WTNV124 - Test of désaturation-consolidation with the model of Barcelona

Summary:

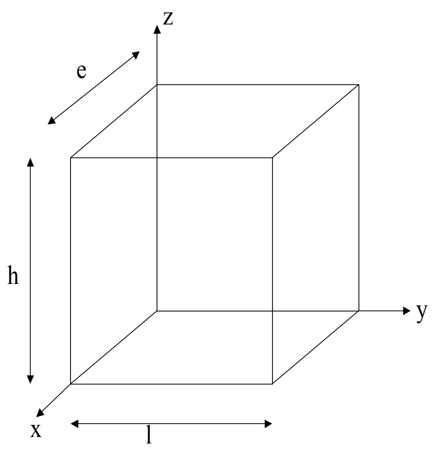
This test makes it possible to validate the model of Barcelona, which integrates an elastoplastic mechanical law coupled with hydraulics (and possibly with thermics) in condition of nonsaturation of the liquid phase. This law integrates an elastoplastic hydrostatic mechanism (of which the elastic part is not - linear and the threshold of flow corresponds to a pressure of variable consolidation with suction) coupled to an elastoplastic mechanism deviatoric. The characteristics of these mechanisms depend on suction (i.e. of the difference between gas pressure and pressure of liquid). There exist in particular two mechanisms of work hardening in completely coupled pressure and suction. The surface of load of the model of Barcelona is appeared (in the diagram pressure hydrostatic-diverter and for a given suction) as an ellipse cutting the hydrostatic axis in two points: the value of the pressure of consolidation and the cohesion of material proportional to suction. In condition of complete saturation, this criterion is reduced to that of the model Camwood-Clay specific to the saturated normally consolidated grounds.
This test carried out in hydro-mechanical coupling (modeling `HHM`) understands two ways of loading:

1) a way of desaturation while making increase the capillary pressure beyond the hydrous threshold of plasticity,
2) a hydrostatic way of compression on the désaturé sample.

Modeling is carried out in `3D`.

1 Problem of reference

1.1 Geometry



height: $h=1\mathrm{m}$
width: $l=1\,m$
thickness: $e=1\,m$

1.2 Properties of material

Thermoelastic properties:

$E=22.4\,E7\,Pa$

$\nu=0.3$

$\rho=2500\,kg/m^3$

- Modulus of rigidity $\mu=7.76\,10^6\,Pa$
- Initial porosity $PORO=0.14$
- Plastic module of compressibility with of saturated $\lambda=0.25$,
- Elastic module of compressibility $\kappa=0.05$,
- Critical line slope $M=0.9$,
- Critical pressure equalizes with half of the pressure of consolidation to saturation $PRES\_CRIT=3.E7Pa$,
- Pressure of reference $PA=1.E5$ Pa
- Parameters allowing to calculate the module of compressibility according to suction $\lambda(p_c)=\lambda(0)\left|(1-r)\exp(-\beta p_c)+r,\right|$
  $r=0.75, \beta=12.5\,E-6$
- Slope of cohesion $k_c=0.6$
- Initial threshold of suction `PC0_INIT` $p_{c0}(0)=6E7$
- Elastic module of compressibility of suction $\kappa_s=0.01$
- Plastic module of compressibility of suction $\lambda_s=0.05$

Hydraulic properties : the hydraulic properties of material which are independent of the model of Barcelona but nevertheless necessary to carry out coupled calculation are presented in the table below:

Liquid water	Density ($kg.m^{-3}$)	1.10^{3}
	Heat with constant pressure ($J.K^{-1}$)	4180
	Opposite of the coefficient of compressibility (Pa^{-1})	$0,510^{-9}$
	Intrinsic permeability (m^{2})	1.10^{-18}
	viscosity	1.10^{-3}
Initial state	Porosity	0.14
	Temperature (K)	293
	Capillary pressure (Pa)	$1.51\ 10^{7}$
	Gas pressure (Pa)	$1.51\ 10^{5}$
	Initial saturation in liquid	0.99
Constants	Constant of perfect gases	8.315
Homogenized coefficients	Homogenized density ($kg.m^{-3}$)	2400
	Capillary curve	$S(P_c) = 0.99(1 - 6\ 10^{-9}\ p_c)$
	Coefficient of Biot	1

1.3 Boundary conditions and loadings

The first way of loading consists in carrying out a desaturation, with a constant hydrostatic pressure $P = 1.E7\ Pa$ (the gas pressure is kept constant with $PRE2 = 1.E5\ Pa$ during all the test). The capillary pressure varies from zero until $PRE1 = 7.E7\ Pa$, beyond the threshold of plasticization equal initially to $PRE1 = 6.E7\ Pa$. Work hardening due to the increase in suction causes an increase in the threshold of consolidation, since two work hardenings hydrous and mechanical are coupled in the model of Barcelona. One checks it while following the second way consisting in putting hydrostatic pressure exceeding the initial threshold ($P_{con} = 6.E7 Pa$) without causing plasticization.

1.4 Initial conditions

The initial constraint (forced effective of Bishop) is selected in such way that the constraint used in the behavior ($\sigma = \sigma_T + p_{gz} 1^d$) is inside the surface of load.

