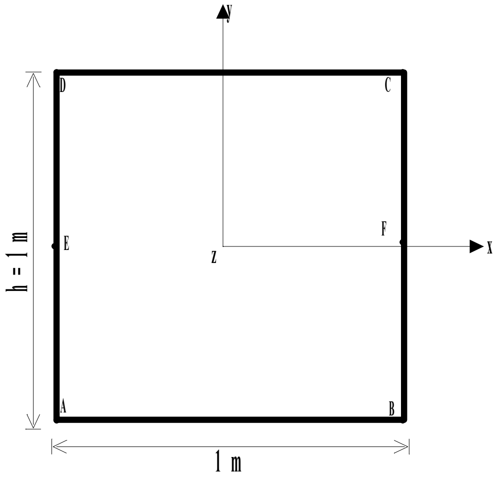
The reference solution is unidimensional because it depends only on the vertical coordinate.

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 modeling `HM` or `THM` by blocking the temperature. The associated law of behavior of the fluid is according to modelings is of type `LIQU_SATU` (modelings A, C, E, G, I, J) that is to say of type `LIQU_GAZ_ATM` (modelings B, D, F, H).

1.2 Geometry



Coordinates 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 material

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

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 modelings THM , $T=0°$.

1.5 Initial conditions

The fields of displacement, of capillary pressure are initially worthless, the air pressure dryness is equal to the atmospheric pressure and the temperature of reference 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 expression:

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

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 flow of fluid has as an expression:

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

However the mass contribution of fluid is defined by the equation (4) where terms N_{ee} and N_{ea} (equation (5)) depend on the degree of saturation S, porosity ϕ, coefficient of Biot b, permeability of the liquid K_e and of the 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 $\dfrac{\partial S}{\partial P_c}=0$. $\Rightarrow N_{ee}=S\left(\dfrac{\varphi}{K_e}+\dfrac{b-\varphi}{K_s}S\right)$ 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:

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

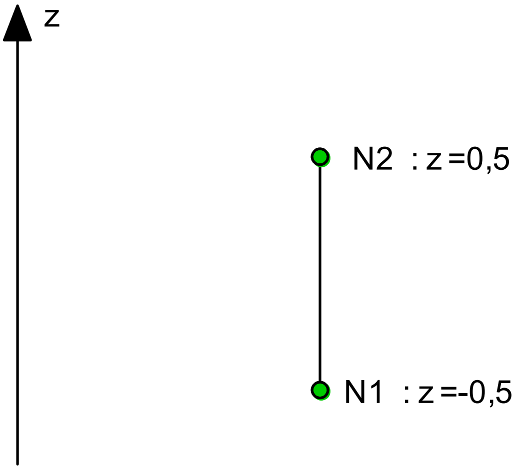
Discretization

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

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

It is supposed in addition that non-linearities are low and that 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:

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

With:

$$\begin{cases} \lambda_1=\frac{1}{2}-z \\ \lambda_2=\frac{1}{2}+z \end{cases} \tag{8}$$

By introducing the matrices and vectors then:

$$\begin{aligned} [A]=[A_{ij}] \quad &; \; A_{ij}=\int_{-1/2}^{1/2} \lambda_i \lambda_j dz \\ [B]=[B_{ij}] \quad &; \; B_{ij}=\int_{-1/2}^{1/2} \frac{d\lambda_i}{dz}\frac{d\lambda_j}{dz} dz \\ \{F_g\}=\{F_{gi}\} \; &; \; F_{gi}=\int_{-1/2}^{1/2} \frac{d\lambda_i}{dz} dz \end{aligned} \tag{9}$$

And while noting:

$$\{p_e\}=\begin{Bmatrix} P_e^1 \\ p_e^2 \end{Bmatrix} \tag{10}$$

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

The equation (6) becomes:

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

The calculation of the matrices $[A]$ and $[B]$ and of the vector $\{f_g\}$ give:

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

(13)

The clean vectors then are defined $[A]^{-1}[B]$ of : $\{v_1\},\{v_2\}$ who have the following properties of orthogonality:

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

And one poses:

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

One finds:

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

$$\begin{cases} a_1=1 \quad ; \quad b_1=0 \quad ; \quad f_1=0\\ a_2=\frac{1}{3} \quad ; \quad b_2=4 \quad ; \quad f_2=-2\mathrm{g}\end{cases} \tag{17}$$

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

$$\{p_e\}=\sum_{i=1}^{2}\alpha_e^i\{v_i\} \tag{18}$$

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

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

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:

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

One places oneself in a case where the flow of fluid 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:

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

One finds while returning to the nodal variables:

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

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

2.2 Reference variable

1) Evolution of the capillary pressure according to time at 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 $E,F(z=\frac{h}{2})$.

