WTNV147 - Coupling hydromechanics in a column poro-rubber band and fractured: use of the method XFEM

Summary:

The goal of this test is to make sure of the good performance DU coupling hydrodynamic between the cohesive interface and the porous matrix for hydraulic elements coupled with XFEM. This test is thus purely hydrodynamic, all the degrees of freedom of displacements are blocked to zero. Modeling A is two-dimensional while modeling B is three-dimensional.

1 Problem of reference

1.1 Geometry of the problem

It is about a column height $LZ=5m$, length $LX=1m$ and of width $LY=1m$. This column presents in $Z=\frac{LZ}{2}$ a discontinuity of the type interfaces. The column is thus entirely crossed by discontinuity.

One represents on the Figure 1.1-a geometry of the column.

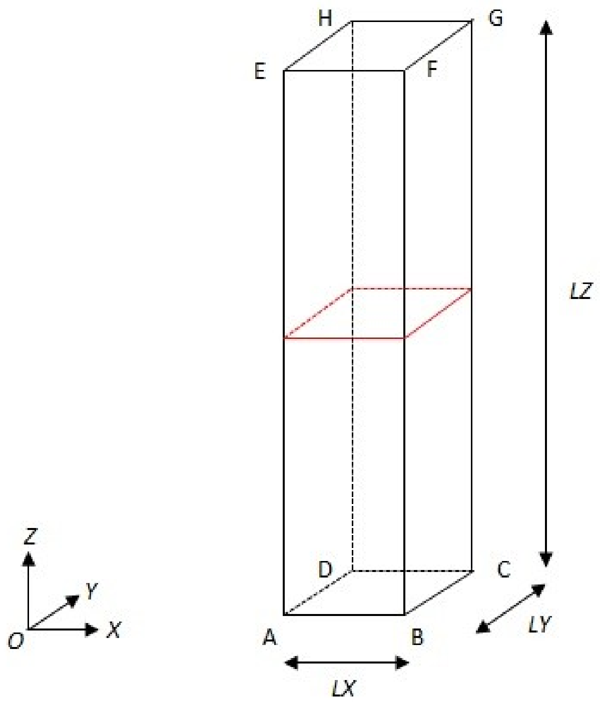


Figure 1.1-a: Geometry of the problem

1.2 Properties materials

Parameters given in the Table 1.2-1, correspond to the parameters used for modeling in the hydraulic coupled case. The mixing rate used is `'LIQU_SATU'`. The parameters specific to this mixing rate are given but do not have any influence on the solution (because we chose to measure a pressure of pore uniformly worthless in all the field). Only the elastic parameters affect the solution of the pseudo-coupled problem.

Liquid (water)	Viscosity $\mu_w(en\ Pa.s)$	1,0
	Module of compressibility $\frac{1}{K_w}(en\ Pa^{-1})$	5.10^{-10}
	Density of the liquid $\rho_w(en\ kg/m^3)$	1
Elastic parameters	Young modulus $E(en\ MPa)$	5800
	Poisson's ratio ν	0
	Thermal dilation coefficient $\alpha(en\ K^{-1})$	0
Parameters of coupling	Coefficient of Biot b	1
	Initial homogenized density $r_0(en\ kg/m^3)$	2,5
	Intrinsic permeability $K^{\mathrm{int}}(en\ m^2)$	$1{,}01937^{-9}$
Parameters of the cohesive law	Critical stress $\sigma_c(en\ MPa)$	1.1
	Cohesive energy $G_c(en\ Pa.m)$	900
	Coefficient of increase r	10

Table 1.2-1 : Properties of material

In addition, the forces related to gravity (in the conservation equation of the momentum) are neglected. The pressure of pore of reference is taken worthless $p_1^{\mathrm{ref}}=0\,MPa$ and the porosity of material is $\varphi=0{,}15$.

1.3 Boundary conditions

L is appliedbe conditions of Dirichlet following :

- in the whole of the field, displacements are blocked to zero ($u_x=0$, $u_y=0$ and $u_z=0$ in the three-dimensional case),
- on Lbe faceS [ABCD] and [EFGH], Lpressure of pore has is blocked to zero,
- in the cohesive interface, one imposes a pressure of fluid $p_f=10\,MPa$.

The initial pressure of pore in the matrix is worthless. One carries out the test over one total duration $t=10\,s$. The parameter θ is taken equal to $0{,}56999999$.

