SSNP144 – The purpose of use of a model at cohesive zones with the method X-FEM

Summarized

This test is validating the cohesive constitutive law put concerned during the cracking of elements $X-FEM$. This approach, described in [R7.02.12] makes it possible to model the opening of an interface by taking account of a force of cohesion between the lips of this one.

The modelizations A with K bring into play a parallelepipedic bar fissured on all its section (one speaks then about interface), subjected to an imposed displacement, which has as a consequence the separation of the two parts of structure in mode I as well as in mode II. The influence of the refinement of the mesh as of the type of elements used is studied.
The modelization L the case of an interface tests which opens and is closed in mode I. One uses in a simultaneous way there penalized contact and control.

The validation is done by comparison of the values of Lagrangian of contact and friction with an analytical reference solution.

Contents

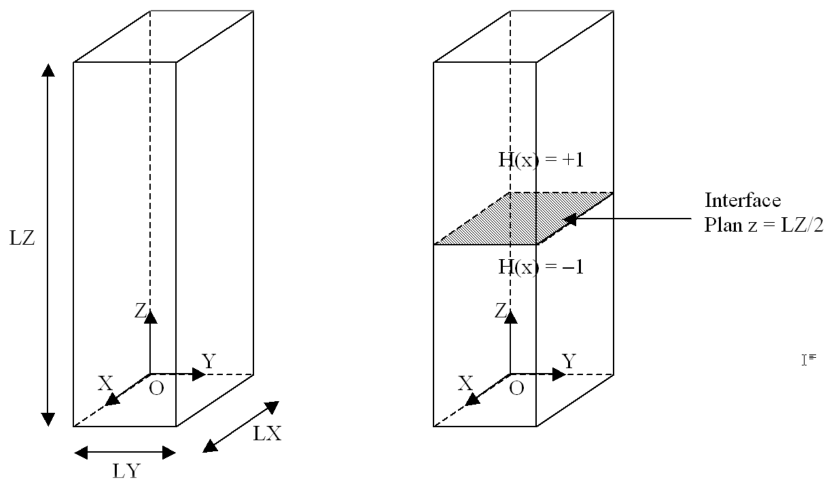
1 Problem of reference

1.1 Geometry 3D

the structure is a right parallelepiped at square base. Dimensions of the bar (see [1.1-a]) are: $LX=5\text{m}$, $LY=5\text{m}$ and $LZ=25\text{m}$.

The interface is introduced by functions of level (level sets) directly into the file orders using operator `DEFI_FISS_XFEM` [`U4.82.08`]. The interface is present in the middle of structure by the means of its representation by a level set LSN (see [1.1-a]) of equation:

$$\text{LSN (pour le plan de l'interface) : } Z-\frac{LZ}{2}$$



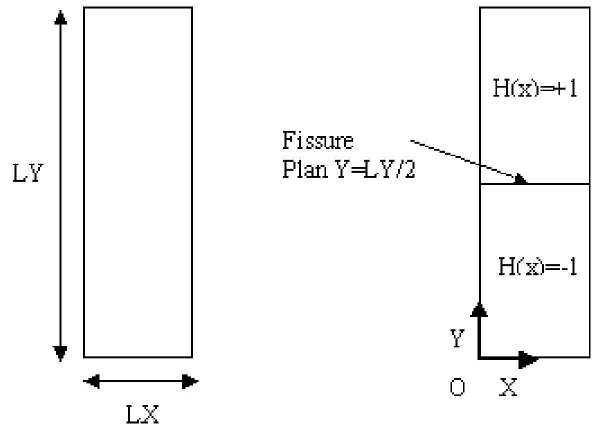
1.1-a : Geometry of the bar and positioning of the interface

1.2 Geometry 2D

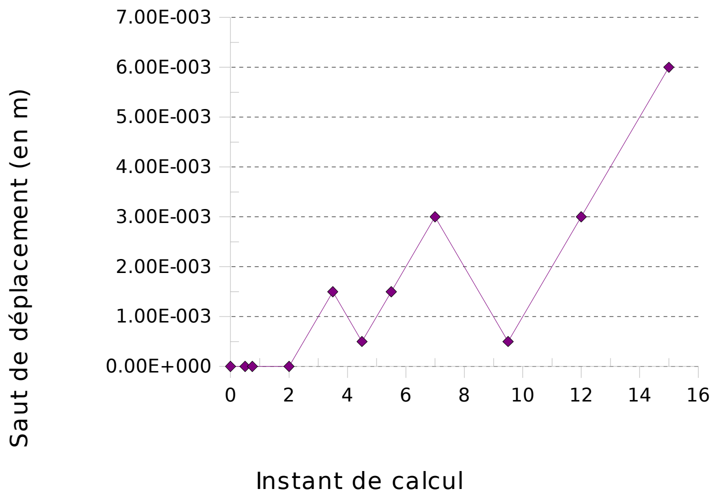
the structure is a rectangle. Dimensions of the bar (see [Appear 1.2-a]) are: $\text{LX}=1\text{m}$ $\text{LY}=5\text{m}$.

The interface is introduced by a function of level (level set) directly into the file orders using operator `DEFI_FISS_XFEM` [U4.82.08]. The interface is present in the middle of structure by the means of its representation by a level set LSN (see [Appear 1.2-a]) of equation:

$$\text{LSN (pour le plan de l'interface) : } Y-\frac{LY}{2}$$



Appear 1.2-a : Geometry of the plate and positioning of the interface



Appears 1.2-b: Evolution of the jump of displacement imposed by control according to the time of computation

1.3 Properties of the material

Modulus Young:	$E = 0{,}5.E6 Pa$
Poisson's ratio:	$\nu = 0{,}0$

The presence of a cohesive model to the interface is indicated using key word `RELATION=' CZM_EXP_REG'` at the time of the definition of the contact zone (command `DEFI_CONTACT`, factor key word `ZONE`). The cohesive model then established has as parameters G_c, σ_c and κ_0, and is explained in detail in documentation [R7.02.11]

Tenacity:	$G_c = 900$ N/m	(key word: `GC`)
Forced critical with the fracture:	$\sigma_c = 1{,}1.E6$ Pa	(key word: `SIGM_C`)
Parameter of regularization of energy:	$\kappa_0 = 1{,}0E\text{-}3$	(key word `PENA_ADHERENCE`)

Note::

The data materials do not have of course authority to represent a material in particular. They are only intended for numerical tests of validation.

1.4 Boundary conditions and loadings

1.4.1 Degrees of freedom nouveau riches and boundary conditions

Let us recall that displacement under $X-FEM$ is the sum of a continuous displacement and a discontinuous displacement. In the case of an interface, without crack tip, the approximation of displacement is written in the following way:

$$u^h(x)=\sum_{i\in N_n(x)} a_i \phi_i(x)+\sum_{j\in N_n(x)\cap K} b_j \phi_j(x) H(lsn(x))$$

Where:

a_i and b_i are the degrees of freedom of displacement to the node i,

ϕ_i the shape functions associated with the node i,

$N_n(x)$ is all the nodes whose support contains the point x,

K is all the nodes whose support is entirely cut by crack,

$H(x)$ is the Heaviside function generalized defined by $H(x)=\begin{cases}-1 & \text{si } x<0\\ +1 & \text{si } x\geq 0\end{cases}$,

$lsn(x)$ is the normal value of the level-set at the point x.

For more details, to refer to documentation of reference $X-FEM$ [R7.02.12].

It is thus possible to want to impose limiting conditions on total displacement (or physical displacement), on its continuous component or its discontinuous component. We initially and the will give various useful relations between this physical displacement existing degrees of freedom in Code_Aster.

Let us take the example represented Appear 1.2-a: an edge of an unspecified $2D$ mesh crossing by an interface:

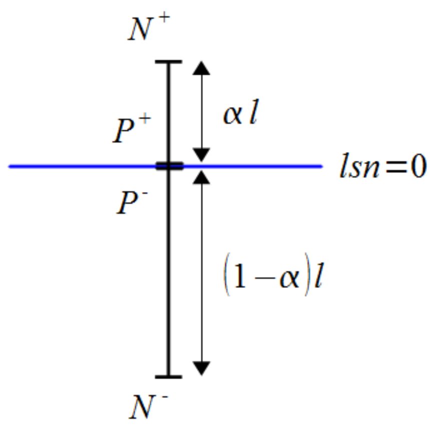


Figure 1.4.1-1: Edge intersected by an interface

and the P^+ Let us call P^- points geometrical belonging to segment and located respectively just in lower part and at the top of the level set and consider without loss of generality of vertical displacements. We have:

$$\begin{cases} DY(N^+) = a_y^+ + b_y^+ \\ DY(N^-) = a_y^- - b_y^- \\ DY(P^+) = \alpha\left(a_y^+ + b_y^+\right) + (1-\alpha)\left(a_y^- + b_y^-\right) \\ DY(P^-) = \alpha\left(a_y^+ - b_y^+\right) + (1-\alpha)\left(a_y^- - b_y^-\right) \end{cases}$$

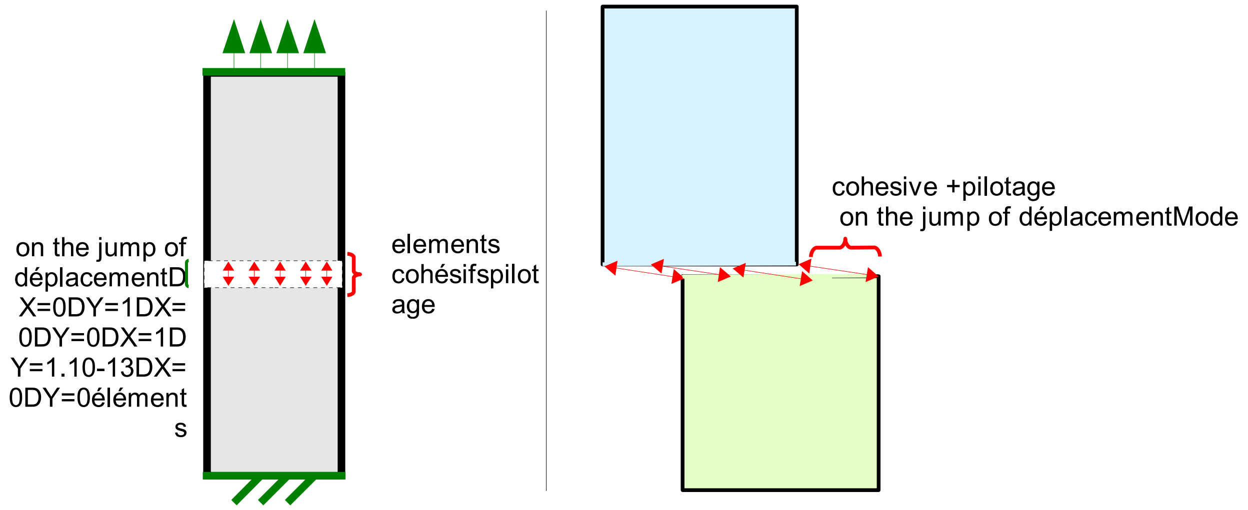
One can draw the statement from it from the jump of displacement for the edge:

$$[\![DY]\!] = DY(P^+) - DY(P^-) = \alpha\, b_y^+ + (1-\alpha)\, b_y^-$$

1.4.2 Loading

In mode I, the nodes of the lower face of the bar are clamped and a vertical displacement is imposed on those of the upper face, as explained on figure 1.4.2-1.
In mode II of opening, the nodes located under the level set are clamped, and one imposes a vertical displacement DY (DZ in $3\mathrm{D}$) of $1{,}0\mathrm{E}\text{-}13$ on all nodes located at the top of the level set. One thus ensures the nullity of the indicator of contact at the level of the interface. We also impose pure shears on the level of the cohesive zone what taking into account the notations of figure 1.4.1-1 amounts imposing for each intersected edge:

$$\begin{cases} DX(P^-) = DX(N^-) = 0 \\ DX(P^+) = DX(N^+) \end{cases}$$



IMode **IIFigure**

1.4.2-1: Loading applied, in mode I and mode II

We see that this requires to impose connections between degrees of freedom on both sides of the edge i which depend on the coefficient α. In order not to weigh down the command file unnecessarily, we will test in mode II only meshes for which:

- either all the intersected edges are it in their medium, i.e. for each one $\alpha = 0{,}5$
- or the interface is in conformity, i.e. $\alpha = 1$

In the first case, where all the edges are intersected in their medium, we on all the ensure the nullity of the indicator of contact by $H1Y=5.\mathrm{E}-14$ imposing nodes ends of the edges intersected by the interface. With regard to the shears, we must impose the relations:

$$\begin{cases} DX(P^-)=DX(N^-)\Leftrightarrow \dfrac{a_x^+-b_x^+}{2}+\dfrac{a_x^--b_x^-}{2}=a_x^--b_x^-=0 \\ DX(P^+)=DX(N^+)\Leftrightarrow \dfrac{a_x^++b_x^+}{2}+\dfrac{a_x^-+b_x^-}{2}=a_x^++b_x^+ \end{cases}$$

We see whereas if we impose the relation $a_x^+=b_x^+$ then $DX(P^-)=0$.
If we impose the relation then $b_x^+=b_x^-$, we have moreover $DX(P^+)=DX(N^+)$.

In the second case, with interface in conformity with the mesh, the jump is represented by the Heaviside degree of freedom at the point confused with the interface and we must thus impose $H1Y=1.\mathrm{E}-13$ on the nodes confused with the interface. With regard to the shears, if N^- corresponds to the point confused with the interface P^- , we must impose:

$$\begin{cases} DX(P^-)=a_x^--b_x^-=0 \\ DX(P^+)=DX(N^+)\Leftrightarrow a_x^-+b_x^-=a_x^+ \end{cases}$$

We see whereas if we impose the relation $a_x^-=b_x^-$ then $DX(N^-)=DX(P^-)=0$.

If we impose the relation then $a_x^-=\dfrac{a_x^+}{2}$, we have moreover $DX(P^+)=DX(N^+)$.

These two relations are imposed for all the nodes in with respect to meshes crossed by the interface.

It should be noted that, in the command file, syntax to impose these various degrees of freedom differs according to the operators. The key word factor `DDL_IMPO` of operator `AFFE_CHAR_MECA` makes it possible to impose total displacement (or physical displacement) thanks to the key keys `DX`, `DY`, and `DZ`, as well as the discontinuous degrees of freedom b_i thanks to key keys `H1X`, `H1Y`, and `H1Z`. On the other hand, the key word factor `LIAISON_GROUP` makes it possible to control the continuous degrees of freedom a_i thanks to the key keys `DX`, `DY`, and `DZ` (and not total displacement) as well as the discontinuous degrees of freedom b_i thanks to key keys `H1X, H1Y, and H1Z.`

1.5 Control of the loading

For the mode I control is carried out on the jump of vertical displacement. The vertical displacement DY (DZ in $3D$) imposed on the nodes of the upper face of the bar is then unit. The real intensity of the displacement of these nodes is thus known during computation via parameter `ETA_PILOTAGE.` One uses one of controls `SAUT_IMPO or SAUT_LONG_ARC` **implemented especially for** $XFEM$, on the normal component $H1Y$ ($H1Z$ in $3D$), corresponding to b_y (b_z in $3D$) with the notations taken above, for all the edges intersected by the interface.

For the mode II control is carried out on the jump of horizontal displacement. Control is then carried out in a way identical to the mode I , but on the tangential component $H1X$.
Lastly, for each mode of opening, controls used make it possible to explore all the phases of the constitutive law: elastic linear load, damage and discharge.

Figures 1.5-1 and 1.5-2 represent the evolution of the jump of displacement according to the time of computation. In order to carry out discharges, several resumptions of computation `(key word`

reuse) are carried out to make it possible to change the value of the coefficient c_{mult} (key word COEF_MULT) making it possible to define the value of the increment of the jump of displacement $\Delta\delta_i$ to be imposed for one time step Δt via the equation of control. As the problem is uniform, this relation is written in a simple way for SAUT_IMPO and SAUT_LONG_ARC : $\Delta\delta_i\ c_{mult}=\Delta t$.
The control of the type PRED_ELAS is not tested yet for this case because it would require a restitution giving the possibility of controlling in discharge, discussed in [R5.03.80], with this kind of control.
The loading is carried out in ten phases, thanks to ten successive calls to STAT_NON_LINE :

Time of final computation	**Phase**	**Jump of final displacement (in m)**	**Cmult DDL_IMPO LONG_ARC**	**Cmult PRED_ELAS**
0,5	Beginning of initial elastic load	2,73E-7	1.833350000E+06	1.500013700E+03
0,75	initial elastic Discharge	1,36E-7	-1.833350000E+06	-1.500013700E+03
2	End of initial elastic load	8,18E-7	1.833350000E+06	1.500013700E+03
3	Damage 1	1,50E-3	1.000545747E+03	1.001000991E+00
3.5				8.001501926E-01
4	elastic Discharge 1	5,00E-4	-1.000000000E+03	-8.501501892E-01
4.5				-1.285714290E+00
5	elastic Load 1	1,50E-3	1.000000000E+03	1.285714286E+00
5.5				8.001501912E-01
7	Damage 2	3,00E-3	1.000000000E+03	2.089908926E+00
9	elastic Discharge 2	5,00E-4	-1.000000000E+03	-1.641475407E+00
9.5				-1.285714290E+00
10	elastic Load 2	3,00E-3	1.000000000E+03	1.285714286E+00
12				1.441475409E+00
15	Damage 3	6,00E-3	1.000000000E+03	4.179817852E+00

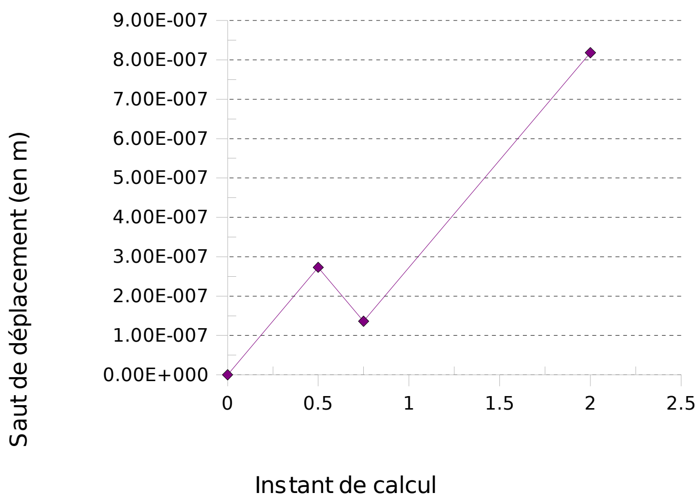


Figure 1.5-1: Evolution of the jump of displacement imposed by control until the time of computation 2.

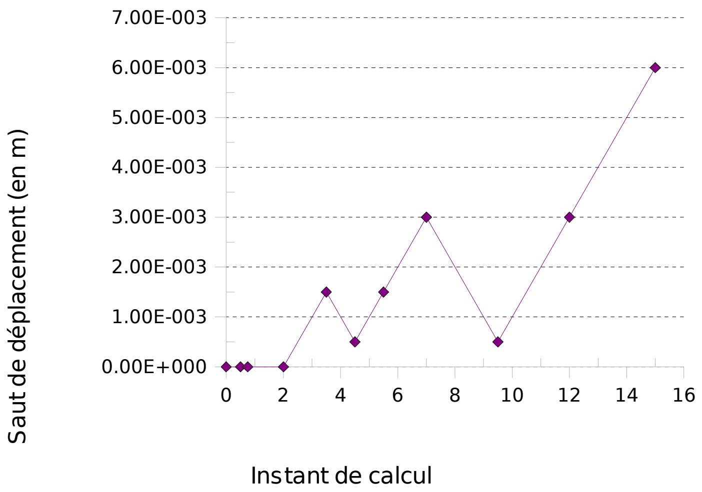


Figure 1.5-2: Evolution of the jump of displacement imposed by control according to the time of computation.

2 Reference solution

the reference solution for this case test is provided by the cohesive behavior model defined in [R7.02.12]:

$$t_c = \frac{\sigma_c}{\alpha} \exp\left(\frac{-\sigma_c}{G_c}\alpha\right)\left([\![u]\!]_n + \beta^2 [\![u]\!]_\tau\right)$$

Where:

- $[\![u]\!]$ is the jump of displacement
- $[\![u]\!]_n = n \otimes n . [\![u]\!]$ is the projection of the jump of displacement following the norm to the interface
- $[\![u]\!]_\tau = (\mathrm{Id} - n \otimes n).[\![u]\!]$ is the projection of the jump of displacement following the tangent plane to the interface
- β is a quantity obtained in experiments representing the relationship between the forces of opening in Mode I and Mode II. For this test, this parameter is selected unit.
- $[\![u]\!]_{eq} = \sqrt{\left\|[\![u]\!]_n\right\|^2 + \beta^2 \left\|[\![u]\!]_\tau\right\|^2}$
- α is a local variable the corresponding to greatest value of $[\![u]\!]_{eq}$ attack during the opening. This local variable has as an initial value $\alpha_0 = \frac{G_c}{\sigma_c} \text{PENA\_ADHERENCE}$. If the material leaves its field of elasticity, one A. $\alpha = [\![u]\!]_{eq}$

One thus knows explicitly the force of cohésion1Force[1] according to the jump of displacement.

