SSNP504 – Contact in great slidings with X-FEM for oblique cracks

Summarized:

The purpose of this test is 2D testing and validating the sliding functionalities of the approach large with X-FEM in the case of structures in plane stresses and plane strains presenting of oblique cracks. This approach, described in [R5.03.53], of the contact allows in particular the taking into account, with friction, on the level of cracks introduced by the method X-FEM, in the presence of large displacements but under the assumption of the small strains. New algorithms, compared to the processing of contact with X-FEM under the assumption of the small disturbances [R7.02.12], which is tested and validated by this benchmark relate to the geometrical reactualization of the lips of cracks, master-slave pairing and the creation of the new hybrid elements of contact.

One tests and validates also the operation and the effectiveness of the algorithm designed for the respect of the condition LBB, algorithm developed initially for the approach HP of the method X-FEM [R7.02.12].

One considers a structure 2D, a rectangle presenting two oblique cracks the beam completely (one will speak then about interfaces). Each interface cuts several stages of elements, requirement to highlight the effectiveness of algorithm LBB. The blocking of horizontal displacements is imposed on the four corners of the rectangle, of vertical displacements are imposed on the edges inferior and superior of the rectangle in order to tighten the block medium which is seen forcing a horizontal displacement to make it slip, while going up along the interfaces. Following the request of compression thus created, contact pressures appear on the zones in contact, with an evolution of their values according to the advance of the block medium.

The validation is done by comparison of the values of the contact pressure with the similar values obtained from a homologous test (even geometry, same boundary conditions etc), treated in the classical frame of the finite element method, with *Code_Aster*, where the interfaces are in conformity with the mesh.

1 Problem of reference

1.1 Geometry

the structure is a healthy rectangle into which two oblique interfaces are introduced. The interfaces parallel and are placed as shown on [Figure 1.1-1]. Dimensions of structure as those concerning the geometry of the interfaces are:

$H = 9\,m$;
$L = 4\,m$;
$B = 4\,m$;
$h = 2.125\,m$;
$\alpha = 13.49$

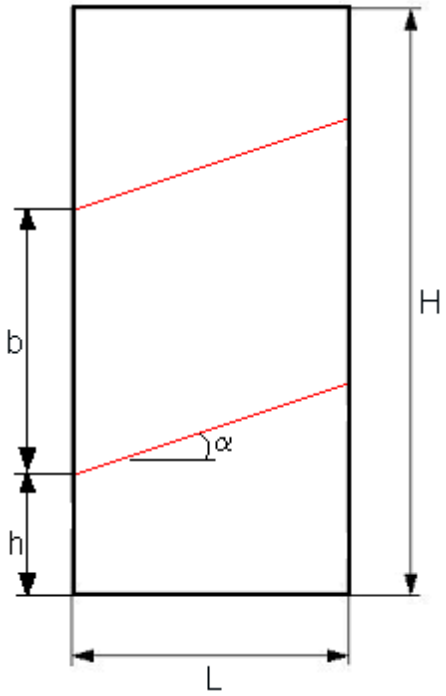

Figure 1.1-1: Geometry of structure and positioning of the interfaces.

1.2 Properties of the material

Young's modulus: $E = 100\,MPa$

Poisson's ratio: $\nu = 0.3$

1.3 Boundary conditions and loadings

the blocking of horizontal displacements is imposed on the four corners of structure (see [Figure 1.3-1]). On the edges inferior and superior of the rectangle, one imposes displacements along the axis Y which will close the interfaces in order to generate contact pressure. The block medium is subjected to an important sliding by applying a displacement controlled along the axis X to its left edge.

The numerical values of imposed displacements are:

$Depl_X = 2.00\,m$;

$Depl_Y = 1.0\mathrm{E}-2\,m$.