2 Reference solution

2.1 Method of calculating

It is about an analytical solution. Pressure of fluid p_f imposed in the cohesive interface is transmitted to the pressure of pore on the level of the lips of the cohesive interface (cf Documentation [R7.02.18]). Taking into account the boundary conditions, all occurs as if a level of pressure of pore were imposed at the end of the two pennies columns formed by the cohesive interface. The problem is thus one-way. These two pennies columns are fixed because displacements are blocked. By neglecting gravity, the conservation equation of the mass in the porous matrix is written in the following way:

$$\frac{\partial m_w}{\partial t}+\nabla\cdot\boldsymbol{M}=0$$

with $m_w=\rho\varphi(1+\epsilon_v)$ mass contributions in the porous matrix and $\boldsymbol{M}=\frac{-\rho K^{\text{int}}}{\mu_w}\nabla p$ the flow of Darcéen fluid in the porous matrix. Displacements being blocked, voluminal deformation ϵ_v is worthless. In addition, $d\varphi=(b-\varphi)(d\epsilon_v+\frac{dp}{K_s})$ with K_s the module of compressibility of the solid matrix. However the solid matrix is supposed to be incompressible because we took $b=1$ (and $b=1-\frac{K_m}{K_s}$ with K_S the module of compressibility of the porous environment). Thus finally $d\varphi=0$. Finally $\frac{d\rho}{\rho}=\frac{dp}{K_w}$. The conservation equation of the mass is thus rewritten:

$$\frac{\rho\varphi}{K_w}\frac{\partial p}{\partial t}-\frac{K^{\text{int}}}{\mu_w}[\nabla p\cdot\nabla\rho+\rho\Delta p]=0$$

EN neglecting the second-order term $\nabla p\cdot\nabla\rho$, it comes:

$$\frac{\varphi\mu_w}{K_w K^{\text{int}}}\frac{\partial p}{\partial t}=\Delta p$$

It is about an equation of diffusion. The coefficient $\frac{\varphi\mu_w}{K_w K^{\text{int}}}$ corresponding to a time over a length squared. In our problem, characteristic dimension for the diffusion is $\frac{LZ}{2}$. One from of deduced a time characteristic of diffusion $\tau=\frac{\varphi\mu_w}{K_w K^{\text{int}}}*(\frac{LZ}{2})^2$. This characteristic time is worth $\tau=0,459842s$. At the end of $t=10s$, the diffusion is thus completed, the pressure of pore in the porous matrix checks then $\Delta p=0$.

According to the boundary conditions, below the interface :

- Lpressure of pore has is worth $p(y)=\frac{2y}{LZ}p_f$ and the flow of fluid in the matrix is worth $\boldsymbol{M}=\frac{-2\rho K^{\text{int}} p_f}{LZ\mu_w}$.

And with the top of the interface :

- Lpressure of pore has is worth $p(y)=(1-\frac{y}{LZ})2p_f$ and the flow of fluid in the matrix is worth $\boldsymbol{M}=\frac{2\rho K^{\text{int}} p_f}{LZ\mu_w}$.

2.2 Sizes and results of reference

One tests the value of outgoing flows of the cohesive interface towards the lower parts and higher of porous column as well as the value of the pressure of pore in $z=4m$ and $z=6m$.

Sizes tested	Value
LAG_FLI (outgoing Flow of the interface towards the lower part of the column)	4.07748 kg·m ² /s
LAG_FLS (outgoing Flow of the interface towards the upper part of the column)	4.07748 kg·m ² /s
PRE1 (in Z=4m)	8Mpa
PRE1 (in Z=6m)	8Mpa

2.3 Uncertainties on the solution

Lsolution has of reference is analytical.

2.4 Bibliographical references

[1] Reference material R7.02.18 (Hydraulic elements coupled with the method Elements Finis Étendue).

3 Modeling A

3.1 Characteristics of modeling

It is about a modeling D_PLAN_HM using quadratic elements HM-XFEM. The bar on which one carries out modeling is divided into 5 QUAD8. The interface is nonwith a grid and cuts the central element. Thus there are 3 classical elements HM-XFEM and 2 elements HM. As indicated on the Figure 3.1-a, 3 elements XFEM undergo under cutting under triangles (to carry out the integration of Gauss-Legendre on both sides of lips of the interface, but these triangular subelements are not elements of the grid).