Time of final computation	Phase	Jump of final displacement (in m)	$\|t_c\|$ (out of Pa)
0,5	Beginning of initial elastic load	2,73E-7	3.66296853301E+05
0,75	initial elastic Discharge	1,36E-7	1.8314842665E+05
2	End of initial elastic load	8,18E-7	1.098890559903E+06
3,5	Damage 1	1,50E-3	1.75867720687844E+05
4.5	elastic Discharge 1	5,00E-4	2.49999999999582E-04
5,5	elastic Load 1	1,50E-3	1.75867720687844E+05
7	Damage 2	3,00E-3	2.8117686527187E+04
9,5	elastic Discharge 2	5,00E-4	4.68628108785798E+03
12	elastic Load 2	3,00E-3	2.8117686527187E+04
15	Damage 3	6,00E-3	7.18731177854856E+02

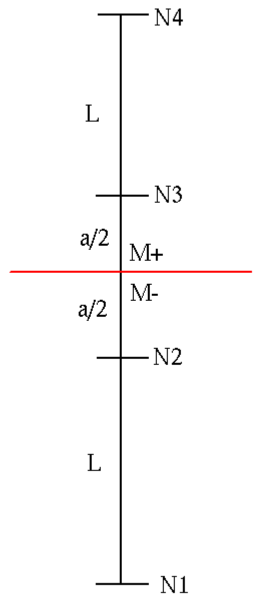
This value will thus be compared with the values of Lagrangian of respectively named contact and friction LAGS_C and LAGS_F1.

Mode I :

For reasons of invariance, let us consider a unidimensional problem. We will also suppose that the structure is with a grid with only three elements, which does not change anything with the validity results stated thereafter. The interface is present in the middle of the central element as shows it

1 per unit of area, homogeneous with a stress

[Appear 2-a]. Since we control by `DDL_IMPO` the degree of freedom $H1Y$ of the node N2 (also noted b_{y2}), let us solve the problem according to this parameter.



Appear 2-a: Unidimensional representation of the problem of reference

Let us express displacements of the various points of structure:

$$\begin{cases} u^1 = 0 \\ u^2 = L\epsilon \\ u^+ = (L+\frac{a}{2})\epsilon \\ u^- = (L+\frac{a}{2})\epsilon + [[u]]_n \\ u^3 = (L+a)\epsilon + [[u]]_n \\ u^4 = (2L+a)\epsilon + [[u]]_n \end{cases}$$

Now let us express displacements of the points N2 M+ , M- and N3 according to the degrees of freedom $X-FEM$.

$$\begin{cases} u^2 = a_{y2} - b_{y2} \\ u^3 = a_{y2} + b_{y3} \\ u^+ = \frac{a_{y2}+b_{y2}}{2} + \frac{a_{y3}+b_{y3}}{2} \\ u^- = \frac{a_{y2}-b_{y2}}{2} + \frac{a_{y3}-b_{y3}}{2} \end{cases}$$

By reversing this system, one obtains:

$$\begin{cases} a_{y2}=\frac{u_2}{2}-\frac{u_3}{2}+u^+ \\ b_{y2}=-\frac{u_2}{2}-\frac{u_3}{2}+u^+ \\ a_{y3}=-\frac{u_2}{2}+\frac{u_3}{2}+u^- \\ b_{y3}=\frac{u_2}{2}+\frac{u_3}{2}-u^- \end{cases}$$

The elastic model of structure gives: $\sigma=E\epsilon$.
The equilibrium of the system gives $\sigma=t_c$.
Lastly, the cohesive constitutive law provides a relation between stress and jump of displacement. This relation is different according to whether the joint remains in its elastic domain or that it is damaged.

If the joint remains in the elastic domain, the local variable α remains constant. One has then $t_c=\frac{\sigma_c}{\alpha}\exp(\frac{-\sigma_c}{G_c}\alpha)[\![u]\!]_n$.

Displacements of the various points of structure are written then:

$$\begin{cases} u^1=0 \\ u^2=\frac{L}{E}\frac{\sigma_c}{\alpha}\exp(\frac{-\sigma_c}{G_c}\alpha)[\![u]\!]_n \\ u^+=\frac{L+\frac{a}{2}}{E}\frac{\sigma_c}{\alpha}\exp(\frac{-\sigma_c}{G_c}\alpha)[\![u]\!]_n \\ u^-=\left(1+\frac{L+\frac{a}{2}}{E}\frac{\sigma_c}{\alpha}\exp(\frac{-\sigma_c}{G_c}\alpha)\right)[\![u]\!]_n \\ u^3=\left(1+\frac{L+a}{E}\frac{\sigma_c}{\alpha}\exp(\frac{-\sigma_c}{G_c}\alpha)\right)[\![u]\!]_n \\ u^4=\left(1+\frac{2L+a}{E}\frac{\sigma_c}{\alpha}\exp(\frac{-\sigma_c}{G_c}\alpha)\right)[\![u]\!]_n \end{cases}$$

By injecting these statements in the formulas giving b_{y2} and b_{y3} , one notes that $b_{y2}=b_{y3}$.
One has thus $[[u]]_n=u^+-u^-=b_{y2}+b_{y3}=2.\mathrm{b}_{y2}$. The problem is thus entirely given for gives degree of freedom b_{y2} , corresponding to the half jump of displacement, and known at any moment thanks to control.

If the joint remains in phase of damage, the local variable α becomes equal to the jump of displacement $[[u]]_n$. One has then $t_c=\sigma_c\exp(\frac{-\sigma_c}{G_c}[\![u]\!]_n)$.

Displacements of the various points of structure are written then:

$$\begin{cases} u^1 = 0 \\ u^2 = \frac{L}{E}\sigma_c \exp(\frac{-\sigma_c}{G_c}[\![u]\!]_n) \\ u^+ = \frac{L+\frac{a}{2}}{E}\sigma_c \exp(\frac{-\sigma_c}{G_c}[\![u]\!]_n) \\ u^- = \frac{(L+\frac{a}{2})}{E}\sigma_c \exp(\frac{-\sigma_c}{G_c}[\![u]\!]_n) + [[u]]_n \\ u^3 = \frac{(L+a)}{E}\sigma_c \exp(\frac{-\sigma_c}{G_c}[\![u]\!]_n) + [[u]]_n \\ u^4 = \frac{(2L+a)}{E}\sigma_c \exp(\frac{-\sigma_c}{G_c}[\![u]\!]_n) + [[u]]_n \end{cases}$$

By injecting these statements in the formulas giving b_{y2} and b_{y3}, one notes that $b_{y2} = b_{y3}$.
One has thus $[[u]]_n = u^+ - u^- = b_{y2} + b_{y3} = 2.\mathrm{b}_{y2}$. The problem is thus entirely given for gives degree of freedom b_{y2}, corresponding to the half jump of displacement, and known at any moment thanks to control.

Mode II :

The boundary conditions and the relations imposed thanks to the key word factor LIAISON_GROUP ensure perfect shears at the level of the interface. The displacement of all the points located under the level set is thus null and the displacement of all the points located at the top of the level set is equal to the jump of displacement.
The force of cohesion in the joint is thus known like an explicit function of the jump of displacement itself known at any moment thanks to control.

3 Modelization A

3.1 Characteristic of the modelization

It acts of a modelization XFEM, in plane stresses, the interface of discontinuity being defined by a function of level (level set noted LN for the level set norm) directly in the command file using operator DEFI_FISS_XFEM [U4.82.08].

The equation of the function of level for the interface is the following one:

$$\mathrm{LN}=Y-2.5$$

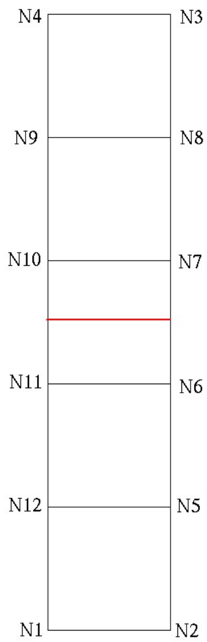
No level set tangential is necessary since one uses key word TYPE_DISCONTINUITE=' INTERFACE', which makes it possible to have structure completely cut in two parts.

The cohesive model is introduced via operator DEFI_CONT, by specifying ALGO_CONT=' CZM', and the cohesive constitutive law is activated thanks to key word RELATION=' CZM_EXP_REG'.

One tests here the modes I and II of opening.

3.2 Characteristics of the mesh

One discretizes structure in 1×5 finite elements QUAD4. The interface is thus present within the central element by the means of level sets.



Appear 3.2-a: Mesh of the modelization A

3.3 Control

One uses a specific control $X-FEM$ SAUT_IMPO on all the edges intersected by crack.

3.4 Quantities tested and Mode

results I :

One tests the values of Lagrangian of contact LAGS_C in all the nodes of the mesh crossed by the interface after convergence of the iterations of each operator STAT_NON_LINE, these values being uniform on the interface. To test all the values in once, one tests the minimum and the maximum of Lagrangian of contact.

Not	Identification	Reference	Tolerance (%)
0.5	H1Y for all the nodes	1.36362396705485E-07	1.0E-6
0,51.0E-6	LAGS_C for all the nodes	3.66296853301E+05	1.0E-6
0.75	H1Y for all the nodes	6.818119835274E-08	1.0E-6
0,75	LAGS_C for all the nodes	1.8314842665E+05	1.0E-6
2	H1Y for all the nodes	4.0908719011645E-07	1.0E-6
2	LAGS_C for all the nodes	1.098890559903E+06	1.0E-6
3.5	H1Y for all the nodes	7.49999999999582E-04	1.0E-6
3,5	LAGS_C for all the nodes	1.75867720687844E+05	1.0E-6
4.5	H1Y for all the nodes	2.49999999999582E-04	1.0E-6
4,5	LAGS_C for all the nodes	58622.573562549	1.0E-6
5.5	H1Y for all the nodes	7.49999999999582E-04	1.0E-6
5,5	LAGS_C for all the nodes	1.75867720687844E+05	1.0E-6
7	H1Y for all the nodes	1.49999999999958E-03	1.0E-6
7	LAGS_C for all the nodes	28117.686527187	1.0E-6
9.5	H1Y for all the nodes	2.49999999999582E-04	1.0E-6
9,5	LAGS_C for all the nodes	4686.28108785798	1.0E-6
12	H1Y for all the nodes	1.49999999999958E-03	1.0E-6
12	LAGS_C for all the nodes	28117.686527187	1.0E-6
15	H1Y for all the nodes	2.99999999999958E-03	1.0E-6
15	LAGS_C for all the nodes	718.731177854856	1.0E-6

Mode II :

One tests the values of Lagrangian of friction LAGS_F1 in all the nodes of the mesh crossed by the interface after convergence of the iterations of each operator STAT_NON_LINE, these values being uniform on the interface. To test all the values in once, one tests the minimum and the maximum of Lagrangian of friction.