2.3 Uncertainties

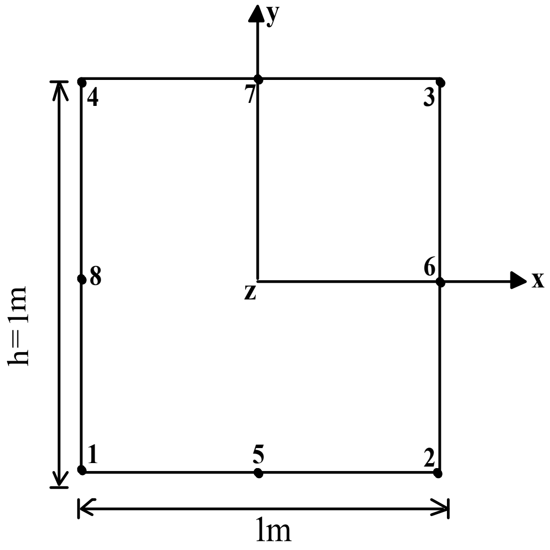
Analytical solution on the equation of hydraulics, uncertainties are thus negligible.

3 Modeling A

Behavior of the fluid: `THMC = LIQU_SATU`

3.1 Characteristics of modeling A

Plane modeling `D_PLAN_HM`



1 mesh `DPQ8` modeling `D_PLAN_HM` : `HM_ DPQ8`

3.2 Sizes tested and results

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

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

Nodal unknown factors, pressures of fluid evaluated in `Code_Aster`, are variations compared to the initial pressures of reference defined under the keyword `THM_INIT`, this is why this table presents variations of pressure in our comparison between calculation `Code_Aster` and the reference solution.

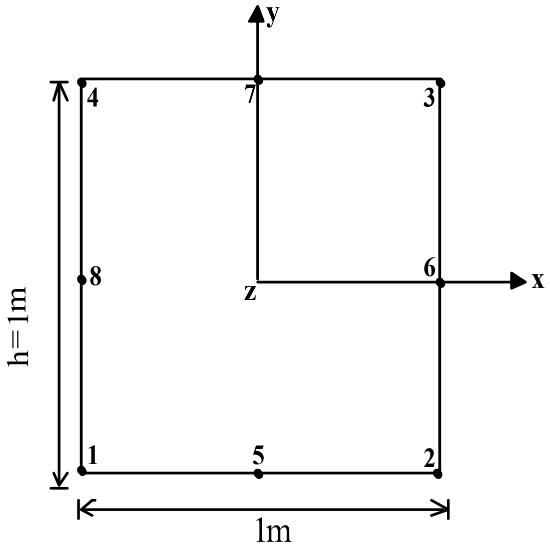
Node/not	**Urgent sequence number/** (s)	**Value**	**Reference** (Pa)	**Tolerance** $(\%)$
$N1/A$	$1(t=1\,s)$	$PRE1$	3,98.10 $^{-2}$	1.0
	$2(t=5\,s)$	$PRE1$	1,99.10 $^{-1}$	1.0
	$3(t=10\,s)$	$PRE1$	3,98.10 $^{-1}$	1.0
	$4(t=50\,s)$	$PRE1$	1.99	1.0
	$8(t=5.10^{3}\,s)$	$PRE1$	1,95.10 $^{+2}$	1.0
	$16(t=10^{10}\,s)$	$PRE1$	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 Modeling B

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

4.1 Characteristics of modeling B

Plane modeling: `D_PLAN_HM`



1 mesh `DPQ8` modeling `D_PLAN_HM` : `HM_ DPQ8`

4.2 Sizes tested and results

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

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

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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