Their application is done according to a function crawls classical, in 4 steps of load.
The coefficient of kinetic friction of Coulomb is taken equal A. $0,5$

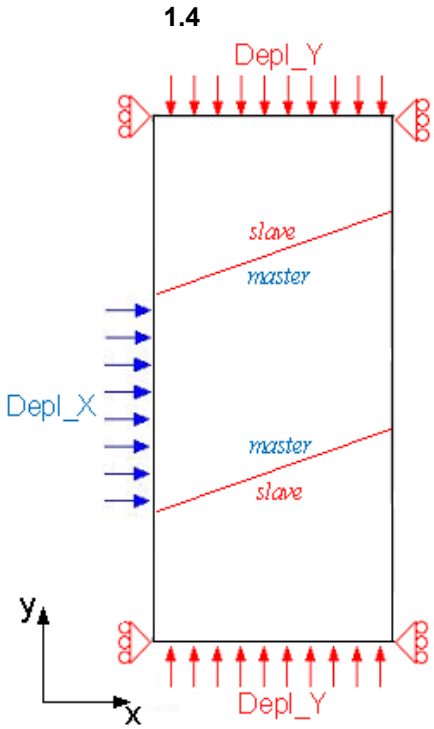

Figure 1.3-1: Illustration of the boundary conditions and the loadings.

2 Reference solution

the reference solution for this benchmark is provided by the results resulting from a computation *Code_Aster*, for same structure but with interfaces respecting the mesh, made with the continuous method of contact already existing in the classical frame of the finite element method [R5.03.52].

The geometry (except for the introduction the interfaces), the boundary conditions, the loadings as well as the parameters of contact are the same ones as those considered for this benchmark modelled with the method X-FEM.

3 Modelization A

3.1 Characteristic of the modelization

It acts of a modelization FEM, in plane strains. The three blocks are with a grid with meshes in conformity and the conditions of contact are imposed on stop these blocks. One and the declares the edges Masters on the block medium edges slaves on the blocks inferior and superior in order to conform to [Figure 1.3-1].

3.2 Characteristics of the mesh

The mesh is regulated (see [Figure 3.2-1]) and comprises 3 blocks made up of meshes of type QUAD4. The 3 blocks have each one meshes 256.

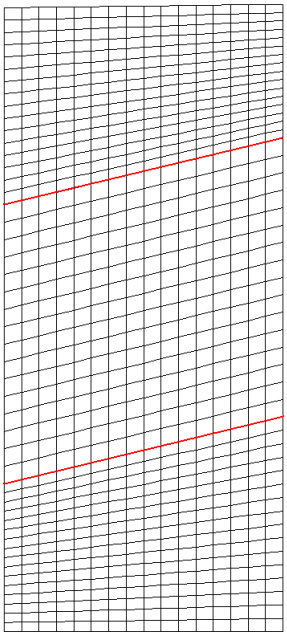

Figure 3.2-1: The mesh of the modelization A

3.3 Quantities tested and results

One tests contact pressures on the upper lip of the lower block, this one being declared slave, at the end of each step of load considered. The site of the nodes which store the degrees of freedom of contact, which one tests the values, is illustrated on [Figure 3.3-1].

Not	Identification	Reference	Tolerance
1	LAGS_C for N10	0.0000000E+00	1.0E-12
	LAGS_C for N60	-6.3355792D+04	5.0%
	LAGS_C for N56	-6.0652836D+04	5.0%
	LAGS_C for N52	-5.0757743D+04	5.0%
	LAGS_C for N9	0.0000000E+00	1.0E-12
2	LAGS_C for N10	0.0000000E+00	1.0E-12
	LAGS_C for N60	-1.8115145E+05	5.0%
	LAGS_C for N56	-1.2479791E+05	5.0%
	LAGS_C for N52	-1.0307176E+05	5.0%
	LAGS_C for N9	0.0000000E+00	1.0E-12
	LAGS_C for N10	0.0000000E+00	1.0E-12
	LAGS_C for N60	0.0000000E+00	1.0E-12