Not	Identification	Reference	Tolerance (%)
0.5	H1X for all the nodes	1.36362396705485E-07	1.0E-6
0,5	LAGS_F1 for all the nodes	3.66296853301E+05	1.0E-6
0.75	H1X for all the nodes	6.818119835274E-08	1.0E-6
0,75	LAGS_F1 for all the nodes	1.8314842665E+05	1.0E-6
2	H1X for all the nodes	4.0908719011645E-07	1.0E-6
2	LAGS_F1 for all the nodes	1.098890559903E+06	1.0E-6
3.5	H1X for all the nodes	7.49999999999582E-04	1.0E-6
3,5	LAGS_F1 for all the nodes	1.75867720687844E+05	1.0E-6
4.5	H1X for all the nodes	2.49999999999582E-04	1.0E-6
4,5	LAGS_F1 for all the nodes	58622.573562549	1.0E-6
5.5	H1X for all the nodes	7.49999999999582E-04	1.0E-6

5,5	LAGS_F1 for all the nodes	1.75867720687844E+05	1.0E-6
7	H1X for all the nodes	1.49999999999958E-03	1.0E-6
7	LAGS_F1 for all the nodes	28117.686527187	1.0E-6
9.5	H1X for all the nodes	2.49999999999582E-04	1.0E-6
9,5	LAGS_F1 for all the nodes	4686.28108785798	1.0E-6
12	H1X for all the nodes	1.49999999999958E-03	1.0E-6
12	LAGS_F1 for all the nodes	28117.686527187	1.0E-6
15	H1X for all the nodes	2.99999999999958E-03	1.0E-6
15	LAGS_F1 for all the nodes	718.731177854856	1.0E-6

3.5 Comments

the values of Lagrangian of contact and friction are explicitly calculated according to the jump of displacement that one controls. It is thus natural to have quasi-null errors.

4 Modelization B

4.1 Characteristic of the modelization

the characteristics of modelization are the same ones as for modelization A.

4.2 Caractéristiques of the mesh

One discretizes structure in 2×5 finite elements TRIA3. The interface is thus present within the central elements by the means of level sets.

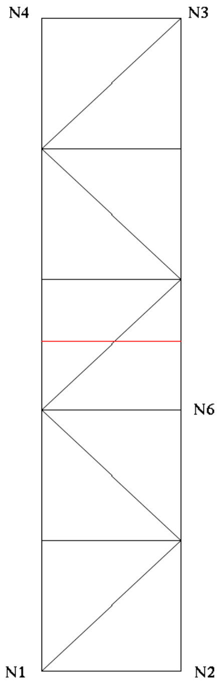


Figure 4.2-a : 4.2-a Mesh of the modelization B

4.3 Control

One uses a specific control $XFEM$ SAUT_IMPO on all the edges intersected by crack.

4.4 Quantities tested and Mode

results I :

One tests the values of Lagrangian of contact LAGS_C in all the nodes of the mesh crossed by the interface after convergence of the iterations of each operator STAT_NON_LINE, these values being uniform on the interface. To test all the values in once, one tests the minimum and the maximum of Lagrangian of contact.

Not	Identification	Reference	Tolerance (%)
0.5	H1Y for all the nodes	1.36362396705485E-07	1.0E-6
0,5	LAGS_C for all the nodes	3.66296853301E+05	1.0E-6
0.75	H1Y for all the nodes	6.818119835274E-08	1.0E-6

0,75	LAGS_C for all the nodes	1.8314842665E+05	1.0E-6
2	H1Y for all the nodes	4.0908719011645E-07	1.0E-6
2	LAGS_C for all the nodes	1.098890559903E+06	1.0E-6
3.5	H1Y for all the nodes	7.49999999999582E-04	1.0E-6
3,5	LAGS_C for all the nodes	1.75867720687844E+05	1.0E-6
4.5	H1Y for all the nodes	2.49999999999582E-04	1.0E-6
4,5	LAGS_C for all the nodes	58622.573562549	1.0E-6
5.5	H1Y for all the nodes	7.49999999999582E-04	1.0E-6
5,5	LAGS_C for all the nodes	1.75867720687844E+05	1.0E-6
7	H1Y for all the nodes	1.49999999999958E-03	1.0E-6
7	LAGS_C for all the nodes	28117.686527187	1.0E-6
9.5	H1Y for all the nodes	2.49999999999582E-04	1.0E-6
9,5	LAGS_C for all the nodes	4686.28108785798	1.0E-6
12	H1Y for all the nodes	1.49999999999958E-03	1.0E-6
12	LAGS_C for all the nodes	28117.686527187	1.0E-6
15	H1Y for all the nodes	2.99999999999958E-03	1.0E-6
15	LAGS_C for all the nodes	718.731177854856	1.0E-6

Mode II :

One tests the values of Lagrangian of friction LAGS_F1 in all the nodes of the mesh crossed by the interface after convergence of the iterations of each operator STAT_NON_LINE, these values being uniform on the interface. To test all the values in once, one tests the minimum and the maximum of Lagrangian of friction.

Not	Identification	Reference	Tolerance (%)
0.5	H1X for all the nodes	1.36362396705485E-07	1.0E-6
0,5	LAGS_F1 for all the nodes	3.66296853301E+05	1.0E-6
0.75	H1X for all the nodes	6.818119835274E-08	1.0E-6
0,75	LAGS_F1 for all the nodes	1.8314842665E+05	1.0E-6
2	H1X for all the nodes	4.0908719011645E-07	1.0E-6
2	LAGS_F1 for all the nodes	1.098890559903E+06	1.0E-6
3.5	H1X for all the nodes	7.49999999999582E-04	1.0E-6
3,5	LAGS_F1 for all the nodes	1.75867720687844E+05	1.0E-6
4.5	H1X for all the nodes	2.49999999999582E-04	1.0E-6
4,5	LAGS_F1 for all the nodes	58622.573562549	1.0E-6
5.5	H1X for all the nodes	7.49999999999582E-04	1.0E-6
5,5	LAGS_F1 for all the nodes	1.75867720687844E+05	1.0E-6
7	H1X for all the nodes	1.49999999999958E-03	1.0E-6
7	LAGS_F1 for all the nodes	28117.686527187	1.0E-6
9.5	H1X for all the nodes	2.49999999999582E-04	1.0E-6
9,5	LAGS_F1 for all the nodes	4686.28108785798	1.0E-6
12	H1X for all the nodes	1.49999999999958E-03	1.0E-6
12	LAGS_F1 for all the nodes	28117.686527187	1.0E-6
15	H1X for all the nodes	2.99999999999958E-03	1.0E-6
15	LAGS_F1 for all the nodes	718.731177854856	1.0E-6

4.5 Comments

the values of Lagrangian of contact and friction are explicitly calculated according to the jump of displacement that one controls. It is thus natural to have quasi-null errors.

5 Modelization C

5.1 Characteristic of the modelization

the characteristics of modelization are the same ones as for the modelization A .

5.2 Characteristics of the mesh

The mesh is refined here compared to that of the modelization A . One discretizes structure in 11×55 finite elements QUAD4. The interface is thus present within the central elements by the means of level sets.

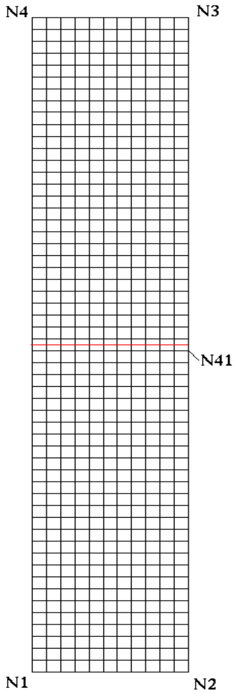


Figure 5.2-a : 5.2-a Mesh of the modelization C

5.3 Control

One uses a specific control $X-FEM$ SAUT_LONG_ARC on all the edges intersected by crack.

5.4 Quantities tested and Mode

results I :

One tests the values of Lagrangian of contact LAGS_C in all the nodes of the mesh crossed by the interface after convergence of the iterations of each operator STAT_NON_LINE, these values being uniform on the interface. To test all the values in once, one tests the minimum and the maximum of Lagrangian of contact.

Not	Identification	Reference	Tolerance (%)
0.5	H1Y for all the nodes	1.36362396705485E-07	1.0E-6
0,51.0 E-6	LAGS_C for all the nodes	3.66296853301E+05	1.0E-6
0.75	H1Y for all the nodes	6.818119835274E-08	1.0E-6
0,75	LAGS_C for all the nodes	1.8314842665E+05	1.0E-6
2	H1Y for all the nodes	4.0908719011645E-07	1.0E-6
2	LAGS_C for all the nodes	1.098890559903E+06	1.0E-6
3.5	H1Y for all the nodes	7.49999999999582E-04	1.0E-6
3,5	LAGS_C for all the nodes	1.75867720687844E+05	1.0E-6
4.5	H1Y for all the nodes	2.49999999999582E-04	1.0E-6
4,5	LAGS_C for all the nodes	58622.573562549	1.0E-6
5.5	H1Y for all the nodes	7.49999999999582E-04	1.0E-6
5,5	LAGS_C for all the nodes	1.75867720687844E+05	1.0E-6
7	H1Y for all the nodes	1.49999999999958E-03	1.0E-6
7	LAGS_C for all the nodes	28117.686527187	1.0E-6
9.5	H1Y for all the nodes	2.49999999999582E-04	1.0E-6
9,5	LAGS_C for all the nodes	4686.28108785798	1.0E-6
12	H1Y for all the nodes	1.49999999999958E-03	1.0E-6
12	LAGS_C for all the nodes	28117.686527187	1.0E-6
15	H1Y for all the nodes	2.99999999999958E-03	1.0E-6
15	LAGS_C for all the nodes	718.731177854856	1.0E-6

Mode II :

One tests the values of Lagrangian of friction LAGS_F1 in all the nodes of the mesh crossed by the interface after convergence of the iterations of each operator STAT_NON_LINE, these values being uniform on the interface. To test all the values in once, one tests the minimum and the maximum of Lagrangian of friction.

Not	Identification	Reference	Tolerance (%)
0.5	H1X for all the nodes	1.36362396705485E-07	1.0E-6
0,5	LAGS_F1 for all the nodes	3.66296853301E+05	1.0E-6
0.75	H1X for all the nodes	6.818119835274E-08	1.0E-6
0,75	LAGS_F1 for all the nodes	1.8314842665E+05	1.0E-6
2	H1X for all the nodes	4.0908719011645E-07	1.0E-6
2	LAGS_F1 for all the nodes	1.098890559903E+06	1.0E-6
3.5	H1X for all the nodes	7.49999999999582E-04	1.0E-6
3,5	LAGS_F1 for all the nodes	1.75867720687844E+05	1.0E-6
4.5	H1X for all the nodes	2.49999999999582E-04	1.0E-6
4,5	LAGS_F1 for all the nodes	58622.573562549	1.0E-6
5.5	H1X for all the nodes	7.49999999999582E-04	1.0E-6
5,5	LAGS_F1 for all the nodes	1.75867720687844E+05	1.0E-6
7	H1X for all the nodes	1.49999999999958E-03	1.0E-6

7	LAGS_F1 for all the nodes	28117.686527187	1.0E-6
9.5	H1X for all the nodes	2.49999999999582E-04	1.0E-6
9,5	LAGS_F1 for all the nodes	4686.28108785798	1.0E-6
12	H1X for all the nodes	1.49999999999958E-03	1.0E-6
12	LAGS_F1 for all the nodes	28117.686527187	1.0E-6
15	H1X for all the nodes	2.99999999999958E-03	1.0E-6
15	LAGS_F1 for all the nodes	718.731177854856	1.0E-6

5.5 Comments

the values of Lagrangian of contact and friction are explicitly calculated according to the jump of displacement that one controls. It is thus natural to have quasi-null errors.

