WTNP128 – Test of splitting per corner concrete under fluid pressure

Summary:

The test presented here makes it possible to check the good performance of the elements of joints with hydraulic coupling and use of the cohesive laws.

The modelled test is a test of splitting per corner with pressure of fluid in the crack.
One has for this test comparisons with experimental and digital tests.

1 Problem of reference

The test of splitting ("wedge splitting test") was proposed initially by Brühwiler and Wittmann[bw] in order to obtain a propagation of stable crack and thus to determine the properties of rupture of the concrete. Slowik and Saouma[ss] then used this test in order to study the effect of a pressure of fluid in the crack. Segura and Carol[sc] modelled this test of splitting under pressure of fluid. One takes again here the test carried out by Slowik and Saouma.

A device, known as of "corner", allows to apply a force to the points B and B' (see figure 1.1-a) in order to separate the sample into two. The experiment is controlled by the CMOD (Ace Mouth Opening Displacement), i.e. imposed displacement enters B and B'.

1.1 Geometry

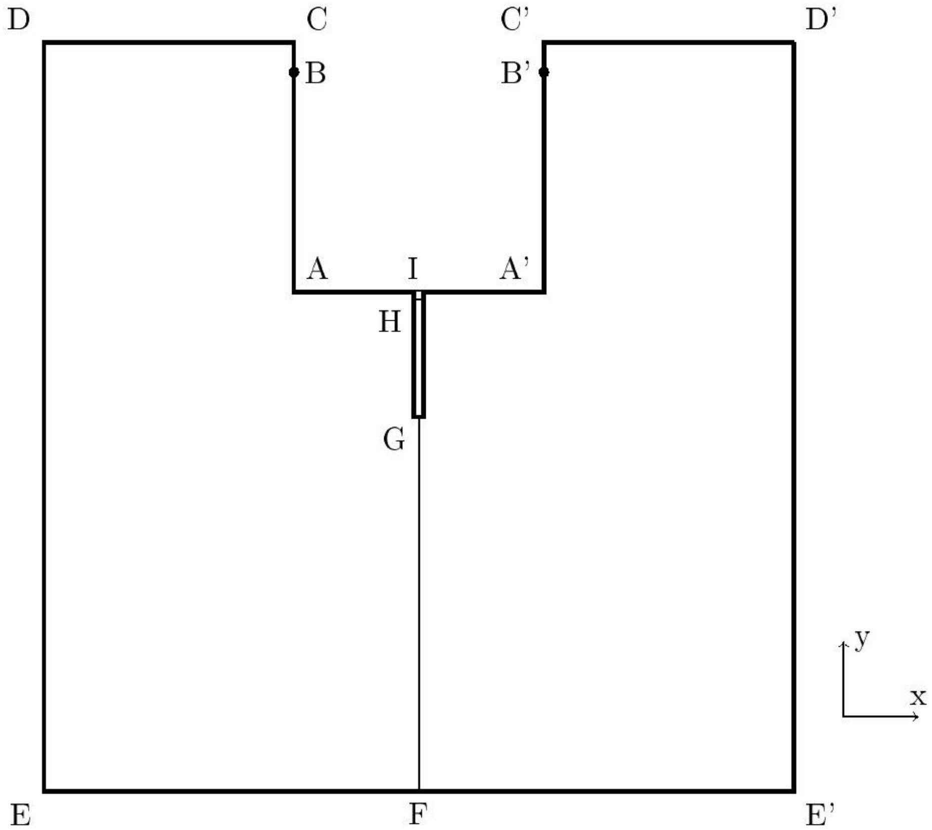


Figure 1.1-a: Geometry of the sample

Coordinates of the points (in mm) :

	x	y		x	y
A	-50	51	A'	50	51
B	-50	138	B'	50	138
C	-50	150	C'	50	150
D	-150	150	D'	150	150
E	-150	-150	E'	150	-150
F	0	-150	G	0	0

H	0	50	I	0	51

The sample has a thickness of $100\,mm$.