3	LAGS_C for N56	-2.0163278E+05	5.0%
	LAGS_C for N52	-1.5784447E+05	5.0%
	LAGS_C for N9	0.0000000E+00	1.0E-12
4	LAGS_C for N10	0.0000000E+00	1.0E-12
	LAGS_C for N60	0.0000000E+00	1.0E-12
	LAGS_C for N56	-3.7985867E+05	5.0%
	LAGS_C for N52	-2.2011907E+05	5.0%
	LAGS_C for N9	0.0000000E+00	1.0E-12

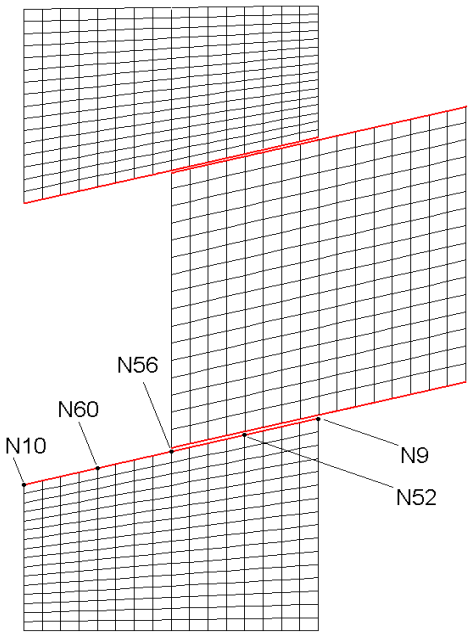

Figure 3.3-1: The site of the nodes which store the degrees of freedom of contact tested

3.4 Remarks

This test is used as reference to the modelization B, it is thus normal to have residues close to zero, which correspond to the accuracy required in operator IMPR_TABLE of the command file. It makes it possible to make sure that there is no evolution in the calculation algorithms for method FEM of contact in great slidings, in which case it would then be necessary also to re-examine the method X-FEM, based on this one.

4 Modelization B

4.1 Characteristic of the modelization

It acts of a modelization X-FEM, in plane strains, with definition of contact on the interfaces defined by functions of level (level sets 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 on the negative side while surface Master is positive side.

The equations of the functions of level for the two oblique interfaces are the following ones:

$$\mathrm{LN}1 = Y - X - \tan\alpha - 2.125 \quad \text{éq 4.1-1}$$

$$\mathrm{LN}2 = -Y + X - \tan\alpha + 6.125 \quad \text{éq 4.1-2}$$

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

4.2 Characteristics of the mesh

The mesh is regulated (see [Figure 3.3-1]) and meshes comprises 576 type QUAD4, 16×36 along the horizontal and vertical axes, respectively. Following the definition of the interfaces, meshes cut by those are transformed into QUAD8 in order to be able to store the degrees of freedom of contact rubbing with the nodes tops and mediums.

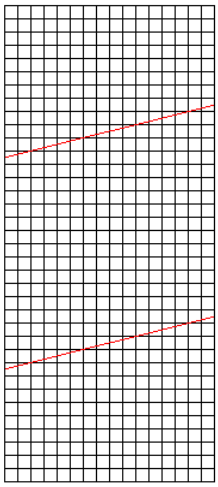

Figure 4.2-1: The mesh of the modelization B

As one can observe it on [Figure 3.3-1], each interface crosses 5 vertical stages of meshes, which leads to a richness of the space of multipliers of contact different from that of the space of geometrical displacements. It is in this situation that the algorithm of respect of the LBB condition will act in order to stabilize the distribution of contact pressure.

4.3 Quantities tested and results

One tests the values of contact pressure on the lip slave of the first interface, at the end of each step of load considered. The comparison compared to the results of reference is given in the following table.

The site of the nodes which store the degrees of freedom of contact, which one tests the values, is illustrated on [Figure 4.3-1].