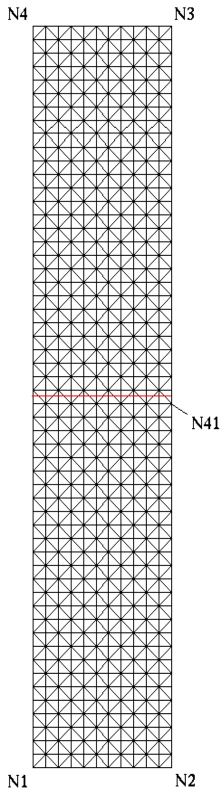
6 Modelization D

6.1 Characteristic of the modelization

the characteristics of modelization are the same ones as for the modelization A .

6.2 Characteristics of the mesh

The mesh is refined here compared to that of the modelization C. One discretizes structure in $2\times(11\times55)$ finite elements TRIA3. The interface is thus present within the central elements by the means of level sets.



Appear 6.2-a: Mesh of the modelization D

6.3 Control

One uses a specific control $XFEM$ SAUT_LONG_ARC on all the edges intersected by crack.

6.4 Quantities tested and Mode

results I :

One tests the values of Lagrangian of contact LAGS_C in all the nodes of the mesh crossed by the interface after convergence of the iterations of each operator STAT_NON_LINE, these values being uniform on the interface. To test all the values in once, one tests the minimum and the maximum of Lagrangian of contact.

Not	Identification	Reference	*Tolerance (%)*
0.5	H1Y for all the nodes	1.36362396705485E-07	1.0E-6
0,5	LAGS_C for all the nodes	3.66296853301E+05	1.0E-6
0.75	H1Y for all the nodes	6.818119835274E-08	1.0E-6
0,75	LAGS_C for all the nodes	1.8314842665E+05	1.0E-6
2	H1Y for all the nodes	4.0908719011645E-07	1.0E-6
2	LAGS_C for all the nodes	1.098890559903E+06	1.0E-6
3.5	H1Y for all the nodes	7.49999999999582E-04	1.0E-6
3,5	LAGS_C for all the nodes	1.75867720687844E+05	1.0E-6
4.5	H1Y for all the nodes	2.49999999999582E-04	1.0E-6
4,5	LAGS_C for all the nodes	58622.573562549	1.0E-6
5.5	H1Y for all the nodes	7.49999999999582E-04	1.0E-6
5,5	LAGS_C for all the nodes	1.75867720687844E+05	1.0E-6
7	H1Y for all the nodes	1.49999999999958E-03	1.0E-6
7	LAGS_C for all the nodes	28117.686527187	1.0E-6
9.5	H1Y for all the nodes	2.49999999999582E-04	1.0E-6
9,5	LAGS_C for all the nodes	4686.28108785798	1.0E-6
12	H1Y for all the nodes	1.49999999999958E-03	1.0E-6
12	LAGS_C for all the nodes	28117.686527187	1.0E-6
15	H1Y for all the nodes	2.99999999999958E-03	1.0E-6
15	LAGS_C for all the nodes	718.731177854856	1.0E-6

Mode II :

One tests the values of Lagrangian of friction LAGS_F1 in all the nodes of the mesh crossed by the interface after convergence of the iterations of each operator STAT_NON_LINE, these values being uniform on the interface. To test all the values in once, one tests the minimum and the maximum of Lagrangian of friction.

Not	Identification	Reference	*Tolerance (%)*
0.5	H1X for all the nodes	1.36362396705485E-07	1.0E-6
0,5	LAGS_F1 for all the nodes	3.66296853301E+05	1.0E-6
0.75	H1X for all the nodes	6.818119835274E-08	1.0E-6
0,75	LAGS_F1 for all the nodes	1.8314842665E+05	1.0E-6
2	H1X for all the nodes	4.0908719011645E-07	1.0E-6
2	LAGS_F1 for all the nodes	1.098890559903E+06	1.0E-6
3.5	H1X for all the nodes	7.49999999999582E-04	1.0E-6
3,5	LAGS_F1 for all the nodes	1.75867720687844E+05	1.0E-6
4.5	H1X for all the nodes	2.49999999999582E-04	1.0E-6
4,5	LAGS_F1 for all the nodes	58622.573562549	1.0E-6
5.5	H1X for all the nodes	7.49999999999582E-04	1.0E-6
5,5	LAGS_F1 for all the nodes	1.75867720687844E+05	1.0E-6
7	H1X for all the nodes	1.49999999999958E-03	1.0E-6
7	LAGS_F1 for all the nodes	28117.686527187	1.0E-6

9.5	H1X for all the nodes	2.49999999999582E-04	1.0E-6
9,5	LAGS_F1 for all the nodes	4686.28108785798	1.0E-6
12	H1X for all the nodes	1.49999999999958E-03	1.0E-6
12	LAGS_F1 for all the nodes	28117.686527187	1.0E-6
15	H1X for all the nodes	2.99999999999958E-03	1.0E-6
15	LAGS_F1 for all the nodes	718.731177854856	1.0E-6

6.5 Comments

the values of Lagrangian of contact and friction are explicitly calculated according to the jump of displacement that one controls. It is thus natural to have quasi-null errors.

7 Modelization E

7.1 Characteristic of the modelization

It acts of a modelization $X-FEM$, in three dimensions, with definition of contact on the interface of discontinuity defined by a function of level (level set noted LN for the level set norm) directly in the command file using operator DEFI_FISS_XFEM [U4.82.08].

The equation of the function of level for the interface is the following one:

$$\mathrm{LN}=Y-12.5$$

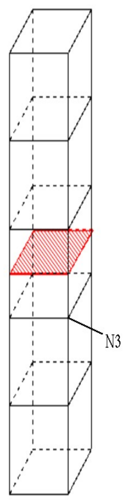
No level set tangential is necessary since one uses key word TYPE_DISCONTINUITE=' INTERFACE', which makes it possible to have structure completely cut in two parts.

L has cohesive model is introduced via operator DEFI_CONT , by specifying ALGO_CONT=' CZM' , and the cohesive lo l of behavior is activated thanks to key word RELATION=' CZM_EXP_REG' .

One tests here the modes I and II of opening.

7.2 Characteristics of the mesh

One discretizes structure in $1\times1\times5$ finite elements HEXA8. The interface is thus present within the central element by the means of level sets.



Appear 7.2-a : mesh with 5 HEXA8

7.3 specific

Control Control of type SAUT_IMPO, one uses the group of the nodes located immediately at the top of crack .

7.4 Quantities tested and Mode

results I :

One tests the values of Lagrangian of contact `LAGS_C` in all the nodes of the mesh crossed by the interface after convergence of the iterations of each operator `STAT_NON_LINE`, these values being uniform on the interface. To test all the values in once, one tests the minimum and the maximum of Lagrangian of contact.

Not	Identification	Reference	Tolerance (%)
0.5	`H1Z` for all the nodes	1.36362396705485E-07	1.0E-5
0,5	`LAGS_C` for all the nodes	3.66296853301E+05	1.0E-5
0.75	`H1Z` for all the nodes	6.818119835274E-08	1.0E-5
0,75	`LAGS_C` for all the nodes	1.8314842665E+05	1.0E-5
2	`H1Z` for all the nodes	4.0908719011645E-07	1.0E-5
2	`LAGS_C` for all the nodes	1.098890559903E+06	1.0E-5
3.5	`H1Z` for all the nodes	7.49999999999582E-04	1.0E-5
3,5	`LAGS_C` for all the nodes	1.75867720687844E+05	1.0E-5
4.5	`H1Z` for all the nodes	2.49999999999582E-04	1.0E-5
4,5	`LAGS_C` for all the nodes	58622.573562549	1.0E-5
5.5	`H1Z` for all the nodes	7.49999999999582E-04	1.0E-5
5,5	`LAGS_C` for all the nodes	1.75867720687844E+05	1.0E-5
7	`H1Z` for all the nodes	1.49999999999958E-03	1.0E-5
7	`LAGS_C` for all the nodes	28117.686527187	1.0E-5
9.5	`H1Z` for all the nodes	2.49999999999582E-04	1.0E-5
9,5	`LAGS_C` for all the nodes	4686.28108785798	1.0E-5
12	`H1Z` for all the nodes	1.49999999999958E-03	1.0E-5
12	`LAGS_C` for all the nodes	28117.686527187	1.0E-5
15	`H1Z` for all the nodes	2.99999999999958E-03	1.0E-5
15	`LAGS_C` for all the nodes	718.731177854856	1.0E-5

Mode II :

One tests the values of Lagrangian of friction `LAGS_F1` in all the nodes of the mesh crossed by the interface after convergence of the iterations of each operator `STAT_NON_LINE`, these values being uniform on the interface. To test all the values in once, one tests the minimum and the maximum of Lagrangian of friction.

Not	Identification	Reference	Tolerance (%)
0.5	`H1X` for all the nodes	1.36362396705485E-07	1.0E-5
0,5	`LAGS_F1` for all the nodes	3.66296853301E+05	1.0E-5
0.75	`H1X` for all the nodes	6.818119835274E-08	1.0E-5
0,75	`LAGS_F1` for all the nodes	1.8314842665E+05	1.0E-5
2	`H1X` for all the nodes	4.0908719011645E-07	1.0E-5
2	`LAGS_F1` for all the nodes	1.098890559903E+06	1.0E-5
3.5	`H1X` for all the nodes	7.49999999999582E-04	1.0E-5
3,5	`LAGS_F1` for all the nodes	1.75867720687844E+05	1.0E-5
4.5	`H1X` for all the nodes	2.49999999999582E-04	1.0E-5
4,5	`LAGS_F1` for all the nodes	58622.573562549	1.0E-5
5.5	`H1X` for all the nodes	7.49999999999582E-04	1.0E-5
5,5	`LAGS_F1` for all the nodes	1.75867720687844E+05	1.0E-5
7	`H1X` for all the nodes	1.49999999999958E-03	1.0E-5
7	`LAGS_F1` for all the nodes	28117.686527187	1.0E-5
9.5	`H1X` for all the nodes	2.49999999999582E-04	1.0E-5

9,5	LAGS_F1 for all the nodes	4686.28108785798	1.0E-5
12	H1X for all the nodes	1.49999999999958E-03	1.0E-5
12	LAGS_F1 for all the nodes	28117.686527187	1.0E-5
15	H1X for all the nodes	2.99999999999958E-03	1.0E-5
15	LAGS_F1 for all the nodes	718.731177854856	1.0E-5

7.5 Comments

the values of Lagrangian of contact and friction are explicitly calculated according to the jump of displacement that one controls. It is thus natural to have quasi-null errors.