1.2 Properties of material

- Properties of the interstitial fluid (liquid water):

Density	$1.10^{-6}\,kg.mm^{-3}$
Viscosity	$1.10^{-9}\,MPa.s$

It is considered that water is incompressible.

- Properties of the solid mass:

The concrete block is elastic and has the following properties:

Young modulus	$27500\,MPa$
Poisson's ratio	$0,2$

Being given the scales of time considered and the permeability of the crack very high comparatively, the concrete is supposed to be impermeable. It is thus modelled by elements D_PLAN classics.

- Properties of discontinuity:

Discontinuity is broken up into three parts:

- The rubber membrane which ensures the sealing of the notch;
- The notch in which one imposes a constant pressure;
- The way of cracking the length whose the crack is propagated.

The membrane has a linear elastic behavior. The law of behavior is used JOINT_BANDIS with the parameter $\gamma=0$ in order to make it linear. The properties of the membrane are the following ones:

Initial normal rigidity K_{ni}	$20\,MPa.mm^{-1}$
Coefficient γ	0

For the notch, the law is used CZM_LIN_REG by initializing the internal variables so as to have initially broken elements.

For the crack, the law is used CZM_EXP_REG with the following parameters:

Energy of cracking G_c	$0,150\,MPa.mm$
Critical stress σ_c	$3,25\,MPa$

The digital parameters of the elements of joints with cohesive law are

PENA_ADHERENCE	1.10^{-3}
PENA_CONTACT	1

- Properties of the point of crack

Module of Biot N	$0{,}3 . 10^{-3}\ MPa.mm^{-1}$
Fictitious opening OUV_FICT	10 mm

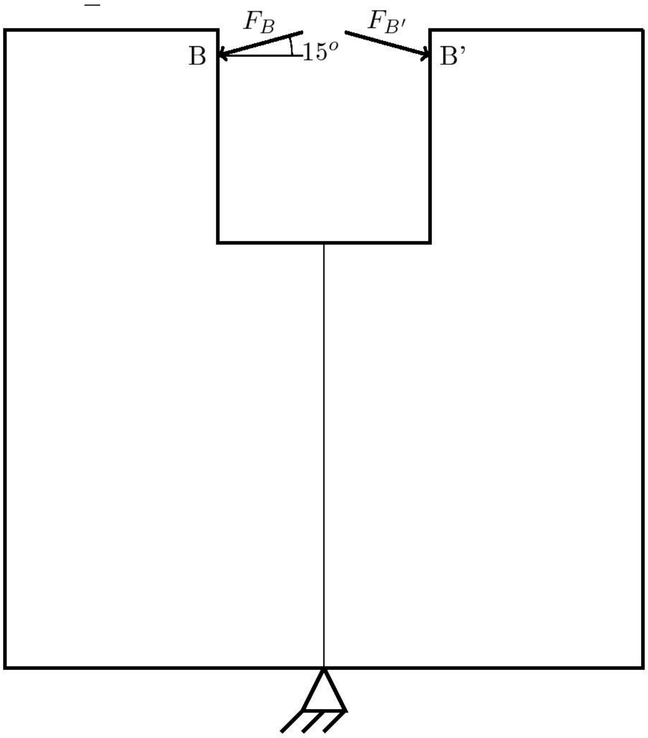
1.3 Initial conditions

The pressure of fluid is initially of $0{,}21\ MPa$ in the notch and $0{,}0\ MPa$ in the future crack.

1.4 Boundary conditions

The boundary conditions mechanical and hydraulic are the following ones:

- In F : displacements blocked in all the direction and imposed worthless pressure;
- In the notch $[GH]$: pressure imposed of $0{,}21\ MPa$;
- In the membrane $[HI]$: pressure imposed of $0{,}0\ MPa$;
- In B and B', displacements are symmetrical;
- In B', one imposes a force in the direction $\begin{pmatrix}\cos(\alpha)\\ -\sin(\alpha)\end{pmatrix}$, of which the intensity is controlled by the component DX displacement at the point B'. At every moment t, the horizontal component of displacement in B' must be equal to $u_x = -\frac{q}{2} t$, where q is the rate loading. One thus uses piloting with the option DDL_IMPO.