Not	Identification	Reference	Tolerance
1	LAGS_C for N45	0.0000000E+00	1.0E-12
	LAGS_C for N230	-6.3355791D+04	5.0%
	LAGS_C for N249	-6.0652835D+04	5.0%
	LAGS_C for N268	-5.0757742D+04	5.0%
	LAGS_C for N83	0.0000000E+00	1.0E-12
2	LAGS_C for N45	0.0000000E+00	1.0E-12
	LAGS_C for N230	-1.8115145E+05	5.0%
	LAGS_C for N249	-1.2479791E+05	5.0%
	LAGS_C for N268	-1.0307176E+05	5.0%
	LAGS_C for N83	0.0000000E+00	1.0E-12
3	LAGS_C for N45	0.0000000E+00	1.0E-12
	LAGS_C for N230	0.0000000E+00	1.0E-12
	LAGS_C for N249	-2.0163278E+05	5.0%
	LAGS_C for N268	-1.5784447E+05	5.0%
	LAGS_C for N83	0.0000000E+00	1.0E-12
4	LAGS_C for N45	0.0000000E+00	1.0E-12
	LAGS_C for N230	0.0000000E+00	1.0E-12
	LAGS_C for N249	-3.7985867E+05	5.0%
	LAGS_C for N268	-2.2011907E+05	5.0%
	LAGS_C for N83	0.0000000E+00	1.0E-12

the analysis was carried out with and without the algorithm of stabilization LBB. In absence of the algorithm, important oscillations were found in the distribution of contact pressures. On the other hand, once activated algorithm LBB, one obtains a stable solution for contact pressures.

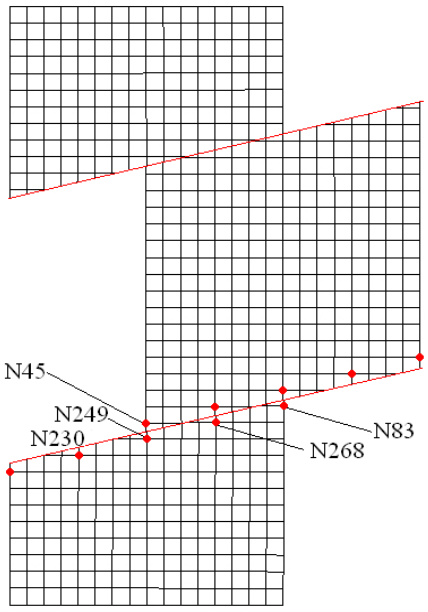

Figure 4.3-1: The site of the nodes which store the degrees of freedom of contact tested

4.4 Remarks

the results got with this modelization are close to those obtained by the classical modelization. The variations are due to the meshes different (the mesh used for the classical modelization is not

regulated in order to respect the geometry of the oblique interfaces) and to stabilization by the algorithm used for satisfaction from the LBB.

5 Modelization C

5.1 Characteristic of the modelization

It is acted of the same characteristics of modelization as the modelization A but as plane stresses.

5.2 Characteristics of the mesh

They is the same characteristics of mesh as modelization A.

5.3 Grandeurs tested and results

One tests contact pressures as for modelization A. the site of the nodes which store the degrees of freedom of contact, which one tests the values, is illustrated on [Figure 3.3-1].

Not	Identification	Reference	Tolerance
1	LAGS_C for N10	0.0000000E+00	1.0E-12
	LAGS_C for N60	-5.6047281D+04	5.0%
	LAGS_C for N56	-5.3536786D+04	5.0%
	LAGS_C for N52	-4.4909070D+04	5.0%
	LAGS_C for N9	0.0000000E+00	1.0E-12
2	LAGS_C for N10	0.0000000E+00	1.0E-12
	LAGS_C for N60	-1.6263864E+05	5.0%
	LAGS_C for N56	-1.1063071E+05	5.0%
	LAGS_C for N52	-9.1544228E+04	5.0%
	LAGS_C for N9	0.0000000E+00	1.0E-12
3	LAGS_C for N10	0.0000000E+00	1.0E-12
	LAGS_C for N60	0.0000000E+00	1.0E-12
	LAGS_C for N56	-1.7966654E+05	5.0%
	LAGS_C for N52	-1.4075455E+05	5.0%
	LAGS_C for N9	0.0000000E+00	1.0E-12
4	LAGS_C for N10	0.0000000E+00	1.0E-12
	LAGS_C for N60	0.0000000E+00	1.0E-12
	LAGS_C for N56	-3.4348434E+05	5.0%
	LAGS_C for N52	-1.9708554E+05	5.0%
	LAGS_C for N9	0.0000000E+00	1.0E-12