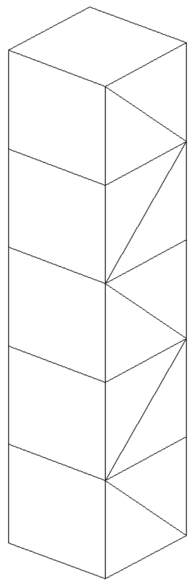
8 Modelization F

8.1 Characteristic of the modelization

the characteristics of modelization are the same ones as for the modelization E .

8.2 Characteristics of the mesh

One discretizes structure in $2\times(1\times1\times5)$ finite elements PENTA6. The interface is thus present within the central elements by the means of level sets.



Appear 8.2-a: Mesh of the modelization F

8.3 Control

One uses a control specific $X-FEM$ SAUT_IMPO using the nodes group located immediately at the top of crack.

8.4 Quantities tested and Mode

results I :

One tests the values of Lagrangian of contact LAGS_C in all the nodes of the mesh crossed by the interface after convergence of the iterations of each operator STAT_NON_LINE, these values being uniform on the interface. To test all the values in once, one tests the minimum and the maximum of Lagrangian of contact.

Not	Identification	Reference	Tolerance (%)
0.5	H1Z for all the nodes	1.36362396705485E-07	1.0E-5
0,5	LAGS_C for all the nodes	3.66296853301E+05	1.0E-5
0.75	H1Z for all the nodes	6.818119835274E-08	1.0E-5
0,75	LAGS_C for all the nodes	1.8314842665E+05	1.0E-5
2	H1Z for all the nodes	4.0908719011645E-07	1.0E-5
2	LAGS_C for all the nodes	1.098890559903E+06	1.0E-5
3.5	H1Z for all the nodes	7.49999999999582E-04	1.0E-5
3,5	LAGS_C for all the nodes	1.75867720687844E+05	1.0E-5
4.5	H1Z for all the nodes	2.49999999999582E-04	1.0E-5
4,5	LAGS_C for all the nodes	58622.573562549	1.0E-5
5.5	H1Z for all the nodes	7.49999999999582E-04	1.0E-5
5,5	LAGS_C for all the nodes	1.75867720687844E+05	1.0E-5
7	H1Z for all the nodes	1.49999999999958E-03	1.0E-5
7	LAGS_C for all the nodes	28117.686527187	1.0E-5
9.5	H1Z for all the nodes	2.49999999999582E-04	1.0E-5
9,5	LAGS_C for all the nodes	4686.28108785798	1.0E-5
12	H1Z for all the nodes	1.49999999999958E-03	1.0E-5
12	LAGS_C for all the nodes	28117.686527187	1.0E-5
15	H1Z for all the nodes	2.99999999999958E-03	1.0E-5
15	LAGS_C for all the nodes	718.731177854856	1.0E-5

Mode II :

One tests the values of Lagrangian of friction LAGS_F1 in all the nodes of the mesh crossed by the interface after convergence of the iterations of each operator STAT_NON_LINE, these values being uniform on the interface. To test all the values in once, one tests the minimum and the maximum of Lagrangian of friction.

Not	Identification	Reference	Tolerance (%)
0.5	H1X for all the nodes	1.36362396705485E-07	1.0E-5
0,5	LAGS_F1 for all the nodes	3.66296853301E+05	1.0E-5
0.75	H1X for all the nodes	6.818119835274E-08	1.0E-5
0,75	LAGS_F1 for all the nodes	1.8314842665E+05	1.0E-5
2	H1X for all the nodes	4.0908719011645E-07	1.0E-5
2	LAGS_F1 for all the nodes	1.098890559903E+06	1.0E-5
3.5	H1X for all the nodes	7.49999999999582E-04	1.0E-5
3,5	LAGS_F1 for all the nodes	1.75867720687844E+05	1.0E-5
4.5	H1X for all the nodes	2.49999999999582E-04	1.0E-5
4,5	LAGS_F1 for all the nodes	58622.573562549	1.0E-5
5.5	H1X for all the nodes	7.49999999999582E-04	1.0E-5
5,5	LAGS_F1 for all the nodes	1.75867720687844E+05	1.0E-5
7	H1X for all the nodes	1.49999999999958E-03	1.0E-5
7	LAGS_F1 for all the nodes	28117.686527187	1.0E-5

9.5	H1X for all the nodes	2.49999999999582E-04	1.0E-5
9,5	LAGS_F1 for all the nodes	4686.28108785798	1.0E-5
12	H1X for all the nodes	1.49999999999958E-03	1.0E-5
12	LAGS_F1 for all the nodes	28117.686527187	1.0E-5
15	H1X for all the nodes	2.99999999999958E-03	1.0E-5
15	LAGS_F1 for all the nodes	718.731177854856	1.0E-5

8.5 Comments

the values of Lagrangian of contact and friction are explicitly calculated according to the jump of displacement that one controls. It is thus natural to have quasi-null errors.

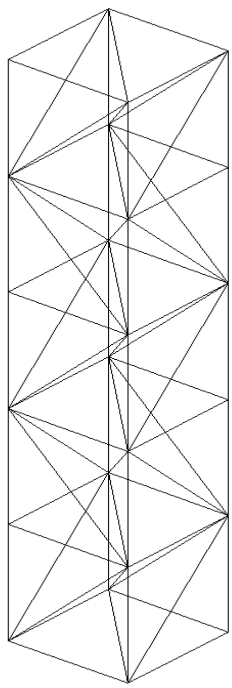
9 Modelization G

9.1 Characteristic of the modelization

the characteristics of modelization are the same ones as for the modelization E.

9.2 Characteristics of the mesh

One discretizes structure in $4\times(1\times1\times15)$ finite elements TETRA4. The interface is thus present within the central elements by the means of level sets.



Appear 9.2-a: Mesh of the modelization G

9.3 Control

One uses a control specific $X-FEM$ SAUT_LONG_ARC using the nodes group located immediately at the top of crack.

9.4 Quantities tested and Mode

results I :

One tests the values of Lagrangian of contact LAGS_C in all the nodes of the mesh crossed by the interface after convergence of the iterations of each operator STAT_NON_LINE, these values being uniform on the interface. To test all the values in once, one tests the minimum and the maximum of Lagrangian of contact.

Not	Identification	Reference	Tolerance (%)
0.5	H1Z for all the nodes	1.36362396705485E-07	1.0E-6
0,5	LAGS_C for all the nodes	3.66296853301E+05	1.0E-6
0.75	H1Z for all the nodes	6.818119835274E-08	1.0E-6
0,75	LAGS_C for all the nodes	1.8314842665E+05	1.0E-6
2	H1Z for all the nodes	4.0908719011645E-07	1.0E-6
2	LAGS_C for all the nodes	1.098890559903E+06	1.0E-6
3.5	H1Z for all the nodes	7.49999999999582E-04	1.0E-6
3,5	LAGS_C for all the nodes	1.75867720687844E+05	1.0E-6
4.5	H1Z for all the nodes	2.49999999999582E-04	1.0E-6
4,5	LAGS_C for all the nodes	58622.573562549	1.0E-6
5.5	H1Z for all the nodes	7.49999999999582E-04	1.0E-6
5,5	LAGS_C for all the nodes	1.75867720687844E+05	1.0E-6
7	H1Z for all the nodes	1.49999999999958E-03	1.0E-6
7	LAGS_C for all the nodes	28117.686527187	1.0E-6
9.5	H1Z for all the nodes	2.49999999999582E-04	1.0E-6
9,5	LAGS_C for all the nodes	4686.28108785798	1.0E-6
12	H1Z for all the nodes	1.49999999999958E-03	1.0E-6
12	LAGS_C for all the nodes	28117.686527187	1.0E-6
15	H1Z for all the nodes	2.99999999999958E-03	1.0E-6
15	LAGS_C for all the nodes	718.731177854856	1.0E-6

Mode II :

One tests the values of Lagrangian of friction LAGS_F1 in all the nodes of the mesh crossed by the interface after convergence of the iterations of each operator STAT_NON_LINE, these values being uniform on the interface. To test all the values in once, one tests the minimum and the maximum of Lagrangian of friction.

Not	Identification	Reference	Tolerance (%)
0.5	H1X for all the nodes	1.36362396705485E-07	1.0E-6
0,5	LAGS_F1 for all the nodes	3.66296853301E+05	1.0E-6
0.75	H1X for all the nodes	6.818119835274E-08	1.0E-6
0,75	LAGS_F1 for all the nodes	1.8314842665E+05	1.0E-6
2	H1X for all the nodes	4.0908719011645E-07	1.0E-6
2	LAGS_F1 for all the nodes	1.098890559903E+06	1.0E-6
3.5	H1X for all the nodes	7.49999999999582E-04	1.0E-6
3,5	LAGS_F1 for all the nodes	1.75867720687844E+05	1.0E-6
4.5	H1X for all the nodes	2.49999999999582E-04	1.0E-6
4,5	LAGS_F1 for all the nodes	58622.573562549	1.0E-6
5.5	H1X for all the nodes	7.49999999999582E-04	1.0E-6
5,5	LAGS_F1 for all the nodes	1.75867720687844E+05	1.0E-6
7	H1X for all the nodes	1.49999999999958E-03	1.0E-6
7	LAGS_F1 for all the nodes	28117.686527187	1.0E-6

9.5	H1X for all the nodes	2.49999999999582E-04	1.0E-6
9,5	LAGS_F1 for all the nodes	4686.28108785798	1.0E-6
12	H1X for all the nodes	1.49999999999958E-03	1.0E-5
12	LAGS_F1 for all the nodes	28117.686527187	1.0E-5
15	H1X for all the nodes	2.99999999999958E-03	1.0E-5
15	LAGS_F1 for all the nodes	718.731177854856	1.0E-5

9.5 Comments

the values of Lagrangian of contact and friction are explicitly calculated according to the jump of displacement that one controls. It is thus natural to have quasi-null errors.

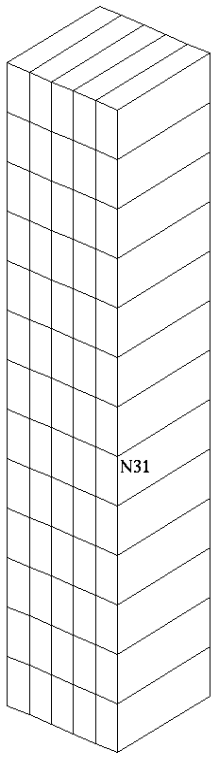
10 Modelization H

10.1 Characteristic of the modelization

the characteristics of modelization are the same ones as for the modelization E.

10.2 Characteristics of the mesh

The mesh is refined here compared to that of the modelization F. One discretizes structure in $5\times1\times13$ finite elements HEXA8. The interface is thus present within the central elements by the means of level sets.



Appear 10.2-a: Mesh of the modelization H

10.3 Control

One uses a control specific $X-FEM$ SAUT_LONG_ARC using the nodes group located immediately at the top of crack.