In addition, the solid mass being impermeable one blocks the exchanges of fluid between crack and solid mass. The pressures of fluid on the edges of the element of joint and the hydraulic multipliers of Lagrange are blocked to zero.

2 Reference solution

The reference solution is resulting from the experimental results from Slowik and Saouma [2]

2.1 Bibliography

1. Brühwiler, E., Witmann, F.H., The wedge splitting test, has new method of performing stable fracture mechanics tests, *Engineering Fractures Mechanics*, 1990,35,1/2/3,117-125

2. Slowik, V., Saouma, V.E., Toilets Presses in Propagating Concrete Aces, *Newspaper of Structural Engineering*, 2000,126,2,235-242

3. Segura, J. Mr., Carol, I., Numerical Modelling of pressurized fracture evolution in concrete using zero-thickness interface elements, *Engineering Fractures Mechanics*, 2010,77,9,1386-1399

3 Modeling A

3.1 Characteristics of modeling A

Modeling is carried out in plane deformations with 3644 elements TRI3 for the solid mass and 201 elements QU4 for discontinuity. The cohesive law adoptee is CZM_EXP_REG. The mechanical loading is slow: rate loading q_t is of $0{,}002\,\mu\, m.s^{-1}$.

Discretization in time: 29 pas de time of $10\,s$.

3.2 Sizes tested and results

One compares the results of digital modeling with those obtained in experiments by Slowik and Saouma[ss].

The figure 3.2-a watch the force applied by the corner according to the CMOD and the figure 3.2-b give the profiles of pressure in the crack.

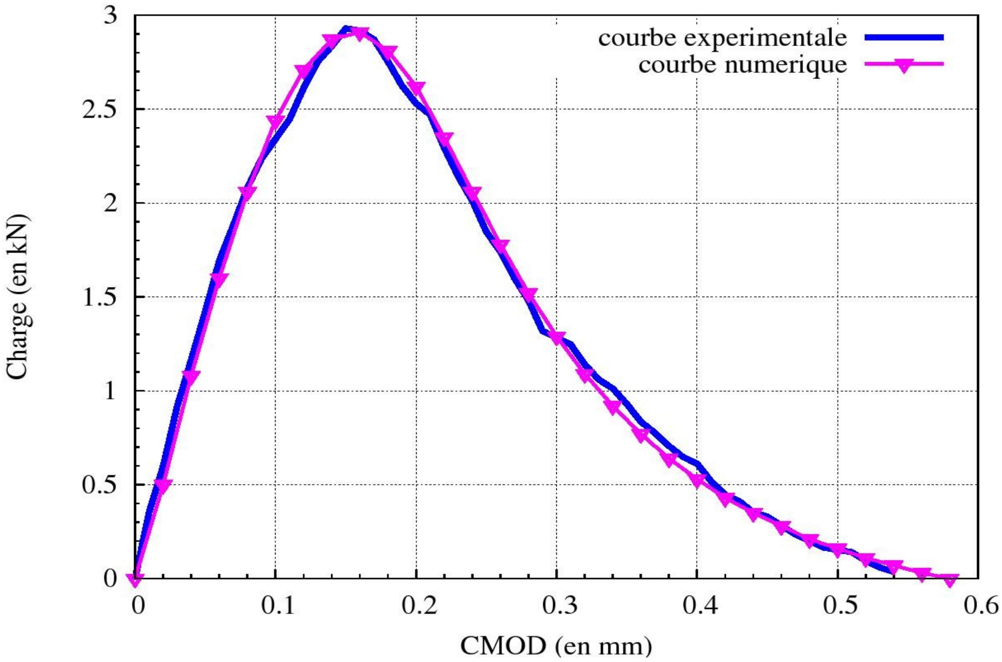


Figure 3.2-a: Curve force-CMOD obtained numerically and comparison with the experimental results of Slowik and Saouma