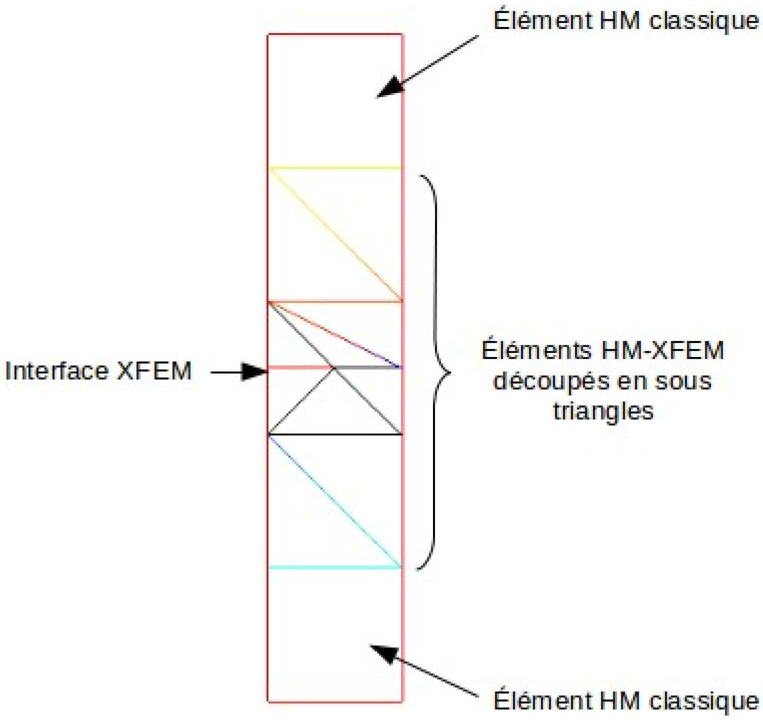


Figure 3.1-a: Characteristics of modeling

3.2 Characteristics of the grid

The grid consists of 5 meshs quadratic quadrangles (QUAD8).

3.3 Sizes tested and results

The results (resolution with STAT_NON_LINE) are synthesized in the table below. To test all the nodes of the bar at the same time, it is calculated MIN and it MAX.

Sizes tested	Type of reference	Value of reference	Tolerance (%)
PRE1 (Y=4mand Y=6m) MIN	'ANALYTICAL'	8 MPa	0.001
PRE1 (Y=4mand Y=6m) MAX	'ANALYTICAL'	8 MPa	0.001
LAG_FLI (with as ofOcustom) MIN	'ANALYTICAL'	4.07748 kg.m ² /s	0.01

`LAG_FLS` (with the top) `MAX`	'ANALYTICAL'	4.07748 kg.m ² /s	0.01

One can note (starting from the Figure 3.3-a) a frank discontinuity DE the derivative first of the field field of pressure of pore in the central element on the level of the cohesive interface. That suggests the good taking into account of enrichment in the approximation of the field of pressure of pore by the Heaviside function. In addition, pressure of fluid in the interface p_f "is well transmitted" to the porous matrix, on both sides of the cohesive interface.