10.4 Quantities tested and Mode

results I :

One tests the values of Lagrangian of contact LAGS_C in all the nodes of the mesh crossed by the interface after convergence of the iterations of each operator STAT_NON_LINE, these values being uniform on the interface. To test all the values in once, one tests the minimum and the maximum of Lagrangian of contact.

Not	Identification	Reference	Tolerance (%)
0.5	H1Z for all the nodes	1.36362396705485E-07	1.0E-5
0,5	LAGS_C for all the nodes	3.66296853301E+05	1.0E-5
0.75	H1Z for all the nodes	6.818119835274E-08	1.0E-5
0,75	LAGS_C for all the nodes	1.8314842665E+05	1.0E-5
2	H1Z for all the nodes	4.0908719011645E-07	1.0E-5
2	LAGS_C for all the nodes	1.098890559903E+06	1.0E-5
3.5	H1Z for all the nodes	7.49999999999582E-04	1.0E-5
3,5	LAGS_C for all the nodes	1.75867720687844E+05	1.0E-5
4.5	H1Z for all the nodes	2.49999999999582E-04	1.0E-5
4,5	LAGS_C for all the nodes	58622.573562549	1.0E-5
5.5	H1Z for all the nodes	7.49999999999582E-04	1.0E-5
5,5	LAGS_C for all the nodes	1.75867720687844E+05	1.0E-5
7	H1Z for all the nodes	1.49999999999958E-03	1.0E-5
7	LAGS_C for all the nodes	28117.686527187	1.0E-5
9.5	H1Z for all the nodes	2.49999999999582E-04	1.0E-5
9,5	LAGS_C for all the nodes	4686.28108785798	1.0E-5
12	H1Z for all the nodes	1.49999999999958E-03	1.0E-5
12	LAGS_C for all the nodes	28117.686527187	1.0E-5
15	H1Z for all the nodes	2.99999999999958E-03	1.0E-5
15	LAGS_C for all the nodes	718.731177854856	1.0E-5

Mode II :

One tests the values of Lagrangian of friction LAGS_F1 in all the nodes of the mesh crossed by the interface after convergence of the iterations of each operator STAT_NON_LINE, these values being uniform on the interface. To test all the values in once, one tests the minimum and the maximum of Lagrangian of friction.

Not	Identification	Reference	Tolerance (%)
0.5	H1X for all the nodes	1.36362396705485E-07	1.0E-5
0,5	LAGS_F1 for all the nodes	3.66296853301E+05	1.0E-5
0.75	H1X for all the nodes	6.818119835274E-08	1.0E-5
0,75	LAGS_F1 for all the nodes	1.8314842665E+05	1.0E-5
2	H1X for all the nodes	4.0908719011645E-07	1.0E-5
2	LAGS_F1 for all the nodes	1.098890559903E+06	1.0E-5
3,5	H1X for all the nodes	7.49999999999582E-04	1.0E-5
3,5	LAGS_F1 for all the nodes	1.75867720687844E+05	1.0E-5
4.5	H1X for all the nodes	2.49999999999582E-04	1.0E-5
4,5	LAGS_F1 for all the nodes	58622.573562549	1.0E-5
5.5	H1X for all the nodes	7.49999999999582E-04	1.0E-5
5,5	LAGS_F1 for all the nodes	1.75867720687844E+05	1.0E-5
7	H1X for all the nodes	1.49999999999958E-03	1.0E-5
7	LAGS_F1 for all the nodes	28117.686527187	1.0E-5

9.5	H1X for all the nodes	2.49999999999582E-04	1.0E-5
9,5	LAGS_F1 for all the nodes	4686.28108785798	1.0E-5
12	H1X for all the nodes	1.49999999999958E-03	1.0E-5
12	LAGS_F1 for all the nodes	28117.686527187	1.0E-5
15	H1X for all the nodes	2.99999999999958E-03	1.0E-5
15	LAGS_F1 for all the nodes	718.731177854856	1.0E-5

10.5 Comments

the values of Lagrangian of contact and friction are explicitly calculated according to the jump of displacement that one controls. It is thus natural to have quasi-null errors.

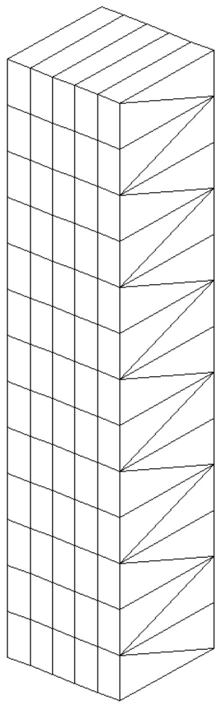
11 Modelization I

11.1 Characteristic of the modelization

the characteristics of modelization are the same ones as for the modelization E .

11.2 Characteristics of the mesh

The mesh is refined here compared to that of the modelization F. One discretizes structure in $2\times(5\times1\times13)$ finite elements PENTA6. The interface is thus present within the central elements by the means of level sets.



Appear 11.2-a: Mesh of the modelization I

11.3 Control

One uses a control specific $X-FEM$ SAUT_IMPO using the nodes group located immediately at the top of crack.

11.4 Quantities tested and Mode

results I :

One tests the values of Lagrangian of contact LAGS_C in all the nodes of the mesh crossed by the interface after convergence of the iterations of each operator STAT_NON_LINE, these values being uniform on the interface. To test all the values in once, one tests the minimum and the maximum of Lagrangian of contact.

Not	Identification	Reference	Tolerance (%)
0.5	H1Z for all the nodes	1.36362396705485E-07	2.0E-6
0,5	LAGS_C for all the nodes	3.66296853301E+05	2.0E-6
0.75	H1Z for all the nodes	6.818119835274E-08	2.0E-6
0,75	LAGS_C for all the nodes	1.8314842665E+05	2.0E-6
2	H1Z for all the nodes	4.0908719011645E-07	2.0E-6
2	LAGS_C for all the nodes	1.098890559903E+06	2.0E-6
3.5	H1Z for all the nodes	7.49999999999582E-04	2.0E-6
3,5	LAGS_C for all the nodes	1.75867720687844E+05	2.0E-6
4.5	H1Z for all the nodes	2.49999999999582E-04	2.0E-6
4,5	LAGS_C for all the nodes	58622.573562549	2.0E-6
5.5	H1Z for all the nodes	7.49999999999582E-04	2.0E-6
5,5	LAGS_C for all the nodes	1.75867720687844E+05	2.0E-6
7	H1Z for all the nodes	1.49999999999958E-03	2.0E-6
7	LAGS_C for all the nodes	28117.686527187	2.0E-6
9.5	H1Z for all the nodes	2.49999999999582E-04	2.0E-6
9,5	LAGS_C for all the nodes	4686.28108785798	2.0E-6
12	H1Z for all the nodes	1.49999999999958E-03	2.0E-6
12	LAGS_C for all the nodes	28117.686527187	2.0E-6
15	H1Z for all the nodes	2.99999999999958E-03	2.0E-6
15	LAGS_C for all the nodes	718.731177854856	2.0E-6

Mode II :

One tests the values of Lagrangian of friction LAGS_F1 in all the nodes of the mesh crossed by the interface after convergence of the iterations of each operator STAT_NON_LINE, these values being uniform on the interface. To test all the values in once, one tests the minimum and the maximum of Lagrangian of friction.

Not	Identification	Reference	Tolerance (%)
0.5	H1X for all the nodes	1.36362396705485E-07	2.0E-6
0,5	LAGS_F1 for all the nodes	3.66296853301E+05	2.0E-6
0.75	H1X for all the nodes	6.818119835274E-08	2.0E-6
0,75	LAGS_F1 for all the nodes	1.8314842665E+05	2.0E-6
2	H1X for all the nodes	4.0908719011645E-07	2.0E-6
2	LAGS_F1 for all the nodes	1.098890559903E+06	2.0E-6
3.5	H1X for all the nodes	7.49999999999582E-04	2.0E-6
3,5	LAGS_F1 for all the nodes	1.75867720687844E+05	2.0E-6
4.5	H1X for all the nodes	2.49999999999582E-04	2.0E-6
4,5	LAGS_F1 for all the nodes	58622.573562549	2.0E-6
5.5	H1X for all the nodes	7.49999999999582E-04	2.0E-6
5,5	LAGS_F1 for all the nodes	1.75867720687844E+05	2.0E-6
7	H1X for all the nodes	1.49999999999958E-03	2.0E-6
7	LAGS_F1 for all the nodes	28117.686527187	2.0E-6
9.5	H1X for all the nodes	2.49999999999582E-04	2.0E-6

9,5	LAGS_F1 for all the nodes	4686.28108785798	2.0E-6
12	H1X for all the nodes	1.49999999999958E-03	2.0E-6
12	LAGS_F1 for all the nodes	28117.686527187	2.0E-6
15	H1X for all the nodes	2.99999999999958E-03	2.0E-6
15	LAGS_F1 for all the nodes	718.731177854856	2.0E-6

11.5 Comments

the values of Lagrangian of contact and friction are explicitly calculated according to the jump of displacement that one controls. It is thus natural to have quasi-null errors.

12 Modelization J

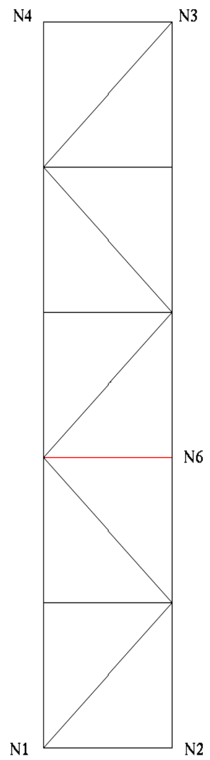
12.1 Characteristic of the modelization

the characteristics of modelization are the same ones as for the modelization A , put except for one changes the position of the level set in order to position it with the interface between two elements. The equation of the function of levels for the interface is the following one:

$$\mathrm{LN} = Y - 2$$

12.2 Characteristics of the mesh

One discretizes structure in 2×5 finite elements TRIA3. The interface is thus present between two elements by the means of level sets.



Appear 12.2-a: Mesh of the modelization J

12.3 Control

One uses a specific control XFEM SAUT_IMPO on all the intersected edges.

12.4 Quantities tested and Mode

results I :

One tests the values of Lagrangian of contact LAGS_C in all the nodes of the mesh crossed by the interface after convergence of the iterations of each operator STAT_NON_LINE, these values being uniform on the interface. To test all the values in once, one tests the minimum and the maximum of Lagrangian of contact.