5.4 Remarks

This test is used as reference to modelization D.

6 Modélisation D

6.1 Characteristic modelization

It acts of the same characteristics of modelization as the modelization B but in plane stresses.

6.2 Characteristics of the mesh

They is the same characteristics of mesh as the modelization B.

6.3 Quantities tested and results

One tests the values of contact pressure as for the modelization B.

Not	Identification	Reference	Tolerance
1	LAGS_C for N43	0.0000000E+00	1.0E-12
	LAGS_C for N228	-5.6047281E+04	5.0%
	LAGS_C for N247	-5.3536786E+04	5.0%
	LAGS_C for N266	-4.4909070E+04	5.0%
	LAGS_C for N81	0.0000000E+00	1.0E-12
2	LAGS_C for N43	0.0000000E+00	1.0E-12
	LAGS_C for N228	-1.6263864D+05	5.0%
	LAGS_C for N247	-1.1063071D+05	5.0%
	LAGS_C for N266	-9.1544228D+04	5.0%
	LAGS_C for N81	0.0000000E+00	1.0E-12
3	LAGS_C for N43	0.0000000E+00	1.0E-12
	LAGS_C for N228	0.0000000E+00	1.0E-12
	LAGS_C for N247	-1.7966654E+05	5.0%
	LAGS_C for N266	-1.4075455E+05	5.0%
	LAGS_C for N81	0.0000000E+00	1.0E-12
4	LAGS_C for N43	0.0000000E+00	1.0E-12
	LAGS_C for N228	0.0000000E+00	1.0E-12
	LAGS_C for N247	-3.4348434E+05	5.0%
	LAGS_C for N266	-1.9708554E+05	5.0%
	LAGS_C for N81	0.0000000E+00	1.0E-12

7 Modelization E

7.1 Characteristic of the modelization

It acts of the same characteristics of modelization as modelization A.

7.2 Caractéristiques of the mesh

The mesh is regulated (see [Figure 7.2-1]) and comprises 3 blocks made up of meshes of type TRI3. It on the whole has approximately 4608 elements, 32×72 along the horizontal and vertical axes, respectively.
The mesh is finer than in the preceding tests because one wants to avoid a loss of accuracy between the methods of contact FEM and X-FEM caused by the differences in mesh. Moreover, it is built for this case (contact FEM) starting from the mesh of visualization X-FEM of the modelization F (contact X-FEM counterpart), in order to limit the differences in mesh between the two approaches of contact.

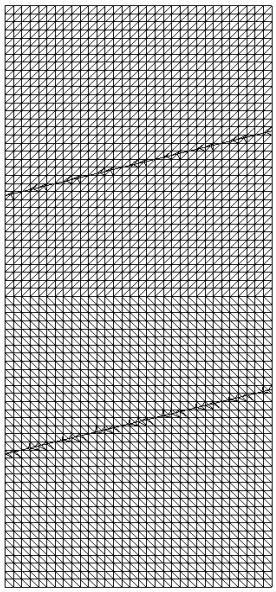

Figure 7.2-1: The mesh of the modelization E

7.3 Quantities tested and results

One tests the values of the contact pressure as for modelization A. the site of the nodes which store the degrees of freedom of contact, which one tests the values, is illustrated on [Figure 7.3-1].