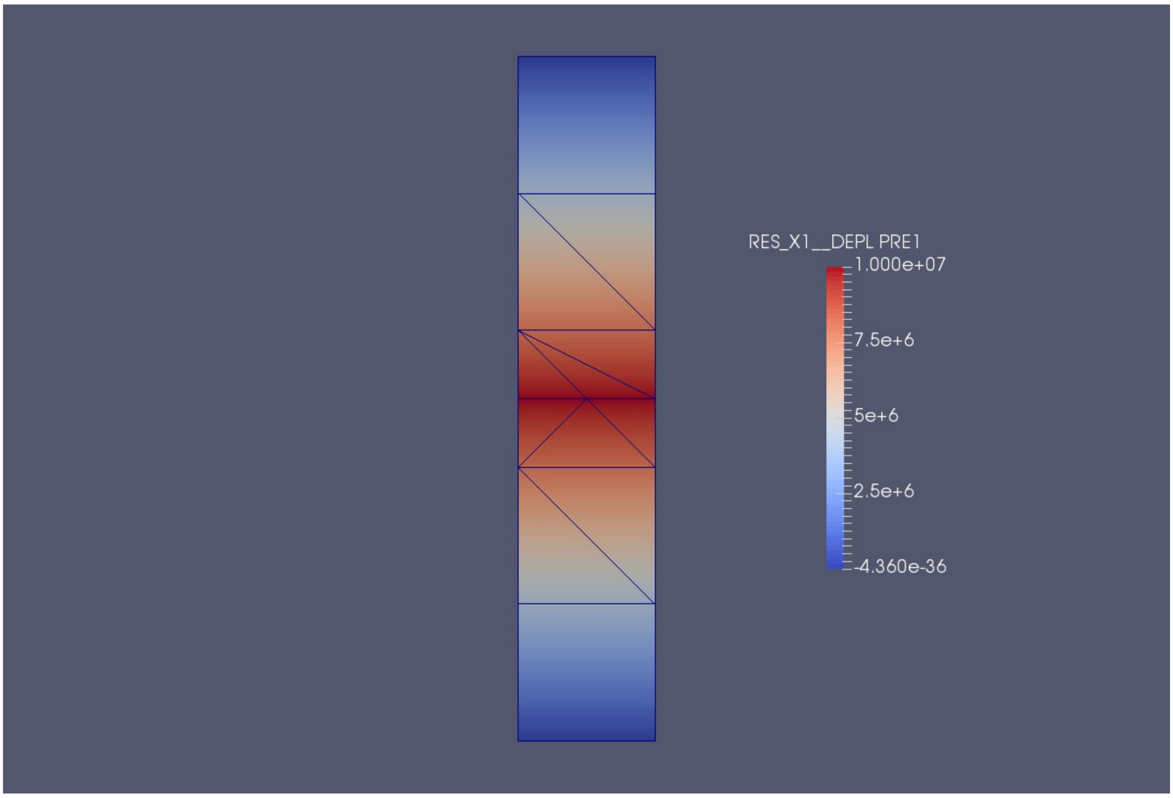


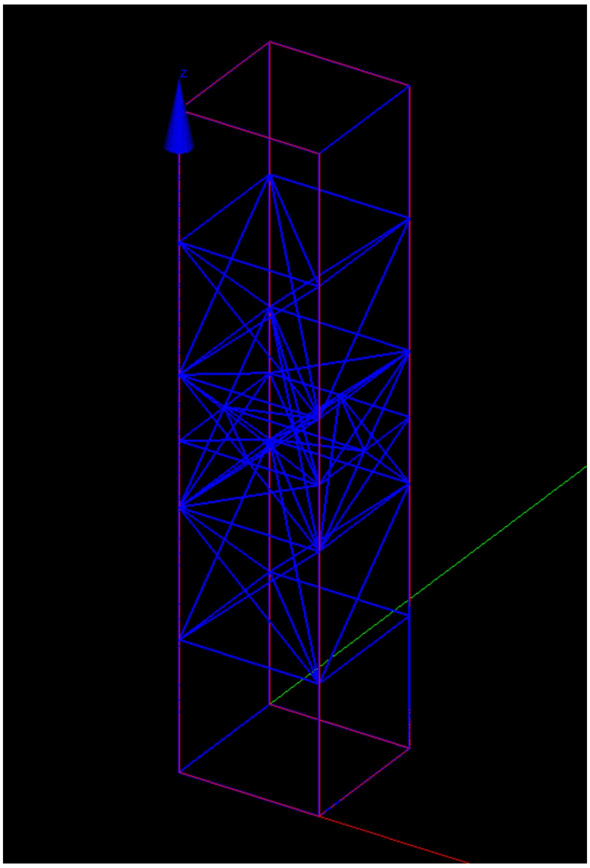
Figure 3.3-a: Field of pressure of pore with t=10s

4 Modeling B

4.1 Characteristics of modeling

It is about a modeling 3D_HM using quadratic elements HM-XFEM. The column on which one carries out modeling is divided into 5 HEXA20. The interface is nonwith a grid and cuts the central element. Thus there are 3 classical elements HM-XFEM and 2 elements HM (two hexahedrons which form the ends of the column). As indicated on the Figure 4.1-a, 3 elements XFEM undergo under cutting under tetrahedrons (to carry out the integration of Gauss-Legendre on both sides of lips of the interface, but these subelements tetrahedrons are not elements of the grid).

Figure 4.1-a: Characteristics of modeling



4.2 Characteristics of the grid

The grid consists of 5 meshs hexaédric quadratic (HEXA20).

4.3 Sizes tested and results

The results (resolution with STAT_NON_LINE) are synthesized in the table below. To test all the nodes of the bar at the same time, it is calculated MIN and it MAX.

Sizes tested	Type of reference	Value of reference	Tolerance (%)
PRE1 (Z=4mand Z=6m) MIN	'ANALYTICAL'	8 MPa	0.001
PRE1 (Z=4mand Z=6m) MAX	'ANALYTICAL'	8 MPa	0.001
LAG_FLI (with as ofOcustom) MIN	'ANALYTICAL'	4.07748 kg.m ² /s	0.01
LAG_FLS (with the top) MAX	'ANALYTICAL'	4.07748 kg.m ² /s	0.01

5 Summary of the results

This test makes it possible to validate the hydrodynamic coupling between the cohesive interface and the porous matrix for cohesive elements HM-XFEM, in particular via outgoing flows of the cohesive interface LAG_FLI and LAG_FLS. One validates also Bonne taken into account of enrichment in the approximation of the field of pressure of pore by the Heaviside function.