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

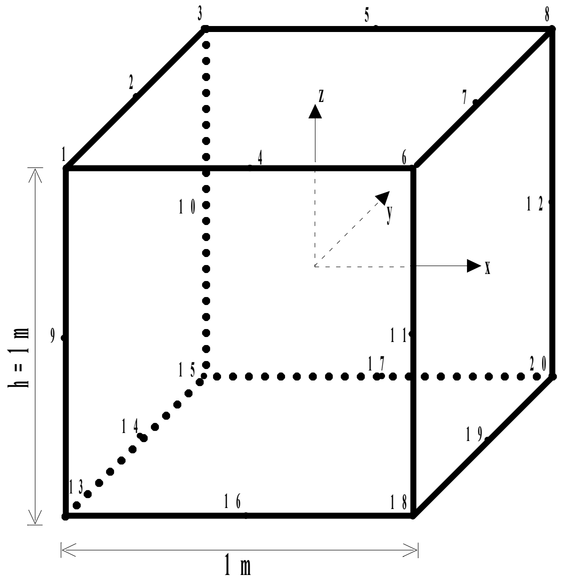
- pressure $PRE1$ evaluated in the code is the pressure of water for the behavior `THMC=LIQU_SATU`,
- $PRE1$ is equal to the capillary pressure for the behavior `THMC=LIQU_GAZ`. The capillary pressure is equal to the difference between the gas pressure and the liquid pressure. In the typical case where 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 Modeling C

Behavior of the fluid: `THMC = LIQU_SATU`

5.1 Characteristics of modeling C

- Voluminal modeling: `3D_HM`
- 1 mesh `HEXA20` modeling `3D_HM` : `HM_HEXA20`



5.2 Sizes tested and results

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

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

Nodal unknown factors of pressure of fluids evaluated in `Code_Aster` are variations compared to the initial pressures of reference defined under the keyword `THM_INIT`, this is why this table presents variations of pressure in our comparison between calculation `Code_Aster` and the reference solution.

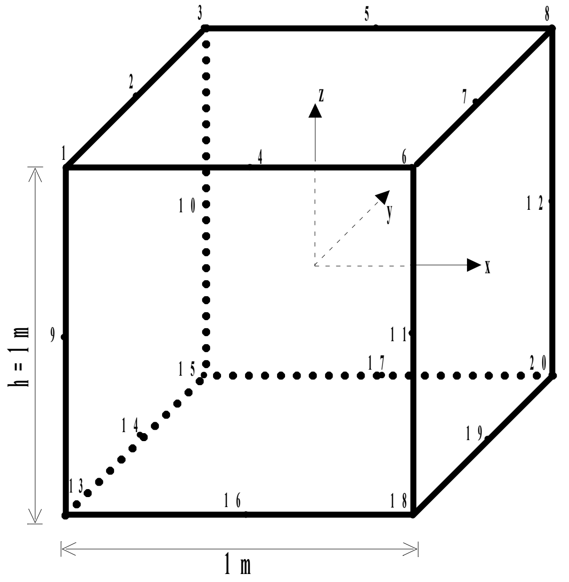
Node	**Sequence number**	**Pressure**	**Reference** (Pa)	**Tolerance** $(\%)$
$NO20$	1 (t=1 S)	$PRE1$	3,98.10^{-2}	1.0
	2 (t=5 S)	$PRE1$	1,99.10^{-1}	1.0
	3 (t=10 S)	$PRE1$	3,98.10^{-1}	1.0
	4 (t=50 S)	$PRE1$	1.99	1.0
	8 (t=5.10^{3} S)	$PRE1$	1,95.10^{+2}	1.0
	16 (t=10^{10} S)	$PRE1$	5.10^{+3}	1.0
$NO1$	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 Modeling D

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

6.1 Characteristics of modeling D

- Voluminal modeling: `3D_HM`
- 1 mesh `HEXA20` modeling `3D_HM` : `HM_HEXA20`



6.2 Sizes tested and results

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

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

Nodal unknown factors of pressure of fluid evaluated in `Code_Aster` are variations compared to the initial pressures of reference defined under the keyword `THM_INIT`, this is why this table presents variations of pressure in our comparison between calculation `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 two-dimensional modeling, one notices that pressures calculated for the two preceding behaviors (`THMC=LIQU_SATU` (model C) and `THMC=LIQU_GAZ_ATM` (model D)) are equal in absolute values. The difference of signs is due to the fact that:

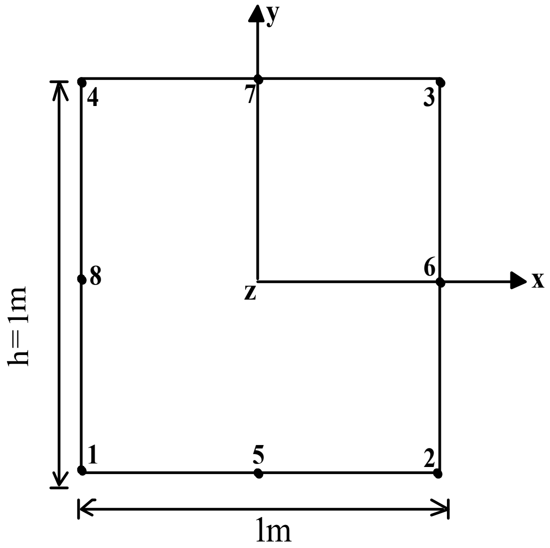
- for the behavior T`HMC=LIQU_SATU`, pressure $PRE1$ evaluated in the code is the pressure of water,
- and for the behavior `THMC=LIQU_GAZ`, $PRE1$ is equal to the capillary pressure. The capillary pressure is equal to the difference between the gas pressure and the liquid pressure. In the typical case 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 Modeling E

Behavior of the fluid: `THMC = LIQU_SATU`

7.1 Characteristics of modeling E

- Plane modeling
- 1 mesh `DPQ8` modeling `D_PLAN_THM: THM_ DPQ8`



7.2 Sizes tested and results

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

List of the moments of calculation in seconds:
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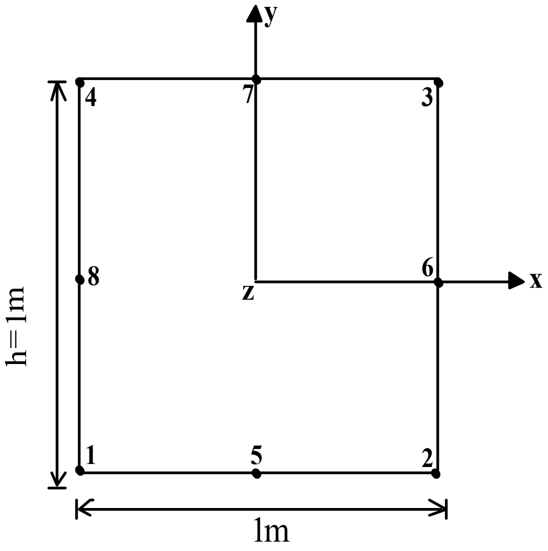
	4 (t=50 S)	$PRE1$	1.99	1.0
	8 (t=5.10 ^{3} S)	$PRE1$	1,95.10 $^{+2}$	1.0
	16 (t=10 ^{10} S)	$PRE1$	5.10 $^{+3}$	1.0
$N3/B$	1 (t=1 S)	$PRE1$	-3,98.10 $^{-2}$	1.0
	2 (t=5 S)	$PRE1$	-1,99.10 $^{-1}$	1.0
	3 (t=10 S)	$PRE1$	-3,98.10 $^{-1}$	2.0
	4 (t=50 S)	$PRE1$	-1.99	2.0
	8 (t=5.10 ^{3} S)	$PRE1$	-1,95.10 $^{+2}$	1.0
	16 (t=10 ^{10} S)	$PRE1$	-5.10 $^{+3}$	1.0

8 Modeling F

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

8.1 Characteristics of modeling F

- Plane modeling
- 1 mesh `DPQ8` modeling `D_PLAN_THM: THM_ DPQ8`



8.2 Sizes tested and results

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

List of the moments of calculation in seconds:
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	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

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

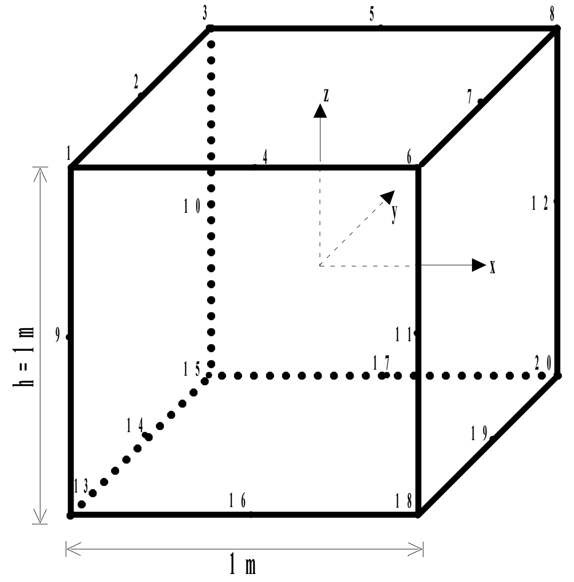
- pressure $PRE1$ evaluated in the code is the pressure of water for the behavior `THMC=LIQU_SATU`,
- $PRE1$ is equal to the capillary pressure for the behavior `THMC=LIQU_GAZ`. The capillary pressure is equal to the difference between the gas pressure and the liquid pressure. In the typical case where 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 Modeling G