Not	Identification	Reference	Tolerance
1	LAGS_C for N2288	0.0000000E+00	1.0E-12
	LAGS_C for N2531	-6.0789654D+04	5.0%
	LAGS_C for N2791	-5.9710311D+04	5.0%
	LAGS_C for N3051	-5.1197045D+04	5.0%
	LAGS_C for N3311	0.0000000E+00	1.0E-12
2	LAGS_C for N2288	0.0000000E+00	1.0E-12
	LAGS_C for N2531	-3.9911326E+05	5.0%
	LAGS_C for N2791	-1.2010508E+05	5.0%
	LAGS_C for N3051	-1.0176447E+05	5.0%

	LAGS_C for N3311	0.0000000E+00	1.0E-12
3	LAGS_C for N2288	0.0000000E+00	1.0E-12
	LAGS_C for N2531	0.0000000E+00	1.0E-12
	LAGS_C for N2791	-1.9289294E+05	5.0%
	LAGS_C for N3051	-1.5195304E+05	5.0%
	LAGS_C for N3311	0.0000000E+00	1.0E-12
4	LAGS_C for N2288	0.0000000E+00	1.0E-12
	LAGS_C for N2531	0.0000000E+00	1.0E-12
	LAGS_C for N2791	-9.4470171E+05	5.0%
	LAGS_C for N3051	-2.0680207E+05	5.0%
	LAGS_C for N3311	0.0000000E+00	1.0E-12

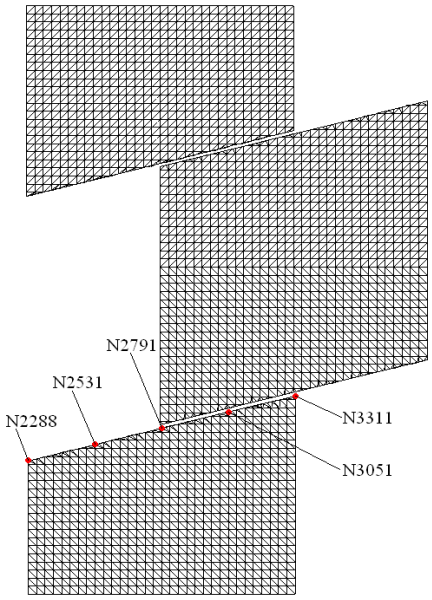

Figure 7.3-1: The site of the nodes which store the degrees of freedom of contact tested

7.4 Remarks

This test is used as reference to the modelization F.

8 Modelization F

8.1 Characteristic of the modelization

It acts of the same characteristics of modelization as the modelization B.

8.2 Characteristic of the mesh

The mesh is regulated (see [Figure 8.2-1]) and meshes comprises 4608 type TRI3. Following the definition of the interfaces, meshes cut with their nodes the degrees of freedom of contact friction store.

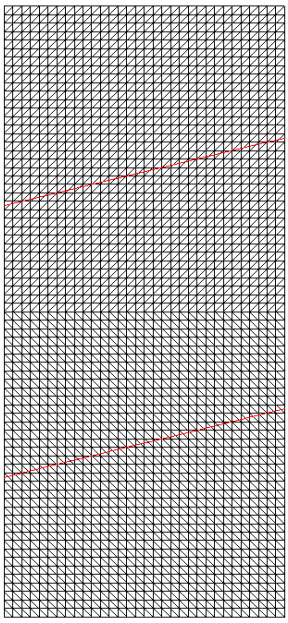

Figure 8.2-1: The mesh of the modelization F

8.3 Quantities tested and results

One tests the values of contact pressure as for the modelization B. the site of the nodes which store the degrees of freedom of contact, which one tests the values, is illustrated on [Figure 8.3-1]. One compares graphically on [Figure 8.3-2] the results of approaches FEM and X-FEMs for the last step of load.