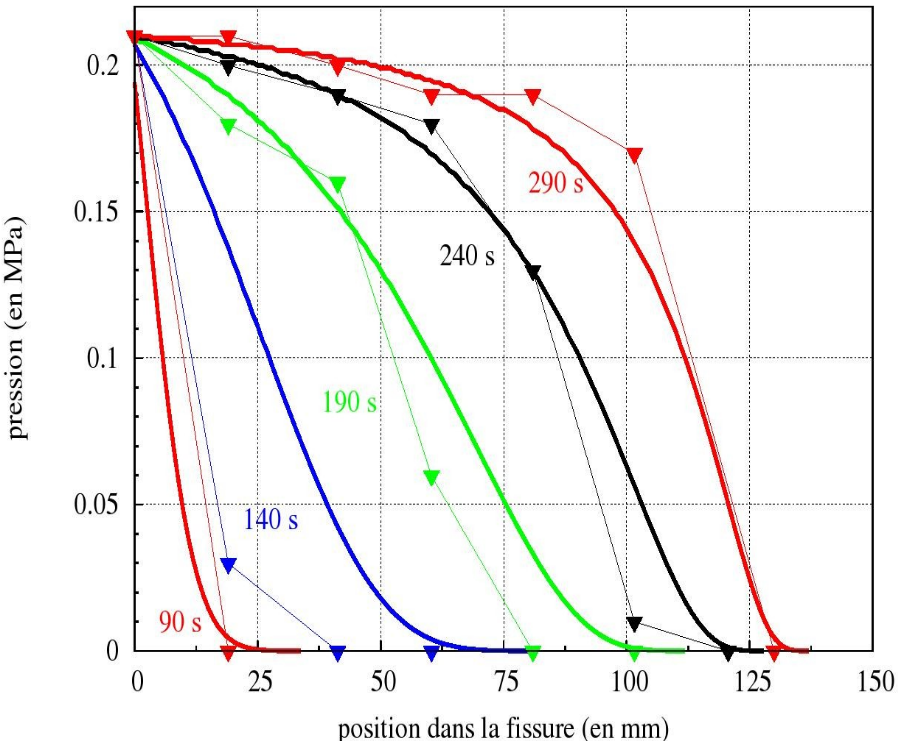


Figure 3.2-b: Profiles of pressure in the crack at various moments. The digital curves are the thick curves. Experimental measurements (Slowik and Saouma) are illustrated by the full triangles.

The curve force-CMOD obtained numerically is very close to the experimental curve. Moreover, the tendencies of evolution of the pressure in the crack are also well reproduced.

It is also noted that these results are very similar to those obtained numerically by Segura and Carol[sc].

One carries out a test of comparison with the experiment on the component according to x force applied in B' (option FORC_NODA) like on the pressure in a point of the crack.

Not	Time (s)	Fx (kN/mm^2) reference	Fx (kN/mm^2) Aster	Difference (%)
B'	100	-12.65	-13.08	3.4
B'	150	-6.41	-6.46	0.76
B'	250	-0.765	-0.792	3.5

X (mm)	Y (mm)	Time (s)	$PRE1$ (Mpa) reference	$PRE1$ (MPa) Aster	Difference (%)
0	-41	140	0.155	0.149	3.8
0	-41	190	0.190	0.188	0.86
0	-41	240	0.200	0.202	0.81

One adds the test of not-regression following:

X (mm)	Y (mm)	**Time** (s)	$PRE1$ (Mpa) **Aster**
0	-41	140	0.1491
0	-41	190	0.1884
0	-41	240	0.2016

4 Modeling B

4.1 Characteristics of modeling

Characteristics of modeling B are identical to those of modeling A, excluded:

- rate loading, which is 100 times higher: q_t is equal to $0{,}2\,\mu\,m.s^{-1}$.
- the parameters following materials

Young modulus	$39000\,MPa$
Energy of cracking G_c	$0{,}178\,MPa.mm$
Critical stress σ_c	$3{,}30\,MPa$
Module of Biot of the cohesive zone N	$0{,}5.10^{-3}\,MPa.mm^{-1}$

Discretization in time: 42 pas de time of $0{,}1\,s$.

4.2 Sizes tested and results

The figure 4.2-a watch the force applied by the corner according to the CMOD.