2 Reference solution

In the absence of loading deviatoric, an exact solution is available for the deformations and the thresholds of work hardening at all the stages of the loading:

Reversible voluminal deformation in mechanical loading $\varepsilon_v = \frac{\kappa}{1+e_0} Ln \frac{P}{P_0}$

Reversible voluminal deformation in hydrous loading $\varepsilon_v = \frac{\kappa_s}{1+e_0} Ln \frac{p_c + p_{atm}}{p_{atm}}$

Total voluminal deformation in hydrous loading, after crossing of the threshold: $\Delta\varepsilon_v = \frac{\lambda_s}{(1+e_0)} Ln \frac{p^+_c + p_{atm}}{p^-_c + p_{atm}}$ si $p_c > p_{c0}$

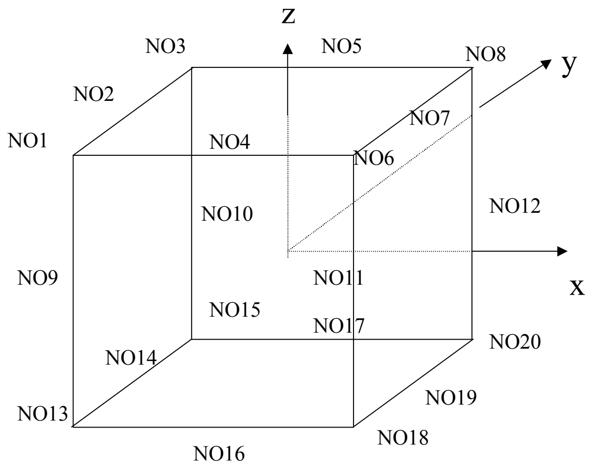
Total voluminal deformation in mechanical loading, after crossing of the threshold of consolidation: $d\varepsilon_v = \frac{\lambda(p_c)}{1+e_0} \frac{dP}{P}$

Coupling of the thresholds: $\frac{dp_{c0}}{p_{c0} + p_{atm}} = \frac{\lambda - \kappa}{\lambda_s - \kappa_s} \frac{dP_{cr}}{P_{cr}}$

3 Modeling A

3.1 Characteristics of modeling

Modeling 3D



3.2 Characteristics of the grid

Many nodes:	20
Many meshs:	1 of type HEXA 20
	6 of type QUAD 8

The following meshs are defined:

DROITE	*NO3 NO5 NO8 NO10 NO12 NO15 NO17 NO20*
GAUCHE	*NO1 NO4 NO6 NO9 NO11 NO13 NO16 NO18*
DEVANT	*NO6 NO7 NO8 NO11 NO12 NO18 NO19 NO20*
DERRIERE	*NO1 NO2 NO3 NO9 NO10 NO13 NO14 NO15*
BAS	*NO13 NO14 NO15 NO16 NO17 NO18 NO19 NO20*
HAUT	*NO1 NO2 NO3 NO4 NO5 NO6 NO7 NO8*

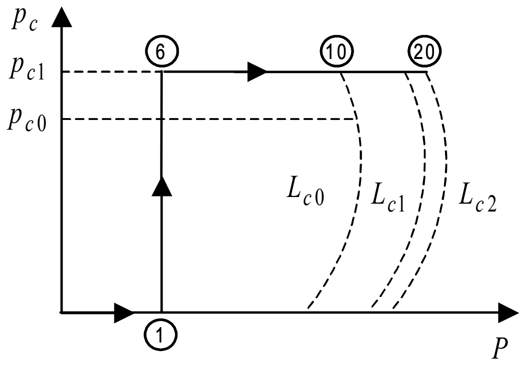
To account for the 1/8ème structure, the boundary conditions in displacement imposed are:

On the face BAS : $DZ=0$
On the face $GAUCHE$: $DY=0$
On the face $DERRIERE$: $DX=0$

The loading is made up by same pressure divided into compression on the 3 meshs: $'HAUT'$, $'DROITE'$ and $'DEVANT'$ to simulate a hydrostatic test. All the nodes are compelled with a constant gas pressure and a suction varying of 0 with $7.10^{7\mathrm{Pa}}$

3.3 Sizes tested and results

It is about a homogeneous test, the place of observation of the fields is indifferent. Displacement will be tested u_z with node 8 at moment 1 (end of the hydrostatic way), at moment 6.0 (crossing of the hydrous threshold) as well as the internal variables of indicator of plasticity and pressure criticizes with the same node. One tests then the same fields at moment 10 (loading purely hydrostatic by crossing the old threshold thus without plasticization) and finally at the moment 20 when the new mechanical threshold is crossed (plasticization).



Values of u_z :

	Moment	Reference
1 er loading	1.	-2.324-03
2nd loading	6.0	-1.0621-02
3rd loading	10.0	-1.3549-02
4th loading	20.	-1.779-02

Plastic indicator (mechanical threshold):

	Moment	Reference
1 er loading	1.	0
2nd loading	6.0	0
3rd loading	10.0	0
4th loading	20.	1

Hydrous indicator of irreversibility:

	Moment	Reference
1 er loading	1.	0
2nd loading	6.0	1
3rd loading	10.0	0
4th loading	20.	0

Value of the hydrous threshold:

	Moment	**Reference**
1 er loading	1.	3E+05
2nd loading	6.0	4E+05
3rd loading	10.0	4E+05
4th loading	20.	4.3913E+5

Value of the mechanical threshold:

	Moment	**Reference**
1 er loading	1.	2E+05
2nd loading	6.0	3.8368E+05
3rd loading	10.0	3.8368E +05
4th loading	20.	4E+05

4 Summary of the results

One gets results on displacements or the values of the thresholds of consolidation very close to the analytical solution and, this, whether one is in the plastic range or reversible.