Not	Identification	Reference	Tolerance
1	LAGS_C for N65	0.0000000E+00	1.0E-12
	LAGS_C for N412	-6.0789654D+04	5.0%
	LAGS_C for N710	-5.9710311D+04	5.0%
	LAGS_C for N1008	-5.1197045D+04	5.0%
	LAGS_C for N1306	0.0000000E+00	1.0E-12
2	LAGS_C for N65	0.0000000E+00	1.0E-12
	LAGS_C for N412	-3.9911326E+05	5.0%
	LAGS_C for N710	-1.2010508E+05	5.0%
	LAGS_C for N1008	-1.0176447E+05	5.0%
	LAGS_C for N1306	0.0000000E+00	1.0E-12
	LAGS_C for N65	0.0000000E+00	1.0E-12
	LAGS_C for N412	0.0000000E+00	1.0E-12

3	LAGS_C for N710	-1.9289294E+05	5.0%
	LAGS_C for N1008	-1.5195304E+05	5.0%
	LAGS_C for N1306	0.0000000E+00	1.0E-12
4	LAGS_C for N65	0.0000000E+00	1.0E-12
	LAGS_C for N412	0.0000000E+00	1.0E-12
	LAGS_C for N710	-9.4470171E+05	5.0%
	LAGS_C for N1008	-2.0680207E+05	5.0%
	LAGS_C for N1306	0.0000000E+00	1.0E-12

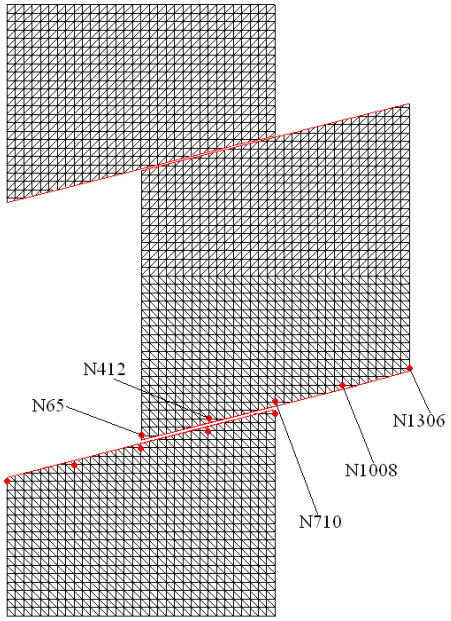

Figure 8.3-1: The site of the nodes which store the degrees of freedom of contact tested

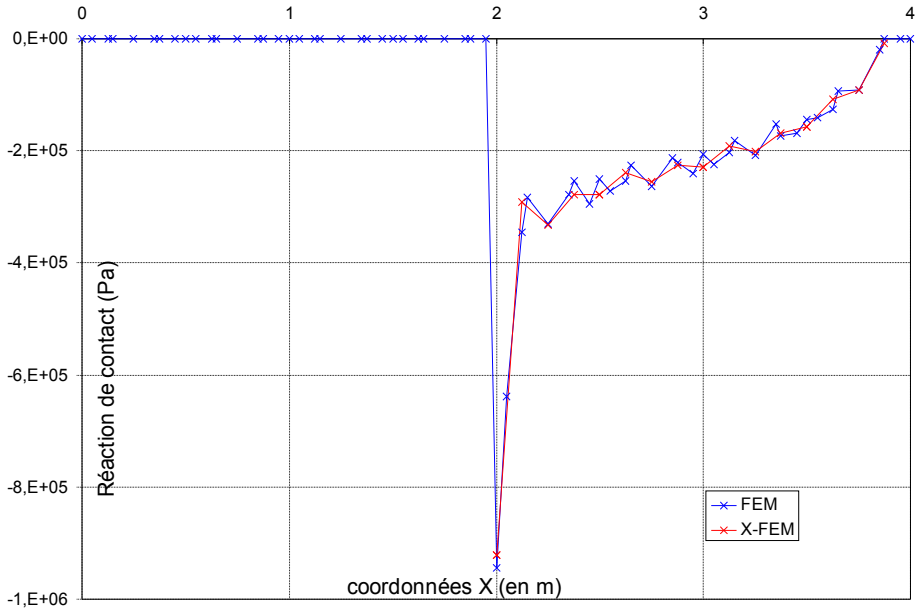

Figure 8.3-2: SSNP503-e and F: Comparison of the reactions of contact (last step of load), for methods FEM (in blue) and XFEM (in red).