Behavior of the fluid: `THMC = LIQU_SATU`

9.1 Characteristics of modeling G

- Voluminal modeling
- 1 mesh `HEXA20` modeling `3D_THM: THM_HEXA20`



9.2 Sizes tested and results

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

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

Nodal unknown factors of pressure of fluids evaluated in `Code_Aster` are variations compared to the initial pressures of reference defined under the keyword `THM_INIT`, this is why this table presents variations of pressure in our comparison between calculation `Code_Aster` and the reference solution.

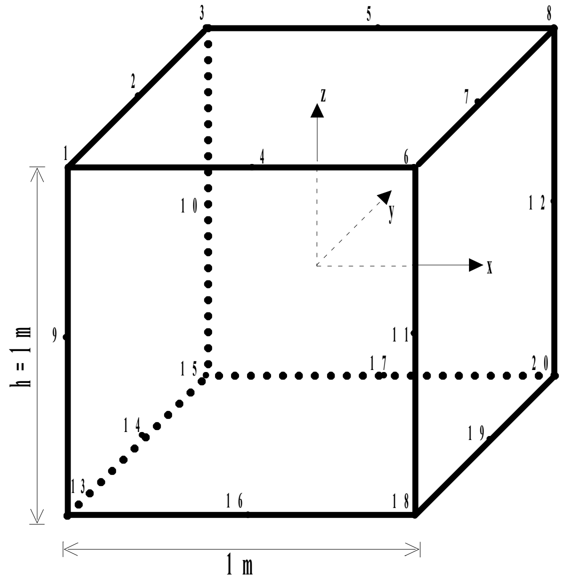
Node	**Sequence number**	**Pressure**	**Reference** (Pa)	**Tolerance** $(\%)$
$NO20$	1 (t=1 S)	$PRE1$	3,98.10^{-2}	1.0
	2 (t=5 S)	$PRE1$	1,99.10^{-1}	1.0
	3 (t=10 S)	$PRE1$	3,98.10^{-1}	1.0
	4 (t=50 S)	$PRE1$	1.99	1.0
	8 (t=5.10^{3} S)	$PRE1$	1,95.10^{+2}	1.0
	16 (t=10^{10} S)	$PRE1$	5.10^{+3}	1.0
$NO1$	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 Modeling H

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

10.1 Characteristics of modeling H

- Voluminal modeling: `3D_THM`



1 mesh `HEXA20` modeling `3D_THM: THM_HEXA20`

10.2 Sizes tested and results

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

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

Nodal unknown factors of pressure of fluid evaluated in `Code_Aster` are variations compared to the initial pressures of reference defined under the keyword `THM_INIT` , this is why this table presents variations of pressure in our comparison between calculation `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 two-dimensional modeling, one notices that pressures calculated for the two preceding behaviors (`THMC=LIQU_SATU` (model G) and `THMC=LIQU_GAZ_ATM` (model H)) are equal in absolute values. The difference of signs is due to the fact that:

- for the behavior `THMC=LIQU_SATU`, pressure $PRE1$ evaluated in the code is the pressure of water,
- and for the 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 Modeling I

Behavior of the fluid: `THMC = LIQU_SATU`

11.1 Characteristics of modeling I

- Voluminal modeling
- 1 mesh `HEXA20` modeling `3D_THMD: THM_HEXA20D`

They ‘acts of the same modeling as G but in lumpé (integration at the tops). The results will be thus appreciably different from the case of reference. It is thus here about a case of nonregression.

11.2 Sizes tested and results

This test being of nonregression, one is satisfied with a simple validation over 2 moments.

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

List of the moments of calculation in seconds: $5.10^3, 10^{10}$

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

12 Modeling J

Behavior of the fluid: `THMC = LIQU_SATU`

12.1 Characteristics of modeling J

- Voluminal modeling
- 1 mesh `HEXA20` modeling `3D_THMS: THM_HEXA20S`

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

12.2 Sizes tested and results

This test being of nonregression, one is satisfied with a simple validation according to 2 moments.

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

List of the moments of calculation in seconds: $5.10^3, 10^{10}$

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

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

Observation	`FIELD`	`CMP`	`EVAL_ELGA`	`EVAL_CHAM`
1	`SIEF_ELGA`	`SIP`	`VALE - NOT =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

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