The figure 4.2-b give the profiles of pressure along the crack. In accordance with what is expected and the loading being faster, the face of fluid was propagated less far with CMOD given.

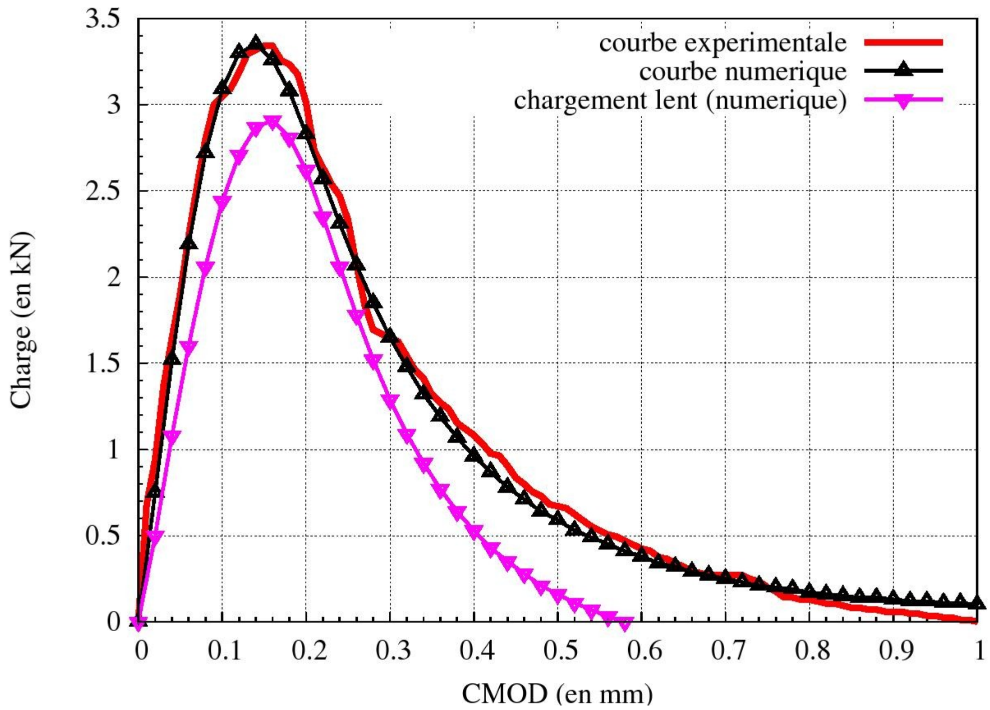


Figure 4.2-a: Curve force-CMOD obtained numerically and comparison with the experimental results of Slowik and Saouma. The curve obtained with a slower loading (modeling A) was added for comparison.