8.4 Remarks

These results validate in 2D the management of integration of the contact with slipping friction when a relation of equality between the degrees of freedom of contact friction is imposed in the contacting passing/not contacting by the algorithm of stabilization of the LBB (see [R5 03 53] and [D9 05 06]).
So that the results of two approaches (methods of contact X-FEM and classical FEM) correspond, one recovered the mesh of the postprocessing of the approach X-FEM to build the mesh for approach FEM (modelization E). The positions of the nodes of the mesh (except interface) are then the same ones, the integration of the stiffness is done on the same triangles and integration of the contact is done on the same segments.
However, according to this approach of construction of mesh, the interfaces of method of contact FEM have almost twice more degrees of freedom (contact and displacement) that those of method of contact X-FEM. One thus does not solve exactly the same numerical problem in the 2 cases.
The convergence of the test of comparison on the profile of the reaction of contact is checked with a maximum tolerance of 12% in one of the points. This relatively great tolerance takes account of the oscillations (see [Figure 8.3-2]) which come from the irregularity of the size of the segments on which one integrates the contact. It is noticed that these oscillations are of less great amplitude in the case X-FEM because of the algorithm of management of condition LBB.

9 Modelization G

9.1 Characteristic of the modelization

It is acted of the same characteristics of modelization as the modelization F, but as penalized formulation.

9.2 Characteristics of the mesh

It is the same mesh as that of the modelization F.

9.3 Quantities tested and results

One tests the values of contact pressure with the same references and tolerances that the modelization F. the site of the nodes which store the degrees of freedom of contact, which one tests the values, is illustrated on it [Figure 8.3-1].

Not	Identification	Reference	Tolerance
1	LAGS_C for N65	0.0000000E+00	1.0E-12
	LAGS_C for N412	-6.0789654D+04	5.0%
	LAGS_C for N710	-5.9710311D+04	5.0%
	LAGS_C for N1008	-5.1197045D+04	5.0%
	LAGS_C for N1306	0.0000000E+00	1.0E-12
2	LAGS_C for N65	0.0000000E+00	1.0E-12
	LAGS_C for N412	-3.9911326E+05	5.0%
	LAGS_C for N710	-1.2010508E+05	5.0%
	LAGS_C for N1008	-1.0176447E+05	5.0%
	LAGS_C for N1306	0.0000000E+00	1.0E-12
3	LAGS_C for N65	0.0000000E+00	1.0E-12
	LAGS_C for N412	0.0000000E+00	1.0E-12
	LAGS_C for N710	-1.9289294E+05	5.0%
	LAGS_C for N1008	-1.5195304E+05	5.0%
	LAGS_C for N1306	0.0000000E+00	1.0E-12
4	LAGS_C for N65	0.0000000E+00	1.0E-12
	LAGS_C for N412	0.0000000E+00	1.0E-12
	LAGS_C for N710	-9.4470171E+05	5.0%
	LAGS_C for N1008	-2.0680207E+05	5.0%
	LAGS_C for N1306	0.0000000E+00	1.0E-12

10 Summary of the results

the purposes of this test is reached.

- It is a question of the contact of showing the feasibility of the taking into account on the oblique crack lips with the approach great slidings X-FEM. Only the case of cracks crossing structure completely was considered (interface).
- One also shows in 2D the effectiveness of the algorithms implemented to improve the results when the relations of equalities introduced on the degrees of freedom of contact by algorithm LBB enter in conflict with a change of contacting statute/not contacting (modelization F).
- The approach was validated with the taking into account of frictions in 2D (plane strains and plane stresses, elements QUAD4 and TRI3)