Not	Identification	Reference	Tolerance (%)
0.5	H1Y for all the nodes	1.36362396705485E-07	1.0E-6
0,5	LAGS_C for all the nodes	3.66296853301E+05	1.0E-6
0.75	H1Y for all the nodes	6.818119835274E-08	1.0E-6
0,75	LAGS_C for all the nodes	1.8314842665E+05	1.0E-6
2	H1Y for all the nodes	4.0908719011645E-07	1.0E-6
2	LAGS_C for all the nodes	1.098890559903E+06	1.0E-6
3.5	H1Y for all the nodes	7.49999999999582E-04	1.0E-6
3,5	LAGS_C for all the nodes	1.75867720687844E+05	1.0E-6
4.5	H1Y for all the nodes	2.49999999999582E-04	1.0E-6
4,5	LAGS_C for all the nodes	58622.573562549	1.0E-6
5.5	H1Y for all the nodes	7.49999999999582E-04	1.0E-6
5,5	LAGS_C for all the nodes	1.75867720687844E+05	1.0E-6
7	H1Y for all the nodes	1.49999999999958E-03	1.0E-6
7	LAGS_C for all the nodes	28117.686527187	1.0E-6
9.5	H1Y for all the nodes	2.49999999999582E-04	1.0E-6
9,5	LAGS_C for all the nodes	4686.28108785798	1.0E-6
12	H1Y for all the nodes	1.49999999999958E-03	1.0E-6
12	LAGS_C for all the nodes	28117.686527187	1.0E-6
15	H1Y for all the nodes	2.99999999999958E-03	1.0E-6
15	LAGS_C for all the nodes	718.731177854856	1.0E-6

Mode II :

One tests the values of Lagrangian of friction LAGS_F1 in all the nodes of the mesh crossed by the interface after convergence of the iterations of each operator STAT_NON_LINE, these values being uniform on the interface. To test all the values in once, one tests the minimum and the maximum of Lagrangian of friction.

Not	Identification	Reference	Tolerance (%)
0.5	H1X for all the nodes	1.36362396705485E-07	1.0E-6
0,5	LAGS_F1 for all the nodes	3.66296853301E+05	1.0E-6
0.75	H1X for all the nodes	6.818119835274E-08	1.0E-6
0,75	LAGS_F1 for all the nodes	1.8314842665E+05	1.0E-6
2	H1X for all the nodes	4.0908719011645E-07	1.0E-6
2	LAGS_F1 for all the nodes	1.098890559903E+06	1.0E-6
3.5	H1X for all the nodes	7.49999999999582E-04	1.0E-6
3,5	LAGS_F1 for all the nodes	1.75867720687844E+05	1.0E-6
4.5	H1X for all the nodes	2.49999999999582E-04	1.0E-6
4,5	LAGS_F1 for all the nodes	58622.573562549	1.0E-6
5.5	H1X for all the nodes	7.49999999999582E-04	1.0E-6
5,5	LAGS_F1 for all the nodes	1.75867720687844E+05	1.0E-6
7	H1X for all the nodes	1.49999999999958E-03	1.0E-6
7	LAGS_F1 for all the nodes	28117.686527187	1.0E-6
9.5	H1X for all the nodes	2.49999999999582E-04	1.0E-6
9,5	LAGS_F1 for all the nodes	4686.28108785798	1.0E-6
12	H1X for all the nodes	1.49999999999958E-03	1.0E-6
12	LAGS_F1 for all the nodes	28117.686527187	1.0E-6

15	H1X for all the nodes	2.99999999999958E-03	1.0E-6
15	LAGS_F1 for all the nodes	718.731177854856	1.0E-6

12.5 Comments

the values of Lagrangian of contact and friction are explicitly calculated according to the jump of displacement that one controls. It is thus natural to have quasi-null errors.

13 Modelization K

13.1 Characteristic of the modelization

the characteristics of modelization are the same ones as for the modelization G, put except for one changes the position of the level set in order to position it with the interface between two elements. The equation of the function of levels for the interface is the following one:

$$\mathrm{LN}=Y-10$$

13.2 Characteristics of the mesh

The mesh is the same one as that of the modelization G.

13.3 Control

One uses a specific control XFEM SAUT_IMPO on all the intersected edges.

13.4 Quantities tested and Mode

results I :

One tests the values of Lagrangian of contact LAGS_C in all the nodes of the mesh crossed by the interface after convergence of the iterations of each operator STAT_NON_LINE, these values being uniform on the interface. To test all the values in once, one tests the minimum and the maximum of Lagrangian of contact.

Not	Identification	Reference	Tolerance (%)
0.5	H1Z for all the nodes	1.36362396705485E-07	1.0E-6
0,5	LAGS_C for all the nodes	3.66296853301E+05	1.0E-6
0.75	H1Z for all the nodes	6.818119835274E-08	1.0E-6
0,75	LAGS_C for all the nodes	1.8314842665E+05	1.0E-6
2	H1Z for all the nodes	4.0908719011645E-07	1.0E-6
2	LAGS_C for all the nodes	1.098890559903E+06	1.0E-6
3.5	H1Z for all the nodes	7.49999999999582E-04	1.0E-6
3,5	LAGS_C for all the nodes	1.75867720687844E+05	1.0E-6
4.5	H1Z for all the nodes	2.49999999999582E-04	1.0E-6
4,5	LAGS_C for all the nodes	58622.573562549	1.0E-6
5.5	H1Z for all the nodes	7.49999999999582E-04	1.0E-6
5,5	LAGS_C for all the nodes	1.75867720687844E+05	1.0E-6
7	H1Z for all the nodes	1.49999999999958E-03	1.0E-6
7	LAGS_C for all the nodes	28117.686527187	1.0E-6
9.5	H1Z for all the nodes	2.49999999999582E-04	1.0E-6
9,5	LAGS_C for all the nodes	4686.28108785798	1.0E-6
12	H1Z for all the nodes	1.49999999999958E-03	1.0E-6
12	LAGS_C for all the nodes	28117.686527187	1.0E-6
15	H1Z for all the nodes	2.99999999999958E-03	1.0E-6
15	LAGS_C for all the nodes	718.731177854856	1.0E-6

Mode II :

One tests the values of Lagrangian of friction LAGS_F1 in all the nodes of the mesh crossed by the interface after convergence of the iterations of each operator STAT_NON_LINE, these values being uniform on the interface. To test all the values in once, one tests the minimum and the maximum of Lagrangian of friction.

Not	Identification	Reference	Tolerance (%)
0.5	H1X for all the nodes	1.36362396705485E-07	1.0E-6
0,5	LAGS_F1 for all the nodes	3.66296853301E+05	1.0E-6
0.75	H1X for all the nodes	6.818119835274E-08	1.0E-6
0,75	LAGS_F1 for all the nodes	1.8314842665E+05	1.0E-6
2	H1X for all the nodes	4.0908719011645E-07	1.0E-6
2	LAGS_F1 for all the nodes	1.098890559903E+06	1.0E-6
3.5	H1X for all the nodes	7.49999999999582E-04	1.0E-6
3,5	LAGS_F1 for all the nodes	1.75867720687844E+05	1.0E-6
4.5	H1X for all the nodes	2.49999999999582E-04	1.0E-6
4,5	LAGS_F1 for all the nodes	58622.573562549	1.0E-6
5.5	H1X for all the nodes	7.49999999999582E-04	1.0E-6
5,5	LAGS_F1 for all the nodes	1.75867720687844E+05	1.0E-6
7	H1X for all the nodes	1.49999999999958E-03	1.0E-6
7	LAGS_F1 for all the nodes	28117.686527187	1.0E-6
9.5	H1X for all the nodes	2.49999999999582E-04	1.0E-6
9,5	LAGS_F1 for all the nodes	4686.28108785798	1.0E-6
12	H1X for all the nodes	1.49999999999958E-03	1.0E-6
12	LAGS_F1 for all the nodes	28117.686527187	1.0E-6
15	H1X for all the nodes	2.99999999999958E-03	1.0E-6
15	LAGS_F1 for all the nodes	718.731177854856	1.0E-6

13.5 Comments

the values of Lagrangian of contact and friction are explicitly calculated according to the jump of displacement that one controls. It is thus natural to have quasi-null errors.

14 Modelization L

14.1 Characteristic of the modelization

It acts of a modelization $X-FEM$, in plane stresses, with definition of contact on the interface of discontinuity defined by a function of level (level set noted LN for the level set norm) directly in the command file using operator DEFI_FISS_XFEM [U4.82.08].
The statute main slave/for a contact surface $X-FEM$ is given by the sign of the normal function of level LN : surface slave is negative side while surface Master is positive side.

The equation of the function of level for the interface is the following one:

$$\mathrm{LN}=Y-2.5$$

No level set tangential is necessary since one uses key word TYPE_DISCONTINUITE=' INTERFACE', which makes it possible to have structure completely cut in two parts.

This tests models an interface in opening and closing for which the jump of displacement is controlled by a control by SAUT_IMPO.

The cohesive model is introduced via operator DEFI_CONT, by specifying ALGO_CONT=' CZM', and the cohesive constitutive law is activated thanks to key word RELATION=' CZM_EXP_REG'. In closing, the contact is managed by a term of penalization understood in the cohesive model.

14.2 Characteristics of the mesh

The mesh is the same one as that of the modelization A. The interface is thus present within the central element by the means of level sets.

14.3 Boundary conditions

the limiting conditions are the same ones as those of the mode I of opening of the modelizations $\mathrm{2D}$. The values of COEF_MULT are modified to carry out time step in opening then time step in closing.

Time of final computation	**Phase**	**Jump of final displacement (in m)**	c_{mult}	$H1Y$ **final**
0,5	Tension	2,73E-7	3.6667E6	1.36362396705485E-07
1,0	Compression	-2,73E-7	-9.16675E5	-1.36362396705485E-07

14.4 Reference solution

In opening, the solution is given by the cohesive model to paragraph 2.
In closing, the penalized solution is equal to the product of the jump of displacement by the coefficient of penalization which is the same one as the adhesion coefficient since we entered PENA_CONTACT=1. (confer to the documentation [R7.02.11]).

14.5 Quantities tested and results

One tests the values of Lagrangian of contact LAGS_C in all the nodes of the mesh crossed by the interface after convergence of the iterations of each operator STAT_NON_LINE. To test all the values in once, one tests the minimum and the maximum of Lagrangian of contact.

Not	Identification	Reference	Tolerance (%)
0.5	H1Y for all the nodes	1.36362396705485E-07	1.0E-10
0,5	LAGS_C for all the nodes	3.66296853301E+05	1.0E-10
1	H1Y for all the nodes	-1.36362396705485E-07	1.0E-10
1	LAGS_C for all the nodes	-3.66296853301E+05	1.0E-10

14.6 Comments

This tests watch which the term of penalization of the contact includes in the cohesive constitutive law for the processing makes it possible to raise the incompatibility between contact of continuous method and control. Remain with the user to check that the interpenetration obtained remains physical, and to increase PENA_CONTACT if such is not the case.

The values of Lagrangian of contact are explicitly calculated according to the jump of displacement that one controls. It is thus natural to have quasi-null errors.

15 Summary of the results

the numerical results are in agreement with the analytical solution. These tests make it possible to validate the cohesive model of contact implemented for the method $X-FEM$ in $2\mathrm{D}$ and $3\mathrm{D}$ in the various modes of opening.
The modelization L makes it possible of more than raise the incompatibility between contact of continuous method and control by means of a term of penalization in the cohesive model.