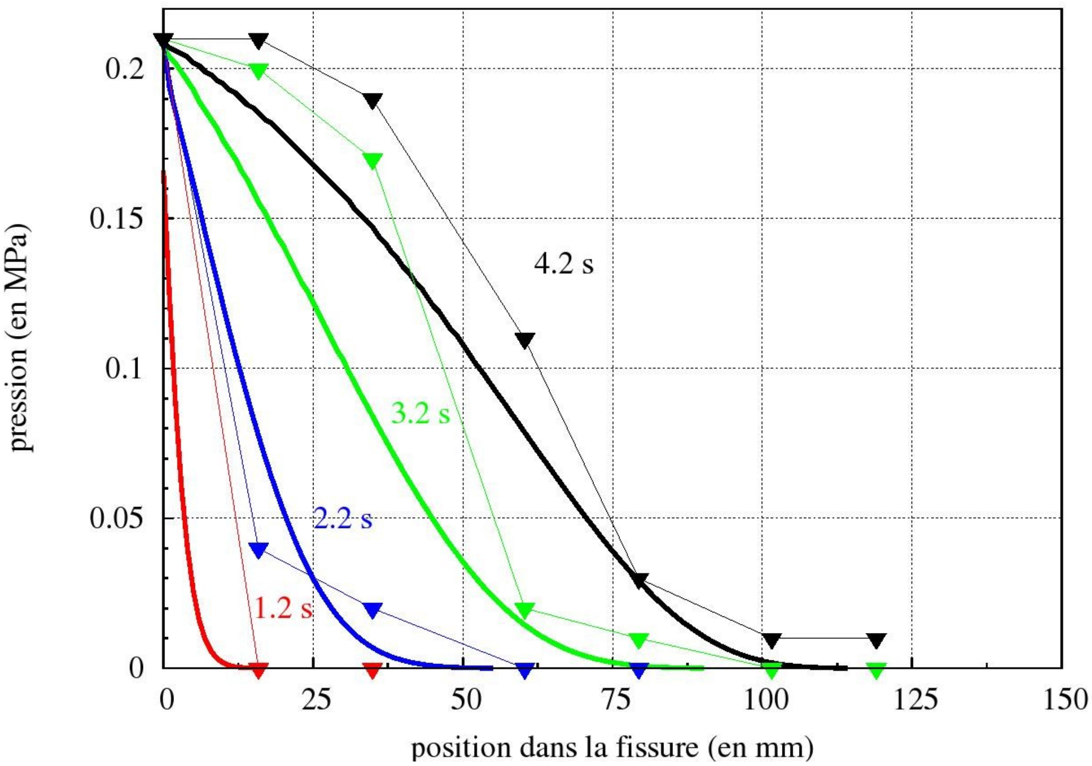


Figure 4.2-b: Profiles of pressure in the crack at various moments. The curves digital are the thick curves. Experimental measurements (Slowik and Saouma) are illustrated by the full triangles

One compares the total mechanical answer obtained to the experimental results.

Not	Time (s)	Fx (kN/mm^2) reference	Fx (kN/mm^2) Aster	Difference ($\%$)
B'	1.0	-15.06	-14.16	6.0
B'	2.0	-5.41	-4.73	13.0
B'	3.8	-0.882	-0.834	5,4

One adds the tests of nonregression following

X (mm)	Y (mm)	Time (s)	$PRE1$ (MPa) reference
0	-60	3.2	$14{,}9.10^{-3}$
0	-60	4.2	$79{,}6.10^{-3}$

5 Modeling C

5.1 Characteristics of modeling

Modeling C is almost identical to modeling A. Only the cohesive law for the crack is amended: the law is used CZM_LIN_REG.

Discretization in time: 24 pas de time of $10\mathrm{s}$.

5.2 Sizes tested and results

One carries out simply the following tests of not-regression:

Not	Time (s)	Fx (kN/mm^2) Aster
B	100	-16.31
B	150	-6.848

X (mm)	Y (mm)	Time (s)	$PRE1$ (MPa) Aster
0	-41	190	0.1473
0	-41	240	0.1884

6 Modeling D

6.1 Characteristics of modeling

Modeling D is almost identical to modeling A . Only elements D_PLAN solid mass are modified. They are replaced by elements D_PLAN_HMS. Thus, rather than a completely impermeable medium, one considers a medium with a low permeability:

Intrinsic permeability K^{int} $1.10-19\,m^2$

The exchanges between crack and solid mass are authorized for this modeling.

Discretization in time: 10 pas de time of $20\,s$.

6.2 Sizes tested and results

One carries out simply the following tests of not-regression:

Not	**Time** (s)	Fy (kN/mm^2) **Aster**
B	100	-11.87
B	200	-2.10

X (mm)	Y (mm)	**Time** (s)	$PRE1$ (MPa) **Aster**
0	-41	140	0.0737
0	-41	200	0.1679

7 Summary of the results

The got results make it possible to validate the good performance of the elements of joints with hydro-mechanical coupling with the regularized cohesive laws.

Modelings A and B test the compatibility of the element of joint with the law CZM_EXP_REG. The results are compared with experimental results. The total mechanical answer of the structure as well as the effect the rate loading on the flow in the crack are reproduced correctly numerically.

Modeling C, by test of not-regression only, the use of the law validates CZM_LIN_REG. The results are completely in conformity with what is expected.

Lastly, modeling D allows to test compatibility with the cohesive laws in the presence of surface elements HM_DPQ8S far from permeable in the solid mass.